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Appendix D

Groundwater Modelling Report – The City of Guelph Water Supply Master Plan Update by Matrix Solutions Inc.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Groundwater Modelling Report - The City of Guelph Water Supply Master Plan Update

Prepared for:
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Prepared by:
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Prepared for AECOM Canada Ltd., October 2021

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Executive Summary

AECOM Canada Ltd. and the City of Guelph (the City) retained Matrix Solutions Inc. to apply the City's groundwater flow model to assess current and potential future municipal water supply scenarios to support the City's Water Supply Master Plan (WSMP) Update. The groundwater model (Tier Three model) was originally developed and peer reviewed as part of the Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment; Matrix 2017) under the province's **Clean Water Act** and has since been refined in local areas of interest by the City as new hydrogeological data has become available. As the Tier Three model was originally developed and calibrated in the area of the municipal wells using data representative of 2008 conditions, a recent evaluation was completed to verify the calibration of the model to more recent municipal pumping and water level data (Matrix 2020). This evaluation confirmed that the calibration result and spatial trends were similar to the original Tier Three model applied for the Tier Three Assessment, and therefore, the model was appropriate for application in the WSMP update. Since this evaluation, the Tier Three model was also locally updated in the southwest quadrant of the City for the purposes of the Guelph South Groundwater Feasibility Assessment (Matrix 2021). The Tier Three model version applied for this current project includes these updates.

This report considers new data collected and builds on the previous WSMP update (AECOM and Golder 2014). The 2014 WSMP update included scenarios that explored potential Future Groundwater Supply Sources within 5 km of City limits, including test wells Logan and Ironwood and three hypothetical wells. The 2014 WSMP update also included two Aquifer Storage Recovery Scenarios in the northeast quadrant of Guelph.

As a part of this project, a Current Capacity Scenario was optimized to estimate the maximum average day capacity of the existing municipal water supply system, including groundwater wells and the Glen Collector. This scenario represents a point of reference for remaining future supply scenarios for estimating additional system capacity and impacts to watercourses. The optimization of the capacity considers maintaining groundwater elevations above safe operating levels, minimizing reductions in groundwater discharge to coldwater streams, and the interpreted individual maximum well withdrawal capacities as upper bounds. The estimated average-day capacity of the current water supply system is 66,760 m^3/day. A similar exercise was completed to optimize the current water supply system under drought conditions. The estimated drought capacity of the current water supply system is 57,560 m^3/day.

Below is a table of the scenarios evaluated as part of this modelling work, including scenario descriptions, each scenario's simulated average day capacity and the difference in simulated capacity relative to the Current Capacity scenario.

Table I Summary of System Capacity for Future Supply Scenarios

Scenario Set	Potential Supply Area	Scenario Number: Potential Additional Supply Description	Simulated Average Day Capacity (m^3/day)	Capacity Over Current Capacity Scenario (m^3/day)
Current System Capacity		Current municipal wells and Glen Collector	66,760	-
A Additional Wells and Existing Collector	Southeast Quadrant	A1-A: Lower Road Collector	69,811[a]	3,051
		A1-B: Lower Road Collector and hypothetical Guelph Southeast location well supply	71,960	5,200
	Southwest Quadrant	A2-A: Additional well supply from: Edinburgh, Steffler, Ironwood, and GSTW1-20	71,480	4,720
	Northeast Quadrant	A3-A: Additional well supply from: Clythe, Fleming, and Logan	70,370	3,610
	Northwest Quadrant	A4-A: Additional well supply from: Sacco, Smallfield, Hauser and hypothetical Sunny Acres Park location	68,260	1,500
		A4-B: Additional well supply from Sacco, Smallfield, Hauser, and hypothetical Guelph North location	70,420	3,660
	Multiple Quadrants	A5-A: Additional well supply from: Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, and Hauser	76,740	9,980
		A5-B: Additional well supply from: hypothetical Guelph East 1 and 2	66,760	0
		A5-C: Additional well supply from: Edinburgh, Ironwood, GSTW1-20, Steffler, Clythe, Fleming, Logan, Hauser, Smallfield, and hypothetical Guelph Southeast and Guelph North	82,370	15,610

Scenario Set	Potential Supply Area	Scenario Number: Potential Additional Supply Description	Simulated Average Day Capacity (m³/day)	Capacity Over Current Capacity Scenario (m³/day)
B Dolime Quarry Water Capture		B1: Dolime Quarry capture considering current municipal wells	71,760[(b)]	5,000[(b)]
C Arkell Recharge/Collector Optimization		C1: Withdraw more water from the Eramosa River, increase pump capacity to 0.32 m^3/second	71,659[(c)]	4,899
		C2: Deactivate the Glen Collector and install a Caisson Collector System	66,402[(d)]	358
D Aquifer Storage and Recovery System		D1: Inject water from the Glen and Lower Road Collectors into the Middle Gasport Formation in Innovation District Lands and extract during periods of high demand	67,501[(e)]	741[(f)]
		D2: Inject water from Guelph Lake into the Middle Gasport Formation in Northeast Guelph and extract during periods of high demand	68,307[(e)]	1,547[(f)]

Notes:
(a) This is a sum of the Current Capacity Scenario well rates and the A1-A scenario steady-state Lower Road Collector and Glen Collector rates
(b) The increase in water supply capacity associated with the Dolime quarry is assumed to be derived from a combination of increased pumping from new or existing wells in addition to the treatment of quarry discharge water.
(c) This is a sum of the Current Capacity Scenario well rates and the C1 scenario steady-state Glen Collector rates considering an Eramosa pump capacity of 0.32 m^3/second
(d) This is a sum of the Current Capacity Scenario well rates (including the removal of Arkell 15) and the C2 scenario steady-state Caisson Collector rate
(e) This is a sum of the Current Capacity Scenario well rates and the average annual ASR extraction rate applied in Scenarios D1 and D2
(f) This is the annual average extraction rate applied in Scenarios D1 and D2

The model scenarios presented in this report are designed to optimize the City's municipal water supply system's long-term constant rate total capacity while considering low water constraints in municipal supply wells, individual well capacities, and potential impacts to baseflow in streams.

The water supply system can produce greater volumes over short-term periods than the rates presented in this report. In any cases where the model evaluates new well locations, the computer modelling results should only be considered as estimates subject to the results of field tests and local model refinements.

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1 Introduction and Objectives

AECOM Canada Ltd. and the City of Guelph (the City) retained Matrix Solutions Inc. to apply the City's groundwater flow model to assess current and potential future municipal water supply scenarios in support of the City's Water Supply Master Plan (WSMP) Update. This report describes the application of this model to provide estimates of the maximum average-day capacity of the current water supply system, and to evaluate multiple scenarios to estimate the incremental average-day capacity of introducing additional wells or water supply sources within and outside of the city.

The groundwater model (Tier Three model) was originally developed and peer reviewed as part of the Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment; Matrix 2017) under the province's **Clean Water Act** and has since been refined in local areas of interest by the City as new hydrogeological data has become available. As the Tier Three model was originally developed and calibrated in the area of the municipal wells using data representative of 2008 conditions, a recent evaluation was completed to verify the calibration of the model to more recent municipal pumping and water level data (Matrix 2020). This evaluation confirmed that the calibration result and spatial trends were similar to that of the original Tier Three model applied for the Tier Three Assessment, and therefore, the model was appropriate for application in the WSMP update. Since this evaluation, the Tier Three model was also locally updated in the southwest quadrant of the City for the purposes of the Guelph South Groundwater Feasibility Assessment (Matrix 2021). The Tier Three model version applied for this current project includes these updates.

The model scenarios presented in this report are designed to optimize the City's municipal water supply system's long-term constant rate total capacity while considering physical construction constraints in municipal supply wells (Figure 1), estimated operating well capacities, and potential impacts in groundwater discharge to streams (Figure 2). The scenarios evaluated estimate an average-day well capacity. The water supply system can achieve greater production rates over short-term periods. The future scenarios in this report consider potential additional sources of water in addition to the existing sources of the current water supply system.

This report summarizes the simulation of current pumping conditions (Baseline Scenario; Section 2), the maximum average day capacity of the current municipal water supply system (Current Capacity Scenario; Section 3), the maximum average capacity under drought conditions (Drought Capacity Scenario; Section 4), and the maximum average capacity considering alternative future groundwater supply sources (Future Potential Supply Scenarios; Section 5). Potential additional sources of groundwater include:

- use of inactive wells and collectors, test wells, and hypothetical wells in areas where additional supply may be available (Section 5.1)
- water management in the Dolime Quarry area (Section 0)
- optimization and reconfiguration of the Arkell recharge and collector system (Section 5.3)
- aquifer storage and recovery systems (Section 5.4)

2 Baseline Scenario

The Baseline Scenario is a steady-state scenario of the most recent representative average pumping conditions in Guelph and establishes the best estimate of baseflow and groundwater levels under current pumping configurations.

2.1 Model Refinements

The Tier Three model has undergone several local updates since its original development in 2008. At the onset of this project, Matrix completed a review of the model to verify that the 2008 calibration statistics remained valid when considering the newer model updates and new groundwater monitoring data collected by the City (Matrix 2020). Various local adjustments were made to the Tier Three model to improve model stability and computation speed prior to scenario optimization. These adjustments include the following:

- the thickness of model layers was increased where needed to a thickness of at least 10 cm
- nodal elevations were updated on the uppermost model slice where needed, to be the same as the elevation of the assigned boundary condition elevation
- local adjustments were made to magnitude and location of local river and wetland boundary conditions
- the magnitude of some bedrock boundary conditions along the outer model boundary were adjusted to represent a smoother gradient
- localized, small hydraulic conductivity adjustments were made around two non-municipal pumping wells that were previously simulated going dry (Permit to Take Water [PTTW] Nos. 3368-9UNH2S and 03-P-2249).

As a result of these minor changes to the model, the model was found to converge in a shorter period of time.

In addition to the refinements made to improve model stability, the representation of the Glen Collector was improved. The Glen Collector is represented by several constant head boundary conditions and the applied elevations of these boundary conditions were refined to better represent the flow gradient toward the Eramosa River in the Glen Collector. The Eramosa infiltration system was previously represented with injection well boundary conditions. These boundary conditions were replaced with lateral multilayer well boundary conditions, which applied a discrete feature along the length of the system. This update was made to simplify the modelling process of updating the applied injection rate.

2.2 Pumping Rates

The Baseline Scenario municipal pumping rates were selected by reviewing average pumping conditions between 2017 and 2019, and selecting the three-year average pumping rate for all municipal wells, except for Burke Well and Calico Well (Table 1, Column C). The 3-year average was not considered representative of current average pumping conditions of the Burke well because it was offline in 2018 and early 2019. Once the Burke well was back online in March of 2019, it was pumped consistently at an average rate of 6,009 m^3/day, which is the rate applied in the Baseline Scenario. Similarly, the Calico well was off-line since August of 2018, but previously pumped at a continuous average rate of 809 m^3/day from 2017 to the fall of 2019. This pumping rate of the Calico well was applied in the Baseline Scenario.

Surface water is seasonally pumped out of the Eramosa River and infiltrated through the Arkell groundwater infiltration system. A portion of this infiltrated water supplements groundwater discharge to the Glen Collector. For the steady-state modelling, the average pumping rate from the Eramosa River between 2017 and 2019 was 3,290 m^3/day. This value represents the average rate of water if evenly spread over the whole year, as opposed to the value representing daily and seasonal variability. The applied Eramosa infiltration rate in the steady-state baseline model was updated from 3,000 to 3,290 m^3/day to represent this 2017-2019 average.

Other permitted pumping rates were also updated in the model within the Wellhead Protection Area for water quantity (WHPA-Q) to represent more recent groundwater pumping conditions. The 2016 reported non-municipal well rates and locations from the Guelph-Guelph Eramosa Threats Management Strategy (Matrix 2018) were applied in the Tier Three model and then updated to 2019 consumptive permitted rates using the province's PTTW database (MECP 2019) where 2016 reported takings were unavailable. Ultimately, three sources from two 2019 PTTWs were added to the model associated with "aggregate washing" (PTTW No. 4551-BBHRVD; 771 m^3/day) and "miscellaneous" (PTTW No. 2370-AWTPH4; 12 m^3/day) purposes. One PTTW was removed associated with aggregate washing (PTTW No. 2718-7S3RM7; 0.6 m^3/day). Finally, the simulated rates of two Guelph/Eramosa Township municipal PTTWs (Nos. 2010-95CQ5Q and 2404-9R8PQV) were updated to reflect 2019 average withdrawals (totalling 251 m^3/day; Guelph/Eramosa Township 2020).

2.3 Low Water Thresholds

Low water thresholds at the municipal wells are used in the WSMP modelling work to evaluate when aquifer water levels fall too low and a municipal well may be unable to reliably withdraw water. Estimates of these thresholds were provided by AECOM (AECOM 2021; Table 1) and may be related to the depth of the pump intake, open borehole interval, water bearing zones, or other operational considerations at a well. Due to differences between the simulated and actual aquifer hydraulics near a well, there are differences between observed and simulated specific capacity and hydraulic head at the municipal wells. The low water threshold of each well was adjusted to account for the difference between simulated and actual specific capacity (Table 1; Column K).

The simulated specific capacity was estimated (Table 1; Column G) by determining the simulated head at each municipal well when its rate is set to zero and when its rate is set to Baseline. There is uncertainty in the estimated specific capacity of each well because of the interaction between some of the municipal wells. For a few wells (i.e., Arkell 8, Membro, Water Street, Dean, University, and Park wells), the specific capacity was re-estimated using municipal water level and pumping data so that the simulated pumping wells could pump at rates closer to what was observed without exceeding the adjusted low water threshold (Table 1).

Historical measured water levels were also reviewed to find the typical water level at the Baseline Scenario pumping rate for each municipal well (Table 1; Column C). From each typical water level and estimated low water level threshold, the available head was calculated (typical water level minus the low water threshold; Table 1 Column E). To account for differences in the well's estimated and simulated specific capacities, the available head was multiplied by the estimated versus simulated specific capacity ratio (Table 1; Column I).

To calculate the adjusted simulated low water threshold, the adjusted available head was then subtracted from the simulated Baseline Scenario head at each municipal well to account for the difference in measured and simulated hydraulic head (Table 1; Column K).

Table 1 Summary of Municipal Pumping Rates and Well Data

City Quadrant	Municipal Well/Source	A	B	C	D	E	F	G	H	I	J	K
		Baseline Simulated Pumping Rate (m^3/day)	AECOM Interpreted Maximum Pumping Rate (m^3/day)	Typical Measured Water Level at Baseline Pumping Rate (m asl)	Low Water Level Threshold (AECOM 2021) (m asl)	Measured Available Head (m)	Estimated Specific Capacity (AECOM 2021) (m^3/day/m)	Simulated Specific Capacity (m^3/day/m)	Estimated/ Simulated Specific Capacity Ratio ( )	Adjusted Simulated Available Head (m)	Baseline Simulated Water Level (m asl)	Adjusted Simulated Low Water Threshold (m asl)
						E=C-D			H=F/G	I=E x H		K=J-I
Southeast	Arkell 1	92	600	323.0	319.1	3.9	550	677	0.8	3.2	322.6	319.5
	Arkell 6	4,464	4,900	311.0	301.6	9.4	860	1,309	0.7	6.2	311.9	305.7
	Arkell 7	5,499	4,900	312.0	301.8	10.2	730	1,219	0.6	6.1	311.8	305.7
	Arkell 8	1,310	4,800	310.0	303.8	6.2	260[d]	1,304	0.2	1.2	312.4	311.1
	Arkell 14	4,527	3,300	313.0	308.5	4.5	350	1,334	0.3	1.2	312.0	310.9
	Arkell 15	2,180	3,300	314.5	307.2	7.3	1,490	1,318	1.1	8.3	312.6	304.4
	Burke[b]	6,009	5,500	315.0	313.1	1.9	340	893	0.4	0.7	324.1	323.4
	Carter[a]	2,455	4,000	320.4	315.0	5.4	1,200	1,316	0.9	4.9	323.5	318.5
Southwest	Membro	1,802	4,300	289.5	275.3	14.2	300[d]	521	0.6	8.5	290.6	282.1
	Water St.	1,108	2,400	287.0	275.9	11.1	207[d]	428	0.5	5.4	294.6	289.2
	Dean	1,096	1,500	287.0	277.8	9.2	110[d]	411	0.3	2.8	292.7	289.9
	University	1,178	2,500	289.0	282.0	7.0	200[d]	726	0.3	1.9	292.3	290.4
	Downey	4,278	5,200	291.0	282.3	8.7	240	593	0.4	3.5	289.9	286.4
Northeast	Park[a]	3,163	6,400	302.5	286.9	15.6	250[d]	209	1.2	18.7	299.7	281.0
	Emma	2,276	2,100	297.5	291.9	5.6	170	89	1.9	10.7	288.9	278.2
	Helmar	749	1,500	302.0	299.9	2.1	45	169	0.3	0.6	324.5	321.4[e]
Northwest	Paisley	820	1,400	297.0	290.4	6.6	45	103	0.4	2.9	301.4	298.5
	Calico[b]	809	1,400	305.0	290.2	14.8	110	78	1.4	20.9	315.1	294.2
	Queensdale	624	1,100	282.0	269.9	12.1	25	103	0.2	2.9	298.9	295.9
	Glen Collector[c]	9,112										
Total (Wells		**44,439**										
Total (Wells + Collector)		**53,551**										

Notes:
(a) The Carter and Park Wells are represented by one simulated well each in the numerical model
(b) The Baseline rate represents the average pumping rate when pumping was taking place in 2019 for Burke and 2017 to 2018 for Calico.
(c) This taking is not assigned in the model like the municipal well takings. The value represents the simulated output of the Glen Collector.
(d) This estimated capacity has been adjusted from the AECOM estimate based on hydrographs and pumping data.
(e) This Low water threshold has been adjusted to account for uncertainty in the aquifer representation
asl - above sea level

2.4 Baseline Groundwater Discharge to Streams

The elevations of watercourses are represented in the model with constant head boundary conditions applied to ground surface in the Tier Three model. Simulated groundwater discharge for a given section of a river/stream is calculated as the net flow rate of the selected boundary conditions (Figure 2). Table 2 summarizes the estimated and simulated baseflows for the watercourses evaluated in this study, as well as the classification of each stream as "coldwater" or "warmwater" according to the Ontario Ministry of Natural Resources (currently the Ministry of Natural Resources and Forestry; 2013) and GRCA (2013) as found in Matrix (2017). The watercourse was assigned a coldwater classification for the purposes of this evaluation if a segment of the entire reach was assessed as coldwater. The range of estimated baseflow for the various watercourses are from previous studies including the Tier Three Risk Assessment (Matrix 2017) and the City of Guelph Southwest Quadrant Water Supply Class Environmental Assessment (Golder 2010). For the larger subwatersheds, model predictions of groundwater discharge nearly all fall within the estimated range of values. The simulated groundwater discharge to Mill Creek is lower than the estimated range of baseflow; however, this range may be an over-estimate as there are documented concerns that ice jamming at the Mill Creek gauge may have been impacting the estimates (Matrix 2017). For the smaller subwatersheds, model predictions of groundwater discharge are generally consistent with observations, but there are some inconsistencies. For these smaller streams, there is less certainty that baseflow measurements reflect average annual conditions. In addition, there is greater likelihood that baseflow is influenced by smaller-scale hydrogeologic features not included in the model or that the regional hydrogeologic model is less representative of that area. Most importantly, the baseflow associated with those small features may be outside of the precision of the model. Routine monitoring programs that include surface water monitoring (flow and water level), as well as shallow groundwater level monitoring in areas of important surface water features (e.g., coldwater streams and streams where groundwater discharge is predicted to be reduced), would improve the characterization of these features in the model and increase the certainty of model predictions.

Clythe Creek was included in this analysis to estimate potential impacts; however, insufficient data were available to calibrate overburden groundwater flow and groundwater discharge to Clythe Creek in the development of the Tier Three groundwater flow model. As a result, there is some uncertainty in the simulated baseflow of the creek. While uncertain, the simulated reductions in the effects on baseflow are the best available estimates at this time. Clythe Creek has been recently studied as part of the York Road Environmental Design (Amec Foster Wheeler 2017). According to this study, the headwaters of Clythe Creek are a coldwater stream that has historically sustained a trout population. The most recent warm water temperature results suggests that the lower and mid-reaches of the creek are considerably degraded. Presently, the creek is highly altered, with numerous drop structures and warm pool areas that restrict fish passage and warm the water. Should the City wish to pursue additional groundwater supplies in the northeast quadrant of the city, any estimated effects to Clythe Creek should be evaluated with additional local calibration of the model as well as consideration of the potential local ecological impacts. The City is currently undertaking additional studies in this area (e.g., as part of the return to service of the Clythe well) and this data can be used to supplement the model at a later date.

Table 2 Estimated and Baseline Scenario Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[(a)]	Minimum Baseflow Estimate	Maximum Baseflow Estimate	Simulated Baseline Groundwater Discharge
		(m^3/day)		
Blue Springs Creek	Coldwater	12,614	149,904	42,336
Chilligo/Ellis Creek	Coldwater	864	18,576	14,947
Clythe Creek	Coldwater	n/a	n/a	2,246
Cox Creek	Warmwater	518	3,802	2,419
Eramosa River	Coldwater	115,171	212,026	124,157
Guelph Lake Tributary	Coldwater	4,320	6,566	9,504
Hanlon Creek	Coldwater	3,801	5,357	4,244
Hopewell Creek	Coldwater	1,123	16,157	21,773
Irish Creek	Warmwater	5,357	9,245	5,875
Lutteral Creek	Coldwater	30,758	47,261	34,214
Marden Creek	Warmwater	1,901	5,789	3,110
Mill Creek	Coldwater	50,890	63,331	39,017
Moffat Creek	Coldwater	7,603	10,454	2,074
Speed River	Coldwater	198,893	293,069	251,510
Swan Creek	Coldwater	1,728	20,131	5,875
Torrance Creek	Warmwater	1,382	2,938	2,938
West Credit River	Coldwater	25,920	31,104	30,672

n/a - not available
(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

2.5 Baseline Hydraulic Head Distribution

Most of the City's groundwater supply comes from the Middle Gasport Formation Aquifer. Figure 3 illustrates the simulated hydraulic head distribution in the Middle Gasport Formation aquifer under baseline pumping conditions. Regionally, within the Middle Gasport Formation aquifer (where the City municipal wells predominantly get their water), groundwater flows from the north into the City, which agrees with the regional understanding (Matrix 2017). Pumping from municipal wells and surrounding non-municipal wells results in drawdown, or lowered water levels, in the aquifer within and around the City.

3 Current Capacity Scenario

The Current Capacity Scenario is designed to estimate the maximum average day capacity of the existing municipal water supply system, including groundwater wells and the Glen Collector. The scenario represents a point of reference for future supply scenarios for estimating the incremental system capacity and reductions in groundwater discharge to watercourses. The optimization of the municipal well pumping rates involves estimating the maximum total pumping rate while maintaining groundwater elevations above safe operating levels (i.e., low water thresholds; Table 1), minimizing reductions in groundwater discharge to coldwater streams (Table 2), and keeping individual well pumping rates below maximum well withdrawal capacities (Table 1; Column B). Optimization of municipal pumping rates was completed using PESTPP-OPT (Parameter Estimation Software; White et al. 2020), which automates the estimation of the maximum pumping rate potentially achievable by each well under each of the three listed constraints.

Table 3 summarizes the results of the Current Capacity Scenario, including maximum simulated pumping rates and simulated available heads under those rates. The estimated average-day capacity of the current water supply system is 66,760 m^3/day. This estimate includes an average day supply of 7,240 m^3/day from the Glen Collector under average annual recharge rates. The system has a higher total permitted rate and has a greater short-term capacity than this average-day capacity. Also, while this Current Capacity Scenario illustrates a precise series of pumping rates across each of the municipal wells, there are infinite combinations of pumping rates across the City's wells that could achieve a similar overall total capacity. For all scenarios, the simulated results should be interpreted as an estimated total capacity across the complete system, as opposed to evaluating individual well capacities.

Figure 4 illustrates the simulated drawdown in the Middle Gasport Formation from the Baseline simulated hydraulic head distribution (Figure 3) in response to pumping at Current Capacity rates. The 1 m drawdown contour extends approximately 1 to 2 km beyond active Current Capacity municipal wells. The largest drawdown is simulated to be approximately 18 m surrounding Park well, where the pumping rate is increased from a Baseline rate of 3,163 to 6,680 m^3/day.

Table 3 Current Capacity Scenario: Municipal Well Constraints and Maximum Pumping Rates

City Quadrant	Municipal Well/ Source	Adjusted Simulated Low Water Threshold (m asl)	Maximum Individual Well Capacity Threshold (m^3/day)	Current Capacity Scenario		Drought Capacity Scenario	
				Maximum Pumping Rate (m^3/day)	Available Head (m)	Maximum Pumping Rate (m^3/day)	Available Head (m)
Southeast	Arkell 1	319.5	2,000	2,000	2	2,000	0.8
	Arkell 6	305.7	8,000	1,500	5.1	2,960	4.7
	Arkell 7	305.7	8,000	8,000	3.6	8,000	3.4
	Arkell 8	311.1	7,000	0	-0.1[b]	0	-0.2[b]
	Arkell 14	310.9	7,000	3,100	-0.0	0	0.3
	Arkell 15	304.4	7,000	7,000	5.3	7,000	5
	Burke	323.4	6,500	5,200	0.2	3,000	0
	Carter Wells[a]	318.5	6,400	6,100	0	4,000	0.6
Southwest	Membro	282.1	5,200	5,200	0.8	5,200	0.5
	Water St.	289.2	2,700	1,950	0.1	1,800	-0.1[b]
	Dean	289.9	1,500	540	0	400	-0.1[b]
	University	290.4	2,500	850	0.3	470	0
	Downey	286.4	5,237	5,240	0.9	5,240	0.1
Northeast	Park Wells[a]	281.0	8,000	6,680	0.1	6,540	0.1
	Emma	278.2	2,800	2,390	0.3	2,360	0.1
	Helmar	321.4	800	670	0.1	550	0.1
Northwest	Paisley	298.5	1,400	940	0	830	0
	Calico	294.2	1,400	1,400	13.2	1,400	11.8
	Queensdale	295.9	1,100	760	0.5	680	0
	Glen Collector	-	-	7,240	-	5,130	-
Total (Wells)		-	-	**59,520**	-	**52,430**	-
Total (Wells + Collector)		-	-	**66,760**	-	**57,560**	-

Notes:
Minor exceedances (<0.2 m) were considered acceptable.
(a) Two or more wells simulated as one well.
(b) Low water level threshold exceedance when negative. Positive values indicate remaining available head at maximum pumping rate.
asl - above sea level

Table 4 summarizes the simulated groundwater discharge to various coldwater and warmwater streams under the Current Capacity Scenario. The model computes this discharge as the net sum of groundwater flow into or out of all constant head stream boundary conditions shown on Figure 2. The estimated groundwater discharge under the Current Capacity Scenario is a reference point to compare against estimated groundwater discharge in future supply scenarios described in Section 5.

Table 4 Current Capacity Scenario: Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Average Groundwater Discharge (m^3/day)
Blue Springs Creek	Coldwater	41,769
Chilligo/Ellis Creek	Coldwater	14,618
Clythe Creek	Coldwater	1,906
Cox Creek	Warmwater	2,354
Eramosa River	Coldwater	122,620
Guelph Lake Tributary	Coldwater	9,430
Hanlon Creek	Coldwater	3,718
Hopewell Creek	Coldwater	21,514
Irish Creek	Warmwater	5,807
Lutteral Creek	Coldwater	34,184
Marden Creek	Warmwater	2,982
Mill Creek	Coldwater	38,566
Moffat Creek	Coldwater	2,061
Speed River	Coldwater	246,216
Swan Creek	Coldwater	5,908
Torrance Creek	Warmwater	771
West Credit River	Coldwater	30,642

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

4 Drought Capacity Scenario

The Drought Capacity Scenario estimates the average-day capacity of the existing municipal water supply system (i.e., groundwater wells and the Glen Collector) under long-term drought conditions, while keeping groundwater elevations above safe operating levels (i.e., low water thresholds) and considering the individual well withdrawal capacities or permitted rates. The same low water thresholds and pumping constraints used for the Current Capacity Scenario apply for the Drought Capacity Scenario.

Table 3 summarizes the results of the Drought Capacity Scenario. Optimization of steady-state municipal pumping rates was completed using PESTPP-OPT (White et al. 2020), using a model with a 25% reduction in applied recharge from the Current Capacity Scenario model. The 25% recharge reduction results in a similar maximum drawdown as predicted using the first 7 years (1960 to 1967) of the 10-year transient drought scenario (1960 to 1970) evaluated in the Tier Three Assessment. The 1960s represents the most significant drought period observed during the period of monitoring in southwestern Ontario. The first seven years were assessed to coincide with the period of time where maximum water level declines were predicted in the Tier Three Assessment. After optimizing the pumping rates with the 25% recharge reduction scenario, the optimized rates were evaluated using the 7-year transient drought scenario with monthly recharge (1960-1967). Table 3 lists the simulated transient minimum available heads.

The estimated capacity of the current water supply system under drought conditions is 57,560 m^3/day. This estimated capacity includes a steady-state collection rate of 5,130 m^3/day from the Glen Collector under reduced recharge conditions.

5 Future Potential Supply Scenarios

Matrix assessed four sets of scenarios to estimate the incremental increase in water supply from potential additional water sources. Table 5 summarizes these sets of scenarios (i.e., A, B, C, and D) described as follows:

- The A scenarios evaluate potential additional supply from inactive or new municipal wells and collectors, as well as hypothetical well locations that have not yet been tested.
- The B and C scenarios test potential additional supply relating to the Dolime Pond Level Management strategy and Arkell recharge/collector system, respectively.
- The D scenario tests potential additional supply from two hypothetical Aquifer Storage and Recovery (ASR) systems.

The Future Potential Supply scenarios estimate the increase in the average-day water supply system capacity relative to the Current Capacity Scenario (Section 3), following the same approach used to estimate the Current Capacity. Simulated pumping was maintained below the interpreted maximum pumping rate of the well (Tables 1 and 6). Similarly, simulated water levels were maintained above the low water level thresholds described in Section 2.3 (Table 1). Low water level thresholds that account for differences in simulated versus estimated specific capacities and hydraulic heads were also calculated for wells evaluated in the future supply scenarios (wells that are currently inactive or are hypothetical; Table 6). These low water thresholds were estimated for these new wells in consultation with AECOM. In most cases an appropriate measured water level was not available at the new wells being evaluated in the future scenarios. In these instances, a nearby (within approximately 1 km of the well) water level observation was used in the estimation of an adjusted simulated low water threshold (Table 6). Similarly, field-derived estimates of specific capacity were not available for the potential well sources. In these cases, specific capacity was estimated as the estimated maximum rate of each well divided by the estimated available head for each well (Table 6).

Changes in groundwater discharge to streams were compared against the Current Capacity Scenario (Section 3, Table 4). In addition to the water level and pumping constraints, each future supply scenario included an additional optimization target of a maximum of 10% reduction of groundwater discharge to the same streams considered as part of the Tier Three Assessment. This threshold is consistent with thresholds used for coldwater streams in the Tier Three Assessment (Matrix 2017), which follow provincial guidance on how to evaluate possible impacts to streams as a result of increased municipal pumping (MOE 2013; MECP 2021).

Table 5 Summary of Future Supply Scenarios

Scenario Set	Potential Supply Area	Scenario Number: Potential Additional Supply Description
A Additional Wells and Existing Collectors	Southeast Quadrant	A1-A: Lower Road Collector
		A1-B: Lower Road Collector and hypothetical Guelph Southeast location well supply
	Southwest Quadrant	A2-A: Additional well supply from Edinburgh, Steffler, Ironwood, and GSTW1-20
	Northeast Quadrant	A3-A: Additional well supply from Clythe, Fleming, and Logan
	Northwest Quadrant	A4-A: Additional well supply from Sacco, Smallfield, Hauser, and hypothetical Sunny Acres Park location
		A4-B: Additional well supply from Sacco, Smallfield, Hauser, and hypothetical Guelph North location
	Multiple Quadrants	A5-A: Additional well supply from Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, and Hauser
		A5-B: Additional well supply from hypothetical wells completed on the Innovation District Lands.
		A5-C: Additional well supply from Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, Hauser and hypothetical Guelph North and Southeast Wells.
B Dolime Quarry Water Capture		B1: Dolime Quarry capture considering current municipal wells
C Arkell Recharge/Collector Optimization		C1: Withdraw more water from the Eramosa River and recharge closer to the Permit to Take Water rates
		C2: Deactivate the Glen Collector and install a Caisson Collector System
D Aquifer Storage and Recovery System		D1: Inject water from the Glen and Lower Road Collectors into the Middle Gasport Formation in Innovation District Lands and extract during periods of high demand.
		D2: Inject water from Guelph Lake into the Middle Gasport Formation in Northeast Guelph and extract during periods of high demand.

Table 6 Summary of Proposed Future Municipal Well Pumping Rates and Adjusted Low Water Level Thresholds

City Quadrant	Municipal Well/Source	A	B	C	D	E	F	G	H	I	J
		Permitted or Estimated Maximum Rate (m^3/day)	Estimated Water Level at Baseline Pumping Rate[(a)] (m asl)	Estimated Low Water Level Threshold (m asl)	Estimated Available Head (m)	Estimated Specific Capacity (m^3/day/m)	Simulated Specific Capacity (m^3/day/m)	Estimated/ Simulated Specific Capacity Ratio ( )	Adjusted Simulated Available Head (m)	Baseline Simulated Water Level (m asl)	Adjusted Simulated Low Water Threshold (m asl)
					D=B-C			G=E/F	H=D x G		J=I-H
Southeast	Guelph Southeast	6,500	332.7	284.2	48.5	134	131.6	1.0	49.4	326.1	276.7
Southwest	Edinburgh	3,000	299.0	282.0	17.0	177	510.7	0.3	5.9	293.9	288.0
	Ironwood	8,000	298.1	274.6	23.5	340	416.9	0.8	19.2	292.8	273.6
	GSTW1-20	4,320	304.0	281.2	22.8	189	227.3	0.8	19.0	307.2	288.2
	Steffler	3,600	298.5	271.7	26.8	134	520.8	0.3	6.9	292.7	285.7
	Sunny Acres	5,000	307.9	285.0	22.9	219	186.6	1.2	26.8	303.5	276.7
Northeast	Clythe	3,395	321.1	294.5	26.6	128	432.7	0.3	7.8	317.2	309.3
	Fleming	2,200	343.8	308.0	35.8	61	119.2	0.5	18.5	329.2	310.7
	Logan	4700	344.0	305.7	38.2	123	89.3	1.4	52.6	334.1	281.5
Northwest	Hauser	900	322.1	280.0	42.1	21	203.5	0.1	4.4	322.1	317.7
	Sacco	1,150	337.9	286.8	51.1	23	232.8	0.1	4.9	326.2	321.2
	Smallfield	1,408	334.2	280.2	54.0	26	203.0	0.1	37.8	322.1	284.3
	Guelph North	5,000	319.5	289.5	54.0	93	156.7	0.6	37.8	335.9	298.1

Notes:
(a) If no water level observations were available at offline or hypothetical well, a water level at a nearby well was used
asl - above sea level

5.1 Potential Water Supply from Additional Wells and Existing Collectors

The set of scenarios described in the following subsections (i.e., Scenarios A1-A to A5-C; Table 5) evaluate the average-day capacity where inactive wells or collectors were restored and put back online or if new hypothetical supply wells were made available (Figure 1).

5.1.1 Southeast Quadrant Scenario A1-A: Lower Road Collector

Scenario A1-A evaluates the potential increase in water supply if the inactive Lower Road Collector were to be brought back into service. The Lower Road Collector is an approximately 1 km continuation of the Glen Collector, running west of the Glen Collector and parallel to the Eramosa River (Figure 1). Similar to the Glen Collector, the Lower Road Collector was originally designed to collect groundwater seeps at the base of the ground surface slope; however, it was taken offline in 2001 due to water quality concerns.

The Lower Road Collector was represented in the groundwater flow model for this scenario by applying constant head boundary conditions in the overburden (model slice 3) with elevations set to the invert elevations of the manholes as reported in the City's Southeast Quadrant Groundwater Study (Jagger Hims 1998).

This scenario was simulated with Current Capacity Scenario pumping rates under steady-state and transient conditions. The transient scenario evaluates monthly recharge rates associated with the first 7 years of the 10-year Tier Three drought scenario (1960-1970) where maximum water level decline was predicted to occur. The results of these model runs are plotted on Chart 1 and summarized in Tables 7 and 8. The estimated steady-state discharge to the Lower Road Collector and Glen Collector is 8,017 m^3/day and 2,274 m^3/day, respectively. The transient discharge rates at the Lower Road Collector range from 5,063 to 11,191 m^3/day and at the Glen Collector range from 0 to 7,558 m^3/day. Table 8 lists the annual minimum simulated discharge rates of the Glen and Lower Road Collectors combined from Chart 1 (cumulative collectors). The lowest simulated cumulative discharge is 4,329 m^3/day, within a drought period. For comparison purposes, Table 8 also includes the annual minimum simulated discharge rate of the Glen Collector if it was operating on its own without the Lower Road Collector.

As illustrated by the scenarios, the Lower Road Collector reduces the amount of water discharged to the Glen Collector but results in an incremental average-day water supply of approximately 3,000 m^3/day under steady-state conditions. The groundwater flow model is not calibrated to field operation of the Lower Road Collector. The simulated discharge rates for the Glen and Lower Road collectors should be considered as a preliminary estimate of the total water that may be available from shallow groundwater collectors in this area, rather than a precise estimate of the relative amounts to be collected by each collector. The certainty of these estimates may be improved should additional calibration data be incorporated into the model from recent and future operational testing data of the collector system.

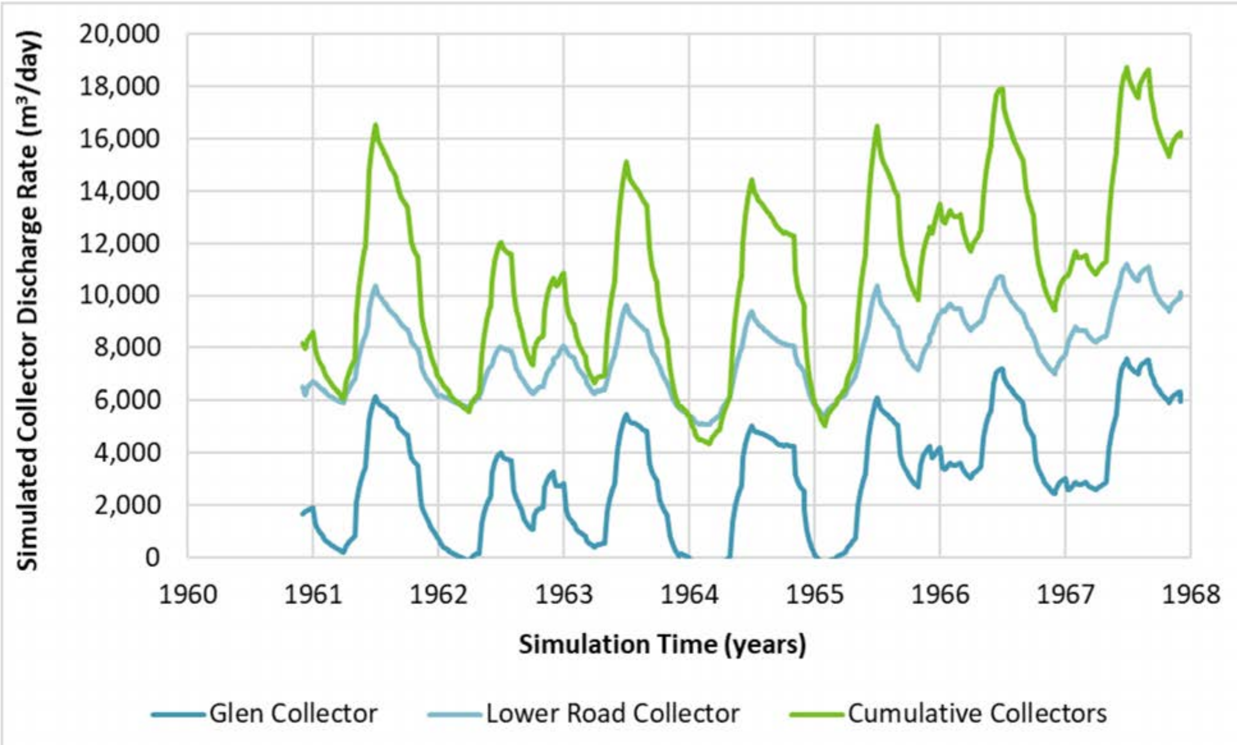

Chart 1 Transient Simulated Discharge Rate at the Glen Collector, Lower Road Collector, and the Sum of the Two Collectors

Table 7 Scenario A1-A: Simulated Lower Road Collector and Glen Collector Rates

Collector	Current Capacity Scenario (m^3/day)	Steady state Discharge (m^3/day)	Transient Scenario (1960 1967)		
			Average Discharge (m^3/day)	Minimum Discharge (m^3/day)	Maximum Discharge (m^3/day)
Lower Road Collector	N/A	8,017	7,835	5,063	11,191
Glen Collector	7,240	2,274	2,988	0	7,558
Total	**7,240**	**10,291**	**10,823**	**5,063**	**18,749**

Table 8 Scenario A1-A: Simulated Lower Road Collector and Glen Collector Annual Minimum Discharge Rates

Year	Minimum Simulated Discharge Rate with Glen Collector Operating[1] (m^3/day)	Minimum Simulated Cumulative Discharge Rate with Lower Road Collector and Glen Collector Operating (m^3/day)
1961	2,442	6,251
1962	1,718	5,652
1963	1,223	5,546
1964	599	4,321
1965	1,146	5,283
1966	4,950	9,429
1967	5,222	10,281

(1) minimum simulated discharge rates for Glen Collector if only the Glen Collector was operating (provided for comparison purposes)

5.1.2 Southeast Quadrant Scenario A1-B: Lower Road Collector, Hypothetical Southeast Guelph Well

Scenario A1-B estimates the increased total system capacity by introducing a hypothetical well (Guelph Southeast) on Maltby Road, east of Victoria Road, just outside of the City of Guelph (Figure 1), in addition to bringing the Lower Road Collector back into service (Scenario A1-A). The hypothetical Guelph Southeast well location was originally selected and modelled during the 2014 WSMP update (AECOM and Golder 2014), but has not yet been field tested. Within the Tier Three model, the well is located within an interpreted zone of relatively lower hydraulic conductivity in the Middle Gasport Formation (Figure 1). The hypothetical Guelph Southeast well is over 3 km south of the interpreted high hydraulic conductivity zone in which the Arkell system and Carter wells are completed.

The estimated total system capacity with the Lower Road Collector and the hypothetical Guelph Southeast well added is 71,960 m^3/day (Table 9). The new hypothetical well contributes 4,000 m^3/day to the total, and the cumulative rate produced by the existing Southeast Quadrant wells is estimated to be 31,100 m^3/day. The analysis shows that decreasing the rates at Arkell 14, Burke, and Carter wells allows for more pumping at the new wells, which increases the overall system capacity. Ultimately, the introduction of the new well, along with decreasing rates at some other wells allows for a net increase in system well capacity of 2,200 m^3/day. The introduction of the new southeast well, as well as bringing the Lower Road Collector back into service, contributes to a net increase in system total capacity of 5,200 m^3/day.

In comparison to the Current Capacity Scenario, the estimated reductions in groundwater discharge because of Scenario A1-B are less than 10% in all evaluated streams (Table 10).

Table 9 Scenarios A1-B, A2-A, A3-A, A4-A and A4-B: Summary of Optimized Well Rates and Available Head Exceedances

City Quadrant	Municipal Well/Source	Maximum Individual Well Capacity Threshold (m^3/day)	Adjusted Simulated Low Water Threshold (m asl)	Current Capacity Scenario		Scenario A1 B			Scenario A2 A			Scenario A3 A			Scenario A4 A			Scenario A4 B		
				Pumping Rate (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)
Southeast	Arkell 1	2,000	319.5	2,000	2.0	2,000	0	1.3	2,000	0	2.0	2,000	0	2.0	2,000	0	2.0	2,000	0	2.0
	Arkell 6	8,000	305.7	1,500	5.1	1,500	0	5.3	1,500	0	5.1	1,500	0	5.0	1,500	0	5.3	1,500	0	5.1
	Arkell 7	8,000	305.7	8,000	3.6	8,000	0	3.7	8,000	0	3.6	7,000[e]	-1,000	3.7	8,000	0	5.1	8,000	0	3.6
	Arkell 8	7,000	311.1	0	-0.1[c]	0	0	0.1	0	0	-0.1[c]	0	0	-0.1[c]	0	0	-1.5[c]	0	0	-0.1[c]
	Arkell 14	7,000	310.9	3,100	-0.1[c]	2,100[e]	-1,000	0.3	3,100	0	0.0	1,800[e]	-1,300	0.1	3,100	0	-0.0[c]	3,100	0	-0.1[c]
	Arkell 15	7,000	304.4	7,000	5.3	7,000	0	5.4	7,000	0	5.3	7,000	0	5.0	7,000	0	4.9	7,000	0	5.3
	Burke	6,500	323.4	5,200	0.2	5,000[e]	-200	-0.1[c]	5,200	0	0.1	5,200	0	0.1	5,200	0	0.2	5,200	0	0.2
	Carter Wells	6,400	318.5	6,100	0.0	5,500[e]	-600	0.1	6,100	0	-0.1[c]	6,100	0	0.0	6,100	0	0.0	6,100	0	0.0
	Guelph Southeast[b]	6,500	276.7	-	-	4,000[d]	4,000	20.7	-	-	-	-	-	-	-	-	-	-	-	-
Southwest	Membro	5,200	282.1	5,200	0.8	5,200	0	0.8	4,700[e]	-500	0.9	5,200	0	0.7	5,200	0	0.7	5,200	0	0.6
	Water Street	2,700	289.2	1,950	0.1	1,950	0	0.0	1,500[e]	-450	0.1	1,950	0	-0.2[c]	1,950	0	-0.1[c]	1,950	0	-0.1[c]
	Dean	1,500	289.9	540	0.0	540	0	0.0	0[f]	-540	0.2	540	0	-0.1[c]	540	0	-0.1[c]	540	0	-0.1[c]
	University	2,500	290.4	850	0.3	850	0	0.3	0[f]	-850	-2.4[c]	850	0	0.2	850	0	0.2	850	0	0.2
	Downey	5,237	286.4	5,240	0.9	5,240	0	0.8	2,250[e]	-2,990	0.1	5,240	0	0.8	5,240	0	0.8	5,240	0	0.8
	Edinburgh[b]	3,000	288.0	-	-	-	-	-	1,250[d]	1,250	-0.1[c]	-	-	-	-	-	-	-	-	-
	Ironwood[b]	8,000	273.6	-	-	-	-	-	3,750[d]	3,750	9.6	-	-	-	-	-	-	-	-	-
	GSTW1-20[b]	4,320	288.2	-	-	-	-	-	4,100[d]	4,100	-0.1[c]	-	-	-	-	-	-	-	-	-
	Steffler[b]	3,600	285.7	-	-	-	-	-	1,500[d]	1,500	0.5	-	-	-	-	-	-	-	-	-
Northeast	Park Wells	8,000	281.0	6,680	0.1	6,680	0	0.1	6,580[e]	-100	1.1	6,300[e]	-380	1.3	6,600	-80	0.2	6,400[e]	-280	0.7
	Emma	2,800	278.2	2,390	0.3	2,390	0	0.2	2,100[e]	-290	3.8	2,100[e]	-290	3.4	2,360	-30	0.3	2,360[e]	-30	0.1
	Helmar	800	321.4	670	0.1	670	0	0.1	650	-20	0.5	450[e]	-220	-0.0	670	0	0.0	0[f]	-670	2.5
	Clythe[b]	3,395	309.3	-	-	-	-	-	-	-	-	1,500[d]	1,500	0.6	-	-	-	-	-	-
	Fleming[b]	2,200	310.7	-	-	-	-	-	-	-	-	1,100[d]	1,100	0.3	-	-	-	-	-	-
	Logan[b]	4700	281.5	-	-	-	-	-	-	-	-	4,250[d]	4,250	0.4	-	-	-	-	-	-
Northwest	Paisley	1,400	298.5	940	0.0	940	0	0.0	840	-100	0.9	940	0	0.0	840[e]	-100	-0.1[c]	800[e]	-140	0.1
	Calico	1,400	294.2	1,400	13.2	1,400	0	13.2	1,400	0	13.2	1,400	0	13.2	1,400	0	12.0	1,400	0	11.9
	Queensdale	1,100	295.9	760	0.5	760	0	0.5	660	-100	0.9	760	0	0.5	760	0	0.1	760	0	0.1
	Hauser[b]	900	317.7	-	-	-	-	-	-	-	-	-	-	-	510[d]	510	0.1	300[d]	300	0.8
	Sacco[b]	1,150	321.2	-	-	-	-	-	-	-	-	-	-	-	150[d]	150	0.7	-[f]	-	0.0
	Smallfield[b]	1,408	284.3	-	-	-	-	-	-	-	-	-	-	-	980[d]	980	30.5	980[d]	980	29.9
	Sunny Acres[b]	5,000	276.7	-	-	-	-	-	-	-	-	-	-	-	0	0	22.3	-	-	-
	Guelph North[b]	5,000	298.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3,530[d]	3,530	35.4
	Glen Collector	-	-	7,240	-	2,240	-5,000	-	7,300	60	-	7,190	-50	-	7,310	70	-	7,210	-30	-
	Lower Collector	-	-	-	-	8,000	8,000	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Wells		**131,710**	-	**59,520**	-	**61,720**	**2,200**	-	**64,180**	**4,660**	-	**63,180**	**3,660**	-	**60,950**	**1,430**	-	**63,210**	**3,690**	-
Total (Wells + Collectors)		-	-	**66,760**	-	**71,960**	**5,200**	-	**71,480**	**4,720**	-	**70,370**	**3,610**	-	**68,260**	**1,500**	-	**70,420**	**3,660**	-

(a) Scenario pumping rate compared to the Current Capacity Scenario Rate
(b) Future Scenario Well
(c) Low water level threshold exceedance
(d) Pumping rate is greater than rate in the Current Capacity Scenario
(e) Pumping rate is less than rate in the Current Capacity Scenario
(f) Pumping rate is set to 0 m^3/day
asl - above sea level

Table 10 Scenario A1-B: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Current Capacity Groundwater Discharge (m^3/day)	Scenario A1 B Groundwater Discharge (m^3/day)	Change in Groundwater Discharge (m^3/day)	Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,486	-283	-1%
Chilligo/Ellis Creek	Coldwater	14,618	14,614	-4	0%
Clythe Creek	Coldwater	1,906	1,919	13	1%
Cox Creek	Warmwater	2,354	2,355	1	0%
Eramosa River	Coldwater	122,620	120,346	-2,274	-2%
Guelph Lake Tributary	Coldwater	9,430	9,433	3	0%
Hanlon Creek	Coldwater	3,718	3,472	-246	-7%
Hopewell Creek	Coldwater	21,514	21,517	3	0%
Irish Creek	Warmwater	5,807	5,761	-46	-1%
Lutteral Creek	Coldwater	34,184	34,185	1	0%
Marden Creek	Warmwater	2,982	2,983	1	0%
Mill Creek	Coldwater	38,566	36,818	-1,748	-5%
Moffat Creek	Coldwater	2,061	2,061	0	0%
Speed River	Coldwater	246,216	243,626	-2,590	-1%
Swan Creek	Coldwater	5,908	5,911	3	0%
Torrance Creek	Warmwater	771	698	-73	-9%
West Credit River	Coldwater	30,642	30,637	-5	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)
(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.3 Southwest Quadrant Scenario A2-A: Edinburgh, Steffler, Ironwood, and GSTW1-20

The estimated average-day capacity for wells within the southwest quadrant of Guelph (i.e., Membro, Water Street, Dean, University, and Downey wells) in the Current Capacity Scenario is 13,780 m^3/day. Scenario A2-A estimates the increased total system capacity by introducing the inactive Edinburgh well, and the Steffler, Ironwood, and GSTW1-20 test wells (Figure 1). The nearest active municipal wells are the University and Dean wells, which are located approximately 900 m and 1,800 m northwest of the Ironwood well, respectively.

The estimated total system capacity with these four wells added is 71,480 m^3/day (Table 9). These four wells contribute 10,600 m^3/day to this total and the cumulative rate produced by the southwest quadrant wells is estimated to be 19,050 m^3/day. The scenario resulted in shutting off the Dean and University wells, allowing new wells to pump at higher rates, which increased the overall system capacity. Ultimately, the introduction of these new wells, along with the shut down and decreased rates at some other wells, including some in the northeast and northwest quadrants, allowed for an increase in total simulated system capacity of 4,720 m^3/day over the Current Capacity.

The largest simulated reductions in groundwater discharge to watercourses were predicted to be 13% (470 m^3/day) and 17% (977 m^3/day) along Hanlon Creek and Irish Creek, respectively (Table 11). While a 10% groundwater discharge target was applied to the scenarios, the optimization technique does not treat this target as an absolute constraint and weighs the effect of groundwater discharge reductions against the water level constraints. The estimated groundwater discharge reduction is considered as a conservative worst-case value and needs to be further evaluated through pumping tests and operational monitoring. The estimated reduction in groundwater discharge along the remaining streams is less than 1%.

Table 11 Scenario A2-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Current Capacity Groundwater Discharge (m^3/day)	Scenario A2 A Groundwater Discharge (m^3/day)	Change in Groundwater Discharge (m^3/day)	Percent Change In Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,716	-53	0%
Chilligo/Ellis Creek	Coldwater	14,618	14,580	-38	0%
Cox Creek	Coldwater	2,354	2,361	7	0%
Clythe Creek	Coldwater	1,906	1,927	21	1%
Eramosa River	Coldwater	122,620	122,556	-64	0%
Guelph Lake Tributary	Coldwater	9,430	9,451	21	0%
Hanlon Creek	Coldwater	3,718	3,249	-469	-13%[b]
Hopewell Creek	Coldwater	21,514	21,548	34	0%
Irish Creek	Warmwater	5,807	4,830	-977	-17%[b]
Lutteral Creek	Coldwater	34,184	34,208	24	0%
Marden Creek	Warmwater	2,982	3,004	22	1%
Mill Creek	Coldwater	38,566	38,276	-290	-1%
Moffat Creek	Coldwater	2,061	2,058	-3	0%
Speed River	Coldwater	246,216	246,332	116	0%
Swan Creek	Coldwater	5,908	5,919	11	0%
Torrance Creek	Warmwater	771	733	-38	-5%
West Credit River	Coldwater	30,642	30,632	-10	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.4 Northeast Quadrant Scenario A3-A: Clythe, Fleming, and Logan

The wells within the northeast quadrant of Guelph (i.e., Park, Emma and Helmar wells) have an estimated average-day capacity of 9,740 m^3/day in the Current Capacity scenario. Scenario A3-A estimates the increase in total system capacity by introducing the inactive Clythe well and the Fleming and Logan test wells (Figure 1). Within the Tier Three model, the Clythe well is located within an interpreted zone of relatively high hydraulic conductivity in the Middle Gasport Formation, and Fleming and Logan are just north of this zone (Figure 1). The nearest active municipal wells are all greater than 3 km away.

The estimated total system capacity with these three wells added is 70,370 m^3/day (Table 9). These three new wells contribute 6,850 m^3/day to the total, and the cumulative rate produced by the northeast quadrant wells is estimated to be 15,700 m^3/day. The analysis shows that decreasing the rates at Emma, Helmar, and Park wells allows for more pumping at the new wells, which increases the overall system capacity. Ultimately, the introduction of these new wells, along with decreasing rates at some other wells allows for a net increase in system capacity of 3,610 m^3/day.

In comparison to the Current Capacity Scenario, the estimated reductions in groundwater discharge as a result of Scenario A3-A are less than 10% in all coldwater streams except for Clythe Creek (24%; Table 12). The Tier Three model is not calibrated to groundwater pumping conditions at the Clythe Creek well location. There is resulting uncertainty with the estimated effects on the creek's baseflow and, as a result, baseflow to the creek was not considered as part of the water supply capacity optimization. However, without additional field data and model calibration, the simulated impacts are the best available estimates of surface water effects from increased pumping. These predicted effects on baseflow may not translate to ecological effects. The headwaters of Clythe Creek are a coldwater stream that has historically sustained a trout population (Amec Foster Wheeler 2017); however, the most recent warm water temperature results suggests that the lower and mid-reaches of the creek are considerably degraded. Should the City wish to pursue additional groundwater supplies in the northeast quadrant, the estimated effects to Clythe Creek should be evaluated with additional local calibration of the model as well as consideration of the potential local ecological impacts. The City is currently undertaking additional studies in this area (e.g., as part of the return to service of the Clythe well) and this data can be used to supplement the model at a later date. Should the City wish to pursue additional groundwater supplies in the northeast quadrant, the estimated effects to Clythe Creek should be evaluated with additional local calibration of the model as well as consideration of the potential local ecological impacts.

Table 12 Scenario A3-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[(a)]	Current Capacity Groundwater Discharge (m^3/day)	Scenario A3 A Groundwater Discharge (m^3/day)	Change in Groundwater Discharge (m^3/day)	Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,860	91	0%
Chilligo/Ellis Creek	Coldwater	14,618	14,602	-16	0%
Clythe Creek	Coldwater	1,906	1,450	-456	-24%[(b)]
Cox Creek	Warmwater	2,354	2,349	-5	0%
Eramosa River	Coldwater	122,620	121,866	-753	-1%
Guelph Lake Tributary	Coldwater	9,430	9,038	-392	-4%
Hanlon Creek	Coldwater	3,718	3,659	-59	-2%
Hopewell Creek	Coldwater	21,514	21,506	-8	0%
Irish Creek	Warmwater	5,807	5,806	-1	0%
Lutteral Creek	Coldwater	34,184	34,166	-18	0%
Marden Creek	Warmwater	2,982	2,939	-43	-1%
Mill Creek	Coldwater	38,566	38,549	-18	0%
Moffat Creek	Coldwater	2,061	2,062	1	0%
Speed River	Coldwater	246,216	242,781	-3,435	-1%
Swan Creek	Coldwater	5,908	5,865	-43	-1%
Torrance Creek	Warmwater	771	752	-19	-2%
West Credit River	Coldwater	30,642	30,603	-39	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.5 Northwest Quadrant Scenario A4-A: Sacco, Smallfield, Hauser and Sunny Acres

The wells within the Northwest Quadrant of Guelph (Paisley, Calico and Queensdale wells) have an estimated average-day capacity of 3,100 m^3/day in the Current Capacity Scenario. Scenario A4-A estimates the incremental system capacity with pumping at the inactive Sacco and Smallfield wells and introducing the Hauser test well and a hypothetical well located in Sunny Acres Park (Figure 1). A location in Sunny Acres Park, based on a monitoring well location (MW06-05), was previously considered as part of the last WSMP update (AECOM and Golder 2014) but has not yet been field tested. Sacco, Smallfield, and Hauser wells are all located 1,700 to 2,800 m northwest of Paisley well, within a relatively lower hydraulic conductivity area of the

Middle Gasport Formation as simulated in the Tier Three model (Figure 1). The hypothetical Sunny Acres well is proposed to the east between the Paisley, Water Street, and Park wells.

The estimated system capacity with these four wells added is 68,260 m^3/day (Table 9). Pumping at Sunny Acres results in a reduction of water levels at the surrounding municipal wells below the applied head constraints, and as result it is removed from consideration as an incremental water supply well. Decreasing the pumping rate at Paisley well allows the new wells to pump at higher rates, which increases the overall system capacity. The three new wells (Hauser, Sacco, and Smallfield wells) contribute 1,640 m^3/day to the total, and the estimated total rate produced by the Northwest Quadrant wells is 4,640 m^3/day. Ultimately, the introduction of these new wells, along with decreasing rates at some other wells, increases the average day capacity by 1,500 m^3/day.

In comparison to the Current Capacity Scenario, all reductions in simulated groundwater discharge to streams as a result of Scenario A4-A are predicted to be less than 10% (Table 13).

Table 13 Scenario A4-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[(a)]	Current Capacity Groundwater Discharge (m^3/day)	A4 A Groundwater Discharge (m^3/day)	Change in Groundwater Discharge (m^3/day)	Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,656	-113	-0%
Chilligo/Ellis Creek	Coldwater	14,618	14,118	-500	-3%
Clythe Creek	Coldwater	1,906	1,910	4	0%
Cox Creek	Warmwater	2,354	2,340	-14	-1%
Eramosa River	Coldwater	122,620	122,473	-147	0%
Guelph Lake Tributary	Coldwater	9,430	9,432	2	0%
Hanlon Creek	Coldwater	3,718	3,709	-9	0%
Hopewell Creek	Coldwater	21,514	21,305	-208	-1%
Irish Creek	Warmwater	5,807	5,800	-7	0%
Lutteral Creek	Coldwater	34,184	34,188	4	0%
Marden Creek	Warmwater	2,982	2,961	-21	-1%
Mill Creek	Coldwater	38,566	38,570	3	0%
Moffat Creek	Coldwater	2,061	2,061	0	0%
Speed River	Coldwater	246,216	245,916	-300	0%
Swan Creek	Coldwater	5,908	5,918	11	0%
Torrance Creek	Warmwater	771	747	-24	-3%
West Credit River	Coldwater	30,642	30,638	-5	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)
(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.6 Northwest Quadrant Scenario A4-B: Sacco, Smallfield, Hauser, and Hypothetical North Guelph Well

The wells within the Northwest Quadrant of Guelph (Paisley, Calico, and Queensdale wells) have an estimated average-day capacity of 3,100 m^3/day in the Current Capacity Scenario. Scenario A4-B estimates the increased system capacity by pumping at the inactive Sacco and Smallfield wells and introducing the Hauser test well and a hypothetical Guelph North well (Figure 1). The location of the hypothetical Guelph North well just north of the city boundary was previously considered as part of the last WSMP update (AECOM and Golder 2014) but has not yet been field tested. Sacco, Smallfield, and Hauser wells are all located 1,700 to 2,800 m northwest of Paisley well, within a relatively lower hydraulic conductivity area of the Middle Gasport Formation as simulated in the Tier Three model (Figure 1). The hypothetical Guelph North well is simulated to be approximately 3.5 km north of Sacco and 3.3 km west of Helmar.

The estimated system capacity with these four wells added is 70,420 m^3/day (Table 9). Due to a simulated hydraulic connection between the hypothetical Guelph North well and nearby pumping wells, pumping at the Guelph North well results in a reduction of water levels at many municipal wells to below the low water level thresholds. However, there is a degree of uncertainty in the actual hydraulic connection between the hypothetical Guelph North well location and the remaining municipal supply system. Further testing and data are required to refine this understanding.

This analysis suggests that decreasing the pumping rate at Park, Emma, and Paisley wells and not pumping from Helmar or Sacco allows for higher rates at the Guelph North hypothetical well and Hauser and Smallfield wells. This well rate trade-off leads to a net increase of the overall system capacity. The three new wells (Hauser, Smallfield, and Guelph North wells) contribute 4,810 m^3/day to the total, and the estimated total rate produced by the Northwest Quadrant wells is 7,770 m^3/day. Ultimately, the introduction of these new wells, along with decreasing rates at some other wells, allows for an increase in average day capacity of 3,660 m^3/day.

In comparison to the Current Capacity Scenario, all reductions in simulated groundwater discharge because of Scenario A4-B are predicted to be less than 10% at coldwater streams (Table 14). The largest reduction in simulated groundwater discharge is simulated to be 13% at the nearby warmwater Marden Creek.

Table 14 Scenario A4-B: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Current Capacity Groundwater Discharge (m^3/day)	A4 B Groundwater Discharge (m^3/day)	A4 B Change in Groundwater Discharge (m^3/day)	A4 B Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,808	39	0%
Chilligo/Ellis Creek	Coldwater	14,618	14,064	-554	-4%
Clythe Creek	Coldwater	1,906	1,908	2	0%
Cox Creek	Warmwater	2,354	2,200	-154	-7%
Eramosa River	Coldwater	122,620	122,649	29	0%
Guelph Lake Tributary	Coldwater	9,430	9,409	-21	0%
Hanlon Creek	Coldwater	3,718	3,821	103	3%
Hopewell Creek	Coldwater	21,514	20,735	-779	-4%
Irish Creek	Warmwater	5,807	5,800	-7	0%
Lutteral Creek	Coldwater	34,184	34,182	-2	0%
Marden Creek	Warmwater	2,982	2,590	-392	-13%[b]
Mill Creek	Coldwater	38,566	38,564	-2	0%
Moffat Creek	Coldwater	2,061	2,061	0	0%
Speed River	Coldwater	246,216	244,718	-1,498	-1%
Swan Creek	Coldwater	5,908	5,894	-14	0%
Torrance Creek	Warmwater	771	771.0552765	0	0%
West Credit River	Coldwater	30,642	30,627	-15	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)
(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.7 Combined Well Sources Scenario A5-A: Edinburgh, Ironwood, GSTW1-20, Steffler, Clythe, Fleming, Logan, Hauser, Sacco, Smallfield

Scenario A5-A combines Scenarios A2-A through A4-A and includes well sources identified to potentially provide additional capacity located on City-owned lands. These additional wells (in addition to the existing municipal supply sources considered as part of the Current Capacity Scenario) include inactive wells Edinburgh, Sacco, Smallfield, and Clythe and test wells Ironwood, Steffler, GSTW1-20, Fleming, Logan, and Hauser.

The estimated average-day capacity with these ten wells added is 76,740 m^3/day (Table 15). These ten wells contribute 18,820 m^3/day to the total. Decreasing the rates at Arkell 7, Arkell 14, Membro, Water Street, Downey, Park, Helmar, Paisley, and Queensdale wells allows these new wells to pump at higher rates, which increases the system capacity overall. The rate reduction of these wells from the Current Capacity Scenario wells is cumulatively 7,390 m^3/day. The optimized scenarios have Dean and University wells not pumping, a cumulative reduction of 1,390 m^3/day, as in Scenario A2-A. The introduction of the new wells results in an increased average-day capacity of 9,980 m^3/day.

The simulated drawdown caused by Scenario A5-A pumping relative to the Baseline Scenario is plotted on Figure 5. The 1 m drawdown contour extends approximately 3.5 km further north and 6.5 km further south of the drawdown simulated under Current Capacity rates (Figure 4) due to the addition of Fleming and Logan wells in the north and GSTW1-20 well in the south. The largest drawdown is simulated to be approximately 53 m surrounding Logan well, where the pumping rate is increased from a Baseline rate of 0 to 4,250 m^3/day.

In comparison to the Current Capacity Scenario, the largest simulated reductions in groundwater discharge to streams are 13% (500 m^3/day), 17% (998 m^3/day), and 24% (468 m^3/day) at Hanlon (coldwater), Irish (warmwater) and Clythe (coldwater) creeks, respectively (Table 16). The simulated reductions at Hanlon and Irish creeks are caused by the increased rates in the southwest quadrant (comparable to Scenario A2-A). The simulated reduction at Clythe Creek is caused by the increased rates in the northeast quadrant, specifically the Clythe well (comparable to Scenario A3-A). As described previously, the model is not well calibrated in the areas around Clythe Creek and there is some uncertainty relating to the estimated effects on this creek. However, without local model calibration, the simulated impacts are the best available estimates at this time. Furthermore, the creek is degraded with warm temperature conditions in the lower and mid-reaches of the creek and any local ecological effects should consider more recent or current aquatic studies, including additional studies in the area currently being undertaken by the City. This data can be used to supplement the groundwater flow model at a later date. The remaining groundwater discharge reductions are less than 5%.

Table 15 Summary of the Optimized Well Rates and Available Head Exceedances for Current Capacity Scenario and Scenarios A5-A, A5-B and A5-C

City Quadrant	Municipal Well/Source	Maximum Individual Well Capacity Threshold (m^3/day)	Adjusted Simulated Low Water Threshold (m asl)	Current Capacity Scenario		Scenario A5 A			Scenario A5 B			Scenario A5 C		
				Pumping Rate (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	Change in Pumping[a] (m^3/day)	Available Head (m)
Southeast	Arkell 1	2,000	319.5	2,000	2	2,000	0	2	2,000	0	2	2,000	0	2
	Arkell 6	8,000	305.7	1,500	5.1	1,500	0	4.9	1,500	0	5.1	1,500	0	4.8
	Arkell 7	8,000	305.7	8,000	3.6	7,000[e]	-1,000	3.6	8,000	0	3.6	8,000	0	3.5
	Arkell 8	7,000	311.1	0	-0.1[c]	0	0	-0.2[c]	0	0	-0.1	0[f]	0	-0.3[c]
	Arkell 14	7,000	310.9	3,100	-0.0	1,800[e]	-1,300	-0.0	3,100	0	-0.0	1,500[e]	-1,600	-0.1[c]
	Arkell 15	7,000	304.4	7,000	5.3	7,000	0	4.9	7,000	0	5.3	7,000	0	4.8
	Burke	6,500	323.4	5,200	0.2	5,200	0	0.1	5,200	0	0.2	5,000[e]	-200	0
	Carter Wells	6,400	318.5	6,100	0	6,100	0	-0.1[c]	6,100	0	0	5,500[e]	-600	0.5
	Guelph East 1[b]	-	303.4	-	-	-	-	-	0	0	8.1	-	-	-
	Guelph East 2[b]	-	303.1	-	-	-	-	-	0	0	9.1	-	-	-
	Guelph Southeast[b]	6,500	276.7	-	-	-	-	-	-	-	-	4,000[d]	4,000	20.5
Southwest	Membro	5,200	282.1	5,200	0.8	4,700[e]	-500	0.8	5,200	0	0.8	4,700[e]	-500	1
	Water St.	2,700	289.2	1,950	0.1	1,500[e]	-450	-0.1[c]	1,950	0	0.1	1,200[e]	-750	0.6
	Dean	1,500	289.9	540	0	0[f]	-540	0.1	540	0	0	0[f]	-540	0.3
	University	2,500	290.4	850	0.3	0[f]	-850	-2.5[c]	850	0	0.3	0[f]	-850	-2.3[c]
	Downey	5,237	286.4	5,240	0.9	2,250[e]	-2,990	0	5,240	0	0.9	2,250[e]	-2,990	0.1
	Edinburgh[b]	3,000	288.0	-	-	980	980	0	-	-	-	980[d]	980	0.3
	Ironwood[b]	8,000	273.6	-	-	3,750[d]	3750	9.5	-	-	-	3,750[d]	3,750	9.6
	GSTW1-20[b]	4,320	288.2	-	-	4,100[d]	4100	-0.1[c]	-	-	-	3,900[d]	3,900	0.7
	Steffler[b]	3,600	285.7	-	-	1,500[d]	1500	0.4	-	-	-	1,500[d]	1,500	0.5
Northeast	Park Wells	8,000	281.0	6,680	0.1	6,300[e]	-380	0.9	6,680	0	0.1	6,300[e]	-380	0.3
	Emma	2,800	278.2	2,390	0.3	2,100	-290	2.9	2,390	0	0.3	2,100[e]	-290	2
	Helmar	800	321.4	670	0.1	400[e]	-270	0	670	0	0.1	0[f]	-670	0.9
	Clythe[b]	3,395	309.3	-	-	1,500[d]	1,500	0.5	-	-	-	1,500[d]	1,500	0.4
	Fleming[b]	2,200	310.7	-	-	1,100[d]	1,100	0.2	-	-	-	1,100[d]	1,100	0.3
	Logan[b]	4,700	281.5	-	-	4,250[d]	4,250	0.1	-	-	-	4,100[d]	4,100	3.2
Northwest	Paisley	1,400	298.5	940	0	790[e]	-150	0.1	940	0	0	400[e]	-540	3.7
	Calico	1,400	294.2	1,400	13.2	1,400	0	11.9	1,400	0	13.2	1,400	0	11.9
	Queensdale	1,100	295.9	760	0.5	700	-60	-0.1[c]	760	0	0.5	700[e]	-60	0.3
	Hauser[b]	900	317.7	-	-	510[d]	510	0	-	-	-	300[d]	300	0.9
	Sacco[b]	1,150	321.2	-	-	150[d]	150	0.6	-	-	-	0[f]	0	-0.0
	Smallfield[b]	1,408	284.3	-	-	980[d]	980	30.4	-	-	-	980[d]	980	30
	Guelph North[b]	5,000	298.1	-	-	-	-	-	-	-	-	3,530[d]	3,530	13.7
	Glen Collector	-	-	7,240	-	7,180	-60	-	7,240	0	-	7,180	-60	-
Total (Wells)		**131,710**	**-**	**59,520**	**-**	**69,560**	**10,040**	**-**	**59,520**	**0**	**-**	**75,190**	**15,670**	**-**
Total (Wells + Collector)		**-**	**-**	**66,760**	**-**	**76,740**	**9,980**	**-**	**66,760**	**0**	**-**	**82,370**	**15,610**	**-**

(a) Scenario pumping rate compared to the Current Capacity Scenario Rate
(b) Future Scenario Well
(c) Low water level threshold exceedance
(d) Pumping rate is greater than rate in the Current Capacity Scenario
(e) Pumping rate is less than rate in the Current Capacity Scenario
(f) Pumping rate is set to 0 m^3/day
asl - above sea level

Table 16 Scenario A5-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Current Capacity Groundwater Discharge (m^3/day)	A5 A Groundwater Discharge (m^3/day)	A3 A Change in Groundwater Discharge (m^3/day)	A3 A Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,653	-116	0%
Chilligo/Ellis Creek	Coldwater	14,618	14,043	-575	-4%
Clythe Creek	Coldwater	1,906	1,438	-468	-24%[b]
Cox Creek	Warmwater	2,354	2,331	-23	-1%
Eramosa River	Coldwater	122,620	121,729	-890	-1%
Guelph Lake Tributary	Coldwater	9,430	9,034	-396	-4%
Hanlon Creek	Coldwater	3,718	3,218	-500	-13%[b]
Hopewell Creek	Coldwater	21,514	21,274	-240	-1%
Irish Creek	Warmwater	5,807	4,809	-998	-17%[b]
Lutteral Creek	Coldwater	34,184	34,174	-10	0%
Marden Creek	Warmwater	2,982	2,933	-49	-2%
Mill Creek	Coldwater	38,566	38,213	-354	-1%
Moffat Creek	Coldwater	2,061	2,057	-4	0%
Speed River	Coldwater	246,216	242,381	-3,835	-2%
Swan Creek	Coldwater	5,908	5,907	-1	0%
Torrance Creek	Warmwater	771	733	-38	-5%
West Credit River	Coldwater	30,642	30,640	-3	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

(b) Reduction in simulated groundwater discharge is greater than 10%

5.1.8 Combined Well Sources Scenario A5-B: Guelph East 1 and 2

Scenario A5-B was designed to evaluate if there is additional capacity with pumping from the simulated high hydraulic conductivity zone that continues west from the Arkell Well system. The scenario includes two hypothetical new well sources located on Guelph Innovation District Lands. These two additional Guelph East wells (in addition to the existing municipal supply sources considered as part of the Current Capacity Scenario) include a well located on the Guelph former

Turf Grass Institute (Guelph East 1) and one at Stone Road East and Watson Road South (Guelph East 2; Figure 1).

Ultimately, the addition of either of these wells to the Current Capacity pumping layout provided no simulated increase in system capacity. Hydraulic heads at wells in the area are interconnected due to the interpreted high transmissivity of the aquifer here, and the addition of any new well sources reduces the heads below assigned low water level thresholds at other municipal wells. The wells that would exceed low water level thresholds if the Guelph East 1 and 2 wells were installed include Arkell 14, Water Street, Park, and Helmar.

5.1.9 Combined Well Sources Scenario A5-C: Edinburgh, Ironwood, GSTW1-20, Steffler, Clythe, Fleming, Logan, Hauser, Sacco, Smallfield, and Hypothetical North and Southeast Guelph Wells

Scenario A5-C was designed based on the combined results of Scenarios A2-A through A5-A and includes well sources, including hypothetical well sources, identified to potentially provide additional capacity both inside and outside City boundaries (Figure 1). These additional wells (in addition to the existing municipal supply sources considered as part of the Current Capacity Scenario) include inactive wells (Edinburgh, Sacco, Smallfield, and Clythe), test wells (Ironwood, Steffler, GSTW1-20, Fleming, Logan, and Hauser), and hypothetical wells (Guelph North and Guelph Southeast wells).

The estimated average-day capacity with these 12 potential wells added is 82,730 m^3/day (Table 15). These twelve wells contribute 25,640 m^3/day to the total. Decreasing the rates at Arkell 14, Burke, Carter, Membro, Water Street, Downey, Park, Emma, Paisley, and Queensdale wells allows these new wells to pump at higher rates, which overall increases the system capacity. The rate reduction of these wells from the Current Capacity Scenario wells is cumulatively 7,910 m^3/day. The optimized scenario has Dean, University, Helmar, and Sacco wells not pumping, which is a cumulative rate reduction of 2,060 m^3/day. The introduction of the 12 new wells results in an incremental average-day capacity of 15,610 m^3/day.

The simulated drawdown caused by pumping at Scenario A5-C rates relative to the Baseline Scenario is plotted on Figure 6. Similar to Scenario A5-A, the 1 m drawdown contour extends approximately 3.5 km further north and 6.5 km further south than the drawdown simulated under Current Capacity rates (Figure 4) due to the addition of Fleming and Logan wells in the north and GSTW1-20 well in the south. The 1 m contour also extends an additional 3.5 km northwest and 6.5 km southeast due to the addition of the hypothetical Guelph North well and Guelph Southeast well, respectively. Also, similar to Scenario A5-A, the largest drawdown is simulated to be nearly 50 m surrounding Logan well, where the pumping rate is increased from a Baseline rate of 0 to 4,100 m^3/day.

In comparison to the Current Capacity Scenario, the largest simulated reductions in groundwater discharge to streams are 30% (578 m^3/day), 18% (662 m^3/day), 17% (990 m^3/day), and 14% (429 m^3/day) at Clythe (coldwater), Hanlon (coldwater), Irish (warmwater), and Marden (warmwater) creeks, respectively (Table 17). The simulated reductions at Hanlon and Irish creeks are in response to the increased rates in the southwest quadrant (comparable to Scenario A2-A). The simulated reduction at Clythe Creek is in response to the increased rates in the northeast quadrant, specifically the Clythe well (comparable to Scenario A3-A). The remaining groundwater discharge reductions are less than 10%.

Simulated steady-state effects on groundwater discharge are conservative estimates of what might be experienced under operation of new wellfields. Under actual operating conditions, municipal pumping rates never occur at a constant rate and vary seasonally and daily. Similarly, streamflow varies daily and seasonally in response to climate events and physical features, such as wetlands and shallow perched aquifers, that are not represented in the model. As a result, decisions to proceed with permitting a municipal well should not be based purely on groundwater model results. Model scenarios identifying areas of higher baseflow effects should be used to focus on the need for additional field data or areas where adaptive environmental monitoring programs can accompany routine water supply operations activities. As an example, the City now has a much larger water supply from the Arkell area, and initial computer modelling predicted potential surface water effects. However, the adaptive monitoring program in the Arkell area has not identified any changes to the surface water flow regime during the period of higher pumping.

As described previously, further calibration work should be completed around Clythe Creek using data from additional studies currently being undertaken by the City for a more accurate evaluation of impacts. While uncertain, the simulated impacts are the best available estimates at this time.

Table 17 Scenario A5-C: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[a]	Current Capacity Groundwater Discharge (m^3/day)	A5 C Groundwater Discharge (m^3/day)	A3 A Change in Groundwater Discharge (m^3/day)	A3 A Percent Change in Groundwater Discharge (%)
Blue Springs Creek	Coldwater	41,769	41,311	-458	-1%
Chilligo/Ellis Creek	Coldwater	14,618	14,030	-588	-4%
Clythe Creek	Coldwater	1,906	1,328	-578	-30%[b]
Cox Creek	Warmwater	2,354	2,188	-166	-7%
Eramosa River	Coldwater	122,620	121,315	-1,305	-1%
Guelph Lake Tributary	Coldwater	9,430	9,013	-417	-4%
Hanlon Creek	Coldwater	3,718	3,057	-662	-18%[b]
Hopewell Creek	Coldwater	21,514	20,713	-801	-4%
Irish Creek	Warmwater	5,807	4,817	-990	-17%[b]
Lutteral Creek	Coldwater	34,184	34,170	-13	0%
Marden Creek	Warmwater	2,982	2,553	-429	-14%[b]
Mill Creek	Coldwater	38,566	36,560	-2,007	-5%
Moffat Creek	Coldwater	2,061	2,057	-4	0%
Speed River	Coldwater	246,216	240,624	-5,592	-2%
Swan Creek	Coldwater	5,908	5,891	-17	0%
Torrance Creek	Warmwater	771	812	41	5%
West Credit River	Coldwater	30,642	30,638	-5	0%

Notes:

(a) From MNR (2013) and GRCA (2013) in Matrix (2017)

(b) Reduction in simulated groundwater discharge is greater than 10%

5.2 Quarry Water Capture Scenario B1

The Quarry Water Capture Scenario B1 evaluates the potential of increasing pumping from municipal wells near the Dolime Quarry (Figure 1) under the conceptual Pond Level Management strategy. This strategy requires inward gradients to the quarry pond to prevent the outflow of poor quality water to the aquifer. The concept tested as part of Scenario B1 is to evaluate potential increased pumping from municipal wells and reduced dewatering rates, while maintaining a 1 m hydraulic head gradient from the Middle Gasport Formation at the MW08-02A location toward the base of the quarry. This 1 m hydraulic head gradient criteria serves to ensure that there is a groundwater gradient into the pond, and that surface water within the pond does not leak into the water supply aquifer. AECOM provided Matrix initial direction to evaluate the scenario with the water level in the quarry equal to 288.39 m above sea level (asl), which is consistent with the current PTTW.

The Dolime Quarry is simulated with a high hydraulic conductivity zone (i.e., 5.00E-01 m/s) to represent the open excavation and a constant head boundary condition at 288.39 m asl reflecting the current quarry pond level and dewatering operations.

The initial scenario results indicated that the proposed quarry water capture scenario could not offer an incremental water supply given that the MW08-02A water level constraint (i.e., 1 m hydraulic gradient) was already violated under the Current Capacity Scenario. As shown in Table 18, the Current Capacity Scenario had a head difference of 0.23 m between the Dolime Quarry pond elevation and MW08-02A.

Two main components of the groundwater flow system influence the gradient between MW08-02A and the quarry. These two components include the hydraulic head applied to the quarry boundary condition (i.e., the water level to which the quarry is dewatered) and the pumping rate at nearby Membro well. Table 18 summarizes the values of these parameters for the Current Capacity Scenario.

The Quarry Water Capture Scenario was further evaluated by evaluating the effects of making adjustments to both the pond elevation and the Membro pumping rate. Table 18 summarizes seven sub-scenarios carried out to further investigate different combinations of Membro pumping rates, Dolime pond water level constraints, and the resulting Dolime dewatering rates. A head difference greater than 1 m between the quarry pond and MW08-02A was only achieved by sufficiently reducing the pumping rate at the nearby Membro well (i.e., Scenarios B1-5 and B1-7). When increasing the quarry pond boundary condition elevation (Scenarios B1-2 and B1-3), the simulated Dolime dewatering discharge rate decreases by approximately 500 m^3/day per meter increase, while the head difference between MW08-02A and the quarry pond decreases. Under Scenario B1-3, the gradient would be inverted from the quarry to the Middle Gasport Formation, which is not the desired outcome. These results suggest that the total capacity of the water supply system may be lower than that predicted by the Current Capacity Scenario by approximately 2,000 m^3/day if a 1 m gradient is enforced between MW08-02A and the Dolime Quarry. For completeness, the simulated water levels at MW08-02A are also provided for all scenarios (A2 through A5).

While this scenario does not identify additional capacity with the City's existing pumping wells and the constraints employed, there is more work required to evaluate the water supply opportunity at Dolime. Some of the alternatives requiring further evaluation include:

- Model refinement and calibration. The City is currently undertaking detailed field testing, and the results of these testing efforts will be used to refine and calibrate the model. The outcome of this work will be to ensure that the model offers the precision and accuracy needed to evaluate this complex water supply alternative.

- Further evaluation of the pond level and hydraulic head gradient constraints. Lowering the pond level and lowering the hydraulic head gradient to below 1.0 m may increase available water supply.

- Modifying the groundwater divide. Modifying the location of the groundwater divide (i.e., closer to the pond) may also impact the estimate of available water.

- Utilizing quarry discharge. Under the current scenarios, the quarry discharge rate ranges from just over 4,500 m^3/day to almost 6,200 m^3/day. This excess discharge suggests that there are alternatives to pumping additional groundwater such as treating the quarry water to potable conditions.

These above and other alternatives will be examined as part of the more detailed work that comes out of the operational testing program currently underway for the Dolime Quarry. For the purpose of this assessment, the incremental water supply capacity of the Dolime Quarry is assumed to be 5,000 m^3/day under the Current Capacity pumping conditions. This supply capacity represents a combination of additional pumping for existing or new wells or the treatment of quarry discharge water.

Table 18 Scenario B1: Summary of Simulated Quarry Water Capture Scenario Results Considering Current Municipal Wells

Scenario	Dolime Quarry BC elevation (m asl)	Dolime Quarry Boundary Condition Discharge Rate (m^3/day)	MW08 02A Water Level (m^3/day)	Head Difference[(a)] (m)	Membro Well Water Level (m asl)	Membro Well Pumping Rate (m^3/day)
Current Capacity	288.39	4,966	288.62	0.23	282.82	5,199
B1-2	289.25	4,542	289.33	0.08	283.43	5,199
B1-3	290.25	4,045	290.16	-0.09	284.14	5,199
B1-4	289.25	4,897	289.57	0.32	284.41	4,700
B1-5	289.25	6,109	290.39	1.14	287.76	3,000
B1-6	288.39	5,820	289.20	0.81	285.18	4,000
B1-7	288.39	6,181	289.44	1.05	286.17	3,500
A2-A	288.39	3,643	288.35	-0.04	282.93	4,700
A3-A	288.39	4,877	288.57	0.18	282.72	5,199
A4-A	288.39	4,801	288.56	0.17	282.73	5,200
A5-A	288.39	3,432	288.29	-0.10	282.85	4,700

(a) Head difference between the Dolime Quarry constant head boundary condition and the MW08-02A simulated head

5.3 Arkell Recharge/Collector Optimization Scenarios

The City operates an artificial groundwater recharge system with a shallow groundwater collector referred to as the Glen Collector. The City pumps surface water from the Eramosa River, followed by infiltration into groundwater through the Arkell groundwater recharge system consisting of a pond and trench. A portion (approximately 50%) of this infiltrated water supplements groundwater recharge to the Glen Collector.

Under the Current Capacity Scenario, the steady-state infiltration of water from the Eramosa River into the Arkell recharge system is simulated as 3,290 m^3/day. This is an average of annual infiltration, recognizing that infiltration rates vary seasonally according to the requirements of the City’s current PTTW. A portion of this water, along with natural shallow groundwater discharge to the Glen Collector, results in 7,240 m^3/day being collected at the Glen Collector (i.e., 220% of what was infiltrated). The Arkell recharge/collector scenarios described in the following sections are designed to evaluate the potential to achieve higher collection rates and efficiencies.

5.3.1 Increased Eramosa River Recharge Scenario C1

Scenario C1 evaluates the increased rate of water collection at the Glen Collector (i.e., total due to Arkell infiltration plus shallow groundwater flow) if the Eramosa River taking is increased to higher rates allowed under the PTTW. The amount of water withdrawn from the Eramosa River is currently limited by:

- seasonal PTTW conditions on maximum daily takings (Table 19)
- a requirement to maintain a minimum flow in the Eramosa River of 37,152 m^3/day (0.43 m^3/s)
- the existing Eramosa pump capacity of 9,072 m^3/d

Table 19 Seasonal Permitted Pumping Rates of the Eramosa River as Listed in the Permit to Take Water

Season	Permitted Pumping Rates (m^3/day)
April 15 to May 31	31,822
June 1 to June 30	22,730
July 1 to July 15	18,184
July 16 to August 31	13,638
September 1 to November 15	9,092

Note:
Water extraction from the Eramosa River is permitted only when the baseflow is greater than 37,152 m^3/day (0.43 m^3/s).

Scenario C1 evaluates the potential increase in Glen Collector flows under both steady-state and transient conditions considering three sets of infiltrations rates. These infiltration rates correspond to the existing pump capacity (0.105 m^3/s or 9,072 m^3/day), double pump capacity (0.21 m^3/s or 18,144 m^3/day), and triple pump capacity (0.32 m^3/s or 27,648 m^3/day).

The objective of the steady-state scenarios is to provide a general prediction of the average annual volumetric rate of water collected by the Glen Collector. The steady-state scenarios include the municipal wells pumping at the Current Capacity Scenario rates, average annual groundwater recharge across the model, and the equivalent average annual infiltration rate into the Arkell pond and trench.

The objective of the transient scenarios is to develop insight into the seasonal variability of the water collected by the Glen Collector. The transient model simulations include the first 7 years of the 10-year Tier Three drought scenario, using the same approach followed for the Lower Road

Collector scenario (Section 5.1.1; Scenario A1-A). The transient scenarios use the pumping rates established in the earlier Drought Capacity Scenario and monthly-varying average infiltration rates into the pond and trench for the 7-year transient period.

To complete this evaluation, observed Eramosa River baseflow data from the Water Survey of Canada Eramosa River Gauge between 1962 and 2006 were evaluated to estimate maximum allowable pumping rates under the seasonal conditions of the PTTW. Average monthly groundwater infiltration rates applied to the model were calculated based on the maximum pump capacity and the amount of river water available while maintaining a flow of 37,152 m^3/day (0.43 m^3/s) in the river. Table 20 summarizes the average monthly infiltration rates for the three pump capacities evaluated.

Table 20 Scenario C1: Average Monthly Infiltration Rates

Month	Existing Eramosa Pump Capacity 0.105 m^3/s (9,072 m^3/day)			Double Eramosa Pump Capacity 0.21 m^3/s (18,144 m^3/day)			Triple Eramosa Pump Capacity 0.32 m^3/s (27,648 m^3/day)		
	Monthly Average (m^3/day)	Minimum Daily Rate (m^3/day)	Maximum Daily Rate (m^3/day)	Monthly Average (m^3/day)	Minimum Daily Rate (m^3/day)	Maximum Daily Rate (m^3/day)	Monthly Average (m^3/day)	Minimum Daily Rate (m^3/day)	Maximum Daily Rate (m^3/day]
January	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0
April	4,682	4,682	4,682	9,365	9,365	9,365	14,270	14,270	14,270
May	9,368	9,072	9,374	18,655	15,725	18,749	28,303	19,354	28,570
June	8,435	4,682	8,779	16,414	7,609	17,559	21,099	6,243	22,730
July	8,326	3,326	9,374	12,250	0	15,725	12,595	0	15,911
August	6,880	0	9,072	10,020	0	13,638	9,867	0	13,638
September	6,276	0	8,779	6,886	0	9,092	6,819	0	9,092
October	8,206	907	9,092	8,565	1,210	9,092	8,415	1,843	9,092
November	4,201	1,171	4,390	8,116	1,171	8,779	8,359	892	9,092
December	0	0	0	0	0	0	0	0	0
Average	4,698	1,987	5,295	7,523	2,923	8,500	9,144	3,550	10,200
Minimum	0	0	0	0	0	0	0	0	0
Maximum	9,368	9,072	9,374	18,655	15,725	18,749	28,303	19,354	28,570

Chart 2 illustrates the transient discharge from the Glen Collector for the three pump capacity scenarios based on the transient infiltration rates provided in Table 20. As illustrated in this chart, increasing the pump capacity results in significant increases in maximum discharge; however, minimum discharge rates into the Glen Collector during periods where pumping is not permitted does not increase.

While the simulated total Glen Collector discharge rate exceeds 25,000 m^3/day for the highest pumping scenario, the collector flows are currently limited in the PTTW to 25,000 m^3/day. The simulated annual minimum Glen Collector discharge rates for each Eramosa pump capacity scenario are summarized in Table 21. The lowest simulated discharge is 1,932; 2,050; and 2,126 m^3/day for the existing, double, and triple pump capacity scenarios, respectively.

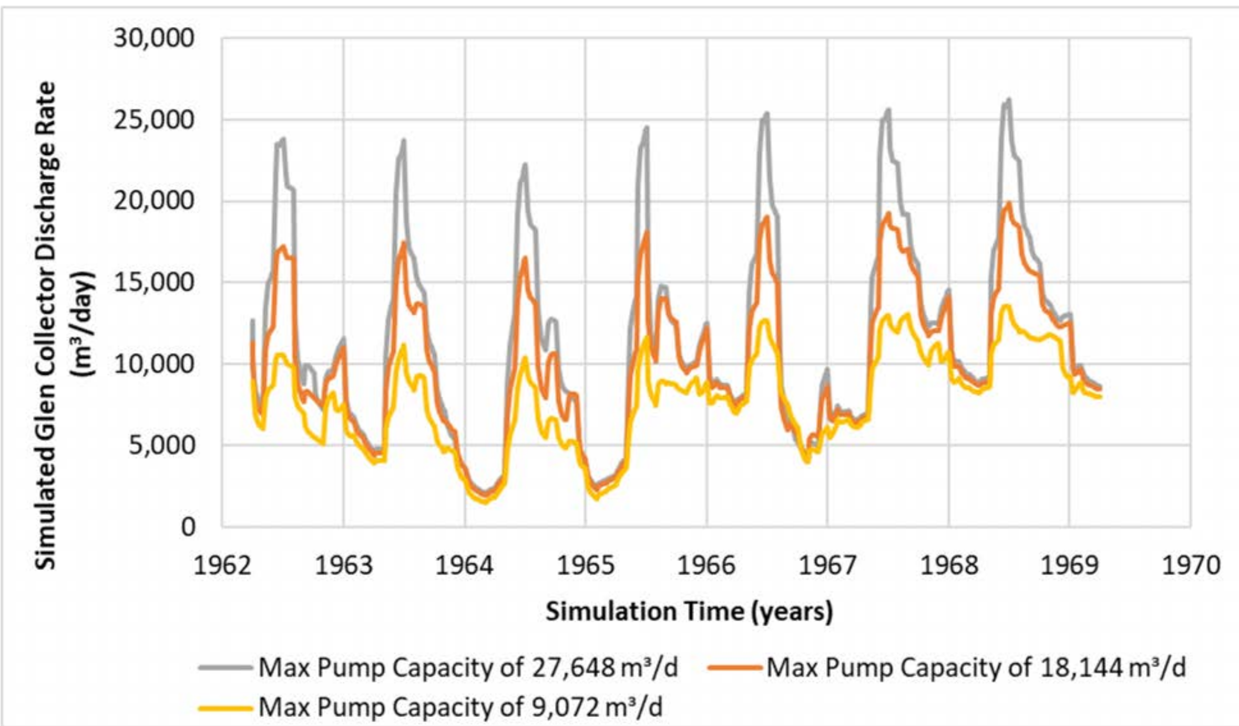

Chart 2 Simulated Total Transient Glen Collector Discharge Under the Various Pump Capacity Scenarios

Table 21 Scenario C1: Simulated Total Glen Collector Annual Minimum Discharge Rates

Year	Glen Collector Discharge (m^3/day)		
	9,072 m^3/d Pump Capacity	18,144 m^3/d Pump Capacity	27,648 m^3/d Pump Capacity
1962	5,126	6,915	7,378
1963	2,353	3,017	3,691
1964	1,957	2,050	2,126
1965	1,932	2,368	2,682
1966	4,269	4,491	4,439
1967	5,519	6,685	6,848
1968	8,268	8,952	8,919

For the evaluation of Glen Collector discharge under steady-state conditions, average annual infiltration rates of 4,698; 7,523; and 9,144 m^3/day were applied for the three pump capacity scenarios (Table 20). Average annual values represent the average pumping rate if the water takings were spread over the whole year. Table 22 summarizes the estimated steady-state discharge rate at the Glen Collector under the three steady-state infiltration rates as well as the collector efficiency (i.e., calculated as the average annual Glen Collector discharge divided by the average annual infiltration). As illustrated in the table, the efficiency is highest within the Current Capacity Scenario when shallow groundwater discharge into the collector is greater than the amount infiltrated. This efficiency decreases as the amount of infiltrated water is increased in the pump capacity scenarios. As the amount of infiltrated water increases, only a portion of that infiltrated water is collected resulting in an apparent decrease in collector efficiency.

Table 22 Summary of Steady-state Arkell Infiltration and Glen Collector Discharge Scenario Results

	Current Capacity Scenario	Pump Capacity Scenario		
		9,072 (m^3/day)	18,144 (m^3/day)	27,648 (m^3/day)
Average Annual Infiltration (m^3/day)	3,290	4,698	7,523	9,144
Average Annual Glen Collector Discharge (m^3/day)	7,240	7,969	10,779	12,139
Collector Efficiency	220%	170%	143%	133%
Incremental Infiltration Over Current Capacity (m^3/day)	-	1,408	4,233	5,854
Incremental Glen Collector Discharge Over Current Capacity (m^3/day)	-	729	3,539	4,899
Incremental Collector Efficiency Over Current Capacity	-	52%	84%	84%

Table 22 also summarizes the incremental infiltration, discharge, and efficiency over Current Capacity Scenario values. The results show that while the overall collector efficiency decreases, the incremental efficiency over Current Capacity generally increases. This suggests that on an average annual basis, as more water is infiltrated and water levels rise, the Glen Collector is able to capture a higher proportion of the infiltrated water.

Table 22 also shows that at a current pump capacity of 9,072 m^3/day operating at optimal conditions, the incremental increase in Glen Collector discharge over the Current Capacity value increases by 10% (or 729 m^3/day). The incremental increase in discharge for the pump capacity of 27,648 m^3/day (tripling pump capacity) is 4,899 m^3/day.

Chart 3 illustrates a comparison of both the estimated steady-state and transient discharge rate at the Glen Collector under the three pump capacities evaluated. Similar to the steady-state results in Table 22, the results illustrated in Chart 3 indicate that increasing the recharge rate up to the maximum rate allowed by the PTTW does not result in the same proportional increase in collector discharge rate. The minimum transient Glen Collector discharge rates range from 1,519 to 2,094 m^3/day (i.e., an increase by a factor of 1.4 relative to a tripling of the pumping rate), while the maximum transient Glen Collector discharge rates range from 13,545 to 26,252 (i.e., an increase by a factor of 1.9 relative to a tripling of the pumping rate). Regardless, these scenarios indicate that if the Eramosa pump is updated to increase the maximum allowable rate, more water can be pumped from the Eramosa River, while following PTTW constraints, and this will lead to an increase in groundwater recovered from the Glen Collector. Note that while the maximum simulated Glen Collector discharge rate is predicted to exceed 25,000 m^3/day, the PTTW limits the collector flows to 25,000 m^3/day.

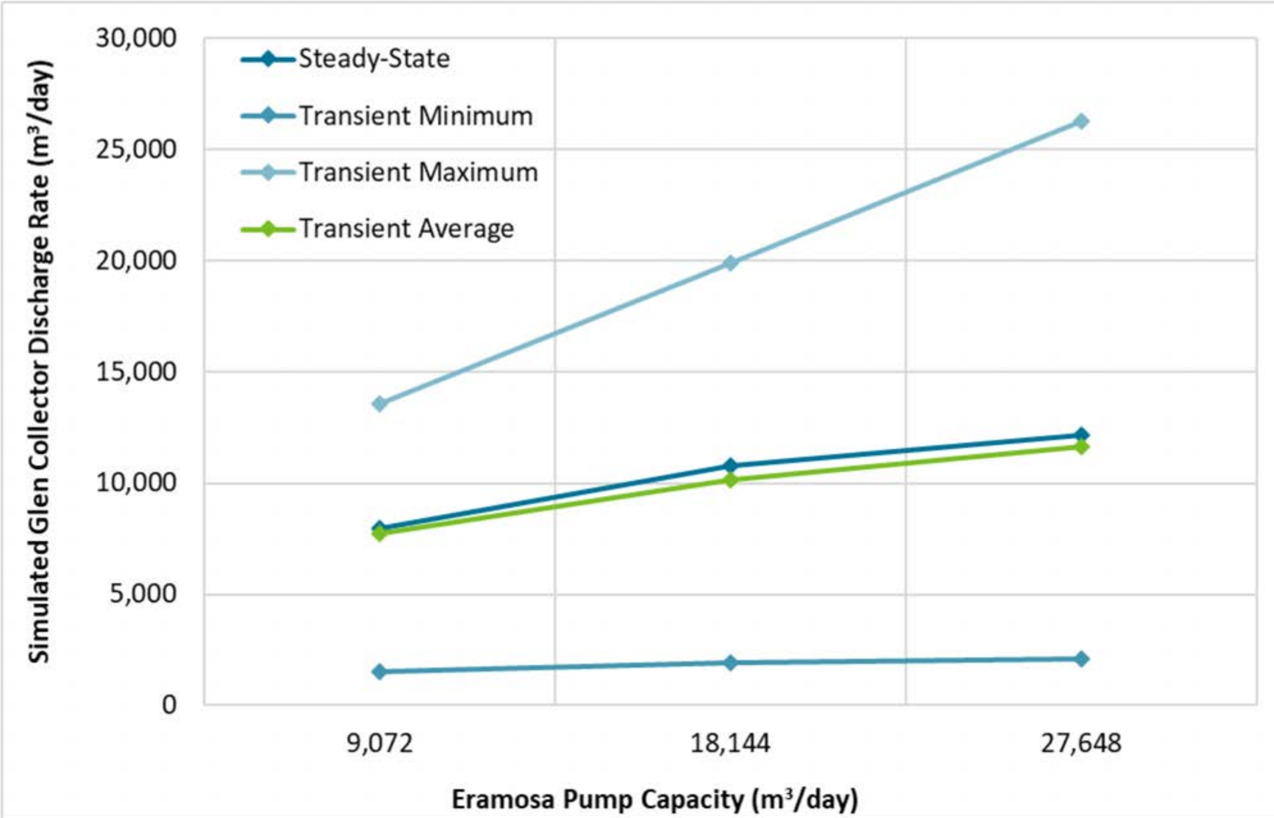

Chart 3 Estimated Glen Collector Collection Rates Versus Maximum Pump Capacity

Note that Scenario C1 only considers the Glen Collector as a possible source of water. Future evaluations may be conducted to predict how much additional water may be collected if the Lower Road Collector were to be reconstructed. Future scenarios may also be designed to evaluate alternative configurations of the collectors and their influence on the overall efficiency of the system.

5.3.2 Alternative Recharge Gallery/Collector Configuration Scenario C2

This scenario evaluates the effectiveness of replacing the Glen Collector with a new Caisson Collector System upgradient (approximately 300 m southeast of the Glen Collector; Figure 1). The location of the Caisson Collector reflects the recommendation of the Stantec Caisson Collector study (Stantec 2006). This assessment does not consider other locations for this collector. This scenario removes the boundary conditions representing the Glen Collector System, with a corresponding simulated steady-state loss of 7,240 m^3/day. This scenario also removes the Arkell 1 well due to its proximity (within 10 m) to the proposed Caisson Collector System. The removal of Arkell 1 corresponds to a simulated loss of 2,000 m^3/day. The boundary conditions representing the artificial recharge from the Eramosa River remained active, at a constant recharge rate of 3,290 m^3/day.

Matrix initially tested several Caisson Collector System layouts under long-term steady-state conditions. The optimal design brought forward for evaluation included a Caisson Collector System with one lateral screen projection, 110 m in length, and oriented perpendicular to the groundwater flow direction. This design is consistent with one of the potential configurations reported in Stantec (2006). The model represents the lateral screen and water withdrawal using nine constant head boundary conditions placed at the base of the coarser overburden unit (i.e., model slice 3) at an assigned elevation of 317.5 m asl. This value corresponds to the highest elevation of the underlying till unit along the length of the lateral screen. The steady-state withdrawal from the Caisson Collector System was simulated to be 9,598 m^3/day (Table 23). Under this withdrawal, groundwater discharge to the Eramosa River was simulated to decrease by 1,744 m^3/day, which corresponds to a reduction of 1% relative to the Current Capacity Scenario.

To test the range of the Caisson Collector System discharge under variable recharge, the Caisson Collector system was also evaluated transiently (using the 7-year monthly transient drought scenario; Chart 4). Under this transient simulation, the Caisson Collector System withdrawal ranged from 4,585 to 13,124 m^3/day, with an average of 8,348 m^3/day (Table 23 and Chart 4). In comparison, the Glen Collector discharge under this transient scenario ranged from 599 to 12,232 m^3/day, with an average of 6,091 m^3/day.

Relative to the Glen Collector layout, the Caisson Collector System estimated withdrawal under drought conditions is greater than that of the Glen Collector (Table 23 and Chart 4). This indicates that the Caisson Collector System provides a more reliable water supply and is less sensitive to seasonal recharge variability. The Caisson Collector System's estimated minimum withdrawal is 1,986 m^3/day greater than the current system under drought conditions (including the 2,000 m^3/day loss from Arkell 1; Tables 23 and 24). The lowest simulated Caisson Collector discharge is 4,585 m^3/day, within a drought period. The Caisson Collector System maximum withdrawal rates under wetter conditions is 1,108 m^3/day less than the current configuration (including the 2,000 m^3/day loss from Arkell 1; Table 23). With the removal of the Glen Collector and Arkell Well 1 and addition of an active Caisson Collector, the system's estimated long-term capacity is 358 m^3/day greater than the Current Capacity Scenario. These results suggest that a deeper configuration such as the Caisson Collector may provide benefits over the Glen Collector by increasing the reliable water supply from the area considering both the infiltrated water and natural groundwater conditions.

The current estimate of the capacity of the Caisson concept is notably smaller than that reported in the Stantec Consulting Ltd. Caisson Collector study (Stantec 2006). Comparison of the current FEFLOW model versus the model reported by Stantec suggests that the overburden sand hydraulic conductivity and saturated thickness of the sand aquifer used by Stantec was twice that of the current model. These combined differences conceptually explain the difference between the current capacity estimates and the Stantec capacity estimate.

Further evaluation of Caisson design alternatives and potentially field studies may be helpful to evaluate the impact of the Caisson design, and its location, on water capture, seasonal variability, and efficiency.

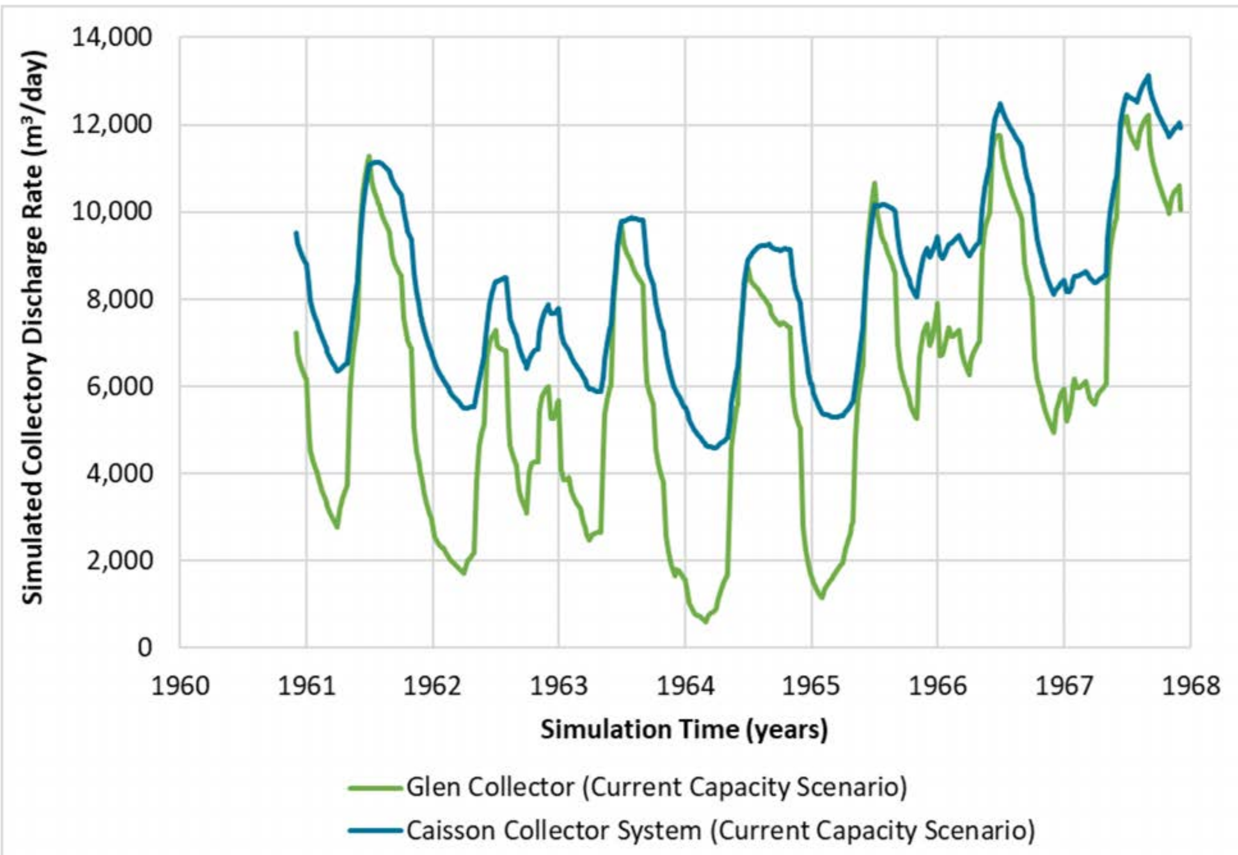

Chart 4 Simulated Transient Glen Collector and Caisson Collector Discharges

Table 23 Summary of Steady-state and Transient Glen Collector and Caisson Collection System Withdrawal Rates

Scenario	System	Steady state Withdrawal (m^3/day)	Transient Minimum Withdrawal (m^3/day)	Transient Maximum Withdrawal (m^3/day)	Transient Average Withdrawal (m^3/day)
Current Capacity	Glen Collector	7,240	599	12,232	6,091
	Arkell 1	2,000	2,000	2,000	2,000
	Glen Collector + Arkell 1	9,240	2,599	14,232	8,091
C2	Caisson Collector System (one lateral screen projection of 110 m)	9,598	4,585	13,124	8,348
Difference between C2 and Current Capacity		358	1,986	-1,108	257

Table 24 Scenario C2: Simulated Caisson Collector Annual Minimum Rates

Year	Glen Collector (Current Capacity Rates)	Caisson Collector (Current Capacity Rates)
	(m^3/day)	
1961	2,442	6,358
1962	1,718	5,506
1963	1,223	5,541
1964	599	4,585
1965	1,146	5,302
1966	4,950	8,305
1967	5,222	8,163

5.4 Aquifer Storage and Recovery Scenarios

Two scenarios were designed to evaluate the effectiveness of implementing an Aquifer Storage and Recovery (ASR) system in the Middle Gasport Formation. Scenario D1 tests an ASR configuration on Guelph Innovation District Lands, with a potential source of water from the Glen Collector and Lower Road Collector (Figure 7). Guelph Innovation District Lands were selected because of the interpreted high hydraulic conductivity zone simulated in the Tier Three model that continues westward from the Arkell well system to below the Innovation District Lands. This zone is interpreted to be a bedrock valley and have high hydraulic conductivity caused by fracturing.

Scenario D2 tests an ASR configuration in the northeast quadrant of Guelph (Figure 7), with a potential water source from Guelph Lake. The simulated ASR injection/extraction wells were positioned between Emma and Helmar municipal wells and based on the ASR configuration tested previously as part of the 2014 WSMP update (AECOM and Golder 2014).

The ASR scenarios are conceived as having a series of new ASR wells that cycle between a period of water injection and a period of extraction (pumping). The model represents the ASR injection/extraction wells as constant head boundary conditions placed at the base of the Middle Gasport Formation; a linear discrete feature with a high hydraulic conductivity (1×10^{-4} m/s) was assigned directly above each boundary condition representing the open well interval through the deep bedrock aquifer (e.g., Middle Gasport Formation to Goat Island Formation). The simulated operation of the ASR systems was defined by time-varying boundary conditions representing annual injection and extraction schedules provided by AECOM.

The first set of ASR scenarios represented the municipal wells pumping at the Current Capacity rates. These scenarios illustrated that during the period of water injection, the water levels in the aquifer quickly increased and dissipated at a large distance from the injection location. During the period of extraction, aquifer drawdown also dissipated quickly resulting in water levels at some of the existing municipal wells dropping below their threshold levels. In response, the ASR scenarios were revised having the municipal wells operating at Baseline Scenario pumping rates.

The following subsections include a summary of each ASR scenario, their simulated efficiencies, and the simulated impacts on heads at municipal wells and discharge to watercourses.

5.4.1 Aquifer Storage and Recovery Scenario D1

The ASR system simulated in Scenario D1 is located within the Guelph Innovation District Lands (Figure 7) and was represented using six ASR extraction/injection wells. The simulated ASR well located furthest to the west was placed at the Guelph Turfgrass Institute (i.e., Guelph East 1 well in Scenario A5-B) and the furthest east ASR well was placed at Stone Road East and Watson Road South (i.e., Guelph East 2 well in Scenario A5-B). The remaining four ASR wells were distributed throughout City-owned land within Innovation District Lands between these two locations. The injection and extraction volumes are summarized in Table 25. Initial tests with the model indicated that the ASR wells could not operate with the extraction volume being equal to the injection volume. An extraction volume of 60% of the maximum extraction volume was applied to maintain hydraulic heads above low water level thresholds at municipal wells. The scenario does not evaluate the opportunity to increase this collection efficiency above 60% by pumping municipal wells (e.g., such as those downgradient) at higher rates.

Table 25 Aquifer Storage and Recovery Scenario D1 Injection and Extraction Flow Rates

Month	Simulation Time (days)	Maximum Extraction Volume	60% of Extraction Volume	Injection Volume
		(m³)		
April	0	-	-	43,300
May	30	-	-	143,900
June	61	-	-	263,800
July	91	52,200	31,320	-
August	122	50,800	30,480	-
September	153	52,100	31,260	-
October	183	49,000	29,400	-
November	214	48,800	29,280	-
December	244	45,800	27,480	-
January	275	49,600	29,760	-
February	306	51,000	30,600	-
March	334	51,700	31,020	-
Total		**451,000**	**270,600**	**451,000**

The scenario results illustrated that the ASR system can function with extraction rates at 60% of the injection rates and the municipal wells pumping at Baseline Scenario rates (Table 26). Within this scenario, some wells have considerable available head and there is likely an opportunity to increase pumping rates at other municipal wells to capture more of the injected water. Further evaluation to optimize the efficiency of the system would be recommended should the City wish to pursue ASR as a future water supply option.

Table 26 Aquifer Storage and Recovery Scenario D1 Summary of Minimum and Maximum Simulated Heads

City Quadrant	Municipal Well/Source	Adjusted Simulated Low Water Threshold (m asl)	Simulated Minimum Head (m asl)	Simulated Available Head (m asl)	Simulated Maximum Head (m asl)	Simulated Range in Head (m)
Southeast	Arkell 1	319.5	321.8	2.3	321.9	0.1
	Arkell 6	305.7	311.4	5.6	315.1	3.7
	Arkell 7	305.7	311.2	5.5	315.1	3.9
	Arkell 8	311.1	311.8	0.7	315.5	3.7
	Arkell 14	310.9	311.5	0.6	315.2	3.7
	Arkell 15	304.4	312.1	7.7	316.1	4.0
	Burke	323.4	323.8	0.5	324.0	0.2
	Carter	318.5	323.0	4.5	323.3	0.2
Southwest	Membro	282.1	290.5	8.4	291.1	0.6
	Water St.	289.2	294.4	5.2	295.6	1.2
	Dean	289.9	292.5	2.6	293.5	0.9
	University	290.4	292.2	1.8	292.7	0.4
	Downey	286.4	289.9	3.5	290.2	0.3
Northeast	Park	281.0	299.4	18.4	301.8	2.5
	Emma	278.2	288.6	10.4	290.7	2.1
	Helmar	321.4	324.3	2.9	325.7	1.4
Northwest	Paisley	298.5	301.4	2.9	301.6	0.3
	Calico	294.2	315.1	20.9	315.1	0.1
	Queensdale	295.9	298.8	2.9	299.0	0.2

asl - above sea level

Chart 5 illustrates the sequence of simulated available head at Arkell 15 and Park Wells. As shown in the figure, water levels in the wells increase during the period of injection but decrease quickly back to baseline levels once the system is extracting. During the period of extraction, the available head at each of these wells is just slightly less than the available head in the Baseline Scenario. It is due to this behaviour that the system cannot operate at higher extraction rates with pumping rates at the Current Capacity Rates; at current capacity rates, many of the water levels at municipal wells operate near their threshold and there is little availability to extract larger volumes of water from the aquifer.

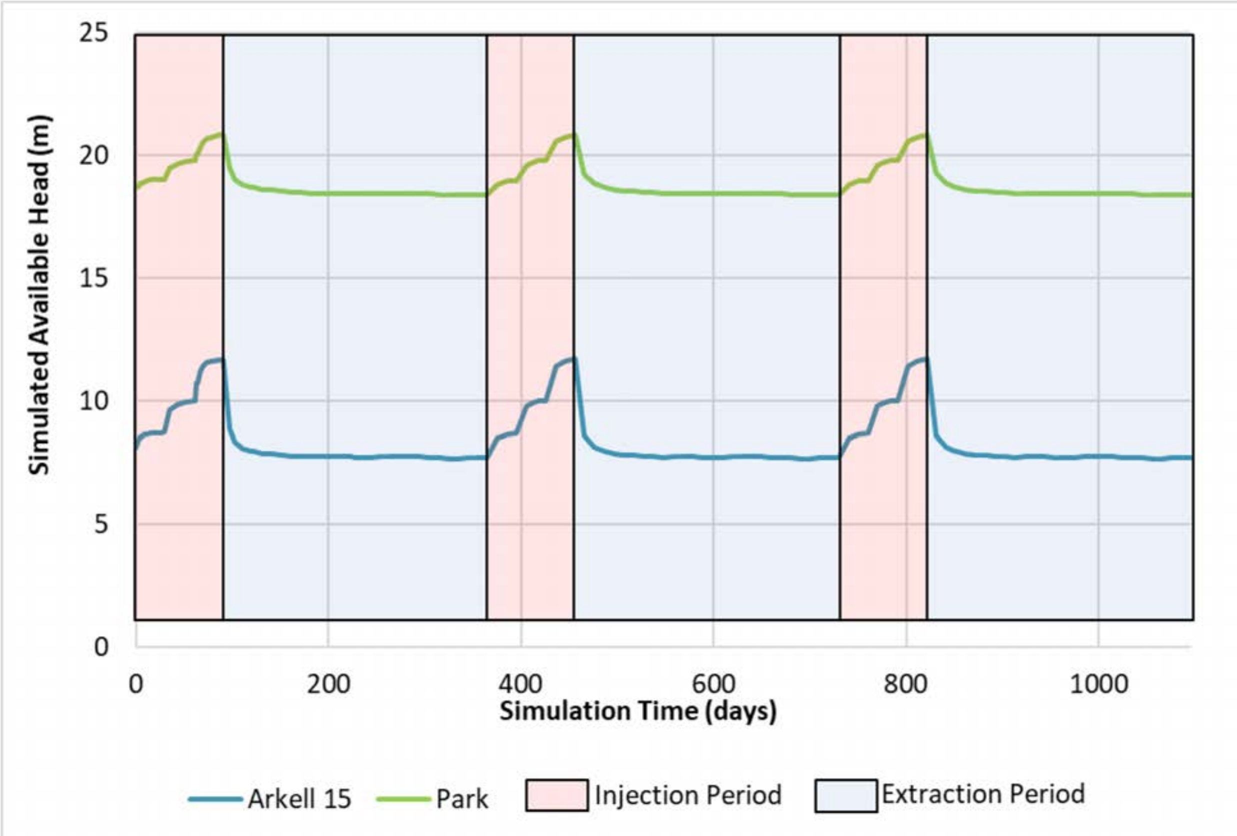

Chart 5 Scenario D1 Simulated Transient Available Head at Arkell 15 and Park Wells

The Arkell wells were simulated as having the largest range in hydraulic head during ASR operation. At the end of the injection period (Simulation Day 91), simulated increase in hydraulic heads greater than 10 cm in the Middle Gasport Formation extended as far as 10 km away from the ASR system (Figure 8). This indicates that aquifer pressure dissipates far from the injection site, and increasing the efficiency of the ASR alternative would require a consideration of increased pumping from existing or new wells a greater distance from the ASR wells.

The Lower Road and Glen Collector were both active for this scenario with the application of a constant average annual infiltration rate. The simulated Baseline Scenario steady-state rate at the Glen Collector is 9,385 m^3/day. With the addition of the Lower Road Collector, the simulated collector cumulative withdrawal rate ranged from 12,543 to 12,955 m^3/day within the transiently simulated extraction and injection periods, respectively (Table 27). The results indicate that the simulated Innovation District Lands ASR system increases the withdrawal rate at the collectors by approximately 400 to 500 m^3/day.

Table 27 Summary of Simulated Flow Rates at Collectors

Collector	Baseline Scenario	Aquifer Storage and Recovery Scenario D1	
	Simulated Withdrawal Rate	Maximum Simulated Withdrawal Rate	Minimum Simulated Withdrawal Rate
	(m^3/day)		
Glen Collector	9,385	4,021	3,788
Lower Collector	-	8,934	8,755
Total	9,385	12,955	12,543

The simulated impact of the ASR system to groundwater discharge to streams is summarized in Table 28. An increase in simulated discharge is due to the increased pressure head in the aquifer after injection, resulting in flow of groundwater vertically upward and discharging to a watercourse. The greatest increase in simulated groundwater discharge during ASR injection is predicted in the Speed River, Eramosa River, and Blue Springs Creek. A reduction in simulated discharge rate is because a portion of the groundwater pumped during the ASR extraction period is sourced from a watercourse. The greatest decrease in groundwater discharge simulated during ASR extraction is predicted in the Eramosa Rivera and Speed River. Finally, while there are both increases and decreases in groundwater discharge in responses to injection and extraction, there is a net average increase in groundwater discharge over the injection and extraction period.

Table 28 Scenario D1: Simulated Groundwater Discharge to Streams

Water Course	Baseline Scenario	Aquifer Storage Recovery Scenario D1			
	Simulated Discharge Rate	Maximum Simulated Discharge Rate	Change in Simulated Discharge Rate from Baseline Scenario	Minimum Simulated Discharge Rate	Change in Simulated Discharge Rate from Baseline Scenario
	(m^3/day)				
Blue Springs Creek	41,715	43,945	2,230	42,300	585
Chilligo/Ellis Creek	15,171	15,216	45	15,196	25
Clythe Creek	2246	2,677	431	2,162	-84
Cox Creek	2,353	2,396	43	2,391	38
Eramosa River	123,226	126,060	2,834	121,920	-1,306
Guelph Lake Tributary	9,499	9,540	41	9,495	-4
Hanlon Creek	4,244	4,167	-77	4,087	-157
Hopewell Creek	21,656	21,826	170	21,798	142
Irish Creek	5,846	5,923	77	5,913	67
Lutteral Creek	34,164	34,189	25	34,188	24
Marden Creek	3,065	3,086	21	3,067	2
Mill Creek	39,017	39,097	80	38,971	-46
Moffat Creek	2,035	2,062	27	2,062	27
Speed River	250,131	255,324	5,193	248,874	-1,257
Swan Creek	5,900	5,916	16	5,915	15
Torrance Creek	2,064	1,949	-115	1,795	-269
West Credit River	30,505	30,638	133	30,637	132

5.4.2 Aquifer Storage and Recovery Scenario D2

The ASR system simulated in Scenario D2 is located between Helmar and Emma wells in the northeast quadrant of Guelph in the same configuration tested previously for the 2014 WSMP update by Golder (2014; Figure 7). The furthest north simulated ASR well was placed approximately 300 m north of the Helmar well and the furthest south simulated ASR well was placed approximately 500 m north of Park and Emma wells. Due to the proximity to the Helmar well, the Helmar well was turned off in this scenario. The remaining four wells were placed along an interpreted linear higher hydraulic conductivity zone simulated in the Middle Gasport Formation of the Tier Three model between the Helmar and Park wells. The injection and extraction volumes are summarized in Table 29. Similar to Scenario D1, 60% of the maximum extraction volume was applied to maintain hydraulic heads above low water level thresholds at municipal wells.

Table 29 Aquifer Storage Recovery Scenario D2 Injection and Extraction Flow Rates

Month	Simulation Time (days)	Maximum Extraction Volume	60% of Maximum Extraction Volume	Injection Volume
		(m³)		
October	0	-	-	122,700
November	31	-	-	121,100
December	61	-	-	165,700
January	92	-	-	114,800
February	123	-	-	86,200
March	151	-	-	84,700
April	182	-	-	97,500
May	212	-	-	92,100
June	243	-	-	56,000
July	273	324,000	194,400	-
August	304	304,100	182,460	-
September	335	312,700	187,620	-
Total		**940,800**	**564,480**	**940,800**

With municipal wells pumping at baseline rates and the ASR system functioning with 60% efficiency, there were no simulated exceedances of low water thresholds at municipal wells (Table 30). Similar to Scenario D1, it is likely possible to optimize the municipal rates along with the transient ASR extraction rates to increase the system's overall capacity. The municipal wells that were simulated to have the largest range in hydraulic head during ASR operation were the Park and Emma wells. At the end of the injection period (Simulation Day 273), the simulated increase in hydraulic heads (i.e., greater than 10 cm) in the Middle Gasport Formation extended as far as 10 km away from the ASR system (Figure 9). This indicates that water pressure in the aquifer dissipates far from the injection site, and the injected water is unlikely available to be extracted locally in its entirety in the area of the northeast quadrant.

Chart 6 illustrates the available head time series of two of the most impacted municipal wells (Emma well and Park well). The transient responses at these wells show a rapid increase in head at the wells at the start of the injection period. Simulated heads are relatively stable through the 9-month injection period then rapidly drop at the start of the extraction period. During the period of extraction, the available head at each of these wells is less than the available head during baseline conditions.

Table 30 Aquifer Storage Recovery Scenario D2 Summary of Minimum and Maximum Simulated Heads

City Quadrant	Municipal Well/Source	Adjusted Simulated Low Water Threshold (m asl)	Simulated Minimum Head (m asl)	Simulated Available Head (m asl)	Simulated Maximum Head (m asl)	Simulated Range in Head (m)
Southeast	Arkell 1	319.5	322.6	3.1	322.7	0
	Arkell 6	305.7	311.4	5.7	312.5	1.1
	Arkell 7	305.7	311.2	5.5	312.4	1.2
	Arkell 8	311.1	311.8	0.7	313	1.1
	Arkell 14	310.9	311.5	0.6	312.6	1.1
	Arkell 15	304.4	312.1	7.7	313.3	1.2
	Burke	323.4	324.1	0.7	324.1	0.1
	Carter	318.5	323.4	4.9	323.5	0.1
Southwest	Membro	282.1	290.2	8.1	291.1	0.9
	Water Street	289.2	293.9	4.7	295.4	1.5
	Dean	289.9	292.1	2.2	293.2	1.1
	University	290.4	292.1	1.7	292.5	0.5
	Downey	286.4	289.8	3.4	290.1	0.4
Northeast	Park	281.0	292.8	11.8	306.7	13.8
	Emma	278.2	281.5	3.3	296.2	14.7
	Helmar	321.4	312.8	-8.6	342.8	30
Northwest	Paisley	298.5	300.9	2.4	302	1.1
	Calico	294.2	314.9	20.7	315.3	0.4
	Queensdale	295.9	298.7	2.8	299.1	0.4

asl - above sea level

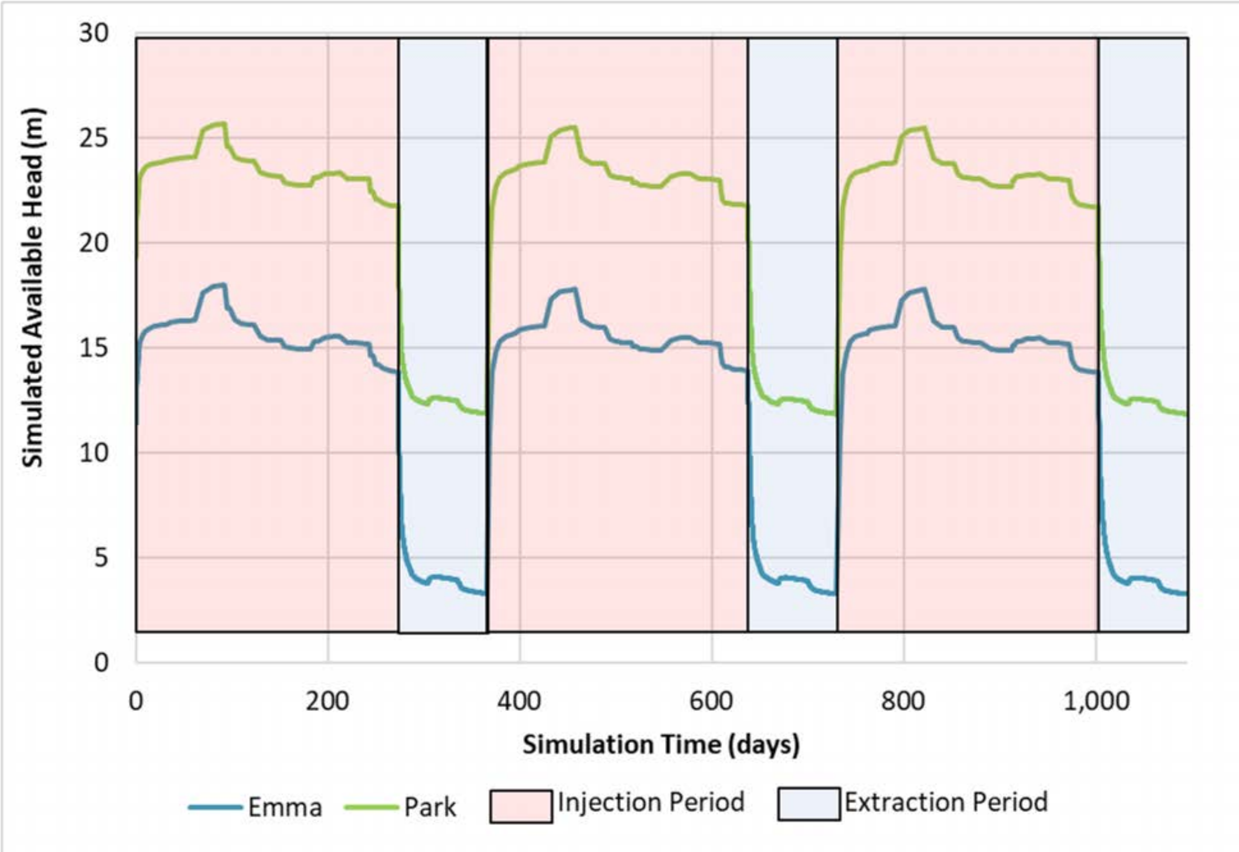

Chart 6 Scenario D2 Simulated Transient Available Head at Emma and Park Wells

The simulated Baseline Scenario steady-state rate at the Glen Collector is 9,385 m^3/day. With the addition of the ASR system in the northeast quadrant of Guelph the Glen Collector withdrawal rate is simulated to range from 9,329 to 9,448 m^3/day (Table 31). This indicates that an ASR system in the northeast quadrant of Guelph would have a relatively low impact to the productivity of the Glen Collector.

Table 31 Summary of Simulated Flow Rates at Collectors

Collector	Baseline Scenario	Aquifer Storage Recovery Scenario D2	
	Simulated Withdrawal Rate	Maximum Simulated Withdrawal Rate	Minimum Simulated Withdrawal Rate
	(m^3/day)		
Glen Collector	9,385	9,448	9,329

The simulated impact of the ASR system to groundwater discharge to streams is summarized in Table 32. Similar to Scenario D1, an increase in simulated discharge is interpreted to be from water that is injected in the ASR wells and flows vertically upwards and discharges to a watercourse. The greatest increase in simulated groundwater discharge during ASR injection is predicted in the Speed River, Eramosa River, and Blue Springs Creek. A reduction in simulated discharge rate is because a portion of the groundwater pumped during the ASR extraction period is sourced from a watercourse. The greatest decrease in groundwater discharge simulated during ASR extraction is predicted in the Speed River and Clythe Creek.

Table 32 Scenario D2: Simulated Groundwater Discharge to Streams

Water Course	Baseline Scenario	Scenario D2			
	Simulated Discharge Rate	Maximum Simulated Discharge Rate	Change in Simulated Discharge Rate from Baseline Scenario	Minimum Simulated Discharge Rate	Change in Simulated Discharge Rate from Baseline Scenario
	(m^3/day)				
Blue Springs Creek	41,715	42,892	1,177	42,248	533
Chilligo/Ellis Creek	15,171	15,305	134	15,163	-8
Clythe Creek	2246	2,317	71	2,026	-220
Cox Creek	2,353	2,446	93	2,364	11
Eramosa River	123,226	125,551	2,325	123,949	723
Guelph Lake Tributary	9,499	9,628	129	9,421	-78
Hanlon Creek	4,244	4,328	84	4,274	30
Hopewell Creek	21,656	21,999	343	21,688	32
Irish Creek	5,846	5,928	82	5,894	48
Lutteral Creek	34,164	34,195	31	34,156	-8
Marden Creek	3,065	3,260	195	2,923	-142
Mill Creek	39,017	39,149	132	39,102	85
Moffat Creek	2,035	2,062	27	2,060	25
Speed River	250,131	256,317	6,186	249,523	-608
Swan Creek	5,900	5,929	29	5,900	0
Torrance Creek	2,064	2,088	24	2,025	-39
West Credit River	30,505	30,638	133	30,438	-67

6 Summary

This report summarizes the modelling results of a number of scenarios evaluated to estimate the average-day capacity of the City's existing water supply sources and potential new sources. Potential future sources of water include:

- use of inactive wells and collectors, test wells, and hypothetical wells in areas where additional supply may be available
- the area of the Dolime Quarry and introduction of the Pond Level Management strategy
- optimization and reconfiguration of the Arkell recharge and collector system
- aquifer storage and recovery systems

Table 33 summarizes the simulated total system capacities for each scenario, as well as the additional simulated capacity over and above that of the current water supply system.

Table 33 Summary of System Capacity for Future Supply Scenarios

Scenario Set	Potential Supply Area	Scenario Number: Potential Additional Supply Description	Simulated Average Day Capacity (m^3/day)	Average Day Capacity Over Current Capacity Scenario (m^3/day)
Current System Capacity		Current municipal wells and Glen Collector	66,760	-
A Additional Wells and Existing Collector	Southeast Quadrant	A1-A: Lower Road Collector	69,811[(a)]	3,051
		A1-B: Lower Road Collector and hypothetical Guelph Southeast location well supply	71,960	5,200
	Southwest Quadrant	A2-A: Additional well supply from: Edinburgh, Steffler, Ironwood, and GSTW1-20	71,480	4,720
	Northeast Quadrant	A3-A: Additional well supply from: Clythe, Fleming, and Logan	70,370	3,610
	Northwest Quadrant	A4-A: Additional well supply from: Sacco, Smallfield, Hauser and hypothetical Sunny Acres Park location	68,260	1,500
		A4-B: Additional well supply from Sacco, Smallfield, Hauser, and hypothetical Guelph North location	70,420	3,660
	Multiple Quadrants	A5-A: Additional well supply from: Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, and Hauser	76,740	9,980
		A5-B: Additional well supply from: hypothetical Guelph East 1 and 2	66,760	0
		A5-C: Additional well supply from: Edinburgh, Ironwood, GSTW1-20, Steffler, Clythe, Fleming, Logan, Hauser, Smallfield, and hypothetical Guelph Southeast and Guelph North	82,370	15,610

Scenario Set	Potential Supply Area	Scenario Number: Potential Additional Supply Description	Simulated Average Day Capacity (m^3/day)	Average Day Capacity Over Current Capacity Scenario (m^3/day)
B Dolime Quarry Water Capture		B1: Dolime Quarry capture considering current municipal wells	71,760[b]	5,000[b]
C Arkell Recharge/Collector Optimization		C1: Withdraw more water from the Eramosa River, increase pump capacity to 0.32 m^3/second	71,659[c]	4,899
		C2: Deactivate the Glen Collector and install a Caisson Collector System	66,402[d]	358
D Aquifer Storage and Recovery System		D1: Inject water from the Glen and Lower Road Collectors into the Middle Gasport Formation in Innovation District Lands and extract during periods of high demand	67,501[e]	741[f]
		D2: Inject water from Guelph Lake into the Middle Gasport Formation in Northeast Guelph and extract during periods of high demand	68,307[e]	1,547[f]

Notes:

(a) This is a sum of the Current Capacity Scenario well rates and the A1-A scenario steady-state Lower Road Collector and Glen Collector rates

(b) The increase in water supply capacity associated with the Dolime quarry is assumed to be derived from a combination of increased pumping from new or existing wells in addition to the treatment of quarry discharge water.

(c) This is a sum of the Current Capacity Scenario well rates and the C1 scenario steady-state Glen Collector rates considering an Eramosa pump capacity of 0.32 m^3/s

(d) This is a sum of the Current Capacity Scenario well rates (including the removal of Arkell 15) and the C2 scenario steady-state Caisson Collector rate

(e) This is a sum of the Current Capacity Scenario well rates and the average annual ASR extraction rate applied in Scenarios D1 and D2

(f) This is the annual average extraction rate applied in Scenarios D1 and D2

The combined set of scenarios, including maximizing the capacity of existing wells, installing new wells, pursuing the Dolime quarry, and optimizing Arkell recharge/discharge, consider alternatives that add up to more than 90,000 m^3/day of average day water capacity for the City. Many of these alternatives need additional field investigations and analysis and some will not be feasible either due to cost, technical practicality, or environmental effects. However, the modelling approach implemented is conservative and should be considered as a reasonable estimate of the water supply capacity available to the City. The model's estimated effects of increased pumping on surface water are also conservative and likely over-estimates what would be observed in actual conditions. However, while these conservative assumptions are built into the modelling approach, the capacity of the water supply may always be limited by the potential for long-term droughts as observed during the 1960's. Most of the City's water supply is taken from the Gasport Formation aquifer, which is relatively resilient to drought conditions. The higher stress associated with long-term dry conditions may decrease the capacity below the steady-state estimates.

6.1 Current Capacity Scenario

The Current Capacity Scenario estimated the average-day capacity of the City's existing municipal wells and the Glen Collector to be 66,760 m^3/day. The estimated capacity of the City's existing municipal wells under drought conditions is 57,560 m^3/day, or 14% lower than the average-day Current Capacity. While this assessment does not evaluate the effect of drought conditions on all water supply alternatives, it could be assumed that long-term drought conditions may have a similar reduction to the estimated capacity for each of the alternatives.

6.2 Additional Wells and Existing Collector

Future scenarios predicted an increase to the capacity of the current water supply system, ranging from 1,500 m^3/day (Scenario A4-A) to 15,610 m^3/day (Scenario A5-C). Potential additional municipal well supplies, including Edinburgh, Ironwood, GSTW1-20, and Steffler in the Southwest Quadrant offer the greatest amount of additional water supply. Scenario A5-A, considering all potential new supplies within the City or on City property, is predicted to provide 9,980 m^3/day of additional supply. Scenario A5-C, considering all potential new supplies within and outside the City, is predicted to provide 15,610 m^3/day of additional supply. All considered scenarios predict groundwater discharge to streams will be reduced by less than 20% as compared to the current capacity scenario, except at Clythe Creek where groundwater discharge is predicted to be reduced by up to 30% (Scenario A5-C). While the headwaters of Clythe Creek are mapped as coldwater, the lower and mid-reaches of the creek are considerably degraded with recent monitoring work suggesting warmwater conditions. Furthermore, the groundwater model is not well-calibrated to local groundwater levels or groundwater discharge to the creek. However, the model results are indicative of potential effects on surface water. Should the City consider additional supplies in the northeast quadrant, including the Clythe Well, local model updates are recommended along with calibration against aquifer testing results. Additional studies in this area are currently being undertaken by the City (e.g., as part of the return to service of the Clythe well) and this data can be used to supplement the model at a later date.

The groundwater model scenarios identify potential effects on surface water with increased municipal pumping. These results highlight the importance of having more current baseflow monitoring, and it is recommended that the City implement a more comprehensive surface water monitoring program. This program would include surface water monitoring (flow and water level), as well as shallow groundwater level monitoring in areas of important surface water features (e.g., coldwater streams and streams where groundwater discharge is predicted to be reduced). These data would help to improve the characterization of these features in the model and increase the certainty of model predictions.

6.3 Dolime Quarry Water Capture

The Dolime Quarry Scenario (Scenario B1) included a constraint requiring a head difference of 1 m between MW08-02A and the quarry pond to ensure groundwater flows toward the quarry. This constraint was violated under the Current Capacity Scenario, and as a result, the Dolime Quarry scenario, as configured, does not suggest that municipal wells could pump at rates higher than the Current Capacity scenario. However, the Dolime scenario also identifies that under the Current Capacity scenario the rate of discharge from the quarry into the Speed River would remain high, and there is a potential to capture this water into the City's water supply. As a result, the estimated quarry discharge rate of 5,000 m^3/day is assumed as the potential incremental water supply associated with the quarry, and this supply could be achieved through a combination of either new municipal wells or treatment of the quarry discharge water. The City's ongoing Dolime project will consider all of the alternatives available to increase the water supply including strategies such as lowering the pond level, lowering the hydraulic head gradient to below 1 m, and moving the location of the groundwater divide closer to the pond may increase the water supply capacity. These options will require operational testing to confirm the feasibility.

6.4 Arkell Recharge/Collector Optimization

The Arkell Recharge Scenario (Scenario C1) predicted that an increase in takings from the Eramosa River and infiltration at the Arkell lands will increase the groundwater produced by the

Glen Collector. Based on the review of historical Eramosa River flow, the City has an opportunity to increase the amount of surface water infiltrated, while respecting the PTTW constraints. Tripling the river pump capacity to 27,648 m^3/day increases the incremental average infiltration rate by 5,854 m^3/day and the incremental average discharge at the Glen Collector by 4,899 m^3/day over the Current Capacity Scenario. The results indicated that as overall collector efficiency decreases with increased infiltration, the incremental efficiency over Current Capacity generally increases. This suggests that on an average annual basis, as more water is infiltrated and water levels rise, the Glen Collector is able to capture a higher proportion of the infiltrated water. However, this increase in water supply remains subject to the seasonality of the infiltration rates, and the dry periods with minimal collection remain the same as the Current Capacity scenario. Future evaluations are recommended to predict how much additional water may be collected if the Lower Road Collector were to be reconstructed.

The replacement of the Glen Collector and Arkell 1 well with a Caisson Collector System (Scenario C2) is not predicted to greatly increase long-term average system capacity. The Caisson System's estimated long-term average capacity results in a gain of 358 m^3/day compared to the Current Capacity Scenario. However, this system would provide a more reliable supply under drought conditions.

6.5 Aquifer Storage and Recovery

The ASR system Scenarios D1 and D2 demonstrated that the highly transmissive Middle Gasport Formation may be able to accommodate large volumes of injected water. However, the aquifer pressure associated with this injected water will quickly dissipate throughout the aquifer and may be challenging to extract locally in times of need. The simulated average day capacities listed in Table 33 for Scenarios D1 and D2 represent the Current Capacity plus the annual average ASR extraction rate simulated in Scenarios D1 and D2. The ASR scenarios were simulated with baseline municipal rates and not all the incremental capacity may be available under Current Capacity municipal rates. To confirm and optimize the possibility of an efficient ASR system in the City of Guelph, and to better estimate the increase in seasonal water supply capacity, field testing, and further modelling is recommended.

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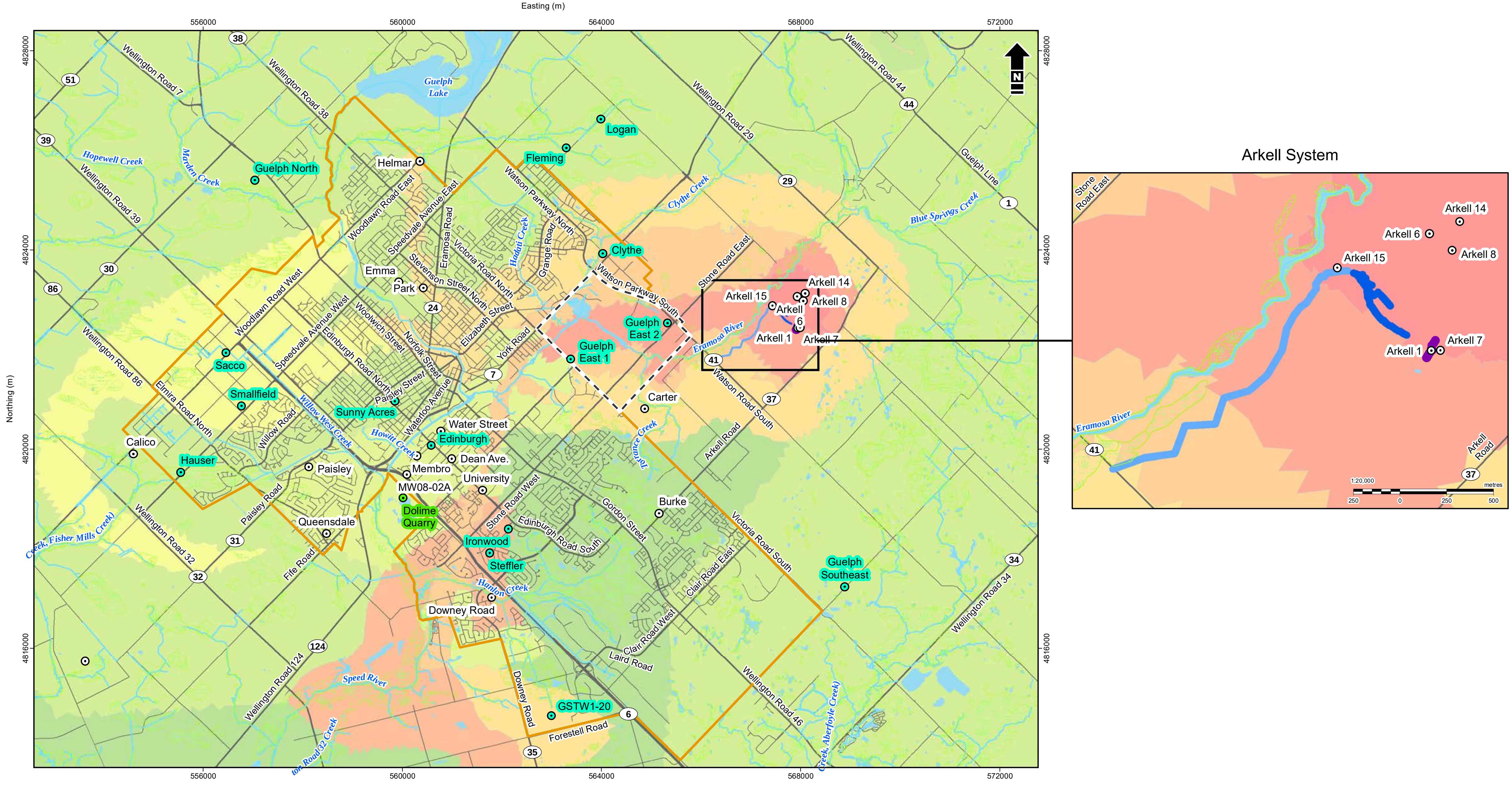

- Simulated Caisson Collection System
- Simulated Glen Collector
- Simulated Lower Collector
- City Boundary
- Guelph Innovation District
- Waterbody
- Wetland
- Watercourse
- Highway
- Road
- Simulated Dolime Quarry Water Taking
- Municipal Well - Future Supply Scenario
- Municipal Well - Current Capacity Scenario

Simulated Middle Gasport Formation Hydraulic Conductivity

1×10^{-3} m/s

1×10^{-6} m/s

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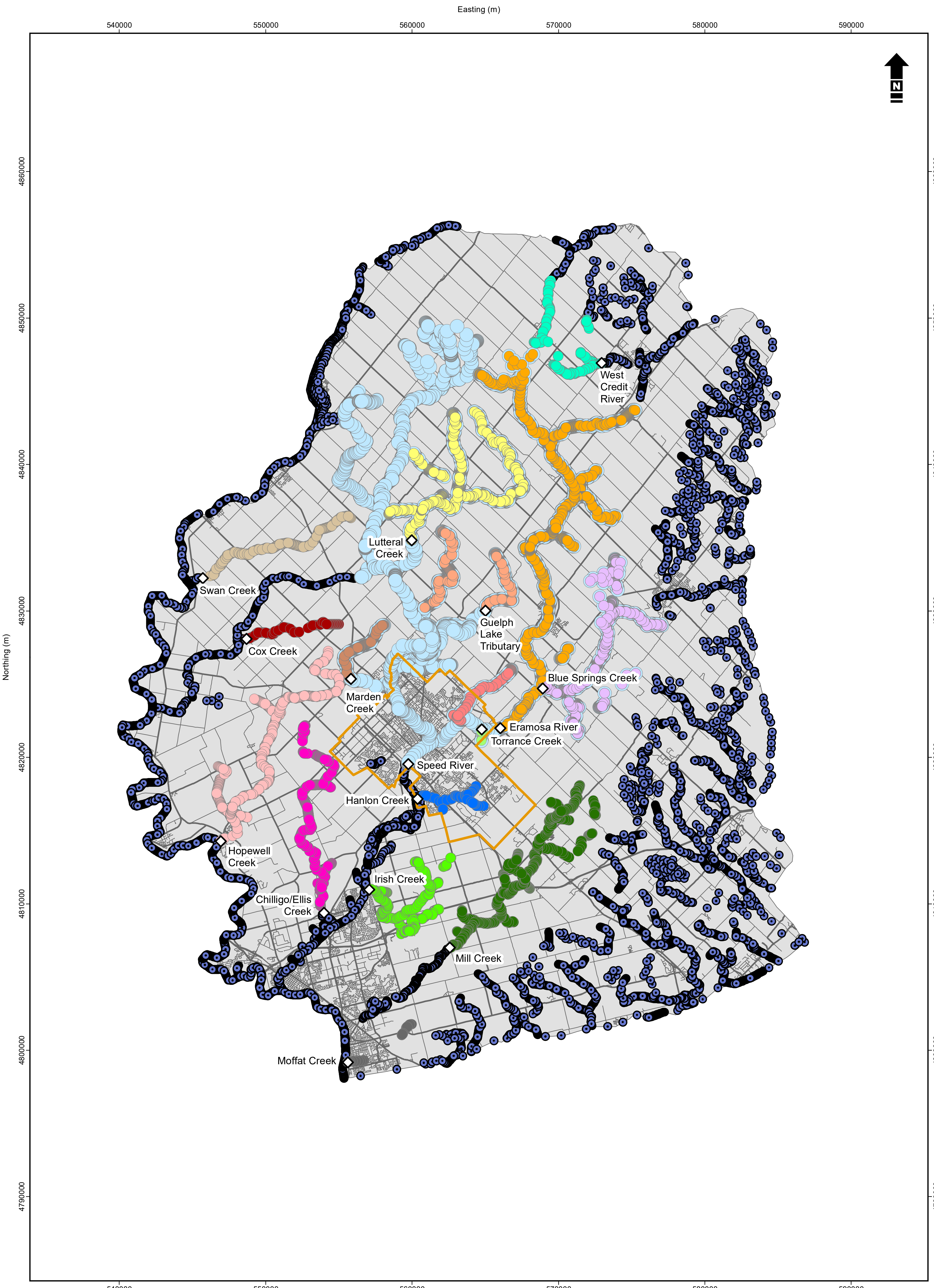
City of Guelph
Water Supply Master Plan

Study Area, Municipal Wells, and Watercourses

Date:	Project:	Submitter:	Reviewer:
August 2021	15072	J. Langford	D. Van Vliet

Figure 1

I:\CityofGuelph\15072\FiguresandTables\QHG\2021\Report\City of Guelph Water Supply Master Plan\Figure-2-Discharge_Boundary_Condition_Selections_within_Model_Domain.mxd - Tabloid_P - 01-Oct-21, 09:59 AM - sylam - TID003



Watercourse Boundary Condition Selection

- Blue Springs Creek
- Chilligo/Ellis Creek
- Clythe Creek
- Cox Creek
- Eramosa River
- Guelph Lake Tributary
- Hanlon Creek
- Hopewell Creek
- Irish Creek
- Lutteral Creek
- Marden Creek
- Mill Creek
- Moffat Creek
- Speed River
- Swan Creek
- Torrance Creek
- West Credit River

- Model Domain
- City Boundary
- Highway
- Road
- Baseflow Measurement Station
- Model Slice 1 Constant Head Boundary Conditions

1:250,000 metres
2,500 0 2,500 5,000
NAD 1983 UTM Zone 17N

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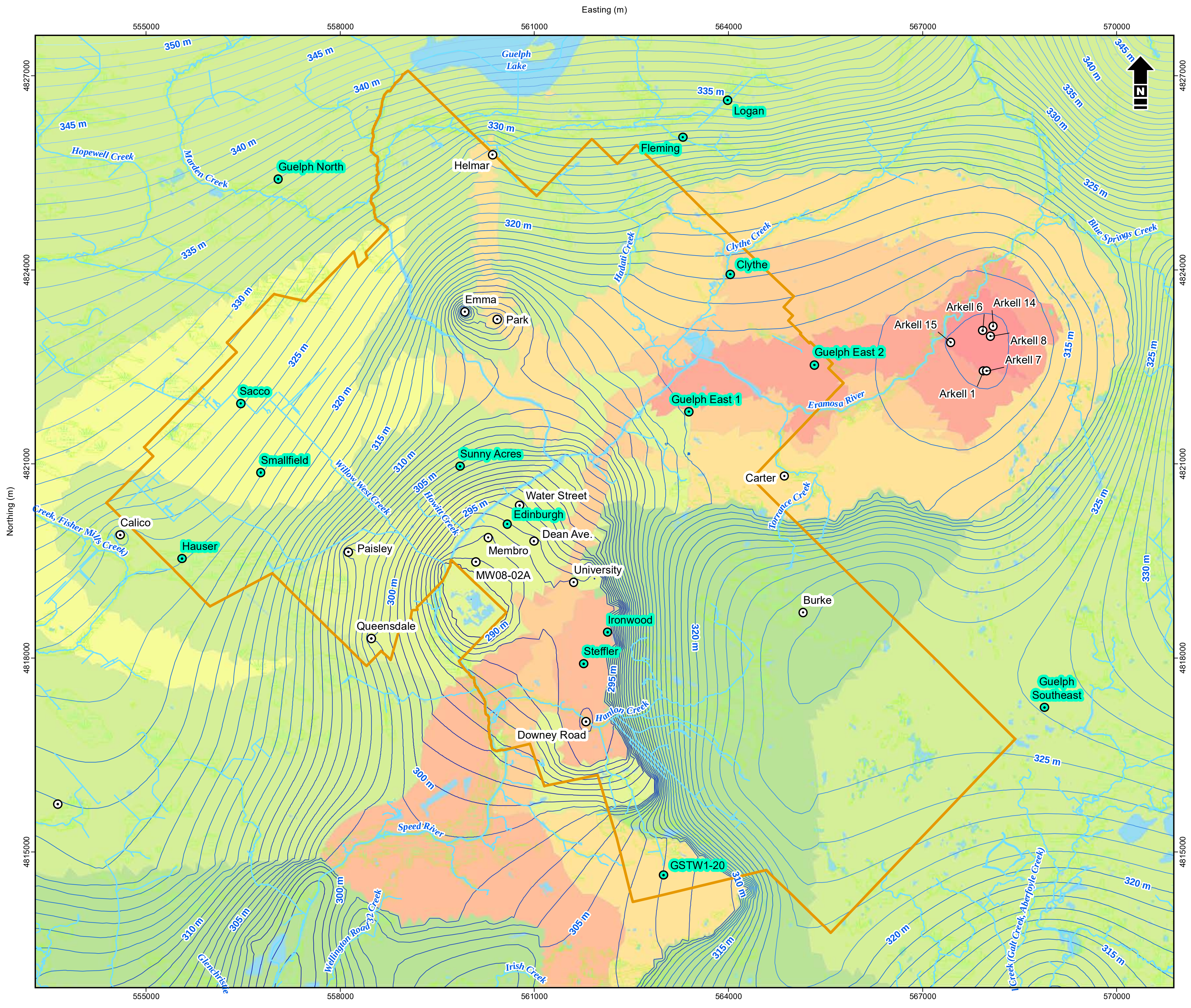
City of Guelph
Water Supply Master Plan

Discharge Boundary Condition Selections within Model Domain

Date:	Project:	Submitter:	Reviewer:
August 2021	15072	J. Langford	D. Van Vliet

Figure 2



Waterbody
Wetland
City Boundary
Watercourse

Hydraulic Head Isolines (m)*

- > 350
- 340 - 350
- 330 - 340
- 320 - 330
- 310 - 320
- 300 - 310
- 290 - 300
- < 290

Municipal Well - Future Supply Scenario
Municipal Well - Current Capacity Scenario

* Note: simulated hydraulic head isolines exported from Middle Gasport Formation (model slice 12)

Simulated Middle Gasport Formation Hydraulic Conductivity

1×10^{-3} m/s

1×10^{-6} m/s

1:60,000 metres
600 0 600 1,200
NAD 1983 UTM Zone 17N

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City of Guelph
Water Supply Master Plan

Baseline Simulated Hydraulic Head Distribution (Middle Gasport Formation)

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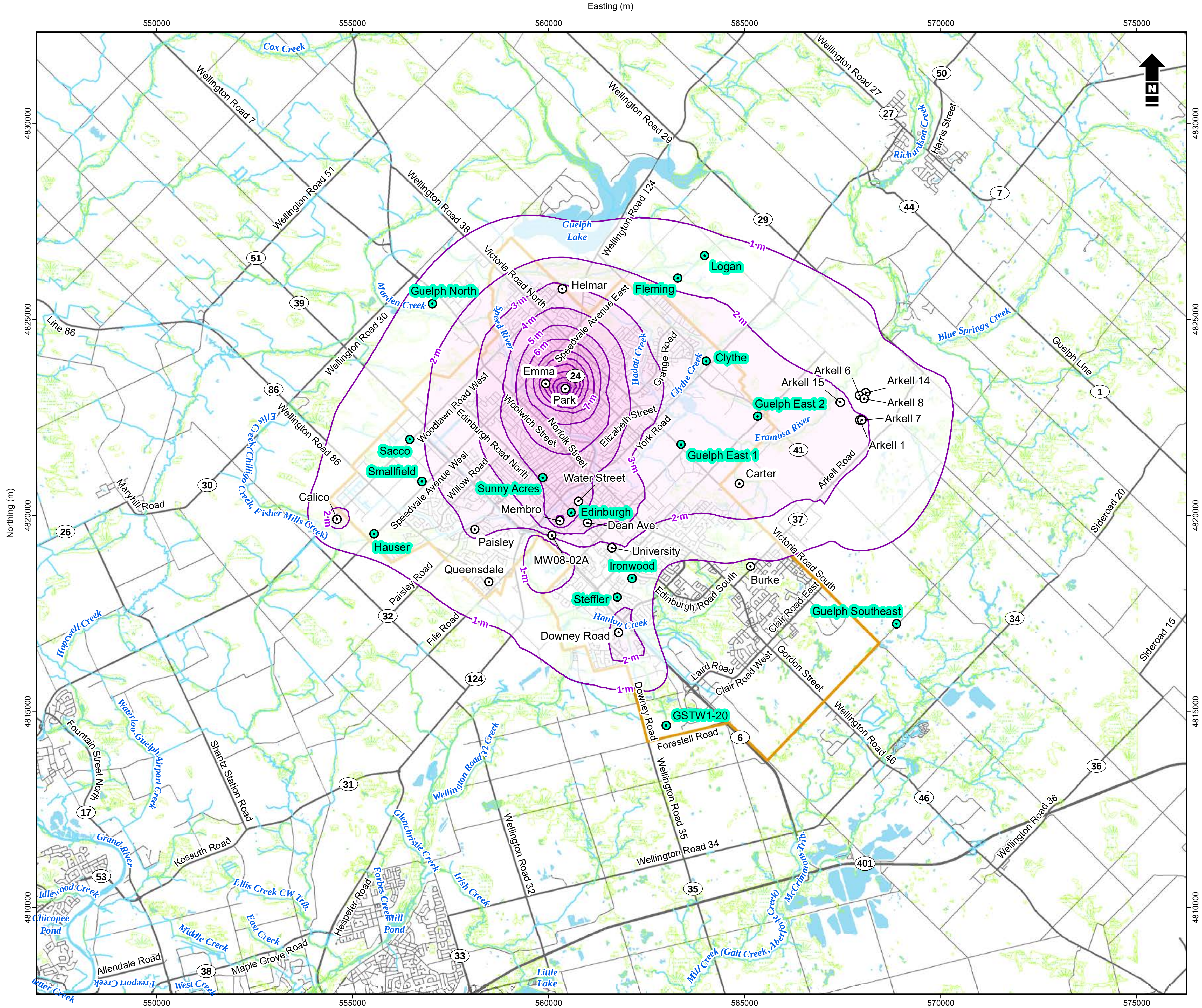
Figure 3



City Boundary
Waterbody
Wetland
Simulated Drawdown*
Highway
Road
Watercourse
Municipal Well - Future Supply Scenario
Municipal Well - Current Capacity Scenario

* Note: Simulated drawdown isolines exported from Middle Gasport Formation (model slice 12) and are compared to baseline hydraulic head (see Figure 3).

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

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City of Guelph
Water Supply Master Plan

Current Capacity Scenario Drawdown Relative to Baseline Scenario (Middle Gasport Formation)

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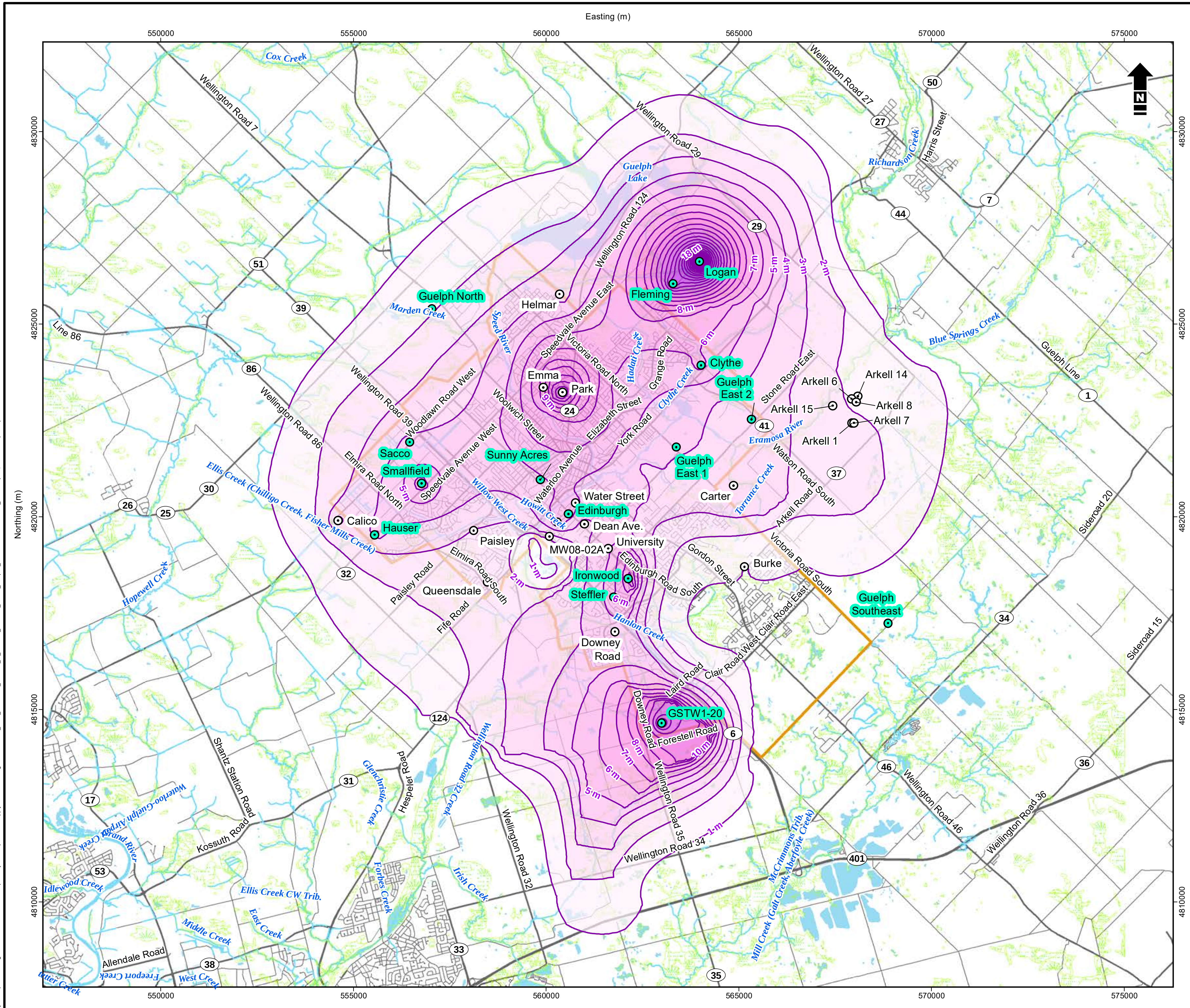
September 2021	15072	J. Langford	D. Van Vliet

Figure
4



- City Boundary
- Waterbody
- Wetland
- Simulated Drawdown*
- Highway
- Road
- Watercourse
- Municipal Well - Future Supply Scenario
- Municipal Well - Current Capacity Scenario

* Note: Simulated drawdown isolines exported from Middle Gasport Formation (model slice 12) and are compared to baseline hydraulic head (see Figure 3).

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

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City of Guelph
Water Supply Master Plan

Scenario A5-A Drawdown Relative to Baseline Scenario (Middle Gasport Formation)

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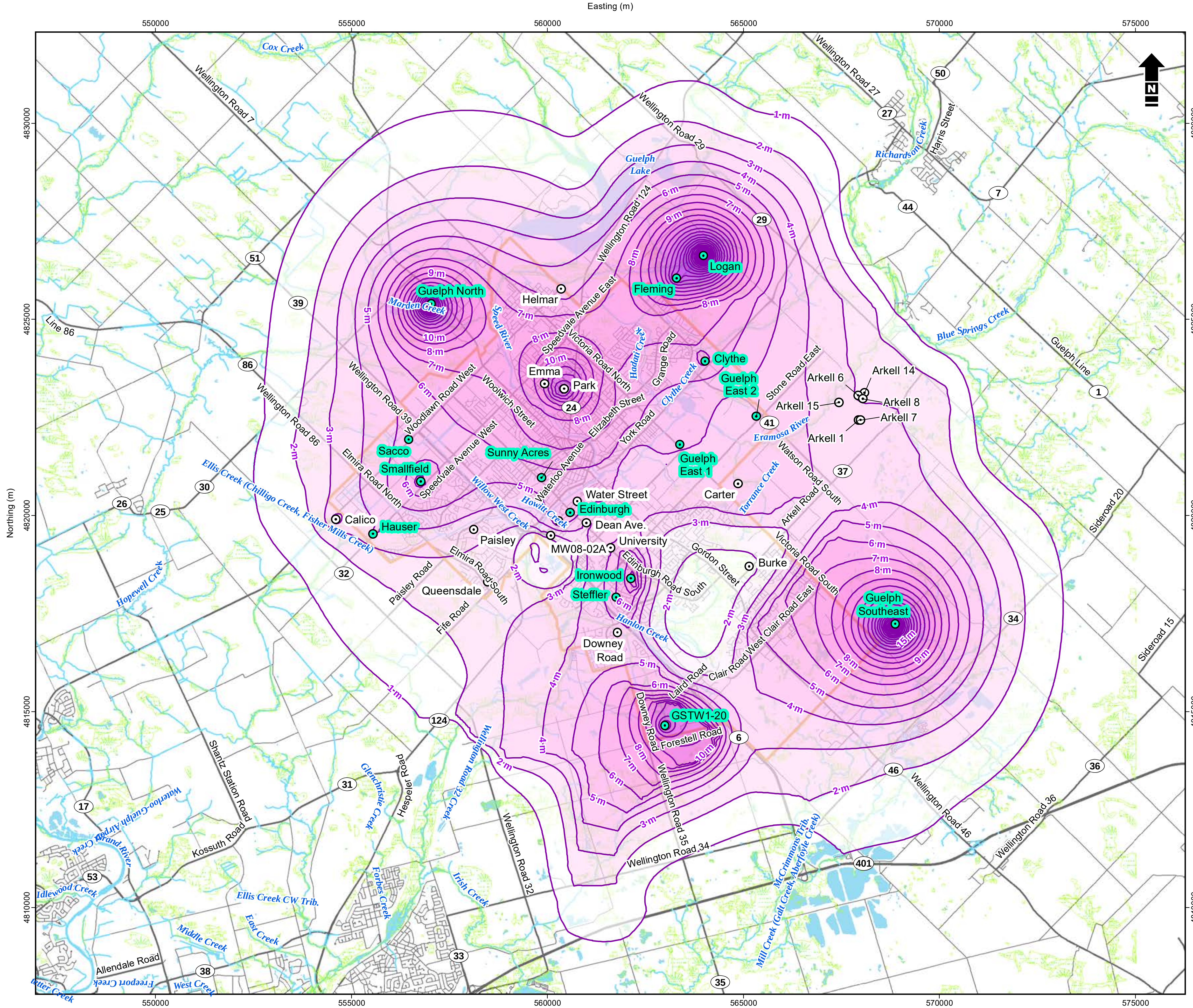
September 2021	15072	J. Langford	D. Van Vliet

Figure
5



- City Boundary
- Waterbody
- Wetland
- Simulated Drawdown*
- Highway
- Road
- Watercourse
- Municipal Well - Current Capacity Scenario
- Municipal Well - Future Supply Scenario

* Note: Simulated drawdown isolines exported from Middle Gasport Formation (model slice 12) and are compared to baseline hydraulic head (see Figure 3).

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

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City of Guelph
Water Supply Master Plan

Scenario A5-C Drawdown Relative to Baseline Scenario (Middle Gasport Formation)

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Figure 6

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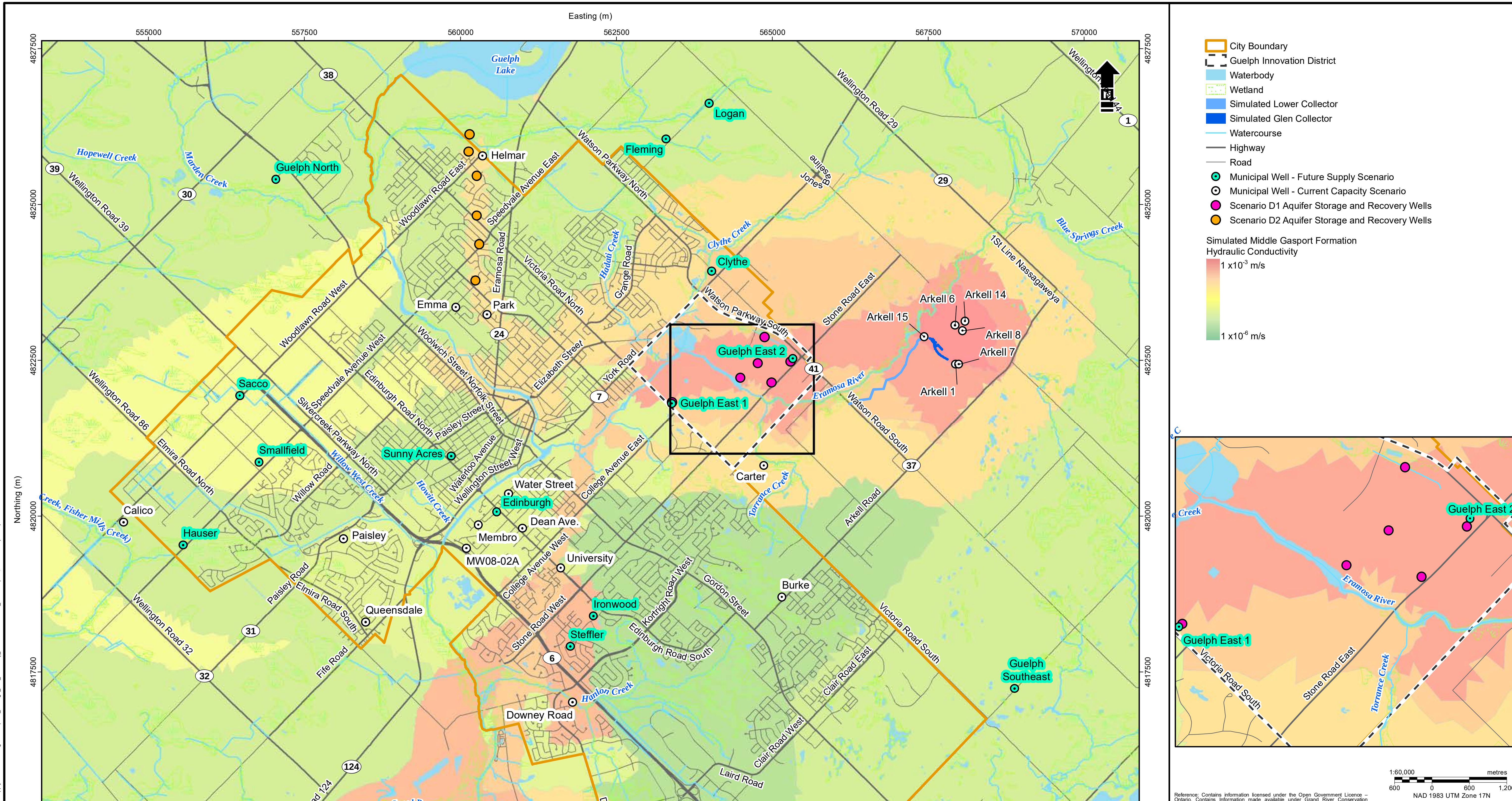

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City of Guelph
Water Supply Master Plan

Aquifer Storage and Recovery Well Locations

Date:	Project:	Submitter:	Reviewer:
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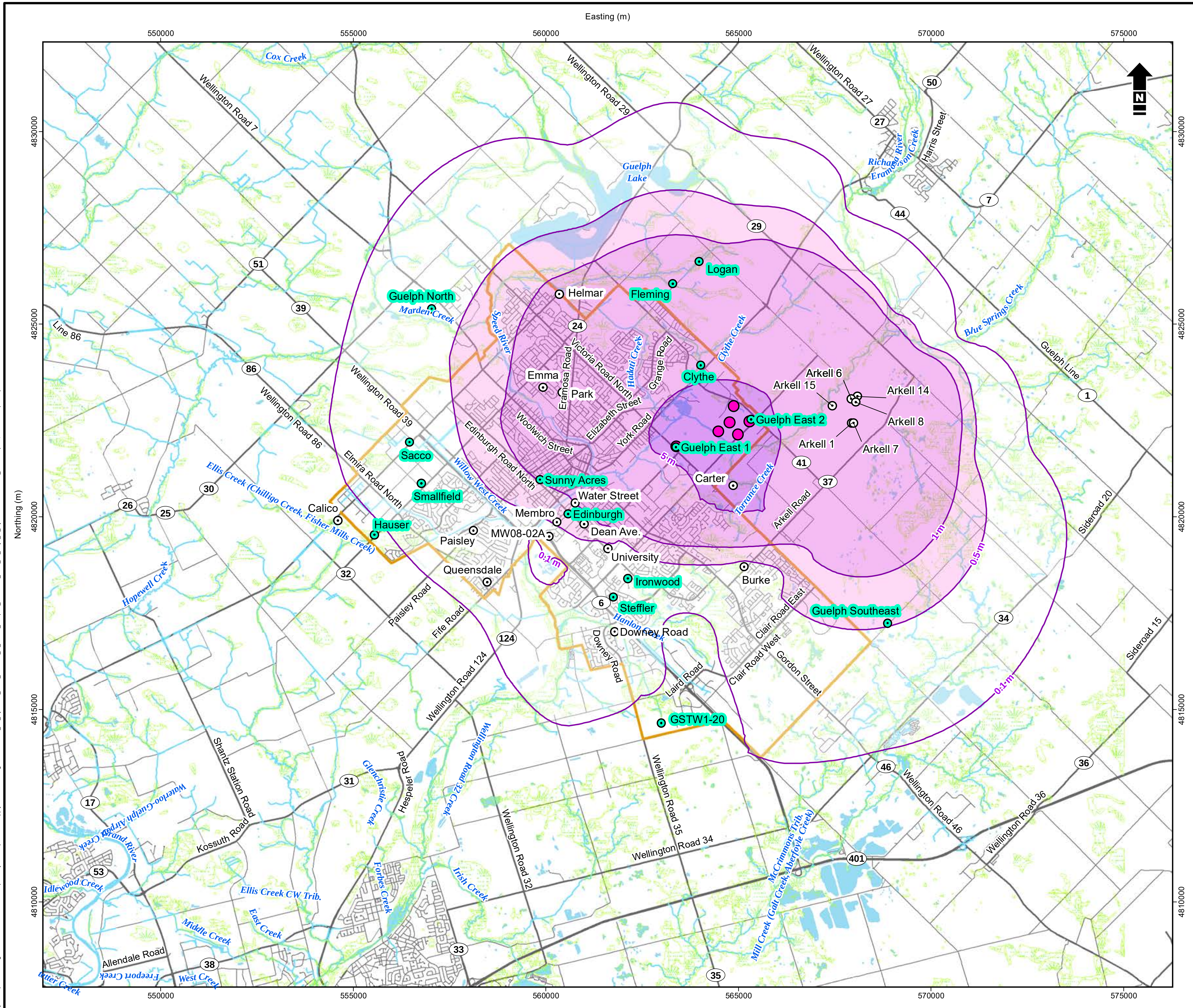
Figure 7



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City of Guelph
Water Supply Master Plan

Scenario D1: Hydraulic Head Increase in Middle Gasport Formation After 91 Days of Injection

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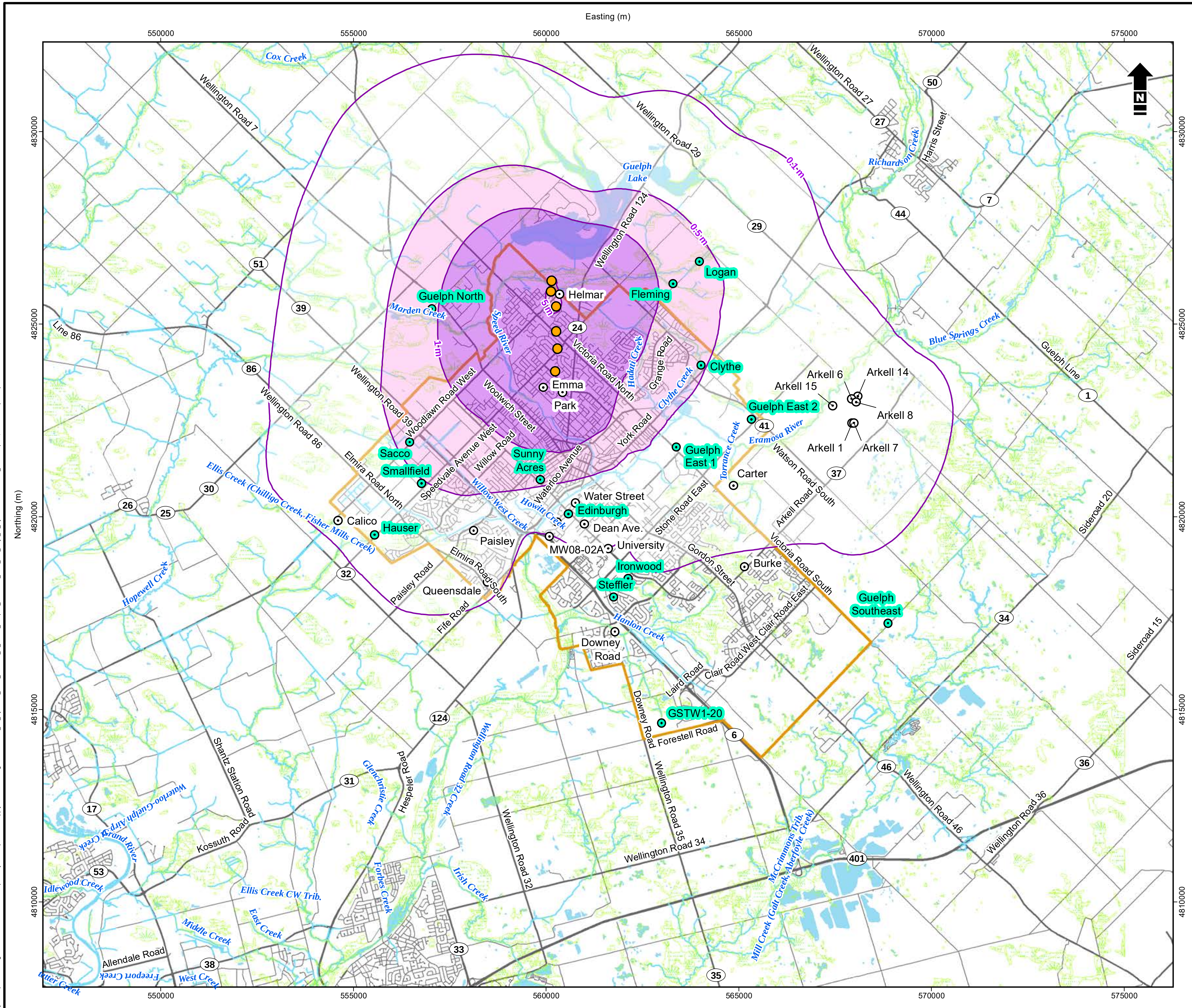
Figure 8



City Boundary
Waterbody
Wetland
Change In Head
Watercourse
Highway
Road
Municipal Well - Future Supply Scenario
Municipal Well - Current Capacity Scenario
Scenario D2 Aquifer Storage and Recovery Wells

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

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City of Guelph
Water Supply Master Plan

Scenario D2: Hydraulic Head Increase in Middle Gasport Formation After 273 Days of Injection

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Figure 9