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Date: 2024 12 09

Re: Technical Review of the *Environmental Impact Assessment* for the Proposed *Crane Mountain Landfill Capacity Augmentation and Life Extension Project*.

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A. PREAMBLE AND IMPLICATIONS OF A PREDOMINANTLY VERTICAL EXPANSION

This memorandum has been prepared at the request of EXP following the submission of an *Environmental Impact Assessment* prepared by GEMTEC and dated 21 June 2023 and hereafter referred to as the "*GEMTEC Report*" for the proposed *Fundy Region Service Commission Crane Mountain Landfill Capacity Augmentation and Life Extension Project Saint John, New Brunswick* and submitted to the Department of Environment and Local Government as part of the **EIA Registration for a significant increase in the Fundy Regional Service Commission's (FRSC) Crane Mountain landfill capacity predominantly through a vertical expansion.**

Since 1998, the Province of Ontario (O.Reg. 232/98) has limited the size of a landfill with a single liner to 140,000 m^3/ha or an average waste thickness of 14m because of the much greater potential for impacts and the longer service life required of the liner for a landfill with thicker waste and generically requires a double liner for larger landfills. This is for good technical reasons that do not respect provincial boundaries. These reasons include

- (i) "All liners leak" (e.g., Giroud and Bonaparte 1989a,b; Giroud 2016; Rowe 1998, 2005, 2012, 2018, 2020; Beck 2015).
- (ii) Actual leakage is likely to be substantially more than originally considered using historical design assumptions due to holes in wrinkles (e.g. Rowe 1998, 2012, 2020) and desiccation of the interface between the geomembrane and compacted clay liner (Rowe 2018).
- (iii) The contaminant impact increases with the waste mass per unit area in a single liner system (Rowe 1991, Rowe et al. 2004, O.Reg. 232, Barakat and Rowe 2024).
- (iv) Doubling the landfill thickness doubles the contaminating lifespan (Rowe 2021).
- (v) Doubling the contaminating lifespan for a single-lined landfill likely means that
    - (a) The leachate escape is more than doubled (due to both a more extended period of leakage and increased leakage due to degradation of the leachate collection and liner system) (Rowe et al. 2004).
    - (b) The contaminating lifespan will likely exceed the service life of any generically specified geomembrane. Hence, the higher probability of failure and increased impacts for a single-liner system during the contaminating lifespan must be considered.
- (vi) Monitoring leakage through a single composite liner over any drainage medium is difficult, especially over fractured rock.
- (vii) Designs before this decade did not consider the presence of PFAS in the leachate, yet it is now recognized as the most critical contaminant in most MSW landfills. Single composite liners will not adequately contain PFAS unless there is a high level of additional natural attenuation (e.g., a thick clay liner) (Rowe and Barakat 2001, Rowe Zhao 2023, Rowe and Barakat 2024).

B. NEED FOR A SOUND TECHNICAL EVALUATION AND ENVIRONMENTAL ASSESSMENT OF THE EXPANSION.

It is my understanding that the EIA guidelines relating to Waste Disposal Facilities require the following:

> *Provide a hydrogeological assessment of the surface and subsurface conditions in and around the facility. The assessment should include test pits, boreholes and/or monitoring wells and provide appropriate detail concerning stratigraphy, hydraulic conductivity, groundwater elevations, topography, flow directions and gradients at various depths. The information should be presented in sufficient detail to determine the flow path and ultimate receptor of a liquid contaminant if that contaminant were released in an uncontrolled fashion at the facility. To aid in interpreting the details, provide cross-sectional drawings of the site showing the stratigraphy, assumed groundwater surface(s) and hydraulic conductivities, where known. Provide a plan of current and future groundwater monitoring wells and surface water monitoring stations.*

However, the EIA Registration document did not contain much of the information listed above or other information required for an independent assessment of the potential impact of the proposed expansion.

Given the need for a technical evaluation identified in Section A and the lack of available information as identified above, the remainder of this technical review briefing note provides additional evidence of the need for a proper evaluation of the suitability of the existing barrier system (i.e. leachate collection plus liner) as a prerequisite to any approval of an expansion. Thus, the remainder of this technical briefing note sets out to address seven issues:

1. The nature of the liner as a single composite liner (not a double liner);
2. The lack of a well-documented construction quality process that involved documentation of the time of day that the liner was covered and any particular actions that were taken to minimize wrinkles, sun exposure, trampolining, or any other adverse conditions affecting liner integrity during construction;
3. The potential for desiccation of the clay liner below the geomembrane and the implication for leakage;
4. The probability and magnitude of leakage given item 1;
5. The absence of knowledge of PFAS in the leachate or consideration of its potential impacts on both groundwater due to the leakage through the primary liner and the effect on liner longevity;
6. The effect of increasing the height of waste on contaminant impact;
7. The inadequacy of isolated monitoring wells for identifying point failures in a geomembrane in any hydrogeologic environment, especially in fractured rock.

C. TECHNICAL REVIEW OF KEY ISSUES

Notation

c_o	Initial contaminant concentration	LDS	Leak detection system (aka SLCS)
CCL	Compacted clay liner	lphd	litres per hectare per day
DWO	Drinking water objective	MSW	Municipal solid waste
GCL	Geosynthetic clay liner	p	Proposition of a contaminant in the waste (by mass)
GMB	Geomembrane	PFAS	Per-and polyfluoroalkyl substances
GTX	Geotextile	PFOA	Perfluorooctanoate
h_w	Leachate head on the liner	SLCS	Secondary leachate collection system (aka LDS)
k_{CCL}	Hydraulic conductivity of compacted clay liner	t_{NF}	Time to nominal failure of a geomembrane
LCS	Check collection system	θ	Interface transmissivity

The barrier system approved for the Crane Mountain landfill was based on a late 1990s design that, at the time, was considered suitable for an MSW landfill with the size originally proposed. Indeed, I was an advisor to GEMTEC for the Crane Mountain landfill in 1998-1999. Unfortunately, there are many factors we, as a profession and as a society, did not adequately appreciate at the time that we have come to understand over the last 25 years, including:

(a) the critical nature of construction and the role of wrinkles in increasing leakage,
(b) need for a leak location survey while recognizing they do not find all holes
(c) the effect of desiccation of the upper surface of clay covered by a geomembrane left exposed to the sun,
(d) the service life of geomembranes used at the time,
(e) the importance of a suitable protection layer for the geomembrane,
(f) presence and significance of PFAS concerning groundwater contamination,
(g) significance of PFAS concerning geomembrane service life,
(h) the difficulties of monitoring a single-lined system without a leak detection layer and secondary liner.

C1. The nature of the liner as a single composite liner (not a double liner)

Crane Mountain liner

Figure 1 shows the barrier system at the Crane Mountain landfill directly from a GEMTEC report[1]. The barrier system is comprised, from top-down, of a leachate collection system (a layer of 25 mm clear stone over geotextile B, over what is presumed to be more gravel, over geotextile A, over a geonet), on

[1] From Environmental Impact Assessment Registration Document Fundy Regional Service Commission Crane Mountain Landfill Capacity Augmentation and Life Extension Project Saint John, New Brunswick GEMTEC Project: 100018.012 dated 21 June 2023., APPENDIX B Typical Landfill Cell Design1/D08FRSC Crane Mountain Landfill Project 2021 – 01 CONTAINMENT Cell # 9)

a geomembrane on a clay soil liner. The nature of the material below the soil liner is not defined (it is understood to be a relatively thick in-situ soil in some areas and much less so in others). The bedrock underlying the landfill is fractured.

The technical literature refers to a single geomembrane over compacted clay as a single composite liner system. In this system, the geomembrane provides the primary barrier to downward fluid flow/migration, with the compacted clay intended to reduce leakage through holes in the geomembrane and provide additional protection related to minimizing the potential for advective and diffusive transport through the liner system.

Primary factors affecting leakage

The effectiveness of this composite liner depends on

(a) the area of wrinkle with holes (Fig. 2),

(b) the hydraulic conductivity of the clay, and

(c) the interface transmissivity between the geomembrane and compacted clay (Fig. 2d).

These three issues will be discussed in the following subsections.

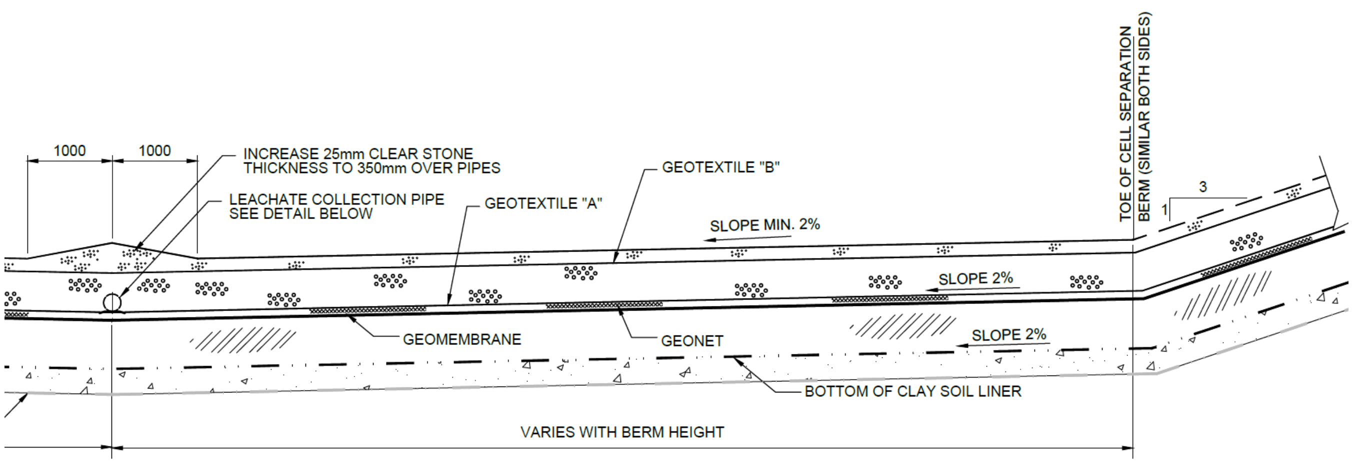

Figure 1: Detail of the barrier system from the GEMTEC Report[1]

Factors affecting leachate head h_w

The primary leachate collection layer, understood to have a nominal 25 mm-diameter gravel, has a finite service life. I presume the pipes are regularly cleaned following good practice, but one cannot clean the gravel. Biologically induced clogging is now well recognized (e.g. Fleming and Rowe 2004, Fleming et al. 1999) as limiting the service life of the drain system. I could find no evidence that any consideration has been given to what the service life may be under existing conditions (e.g., Using Rowe and Yu 2015) nor how the increased mass of waste and consequent biological loading will affect the service life of the leachate collection system. **Once the leachate collection system reaches its service life (by definition, when it no longer controls the head to the design head, typically 0.3 m), the leachate head on the liner builds up and increases the leakage through any holes in the liner.**

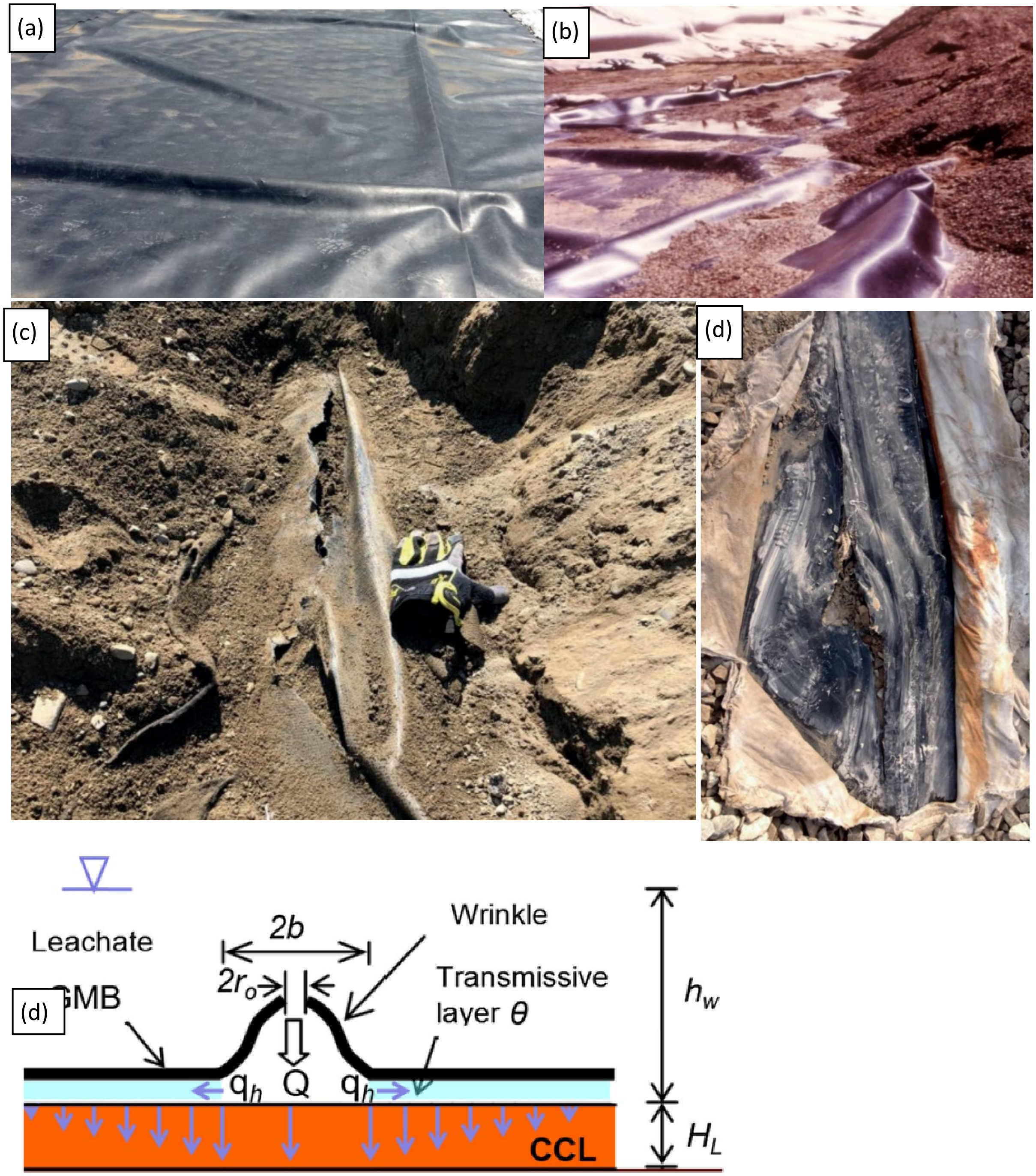

Figure 2: Wrinkle network in geomembrane (a) before covering, (b) during covering, (c) wrinkles are easily damaged during covering, (d) leakage through a wrinkle depends on the area below wrinkle, the interface transmissivity between intact clay and geomembrane, θ, hydraulic conductivity of CCL, *k*, and leachate head over the geomembrane, h_w.

The fact that one continues to collect approximately the same amount of leachate does not mean the leachate collection system has not clogged nor that the leakage is not significant.

Double liner systems

The factors (a) to (i) have led to the replacement of single composite liners (Figure 3a) by double composite liners (Figure 3b and 3c) for MSW landfills. The double-lined landfill typically includes a leak detection (secondary leachate collection) drainage layer to collect most of the leakage through the primary liner. A second liner below the leak detection layer minimizes further leakage and directs fluid to the sump in the secondary leachate collection system. Only by collecting fluid from this layer could we understand the leakage through the primary single composite liners. It significant environmental protection measure provided by the secondary liner is the reduction in driving head through the composite liner system since capturing and draining the leachate in the secondary collection system significantly reduces the potential for downward contaminant flux.

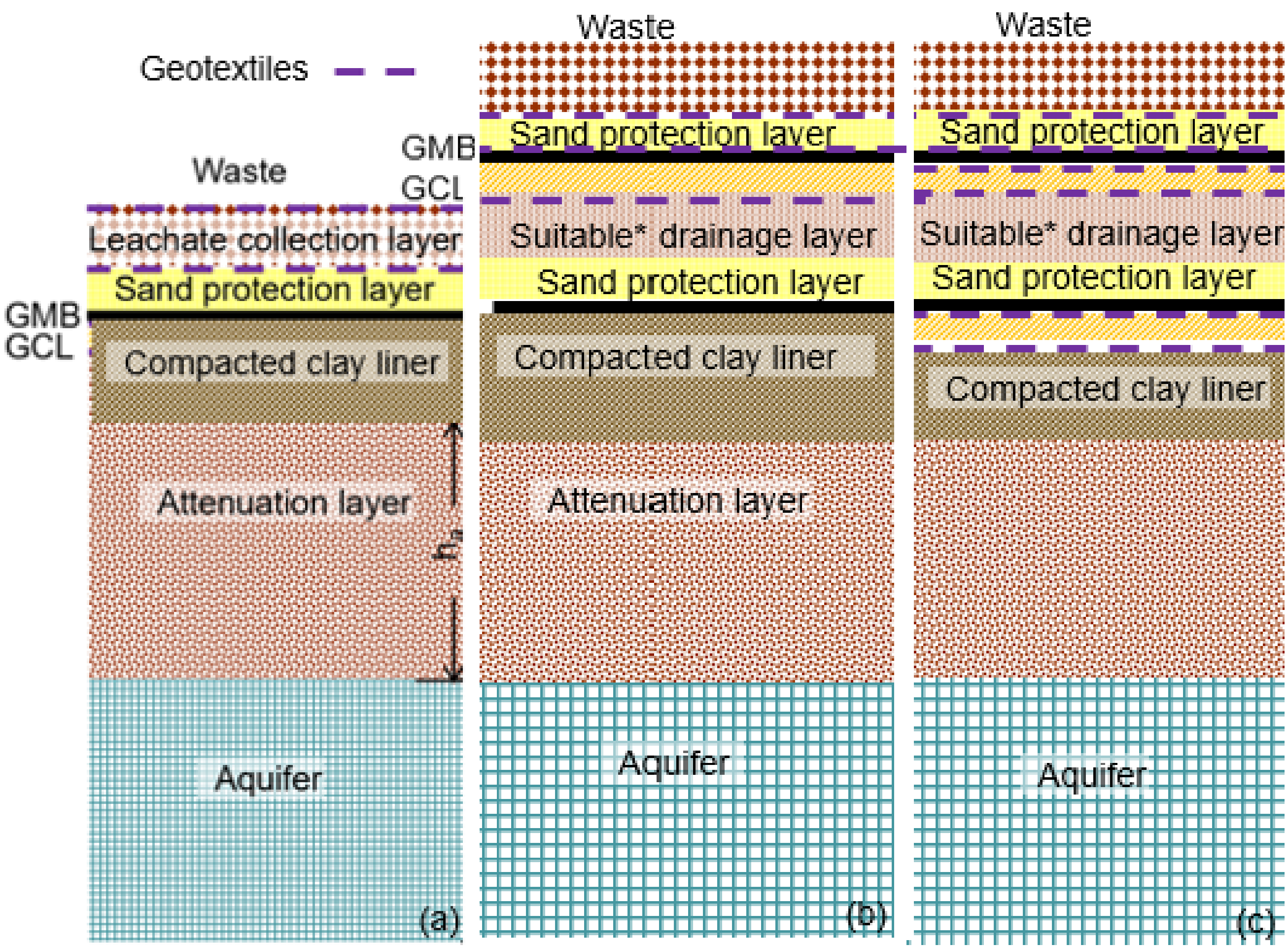

Figure 3: (a) Single composite liner. (b) double composite liner with (from top-down) a primary composite liner (GMB+GCL), leak detection (secondary leachate collection) system above a secondary. (c) GCL between the secondary geomembrane and the secondary compacted clay liner to mitigate desiccation cracking

C2. Unavailability of a well-documented construction quality process

Compacted clay CQA

Apart from the QA/QC report on the Leachate Surge Lagoon dated April 2005, there appears to be no documentation of the quality assurance conducted on the liner system for the waste. The 2005 report partially documents the construction work carried out by Keel Construction between September 1, 2004 and November 30, 2004. It involves the construction of a 0.6 m thick remoulded Marine clay and 2 mm textured HDPE. The maximum CCL design hydraulic conductivity is 2.3×10^{-10} m/s. The water content of the compacted liner soil selected as k-test specimens was between 25% and 27.9 %. The optimum water content was 17.6%, and the plastic limit ranged from 22.1% and 18.9%. Thus, the liner was compacted between 3% and 7% of the plastic limit's moisture content. The hydraulic conductivity of the intact material was below the design value. The clay, however, was susceptible to desiccation cracking directly below the geomembrane (e.g., Fig. 4). Even though the ambient temperature was around freezing at the time the geomembrane was installed if the sun was shining, the black geomembrane can heat up sufficiently to cause evaporation from the underlying compacted clay liner resulting in the accumulation of water below wrinkles. On condensation at sunset, this water accumulates in low spots, which dry as water evaporates the next day. This process desiccates the surface to a variable depth across the surface.

Figure 4. Desiccation cracking of a compacted clay liner (different site) beneath a black HDPE geomembrane. For scale, the diameter of the lens cap is 60 mm.

Geomembrane CQA

The quality assurance program for the geomembrane involved routine documentation without any specifics concerning the criteria being conducted for approval. I could not find any record of

(i) How long the GMB was exposed before it was covered,

(ii) Geomembrane temperature during the day,
(iii) The limits on welding parameters (thickness reduction, squeeze-out) to ensure the longevity of welds(e.g. Fig. 5), or
(iv) a leak location survey with the resolution well documented since without this, the defects shown in Figures 2 & 6 can give rise to leakage, and the defect shown in Figure 6 can go undetected.

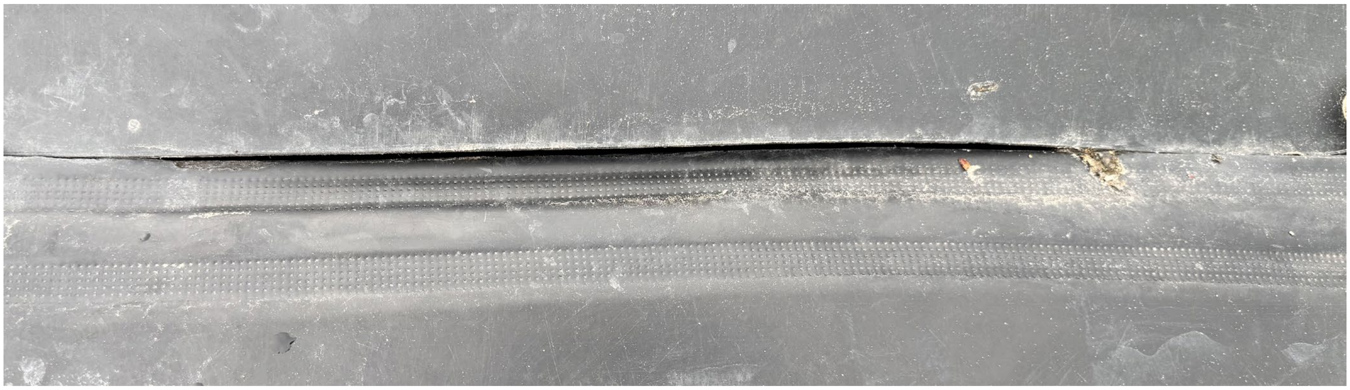

Figure 5: Stress cracking about ten years after welding adjacent to poor weld that passed all standard tests

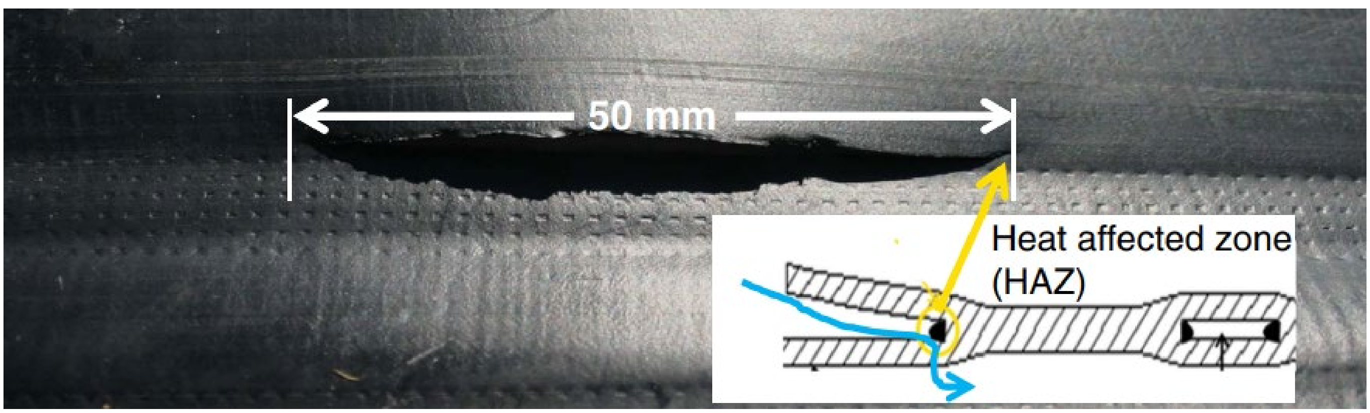

Figure 6: Tear on the underside of a white (upper surface) geomembrane adjacent to the weld (not visible to the inspector without lifting the flap) and not detected by a weld pressure test or some ELLS methods.

C3. Service-life of geosynthetic components of the liner system

Protection layer and stress cracking due to gravel if it is not adequate

The geotextile and geonet protection layers are critical in minimizing strains induced in the geomembrane from the overlying gravel. The information provided (Appendices B and D) has no information regarding the parameters that affect long-term performance (Std-OIT, HP-OIT) for either the geonet or geotextile.

Furthermore, it is unclear how this design was developed. It involves the combination of a 790 g/m^2 geonet with a 675 g/m^2 geotextile with a total mass per unit area of 1465 g/m^2. I can find no evidence of testing that would verify that this was sufficient to maintain strains below 3% under the existing loads. Tests should have been conducted to confirm that the strains induced over a compacted clay liner compacted significantly wet of the plastic limit were sufficiently robust to minimize the strains to less than 3% under current loading conditions (e.g. see Brachman and Gudina 2008a,2008b, Brachman and Sabir 2010,2014, Ewais et al. 2014; Abdelaal et al. 2014). Also, assuming that was done, the test(s) must be repeated for a load corresponding to 40% greater than the expected maximum load for 100 hours, with the 40% reflecting time effects. Failure to adequately protect the geomembrane will result in excessive stress cracking back shown in Figure 7. The implications of this situation become far worse when the load is increased by another 275 kPa to a total of about 475 kPa for the proposed expansion. This increase in stress will likely substantially decrease the service life of the geomembrane.

Figure 7: End of Service life for HDPE GMB. 0.6 m diameter specimen under 250 kPa of pressure with 61 2014)

Geomembrane service-life

Little appears to be known about the geomembrane installed in 2005 or earlier other than Cell 9 in Appendix B. The Cell 9 geomembrane resembles GRI GM 13 from after November 2014. Fortunately, I obtained a geomembrane from Solmax at approximately the same time (manufactured 2006-06-06' denoted generically as "xA20"). This is likely the same as or similar to the geomembrane used in 2005. At that time, the stress crack resistance was only required to exceed 300 hours (GRI did not introduce the 500 hours shown in Appendix B into GM 13 until November 2014). The properties of the roll we tested are given in Table 1, and the findings after seven years of testing are shown in Table 2 in terms of the time to antioxidant depletion, t_d, and the time to nominal failure t_{NF}.

Table 1: Properties of three Solmax geomembranes produced in 2005. Geomembrane xA20 is the 2 mm (80 mil) geomembrane examined by Rowe et al.(2014), from which this table is extracted.

Properties	Method	Unit	Value (mean ± SD)		
Nominal thickness	ASTM D5199 (ASTM 2012)	mm	1.5	2.0	2.5
GMB designator	—	—	xA	xA20	xA25
Date of manufacture	—	—	July 28, 2005	June 6, 2005	July 25, 2005
Std-OIT[a]	ASTM D3895 (ASTM 2007b)	min	135 ± 2.2	150 ± 1.2	136 ± 0.43
HP-OIT[a]	ASTM D5885 (ASTM 2006b)	min	244 ± 13	265 ± 10	235 ± 13
Measured antioxidant	Irganox 1010	ppm	1,620	1,205	1,665
concentrations[b]	Irganox 1076	ppm	<50[c]	<50[c]	<50[c]
	Irgafos 168 (PO_3)	ppm	735	605	880
	Irgafos 168 (PO_4)	ppm	475	415	165
Crystallinity	ASTM E794 (ASTM 2006a)	(percentage)	47.6 ± 1.4	50.3 ± 0.75	46.6 ± 1.7
MI (190°C/21.6 kg)	ASTM D1238 (ASTM 2013)	g/10 min	14.3 ± 0.8	11.1 ± 0.5	14.5 ± 0.5
Density	ASTM D1505 (ASTM 2010)	g/mL	0.947	0.946	0.946
Single point stress-crack resistance	ASTM D5397 (ASTM 2007a)	h	1,432 ± 186	1,252 ± 122	624 ± 61
Tensile properties	ASTM D6693 (ASTM 2004)	—	—	—	—
Strength at yield	Machine direction	kN/m	26.7 ± 0.86	38.4 ± 0.48	45.8 ± 1.7
Strength at break		kN/m	46.0 ± 5.3	60.3 ± 4.5	62.3 ± 10.2
Strain at yield		(percentage)	23.9 ± 1.7	20.8 ± 0.25	20.3 ± 0.51
Strain at break		(percentage)	825 ± 81	788 ± 57	767 ± 58
Tensile properties	ASTM D6693 (ASTM 2004)	—	—	—	—
Strength at yield[d]	Cross-machine direction	kN/m	29.0 ± 0.48	39.1 ± 0.75	46.9 ± 0.56
Strength at break		kN/m	43.7 ± 6.1	61.6 ± 3.9	38.5 ± 8.4
Strain at yield		(percentage)	18.5 ± 0.40	21.4 ± 0.76	19.4 ± 0.75
Strain at break		(percentage)	830 ± 95	785 ± 41	634 ± 143

[a]Values measured when the study was initiated in January 2006 (Rowe et al. 2010). GMB properties are subjected to changes with time caused by storage of the roll at room temperature for long periods, variability of the material within the same roll (e.g., distribution of additives; resin imperfections), etc. Thus, the initial values of samples used for testing initiated in 2010 were not the same as initially in 2006 even though they came from the same roll. The changes in roll properties caused by aging with time at room temperature are presented in Abdelaal (2013).

[b]Analyzed at the Ciba Testing Services as reported by Islam (2009).

[c]Trace amount was detected.

[d]Cross-machine direction yield strength was used in measuring the initial SCR values.

Studies of the performance of the same geomembrane immersed in a simulated MSW leachate solution together with those where it is in a simulated liner system (Rowe et al. 2010) allow the conversion of t_{NF}, the time to nominal failure, immersed in leachate to that for a composite liner. Rowe et al. (2014) evaluated the time to nominal failure in two different ways. In the first[a], t_{NF} was taken to have been reached when the stress crack resistance, SRC(t), had decreased to 50% of the original stress crack resistance, SCR_o (i.e., SCR(t_{NF}) =0.5 SCR_o). In the second[b], t_{NF} was 150 hours or half the GRI GM 13 specification at the time.

Table 2: Data for 2 mm GMB xA20 in simulated MSW leachate

	Rowe et al. (2014)			$t_{NFComposite} = 3.4*t_d+(t_{NF}-t_d)$	
Temperature. oC	t_d (years)	t_{NF} [a] (years)	t_{NF} [b] (years)	$t_{NFComposite}$ [a] (Years)	$t_{NFComposite}$ [b] (Years)
20	72	138	180	310	350
30	29	62	88	130	160
35	19	43	65	89	110
40	12	30	47	59	76

The times given in Table 2 are short compared to the likely contaminating lifespan of the landfill, even without the expansion. The service life will be even shorter than shown in Table 2, given the likely unsuitability of the protection layer and the likely low service life of the material that would've been used, as discussed below, combined with uncertainty regarding temperatures on the liner. The latter point is to be remembered because biologically active waste that generates gas frequently maintains an elevated temperature of 35 to 40°C during the primary gas-generating period. After that period, the temperature gradually decreases as the organic matter is consumed. Given a time-temperature history, it is possible to estimate the service life from data shown in Table 2, providing agreement can be reached regarding the likely time spent in each temperature range (e.g. ambient to 20°C, 20-30°C, 30-35°C, 35-40°C etc.)

Based on the results in Table 2, it is evident that between about 60 and about 80 years at 40°C would be sufficient to consume the service life, and even 20 years for the existing landfill would consume ⅓ to ¼ of its service life. The length of time the temperature is maintained is related to the mass of waste available for microbiological breakdown and hence increases in direct proportion to the thickness of the waste. The proposed increase in that thickness will substantially lengthen the time at around 40°C.

The predictions in Table 2 assume minimal strains in the geomembrane. Even with current loading, the combination of the 25 mm gravel and an inappropriate protection layer can be expected to substantially reduce the service life from that indicated in Table 2. An increase in loading vertical pressure on the liner by 275 kPa can be expected to severely exacerbate the problem, reducing the service life substantially. The test giving the failures in Figure 7 was at 250 kPa, which is less than the proposed increase in stress.

The service life of Solmax commodity geomembranes from 2005 and before 2005 is poor. Solmax now has a product line (Premium HD 2.00 White reflective RT smooth or textured but NOT conductive) intended for landfill and tailings applications with longer service life requirements. These are premium geomembranes which are more expensive because a better antioxidant package is more expensive. You get what you pay for! These are also substantially better than today's commodity geomembranes which are also not good for landfill applications. Put simply GRI GM13 is NOT suitable for landfill applications. It is a necessary but not sufficient requirement.

The forgoing indicated a relatively low service life (compared to contaminating lifespan) for the geomembrane but the situation is far worse for the geotextiles and geonet that were likely used. I have supervised tests on both geonets and geotextiles that show they are generally very poorly stabilized (protected from degradation) and may have a very poor distribution of the protective antioxidants. In the context of service-life the geotextile and geonet will be discussed separately below.

Geotextile service-life

Gemtec state that "Depending on the materials used in the manufacture of the geotextile, geotextiles are anticipated to last for decades, ranging from 20 to over 100 years". This is a broad range without specifying temperature and exposure conditions, which can significantly impact service life. The protection layer is required to protect the geomembrane for the contaminating lifespan; however, without any consideration of antioxidants and stress crack resistance, it is impossible to see how an engineering design was developed that could ensure the service life was sufficient even for the contaminating lifespan without considering PFAS.

To illustrate the poor stabilization of geotextiles, Table 3 summarizes data for geotextiles used as part of a protection layer for a geomembrane in the project with a 100-year design life at 5°C. In that project, two layers of 1000 g/m^2 were used as a protection layer. The standard OIT was found to be low (76 minutes at 160° or about 5 minutes at a normal test temperature of 200°C compared with 150 minutes for the geomembrane) and wide distribution (standard deviation of 23 minutes and coefficient of variation of 30%).

Table 3: Initial values and time to OIT depletion for the geotextiles (Modified from Rowe and Reinert 2023)

Property	Method (ASTM)	Unit	Values (Mean ± SD) S1000	GTX A
Mass per unit area	D 3776	g/m^2	967 ± 32	675
Std-OIT @ 160°C	D 3895	min	76 ± 23	?
Maximum Tensile Force	D 5035-1C	kN/m	82.3 ± 8.1	?
Time to depletion (Years) @ 10°C			79-95	?
Time to depletion (Years)@20°C			31-37	?
Time to depletion (Years)) @ 30°C			13-15	?
Time to depletion (Years) @ 40°C			6-7	?

Tests with simulated municipal solid waste leachate gave a time-to-depletion that is adequate at 5° C and a 100-year-service-life but are not sufficient if one considers that a municipal solid waste landfill could spend 2 to 8 decades (depending on the size of the landfill and length of operations) in the 30 to 40°C range. At these temperatures, the geotextile in Table 3 (likely better than the one used in the Crane Mountain landfill) would last less than two decades. The liner is still needed for the rest of the contaminating lifespan, but it will not be there (e.g., see Figure 8, where most of the geotextile over the geonet has become microplastic and washed into the collapsing geonet). In other words, I have grave doubts that the existing geotextile is even suitable for the landfill at its current height, let alone twice as high.

Geonet service-life

There is virtually nothing known about the stabilization of the geonet used at the Crane Mountain landfill. Appendix C does not specify any Std-OIT or HP-OIT, although these are just as critical for the HDPE geonet as they are for the HDPE geomembrane. Two decades after the geonet was installed at Crane Mountain, I had a modern geonet for testing for one of my projects (Table 4). It is better stabilized than the geotextile at 69 minutes at 190°C (about 35 minutes at 200°C, the usual reference temperature for geomembranes) but still poorly stabilized compared to the 150 minutes at 200°C for the geomembrane. Based on tests conducted on this geonet, the time to failure was quite variable due to variability within the material itself, which also had a relatively large standard deviation and coefficient of variation—time to failure ranged from 42 to 180 years at 10° C (Table 4). At practical temperatures during the actively anaerobic and gas-generating stage of the landfill life, the service life is less than 20 years, then it will begin collapsing like the one shown in Figure 8. The indentations from the ribs of the geonet shown in Figure 8 were visible in the underlying geomembrane, demonstrating that they were focusing stress on narrow zones corresponding to the geonet ribs, thereby increasing tensions due to bending in the geomembrane.

Table 4: Initial values for Geonet (GNT) materials (Modified from Rowe and Reinert 2023)

Property	Method (ASTM)	Unit	Values (Mean ± SD) 1300	Crane
Structure	-	-	tri-planar	
Nominal Thickness	D 5199	mm	7.6	5
Std-OIT @ 190°C	D 3895	min	69 ± 24	??
	Time to failure (Years) @ 10oC		42-180	??
	Time to failure (Years) @ 20°C		17-52	??
	Time to failure (Years) @ 30°C		8-16	??
	Time to failure (Years) @ 40°C		3-6	??

Site rationale

The original site appears to have been selected on the basis that there was a “thick” surficial soil over bedrock – this may be the case, but for at least a portion of one of the cells (Cell 2), it appears that there was little or no clay and the foundation soil had to built to get the minimum design of 1.5 m soil over bedrock at that time. It appears that while the clay has an intact low hydraulic conductivity, there are desiccation cracks and fractures that would substantially increase the bulk hydraulic conductivity.

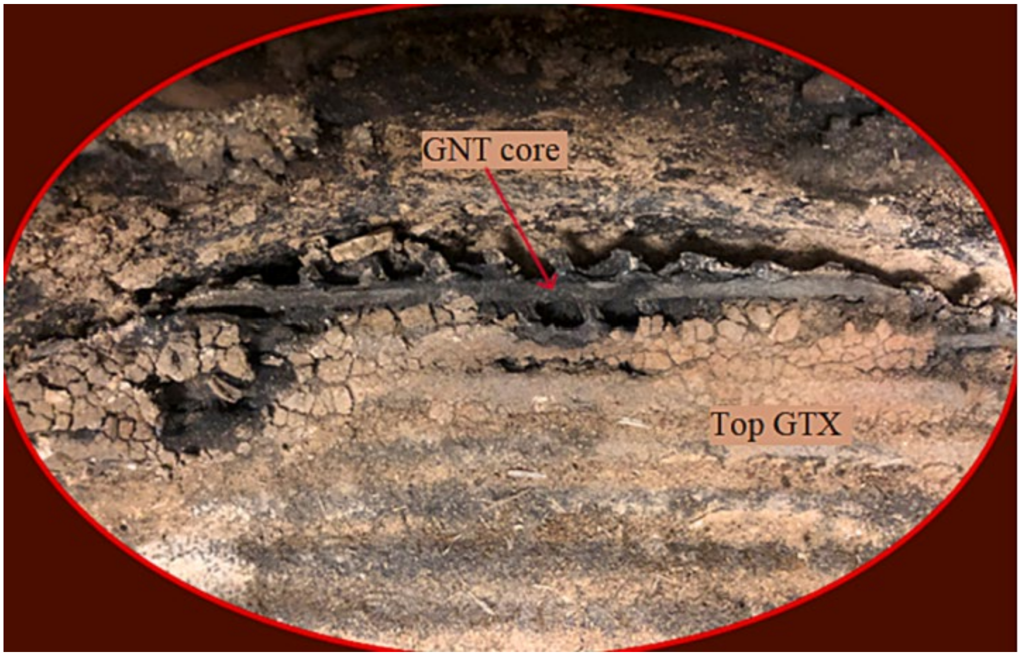

Figure 8: Disintegration of the geotextile over the due net into microplastics and buckling and cracking of the geonet (after Rowe et al. 2023).

C4. The potential for desiccation of the clay liner below the geomembrane

One of the challenges of placing black plastic over compacted clay wet of optimum (in this case, about 4% above the plastic limit – the moisture content where the medium can no longer be remoulded without cracking – is that the clay will be very soft making indentation by stones much easier. It also means it will be more prone to shrinkage when the black geomembrane heats up to about 30° hotter than the ambient temperature on a sunny day. Shrinkage and desiccation cracks, such as shown in Figure 4, have little effect on the overall bulk hydraulic conductivity of the clay liner as long as the desiccation is shallow. By contrast, cracks even a few millimetres deep greatly impact interface transmissivity and hence leakage. This was illustrated by Rowe (2018; Table 5 below), where even tiny crack apertures can increase the transmissivity by three orders of magnitude. Figure 4 shows openings larger than any examined in Table 5.

Table 5: estimated transmissivity of the desiccated zone in CCL beneath the GMB (after Rowe 2018)

Thickness of cracked zone (m)	0.003	0.005	0.01
Crack aperture (m)		Transmissivity (m^2/s)	
0.0001	1.9×10^{-8}	3.2×10^{-8}	6.4×10^{-8}
0.0002	1.5×10^{-7}	2.6×10^{-7}	5.1×10^{-7}
0.0005	2.4×10^{-6}	4.0×10^{-6}	8.0×10^{-6}
0.001	1.9×10^{-5}	3.2×10^{-5}	6.4×10^{-5}

As illustrated by Rowe (2018), this can increase the leakage that will be attained with a good geomembrane/CCL interface ($\theta=1.6\times10^{-8}$ m^2/s) from 116 lphd for a 200 m long wrinkle with a hole to

640 lphd with only a modest increase in θ=5.1.6x10^{-7}m^2/s. Both are excessive, particularly if there is PFAS in the leachate.

C5. The absence of knowledge of PFAS or consideration of its potential environmental impact

Need to sample and analyze for PFAS every quarter

There is extensive evidence that PFAS can be expected in MSW. Based on a comprehensive literature review (e.g., Eggen et al. 2010, Li 2011, Huset et al. 2011, Benskin et al. 2012, Li et al. 2012, Clarke et al. 2015, Lang 2016, Gallen et al. 2018), the initial concentrations of Perfluorooctanoic Acid (PFOA) in the MSW leachate, c_o, and the mass proportion PFOA in the waste, p, may be assessed (see Table 6). This allows the contaminating lifespan to be calculated.

Table 6: Reasonable range of parameters in MSW landfill for PFOA (Based on Barakat and Rowe 2024)

Barakat and Rowe (2024)		
Health Canada DWO	200 ng/L	
	c_o (ng/L)	p (g PFOA/ kg waste)
Peak	3450	2.4x10^{-4}
Average (many landfills)	1500	6x10^{-5}
Geometric mean of peak and minimum	1500	7.4x10^{-6}
Minimum	660	2.3x10^{-6}

* Based on experience, assume PFOA is 10% of Total PFAS limited to 30 ng/L. Numbers rounded.

It is much more likely than not that the Crane Mountain Landfill contains PFAS, which will likely be found by adopting good analysis techniques. For a landfill I am working on in Ontario, we needed to decide if we needed a PFAS design. To do so, we analyzed the leachate (sampled and analyzed regularly now) for PFAS, and many PFAS compounds were identified, including PFOA at 1550 ng/L in Cell 1 and at 2450 ng/L in Cell 2 (with thicker waste).

From their response to questions relating to PFAS, it appears that the proponents are aware of PFAS (aka the “forever chemicals”) but have no apparent interest in assessing the concentrations in the landfill or examining the impact of expanding the landfill, both of which are likely significant.

Public bodies and professional engineers have a foremost duty to the Public and can not justifiably ignore PFAS. Continued failure to either:

(a) assume it is present and do an impact assessment using typical values (e.g. Table 6); or

(b do tests to establish the level of PFAS in the leachate (several sampling times at several wells are required) and then do an impact assessment for the observed concentrations,

could be regarded as negligence and professional misconduct given the knowledge, widely accepted in the industry, that PFAS compounds (e.g. PFOA, PFOS):

- are generally found in landfill leachate (see above list of references),
- have significant health implications, with US EPA limiting both PFOA and PFOS each to a maximum of 4 ppt (4 ng/L) in drinking water,
- Health Canada presently limits PFOA to 200 ppt (200 ng/L) in drinking water,
- Health Canada has proposed reducing total PFAS in drinking water to less than 30 ng/L,
- US EPA has 10 ppt (10 ng/L) limits on Gen X, PFBS, and PFHxS and a 2000 ppt limit on PFBS, plus a limit on an index incorporating all four contaminants, and
- The most critical PFAS are highly mobile, essentially conservative, species that bioaccumulate in the food chain.

Contaminating lifespan

Because PFAS do not break down readily and do not significantly attach to soil or organic matter over the longer-term (short-term tests in the literature can be misleading), they have been named the "forever chemicals". The presence of these compounds in landfill leachate and in the waste stream from which the PFAS will continue to be leached directly influences the contaminating lifespan. The contaminating lifespan is the period that a containment facility still has chemicals at a level that could have an acceptable impact if released into the environment. It, therefore, defines the period that containment is necessary and, hence, the service life of the containment system. Based on the lowest concentration and mass of perfluorooctanoic acid (PFOA) given in Table 6, the most optimistic contaminating lifespan was calculated to be 400 years for the currently approved landfill, which has an average thickness of waste of H_w=14.5 m and 600 years for the proposed expansion with H_w = 21.6 m (Table 7). These figures are overly optimistic and should not be used for design. The lowest justifiable estimates for the contaminating lifespan would use the geometric mean of the highest and lowest values in Table 6. This more than doubles the contaminating lifespan to 960 years with the current landfill as approved and 1400 years for the proposed expansion.

Comparing these contaminating lifespans with the service lives in Table 2 indicates that even the existing approved design needs to be redesigned for cells 10 to 16 using a double-lined system and geomembrane with a service life of over 2000 years (with care, appropriate geomembranes can be selected). The lowest justifiable estimates for the contaminating lifespan from 960 to 1400 years of the existing and expanded landfill, respectively, far exceed the service life of the composite liner system that has already been installed. **Hence, an environmental assessment is required for the proposed expansion. What was approved about 25 years ago and is being done now is no longer appropriate. As facts change, so must the design.** The original design was never intended to deal with the containment of the PFAS, and, in my opinion, it was perfectly appropriate given what we knew when it was approved in the late 1990s. The benefit of 25 years of experience and knowledge, particularly the new game-changing group of toxic compounds called PFAS, dictates a change from the original design.

Table 7: Estimated contaminating lifespan (Years). Health Canada DWO=200 ng/L

			Contaminating lifespan (Years)	
Rowe (2024)	c_o (ng/L)	*p* (g/kg)	Existing	Expanded
Landfill average waste thickness			14.5m	21.6m
Minimum Contaminating lifespan	660	2.3×10^{-6}	400	600
Geometric mean of high and low	1500	7.4×10^{-6}	960	1400

Numbers rounded.

C6. Leakage through primary composite liners

The impact of PFAS in the leachate will depend on leakage through the composite liner. The best available data arises from New York State's requirement for double-lined MSW landfills and annual reporting of actual leakage through the primary liner. Beck (2015) collected and analyzed this leakage rate data from 122 discrete landfill cells with good construction quality control but no electrical leak location survey (no ELLS). Leakage rate data was also analyzed for 60 discrete landfill cells where a dipole method electrical leak location survey was conducted (ELLS). Based on the data, a plot of the probability of leakage exceeding a given value was constructed. This data is given in Figure 9a for no ELLS and in Figure 9b with a dipole ELLS. The landfills in Figure 9 involve a composite liner comprised of a GMB over a GCL (GMB/GCL) and a GMB over a CCL (GMB/CCL).

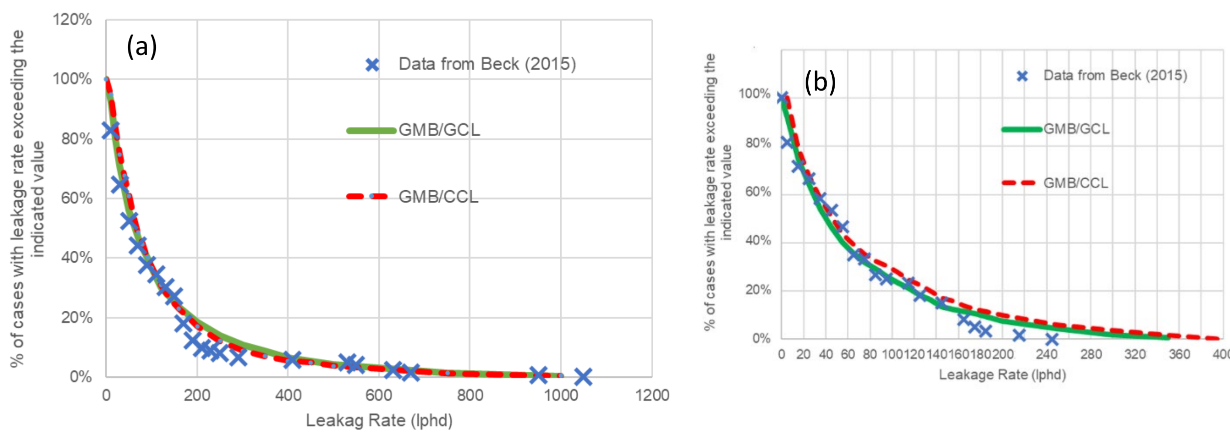

Figure 9. *Probability that a given leakage rate is exceeded together with calculated rates for GMB/GCL and GMB/CCL. (a) No leak location survey (b) with a leak locations survey, as a percentage of the (122 for (a) and 60 for (b)) landfills cells for which data is reported by Beck (2015)*

Estimated probability of exceeding regulatory requirements

A study by Barakat and Rowe (2024) for a landfill with an average 25 m height of waste and a single composite liner calculated a probability of exceeding regulatory limits at the property boundary as 84% for c_o=3450 ng/L and 52% for c_o=1000 ng/L. while these calculations were not specifically for the conditions at Crane Mountain, they are sufficient to act as a warning that the potential for PFAS escape and impact must be taken seriously and not ignored. The probabilities of not meeting regulatory requirements increase substantially to 97 and 92% if the proposed limit of 30 ng/L total PFAS is adopted.

C7. The effect of increasing the height of waste on contaminant impact

The potential impact of the existing landfill needs to be quantified based on a realistic assessment of leakage through the liner system. Reference is made in the response to comment 11 (Round 1) that "*Theoretical breakthrough calculations for each cell are included in the annual monitoring report…* "
For a typical design head of 0.3 m and a low permeability material with a hydraulic conductivity, *k*, said to be 1.7×10^{-10} m/s (Surge Pond QC report) the breakthrough time through a 0.6 m, 0.9m and 1.3m thick clay liner would be about 30, 50 and 80 years, respectively. These numbers are meaningless. They neglect diffusion. Within about 20-25 years I have observed PFAS diffusion through a 1.2-1.5 m thick compacted clay liner (with a similar hydraulic conductivity based on similar testing to that reported for the Crane Mountain liner below the surge Pond) into the underlying drainage layer despite an inward gradient. This can be readily demonstrated with a diffusion calculation. More importantly, not only are **breakthrough calculations** based on advection meaningless in terms of the actual time it takes for contaminants to reach the bottom of the liner they **also do not provide any information regarding potential long-term impact.** It is the leakage mass loading that controls impact. There appears to be no consideration of leakage. The case considered above the leakage would be about 220, 200, and 180 lphd for a 0.6 m, 0.9 m, and 1.3 m thick liner, respectively. My more realistic assessment of the leakage considering the presence of the geomembrane would be about 50-75 lphd.

There is a very high probability that PFAS at levels above drinking water objectives will be detected in the leachate if a proper analysis is performed. Increasing the average height of the landfill will have the following effects:

(a) increase the mass of waste per unit area;
(b) increase the concentration or conservative species such as PFAS in the leachate due to the greater mass and longer travel time to the leachate collection system,
(c) increase the contaminating lifespan of the landfill and hence likely exceed the design life of both the leachate collection system and the geomembrane liner.
(d) Increase leachate mounding to the contaminating lifespan landfill and hence leakage once the service life of the leachate collection system is reached.
(e) Further increase leakage through the geomembrane due to increased tensile stress in the geomembrane because of higher waste loading and hence more stress cracking of the geomembrane (see Figure 7).

In response to a request for more information regarding quality assurance on the liner systems as installed, GEMTEC responded with

> "*Manufacturers quality control records, quality assurance records, photographs, and leak detection surveys for geosynthetics used in all cells constructed at Crane Mountain Landfill: These are including in the QA/QC reports submitted to NBDELG after the construction of each cell.* ***This is not relevant to the EIA since all liners have been installed*** *and testing in accordance with*

industry standards, by qualified and certified QA/QC technicians under the guidelines of qualified Professional Engineers licensed to practice in the province of New Brunswick"

This is an unfortunate and ill-considered statement that highlights the problem of proceeding with the proposed expansion without an appropriate environmental assessment.

First, while these reports are said to exist, it has been difficult to obtain access to them.

Second, and far more importantly, I do not dispute that the quality assurance and quality control were done following industry standards at the time it was conducted. However, we now know that leakage is substantially more than has been anticipated at the time of design or construction (see Figure 9). Thus, past CQA has not been sufficient and the impact of this landfill will have increased relative to design assumptions because the effectiveness of the techniques alluded to in the QA/QC reports was not as good as was hoped.

Third, the statement that the QA/QC "is not relevant to the EIA since all liners have been installed…," fails to recognize that the demands on this system will be substantially increased by the increase in mass per unit area and all the consequences that follow from that as noted above. This is true even for the existing waste stream but assumes a much greater importance with PFAS in the leachate as it is far more likely than not may have benefits in reducing the biologically active lifespan, the proponent needs to remember the law of unintended consequences. Reducing the amount of organic matter will have an effect on leachate chemistry that may not be beneficial. One can anticipate an increase in PFAS concentrations and as the proportion of waste containing PFAS increases with the decrease in organic waste not containing PFAS so does the contaminating lifespan. An Environmental Assessment offers the opportunity to evaluate the pros and cons of both the proposed expansion and diversion of organic waste but also to ask the questions "what can go wrong" and "what are the unintended consequences of what is proposed".

C8. The inadequacy of isolated monitoring wells for identifying point failures in a geomembrane in any hydrogeologic environment but especially in fractured rock.

I leave a detailed discussion of the hydrogeology to others. However, I have been advised that the landfill is underlain by fractured till and fractured rock. It is difficult to monitor contaminant plumes from a point source through fractured rock domains. A hole in a geomembrane liner including one in a wrinkle represents a very small proportion of the overall site and the vast majority of leakage (estimated to be 50 to 75 lphd) will be over less than 0.2% of the typical site. The only way of confidently and effectively detecting this leakage is with a leak detection system underlain by a composite liner to minimize losses to the environment. Instead, it is understood that the liner is underlain by a 300 mm granular layer which will serve to distribute the leakage to the nearest fracture in the either underlying till or bedrock. The probability of this fracture being intersected by monitoring boreholes must be regarded as very low. Thus, reliance cannot be placed on monitoring using traditional wells in landfills with single liners overlying fractured material.

D. CLOSING COMMENTS

Comparing these contaminating lifespans (Table 7) with the service lives that can be expected (based on extensive testing of similar materials (Table 2) indicates that even the existing design needs a redesign of cells 10 to 16 using a double-lined system (if requested I could advise on what would be needed) with carefully selected GCLs and geomembranes with a service life of over 2000 years (with care appropriate geomembranes can be selected) with protection layers and training players with consistent long-term performance. Furthermore, an **environmental assessment is required for the proposed expansion.**

The original design was, in my opinion, appropriate given what we knew when it was approved in the late 1990s. However, when the assumptions in the original design are known to be flawed, then the design should change. The leakage is almost certainly more than was assumed in the design, likely 10 to 100 times higher than was assumed in the design. Also, the Crane Mountain landfill was never intended to deal with the containment of the PFAS .We are now in 2024 with the benefit of 25 years of experience and knowledge and with the new game-changing group of toxic compounds (up to about 15,000 by current estimates) called PFAS which dictate the need for a change from what was proposed 25 years ago.

DISCLAIMER

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APPENDIX A THE KEY ELEMENTS OF THE PROPOSED EXPANSION AS DESCRIBED IN THE GEMTEC REPORT

The *GEMTEC Report* states the following expectations if the facility is expanded as described:

(i) The landfill operating life will be extended by 22 years.

(ii) The landfill remaining capacity will be essentially doubled by increasing the capacity by 2.4 Mm^3 and hence allow broadcast placements of another by 2,400,000,000 kg.

(iii) The landfill maximum elevation will increase by 27.5 m (from 90 to 117.5m) which can be expected to increase the vertical stress over the central portion of the landfill by something of the order of 275 kPa.

(iv) The proposed additional waste storage will utilize the existing leachate collection system and leachate treatment system.

(v) The resistance to contaminant escape is to be provided by the mostly already installed single composite liner with a 600 mm thick re-compacted clay liner overlain by one (1) High Density polyethylene (HDPE) 80 mil geomembrane liner.

(vi) Leachate head acting on the liner will be controlled by leachate collection layers consisting of a layer of geonet, overlain by geotextile, overlain with leachate collection pipes and leachate collection aggregates (300 mm of rounded clear stone, overlain by geotextile, overlain by 150 mm of crushed rock).

(vii) "The additional weight resulting from the proposed waste containment cells height increase is not expected to compromise the existing, or future planned, leachate collection system"

(viii) The predicted fastest time of for the contaminant to travel to downstream boundaries is 20 to 50 years, and the median time is 200 years.

(ix) There is a 300 mm granular subbase below the compacted clay liner (Figure A1 below).

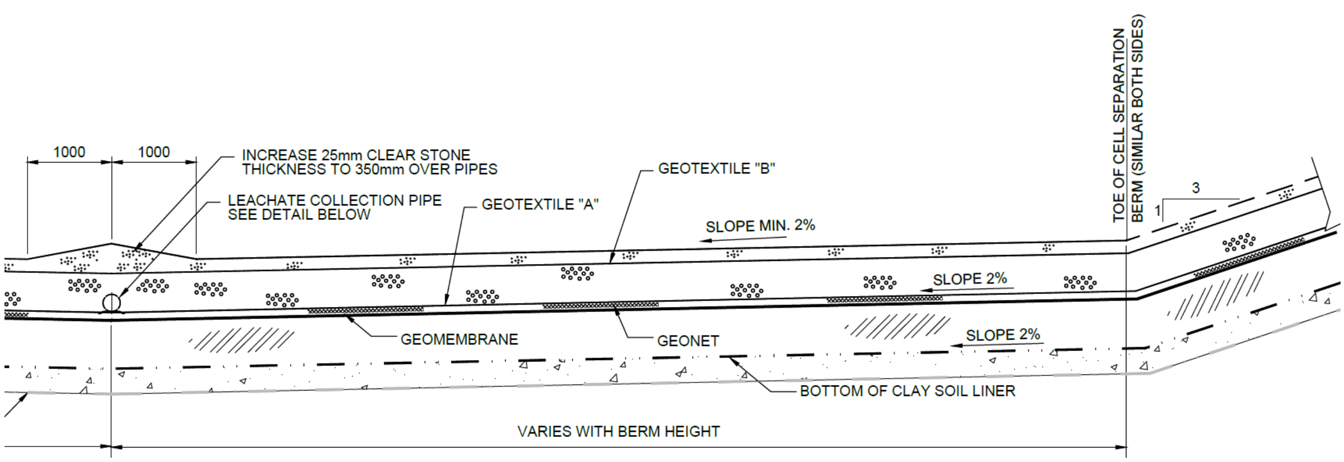

Figure A1: Detail of the barrier system from the Gemtec Report.

APPENDIX B: Geomembrane used in Cell 9 at Crane Mountain Landfill.

TABLE 02499-1 TYPICAL GEOMEMBRANE PROPERTIES			
HDPE Material Property	**Minimal Average Roll Values (Metric)**		
Nominal Thickness		**2.0 mm (80 mils)**	**1.0 mm (40 mils)**
	Units	**Value**	**Value**
Thickness, ASTM D5199, MARV	mm	1.98	0.99
Density, ASTM D1505/D792	g/cm³	0.94	0.94
Tensile Properties (Min.) ASTM D6693			
Yield Strength	kN/m	15	29
Break Strength	kN/m	27	53
Yield Elongation	percent	12	12
Break Elongation	percent	700	700
Carbon Black Content, ASTM D4218	percent	2.0 - 3.0	2.0 - 3.0
Carbon Black Dispersion, ASTM D5596	Category	*See Note	*See Note
Tear Resistance, ASTM D1004	N	249	125
Puncture Resistance, ASTM D4833	N	640	320
Stress Crack Resistance ASTM D5397	Hour	500	500
Oxidative Induction Time (OIT) (Min)			
a) Standard OIT ASTM D3895	min	100	100
b) High Press. OIT ASTM D5885		400	400
OIT Oven Aging at 85°C ASTM D5721			
a) Standard OIT ASTM D3895	Percent	55	55
b) High Press. OIT ASTM D5885		80	80
UV Resistance ASTM D7238			
a) Standard OIT ASTM D3895	Percent	NR	NR
b) High Press. OIT ASTM D5885		50	50

* Note- Only near spherical agglomerates: 10 views in Category 1 or 2

For HDPE liner design, the "half-life" (time it takes for the liner to degrade 50%) is considered t be the design life. Published predicative design values for the half-life of unexposed (buried) HDPE liners ranges from 69 to 446 years (Geosynthetic Institute; GRI White Paper #6:

APPENDIX C: GEONET USED IN CELL 9 AT CRANE MOUNTAIN LANDFILL.

.1 Geonet shall be manufactured by extruding two sets of polyethylene strands to form a three (3) dimensional structure to provide planar water flow. The geonet shall contain stabilizers to prevent ultraviolet light degradation.

.2 Geonet shall be Transnet 220 as manufactured by SKAPS Industries Inc.or approved equal and conform to Table 02511-1.

Table 02511-1

PROPERTY	TEST METHOD	UNIT	QUALIFIER	VALUE
Resin Density*	ASTM D1505	g/cm^3	minimum	0.94
Resin Melt Index	ASTM D1238	g/10 min	maximum	1.0
Carbon Black Content	ASTM D4218	%	range	2-3
Thickness	ASTM D5199	mm	minimum	5
Mass per Unit Area	ASTM D5261	kg/m^2	minimum	0.79
Tensile Strength	ASTM D5053	kg/mm	minimum	0.75

*Fully compounded

.3 The Contractor shall submit on request, notarized certifications from the manufacturer indicating that the material meets the above specification.

All geonet and geomembrane materials used on containment cells at Crane Mountain Landfill are reviewed to ensure they meet the above parameters. The liners are all installed by experienced, qualified installers and Quality Control (QC) and Quality Assurance (QA) testing performed by experienced, qualified technicians, in accordance with industry standards. A robust QA/QC program is implemented for geomembrane liner installation, with destructive and non-destructive testing on all seams and welds. All specifications have been developed and QA/QC testing is conducted under the supervision and guidance of Professional Engineers licenced in the province of New Brunswick. All test results are compiled in a comprehensive report provided to NBDELG for consideration and record.

APPENDIX D: GEOTEXTILE USED IN CELL 9 AT CRANE MOUNTAIN LANDFILL.

.1 The geotextiles shall be of non-woven construction comprising synthetic, non-biodegradable fibres. Fibres used in the manufacture of geotextiles and the threads used in joining geotextiles by sewing shall consist of long chain synthetic polymers composed of at least 85% by weight polyolefins, polyesters, or polyamides. They shall be formed into a network such that the filaments or yarns retain dimensional stability relative to each other, including selvages

.2 Minimum average roll value (MARV) requirements for Geotextile A material shall be as follows:

	Geotextile A	Method
POA (%)	-	CWO-22125
AOS or FOS* (mm)	0.15	ASTM D4751 or CGSB 148.1 Method 10
Grab Strength, N	2045	ASTM D4632
Trap. Tear., N	555	ASTM D4533
Puncture, N	930	ASTM D4833
CBR Puncture Strength, kPa	2800	ASTM D6241
Wide Width Tensile, kN/m	-	ASTM D4595
Mass Per Unit Area, gr/m^2	675	ASTM D5261

GEMTEC

Letter to: CMEI & EXP
GEMTEC Project: 100018.012 (March 4, 2024)