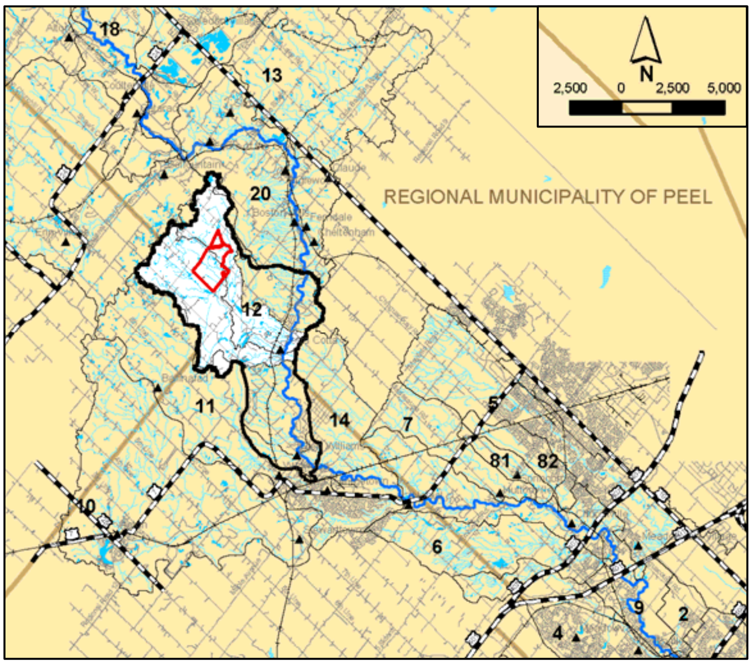
# Peer Review of Hydrogeological Studies Conducted in Support of the Proposed Rockfort Quarry

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**To the attention of R.K. Webb**

**Davis Webb LLP**

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**Ref: 20081/1/Caledon**

## EXECUTIVE SUMMARY

This report has been prepared on behalf of the Coalition of Concerned Citizens in Caledon, Ontario. It reviews the hydrogeological work conducted in support of a proposed dolostone quarry on the property of the former Rockfort Farm and adjacent properties. The proposed site lies immediately west of the Niagara Escarpment in an area that provides headwater springs for numerous tributaries of the Credit River. Concerns have been raised that dewatering operations required for quarry development will seriously impact aquifer water levels in the region, thereby inconveniencing local well users and seriously affecting stream flows.

In this report, I focus my interest on:

1) The program of hydrogeological investigation conducted in the region.
2) The quality of the hydrogeological interpretation.
3) The modeling studies conducted in support of the hydrogeological interpretation and proposed mitigation measures.
4) The nature and appropriateness of the Adaptive Management Plan.

### 1) The Hydrogeological Investigation Program

The program of hydrogeologic investigation conducted in support of the Rockfort Quarry licence application has been ongoing for well over a decade. Overall, the volume of data collected for the site has been considerable and goes a long way towards meeting the minimum base data requirements for a project of the magnitude proposed. However, the investigation program has been deficient in a number of key areas, notably as they relate to the karstic nature of the bedrock aquifer system and the likely transient (temporal) response of the aquifer during de- and re-watering. Specifically, the investigation program lacks tracer studies that would determine the rapidity with which any groundwater that becomes contaminated will move through the aquifer to a well or spring, and borehole geophysics that would allow the continuity of fractures in the aquifer to be understood and mapped on a regional basis. The hydrogeological investigation program has also failed to provide a range of data that are considered essential for performing reliable predictions of impact. These data include specific yield which determines the rate at which the water table declines when water is pumped, and values of hydraulic conductivity in the vertical direction which are conspicuously absent despite their importance in determining upward and downward rates of flow. While values of hydraulic conductivity in the horizontal direction are generally available, many values are unreliable as a significant number of the pumping tests have not been adequately interpreted.

### 2) The Interpretation

The quantity of good quality hydrogeological data collected matters very little if this information is not translated into a sound conceptual understanding of the aquifer system. This understanding is called a “conceptual model” and is the foundation of reliable predictive analysis. The proponent’s conceptual model for the study area aquifer is fundamentally flawed. It assumes that preferential flow via fractures, a well established hydrogeological attribute of carbonate systems, can be conveniently ignored, and that the aquifer can be adequately represented by an “equivalent porous medium”. The proponents persist with this fallacious notion despite data and field observations that clearly depict the contrary.

## 3) The Modeling

Reliable, well-calibrated, groundwater flow models have become essential components of all investigations involving groundwater. For investigations that rely heavily on quantitative analysis, models often underpin the entire study. In the present study, modeling is used:

- To demonstrate the validity of the conceptual understanding of the aquifer system.
- To predict the susceptibility of water features and functions to land use changes associated with quarry development.
- To provide an essential platform for planning quarry development and for identifying and testing strategies required to limit and mitigate impacts.

During the study, three models have been developed and none has performed adequately. Key problems include:

- The "equivalent porous media" approach which fails to recognise that preferential flow via discrete fractures will significantly influence the propagation of dewatering impacts, with the strong possibility that remote wells and springs will be just as seriously affected as those in close proximity.
- Weak, or non-existent steady state model calibrations, especially with regards to stream flows and to groundwater levels in the upper reaches of the catchment. Adoption of the "equivalent porous media" approach would account for the calibration failure.
- Absence of transient flow calibrations and inadequate specific yield data meaning the models are incapable of predicting how the aquifer will respond with time.
- Absence of model verifications and thus no evidence that the models will provide reliable predictions for situations that extend beyond those experienced by the aquifer under natural conditions.

Without a reliable, adequately calibrated and properly verified groundwater flow model, the proponents are unable to predict the environmental impact of quarry development. Neither are they able to evaluate the potential benefits of the remediation measures they propose.

## 4) The Adaptive Management Plan (AMP)

The benefit of Adaptive Management Plans (AMPs) is that they offer flexibility to adjust and fine tune the management approach as more is learned about the aquifer and its behaviour. AMPs should <u>not</u> be regarded as a substitute for a full scientific understanding of the aquifer system and a sound appreciation of how it will respond to a wide range of management scenarios. Using an "equivalent porous medium" conceptual understanding of the system, the proponents have developed aquifer simulation models that are overly simplistic and thus incapable of making the types of prediction so urgently required. Based on the deficient dataset and the models at their disposal, I can't believe that anyone has the first idea how the aquifer (grossly modified by the injection of grout) will respond to the inordinate pumping stresses and complicated artificial recharge schemes required for quarry development. As adopted for the Rockfort Quarry Proposal, the AMP is simply an admission of failure. The AMP is not about refining a solid, scientifically supported aquifer management plan. It's not about making minor adjustments to a fundamentally robust predictive model as more data become available. The AMP is tantamount to saying "we can't predict what will happen, but when problems occur, we'll find some way of dealing with them". The AMP lacks a sound scientific foundation and is destined to fail.

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## 1. Introduction

In February, 1998, James Dick Construction Limited (JDCL) applied to the Town of Caledon for an Official Plan Amendment and Zoning By-law Amendment to permit construction of a dolostone quarry on the property of the former Rockfort Farm and adjacent properties in the Town of Caledon, Region of Peel. The proposed 220 acre site lies at the north-east corner of Olde Base Line Road and Winston Churchill Boulevard, immediately west of the Niagara Escarpment (Figure 1). Construction of a quarry at this site has always proved contentious as it involves the pumping and excavation of an aquifer that is used by well owners locally and provides headwater springs for numerous creeks and tributaries of the Credit River.

In July, 2007, I was invited by the Coalition of Concerned Citizens in Caledon, Ontario to provide a professional opinion on the hydrogeological work conducted in support of the proposed quarry and the potential impacts of the proposed mitigation measures. Concerns had been raised that dewatering operations associated with the proposed development would seriously impact aquifer water levels in the region, thereby inconveniencing local well users and seriously affecting stream flows. I was specifically asked to comment upon:

1) the program of hydrogeological investigation conducted in the region
2) the quality of the hydrogeological interpretation
3) the modeling studies conducted in support of the hydrogeological interpretation and proposed mitigation measures
4) the nature and appropriateness of the Adaptive Management Plan (AMP).

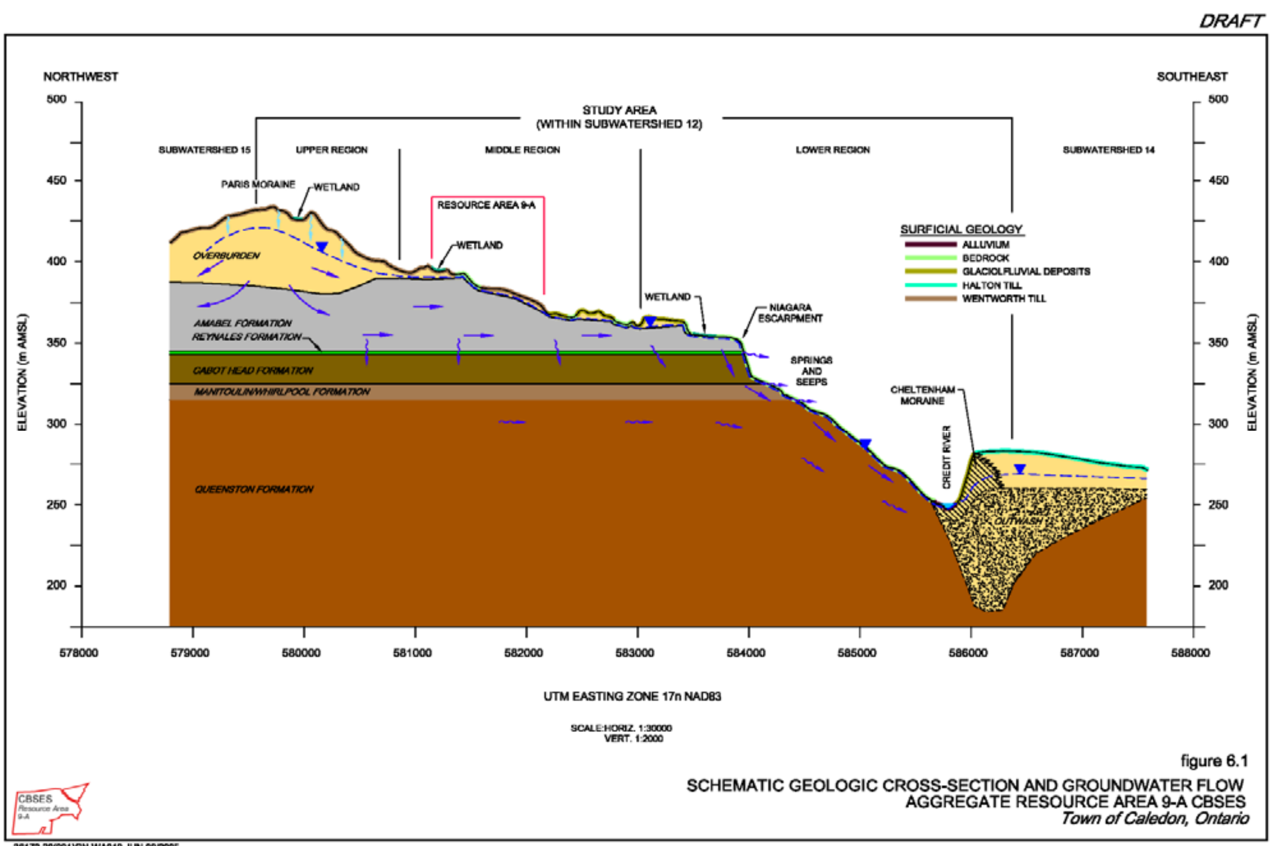


**Figure 1. Figure 6.1 of the CBSES Part A: Characterisation Report [3] depicts Conestoga Rovers and Associates' (CRA's) conceptual model of the aquifer system.**

To provide context for my review and analysis, I visited the study area on August 7th, 2007 and met with staff and representatives of Credit Valley Conservation on September 26th, 2007. On January 22nd, 2008 I attended a public meeting organised by proponents of the quarry and on February 14th, I prepared a comprehensive report [1] detailing my serious concerns with the groundwater flow model developed by AquaResource Inc. [2] and used in support of the Comprehensive Broader Scale Environmental Study (CBSES) [3, 4, and 5] to:

- test the validity of the conceptual understanding of the aquifer system,
- predict potential impacts, and
- aid in the development of mitigation techniques.

Documents I have examined during my review include:

- AquaResource Inc., 2007. Comprehensive Broader Scale Environmental Study Part B Hydrogeological Modeling Task – Draft Report – June 2007. [2]
- Conestoga-Rovers & Associates Limited (CRA) *et al*. 2006. Part A: Characterisation Report Of The Comprehensive Broader Scale Environmental Study: Caledon Aggregate Resource Area 9-A Volume 1 – Report, Tables, and Appendices Draft – November 2006. [3]
- Conestoga-Rovers & Associates Limited (CRA) *et al*. , 2007. Part B: Sensitivity Analysis Report Comprehensive Broader Scale Environmental Study: Caledon Aggregate Resource Area 9-A Volume 1 - Report, Tables, and Appendices Draft – June 2007. [4]
- Conestoga-Rovers & Associates Limited (CRA) *et al.* , 2007. Part C: Implementation Report Comprehensive Broader Scale Environmental Study: Caledon Aggregate Resource Area 9-A Volume 1 - Report, Tables, Figures And Appendices. Draft – October 2007. [5]
- Harden Environmental Services Ltd., 1997. Site Characterization and Evaluation of Water Resources for Proposed Rockfort Quarry. December, 1997. [6]
- Golder Associates Ltd., 2001. Rockfort Quarry Licence Application. Peer Review of Mining Plan and Physical Barriers. December, 1998. [7]
- Harden Environmental Services Ltd., 1999. Preliminary Response to Peer Review, and January 28 meeting. January, 1999. [8]
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- Conestoga-Rovers & Associates Limited (CRA), 2003. Proposed modifications to AMP. Proposed Rockfort Quarry, Town of Caledon, Ontario. February, 2003. [17]
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- Conestoga-Rovers & Associates Limited (CRA), 2008. Water Resources Evaluation and Design Addendum. Rockfort Quarry, Town of Caledon, Ontario. July, 2008. [20]
- Town of Caledon, Planning and Development Dept., 2008. Rockfort Quarry Update including Schedules A and B. November, 2008. [21].
- Conestoga-Rovers & Associates Limited (CRA) *et al.*, 2008. Updated Adaptive Management Plan Water Resources Protection Rockfort Quarry Town of Caledon, Ontario. July, 2008. [22].

## 2. Review and Analysis

### 2.1 Hydrogeological Investigation Program

The program of hydrogeologic investigation conducted in support of the Rockfort Quarry licence application has been ongoing for well over a decade. Harden Environmental Services Ltd. (HES) issued a “Site Characterization and Evaluation of Water Resources” Report in 1997 [6], and a comprehensive “Water Resources Evaluation Report” was prepared by Conestoga-Rovers & Associates Limited (CRA) in 2000 [12]. CRA updated this report with an addendum in July, 2008 [20]. Overall, the volume of data collected for the site has been considerable and goes a long way towards meeting the minimum base data requirements for a project of the magnitude proposed. The monitoring program, in particular, has been commendable.

However, the investigation program has been deficient in a number of key areas, notably as they relate to the karstic nature of the bedrock aquifer system and the likely transient (temporal) response of the aquifer due to de- and re-watering. In fairness, much of the fieldwork was undertaken prior to the tragic events in Walkerton, Ontario during May 2000, [23] when awareness was considerably heightened for the critical role chemically widened fractures play in the flow of groundwater in karstic / semi-karstic aquifers (Figure 2) [24, 25, 26]. However, there is no evidence to indicate that the hydrogeological investigation program was amended in any way. As a result, the program lacks:

- Tracer studies [27, 28] that would determine the rapidity with which any groundwater that becomes contaminated will move through the aquifer to a well or spring.
- Borehole geophysics [29 and 30] that would allow the continuity of fractures in the aquifer to be understood and mapped on a regional basis.

**Figure 2. Outcrop of the Amabel dolostone showing significant "karst" secondary permeability features – fractures and bedding planes that have been opened by chemical dissolution.**

The hydrogeological investigation program has also failed to provide a range of data that are considered essential for performing reliable predictions of impact. These data include the following:

- Specific Yield ($S_y$)

  Specific yield determines the rate at which water levels decline in an aquifer when groundwater is pumped. While it is often convenient and reasonable to ignore specific yield under steady and quasi-steady state conditions that currently prevail in the region, such data are critical for predicting the rate at which water levels will rise and fall under conditions of pumping stress i.e. intensive, long-term, dewatering activities. This would be equally true under adaptive management. Typically, specific yield data are obtained by the careful processing and analysis of long-term pumping tests. However, although several long-term pumping tests were conducted in the area, inappropriate care was taken in conducting the analyses (Appendix C of the Water Resources Evaluation

Report Volume 3 [12]), and as a consequence, few, if any, reliable values of specific yield ($S_y$) were obtained. A review of the analysis suggests that the effects of delayed yield on the aquifer response was ignored, thus seriously compromising the pumping test results.

- $K_{horizontal}$

  The property of hydraulic conductivity (permeability) varies both spatially and directionally. $K_x$ and $K_y$ refer to values of hydraulic conductivity in the x and y directions of the horizontal plane, while $K_z$ (also known as $K_{vertical}$) is the value of hydraulic conductivity in the vertical direction. Typically, at any point, the value of $K_x$ equals the value of $K_y$ and, in such cases, it is convenient to refer to this value as $K_{horizontal}$ .

  $K_{horizontal}$ values have been obtained for the study using packer tests and pumping tests. Unfortunately, many of the pumping test values are unreliable as a significant number of the pumping tests have not been adequately interpreted with very poor agreement frequently obtained between observed data and theoretical drawdown curves used for the analysis. Where reliable data have been obtained, $K_{horizontal}$ values for the Amabel Formation exhibit considerable variability both vertically and regionally, a trademark characteristic of carbonate aquifers that rely on bedding planes and discrete fractures, widened by chemical dissolution, to convey the flow of groundwater. Unfortunately, while CRA acknowledges that "*the principal mode of water transmission in the Amabel is within secondary features such as along bedding planes, solution channels, joints and fractures"*, it persists with the fallacious notion that the aquifer can be adequately represented by a homogeneous "*equivalent porous medium*" (pg. 52, Vol.1 [12]). As a result, very little fracture-specific data have been collected for the study area and the hydrogeologic role of the preferential pathways associated with secondary features has not been well characterised.

- $K_{vertical}$

  $K_{vertical}$ is normally an order of magnitude or more lower than $K_{horizontal}$, but can exceed $K_{horizontal}$ where there is a significant presence of open vertical fractures. $K_{vertical}$ is not an important parameter in unstressed systems where flow is predominantly horizontal. However, high rates of pumping introduce significant components of vertical flow within individual aquifers and a good knowledge of $K_{vertical}$ becomes critical if impacts are to be reliably predicted. Moreover, pumping can readily induce flows across aquitards which, in normal circumstances, may play a benign role. For pumping situations, a knowledge of $K_{vertical}$ allows leakage rates to be calculated. Unfortunately reliable $K_{vertical}$ data for the study area are conspicuously absent.

### 2.2 Hydrogeological Interpretation

The quantity of good quality hydrogeological data collected matters very little if this information is not translated into a sound conceptual understanding of the aquifer system. This understanding is referred to as a "conceptual model" and would include knowledge of:

- The regional geologic framework including structure contour information for the upper and lower boundaries of major geological units.
- Reliable estimates of aquifer properties ($K_{vertical}$ and $K_{horizontal}$), $S_y$ (specific yield) and S (storativity) for all aquifer and aquitard units, and how these properties vary spatially.
- The nature, distribution and functional role of secondary porosity (e.g. fractures and dissolution features) where present.
- Regional and temporal distribution of aquifer recharge.
- Reliable estimates of aquifer fluxes.
- Location of all surface water bodies together with knowledge on ground - surface water interactions and data on water levels (stage) and stream/lake discharge (baseflow) as a function of time.
- Past and present hydraulic head data for all aquifer and aquitard units present.
- Surface and subsurface inflows / outflows across site boundaries as a function of time.

Despite the wealth of information collected for the site and surrounding region, data crucial to the study outcome have either not been collected or have been inadequately interpreted. In other cases, appropriate data have been collected but have not been included in the models used to predict the impacts of quarry development.

The foundation of all predictive analysis is the development of an appropriate conceptual model. During model conceptualisation, data describing field conditions are systematically processed to fully characterise all aspects of groundwater flow and, where appropriate, contaminant transport processes at a site. Formulating a valid conceptual model of the system is critical [31] as it defines the fundamental characteristics of the system, and clearly specifies the features and functional components of the system that must be adequately represented. Without an adequate conceptual model, it is impossible to select the appropriate flow model code (or modeling approach) or, for situations where a model is not used, to select the appropriate set of predictive equations.

The conceptual model for the study area should incorporate all the characterisation information listed above, but additionally include a full description of how the system functions. Important issues to consider include:

- the nature of aquifer recharge and the possibilities of by-pass flow,
- the role of preferential flow via fractures,
- the influence of aquifer heterogeneities and anisotropies on groundwater flow velocities, and
- the relationship between baseflow, aquifer water levels and the characteristics of the aquifers and aquitards [32].

The conceptual model must also consider the proposed project activities and the anticipated management issues. For aquifers that will be subjected to significant stresses due to pumping, the conceptual model should have a clear understanding of the flow mechanisms, including the role of vertical components of flow in the release of water from storage, and a good knowledge of the source(s) of the pumped water and of the receiving springs and pumping wells that are to be deprived of supply. A simple understanding of anticipated changes to the annual water balance of the study area is insufficient. It is essential that base knowledge incorporated in the conceptual model reflects an understanding of the transient nature of the aquifer and the likely time frame over which changes will occur.

CRA's conceptual model for the study area is illustrated in Figure 1. The model is not explicitly described in CRA reports but, on the basis of the steady state, "equivalent porous medium" numerical models selected for aquifer simulation, their conceptual model clearly ignores critically important hydrogeological features of the study area such as preferential flow via fractures and the role of aquifer storage. I raise this issue because data for the site and for hydrogeologically comparable areas in southern Ontario support a conceptual model that is strongly founded on the principle of "fracture flow" through a complex network of rock discontinuities, locally enlarged by chemical dissolution [24, 25, 26, 27, 28]. This conceptual model sits in stark contrast to that adopted by CRA, but is well endorsed by pumping test results and by the highly sensitive and temporal, hydrologic response of study area springs to changes in aquifer water level. The model is illustrated in Figure 3. It includes laterally extensive fractures that individually support the area's numerous discrete springs and intermittently-isolated ponds.

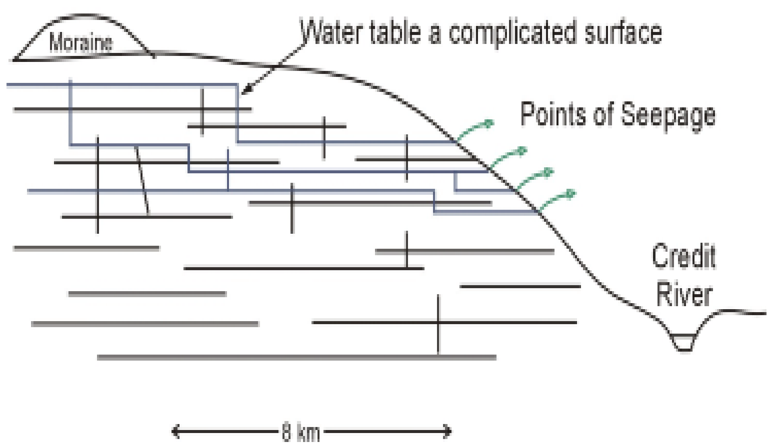


**Figure 3. A conceptual model based on fracture flow best explains the hydrologic response of springs to changes in aquifer water level and the numerous discrete points of groundwater seepage along the Niagara Escarpment .**

### 2.3 Aquifer Modeling

Groundwater flow models have become key components of all investigations involving groundwater. For investigations that depend heavily on quantitative analysis they often underpin the entire study. In the present study, modeling has been relied upon:

- To demonstrate the validity of the conceptual understanding of the aquifer system.
- To predict the susceptibility of water features and functions to land use changes associated with quarry development.

- To provide an essential platform for planning quarry development and for identifying and testing strategies required to limit and mitigate impacts.

Since the inception of the project, three aquifer simulation models have been developed and none has performed adequately. Key problems include:

- The use of an "equivalent porous media" approach which fails to recognise that preferential flow via discrete fractures will significantly influence the propagation of dewatering impacts, with the strong possibility that remote wells and springs will be just as seriously affected as those in close proximity.
- Weak or non-existent steady state model calibrations, especially with regard to stream flows and to groundwater levels in the upper reaches of the catchment.
- Absence of transient flow calibrations and poor specific yield data, meaning none of the models are capable of predicting how the aquifer will respond as a function of time.
- Absence of model verifications and thus no evidence that the models will provide reliable predictions for situations that extend beyond those experienced by the aquifer under natural conditions.
- "Worst-case scenario" simulations fail to provide "worst-case impacts" since they show deviation from calibrated "average aquifer conditions". The most serious impacts are expected to occur where stream flows are not "average" but are in low flow condition.

Without a reliable, adequately calibrated and properly verified groundwater flow model, the proponents are unable to predict the environmental impact of quarry development. Neither are they able to evaluate the potential benefits of the remediation measures they propose.

The first model was developed by Harden Environmental Services (HES) (1997) [6] using an early version of Visual MODFLOW. The model used a fairly coarse grid (144 rows by 124 columns with cell sizes ranging up to 100m square) but, to its credit, did include 5 models layers, three of which were dedicated to the Amabel Dolostone. In this way, HES were able to represent, at least to some extent, vertical heterogeneities in the Amabel formation that were clearly apparent from the field data. This model no longer plays a role in the proposed quarry development, and is not discussed further here.

When CRA took over the investigation, a new model was developed in support of its August 2000 Water Resources Evaluation report [12]. The model is described in Volume 3 of the document, Appendix E. According to CRA, the model was developed (Pg. E-1, Section 1.2 Objectives) "*to serve as an assessment tool to evaluate potential changes to the groundwater and surface water flow systems within and surrounding the Site as a result of the quarry development*". In particular, the model's purpose (Page E-2) was "*to:*

- *assess mitigation options and provide assistance in the quarry design process,*
- *evaluate rehabilitation scenarios and estimate the time needed to fill the quarry with water,*
- *evaluate the potential influences of quarry operations in the Site Vicinity, such as residential wells, creeks, fisheries, and wetlands; and*
- *facilitate the completion of a water budget for quarry and mitigation operations."*

In truth, the model was never capable of fulfilling any of these purposes. The reasons are as follows:

1. The model was developed in just 2-dimensions using MODFLOW-96, a code notoriously inadequate for simulating, at the local scale, aquifers in which flow predominantly takes place along discrete open fractures.
2. The Amabel Formation, the most important aquifer (and the quarry target rock) is represented as a single model layer, thus ignoring vertical variations in hydraulic conductivity (permeability). In this one respect alone, the CRA model can be considered inferior to that developed by Harden Environmental Services. One important disbenefit of such a gross simplification of the flow system is that vertical components of flow (important features in an aquifer that is dewatered) can never be adequately simulated.
3. The model is only calibrated against water levels (for June, 1987) and even then the match is described by CRA as only "*reasonable*" (Page E-16). The model is not calibrated against stream flows which is a crucial deficiency, as there is no evidence that the model is simulating the correct volumetric rates of flow.
4. Contrary to the assertions made (Page E-14), the model is only calibrated for steady state and is <u>not</u> calibrated for transient flow conditions. Only cursory evidence is provided that the model can reproduce the long-term pumping tests i.e. the changes / fluctuations of water level with time, and even then delayed yield effects of pumping are totally ignored. Without a reliable transient flow calibration (i.e. demonstration that i) the time-variant pumping test responses can be reproduced and ii) that seasonal changes in spring flow can be reproduced), there can be no confidence in the model's ability to predict how water levels and spring discharges will change with time in response to dewatering.

In effect, the model's serious limitations render as meaningless the results that emanate from its subsequent use (pages E-22 to E-27) to predict the impacts that will occur during 5 phases of quarry development and the following rehabilitation. Moreover, there is no indication that the MODFLOW-96 model, developed almost ten years ago to assist with quarry development plans, has been updated or revised in terms of the model layering, model software or additional field data.

For the purposes of the Part B Sensitivity Analysis Report of the Comprehensive Broader Scale Environmental Study (CBSES), an independent model was developed by AquaResource Inc. [2] and is described in a document entitled "Hydrogeological Modeling Task – Draft Report – June 2007" [2]. The precise relationship(s) between this model and the CRA model, and the relative roles that the two models play in the current status of the proposed quarry development program, is not made clear by the proponents. By all appearances, CRA's highly deficient two-dimensional model of August 2000 seems to be the primary driving force behind the quarry design and adaptive management plan.

The groundwater flow model developed by AquaResource Inc. was not designed for the expressed needs of the CBSES but was developed using an existing regional model originally created by Waterloo Hydrogeologic Inc. (WHI) for Credit Valley Conservation (CVC).

AquaResource Inc. created a CBSES subdomain model as a subset of the existing regional model, and used this model to run a series of hypothetical simulations. In total, four scenarios were examined:

- **Scenario A** - Existing Conditions. This condition represented the existing understanding of hydrologic and hydrogeologic conditions within the Study Area.
- **Scenario B** - Full Active Extraction Conditions. This scenario was designed to represent a hypothetical "worst-case" scenario and considered unmitigated dewatering impacts associated with the extraction of material in three cells.
- **Scenario C** - Rehabilitation Conditions. This scenario considered several possible rehabilitation conditions for Resource Area 9A. It was based on the assumption that once the aggregate extraction is complete, quarried cells will be filled with water creating large lakes.
- **Scenario D** - Interim Extraction Conditions. An interim extraction system scenario was examined to demonstrate the immediacy of potential dewatering effects from aggregate extraction in Resource Area 9A. In this scenario, the impacts were examined after one third of the competent Amabel Formation bedrock had been removed.

I reviewed the "Hydrogeological Modeling Task – Draft Report of June 2007" in February 2008, considering seven elements that are key to the modeling process:

- Hydrogeologic Characterisation of the Site.
- Model Conceptualisation.
- Model Software Selection.
- Model Development and Calibration.
- Model Verification / History Matching.
- Sensitivity Analysis.
- Model Implementation.

Full details of my review can be found in Howard, 2008 [1]. I came to the conclusion that the model, while pivotal to the study, failed to deliver on numerous counts. I felt the majority of problems could relate more to the quality of the dataset and the conceptual understanding of the system provided to AquaResource Inc., than to the modelers who had the appropriate model code and modeling experience but lacked the necessary base information to achieve their task. Major concerns with the model included the following:

- The modelers selected the appropriate model code (an advanced finite element code developed by FEFLOW® [33]) but failed to utilise one of its most valuable features i.e. its ability to represent the influence of discrete fractures on groundwater flow. Instead the modeler's used CRA's "equivalent porous media" approach which ignores the role of fractures and entirely misrepresents aquifer behaviour and its likely response to dewatering. An unfortunate aspect of the equivalent porous medium modeling approach is that it automatically generates impacts that are greatest close to the site of dewatering and negligible at large distances. In fractured carbonate aquifers such as the Amabel, the degree to which an individual stream is affected is likely to be as much a function of the pathways for flow provided by the fracture network as much as its distance from the dewatering site. Springs along the Niagara Escarpment that are well connected to the aquifer via discrete but laterally extensive fracture zones may be just as sensitive to quarry dewatering as springs immediately adjacent to the dewatering site. However, since secondary permeability features were not incorporated in the model, such impacts would not be predicted.

- Attempts were made to calibrate the model with respect to both heads (water levels) and stream flows. However, the quality of the calibration is poor and inadequate. Model head calibration statistics between about 340 masl and 410 masl (the expected range for the Amabel Formation in the vicinity of the Resource Area) are shown in Figure 4. They show a considerable scatter which exceeds normal levels of tolerance by any "rule of thumb". In some cases, model heads and field heads differ by 20 m or more. The severity of the problem becomes worse for data within and beneath the Paris Moraine (Figures 5 and 6). Here the statistical scatter becomes more pronounced and the model appears to consistently overestimate heads in the CBSES target wells (denoted by the black squares) by several metres. Given the very high sensitivity of study area stream flows to potentiometric head, the quality of calibration is unacceptable, especially for a model that is being used to investigate and evaluate the sensitivity of water features and functions to changes in land use. The model exhibits similar calibration problems with respect to stream flows. A steady state model calibrated using mean annual values of aquifer recharge should reproduce mean annual stream flows within ± 20%. No such comparisons are provided. As shown in Figure 7, the model is merely capable of generating flows that are found within the second and third quartile of stream flow observations. Even then, the success rate is approximately two out of every three. Calibration targets that are based on quartiles are too broad in scale, especially given that stream flows often vary annually over several orders of magnitude. Compliance with more rigorous targets is required for a model used to investigate and evaluate the sensitivity of water features and functions to changes in land use.

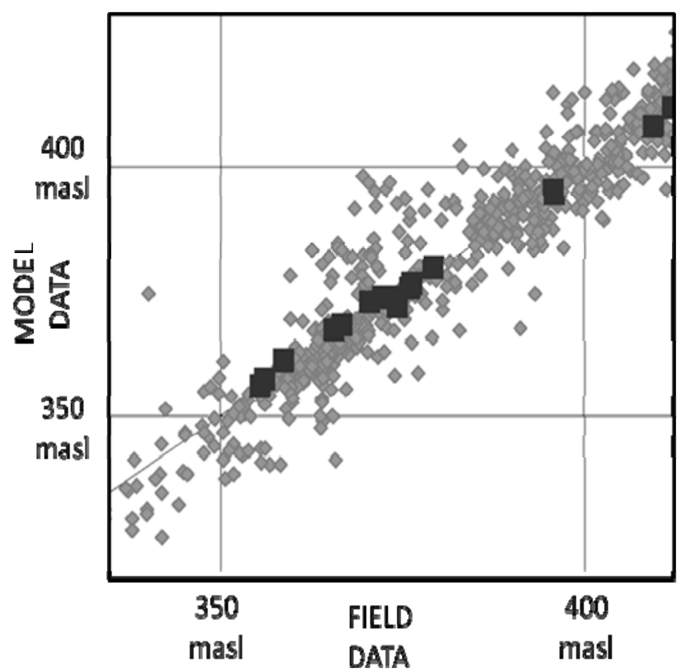


**Figure 4. Model head calibration statistics from about 340 masl to 410 masl (the expected range for the Amabel Formation in the vicinity of the Resource Area) (extracted from AquaResource Inc. ([2], Figure 28)).**

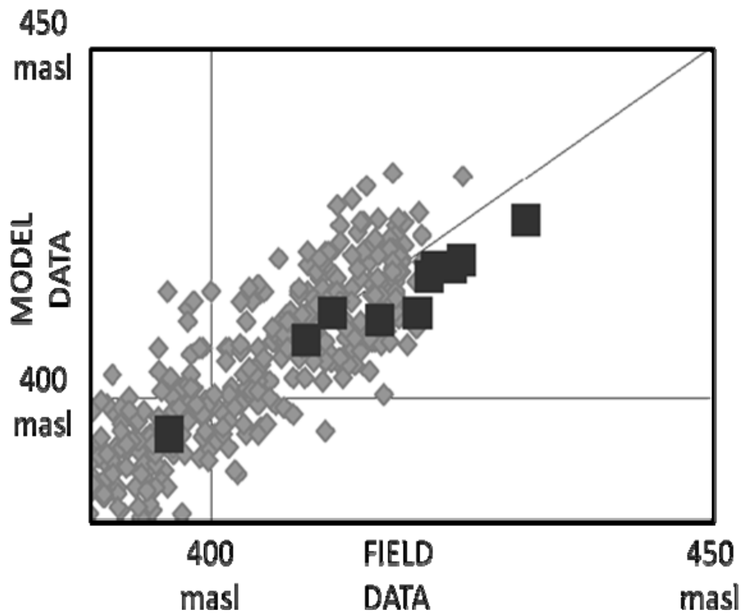


**Figure 5. Model head calibration statistics above about 390 masl (the expected range of heads within and beneath the Paris Moraine in the Upper Region, north west of the Resource Area (extracted from AquaResource Inc. ([2], Figure 28)).**

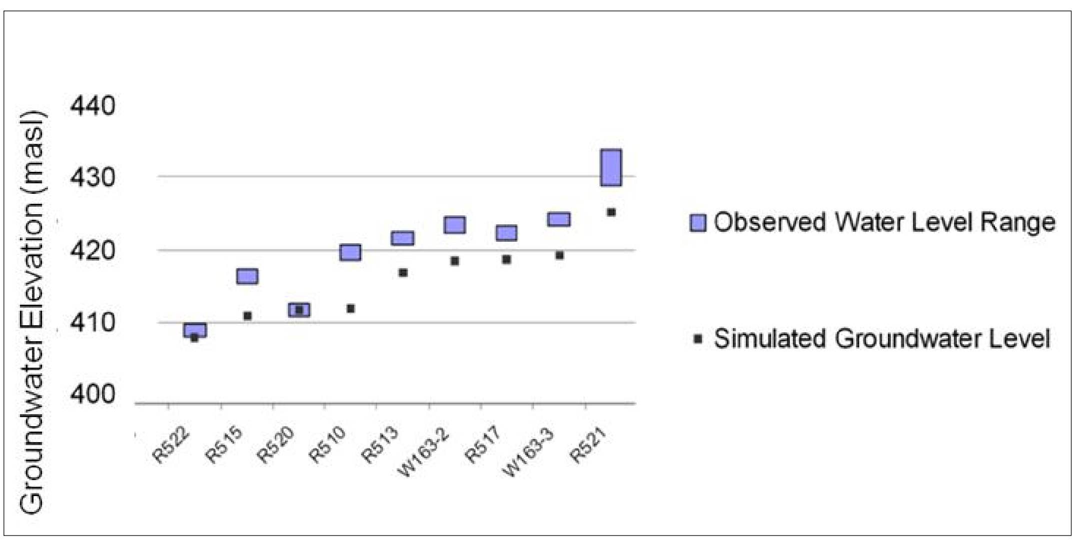


**Figure 6. Model head calibration for calibration target wells with heads above 400m. Three wells are in overburden and six are in the Amabel Formation (modified after AquaResource Inc. ([2], Figure 28)).**

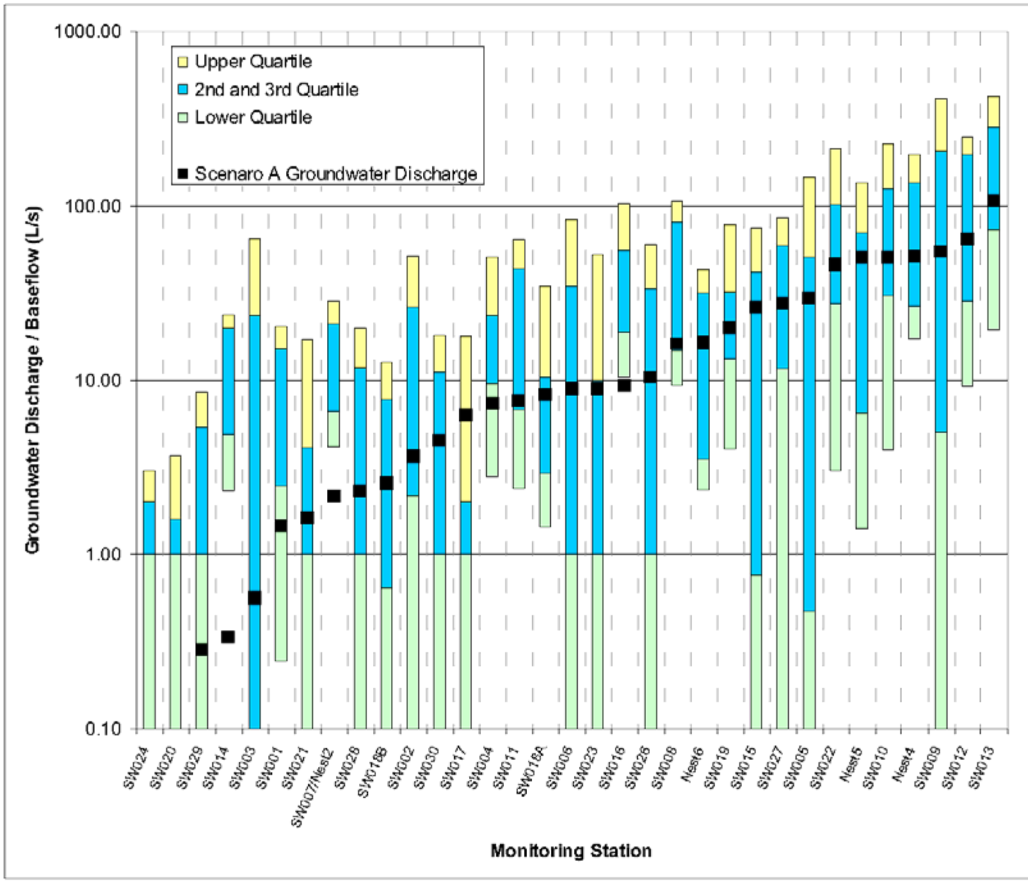


**Figure 7. Model calibration data for baseflow (from AquaResource Inc. ([2], Figure 29)).**

- No attempt was made to calibrate the model for transient (unsteady state) flow. It is therefore unable to predict the rate at which heads will change with time when the aquifer is stressed by pumping. Neither can the model predict the rate at which water levels will recover (in the aquifer or in site ponds) when water is returned to the system.
- The model was not subjected to a verification process; thus, there is no evidence to suggest that the model can provide reliable impact predictions for pumping conditions that extend beyond those that already exist. Verification is essential for models used to predict environmental impacts for pumping scenarios that differ significantly from the conditions used to provide calibration.
- All model simulations ignored the role of aquifer storage and were performed assuming steady state conditions. Model simulations described as representing “worst-case scenarios” fail to provide “worst-case impacts” since they show the predicted deviations from calibrated “average aquifer conditions” . The most serious impacts will undoubtedly occur where stream flows are not “average” but are in low flow condition.
- AquaResource Inc. performed sensitivity analysis to determine the sensitivity of the model simulations to uncertainty in values of model input data. This can be important as it indicates which parameters need to be known with the greatest degree of confidence, and which parameters have little influence on model behaviour and are therefore less important. AquaResource Inc. found the model to be insensitive to the hydraulic characteristics of the deeper bedrock units, thus ameliorating fears that very few (if any)

hydraulic conductivity data are available for these units. However, the reason for the apparent insensitivity is simply because these units were assigned very low values of hydraulic conductivity, thus virtually excluding them from the active flow system. A model that included fracture flow characteristics would be considerably more sensitive to the hydraulic characteristics of the deeper bedrock units, and would require that such characteristics be known with a much higher level of certainty than at present.

In summary, the groundwater flow model created for the CBSES has not been adequately refined and calibrated and there can be little confidence in its value for predictive purposes, even under steady state conditions. In effect, and despite its level of sophistication, the model is no more effective than those developed previously.

## 2.4 Adaptive Management Plan (AMP)

Adaptive management is becoming a popular approach for managing aquifer systems, offering some important benefits. The most valuable of these is the flexibility to adjust and fine tune the management approach as more is learned about the aquifer and its behaviour. The AMP, however, should not be considered as a convenient substitute for a full scientific understanding of the aquifer system and a sound appreciation of how it will respond to a wide range of management scenarios. Using an "equivalent porous medium" conceptual understanding of the system, the proponents have developed aquifer simulation models that are overly simplistic, poorly calibrated and quite incapable of making the types of prediction so urgently required. Based on the dataset and the models available to them, I don't believe anyone has the first idea how the aquifer (modified by the injection of grout) will respond to the inordinate pumping stresses and complicated artificial recharge schemes quarry development will require. As adopted for the Rockfort Quarry Proposal, the AMP is no more than an admission of failure. The AMP is not about refining a solid, and reliable management plan. It's not about making minor adjustments to a fundamentally robust model as more data become available The AMP is tantamount to saying "we can't predict what will happen, but when problems arise, we'll find a way of dealing with them". The AMP will inevitably fail.

We need to learn from experience. About 5 years ago, construction of the York Durham Sewer System (YDSS) ran into difficulties when a tunnel boring machine encountered a permeable sand while drilling along 16$^{th}$ Avenue. Additional dewatering was required to depressurise the aquifer and ensure worker safety. The resulting chain of events caused unacceptably high impacts on the local environment requiring the design of an adaptive management plan (the 16$^{th}$ Avenue Phase II EMP) that is estimated to have cost $30 million to implement [34]. Subsequent work on the YDSS has heeded the lesson. The management plan developed to deal with problems along 16$^{th}$ Avenue was obligated to be "adaptive" because the hydrogeology of the system was insufficiently known for remedial plans to be developed with any degree of reliability. AMPs for ongoing phases of the YDSS are backed with a thorough hydrogeological understanding of the aquifer system and aquifer simulation models that have been painstakingly tested and calibrated against heads and flows under both steady and transient (time variant) conditions. Thus, unlike the AMP for the proposed quarry development, potential impacts are known with a high degree of confidence and management options are well established and are ready for refinement as necessary.

## 3. Conclusion

Hydrogeological studies conducted in support of the proposed Rockfort Quarry began well but have seriously deteriorated. Comprehensive field studies conducted by HES in the mid- to late- 1990's gave rise to a conceptual model of the aquifer system that rightly acknowledged the influence of fractures on groundwater flow, and the first aquifer simulation model developed on the basis of this concept included a creditable attempt to incorporate vertical heterogeneities observed in the field. In the late 1990's CRA decided, for reasons unknown, to abandon HES' approach. Instead they favoured an "equivalent porous medium" approach that conveniently ignores the important role fractures can play. Subsequent models were based on this concept and not surprisingly, have failed to perform adequately. Calibrations against observed heads tend to be poor in the areas of greatest concern and calibrations against stream flows are either non-existent or very weak. The models are unreliable and simply incapable of providing direction on aquifer management for the type of project proposed. Based on the quality of the dataset and the types of model developed, I fail to understand how anyone can even hope to predict how the aquifer (grossly modified by the injection of grout) will respond to the complex water management schemes proposed. CRA claim that adoption of an Adaptive Management Plan is the ideal way to proceed. I would argue that this approach is only suitable when the aquifer is well understood and the existing management plan is well supported scientifically. Since the impacts of large-scale dewatering can't be predicted with a reasonable degree of scientific certainty prior to the project, the AMP is destined to fail.

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