APPENDIX D
Groundwater Flow Model Update – Rockwood and Hamilton Drive

CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA
TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX D
GROUNDWATER FLOW MODEL UPDATE - ROCKWOOD AND HAMILTON DRIVE

Report Prepared for:
LAKE ERIE SOURCE PROTECTION REGION

Prepared by:
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March 2017
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CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA

TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX D

GROUNDWATER FLOW MODEL UPDATE - ROCKWOOD AND HAMILTON DRIVE

Report prepared for Lake Erie Source Protection Region, March 2017

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DISCLAIMER

TABLE OF CONTENTS

LIST OF TABLES

LIST OF CHARTS

APPENDIX

LIST OF FIGURES

1 INTRODUCTION

This appendix describes updates made to the City of Guelph and Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment) groundwater flow model. These updates implemented newly acquired data for the areas around Hamilton Drive and Rockwood including pumping rates, observed water levels, and borehole data that led to an updated hydrogeologic characterization.

A three dimensional (3D) groundwater flow model was developed and calibrated for the Tier Three Assessment and peer reviewed in 2011. The groundwater flow model is described in Appendix B (Groundwater Flow Model Report) and is based on the Tier Three Assessment characterization completed by Golder in 2011 (Appendix A - Characterization Final Report).

This appendix reports on changes to the groundwater model and incorporates the data described in Appendix C - Characterization Update - Rockwood and Hamilton Drive.

The work undertaken in the characterization update for Rockwood and Hamilton Drive (Appendix C) included the following:

- describing the local study areas including water use, topography, physiography, and surface water features
- summarizing the regional geology and hydrogeology
- revising the conceptual stratigraphy including the top of bedrock surface, conceptual geologic unit distributions and layer elevations
- analyzing cross-sections to evaluate the representation of buried bedrock channels near and northeast of Rockwood
- repicking borehole lithology from borehole and water well records
- reinterpolating bedrock layers along inferred buried channel thalwegs to capture continuity and depth
- reinterpreting buried channel infill texture based on boreholes drilled by the Ontario Geologic Survey (OGS)
- summarizing municipal and non-municipal groundwater demands
- summarizing groundwater level monitoring data

2 MODEL UPDATE

2.1 Objectives

The objectives of the model update were to incorporate newly available hydrogeologic data, ensure the numerical model is consistent with the conceptual model for the study area, recalibrate the model as necessary, and verify the model against observed data. The model update included the following:

- revisions to the distribution and properties of hydrogeologic units
- addition of two municipal pumping well locations and mesh refinement around them
- analysis and inclusion of revised municipal well pumping rates
- model recalibration to account for updated hydrogeologic zones and bedrock layer adjustments
- verification of groundwater discharge in the updated model against baseflow estimates
- verification of transient groundwater levels in monitoring wells

2.2 Model Structure and Parameters

This section describes the updates to the structure and parameters of the City of Guelph and Township of Guelph/Eramosa (in Rockwood and Hamilton Drive) Tier Three Assessment groundwater flow model based on the revised conceptual model. The development of the revised conceptual model is described in Appendix C (Characterization Update - Rockwood and Hamilton Drive). The updated calibration and verification of the groundwater flow model is described in Section 3.

2.2.1 Model Domain and Model Discretization

No changes were made to the extents of the model domain; however, the finite element mesh was refined horizontally (i.e., smaller element sizes) around the locations of two Rockwood wells (Rockwood wells 3 and 4). The refined mesh is shown on Figure 2-1. The elevations of several model layers were adjusted to update the top of bedrock surface in the area of the bedrock valley near and northeast of Rockwood. The difference between the previous and updated top of bedrock surface is shown on Figure 2-2 with the area adjusted in the model highlighted in cross-hatching. No layers were added to the model; thus, the vertical discretization remained unchanged.

2.2.2 Distribution and Properties of Hydrogeologic Units

The spatial distribution of hydrogeologic units was modified to incorporate the updates to the hydrogeology characterization and to ensure that the numerical model was consistent with the revised conceptual model described in Appendix C.

Updates to the model required the addition of a hydrogeologic unit (zone) to represent the coarse material infilling the bedrock valley near and northeast of Rockwood. The modifications to hydrogeologic zones to represent the coarse material infill in model layer 3 are shown as the cross-hatched area on Figure 2-3 and the hydraulic properties assigned are summarized in Table 2-1.

TABLE 2-1 Additional Conductivity Zone Properties

Zone Name	Initial K (m/s)		Calibrated K (m/s)	
	Horizontal	Vertical	Horizontal	Vertical
Coarse Grained Buried Valley Infill	5.0E-4	5.0E-4	3.0E-5	3.0E-5

Cross-section analysis revealed that openings (or holes) in the Vinemount Member of the Eramosa Formation, the key bedrock aquitard in the Study Area, near Guelph Lake were more prevalent in the model than what was supported by the updated characterization. Modifications to hydrogeologic zones to reduce the size of the holes in the Vinemount Member near Guelph Lake are illustrated for model layer 9 on Figure 2-4. The cross-hatched areas were changed from the Upper Gasport to Vinemount unit.

Cross-section analysis also revealed that the subcropping of the Middle Gasport unit for model layers 10 and 11 was more extensive in the previous model than what is supported by the updated characterization. Modifications to hydrogeologic zones to reduce the extent of the Middle Gasport unit subcrop are illustrated for model layer 10 on Figure 2-5**.** The cross-hatched area shows where the Middle Gasport unit was changed to the less conductive Goat Island unit that is prevalent in layer 10.

2.2.3 Model Pumping Rates

The model was updated to include Rockwood wells 3 and 4 in Rockwood and the extraction rates for all wells in Rockwood and Hamilton Drive were updated as summarized in Table 2-2.

TABLE 2-2 Updated Well Rates

Well Name	Average Annual Reported Taking (2009-2010) (m^3/day)
Hamilton Drive	
Cross Creek Well	87.0
Huntington Estates Well	92.1
Rockwood	
Rockwood wells 1 and 2	545.6
Rockwood Well 3	421.7
Rockwood Well 4	0

3 MODEL CALIBRATION AND TRANSIENT VERIFICATION

3.1 Model Calibration

The updated model was calibrated to the existing Tier Three Assessment hydraulic head and baseflow calibration targets along with six additional groundwater observation points in the updated areas as shown on Figures 3-1 and 3-2. To improve the match between simulated and observed groundwater levels, the hydraulic conductivity of the new conductivity zone infilling the Rockwood bedrock valley (Coarse Grained Buried Valley Infill), was reduced from the initial estimate of 5.0E-4 m/s to 3.0E-5 m/s as shown in Table 2-1.

3.1.1 Calibration Results

The calibration results of the updated model for hydraulic head and baseflow are presented below. Due to updates to the numerical model and the addition of the new head calibration targets, the calibration results changed slightly from the previous calibrated model.

3.1.1.1 Hydraulic Head Calibration

The hydraulic head calibration statistics for the updated and previous model are summarized in Tables 3-1 and 3-2. Statistics are calculated for all the calibration targets within the regional Study Area, and for three subsets of targets: high-quality wells throughout the Study Area, targets surrounding Rockwood, and targets local to Hamilton Drive. The calibration statistics of the updated model do not deviate significantly from those of the previous model.

The mean error for all targets of the updated model is -0.3 m, which indicates that the simulated heads are lower on average than the observed by -0.3 m. This is further from zero than the previous model, which had a mean error of -0.1 m. For the Rockwood group of targets, the mean error of the updated model (-1.5 m) indicates a greater residual error than the previous model (-1.1 m). These changes in the calibration statistics are insignificant given the degree of updates to the conceptual model represented in the numerical model. Although the updates to the model do not improve the calibration statistics, the model remains suitably calibrated.

TABLE 3-3 Head Calibration Statistics for the Updated Mode

Calibration Statistic	All Targets	High-quality Wells	Rockwood	Hamilton Drive
Number of Calibration Targets	11,047	404	1,686	296
Mean Error (ME)	-0.3 m	-1.0 m	-1.5 m	-0.1 m
Mean Absolute Error (MAE)	4.2 m	2.8 m	5.0 m	3.8 m
Root Mean Squared Error (RMS)	5.7 m	4.0 m	6.8 m	5.5 m
Normalized Root Mean Squared Error (NRMS)	2.1%	2.8%	6.1%	7.9%
Range in Observed Water Levels	266.3 m	143.6 m	110.3	69.8

TABLE 3-4 Head Calibration Statistics for the Previous Model

Calibration Statistic	All Targets	High-quality Wells	Rockwood	Hamilton Drive
Number of Calibration Targets	11,041	398	1,682	294
Mean Error (ME)	-0.1 m	-1.0 m	-1.1	-0.1 m
Mean Absolute Error (MAE)	4.2 m	2.7 m	4.9 m	3.9 m
Root Mean Squared Error (RMS)	5.6 m	4.0 m	6.6 m	5.5 m
Normalized Root Mean Squared Error (NRMS)	2.1%	2.8%	6.0%	7.9%
Range in Observed Water Levels	266.3 m	143.6 m	110.3 m	69.8 m

3.1.2 Baseflow Calibration

The model simulated baseflow and estimated observed baseflow at the baseflow target locations used in the Tier Three Assessment are shown for the larger and smaller subwatersheds on Charts 3-1 and 3-2. On these charts the simulated results for the updated model are labelled as "RW/HD Update." The simulated results for the previous model are labelled as "Current Conditions." The estimates of baseflow were generally the same for the models.

For the larger subwatersheds, slight increases of baseflow (10 to 20 L/s) in the Eramosa River at Everton and Rockwood are seen in the updated model. This corresponds to changes made to the buried valley that was updated from Rockwood northeast through Everton up to Erin.

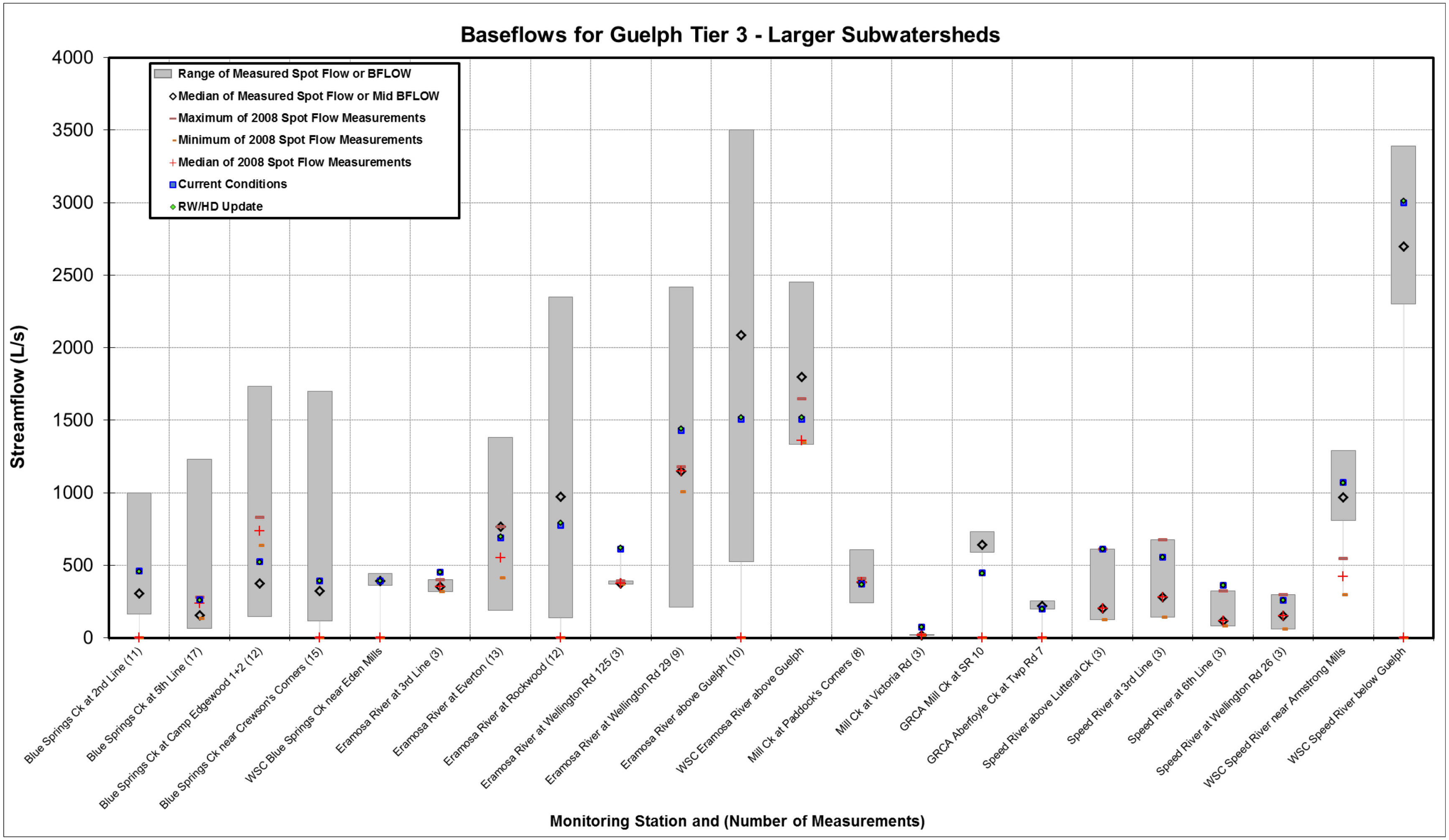


CHART 3-1 **Baseflow Calibration for Larger Subwatersheds**

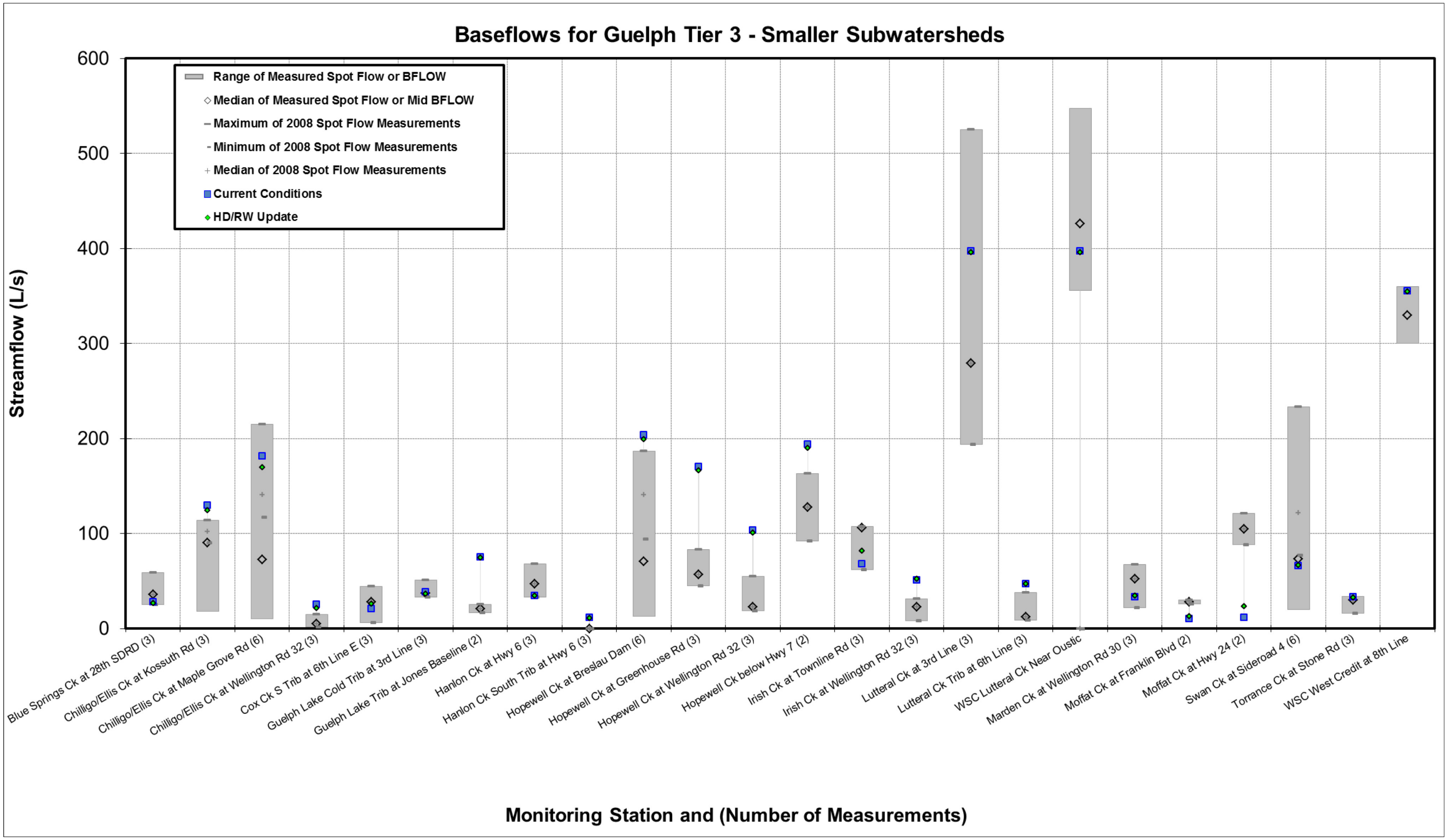


CHART 3-2 Baseflow Calibration for Smaller Subwatersheds

The smaller subwatersheds of Chilligo/Ellis, Cox, and Hopewell creeks had slightly reduced baseflow (5 to 12 L/s) in the updated model. These reductions improved the baseflow calibration over the previous model by bringing the simulated baseflow closer to the average estimated observed baseflow. Reductions in groundwater discharge to these subwatersheds in the west of the study area correspond to the conceptual model updates made by moving the subcrop of the Middle Gasport unit further west and reducing of the extent of openings in the Vinemount Member aquitard around Hamilton Drive.

3.2 Transient Model Verification

The updated model was verified for the Rockwood and Hamilton Drive areas by comparing simulated hydraulic head to observed hydraulic head between 2008 and the end of 2012. To complete this verification, the transient recharge used in calibrating the previous model was extended from 2005 to 2012. Transient recharge for the Tier Three Assessment was derived from a GAWSER model covering 1960 to 2005. Details of this model are provided in Appendix B. For 2005 to 2012, equivalent monthly recharge was approximated using precipitation for those years and the GAWSER-derived relationship between monthly precipitation and estimated monthly recharge for equivalent months.

Time series plots comparing simulated and observed hydraulic heads at pumping and monitoring well locations including Huntington, Cross Creek, MW2S, MW2I, Rockwood Well 1, Rockwood Well 2, Rockwood Well 3, Oelbaum, Perkes, OW3R-08-S, and OW3R-08-D are shown on Charts 3-3 to 3-13**.** Some of the plots show discrepancies between simulated and observed head at various times, but a good match is seen for a majority of the locations.

The pumped water supply wells display greater discrepancies between simulated and observed water levels than the monitoring wells. The supply wells are Huntington and Cross Creek in Hamilton Drive; and Rockwood wells 1, 2, and 3 in Rockwood. These descrepancies were expected as the observed data includes water levels from the full range of pumping conditions (e.g., variable pumping rates, and pumps cycling on and off). The wells were modelled with monthly average pumping rates and the transient verification model used 7-day time steps. These factors inhibit the exact match of simulated to observed water levels especially for pumping wells that may vary in pumping rates on an hourly basis.

Of the pumped wells, Rockwood wells 1 and 2 show greater discrepancies between the simulated and observed water levels for various times, but most particularily during 2011. These periods correspond to times when one well was not pumping and the other was pumped at higher rates to compensate. At times in the pumping record, one well is pumping while the other is reduced in rate or turned off. Pumping history is provided on Chart 3-2 in Appendix C (Characterization Update - Rockwood and Hamilton Drive) and water level record are provided on Charts 3-5 and C3-2 in Appendix C.

Due to their proximity to each other, Rockwood wells 1 and 2 are represented as one pumping well in the model using the total rate of the two wells, but in reality there are two wells with separate rates. Each well responds differently to pumping at different rates (due to aquifer and well physics; e.g., well losses) and each exerts a unique influence on the water level in the other well and the surrounding aquifer.

In the Guelph Tier Three Assessment, this method of representing two wells as one modelled well is also used for Carter wells 1 and 2, and Park wells 1 and 2. For the purposes of this study, this method is valid for the steady-state, average climate scenarios and the transient long-term drought scenarios that are assessed.

In general, the updated model is able to represent the transient pattern and response in water levels within pumping and monitoring wells near Hamilton Drive and Rockwood. While the simulated and observed water elevations may not match exactly, the range of fluctuation is represented. As the model will be used to assess the relative change from baseline conditions to future conditions under various scenarios, it is concluded that the model is suitably calibratated and verified to represent the groundwater flow system.

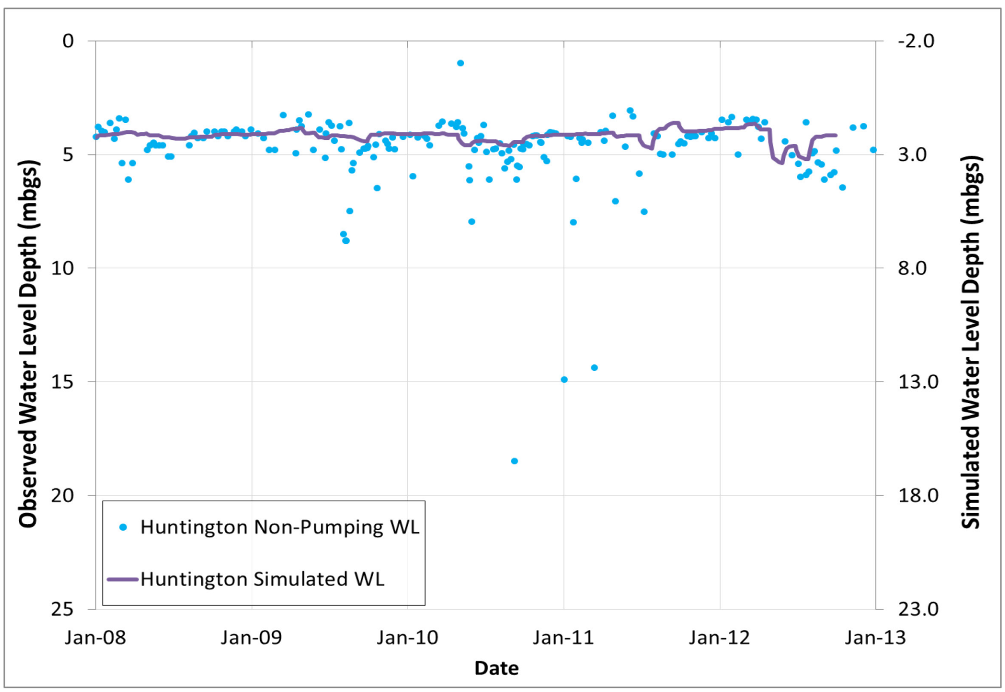


CHART 3-3 Transient Verification - Huntington Estates Well Water Levels (2008-2012)

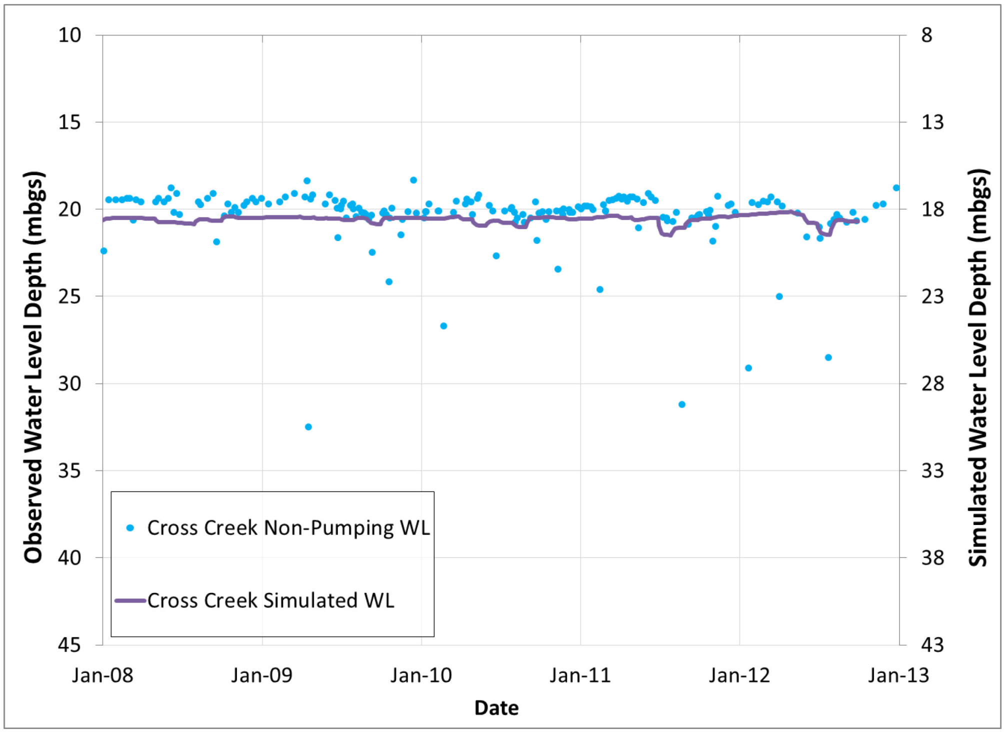


CHART 3-4 Transient Verification - Cross Creek Well Water Levels (2008-2012)

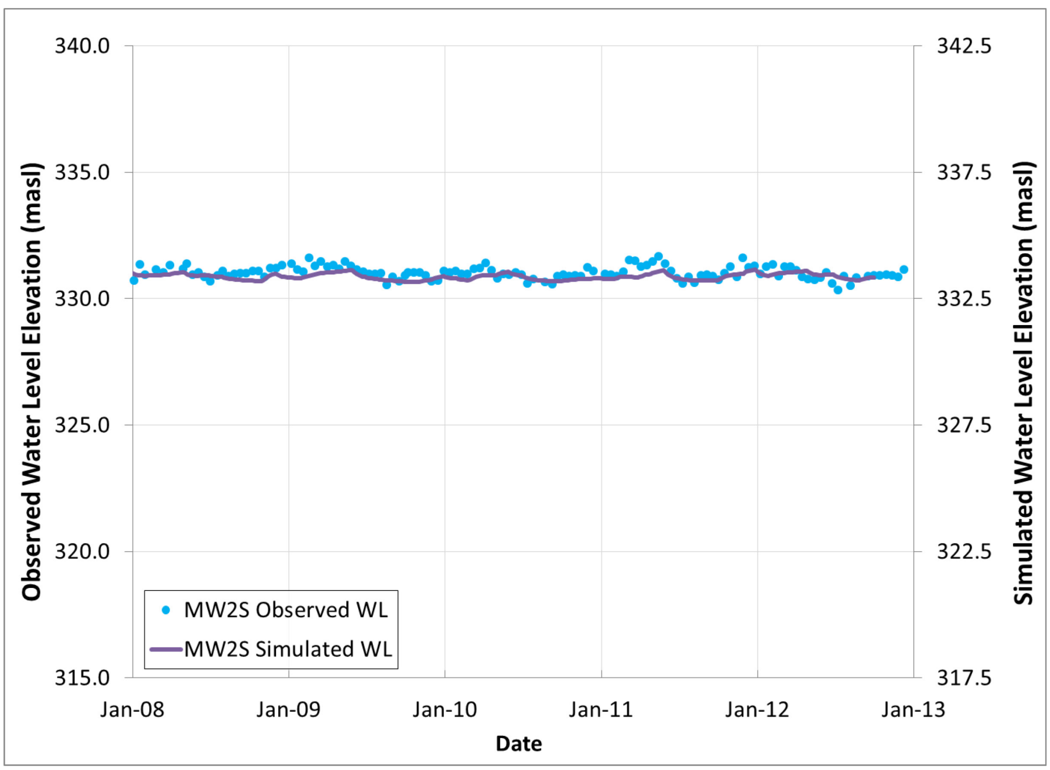


CHART 3-5 Transient Verification - MW2S Water Levels (2008-2012)

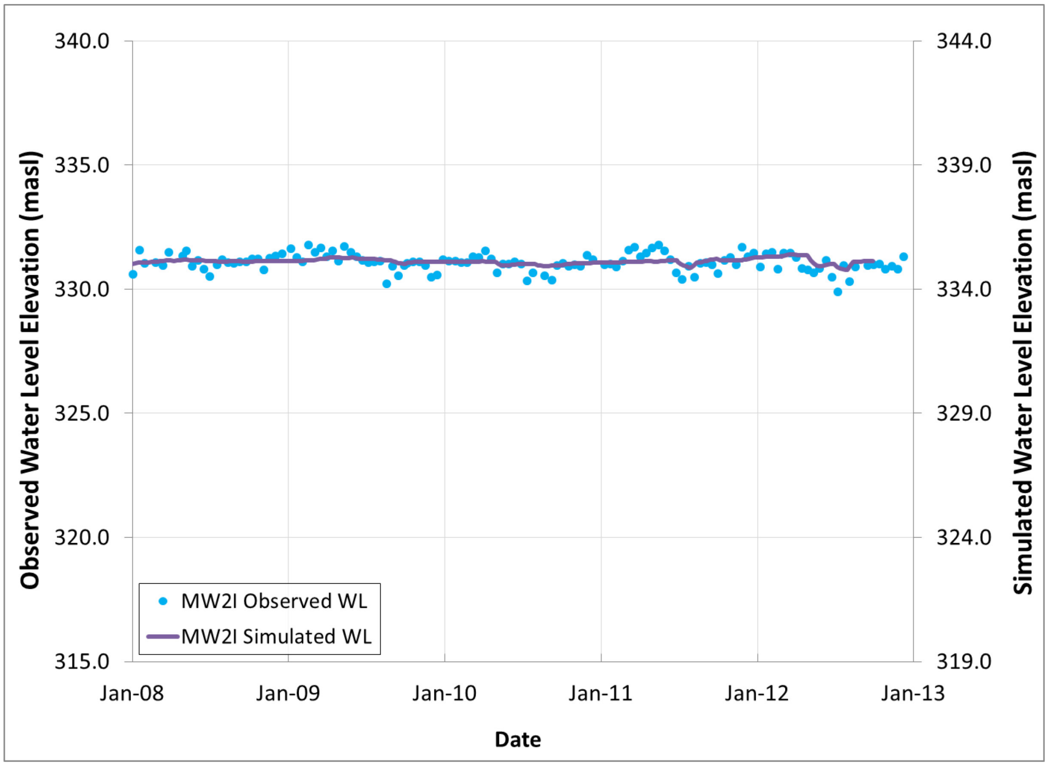


CHART 3-6 **Transient Verification - MW2I Water Levels (2008-2012)**

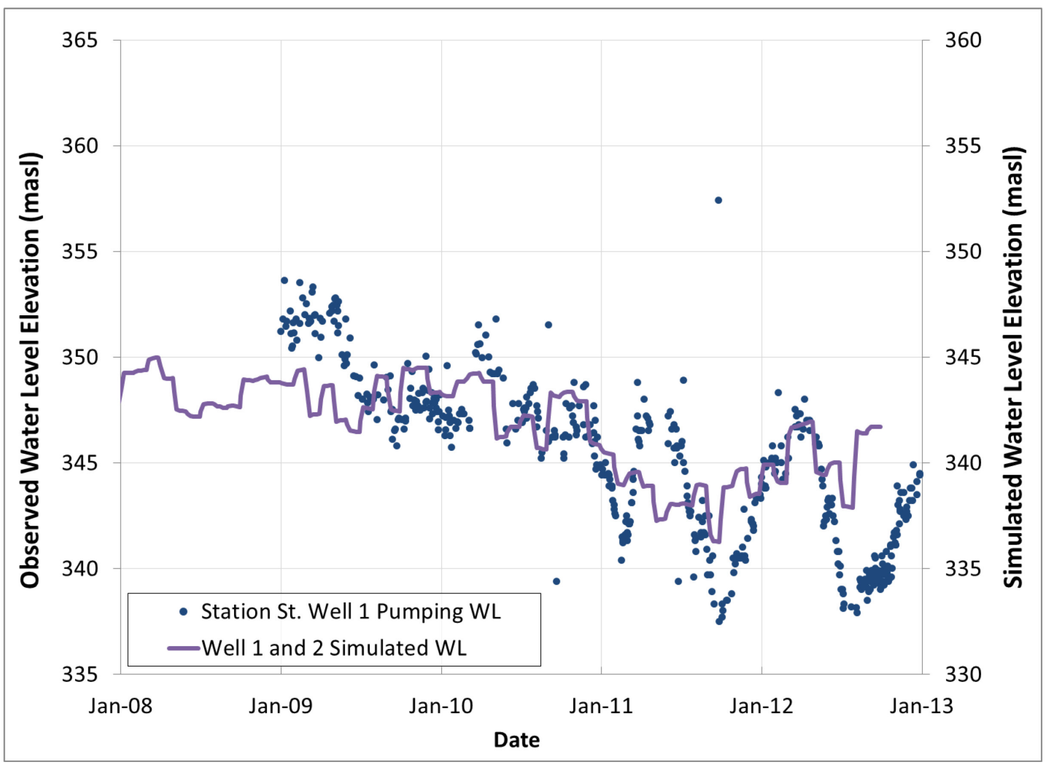


CHART 3-7 **Transient Verification - Rockwood Well 1 Water Levels (2008-2012)**

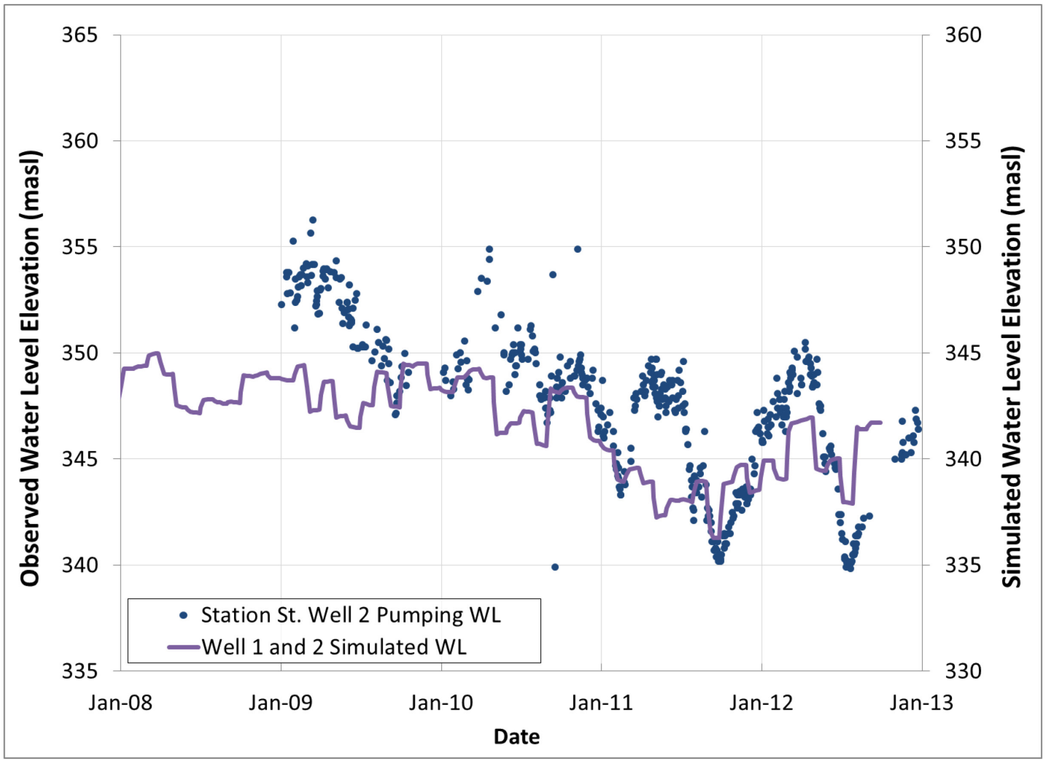


CHART 3-8 Transient Verification - Rockwood Well 2 Water Levels (2008-2012)

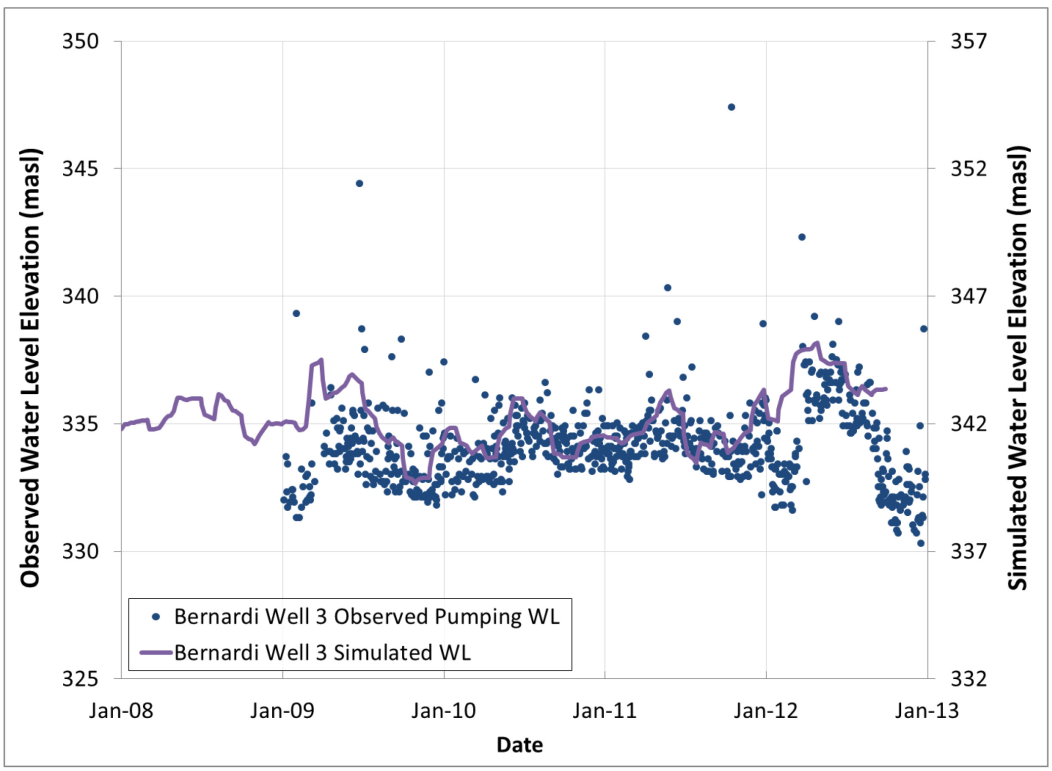


CHART 3-9 Transient Verification - Rockwood Well 3 Water Levels (2008-2012)

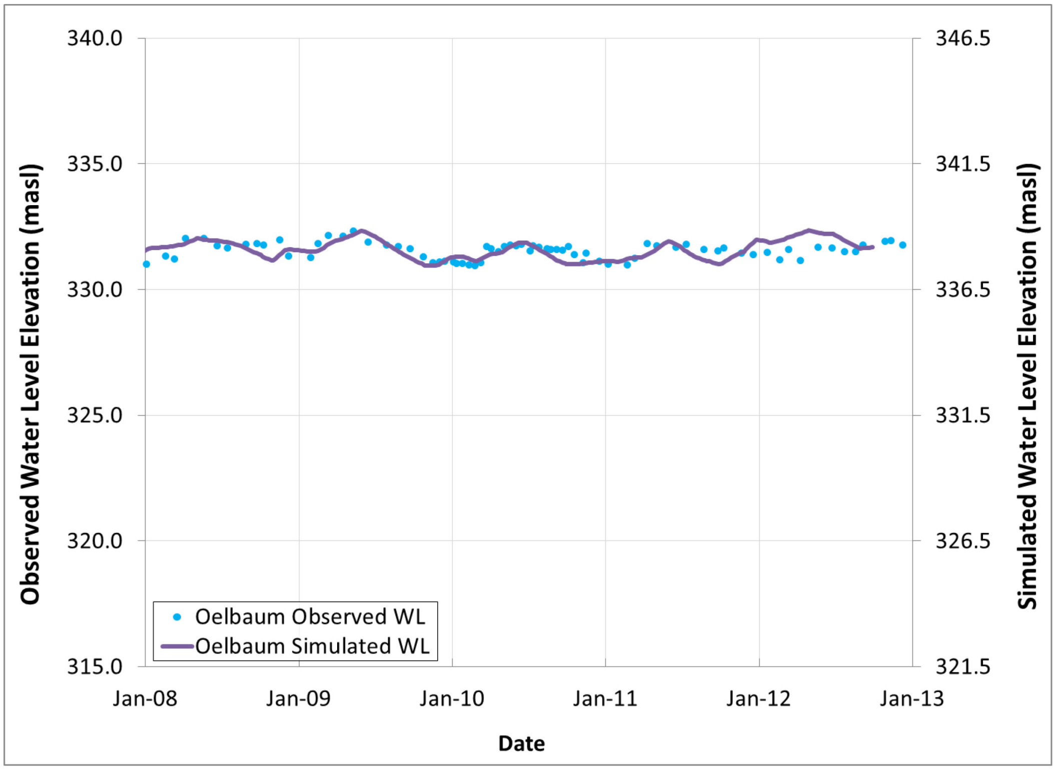


CHART 3-10 Transient Verification - Oelbaum Water Levels (2008-2012)

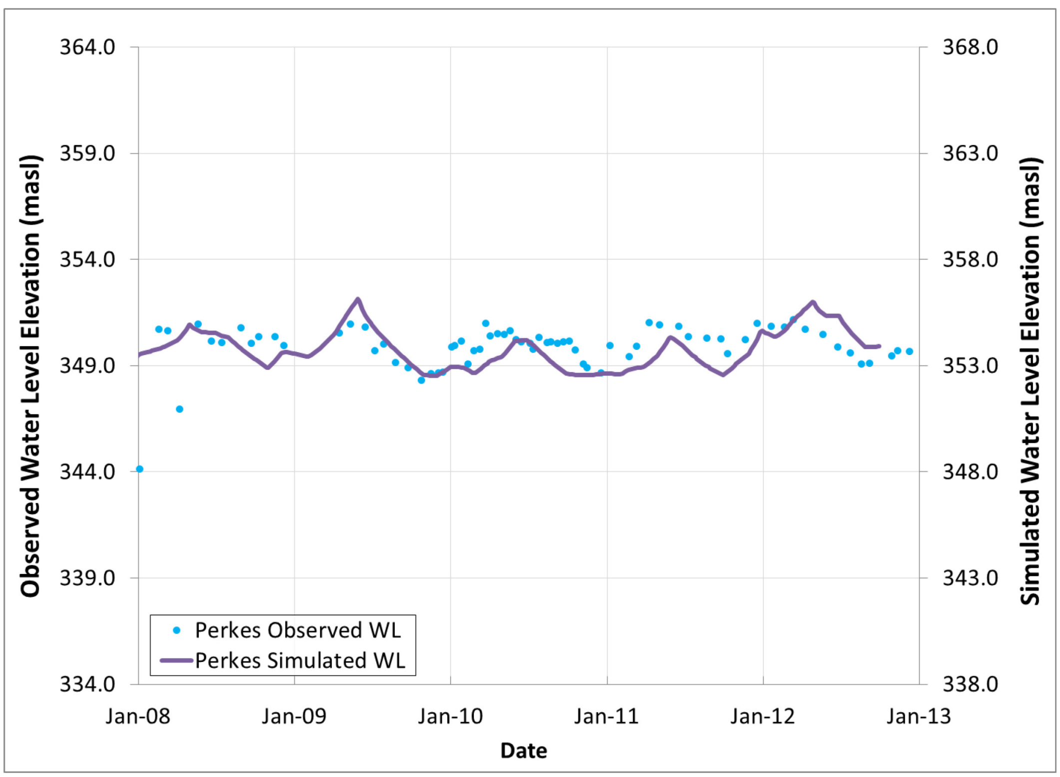


CHART 3-11 Transient Verification - Perkes Water Levels (2008-2012)

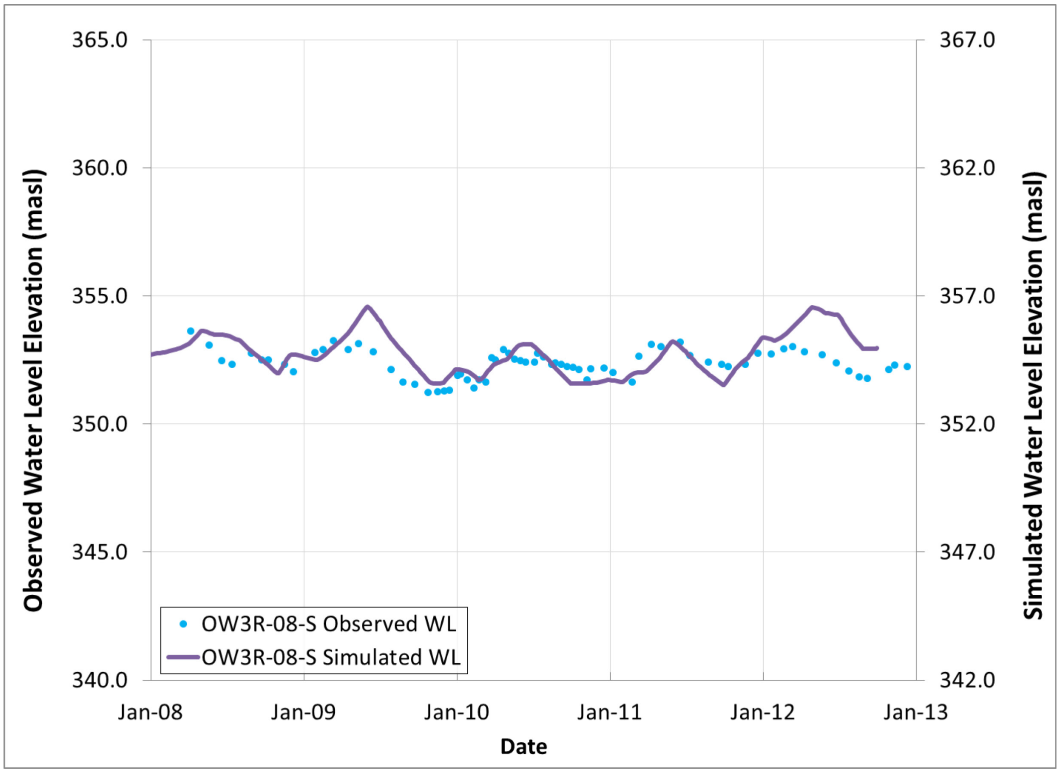


CHART 3-12 Transient Verification - OW3R-08-S Water Levels (2008-2012)

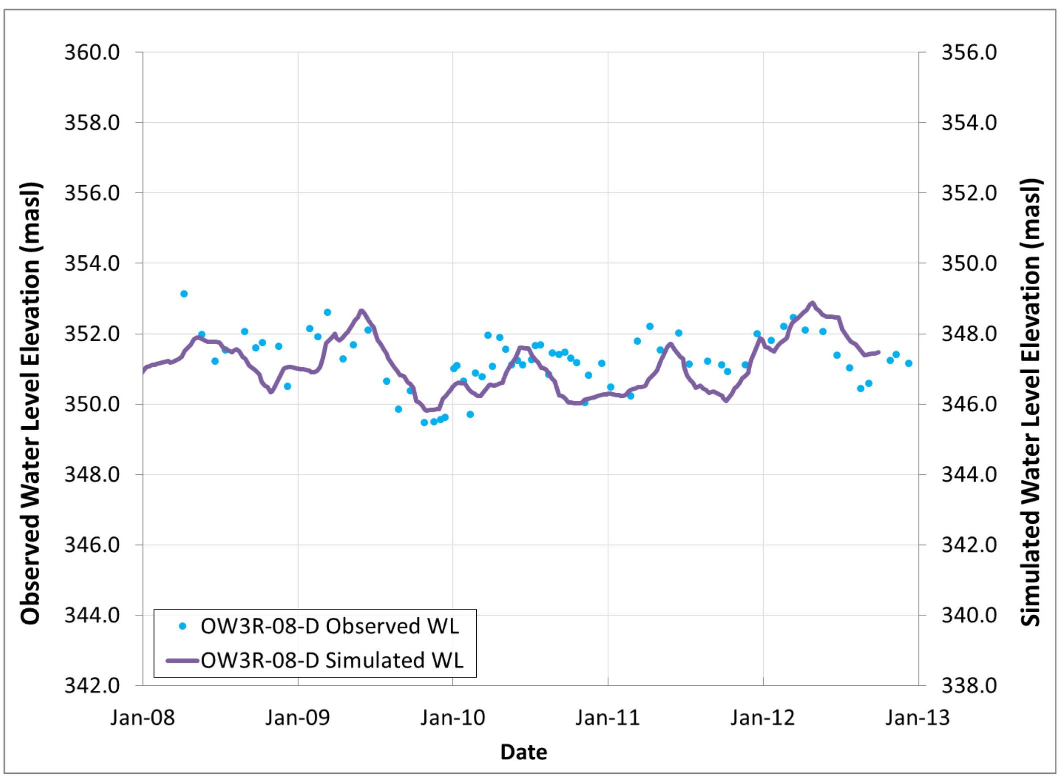


CHART 3-13 Transient Verification - OW3R-08-D Water Levels (2008-2012)

4 SUMMARY

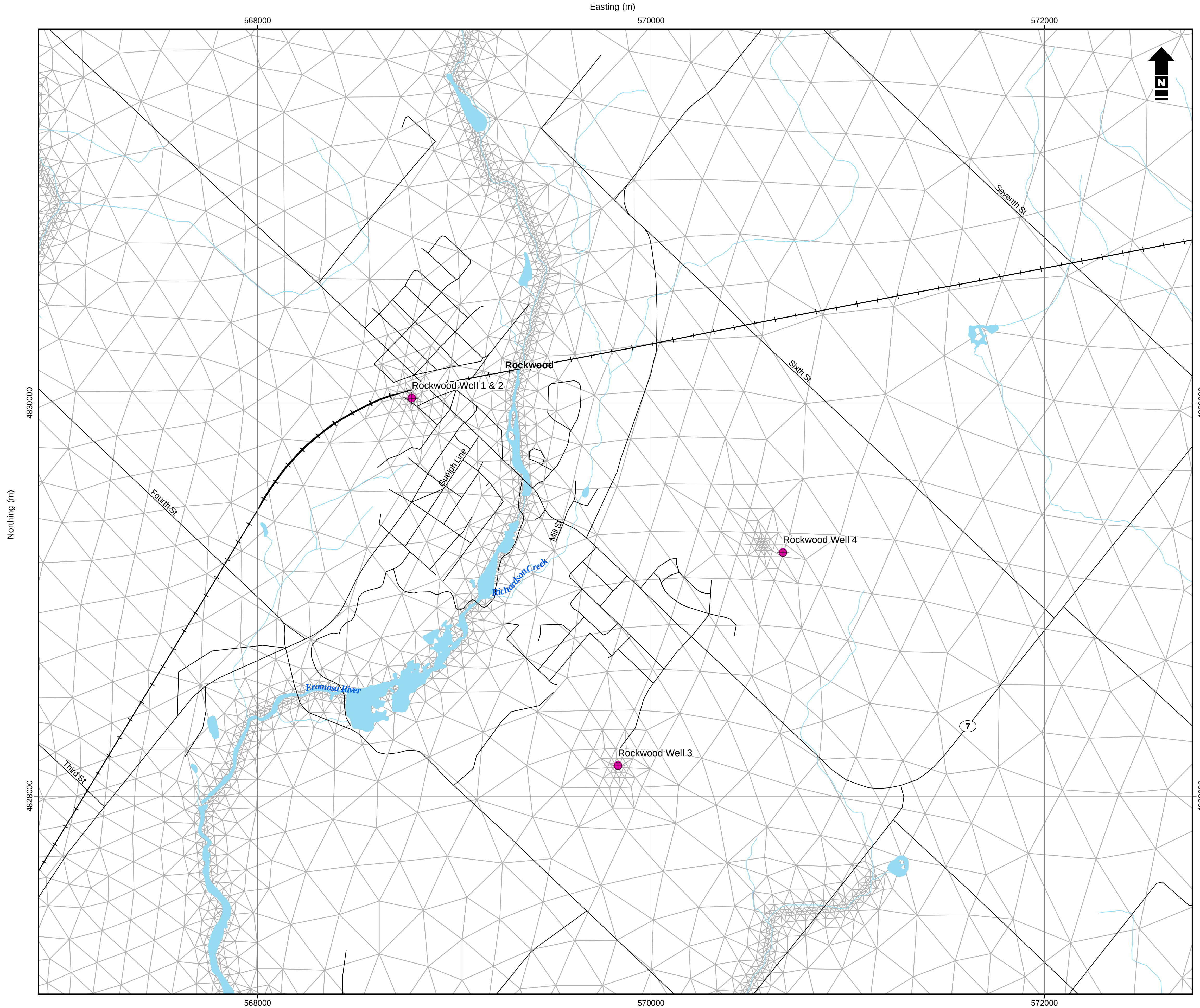
The groundwater flow model developed for the City of Guelph and Township of Guelph/Eramosa Tier Three Assessment was updated to ensure consistency with revisions to the hydrogeologic characterization for the Rockwood and Hamilton Drive areas. These updates included layer elevations, element sizes, hydrogeologic zone distributions, material properties, and well pumping rates and locations.

The model was calibrated after incorporating the updates, and the results indicate that the updated model is suitably calibrated. The hydraulic head calibration statistics are similar to those achieved by the previous model and the simulated groundwater discharge rates agree favourably with the observed baseflow estimates. Transient verification simulations have shown the model is able to represent the response of the shallow and deeper groundwater systems to varying recharge and pumping stresses.

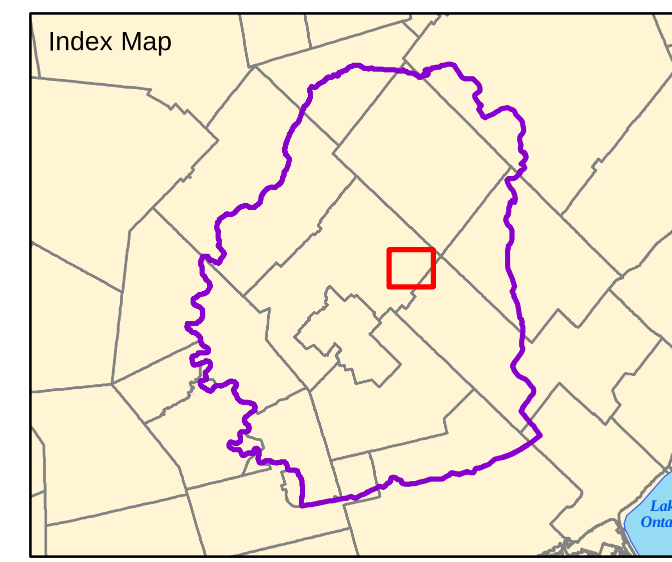
The updates to the model incorporated more detailed hydrogeologic characterization for the Hamilton Drive and Rockwood areas and resulted in an improved representation of the subsurface flow systems. This update model is suitable for use in the Tier Three Assessment in the City of Guelph and the Township of Guelph/Eramosa (Rockwood and Hamilton Drive the municipal wells).

Appendix D1

Figures



Updated Mesh
Water Body
Watercourse
Road
Railroad
Municipal Well (Guelph/Eramosa Township)



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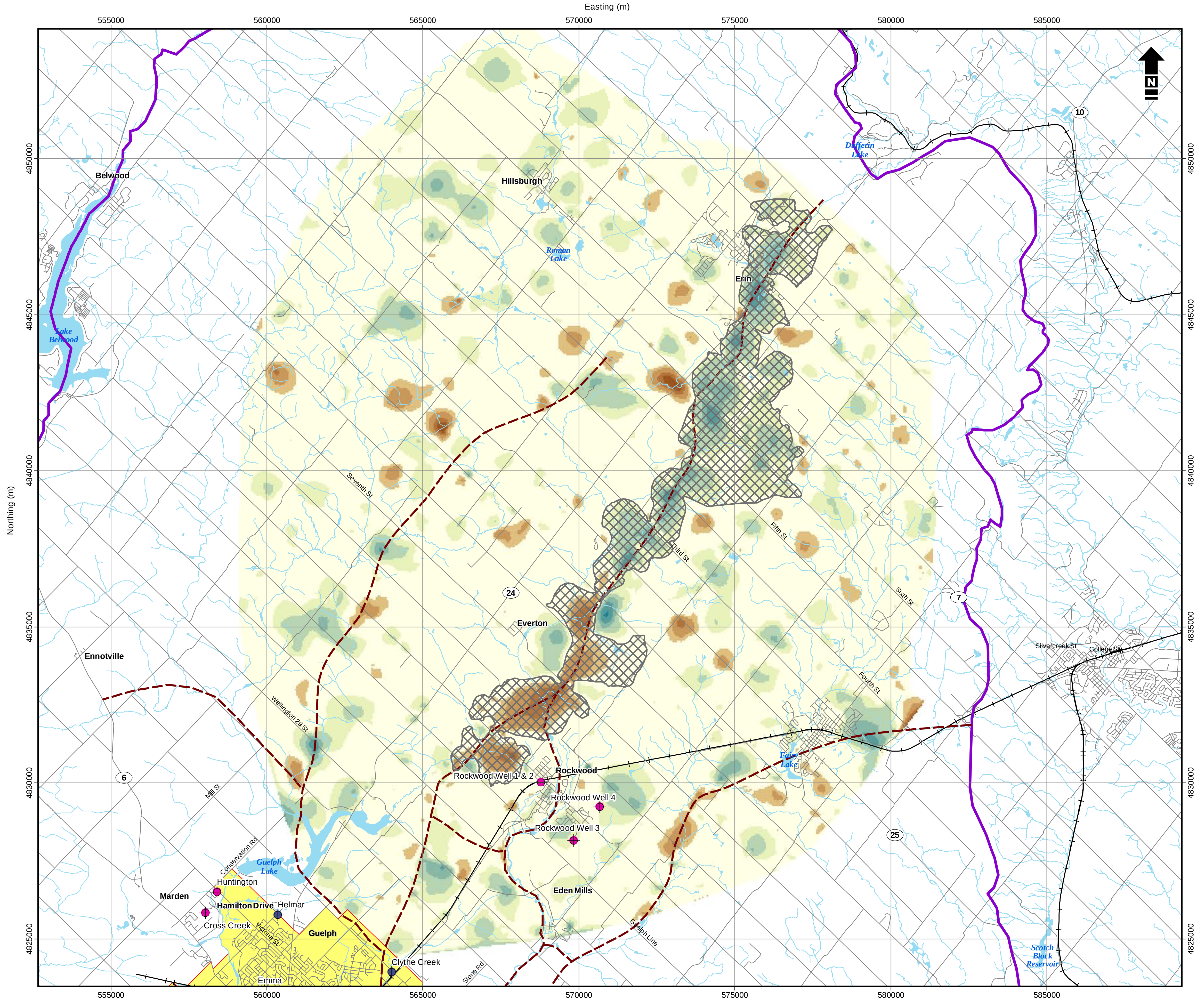
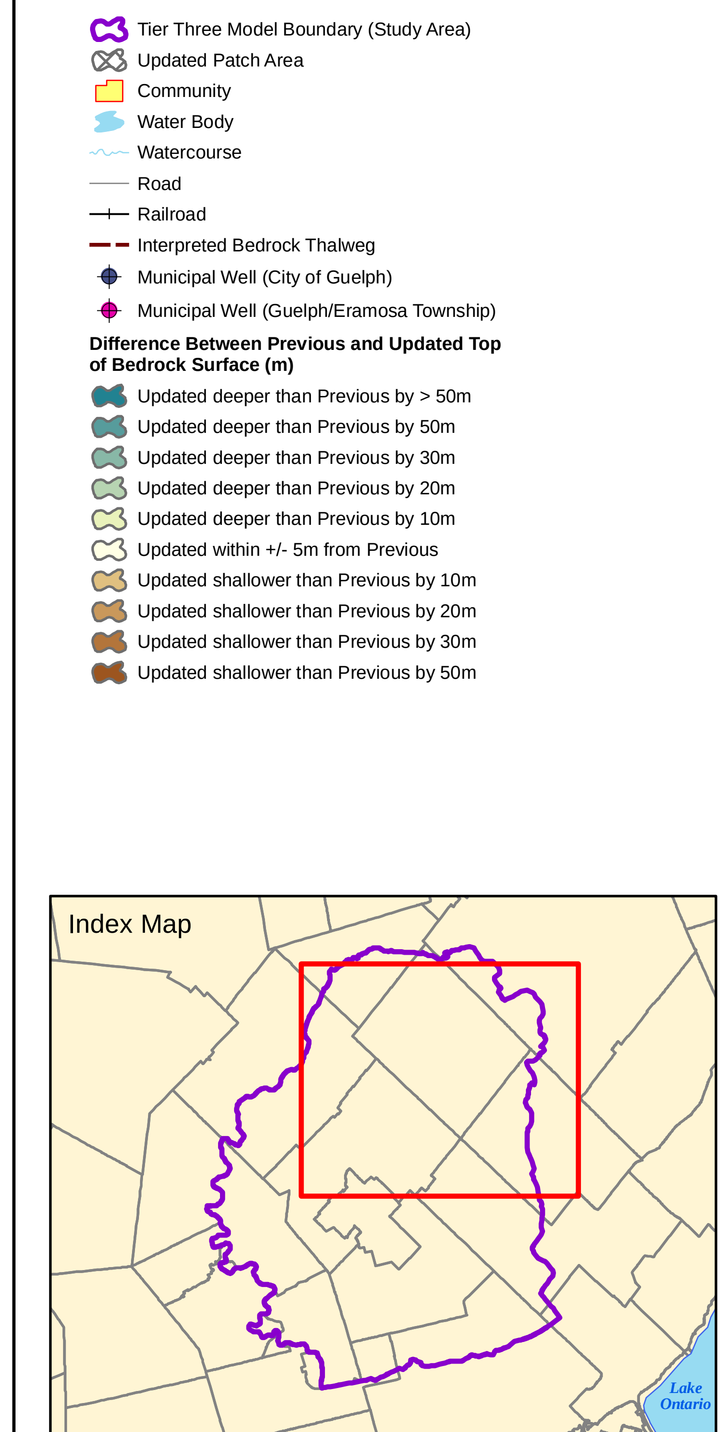
Tier Three Water Budget and Local Area Risk Assessment
Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Mesh Refinement Around Wells

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure
2-1





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Tier Three Water Budget and Local Area Risk Assessment
Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Revision to Top of Bedrock Surface

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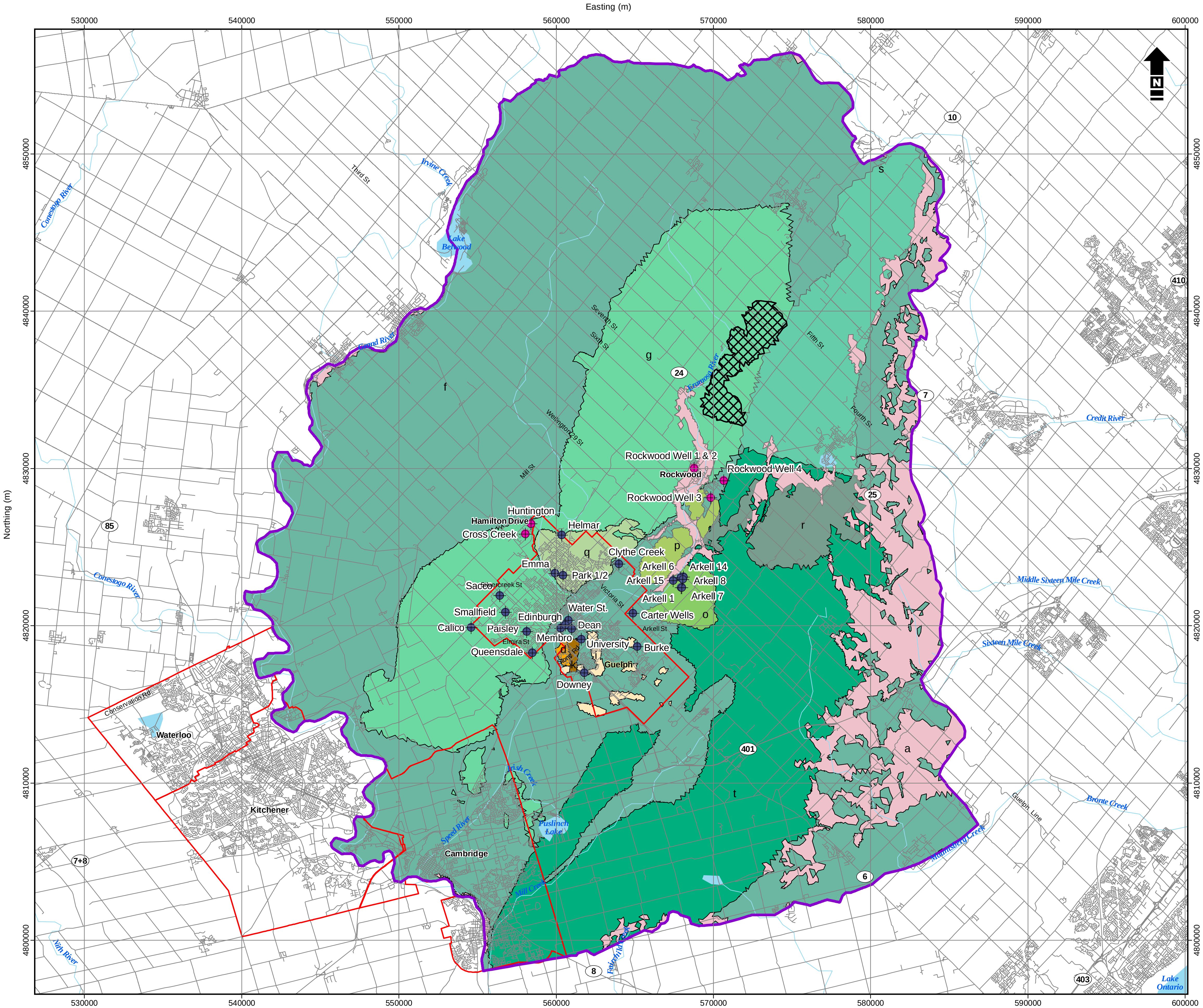
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

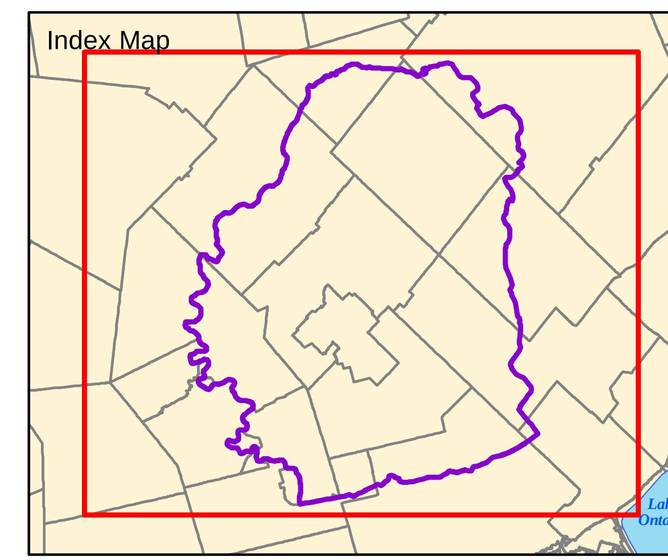
Figure 2-2



Tier Three Model Boundary (Study Area)
Conductivity Zone Change
Community
Water Body
Watercourse
Road
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)

Conductivity Zone

- a, Bedrock
- d, Hanlon Buried Valley Low K Zone
- f, Port Stanley Till A
- g, Port Stanley Till B
- i, Sand and Gravel
- k, Sand and Gravel - Hanlon Buried Valley
- o, Till - Arkell
- p, Till - Clythe Creek
- q, Till - Eastview Area
- r, Till - Moffat Moraine
- s, Wentworth Till - North
- t, Wentworth Till - South



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Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Hydraulic Conductivity Distribution Alterations - Layer 3 - Coarse Grained Buried Valley Infill

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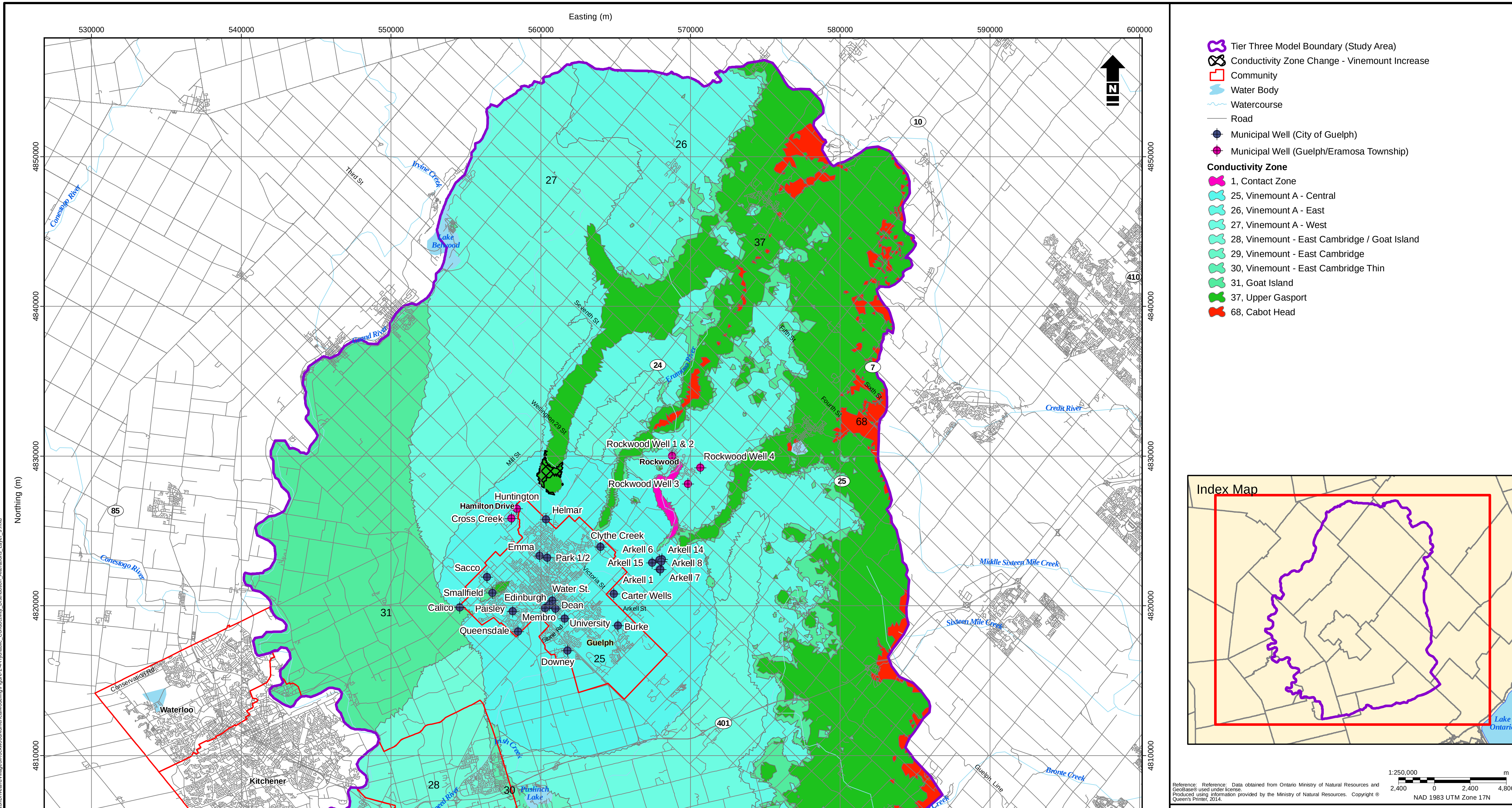
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 2-3

I:\City\Guelph\15072\Figures and Tables\GIS\2014\Report\AppendixD_HamiltonDriveandVillageofRockwood\NumericalModeling\Figure-2-3-Hydraulic_Conductivity_Distribution_Alterations_L3_Coarse_Grained_Buried_Valley_Infill.mxd



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Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Hydraulic Conductivity Distribution Alterations - Layer 9

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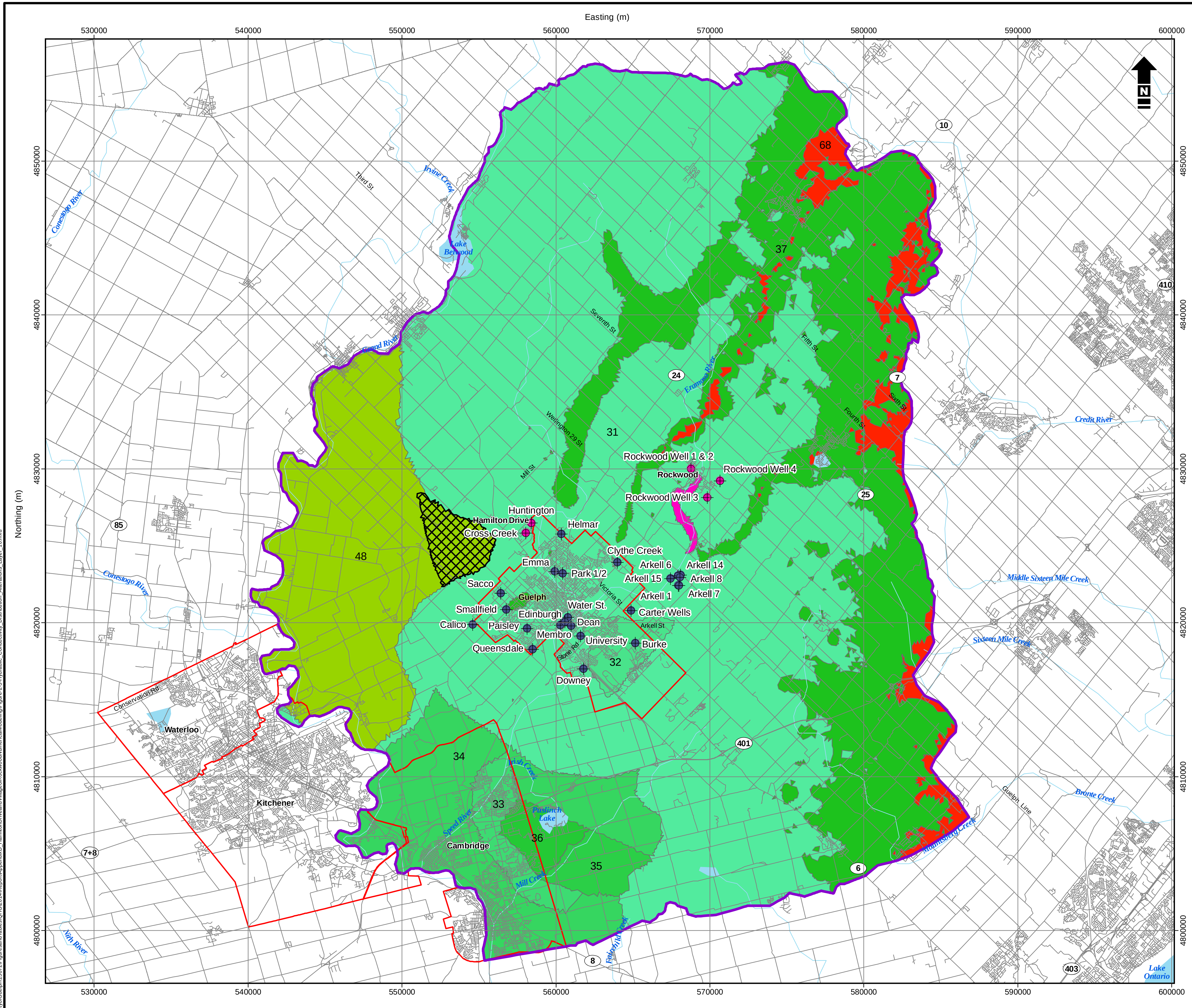
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

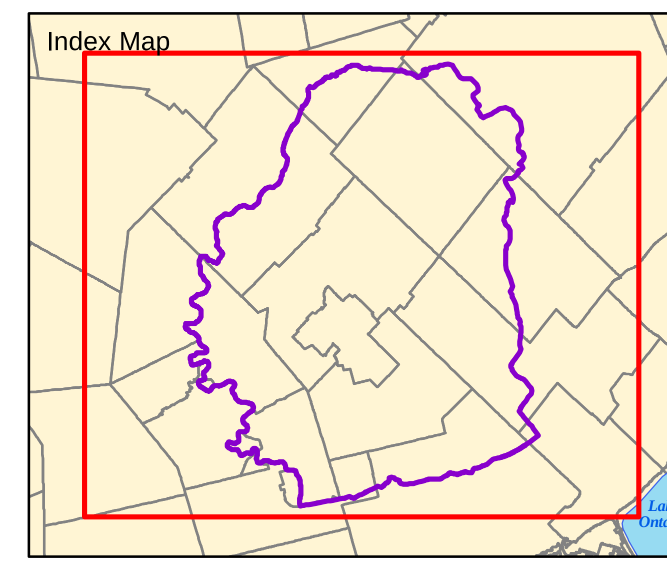
Figure
2-4



- Tier Three Model Boundary (Study Area)
- Conductivity Zone Change - Gasport Subcrop
- Community
- Water Body
- Watercourse
- Road
- Municipal Well (City of Guelph)
- Municipal Well (Guelph/Eramosa Township)

Conductivity Zone

- 1, Contact Zone
- 31, Goat Island
- 32, Goat Island - South City
- 33, Goat Island - East Cambridge Middle and Clement Mill
- 34, Goat Island - East Cambridge West
- 35, Goat Island - East Cambridge
- 36, Goat Island - East Cambridge Central
- 37, Upper Gasport
- 48, Middle Gasport A - Regional
- 68, Cabot Head



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Tier Three Water Budget and Local Area Risk Assessment
Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Hydraulic Conductivity Distribution Alterations - Layer 10

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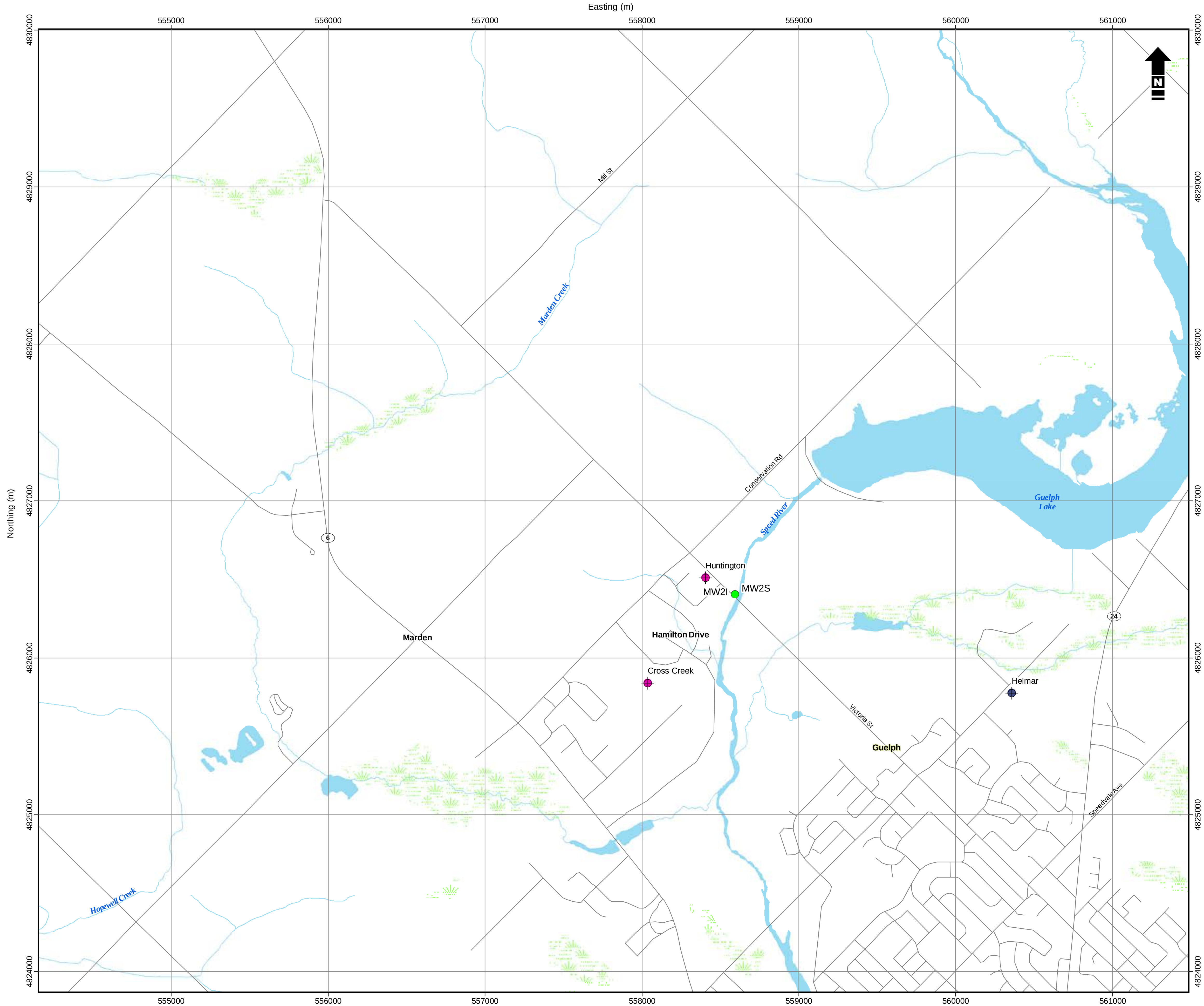
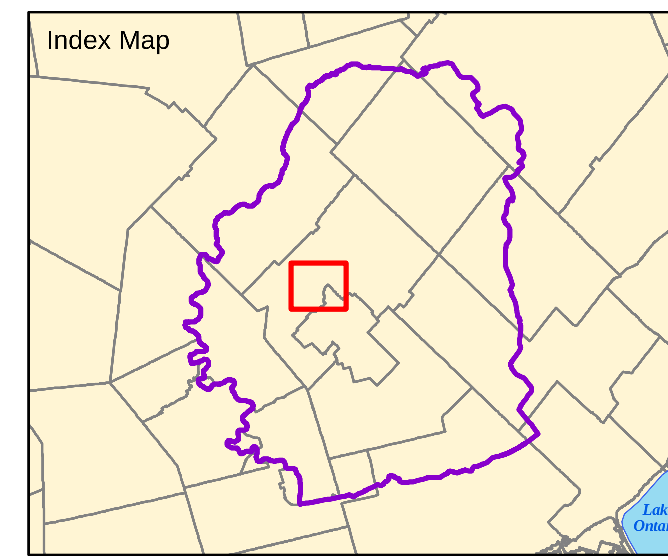
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 2-5



Wetland
Water Body
Watercourse
Road
Municipal Well (City of Guelph)
Municipal Well (Guelph/Eramosa Township)
Monitoring Well



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1:25,000 m
250 0 250 500
NAD 1983 UTM Zone 17N

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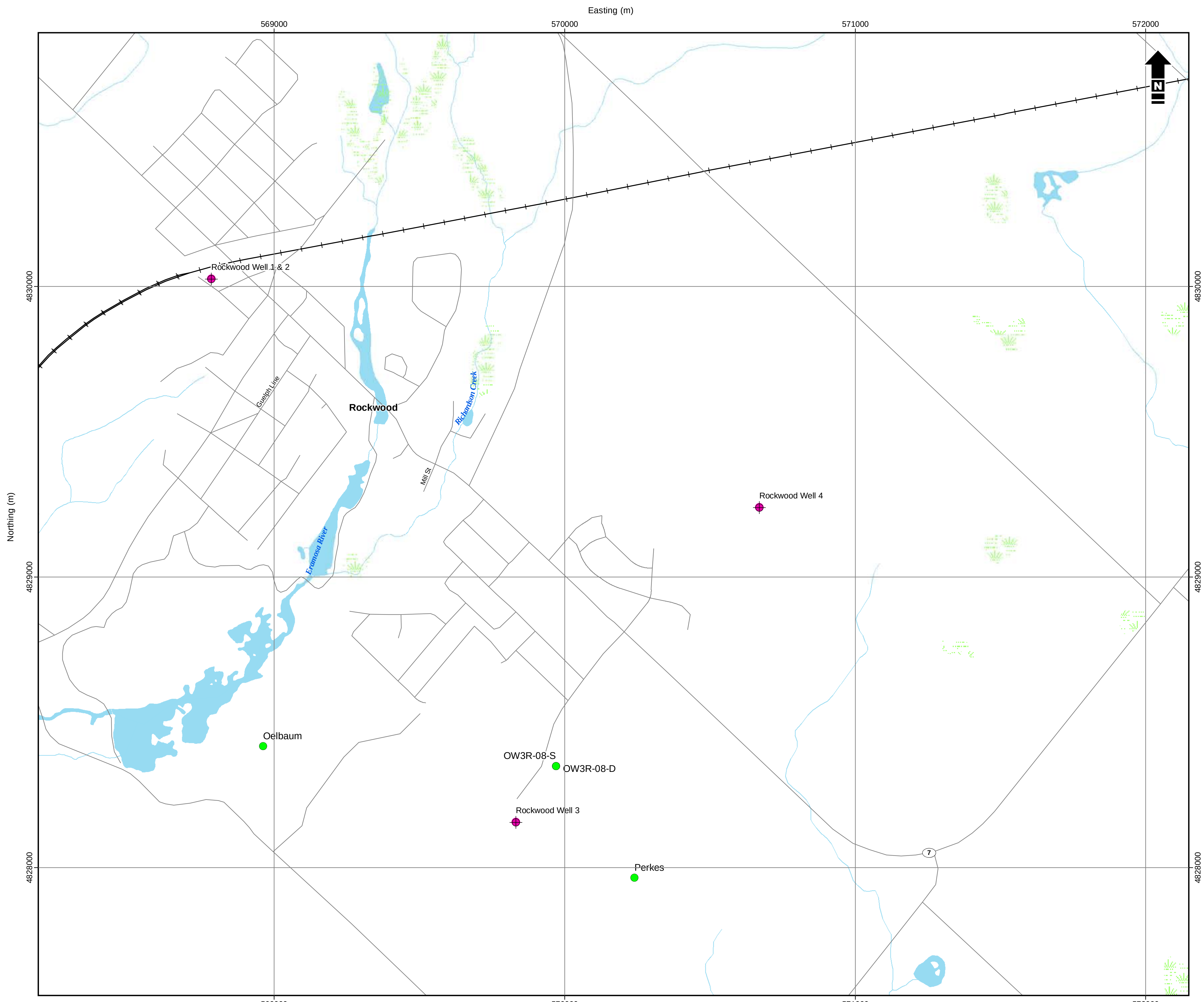
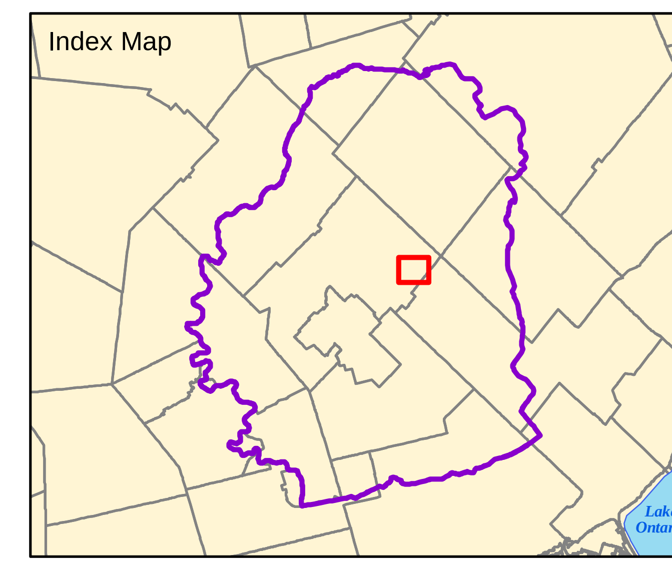
Tier Three Water Budget and Local Area Risk Assessment
Appendix D Groundwater Flow Model Update - Rockwood and Hamilton Drive

Calibration Targets - Hamilton Drive

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure
3-1





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Calibration Targets - Rockwood

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 3-2

APPENDIX E
2016 Groundwater Flow Model Updates

CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA
TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX E
2016 GROUNDWATER FLOW MODEL UPDATES

Report Prepared for:
LAKE ERIE SOURCE PROTECTION REGION

Prepared by:
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CITY OF GUELPH AND TOWNSHIP OF GUELPH/ERAMOSA
TIER THREE WATER BUDGET AND LOCAL AREA RISK ASSESSMENT

APPENDIX E: 2016 GROUNDWATER FLOW MODEL UPDATES

Report prepared for Lake Erie Source Protection Region, March 2017

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March 28, 2017

DISCLAIMER

We certify that this report is accurate and complete and accords with the information available during the site investigation. Information obtained during the site investigation or provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care, and diligence in assessing the information obtained during the preparation of this report.

This report was prepared for Lake Erie Source Protection Region under contract with the City of Guelph. The report may not be relied upon by any other person or entity without our written consent and that of the City of Guelph. Any uses of this report by a third party, or any reliance on decisions made based on it, are the responsibility of that party. We are not responsible for damages or injuries incurred by any third party, as a result of decisions made or actions taken based on this report.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF CHARTS

LIST OF APPENDICES

LIST OF FIGURES FROM APPENDIX E1

1 INTRODUCTION

An integrated hydrologic model framework was developed and calibrated for the City of Guelph (the City) and the Township of Guelph/Eramosa (GET) Tier Three Water Budget and Local Area Risk Assessment (Tier Three Assessment), and peer reviewed in 2011. The model framework comprised a three dimensional (3D) groundwater flow model with capacity for transient-flow analysis (FEFLOW) coupled with areal and temporal varied recharge calculated from a streamflow-generation model (GAWSER). These models are described in Appendix B (Groundwater Flow Model Report) and are based on the Tier Three Assessment characterization completed by Golder Associates Ltd. in 2011 (Appendix A – Characterization Final Report). The groundwater flow model was updated in 2014, related to the inclusion of the GET communities of Hamilton Drive and Rockwood into the Tier Three Assessment. These updates are presented in Appendix D (Groundwater Flow Model Update – Rockwood and Hamilton Drive) and were based on the characterization work completed in that area, as documented in Appendix C (Characterization Update – Rockwood and Hamilton Drive).

This appendix describes updates made to the Tier Three Assessment groundwater model in 2016, since those documented in Appendix D. Updates include the implementation of newly acquired data for the areas around the community of Rockwood, the Dolime Quarry, community of Aberfoyle (Figure 1-1), as well as the removal of two permits to take water (PTTWs).

2 MODEL UPDATE

2.1 Objectives

The objectives of the model update were, for the areas of interest, to incorporate newly available hydrogeologic data, ensure the numerical model is consistent with the conceptual model, re-calibrate the model as necessary, and verify the model against longer-term observed data. The model update included the following:

- updates to the top and bottom elevations of hydrogeologic units
- revisions to the distribution and properties of hydrogeologic units
- relocation of boundary conditions
- removal and addition of pumping well locations
- mesh refinement around pumping wells
- transient and steady-state model re-calibration to account for the above refinements
- verification of groundwater discharge in the updated model against baseflow estimates
- verification of transient groundwater levels in production wells and monitoring wells

The following sections summarize the new characterization data that prompted an update to the conceptual and numerical models for the areas surrounding Rockwood, the Dolime Quarry, Aberfoyle, and other PTTWs.

2.2 Rockwood Area

Various refinements were made to the numerical model in the Rockwood area based on new information regarding the extent of the Vinemount Member of the Eramosa Formation and the status of Rockwood Well 4.

2.2.1 Vinemount Member

Previous interpretations of the geology of the area near and east of Rockwood suggested that the Vinemount Member, a regional bedrock aquitard unit, was present and continuous across the entire area. However, previously obtained and new data were reviewed as part of this model update process, which suggested that the Vinemount was absent. These data included the following:

- the original characterization data for the Tier Three Assessment, including picks of the Vinemount Member and Eramosa Formation, and picks of “black rock” in water well records and other logs
- results of the 2008, 2009, and 2010 Ontario Geological Survey (OGS) drilling programs in the Orangeville–Fergus area of southwestern Ontario (Burt and Webb 2013)
- well logs from Rockwood test wells TW3/02 and TW2/02, as well as MW15 at Hidden Quarry (Harden 2012)
- the Town of Rockwood – Town of Guelph/Eramosa, New Rockwood Well 4 Category 3 PTTW Application (Burnside 2015)
- Rockwood Environmental Assessment, Hydrogeologic Report, Construction and Testing of TW3/02, Proposed Rockwood Well 3, Township of Guelph/Eramosa (Burnside 2002)

Based on these reference materials, the shallow bedrock units in the area between the Eramosa River and Blue Springs Creek (Figure 2-1) above the Gasport Formation were re-interpreted to be the Upper Gasport, Goat Island and Reformatory Quarry formations. The hydraulic conductivity of these layers in the groundwater flow model was updated to reflect that of the modelled Upper Gasport unit and more fractured Goat Island and Reformatory Quarry formations. The vertical hydraulic conductivity value in this area was increased to 2×10^{-7} m/s from 3 to 8×10^{-8} m/s. Rockwood Cross-Section West-East (Figure 2-2) shows the absence of the Vinemount Member in this area.

2.2.2 Rockwood Well 4

Three municipal wells (Rockwood wells 1 and 2 in the Station Street pump house and Rockwood Well 3 in the Bernardi pump house) in Rockwood were identified during the characterization update completed in early 2014. Since that time, a fourth municipal well (Rockwood Well 4) was constructed and tested in early 2015. It is expected that this well will be connected to the Rockwood system in 2017.

With the addition of the fourth well to the municipal system, a well boundary condition was inserted into the groundwater flow model to represent Rockwood Well 4 and to simulate it in the Risk Assessment scenarios. The finite element mesh surrounding this well was refined to capture the steep hydraulic gradients that would be induced in the model due to pumping (Figure 2-3). The transient calibration and associated hydraulic conductivity updates made surrounding this well, Rockwood Well 3 and the Rockwood area in general, are described in detail in Section 3.1.

2.3 Dolime Quarry Area

The Dolime Quarry is situated on the western side of the City and is bounded by the Speed River to the north and west and the Hanlon Expressway to the east. In 2016, the City and River Valley Developments (RVD) Inc. entered into a data-sharing agreement to ensure that the most current hydrogeologic understanding of the area surrounding the Dolime Quarry was included in the Tier Three Assessment model. Matrix provided an interim version of the Tier Three Assessment model to a third party, under contract to the City, for the purposes of refining and calibrating the model in the immediate vicinity of the quarry based on local data. The City and RVD cooperatively guided the conceptual and numerical model refinements to ensure that hydrogeological interpretations of the field data, and their representation in the model were agreed on by both parties. The resulting Dolime Quarry model was provided to Matrix to review and significant updates were transferred into the Tier Three Assessment model.

The Dolime Quarry model was reviewed by Matrix and model updates were applied within a 6.8 km × 6.8 km area (“Quarry Update Area”, Figure 1-1) of the Tier Three Assessment model. A buffer width of 0.4 km inside this area was used to merge the refined quarry interpretation with that of the existing model. The specific features that were updated in the Tier Three Assessment model include model layer elevations, hydraulic conductivity, the addition of a planar fracture zone, and the relocation of a boundary condition representing the quarry sump and pond. Figure 2-4 and 2-5 illustrate the differences between the previous and updated Tier Three Assessment models within the Quarry Update Area for the Middle Gasport and Upper Gasport Formations, respectively. A conceptual cross-section of the area is shown on Figure 2-6, which illustrates the differences between the two models.

2.3.1 Hydrostratigraphic Unit Surface Elevations

All model layer surface elevations were updated in the Quarry Update Area to reflect the refinements made within the Dolime Quarry model. A significant update included the new conceptualization of the presence of reef mounds within the Upper Gasport (Figure 2-5 and 2-6). Numerical model layers representing hydrostratigraphic units were deflected upwards in the area of this interpreted reef mound structure within the updated model.

2.3.2 Hydraulic Conductivity

All model layers were updated with the refined hydraulic conductivity values incorporated into the Dolime Quarry model. Significant changes include the following:

- the inclusion of a high conductivity zone (5×10^{-1} m/s) extending from ground surface to the Goat Island Formation, representing the quarry pit and a window in the Vinemount Member created by quarry operations (Figure 2-6)
- the expansion of a hydraulic conductivity zone and increase from 1×10^{-5} to 5×10^{-3} m/s in the Upper Gasport Formation to represent more prevalent reef mounds with higher hydraulic conductivity (Figures 2-5 and 2-6)
- the decrease of conductivity from 5×10^{-4} to 1×10^{-4} m/s in the Middle Gasport Formation (Figures 2-4 and 2-6)
- the vertical hydraulic conductivity of the Vinemount Formation was increased within the Quarry update area from 1×10^{-9} to 3×10^{-9} m/s. The horizontal hydraulic conductivity remained the same (Figure 2-6)

2.3.3 Planar Fracture Zone

A planar fracture zone was added into the model domain, on top of the Middle Gasport, representing a conductive horizontal fractured area between the quarry and municipal wells to the northeast (Figure 2-4). This feature was parameterized as a 1 m thick, horizontal, discrete planar feature with a conductivity of 5×10^{-3} m/s and specific storage of 1×10^{-10} m^{-1}. The addition of this feature increased the hydraulic connection between the quarry and Edinburgh, Membro, Water Street, and Dean Avenue municipal wells that was compensated by the reduction of the hydraulic conductivity in the Middle Gasport Formation described in Section 2.3.2. The net effect was an improved model calibration at the monitoring and pumping wells.

2.3.4 Quarry Sump Boundary Condition

The fixed head boundary condition representing quarry pond sump elevation (290 m asl) was relocated from the top of the Upper Gasport Formation (previous model) to within the quarry pit (represented by the very high conductivity zone in the updated model) (Figure 2-7).

During the construction of the original model, excavation of the quarry had progressed to a level where a window in the Vinemount Formation was observed and the Upper Gasport Formation was exposed in the bottom of the quarry. Thus it had been conceptualized that a direct hydraulic connection between the quarry pond sump and the Upper Gasport Formation existed. In the previous model, the quarry pit and the window in the Vinemount Formation were not discretely represented (Figure 2-7) so this hydraulic connection was established by using fixed head boundary conditions placed at the top of the Upper Gasport Formation beneath the interpreted Vinemount and Goat Island formations. This arrangement of boundary conditions fixed the hydraulic head at the top of the Upper Gasport Formation under the quarry to 290 m asl (the quarry pond elevation) and effectively eliminated the influence of the overlying confining units (Goat Island and Vinemount formations).

The updated model includes a discrete representation of the quarry pit and the window through the Vinemount and Goat Island formations using a very high conductivity zone (5×10^{-1} m/s; Figure 2-7) and allows for the boundary condition to be placed at 290 m asl within the quarry pit. The very high conductivity zone permits the hydraulic head of the quarry pond to be transmitted to the Upper Gasport Formation. The end result is a more improved representation of the geology, which improves the representation of the impact of the quarry on the water table and surrounding wells.

2.4 Aberfoyle Area

The initial hydrogeologic characterization in the area of Aberfoyle (Figure 2-8), located approximately 5 km south of the City of Guelph was based on limited reports and data available at the time. Additional hydrogeological reports and data were obtained and reviewed in this area to improve the hydrogeological characterization. These materials include:

- Nestlé Waters Canada, Test Pumping Investigation, Supply Well TW3-80 (CRA 2004)
- Nestlé Waters Canada, 2010 Annual Monitoring Report (CRA 2011)
- Nestlé Waters Canada, Test Pumping Investigation for TW2-11 (CRA 2012)
- Meadows of Aberfoyle – 2014 Annual Monitoring Report, Permit to Take Water No. 5626-7WLQ3W - Banks Groundwater Engineering Ltd. (Banks 2015)
- Royal Canin Canada, Hydrogeological Assessment and Pumping Test, Highway 401 and County Road 46, Puslinch, Ontario – SNC Lavalin Engineers and Constructors Inc. (SNC Lavalin 2005)

Estimates of hydraulic conductivity documented in these reports based on hydraulic test interpretations were compared to modelled values. Key borehole logs and information regarding high yield bedrock zones provided in these reports were reviewed to ensure the simulated wells in the model were extracting water from the correct modelled hydrostratigraphic units.

With the availability of pumping test data from Nestlé Waters Canada (Nestlé; CRA 2011), refinements were made to the groundwater flow model to ensure adequate well-field scale response to pumping including:

- adjusting the horizontal and vertical location of the Nestlé well
- refining of the finite element mesh around the Nestlé well to capture steep hydraulic gradients (Figure 2-8)
- updating hydraulic conductivity values applied in the Goat Island Formation based on transient calibration (detailed in Section 3.1.3; Figure 2-8) and guided by hydrogeologic data

2.5 Other Permits to Take Water

Re-examination of PTTWs in Puslinch Township revealed two permits, which should no longer be represented in the Tier Three Assessment model. The first permit, PTTW 02P-2064 (Kraus Nurseries), is an expired permit for a property in Waterdown, not Puslinch. It was represented in the model at a rate of 39 m^3/day. The second permit, PTTW 99P-2132 (Kats Okashimo Fish Farm), was not renewed in 2009 and a site discussion with the current tenant suggested that the water taking has not occurred for the last 12 years at a minimum (Harden 2015). This permit was represented in the model at a rate of 1,636 m^3/day. Both water takings were removed from the Tier Three Assessment model. Their original locations are identified on Figure 1-1.

3 CALIBRATION

Given the model updates described in Section 2.1 and the availability of additional pumping test data, local transient calibration was completed at Rockwood Well 4 (Section 3.1.1), Rockwood Well 3 (Section 3.1.2) and Nestlé Well TW3-80 (Section 3.1.3) where the hydraulic conductivity was refined further. Long-term transient verification of well response was subsequently conducted for the City wells (Section 3.2.1) and Rockwood wells (Section 3.2.2). The final steady-state calibration to hydraulic heads and baseflows is provided in Section 3.3.

3.1 Transient Calibration

3.1.1 Rockwood Well 4

With the identification of Rockwood Well 4 as a water supply source to be considered in the Tier Three Assessment, and the interpretation that the Vinemount Member aquitard is absent in the area, local refinements to hydraulic conductivity were made to the groundwater flow model during the transient calibration to a 72-hour constant rate pumping test conducted at Rockwood Well 4 (Burnside 2015).

The objective was to calibrate the model to the observed water level response data at the pumping well, as well as at 13 shallow and deep monitoring wells. The constant rate test took place in early 2015 at a rate of 1,244 m^3/day (Burnside 2015). Special attention was given to calibrating drawdown in the immediate vicinity of Rockwood Well 4 (i.e., OW2D/I/S located 20 m northeast of Well 4; Figure 3-1), as well as drawdown at wells near the Hidden Quarry site (i.e., M2, M15I/II/III located approximately 1.1 km east of Well 4; Figure 3-1).

Hydraulic conductivity values were refined during model calibration, and the values assigned were guided by the range of interpreted hydraulic conductivity and transmissivity values for those hydrogeologic units as presented in Golder (2011), Burnside (2015; 2002) and Harden (2012). The final range of hydraulic conductivity values applied to each refined area during model calibration is presented in Table 3-1 along with those values derived from previous studies. Figure 3-1 shows the final conductivity values applied near Rockwood Well 4 in the Middle Gasport.

TABLE 3-1 Summary of Bedrock Hydraulic Conductivity Values near Rockwood

Unit	Hydraulic Conductivity from Previous Studies (m/s)[1]		Area in Numerical Model	Simulated Hydraulic Conductivity (m/s)	
	Min	Max		Min	Max
Middle Gasport	2×10^{-6}	1×10^{-2}	Rockwood Well 4	3×10^{-5}	4×10^{-4}
			Rockwood Well 3	1×10^{-5}	4×10^{-4}
Upper Gasport	2×10^{-8}	5×10^{-4}	Rockwood Well 4	2×10^{-6}	2×10^{-5}
Goat Island	9×10^{-8}	4×10^{-4}	Rockwood Well 4	2×10^{-6}	2×10^{-5}
Reformatory Quarry	7×10^{-9}	2×10^{-4}	Rockwood Well 4	2×10^{-6}	2×10^{-5}

[1] Golder 2011, Burnside 2015; 2002, and Harden 2012

The observed and simulated drawdown and recovery curves for 13 monitoring wells and Rockwood Well 4 are presented on Charts 3-1 to 3-14. The locations of the monitoring wells are shown on Figure 3-1. An excellent fit was achieved to the observed data at Rockwood Well 4 (Chart 3-1). The remaining wells show a good match between observed and simulated data, especially the deep (Chart 3-2), intermediate (Chart 3-3) and shallow (Chart 3-4) monitoring wells located 20 m away and monitoring wells located at Hidden Quarry (Charts 3-5 to 3-8).

The discrepancy between simulated and observed drawdown occurring at other monitoring wells (e.g., Charts 3-9 to 3-11), where the model slightly over- and under-predicts drawdown, may be due to the heterogeneities associated with the fractured rock environment. Given the complex nature of the orientation and connectivity of these fractures and fracture zones, this level of calibration is considered acceptable for the Risk Assessment.

These results suggest that the updated model appropriately represents Rockwood Well 4 and is suitable to assess drawdown due to increased pumping in the Risk Assessment.

A portion of the drawdown observed in Rockwood Well 4 is caused by non-linear well losses due to well inefficiencies. The groundwater model does not explicitly simulate non-linear well losses within the well itself and thus the amount of drawdown due to non-linear well losses has been added to the simulated drawdown. This approach permits simulated and observed drawdown to be compared. Non-linear well losses were estimated for Well 4 using step test data (Burnside 2015) and calculated using the method summarized in Appendix F (Safe Additional Available Drawdown).

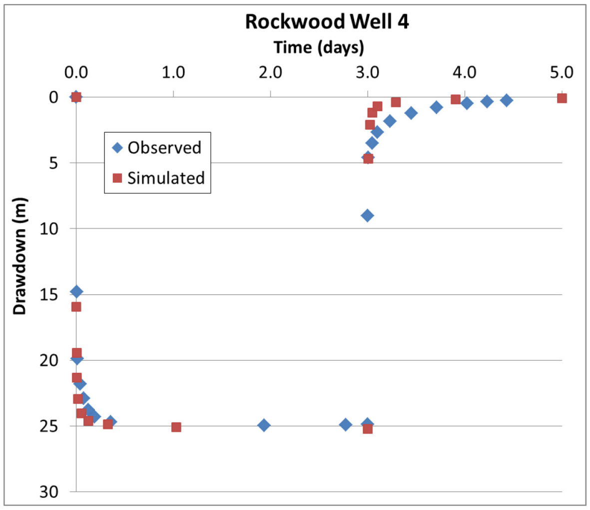

CHART 3-1 **Drawdown Response at Rockwood Well 4**

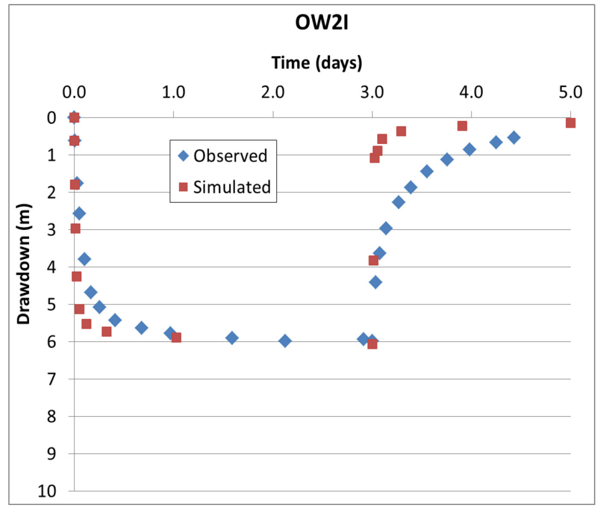

CHART 3-3 **Drawdown Response at OW2I, 20 m from Rockwood Well 4**

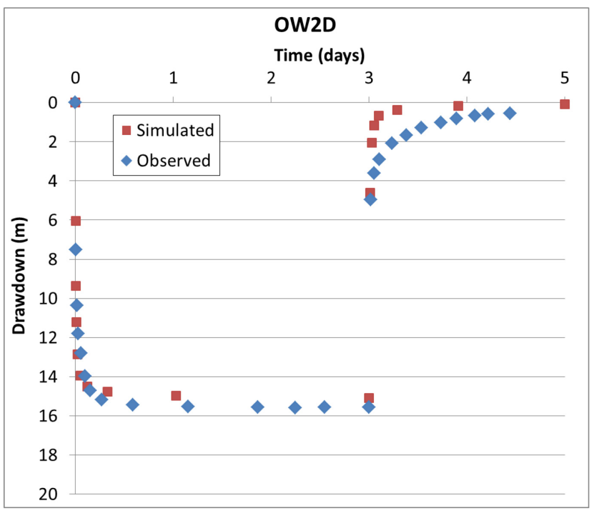

CHART 3-2 **Drawdown Response at OW2D, 20 m from Rockwood Well 4**

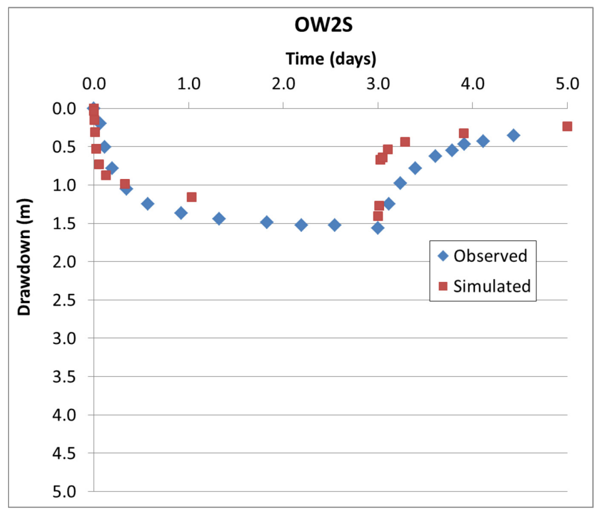

CHART 3-4 **Drawdown Response at OW2S, 20 m from Rockwood Well 4**

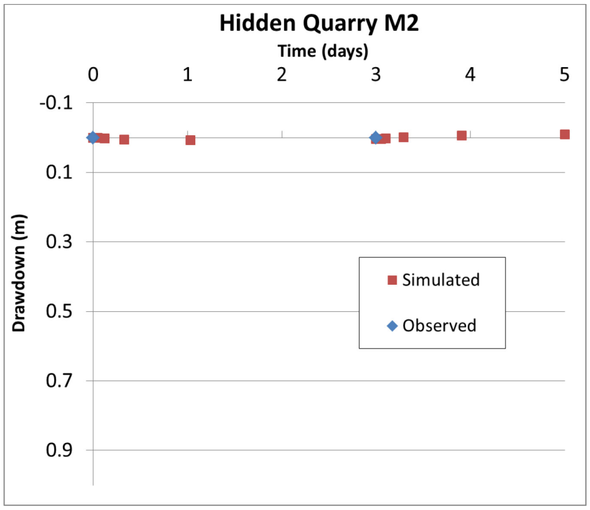

CHART 3-5 **Drawdown Response at Hidden Quarry - M2, 1.2 km from Rockwood Well 4**

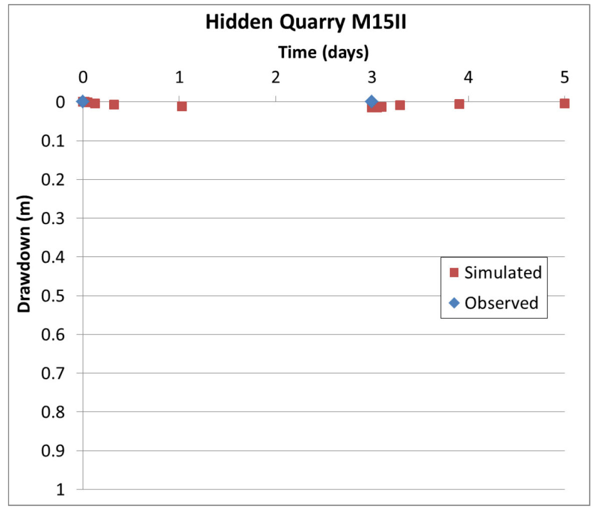

CHART 3-7 **Drawdown Response at Hidden Quarry - M15II, 1.3 km from Rockwood Well 4**

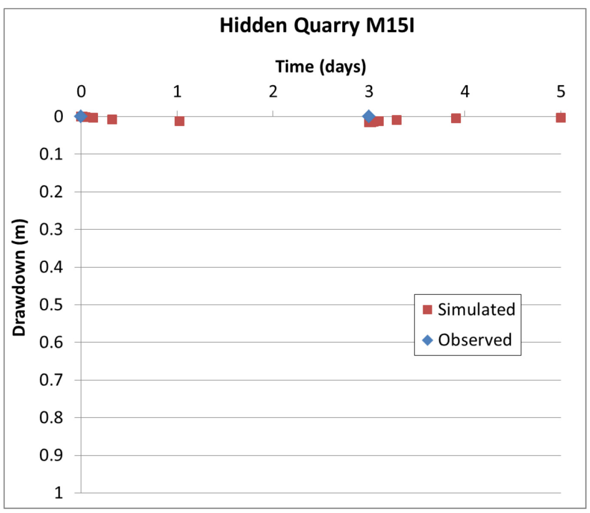

CHART 3-6 **Drawdown Response at Hidden Quarry - M15I, 1.3 km from Rockwood Well 4**

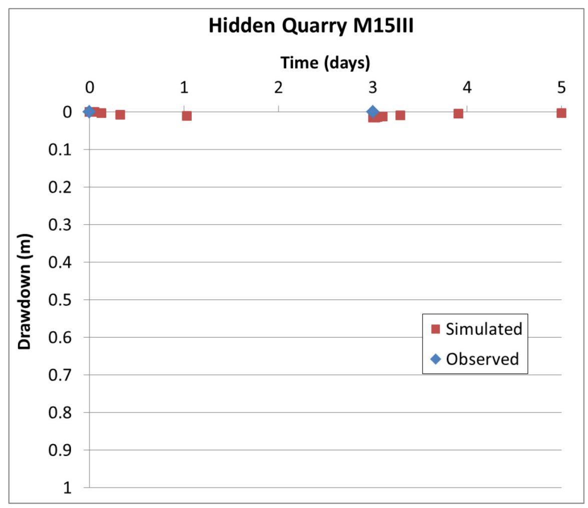

CHART 3-8 **Drawdown Response at Hidden Quarry - M15III, 1.3 km from Rockwood Well 4**

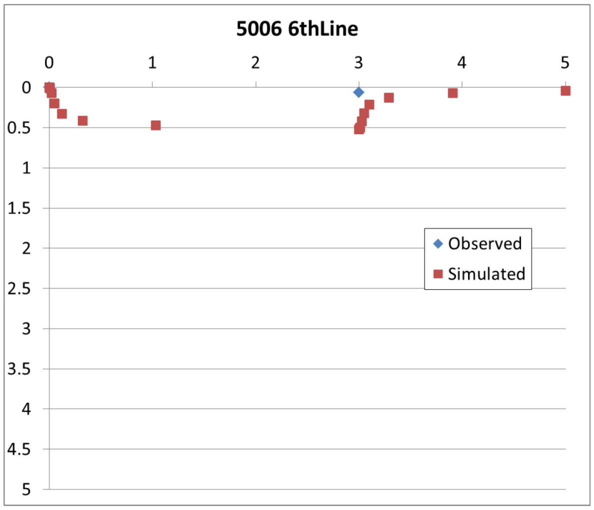

CHART 3-9 **Drawdown Response at 5006 6th Line, 0.4 km from Rockwood Well 4**

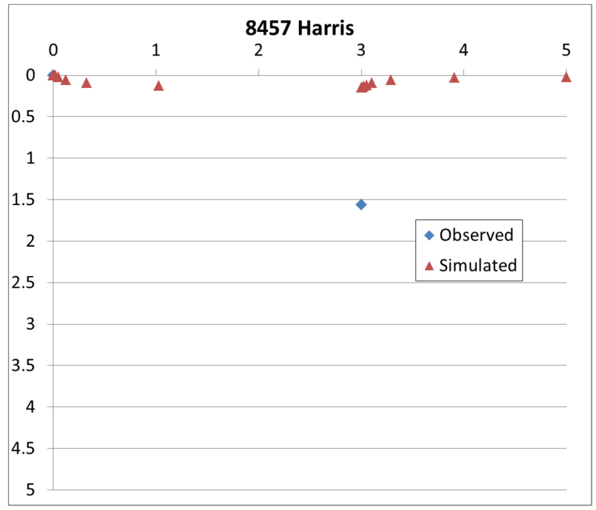

CHART 3-11 **Drawdown Response at 8457 Harris St, 0.9 km from Rockwood Well 4**

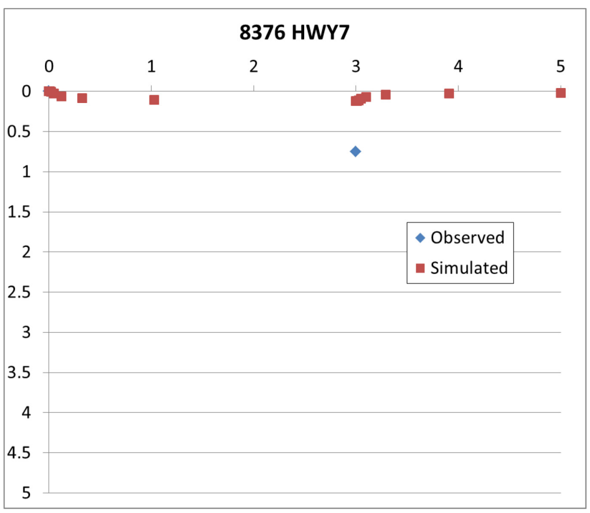

CHART 3-10 **Drawdown Response at 8376 HWY7, 0.68 km from Rockwood Well 4**

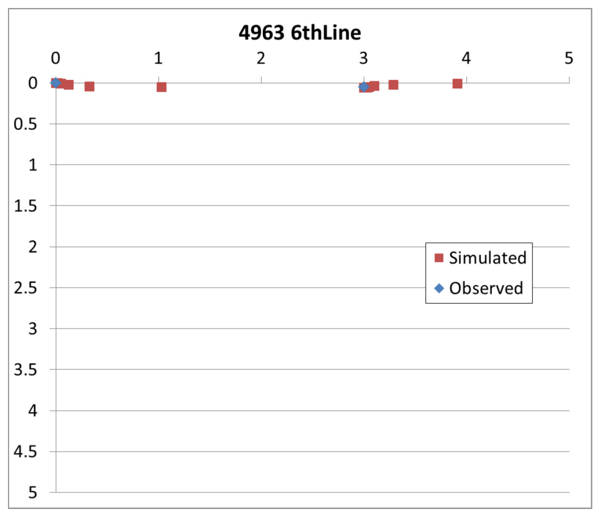

CHART 3-12 **Drawdown Response at 4963 6th Line, 0.88 km from Rockwood Well 4**

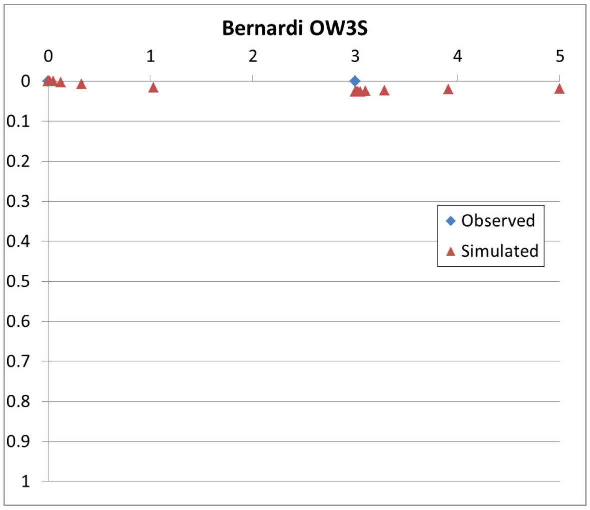

CHART 3-13 **Drawdown Response at Bernardi OW3S, 1.13 km from Rockwood Well 4**

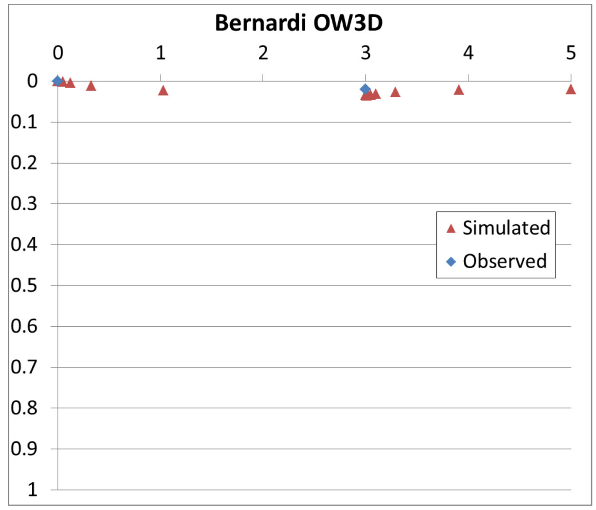

CHART 3-14 **Drawdown Response at Bernardi OW3D, 1.13 km from Rockwood Well 4**

3.1.2 Rockwood Well 3

Calibration of the model in the area surrounding Rockwood Well 3 was completed due to the removal of the Vinemount Member in this area and the proximity to the hydraulic conductivity updates upgradient of Well 3, and surrounding Well 4. The calibration effort was conducted in a similar manner as Rockwood Well 4. Observed drawdown data from a 72-hour constant rate (1,175 m^3/day) test of Rockwood Well 3, conducted in May 2002 (Burnside 2002), was used to calibrate the numerical model. Nineteen wells were monitored during the test and used as calibration targets. Special attention was given to calibrating drawdown in the immediate vicinity of Well 3 (i.e., OW3D, 4D and 5D located 300 to 500 m north of Well 3), as well as drawdown in domestic wells (e.g., Perkes located 480 m southeast of Well 3 and Hilts located 680 m east of Well 3). Figure 3-1 illustrates the location of these five pumping test monitoring wells.

The final hydraulic conductivity values applied in the area of Rockwood Well 3 were guided by the range of interpreted hydraulic conductivity and transmissivity values for those hydrogeologic units, as presented in Golder (2011), Burnside (2015; 2002) and Harden (2012). Both simulated and previously estimated values of hydraulic conductivity are summarized in Table 3-1. Figure 3-1 shows the final conductivity values applied near Rockwood Well 3 in the Middle Gasport.

The observed and simulated drawdown and recovery curves for Rockwood Well 3 and the monitoring wells are presented on Charts 3-15 to 3-20. These figures show an excellent match between observed and simulated drawdown suggesting that the numerical model is appropriate to assess drawdown at Rockwood Well 3 for the Risk Assessment. As with the constant rate test at Rockwood Well 4, drawdown due to non-linear well losses at Rockwood Well 3 were estimated and added to the simulated results.

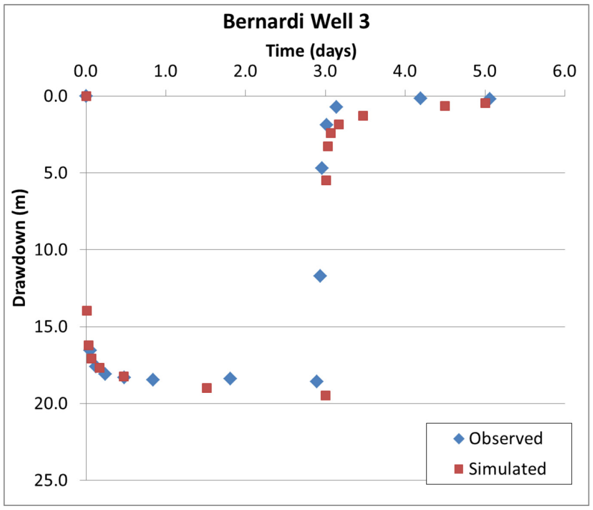

CHART 3-15 **Drawdown Response at Rockwood Well 3**

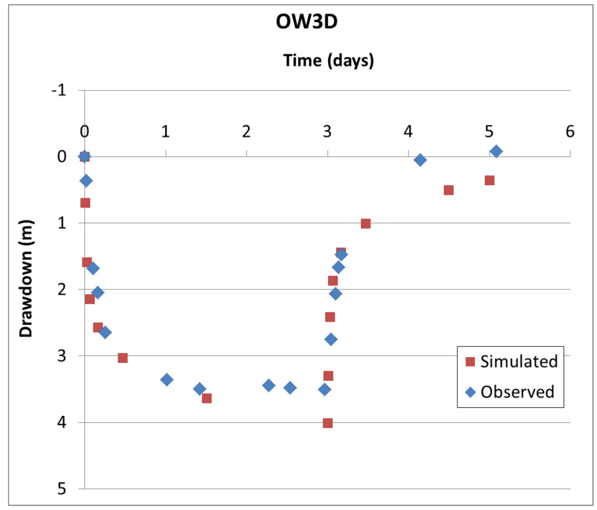

CHART 3-17 **Drawdown Response at OW3D, located 420 m from Rockwood Well 3**

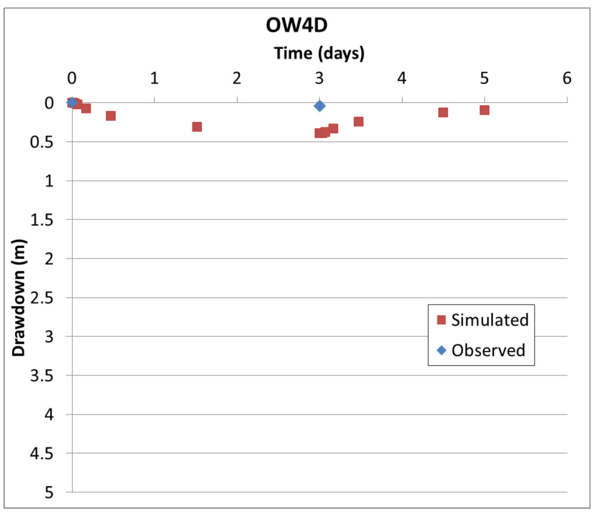

CHART 3-16 **Drawdown Response at OW4D, located 500 m from Rockwood Well 3**

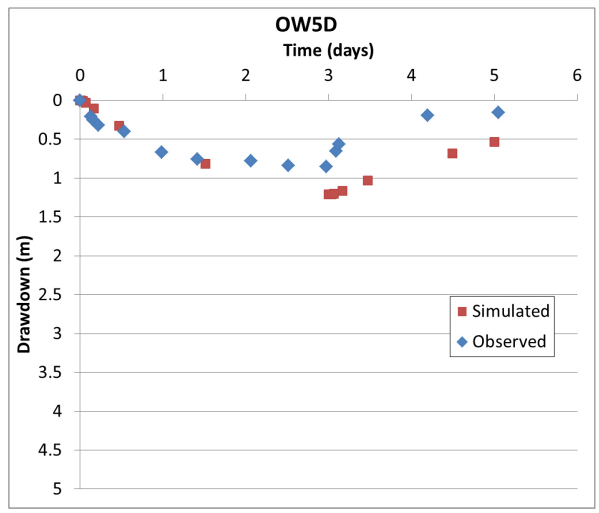

CHART 3-18 **Drawdown Response at OW5D, located 300 m from Rockwood Well 3**

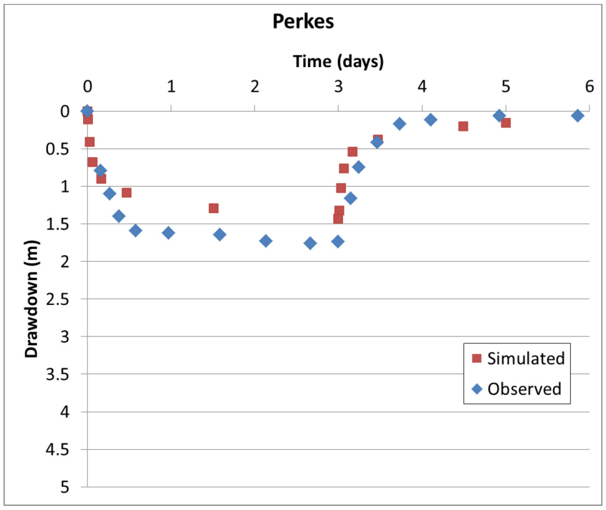

CHART 3-19 **Drawdown Response at Perkes (Domestic Well), located 480 m from Rockwood Well 3**

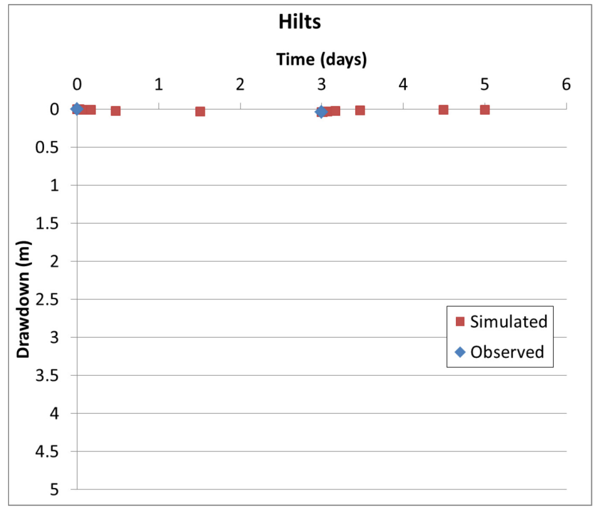

CHART 3-20 **Drawdown Response at Hilts (Domestic Well), located 680 m from Rockwood Well 3**

3.1.3 Nestlé Well TW3-80

Additional hydrogeological reports and data in the Aberfoyle area (Figure 2-8) were examined to determine whether the hydrogeological characterization could be improved. Water level response data during a 40-day constant rate pumping test was obtained for Nestlé well TW3-80 (CRA 2011), which represents a sizable water taking in this area with an average annual pumping rate of 2,396 m^3/day (2008). The test took place from August to October 2010, at a rate of 3,542 m^3/day, and observed water levels in monitoring wells were used to calibrate the Tier Three Assessment model near the Nestlé Aberfoyle plant. Other constant rate pumping test data at the site were also reviewed (i.e., 3-day pumping test [CRA 2004] and 11-day test [CRA 2012]); however, the 40-day test was selected for model calibration as the long duration ensures a more complete development of the area of influence of the pumping well.

The observed 40-day drawdown cone based on monitoring water level data from bedrock wells completed within the reported “Amabel Formation” was used as a calibration target. Focus was given to calibrating drawdown centrally at TW3-80 and non-linear well losses were taken into account. The final hydraulic conductivity values applied in the area of Nestlé were guided by the range of interpreted hydraulic conductivity values for hydrogeologic units presented in Golder (2011), CRA (2011; 2004) and SNC Lavalin (2005). Both simulated and field-derived values of hydraulic conductivity are summarized in Table 3-2. Figure 2-8 shows the final conductivity values applied near Nestlé Well TW3-80 in the Goat Island Formation.

TABLE 3-2 Summary of Bedrock Hydraulic Conductivity Values near Aberfoyle

Unit	Hydraulic Conductivity from Previous Studies (m/s)[1]		Area in Numerical Model	Simulated Hydraulic Conductivity (m/s)	
	Min	Max		Min	Max
Goat Island	9×10^{-8}	4×10^{-4}	Nestlé / Royal Canin	5×10^{-6}	2×10^{-4}

[1] CRA 2011; 2004 and SNC Lavalin 2005.

The updated model slightly over predicted drawdown locally at TW3-80, with 0.8 m more drawdown than observed when non-linear well losses are considered. Conversely, the areal extent and magnitude of the simulated drawdown cone is slightly under-predicted. In order to match the observed drawdown exactly, an increase in the complexity of zones of hydraulic conductivity is necessary in this fractured rock environment. As this is beyond the scope of the Tier Three Assessment, the present level of calibration of the model in this area is suitable and the model is considered appropriate for evaluation of the Risk Assessment scenarios.

3.2 Transient Verification

Two transient verification exercises were undertaken to confirm the performance of the model under transient, long-term variable climatic and municipal pumping conditions in the City and in Rockwood.

3.2.1 City of Guelph

Transient model verification in the City wells followed the same process described in Appendix B. A long-term simulation covering a nine-year period from 1997 to 2005 was conducted with the goal to compare the simulated head response in the municipal wells and the predicted groundwater discharge to the Arkell Glen Collectors with the observed data from that time period. The model was simulated with the following parameters:

- monthly average groundwater recharge rates as predicted by the surface water model (GAWSER) from 1997 to 2005 (Appendix B)
- monthly average historical pumping rates for the Guelph municipal wells
- monthly average pumping to the Arkell Recharge System-according to the Eramosa River Intake pumping records (described in Appendix B)

3.2.1.1 Head Response in Municipal Wells

Charts 3-21 to 3-27 illustrate the previous (black line) and updated (green line) simulated depth to water results of the long-term model simulation for wells in the Quarry Update Area (Figure 2-4) discussed in Section 2.3 and also show the monthly average pumping rates associated with each well. The results for the other City municipal wells are provided in Appendix E2. In order to compare the simulated and observed pattern of head fluctuations in the pumping wells, the model-predicted heads have been adjusted on a well-by-well basis, where required, to account for the absolute difference between the steady-state model-predicted heads and the observed head target used to calibrate the steady-state model. Presenting this data with a normalization of the model-predicted heads focuses the analysis on the model's response to the stress conditions and removes the effects of well losses, model geometry (e.g., difference between actual and modelled top of well elevations), using monthly average pumping and water levels, and other artefacts arising from the model's approximation of a real-world system. Table 3-3 below summarizes the adjustments to the simulated depth to water levels for the previous and updated transient models as compared to the difference (residual error) between the observed and updated simulated heads for the calibrated steady-state model. As shown, the magnitude of the updated transient simulation adjustment has either stayed the same as the previous simulation or decreased for the majority of the municipal wells and is of similar magnitude to the steady-state residual error. An increase in the adjustment was required for Calico and University wells. Note that simulation results for the Smallfield well are not presented here due to a lack of observation data during the period of interest.

TABLE 3-3 Adjustments to Simulated Depth to Water for City of Guelph Pumping Wells

Municipal Pumping Well	Observed Water Level (Calibration Target) (m asl)	Updated Steady-state Simulated Water Level (m asl)	Updated Steady-state Residual Error (m)	Previous Transient Simulation Adjustment Required (m)	Updated Transient Simulation Adjustment Required (m)
Arkell 1	322.9	322.5	-0.4	0.0	0.0
Arkell 14	316.0	315.4	-0.6	0.0	0.0
Arkell 15	317.6	315.5	-2.1	0.0	0.0
Arkell 6	313.7	314.7	1.0	0.0	0.0
Arkell 7	313.9	314.7	0.8	0.0	0.0
Arkell 8	313.9	314.7	0.8	0.0	0.0
Burke	319.2	324.1	4.9	4.5	4.5
Calico	309.1	315.7	6.6	3.5	4.0
Carter Wells	320.2	321.3	1.1	-3.0	-2.5
Clythe Creek	321.4	317.2	-4.2	-8.0	-6.7
Dean Avenue	289.7	293.4	3.7	6.0	3.0
Downey Road	297.0	295.1	-1.9	2.5	2.0
Emma	293.2	277.8	-15.4	-15.0	-15.0
Helmar	303.5	321.7	18.2	18.0	18.0
Membro	287.7	289.8	2.1	5.0	2.5
Paisley	299.1	303.5	4.4	3.0	1.5
Park 1 and 2	291.8	283.3	-8.5	-8.0	-8.0
Queensdale	289.9	299.9	10.0	18.0	13.0
Sacco	337.9	325.8	-12.1	-12.5	-12.0
University	293.0	297.6	4.6	5.0	8.0
Water Street	290.4	294.7	4.3	5.0	2.0

There is excellent agreement between the pattern of observed and model-predicted heads for most of the wells examined in the previous and updated calibrations. Some of the wells have observed water level fluctuations that are greater than the water level fluctuations predicted by the previous and updated versions of the model. This is attributed to the averaging of municipal pumping rates over the monthly stress periods used in the simulation. The average monthly pumping rates produce model-predicted water levels that do not reflect the influence of day-to-day changes in pumping. Other noise in the observation data is introduced by a majority of the water levels being measured though air line type gauges that have their inherent inaccuracy and imprecision.

The steady-state model calibration effort concentrated on matching the 2008 data as representative of current conditions. Because of that, the geometry and condition of the pumping wells in 2008 will be most closely represented in the model, and thus the later period of the transient simulation will have a better match between observed and modelled data. Any changes to the wells (e.g., installation of liners, or rehabilitation of the well) that occurred in the time period of the transient verification exercise (1997 to 2005) may cause a mismatch between the observed and model-simulated data up to the time of the change, and a better match after the change. In general, the match is better after 2002, which also appears to correspond with an improvement in the quality (and quantity) of the field data being collected by the City.

Seven municipal wells within the area of the Dolime Quarry model update are discussed here as they had the greatest potential to be impacted as a result of the most recent model updates; these wells include: Dean, Downey, Membro, Paisley, Queensdale, University, and Water Street (Figure 2-4).

Four of the seven wells in the Dolime Quarry area have updated simulated responses, which are similar to their previous counterparts, including Dean (Chart 3-21), Downey (Chart 3-22), Membro (Chart 3-23), and Water Street (Chart 3-27). However, all of these wells have substantial improvements in the magnitude of the required absolute adjustments, with improvements ranging between 0.5 to 3.0 m.

The magnitude of the updated simulated water level fluctuations has increased at Paisley (Chart 3-24) and Queensdale (Chart 3-25) when compared to the previous results; however, these fluctuations tend to correspond with greater fluctuations in the observed data as well, resulting in an improved fit between simulated and observed head variations. The magnitude of the adjustment between the updated simulated and observed absolute depth to water has also improved by 1.5 m at Paisley and by 5 m at Queensdale.

The previous and updated results for University are shown on Chart 3-26. The updated model shows less water level variation than the previous version but the simulated response still falls within the observed water level fluctuation. The absolute offset in depth to water increased by 3 m due to the changes to the transmissivity of the Gasport Formation east of University made during the Quarry Model updates (Figure 2-4).

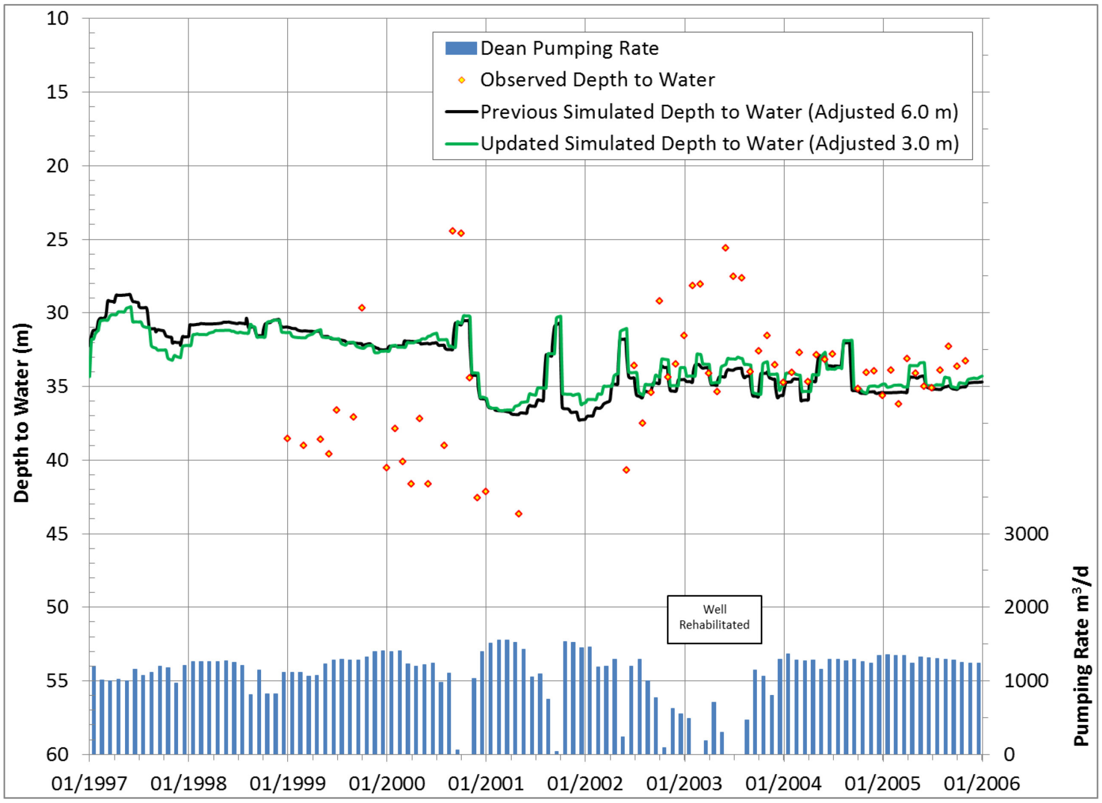

CHART 3-21 Transient Verification - Dean Well Depth to Water (1997 - 2005)

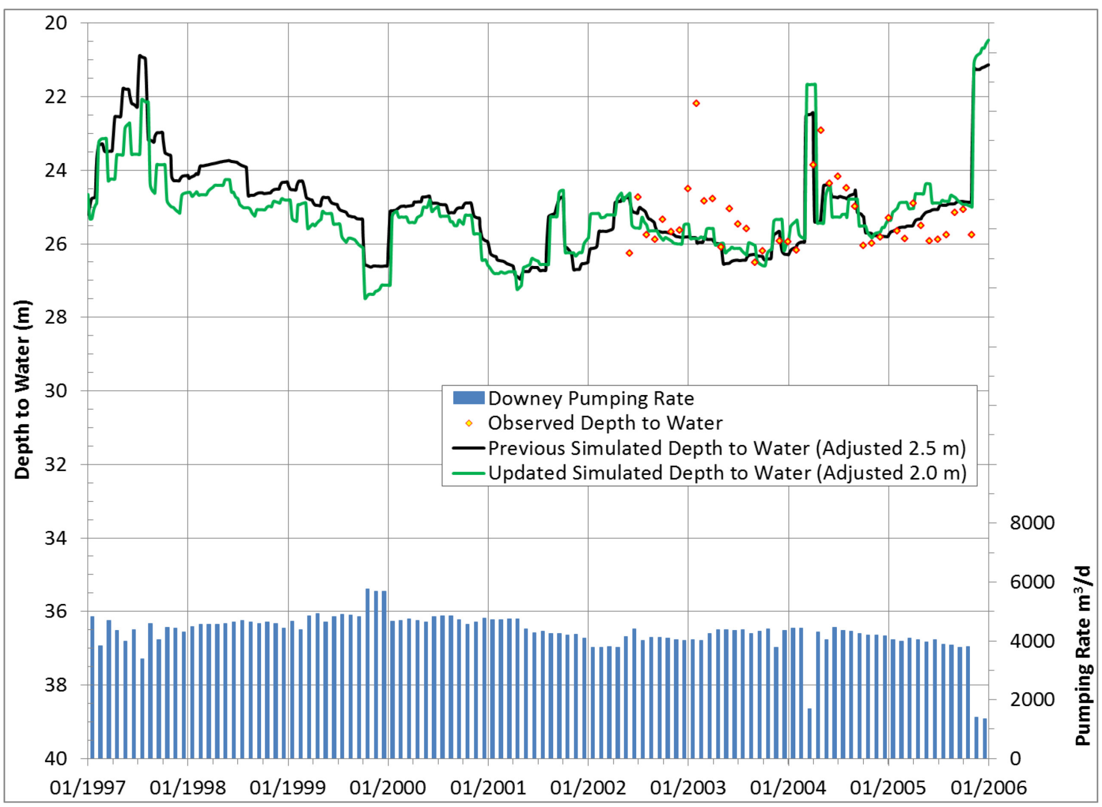

CHART 3-22 Transient Verification - Downey Well Depth to Water (1997 - 2005)

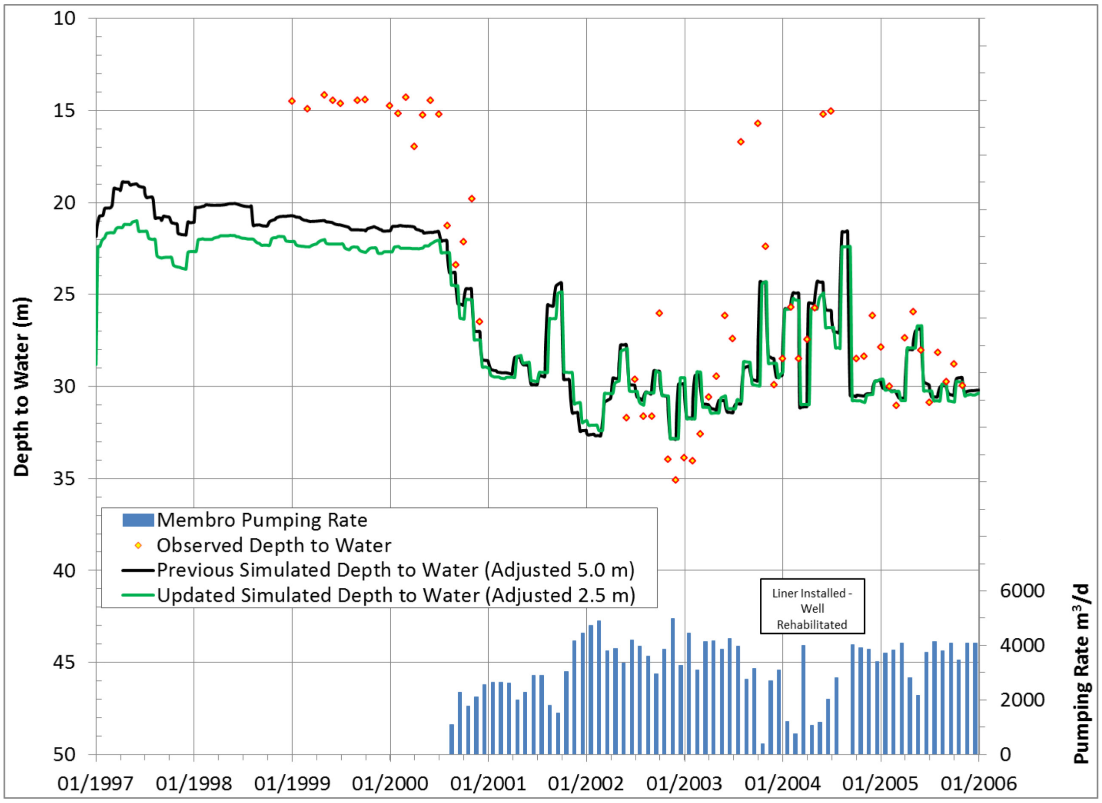

CHART 3-23 Transient Verification - Membro Well Depth to Water (1997 - 2005)

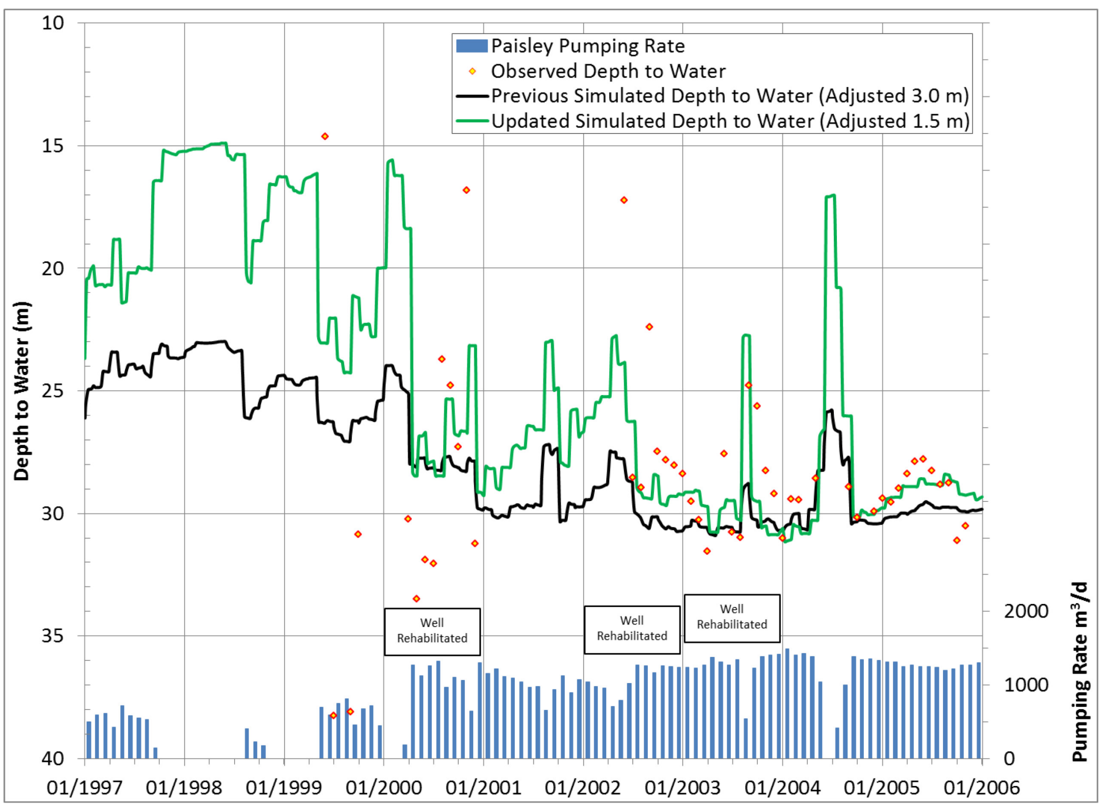

CHART 3-24 Transient Verification - Paisley Well Depth to Water (1997 - 2005)

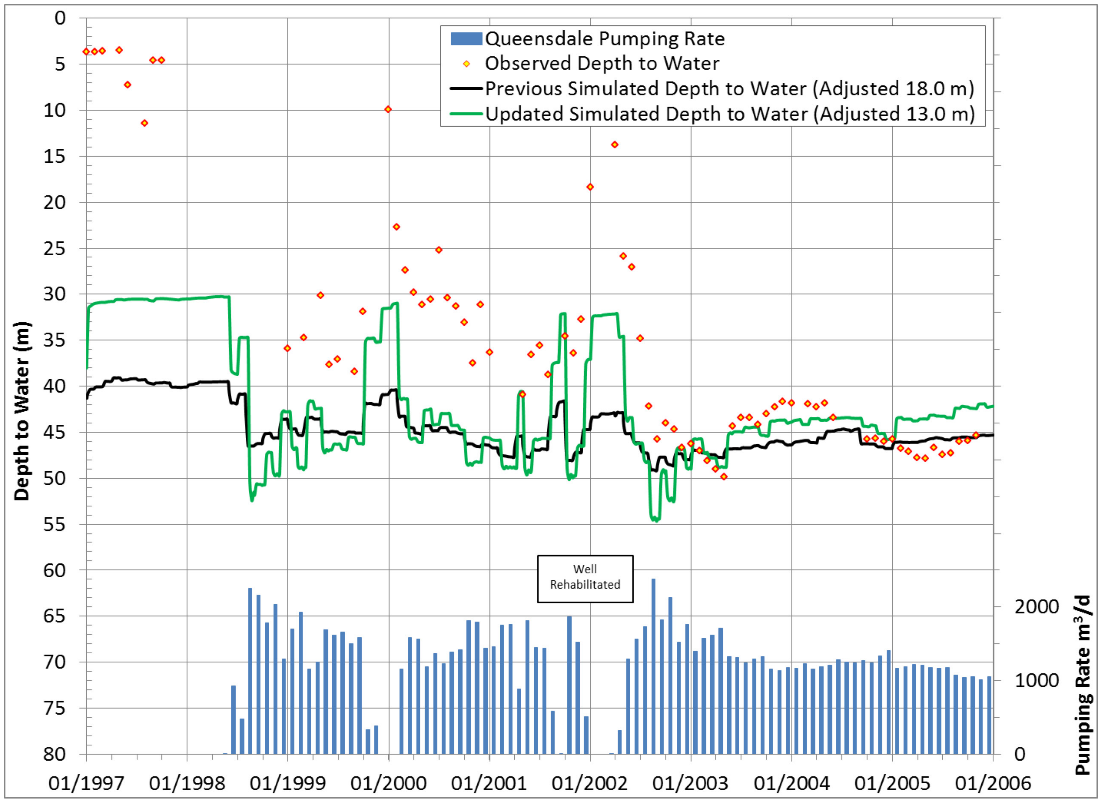

CHART 3-25 Transient Verification - Queensdale Well Depth to Water (1997 - 2005)

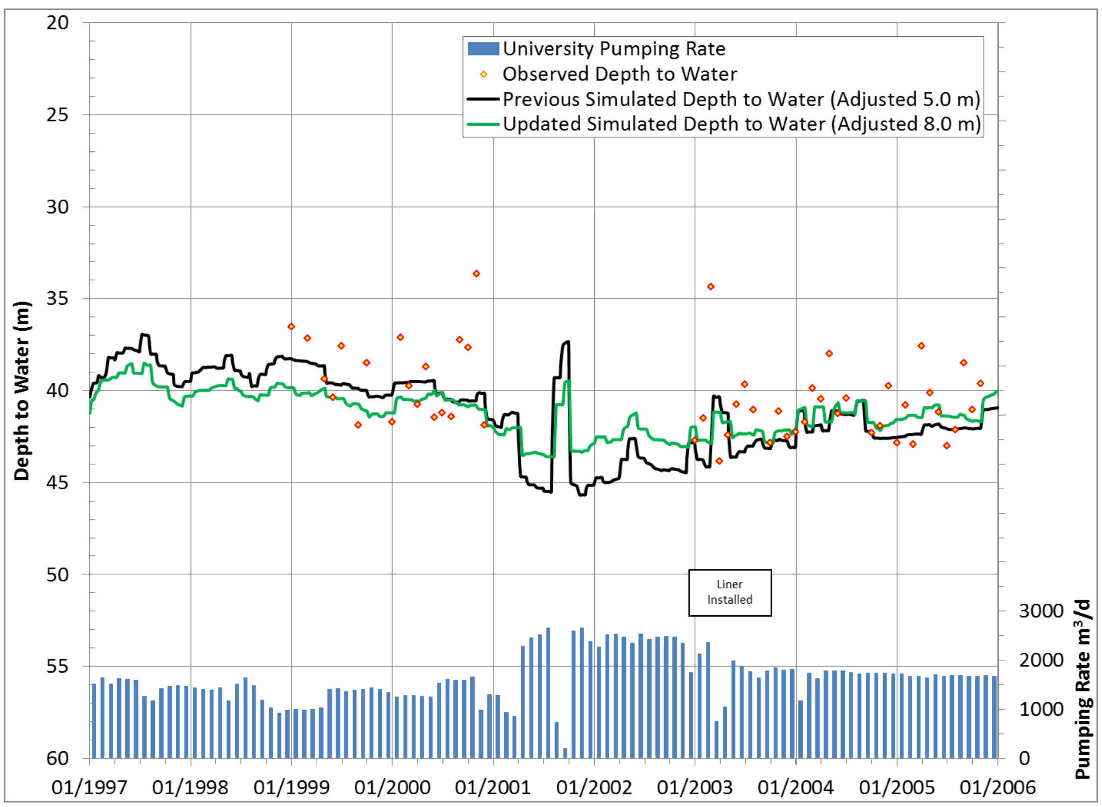

CHART 3-26 Transient Verification - University Well Depth to Water (1997 - 2005)

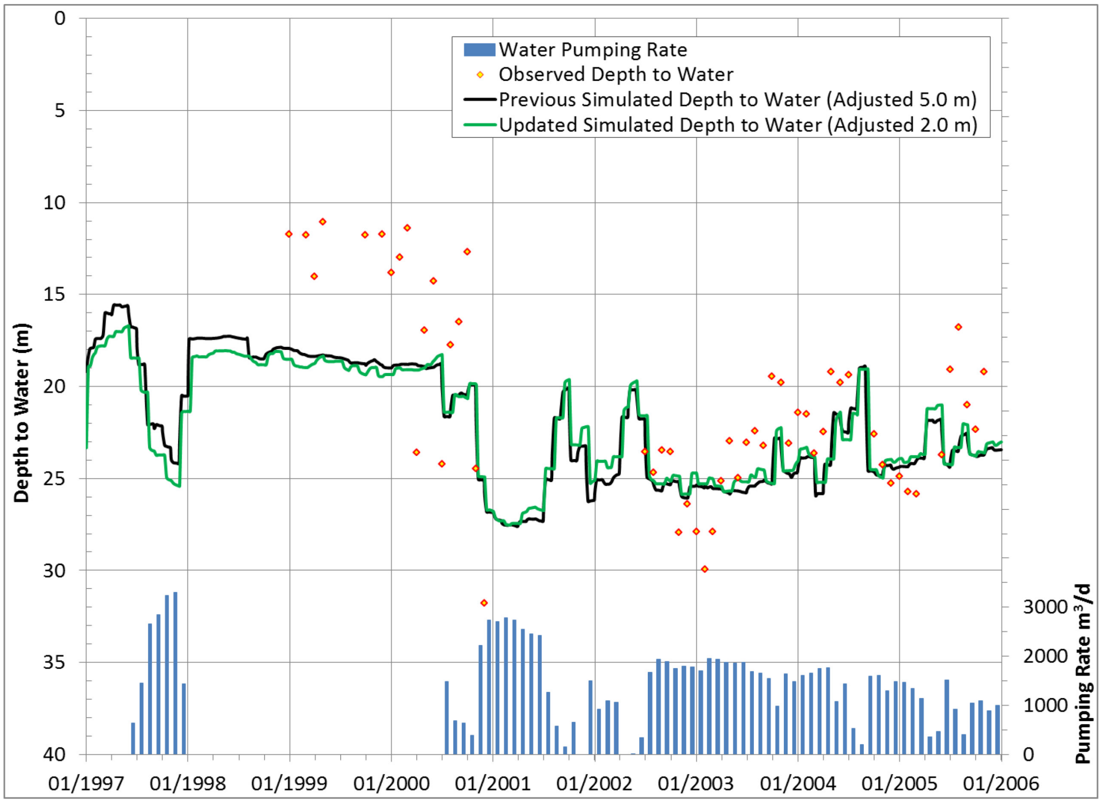

CHART 3-27 Transient Verification - Water Street Well Depth to Water (1997 - 2005)

3.2.1.2 Discharge to Arkell Glen Collector

Groundwater discharge at the Arkell Glen Collector was also predicted during the updated long-term transient simulation and is compared with the previous transient simulation and observed flow data on Chart 3-28. The average monthly pumping rate from the Eramosa River to the Arkell Recharge System is also shown on this figure. The previous and updated model-simulated flows are illustrated as the black and green lines, respectively and the observed daily flows are shown as grey dots. Additionally, the monthly average observed collector flows are shown as a dashed red line. In general, both the previous and updated models are slightly under-predicting the quantity of flow at the collector during peak flow conditions, but there is a good match in the timing of flows between simulated and observed data especially for the later time period. Discrepancies may be accounted for by the following factors:

1. Until recently, the flows recorded for the Glen Collector were not observed directly, but were back-calculated by subtracting the volume of water extracted from the Arkell and Carter wells daily from the total volume of water flowing to the Woods Pumping Station through an aqueduct that includes the Glen Collector flows. Thus, because of storage in the aqueduct system, daily fluctuations in the pumping rates at the wells led to inaccuracies in the recorded Collector flows. This effect was observed in the field during a pumping test and documented in “Arkell Spring Grounds – Groundwater Supply Investigation” (Gartner Lee Limited 2003).

2. The observed Arkell Glen Collector flows originally included flows from the Lower Road Collectors that were sealed in 2001 due to poor water quality. The Lower Road Collectors collected a large proportion of water that was recharged to the shallow aquifer by the Arkell Recharge System and these collectors contributed approximately 4,000 m^3/day of flow during peak flow seasons. The model only simulates the current configuration of the Arkell Glen Collectors and thus the discharge simulated does not include the pre-2001 contribution of the Lower Road Collectors.

3. During 2000 and 2001 the Arkell Spring Grounds were undergoing testing for the above mentioned study (Gartner Lee Limited 2003). The Arkell pumping wells and the Eramosa Intake/Arkell Recharge System were used sporadically during these periods and this contributes to deviation in the data prior to 2002.

4. The model simulation used monthly averaged pumping rates for the wells and the Eramosa Intake/Arkell Recharge System, which tends to smooth the simulated flow response by lowering the peaks and raising the valleys, as well as shifting the timing of the response slightly.

Given these factors, it is demonstrated that the updated model reasonably represents the discharge at the Arkell Glen Collector and that the conceptual model for the Arkell area is plausible.

Overall, there is good agreement between the updated model-simulated response of the groundwater system and the observed response for the municipal water-supply system. The pattern of changes in the water levels in the municipal wells and the groundwater discharge at the Arkell Glen Collector is reasonably matched by the model thereby verifying its ability to represent transient stress conditions.

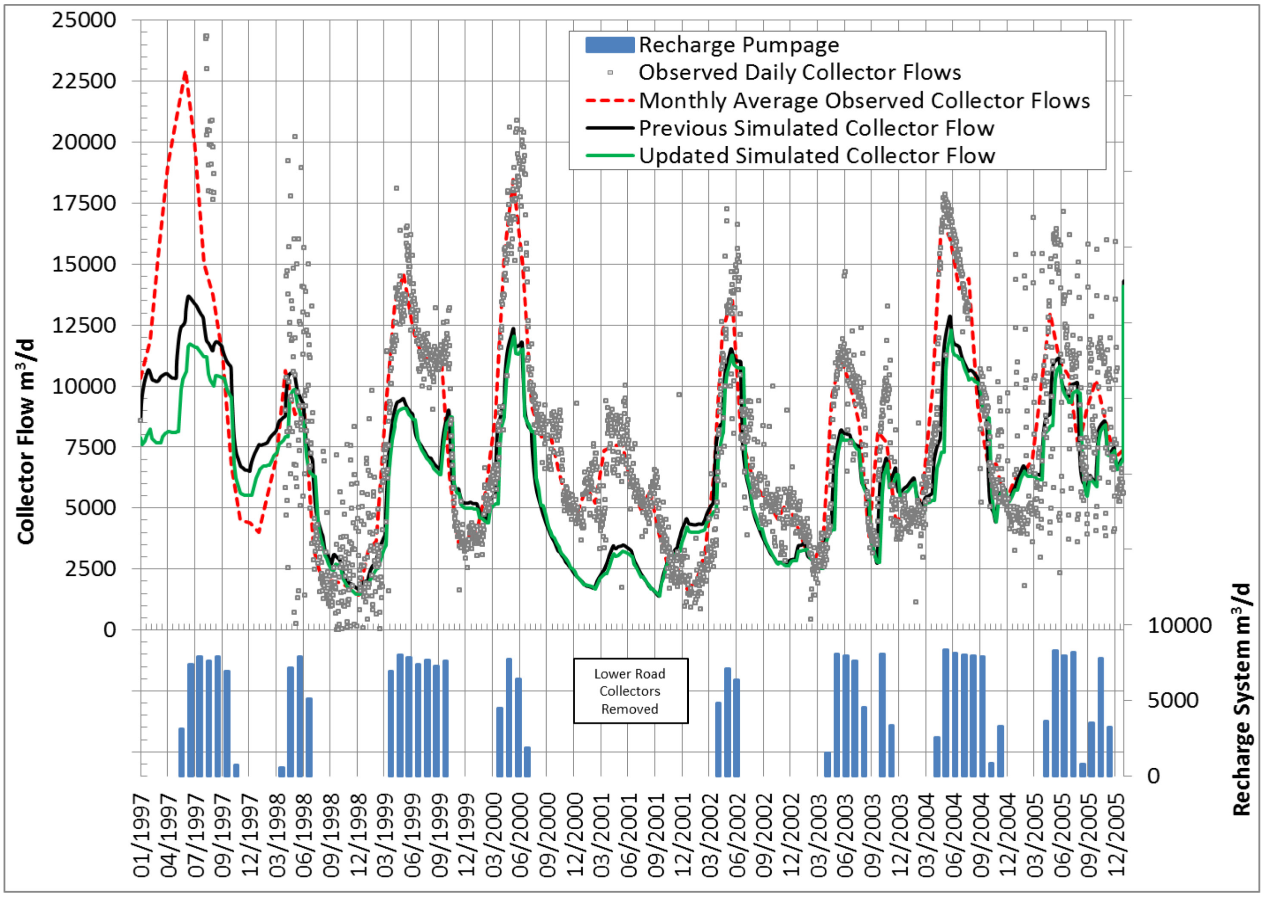

CHART 3-28 Transient Verification - Arkell Glen Collector Flows (1997 - 2005)

3.2.2 Rockwood and Hamilton Drive

The updated model was verified for the Rockwood and Hamilton Drive area by comparing simulated hydraulic head to observed hydraulic head between 2008 and the end of 2012 and in a similar manner described in Appendix D. Transient recharge for the Tier Three Assessment was derived from a GAWSER model covering 1960 to 2005 (Appendix B). This GAWSER model was extended to the end of 2012 for Zone of Uniform Meterology 13 (ZUM13) to provide rechage estimates for the long-term verification for the Rockwood and Hamilton Drive area using a combination of climate data from the Elora RCS and Waterloo Wellington 2 climate stations. The resulting recharge from GAWSER was applied in the Tier Three Assessment model. This method of determining recharge is more representative of actual climate conditions during the assessed period (2008 to 2012) than that used in the previous model update (Appendix D). The previous model update used approximated equivalent monthly recharge estimated by using precipitation for the years of interest and the GAWSER-derived relationship between monthly precipitation and estimated monthly recharge for equivalent months during prior years (1960 to 2005).

Table 3-4 below summarizes the adjustments to the simulated depth to water or water level elevations for the previous and updated transient models. The required adjustments remained the same for all of the Hamilton Drive wells and the Station Street pump house wells (Rockwood wells 1 and 2).

The magnitude of the required adjustment decreased for all of the remaining wells in Rockwood by 1 to 3.5 m, except for Rockwood Well 3 whose absolute offset increased by 2 m.

TABLE 3-4 Adjustments to Simulated Depth to Water or Water Level Elevation for Rockwood and Hamilton Drive Wells

Well	Observed Water Level (Calibration Target) (m asl)	Updated Steady-state Simulated Water Level (m asl)	Updated Steady-state Residual Error (m)	Previous Transient Simulation Adjustment Required (m)	Updated Transient Simulation Adjustment Required (m)
Huntington	333.4	336.1	2.7	-2.0	-2.0
Cross Creek	331.8	333.0	1.2	-2.0	-2.0
MW2S	331.0	333.4	2.4	-2.5	-2.5
MW2I	331.1	335.4	4.3	-4.0	-4.0
Rockwood Well 1	346.3	342.9	-3.4	5.0	5.0
Rockwood Well 2	345.8	342.9	-2.9	5.0	5.0
Rockwood Well 3	336.0	342.0	7.8	-7.0	-9.0
Oelbaum	331.5	337.1	5.6	-6.5	-5.5
Perkes	349.1	352.2	3.1	-4.0	-2.0
OW3R-08-S	352.2	353.3	1.1	-2.0	-1.0
OW3R-08-D	351.0	350.7	-0.3	4.0	0.5

Time series plots comparing previously simulated, updated simulated, and observed hydraulic head variation at pumping and monitoring well locations in Rockwood and Hamilton Drive are shown on Charts 3-29 to 3-39. Pumping and monitoring well locations for Rockwood are shown on Figure 3-1, while those for Hamilton Drive are shown on Figure 3-2. As with the previous simulated water levels, some of the update plots show discrepancies between simulated and observed head at various times, but a good match is seen for a majority of the locations.

The pumped water supply wells display greater discrepancies between simulated and observed water levels than the monitoring wells. The supply wells are Huntington and Cross Creek in Hamilton Drive, and Rockwood Well 1 and 2 in the Station Street pump house and Rockwood Well 3 in the Bernardi pump house in Rockwood. These discrepancies were expected as the observed data includes water levels from the full range of pumping conditions (e.g., variable pumping rates, pumps cycling on and off, etc). The wells were modelled with monthly average pumping rates and the transient model used 7-day time steps. These factors inhibit the exact match of simulated to observed water levels especially for pumping wells that may vary in pumping rates on an hourly basis. Rockwood Well 4 was not in operation during this time and therefore was not simulated.

In Hamilton Drive, the updated simulated response at the pumping wells and monitoring wells were comparable to the previous model.

In Rockwood, Rockwood Well 1 (Chart 3-33) and Well 2 (Chart 3-34) show greater discrepancies between the simulated and observed water levels for various times, but most particularily during 2011 and 2012. These periods correspond to times when one well was not pumping and the other was pumped at higher rates to compensate. At times in the pumping record, one well is pumping while the other is reduced in rate or turned off. For pumping history, see Charts 3-2, 3-5, and C3-2 in Appendix C.

Rockwood Well 3 (Chart 3-35) also shows discrepencies between simulated and observed water levels; however, the updated simulated data shows greater variability, which fits the observed data closer than the previous simulation (e.g., mid-2011).

The updated simulated patterns of water level fluctuation in Rockwood monitoring wells (Charts 3-36 to 3-39) were comparable to the previous modelled results when examined in concert with the observed data. All of these wells had simulated absolute water levels, which were closer to the observed values than the previous model.

In general, the updated model is able to represent the transient pattern and response of water levels within pumping and monitoring wells near Hamilton Drive and Rockwood. While the simulated and observed water elevations may not match exactly, the range of fluctuation is represented. As the model will be used to assess the relative change of water levels from base line conditions to future conditions under various scenarios, it is concluded that the model is suitably calibratated and verified to represent the groundwater flow system.

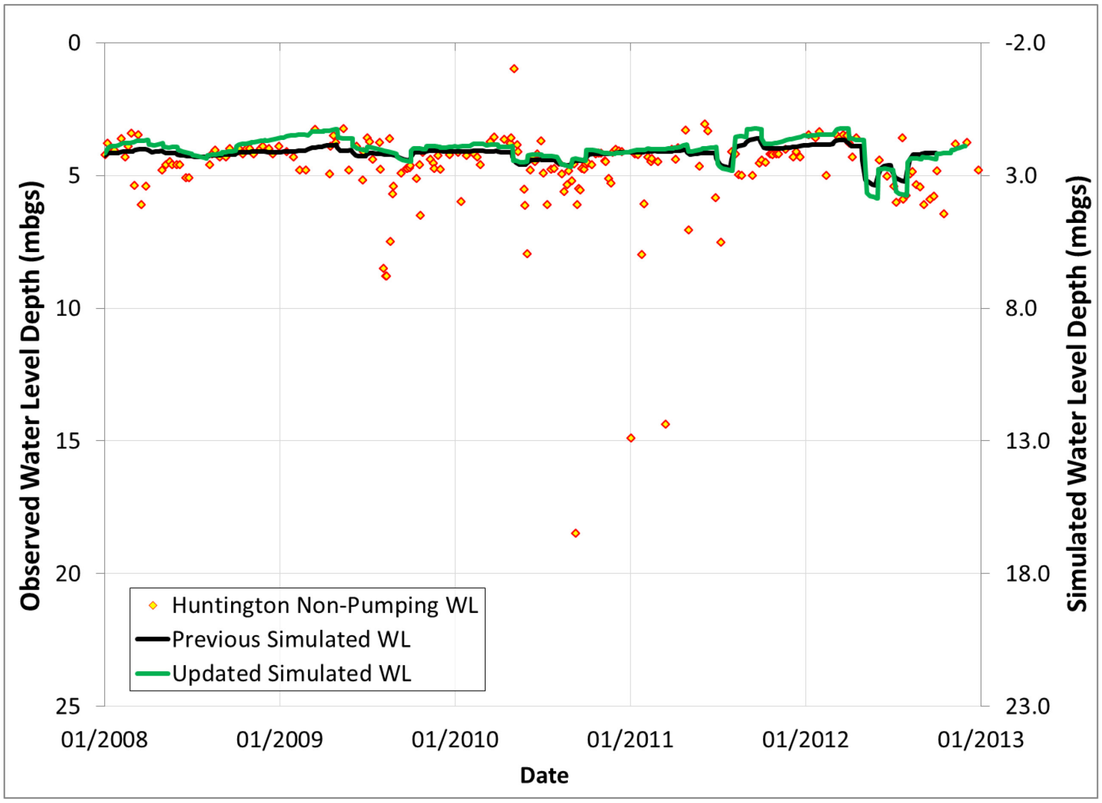

CHART 3-29 **Transient Verification - Huntington Estates Well Water Levels (2008 - 2012)**

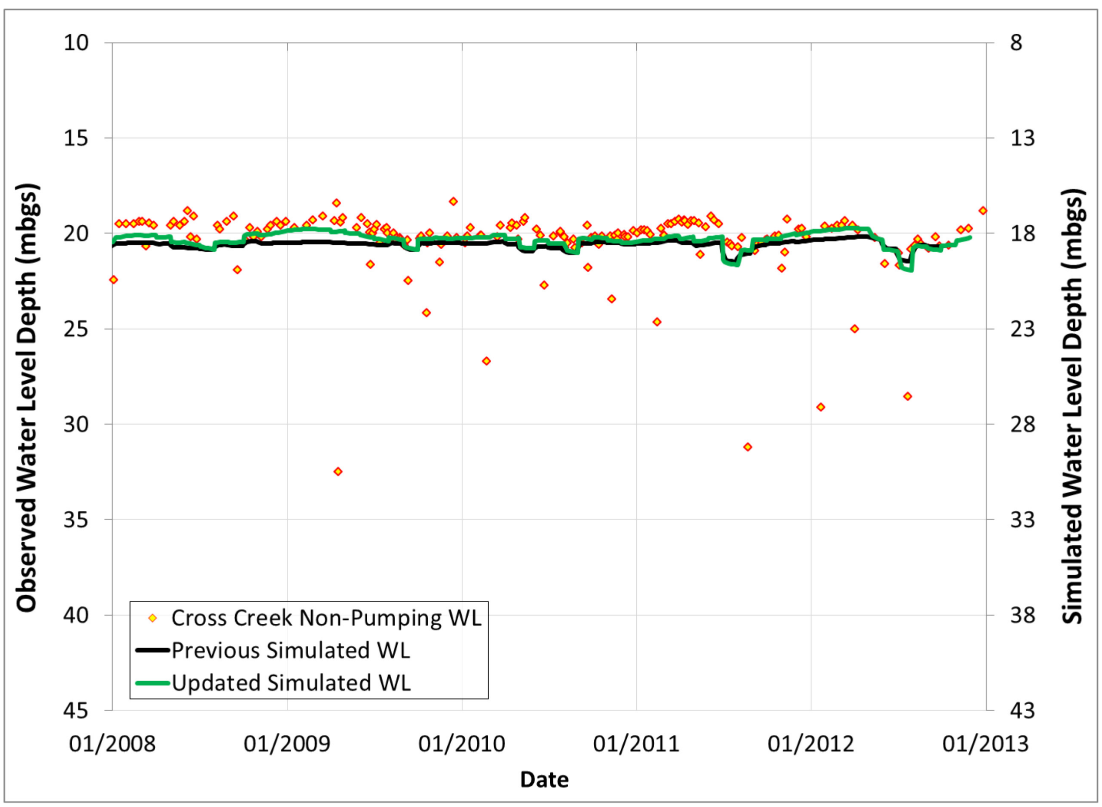

CHART 3-30 **Transient Verification - Cross Creek Well Water Levels (2008 - 2012)**

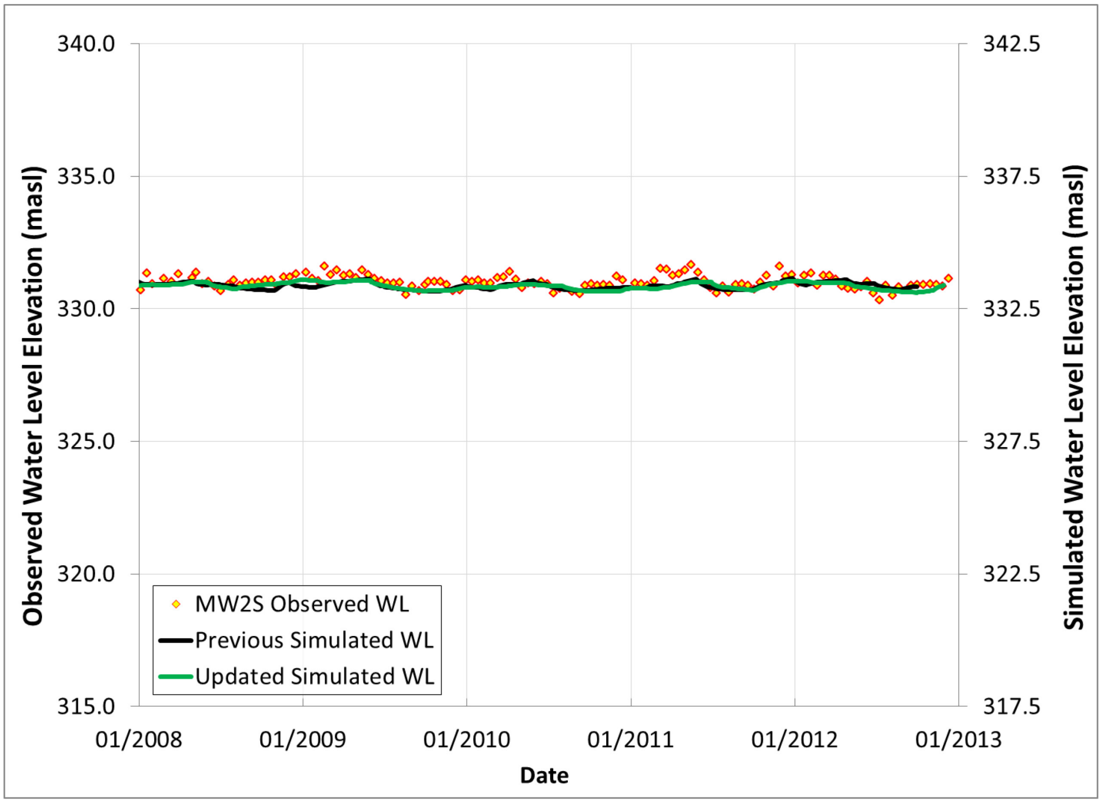

CHART 3-31 Transient Verification - MW2S Water Levels (2008 - 2012)

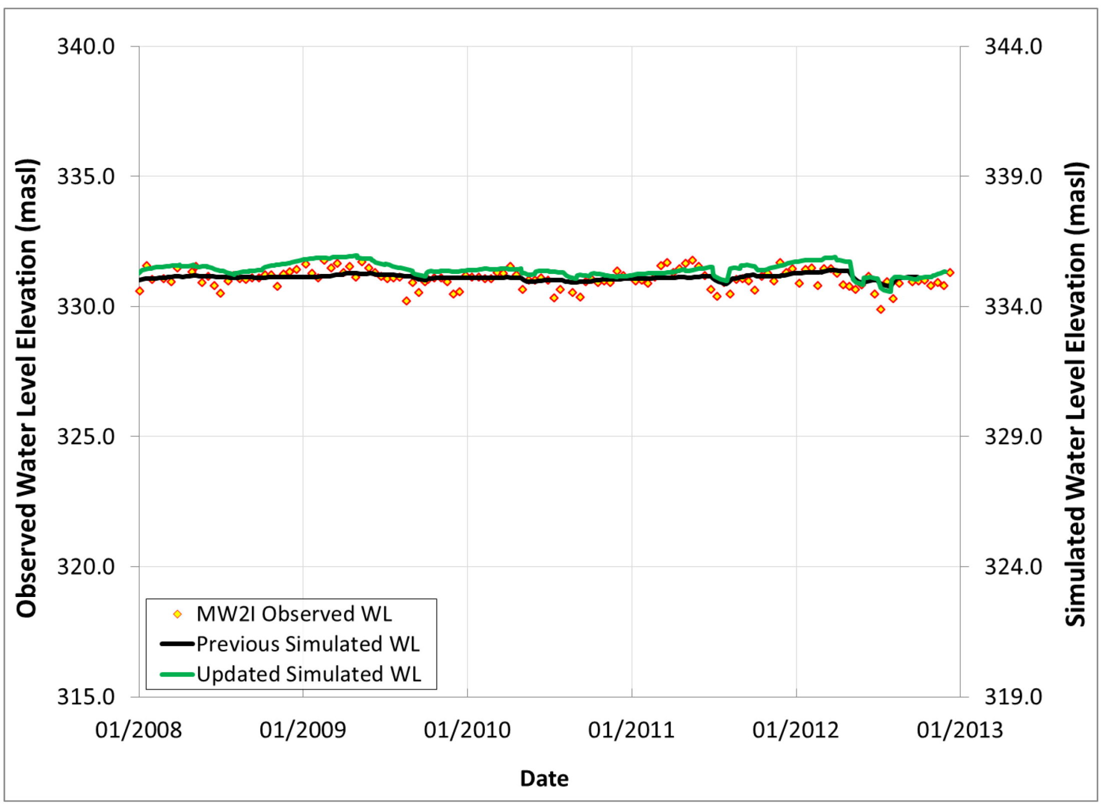

CHART 3-32 Transient Verification - MW2I Water Levels (2008 - 2012)

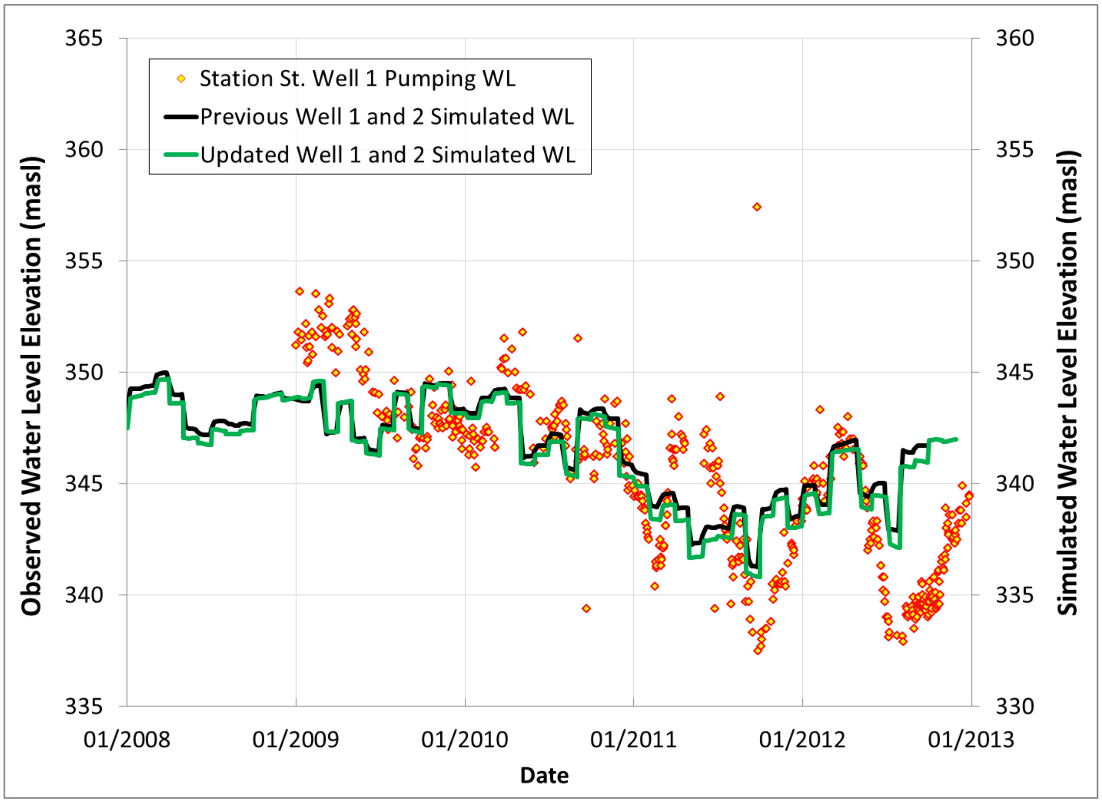

CHART 3-33 Transient Verification - Rockwood Well 1 Water Levels (2008 - 2012)

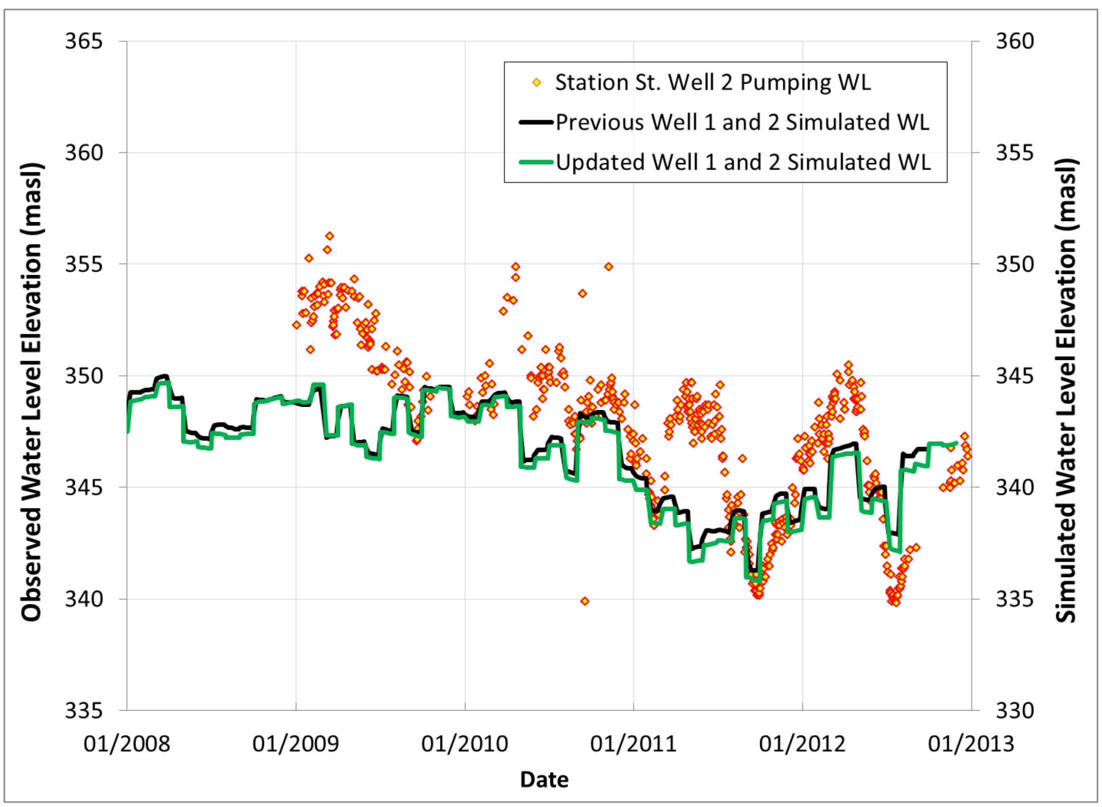

CHART 3-34 Transient Verification - Rockwood Well 2 Water Levels (2008 - 2012)

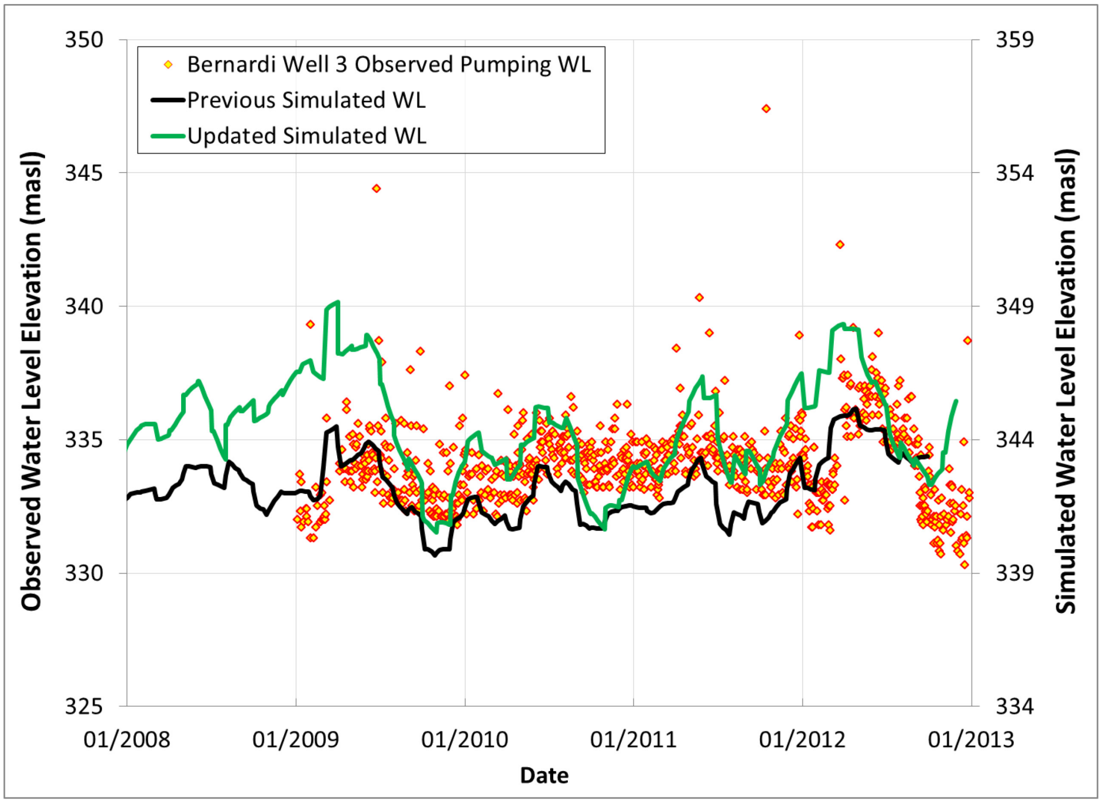

CHART 3-35 Transient Verification - Rockwood Well 3 Water Levels (2008 - 2012)

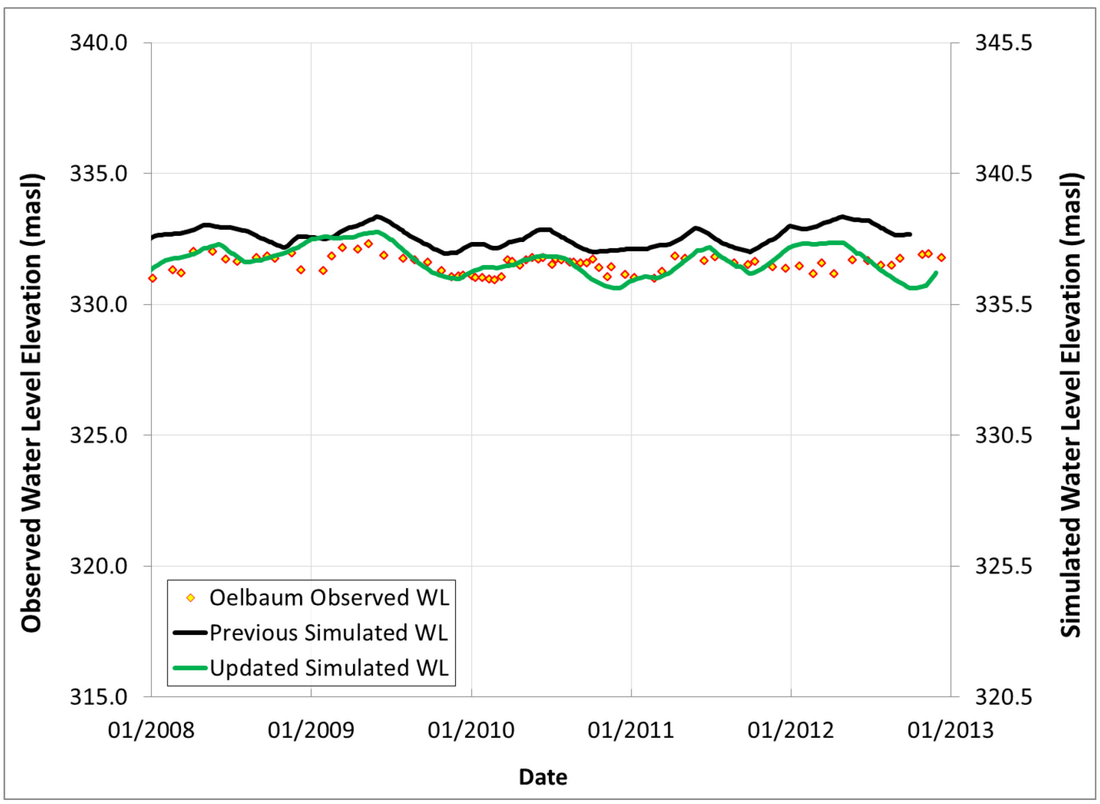

CHART 3-36 Transient Verification - Oelbaum Water Levels (2008 - 2012)

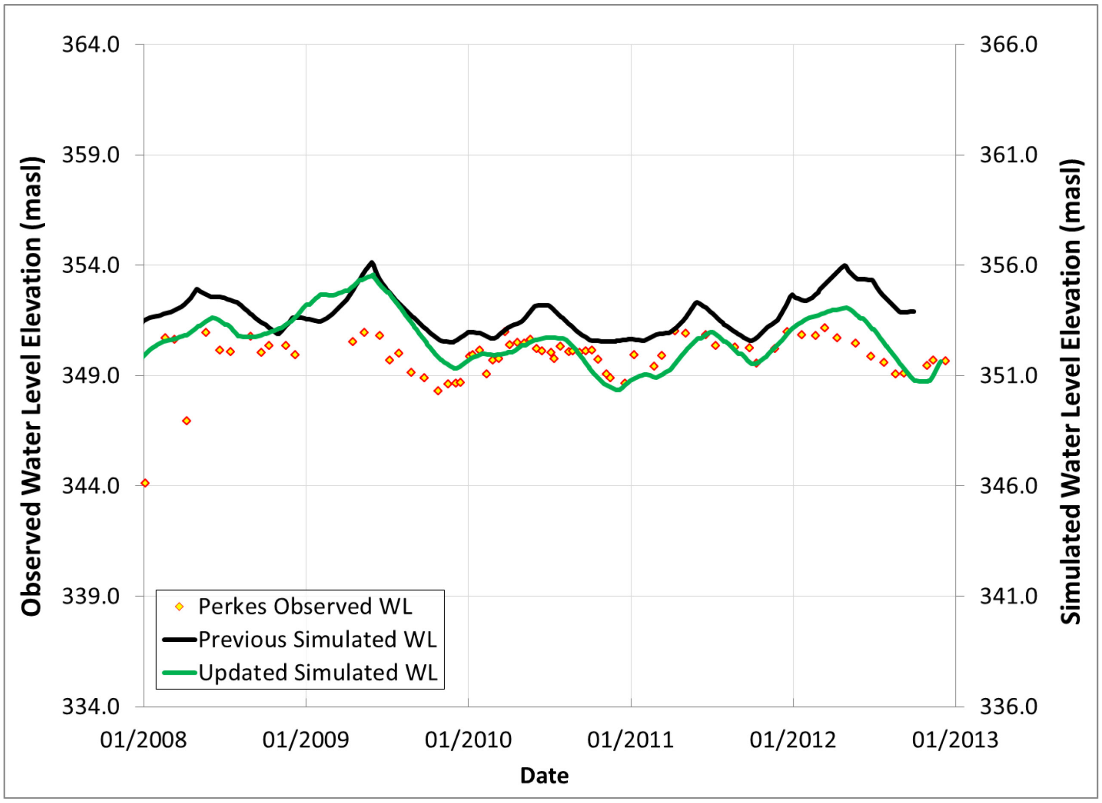

CHART 3-37 Transient Verification - Perkes Water Levels (2008 - 2012)

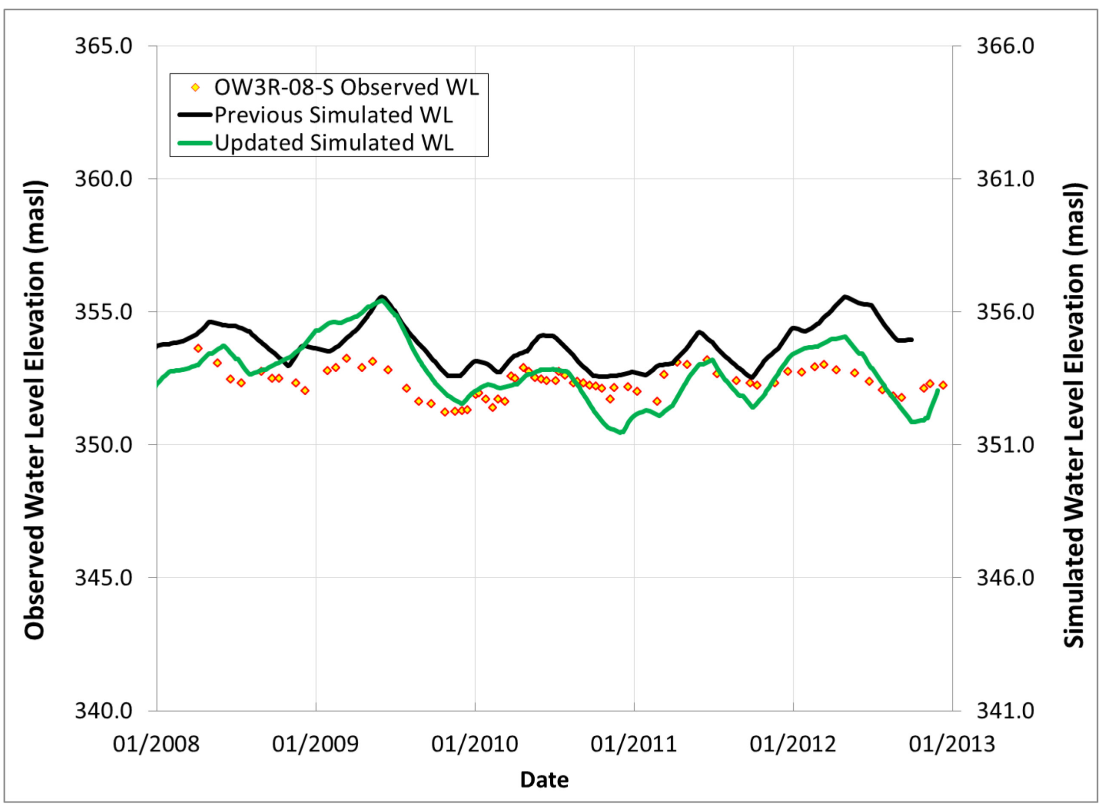

CHART 3-38 Transient Verification - OW3R-08-S Water Levels (2008 - 2012)

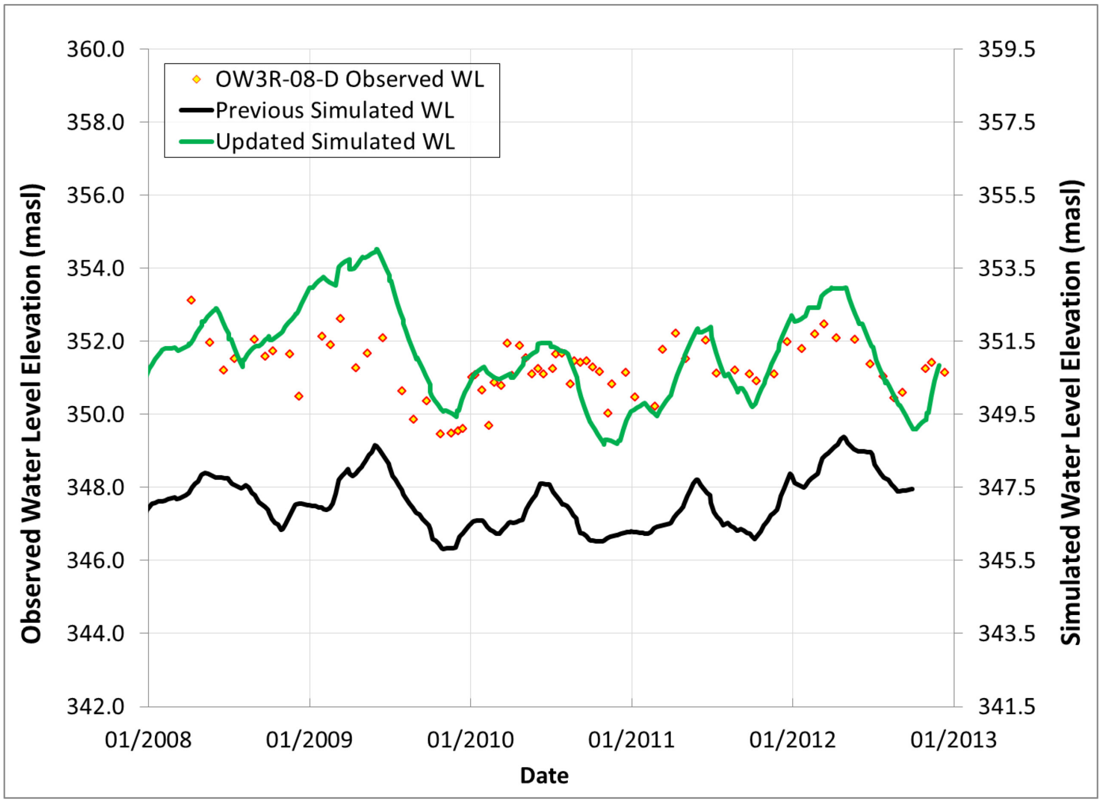

CHART 3-39 Transient Verification - OW3R-08-D Water Levels (2008 - 2012)

3.3 Steady-State Calibration

The steady-state calibration results of the updated model for hydraulic head and baseflow are presented below. Due to updates to the numerical model, the calibration results changed slightly from the previous calibrated model.

3.3.1 Hydraulic Head

The hydraulic head calibration statistics for the updated and previous model are summarized in Tables 3-5 and 3-6. Statistics are calculated for all the calibration targets within the regional study area, and for three sub-sets of targets: high-quality wells throughout the study area, targets surrounding Rockwood, and targets local to Hamilton Drive. The calibration statistics of the updated model do not deviate significantly from those of the previous model.

The mean error for all targets of the updated model is -0.4 m, which indicates that the simulated heads are lower on average than the observed by -0.4 m. This is similar to the previous model, which had a mean error of -0.3 m. For the Rockwood group of targets, the mean error of the updated model (-1.5 m) is the same as the previous model. These changes in the calibration statistics are insignificant given the degree of updates to the conceptual model represented in the numerical model and the model remains suitably calibrated.

TABLE 3-5 Head Calibration Statistics for the Updated Model

Calibration Statistic	All Targets	High-quality Wells	Rockwood	Hamilton Drive
Number of Calibration Targets	11,049	406	1,688	296
Mean Error (ME)	-0.4 m	-1.0 m	-1.5 m	0.1 m
Mean Absolute Error (MAE)	4.2 m	2.7 m	5.1 m	3.8 m
Root Mean Squared Error (RMS)	5.8 m	4.1 m	6.8 m	5.5 m
Normalized Root Mean Squared Error (NRMS)	2.2%	2.8%	6.2%	7.9%
Range in Observed Water Levels	266.3 m	143.6 m	110.3 m	69.8 m

TABLE 3-6 Head Calibration Statistics for the Previous Model

Calibration Statistic	All Targets	High-quality Wells	Rockwood	Hamilton Drive
Number of Calibration Targets	11,047	404	1,686	296
Mean Error (ME)	-0.3 m	-1.0 m	-1.5 m	-0.1 m
Mean Absolute Error (MAE)	4.2 m	2.8 m	5.0 m	3.8 m
Root Mean Squared Error (RMS)	5.7 m	4.0 m	6.8 m	5.5 m
Normalized Root Mean Squared Error (NRMS)	2.1%	2.8%	6.1%	7.9%
Range in Observed Water Levels	266.3 m	143.6 m	110.3 m	69.8

3.3.2 Baseflow

The model simulated baseflow and estimated observed baseflow at the baseflow target locations used in the Tier Three Assessment are shown for the larger and smaller subwatersheds on Charts 3-40 and 3-41. On these charts, the simulated results for the updated model are labelled as “2016 Model.” The simulated results for the previous model are labelled as “2014 Model.” The estimates of baseflow were generally the same for the models.

For the larger subwatersheds, the updated model shows slightly decreased baseflow for Blue Springs Creek (-20 L/s; -5%), the Eramosa River below Wellington Road 29 (-45 L/s; -3%), and the Speed River below Guelph (-73 L/s; -2%). These are due to the model updates in the Rockwood and Dolime Quarry areas. Mill Creek at Side Road 10 had an increased baseflow (+4 L/s; 1%) due to the model updates near Aberfoyle.

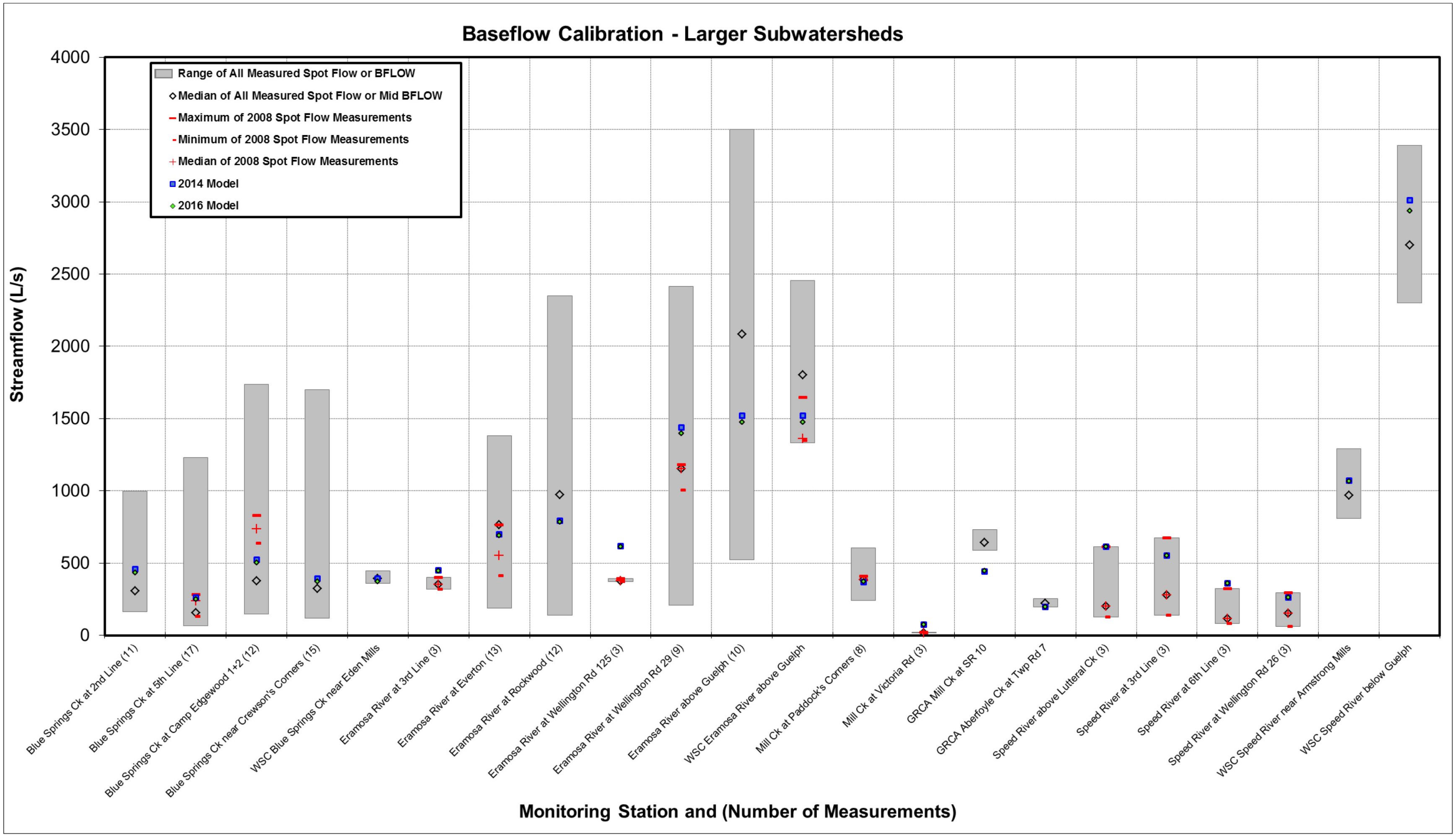

CHART 3-40 Baseflow Calibration for Larger Subwatersheds

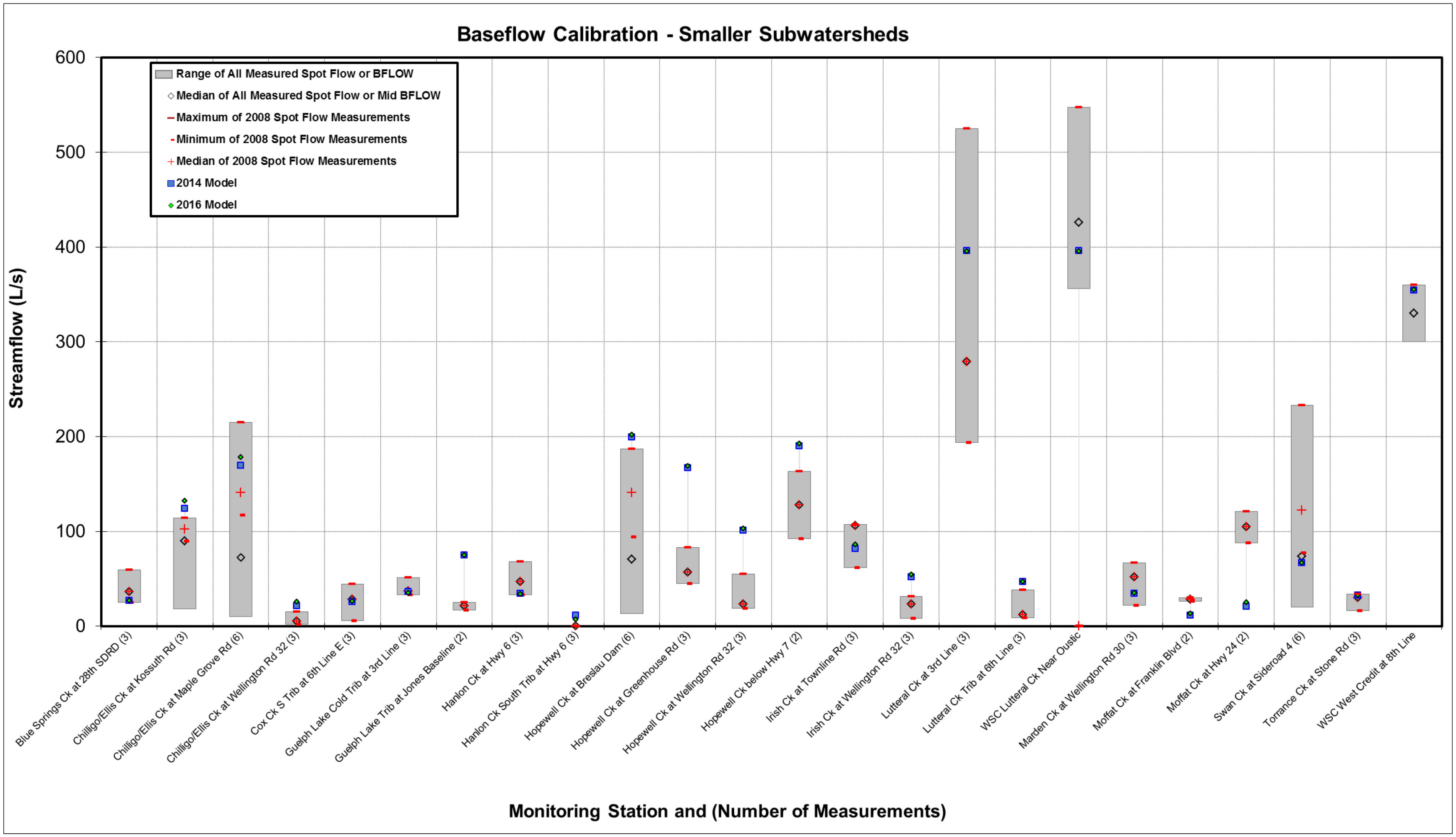

CHART 3-41 Baseflow Calibration for Smaller Subwatersheds

The smaller subwatersheds of Chilligo/Ellis, Hopewell, Irish, and Moffat Creeks had slightly increased baseflow (2 to 9 L/s) in the updated model, but are within the range of observed baseflow. Hanlon Creek South Tributary at Highway 6 was simulated to have 7 L/s baseflow, which was 36% less than the previous model (11 L/s), but this is closer to the range of observed spotflow. This change is due to the update of the model in the Dolime Quarry area.

4 SUMMARY

The groundwater flow model developed for the City of Guelph and Township of Guelph/Eramosa Tier Three Assessment was updated to ensure consistency with new conceptual and transient hydrogeologic data and interpretations in the areas of Rockwood, Aberfoyle, and the Dolime Quarry. These updates included layer elevations, mesh refinement, hydrogeologic zone distributions, material properties, relocation of boundary conditions, as well as removal, addition and refinement of pumping well locations and rates.

After incorporating the updates, the model was calibrated transiently in the areas of Rockwood Well 3, Rockwood Well 4, and Nestlé Well TW3-80, and then was assessed transiently through repetition of two longer-term verification exercises originally completed during earlier stages of the study in the City and communities of Rockwood and Hamilton Drive. The results indicate that the updated model remains suitably calibrated. The steady-state hydraulic head calibration statistics are similar to those achieved by the previous model and the simulated groundwater discharge rates agree favourably with the observed baseflow estimates. Transient calibration and verification simulations have shown the model is able to represent the response of the shallow and deeper groundwater systems to varying recharge and pumping stresses.

The updates to the model incorporated more detailed hydrogeologic characterization and resulted in an improved representation of the subsurface flow systems. This updated model is suitable for use in the Tier Three Assessment of the municipal wells of the City of Guelph and Township of Guelph/Eramosa.

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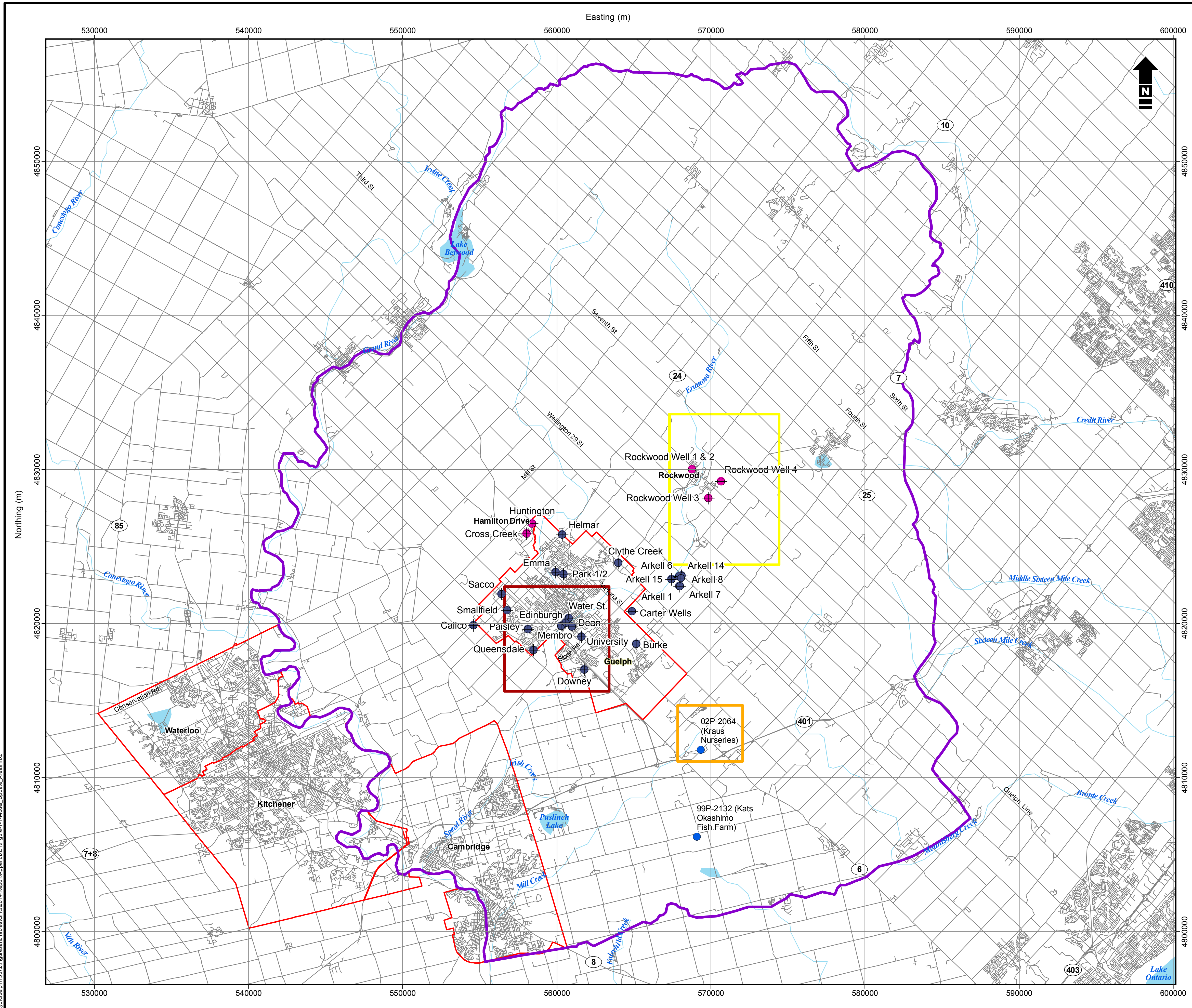
APPENDIX E1

FIGURES



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City of Guelph and Township of Guelph/Eramosa
Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Model Update Areas

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

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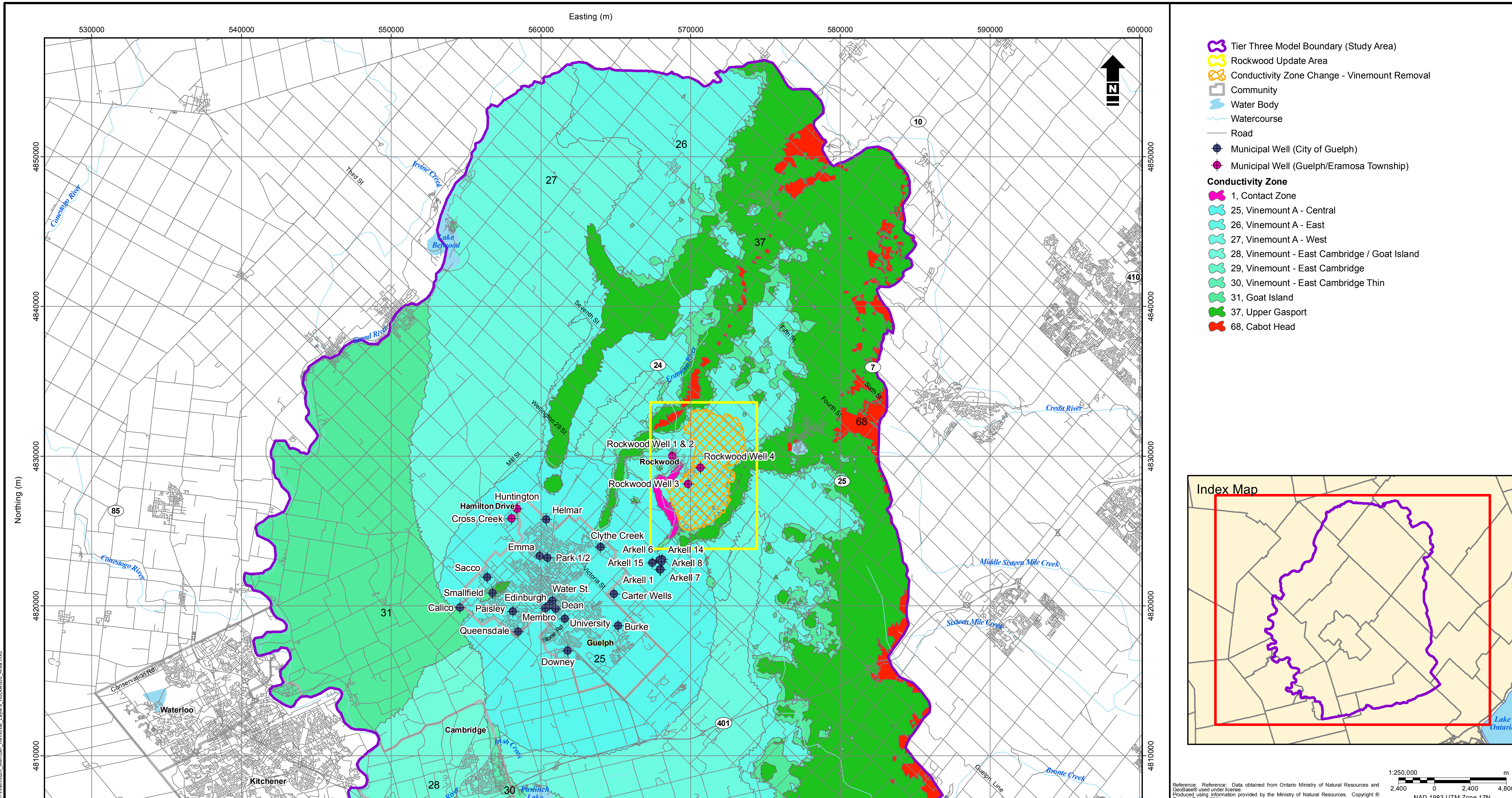
Figure 1-1



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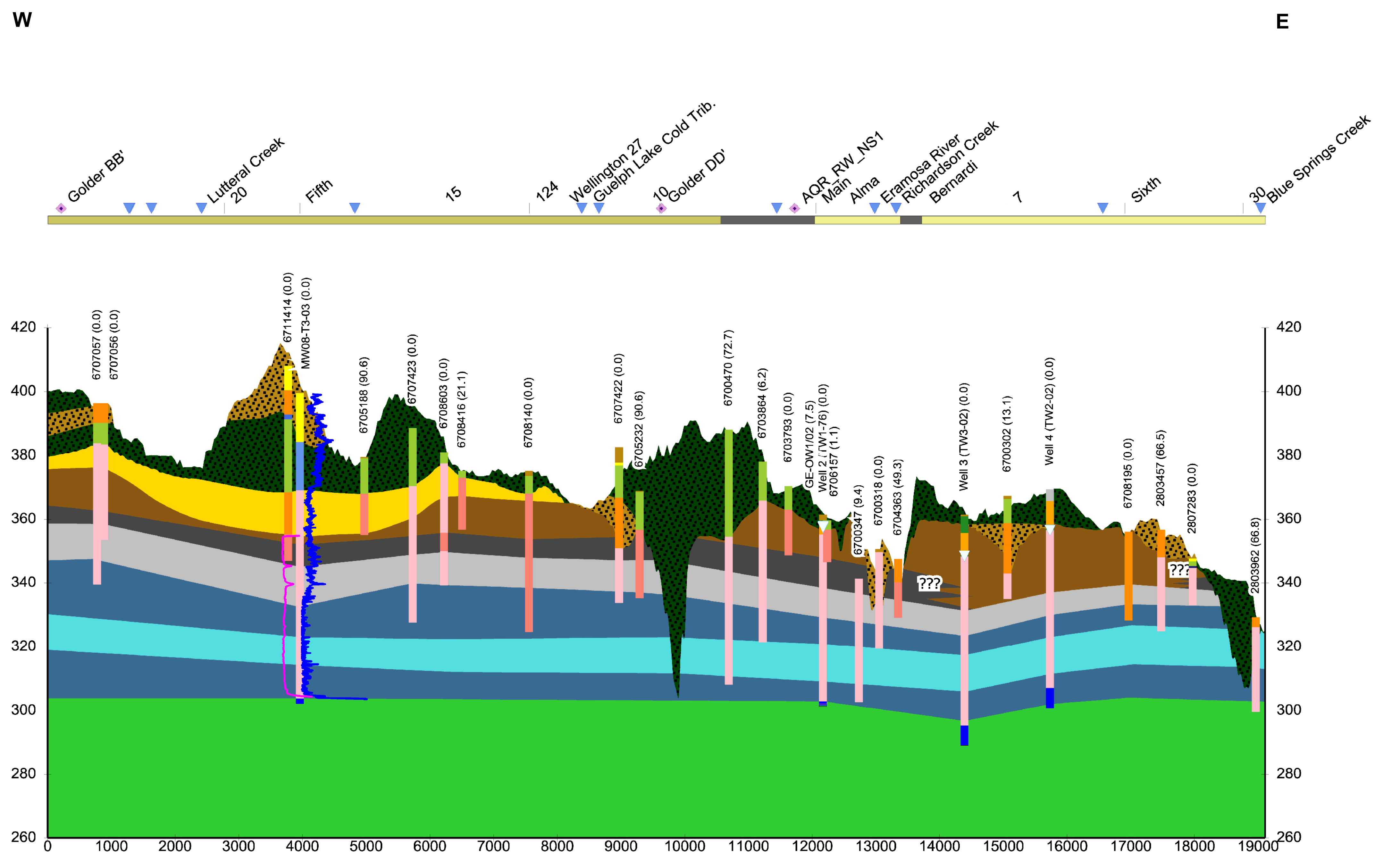
Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Vinemount Member Removal - Layer 9 - Rockwood Area

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 2-1



LEGEND

Cross-Section Intersection
- Drainage
- Road
- Cross-Section

Response Log
- Conductivity Log (first log track)
- Gamma Log (fourth log track)

Previous Interpretation(s)
- Top of Guelph Fm
- Top of Eramosa Fm (Reformatory Quarry Mbr or Stone Road Member)
- Top of Eramosa Fm (Vinemount Member)
- Top of Goat Island Fm (Ancaster or Niagara Falls Mbrs)
- Top of Amabel Fm/Gasport Fm
- Top of Cabot Head Fm
- Top of Irondequot, Merriton, or Rockway Fms
- Top of Queenston Fm

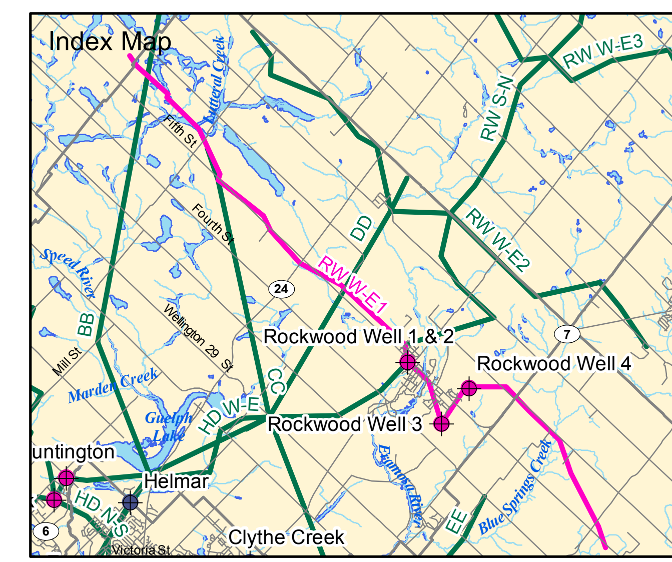
- Ground Surface, Top of Bedrock Surface

Bedrock Supcrop (Armstrong and Dodge, 2007) (along top of section)
- Amabel Fm/Gasport Fm
- Eramosa Fm
- Guelph Fm

Borehole Lithology (third log track)
- Clay, silty clay
- Silt, clayey silt, sandy silt
- Diamict, cl/si matrix
- Diamict, si/sa matrix
- Sand, silty sand
- Gravel, gravelly sand
- Organic
- Fill, topsoil
- Limestone, dolostone
- Limestone, Shale
- Shale
- Undifferentiated bedrock
- Unknown

Hydraulic Conductivity (Kh) Estimate from Field Test (m/s) (second log track)
- <1E-8
- 1E-8...1E-7
- 1E-7...1E-6
- 1E-6...1E-5
- 1E-5...1E-4
- 1E-4...1E-3
- >1E-3

Hydrostratgraphic Unit
- Overburden, Coarse
- Overburden, Fine
- Contact Aquifer
- Guelph Fm (including Stone Road Mbr of Eramosa Fm)
- Reformatory Quarry
- Eramosa Fm, Vinemount Mbr
- Goat Island Fm
- upper/lower Gasport Fm, Irondequit Fm, Rockway Fm, and Merriton Fm
- middle Gasport Fm
- Cabot Head Fm



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Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Rockwood Cross-Section: West-East 1

Date:	Project:	Technical:	Reviewer:	Drawn:
08 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure
2-2

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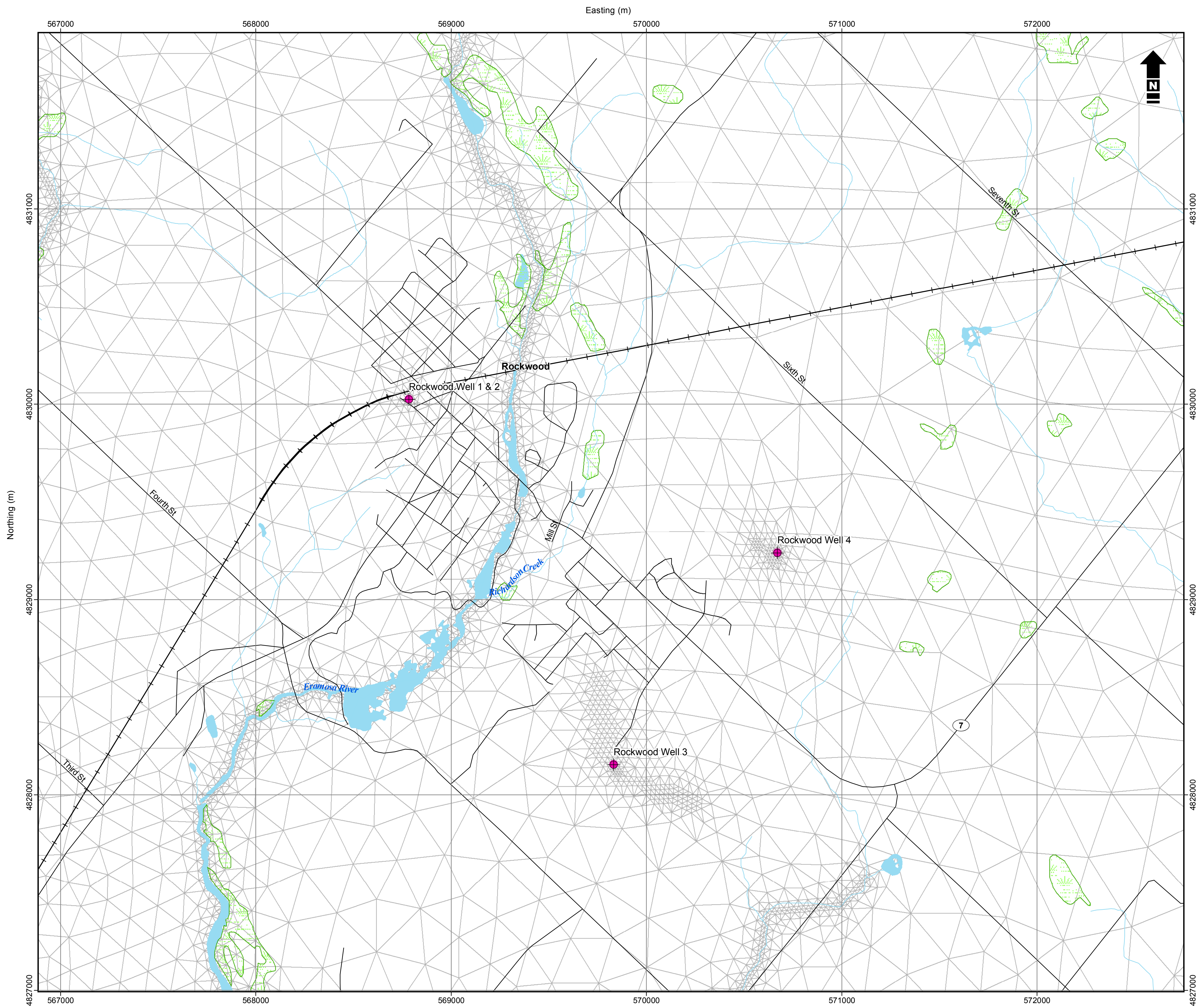
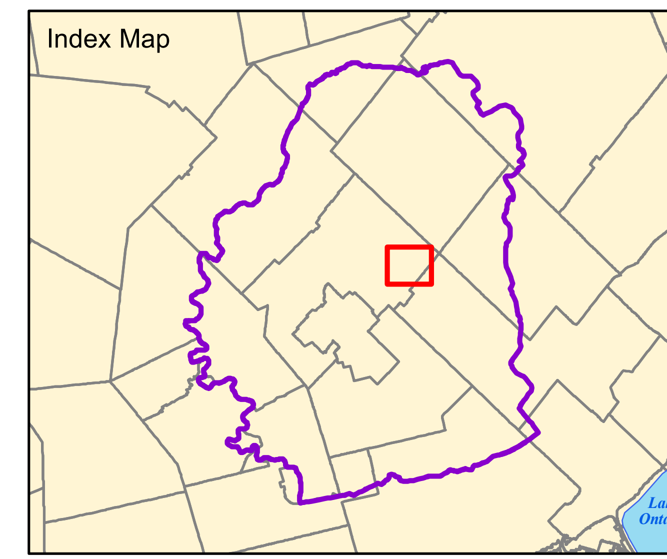


Updated Mesh
Wetland
Water Body
Watercourse
Road
Railroad
Municipal Well (Guelph/Eramosa Township)



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NAD 1983 UTM Zone 17N

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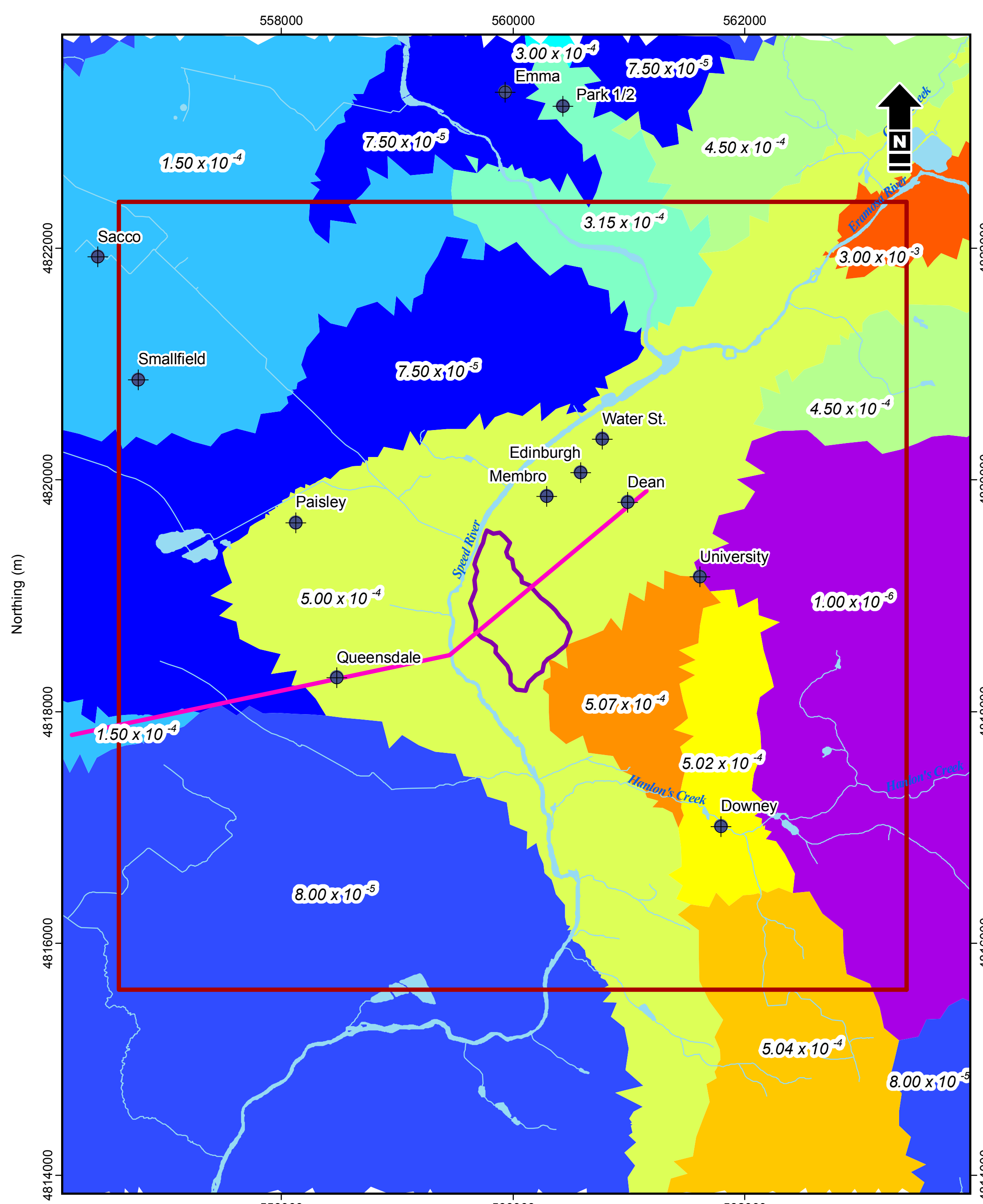
Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Mesh Refinement Around Rockwood Wells

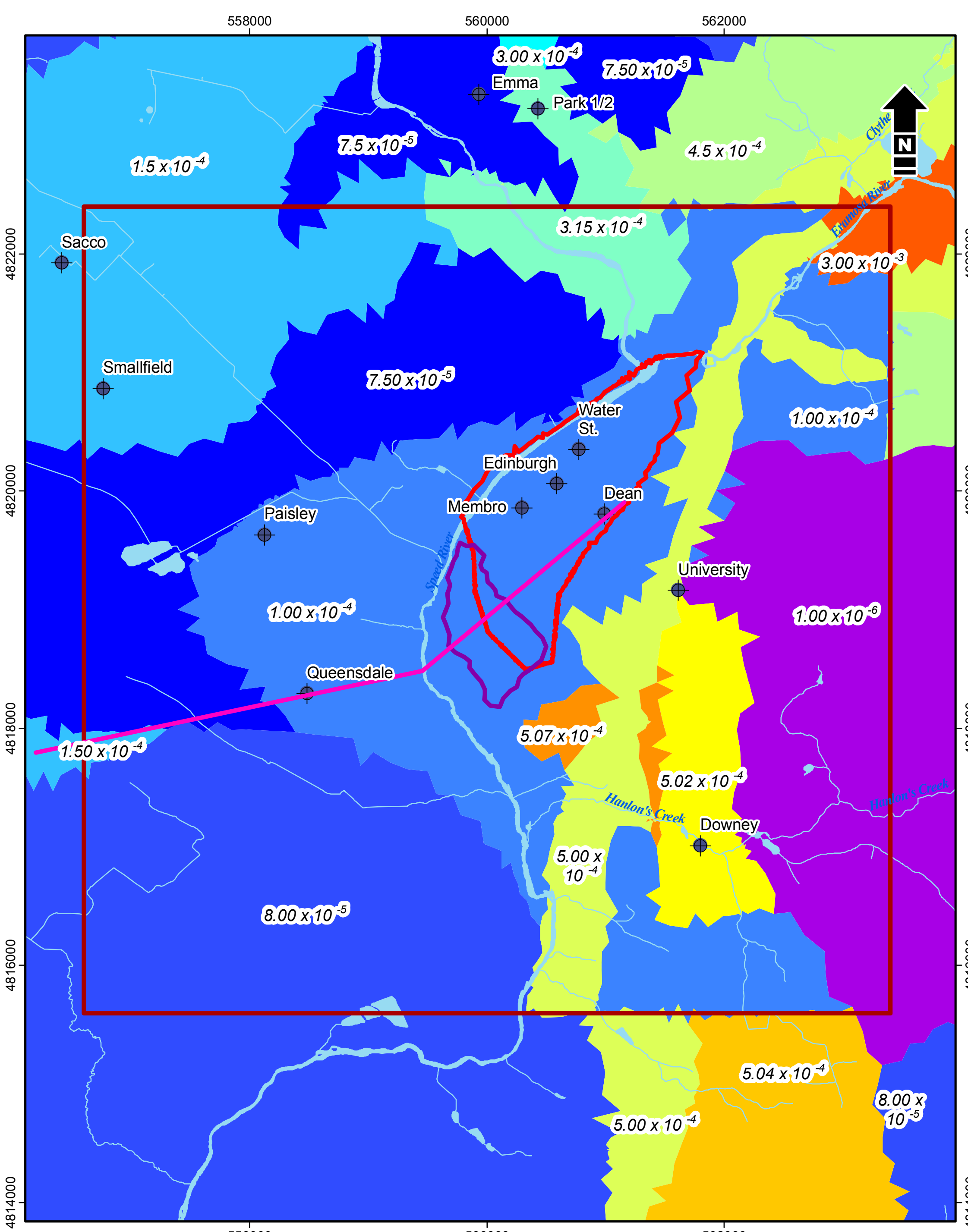
Date: 08 Mar 2017	Project: 15072	Technical: J. Melchin	Reviewer: P. Chin	Drawn: C. Curry

Figure 2-3

Easting (m)



Middle Gasport Formation - Previous

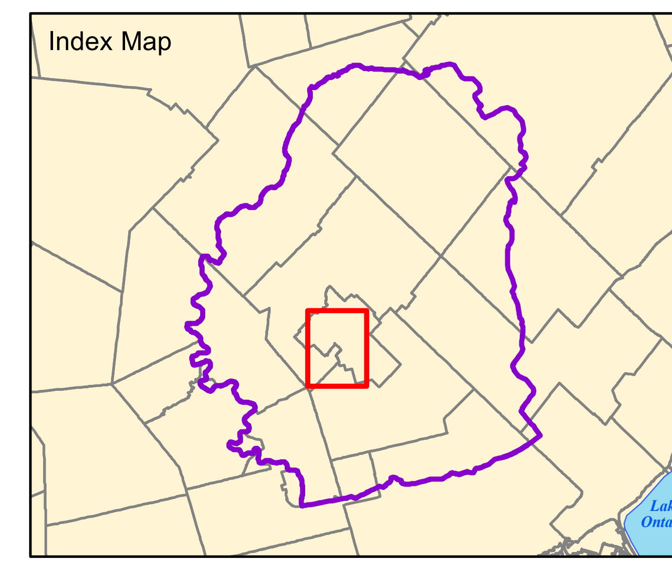


Middle Gasport Formation - Updated

- Quarry Update Area
- Surficial Expression of Quarry
- Planer Fracture Zone
- Surfical Expression of Water Body
- Surfical Expression of Watercourse
- Conceptual Regional Cross-Section
- Municipal Well (City of Guelph)

Horizontal Hydraulic Conductivity (m/s)

- 3.00×10^{-3}
- 5.07×10^{-4}
- 5.04×10^{-4}
- 5.02×10^{-4}
- 5.00×10^{-4}
- 4.50×10^{-4}
- 3.15×10^{-4}
- 3.00×10^{-4}
- 1.50×10^{-4}
- 1.00×10^{-4}
- 8.00×10^{-5}
- 7.50×10^{-5}
- 1.00×10^{-6}



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Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Quarry Update Area - Middle Gasport Formation Comparison

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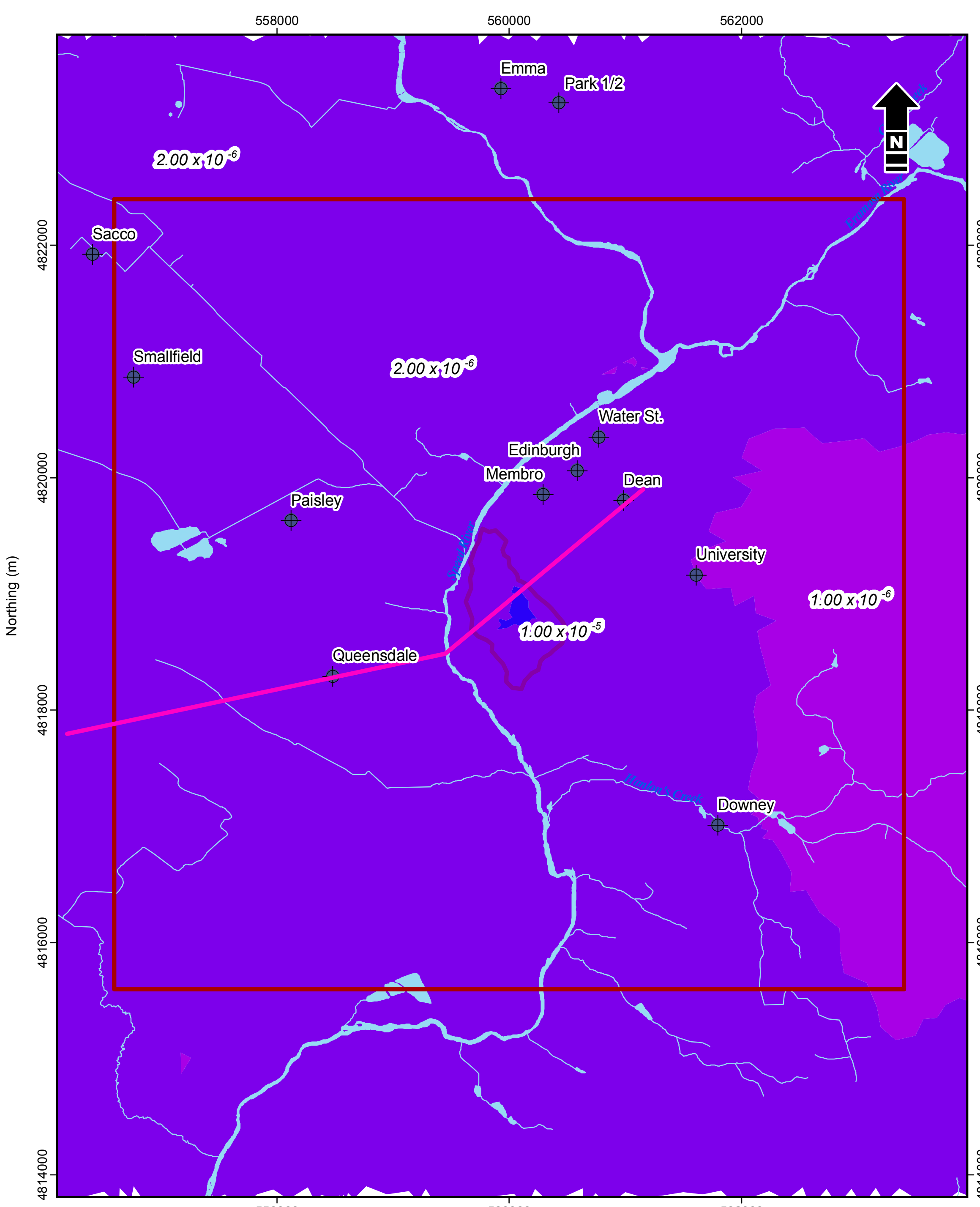
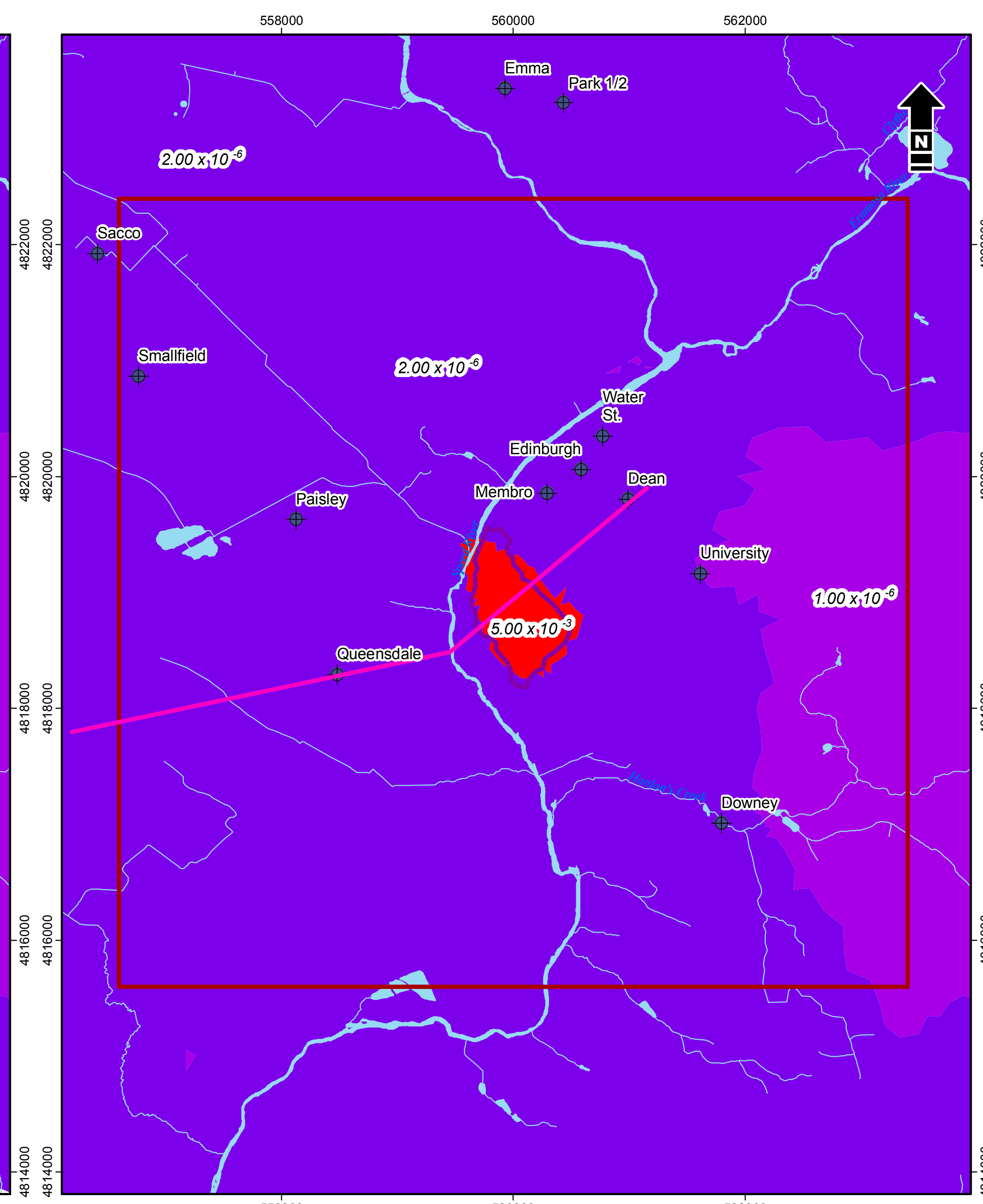
17 Jan 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 2-4

Easting (m)



Upper Gasport Formation - Previous

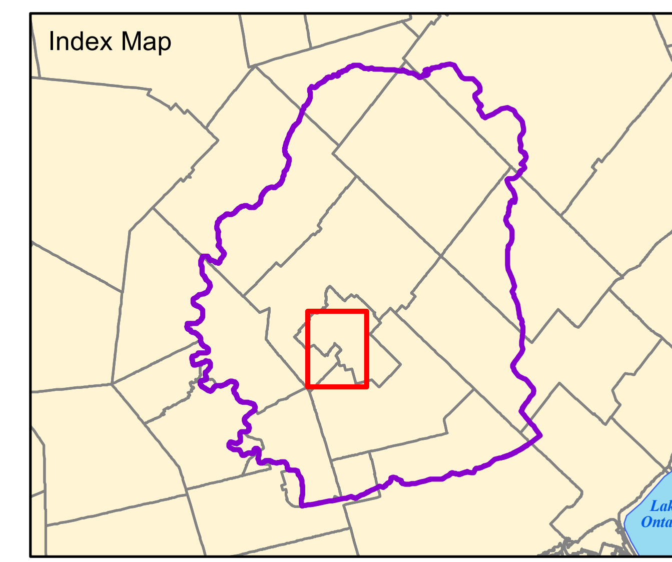


Upper Gasport Formation - Updated

- Quarry Update Area
- Surficial Expression of Quarry
- Surfical Expression of Water Body
- Surfical Expression of Watercourse
- Conceptual Regional Cross-Section
- Municipal Well (City of Guelph)

Horizontal Hydraulic Conductivity (m/s)

- 5.00×10^{-3}
- 1.00×10^{-5}
- 2.00×10^{-6}
- 1.00×10^{-6}



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Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Quarry Update Area - Upper Gasport Formation Comparison

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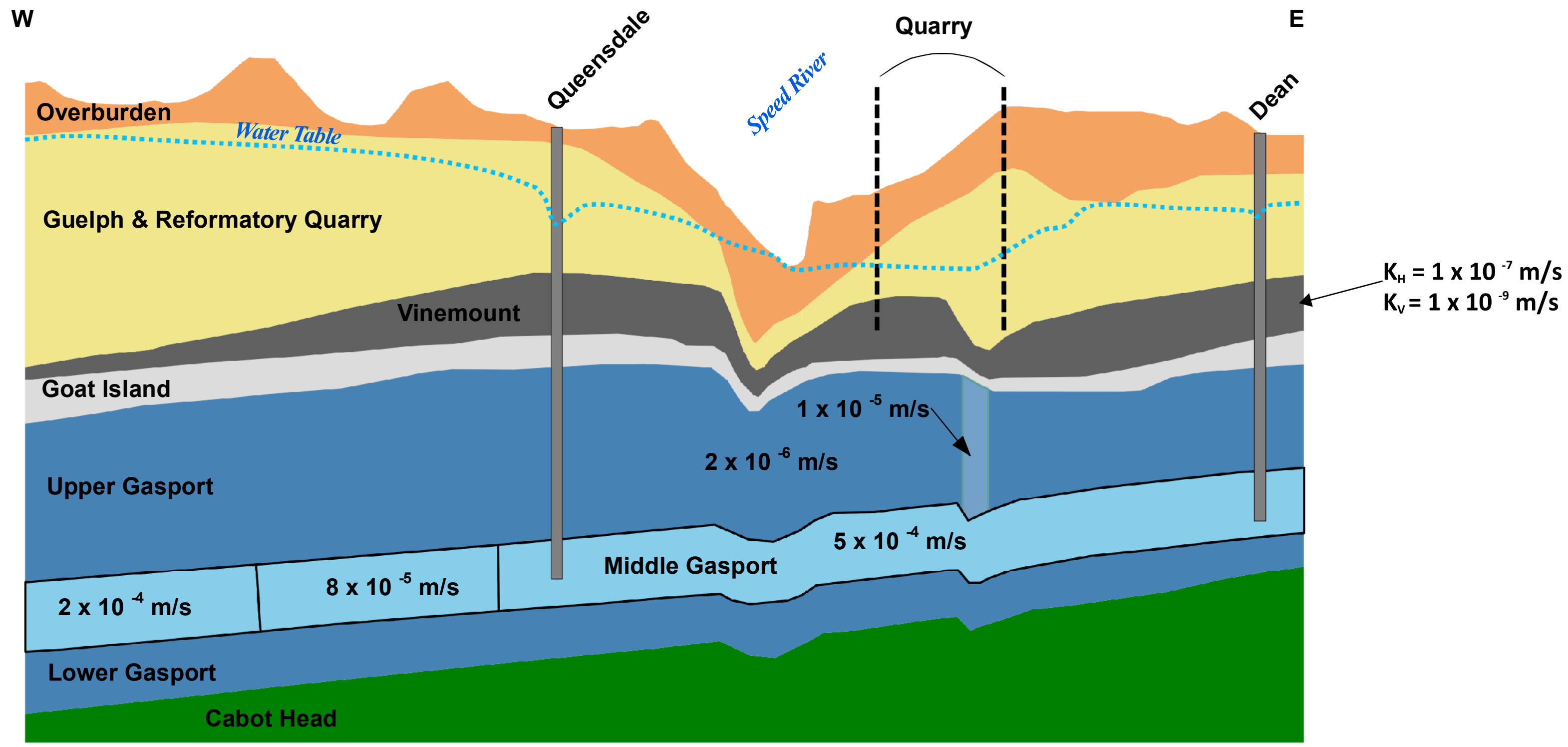
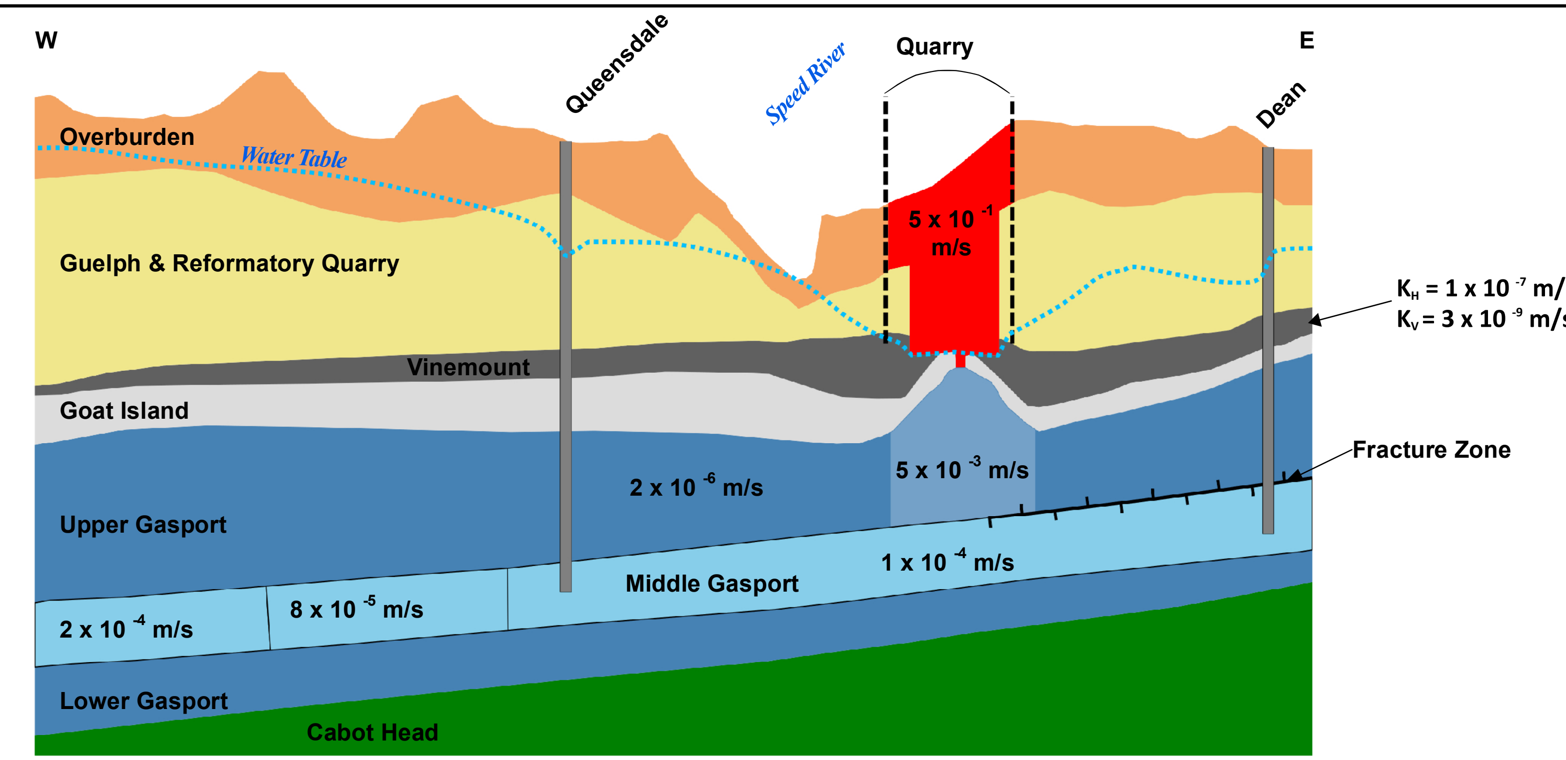
17 Jan 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 2-5

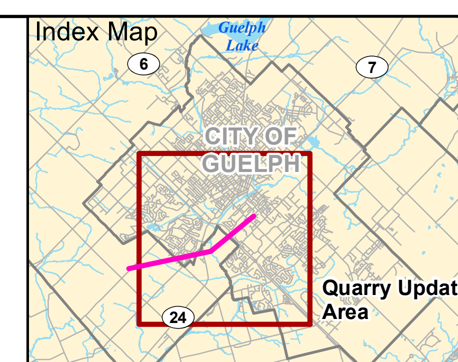
Regional Conceptual Cross Section - Previous



Regional Conceptual Cross Section - Updated



NOTE: *Hydraulic Conductivity Values = Kh (m/s) (unless otherwise indicated)*



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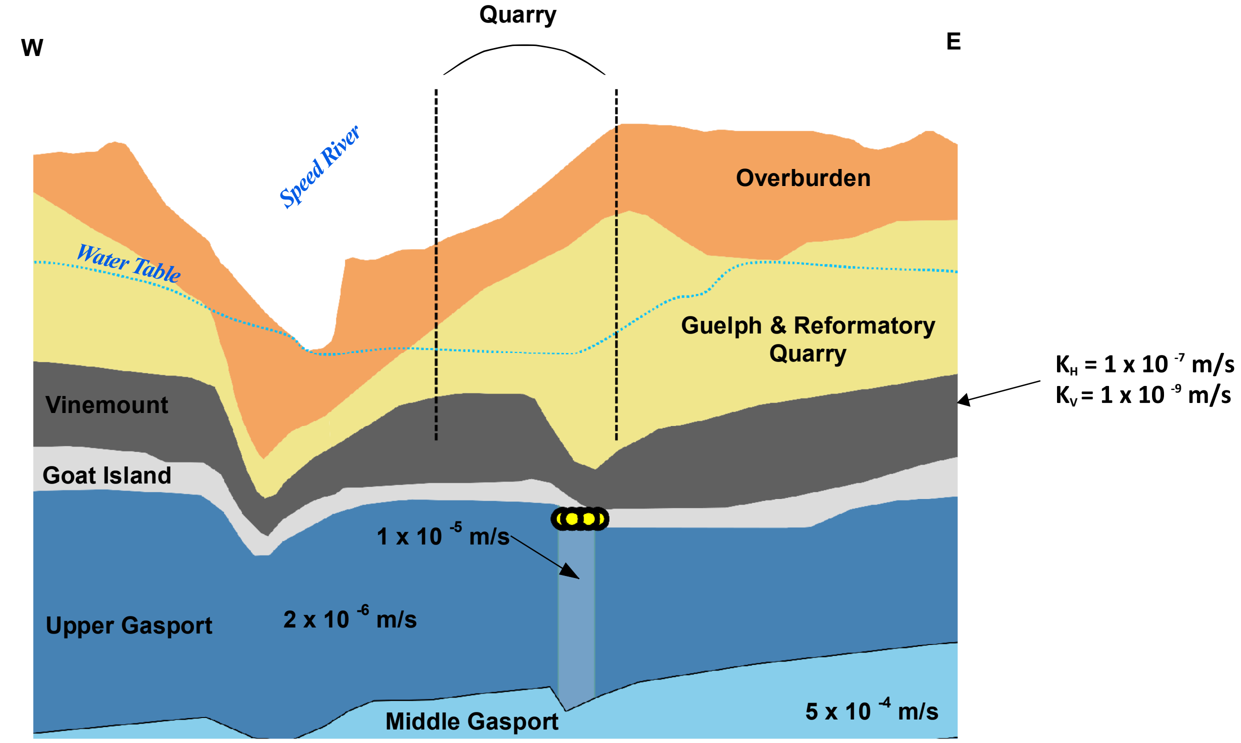
Appendix E1

Quarry Update Area - Regional Conceptual Cross-Section Comparison

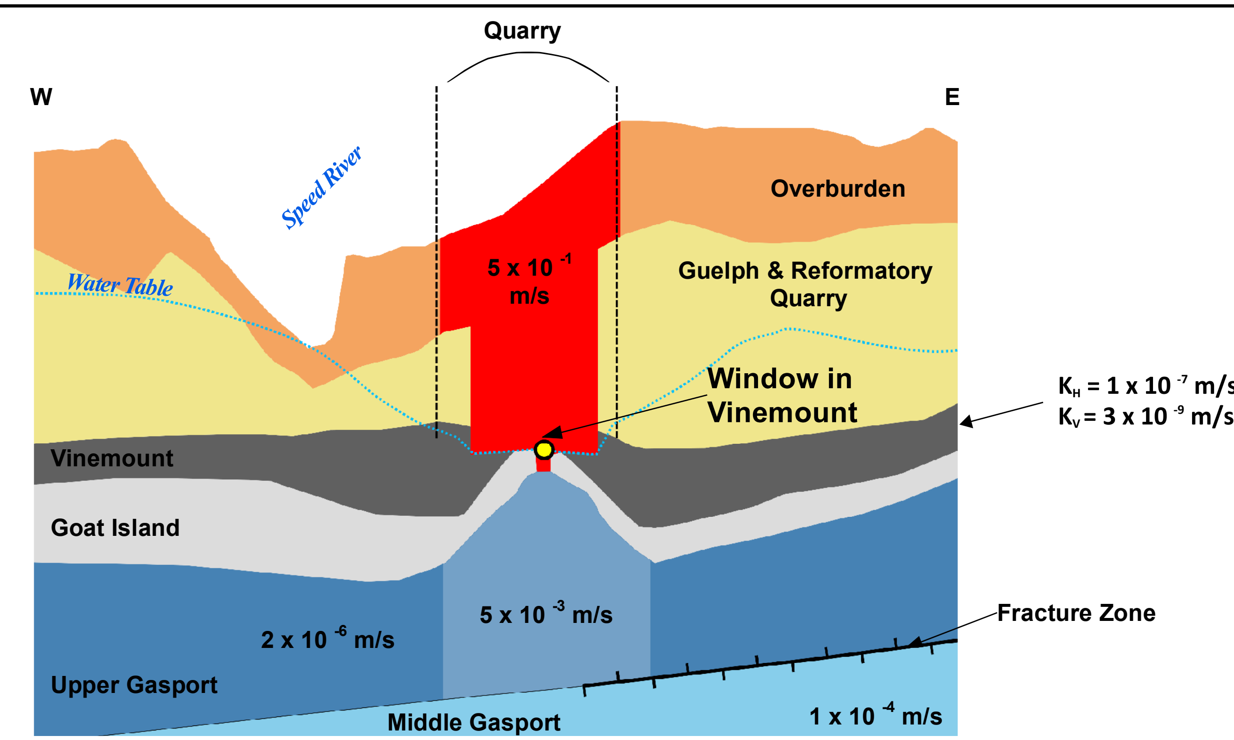
Date:	Project:	Technical:	Reviewer:	Drawn:
17 Jan 2017	15072	J. Melchin	P. Chin	C. Curry

Figure
2-6

Local Conceptual Cross Section - Previous

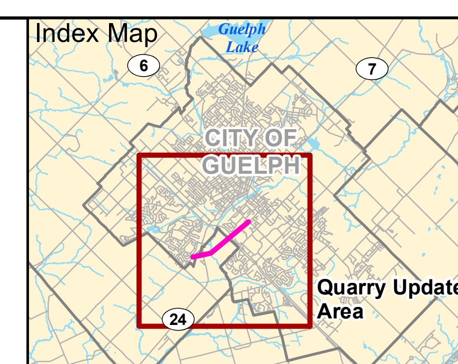


Local Conceptual Cross Section - Updated



Constant Head Boundary Condition Representing Quarry Pond Sump Elevation

NOTE: *Hydraulic Conductivity Values = Kh (m/s) (unless otherwise indicated)*



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Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Quarry Update Area - Local Conceptual Cross-Section Comparison

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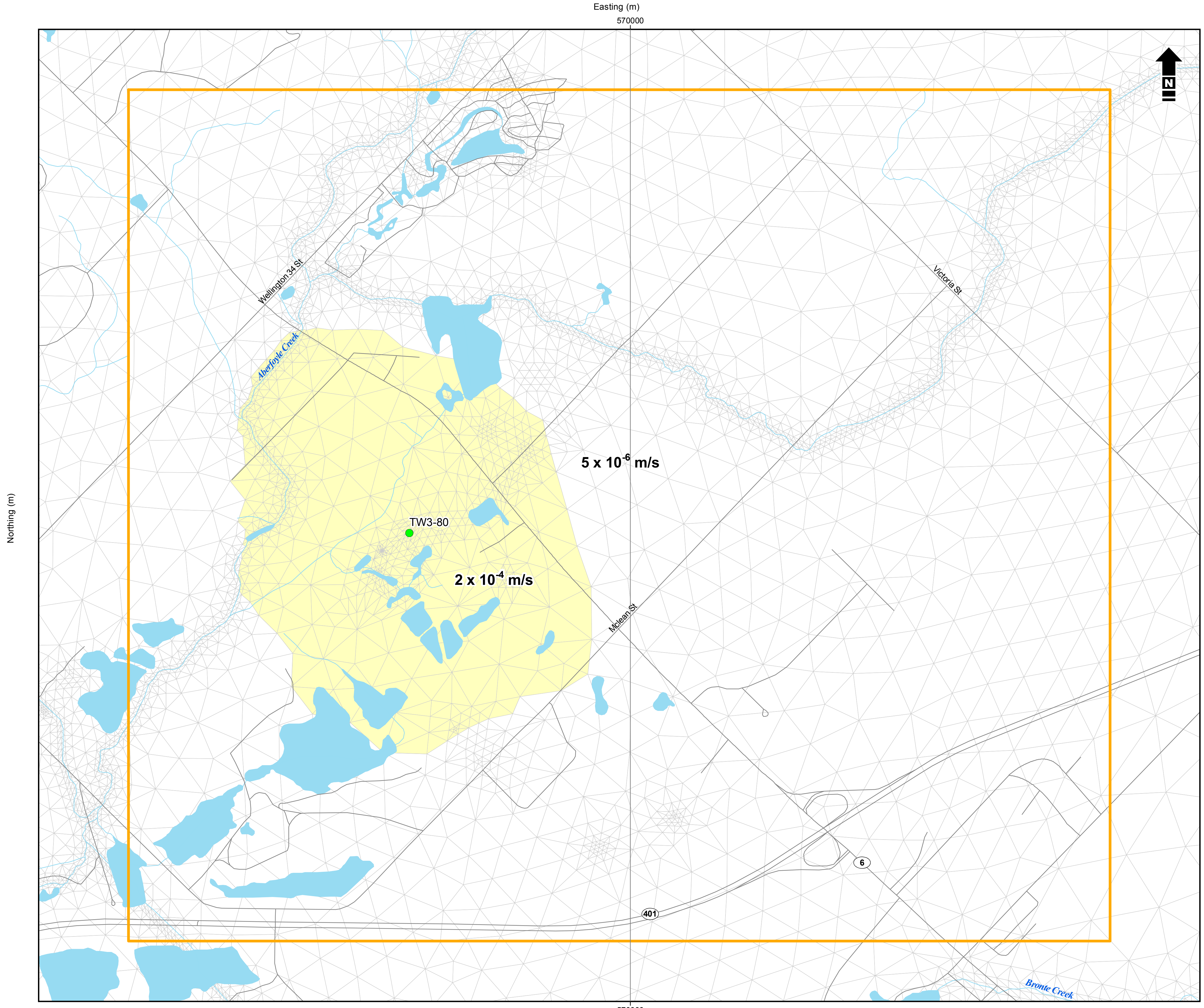
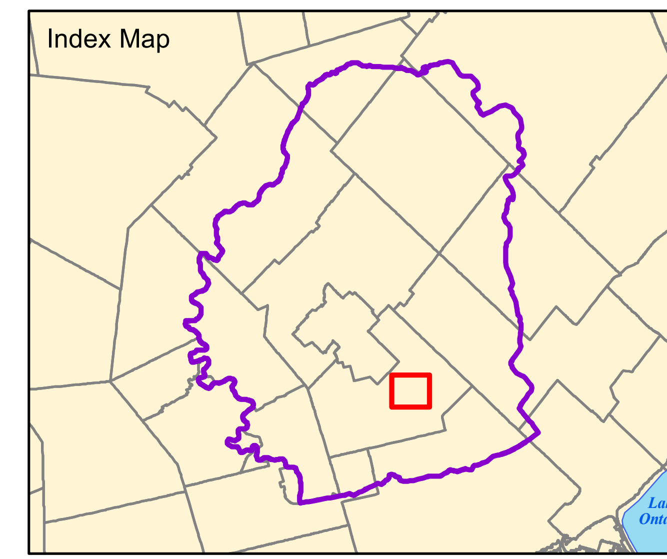
Figure 2-7



Updated Mesh
Aberfoyle Update Area
Water Body
Watercourse
Road
Nestle Well

Horizontal Hydraulic Conductivity (m/s)

5×10^{-6}
2×10^{-4}



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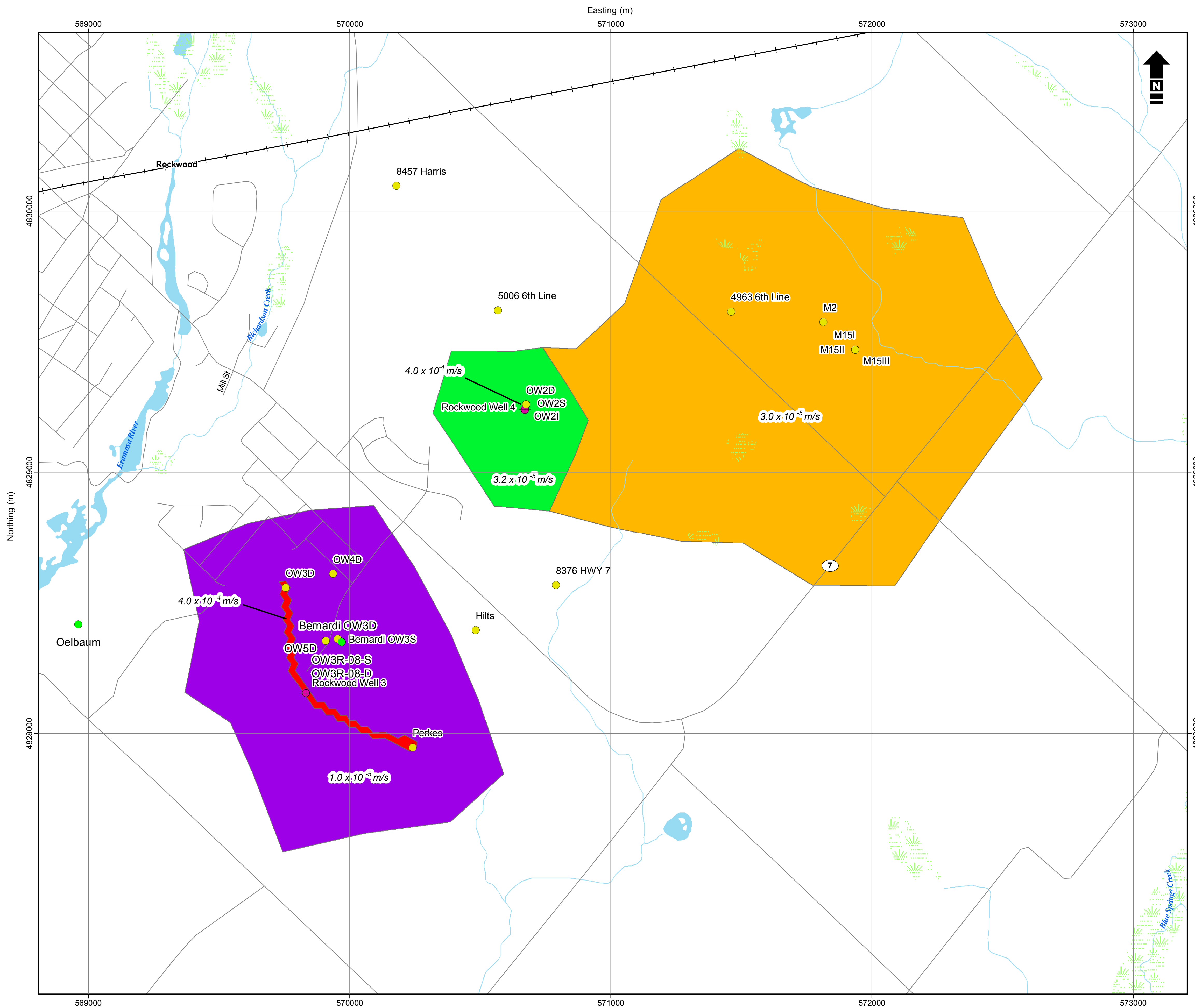
Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Aberfoyle Update Area and Hydraulic Conductivity Updates - Layer 10

Date:	Project:	Technical:	Reviewer:	Drawn:
17 Jan 2017	15072	J. Melchin	P. Chin	C. Curry

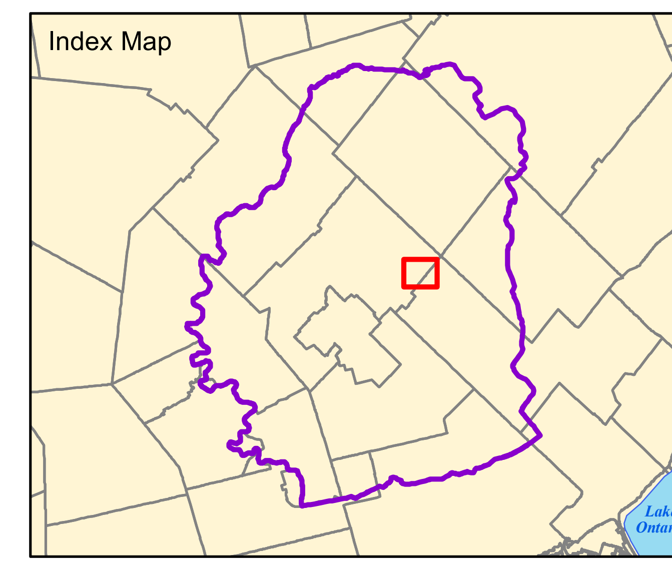
Figure 2-8



Wetland
Water Body
Watercourse
Road
Railroad
Municipal Well (Guelph/Eramosa Township)
Monitoring Well
Pumping Test Monitoring Well

Horizontal Hydraulic Conductivity (m/s)

- 4.0×10^{-4}
- 3.2×10^{-5}
- 3.0×10^{-5}
- 1.0×10^{-5}



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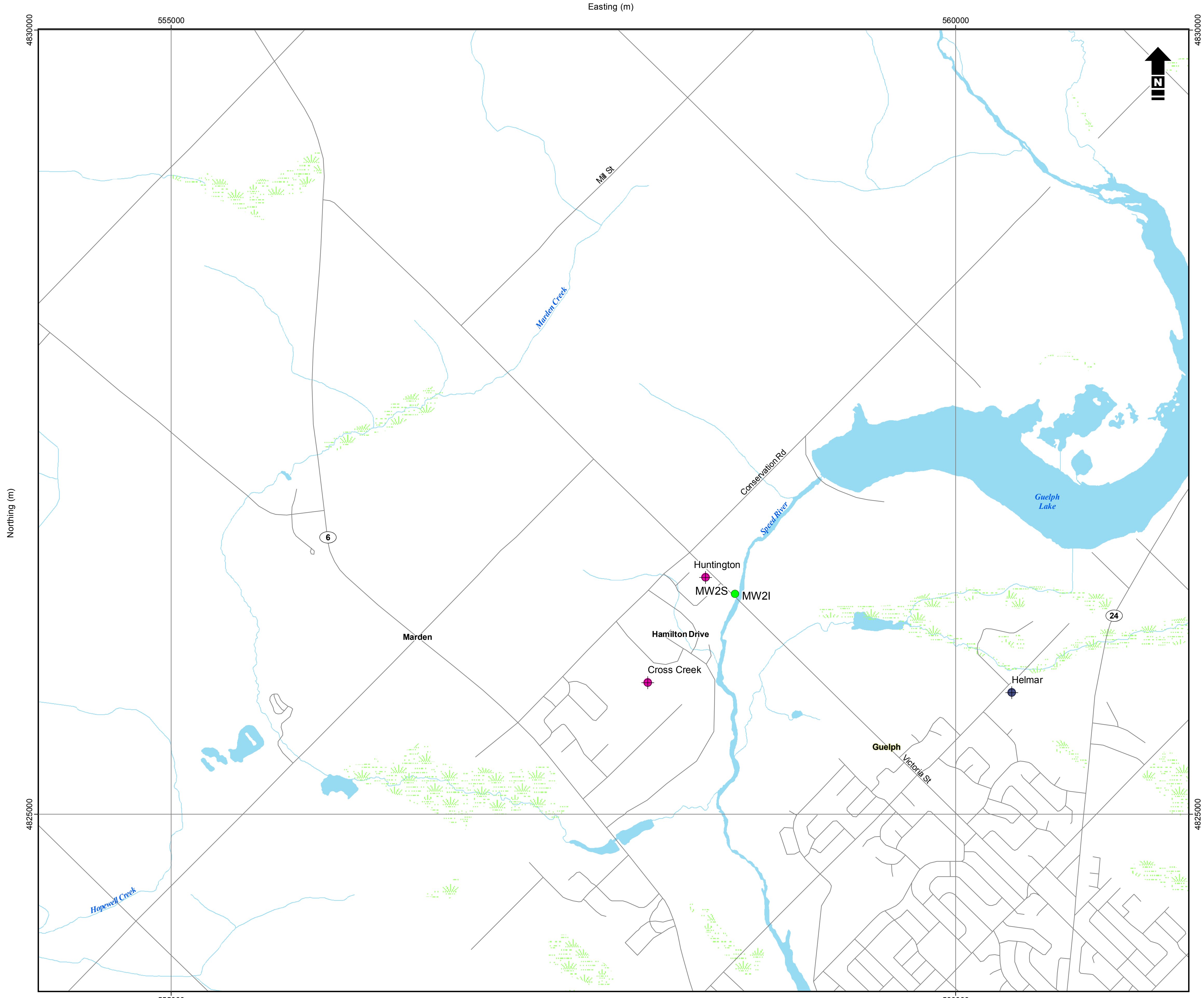
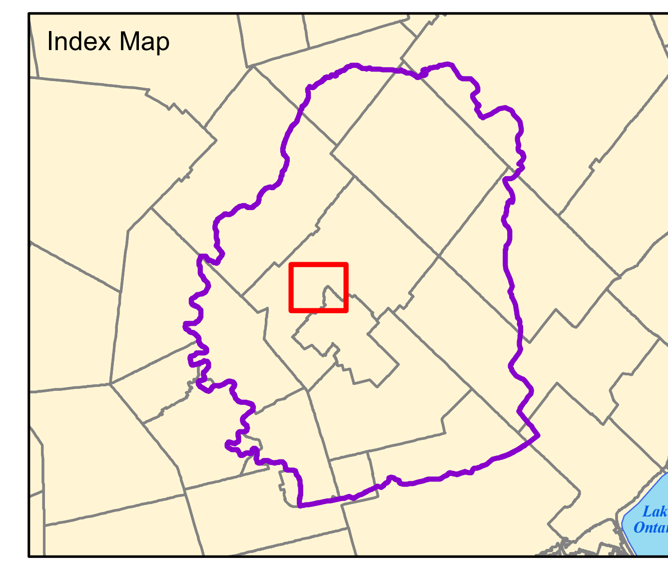
Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Hydraulic Conductivity Updates - Rockwood Layer 12

Date:	Project:	Technical:	Reviewer:	Drawn:
10 Mar 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 3-1





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Tier Three Water Budget and Local Area Risk Assessment
Appendix E1

Long Term Verification Monitors - Hamilton Drive

Date:	Project:	Technical:	Reviewer:	Drawn:
17 Jan 2017	15072	J. Melchin	P. Chin	C. Curry

Figure 3-2

Appendix E2

City of Guelph Transient Verification Results

Hydraulic Head - Municipal Wells

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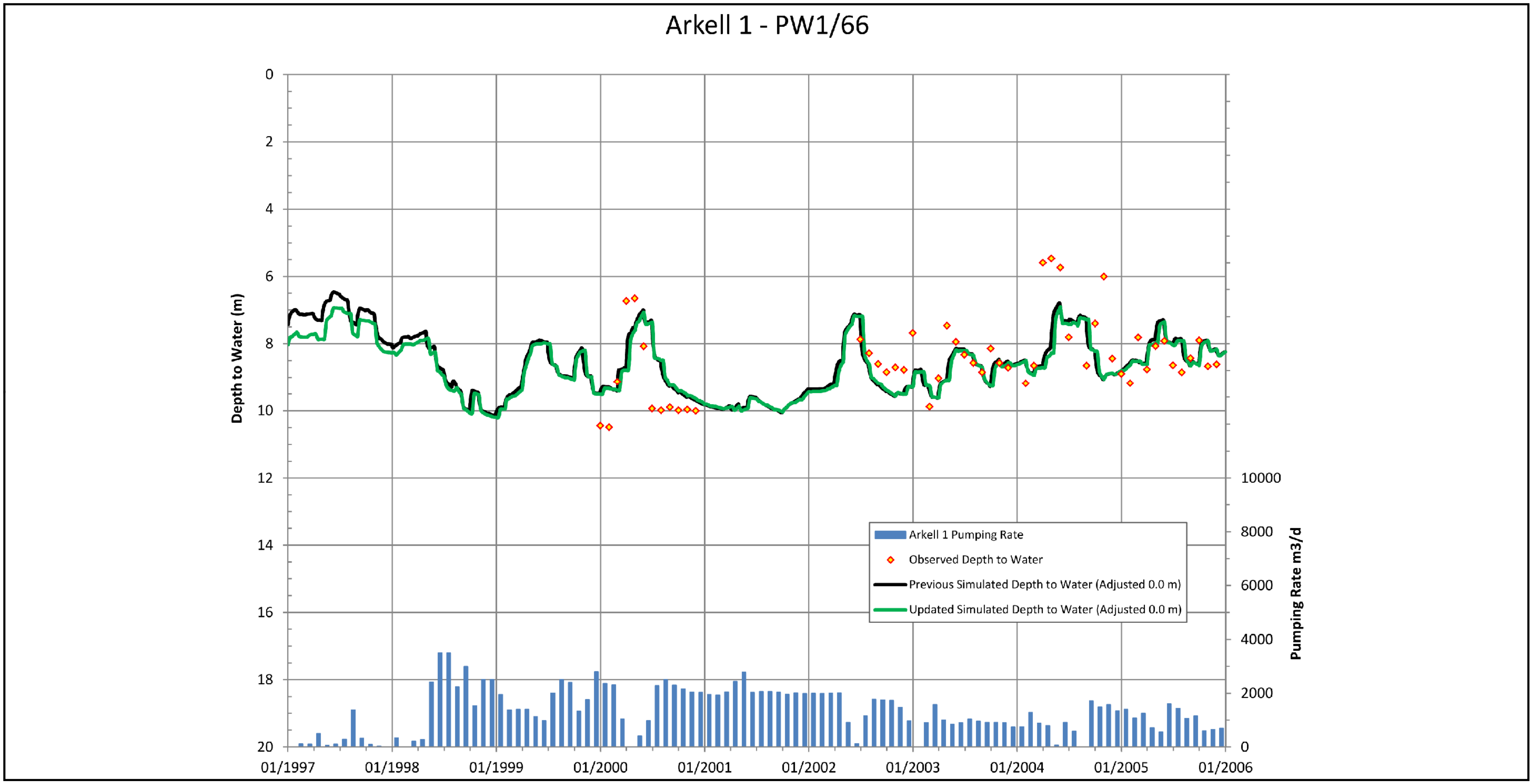

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 1

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.1

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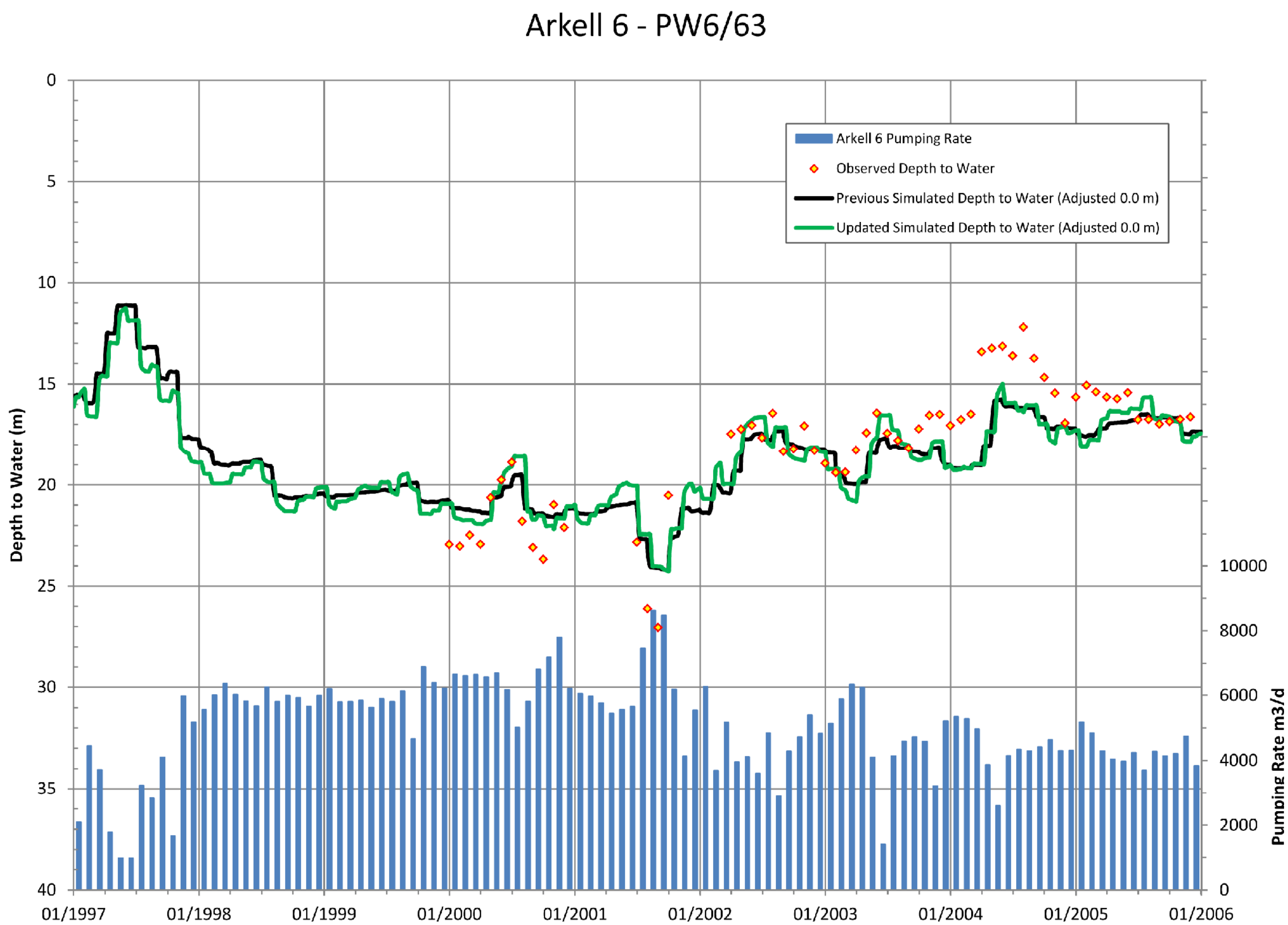

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 6

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.2

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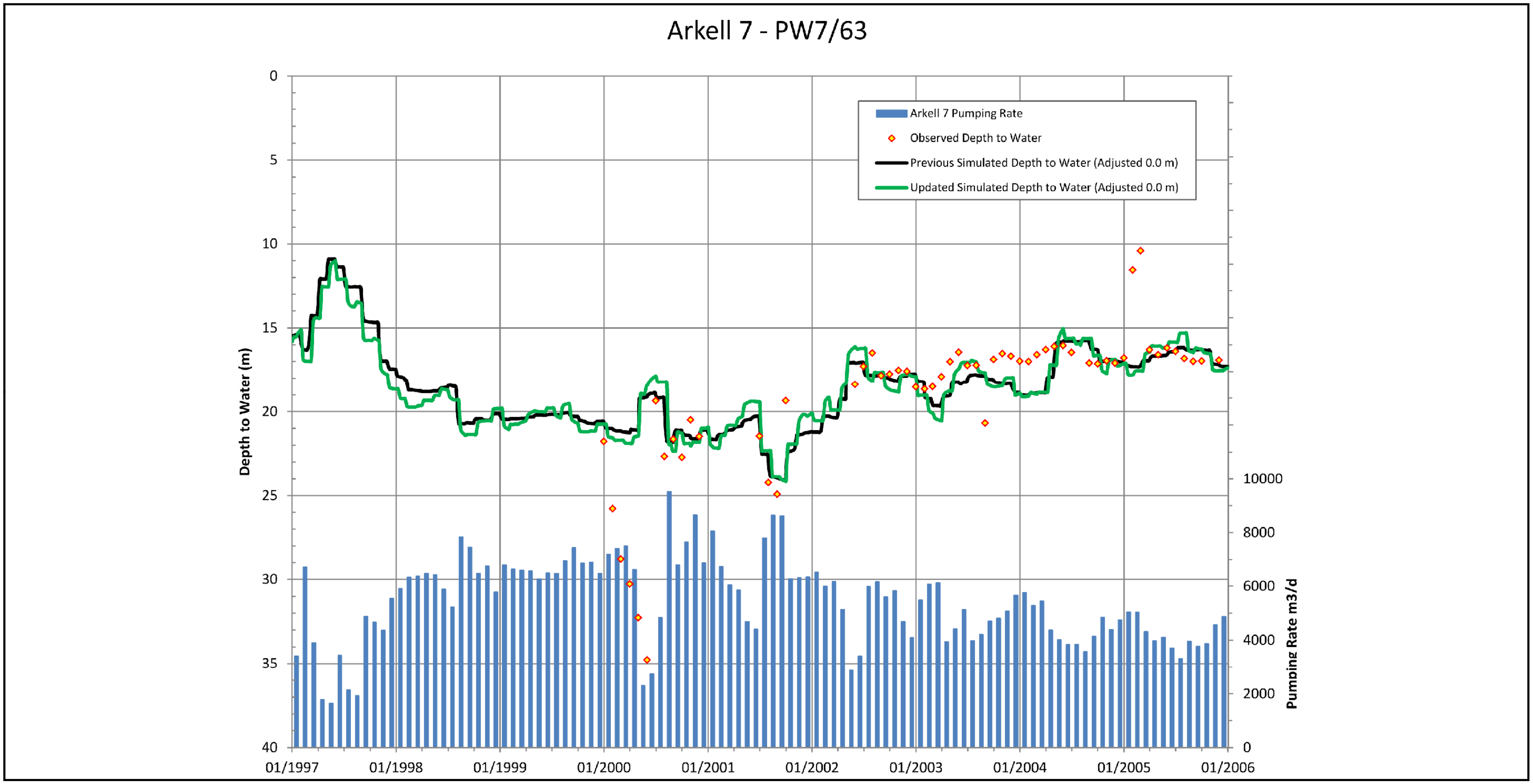

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 7

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.3

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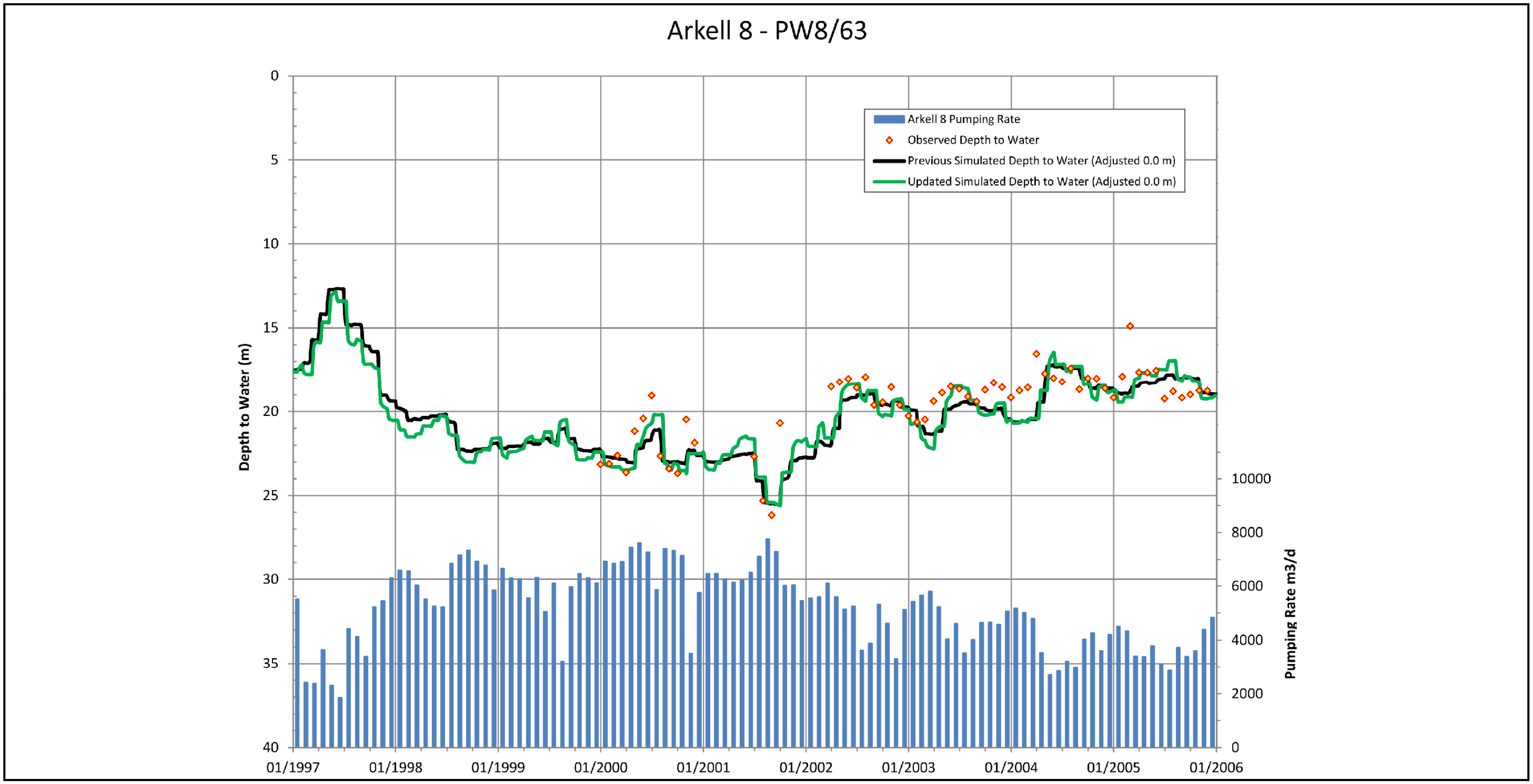

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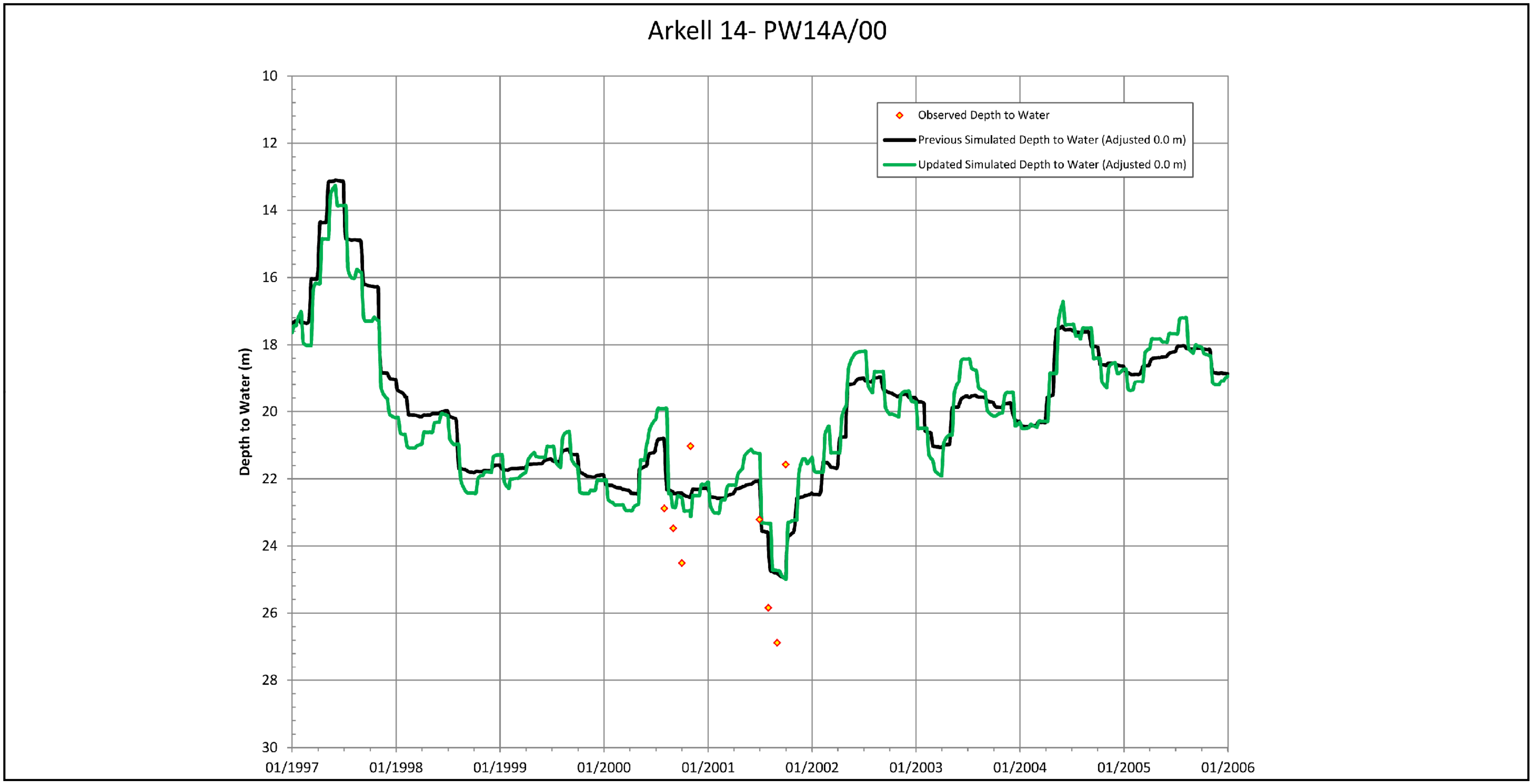
City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 8

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.4



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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 14

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.5

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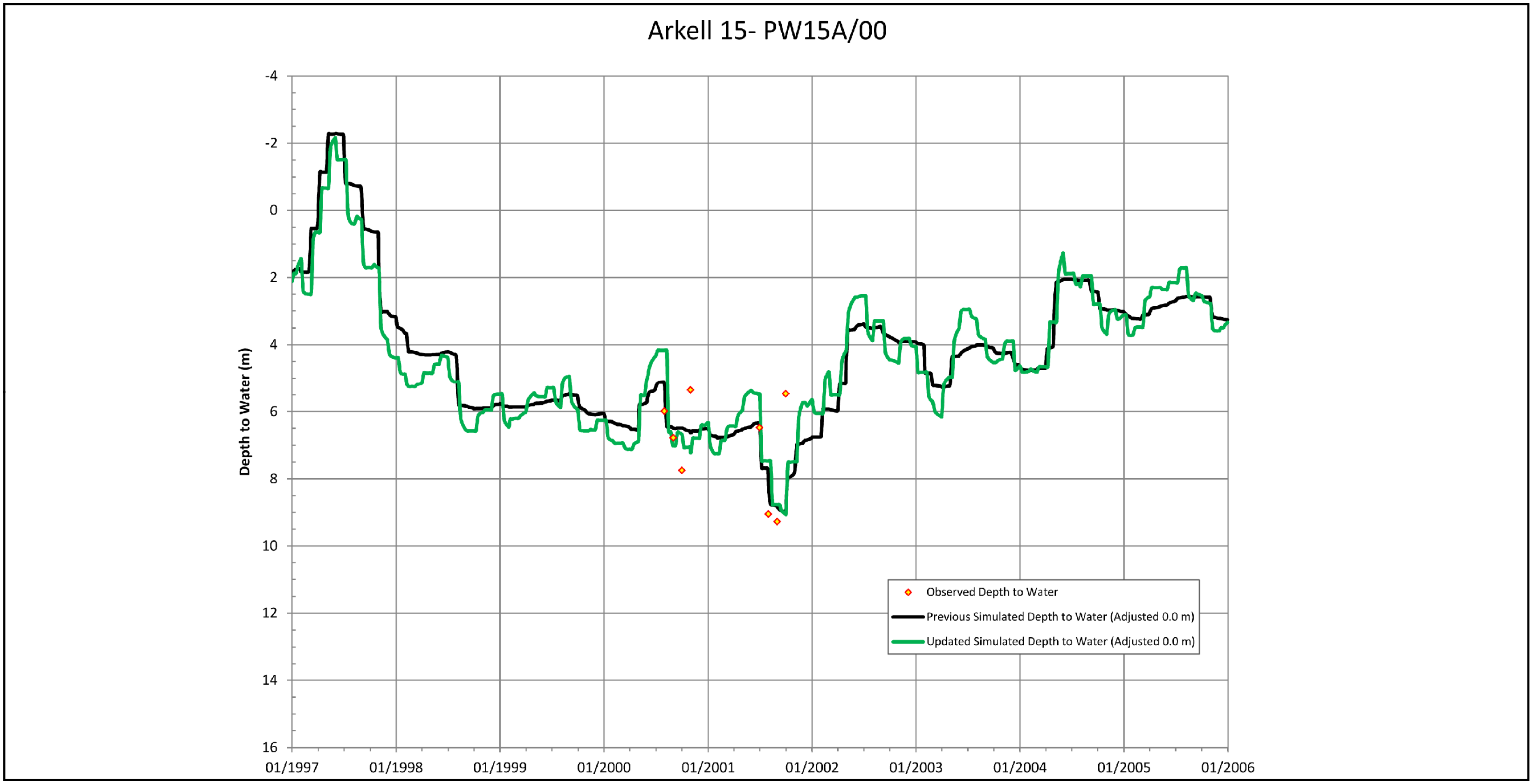

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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Arkell 15

Date:	Project:	Technical:	Reviewer:	Drawn:
04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.6

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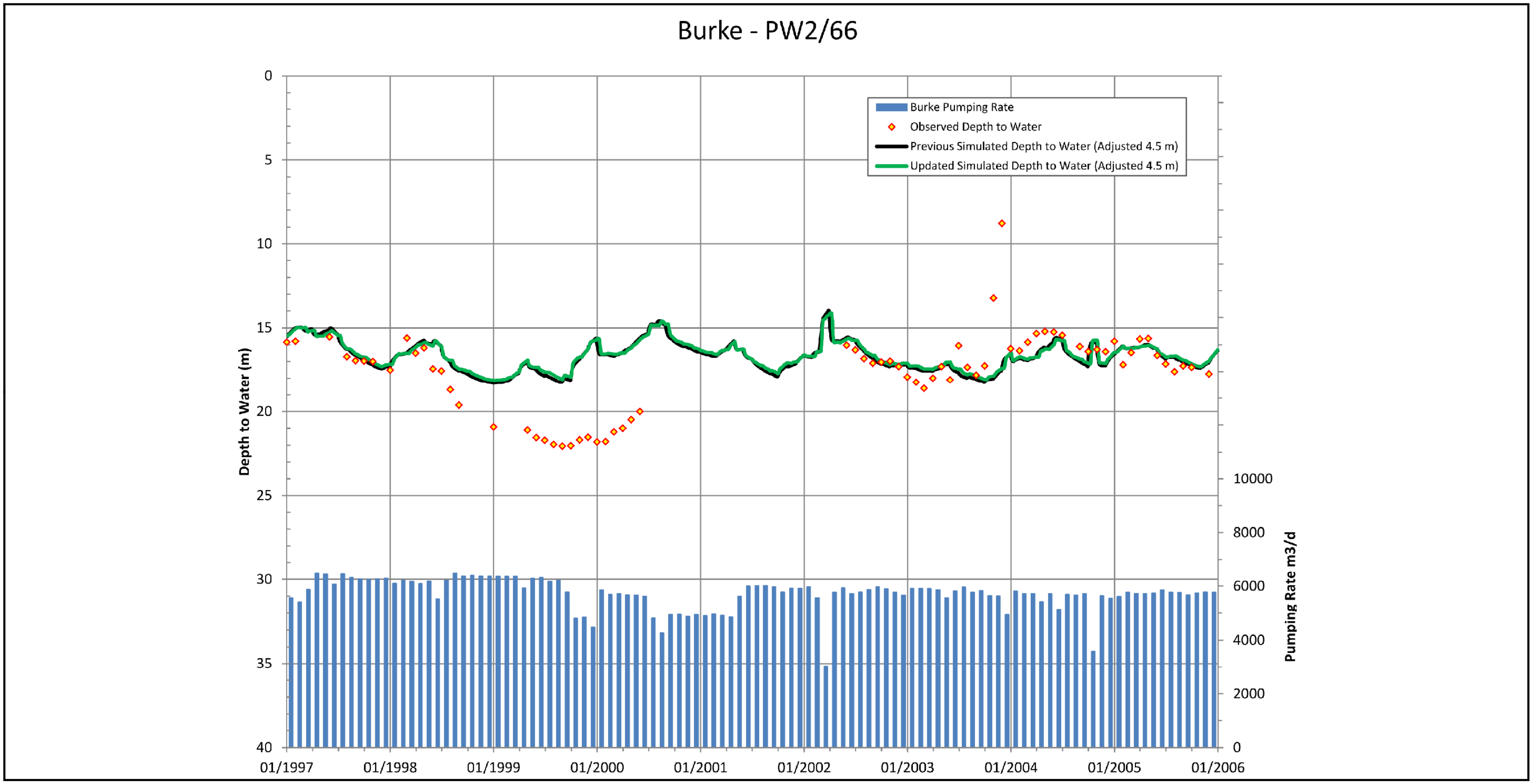

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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Burke

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04 Jul 2016	15072	J. Melchin	P. Chin	C. Curry

Figure
E2.7

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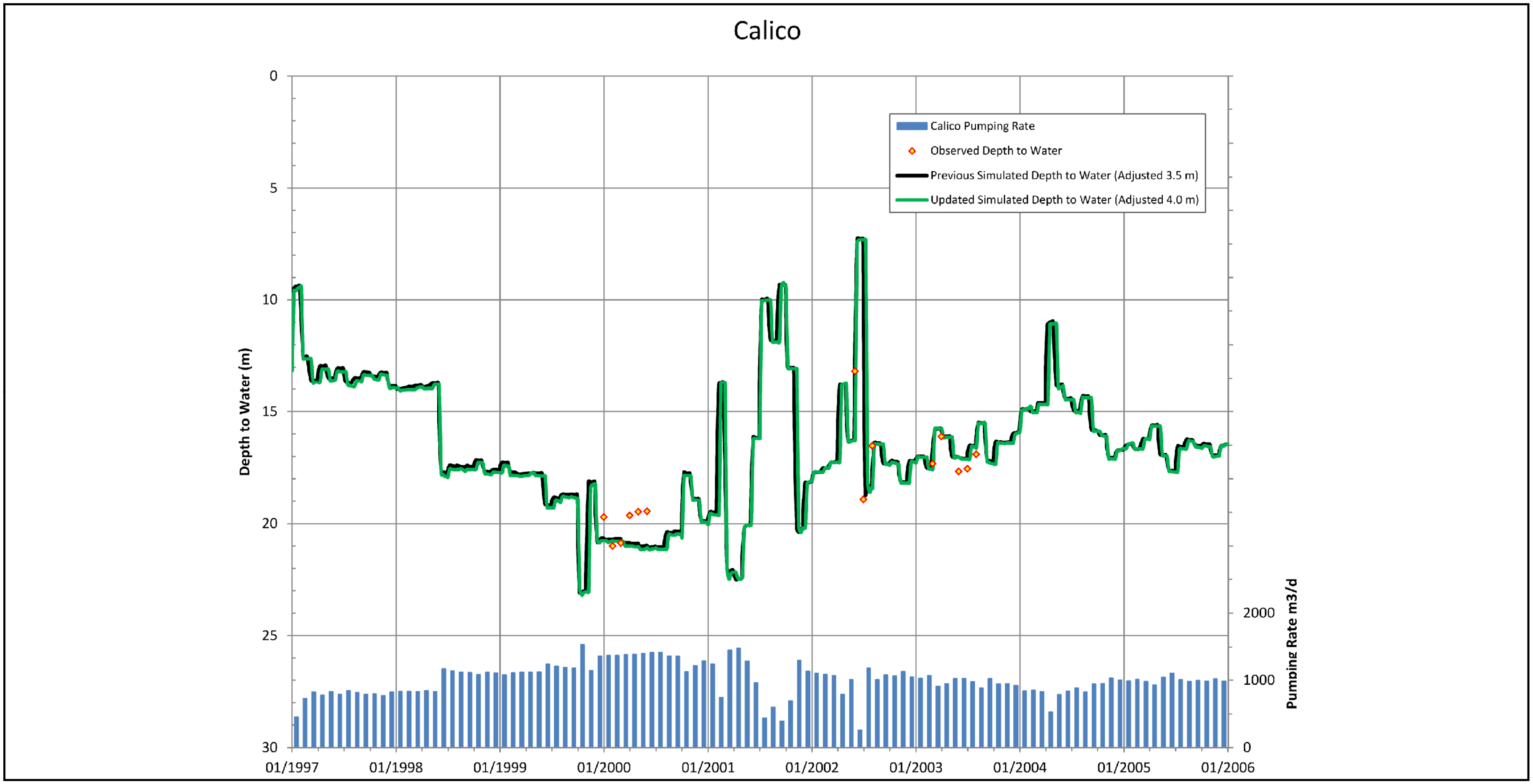

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Calico

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Figure
E2.8

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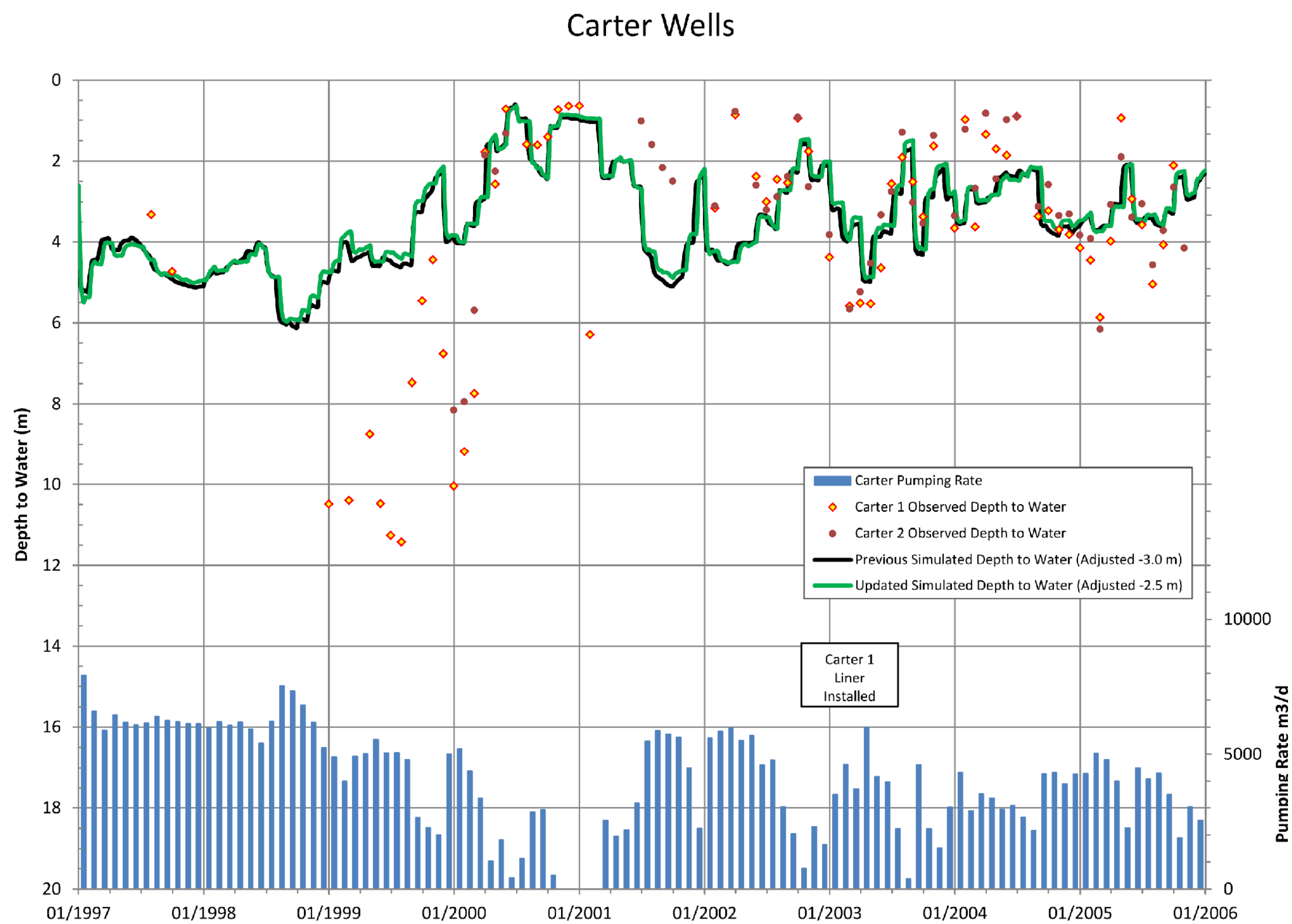

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Carter Wells

Date:	Project:	Technical:	Reviewer:	Drawn:
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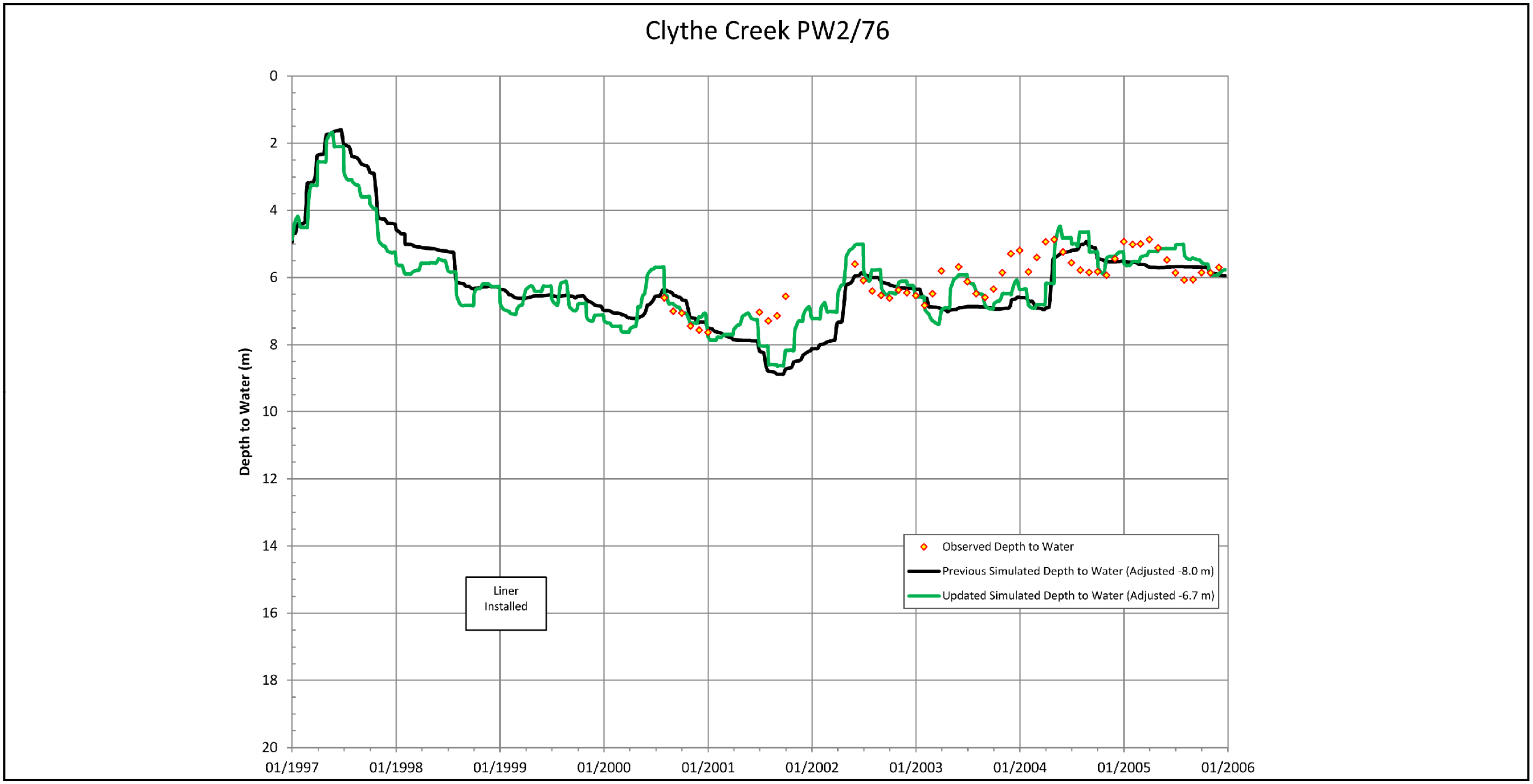

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City of Guelph and Township of Guelph/Eramosa
Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Clythe Creek

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure
E2.10

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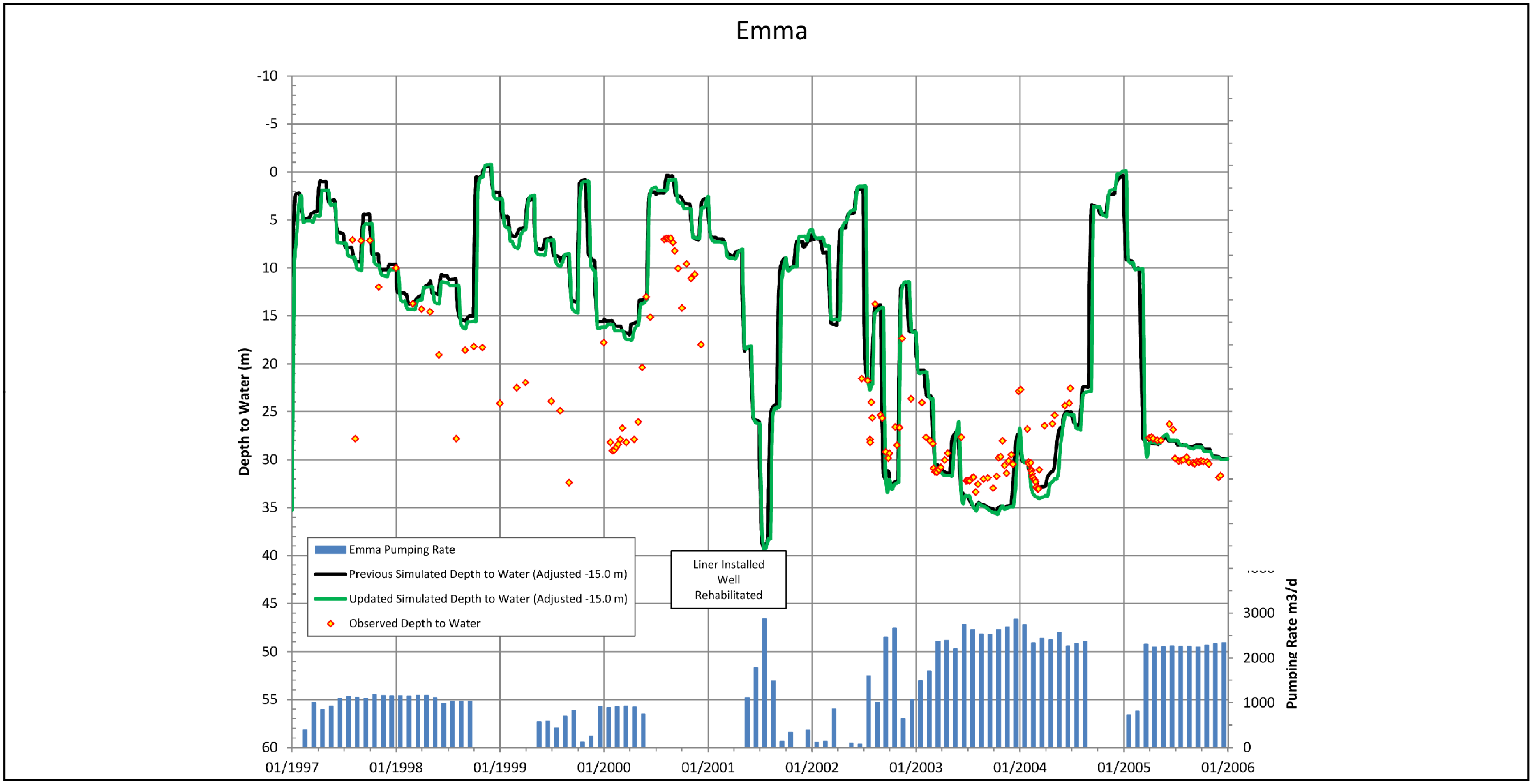

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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Emma

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure
E2.11

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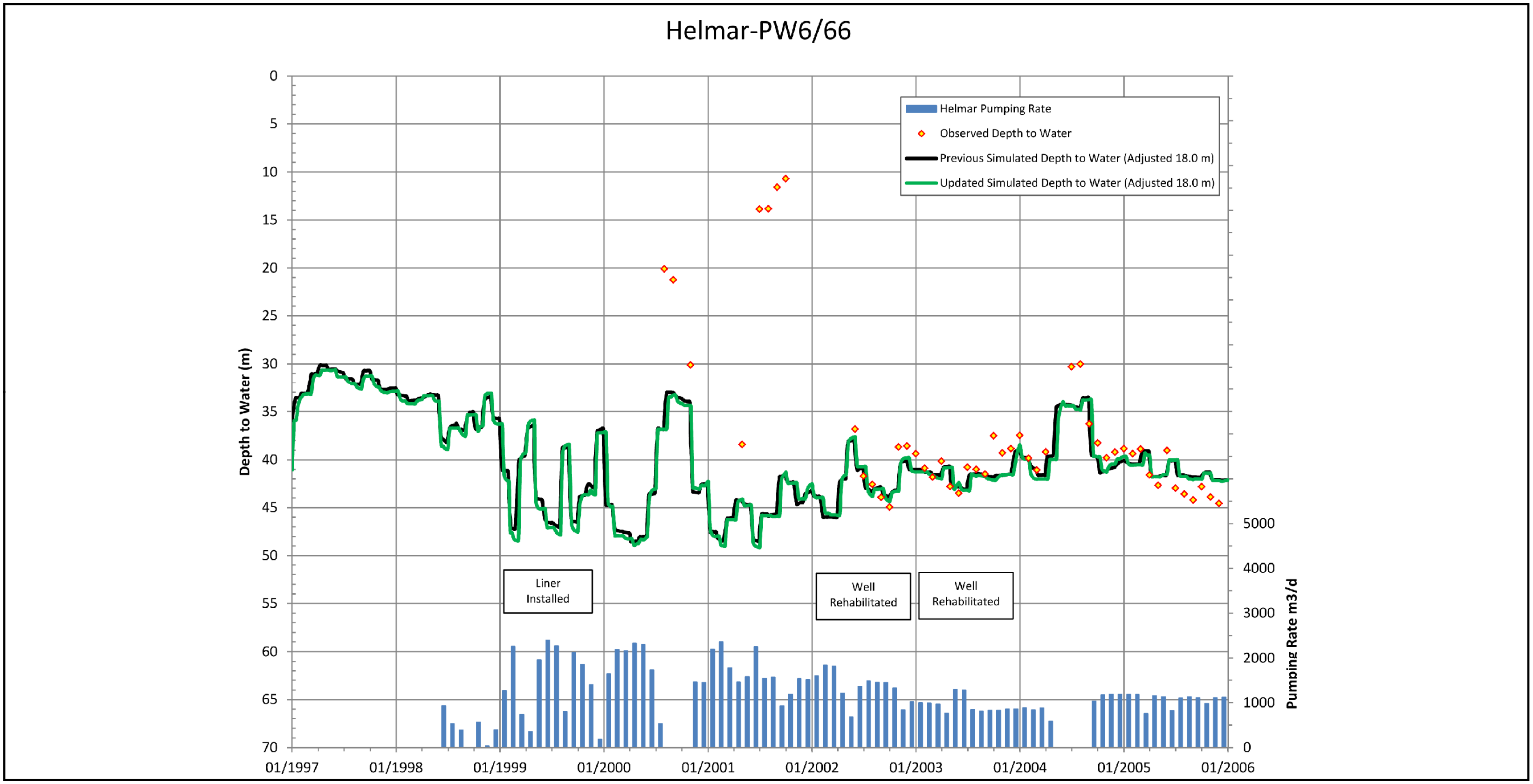

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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Helmar

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure
E2.12

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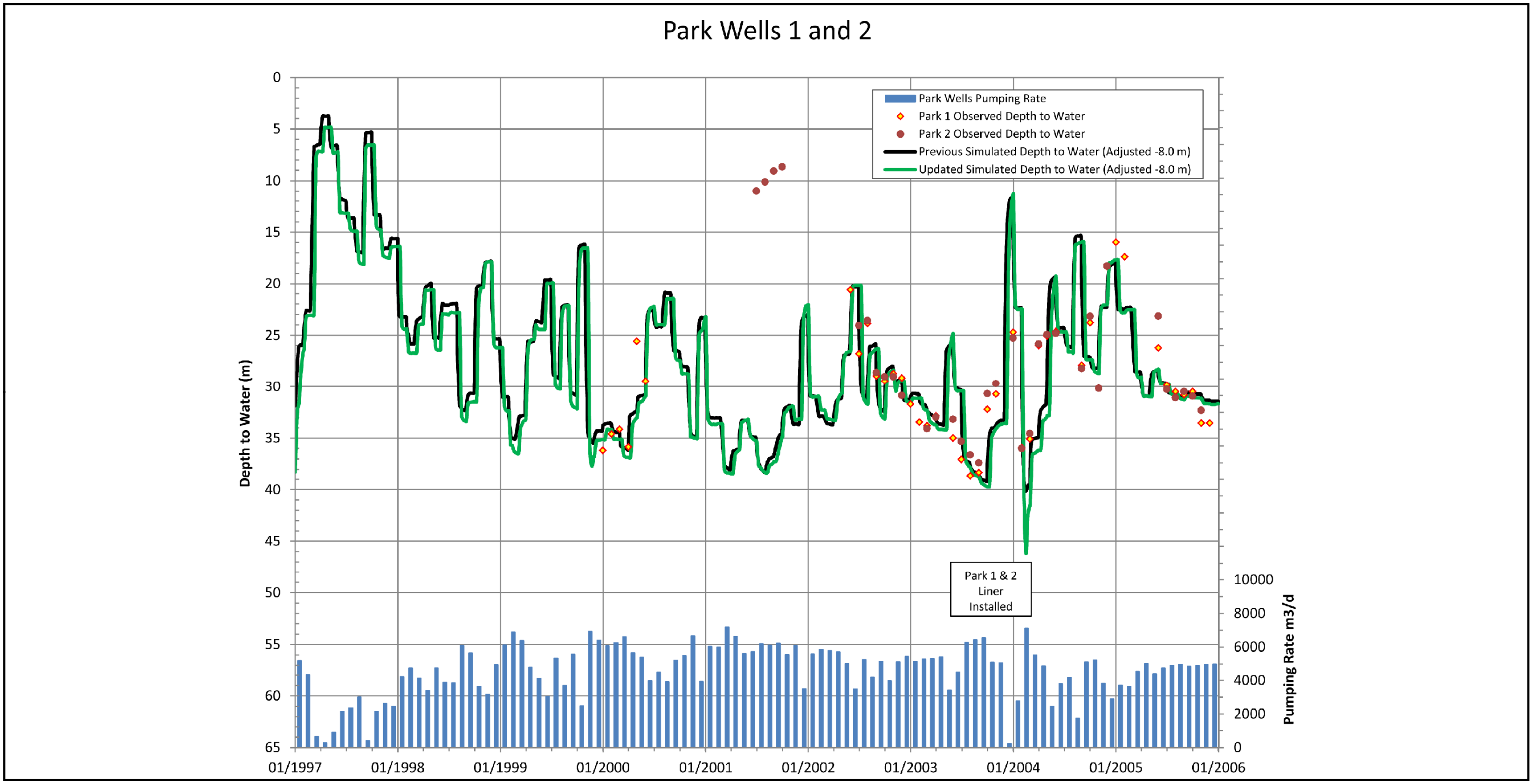

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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Park Wells

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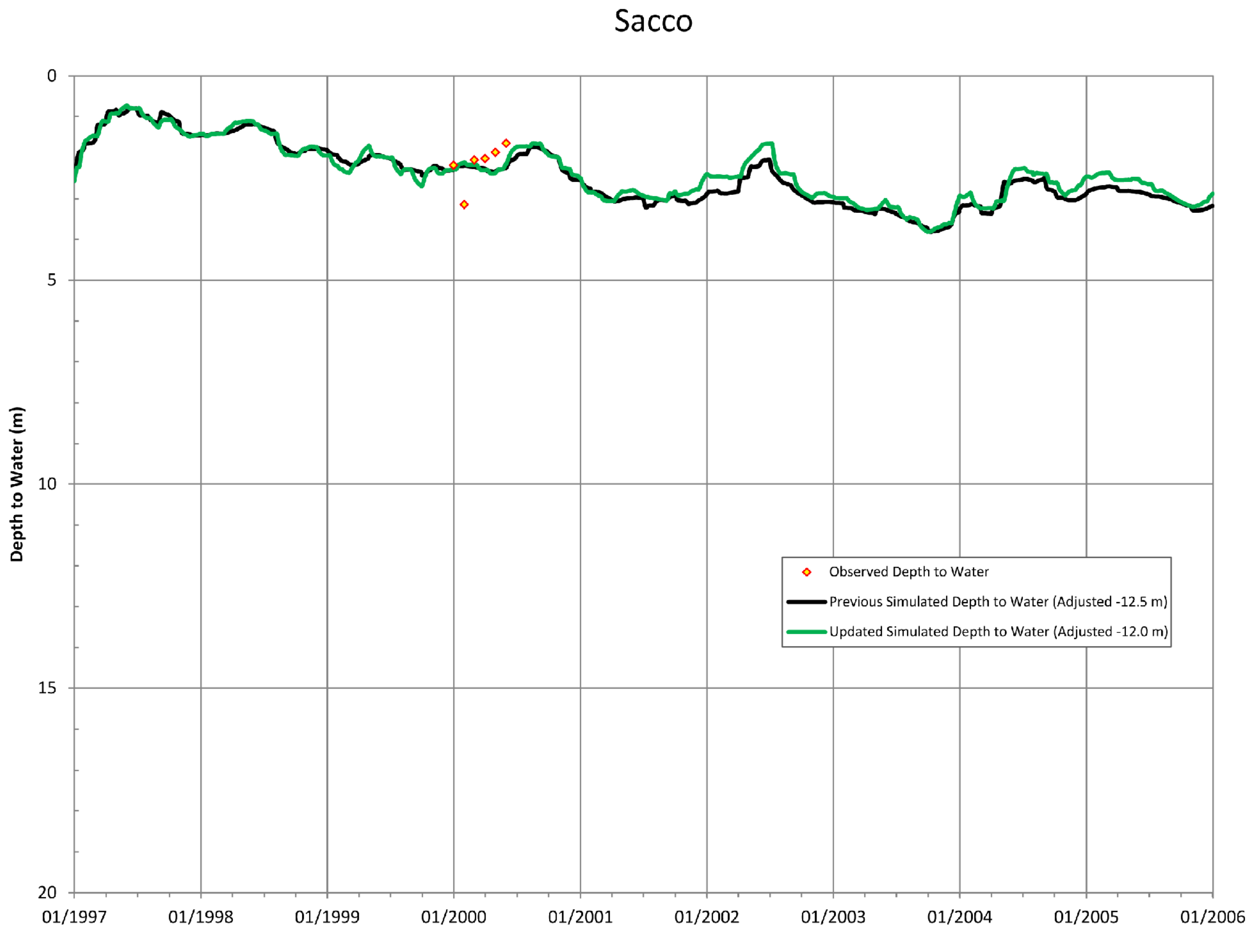
Figure
E2.13



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Tier 3 Water Budget and Local Area Risk Assessment
Appendix E2 City of Guelph Transient Verification Results - Hydraulic Head - Municipal Wells

Transient Verificiation Results
Sacco

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Figure
E2.14