Appendix B

Water Supply Master Plan Sustainability Assessment

AECOM Canada Ltd.
50 Sportsworld Crossing Road, Suite 290
Kitchener, ON N2P 0A4 Canada

T: 519.650.5313
F: 519.650.3424
www.aecom.com

To: Dave Belanger, City of Guelph

From: Matt Alexander, Patty Quackenbush, AECOM

Date: October 18, 2021

Project #: 60612820

Memorandum

Subject: **Water Supply Master Plan Sustainability Assessment Summary**

1. Introduction

In August 2020, the province of Ontario updated the Place to Grow plan ('the Growth Plan') to include population targets to the year 2051 (MMAH, 2020). Prior to this update, the Water Supply Master Plan (WSMP) update project planning period extended to 2041 and considered the associated growth targets (MMAH, 2019). The City has adopted the amended planning period included in the Growth Plan, including the 'reference' population targets presented in **Table 1**. Also shown in this table is the 'low' target included in the preliminary June 2020 version of the Growth Plan, issued for discussion. During Task 2 of the WSMP project, these growth projections were utilized, along with historical water demands to estimate future water supply demands (**Table 2** and **Figure 1**).

Table 1: Growth Plan Population and Employment Forecasts

Planning Horizon	Population Forecast	Employment Forecast
2031	177,000	94,000
2041	191,000	101,000
2051: Low	198,000	115,000
2051: Reference	203,000	116,000

Table 2: Projected ‘Low’ and ‘Reference’ Growth Rate Average Day and Maximum Day Water Demands

Growth Rate^	Demand Type	2021	2026	2031	2036	2041	2046	2051
Low	Avg. Day Demand (m^3/d)	49,171	52,139	55,107	58,075	61,043	64,011	66,978
Low	Max Day Demand using MDF* of 1.34 (m^3/d)	65,889	69,866	73,843	77,820	81,797	85,774	89,751
Reference	Avg. Day Demand (m^3/d)	49,254	52,429	55,605	58,780	61,955	65,131	68,306
Reference	Max. Day Demand using MDF* of 1.34 (m^3/d)	66,000	70,255	74,510	78,765	83,020	87,275	91,530

Note: ^Values taken from Gauley and Associates and AECOM, 2020.
*MDF = Maximum Day Factor

AECOM also assessed potential risks to the water supply system for the purpose of evaluating the security of the City’s water supply (AECOM, 2020). A number of potential risks were identified including:

- Climatic conditions (drought);
- Loss of groundwater supply source to short/long term maintenance or contamination;
- System mechanical failures;
- Reduction in permitted capacity through regulatory approval process; and,
- Surface water contamination.

This assessment concluded that 15% of the existing and future water supply capacity should be reserved such that it is available to manage the identified risk scenarios. Stated another way, the firm capacity of the system is evaluated to be 15% less than the maximum system capacity, meaning that an additional 15% capacity above the future demands identified in **Table 2** will be required. The required future water supply capacity, including this 15%, is provided in **Table 3**.

Table 3: Estimated Future Capacity Required for Security of Supply

Capacity	2026	2031	2036	2041	2046	2051
Future Required Capacity - Low (m^3/d)	80,346	84,919	89,493	94,067	98,640	103,214
Future Required Capacity - Reference (m^3/d)	80,793	85,687	90,580	95,473	100,366	105,260

The amended Growth Plan will place increased pressure on the water supply resources available to the City within the 2051 planning horizon. The Tier 3 Water Budget study (Matrix Solutions Inc., 2017), completed as an element of Source Water Protection requirements under the Clean Water Act, has shown that the City's existing water resources (primarily groundwater) are potentially at risk of not meeting future (2031) system demand, particularly during drought conditions.

Future City water supply planning is further complicated by capacity limitations in the main water supply aquifer within the City limits. While additional water (surface water and groundwater) is likely available in the surrounding area, there are significant political challenges associated with developing these water supply sources to service the City.

In order to evaluate the sustainability of the existing groundwater resources and the potential future resources within the City or on City owned land, the City commissioned a groundwater flow modelling assessment. This assessment was completed by Matrix Solutions Inc., working as a subconsultant to AECOM, and is documented in **Attachment A**. The objective of this Technical Memorandum is to discuss the modelling results within the context of the Growth Plan and the overall WSMP process.

2. Sustainability Assessment Results

2.1 Existing Capacity Assessment

The capacity of the existing City groundwater supply sources was evaluated using the groundwater flow model. This included a steady-state assessment of the long-term sustainable system pumping rates under the constraints of minimum feasible pumping water level elevations (AECOM, 2021) and minimizing baseflow reduction to cold water streams. The modelling assessment identified the long-term sustainable average day capacity of the existing system to be 66,740 m^3/d (**Attachment A**). The maximum day capacity of the system with all wells operating concurrently has been evaluated at 79,422 m^3/d[1], reflecting the ability of the wells to reliably produce higher short-term flow rates to meet high demand periods in the City. Both of these capacity values are below the overall system Permit to Take Water (PTTW) maximum capacity of approximately 124,000 m^3/d. This capacity assessment should not be interpreted to suggest that individual PTTW should be reduced. Rather, the permitted values are required to maintain operational flexibility in the system such that production rates at certain groundwater sources can be increased seasonally to capture additional water available

1. *The maximum day capacity of the existing system was determined by AECOM through a review of operational data for each water source and discussions with City Water Services Operations staff.*

locally, or sources can be pumped at increased rates to support regular well maintenance or wells being off-line for extended periods of time.

The results of the existing capacity assessment are shown in **Figure 1** in relation to the demand projections in **Tables 2** and **3**. As shown on the figure and in **Table 4**, the existing capacity values result in water supply deficits relative to the projected 2051 demand and the total capacity required to address security of supply.

A transient simulation was completed to evaluate the potential impact of drought on the existing system average day capacity. This resulted in an estimated capacity of 57,561 m^3/d (**Attachment A**), or a 14% reduction relative to the estimated existing system average day capacity.

Table 4: Existing Water Supply Capacity Versus 2051 Demand Projections

Demand Type	2051 Low Demand vs. Existing Capacity^	2051 Reference Demand vs. Existing Capacity^
Max. Day (m^3/d)	-10,329	-12,108
Max. Day +15% (m^3/d)*	-23,792	-25,838

Notes: ^Existing maximum day capacity of 79,422 m^3/d.
*Includes 15% capacity to address security of supply.

2.2 Future Water Supply Sources

This assessment includes the potential future sources that are within the City or outside of the City on City-owned lands. This distinction was drawn as it is considerably more challenging to develop sources in other political jurisdictions where land acquisition is required. Future stages of the WSMP update process will assess the viability of these more challenging sources.

The potential future groundwater supply sources (**Table 5**) included in the Sustainability Assessment were evaluated in four categories established by roughly dividing the City in quadrants (i.e., northeast, southeast, southwest, northwest). This project is an update to the 2014 WSMP. As such, the future water supply sources identified in the 2014 plan serve as a basis for the sources being evaluated for the master plan update. The potential sources not considered previously, identified in **Table 5**, are as follows:

- **Increase to Arkell Recharge System Rates** – The City pumps water from the Eramosa River at the Arkell Spring Grounds under a stepped PTTW that allows for a maximum taking of 31,822 m^3/d from April 15th to May 31st, annually. This water is used to recharge the groundwater system via a series of infiltration trenches. Infiltrated water flows according to the local hydraulic gradient towards the Eramosa River, where it is intercepted by the Glen Collector. The current recharge system configuration can provide a maximum of 8,640 m^3/d from the river to the infiltration trenches. The Sustainability Assessment considered potential collector flow increases related to recharging at rates up to the PTTW maximum.

- **Caisson Collector System** – Previous reviews of potential improvements to the Arkell site collector systems (Stantec, 2004; Stantec, 2006; Woerns, 2004) have included recommendations to replace the existing Glen Collector with a caisson system. The Sustainability Assessment evaluated the potential capacity of a replacement caisson system.
- **GSTW1-20 Test Well** – Since the 2014 WSMP was completed, the City has drilled and tested a test well near the southwest City boundary (**Attachment A; Figure 1**). This new potential water supply was included in the Sustainability Assessment.
- **Dolime Quarry Pond Level Management** – The City is currently undertaking the Southwest Guelph Water Supply Class Environmental Assessment to evaluate potential new water supply within this area of the City. This project includes a detailed, long-term Operational Testing Program (OTP), designed to evaluate a strategy for protecting the quality and quantity of the City groundwater supply by managing surface water levels in the Dolime Quarry (referred to as Pond Level Management, or PLM). The Sustainability Assessment evaluated the potential optimized water supply system capacity under PLM, which will be assessed in the field through the OTP.

Table 5: Potential Future Water Supply Sources Evaluated for Sustainability Assessment

City Quadrant	Potential Future Water Supply Source	Sources Not Considered in 2014 Plan
Southeast	Lower Road Collector, Increase to Arkell Recharge System Rates*, Caisson Collector System	Increase to Arkell Recharge System Rates*, Caisson Collector System
Southwest	Edinburgh Well, Steffler Well, Ironwood Well, GSTW1-20 Well, Dolime Quarry Pond Level Management	GSTW1-20 Well, Dolime Quarry Pond Level Management
Northeast	Clythe Well, Fleming Well, Logan Well	-
Northwest	Sacco Well, Smallfield Well, Hauser Well, Sunny Acres Park site (potential future well)	-

Notes: *Recharge rates above the current Eramosa River PTTW maximum are not being considered.

2.2.1 Groundwater Sources

As described above, the potential capacity of additional sources in each City quadrant were evaluated separately, subject to the same pumping level and baseflow reduction restrictions imposed on the existing capacity assessment (**Attachment A**). The result provides an indication of the additional capacity potentially available in each City quadrant (**Table 6**). An additional simulation was completed to evaluate the overall increased system capacity that may be available with new sources located in *all* City quadrants (**Table 6**). This resulted in an estimated 10,000 m^3/d in additional available capacity from the evaluated sources.

Table 6: Results of Additional Groundwater Sources Modelling Analysis

City Quadrant	Average Day System Capacity (m^3/d)	Increased Capacity Over Existing (m^3/d)
Southeast	69,791	3,051
Southwest	71,463	4,723
Northeast	70,347	3,607
Northwest	68,242	1,502
All Quadrants*	76,740	10,000

Notes: Above table is taken from Table 18 in Attachment A.
* This scenario included a series of potential future groundwater wells, none of which are within the southeast quadrant.

2.2.2 Arkell Spring Grounds Collector System

The Arkell Spring Grounds property was developed by the City in 1908 to replace the Eramosa River as a source of water supply. As part of this development, a collector system was installed to intercept groundwater springs/seeps from the outwash sands and gravels that are exposed along the south valley wall of the Eramosa River. An aqueduct was constructed to convey the groundwater collected from the spring grounds to the York Road pumping station. Over the past century, the collector system has been expanded and upgraded. The collector system is subdivided into two sub-systems, referred to as the Lower Road Collector (currently off-line) and the Glen Collector.

A key component of the system is a groundwater infiltration system, where water is pumped from the Eramosa River between mid-April and mid-November and discharged to an infiltration pond that recharges the groundwater locally through a series of infiltration trenches. A portion of the recharge, estimated to range from 22% to 90% and average 51% (C3 Water, 2019), is then captured by the Glen Collector.

The Sustainability Assessment modelling analysis considered three potential modifications to the collector system to increase the system capacity with a focus on optimizing the water supply from the collector system available on a year-round basis, i.e. increase to the City's water supply capacity. These modifications included:

- Replacement of the off-line Lower Road Collector;
- Increasing the volume of water recharged through the infiltration system; and,
- Replacement of the Glen Collector.

The results for each of these potential options are discussed in the following subsections.

2.2.2.1 Lower Road Collector Replacement

This scenario was assessed in the model by simulating a collector in the location of the existing off-line Lower Road Collector and evaluating the combined capacity with the Glen Collector. Both steady-state and transient simulations were completed to evaluate average and seasonal capacity as the collector flow is heavily influenced by seasonal conditions. The steady-state results indicate that the average capacity of the collectors could be increased by about 3,000 m^3/d by replacing the Lower Road Collector and operating both collectors simultaneously.

The transient results provide a range in minimum and maximum combined collector flows during the period of assessment. The minimum flows during the transient period range from approximately 4,000 m^3/d to 10,000 m^3/d. The maximum flows during the transient period range from approximately 11,000 m^3/d to 19,000 m^3/d. The assessed transient period is the Tier Three drought scenario, meaning that the values at the low end of these ranges represent below average recharge conditions while the values at the high end of these ranges represent average to slightly above average conditions (Matrix Solutions Inc., 2017).

The maximum flows from the collector system provide the City with operational flexibility as they allow an increase in total production from the Arkell site, which can off-set the capacity of wells that are off-line for scheduled maintenance, facility upgrades, etc. Due to the seasonal nature of the collector flows, these maximum values cannot be considered in the capacity of the overall City system, as the maximum system demand may not occur during the period of maximum collector flow. Therefore, the minimum reliable collector flow value is used in the estimate of overall system maximum capacity. The determination of the overall existing system maximum capacity of 79,422 m^3/d, included a contribution of 5,100 m^3/d from the Glen Collector, reflecting the average minimum flow value during the period of no artificial recharge between 2017-2019 (AECOM, 2021). The Sustainability Assessment results suggest that the combined flow from the two collector systems, during the low flow period could be 4,900 m^3/d higher than the recent productivity of the Glen Collector during this same period (i.e., 5,100 vs. 10,000 m^3/d). Conservatively, the discussion herein assumes a value of 4,000 m^3/d for the collector replacement as the transient modelling assessment includes variable annual recharge conditions.

2.2.2.2 Recharge System Volume Increase

The modelling analysis considered three pumping rates for the Eramosa River intake, which provides flow to the artificial recharge system. This included the approximate current system maximum of 105 L/s, double this rate or 210 L/s and triple the current maximum or 320 L/s. Both steady-state and transient simulations were completed. The steady-state results indicate that the average capacity of the Glen Collector under increased recharge conditions would range from 7,969 m^3/d (while recharging at a maximum of 105 L/s) to 12,139 m^3/d (while recharging at a maximum of 320 L/s).

The transient results provide a range in minimum combined collector flows during the annual period with no artificial recharge, and maximum combined flows during the annual artificial recharge period. The minimum flows during the transient period range from approximately 2,000 m^3/d to 9,000 m^3/d; however, there is little variability between the minimum values for each recharge rate. This suggests the model does not predict that significant mounding would occur at the water table due to the high transmissivity of the shallow aquifer. The maximum flows during the transient period range from approximately 23,000 m^3/d to greater than the PTTW maximum of 25,000 m^3/d.

These modelling results indicate that increasing the recharge rates and total seasonal recharge volume would not have a significant impact on the minimum annual collector flows. Therefore, this option is not anticipated to contribute significant additional flow to the overall system capacity. Maximum Glen Collector flows between 2017 and 2019 have been on the order of 18,000 to 19,000 m^3/d. The modelling assessment suggests that maximum rates up to the PTTW limit could be achieved; however, significant field testing and modifications to the existing recharge/infiltration system would likely be required to implement the rates tested in the model.

It is noted that re-construction of the Lower Road Collector could improve the overall efficiency of the Collector system, i.e., a higher percentage of the artificial recharge volume could be collected by the overall system as compared to the performance with only the Glen Collector active. Further, the potential effect of increased artificial recharge on shallow groundwater quality would need to be assessed as part of the pilot testing program(s).

2.2.2.3 Caisson Collector System

Previous reviews of potential improvements to the Arkell site collector systems (Stantec, 2004; Stantec, 2006; Woerns, 2004) have included recommendations to replace the existing Glen Collector with a caisson system. The Sustainability Assessment evaluated the potential capacity of a replacement caisson system using the groundwater model. Given the proximity of the recommended conceptual caisson system to the existing Arkell 1, an overburden well, the modelled capacity values represent the total flow that would be derived from the caisson system and Arkell 1 or just the caisson system if Arkell 1 was decommissioned.

The steady-state results indicate that the average capacity of the caisson system would be approximately 9,598 m^3/d, a minor increase above the average flow rate of 9,240 m^3/d modelled for the existing Glen Collector combined with Arkell 1.

The transient results provide a range in minimum and maximum caisson collector flows. The minimum flows during the transient period range from approximately 4,600 m^3/d to 8,000 m^3/d, suggesting that this system may buffer the impact of drought, relative to the existing Glen Collector. The maximum flows during the transient period range from approximately 8,500 m^3/d to 13,000 m^3/d. In consideration of the minimum reliable flow from the caisson collector this assessment indicates that a replacement system could add up to 2,900 m^3/d (5,100 m^3/d vs. 8,000 m^3/d) in capacity, relative to the existing Glen Collector; however, when the capacity of the Arkell 1 well is taken into consideration (2,000 m^3/d), the increase is reduced to 900 m^3/d. It is unlikely that this minor predicted capacity increase would justify the cost associated with installation of a caisson collector.

3. Discussion

The results of the Sustainability Assessment modelling indicate that the evaluated future groundwater sources could provide up to 10,000 m^3/d of additional water supply to the City. Further, the modelling indicates that re-establishing the Lower Road Collector could add up to 4,000 m^3/d in capacity. These results are shown on **Figure 1** along with the future demands estimated based on the Growth Plan population and employment targets and the required 15% additional reserve supply. The maximum available supply shown for 2051 is 93,422 m^3/d, which is the existing system maximum day capacity of 79,422 m^3/d plus the 14,000 m^3/d identified in this assessment. This is considered to be a conservative result, as individual well supplies are routinely operated at flow rates in excess of the steady-state (or average) rates provided by the model. As there is uncertainty regarding which future water sources may prove to be viable when detailed field testing is completed and it is uncertain whether the Ministry of the Environment, Conservation and Parks would permit additional sources at rates in excess of those demonstrated by the model, it is considered prudent to take this approach for the purpose of the Master Plan. There is additional uncertainty associated with the groundwater flow model and continuous improvement in the model through ongoing field studies and additional model calibration will help to reduce uncertainties and improve the reliability of the model scenarios; however, the model, at this time, represents the best available approach to water supply capacity assessments.

When considering the full system capacity requirement, including a 15% reserve for security of supply, the results provided in **Figure 1** and summarized in **Table 7** show that the estimated 2051 deficit is 9,792 m^3/d and 11,838 m^3/d for low and reference demand, respectively.

This assessment includes evaluation of the potential future sources that are within the City or outside of the City on City-owned lands. Future stages of the WSMP update process will also assess the viability of potential sources located outside of the City. This work underscores the potential challenges associated with servicing future growth using the identified sources and the pressure that the revised Growth Plan targets impose on the City water supply planning process.

Table 7: Future Water Supply Capacity Versus 2051 Demand Projections

Demand Type	2051 Low Demand vs. Future Capacity	2051 Reference Demand vs. Future Capacity
Max Day Demand (m^3/d)	89,751	91,530
Max Day Demand +15% (m^3/d)*	103,214	105,260
Existing Water Supply Capacity (m^3/d)	79,422	79,422
Future Estimated Water Supply Capacity (m^3/d)	93,422	93,422
Deficit based on existing supply capacity (m^3/d)	-23,792	-25,838
Deficit based on estimated future supply capacity (m^3/d)	-9,792	-11,838

Notes: *Includes 15% capacity to address security of supply.

4. References

AECOM, 2020:
Determination of Required Water Supply Capacity – Firm Capacity Assessment. (Draft Technical Memorandum).

AECOM, 2021:
City of Guelph Water Supply Master Plan. Task 3 – Water Supply Capacity Assessment. (Draft Technical Memorandum).

Gauley and Associates and AECOM, 2020:
Task #2 – Population and Water Supply Demand Forecasts (Final Draft Technical Memorandum).

Matrix Solutions Inc., 2017:
City of Guelph and Township of Guelph/Eramosa Tier Three Water Budget and Local Area Risk Assessment.

Ministry of Municipal Affairs and Housing (MMAH), 2019:
A Place to Grow – Growth Plan for the Greater Golden Horseshoe.

Ministry of Municipal Affairs and Housing (MMAH), 2020:
A Place to Grow – Growth Plan for the Greater Golden Horseshoe.

Stantec, 2004:
Technical Memorandum No. 3 – Conceptual Assessment of Collector Rehabilitation and/or Replacement Alternatives.

Stantec, 2006:
Hydrogeological Study in Support of a Caisson Collector System, Arkell Spring Grounds, Guelph (Draft).

Woerns. N., 2004:
Rehabilitation of the Lower Road Collector System Arkell Spring Grounds (Draft Report).

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Attachment A

Version 2.0
October 4, 2021 Matrix 15072-527

Mr. Matthew Alexander
AECOM Canada Ltd.
215-55 Wyndam St. N
Guelph, ON N1H 7T8

Subject: City of Guelph Water Supply Master Plan, Places to Grow Scenarios

Dear Mr. Alexander:

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 response to a Places to Grow Amendment from the Province of Ontario. The groundwater 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. 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, estimated operating well capacities, and potential impacts in groundwater discharge to streams. 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 located on City lands in addition to the existing sources of the current water supply system.

This report summarizes the simulated maximum average day capacity of the current municipal water supply system (Section 1), the maximum average capacity under drought conditions (Section 2), and the maximum average capacity considering alternative future groundwater supply sources (Section 3). 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 3.1)
- water management in the Dolime Quarry area (Section 3.2)
- optimization and reconfiguration of the Arkell recharge and collector system (Section 3.3)

1 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, while maintaining groundwater elevations above safe operating levels (i.e., low water thresholds), minimizing reductions in groundwater discharge to coldwater streams, and keeping individual well pumping rates below maximum well withdrawal capacities. Optimization of municipal pumping rates was completed using PESTPP-OPT (Parameter Estimation Software; White et al. 2020). PESTPP-OPT helps to automate the estimation of the maximum pumping rate potentially achievable by each well under each of the three constraints. The scenario represents a point of reference for future supply scenarios for estimating the incremental system capacity and reductions in groundwater discharge to watercourses.

Low water thresholds at the municipal wells are used in the 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 (2021) and subsequently adjusted (Table 1) to account for differences between the model's simulated water level and the measured water levels at each well, as well as estimated hydraulic head under average pumping conditions and specific capacities. AECOM also provided the maximum individual well capacities and/or permitted rates as upper bounds to the optimization process (Table 1). Additional details about the development of the Current Capacity Scenario and associated thresholds are provided in the City of Guelph Water Supply Master Plan Update report and associated appendices (e.g., AECOM 2021, Matrix 2021).

Table 1 summarizes the results of the Current Capacity Scenario, including maximum simulated pumping rates and simulated available heads under those rates; available head is calculated as the difference between the simulated low water threshold and the simulated water level in the scenario. 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.

Table 2 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 all constant head stream boundary conditions shown on Figure 2. The thermal classification of each watercourse is from Matrix (2017) and the references therein (i.e., MNR [2013] and GRCA [2013]). The watercourse was assigned a coldwater classification for the purposes of this evaluation if a segment of the entire reach was assessed as coldwater.

Table 1 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	Available Head
Southeast	Arkell 1	319.5	2,000	2,000	-2.0	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[(2)]	0	0.2[(2)]
	Arkell 14	310.9	7,000	3,100	0.0[(2)]	0	-0.3
	Arkell 15	304.4	7,000	7,000	-5.3	7,000	-5.0
	Burke	323.4	6,500	5,200	-0.2	3,000	0.0[(2)]
	Carter Wells[(1)]	318.5	6,400	6,100	-0.0	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[(2)]
	Dean	289.9	1,500	540	-0.0	400	0.1[(2)]
	University	290.4	2,500	850	-0.3	470	0.0[(2)]
	Downey	286.4	5,237	5,240	-0.9	5,240	-0.1
Northeast	Park Wells[(1)]	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	-0.0	830	0.0[(2)]
	Calico	294.2	1,400	1,400	-13.2	1,400	-11.8
	Queensdale	295.9	1,100	760	-0.5	680	-0.0
	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.
(1) Two or more wells simulated as one well.
(2) Low water level threshold exceedance when positive. Negative values indicate remaining available head at maximum pumping rate.

Table 2 Current Capacity Scenario: Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[1]	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

Notes:
(1) From MNR (2013) and GRCA (2013) in Matrix (2017)

2 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 1 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 (1960-1967) of the 10-year transient drought scenario (1960-1970) evaluated in the Tier Three Assessment. The first 7 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 1 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.

3 Future Supply Scenarios

Matrix assessed three sets of scenarios to estimate the incremental increase in water supply from potential additional water sources located on City property. Table 3 summarizes these sets of scenarios (i.e., A, B, and C). The A scenarios test potential additional supply from inactive or new municipal wells and collectors. The B and C scenarios test potential additional supply relating to the Dolime strategy and Arkell recharge/collector system, respectively.

The Future Potential Supply scenarios estimate the increase in the average-day water supply system capacity relative to the Current Capacity Scenario (Section 1), following the same approach used to estimate the Current Capacity. Changes in groundwater discharge to streams were compared to the Current Capacity Scenario. In addition to the well constraints described in Section 1, 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 3 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
	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
	Multiple Quadrants	A5-A: Additional well supply from Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, and Hauser
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

3.1 Potential Water Supply from Additional Wells and Existing Collectors

The set of scenarios described in the following subsections (i.e., A1-A to A5-A; Table 3) 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).

3.1.1 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. 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 Table 4 and 5. 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 5 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 5 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.

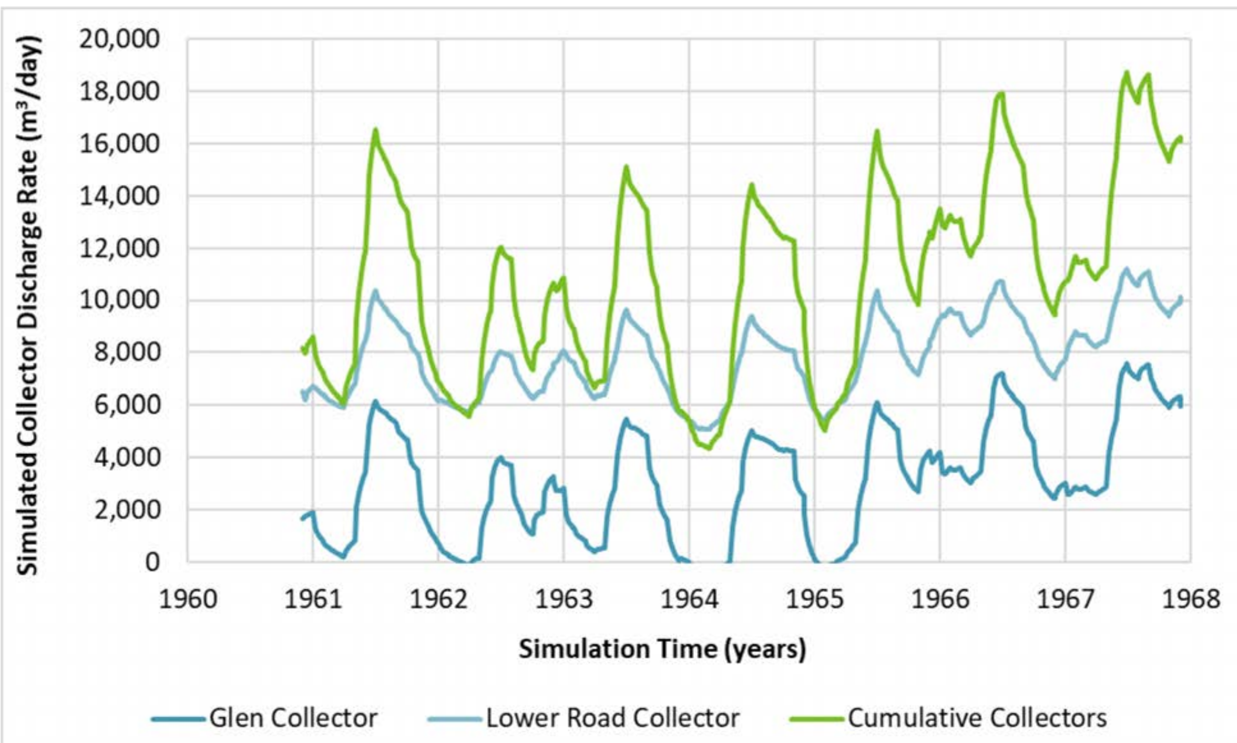

Chart 1 Transient Simulated Discharge Rate at the Glen Collector, Lower Road Collector, and the Sum of the Two Collectors

Table 4 Scenario A1-A: Simulated Lower Road Collector and Glen Collector Rates

Collector	Current Capacity Scenario (m^3/d)	Steady state Discharge (m^3/d)	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 5 Scenario A1-A: Simulated Lower Road Collector and Glen Collector Annual Minimum Discharge Rates

Year	Minimum Simulated Discharge Rate while Glen Collector is Solely Operating (Current Capacity Rates)[(1)] (m^3/day)	Minimum Simulated Cumulative Discharge Rate while Lower Road Collector and Glen Collector are Operating (Current Capacity Rates) (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

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

3.1.2 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. 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 6). 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 system capacity of 4,720 m^3/day over the Current Capacity.

The largest simulated reductions in groundwater discharge to watercourses (in comparison to the Current Capacity Scenario) were predicted to be 13% (470 m^3/day) and 17% (977 m^3/day) along Hanlon Creek and Irish Creek, respectively (Table 7). 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 estimated to be less than 1%.

Table 6 Scenarios A2-A, A3-A, and A4-A: 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 A2 A			Scenario A3 A			Scenario A4 A		
				Pumping Rate (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A2 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A3 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A4 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)
Southeast	Arkell 1	2,000	319.5	2,000	-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	-5.1	1,500	0	-5.0	1,500	0	-5.3
	Arkell 7	8,000	305.7	8,000	-3.6	8,000	0	-3.6	7,000(4)	-1,000	-3.7	8,000	0	-5.1
	Arkell 8	7,000	311.1	0	0.1(2)	0	0	0.1(2)	0	0	0.1(2)	0	0	1.5(2)
	Arkell 14	7,000	310.9	3,100	0.0(2)	3,100	0	0.0(2)	1,800(4)	-1,300	-0.1	3,100	0	0.0(2)
	Arkell 15	7,000	304.4	7,000	-5.3	7,000	0	-5.3	7,000	0	-5.0	7,000	0	-4.9
	Burke	6,500	323.4	5,200	-0.2	5,200	0	-0.1	5,200	0	-0.1	5,200	0	-0.1
	Carter Wells	6,400	318.5	6,100	-0.0	6,100	0	0.1	6,100	0	0.0(2)	6,100	0	0.0(2)
Southwest	Membro	5,200	282.1	5,200	-0.8	4,700(4)	-500	-0.9	5,200	0	-0.7	5,200	0	-0.7
	Water St.	2,700	289.24	1,950	-0.1	1,500(4)	-450	-0.1	1,950	0	0.2(2)	1,950	0	0.1(2)
	Dean	1,500	289.9	540	-0.0	0(5)	-540	-0.2	540	0	0.1(2)	540	0	0.1(2)
	University	2,500	290.4	850	-0.3	0(5)	-850	2.4(2)	850	0	-0.2	850	0	-0.2
	Downey	5,237	286.4	5,240	-0.9	2,250(4)	-2,990	-0.1	5,240	0	-0.8	5,240	0	-0.8
	Edinburgh(1)	3,000	288.0	-	-	1,250(3)	1,250	0.1(2)	-	-	-	-	-	-
	Ironwood(1)	8,000	273.6	-	-	3,750(3)	3,750	-9.6	-	-	-	-	-	-
	GSTW1-20(1)	4,320	288.2	-	-	4,100(3)	4,100	0.1(2)	-	-	-	-	-	-
	Steffler(1)	3,600	285.7	-	-	1,500(3)	1,500	-0.5	-	-	-	-	-	-
Northeast	Park Wells	8,000	281.0	6,680	-0.1	6,580(4)	-100	-1.1	6,300(4)	-380	-1.3	6,600	-80	-0.2
	Emma	2,800	278.2	2,390	-0.3	2,100(4)	-290	-3.8	2,100(4)	-290	-3.4	2,360	-30	-0.3
	Helmar	800	321.4	670	-0.1	650	-20	-0.5	450(4)	-220	-0.0	670	0	0.0(2)
	Clythe(1)	3,395	309.3	-	-	-	-	-	1,500(3)	1,500	-0.6	-	-	-
	Fleming(1)	2,200	310.7	-	-	-	-	-	1,100(3)	1,100	-0.3	-	-	-
	Logan(1)	4,700	281.5	-	-	-	-	-	4,250(3)	4,250	-0.4	-	-	-

City Quadrant	Municipal Well/Source	Maximum Individual Well Capacity Threshold (m^3/day)	Adjusted Simulated Low Water Threshold (m asl)	Current Capacity Scenario		Scenario A2 A			Scenario A3 A			Scenario A4 A		
				Pumping Rate (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A2 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A3 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A4 A Pumping vs. Current Capacity Pumping (m^3/day)	Available Head (m)
Northwest	Paisley	1,400	298.5	940	-0.0	840	-100	-0.9	940	0	-0.0	840(4)	-100	0.1(2)
	Calico	1,400	294.2	1,400	-13.2	1,400	0	-13.2	1,400	0	-13.2	1,400	0	-12.0
	Queensdale	1,100	295.9	760	-0.5	660	-100	-0.9	760	0	-0.5	760	0	-0.1
	Hauser(1)	900	317.7	-	-	-	-	-	-	-	-	510(3)	510	-0.1
	Sacco(1)	1,150	321.2	-	-	-	-	-	-	-	-	150(3)	150	-0.7
	Smallfield(1)	1,408	284.3	-	-	-	-	-	-	-	-	980(3)	980	-30.5
	Sunny Acres(1)	5,000	276.7	-	-	-	-	-	-	-	-	0		-22.3
	Glen Collector	-	-	7,240	-	7,300	60	-	7,190	-50	-	7,310	70	-
Total Wells		**131,710**	**-**	**59,520**	**-**	**64,180**	**4,660**	**-**	**63,180**	**3,660**	**-**	**60,950**	**1,430**	**-**
Total (Wells + Collector)		**-**	**-**	**66,760**	**-**	**71,480**	**4,720**	**-**	**70,370**	**3,610**	**-**	**68,260**	**1,500**	**-**

Notes:
(1) Future Scenario Well
(2) Low water level threshold exceedance
(3) Pumping rate is greater than rate in the Current Capacity Scenario
(4) Pumping rate is less than rate in the Current Capacity Scenario
(5) Pumping rate is set to 0 m^3/day

Table 7 Scenario A2-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater(1)	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%(2)
Hopewell Creek	Coldwater	21,514	21,548	34	0%
Irish Creek	Warmwater	5,807	4,830	-977	-17%(2)
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:
(1) From MNR (2013) and GRCA (2013) in Matrix (2017)
(2) Reduction in simulated groundwater discharge is greater than 10%

3.1.3 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. 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 6). 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 allow 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 8). 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 warmwater 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 8 Scenario A3-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[1]	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%[2]
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:
(1) From MNR (2013) and GRCA (2013) in Matrix (2017)
(2) Reduction in simulated groundwater discharge is greater than 10%

3.1.4 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 Water Supply Master Plan 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 as simulated in the Tier Three model. 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 6). Pumping at Sunny Acres results in a reduction of water levels at the surrounding municipal wells below the applied head constraints. Decreasing the pumping rate at Paisley well allows these 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, allows for an increase in average day capacity of 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 9).

Table 9 Scenario A4-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater(1)	Current Capacity Groundwater Discharge (m^3/day)	A3 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	41,656	-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:
(1) From MNR (2013) and GRCA (2013) in Matrix (2017)
(2) Reduction in simulated groundwater discharge is greater than 10%

3.1.5 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. 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 10). 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.

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 11). 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 10 Summary of the Optimized Well Rates and Available Head Exceedances for Current Capacity Scenario and Scenario A5-A

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		
				Pumping Rate (m^3/day)	Available Head (m)	Pumping Rate (m^3/day)	A5 A versus Current Capacity Pumping (m^3/day)	Available Head (m)
Southeast	Arkell 1	2,000	319.5	2,000	-2.0	2,000	0	-2.0
	Arkell 6	8,000	305.7	1,500	-5.1	1,500	0	-4.9
	Arkell 7	8,000	305.7	8,000	-3.6	7,000(4)	-1,000	-3.6
	Arkell 8	7,000	311.1	0	0.1(2)	0	0	0.2(2)
	Arkell 14	7,000	310.9	3,100	0.0(2)	1,800(4)	-1,300	0.0(2)
	Arkell 15	7,000	304.4	7,000	-5.3	7,000	0	-4.9
	Burke	6,500	323.4	5,200	-0.2	5,200	0	-0.1
	Carter Wells	6,400	318.5	6,100	-0.0	6,100	0	0.1(2)
Southwest	Membro	5,200	282.1	5,200	-0.8	4,700(4)	-500	-0.8
	Water St.	2,700	289.24	1,950	-0.1	1,500(4)	-450	0.1(2)
	Dean	1,500	289.9	540	-0.0	0(5)	-540	-0.1
	University	2,500	290.4	850	-0.3	0(5)	-850	2.5(2)
	Downey	5,237	286.4	5,240	-0.9	2,250(4)	-2,990	0.00
	Edinburgh(1)	3,000	288.0	-	-	980	980	-0.0
	Ironwood(1)	8,000	273.6	-	-	3,750(2)	3,750	-9.5
	GSTW1-20(1)	4,320	288.2	-	-	4,100(2)	4,100	0.1(2)
	Steffler(1)	3,600	285.7	-	-	1,500(2)	1,500	-0.38
Northeast	Park Wells	8,000	281.0	6,680	-0.1	6,300(4)	-380	-0.9
	Emma	2,800	278.2	2,390	-0.3	2,100	-290	-2.9
	Helmar	800	321.4	670	-0.1	400(4)	-270	-0.0
	Clythe(1)	3,395	309.3	-	-	1,500(2)	1,500	-0.5
	Fleming(1)	2,200	310.7	-	-	1,100(2)	1,100	-0.2
	Logan(1)	4,700	281.5	-	-	4,250(2)	4,250	-0.1
Northwest	Paisley	1,400	298.5	940	-0.0	790(4)	-150	-0.1
	Calico	1,400	294.2	1,400	-13.2	1,400	0	-11.9
	Queensdale	1,100	295.9	760	-0.5	700	-60	0.1(2)
	Hauser(1)	900	317.7	-	-	510(2)	510	-0.0
	Sacco(1)	1,150	321.2	-	-	150(2)	150	-0.6
	Smallfield(1)	1,408	284.3	-	-	980(2)	980	-30.4
	Glen Collector	-	-	7,240	-	7,180	-60	-
Total (Wells)		**131,710**	**-**	**59,520**	**-**	**69,560**	**10,040**	**-**
Total (Wells + Collector)		**-**	**-**	**66,760**	**-**	**76,740**	**9,980**	**-**

Notes:
(1) Future Scenario Well
(2) Low water level threshold exceedance
(3) Pumping rate is greater than rate in the Current Capacity Scenario
(4) Pumping rate is less than rate in the Current Capacity Scenario
(5) Pumping rate is set to 0 m^3/day

Table 11 Scenario A5-A: Change in Simulated Groundwater Discharge to Streams

Watercourse	Coldwater or Warmwater[1]	Current Capacity Net Groundwater Discharge	A3 A Net Groundwater Discharge	A3 A Change in Net Groundwater Discharge	A3 A Percent Change in Net 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%[2]
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%[2]
Hopewell Creek	Coldwater	21,514	21,274	-240	-1%
Irish Creek	Warmwater	5,807	4,809	-998	-17%[2]
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:

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

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

3.2 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 12, 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 12 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 12 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 4,50 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 12 Scenario B1: Summary of 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(1) (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

Note:

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

3.3 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.

3.3.1 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 13)
- 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 13 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 3.1.1; 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 14 summarizes the average monthly infiltration rates for the three pump capacities evaluated.

Table 14 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)	Min Daily Rate (m^3/day)	Max Daily Rate (m^3/day)	Monthly Average (m^3/day)	Min Daily Rate (m^3/day)	Max Daily Rate (m^3/day)	Monthly Average (m^3/day)	Min Daily Rate (m^3/day)	Max 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 14. 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 15. 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.

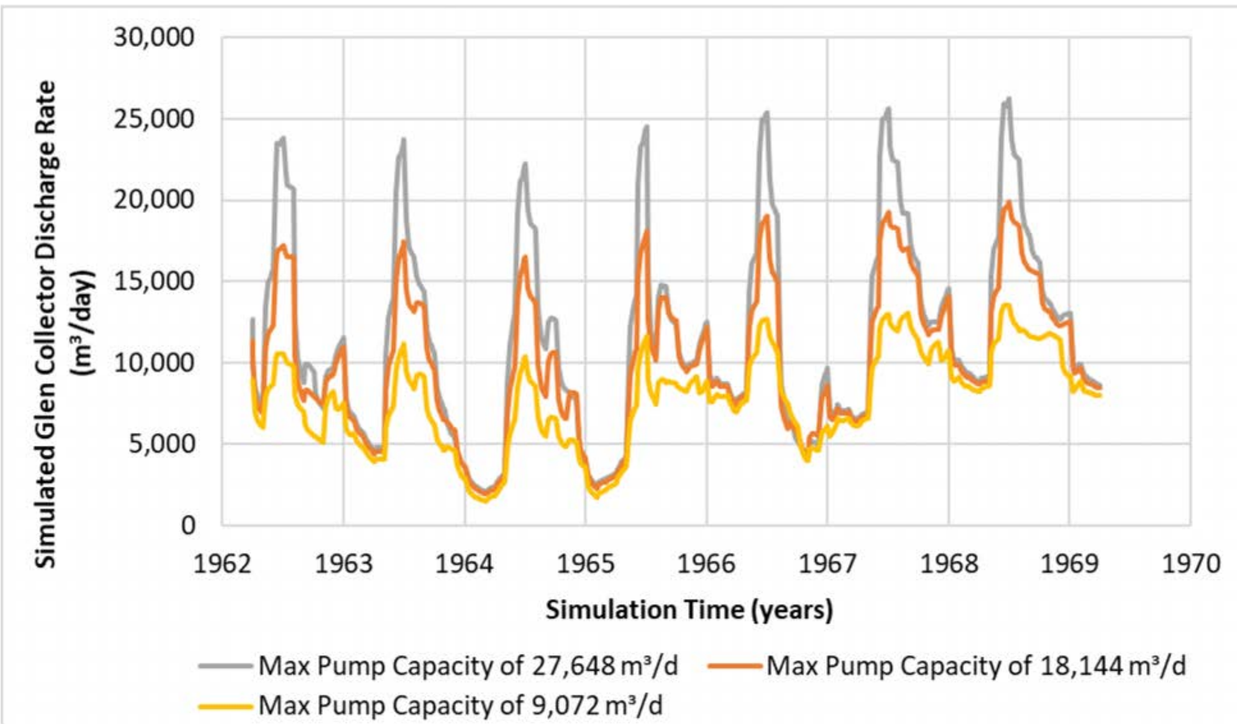

Chart 2 Simulated Total Transient Glen Collector Discharge Under the Various Pump Capacity Scenarios

Table 15 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 14). Average annual values represent the average pumping rate if the water takings were spread over the whole year. Table 16 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 16 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 16 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 16 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 16, 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.

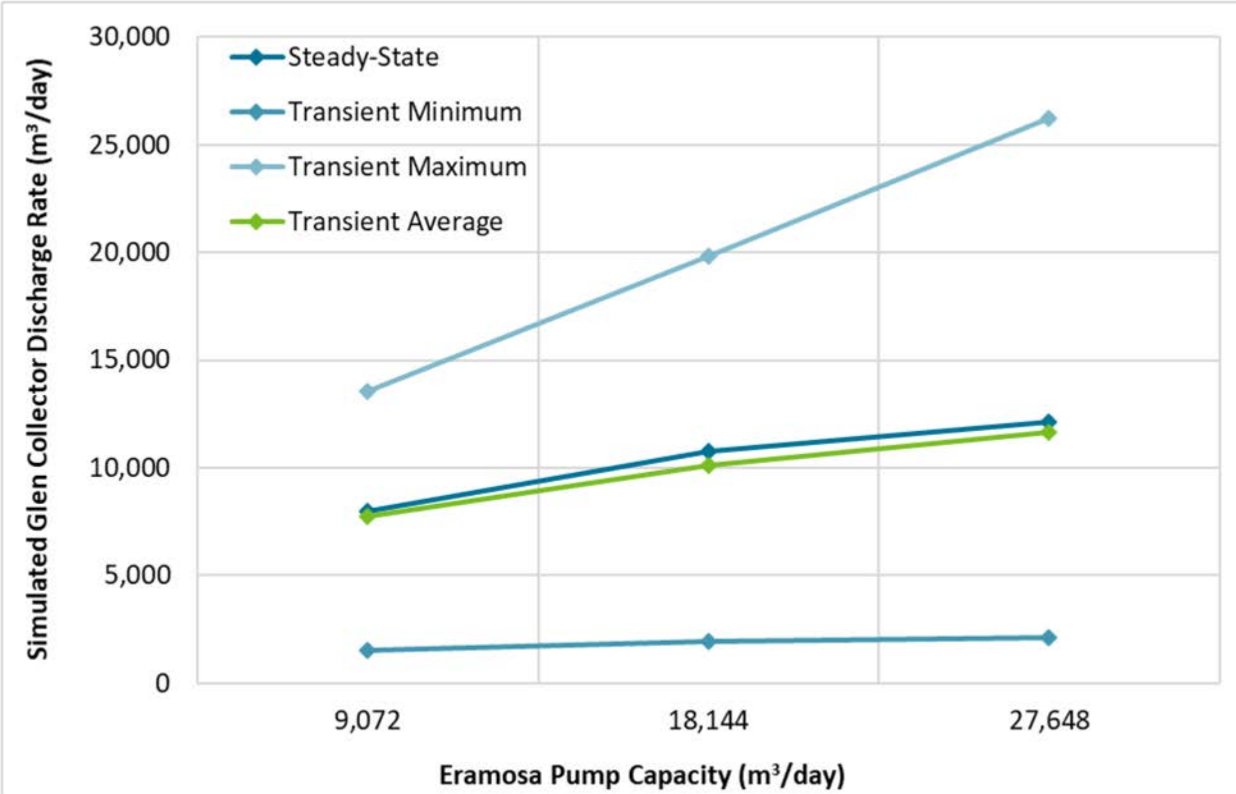

Chart 3 Estimated Glen Collector Collection Rates Versus Maximum Pump Capacity

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.

3.3.2 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 17). Under this withdrawal, 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 17 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 17 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; Table 17 and 18). 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 17). 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.

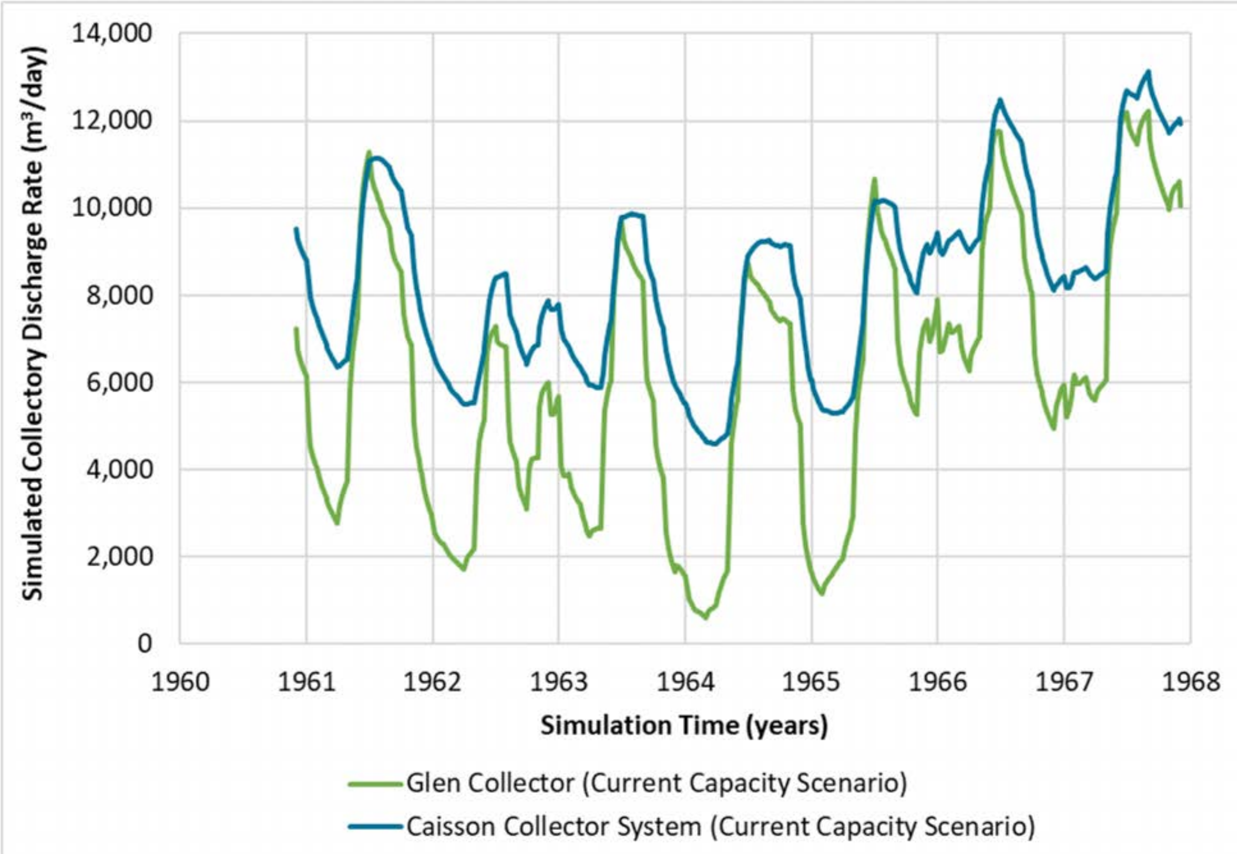

Chart 4 Simulated Transient Glen Collector and Caisson Collector Discharges

Table 17 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 18 Scenario C2: Simulated Caisson Collector Annual Minimum Rates

Year	Glen Collector (Current Capacity Rates) (m^3/day)	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

4 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 within the City. 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

Table 19 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 19 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(1)	3,051
	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
	Multiple Quadrants	A5-A: Additional well supply from: Edinburgh, Steffler, Ironwood, GSTW1-20, Clythe, Fleming, Logan, Sacco, Smallfield, and Hauser	76,740	9,980
B Dolime Quarry Water Capture		B1: Dolime Quarry capture considering current municipal wells	71,760(2)	5,000(2)
C Arkell Recharge/Collector Optimization		C1: Withdraw more water from the Eramosa River, increase pump capacity to 0.32 m^3/s.	71,659(3)	4,899
		C2: De-activate the Glen Collector and install a Caisson Collector System.	66,402(4)	358

Notes:
(1) 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
(2) 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.
(3) 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
(4) 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

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 approximately 85,000 m^3/day of average day water capacity for the City of Guelph. 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.

4.1 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.

4.2 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 9,980 m^3/day (Scenario A5-A). Potential additional municipal well supplies, including Edinburgh, Ironwood, GSTW1-20, and Steffler in the southwest quadrant offer the greatest amount of additional water 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 24% (i.e., Scenarios A3-A and A5-A). 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.

4.3 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.

4.4 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.

5 Closure

We trust that this letter report suits your present requirements. If you have any questions or comments, please call either of the undersigned at 519.722.3777.

Yours truly,

MATRIX SOLUTIONS INC.

Joelle Langford, M.Sc., G.I.T.
Geoscientist-in-Training

Reviewed by

David Van Vliet, M.A.Sc., P.Eng.
Vice President, Technical Practice Areas

Jeffrey Melchin, M.Sc., P.Geo.
Hydrogeologist

October 4, 2021

JL/vc
Attachments

Disclaimer

Matrix Solutions Inc. certifies that this report is accurate and complete and accords with the information available during the project. Information obtained during the project or provided by third parties is believed to be accurate but is not guaranteed. Matrix Solutions Inc. has exercised reasonable skill, care, and diligence in assessing the information obtained during the preparation of this report.

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Contributors

Name	Job Title	Role
Joelle Langford, M.Sc.	Geologist In Training	Primary Author
Louis-Charles Boutin, P.Eng.	Principal Hydrogeologist	Technical Reviewer
David Van Vliet, M.A.Sc., P.Eng.	Vice President, Technical Practice Areas	Technical Reviewer
Daron Abbey, M.Sc., P. Geo	Practice Lead, Geosciences	Technical Reviewer
Jeffrey Melchin, M.Sc., P.Geo.	Hydrogeologist	Project Manager

Version Control

Version	Date	Issue Type	Filename	Description
V0.1	21-May-2021	Draft	15072-527 Places to Grow Modelling LR 2021-05-21 draft V0.1.docx	Issued to client for review
V1.0	27-May-2021	Final	15072-527 Places to Grow Modelling LR 2021-05-27 final V1.0.docx	Issued to client
V2.0	04-Oct-2021	Final revised	15072-527 Places to Grow Modelling LR 2021-10-04 final V2.0.docx	Revisions issued to client

References

AECOM Canada Ltd. (AECOM). 2021. **City of Guelph Water Supply Master Plan, Task 3 Water Supply Capacity Assessment (Draft)**. Prepared for City of Guelph. Guelph, Ontario. July 2021.

Amec Foster Wheeler. 2017. **Environmental Impact Study (EIS), York Road Environmental Design, City of Guelph**. Prepared in association with Dougan & Associates, Matrix Solutions (including Parish Aquatic Services), and Blackport and Associates. Prepared for City of Guelph, River Systems Advisory Committee (RSAC). March 2017.

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

Jagger Hims Limited. 1998. A**quifer Performance Evaluation, Volume 1, Southeast Quadrant**. Prepared for the City of Guelph. St. Catharines, Ontario. November 1998.

Matrix Solutions Inc. (Matrix). 2021. **Groundwater Modelling Report The City of Guelph Water Supply Master Plan Update**. Version 1.0. Prepared for the City of Guelph. Guelph, Ontario. October 4, 2021.

Matrix Solutions Inc. (Matrix). 2017. **City of Guelph and Township of Guelph/Eramosa, Tier Three Water Budget and Local Area Risk Assessment**. Prepared for Lake Erie Source Protection Region. Breslau, Ontario. March 2017.

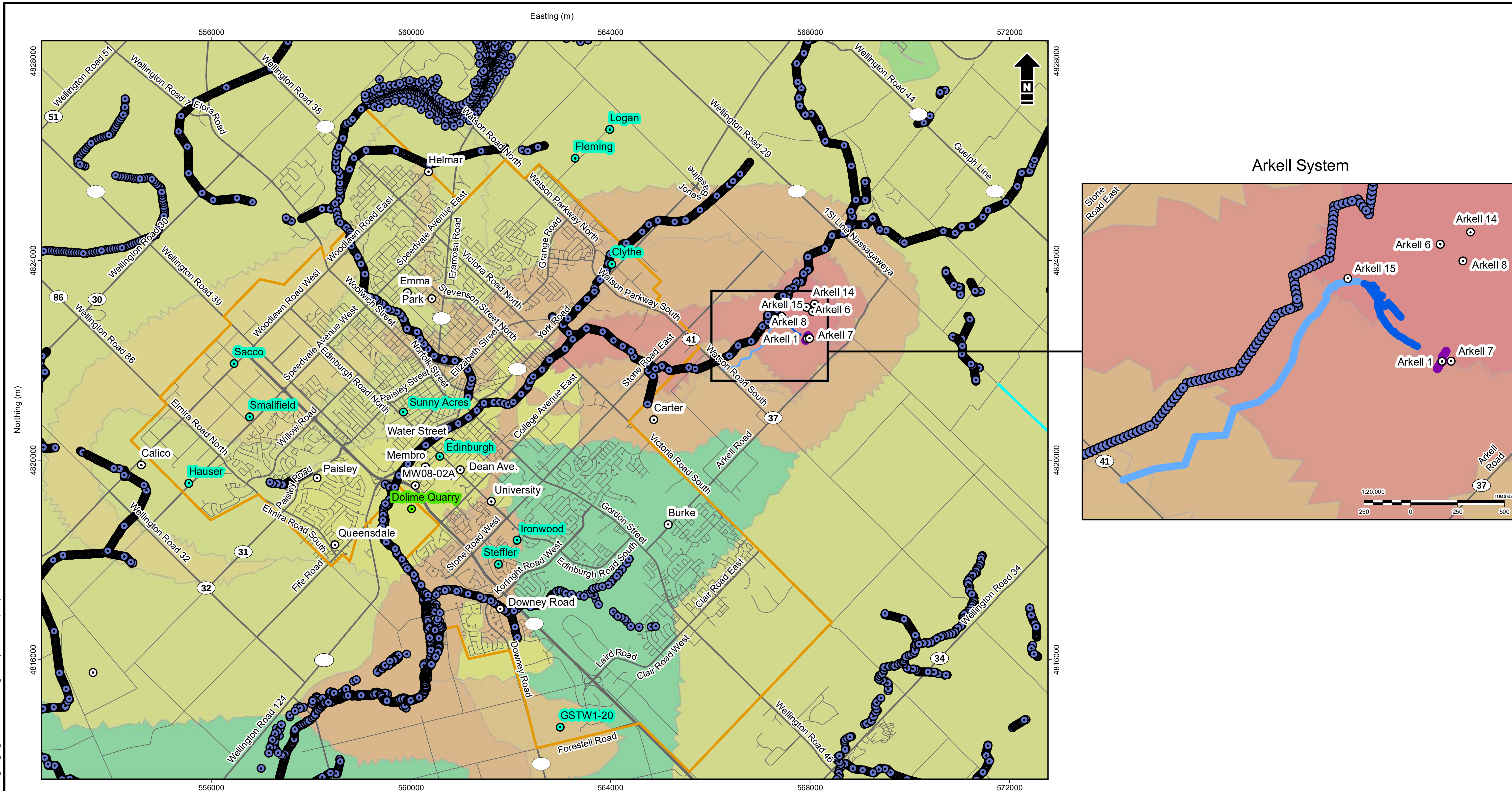
Ontario Ministry of Environment, Conservation and Parks (MECP). 2021. **2017 Technical Rules under the Clean Water Act**. Published June 13, 2017. Updated April 17, 2021. 2021. https://www.ontario.ca/page/2017 technical rules under clean water act

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

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

Stantec Consulting Ltd. (Stantec). 2006. "Hydrogeological Study in Support of a Caisson Collector System, Arkell Spring Grounds, Guelph." Draft prepared for City of Guelph. March 2006.

White J.T. et al. 2020. A**pproaches to Highly Parameterized Inversion: PEST++ Version 5, a Software Suite for Parameter Estimation, Uncertainty Analysis, Management Optimization and Sensitivity Analysis: U.S. Geological Survey Techniques and Methods 7C26**. 2020. 52 pp. https://pubs.er.usgs.gov/publication/tm7C26



Simulated Caisson Collection System
Simulated Glen Collector
Simulated Lower Collector
City Boundary
Highway
Road
Constant Head Boundary Condition
Constant Head Boundary Condition - Dolime Quarry
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

1:75,000
metres
1,000 0 1,000 2,000
NAD 1983 UTM Zone 17N

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph
Water Supply Master Plan

Study Area, Municipal Wells, and Watercourses

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

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Figure
1

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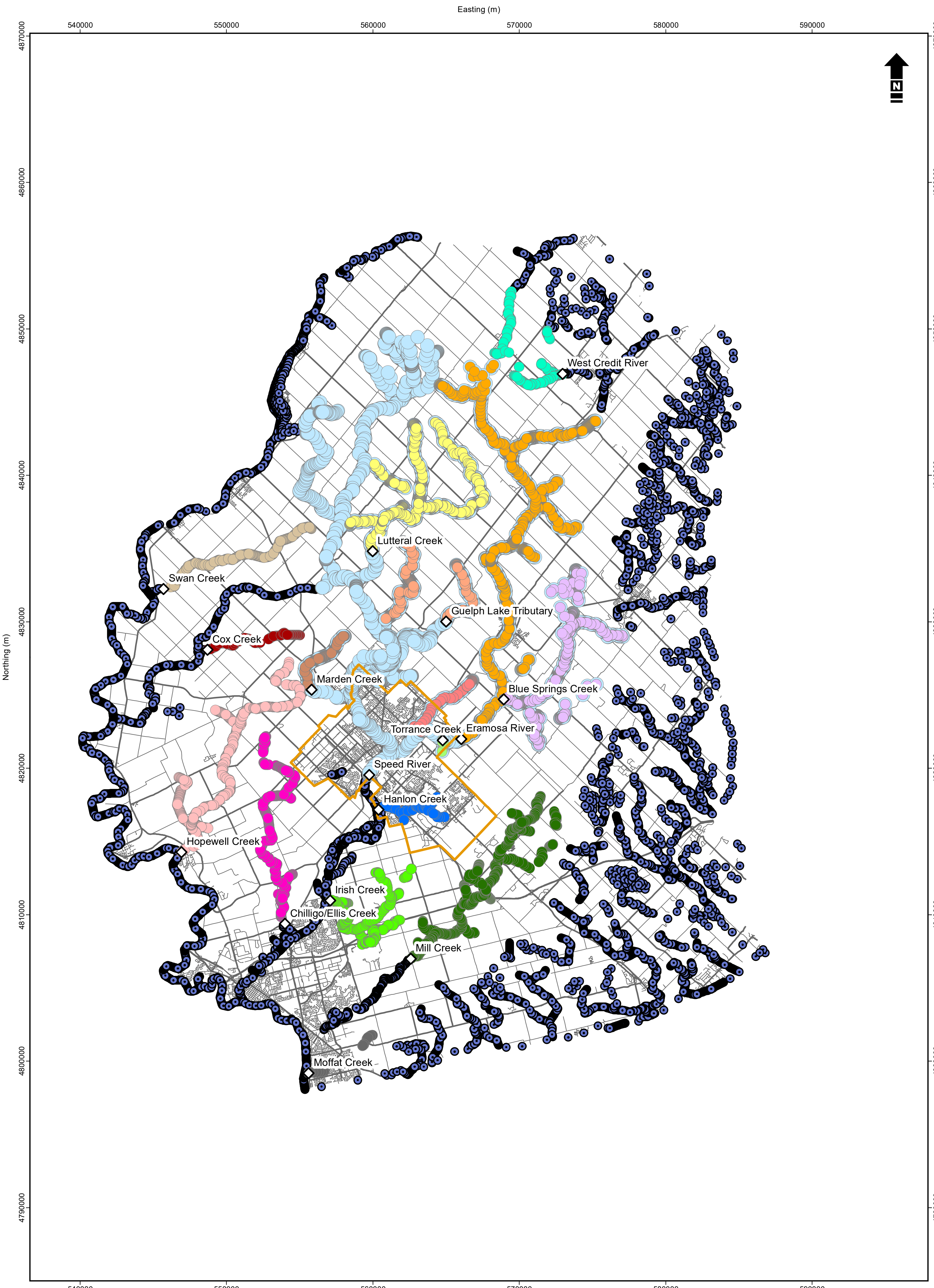

City Boundary
Highway
Road
Baseflow Measurement Station
Constant Head Boundary Condition

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

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

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Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Guelph
Water Supply Master Plan

Discharge Boundary Condition Selections within Model Domain

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

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Figure 2