Centre Wellington Scoped Tier 3 Water Budget Study: Discussion on draft Groundwater Flow Model Development and Calibration Report

Location: Grand River Conservation Authority Head Office, Cambridge
Date: August 13, 2018
Time: 1:30 pm to 3:30 pm

Meeting Objective: To discuss and provide clarification to comments provided by S.S. Papadopulos & Associates on behalf of Nestlé Waters Canada (NWC) on the draft Groundwater Model Development and Calibration Report prepared as a part of the Centre Wellington Scoped Tier 3 Water Budget Study.

Discussion Items: A list of discussion items are included in the meeting agenda in Appendix A.

Participants: A list of participants is available in Appendix B.

Comments: Comments provided by S.S. Papadopulos & Associates on behalf of NWC are provided in Appendix C.

Summary
Project consultants discussed NWC's comments with the group; the discussion has been summarized into the follow sections:

- Model domain and boundary conditions
- Model calibration
- Data gaps and uncertainty assessment
- Water budget
- Middlebrook well
- Model purpose

Model Domain and Boundary Conditions
Matrix provided an overview as to:

- How the current groundwater flow model was expanded beyond the previous boundaries of the Golder groundwater model,
- The development of the three water level contour maps for the study area (overburden; contact zone and Upper Guelph Formation; Lower Guelph, Goat Island and Gasport Formations),
- How boundary conditions were set for each of these layers in the 3D model.

There was further discussion with the OGS regarding the lower Guelph Formation's characterization as an aquitard [to the north] and how this is supported by available data.

SSPA inquired about the boundary conditions around the outside of the model and if surface water boundary conditions are fixed and controlled by the DEM. Matrix described how the boundary conditions for each of the aquifers were derived from available water well records and confirmed that surface water boundaries are fixed and based on the hydraulically corrected DEM.

Matrix further reviewed model recharge as another boundary condition. SSPA noted that the important questions to answer with the model overall are: where does the water come from and where does the water go? OGS suggested providing figures for the various interpreted flow zones that show the key wells used to inform the model with regard to water levels, hydrostratigraphic characterization, and flow directions across model boundaries. SSPA is interested in how the model fits into the sub-watershed budgets from the Tier 2 analysis. The discussion following expanded upon the comparison of the Tier 2 and Tier 3 water budgets presented in the draft Groundwater Flow Model Development and Calibration report.

Matrix reviewed how the model fits into the sub watershed budgets from the Tier 2 analysis by reviewing Table 8 of the report. The conceptual model and information available has evolved significantly from the Tier 2 water budget study. Previously, consultants were using an older configuration of Guelph-Eramosa bedrock units, which is different from those that have been characterized more recently.

Matrix also noted that none of the previous Tier 3 models followed Tier 2 boundaries; this same process was followed in the City of Guelph / Guelph Eramosa Township Tier 3 study. Most of the data for Tier 3 studies is concentrated around municipal wells.

MECP suggested that a limitation of the Golder Report in completing the water capacity assessment was data availability, and questioned why this did not remain a limitation in the current Tier 3 study when the domain is larger than in the Golder Report. Matrix responded that the size of the Golder model was a concern, and not the data available. With extensive capture zones, many wellhead protection areas in Ontario bedrock aquifers extend well beyond the municipal data available.

MECP requested Matrix to document areas where data availability is limiting, and how things may change in the future, and how to use/interpret the existing information. Matrix replied that beyond the data gaps already discussed within the draft Groundwater Flow Model Development and Calibration report, they will be better able to identify areas where additional data is needed once the uncertainty analysis and risk assessment is completed. This will tell them which areas of uncertainty most-affect the municipal wells.

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Model Calibration

Matrix provided a discussion on their approach to model calibration. There are fairly uniform hydraulic conductivities throughout the study area. The Guelph Formation acts as an aquitard. SSPA inquired where the aquitard in the Guelph Formation is located. Matrix explained that the Guelph Formation aquitard is represented as fairly ubiquitous through the model, upgradient of the municipal wells.

Matrix provided further discussion on their approach to steady state calibration. SSPA requested two versions for the steady state model calibration chart, one with the high-quality data and one with the low-quality data.

Matrix noted that water well records may carry 5-10 m average uncertainty. That is essentially the most accuracy a model can attain, as that is the average variability of groundwater level observations over an area. SSPA inquired about the probability distribution of the calibration residuals. Matrix discussed with the group the general challenge of calibrating to municipal wells because water levels change hourly and can vary by > 30m within a day depending on pumping demand. Further discussion ensued regarding how they are addressing these challenges.

MECP inquired if observation wells (located near to municipal wells) can provide data that is a better fit for the model. Matrix responded that observation wells can provide tighter ranges on data. They stated that there were challenges matching both the overburden and the bedrock sets. Some clusters of observation wells are multilevel well systems with large water level changes (e.g., 20-25m) over relatively short vertical elevation differences (e.g., 5m).

SSPA commented that pumping well data is not a reflection of the variability of the water levels, but rather of the variability of the pumping and non-pumping conditions. SSPA suggested that water levels recorded for older private water well records could reflect conditions that pre-date pumping, and further suggested filtering these data sets to ensure the model calibration focuses on data that reflects stressed conditions. SSPA noted that E4 has very wide ranges, which can be ascribed to the difference between pumping and non-pumping.

MECP stated that if there appears to be a large head difference between the overburden and the bedrock, then water is moving through. Matrix responded that the multi-level well data, and the gradients they indicate, are key data for calibrating the hydraulic conductivity of the Guelph Formation bedrock aquitard. The calibrated water levels are very sensitive to the hydraulic conductivity of the aquitard. Within the Fergus and Elora Area, Matrix has a relatively high level of confidence in the hydraulic conductivity.

SSPA inquired if there was accounting for well losses. Matrix responded that well losses for existing pumping conditions were accounted for in the model calibration. Through the transient calibration efforts, well responses to pumping were directly incorporated into the model, as demonstrated by the ability to match the long-term pumping and shut-down data collected during Fall, 2012. Additional well losses are added manually when evaluating potential responses to future pumping, beyond rates experienced during tested in 2012.

OGS inquired if the E3 and E4 pumping tests were fairly reliable. Matrix responded that they were, and that the model-simulated and observed values match very well. Matrix responded that the drawdown data sets are unique for each well and that local hydraulic conductivities are independently assigned. There is a good match in both locations between the observed and simulated responses to pumping as documented in the calibration report. The response to pumping is simulated to propagate across the Guelph Formation aquitard. Simulated responses across the aquitard are a good match to those observed at key multi-level wells (report Figure 13a-d), but was less than observed in MW1 and MW4. Throughout the bedrock system there were good matches in response to timing and magnitude between the model simulation and observed data. This includes the Middlebrook well, where the model adequately reflects observed pumping-response data. Although not perfect, the magnitude is a decent match, which gives a sense the model is simulating the propagation of hydraulic head changes between those locations reasonably well.

SSPA inquired if everything apart from the pumping is held constant. Matrix responded that everything else is held constant. Achieving the steady state and transient calibrations provides confidence moving forward with the water quantity risk assessment.

SSPA inquired if there was a good match around the Guelph Formation, and if the hydraulic conductivities are similar to what Golder inferred in their analysis. Matrix responded that they started working with the Golder characterization of hydraulic conductivity (zones of uniform hydraulic conductivity) and adjusted them to ensure observed water levels were matched as well as possible. The absolute values were different, but similar.

Matrix also noted that they had a reasonable match to simulated groundwater discharge in Irvine Creek, based on the best available information. SSPA noted this is the only stream monitoring station not affected by a reservoir.

SSPA inquired how much variability was observed and simulated at the Middlebrook well during the 2012 pumping test, as illustrated in Figure 13d of the groundwater modelling report. Matrix replied there were about 2 m of variability.

Matrix responded to SSPA's inquiry about the degree of scatter present in Figure 11 of the draft Groundwater Model Development and Calibration Report. The scatter shown in Figure 11 reflects:

- The transient nature of the water level measurement, and whether it is actually contiguous with the pumping conditions or not.
- Structural error and measurement error. For structural error, a water level is being associated with a specific hydrostratigraphic unit within the bedrock; the accuracy of that association depends on the local fractures and where those local fractures are intercepted by that well.
- The assumption is that the water level in the well is representative of the deepest unit the well extends into.

MECP inquired how timing fits into that the selection of the calibration dataset: how data may be from the 1980s and 1990s, and some are from today, and then combined. Matrix responded that is one reason why they expect it to be scattered.

MECP noted that if the same spots are measured today, those same points may be different. Matrix highlighted that the Provincial Groundwater Monitoring Network (PGMN) data don't change a lot over time, reflecting that we should expect background water levels to be relatively consistent outside the influence of pumping.

MECP suggested a clearer qualifying statement be included and highlighted that private well data are not all high quality. Matrix responded that the bigger issue is the location of older data (as measurements of location in past decades are less certain); but the decision to include that data is based on the idea that it is better to have more data than less.

Matrix noted that on the baseflow data, the Irvine River has a drainage area of 195 km^2. They don't have better information on other streams, but the up-gradient area is what is most important from an impact perspective. SSPA replied that they thought down-gradient areas would be more important because pumped water would otherwise discharge further downstream, so with respect to sustainable yield it is how much toleration there can be for a reduction in base flow. Matrix responded that the effect of municipal pumping is small relative to flow in the Grand River and as such pumping effects are unlikely to be evident on the Grand River, but would be evident further downgradient in smaller streams. SSPA suggested identifying where the consulting team would want stream gauges located, to improve stream flow monitoring through time.

Data Gaps and Uncertainty Assessment

In response to SSPA's concern about addressing data gaps and the uncertainty approach, Matrix noted that a Null Space Monte Carlo (NSMC) assessment is planned and will employ PEST (a model-independent parameter estimation and uncertainty analysis tool). This is a substantial process and will be executed once Matrix is confident that no further changes to the model are required.

Regarding concerns about ensuring sufficient high-quality monitoring targets, Matrix responded that high quality monitoring wells are mostly focused around pumping well locations. This is typical of most municipal systems, including those where a Tier 3 analysis has been completed. SSPA further inquired about high quality monitoring targets, and if there are as many as in most other comparable studies, including any PGMN wells. Matrix noted that there is a gap in high quality data between Fergus and Arthur, and this recommendation will be included in the report.

Water Budget

Matrix provided an overview of the water budget and groundwater movement within the Tier 3 study area.

Regarding SSPA's concerns about the majority of water staying shallow and supplying local streams, Matrix noted that this is consistent with their analysis and understanding of most Ontario groundwater systems. Low topographic relief results in low energy (i.e., driving force) that would yield large regional groundwater flow. Pumping is approximately 4% of total inflow.

> ***Kast Subdiscussion***
>
> OGS provided discussion on the groundwater flow through the karst system within the study area. They assert that this was not adequately integrated into the model. Matrix stated they haven't seen the hydraulic data to support those solution cavities extending over large distances. The Equivalent Porous Media (EPM) approach that is being used for this model assumes there are interconnections of fractures and open zones that happen throughout. If there was one strong interconnection, it would be evident in the pumping data.
>
> OGS referenced numerous reports from Florida where attempts have been made to map karst conduits. Researchers have had similar challenges as in Ontario when trying to model karstic system. There needs to be a discussion about the Fergus and Elora flow system regarding the fact that a lot of the water entering the wells comes from very specific horizons (not uniformly throughout a given formation). Discussion ensued with the OGS regarding the connectivity of the karst conduit system.
>
> SSPA requested a figure showing cross boundary flow arrows with attached values.

SSPA inquired if the 6% of the water budget noted as leakage/recharge would impact or place a limit on how much water can be pumped, or if pumping would induce more leakage. Matrix responded that more pumping would induce more leakage. SSPA noted that it would be wrong to read the water budget figure and state that 6% is the maximum that users can take from the system, as that would be an incorrect analysis of the situation.

SSPA inquired if the model conserves flow at the scale of the new areas. Matrix noted that the water budget values are directly from the model simulations without adjustment and reflect that the model conserves flow.

SSPA suggested that Matrix show what the rainfall and evapotranspiration numbers are for the water budget. Matrix noted that this would probably show that the shallow flow that occurs is fairly local, and not all of it is going through long groundwater flow paths.

Middlebrook Well

Matrix noted that the Middlebrook well is not simulated as a well or an open conduit. Matrix provided an overview of how the model was calibrated to observations at the Middlebrook well, and responded to SSPA's concerns about over-simulation of drawdown at the Middlebrook well. Matrix hypothesized that including a strong karstic zone at depth would reduce the simulated drawdown at the Middlebrook well, but that is not yet implemented in the model.

MECP noted it is important for the report to be clear about what data gaps are present and what next steps should occur to strengthen the model, and where the model needs refinement.
Matrix responded that the data gaps discussion in the calibration report and future recommendations will remain focused on what the municipality needs to do to evaluate their water quantity risk assessment. GRCA noted that instead of making recommendations on the aforementioned topics, the consultants could make a statement that outlines what the boundaries are in which the consultants completed this project, and provide recommendations within. This could be a statement about what the appropriate use of the model is and is not, in its current state.

The Township of Centre Wellington noted that the model will inform where they place new wells to keep up with growing water demands.

Matrix noted that as wells are drilled, and additional long and short-term pumping tests are completed, those data sets will provide additional data that can be used to continuously improve the model.

MECP inquired if the water budget percentages reflect maximum or average pumping. Matrix responded that the current water budget numbers reflects 2016 pumping, not maximum pumping. MECP requested that water budget percentages also be reported under high pumping conditions. Matrix stated that was possible and reminded the group that those numbers will change based on the demand on different parts in the strata.

SSPA asked whether the simulated transmissivity in the model local to the Middlebrook well reflected that estimated through pumping tests (i.e., 300 m^2/d). Matrix provided data that indicated that the simulated transmissivity of the Gasport layer alone was 75 m^2/d, but that they did not have information for the simulated cumulative transmissivity along the entire length of the Middlebrook well; such detailed assessment of the Middlebrook well is considered outside the scope of the Tier 3 study.

Model Purpose

Matrix discussed that they do not dispute the existence of karst zones; their understanding will evolve through time and new information, as it becomes available, should be used to refine the model to that it can continue to be a useful tool for understanding and managing local water resources. Generally, the model is a reasonable representation of the system.
Matrix further summarized the stated purpose of the model:

- To simulate the ability for municipal wells to meet future / allocated rates under steady state and drought conditions;
- To assess the impact of changes in pumping and land use development on municipal wells and other water uses, such as cold-water streams and Provincially Significant Wetlands.

The model is well-calibrated to both steady-state and transient responses in multiple aquifers. The model has also met the standard of other Tier Three assessments and has been reviewed by a team of provincially appointed expert peer reviewers.

The current state of the model calibration is suitable for the scoped Tier 3 water quantity risk assessment. It can be considered a “living” tool that can be updated as new data / knowledge becomes available to meet needs outside of the Tier Three assessment. Centre Wellington maintains an active groundwater monitoring network and will continue to build system knowledge.

OGS requested additional information be provided to show what wells are used to make various statements. They questioned how any groundwater flow can be modelled in the Gasport as there are very few wells in that area. Matrix responded that they have implemented the best available conceptualization, and applied hydraulic conductivities that are similar to those applied in neighbouring studies to simulate conditions in the deep bedrock, even though the observation data for these units is lacking.

SSPA noted that it is important to qualify that the model’s best fit is in the immediate vicinity to municipal wells where there is high quality data. SSPA noted that the Irvine Creek data used to calibrate groundwater – surface water interaction only constrains conditions upgradient of the municipal wells, not down-gradient of the municipal wells, where pumping impacts are most-likely to be observed. As such, SSPA stated that in their opinion, the model will not be able to reliably answer the question of how increased municipal pumping will impact surface water features downgradient.

Meeting Outcomes

The following list details how the draft Groundwater Model Development and Calibration Report will be updated based on the discussion provided in the meeting summary below.

- Additional documentation will be provided to support the selection of boundary conditions. A table will be generated within the Risk Assessment report with boundary condition values and the range of uncertainty given the potentiometric surface and the number of points used to interpolate values.

- A work plan will be developed by Matrix to complete the following:
    - Three to four model scenarios to test the sensitivity of the model calibration and water balance to changes in boundary condition values. Results will be documented in the Risk Assessment.
    - A karst assessment through the creation of a 3D conceptual model of a karst feature. PEST optimization will be completed to evaluate the hydraulic conductivity of the proposed karst feature. Simulated flow conditions with the calibrated karst feature will be reviewed to document new insights gained. Results will be documented in the Risk Assessment report.

- The draft Groundwater Model Calibration report will be updated with the following:
    - a figure showing cross-boundary groundwater flows
    - independent steady state calibration scatterplots for high-quality data and low-quality data. a cumulative probability distribution plot of residuals

Next Steps

The GRCA will publish a summary of the meeting to the project web page. Matrix will finalize the groundwater model development and calibration report and move onto completing the uncertainty and risk assessment.

Appendix A – Agenda

Centre Wellington Scoped Tier 3 Water Budget Study: Discussion on draft Groundwater Flow Model Development and Calibration Report

Location: Grand River Conservation Authority Head Office, Cambridge
Date: August 13, 2018
Time: 1:30pm to 3:30pm

Invited Participants:

Grand River Conservation Authority
Ontario Geological Survey
Lura Consulting
S.S. Papadopulos & Associates
Matrix Solutions Inc.
Ministry of Environment, Conservation, and Parks
Nestlé Waters Canada
Township of Centre Wellington
Wellington Source Water Protection
Aqua Insight

Meeting Objective: To review and discuss comments provided by Nestle Waters Canada on the draft Groundwater Flow Model Development and Calibration Report.

Agenda:

- Selection of model domain and boundary conditions
- Water budget
- Data gaps and uncertainty assessment
- Model calibration
- The use of the model to evaluate potential reductions in groundwater discharge to surface water features
- Middlebrook well

Appendix B: List of Participants

Aqua Insight

- Paul Martin

Grand River Conservation Authority (GRCA)

- Martin Keller
- Sonja Strynatka

Lura Consulting

- Alex Lavasidis

Matrix Solutions Incorporated

- Christian Gabriel
- David Van Vliet

Ministry of Environment, Conservation and Parks (MECP)

- Abdul Quyum
- Kathryn Baker

Nestle Waters Canada (NWC)

- Andreanne Simard
-

Ontario Geological Survey (OGS)

- Frank Brunton

SS Papadopulos (SSPA)

- Chris Neville

Township of Centre Wellington

- Colin Baker

Wellington Source Protection

- Emily Vandermeulen
- Kyle Davis

Appendix C: Comments provided by S.S. Papadopulos on behalf of Nestle Waters Canada

Dr. Andreanne Simard, Ph.D.
Natural Resources Manager
Nestlé Waters Canada
101 Brock Road S.
Puslinch, Ontario
N0B 2J0

Subject: Centre Wellington Scoped Tier Three Water Budget Assessment

Review comments on the draft Groundwater Flow Model Development and Calibration Report

Dear Dr. Simard:

In this letter we provide comments on the **Centre Wellington Scoped Tier Three Water Budget Assessment: Groundwater Flow Model Development and Calibration Report** (*2018_05_08_draft-groundwater-model-development_calibration-report.pdf*). The draft report is dated May 8, 2018.

We have assembled our comments in three main sections:

1. Overall impression and recommendation;
2. Major comments; and
3. Comments specifically related to the Middlebrook well.

1. Overall impression and recommendation

The groundwater model has been developed to support a *scoped* Tier Three assessment. The motivations for developing the model are indicated on Page 1 of the report:

- To simulate the drawdown at municipal pumping wells;
- To evaluate potential reductions in groundwater discharge to surface water features under existing and proposed future conditions; and
- To assess the impact of changes in pumping and land use development on municipal wells and other water uses, such as coldwater streams and Provincially Significant Wetlands.

We concur with the recommendation provided on Page 3 of the report: the Centre Wellington Tier Three model has been developed to focus on municipal water supply systems in the Study Area.

The hydrogeology of the Centre Wellington Study Area is complex and historical monitoring has been limited to areas around the existing wells in Fergus and Elora. If the model is applied to predict the potential effects of groundwater takings beyond these areas, we recommend that analyses start with an assessment of the adequacy of the representation of conditions at the locations of the proposed takings.

2. Major comments

1. We recommend that the results of the Tier Three model be better integrated with the results of the Tier Two analyses.

We concur with the indication in the report that, when establishing the model domain for a groundwater flow model, it is desirable to have the model domain extend to natural groundwater flow divides whenever possible. Large rivers or topographic highs such as moraines often act as groundwater flow divides that are commonly used to establish the model limits. It is indicated on Page 2 that the Study Area boundaries were guided by surface water features and interpreted groundwater flow in the overburden and bedrock. However, referring to Figure 1 here, it is clear that the model area straddles several sub-basins of the Grand River Watershed. Although these sub-basins may not be self-contained, they are hydrologically meaningful, and integrated water budgets were developed for each sub-basin during the Tier Two study.

It is indicated in the report that the Tier Two watershed scale model was not selected for use in the groundwater modelling portion of the Tier Three Assessment due to the regional-scale focus of the watershed scale model. Our impression from Figure 1 is that no consideration was given to the boundaries of the sub-basins. In our opinion, these boundaries would have made for a more appropriate basis for setting the limits of the Tier Three groundwater model. Aligning the model with the boundaries of the sub-basins would have provided for a more meaningful integration of the Centre Wellington Tier Three model within its regional context. Since the model straddles the sub-basins it is not possible to check directly the consistency of the components of the water budgets between the Tier 2 and Tier 3 analyses.

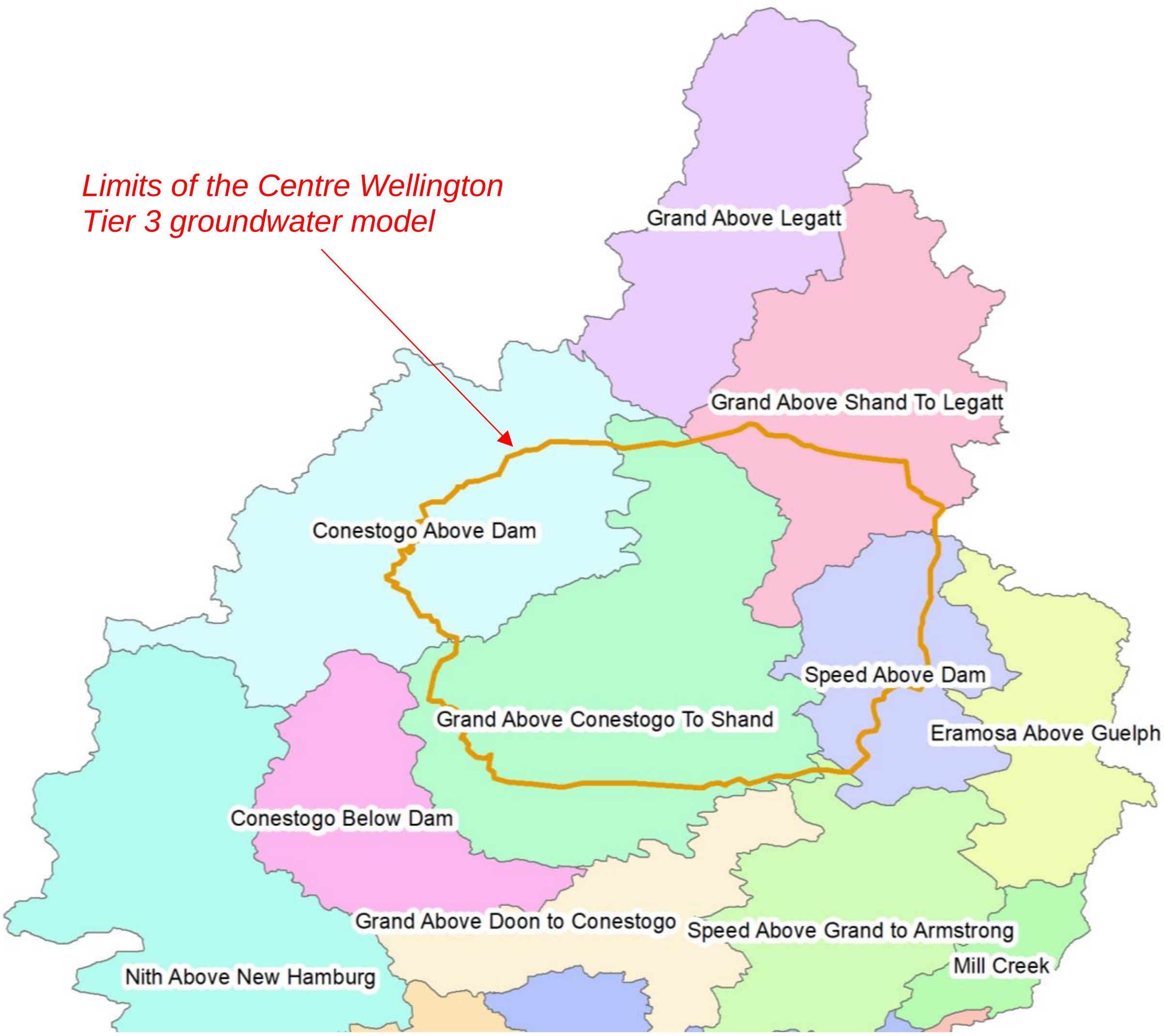


Figure 1. Centre Wellington Tier Three model within the Grand River watershed sub-basins

2. We recommend that additional discussion be provided to support the specification of the model boundary conditions, and the implications of the specification with respect to the water budget calculations.

It is indicated that when designing a groundwater model, the model domain should be far enough away from areas where the model will be used to make predictions, to minimize potential bias that may be introduced by the specification of conditions around the perimeter of the model. In general, this is illusory. Regardless of how far the model boundaries are from municipal wells, the boundaries will have some effect on the local results. This is because the boundaries control the magnitude and direction of regional groundwater flow across the model. The specifications of the model boundaries embed important assumptions in the model regarding entrance and exit points for water. At a minimum, we would expect to see that the simulated flows across the model boundaries are consistent with larger scale results of the Tier Two analyses.

It is indicated in the report that all of the water level elevations applied at constant-head boundary conditions in the model domain were guided by the bedrock water level mapping of values of water levels reported in water well records (WWIS database) near the model boundaries. However, on Page 25 it is suggested that observed water levels from the WWIS have an expected range of uncertainty of approximately 10 m ("i.e., the observed value may be 5 m higher or lower than the value reported in the WWIS"). Our experience suggests that the reliability of a typical water level reported in a water well record may be significantly larger than 5 m. Referring to Figure 11 of the report, it appears that the scatter in the match to WWIS water levels is closer to ±15 m. There is no indication in the report how the low reliability of WWIS water levels propagates through the specification of water levels along the model boundaries or the calculation of groundwater inflows and outflows across the model boundaries.

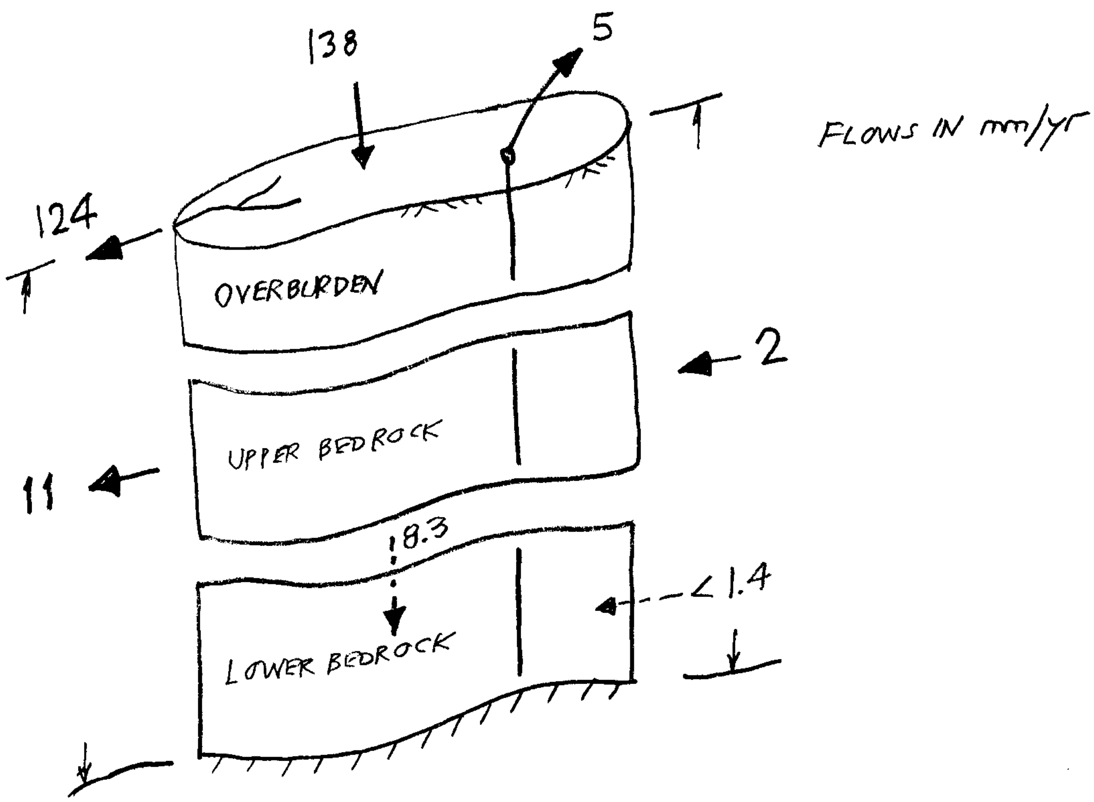
3. The information presented regarding the overall water budget is so important it deserves an extended discussion.

Only an overall groundwater budget is presented (Table 8 of the report). In our Comment #3 we will discuss our reservations regarding this limited presentation. But before we present our reservations, it is important to note that the results on Table 8 are very important and should be discussed further. The results establish a context for appreciating the relative importance of any additional groundwater takings in the Study Area.

The overall water budget presented in the report is reproduced below and illustrated schematically below.

TABLE 8 Groundwater Budget for the Study Area

In/ Out Flow	Component	Flow (mm/y)		Percentage of Total (%)	
		Tier Two	Tier Three	Tier Two	Tier Three
Inflow	Groundwater Recharge	157	138	100%	98%
	Cross-boundary Flows	-	2	-	2%
	Total	157	140		
Outflow	Net Groundwater Discharge to Surface Water Features	125	124	80%	88%
	Groundwater Demand (Pumping Wells)	12	5	8%	4%
	Cross-boundary Flows	20	11	12%	8%
	Total	157	140		



There are two key results in the overall groundwater budget that should be highlighted immediately.

- Assuming that the results presented on Table 8 are reliable, the simulated flows across the boundaries of the model are an insignificant portion of the total water budget. Therefore, in answer to a key question that has been asked previously, “Where does the water come from?”, the answer inferred from the modeling is: “From recharge over the model area.” 98% of the inflow to the model comes from recharge, and 88% leaves as groundwater discharge to surface water features. Figure 4 is particularly evocative in this regard, there is a well-developed surface water network in the model. We suspect that most of the recharge that enters the groundwater system discharges to surface water features within a relatively short distance.

- The results on Table 8 show that the groundwater takings – that is, the total groundwater takings, not just municipal pumping - represent only 4% of the inflow to the model. That is small, regardless of the criterion anyone uses to assess the relative magnitude of the pumping. We expect that if there was no pumping at all, the 4% would be split between groundwater discharge to streams and outflow across the southern boundaries of the model. Since the NWC Middlebrook well is close to the southern boundary of the model, any pumping from the well would probably be balanced by a small reduction in the outflow across the southern boundary and a reduction in groundwater discharge to the streams that leave the Study Area. It is important to note that the Middlebrook well would not be competing for water with the municipal supplies. We expect that a significant increase in municipal pumping would come at the expense of water available to the Middlebrook well. But it does not work the other way around – pumping from the Middlebrook well would be unlikely to cause a reduction in the water that can be withdrawn for municipal supplies.

The Tier 3 model is to be regarded as a refinement of previous (i.e., Tier 2) modeling efforts. The results of the refined analyses show that pumping is an even smaller fraction of the overall flow in the system than was predicted with the Tier 2 analyses.

4. To be most useful in supporting the understanding of the hydrogeological setting, we recommend that the reporting of groundwater flows be expanded.

As indicated in the previous comment, only the overall simulated groundwater budget is presented, and this serves only to confirm that there is overall consistency between groundwater inflows and outflows. To be genuinely useful, the reporting of the modeling should attach magnitudes to the flows indicated in the conceptual model reproduced here in Figure 2.

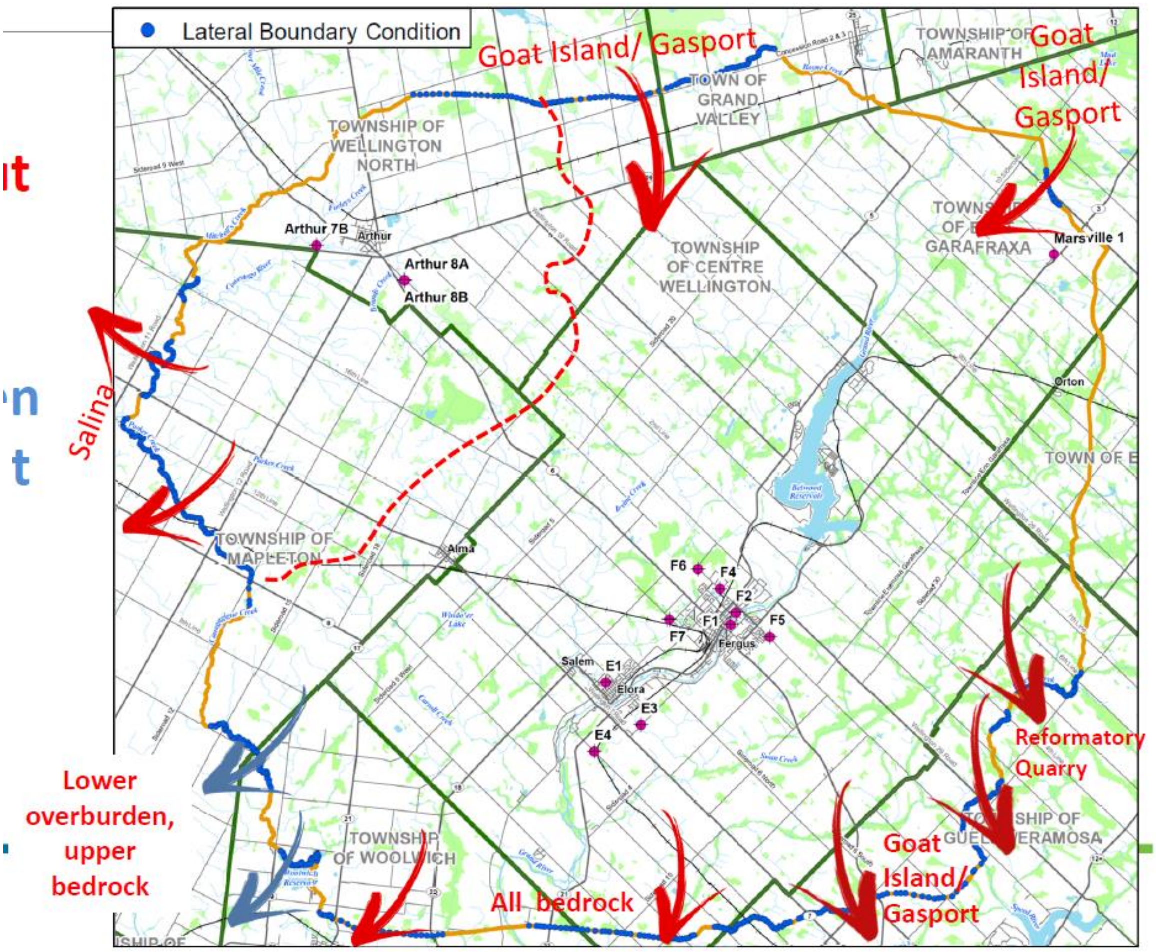
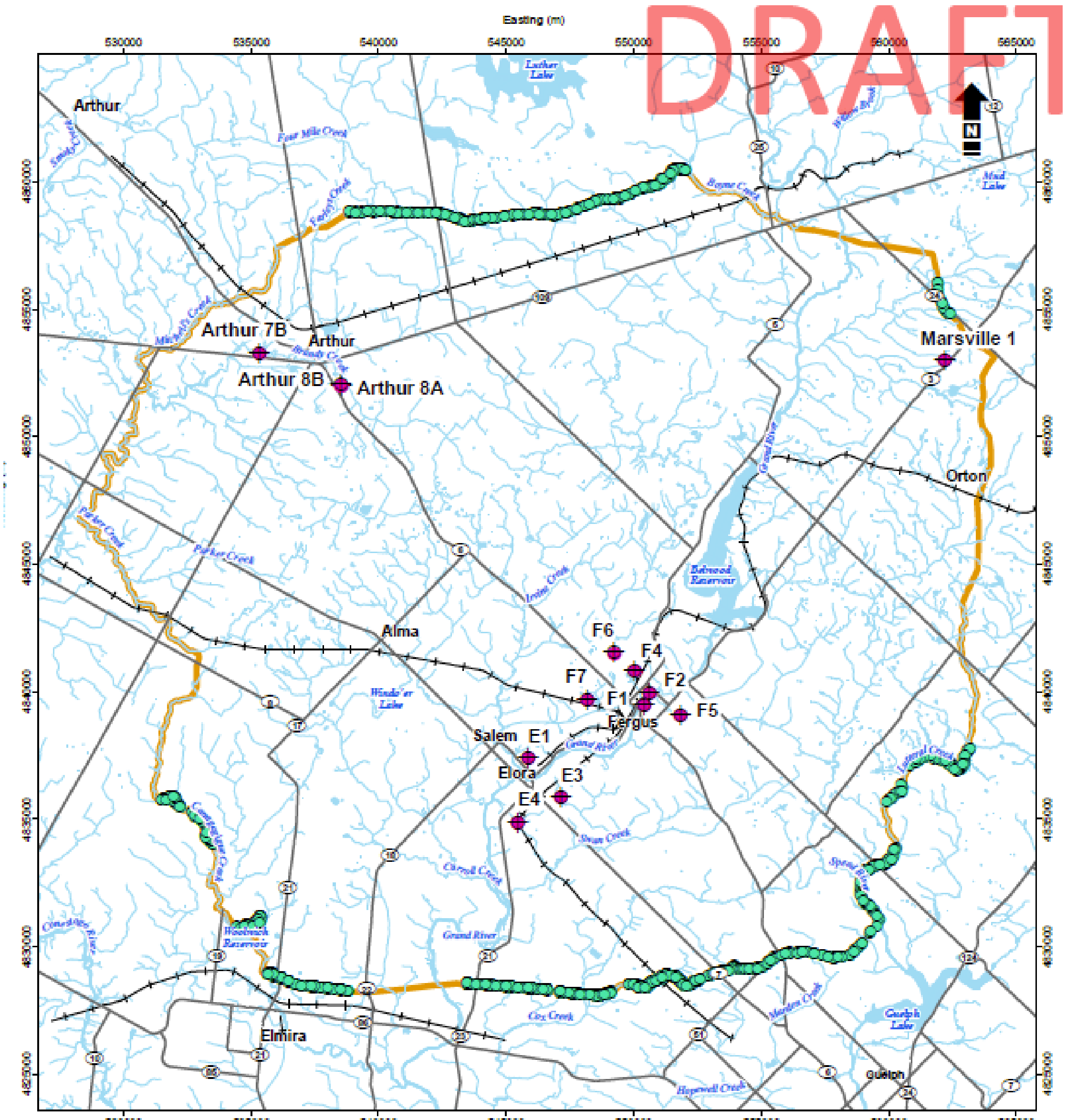


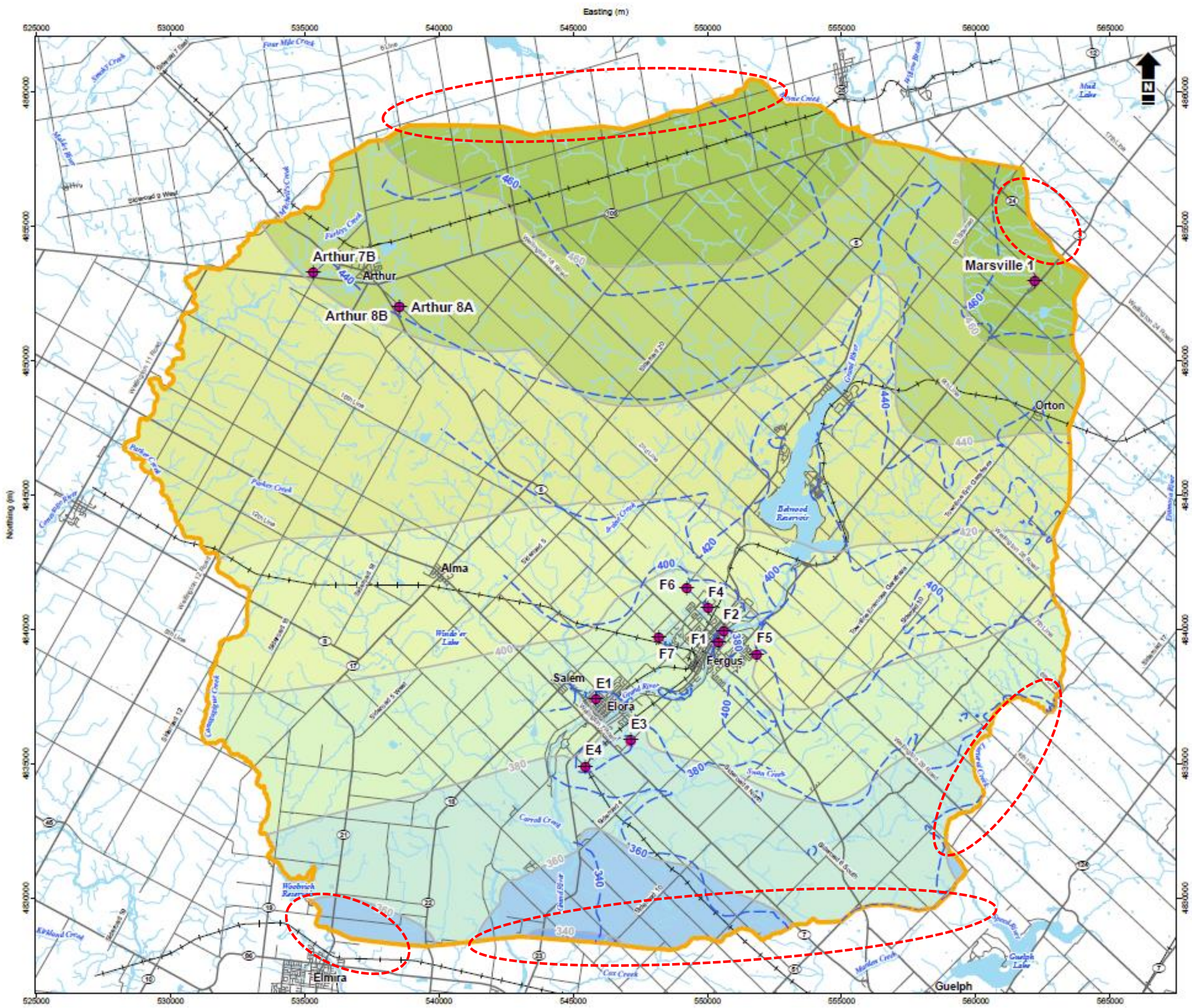
Figure 2. Conceptual groundwater inflows and outflows for the Study Area

5. We recommend that that discussion of the overall groundwater budget be expanded to confirm that the budget is consistent with the results presented elsewhere in the report.

The map of the boundary conditions for the Lower Bedrock Aquifer is reproduced below from Figure 5 of the report. The green circles denote sections along the perimeter of the model along which the groundwater levels are specified, thus allowing water to enter or leave the model area from areas outside the model. As shown in the figure, these sections are relatively long.



The map of the calculated groundwater levels in the Lower Bedrock Aquifer is reproduced from Figure 18 of the report. The red ellipses identify the sections of specified groundwater levels. The spacings of the contours suggest that the flow across the model area is relatively uniform. At first glance, it appears that the inflows and outflows must be correspondingly relatively large. However, referring to Table 8, the *total* cross-boundary flows comprise only a small portion of the water budget (2 mm/140 mm for inflows and 11 mm/140 mm for outflows). This does not appear to be consisent with the clear, general north to south flow patterns shown in Figure 18. Are the lateral flows into and out of the Lower Bedrock Aquifer really that small?



6. It would also be valuable to see the results of a complete water budget for the Study Area.

It is possible to develop a complete water budget, not just an overall water budget for the groundwater model. Matrix Solutions indicate on page 17 that the GAWSER streamflow generation model was updated slightly for the Tier 3 study. Therefore, all of the components of the water budget have been calculated in the analyses. It would be useful to know how much of the annual average precipitation over the Study Area ends up as recharge to the groundwater system. Referring to Table 8, the total recharge is 138 mm/y. As a first guess, the average annual precipitation is probably about 1000 mm/y, so the recharge is actually a relatively small fraction of the precipitation. As a rule-of-thumb in Ontario, we usually assume that the recharge is about 30% of the precipitation. Are we correct in suspecting that in this model area, half of the infiltration never even makes it to the water table as recharge, instead discharging as shallow interflow to streams (i.e., interflow)?

7. The components of the water budget should be expressed in terms that can be understood against any pumping rates.

In our opinion, it is important to see the flows expressed in terms that can be understood against any pumping rates: m^3/d rather than mm/y [to convert to flow rates we'll have to know the model area, multiply the reported values by that area, and then convert units].

It would also be useful to know whether the perfect flow balance that is reported is actual output from the FEFLOW model, or whether Matrix Solutions has had to re-balance the FEFLOW results to end up with outflows that match inflows exactly.

8. We recommend that additional discussion be provided of the implication of the data gaps identified in Sections 7.1 of the report.

Important data gaps are identified in Sections 7.1.1 through 7.1.4. We concur with the text preceding these sections, in which it is indicated that the key question with respect to these gaps is: *What is the impact of those data gaps or unknowns on the model's ability to make predictions?* We would broaden this question to include the model's ability to represent *current* conditions.

For groundwater flow modelling studies, the implications of major assumptions and major data gaps are examined through an uncertainty assessment. The results of an uncertainty assessment are important to understand what really makes a difference in a model: a difference with respect to matching the available data, and a difference with respect to the predictions of the potential effects of changes in the groundwater system. Although an uncertainty assessment is mentioned on Page 45 of the report, as far as we are aware, no uncertainty assessment has been conducted.

We also note that it is now standard practice to use computer-assisted calibration techniques during the development of the model (for example, application of the code PEST). These methods are important for three reasons. First, the use of a code like PEST confirms that the parameter values inferred through calibration are in some sense optimal – no improvement of the overall match to the observations can be achieved for the model structure designed by the analyst. Second, when using a code like PEST, the analyst must assign bounds within which the parameter values can be adjusted. When PEST wants to apply values up to or beyond these boundaries it is a sign that there is a structural problem in the underlying groundwater model. Finally, codes such as PEST provide a formal means of identifying those parameters that affect the match to the available observations. As far as we are aware, no use was made of computer-assisted calibration methods.

9. We recommend that additional results be presented to assess the match between the model results and the calibration targets.

The match to the water levels from the high-quality targets is shown in format in Figure 10. A different format is adopted in Figure 11 to illustrate the match to all of the calibration targets. Goodness-of-fit statistics are reported on Page 27 of the report, but it is not indicated whether the statistics apply to the high-quality or low-quality targets.

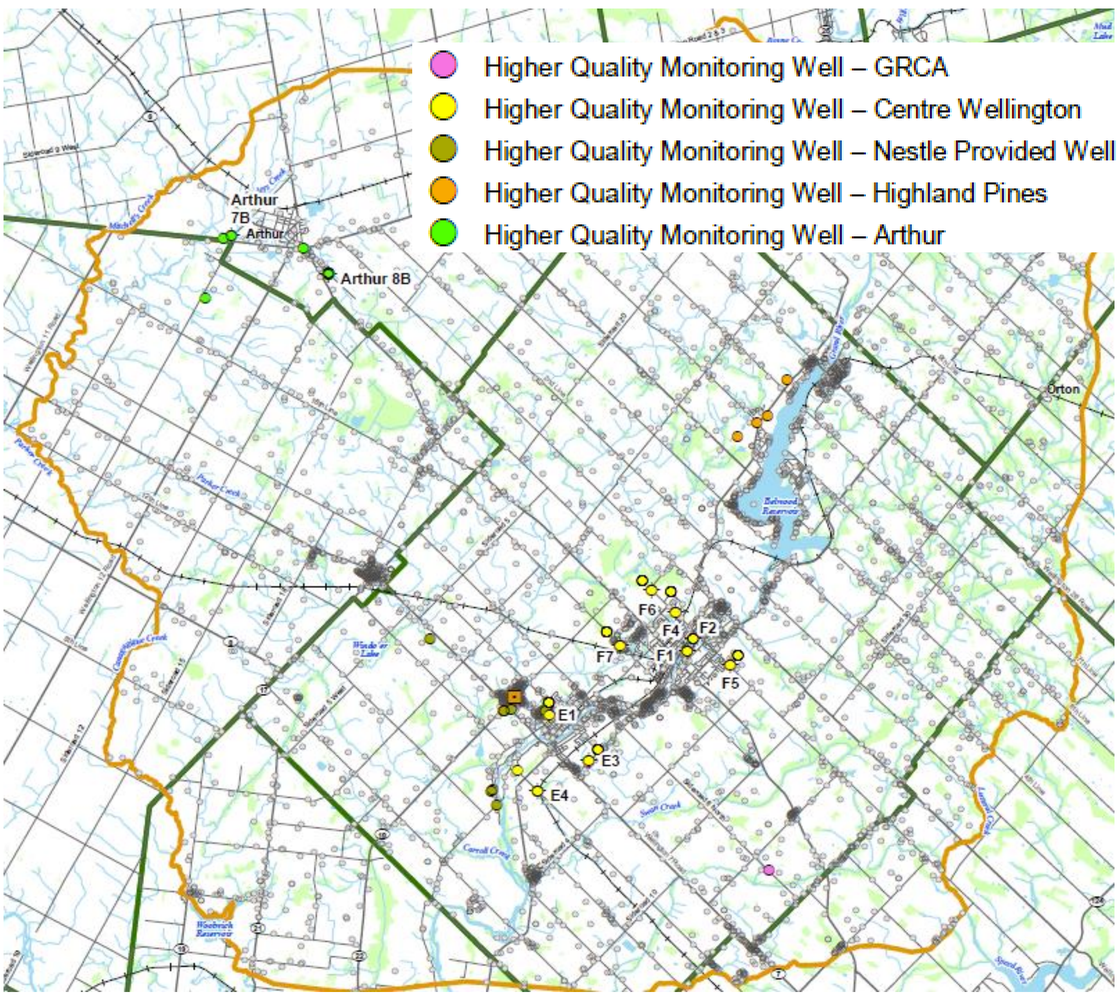
In our experience, the statistic that provides the most insight is the Root Mean Square (RMS) Error. This statistic provides a sense of how closely the model matches a water level target at any one location. It is reported that the RMS Error is 6.3 m. Is this degree of mismatch acceptable to support the delineation of defensible WHPA-Q1?

It is important to note that the mismatch may not be due to systematic model error. If the targets are derived from the water well records, the mismatch may in some cases be due to reported water levels that are not reliable. For this reason, we recommend that the scatterplot shown in Figure 11 be supplemented with a plot of the cumulative probability distribution of the residuals (observed – simulated water level). The cumulative probability plot provides a good means of visualizing outliers in the set of water targets, that is, targets that no model could be expected to match.

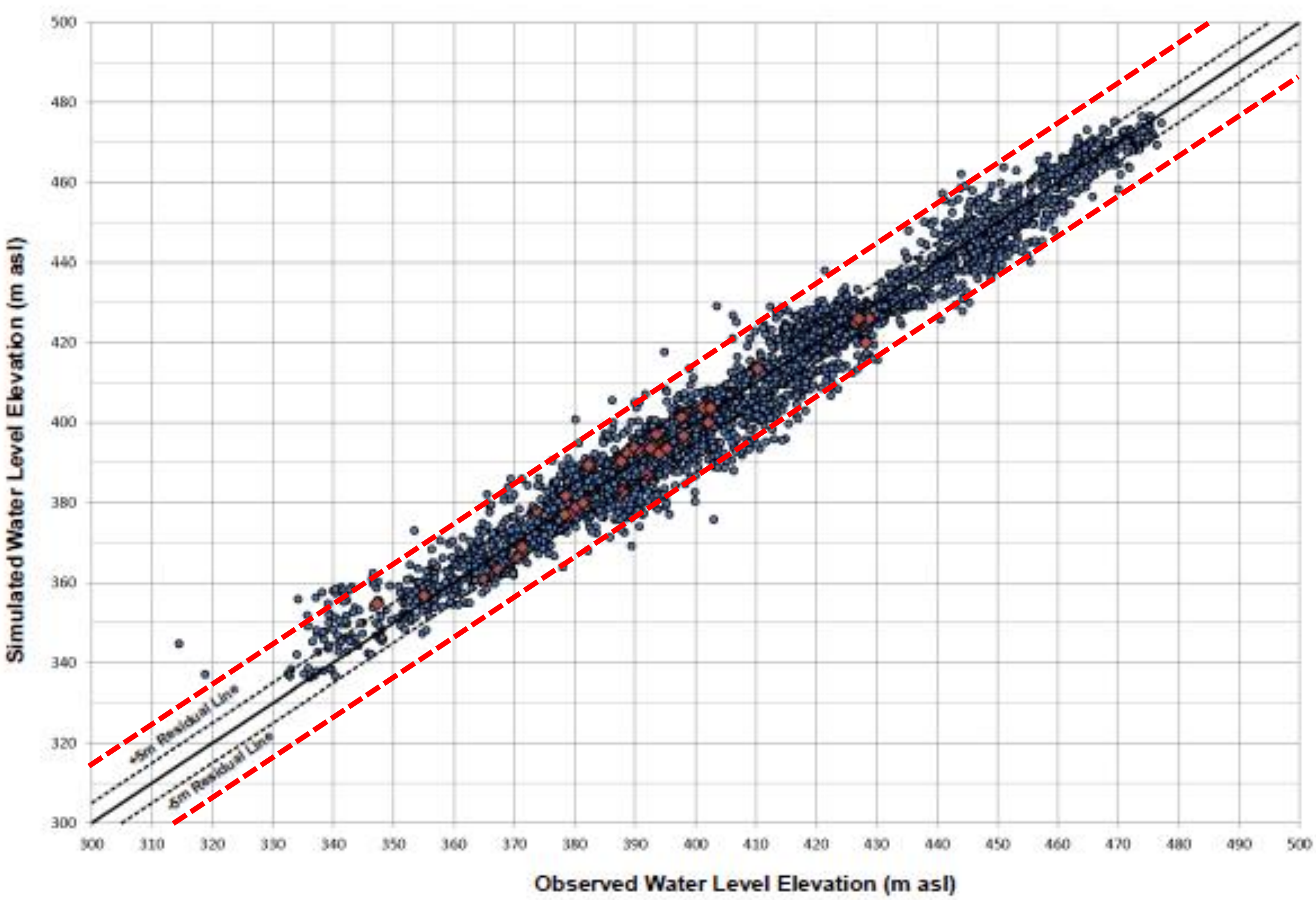
Referring to Figure 10, are the simulated levels on average higher or lower than the targets? In the case of the pumping wells, it is clear that the observed water levels vary over relatively wide ranges. In the case of well F4, the reported range in the observed water levels is from about 353 m asl to 424 m asl, a range of **71 m**. Is it possible that the levels shown for all of the municipal production wells might represent the full ranges of water levels under *both* pumping and non-pumping conditions? Does this make sense considering that the simulation is supposed to be representative of steady-state conditions?

10. We recommend that additional discussion be provided to identify explicitly where there may not be sufficient data to constrain the model results.

The map showing the locations of targets for the model calibration is reproduced from Figure 8 of the report. As shown in the figure, the high-quality targets are concentrated around the Fergus and Elora municipal wells. There are no high-quality targets over much of the Study Area. It is indicated that the model developed by Golder (2013) was considered for use in this project but was not applied because of the advances made to the overburden and bedrock conceptual geologic and hydrostratigraphic models in this area since completion of the Golder (2013) report. What new hydrogeologic data are available since 2013 to update the characterization of the groundwater system? What new wells have been drilled, logged, and equipped for continuous water level measurements?



The well records for private domestic wells cover the Study Area. However, the limitations of the information from these records are evident from Figure 11 of the report. Bands of model mismatch of ±5 m are shown in Figure 11. In our opinion, these bands are much too narrow to provide a sense of how reliable the water level might be at a specific location. As indicated by the dashed red lines that have been added below, bounds of ±15 m provide more realistic impressions of the differences between the model results and the water levels reported in the water well records.



11. We recommend that additional discussion be provided to assess whether the data that are currently available are sufficient to support predictions of potential reductions in groundwater discharge to surface water features under existing and proposed future conditions.

A demonstration of the ability of a model to match flow targets is important for two reasons. First, a match to flow targets is a more stringent confirmation of the reliability of a model compared to matching water level targets. Second, achieving a good match provides some assurance that the model predictions with respect to flows may be reliable. A good match is reported between the interpreted average annual baseflow at the Irvine Creek gauge (0.7 m^3/d, with a seasonal range from 0.2 to 1.6 m^3/d) and the model-simulated groundwater discharge upstream of the Irvine Creek gauge, 0.6 m^3/d. However, in our opinion, one point along a relatively small stream is not a sufficient demonstration.

The results of the modeling indicate that 98% of the inflow to the model comes from recharge, and that 88% leaves as groundwater discharge to surface water features. This suggests that any additional groundwater takings will represent water that would otherwise discharge to streams. However, data to support inferences of changes in groundwater discharge to streams are very limited. A model is only as good as the data that available to check its calculations. To assess the impacts of any planned additional groundwater takings, continuous monitoring of streamflows at additional monitoring locations will need to start well ahead of the start of the takings.

3. Comments specifically related to the Middlebrook well

The ability to accurately represent conditions around the Nestlé Waters Canada (NWC) Middlebrook well is not only of keen interest to NWC. The potential for development of groundwater takings at the Middlebrook well has been one of the motivations for the Centre Wellington Tier Three Water Budget Study. In this section we offer comments specifically related to the representation of conditions in the vicinity of the Middlebrook well.

1. The data from a high-quality Ontario Geological Survey (OGS) multilevel well close to the Middlebrook well do not appear to have been included in the analyses.

The OGS borehole DDH5-09 is not indicated in the figure that shows the high-quality wells that have been considered in the calibration. Elizabeth Priebe has indicated to us that the data from two rounds of water level measurements have been provided to the study team. In Figure 3, profiles of hydraulic head from the two rounds are superimposed on the stratigraphic interpretation of Brunton and Brintnell (reproduced in Priebe and Lee, 2016). Continuous water level data have also been collected but are not yet available (E. Priebe, personal communication August 1, 2018).

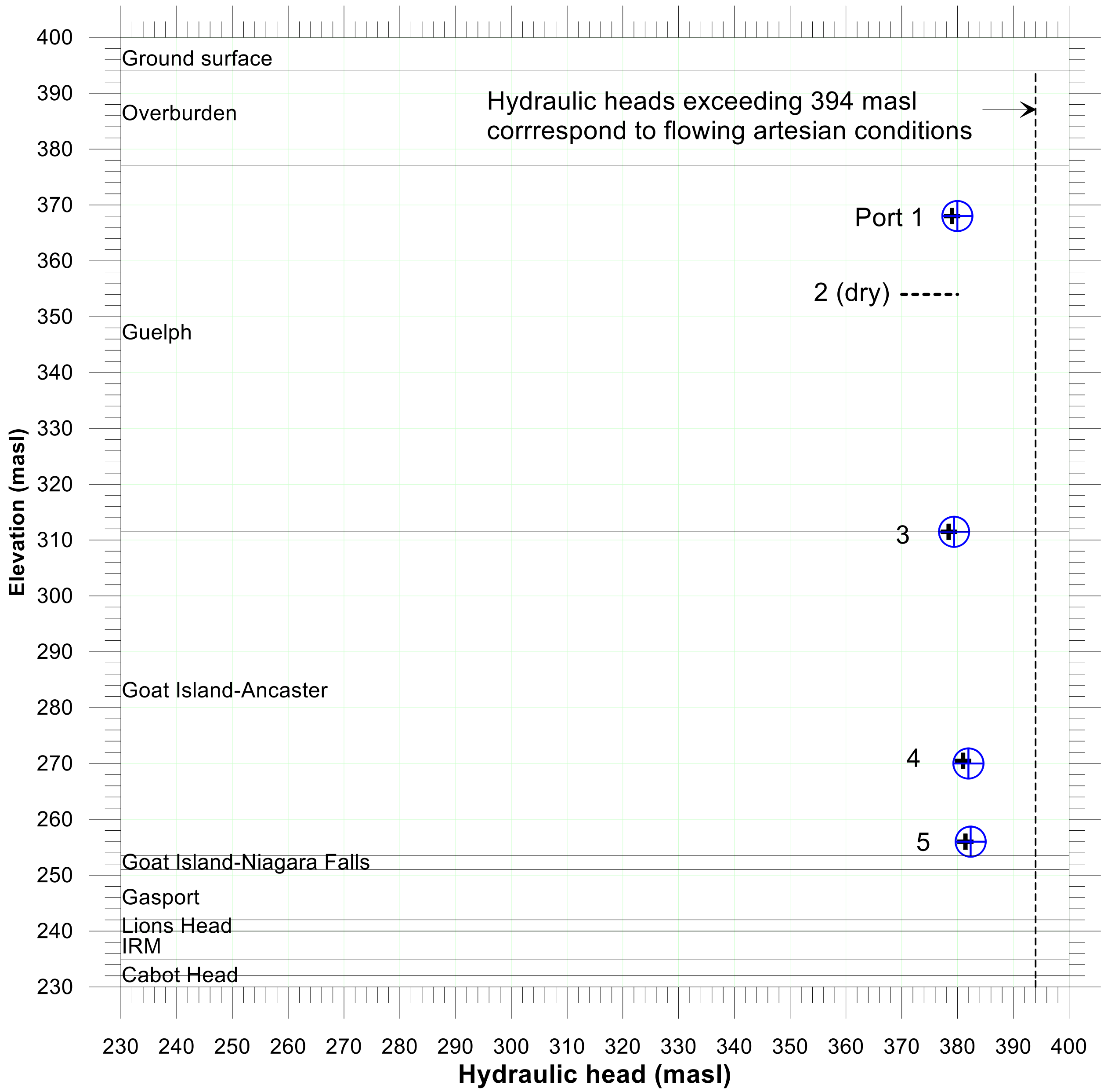
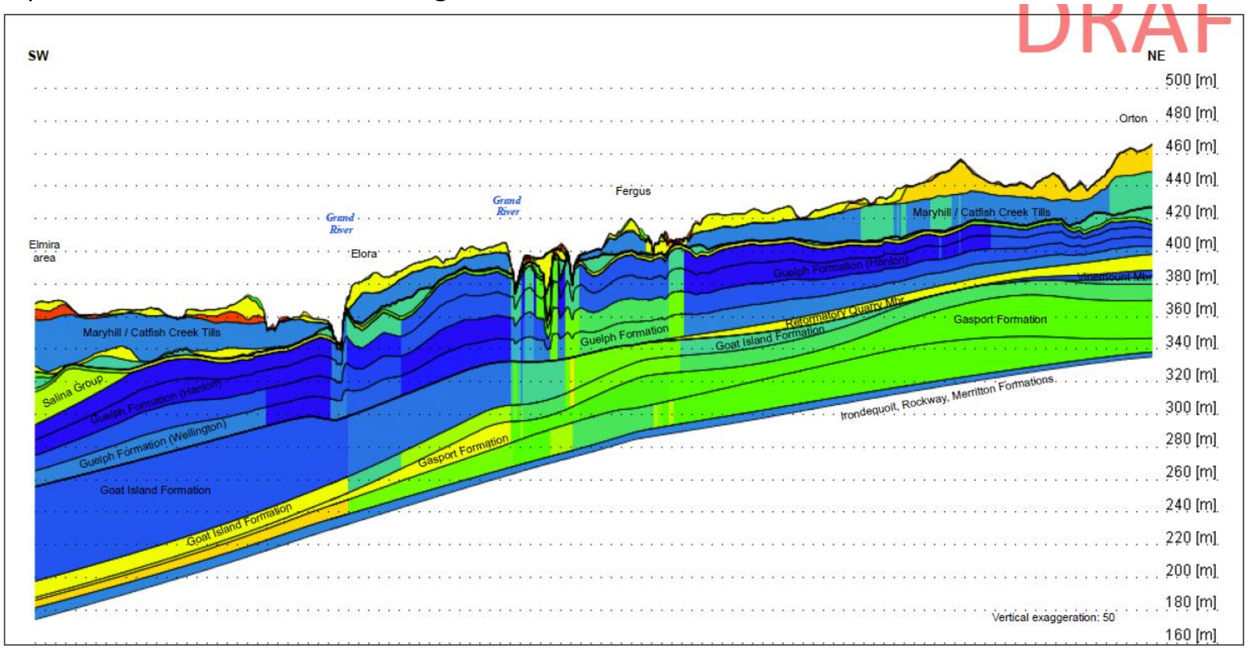


Figure 3. DDH-05 profiles of hydraulic head (data from the Ontario Geological Survey)

2. It is not clear how the Middlebrook well has been incorporated in the analyses.

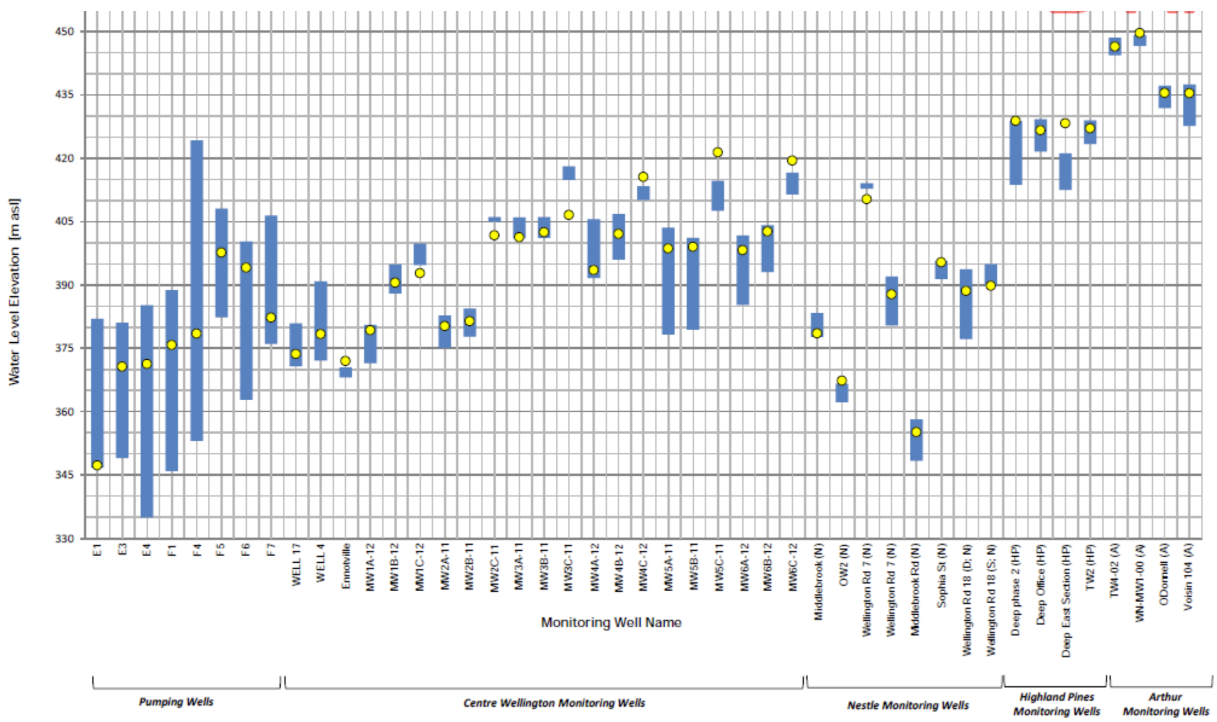
The flow profile and photos from the downhole video collected in the Middlebrook well show that the flow to the long open-interval well is limited to a zone at the lowermost 2 m of the well (Lotowater 2015b). Lotowater describe this zone as a “cavern”. This zone is interpreted to provide over 95% of the water that enters the well. Based on cross-section through the model, reproduced here from Figure 15 of the report, we place the water-producing zone of the Middlebrook well at the bottom of the Goat Island Formation. How is the well simulated in the model? Is the well effectively open across only model layer 19, consistent with the results from the flowmeter profiling or is the well simulated to be open across its entire length, and the model correctly simulates that the flow is concentrated at its bottom?

Frank Brunton (OGS) interprets the lowermost production zone in the Middlebrook Well, and the fracture zones noted in the municipal pumping wells as evidence of karst in the Study Area. The borehole log of DDH-05 presented in Brintnell (2012) includes references to fracture zones within the well as “karst” or “rubble zones.” These areas with enhanced fractures exist at many boreholes within the Study Area; however, mapping the three-dimensional continuity of these zones of enhanced transmissivity is difficult due to the irregular nature of bedrock fractures and the limited extent of high quality data outside the Fergus and Elora areas. As it is difficult to map in three dimensions the locations and spatial distributions of these zones, it is difficult to capture this information within a groundwater flow model.



3. It is not clear what data have been matched around the Middlebrook well.

Figure 10 of the draft modeling report shows the match to the “higher quality wells”, with the Middlebrook well included among the 8 Nestlé Monitoring Wells. The reported simulated water level for the Middlebrook well is about 378.5 m asl, with the observations reported to range from about 378 m asl to 383 m asl. It is not clear what these levels represent.



Referring to Gartner Lee (2005), the shut-in (i.e., non-pumping) water level in the Middlebrook well is about 15 m above ground surface (the well logs at the time of completion of the well report 47 ft above ground surface, and 20.5 psi [47.3 ft]). For a ground surface elevation of 365 masl, this corresponds to a hydraulic head of about 380 masl. This represents the composite water level for the long open interval of the well. The packer testing conducted by Lotowater (2015) showed that when the water-producing zone at the bottom of the well is isolated, there is a head differential of about 14 and 17 m between the water-producing zone and the shallow bedrock. Our interpretation of the separation between water levels when the flow zone at the bottom of the well is isolated, or the averaging of water levels when it is not, is illustrated here in Figure 3. Has any attempt been made to match the data and the well discharge rate observed under flowing conditions?

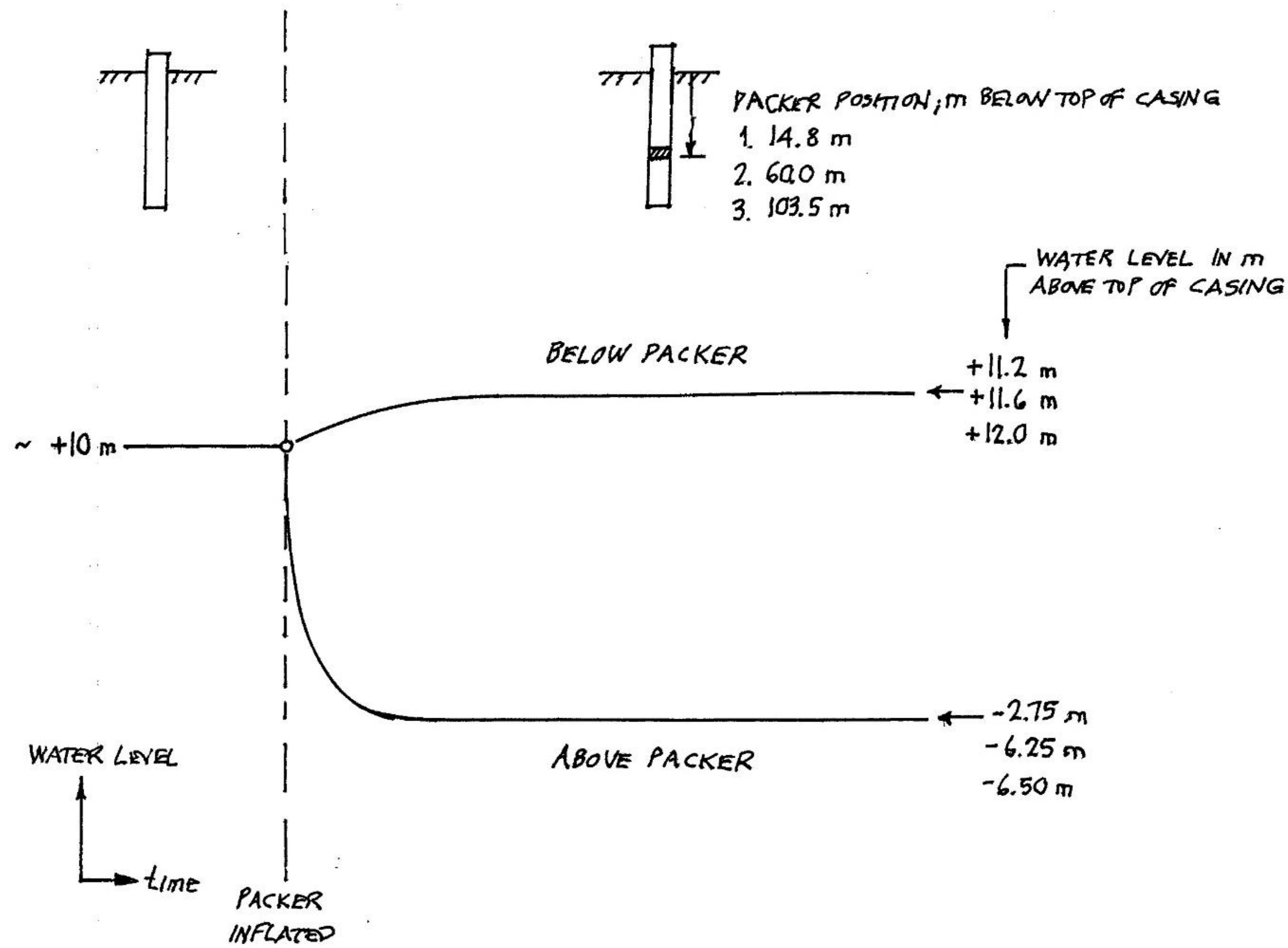
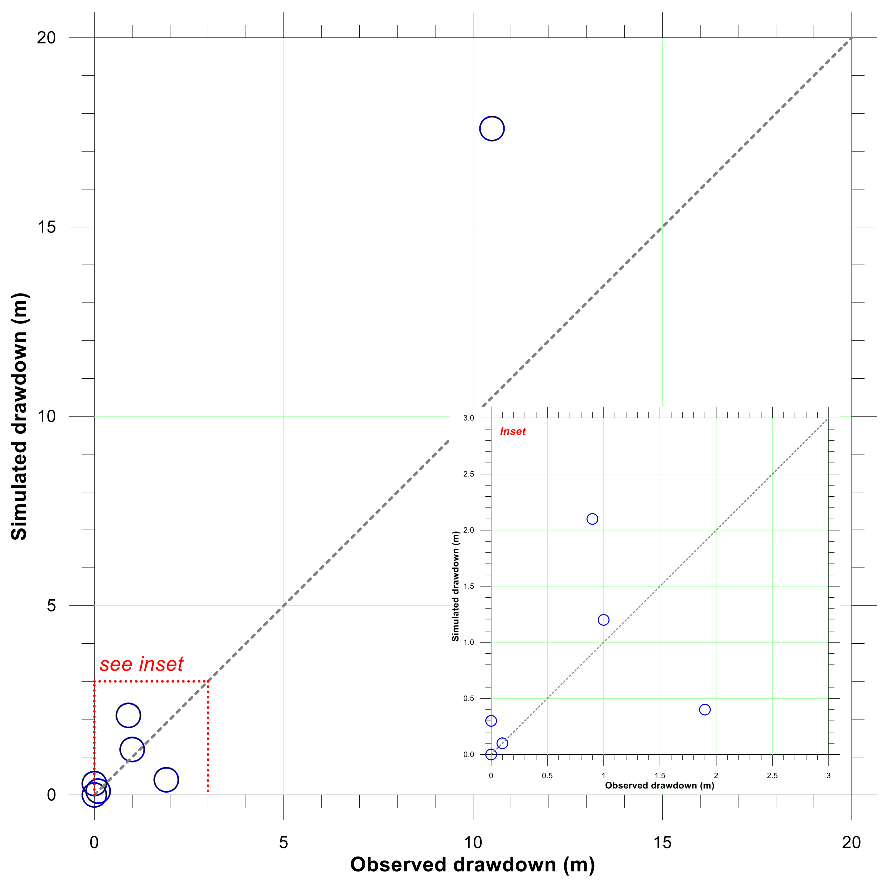


Figure 3. Conceptual model for shallow and deep bedrock levels at the Middlebrook well

4. It is not clear what data from the Middlebrook 30-day pumping test are matched.

On Table 5 of the report (page 33). Matrix Solutions refer to "Simulated and Observed Drawdown during the 30-day Middlebrook Pumping Test". What does "during" mean? Are these the simulated drawdowns at the end of 30 days? We are not convinced that they have as good a match as they claim. It is noted in the report that the model does not reproduce conditions around the pumping well. This is important, as the drawdowns in the well are so much larger than the drawdowns observed at the other observation locations. The observed drawdown (and it is really a stabilized drawdown) is 10.5 m, while the simulated drawdown of 17.6 m is much larger. It is indicated in the report that conditions around the Middlebrook well are a "local feature" and that the equivalent porous medium approach used in the study was able to represent the hydraulic responses in the larger groundwater flow system. We are not convinced. The matches to the observed drawdowns at W2 and W4 are not very close either. Our understanding is that one of the objectives of the Tier 3 model was to represent conditions at the Middlebrook well reliably; in our opinion this objective has not yet been accomplished.



5. It is not clear what material properties at the Middlebrook well have been inferred through calibration.

The data from the Middlebrook well provide important insights into the presence of a karst feature at the Middlebrook well that acts to attenuate the drawdowns in the pumping well. Our analyses of the data suggested that the transmissivity immediately at the well is about 300 m^2/d, in contrast to the bulk-average transmissivity around the well of about 60 m^2/d. The discrepancy of these two estimates is consistent with the observation of voids at the bottom of the well in the Lotowater video logs. What transmissivities have been inferred in the model at the Middlebrook well?

Closing

We appreciate the opportunity to review the draft **Groundwater Flow Model Development and Calibration Report**. We hope that our comments are useful. If you have any questions regarding our comments, please contact Christopher Neville by E-mail at *cneville@sspa.com*.

Sincerely,

S. S. PAPADOPULOS & ASSOCIATES, INC.

CJNeville

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  (valid through June 30, 2019)

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