Stephen Bruce Medd, 49 Graham St. East, Napanee, Ontario, K7R 1L8
613-354-6171 sb.medd@sympatico.ca

A Review of the Richmond Landfill Expansion Environmental Assessment:

Landfill Siting, Contaminating Lifespan, Liner Integrity, Leachate Monitoring, Vertical Fracture Investigation and Contaminant Transport

Richmond Landfill Expansion, Greater Napanee, Ontario

by

Stephen Bruce Medd (Geologist)
Resident of Greater Napanee

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Executive Summary

The issue of proper landfill siting has never been addressed over the 51-year lifespan of the existing Richmond Landfill. Nor does the Environmental Assessment of the proposed expansion submitted by the proponent, Waste Management of Canada Corporation (WM), address this issue. Even with the proposed G2 double composite liner, siting the expansion on fractured bedrock will create unacceptable and unmanageable long-term risks to the underlying groundwater.

This document challenges the proponent's hydrogeological impact conclusion (related to groundwater) that,

> "*There will be no significant impact to groundwater or surface water quality as a result of the expanded landfill. In the worst-case scenario, if the liner were to fail, leachate may at that point infiltrate into the underlying soil and groundwater. Implementation of the proposed contingency (blast-induced fracture trench) would alleviate this issue.*" (WM, 2005, Summary Binder, pg. 6_12)

All landfill liners eventually leak. This document shows that there are significant threats to the integrity of the G2 double composite liner proposed for the Richmond Landfill expansion. The liner integrity is threatened by the contaminating lifespan of certain leachate chemicals, such as toluene, that will surpass the service life of the critical lower geomembrane of the liner. The service life of the various components of the liner will be reduced by leachate recirculation proposed for a gas-to-energy project. The liner integrity is also threatened by holes, rips and tears in the upper and lower geomembrane layers.

When the liner eventually leaks, the risk of contamination to the groundwater is high since critical preferential contaminant pathways, such as vertical fractures, have not been thoroughly investigated and are exceedingly difficult to detect in the complex fractured bedrock on which the landfill is located. There is little confidence in leachate monitoring and mitigation measures when there is a large uncertainty in detecting critical preferential contaminant pathways in the first place.

There is a considerable criticism by the Agency and Peer Reviewers of the proponent's methodology and understanding of contaminant transport and contaminant attenuation once leachate has leaked into the groundwater. With such diverging opinions between the review experts and the proponent on these critical issues, the risk is high that leachate will pose a long term threat to the groundwater within and beyond the property boundary.

Many experts agree that the wisest step that decision-makers can take in assessing landfill locations is to put it in the right hydrogeological environment in the first place. Fractured bedrock is not the right place because of its complex and erratic hydrogeological characteristics that make it nearly impossible to monitor reliably for migrating contaminants.

Six arguments against the proponent's conclusion are listed below and are presented in detail in the body of this report. These arguments support the author's conclusion that the Richmond Landfill site is unsuitable for expansion.

1. **Proper landfill siting shows the Richmond Landfill site to be unsuitable for expansion.**
    - The Richmond Landfill site is located at the headwaters of Marysville Creek near the biologically diverse Salmon River watershed that features 10 Areas of Natural and Scientific Interest (ANSI).
    - The Richmond Landfill site is located in a region underlain by large expanses of fractured limestone bedrock with shallow soils. The Salmon River watershed contains one of Ontario's richest alvars in terms of plant species located downstream and downwind of the landfill site. Alvars are unique and diverse ecosystems that live on sparsely vegetated rock limestone barrens with shallow soils.
    - A regional groundwater study by the Quinte Conservation Authority (2004) concluded that because of predominance of fractures in the bedrock, the high vulnerability of the aquifer make the study area

susceptible to contamination. This is evident on the Mohawk Tyendinaga Territory where 50% of households are on a boil-water advisory.
- The majority of Tyendinaga Territory and its neighbour Tyendinaga Township in Hastings County rely on groundwater for its potable water supply.

2. **The contaminating lifespan of the proposed expansion surpasses the service life of the critical lower geomembrane of the proposed G2 double composite liner.**
   - Although the proponent calculates the contaminating lifespan for the existing landfill, it does **not** calculate the contaminating lifespan for the **proposed** expanded landfill as required by Section 6 (2)(c)(xix) of the Ministry of Environment Landfill Standards O.Reg 232/98 (MOE, 1998).
   - Using an infiltration rate of 0.15 m/yr, the author calculates contaminating lifespans (512 years for the northern area and 436 years for the southern area of the proposed expansion) to be substantially higher than the service life of 350 years of the critical lower geomembrane of the G2 double composite liner.
   - In the leachate recirculation scenario, where the infiltration rate is estimated to be 0.20 m/yr, the contaminating lifespan surpasses the 350-year service life of the lower geomembrane at the northern area (384 years) and is close to the service life of the lower geomembrane at the southern area (327 years).
   - The average height of the northern waste mound (27m) has been designed too high to support a contaminating lifespan that is less than the 350-year service life of the critical lower geomembrane.
   - The WM Environmental Assessment is deficient in providing critical and necessary assessments of the following:
     i. Contaminating lifespan of the proposed expanded landfill
     ii. The impact of landfill height design and waste heterogeneity on the contaminating lifespan of the proposed expanded landfill.
     iii. The impact of leachate recirculation in developing a gas-to-energy project (bioreactor) on the service life of the liner components.

3. **The proposed G2 double composite liner will likely start leaking into the underlying bedrock during its 25-year operational lifetime.**
   - The proponent does not provide an estimate of leachate leakage through holes in the upper and lower geomembrane components of the liner and through cracks in the underlying compacted clay layers. Nor does it estimate leakage due to the diffusion of Volatile Organic Compounds (VOC's) through the geomembrane.
   - The author estimates the primary liner system (upper composite liner) will leak approximately 2,000,000 litres of leachate per year shortly after being put into service due to holes in the geomembrane, and at least 200,000 litres (or 1000 45-gal drums) per year of leachate will likely start leaving the bottom of the landfill during its 25-year operational lifetime.
   - The usefulness of a blast-induced leachate collection trench as a mitigation measure to trap leachate leaking from the bottom of the landfill presupposes an early detection of leachate-impacted groundwater based on a reliable placement and separation of monitoring wells. The likelihood is large that leachate will have migrated for a considerable time and distance before it is detected, if at all, by the proposed monitoring system.
   - A blast-induced leachate collection trench can cause irreversible and negative changes to local groundwater quality if the shallow freshwater aquifer is exposed to deeper saline groundwater due to fracturing.

4. **Monitoring of groundwater contamination in fractured bedrock is highly unreliable.**
   - The proposed monitoring system for the Richmond Landfill expansion does not provide stringent safeguards. The probability of detecting groundwater contamination by monitoring wells spaced hundreds of meters apart in complex fractured bedrock is very low.

5. **The identification of critical vertical fractures is inadequate and exceedingly difficult.**
   - The identification of vertical fractures is difficult but critical because the fractures can provide preferential pathways for leachate migration. Vertical fractures at the Richmond Landfill have been inadequately investigated making the existing and proposed monitoring programs at the site unreliable and uncertain in detecting the migration of leachate through vertical fractures.
   - The risk to groundwater in not locating vertical features is unacceptable. Contaminant migration beyond the property boundary may not be detected until it is too late.

6. **The proponent's choice of monitoring locations creates unacceptable uncertainties in determining leachate indicators, reasonable use objectives, background values and groundwater velocities for determining contaminant transport.**
    - The determination of leachate indicators, reasonable use objectives and background values is unnecessarily complicated by the choice of monitoring locations that are in close proximity to the existing landfill, especially when one considers the 51-year history of the site.
    - In fractured bedrock, there is no easy way to determine a representative groundwater velocity for the purpose of contaminant transport modeling.
    - Averaging of groundwater velocities is more appropriate for determining contaminant transport in a homogenous porous medium. Leachate movement in fractured bedrock does not occur in a uniform plume extending out from the landfill. Its path is tortuous and highly irregular, even within individual fractures. Thus, contaminant transport modeling needs to be carried out using a range of possible values for velocity, ***not*** an average velocity, since it only takes one critical high velocity fracture to transport leachate off the property.

The proponent's hydrogeological impact conclusion, stated above, forms the foundation of several other impact assessments described in Discussion Paper # 7 - Hydrogeology Impact Assessment (WM, 2005, Binder #3, Appendix D) in particular: agricultural; human health risk; land use; natural environment; and social. These impact assessments will need to be revisited in light of the uncertainties in the proponent's hydrogeological impact assessment.

1. Proper landfill siting shows the Richmond Landfill site to be unsuitable for expansion.

The Richmond Landfill was first created in 1954 by a local resident who operated a privately run garbage disposal service on his family farm. In those days, the environmental standards for waste dumping were virtually non-existent. Over the last 51 years the dump has grown ever larger with each successive owner. Unfortunately, the issue of proper siting has never been addressed even though today's experts agree that this is critical in deciding where to establish a landfill.

The expansion proposal of the Richmond Landfill would increase its footprint size from the present 16.2 hectares to 109.5 hectares. The annual volume of waste into the site would increase six-fold from 125,000 tonnes/year to 750,000 tonnes/year. This significant increase in size and volume makes the issue of landfill siting all that more relevant.

It is neither prudent nor correct to suggest that,

> "*In the construction of a modern landfill, the quality of the liner and the overall engineering system of the landfill are more relevant than the type of ground the liner sits on*", as the proponent has publicly stated (WM, 2005, Community Update).

Experts would argue that a thorough understanding of "*the type of ground the liner sits on*" is absolutely essential in choosing a safe site to locate a landfill.

1.1 Making the case for proper landfill siting.

On February 12, 2004 I attended a talk by Dr. Allan Freeze entitled "*Some Awkward Truths about Waste Disposal*" hosted by Queen's University (Freeze, 2004). Dr. Freeze pointed out that double liners delay early failure but eventually leak, transferring the risk to future generations. He stressed that good siting is critical in order to minimize the risk of eventual leachate leakage and to maximize confidence in detecting and properly mitigating leakage.

On September 28, 2001 the University of Michigan hosted a talk by Dr. Allan Freeze entitled, "*The Dilemma of Waste: Unpleasant Truths and Difficult Decisions*". In the abstract for his talk he wrote,

> "*Proper siting represents the best possible route to environmental protection, but current socially-driven siting promotes poor sites at the expense of good ones.*" He continued, "*Wise environmental policy would promote prevention rather than remediation, regional aquifer protection rather than site-scale engineering design, and consideration of long-term risks rather than short-term economics.*" (Freeze, 2001)

On January 21, 2005 I attended a talk by Dr. Kerry Rowe entitled "*From Beyond dump and Cover: the myths and realities of modern landfill*" hosted by the Kingston Technology Council (Rowe, 2005). Dr. Rowe explained that in order to create a safe landfill ***all*** of the following five steps need to be carefully undertaken:

- Siting a landfill in the right environment
- Controlling the types of waste entering a landfill
- Designing a landfill to suit the site conditions
- Constructing a landfill properly
- Operating and monitoring a landfill properly

Dr. Rowe specifically mentioned fractured bedrock as being a potential concern for landfill siting. Richmond Landfill is situated on fractured limestone bedrock.

Lee and Jones-Lee (2004) describe the importance of proper landfill siting,

> "*The landfill should be sited so that it provides, to the maximum extent possible, natural protection of groundwaters when the liner system fails. Siting landfills above geological strata that do not have readily monitorable flow paths for leachate-polluted groundwaters should be avoided. Of particular concern are fractured rock and cavernous limestone areas, as well as areas with sandy lenses.*"

Improperly sited landfills leave a negative legacy that communities will have to grapple with in the future. The Environmental Commissioner of Ontario, Gord Miller, stated in his 2002-2003 annual report entitled,

> "*Thinking beyond the Near and Now*", "*Short-term concerns dominate our thoughts and actions, while the far-ranging or long-term consequences are not given much serious attention.*" (Miller, 2003)

The issue of proper landfill siting takes on an even greater importance when considering the new groundwater source protection plans of the provincial government. A report by the MOE's Committee on Watershed-based Source Protection Planning stated,

> "*Planning to protect drinking water sources must happen on a watershed-basis because it allows an entire water resource system to be considered as a whole –water does not stop at county lines or municipal boundaries.*
>
> *Protecting Ontario's drinking water at its source is the first line of defence in what experts refer to as the 'multi-barrier approach'to ensuring the safety of drinking water. Each barrier in the system works together to prevent or reduce the risk of contaminants reaching your tap.*
>
> *Source protection is recognized as playing a critical role in drinking water safety as the first barrier in this system. The primary objective of source protection, like the other barriers, is the protection of human health.*" (MOE, 2003)

1.2 Assessing landfill siting characteristics of the Richmond Landfill.

There are a number of obvious reasons why the Richmond Landfill is not suitable for expansion. The landfill site is located at the headwaters of Marysville Creek near the biologically diverse Salmon River watershed that features 10 Areas of Natural and Scientific Interest (ANSI). The Ontario Ministry of Natural Resources states:

> "*The Salmon River watershed features 10 Areas of Natural and Scientific Interest (ANSI) and is an important watershed to protect and restore*." (MNR, 2005)

The Richmond Landfill site is located in a region underlain by large expanses of fractured limestone bedrock with shallow soils that experts commonly cite as making poor locations for building landfills. The region is known for its alvars that are unique and diverse ecosystems living on sparsely vegetated limestone barrens with shallow soils. One of Ontario's richest alvars, the Salmon River Alvar, is home to Canada's only known population of Juniper Sedge, an endangered plant (MNR, 2005). The Salmon River Avlar is located in an area downstream and downwind of the Richmond Landfill site.

The Ontario Ministry of the Natural Resources sponsored a regional groundwater study (Quinte Conservation Authority, 2004) undertaken by the Quinte Conservation Authority in order to develop management strategies for the protection of groundwater resources in the Quinte region. One of the study areas included Tyendinaga that is a downgradient receptor of surface and groundwater from the vicinity of the Richmond Landfill. The study describes a number of findings that make it apparent the region is not suitable for expanding the Richmond Landfill. For example, the study stated,

> "*The entire Study Area can be considered a groundwater recharge area because of the predominance of fractures within the top portions of the bedrock aquifer. Precipitation that falls on the land will rapidly infiltrate these fractures and percolate to the aquifer below.*" (Quinte Conservation Authority, 2004)

and

> "*The majority of the Study Area has been mapped as highly vulnerable. Isolated occurrences of clay are present in some localities, but rarely attain thicknesses that would allow significant protection of the underlying bedrock aquifer. The high vulnerability of the aquifer makes the entire Study Area susceptible to contamination.*" (Quinte Conservation Authority, 2004)

The susceptibility of the area to contamination is evident on the Mohawk Tyendinaga Territory where 50% of households are on a boil-water advisory. The majority of Tyendinaga Territory and its neighbour, Tyendinaga Township in Hastings County, rely on groundwater for its potable water supply. There is no wisdom in greatly expanding the Richmond Landfill in an area where a significant portion of the surrounding population is reliant on potable groundwater from an aquifer that is already susceptible to contamination.

2. The contaminating lifespan of the proposed expansion surpasses the service life of the critical lower geomembrane of the proposed G2 double composite liner.

The WM Environmental Assessment (WM, 2005, Summary Binder, pg. 3_11) describes *landfill reclamation* as the preferred option of leachate control for the proposed expansion. This option utilizes the Generic Design II (G2 double composite liner) as described in the MOE Landfill Standards O.Reg 232/98 (MOE, 1998). The MOE Landfill Standards describe specifications of the primary and secondary components of the G2 double composite liner including the high density polyethylene (HDPE) geomembranes, the compacted clay layers and the leachate collection systems.

During the autumn of 2005 a WM ad (included in this report as Appendix 2) ran several times in two local Napanee newspapers – the Napanee Guide and the Napanee Beaver – claiming,

> "*The high density polyethylene we use will be good for at least a thousand years…*'. (The Napanee Guide, 2005)

This statement is erroneous and misleading. The MOE Landfill Standards record a service life of 150 years for the primary (upper) HDPE geomembrane and a service life of 350 years for the secondary (lower) HDPE geomembrane. In addition to years of service, the integrity and effectiveness of the liner will be compromised by other factors such as leachate recirculation and holes as described in subsequent Sections 2.2 and 3 of this report.

The lower geomembrane forms a composite layer with underlying compacted clay, providing the liner's last defence against leachate entering the groundwater underneath the expanded landfill. When the service life of the lower geomembrane has expired in 350 years, the lower geomembrane can no longer protect the groundwater as originally intended if chemical compounds have the potential of contaminating for a period beyond the service life. This is known as the contaminating lifespan and is unique to different chemical compounds.

The analysis of contaminating lifespan is an important landfill design tool as pointed out by WM in Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part B (WM, 2005, Binder #2, Appendix C, pg. K1).

> "*Contaminating lifespan estimates are used to determine the required design life of landfill engineered components, as well as the source function and ultimately the basis for conducting a contaminant transport analysis*."

However, the proponent only calculates the contaminating lifespan for the existing landfill but **not** for the proposed expanded landfill as required by Section 6 (2)(c)(xix) of the MOE Standards O.Reg 232/98 (MOE, 1998). Section 6 lays out the design specifications required for new and expanded landfills where subsection (2)(c)(xix) requires:

> "*an estimate of the contaminating lifespan of the site with respect to contaminants in leachate, unless a new landfilling site is being established and the design for groundwater protection features of the site meets the criteria set out in subsection 10 (4) or (5).*"

Since the Terms of Reference for the Environmental Assessment (WM, 2005, Binder #1, Appendix A) are for an **expanded** Richmond Landfill, the contaminating lifespan should have been provided in Discussion Paper # 7 - Hydrogeology Impact Assessment (WM, 2005, Binder #3, Appendix D). This estimate should have been compared to the 350-year service life of the lower geomembrane of the proposed G2 double composite liner system.

The contaminating lifespan is directly proportional to the average thickness of waste on the landfill. With other factors remaining the same, the higher the waste mound the longer will be the contaminating lifespan. The subsequent section clearly shows the designed height of the proposed expanded landfill is too great to support a contaminating lifespan that is less than the 350-year service life of the critical lower geomembrane.

2.1 Calculating the contaminating lifespan of the proposed Richmond Landfill expansion

For the proposed expansion, the calculation is shown below for the contaminating lifespan of toluene using the equations provided in Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part B (WM, 2005, Binder #2, Appendix C, pg. K2).

Table 1: Parameters used to calculate the contaminating lifespan of the proposed expanded Richmond Landfill

Parameter	Definition	Value	Sources and Assumptions
A_0	Landfill area	652,000 m^2 for the northern area 443,000 m^2 for the southern area	From Discussion Paper # 8 - Preliminary Design, Development and Operation Plans (WM, 2005, Binder #4, Appendix G, pg. 4_3) there are two landfill areas planned: - Northern area: 65.2 hectares - Southern area: 44.3 hectares
H_W	Average thickness of waste on the landfill	27m for the northern area 23m for the southern area	From Discussion Paper # 8 - Preliminary Design, Development and Operation Plans (WM, 2005, Binder #4, Appendix G, pg. 4_3) there are two landfill areas planned: - Northern area: 65.2 hectares, 48m high - Southern area: 44.3 hectares, 40m high The thickness of the proposed liner (3m) was subtracted from final height of each area yielding heights of 45m and 37m respectively. A 1:4 slope ratio is assumed with the landfill rising to 32m where the slope flattens out to 5%. An average height of each slope segment was calculated. The estimated average waste thickness is based on the height average of all slope segments weighted by area.
ρd_W	Dry density of the waste	700 kg/m^3	From Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part B (WM, 2005, Binder #2, Appendix C, pg. K2)
q_0	Infiltration through the landfill	0.15 m/yr 0.20m/yr	0.15 m/yr represents the minimum rate required by the MOE Landfill Standards (MOE, 1998) 0.20 m/yr is an estimate of infiltration due to leachate recirculation from Discussion Paper # 7 - Hydrogeology Impact Assessment (WM, 2005, Binder #3, Appendix D, pg. 7)
C_0	Peak concentration of the contaminant	0.587 mg/L	From Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part B (WM, 2005, Binder #2, Appendix C, pg. K3) for toluene
C(t)	Concentration in the landfill at time t	0.0195 mg/L	From Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part B (WM, 2005, Binder #2, Appendix C, pg. K3) for toluene
mp	Mass proportion of the total wet mass of waste	0.7 mg/kg	From MOE Landfill Standards (MOE, 1998)
p	Ratio of the contaminant in the waste		Equation 1: $p = mp/(1x10^6)$
M_t	Total mass of waste		Equation 2 (kg): $M_t = \rho d_W \times A_0 \times H_W$
mtc	Total mass of contaminant species of interest in waste		Equation 3 (kg): $mtc = p \times M_t$
H_r	Reference height of leachate		Equation 4 (m): $H_r = mtc/(C_0 \times A_0)$
t	Time required for the leachate strength to reduce to some specified value (C’)		Equation 5 (yr): $t = (-H_r/q_0) \times \ln(C'/C_0)$

The contaminating lifespan of toluene is calculated separately for two infiltration rates at the northern and southern areas of the proposed expansion. An infiltration rate of 0.15 m/yr represents the MOE’s required minimum rate through the final cover of the landfill (MOE, 1998). An infiltration rate of 0.20 m/yr represents WM's estimated rate due to leachate recirculation as described in Discussion Paper # 7 - Hydrogeology Impact Assessment (WM, 2005, Binder #3, Appendix D, pg. 7).

Using an infiltration rate of 0.15 m/yr, the author calculates contaminating lifespans (512 years for the northern area and 476 years for the southern area of the proposed expansion) to be substantially higher than the service life of 350 years of the critical lower geomembrane of the G2 double composite liner.

In the leachate recirculation scenario, where the infiltration rate is estimated to be 0.20 m/yr, the contaminating lifespan surpasses the 350-year service life of the lower geomembrane at the northern area (384 years) and is close to the service life of the lower geomembrane at the southern area (327 years).

Clearly, the average height of the northern waste mound (27m) has been designed too high to support a contaminating lifespan that is less than the 350-year service life of the lower geomembrane.

Table 2: Contaminating lifespan of toluene versus infiltration rates for the proposed expanded Richmond Landfill

Landfill Area	Average Waste Height	Infiltration Rate (q_0)	Contaminating Lifespan (t)
Northern Area	27m	0.15m/yr MOE minimum infiltration rate	512 years
		0.20m/yr WM estimated infiltration rate due to leachate recirculation	384 years
Southern Area	23m	0.15m/yr MOE minimum infiltration rate	436 years
		0.20m/yr WM estimated infiltration rate due to leachate recirculation	327 years

In reality waste is highly heterogeneous. The waste mounds would contain a large quantity of unbroken or partially broken bags and containers whose contents would be isolated to a certain degree from the effects of infiltration and thus behave as future "time bombs" that would extend the contaminating lifespan estimate calculated above.

2.2 Leachate recirculation in the proposed Richmond Landfill expansion

WM proposes to develop a gas-to-energy project (bioreactor) from the landfill that will capture the landfill gas and turn it into energy (WM, 2005, Community Update). Landfill gas production would be accelerated by leachate recirculation as stated in Discussion Paper # 8 - Preliminary Design, Development and Operation Plans (WM, 2005, Binder #4, Appendix G, pg. 4_4),

> "*WM proposes to equip the landfill with piping to allow leachate recirculation within the landfill*."

This proposal has several consequences for the integrity and service life of the G2 double composite liner system such as:

- Accelerated corrosion of the upper and lower geomembranes since recirculated leachate is stronger than leachate produced by normal infiltration
- Accelerated clogging of the leachate collection components of the liner
- Increased potential for liner seeps
- Leachate mounding on the liner
- Elevated liner temperature
- Increased potential for fires

The MOE Landfill Standards O.Reg 232/98 (MOE, 1998) do not provide any requirements or guidance on landfill design specifically employing leachate recirculation. Nor does it consider the effects of leachate recirculation on the service life of the components of the G2 double composite liner. For this reason, it can be argued that extensive leachate recirculation for the purpose of developing a gas-to-energy project (bioreactor) falls outside of the scope of the MOE Landfill Standards.

This is corroborated in a letter (MOE, 2005) received by the author from the MOE Kingston/Cornwall District Office in response to a number of questions asked by the author and another local citizen during a private meeting on July 21, 2005. The letter is included in this report as Appendix 1. The pertinent question and response are outlined below.

> "*Q15: Are there standards, in the Landfill Regulation 232/98, for geotechnical liners designed for use in sites that are being operated as bioreactors? Is the service life of a geotechnical liner different if a site is a bioreactor?*"
>
> "*MOE Answer: The standards in the Regulation 232/98 are not for landfill sites operating as bioreactors. The regulation approves generic designs that are based on a conventional operating landfill. Service life of a liner has to be addressed as part of any application for approval regardless of the type of operation, ie. conventional landfill vs. bioreactor. All landfill sites that are approved will have site specific conditions on the Certificate of Approval. All facilities in Ontario must comply with the Environmental Protection Act and applicable regulations under the Act.*"

To summarize, the WM Environmental Assessment is deficient in providing critical and necessary analyses of the following:

- Contaminating lifespan of the proposed expanded landfill
- The impact of landfill design height and waste heterogeneity on the contaminating lifespan of the proposed expanded landfill
- The impact of leachate recirculation in developing a gas-to-energy project (bioreactor) on the service life of the liner components.

3. The proposed G2 double composite liner will likely start leaking into the underlying bedrock during its 25-year operational lifetime.

The WM Environmental Assessment does not provide an estimate of leachate leakage through holes in the upper and lower geomembrane components and through cracks in the underlying compacted clay layers. Nor does it estimate leakage due to the diffusion of Volatile Organic Compounds (VOC's) through the geomembrane.

Holes will develop in the geomembrane components of the G2 double composite liner shortly after it is put into service. Rowe (2004) explained that even after holes have been detected and repaired during liner installation, other holes will develop under combined overburden pressure, elevated temperature and chemical exposure for years after installation. Wrinkles, rips and tears, which are inevitable during installation, are also sources of holes and stress cracking years after installation.

Rowe (2004) wrote,

> "*Thus even following a leak detection survey and repairs to any detected holes, it is prudent to assume a number of holes in geomembrane for design.*"

Based on leakages observed at other landfills, Rowe (2004) suggested that a common (low) default of 2.5 holes per hectare be considered during landfill design. He also referred to a survey of landfills that found 50% of the holes were greater than 1 cm^2 in area.

Furthermore, the underlying compacted clay liner is also prone to leakage as described by Lee and Jones-Lee (2004),

> "*There is increasing evidence that, in addition to general permeability, such liners leak through imperfections that are created at the time of liner construction. Further, compacted clays used as liners are subject to desiccation cracking, cation exchange shrinking, cracking due to differential settling, impacts of chemicals, etc., creating additional points through which leachate can leak, and allowing transport of leachate through the liner at a rate greater than would be expected based on the design permeability.*"

3.1 Determining leakage through holes in the upper composite liner of the proposed Richmond Landfill expansion

The calculated leakage rate through the upper composite geomembrane-compacted clay liner is estimated at 50 litres per hectare per day, using the *Design Calculator for Leakage Rate Through Composite Liner* based on equations by Giroud et al. (1997). This translates to approximately 2,000,000 litres per year for the 109.5 hectare proposed expansion. The parameters used to calculate the leakage rate are listed below:

Geometry of circular defect

- Unit geomembrane area: 10,000 m^2 (1 hectare)
- Hydraulic head on top of the geomembrane: 0.3 m
- Thickness of the low-permeability soil: 0.75 m
- Permeability of the low-permeability soil: 1.00E-7 m/s (compacted clay)

Properties of circular defect

- Contact (good or poor): Good
- Number of defects: 3 (Low)
- Diameter of defect: 0.0113 m (1cm^2 has radius of 1.13cm)

Lee and Jones-Lee (1997) caution,

> "*Whenever the upper composite liner in a double composite-lined landfill leaks leachate at a sufficient rate to cause groundwater pollution if the lower composite liner were not present, it is essential that action be taken by the landfill owner/operator to stop leachate generation through maintenance of the cover or remove the municipal solid wastes from the landfill through landfill mining. Failure to take this action will eventually lead to groundwater pollution even in double composite-lined landfills.*"

Discussion Paper #6 – Facility Characteristics (WM, 2005, Binder #4, Appendix F) does not provide information on maintenance measures that would be required under the scenario outlined above by Lee and Jones-Lee.

3.2 Assessing the effectiveness of the lower leachate collection system of the proposed Richmond Landfill expansion

Discussion Paper #6 – Facility Characteristics (WM, 2005, Binder #4, Appendix F, pg.4_2) states,

> "*The secondary drainage layer [lower leachate collection zone] will be accessible and be capable of future leachate removal as a contingency should the primary liner system fail.*"

It is not a question of "***should** the primary liner system fail*". As demonstrated above using the *Design Calculator for Leakage Rate Through Composite Liner*, the primary liner system (upper composite liner) will leak approximately 2,000,000 litres of leachate per year shortly after being put into service due to holes in the geomembrane.

Discussion Paper #6 does not provide information on the rate and extent of clogging that will determine the capture efficiency of the lower leachate collection system. The narrow sump areas are especially prone to increased rates of clogging. Furthermore, the collection pipes are spaced 80m apart as shown in Drawing No. 197715-D6-19C, Discussion Paper #6 – Facility Characteristics (WM, 2005, Binder #4, Appendix F) allowing large areas of the lower composite liner (which will contain holes) to be exposed to leachate before it migrates to the collection sumps.

Discussion Paper #6 – Facility Characteristics does not provide information on the proposed method and frequency of measuring the hydraulic head within the lower leachate collection zone. Nor does it provide information on what will trigger the activation of the lower leachate collection system.

3.3 Determining leakage through holes in the lower composite liner of the proposed Richmond Landfill expansion

Because of a lack of details regarding the lower leachate collection system in Discussion Paper #6 – Facility Characteristics, it is difficult to estimate the leakage through the lower composite liner. However, this author believes it reasonable to assume that the hydraulic head in the lower leachate collection zone could rise to at least 5cm over the 25-year operating life of the proposed expansion, resulting in at least 200,000 litres (or 1000 45-gal drums) per year of leachate leaving the bottom of the landfill.

3.4 Assessing diffusion of volatile organic compounds through the liner of the proposed Richmond Landfill expansion

In addition to leakage through holes in the liner, Volatile Organic Compounds (VOC's) such as chlorinated solvents, benzene, TCE and its degradation products such as vinyl chloride can diffuse through intact geomembrane in a short period of time as dilute or concentrated aqueous solutions of solvent.

Rowe (2004) wrote,

> "*VOC's [Volatile Organic Compounds] can break through intact 1.5mm HDPE geomembrane (by diffusion) within a matter of days to weeks (depending on the contaminant and temperature). There is an extensive body of literature dealing with diffusion of organic compounds through geomembranes … and techniques are readily available for modeling the transport of VOC's through composite liner systems and to the groundwater*".

3.5 Mitigation measures are ineffective for leachate leakage from the proposed Richmond Landfill expansion

Discussion Paper #6 – Facility Characteristics (WM, 2005, Binder #4, Appendix F, pg.4_2) states,

> "*WM's hydrogeological consultant indicates that the capture of any leachate-impacted groundwater, should it be necessary for any reason, can be accomplished through a shallow or, if necessary, somewhat deeper blast-induced fracture trench within the bedrock.*"

The usefulness of this mitigation measure presupposes an early detection of leachate-impacted groundwater based on a reliable placement and separation of monitoring wells. Of course, a reliable monitoring system depends on a thorough understanding of the fractured bedrock including vertical fractures. However, WM has not demonstrated this understanding as described in the subsequent sections. The likelihood is large that leachate will have migrated for a considerable time and distance before it is detected, if at all, by the proposed monitoring system.

Also, the groundwater flow system at the Richmond Landfill site is characterized by a shallow irregular freshwater aquifer overlying very saline groundwater in the deeper bedrock. At a similar setting at the Glenridge Landfill in St. Catherines, Ontario a blast-induced leachate collection trench caused irreversible and negative changes to local groundwater quality (Ruland, 2005).

4. Monitoring of groundwater contamination in fractured bedrock is highly unreliable.

It is clear from the assessment of contaminating lifespan, liner service life, and leakage rate, that the issue of understanding "*what is underneath the liner*" and the placement and reliability of monitoring wells are essential to safeguard the groundwater.

MOE Procedure B-7-1 states,

> "*As there are environments which the Ministry does not believe are appropriate for waste disposal, the Ministry will either oppose the use of such environments or will insist that stringent safeguards be incorporated in any design for the disposal site and that there be appropriate monitoring and contingency plans.*"

The proposed monitoring system for the Richmond Landfill expansion does not provide stringent safeguards. The probability of detecting groundwater contamination by monitoring wells spaced hundreds of meters apart in complex fractured bedrock is very low.

The uncertainties and difficulties in monitoring for contaminated groundwater around lined landfills are well documented. Lee and Jones-Lee (1993) describes this problem for a lined landfill situated on a porous soil by writing,

> "*… it is clear that leakage from point sources such as holes in liners will move downgradient as narrow fingers of leachate rather than in the traditionally assumed fan-shaped plumes… Since the lateral spread of a finger of leachate contaminated groundwater from a lined landfill is minimal, monitoring wells that are spaced hundreds of feet apart at the downgradient edge of a lined landfill have a very low probability of detecting the fingers of leachate produced by leaks in the liner system. Those fingers of leachate could travel long distances before groundwater pollution by the landfill is detected.*"

Lee and Jones-Lee explained that because the capture zone around a monitoring well during sampling is in the order of one foot, the wells would have to be spaced no more than a few feet apart along the entire down-gradient edge of the landfill to confidently detect the plume.

Even more difficult is monitoring for groundwater contamination in fractured bedrock around a lined landfill. Lee and Jones-Lee (1996) wrote,

> "*It is well-known that groundwater monitoring in fractured rock is virtually impossible to carry out reliably. The basic problem is that the flow occurs through fractures-cracks in the rock. This means that monitoring wells spaced even a few feet apart may not be able to detect leachate transport through the bedrock unless they happen to intercept the fracture(s) that are principally responsible for leachate transport.*" He continued, "*Great caution must be exercised in permitting landfills sited within or above complex geological strata where the hydrogeology of the region is not adequately defined to be able to predict with a high degree of certainty the ability of a groundwater monitoring well(s) to detect leachate pollution of groundwaters at the point of compliance before passage of this leachate beyond this point occurs.*"

Haitjema (1991) wrote,

> "*Monitoring wells in the regional aquifer [consisting of fractured rock] are unreliable detectors of local leaks in a landfill.*" He continued, "*The design of monitoring well systems in such an environment is a nightmare and usually not more than a blind gamble.*"

5. The identification of critical vertical fractures is inadequate and exceedingly difficult.

The identification of vertical fractures is difficult but critical because the fractures can provide preferential pathways for leachate migration. Vertical fractures at the Richmond Landfill have been inadequately investigated making the existing and proposed monitoring programs at the site unreliable and uncertain in detecting the migration of leachate through vertical fractures.

To date, investigations of vertical fractures at the Richmond Landfill site have been spotty and disjointed. Vast sections of bedrock remain untested for vertical fractures between a small number of inclined boreholes and widely spaced test pits. Prior to 2000, only three inclined boreholes had been drilled over the entire property, boreholes: M57, M60 and M62 (WESA, 1999). An additional seven inclined boreholes were drilled as part of the baseline audit that Terraprobe conducted for the Town of Greater Napanee (Terraprobe, 2001).

The core from the inclined drilling indicated predominantly horizontal fracturing along bedding planes with occasional vertical fractures. However, the paucity of vertical fractures in such as small number of drill cores simply means that considerably more effort is needed to locate them because of their vertical orientation and wide areal separations.

There has been no clear geological or geophysical rationale for the placement and direction of all inclined boreholes. For example, are these holes positioned to intersect specific geophysical targets or geological features extrapolated from outcrops and test pits?

Terraprobe (2000) concluded during its baseline audit of the Richmond Landfill that,

> "*Ground water flow primarily occurs within bedrock fractures. Due to the fractured hydrogeological setting, leachate migration in groundwater is more unpredictable and more difficult to track than it is in other settings*".

This is especially true of vertical fractures that are even more difficult to locate than horizontal fractures, but nevertheless critical to understanding the entire leachate migration question.

Cherry (1990) wrote,

> "*One of the reasons why groundwater contamination is now so common in industrial regions is the leakiness of aquitards due to fractures, primarily vertical fractures*." He explained that vertical fractures thinner than a human hair are important. He goes on to say, "*The usefulness of vertical boreholes/vertical monitoring wells is often very limited because of the low probability of detecting the critical fractures*."

To locate the critical vertical fractures a property-wide, systematic inclined drilling program should have been undertaken. Once there is a reasonable attempt at locating the vertical fractures, then detailed hydrogeological work can be done to identify problem fractures that threaten the groundwater.

5.1 Geophysical survey to locate vertical features at the Richmond Landfill

A VLF geophysical survey was,

> "*…primarily undertaken to locate geophysical anomalies that may be indicative of major faults traversing the survey area*" (Hyd-Eng, 1998).

Several VLF anomalies were identified, generally trending in a west-southwest direction typical of the fault structures that are known to occur in the region. Only a few of the strongest and most continuous anomalies were drilled. Two of the stronger anomalies appear to be associated with two groundwater divides identified by WESA (1999). They wrote,

> "*There are positive indications of higher hydraulic connection along the lineations at each location. Ground water flow in the intermediate zone would appear to be primarily controlled by fracture orientation in the bedrock*."

VLF can be effective in locating broad, continuous fracture zones. Conversely, VLF may not always provide suitable drilling targets because of its lack of resolution in locating very narrow and weakly conductive, discontinuous vertical fractures overlain by overburden. However, very narrow discontinuous fractures and joints are also important conduits for leachate movement given the right hydrogeological conditions. The risk to groundwater in not locating these features is unacceptable. Contaminant migration beyond the property boundary may not be detected until it is too late.

Where specific targets are not clear then borehole fences are required over key sections of the bedrock. A borehole fence is comprised of a series of inclined holes drilled back-to-back so that no horizontal gaps exist between holes. This may be the only rigorous method of finding vertical fractures.

A few inclined boreholes targeted VLF anomalies however the geophysical target appears not to have been intersected. Explanations should have been provided (if applicable) for boreholes not intersecting the anticipated targeted VLF linear features. These geophysical targets represent real structural features. If drilling does not intersect these targets then there needs to be a reassessment of the placement, direction and length of the inclined boreholes; and also the axis and downward projection of the geophysical target. Linear VLF features should be drilled at several points along their strike and dip to clearly understand their extent.

6. The proponent's choice of monitoring locations creates unacceptable uncertainties in determining leachate indicators, reasonable use objectives, background values and groundwater velocities for determining contaminant transport.

I share the concerns of the Agency & Peer Reviewers whose comments (in particular Nos. 15-19, 168, 211, 228-230, 239-240) are found in Discussion Paper # 5 - Environmental Baseline Conditions (WM, 2005, Binder #1, Appendix B). These concerns relate to the determination of leachate indicators; reasonable use objectives; background values; and groundwater velocities for determining contaminant transport.

I agree with the Peer Review Team's comment #168, specifically with regard to the Hydrogeology Baseline Conditions Report, that,

> "*The PRT concludes that, in their current form, the HBCR [Hydrogeology Baseline Conditions Report] and NEBCR [Natural Environment Baseline Conditions Report] do not meet the tests of transparency and replicability*."

6.1 Leachate indicators, reasonable use objectives and background values

A wider variety of chemicals typically found in landfill leachate need to be included as leachate indicators. The selection criteria need to be revisited including the use of prediction limits for determining reasonable use objectives.

The determination of background values for potential leachate indicators, such as chloride, is unnecessarily complicated by the choice of monitoring locations that are in close proximity to the existing landfill. This takes on added significance due to the uncertainties inherent in the lengthy period (51 years) that the present landfill has been operating. A better picture of background values could be derived from additional monitoring wells drilled on the north side of Marysville Creek where the area is less likely to have been impacted by landfill activities in site's early past.

6.2 Groundwater velocity

In fractured bedrock, there is no easy way to determine a representative groundwater velocity for the purpose of contaminant transport modeling. Discussion Paper # 5 - Hydrogeology Baseline Conditions – Part A (WM, 2005, Binder #2, Appendix C, pg. 50) estimates groundwater velocities in shallow bedrock fractures to range from 5 to 81,794 m/yr. An average velocity of 98m/yr was used for solute transport analysis. With such a large divergence in individual velocities, averaging is inappropriate.

Terraprobe (2001) recognized this by concluding in its baseline audit for the Town of Greater Napanee that,

> "*The geology and hydrogeology at the Richmond Landfill site supports the conceptual model originally proposed by Terraprobe. This flow system is highly dependent upon specific pathways rather than flow based upon average values of the porous media*."

Averaging of groundwater velocities is more appropriate for determining contaminant transport in a homogenous porous medium. Leachate movement in fractured bedrock does not occur in a uniform plume extending out from the landfill. Its path is tortuous and highly irregular, even within individual fractures. Thus, contaminant transport modeling needs to be carried out using a range of possible values for velocity, ***not*** an average velocity, since it only takes one critical high velocity fracture to transport leachate off the property.

7.0 Conclusions

All landfill liners eventually leak. This document shows that there are significant threats to the integrity of the G2 double composite liner proposed for the Richmond Landfill expansion. The liner integrity is threatened by the contaminating lifespan of certain leachate chemicals, such as toluene, that will surpass the service life of the critical lower geomembrane of the liner. The service life of the various components of the liner will be reduced by leachate recirculation proposed for a gas-to-energy project. The liner integrity is also threatened by holes, rips and tears in the upper and lower geomembrane layers.

When the liner eventually leaks, the risk of contamination to the groundwater is high since critical preferential contaminant pathways, such as vertical fractures, have not been thoroughly investigated and are exceedingly difficult to detect in the complex fractured bedrock on which the landfill is located. There is little confidence in leachate monitoring and mitigation measures when there is a large uncertainty in detecting critical preferential contaminant pathways in the first place.

There is a considerable criticism by the Agency and Peer Reviewers of the proponent's methodology and understanding of contaminant transport and contaminant attenuation once leachate has leaked into the groundwater. With such diverging opinions between the review experts and the proponent on these critical issues, the risk is high that leachate will pose a long term threat to the groundwater within and beyond the property boundary.

Many experts agree that the wisest step that decision-makers can take in assessing landfill locations is to put it in the right hydrogeological environment in the first place. Fractured bedrock is not the right place because of its complex and erratic hydrogeological characteristics that make it nearly impossible to monitor reliably for migrating contaminants.

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Appendices

1. MOE (Ontario Ministry of the Environment), October 7, 2005, A letter from Penny S. Stewart, Issues Coordinator, Kingston/Cornwall District, Eastern Region to Dr. John A. McKinney MD and cc Stephen Medd.
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Respectfully submitted,

Stephen Bruce Medd (Geologist)
Resident of Greater Napanee, Ontario

CC:
Leona Dombrowsky; MPP of Hastings-Frontenac-Lennox & Addington
Ernie Parsons; MPP of Prince Edward-Hastings
Laurel Broten; Minister of the Environment
Doug Bearance; Warden of Lennox and Addington County
Gord Schermerhorn (Mayor) and Council; Greater Napanee
Marg Walsh; Reeve of Tyendinaga Township, Hastings County
R. Donald Maracle; Chief of the Mohawks of the Bay of Quinte
Scott Reid; MP of Lanark-Frontenac-Lennox & Addington
Paul Schafer; Canadian Environmental Assessment Agency
Stephen Geneja; Chair of the Concerned Citizens of Tyendinaga Township
Don Ryan; Chair of Citizens Against the Richmond Landfill Expansion – Napanee Chapter
Richard Lindgren; Canadian Environmental Law Association
Dr. Wilf Ruland; Professional Geoscientist
Dr. Poh-Gek Forkert; Dept. of Anatomy and Cell Biology; Queens University
Dr. Alban Goddard-Hill; Former Acting Medical Health Officer of Hastings-Prince Edward
Dr. John McKinney; Retired MD, Greater Napanee
Drs. Tom and Liz Touzel; MD, Greater Napanee
Dr. Paul Kenny; MD, Greater Napanee
Dr. Ed File; Resident of Tyendinaga Township
Al Gardiner; Resident of Greater Napanee
Karen Smart; Resident of Greater Napanee
Ian Munro; Resident of Greater Napanee