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ENVIRONMENTAL & WATER-RESOURCE CONSULTANTS

December 16, 2020

Mr. Joe Nethery, MCIP, RPP
Manager, Community Planning
Planning Services
Legislative & Planning Services
Halton Region

Subject: Initial review comments on the hydrologic and hydrogeologic analyses for the impact assessment of the proposed Burlington Quarry Extension

Dear Mr. Nethery:

On behalf of the Regional Municipality of Halton and the Joint Agency Review Team we have conducted an initial review of the hydrologic and hydrogeologic analyses for the impact assessment of the proposed extension of the Nelson Aggregates Burlington Quarry. The analyses are documented in the report **Level 1 and Level 2 Hydrogeological and Hydrological Impact Assessment of the Proposed Burlington Quarry Extension, Nelson Aggregates Co.** (Earthfx, April 2020).

Our review is divided into seven main sections:

1. General impressions;
2. Major comments;
3. Detailed technical comments;
4. Requests for clarification;
5. Missing references; and
6. Details that appear to be incorrect.

We have deliberately referred to an *initial* review, as we have not commented on the predictions of the potential effects of the proposed extension. In our opinion, it has not been demonstrated that the modelling that has been conducted provides an adequate basis for making such predictions.

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1. General impressions

We begin by noting that the Terms of Reference for the Level 1 and 2 Hydrogeologic and Hydrologic Impact Assessment of the Proposed Burlington Quarry Extension are dated February 2020 (Earthfx, Inc., Azimuth Environmental Consulting, Inc., Tatham Engineering, and Worthington Groundwater, February 2020). The field investigations and modelling analyses must have been largely completed by the date of the Terms of Reference.

Referring to page 92, the analyses are referred to as an "integrated model-driven, quarry assessment approach". The objectives are summarized on page 22:

> *The objective of this Level 2 ARA investigation is to characterize the existing conditions at the Burlington quarry site, describe the development of an integrated groundwater/surface water assessment model, and predict any likely changes to the hydrologic and hydrogeologic conditions at different phases of extraction and final rehabilitation.*

In our opinion, the modelling described in the Level 1/2 report does not achieve the objective of providing defensible predictions of the potential impacts of the proposed development. The analyses described in the Level 1/2 report are extraordinarily complex from a process perspective, but highly simplified with respect to the assignment of material properties. It is not clear what parameters have the greatest influence of the predictions, whether there are sufficient data to constrain the assignment of parameter values, and whether the parameter values inferred through calibration are consistent with the available data.

Our review of the GSFLOW results suggests that, in general, the calibrated model is capable of matching variations in water levels arising from seasonal climate fluctuations. However, we have fundamental concerns regarding the treatment of the available data and the approaches that have been adopted for simulating groundwater flow in the bedrock. We could not find evidence in the report that confirmed the GSFLOW model was capable of yielding acceptable matches to observed declines in groundwater levels arising from ongoing quarry operations.

2. Major comments

1. Precipitation data is the key driver for the PRMS analyses. It is indicated on page 92 that measured precipitation is added to the top of the model. It is important to note from the outset that no measurements of precipitation are available within the study area. Referring to Figure 4.1, there are no climate stations close to Mount Nemo.

2. No indication is provided in the report that a distinction has been made between data from climate stations above and below the Niagara Escarpment. Our experience suggests that this distinction is important, affecting whether a station provides data that is or is not representative of conditions on Mount Nemo. Our expectation is that the climate data from Millgrove and Mountsberg are likely to be most representative. However, referring to Figure 4.2, there are no recent data from either station. The Millgrove station is about 9.3 km from the quarry.

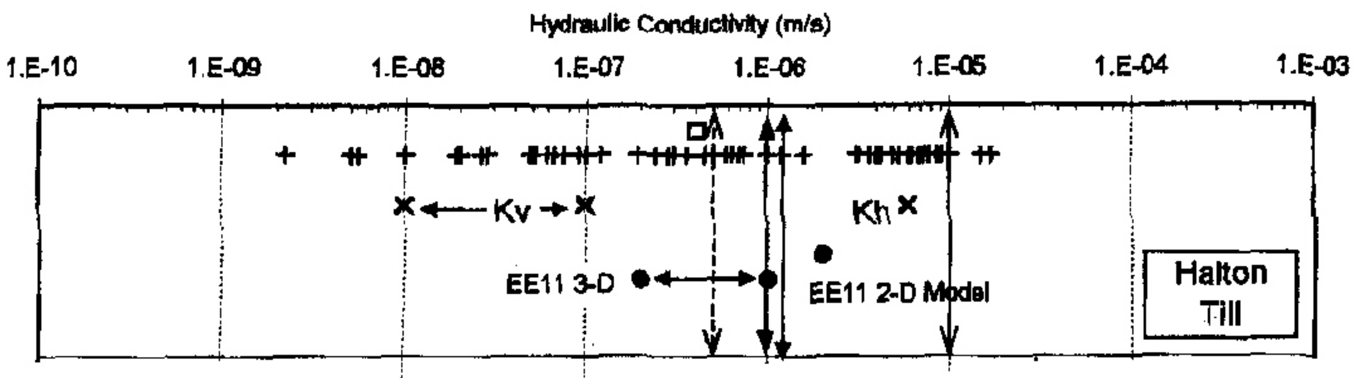
3. Referring to Figure 4.10, there are only three WSC stream gauges in the model area, with two of the stations close to each other on Grindstone Creek (above Highway 403 and near Aldershot). None of the three WSC stations are located on Mount Nemo.

4. Referring to Section 6.6, it is indicated that soil properties have a “significant influence on hydrological processes”. However, our understanding is that tabulated look-up values are specified for many of the parameters in the analyses, rather than site-specific data. How much uncertainty should be assigned to the values assumed in the analyses? Which parameters have the most important influence on the predictions of potential impacts?

   As just one example, we refer to the estimation of potential evapotranspiration, an important component of the water budget. It is indicated on page 443 that the modified Jensen-Haise method only requires values for daily temperature, incoming global solar radiation, and “two other user-specified parameters.” Based on our reading of Table A1-14 of the GSFLOW documentation, we think these parameters are *jh_coef* and *jh_coef_hru*, the “monthly air temperature coefficient” and the “air temperature coefficient for each HRU”. There is no indication in the reporting of what these values are, what data have been considered in their assignment, and how significant they are with respect to the model results.

5. Our expectation is that the horizontal and vertical hydraulic conductivity of the Halton Till is a critical parameter in the analyses, particularly the vertical hydraulic conductivity. Are the values of the horizontal and vertical hydraulic conductivities inferred through calibration, 5×10^{-7} m/s and 2×10^{-7} m/s (Table 18.4) consistent with estimates reported for other sites?

   A compilation of hydraulic conductivity estimates for the Halton Till is reproduced below (Gerber and Howard, 2000).



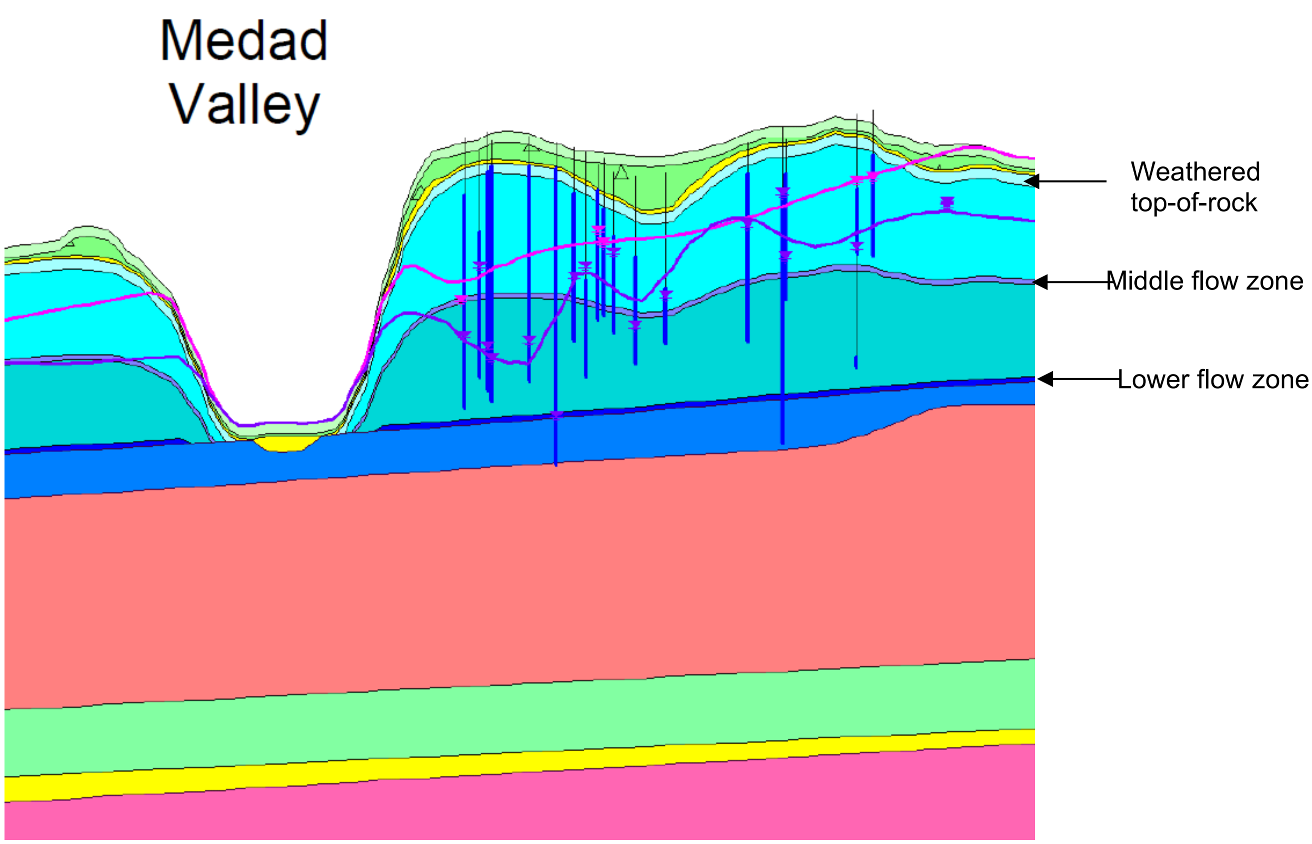
   Gerber (2010) has suggested the following representative average values for the Halton Till (Gerber, 2010):

   - Weathered Halton Till: $K_H \sim 5\times10^{-6}$ m/s; $K_V = K_H$; and
   - Unweathered Halton Till: $K_H \sim 5\times10^{-7}$ m/s; $K_V = 0.1\ K_H$.

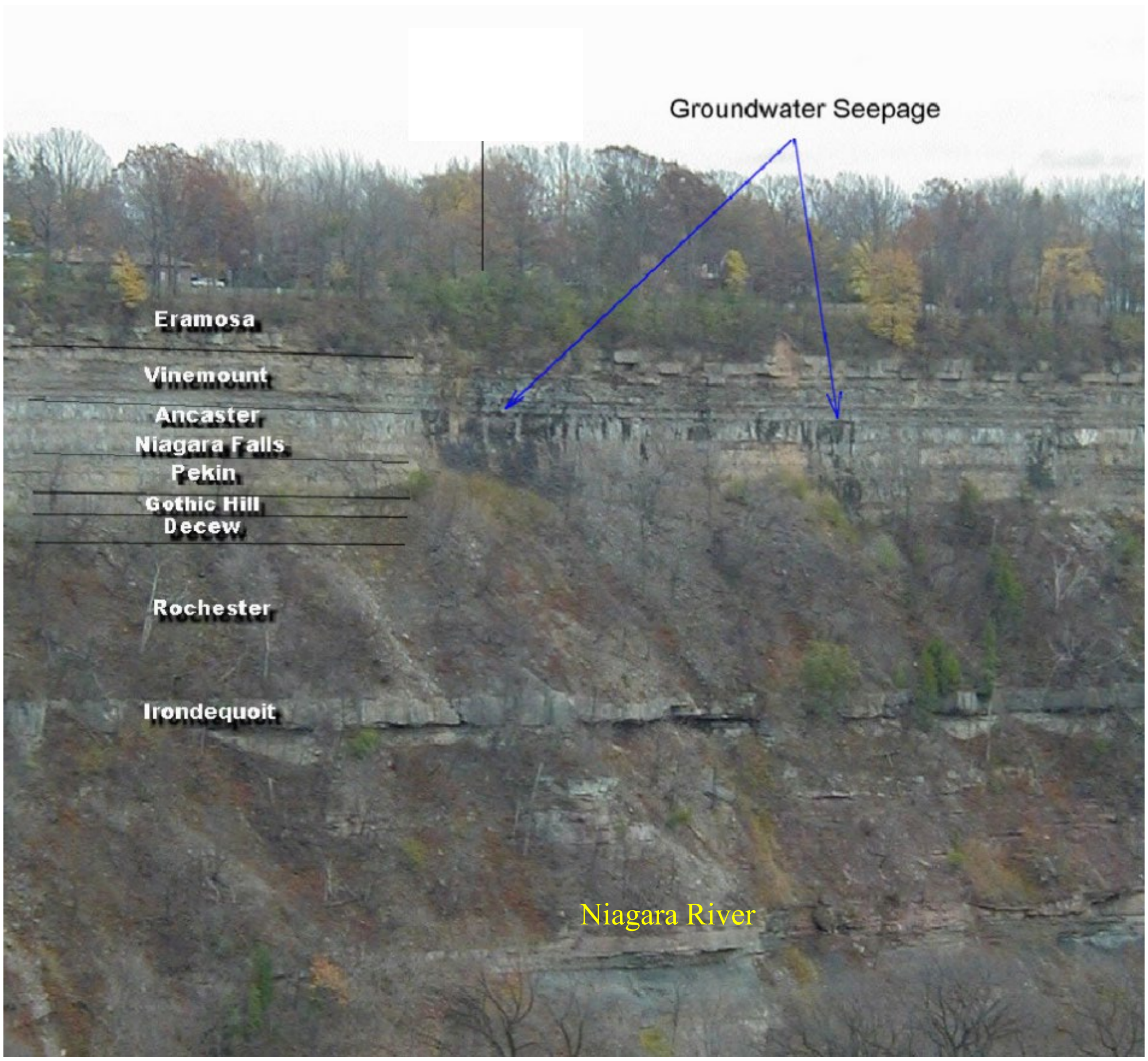
   Sharpe et al. (2013; Table 4) suggest a value of 2×10^{-5} m/s for the vertical hydraulic conductivity of the weathered Halton Till.

   The value of the vertical hydraulic conductivity of the Halton Till inferred through calibration appears to be substantially smaller than literature values. This is not to imply that the values specified in the groundwater model are inappropriate. However, there is no discussion of how the values were inferred through calibration. How sensitive is the match of the calibration targets to the values of the vertical hydraulic conductivity of the Halton Till that are specified? How sensitive are the predictions to the vertical hydraulic conductivity of the Halton Till, in particular the predicted impacts to shallow features such as wetlands?

6. It is indicated on page 92 that the layers of the MODFLOW and GSFLOW models must be continuous across the model domain. This requirement has been interpreted in a way that we consider to be non-physical. The results close to the deep cutting features, including the Medad Valley and the existing quarry are not realistic. An excerpt from a cross-section through the model along 2nd Side Road is reproduced below (Figure 5.2), As shown in the figure, the model layers are "pushed down" below the base of the Medad Valley.

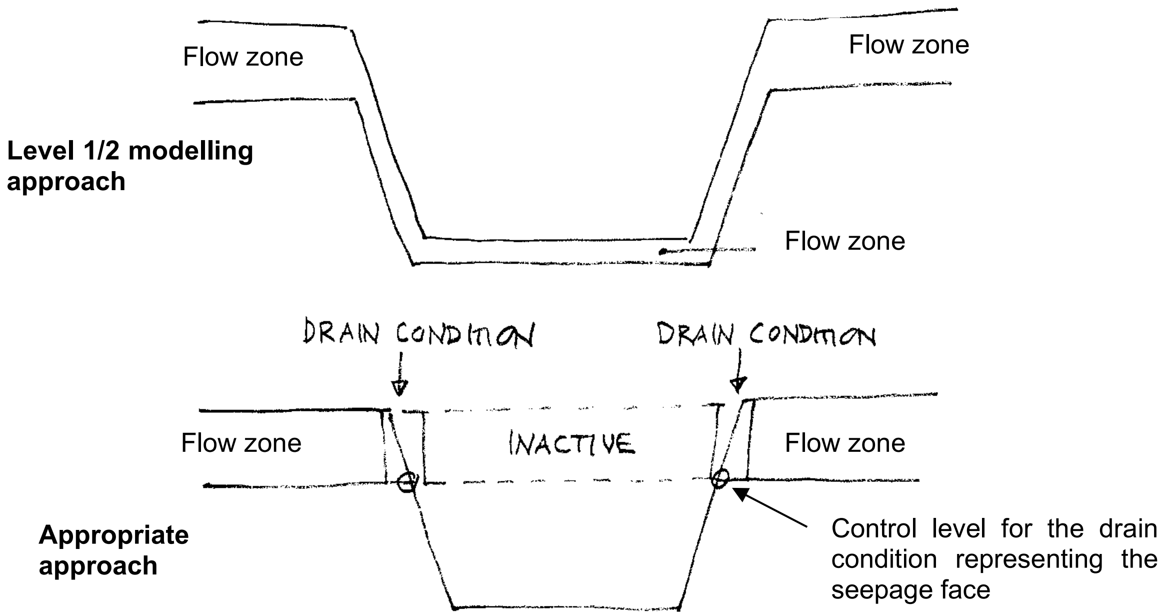


In our experience, this is <u>not</u> a realistic representation of the bedrock flow zones in the rocks of the Niagara Escarpment. For example, a view across the gorge of the Niagara River downstream from Niagara Falls is shown on the next page. Rather than diving down below the Niagara River, the bedrock flow zones daylight at the gorge. Groundwater exits at the base of each flow zone, forming stacked seepage faces.

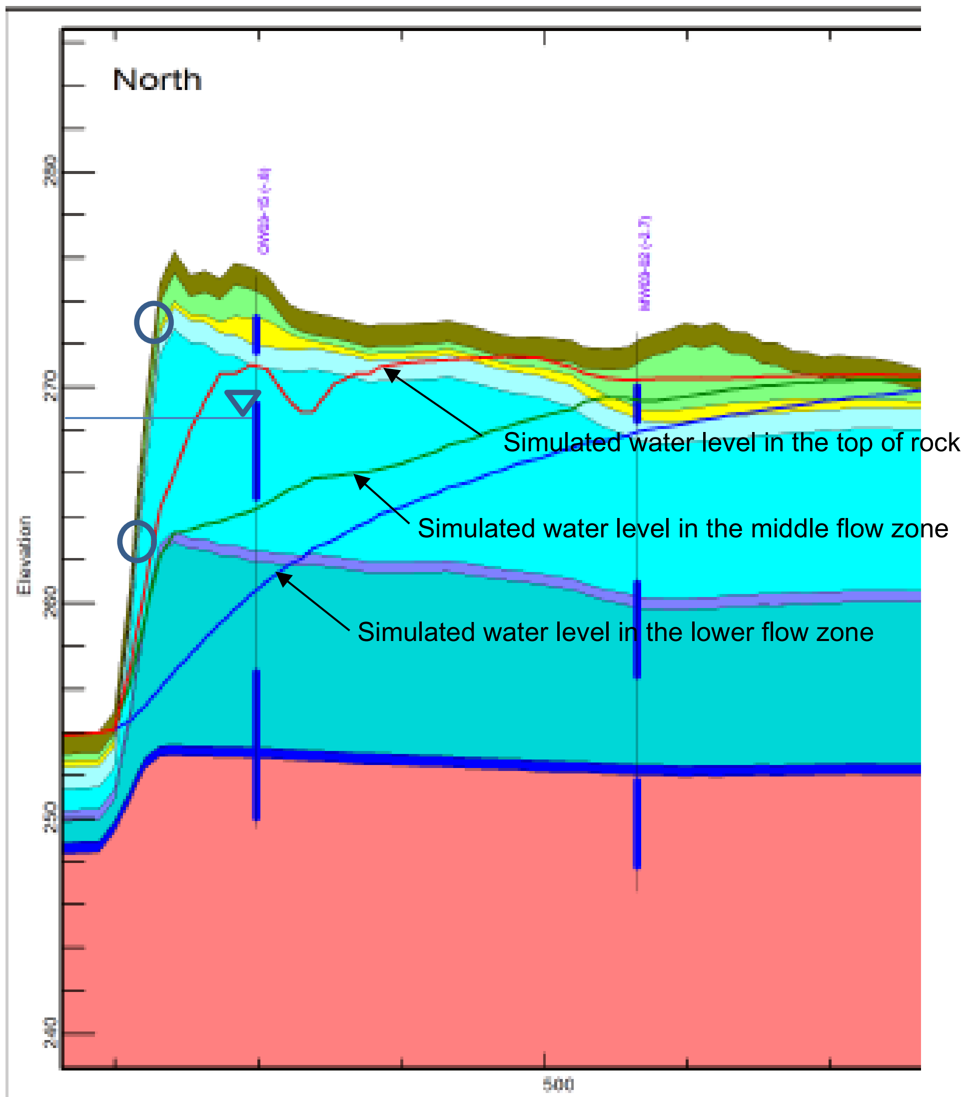


Photograph of the gorge of the Niagara River across from the Hyde Park Landfill site
[Photograph by the author]

A physically realistic approach for representing this situation is shown schematically below.



The results shown in Figures 5.2-5.4 and 19.18-19.20 of the report illustrate why the representation of conditions along the Medad Valley and Niagara Escarpment and around the existing quarry is important. A portion of Figure 19.18 is reproduced below. There is no evidence to suggest that the water levels in the weathered top-of-rock and in the middle flow zone decline steeply as predicted with the model. Hydrographs for observation well OW03-15 between April 2003 and July 2010 and between July 2009 and January 2015 are reproduced here on page 9. The long-term average water levels in the shallow “C” and deeper “B” and “A” monitoring intervals are about 273 m, 269 m and 259 m amsl, respectively. Since 2003, the water levels have varied by only about ± 1 m with respect to the average levels. The water levels are controlled by the elevations at which the flow zones daylight at the quarry, indicated by the circles added to the excerpt from Figure 19.18. In our opinion, the non-physical simulation approach that has been adopted compromises severely the reliability of predictions of potential impacts of the quarry extension.


North
Simulated water level in the top of rock
Simulated water level in the middle flow zone
Simulated water level in the lower flow zone
Elevation
280
270
260
250
240
500

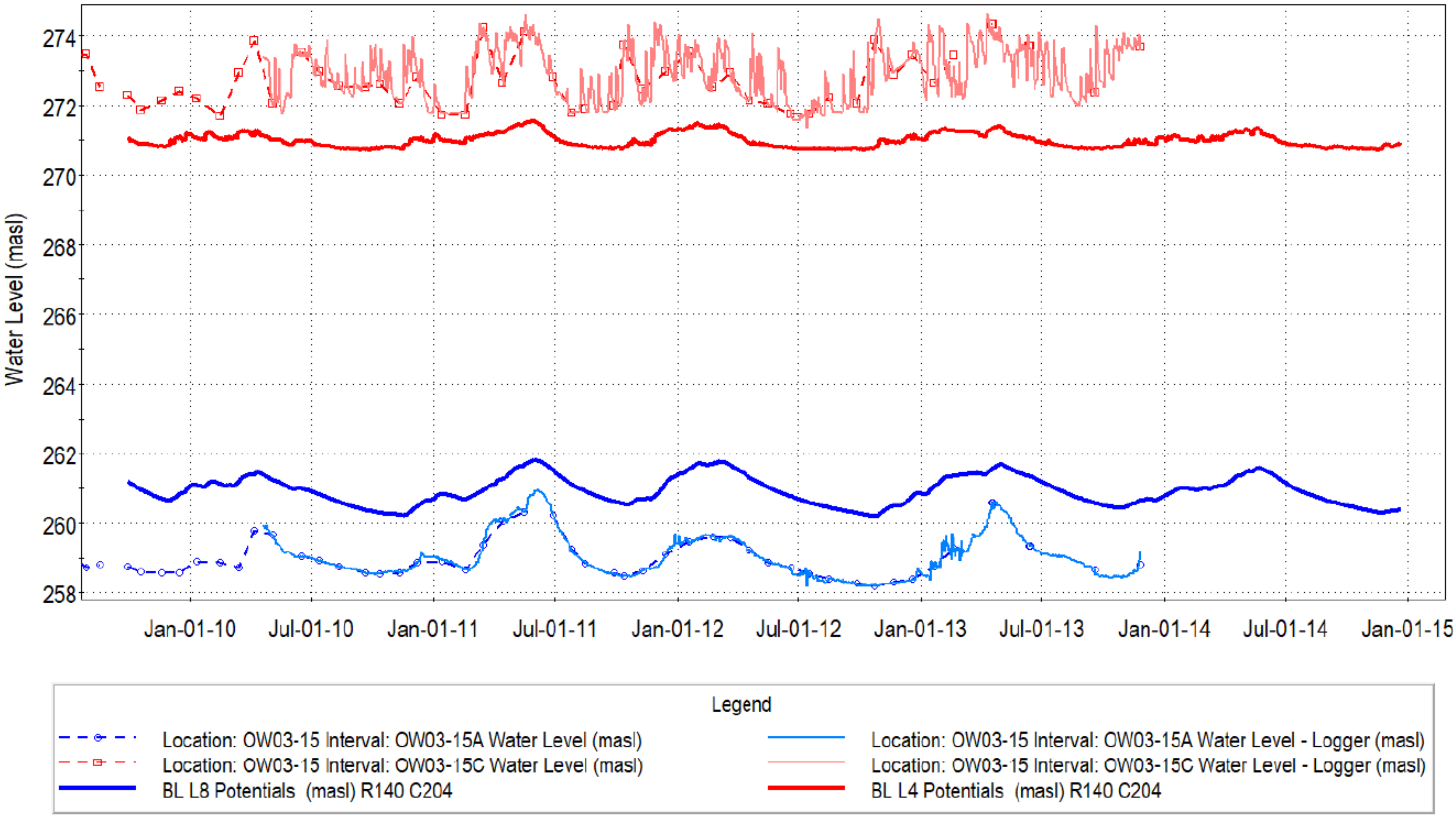
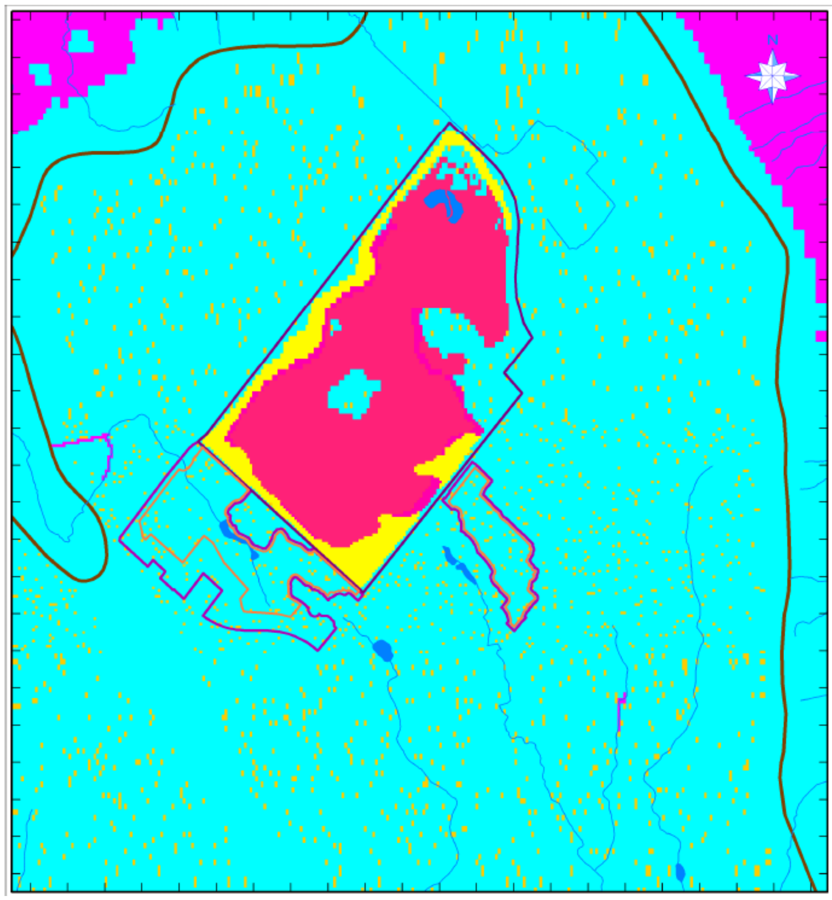
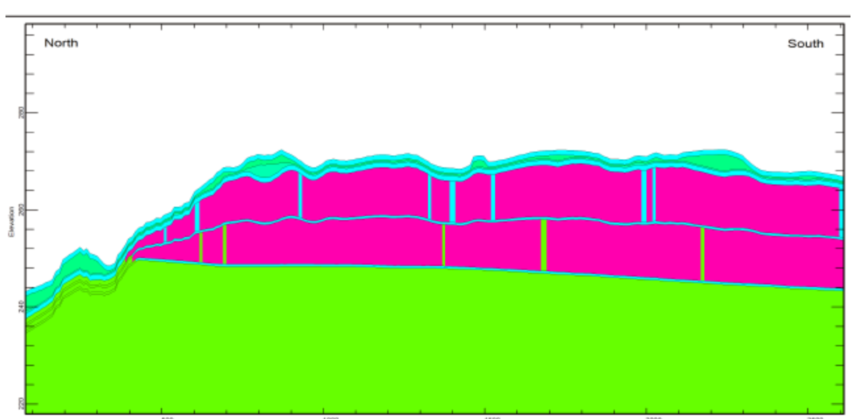


Figure 19.22: Comparison of observed and simulated water levels at monitor OW03-15.

7. The approach that has been adopted to incorporate hydraulic connections between the weathered top of rock and the middle flow zone, and between the middle and lower flow zones is shown in Figures 18.20, 18.21 and 18.7 of the report. The approach is illustrated below. In our opinion, the approach that has been adopted to incorporate the vertical hydraulic connections is not physically based.

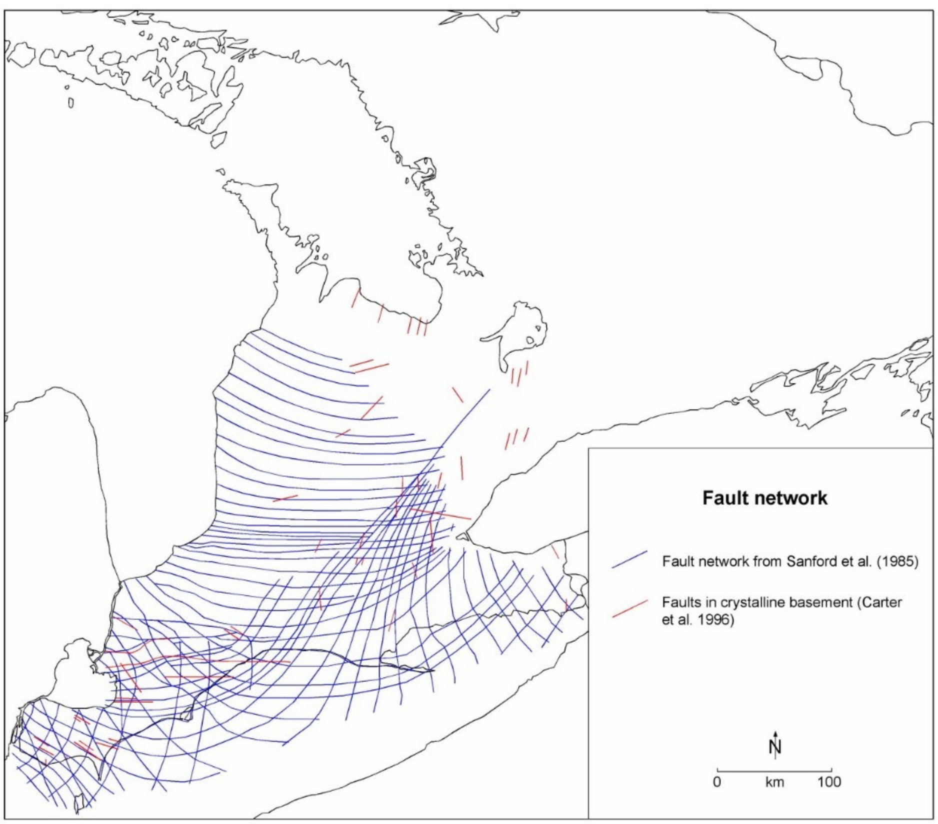




The approach does not provide either an improved representation of the fractures in the bedrock system, or the hydraulic connections between the flow zones. The approach that has been adopted is not internally consistent. Finally, the approach compromises the reliability of the predictions of potential impacts of the quarry expansion.

Although reference is made in the reporting to “fractures”, the features incorporated in the model are in fact a random distribution of “chimneys”. In the area of the model with a refined grid, the chimneys are prisms with areas of 15 m by 15 m. In our experience, we have yet to encounter a site where such chimneys are encountered.

There are no data to constrain the assumed distribution or properties of the chimneys. At a minimum, we would expect the fractures to follow the jointing patterns in the underlying rock. As shown below, the distribution of the chimneys bears no relation to regional joint patterns interpreted by Mazurek (2004) [based on the work of Sanford et al. (1985) and Carter et al. (1996)].



Regional faulting in southern Ontario (from Mazurek, 2004)

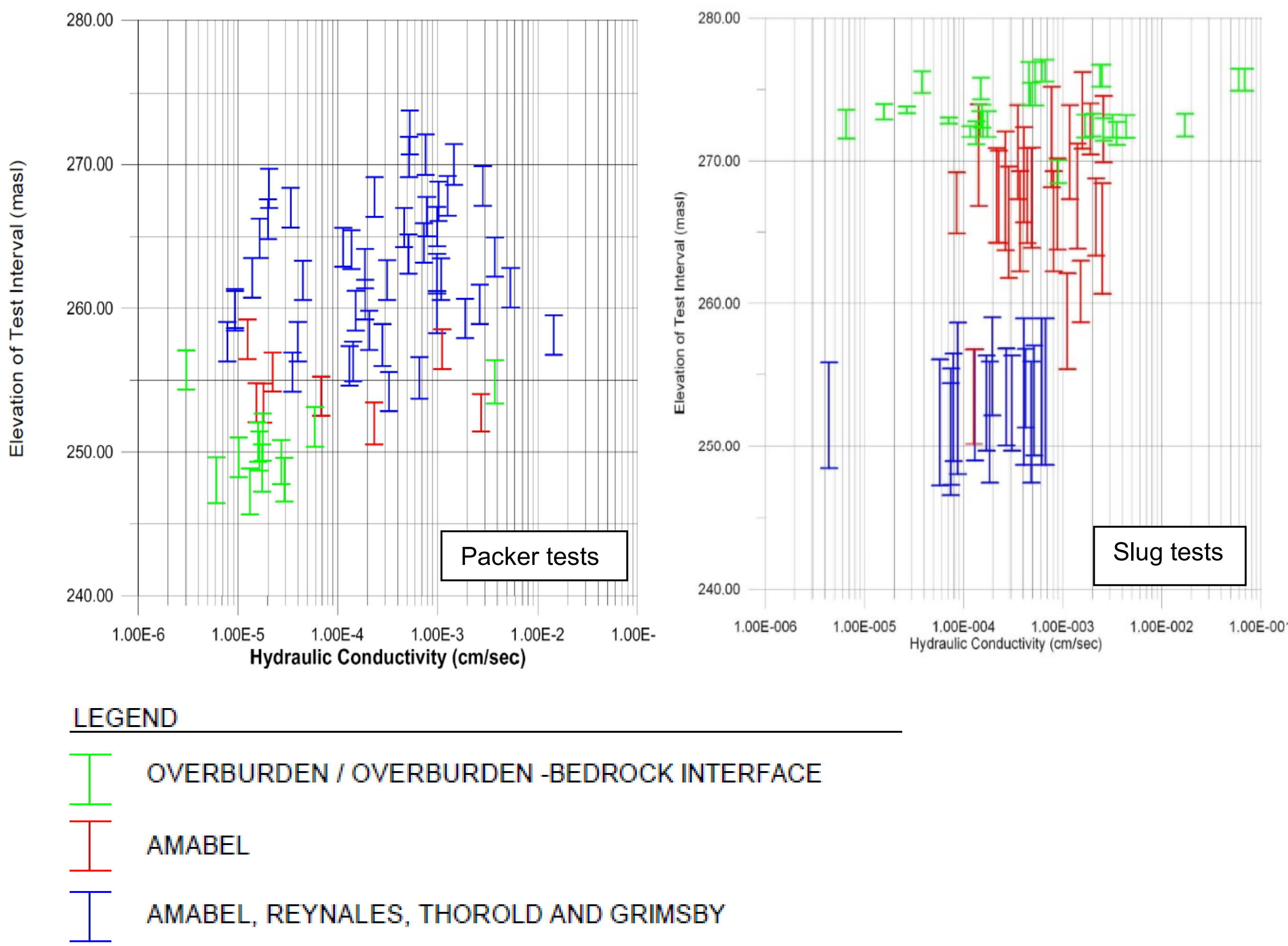
The bedrock in the study area has been simulated using the equivalent porous medium (EPM) approach. Bulk-average hydraulic conductivities are assigned to the bedrock units, the weathered top-of-rock zone and the middle and lower flow zones. In our opinion, this approach is appropriate given the scale of the potential impacts of the development, and recognition that the results of the model are not predictions of what is likely to happen at discrete locations but what is likely to happen *on average*. However, the introduction of the chimneys runs counter to the EPM approach. A consistent approach involves specifying bulk-average vertical hydraulic conductivities, rather than introducing discrete artificial features. The bulk-average vertical hydraulic conductivities would account, *in an average sense*, for the presence of discontinuities that might give rise to enhanced connections between the horizontal flow zones.

The introduction of the chimneys compromises the reliability of the predictions of potential impacts of the quarry expansion. The predictions of the model at particular locations will depend on the proximity to one of the simulated chimneys, about which nothing is known. The simulation approach introduces an impression of exactitude that is not supported by any data.

8. Although the model has been developed to predict the potential impacts of the quarry expansion, the predictive capacity of the model has not been demonstrated. In general, the hydrographs presented in the report demonstrate that the model is capable of reproducing changes in water levels that are driven by seasonal variations in climate. However, no comparison is presented between observed and simulated average declines in water levels caused by the quarry operations. The quarry has been operating sufficiently long that is should be possible to identify the declines for at least some key monitoring locations. An appropriate application of the MODFLOW model would be to simulate time-averaged water levels for different positions of the quarry face. Did the position of the quarry face change 2003/2004 and 2007/2010? Has the position of the quarry face changed between 2010 and 2020? The results of time-averaged simulations of the different time periods would be important for confirming that the predicted effects of the quarry expansion on bedrock groundwater levels are within the realm of possibility.

   Referring the hydrographs in Golder (2010), we estimate that for OW03-14A, the average level between April 2003 and July 2004 was about 272 m amsl, and between July 2007 and July 2010 the average level was about 261 m amsl. For monitoring well OW03-15A, the average level between April 2003 and July 2004 was about 260 m amsl, while the average level between July 2007 and July 2010 was about 259 m amsl. Substantial drawdowns were also observed at OW03-21. Golder (2010) present hydrographs for three other wells that show clear long-term declining trends and that might be used for this demonstration: Onsite quarry well 5 (Golder, 2010; Figure D.1.77); Onsite quarry well Goodchild (Golder, 2010; Figure D.1.78); and Onsite quarry well Sterrett (Golder, 2010; Figure D.1.79).

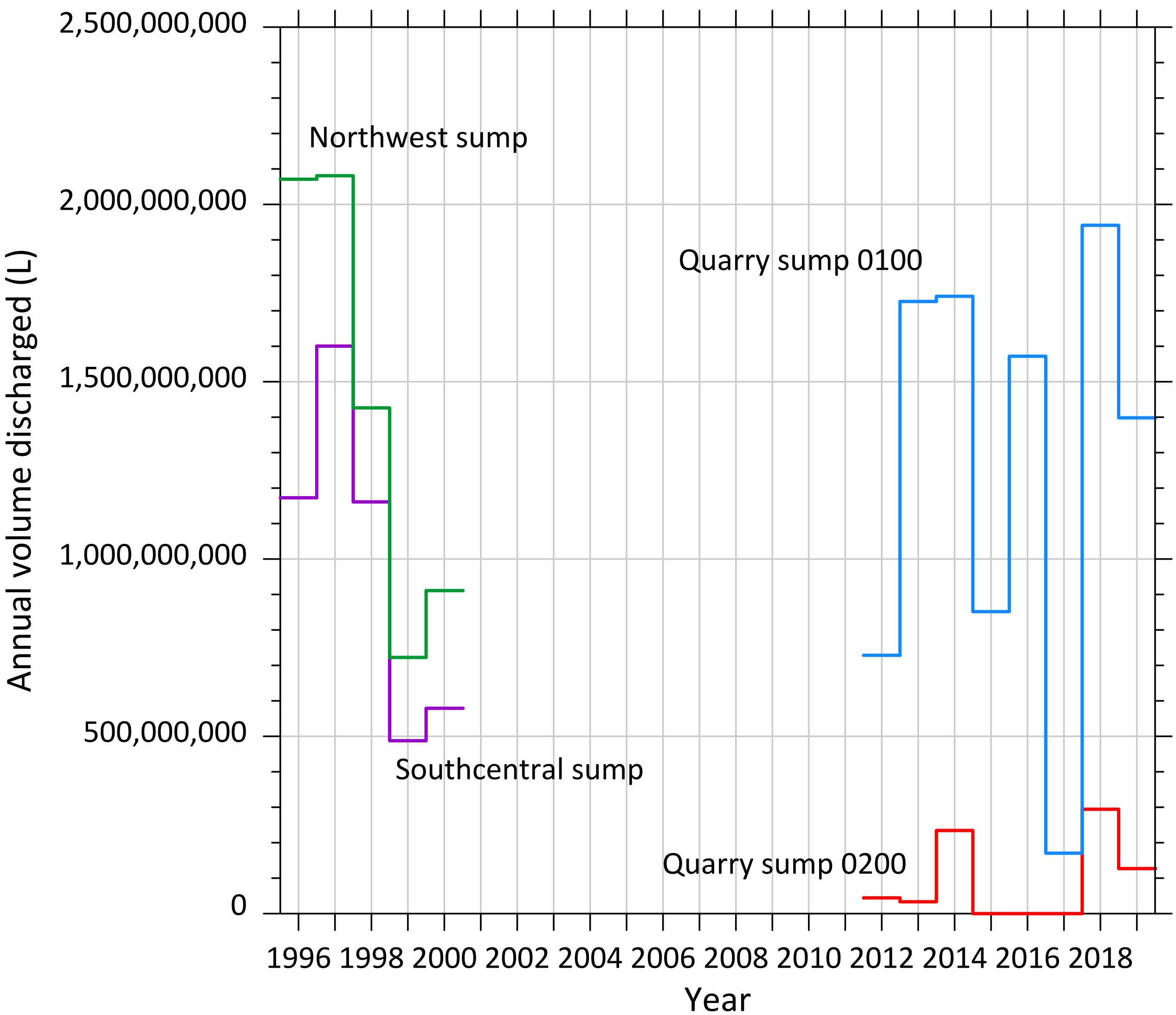
9. Final calibrated values of the hydraulic conductivities for each model layer are listed on Table 18.4. There is no indication as to whether the inferred uniform values for each hydrostratigraphic unit are consisent with the results of independent testing. In our opinion, this is an essential check for model acceptance. Previous summaries of hydraulic testing presented are reproduced below (Golder, 2010; Figures C.2 and C.3). These compilations should be updated, with the values inferred through calibration superimposed. We do not expect a well-by-well, or test-by-test review. Rather, we expect some general appraisal of whether the hydraulic conductivity values inferred through calibration are consistent with the bulk of the available estimates from site hydraulic testing.



10. No mention is made in the report of the two well-instrumented constant-rate pumping tests that have been conducted near the quarry. In our opinion, these tests provide useful opportunities to test the predictive capabilities of the calibrated groundwater flow model. The pumping test conducted in March 2004 is reported in Golder (2004; Appendix B). The pumping test conducted in February 2006 is reported in Golder (2006).

11. A key result for any model calibration is the match to observed groundwater discharges. Our understanding is that the North Quarry discharge corresponds to the flows measured at SW1, and that the final model results are compared against the observations in Figure 19.10. Why is the discharge shown for only 5 years? Our impression is that the model results do not approximate the observations. We further understand that the South Quarry discharge corresponds to the flows measured at SW6, and that the final model results are compared against the observations in Figure 19.11? Why is the discharge shown for only 7 years? Our impression is that again the model results do not approximate the observations.

    The annual quarry discharges from 2012-2019 are listed in Tatham (2020; Table 1). In the following figure the values reported by Tatham are supplemented with sump pump between 1996 and 2003 (Golder, 2010; Table E-8). Our impression is that there have been important variations in the quarry discharges. How have these variations been considered in the analyses?


2,500,000,000
2,000,000,000
1,500,000,000
1,000,000,000
500,000,000
0
Annual volume discharged (L)
Northwest sump
Southcentral sump
Quarry sump 0100
Quarry sump 0200
1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018
Year

12. The final calibration of the GSFLOW model is presented in Appendix E (Section 19). It is not clear from the presentation what the targets for the calibration were (apart from the total streamflow at Aldershot), what parameters were varied during the calibration, and how the ranges were established over which the parameter values would be adjusted to match the calibration targets. Upon review of this section, we were left asking: Which parameters make a real difference in the calibration, and are there data to constrain the most important parameters?

13. Streamflow monitoring

    A relatively small subset of the existing streamflow monitoring locations has been considered in the modelling analyses. Furthermore, inconsistent sets of streamflow monitoring stations have been considered for the GSFLOW calibration and the representation of baseline conditions. We were left with the impression that selective use has been made of the available data in the GSFLOW calibration and the representation of baseline conditions. At a minimum, all stations considered for the representation of baseline conditions should have calibration records that extend across the 10-year period WY2010 to WY2019. In addition, if it is not feasible to include all the existing streamflow monitoring locations in the calibration analyses/baseline conditions simulations, the documentation should include explanations regarding why some stations are included and others are not.

13.1 Existing streamflow monitoring locations

Referring to Tatham Engineering (2020; Table 2), there are 20 existing streamflow monitoring locations.

SW01	SW23
SW02	SW24
SW06	SW25
SW07	SW26
SW09	SW28
SW10	SW29
SW14	SW30
SW15	SW31
SW21	SW34
SW22	SW35

13.2 Streamflow monitoring stations included in the GSFLOW calibration

Referring to Earthfx (2020; Sections 6 and 19), results from the calibration of the GSFLOW model are presented for 7 stream monitoring stations plus the Water Survey of Canada gauge at Grindstone Creek near Aldershot.

1. Grindstone Creek near Aldershot (02HB012): WY2010-WY2013 [Figure 6.18, 19.1]
2. SW01 (Main quarry discharge [north sump]): 2014-2019 [Figure 19.10]
3. SW02: WY2015-WY2019 [Figure 19.13]; 2017 [Figure 19.14]; 2018 [Figure 19.15]
4. SW06 (South quarry discharge [south sump]): WY2015-WY2019 [Figure 19.11]; 2017 [Figure 19.12]
5. SW09: WY2017-WY2019 [Figure 19.7]; 2019 [Figures 6.20 and 19.8]
6. SW10[B]: WY2019 [Figure 6.19]; WY2017-WY2019 [Figure 19.5]; 2019 [Figure 19.6]
7. SW29: WY2017-WY2019 [Figure 19.9]

We have been left with the impression that selective use has been made of the available data in the GSFLOW calibration.

- Results from the GSFLOW calibration analyses are presented for 6 of the 20 existing streamflow monitoring locations. No explanations are provided regarding why calibration results were not presented for the other 14 streamflow monitoring locations.

- Our understanding is that the GSFLOW calibration period extends from WY2015 to WY2019 (i.e., 5 years); however, matches to the observations are reported only for varying intervals within this period.

Referring to Earthfx (2020; Section 7), GSFLOW model results for baseline conditions are presented for only 6 on-site stream monitoring stations.

1. SW07: Figures 7.14 and 7.15
2. SW09: Figures 7.4 and 7.5
3. SW10[B]: Figures 7.12 and 7.13
4. SW28: Figures 7.10 and 7.11
5. SW29: Figures 7.6 and 7.7
6. SW36A: Figures 7.8 and 7.9

The results for the streamflow stations are not sufficient to confirm that the GSFLOW simulation are a reliable representation of baseline conditions.

- Only three (3) of the stations selected for the representation of baseline conditions have corresponding results from the GSFLOW model calibration.

- The simulation of baseline conditions with GSFLOW extends from WY2010 to WY2019 (i.e., 10 years). However, as indicated in the notes on the streamflow stations included in the GSFLOW calibration, matches to the data over the full duration of this time period are not presented.

Results for a relatively small subset of the existing groundwater monitoring locations have been reported for the calibration of the GSFLOW model. Furthermore, the calibration time interval is restricted to the five (5) year period, Water Years 2010-2014. No comparisons are presented for the extensive monitoring data collected between 2003 and 2010 (Golder, 2010; Appendix D). We have been left with the impression that selective use has been made of the available data in the GSFLOW calibration. At a minimum, all locations for which water level data are available should have been considered in the calibration, for the full period for which data are available. If it was not feasible to include all the existing groundwater monitoring locations in the calibration analyses, the reporting should have at least included explanations regarding why some locations were included and others were not, and whether conditions changed between 2003 and 2015.

14. Groundwater level monitoring

The groundwater monitoring stations considered in the Level 1/2 Hydrogeological and Hydrological Impact Assessment are shown in Figure 2.1 of the Earthfx (2020) report. Three different types of monitoring locations are indicated in the figure:

- "GW Monitoring Nests";
- "Minipiezometers"; and
- "MECP Wells".

As far as we are aware, a listing of the wells shown in Figure 2.1 is not presented in the report. It is indicated in Earthfx (2020) Section 15.5 that between November 2018 and October 2019, a total of 100 monitoring wells were monitored at 39 locations.

An extensive compilation of earlier water level records (hydrographs) is presented in Golder (2010; Appendix D). Many of the records extend from April 2003 through August 2010. Hydrographs are presented for 133 monitoring intervals at 81 locations:

- 31 nests of the "MW" series, with 85 monitoring intervals;
- 6 wells of the "GP" series;
- 2 wells "Pump well 1" and PW-2;
- 6 on-site quarry wells;
- 35 minipiezometers of the "MP" series; and
- 1 staff gauge, SG-4.

14.1 Monitoring locations for which results from the GSFLOW model calibration are reported

We have reviewed the Level 1/2 Hydrogeological and Hydrological Impact Assessment and we note that:

- The GSFLOW model has been calibrated for the five (5) year period, WY2010-WY2014 (October 2009 to September 2014); and

- Our summary of the number of wells for which GSFLOW simulation results are reported in the Level 1/2 report is presented on Table 1. Comparisons between observations and simulation results are presented for 39 locations.

As far we can tell, no explanation is provided for restricting the GSFLOW calibration to the five-year period 2009-2014. Excellent data are available since 2003, and at a minimum we would expect there to be some discussion of the consistency between the model results and earlier data. This is particularly important for assessing the ability of the GSFLOW model to match long-term changes in groundwater conditions caused by the evolution of the existing quarry, in particular the 2005-2019 advancement of the south extraction face).

We also could not find any rationale for considering only 39 of the 100 monitoring wells in the GSFLOW analyses. At a minimum we would expect there to be some explanation regarding why some results have been presented for some wells and not others.

Table 1. Reported comparisons between observations and GSFLOW simulation results

Count	Well for which GSFLOW calibration results are presented	Figure
1	MW03-01 A	Figure 19.29
2	MW03-01 C	Figure 19.29
3	MW03-02 A	Figure 19.28
4	MW03-02 C	Figure 19.28
5	MW03-09 A	Figure 19.25
6	MW03-09 B	Figure 19.25
7	OW03-14 A	Figure 19.23
8	OW03-14 C	Figure 19.23
9	OW03-15 A	Figure 6.24, Figure 19.22
10	OW03-15 C	Figure 6.24, Figure 19.22
11	OW03-17 A	Figure 19.30
12	OW03-17 B	Figure 19.30
13	OW03-18 A	Figure 19.31
14	OW03-18 C	Figure 19.31
15	OW03-19 A	Figure 19.33
16	OW03-19C	Figure 6.34, Figure 19.33
17	OW03-21 A	Figure 6.25, Figure 19.24
18	OW03-21 B	Figure 6.25, Figure 19.24
19	OW03-21 C	Figure 6.25, Figure 19.24
20	OW03-29 A	Figure 6.27, Figure 19.32
21	OW03-29 B	Figure 6.27, Figure 19.32
22	OW03-30 A	Figure 19.26
23	OW03-30 B	Figure 19.26
24	OW03-31 A	Figure 6.26, Figure 19.27
25	OW03-31 B	Figure 6.26, Figure 19.27
26	MP6	Figure 6.30, Figure 19.40
27	MP16	Figure 6.29, Figure 19.44
28	SG-2 (SG2)	Figure 6.31; Figure 19.43
29	MP5	Figure 6.31, Figure 19.43
30	MP-33	Figure 6.33
31	SW5A-SG	Figure 6.34
32	GP03-37	Figure 19.35
33	MP17	Figure 19.36
34	MP13	Figure 19.37
35	MP11	Figure 19.38
36	MP29	Figure 19.39
37	SW13A-SG	Figure 19.41
38	SG-3	Figure 19.42
39	SW16A-SG	Figure 19.45

14.2 Monitoring locations recommended for long-term monitoring

The wells recommended for inclusion in the long-term monitoring network are listed on Table 10.1 of the Level 1/2 report. The check marks on Table 2 denote those wells for which GSFLOW calibration results are reported. The results for the GSFLOW calibration are reported for only about half of these wells. In our opinion, the GSFLOW calibration should have included all of the wells recommended for inclusion in the long-term monitoring program.

The GSFLOW results represent a prediction of what is likely to occur in the future, and the data from the long-term monitoring program will serve in an ongoing assessment of the realism of that prediction. In our opinion, as a minimum condition for reliability, it should be confirmed that the GSFLOW results provide a reasonable match to data that are *already* available.

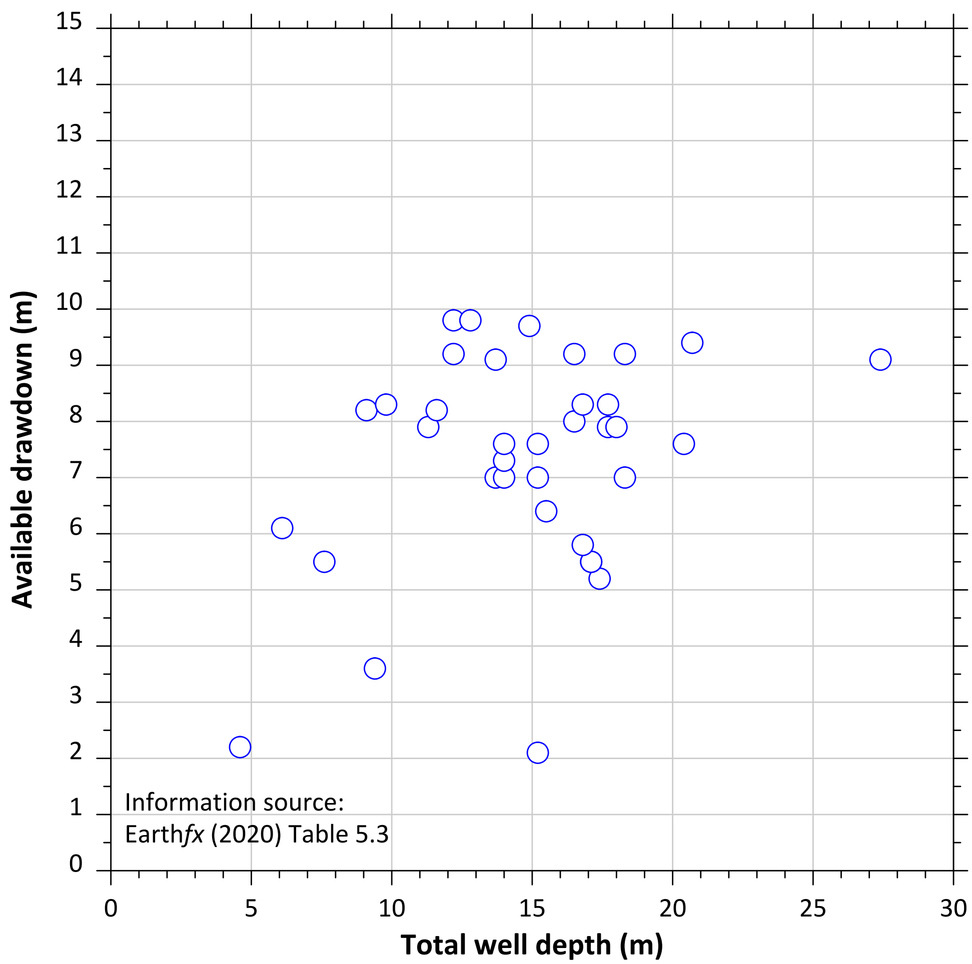
Table 2. Wells recommended for long-term monitoring

Well recommended for long-term monitoring	Well included in reporting of GSFLOW calibration results?
MW03-01 A	√
MW03-01 B	-
MW03-07 A	-
MW03-07 B	-
(OW) MW03-09 A	√
(OW) MW03-09 B	√
(OW) MW03-14 A	√
(OW) MW03-14 B	√
(OW) MW03-15 A	√
(OW) MW03-15 B	√
(OW) MW03-17 A	√
(OW) MW03-17 B	√
(OW) MW03-18 A	√
(OW) MW03-18 B	√
(OW) MW03-19 A	√
(OW) MW03-19 B	√
MW03-20 A	-
MW03-20 B	-
(OW) MW03-21 A	√
(OW) MW03-21 B	√
MW03-28 A	-
MW03-28 B	-
(OW) MW03-29 A	√
(OW) MW03-29 B	√
(OW) MW03-30 A	√
(OW) MW03-30 B	√
BS-01 A	-
BS-01 B	-
BS-02 A	-
BS-02 B	-
BS-03 A	-
BS-03 B	-
BS-04 A	-
BS-04 B	-
BS-05 A	-
BS-05 B	-
BS-07	-
P-MW-08	-
P-MW-09	-
P-MW-10	-
P-MW-11	-

15. The next-to-last paragraph on page 167 of the Earthfx report reads:

> *Figure 7.3 presents a summary of the groundwater supply conditions in the study area. This figure shows the available groundwater drawdown in the Amabel Formation. At any location in the vicinity of the quarry a private water well could be drilled to the Layer 8 fracture zone and would have up to 22 m of available drawdown. Near the existing quarry that drawdown is reduced by the effects of the quarry dewatering, but many wells are both shallow, and in close proximity to the quarry, and yet have had suitable water supply for many years.*

It is not clear why model Layer 8 [Amabel Lower Fracture Zone] has been selected for the assessment of the available drawdown for baseline conditions. The depths of private wells within 500 m of the extraction boundary are reported on Table 5.3 of the Earthfx report. As shown in the plot of these data below, it is likely that private wells extend only into the weathered top of rock (model Layer 4) or model Layer 6 [Amabel Middle Fracture Zone].



Our impression is that it has been assumed in the modelling that the lower portion of the Amabel Formation is a productive aquifer. This assumption does not appear to be consistent with the results of packer testing (Figure 5.6), which does not show an interval of consistently higher productivity at the bottom of the Amabel (i.e., relatively higher hydraulic conductivity). It appears that the greatest weight has been placed on the results of the testing of BS-01 (Figure 3.25), a location that does not seem to be typical of the bottom of the Amabel Formation as shown on the profiles of packer testing (Figures 5.6, 5.7 and 5.8).

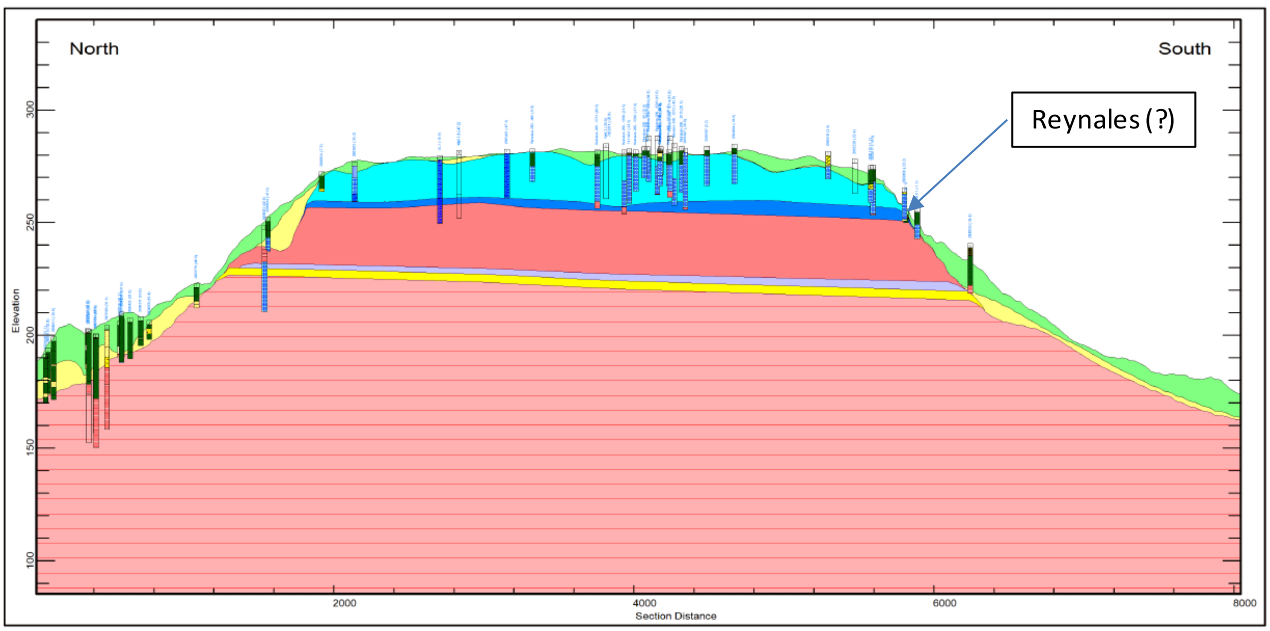
Figure 7.3 shows a map of calculated values derived from two other maps of calculated values that are not provided. It appears that what is shown is the difference between (1) the simulated average water level in Layer 8 of the model (Lower Fracture Zone) for the period of WY2010-WY2019, and (2) the assumed elevation of the top of Layer 8. It is not possible to assess the reliability of this figure with the information provided in the report. As far as we are aware, no map of simulated water levels in Layer 8 is included in the report. Our interpretation of the time period may not be correct. The description of Figure 7.17 in the preceding paragraph refers to a time period of WY2015-WY2019. We could also be wrong about the assumed elevation for calculating the available drawdown. It might be the middle or the bottom of Layer 8. We have not been able to find the reporting of the thickness for layer 8. It is described as 'representing a thin lower fracture zone' (page 481 second last paragraph).

More important than simply checking the reliability of the calculation of the values of the available drawdown shown in Figure 7.3, it is not possible to assess the reliability of the simulated groundwater levels used in the calculations. In Figures 18.3 and 19.3, simulated average water levels are compared with water levels reported in the well records for the private wells beyond the site boundary. The results shown in these two figures suggest that the likely mismatch at the location of an individual well is relatively large, on the order of ±10 m.

No comparable assessment of the match to the average water levels for on-site monitoring intervals in the Amabel Lower Fracture Zone is presented in the report. Observed and simulated hydrographs for 12 observation wells are presented in Figures 19.22 through 19.33; however, there is no indication of the average levels, nor is it indicated which of the wells are open across only the Lower Fracture Zone. We note that there is a phase shift in these hydrographs resulting in a difference of 0.5 to 1.0 m at the south end of the southern extension between measured and simulated water levels of the lower Amabel (OW03-17A, 18A, 19A, 29A -Figures 19-30, 19-31, 19-33, and 19-32, respectively). A similar difference is noted along the west side of the southern extension at MW03-01 (Figure 19-29). This difference increases to several metres closer to the existing quarry at MW03-02 (Figure 19-28).

3. Detailed technical comments

1. Page 58: It is indicated in the text that "while Brunton (2008) was able to subdivide the Reynales, these units are hydrogeologically similar (dolostone with shale partings) and are un-subdivided in the Golder and MECP logs; for simplicity, the Rockway and Merritton unit is referred to herein as the Reynales Formation." We have checked with Mr. Brunton, and he writes, "There is no Reynales at this quarry. In fact the greenish unit below Merritton or upper Fossil Hill Fm may in fact be a thin Grimsby Formation unit" (written communication, October 15, 2020).



2. Page 105: It is indicated that downward leakage tends to minimize the differences in the head between the shallow and deeper bedrock layers. This seems to be in direct conflict with the water level data shown in Figure 5.11. There is a substantial difference in the water levels between the "A" and "B" intervals (~10 m), and it may only be possible to sustain this head difference if the intervening rock has relatively low vertical hydraulic conductivity at this location.

3. Figures 5.11, 5.12, 19.6, 19.12, 19.15: In our opinion, the connecting of the hydrographs across time long gaps provides a misleading impression. The lines connecting the gaps are in effect speculations regarding what might have happened during the gaps. We have reproduced alternate hydrographs for OW-3-14 to illustrate our objections to the presentation and to illustrate an appropriate approach.

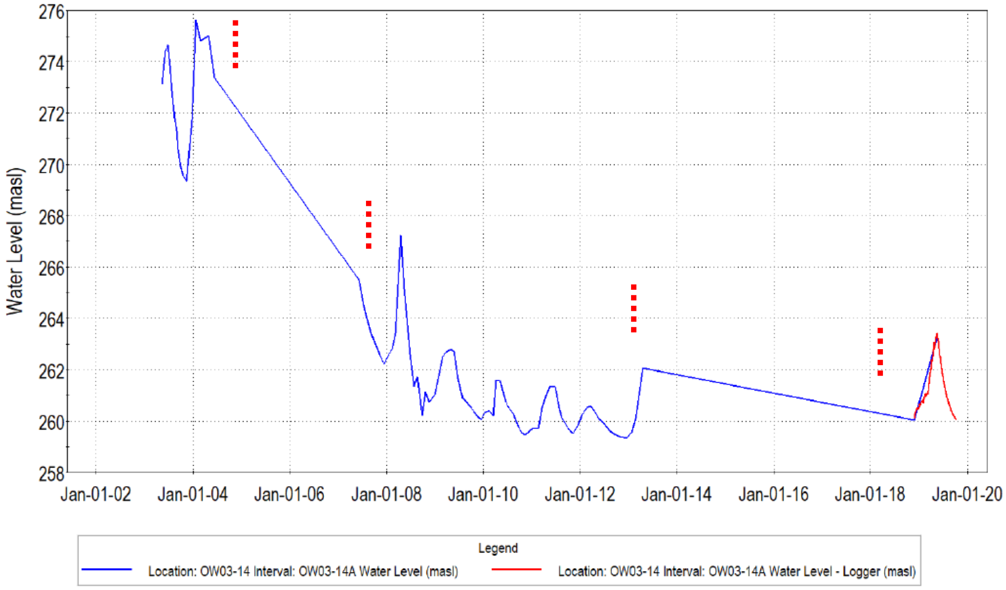
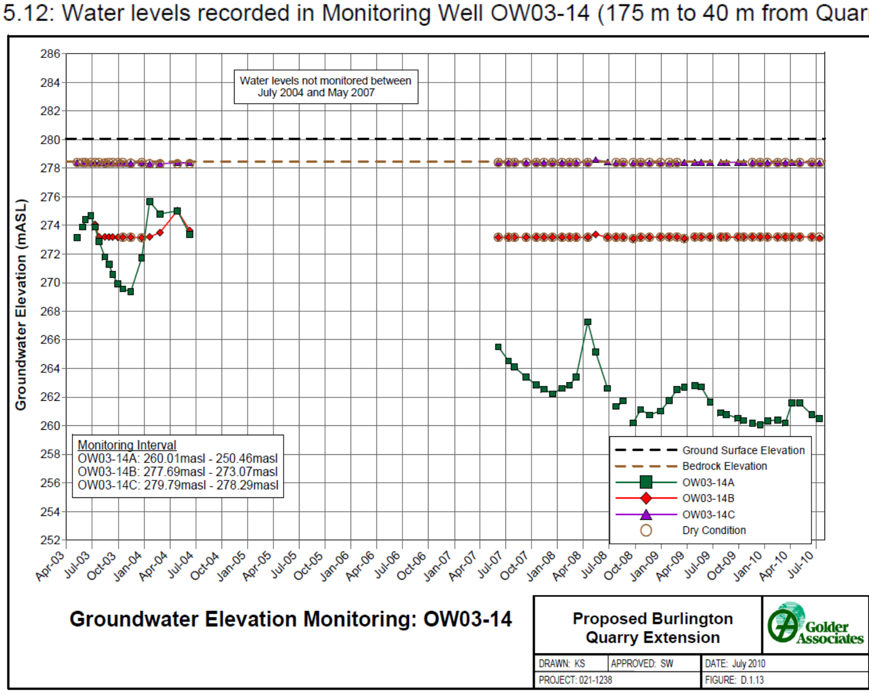


Figure 5.12: Water levels recorded in Monitoring Well OW03-14 (175 m to 40 m from Quarry face).



4. Page 109: When presenting water levels and interpretations, it is important to note from the outset the important differences in the reliability of the levels in the MECP WWIS database and the average water levels inferred from the records for the Site monitoring wells.

6. Page 124: Does it make sense to conceive of and distinguish between Hortonian and Dunnian runoff when only daily values of precipitation are available and the PRMS analysis has 1-day time steps? Wouldn't the simulated intensity of the rainfall generally be quite different from the actual intensity?

7. Page 132: It is indicated that an "acceptable" Nash-Sutcliffe efficiency of 0.44 was achieved with the PRMS-only analysis of the Aldershot gauge, and an efficiency of 0.67 was achieved with the GSFLOW analysis. Chiew and McMahon (1993) is cited for the consideration of 0.6 as "a reasonable calibration value". It is worthwhile to consider exactly what Chiew and McMahon (1993) wrote.

> For typical hydrology and water resources studies (in particular, reservoir and catchment yield analyses), a flow estimate can generally be considered to be
>
> PERFECT if
> $E \geq 0{\cdot}93$ or $R^2 \geq 0{\cdot}97$ or $R^2 \geq 0{\cdot}93$ with mean estimated flow within 10% of mean recorded flow.
>
> ACCEPTABLE if
> $E \geq 0{\cdot}80$ or $R^2 \geq 0{\cdot}90$ or $R^2 \geq 0{\cdot}77$ with mean estimated flow within 10% of mean recorded flow.
>
> Simulations with $E \geq 0{\cdot}60$ are generally satisfactory (inspection of graphical plots would be useful) and can be used to at least provide approximate flow volumes and for preliminary investigative studies.

Generally satisfactory results for approximate flow volumes and preliminary investigative studies is not the same as "reasonable".

8. Page 523: Simulation results are presented for stream gauge SW2 in the Medad Valley. Referring to Figure 19.4, were results also obtained for the other stream gauges in the Medad Valley, SW14 and SW7? Our impression is that the reach between SW14 and SW7 will be critical with respect to an appreciation of potential impacts to streamflows of the proposed extension.

9. Page 536: It is indicated that the simulated deep water levels at MW03-2 is "somewhat higher than the observed values." Our inspection of Figure 19.28 suggests that the simulated average water level is about 267.5 m amsl, substantially higher than the observed average of 259.5 m amsl. We also note that the match shown to MW03-01A levels is also relatively poor, capturing none of the significant declines that are observed through time. The observed levels range from 271.5 to 267 m amsl, compared with the simulated range of 271 to 269 m amsl.

4. Requests for clarification

1. The control points for mapping the elevations of the top of the Cabot Head Formation are shown in Figure 3.13. What control points were used to map the thickness of the Cabot Head Formation shown in Figure 3.14?

2. The control points for mapping the elevations of the top of the Reynales Formation [sic - see Detailed technical comment #1] are shown in Figure 3.15. What control points were used to map the thickness of the Reynales Formation shown in Figure 3.16?

3. Page 67: What is the basis for the indication that the Irondequoit, Gasport and Goat Island formations are hydrogeologically similar? Our experience elsewhere in southern Ontario suggests that their hydrogeologic characteristics are distinct. Has any attempt been made at the site to conduct hydraulic tests on the separate units? Referring to Figure 3.25, no packer test results are shown for the Goat Island Formation, and substantially lower values of hydraulic conductivity are estimated for the rocks between the Gasport Formation and the Cabot Head Formation.

4. What control points were specified to support the mapping of the elevations of the top of bedrock? Does the mapping shown in Figure 3.23 lump high-quality data from site monitoring wells and the information from the MECP water well record database?

5. What control points were specified to support the mapping of the thickness of the Amabel Formation in Figure 3.24 [Goat Island Formation + Gasport Formation + Irondequoit/Merritton/Rockway]?

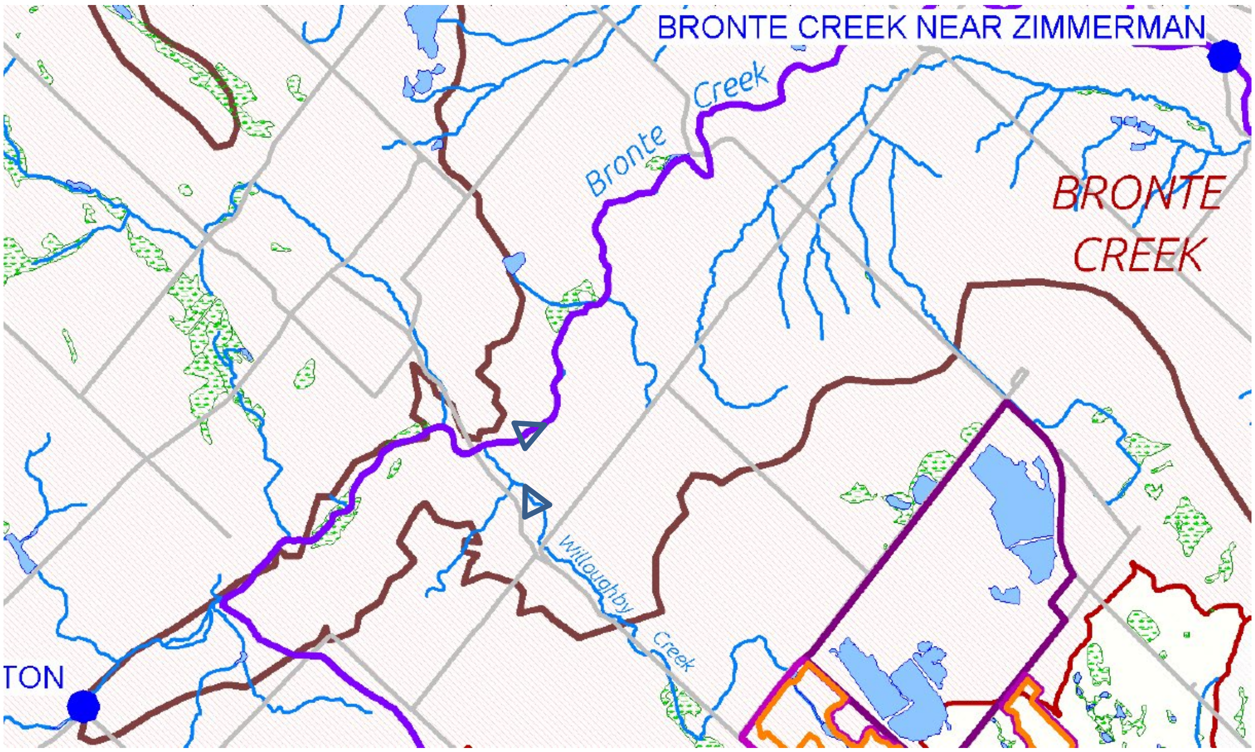
6. What control points were specified to support the mapping of the thickness of the Halton Till in Figure 3.27?

7. What control points were specified to support the mapping of the thickness of the MIS sands and ORAC in Figure 3.28?

8. Page 86: Is there a record of flows in Willoughby Creek?

Mr. Joe Nethery, MCIP, RPP
December 16, 2020
Page 30

9. Page 86: Referring to Figure 4.10, are we correct in understanding that Willoughby Creek is almost perpendicular to Bronte Creek where it discharges to Bronte Creek?



10. Page 87: It is indicated that the discrepancy between the Ontario Hydro Network (OHN) mapping and the observed golf course and quarry pond is due to the time period during which the OHN mapping was conducted. Documentation of the OHN mapping is not cited in the list of references. What was time period for the OHN mapping?

11. Page 102: Is this bedding plane fracture shown in Figure 5.9 at an elevation close to the elevations assigned for the middle flow zone in the model (model layer 6)?

12. Page 105: It is indicated that municipal supply wells FDF01 and FDF03 "have been interpreted to intersect the highly permeable fractured zone in the middle of the Gasport Formation." Who has made this interpretation?

13. Page 108: It is indicated that a horizontal hydraulic conductivity of 1×10^{-7} m/s (1×10^{-8} m/s, vertical) was selected for the Lower Aquitard (collectively the Lower Gasport through Manitoulin formations). What is the basis for this selection? Are the model results sensitive to the value of the hydraulic conductivity assigned to Layer 9?

14. Page 109, Figures 5.13 and 5.14: Are the water level maps developed exclusively from levels reported in the MECP WWIS database? If yes, how do maps compare with the high-reliability data from dedicated Site monitoring wells? If no, how were the data of very different reliability synthesized?

15. Page 109, Figures 5.13 and 5.14: How do the water level maps compare with the interpreted hydrostratigraphy? For example, are the levels for wells with completion depths less than 15 m representative of the weathered top of rock, the “middle Amabel flow zone”, or some synthesis of both? Are the levels for wells with completion depths greater than 15 m representative of the “middle Amabel flow zone”, the “lower Amabel flow zone”, or again some kind of average for both intervals?

16. Page 110, Figure 5.15: What is the sign convention adopted for the mapping of the head differences in Figure 5.15? Is the following interpretation correct (with h denoting hydraulic head)?

    - Negative values: $h(<15\text{ m}) > h(>15\text{ m}) \longrightarrow$ downward flow
    - Positive values: $h(<15\text{ m}) < h(>15\text{ m}) \longrightarrow$ upward flow

17. Page 118: Why has a distance of 500 m from the proposed extraction area been selected for particular focus. Is it expected that beyond this distance the potential impacts to private wells will be negligible? Does the calibrated model support this expectation?

18. Figure 6.8: How is convergence checked in the GSFLOW simulation?

19. Page 129: Reference in the text is made to MNR Soil Survey Complex (2013). However, the date of reference in Section 14 is 2003, accessed in October 2014. What is the correct date for this mapping?

20. Page 129: It is indicated that parameters that controlled the partitioning of flow between interflow and percolation to the water table were also specified as soil-type properties. What parameters are referred to here, and what are the bases for the specification of their values?

21. Page 135: Referring to Figure 6.4, what are the capillary and drainage reservoirs?

22. Pages 140-141: It is indicated that Layer 4 has a minimum thickness of 1.0 m. However, on page 103 it is indicated that an assumed depth of weathering equal to 0.3 m was applied across the model, extending down from the top of bedrock. What is the correct thickness of model layer 4? Do the available hydraulic testing data support an inference of the depth of weathering in the rock?

23. Page 523: It is indicated that the model does not include the "many" constructed in-line and off-line ponds in the Medad Valley. On page 486 it is indicated that the final model included 40 MODFLOW "lakes" and our inspection of Figures 6.21 and 18.9 suggests that this includes many small features elsewhere. Why were small ponds included in some areas but not others?

24. We are confused by the color scheme in Figure 6.39 and Figures 19.48. In our copy of the report, the terms "Net outflow from storage" and "Net boundary flow in" have identical colors. Are we correct in understanding that the positive blue quantities denote the "Net boundary flow in" and the negative blue quantities denote the "Net outflow from storage"? We are also confused by the term "Net outflow from storage". If this is indeed a negative quantity, shouldn't it correspond to sink for the groundwater system, with water going <u>into</u> storage, as MODFLOW would simulate during months of rising groundwater levels? And wouldn't there be months during which groundwater levels declined and the changes in storage would be interpreted as sources in the groundwater budget?

5. Missing references

Although the Level 1 and Level 2 report is extensive, it is not complete. Complete references for may of the documents cited in the report are missing. Missing references are listed below.

Page 52: Brunton, 2008

Page 52: Brunton, 2009

Page 52: Johnson et al., 1991

Page 54: Liberty et al., 1976

Page 54: Brett et al., 1990

Page 54: Bond et al., 1976

Page 54, 67: Johnson et al., 1992

Page 57: Brett et al., 1995

Page 57: Voss, 1969

Page 57, 103: Golder, 2004 (also Figure 5.9)

Page 71: Karrow, 1987. In addition to including the complete citation in the list of references, the specific map sheet should be indicated, Map 2508.

Page 71: OGS, 2010 [and Figure 3.26]

Page 71: White, 1975

Page 71: Karrow, 2005

Page 71: Chapman and Putnam, 1984

Page 71: Barnett, 1992

Page 82, 132: Earthfx, 2010

Page 82, 132: Hargreaves and Samani, 1982

Page 82: MNRF, 2013 (also Figure 4.9)

Page 86: Worthington Water, 2020

Page 86: Worthington, 2020

Page 86: Worthington Groundwater, 2020

Page 104: Golder, 2005

Page 104: Jagger Himms [sic] (2003) [should read “Hims”]

Page 104: Charlesworth & Associates (2006)

Page 104: Dillon (2008)

Page 104: Gartner Lee (2005)

Page 104: AECOM (2009)

Page 104: OGS (2010)

Page 104: Wood (2018a)

Page 104: Earthfx (2020)

Page 105: Brunton, 2007

Page 109: Kassenaar and Wexler, 2006

Page 121: Huntington and Niswonger, 2014

Page 121: Hunt et al., 2013

Page 121: Ely and Kahle, 2012

Page 121: Tanvir Hassan et al., 2014

Page 121: Niswonger et al., 2014

Page 121: Leavesly et al., 2011 [should be Leavesley]

Page 142: The reference in the text of the report is to Golder Associates (2007). Is that to Golder Associates (2007a) or Golder Associates (2007b) in the list of references?

Page 143, 512: Chiew and McMahon, 1993

Page 460: [Figure 17.10] MNR, 2013

6. Details that appear to be incorrect

1. The references for the SOLRIS land use mapping are not consistent. In the text, reference is made to SOLRIS v.3 (2019) (pages 82, 132, 446, Figures 4.8, 6.11, 17.12). However, the citation in the list of references is to MNRF (2014), accessed August 2015.

2. Page 481: The northing coordinate for the model lower left-hand corner cannot be 4,794,585,500 m. Although no coordinates are indicated in Figure 18.4, we think the coordinate must be wrong by a factor of 1,000.

3. Page 483: The right side of Equation (18.4) is missing an area term.

4. Page 554: Referring to Table 19.1, the "inflow" reported for evaporation from interception represents 125% of the precipitation. If the correct percentage of the precipitation is indeed 12.8%, the correct value must be 26,070 m^3/d.

5. Page 554: It is not possible to reproduce the reported overall discrepancy in the GSFLOW groundwater budget for WY2010-WY2014 (Table 19.1). The components of the budget are reproduced below.

Item	Volumetric rate (m^3/d)
INFLOWS	
Recharge	28,155
Stream leakage	2,885
Lake leakage	2,103
Total inflows	**33,143**
OUTFLOWS	
Evapotranspiration from the water table	-2,817
Discharge to the soil zone (rejected recharge?)	-28,482
Net boundary outflows	-84.3
Groundwater discharge to streams	-2,498
Groundwater discharge to lakes	-1,229
Total outflows	**-35,110.3**

Assuming that "net outflow from storage" represents a source of water to the groundwater system from a net decline in groundwater levels, the overall water budget discrepancy is written as:

$$\%\ \text{Discrepancy} = 100 \times \frac{(\text{Total inflows} + \text{Net outflow from storage}) - \text{Total outflows}}{\frac{1}{2}[(\text{Total inflows} + \text{Net outflow from storage}) + \text{Total outflows}]}$$

$$= 100 \times \frac{(33{,}143 + 852) - 35{,}110.3}{\frac{1}{2}[(33{,}143 + 852) + 35{,}110.3]} = \mathbf{-3.2}\%$$

In contrast, the reported % Discrepancy is **-0.6%**.

Closing

We appreciate the opportunity to serve Halton Region on this interesting and important assignment. If you have any questions regarding our comments, please contact Christopher Neville by E-mail at *cneville@sspa.com*, or by phone at (519) 579-2100.

Sincerely,

S.S. PAPADOPULOS & ASSOCIATES, INC.

LICENSED PROFESSIONAL ENGINEER
C. J. NEVILLE
PROVINCE OF ONTARIO

Christopher J. Neville, M.Sc., P.Eng.
Chief Hydrogeologist

- Christopher J. Neville: PEO #100013705
  (valid through December 31, 2021)
- S.S. Papadopulos & Associates, Inc.: PEO Certificate of Authorization #100077381
  (valid through June 30, 2021)

CJN/cjn
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Golder Associates, 2010: Consolidated Water Resource Assessment Report for the Proposed Nelson Aggregate Co., Burlington Quarry Extension, Burlington, Ontario, submitted as part of the Witness Statement of Mr. Sean McFarland, P.Geo., submitted to Nelson Aggregate Co., Burlington, Ontario, September 2010.

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