The Adams Mine Landfill Proposal

An Independent Review and Critical Analysis of Hydrogeological Investigations and Recent Monitoring Data

August 12th, 2003

Ken W.F. Howard MSc, PhD, PHG, PGeo, CGeol FGS
University Professor and Groundwater Consultant

Ref: 2003/2/AdamsRep

EXECUTIVE SUMMARY

In this report, I present the results of an independent, scientific review of the hydrogeological investigations conducted at the Adams Mine site. I focus on the database, the methodology used for analysis (including numerical modeling), and the scientific credibility of the interpretations.

Technical studies for the Environmental Assessment for the Adams Mine Landfill were instigated in 1995 by the Municipality of Metropolitan Toronto (Metro Toronto) with much of the hydrogeological work conducted by Golder Associates. Gartner Lee was appointed the main technical peer reviewer. When Metro Toronto decided not to proceed as proponents of the landfill project, Notre Development Corporation (Notre) took over and completed the Environmental Assessment using Metro Toronto's original team. Documents were formally submitted in December, 1996.

In December, 1997, the Ontario Ministry of the Environment (MOE) made the controversial announcement that only a very small part of the project – the effectiveness of the landfill's hydraulic containment design – would be subjected to the scrutiny of the Environmental Assessment Board (EAB). The "scoped" hearing commenced February 24, 1998 and ended April 29, 1998 with only 15 hearing days. In June, 1998, the EAB issued a 2 to 1 majority decision approving the Adams Mine Landfill hydraulic containment design *subject to 26 conditions*. Condition #10 was one of the more critical stipulations. It required installation and testing of two deep boreholes (later known as DH 98-1 and DH 98-2) to supplement the one existing deep borehole (DH 95-12). The Board insisted that no waste be placed in the South Pit until the Director (as appointed by the Minister of the Environment) had evaluated the results of the tests and determined, *without reservation*, that the recorded groundwater levels would sustain hydraulic containment throughout the pumping and gravity drainage phases of the project. The drilling and testing were carried out in November, 1998 and the results were released in December, 1998. Four months later, the Director issued a Certificate of Approval (CofA). The primary issue I address in this report is whether the Director's momentous decision is adequately justified by the hydrogeological data, including data collected as recently as July, 2003.

My key findings are listed below. They are presented in chronological order to acknowledge the long history of the Adams Mine Landfill approval process and the fact that the scientific objectives, methodologies and database have evolved considerably over time.

1) The EAB Decision. Based on a detailed review and analysis of the data that existed at the time, I believe the Board's decision (in effect, a "stay of execution" for the landfill proposal) was appropriate. Certainly, head data (water levels) from the lone deep borehole that existed at the time (DH 95-12) were persuasive with 25 out of 26 head measurements well above 325 masl (metres above sea level), the elevation of the proposed outlet that would control the level of the leachate during the gravity drainage phase. This demonstrated extremely high pressure gradients for upward flow into the pit. Only a single measured head value indicated the potential for outward flow and this could easily have been dismissed as “anomalous”. In stipulating Condition #10, the Board acted prudently. On one hand, the Board was impressed by the preponderance of favourable head measurements, yet on the other, it was clearly concerned by the very serious lack of reliable field data.

2) DH 98-1, DH 98-2 and the Modeling Studies. Head data from the two new boreholes must have sent “shockwaves” through the proponent’s camp. The vast majority of heads were unexpectedly low and simply failed to confirm the strong inward gradients that had been implied previously by DH 95-12. Under the conditions of its agreement with the MOE, Golder had no choice but to invoke the use of numerical modeling tools in an attempt to show that the low groundwater heads, deep in the aquifer, would rise dramatically as the leachate level in the pit rose towards its final resting level of 325 masl. I examined the Golder models in detail and found them all *seriously deficient,* notably with respect to calibration. In particular, the models developed to convince the Director that heads in DH 98-1 and DH 98-2 would recover sufficiently to sustain hydraulic containment, have virtually no scientific merit and are effectively worthless for predictive purposes. The outcome of these models was entirely predetermined by the models’ unverified boundary conditions, such that none of the data observed in any of the boreholes would have had the slightest bearing on the model result.

3) Issuance of a Certificate of Approval. The Director’s decision was patently premature and scientifically unjustified. At the EAB hearing, Notre acknowledged that numerical models suffer from inherent uncertainties, and indicated that “no important decisions would be based on modeling predictions”. The Director, it appears, had no such qualms, making a crucial decision based on the findings of two seriously flawed models that his scientific advisors should have rejected without hesitation. I do not criticise Golder for presenting its client’s data in the best possible light but I do fault the Ministry of the Environment for failing to conduct a thorough scientific review of the model results.

4) Through-flow Lakes. In September 2000, Gartner Lee seriously misled the Mayor and Council for the Town of Kirkland Lake when it issued a report stating “*claims by some individuals to the media that groundwater enters one side of the pit and exits the other are factually incorrect because they contradict the principals of ground water flow which are based on the fundamental law of gravity*”. This statement has no scientific foundation. Lakes that both receive and lose groundwater are known as through-flow lakes. Such lakes are common and well documented. The statement may have been designed to reassure the public but it was misguided and irresponsible.

5) Recent Data. Much of the debate in recent years has concerned water levels in the pit lake. Based on just three measurements of pit lake level in over four years, the proponents claim that an overall rise in water level supports their contention that no leakage occurs. Others argue that the pit water levels often stabilise or decline for extended periods of time, thus suggesting the pit leaks. After close examination of the data, I am unable to endorse either position. A lowering of pit water level could indicate leakage but may also reflect high evaporation rates which, during some periods, may significantly exceed the net flow of water into the pit. The term “net flow” is very important. A rise in water level simply means that the amount of water entering the pit as runoff and shallow groundwater flow, exceeds the amount of water lost by evaporation and leakage. Rising pit water levels do not constitute evidence for zero leakage.

In conclusion, I find that hydraulic containment has never been adequately proven at the Adams Mine site. Long term containment was certainly never “proved” at the EAB hearing. Through Condition #10, the Board effectively reserved judgment until considerably more field data could be made available. Neither was long term containment subsequently “proved” to the Ministry of the Environment – the Director issued his decision on the basis of two seriously flawed groundwater flow models. Modeling can be a valuable hydrogeological tool; however, it is not, and never was, an appropriate solution for the task at hand. Given the hydrogeological complexity of the site, the integrity of the hydraulic containment design can only be reliably demonstrated by good field data.

On the basis of my work, *I strongly believe that the Certificate of Approval for the Adams Mine Site should be suspended until such time as hydraulic containment can be demonstrated by field (not modeled) data*. To provide the appropriate data I recommend that:

1) One deep angled borehole be constructed on the south side of the pit where deep data are seriously lacking.
2) Westbay Multiport Systems (or similar) be installed in all four deep boreholes, thus allowing heads beneath the pit to be monitored at discrete intervals.
3) A pressure transducer (water level recorder) and data logger be installed in the pit lake.
4) A simple weather station be installed for the collection of meteorological data including daily precipitation and Class “A” pan evaporation.
5) A comprehensive monitoring program be established as follows:
   - Hourly measurements of lake water levels
   - Daily measurements of precipitation and pan evaporation
   - Monthly measurements of head in the Westbay Multiports

   all for a minimum of three years or until such time as heads measured in the subsurface either consistently exceed 325 masl or demonstrate rates of recovery that show, with a high degree of statistical certainty, that a level of 325 masl would be exceeded by the time the lake recovers to 325 masl.

If this program of work were implemented immediately, and the pit lake water level were allowed to recover naturally with no disturbance, the issue of hydraulic containment could be resolved with a high level of confidence within a matter of three to five years.

Ken W.F. Howard, August 12th, 2003

1 Background and Objectives

In February, 2003 I was invited by the Temiskaming Federation of Agriculture (TFA) to conduct an independent review and critical scientific analysis of the hydrogeological investigations performed at the proposed Adams Mine Landfill Site. Initially, I was asked to focus my review on data collected from two deep boreholes (DH 98-1 and DH 98-2) that were drilled in the fall of 1998 as one of 26 conditions imposed by the Environmental Assessment Board of Ontario (EAB) when it narrowly approved the Adams Mine Landfill hydraulic containment design in June of the same year. The Board had emphasised, "*no waste shall be placed in the South Pit until the Director* [as designated by the Minister of the Environment for purposes of Section 39 of the Environmental Protection Act] *evaluates the results of the tests and determines, without reservation, that the recorded groundwater levels will sustain hydraulic containment in the South Pit such that the environment will be protected, during both the pumping and gravity drainage phases*". Based on my early findings, I subsequently expanded my review to include all hydrogeological field and modeling studies carried out at the site. I visited the area in June, 2003, inspected the pit from a light aircraft, walked parts of the site perimeter and examined several of the hydrologic features that were used by the proponent's consultants as boundaries for their aquifer modeling studies.

This report is based largely on a review of data and reports generated by the landfill proponents prior to and immediately following the "scoped" Environmental Assessment Board hearing held in 1998. However, it also considers data and material generated by all concerned parties over the past five years, including water level data collected by both proponents and opponents as recently as July 25, 2003. I am grateful to Mr. McGuinty of Adams Mine Rail Haul and his consultants for co-operating with my investigation and providing access to material. A list of documents consulted during the work is provided in Appendix 1.

In presenting this report, I am sensitive to the bitter political and personal debates that have developed over the Adams Mine Landfill. I also acknowledge that the Adams Mine Landfill has been the subject of a formal, legal, approval process and I give appropriate regard to documented decisions that have formed part of that process. I emphasise, however, that the primary purpose of this report is to critically assess the scientific aspects of the hydrogeological investigation conducted at the Adams Mine site with a focus on the scientific database, the methodology used for analysis (including numerical modeling), and the scientific credibility of the interpretations.

In April, 1999, the Director issued a Certificate of Approval (CofA) for the Adams Mine site (Appendix 1, Document 14), evidently deciding "*without reservation*", that data from the two new deep boreholes required by the EAB were sufficient to demonstrate that hydraulic containment of leachate will be sustained throughout the landfill's 1000-year contaminating lifespan. The key issue addressed in this scientific review is whether such an important conclusion is adequately supported by the available hydrogeological data.

2 Report Format

The Adams Mine Landfill approval process dates back many years with some of the earliest hydrogeological studies published by Golder Associates in 1990. The scientific process including methodologies, the database and scientific objectives, has evolved considerably over the intervening years; it is thus appropriate that this report follows the hydrogeological investigations in a chronological order as follows:

- Issues up to and including the 1998 scoped EA hearing.
- Boreholes DH 98-1 and DH 98-2 and the issuance of a Certificate of Approval.
- Data and events since the year 2000.

3 Analysis

3.1 Issues up to and including the 1998 scoped EA hearing

Large excavated pits have always been attractive options for waste disposal (Eyles and Boyce, 1997; Howard et al., 1997). The South Pit at the Adams Mine site is clearly no exception. Today's advanced engineering technologies (liners, drainage blankets and pumping controls etc.) allow such pits to be developed as landfills with a measure of environmental protection, particularly during the early decades of landfill development when the landfill leachate is often most potent. Ultimately, however, pumping must cease, engineered components fail, and the impacts of contaminants on the environment will depend on the hydrogeological properties of the host rock in its natural state. If "hydraulic containment" is to be maintained, then it is vital that groundwater "heads" (pressures) in the surrounding rock remain <u>at all times</u> well in excess of the head in the landfill. Ideally, the contaminating lifespan of a landfill is relatively short such that reliance on the natural containment properties of the rock is minimised. Concerns are heightened when the contaminating lifespan of the landfill far exceeds either the service life of the engineered components or the period that pumping is used to control leachate levels. In such cases, it becomes essential that the hydrogeological properties of the rock and its natural containment properties be established with a very high degree of confidence.

Few can deny that the conversion of a disused iron ore pit at Adams Mine into a modern sanitary landfill capable of holding leachate throughout a contaminating lifespan of 1000 years represents an enormous challenge. Properly designed, maintained and operated, the engineered components of the landfill should readily ensure hydraulic containment of the leachate in the early years. The primary concern comes after 100 years when pumping is no longer used to artificially lower the level of the leachate in the landfill, and the hydraulic containment properties of the host rock are put to the test.

Hydrogeologists well recognise that groundwater conditions in the Canadian Shield are inherently complex, with billions of years of sedimentation, deep burial, volcanic activity, meteorite impact and tectonism imparting some of the most heterogeneous and anisotropic hydrogeological conditions found on planet Earth. At the Adams Mine site, the hydrogeological complexity has been further compounded by recent glaciations which have significantly modified both the landscape and shallow aquifer conditions, and by many years of mining activity with drilling, blasting and the removal of millions of tonnes of rock, which have radically altered the aquifer at a local scale. To complicate the issue further, decades of intensive pumping for mine dewatering purposes have heavily depressurised the aquifer system, effectively preventing all short-term hope of establishing reliably the baseline hydrogeological conditions so critically needed if the potential impacts of future landfilling are to be reliably predicted.

Technical studies for the Environmental Assessment for the Adams Mine Landfill were initiated by the Municipality of Metropolitan Toronto (Metro Toronto) in 1995 with much of the hydrogeological work conducted by Golder Associates Ltd. and Senes Consultants Ltd. As part of the evaluation process, Metro Toronto set up a Public Liaison Committee (PLC) which hired Gartner Lee Ltd. as the main technical peer reviewer. Gartner Lee performed a valuable function at this time and deserves credit for identifying a number of shortcomings in the work. Most notably, the construction of deep angled borehole DH 95-12 and the hydrogeological study of the Munro Esker, both subsequently conducted by Golder, were a direct result of Gartner Lee's peer review studies. When Metro Toronto decided not to proceed as proponents of the landfill project, Notre Development Corporation (Notre) took over and completed the Environmental Assessment using Metro Toronto's original team. Documents were formally submitted in December, 1996.

Twelve months later, the Ontario Ministry of the Environment made the controversial announcement that only a very small part of the project – the effectiveness of the landfill's hydraulic containment design – would be subjected to the scrutiny of the Environmental Assessment Board (EAB). This meant that the Board would have no jurisdiction to review other critical issues such as leachate treatment, landfill gas management and surface water contamination (except as it related to the accidental release of leachate). The "scoped" hearing commenced February 24, 1998 and ended April 29, 1998 with only 15 hearing days.

In June, 1998, the EAB issued a 2 to 1 majority decision approving the Adams Mine Landfill hydraulic containment design subject to 26 conditions, mainly related to site operations, long term monitoring, contingencies, community participation and financial assurances. Condition #10 was one of the more critical stipulations. It required that two additional deep, angled boreholes, be installed and tested at the site, and that the results be reported to the Director as part of the application for a Certificate of Approval. The Board insisted that no waste be placed in the South Pit until the Director had evaluated the results of the tests and determined, *without reservation*, that the recorded groundwater levels would sustain hydraulic containment in the South Pit throughout the pumping and gravity drainage phases of the project.

The Board's "Decision and Reasons for the Decision" dated June 19, 1998 (Appendix 1, Document 1) provides a valuable insight to the scientific knowledge base that existed at the time and the issues (recognising this was a "scoped" hearing) that the Board deemed important for the decision it was asked to make.

The proponent's evidence for long term hydraulic containment at the site was very limited. Shallow water table data certainly indicated that inward flow would be maintained around the pit circumference but this was not the real issue. The critical concern was the potential loss of leachate to the deep groundwater system via the pit floor, and the only evidence worthy of consideration comprised:

1) Head data from DH 95-12 (Appendix 1, Document 9), a deep, angled borehole, 500 m in length, drilled to a depth of 200 m below the base of the pit. The borehole had been installed because Gartner Lee, as peer reviewer for the PLC, argued that inflow of groundwater from beneath the pit had only been postulated theoretically, and that it was important to demonstrate hydraulic containment with field measurements.

2) Head data generated by the proponent's regional SEEP/W 2-dimensional (2-D) groundwater flow models (Appendix 1, Document 8).

As it turned out, only the borehole results were seriously considered by the Board. Reference to the borehole data (Appendix 1, Document 9) and the model simulations (Appendix 1, Document 8 - Figures F7.2 and F7.4), reveals very serious discrepancies between model heads beneath the site and the borehole data (for example, 150 m below the base of the pit at an elevation of 0 masl (metres above sea level), a head of 350 masl was measured in the borehole while a head of about 280 masl was predicted by the model). The model was clearly deficient and would certainly prove unreliable for predicting sub-pit head conditions. At the hearing, Notre consultants acknowledged that numerical modeling, as a technique, had "inherent uncertainties" and the Board was no doubt relieved to learn that "Notre would not rely exclusively on modeling results for crucial decisions". Aquifer modeling may have its virtues, but the importance of reliable <u>field</u> measurements for making decisions of major importance was clearly uppermost in the Board's mind when it sought the construction of two new deep wells as a condition of approval.

Significantly, most of the criticism of the proponent's work during the hearing came from Paul Bowen, Hydrogeologist and Principal of Terraprobe Ltd. Mr. Bowen argued that the intrinsic hydrogeological characteristics of the fractured bedrock environment were such that hydraulic containment could not be reliably demonstrated given the very limited dataset (essentially one deep angled borehole (DH 95-12)). He raised concerns about the wide variability of head data obtained from the deep borehole and discussed the potentially serious implications of a single, anomalously low head value that was observed. He also questioned the extent to which the lone borehole could be considered representative of hydrogeological conditions deep beneath the pit, given the immense size of the site and the geological structures that are present. I found Mr. Bowen's analysis to be thorough and scientifically sound. I endorse his views on every hydrogeological issue he raised.

The EAB's decision was a serious disappointment to those who opposed the landfill. However, recognising the evidence available to the Board, I believe the decision (in effect, a "stay of execution" for the landfill proposal), was appropriate at the time. Certainly, the head data from borehole DH 95-12 (**Table 1**), the centerpiece of discussion and debate, were persuasive. 25 out of 26 head measurements conducted along the 500 m borehole were between 8 and 50 m above 325 masl, the elevation of the proposed outlet that would control the level of the leachate during the gravity drainage phase. This demonstrated extremely high hydraulic gradients[1] of flow upwards into the pit. Only a single measured head value indicated the potential for outward flow and this could easily have been dismissed as "anomalous". To its credit, I believe the Board acted prudently. On one hand, it was heavily swayed by the preponderance of favourable head measurements, and on the other it was clearly influenced by the evidence of Mr. Bowen that had suggested a serious lack of reliable head data from beneath the site. In the end, the Board asked for two additional deep boreholes. With the benefits of hindsight, I'm now inclined to agree with the opinion voiced by Mr. Don Smith, the Board's dissenting member. Mr. Smith was so convinced by Mr. Bowen's concerns over the hydrogeological complexity of the 27 ha site "in fractured bedrock with possible faults and dykes", he felt that two additional deep boreholes would be insufficient. Only now do we appreciate how prophetic his opinion would be.

3.2 Boreholes DH 98-1 and DH 98-2 and the issuance of a Certificate of Approval

The additional boreholes were drilled by lead consultants Golder Associates who published its findings in a November 1998 document entitled "Results of drilling,

[1] The hydraulic gradient is the difference in head (pressure) between two points, divided by the distance between the two points. It is essentially a measure of the gradient of pressure that drives flow.

packer testing and groundwater flow modeling of boreholes DH 98-1 and DH 98-2 Adams Mine Landfill 981-1464" (Appendix 1, Document 10). The results (summarised in **Table 1**), were radically different from those found in the previous borehole (DH 95-12) and must have sent "shockwaves" through the proponent's camp. The data simply failed to confirm the strong inward gradients that had been implied by data from DH 95-12, and raised far more questions than they resolved. Hydrogeologists often suggest, only partly in jest, that "the hydrogeological complexity of a site is directly proportional to the number of boreholes drilled into it". This maxim clearly held true for the data from boreholes DH 98-1 and DH 98-2. The results beg the question as to what would be revealed by further deep boreholes.

Table 1. Summary of head data from DH 95-12, DH 98-1 and DH 98-2

	Borehole		
	DH 95-12	**DH 98-1**	**DH 98-2**
Number of head measurements	**26**	**14**	**13**
Depth range of measurements (masl)	**-46 to 338**	**126 to 321**	**129 to 301**
Head range (masl)	**306 to 375***	**292 to 316**	**274 to 438**
Head measurements equal to or less than the 306 masl "anomaly"	**1**	**10**	**4**
Head measurements equal to or less than the 325 masl outlet level	**1**	**All 14**	**5**

***25 out of 26 measurements were between 333 and 375 masl, suggesting the single value of 306 masl was anomalous (a conclusion not supported by data from DH 98-1 and DH 98-2).**

In DH 98-1, every single head measurement was found to be below 325 masl, the elevation of the outlet that would control the level of the leachate during the gravity drainage phase. 10 out of 14 measurements were less than the value of 306 masl, the unusually low head observed in DH 95-12 that was postulated as being anomalous. In DH 98-2, almost half the values were less than the 325 masl outlet level, while one third were below the supposedly anomalous level of 306 masl. With 19 out of 27 measurements showing heads as much as 65 m below the 325 masl target, it was obvious to all that long term hydraulic containment of leachate would be impossible at the Adams Mine Site unless reliable evidence could be found to demonstrate groundwater heads beneath the pit would rise significantly.

At the time of the work, the proponents met with the Ontario Ministry of Environment Approvals Branch to establish the “Acceptance Criteria” for the test results. The agreement was that:

Groundwater levels in the test intervals were to be:

a) *above the current water level in the South Pit, confirming the existence of inward hydraulic gradients from the deep bedrock beneath the South Pit under existing conditions and during the pumping phase when the water level in the drainage layer is maintained at the base of the pit, and*
b) *either above or near the proposed perimeter collection system installation elevations such that these groundwater levels will be sustained above the installation elevations following the flooding of the drainage layer, confirming existence of hydraulic gradients from the deep bedrock, beneath the South Pit during the gravity drainage phase.*

Acceptance criterion a) was successfully met. However, the groundwater levels measured in the test intervals did not come even remotely close to meeting criterion b).

Fortunately for the proponents, there was an “escape clause” included in the “Acceptance Criteria”. I hesitate to consider what the “field-data conscious” EAB would have said about this clause, recognising that DH 98-1 and DH 98-2 had demonstrably failed to confirm the dataset previously obtained from DH 95-12, but it stated:

In order to satisfy this requirement, [referring to *b)* above] *additional groundwater modeling may be undertaken using the measured groundwater levels to demonstrate the existence of hydraulic containment during the gravity drainage phase. The necessity for this modeling will be evaluated based on the test results.*

Effectively, this gave Golder the opportunity to resurrect its 2-D groundwater flow model (SEEP/W) in an attempt to show that measured groundwater heads, deep in the aquifer, would rise dramatically as the leachate level in the pit rose towards its final resting level of about 325 masl. On the basis of this modeling exercise (critically reviewed below) Golder was able to predict that groundwater heads beneath the pit would, in every single case, rise comfortably above 325 masl and thereby maintain hydraulic containment during the gravity drainage phase.

I am a strong advocate of numerical modeling tools for hydrogeological investigation and I use them frequently. However, I am also aware:
1) that it is essential to select the model code appropriate to the task, and
2) that model predictions, irrespective of model code, are extremely unreliable in the absence of the types of data necessary to provide adequate

calibration, verify model assumptions and confirm the model boundary conditions that critically influence model behaviour.

Golder first introduced its regional, 2-D vertical section models based on the SEEP/W model code[2], in the 1996 EA documents. I refer to these models below as Golder's "Regional Models". One of the regional 2-D model sections was subsequently used during the EAB hearing in an effort to convince the Board that the "anomalously low" water level of 306 masl observed in DH 95-12 would rise to 329 masl during the gravity drainage phase, and thus maintain hydraulic containment by exceeding the leachate level of 325 masl.

We are perhaps fortunate that the EAB did not rely on the predictive ability of Golder's early regional models, as Golder came to acknowledge the limitations of its 2-D equivalent porous medium approach when it embarked upon the task of predicting the long-term recovery of heads in DH 98-1 and DH 98-2. Logically, it would have been appropriate at this time to abandon SEEP/W entirely and consider a fully 3-dimensional model of the pit and its surroundings that could integrate data from all three deep boreholes and incorporate fracture flow characteristics. Instead, Golder persisted with its SEEP/W "equivalent porous medium" 2-D modeling approach, manipulating the hydraulic conductivity and anisotropy of the various bedrock units in an attempt to simulate fracture flow behaviour. Golder finally produced three totally independent models, one for each borehole. This was the wrong decision.

I have examined all the Golder models, in some cases running comparable simulations of my own using various multi-dimensional finite element and finite different model codes. I find all the Golder models *seriously deficient* and believe none should have been employed to perform the types of predictive analysis for which they were eventually used. The borehole models ("DH models") developed to demonstrate, for the benefit of the Director, that heads in boreholes DH 98-1 and DH 98-2 would eventually recover, have virtually no scientific merit and are effectively worthless.

I discuss the models below. Except where specified, the problems I identify relate both to the regional models and to the DH models.

- **The Model Code:**

  SEEP/W is a sophisticated, 2-D vertical slice, finite element model capable of simulating steady state and transient flow in saturated and unsaturated conditions. It is ideally suited to seepage flow problems such as the flow of

[2] Seep/W is a 2-D "equivalent porous medium" model in which heterogeneously fractured rock is represented by homogenous material that is equivalent in terms of the fractured rock's average flow and storage characteristics.

water through or beneath a dam, or flow into a tunnel or trench, i.e. situations where flow can be reasonably assumed as 2-dimensional (meaning all the water moves and remains contained within the same 2-D vertical slice). It is not designed to handle fracture flow, and it is certainly inappropriate for use in:

1) hydrogeologically complex 3-dimensional flow systems where flow directions often vary with depth, and
2) groundwater systems where permeable structures such as faults and fractured dykes lie and transmit groundwater *oblique* to the modeled vertical sections.

The regional model sections used in the Golder analysis (Appendix 1, Document 8 (F7)) are constructed in vertical planes to follow the flow directions indicated by *the shallow water table*. The DH models (Appendix 1, Document 10 (Appendix C)) are constructed to include the vertical plane containing the borehole. In effect, both models assume that water particles at considerable depth in the groundwater system move in the same vertical plane as the shallow groundwater, a sweeping assumption that is not only unsubstantiated by Golder, but is likely seriously in error. It is well known, for example, that shallow groundwater tends to be strongly influenced by surface water features such as rivers and streams (local discharge boundaries) while deeper groundwater often crosses hydrological catchment boundaries, in some cases moving perpendicular to shallow groundwater flow. Golder’s own data demonstrate that head conditions at depth (boreholes DH 95-12, DH 98-1, and DH 98-2) are significantly different from heads at shallow levels. Since heads dictate flow directions, there is every reason to believe flow directions at depth in the aquifer bear little or no resemblance to flow directions in the shallow aquifer. The 2-D regional models developed by Golder may begin to approximate reality in the top of the aquifer, close to the water table; however, for representing flow conditions below the base of the pit, *the models are meaningless* – they are simply unable to account for the water that can be expected to move into and out of the 2-D model plane.

If Golder were serious about using models to reliably predict long-term head changes in the pit and deep groundwater system, it should have considered adopting, and appropriately calibrating, a fully 3-D model such as provided by the FEFLOW model code. FEFLOW is significantly more versatile than SEEP/W and would have allowed the regional hydrogeological significance of potentially important cross-cutting features such as the Boston Fault to be fully incorporated and properly evaluated. A major additional benefit of FEFLOW is its ability to handle fracture flow conditions.

- **Model Calibration:**

  Models used for any sort of prediction must be reliably calibrated for *both* heads and flow. For example, calibration against known heads is adequate if aquifer recharge (a flow) is reliably and independently known. However, the practice of achieving calibration against known heads by arbitrarily adjusting recharge across the top of the model (in Golder's case from between 0 and 300 mm per year) is not recommended as it often leads to unreliable models.

  An equally serious problem is the lack of calibration at depth beyond the shallow water table zone. The serious discrepancy between regional model heads and the data obtained for DH 95-12 is mentioned above. However, there are also serious problems with the calibration of the DH models (Appendix 1, Document 10 (Appendix C)). These are as follows:

  1) It is inappropriate to calibrate the model by making arbitrary adjustments to the anisotropy of the layers unless there is reliable evidence to justify such a change.
  2) The failure to achieve calibration with a single set of data cannot be compensated for by developing four calibration scenarios that collectively cover the range of the observed data. There can only be one correct solution and if the best selected dataset fails to reproduce the observed data, there is something seriously amiss with the model.
  3) Using four calibration scenarios to generate a range of predictions that fall within the acceptable range is inappropriate because, for reasons alluded to above, none of the model scenarios can be considered in themselves valid.
  4) It is inappropriate to calibrate the model by comparing model heads against only selected data (i.e. "the lower range of groundwater levels measured during the packer testing of the deep drillholes" (Appendix 1, Document 10 (Appendix C - Page C-11))). If the model cannot reproduce the high groundwater heads equally as well, it means there is something wrong with the model. The model for DH 98-2 is the worst offender and clearly indicates serious calibration problems. Despite the broad range of head data generated for existing conditions by four calibration scenarios (Appendix 1, Document 10 (Figure 5a)), only 2 of 13 head measurements are adequately satisfied. This highlights a serious problem. The model for DH 98-1 fairs somewhat better with 10 out of 14 heads satisfied (Appendix 1, Document 10 (Figure 4a)) but this calibration is still unacceptable.

To some extent the modelers' inability to calibrate the models at depth reflects, as explained above, the inadequacy of 2-D vertical slice models to simulate complex 3-D conditions where flow commonly moves in different directions at different depths. The problem is compounded, however, by the inadequate database. Modelers can hardly be expected to develop reliable and useful models of 500 m thick groundwater systems when the vast majority of the data are from the top 50 m of the aquifer.

- **Boundary Conditions:**

Reliable model boundary conditions are the most critical component of any model and need to be carefully selected and fully verified. As indicated above, I have some concerns with the recharge boundary and the fact that the recharge rates were not determined independently but as part of the calibration process. However, with some exceptions, I am generally satisfied with the choice of the various constant head boundaries *along the upper boundary of the model,* and also with the choice of an impermeable boundary along the model base.

My main concern is the designation of lateral boundaries to the model. Lateral boundaries come in many varieties, but essentially there are three types:

1) Impermeable boundaries or "no flow" boundaries that provide a barrier to flow.
2) Constant head boundaries for which the head remains fixed for all time and under all conditions (examples are large lakes and perennial streams and wetlands).
3) Flux boundaries where the flow of water is either stipulated or set as a function of local head conditions.

Golder's models use types 1) and 2). Type 2) "constant head" boundaries are especially critical since they can have a profound effect on model behaviour. They potentially represent an infinite source of water when heads in the model are relatively low and an infinite sink for groundwater discharge if model heads are relatively high. In effect they control how much water moves via the subsurface into and out of the model domain. They also have an immense influence on the range of head values in the model. As modelers well know*, it is impossible for heads in the model to fall below the lowest specified constant head value unless the aquifer is pumped*. The choice of constant head values is therefore extremely important.

I have very serious concerns about the selection of constant head values in all Golder's models. For example, it is totally unacceptable to establish lateral boundaries by arbitrarily "*extending the constant fixed head bound*ary [as used at the surface of the model] *to the bottom of the aquifer*" (Appendix 1, Document 8 (F7; Page F7.2-2)). Why aren't all the other constant heads extended to the base of the aquifer in the same way? That, of course, would be equally indefensible. The reason, I'm convinced, was simply expediency. Model boundaries need to be assigned and choices have to be made. Golder's own deep data (boreholes DH 95-12, DH 98-1, and DH 98-2 in **Table 1**) clearly demonstrate that heads in the aquifer vary considerably with depth, but in the absence of data below a depth of 50 m near the model boundaries, the choice was made to use exactly the same head value from top to bottom, a vertical distance of over 500 m. Such an arbitrary assignment of an important model property is unacceptable for a model that is subsequently used for predictive purposes. The practice automatically imparts a strong tendency for horizontal flow in the aquifer when there is no field evidence to suggest this is happening at all.

I reserve my most serious criticism for the two DH models that were specifically devised to convince the Director that the suite of very low heads measured in DH 98-1 and DH 98-2 will rise to above 325 masl during the gravity drainage phase. Golder went to considerable trouble (and failed, as discussed above) to calibrate these two models with "repeated model runs". The groundwater flow modeling work alone generated a document that is an inch thick containing seemingly dozens of maps and figures. As it turns out, this was a waste of everyone's time and effort. <u>The outcome of the work on DH 98-1 and DH 98-2 was entirely predetermined by the constant head conditions selected for the two models.</u> Simply, if all constant heads in the model are set at or above 325 masl (as shown in Golder's Figures C.1.7 and C.2.7 (Appendix 1, Document 10 (Appendix C))), it doesn't matter if the aquifer is made of chalk or cheese……in the absence of pumping, all heads anywhere in the model domain will eventually come to rest at or above 325 masl. Without field data that can corroborate the selection of constant heads down to the base of the aquifer and, of course, there are none, the models (and results!) for DH 98-1 and DH 98-2 are completely worthless.

- **Model Layering and the Presence of Preferential Flow Zones**

Golder acknowledges the importance of preferential flow zones (fracturing and permeable faults) when it helps explain why so many of the heads in the deep boreholes are low, but dismisses the potential role these zones may play in the transmission of leachate from the pit during the gravity drainage stage of the program. The unfortunate reality is that virtually nothing is known about the hydrogeological properties of the rocks or boundary conditions at depth. The groundwater flow system models developed by Golder extend down to an elevation of -200 masl (over 400 m below the base of the pit), but the knowledge base in the region below about 300 masl (i.e. representing about 500 m thickness of aquifer) is limited to just three boreholes - DH 95-12, which ends at -46 masl and DH 98-1, and DH 98-2 which penetrate just 100 m below the pit base to finish at elevations of 126 and 129 masl, respectively. For the regional modeling (completed prior to the construction of boreholes DH 98-1 and DH 98-2) Golder takes hydraulic conductivity data obtained from "deep bedrock" in DH 95-12 (i.e. below an elevation of 100 masl) and combines these data (themselves averages over 20 m packered sections) to form a single average "equivalent porous medium" value that is subsequently applied to 80% of the model domain. Golder argues that this practice is acceptable given the scale of the model. I disagree. This approach may be acceptable for aquifer resource models that are used for estimating groundwater fluxes (i.e. the amounts of water that are moving around the aquifer per unit time), but it is not acceptable for models concerned with the reliable prediction of groundwater heads and the maintenance of head differences required for total hydraulic containment.

Golder seems to believe that the low values of hydraulic head measured in all the deep boreholes are a legacy of depressurization during mine dewatering and that all these levels will recover in a timely fashion as leachate levels in the pit rise to the final outlet level of 325 masl. This theory is automatically supported by their regional models since the use of average values of hydraulic conductivity over large parts of the models precludes any response other than a simple recovery of groundwater levels in response to a rise in pit level. An alternative and equally plausible theory is that many of the low heads have little to do with mine dewatering but are maintained by one or more boundary conditions remote from the site, the connection to these boundaries being maintained by discrete but very permeable fractures. Under this scenario, not all the deep water levels will rise as the pit level recovers, and hydraulic containment would be lost in discrete zones. Borehole data certainly confirm the presence of fractures beneath the pit and some may be quite permeable. While packer tests conducted by Golder reveal relatively low values of hydraulic conductivity for the deep bedrock, all these values are averages over 20 m test sections. Thus, a relatively low hydraulic conductivity value of 10^{-5}cm/s for a 20 m section could easily mean that the entire section is virtually impermeable with the exception of a discrete zone 2 cm thick with a hydraulic conductivity of 10^{-2} cm/s i.e. three orders of magnitude greater than the section "average" and as permeable as sand.

The DH model findings were reported to the Director in December, 1998 as part of Notre's application for a Certificate of Approval. Within a matter of months, approval was granted by the Director who had evidently decided "*without reservation*" that data from the two new deep boreholes were sufficient to demonstrate that hydraulic containment will be sustained throughout the landfill's 1000-year contaminating lifespan. At the EAB hearing, Notre consultants had acknowledged that numerical models suffer from inherent uncertainties, and indicated that no important decisions would be based on modeling predictions. The Director, it appears, had no such qualms, making a crucial decision based on the findings of two seriously flawed models that his scientific advisors should have rejected without hesitation. I don't criticise Golder for presenting their client's data in the best possible light but I do fault the Ontario Ministry of the Environment for failing to conduct a thorough scientific review of the results.

The Director's decision was patently premature and scientifically unjustified. I firmly believe the Ministry should have exercised one of two options:

1) Reject the application outright, or
2) Require additional field data.

At the time, my preference would have been the latter. We need to recognise that reliable baseline conditions have never been established for groundwater heads deep beneath the pit. The system is still undergoing a transient response to historically heavy pumping such that groundwater heads observed in boreholes DH 95-12, DH 98-1 and DH 98-2 should be regarded as no more than "snapshots in time". Reliable baseline data will not be available until the pit water level has recovered fully and groundwater heads beneath the pit reach quasi-steady state. Modeling is a valuable hydrogeological tool; however, it is not , and never was, an appropriate solution for the task at hand. The EAB was certainly aware of this and its message was implicitly clear. The integrity of the hydraulic containment design can only be reliably demonstrated by good field data. To resolve this issue, the Ministry of the Environment should have demanded:

1) Installation of Westbay multiport systems (or similar) in all three deep boreholes, thus allowing heads to be monitored at discrete intervals.
2) Installation of a pressure transducer (water level recorder) and data logger in the pit lake.
3) Construction of a simple weather station at the site for the collection of meteorological data including daily precipitation and Class "A" pan evaporation.
4) Monitoring of water levels at no less than monthly intervals for the Westbay multiport systems and "continuously" (e.g. hourly) for pit lake water levels, for a minimum of three years or until such time as all heads measured in the subsurface either exceed 325 masl or demonstrate rates of recovery that show, with a statistically significant degree of confidence that a level of 325 masl would be exceeded by the time the pit lake recovers to 325 masl.

In addition, I believe at least one additional deep, instrumented borehole should have been required along the south side of the pit where good quality data are conspicuously lacking.

If the prescribed action had been taken in the spring of 1999, I have no doubt that by today, the issue of hydraulic containment would have been resolved with a high level of confidence.

3.3 Data and events since the year 2000.

The Ministry of the Environment's premature and scientifically indefensible issuance of a CofA in 1999 created a furor that, four years later, refuses to abate. Political rancor and bitter personal feuds have now escalated into legal suits and counter suits. There are many who remain incensed that the Director was able to pass judgment without articulating the scientific reasoning behind his (or his advisors') analysis and conclusion. It seems that while the EAB has a public duty to be open and transparent, Ontario's premier regulatory authority has no such obligation.

Procedural and political issues aside, much of the debate during the past four years has concerned water levels in the pit. In practice, the greatest propensity for leakage from the pit will occur when the pit water level reaches its maximum value (about 325 masl if the landfill is constructed). Some argue that the pit already leaks and that changes in water level during the past four years support that argument. However, in my opinion, the data presented by both proponents and opponents are inconclusive. Regular pit level observations made by the TFA reveal extended periods during which water levels in the lake stabilise or even decline. The TFA argues, not unreasonably, that the observed response is consistent with water leaking from the pit. The proponents, on the other hand, have made just three pit level measurements in the past four and a half years and use these data to demonstrate a "continuous" (uninterrupted) rise in water level which they suggest supports their contention that no leakage occurs.

After close examination of the data, I am unable to endorse either position. If good quality data had been collected over the past 4 years, daily or even weekly, the issue would likely have been much closer to a resolution. The proponents can hardly be blamed for failing to collect data that could well have compromised their position, but the Ontario Ministry of the Environment could and should have insisted that potentially valuable scientific data be collected on a continuing basis.

The TFA pit level data could indicate leakage but may also reflect high evaporation rates which, during some periods, may significantly exceed the <u>net flow</u> of water into the pit. The term "net flow" is a very important one. A rise in water level simply means that the amount of water entering the pit as runoff and groundwater flow exceeds the amount of water lost by evaporation and leakage. <u>Rising pit water levels provide no confirmation that leakage rates are zero.</u>

In September, 2000 Gartner Lee wrote to Mr. Lastman, Mayor of the City of Toronto (Appendix 1, Document 4), expressing support for the landfill design and raising concern for “the amount of incorrect and misleading information being reported by the media”. Twelve months later (September, 2001) Gartner Lee issued a report for the benefit of Council for the Town of Kirkland Lake (Appendix 1, Document 5) in which it provided assurances for the environmental safety of the site and stated “*claims by some individuals to the media that groundwater enters one side of the pit and exits the other are factually incorrect because they contradict the principals of ground water flow which are based on the fundamental law of gravity*”. This statement may have been designed to reassure the public, but, it has no scientific foundation. It brings discredit to the company and to the profession. Lakes that both receive and lose groundwater are known as through-flow lakes. They are extremely common. Schwartz and Zhang (2003, page 207) go so far as to suggest “most lakes are through-flow lakes”.

Through-flow scenarios vary widely. Typically, groundwater either enters around the periphery of the lake and leaves via the centre, or enters at one end of the lake and leaves via the other. Musselman Lake on the Oak Ridges Moraine (Kaye, 1986) is an example of the latter. Some of the most cited work on lake/ground water interaction was carried out by the United States Geological Survey (Winter, 1976; 1978). It demonstrated that regional boundary conditions and deep aquifer properties - notably the presence of discrete permeable zones - can have a major influence on the degree to which lakes leak water (**Figure 1**). This is precisely why it is essential that deep aquifer conditions and deep boundary conditions be established at the Adams Mine site with a high degree of certainty. The clarification provided here may disappoint the Mayor, Council and the people of Kirkland Lake but they were misled. Gartner Lee owes them an apology.

My final comments relate to the proponent’s recent application to the Ministry of the Environment for a permit to begin removing water from the pit. Under the tranquil conditions that presently exist at the site, there still remains an opportunity to install monitoring equipment capable of testing the proponent’s unsubstantiated theory that groundwater heads in the deep boreholes will recover as lake levels rise. At present, the only “proof” that groundwater levels will recover is provided by two Golder models that depend far too heavily on unconfirmed boundary conditions. Lake water levels have risen by nearly 15 metres since the EAB hearing; yet no measurements of deep groundwater head have been made that could support if not confirm the proponent’s theory. I believe it would be irresponsible to issue a permit to remove water until confirmatory measurements have been made. Once pumping begins, the opportunity for obtaining such crucial information is lost.

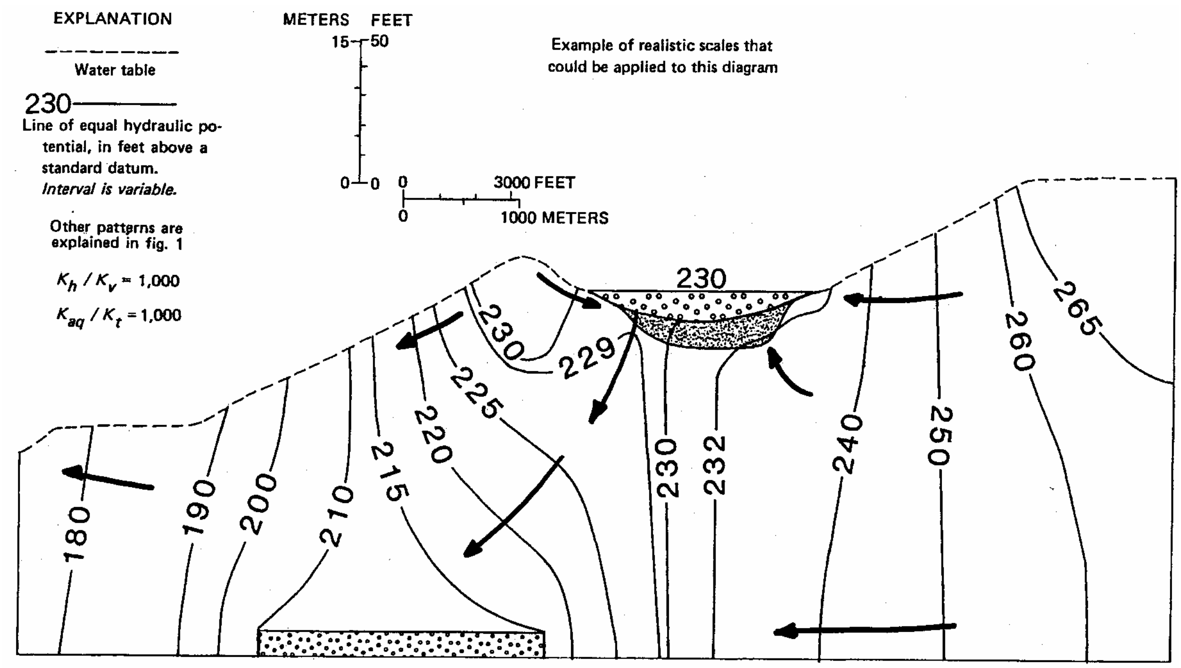

Figure 1. Example to demonstrate the inflow and outflow of groundwater to a lake. In the example shown, the loss of water is enhanced by a zone of permeable rock (deep stippled area, e.g. a sand lens or open fracture) of limited lateral extent, with a hydraulic conductivity three orders of magnitude higher than the surrounding matrix (after Winter, 1976).

4 Concluding Remarks

Recognising the complex hydrogeological conditions that exist in the Canadian Shield, it is important to work on the premise that leachate will leak from Adams Mine unless it can be proved otherwise. Despite assertions by some to the contrary, long term containment was never "proved" to the EAB. Through its list of conditions, the Board effectively reserved judgment until considerably more field data could be made available. Neither was long term containment subsequently "proved" to the Ministry of the Environment. The EAB passed a "well flighted ball" to the Ministry of the Environment, and the Ministry promptly dropped it by accepting the results of two seriously flawed groundwater flow models. That probably "proves" more about the scientific ability of the Ministry of the Environment than it does about hydraulic containment.

As I have indicated, issuance of a Certificate of Approval for the Adams Mine site was premature and scientifically unjustified. This should not be considered a bad reflection on Golder Associates who, as the primary consultant to Notre, was obliged to present its client's very limited subsurface dataset in the best possible light. Neither do I criticise the EAB whose decision was appropriate at that time. I believe, however, the Ministry of the Environment made a succession of serious errors:

- **The Scoped Hearing**
  The interests of everyone involved in the project would have been best served if the EAB had been given the opportunity to conduct a full and unfettered environmental assessment of the project. The modeling work would have received appropriate detailed attention, and the Board would have ensured all the field data it felt necessary to make the correct decision (including additional borehole data) were brought to the table.

- **The Scientific Review of the Borehole Models**
  The Ministry failed to conduct a sufficiently thorough scientific evaluation of Golder's modeling studies. It placed too great a reliance on the reliability of modeling techniques and too little on the value of good quality field data.

- **Monitoring**
  The Ministry missed a valuable opportunity to institute a monitoring program at the site that would have confirmed or denied the results implied by the Golder models. As a result, nearly five years later, no data have been collected to determine if heads are recovering beneath the site and there have been only three measurements of the pit lake water level.

On the basis of my work I strongly believe *that the Certificate of Approval for the Adams Mine Site should be suspended until such time* hydraulic containment can be demonstrated by field (not modeled) data. To provide the appropriate data I recommend that:

1) One deep angled borehole be constructed on the south side of the pit where deep data are seriously lacking.
2) Westbay Multiport Systems (or similar) be installed in all four deep boreholes, thus allowing heads beneath the pit to be regularly monitored at discrete intervals.
3) A pressure transducer (water level recorder) and data logger be installed in the pit lake.
4) A simple weather station be installed at the site for the collection of meteorological data including daily precipitation and Class "A" pan evaporation.
5) A comprehensive monitoring program be established as follows:
    - Hourly measurements of lake water levels
    - Daily measurements of precipitation and pan evaporation
    - Monthly measurements of head in the Westbay Multiports

   all for a minimum of three years or until such time as heads measured in the subsurface either consistently exceed 325 masl or demonstrate rates of recovery that show, with a high degree of statistical certainty that a level of 325 masl would be exceeded by the time the pit lake recovers to 325 masl.

If this program of work were implemented immediately, and the pit water level were allowed to recover naturally with no disturbance, the issue of hydraulic containment could be resolved with a high level of confidence within a matter of three to five years.

5 References

Eyles, N. and Boyce, J. I., 1997. Geology and urban waste management in southern Ontario. In: Eyles, N. (ed.) Environmental Geology of Urban Areas. Special Publication of the Geological Association of Canada. Geotext #3, 297-322.

Howard, K.W.F., Eyles, N. and Livingstone, S., 1996. Municipal landfilling practice and its impact on groundwater resources in and around urban Toronto. Hydrogeology Journal 4, no. 1, 64-79.

Kaye, B.G. 1986. Recharge characteristics of the Oak Ridges Moraine Complex: the role of Musselman Lake. Unpublished MSc. Thesis. Univ. Waterloo. 187 pp.

Schwartz, F. W. and Zhang, H., 2003. Fundamentals of Ground Water. John Wiley and Sons, Inc. 583 pp.

Winter, T.C., 1976. Numerical simulation analysis of the interaction of lakes and ground water. USGS Professional Paper 1001. 45 pp.

Winter,T.C.,1978. Numerical simulation of steady state 3-dimensional groundwater flow near lakes. Water Resources Research vol. 14, no. 2, 245-254.

Appendix 1

Documents Reviewed

Document

1. Environmental Assessment Board, 1998. EAB Decision: Notre Development Corporation EA-97-01 (Adams Mine Site) Decision and Reasons for Decision, June 19, 1998.

2. Environmental Assessment Branch (MOEE), 1997. Review under the Environmental Assessment Act prepared by Ministries and Agencies of the Province of Ontario. July 1997.

3. Gartner Lee, 1995. Temiskaming Clay Plain Preliminary Hydrogeologic Study *Final Report Prepared For the Adams Mine Public Liaison Committee* December 1995, Report Documented for Notre Development Corporation, May 1996.

4. Gartner Lee, 2000. Letter entitled, "Adams Mine Landfill – setting the record straight", to Mayor Mel Lastman, City of Toronto. Sept. 14, 2000 GLL 20-256.

5. Gartner Lee. 2001. Overview of the Environmental Security of the Adams Mine Landfill. Prepared for the Corporation of the Town of Kirkland Lake. GLL 21-441. September, 2001.

6. Golder Associates Limited, 1990. Preliminary hydrogeological investigation, Adams Mine, Kirkland Lake, Ontario. Doc. 901-3045-1. Dec. 1990.

7. Golder Associates Limited, Adams Mine Environmental Assessment, Technical Appendix F – Geology/Hydrogeology (1995), (Attachments), December 4, 1995, Report Submitted to Notre Development Corporation.

8. Golder Associates Limited, Adams Mine Environmental Assessment, Addenda F5-F7, Addenda to Technical Appendix F-Geology/Hydrogeology (1995), Report Submitted to Notre Development Corporation, December 1996.

9. Golder Associates Limited, 1996. Appendix F: Geology/Hydrogeology Addendum 1: Results of Drilling and Testing of Drillhole DH95-12 (including summary of log of Borehole DH 95-12 and Attachment F1A).

10. Golder Associates Limited, 1998. Results of drilling, packer testing and groundwater flow modeling of drillholes DH 98-1 and DH 98-2, Adams Mine Landfill. Doc. 981-1464. November 1998. Plus Appendices: Appendix A Drilling and coring procedures. Appendix B Packer testing methodology and detailed results. Appendix C Groundwater flow modeling – Sections F-F', G-G', H-H'.

11. Golder Associates Limited, September 15, 2000. Letter to City of Toronto Mayor Mel Lastman, Adams Mine Landfill - Setting the Record Straight.

12. M.M. Dillon Ltd., 1995. Adams Mine Environmental Assessment Technical Appendix G Surface Water (1995). December 4, 1995 (plus attachments).

13. Metro Works Public Consultation Unit, 1995. Technical Appendix B, Design and Operations (1995) Adams Mine Environmental Assessment, December 4, 1995, Report Submitted to Notre Development Corporation.

14. Ministry of the Environment, Environmental Assessment and Approvals Branch, 1999. Adams Mine Landfill Site-South Pit Provisional Certificate of Approval No. A612007 Issued to Notre Development Corporation, April 23, 1999. 24pp.

15. Notre Development Corporation, 1996. Addendum A1 – Public and agency consultation. December, 1996.

16. Notre Adams Mine Environmental Assessment (undated). Response to Ministry of the Environment and Energy letter dated March 21, 1997 – Attachment 1, comment 2 (c) and Attachment 2, comment 1. Sensitivity analyses - early closure and low filling rate scenarios (South Pit Landfilling Scenarios).

17. Ontario Court of Justice, 1999. Affidavit of Paul Bowen. Court File 580/98. 19^{th} March, 1999.

18. Province of Ontario, Dept. of Mines, Map #1957-4. Boston Township and Part of Pacaud Township, District of Temiskaming.

19. SENES Consultants Limited, 1997. Responses to Government Review Agencies and Public Comments on Adams Mine Environmental Assessment December 1996. April 25, 1997.

20. Temiskaming Federation of Agriculture, 2003. Post-environmental Assessment Monitoring Results – Adams Mine Landfill Project. Media Kit. May 26, 2003.