**INTERA ENGINEERING LTD.**
**1 Raymond Street, Suite 200**
**Ottawa, ON K1R 1A2**
**Tel: (613) 232-2525**
**Fax: (613) 232-7149**

May 17, 2009

Ref. No.: 04-233-6

Friends of the Rural Communities and Environment (FORCE)
c/o Lawson Park Ltd.,
P.O. Box 15, R.R. #1
Freelton, Ontario L0R 1K0

**Attention: Graham Flint, Chair, FORCE**

**Re: Hydrogeological Review of Aggregate Resources Act Application, St. Marys Flamborough Quarry Site, City of Hamilton**

Dear Mr. Flint,

Please accept this letter as INTERA Engineering Ltd. report on hydrogeologic review of the Aggregate Resources Act (ARA) Application and supporting documentation for the proposed Flamborough Quarry submitted by St. Marys Cement (Canada) Inc. The St. Marys Cement property is the site of a proposed Quarry is to be developed in the Amabel Formation dolostone to depths of about 36 to 40 m in Part of Lot 1, and Lots 2 and 3, Concession 11, geographic Township of East Flamborough, now the City of Hamilton.

The ARA Application was initially submitted to the Ministry of Natural Resources (MNR) on January 22, 2009 and following resubmission on February 13, 2009, was found by MNR to be complete on March 3, 2009. Because the proposed Quarry will be excavated below the water table in a very permeable bedrock formation surrounded by sensitive surface water-related ecological features and private groundwater supplies, there are important hydrological and hydrogeological issues associated with the Application that are raised in this letter.

This review letter, in addition to reviewing the ARA Application and primary supporting hydrogeological documentation, summarizes relevant parts of the proponents previous hydrogeological reports and corresponding review letters I have prepared for this site since March, 2005 that are important to the Application review. I have previously reviewed the following seven major hydrogeological documents and sets of documents for this site:

- *Phase 1 Pumping Test Report, PTTW #8461-7CFLG5 - Condition 4.22,* report prepared by Gartner Lee Limited in August, 2008 - reviewed September 28, 2008;
- *MOE Draft Permit to Take Water and Supporting Documentation,* reports prepared by MOE and Nova Hydrogeology Inc. in May, 2008 - reviewed on May 31, 2008;
- *Final Hydrogeological Work Plan,* Report prepared by Gartner Lee Limited in March, 2008 - reviewed on April 30, 2008;

- *Final Draft – Hydrogeological Work Plan,* report prepared by Gartner Lee Limited in August, 2007 - reviewed on November 19, 2007;
- *Revised Work Plan for the Evaluation of Groundwater Recirculation System,* report prepared by Gartner Lee Limited in September 2006 – reviewed on November 26, 2006;
- *Draft Three-Volume Hydrogeological Level 2 Report*, report prepared by Gartner Lee Limited in June, 2005 – reviewed on November 11, 2005; and
- *Preliminary Hydrogeological Assessment Report*, report prepared by Gartner Lee Limited in August, 2004 – reviewed on March 28, 2005.

This report was prepared by Kenneth G. Raven, P.Eng., P.Geo., Principal and Senior Hydrogeologist of INTERA Engineering Ltd.

This letter is organized by the following three sections:

1. Primary Documents Reviewed
2. Hydrogeological Review Comments
3. Conclusions

## 1 PRIMARY DOCUMENTS REVIEWED

The following four primary documents were the focus of this review:

- *Aggregate Resources Act Summary Statement, St. Mary's Flamborough Quarry, St Marys Cement Inc. (Canada) Inc.,* report prepared by Glen Schnarr & Associates Inc., February, 2009.
- *Hydrogeological Level 2 Report – St Marys Flamborough Quarry, Volume 1,* Report prepared by AECOM Canada Ltd. for St. Marys Cement (Canada) Inc., February 26, 2009.
- *Hydrogeological Level 2 Report – St Marys Flamborough Quarry, Volume 2 - Groundwater Flow Model,* Report prepared by AECOM Canada Ltd. for St. Marys Cement (Canada) Inc., February 26, 2009.
- *Hydrogeological Level 2 Report – St Marys Flamborough Quarry, Volume 3 - Appendices,* Report prepared by AECOM Canada Ltd. for St. Marys Cement (Canada) Inc., February 26, 2009.

## 2 HYDROGEOLOGICAL REVIEW COMMENTS

Based on my review of the primary documents outlined in Section 1 and in consideration of previous hydrogeological reports prepared for this site as listed above, I have the following three main hydrogeologic issues and concerns for the ARA Application and supporting documentation:

1. Proposed Use of an Unproven GRS Technology
2. Reliance on an Unrealistic Groundwater Flow Model
3. Reliance on an Ambiguous Adaptive Management and Contingency Plans

Detailed discussion of these issues and concerns is provided in the following sections.

### 2.1 Proposed Use of an Unproven GRS Technology in a Complex Bedrock Hydrogeological Setting

The *Draft Hydrogeological Level 2 Report – Volume 1* prepared by Gartner Lee Limited (GLL) in June 2005 clearly states (page 73) that unmitigated development of the Quarry (i.e., without an effective groundwater recirculation system (GRS)), will have unacceptable impact on the local Provincially Significant Wetlands and local residential wells. Similar, although less definitive statements concerning impact of unmitigated Quarry development are provided in the *Hydrogeological Level 2 Report - Volume 1* (page 35). Such unacceptable impact will include dewatering of the adjacent wetlands (which are currently sustained at least seasonally by groundwater) and loss of water supply for many surrounding private wells. Consequently, effective implementation of a GRS at the proposed Quarry is considered essential for Quarry development to proceed without adverse hydrogeological and hydrological effects.

The only quantitative assessment of unmitigated impact on surrounding wetlands is provided in the *Draft Hydrogeological Level 2 Report – Volume 1, Section 5.1.2.* The *Hydrogeological Level 2 Report - Volume 1* does not quantify such effects. The *Draft Hydrogeological Level 2 Report* notes that unmitigated development of the Quarry would result in 86.8% reduction of groundwater flow to the Mountsberg Creek wetland and 79% reduction of groundwater flow to the wetland near Flamboro Creek, and an estimated reduction of baseflow in Mounstberg Creek of 3.7 to 13%. Since surrounding wetlands are sustained on groundwater flow, unmitigated development would effectively dewater and dry-up these wetlands.

The *Hydrogeological Level 2 Report - Volume 1* prepared by AECOM states (page 38) that the GRS will be implemented using recharge wells, with back-up or contingency use of recharge trenches, recharge trenches with passive boreholes and/or combined extraction and recharge wells as part of an Adaptive Management Plan for the GRS. Recharge wells are preferred (page 37 and 38), because they are less physically disruptive than trenches, there is greater flexibility in installation location, and recharge can be specifically directed to locations and depths where mitigation is needed. This last advantage recognizes that the Amabel bedrock has highly heterogeneous hydraulic properties and flexibility in where one injects groundwater is key to ensuring effective GRS performance.

Although the *Hydrogeological Level 2 Report - Volume 1* (page 38) considers GRS concepts to be "g*enerally feasible at the Flamborough Quarry site given site geology and hydrogeology"*, the proposed GRS remains unproven technology for the Quarry and faces many implementation challenges that may render the GRS ineffective at this site. Most of these challenges are related to attempting to implement the system in the Amabel dolostone bedrock which all site investigations clearly show has highly variable and unpredictable hydraulic properties. Measured transmissivities of the Amabel dolostone at site range from less than 1 $m^2$/day up to 3000 $m^2$/day (page 15), which implies over a 1000 fold range of possible groundwater injection flowrates for the proposed GRS. Managing such a wide range of injection flowrates over the large perimeter of the proposed GRS will not be a simple task.

The following practical implementation challenges exist for long-term effective operation of a GRS at the Flamborough Quarry site.

1. **Unpredictable bedrock hydraulic properties**.
   It is clear from the extensive hydrogeological data summarized in the AECOM *Hydrogeological Level 2 Report Volume 3 – Appendices* (notably the Lotowater borehole geophysical/ dynamic flow logging and packer testing) that groundwater flow within the Amabel dolostone is controlled by the presence of very permeable productions zones. The depth occurrence and lateral continuity of these permeable bedrock horizons or production zones are clearly not predicable and will create design and operational problems for any GRS. For example, the dynamic flow logging and the packer testing show that there are very permeable horizons (production zones) within the bedrock that are separated by intervening low permeability thicknesses of bedrock. Such production zones are shown to sporadically exist at depths of 5-15 m, 20-25 m and 30–35 m depth in different wells across the site. The presence of these production zones separated by low permeability intervening zones will complicate and compromise the design and functioning of a GRS at the Quarry site.

2. **Enhancement of bedrock hydraulic properties between the GRS and the Quarry resulting in inability to maintain water levels in the GRS injection wells.**
   The ability to maintain water levels in proximity to the Quarry requires that a sufficient quantity of water is available for injection such that water levels and hydraulic heads can be maintained in the vicinity of the injection wells. The controlling variable in the water level that can be generated at an injection well is the permeability of the bedrock surrounding the well. If the bedrock between the GRS and the Quarry is highly permeable, the GRS will be unable to maintain water levels in the vicinity of the Quarry with the majority of the injected fluid simply short-circuiting back to the Quarry, rather than flowing into the bedrock away from the GRS to maintain groundwater levels beyond the perimeter of the GRS.

   There are two processes that will act to enhance the permeability of the bedrock between the injection wells and the Quarry face – bedrock dissolution due to carbonate rock dissolution (i.e., karstification) and stress relief due to relaxation of the Quarry face. Karstification will occur due to dissolution of the carbonate bedrock by re-injected groundwater. The re-injected groundwater collected from the Quarry floor will be continually exposed to the atmospheric sources of carbon dioxide which will form carbonic acid, and to other sources of acidity (e.g., organics in surface water/runoff, oxidation of trace sulphides in quarry rock) that will be consumed during closed-system dissolution of the carbonate bedrock. The dissolved carbonate bedrock will precipitate on the floor of the Quarry as calcite and dolomite. This dissolution process, which normally occurs quite slowly in nature forming karst features, will be accelerated by the large volumes of water proposed to be injected in the GRS.

   Bedrock near the Quarry face also has the potential to be subject to permeability enhancements due to stress release of the Quarry face and due to blasting effects. Increases in the bedrock hydraulic conductivity on the Quarry side of the GRS due to stress relief will again result in the preferential flow of injected water directly to the Quarry face and therefore an inability of the GRS to maintain water levels in the bedrock beyond the perimeter of the GRS. This stress relief GRS implementation challenge will be greatest where the GRS is proposed to be closest to the Quarry face, which is along the western side of the Quarry.

   Because water flow in the bedrock occurs along fractures, and such water flow is proportional to the cube power of the fracture opening, small increases in the opening of such fractures by dissolution or stress relief will result is large increases in bedrock permeability. Consequently, there is a very real threat of substantial increases in bedrock permeability that will prevent the GRS from maintaining required elevated water levels adjacent to the Quarry as proposed.

3. **Local plugging of injection wells resulting in inability to maintain water levels in surrounding bedrock.**
The ability to maintain water levels in proximity to the Quarry via the GRS also requires that the injection wells continue to function and allow required volumes of groundwater to be injected into the bedrock. If the GRS experiences reduction of injection flowrates due to local clogging of injection wells, then the GRS will be unable to maintain water levels in bedrock and to prevent propagation of drawdowns away from the proposed Quarry. Although this implementation issue is opposite to that described in 2. above, it is nonetheless a very real and critically important factor that will affect long-term GRS performance that is recognized in the supporting literature noted in *Appendix J* to the AECOM *Hydrogeological Level 2 Report – Volume 3*.

For example, Huxley et al. (2004, page 59, points 7.2.1 and 7.2.2) as cited in Appendix J concludes:

*"The main concern expressed in published literature, and reference design guides, related to the potential reduction in infiltration capacity with time as a result of clogging with fines, micro-organisms, or precipitates as a result of exposing groundwater at the surface and mixing of waters of different chemistries.*
*Consideration of the groundwater chemistry has been shown to be important. In the case of the Eversley Quarry, trial recharge trenches became rapidly clogged with iron oxide deposits within the space of only a few days as a result of low pH groundwaters, with high iron concentrations being discharged at surface."*

And on page 60 (points7.2.3 and 7.2.6) they add:

*"Experiments undertaken at the Rock Mountain Arsenal in the early 1990s found that sedimentation and microbial fouling tended to be restricted to the gravel filled trench and that it had not progressed far into the aquifer. It was observed that 100 days (over 3 months) after recharging of the trench with water laden with sediment and micro-organisms significant reductions in the recharge rates were observed.*

*It has not been possible to investigate these long-term clogging issues in the field experiments, since these were of limited duration."*

The reports by Huxley et al. (2004) and Corcoran et al.(2005) cited in *Appendix J* note that long-term deterioration of groundwater recharge rates due to particulate plugging, chemical precipitation, bio-fouling and air bubble entrainment are recognized as the most common problematic feature and concern with GRSs. The research report by Huxley et al. also notes (page 13) that suspended solids concentrations as low as a few mg/L can create GRS plugging problems. Since most MOE sewage works approvals for quarry dewatering set average effluent concentrations at 25 mg/L suspended solids, typical quarry effluents for re-injection can create GRS plugging problems and hence may not be suitable for long-term re-injection.

4. **Potential for escape of injected water**.
In the permeable and complex fractured bedrock setting of the proposed Quarry, there is also the potential for escape of injected water from the GRS that will not be captured by the Quarry. Consider the simple case of an injection well that is open to depth of 35 m and is drilled to target injection to a deep "production zone". If the permeability of the production zone is locally reduced due to heterogeneity and other perhaps shallow bedrock zones have higher permeability, then injected water will preferentially recharge the shallow bedrock over the targeted "production zone". If water levels are maintained in the "production zone" by overall operation of the GRS, then this shallow injected water may escape from the GRS. Given the extremely heterogeneous nature of

the bedrock, this escape is a very real possibility.

The depth occurrence of the permeable bedrock horizons or production zones as evident from field testing of the proposed injection wells for pilot-scale GRS (e.g., TW-13, TW-14 and TW-15) provide examples of the conditions under which escape of injected water is probable. The bottom of TW-14 is permeable (transmissivity, T = 84 $m^2$/day), but only the top of TW-13 is permeable (T=1350 $m^2$/day), while the bottom of TW-15 is permeable, but less that than for TW-14. The occurrence of the very high transmissivity in the shallow zone of TW-13 with little to no transmissivity in the deeper zones of TW-13 is the kind of bedrock transmissivity distribution that can contribute to escape of injected water during the GRS.

The very real and significant practical difficulties of implementing an effective GRS in the complex bedrock hydrogeological setting of the Flamborough Quarry is perhaps best demonstrated by the outcome of the proponent's pilot-scale GRS. This pilot scale testing which was agreed to, acknowledged by, and committed to by the proponent as a necessary requirement to demonstrate GRS applicability at the Flamborough site (*St. Mary's Flamborough Quarry Community Newsletter, Issue #6, Fall, 2007*) has been unsuccessful and abandoned. Consequently, the proponent has been unable to *"prove that the GRS will work in Flamborough"* and to *"demonstrate that GRS is applicable to the unique geological and hydrogeological conditions of Flamborough."*

Given the lack of demonstrable field proof that GRS can work at the Flamborough site, the GRS is proposed based solely on the results of a computer groundwater flow model *(Hydrogeological Level 2 Report Volume 2 – Groundwater Flow Model*), inferences of successful performance at other locations (*Hydrogeological Level 2 Report Volume 3 – Appendix J*), and the belief that GRS can be made to work under an Adaptive Management Plan.

The groundwater flow model, which is reviewed in Section 2.2 of this letter, presents a simplified and unrealistically favourable assessment of the expected GRS performance based on over-simplified conceptualization and representation of the bedrock groundwater flow system at the proposed Flamborough Quarry and in the surrounding area.

*Appendix J* and other parts of the *Hydrogeological Level 2 Report – Volume 1* (page 37), note that there is abundant experience in use of artificial recharge systems that can be cited in support of the proposed successful performance of GRS at the Flamborough Quarry. Review of this documentation shows that in fact there are no identifiable examples of proven successful application of GRS at deep permeable fractured dolostone bedrock sites similar to Flamborough. Most of the applications are for shallow overburden systems which show mixed success, and the two examples noted for Ontario sedimentary bedrock (Milton and Rockfort Quarries) have either not conclusively demonstrated successful long-term performance (Milton Quarry) or are under regulatory review and include other groundwater control systems (Rockfort Quarry with additional slurry wall). Regardless of what these possible examples of GRS application show at other sites, demonstration of successful GRS performance at the Flamborough site is, as the proponent has stated, necessary to address the unique geological and hydrogeological conditions of the site.

Given all of the above it is apparent that application of GRS at the Flamborough Quarry site remains an unproven technology. There has been no demonstration or proof of the ability of GRS to mitigate the acknowledged adverse effects of development of the Quarry on sensitive surface water-related ecological features and local groundwater supplies. As there are numerous credible and probable means by which the GRS will fail to perform in accordance with requirements, demonstration of successful application of GRS should be required prior to considering an ARA license application.

## 2.2 Reliance on an Unrealistic Groundwater Flow Model

The AECOM *Hydrogeological Level 2 Report Volume 2 – Groundwater Flow Model*, describes the conceptualization, construction, calibration and application of a regional sub-watershed scale, 3-D groundwater flow model of the Flamborough Quarry and surrounding area including the Carlisle municipal wells that obtain drinking water from the Amabel dolostone. This 2009 AECOM model is the second and most recent conceptual and numerical groundwater flow model that been developed for the area over the past four years. The first conceptual and numerical groundwater flow model is described in the *Draft Hydrogeological Level 2 Report Volume 2 – Groundwater Flow Model*, prepared by Gartner Lee Limited in June 2005. There are major and important differences in the conceptualization, construction and application of these two groundwater flow models that are relevant to this review which are discussed and described below.

The significant differences in conceptualization and construction of the 2009 AECOM models and the 2005 Gartner Lee models are principally in the characterization of the Amabel dolostone bedrock. The 2009 AECOM groundwater flow model considers of the entire 34 m average thickness of Amabel dolostone as a simple homogeneous, although mildly anisotropic ($K_h$ /$K_v$ = 10) bedrock aquifer. This is a major change from the characterization that was presented for the 2005 Gartner Lee model that concluded that there were high permeability production zones within the Amabel that controlled most of the groundwater flow and the propagation of drawdowns away from the Quarry.

This revised interpretation and conceptualization "*discarding the presence of distinct production zones in the Amabel Formation at the site*" (*Hydrogeological Level 2 Report Volume 2 – Groundwater Flow Model, page 10)* is attributed in part to a review by Worthington Groundwater (*Hydrogeological Level 2 Report Volume 3 – Appendix E*) and to a review by S.S. Papadopulos & Associates Inc. (*Hydrogeological Level 2 Report Volume 3 – Appendix F3-4*). The Worthington Groundwater review concludes that because of a lack of fine-grained or argillaceous layers in the bedrock evident from borehole geophysical gamma logging at the site, it is unlikely that there would be development of regionally predictable, laterally extensive karstic production zones. This conclusion does not say that such production zones are absent, only that their occurrence is not predictable at a regional scale. Clearly based on the extensive hydraulic testing completed at site, it is obvious that production zones exist within the Amabel dolostone near the Quarry. Furthermore, I cannot find any statements in the cited S.S. Papadopulos review that indicate the presence of distinct productive zones within the Amabel should be discarded.

I am of the opinion that conceptualizing the Amabel dolostone as a simple homogeneous, mildly anisotropic single aquifer or hydrostratigraphic unit without production zones and low permeability layers is an unrealistic and overly optimistic characterization of the aquifer particularly given the issues at hand. The following site conditions and arguments support a conceptual and numerical model that includes bedrock production zones overlain and underlain by layers of reduced permeability.

1. AECOM extends the observation that production zones are not predictable to conclude that their presence can be ignored or discarded in groundwater modeling. This is unfounded and erroneous conclusion. Cleary such zones are present and their presence and the presence of low K layers will control groundwater flow and performance of a GRS. To ignore them in the groundwater flow model is a gross simplification.

2. The selection of injection wells as the preferred method of implementing GRS at the Quarry for reasons of flexibility in directing recharge to locations and depths where mitigation is needed, indicates that AECOM acknowledges the Amabel dolostone is not a simple homogeneous aquifer or single hydrostratigraphic unit.

3. The 2005 Gartner Lee groundwater flow model explicitly included laterally extensive production zones within the middle of the Amabel dolostone with lower permeability layers above and below these production zones. This is a conceptualization that was developed and endorsed by Gartner Lee based on review of all of the site hydrogeological data. While one may argue that the production zones are not evident in all boreholes at the mid-depth of the Amabel, it is more realistic to include them as was done with the 2005 Gartner Lee model than to discard them as was done in the 2009 AECOM model. Groundwater modeling always involves simplifications and including extensive production zones is an appropriate simplification that captures an essential element of the correct conceptual hydrogeologic model of the site – discarding them is not.

4. AECOM states (*Hydrogeological Level 2 Report, Volume 1, page 17)* that the similarity of groundwater head patterns in the shallow, intermediate and deep bedrock groundwater systems and the limited vertical gradients between these systems indicate the Amabel dolostone can be treated as single hydrostratigraphic unit for the purposes of evaluation and modeling. Although such similar head conditions can be reflective of single aquifer system with good vertical hydraulic interconnection, they do not prove that to be the case. A more direct assessment of vertical hydraulic interconnection and presence/absence of production zones is the analysis of the many pumping tests that have been completed at the site. The nature of the observed water responses to well pumping and rainfall at different bedrock depths (*Hydrogeological Level 2 Report Volume 3 – Appendix F2-3, Section 4.2*) are more consistent with strong lateral flow in deep permeable production zones with delayed responses in overlying low permeability intervals, than they are of a homogenous, mildly anisotropic single aquifer. If the bedrock was a homogeneous, mildly anisotropic single aquifer, there would much greater similarity in the responses of the aquifer to pumping at different depths. The AECOM interpretation of the latest *Phase 1 GRS Pumping Test Report (Appendix F2-3, page 10)* notes that *"deeper portions of the bedrock may be more or less confined or semi-confined in areas with poorer vertical connections"* – an interpretation that is not consistent with a characterization of the entire Amabel dolostone as a homogeneous, mildly anisotropic single aquifer.

5. There is stratification or depth variation of groundwater quality at the site that requires that there be low permeability layers in the bedrock. For example, detections of elevated nitrate in groundwater were reported only in the upper 10 m of Amabel dolostone. Such occurrences are not consistent with the conceptualization of the entire Amabel dolostone as a homogeneous single aquifer.

6. The delayed hydraulic responses of those bedrock intervals that overly the pumped permeable production zones can be analysed for vertical hydraulic conductivity, $K_v$, using the 1971 Neuman and Witherspoon ratio method for determination of aquitard hydraulic properties. Based on transmissivity and storativity of the water production zone measured in the 72-hour pumping test (*Draft Hydrogeological Level 2 Report)*, the reported shallow water level responses in BH-1S, BH-3S, BH-4S and BH-BS during the 7-day pumping test were analysed to determine $K_{v..}$ The resulting $K_v$ values range from $2 \times 10^{-9}$ to $1 \times 10^{-8}$ m/s. These results are similar to values reported

in the same or comparable bedrock formations at Cambridge, Smithville and Niagara Falls, Ontario and indicate that the production zones are overlain and most likely underlain by bedrock with much lower hydraulic conductivity that that assumed in the AECOM homogenous aquifer model (i.e., $K_h = 3.5 \times 10^{-5}$ m/s, $K_v = 3.5 \times 10^{-6}$ m/s). Hydraulic conductivity anisotropy ($K_h / K_v$) of the Amabel bedrock is therefore much greater than the 10 assumed in the AECOM model.

7. The results of the sensitivity analyses performed on the AECOM homogeneous model (*Hydrogeological Level 2 Report Volume 2 – Groundwater Flow Model, page 20, Table 8)* indicate that the model is not sensitive to order of magnitude increases and decreases in vertical hydraulic conductivity of the bedrock and to order of magnitude increases in the horizontal hydraulic conductivity of the bedrock. These sensitivity results indicate that the anisotropy and the horizontal hydraulic conductivity of the Amabel dolostone can be much greater than assumed in the AECOM model. Such changes of bedrock hydraulic properties would be consistent with a conceptual groundwater model that includes production zones with overlying/underlying layers of reduced bedrock permeability.

There are implications of this new homogeneous aquifer conceptualization to the predicted performance of the GRS in protecting adjacent wetlands and local private water supply wells, and to the delineation of capture zones for the Carlisle municipal wells. If the bedrock aquifer is considered a simple homogeneous aquifer with constant and uniform hydraulic properties, the modeling will show that GRS will work easily in all circumstances and will protect adjacent wetlands and private wells. However, this is an unrealistic and unreliable assumption that leads to an unrealistic and unreliable conclusion. It is the natural heterogeneity in bedrock flow properties and the GRS-induced changes in these properties that pose the real challenge to successful GRS. Such heterogeneity in hydraulic properties as indicated by the presence of production zones and intervening low permeability horizons and changes in such properties as described in Points 2 and 3 of Section 2.1, are not included in the current AECOM groundwater flow model.

Applying the simple homogeneous model of the Amabel dolostone to the Carlisle municipal water supply wells results in well capture zones that are a small fraction of those previously reported as part the City of Hamilton Groundwater Resources and Well Head Protection Area Study and those adopted by the Halton-Hamilton Source Water Protection as of April 2008. This is primarily because the conceptualization of the bedrock as a homogeneous aquifer without production zones and overlying low permeability layers allows unrealistic amounts of water to infiltrate the bedrock which limits the extent of the well capture zones. Again because the aquifer conceptualization is too simple, the predicted capture zones developed with the AECOM homogeneous model are unrealistic and not reliable. Consequently, we remain concerned that the Carlisle municipal wells may be affected by Quarry operations if the GRS system is ineffective and later when the Quarry becomes a lake as the Quarry appears to be within the 2-year capture zone for the Carlisle Municipal wells as defined by the earlier City of Hamilton Groundwater Resources and Well Head Protection Area Study.

One of the important observations from the updated groundwater flow modeling is the steady state water balance for full scale GRS. This water balance shows about 93,000 $m^3$/day would need to be pumped to maintain the GRS for the full Quarry footprint. These are very large numbers that are about 9-10 times greater than the Gartner Lee estimated full Quarry pumping volumes without GRS as reported in the *Draft Hydrogeological Level 2 Report.* The reason for these high pumping rates is the very large volume of water that is recirculated to maintain the GRS. There are four GRS performance issues that stem from this observation.

1. It is costly to maintain such pumping and the GRS plan minimizes these pumping rates and costs by putting the GRS as far as possible from the Quarry face and not having it in areas that are not perceived to be necessary (i.e., adjacent to the proponent's own abutting property).

2. Recirculation of such very large volumes of water greatly increases the potential for karstification of the bedrock and/or plugging of the injection wells, which as described in Points 2 and 3 of Section 2.1 can cause the GRS to fail.

3. Given these high pumping rates, there will need to be contingency plans/backup systems to address the inevitable interruptions due to pump failure and maintenance and other upsets including power outages.

4. Sudden failure of GRS pumps in areas where the GRS is very close to the Quarry (e.g., along the southwestern edge) may have the potential to create Quarry wall stability problems due to high water tables, reduced effective stresses and increased seepage forces, especially during winter when the Quarry face may be frozen.

### 2.3 Reliance on an Ambiguous Adaptive Management and Contingency Plans

The *Hydrogeological Level 2 Report Volume 1* places enormous and undue reliance on an Adaptive Management Plan (AMP) and on Contingency Plans for ensuring that the GRS system performs as intended in mitigation of adverse hydrologic and hydrogeologic effects of the proposed Quarry development. Such reliance is in the absence any "proof of concept" or demonstration that the proposed GRS is feasible for the Quarry and its unique geologic and hydrogeologic setting. The promised pilot study intended to demonstrate GRS feasibility at the site has not been completed, the demonstration of feasibility using a grossly simplified and unrealistic groundwater flow model is unreliable, and there has been no documented demonstration of successful performance at similar bedrock Quarry sites in Ontario.

For Adaptive Management and Contingency Plans to be appropriate and useful methods for GRS implementation there must be some basic demonstration of the feasibility of the concept at the Flamborough Quarry site at the pre-licensing stage and appreciation for the range of likely performance issues. AMP is after all, a process of refinement of approved systems to optimize performance in the presence of natural variability and uncertainty. It is not intended as a substitute for the basic demonstration of engineering and hydrogeolgic feasibility that is currently lacking for the proposed Flamborough Quarry GRS.

Despite the critical importance of the AMP and Contingency Plans to GRS performance, the AMP and the Contingency Plans are ambiguous concerning the exact scope and in particular the specific adjustments that would be made and the actions that would be taken to address unexpected or unacceptable events or effects. Although performance goals, monitoring locations and triggering mechanisms are reasonably defined, site-specific AMP adjustments and contingency actions are not. Without knowing the site-specific AMP adjustments and contingency actions it is not possible to judge the adequacy of the proposed AMP and the Contingency Plans.

While the *Hydrogeological Level 2 Report Volume 1* states that these ambiguities in scope and range of possible adjustments and actions are due to outstanding stakeholder and regulatory agency consultations (page 48 and 53), these ambiguities are also due to uncertainty and basic lack of understanding of potential GRS performance issues at the Flamborough Quarry site. Without some basic knowledge of GRS performance at the site it is not possible to reliably identify the types of problems that AMP and Contingency Plans would need to address. Clearly, one cannot identify practical solutions to problems that one cannot foresee.

## 3. CONCLUSIONS

The ARA Application and AECOM primary supporting hydrogeological documentation outline several hydrological and hydrogeologic concerns for the proposed licensing of the St Marys Flamborough Quarry. The key hydrological and hydrogeological concerns identified in this review include:

1. There is no "proof of concept" or demonstration that the proposed GRS is feasible for the Quarry and its unique geologic and hydrogeologic setting. The promised pilot study intended to demonstrate GRS feasibility at the site has not been completed, the demonstration of feasibility using a grossly simplified and unrealistic groundwater flow model is unreliable, and there has been no documented demonstration of successful performance at similar bedrock Quarry sites in Ontario.

2. It is critically important that the proposed GRS work at the Quarry site. As acknowledged by the proponent, failure of the proposed GRS will create significant lowering of groundwater tables away from the Quarry causing unacceptable adverse hydrologic and hydrogeologic impacts on the surrounding wetlands and local private water supply wells. Such adverse impacts will include dewatering of the adjacent wetlands, reduction of base flow in proximate streams, and loss of water supply within many private wells that surround the proposed Quarry.

3. GRS remains an unproven technology for the proposed Quarry site. As there are numerous credible and probable means by which the GRS will fail to perform in accordance with requirements, demonstration of successful application of GRS should be required prior to considering an ARA license application.

4. The 2009 AECOM groundwater flow model is an overly simplified, unrealistic and unreliable representation of the Amabel dolostone that fails to incorporate critically important bedrock features including high permeability production zones and low permeability bedrock layers. It provides overly optimistic and unrealistic assessments of the likely performance of GRS at the Quarry site in protecting adjacent wetlands and local private water supply wells, as well as the extent of the capture zones for the Carlisle municipal supply wells.

5. The potential for adverse impact of the proposed Quarry on the Carlisle municipal well water supplies during operations and following Quarry rehabilitation remains an issue and has not been satisfactorily addressed.

6. The proposed GRS places enormous and undue reliance on an Adaptive Management Plan (AMP) and on Contingency Plans for ensuring that the GRS system performs as intended in mitigation of adverse hydrologic and hydrogeologic effects of the proposed Quarry development. For Adaptive Management and Contingency Plans to be considered appropriate and useful methods for GRS implementation there must be some basic demonstration of the feasibility of the concept at the Flamborough Quarry site at the pre-licensing stage.

7. The AMP and the Contingency Plans are ambiguous concerning the exact scope and in particular the specific adjustments that would be made and the actions that would be taken to address unexpected or unacceptable events or effects because there is no reliable site-specific information on expected performance of GRS at the Quarry site. Without knowing the site-specific problems and the site-specific AMP adjustments and contingency actions to address these problems, it is not possible to judge the adequacy of the proposed AMP and the Contingency Plans.

Respectfully submitted,

Intera Engineering Ltd.

Kenneth Raven, P.Eng., P.Geo.
Principal

Doc. No.: 04-235-6_ARA Apllication Review Letter_May 17 09_R0.doc