COMPOSITE LINERS AS BARRIERS: CRITICAL CONSIDERATIONS

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Abstract

The finite service life of engineered components of composite liner systems is a critical consideration in the design of such systems. Four different barriers incorporating composite liners are examined with respect to service life, leakage through the geomembrane, and the hydraulic conductivity of the geosynthetic clay liner.

Introduction

Composite liners consisting of geomembranes over compacted clay and geomembranes over geosynthetic clay liners (GCL) are gaining wide acceptance in the design of barrier systems for waste disposal. This paper examines a number of key considerations with respect to the design of these systems, with particular emphasis on the finite service life of the engineered systems and the effective hydraulic conductivity of the geomembrane and GCL.

The primary goal of barrier systems in landfills is to minimize the migration of contaminants. The effectiveness of a barrier design can be assessed by examining the impact of the landfill on an underlying aquifer. For the purposes of this paper the migration of chloride and dichloromethane will be examined. Initial source concentrations of 1500 mg/L for Chloride, and 1500 μg/L for dichloromethane are assumed. In addition the mass of the chloride is assumed to represent 0.2% of the total mass of waste, which is has a density of 600 kg/m^3. It is also assumed that the mass of dichloromethane is in direct proportion to the initial source concentration.

The service life of the engineered systems is expected to be finite, due to chemical and biological clogging of the leachate collection systems and ageing (eg. due to chain scission) of the geomembrane. In this analysis the service lives of the engineered systems are assumed to be 50 years for the primary leachate collection system, 125 years for the primary geomembrane, 175 years for the secondary geomembrane, and 200 years for the secondary leachate collection system unless otherwise specified.

Prior to failure of the primary leachate collection system the leachate mound is taken to be 0.3 m above the primary liner, after failure the mound is assumed to build at a rate of 0.25 m/a up to it's full height of 11 m above the primary liner (where the maximum height of the mound is controlled by the thickness of waste in the example being considered).

All the analyses reported herein were performed using a finite layer contaminant transport model [Rowe and Booker, 1985, 1987] as implemented in the computer program POLLUTE v.5 [Rowe and Booker, 1990].

Barrier Designs

Four different composite liners are considered for a hypothetical landfill excavated into a relatively permeable silt till which extends 3 m below the top of the primary composite liner, and overlies a 1 m thick aquifer. The silt till is assumed to have a hydraulic conductivity of 1 x 10^{-5} cm/s, a porosity of 0.25, an effective diffusion coefficient of 0.015 m^2/a for chloride and dichloromethane, with the product of soil density, ρ, and dichloromethane partitioning coefficient, K_d, given by $\rho K_d=2$.

The underlying aquifer is assumed to have a porosity of 0.3, a hydrostatic head of 1 m above the aquifer, and a horizontal flow at the up-gradient edge of 20 m/a. Upon failure of the leachate collection systems the mounding of the leachate will cause an increase in the downward Darcy velocity with a resulting increase in the horizontal flow in the aquifer.

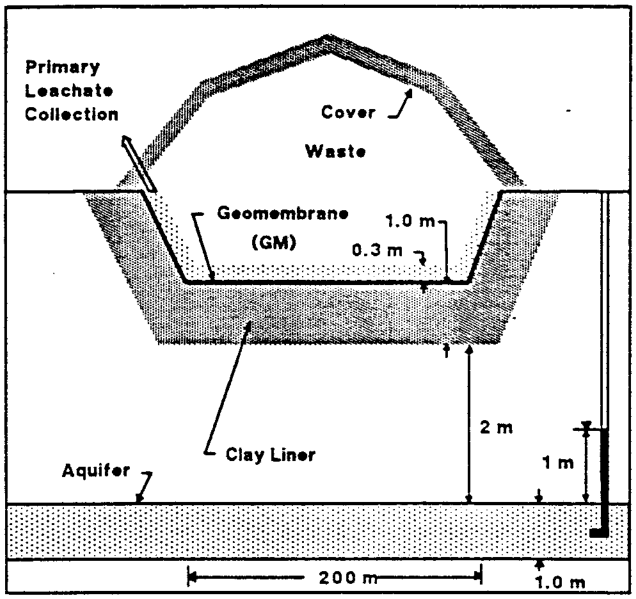

Figure 1. Design 1: Single Liner - Geomembrane & Clay.

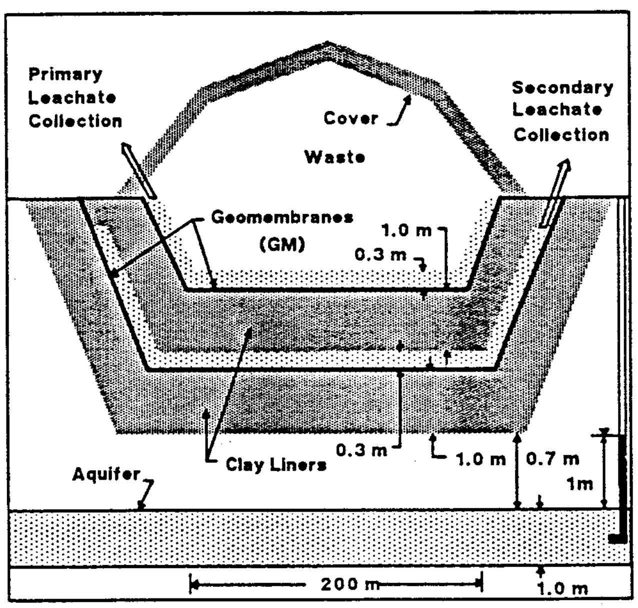

Figure 2. Design 2: Double Liner - Geomembrane & Clay.

The first barrier design incorporates a primary leachate collection system and composite primary liner consisting of a 80 mil geomembrane and 1 m of compacted clay (Figure 1). In this and subsequent designs the geomembrane is assumed to have an effective hydraulic conductivity of 10^{-12} cm/s which has been backfigured based on consideration of the likely leakage through a "well constructed" composite liner, with some holes (using information provided by Giroud and Bonaparte, 1989), and an effective diffusion coefficient of 3 x 10^{-5} m^2/a, unless otherwise stated.

The compacted clay for this and the second barrier design is 1 m thick and has a hydraulic conductivity of 2 x 10^{-8} cm/s, a porosity of 0.35, an effective diffusion of 0.019 m^2/a. The sorption of dichloromethane is controlled by $\rho K_d = 2$. Leachate collection systems in these designs consists of a granular layer normally 0.3 m thick with a porosity of 0.3. In this design there is 2 m of silt till, below the liner.

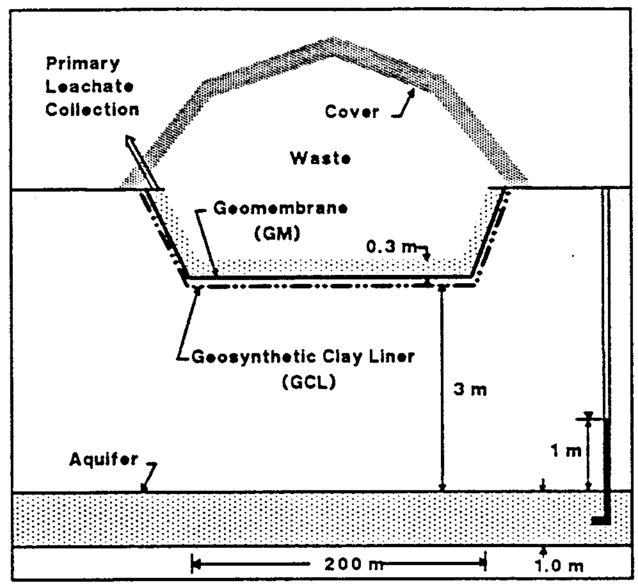

Figure 3. Design 3: Single Liner - Geomembrane & Geosynthetic Clay Liner.

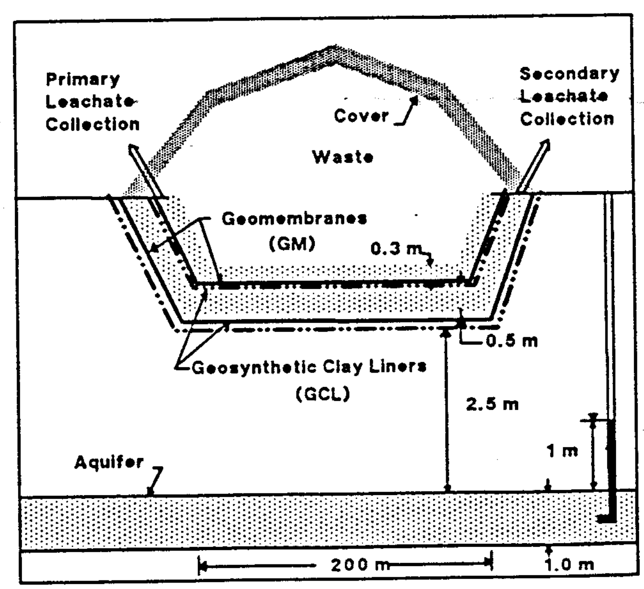

Figure 4. Design 4: Double Liner - Geomembrane & Geosynthetic Clay Liner.

In the second barrier design, primary and secondary leachate collection systems and primary and secondary composite liners are utilized (Figure 2). Both the primary and secondary liners consist of a 80 mil geomembrane over 1 m of compacted clay. The remaining silt till is only 0.7 m thick, if the base of the landfill is maintained at approximately the same elevation as the first design.

The third and fourth barrier designs (Figures 3 and 4) are similar to the first and second designs respectively, except in these designs the composite liners consist of a 80 mil geomembrane over a geosynthetic clay liner (GCL). The thickness of silt till is 3 m below the engineering for the third design and 2.5 m for the fourth design in order to keep the base of the landfill at the same level above the aquifer as in the first and second designs. In these designs the GCL is assumed to have a hydraulic conductivity of 4 x 10^{-10} cm/s, a porosity of 0.75, an effective diffusion coefficient of 0.0047 m^2/a, and the sorption of dichloromethane is given by $\rho K_d = 2$. In the fourth design the secondary leachate collection system was assumed to be 0.7 m thick to allow for a granular - geosynthetic cushioning layer above and below a coarse stone collection layer.

In the analysis that follows the infiltration through the cover is taken to be 0.15 m/a based on experience in Southern Ontario, the waste thickness is 12.5 m, and the landfill length is 200 m in the direction of groundwater flow. The effect of the mass of contaminant was modelled as described by Rowe [1991]. Due to space limitations, only one hydrogeologic system is considered here. However, as noted by Rowe [1992], the impact of a given landfill will depend on the interaction between the engineered barrier system and the hydrogeology. Thus care should be taken not to generalize the numerical results beyond the level discussed in the paper.

Service Life of Geomembrane

The service life of the geomembranes is assumed to be finite, due to ageing (eg. chain scission caused by chemical attack). To illustrate the effects of the service life of the geomembrane on the migration of contaminants, a range of service lives of the primary geomembranes were examined for the four designs. Once the primary geomembrane ceases to be effective there will be a significant increase in contaminant contact with the secondary leachate collection system and secondary geomembrane for designs 2 and 4. This increased contact is then expected to accelerate degradation of these systems. Thus, for this paper the secondary geomembrane and secondary collection leachate system are assumed to fail at 50 years and 75 years respectively after failure of the primary geomembrane. Space does not permit an examination of the effect of this assumption which will be discussed in another paper.

If the service lives of the geomembrane are assumed to be effectively infinite (ie. it's hydraulic containment characteristics are maintained for the entire contaminating lifespan of the landfill) then the impact on the aquifer would be controlled by diffusion of contaminants through the barrier system, even with failure of the primary leachate collection system. For this case the calculated peak increase in chloride concentration would be 14, 10, 12, and 8 mg/L and the peak dichloromethane concentration would be 4, 3, 3, and 2 μg/L for the first, second, third and fourth designs respectively.

For comparison purposes, Figures 5 and 6 show the calculated impact on the aquifer for chloride and dichloromethane, assuming that the service life of the geomembranes is finite and that the service life of the primary geomembrane is between 100 and 150 years. It can be seen that the peak concentration of the contaminants decreases with increasing service life, with the decrease being most noticeable for the barrier designs having primary barriers only (i.e. the first and third designs).

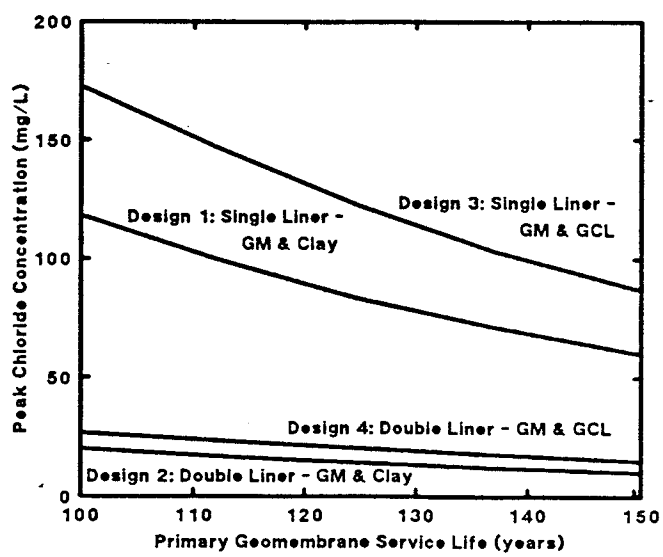

Figure 5. Geomembrane Service Life - Chloride.

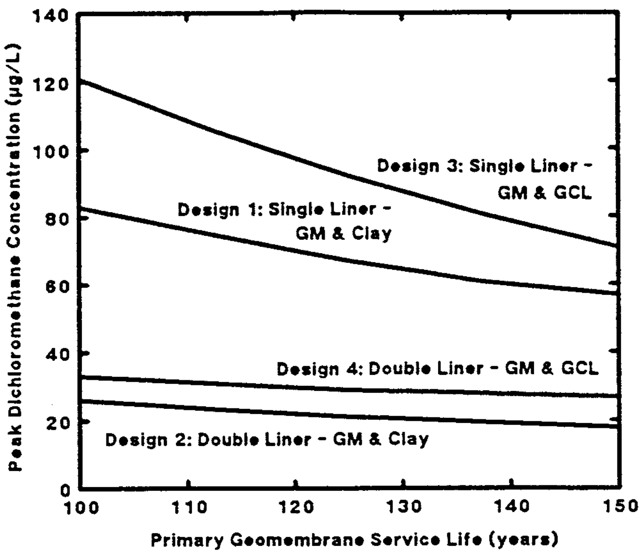

Figure 6. Geomembrane Service Life - Dichloromethane.

The designs with a secondary system (ie. 2 and 4) result in substantially reduced impact compared to those with only a single composite liner (ie. 1 and 3). Neglecting biodegradation of dichloromethane, it is seen that for designs 1 and 3 the calculated impacts are quite significant compared to a drinking water objective of 50 μg/L, even with a substantial service life of 150 years for the primary geomembrane.

In the Province of Ontario, Canada, the Ministry of Environment and Energy's 'Reasonable Use' Policy [MOEE, 1993a] would limit increases in the concentration of contaminants in the aquifer to a maximum of 125 mg/L for chloride and 12 μg/L for dichloromethane, assuming a negligible background concentration. Under this policy the first, second, and fourth barrier designs would be acceptable for chloride for all the service lives examined, however the third design would require a geomembrane service life greater than 125 years to be acceptable for the conditions assumed. None of these designs would be acceptable for dichloromethane with service lives of the primary geomembrane of 150 years or less, although the second design is close to being acceptable if the service life of the primary geomembrane is 150 years.

Leakage through the Geomembrane

The leakage through a geomembrane which forms part of a composite liner system depends primarily on the applied leachate head, the number of 'holes' in the geomembrane and the nature of the contact between the geomembrane and the underlying clay liner [Giroud and Bonaparte, 1989]. In order to allow an 'intuitive' comparison with traditional geotechnical barrier materials (eg. clay liners) it is convenient to backfigure a effective hydraulic conductivity of the geomembrane (considering the factors discussed above) as a measure of the quality of the installed geomembrane and hence to examine the effect of reasonable variation in workmanship in terms of this effective hydraulic conductivity as illustrated in Figures 7 and 8.

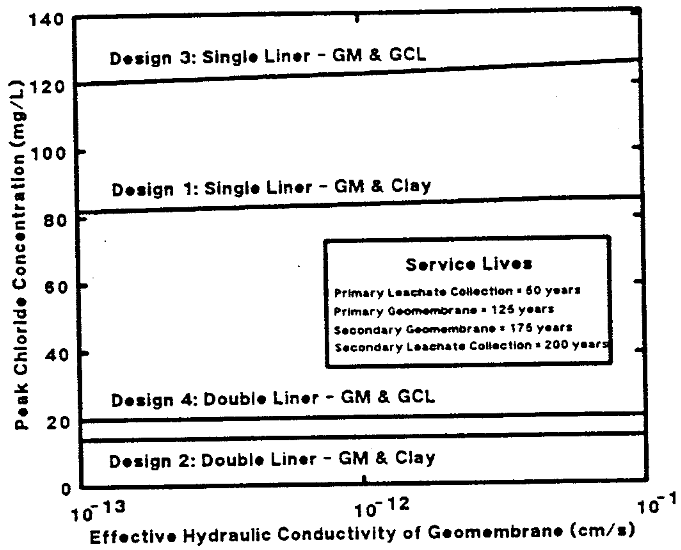

Figure 7. Effective Geomembrane Hydraulic Conductivity - Chloride.

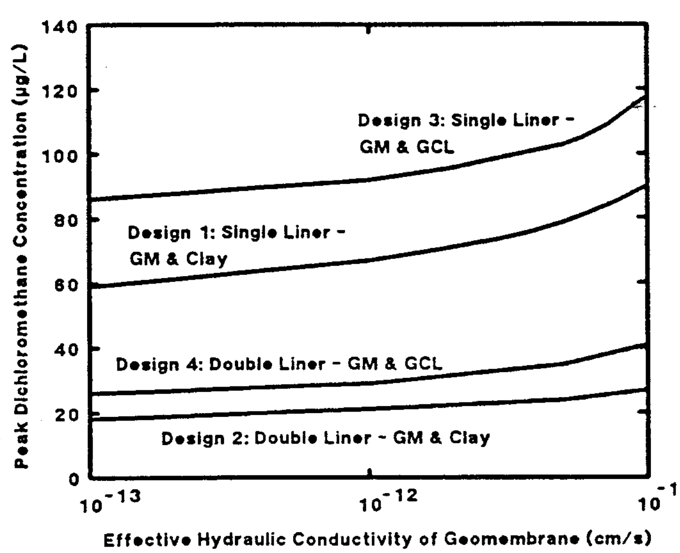

Figure 8. Effective Geomembrane Hydraulic Conductivity - Dichloromethane.

Over the range of effective hydraulic conductivities examined, the peak chloride concentration does not vary appreciably for the four designs (Figure 7). This insensitivity is due to the contaminant migration process being predominantly diffusive while the geomembranes are intact, and then being dominated by advection upon failure of the geomembranes. Due to the effect of sorption, the peak concentration of dichloromethane is more sensitive to the leakage through the geomembrane and the results show a moderate decrease in peak concentration with decreasing effective geomembrane hydraulic conductivity (Figure 8), with the effect being greatest for the single composite liner systems (ie. designs 1 and 3).

The effectiveness of the geomembrane(s) can be assessed by comparison of the peak impacts given in Figures 7 and 8 with those that would be predicted for designs 1, 2, 3, and 4 assuming no geomembrane: namely 199, 40, 349, and 192 mg/L for chloride and 164, 37, 350, and 98 μg/L for dichloromethane.

When examined with respect to the MOEE's 'Reasonable Use' Policy, all of the designs would be acceptable for chloride over the range of workmanship (ie. effective geomembrane hydraulic conductivity) considered. None of the designs would be acceptable for dichloromethane, however the second design comes close to being acceptable for excellent workmanship (ie. an effective geomembrane hydraulic conductivity of 10^{-13} cm/s).

Hydraulic Conductivity of GCL

A range of hydraulic conductivities of the geosynthetic clay liner were examined to illustrate the sensitivity of the peak aquifer contaminant concentration to this parameter. Only the third and fourth designs incorporate GCLs and would be sensitive to changes in the hydraulic conductivity of the GCL, in the figures that follow the peak aquifer concentrations of the first and second designs are plotted as constants for reference purposes only.

Figures 9 and 10 show the calculated peak concentration of chloride and dichloromethane in the aquifer, for a range of GCL hydraulic conductivities. The third and fourth designs are quite sensitive to the hydraulic conductivity, since after the geomembrane fails the migration process is predominantly advective with the rate being controlled by the hydraulic conductivity of the GCL. The third design is the most sensitive since there is no secondary leachate collection system to remove contaminant after failure of the geomembrane, whereas in the fourth design the majority of the contaminant is removed by the secondary leachate collection system prior to the failure of the secondary geomembrane.

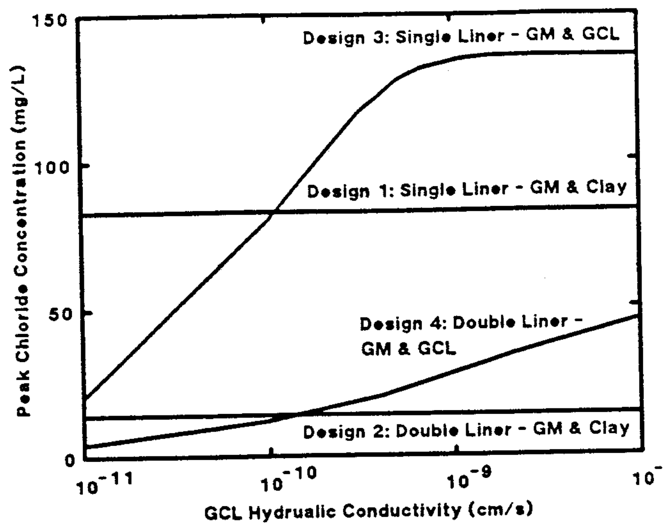

Figure 9. GCL Hydraulic Conductivity - Chloride.

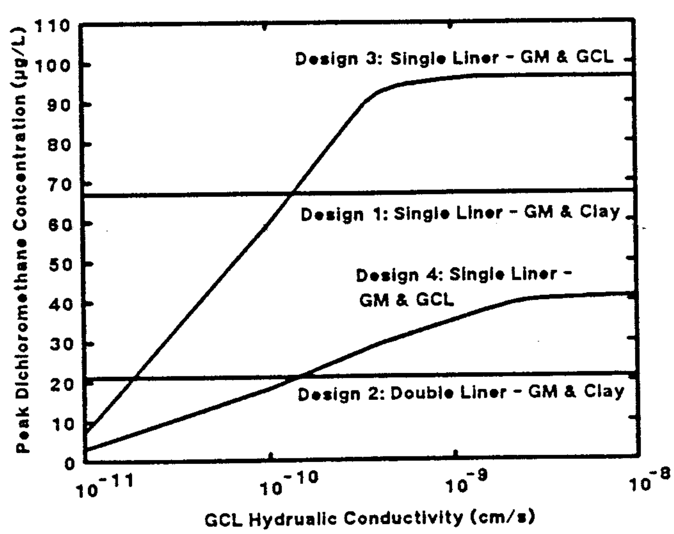

Figure 10. GCL Hydraulic Conductivity -Dichloromethane.

From these figures one can assess the hydraulic conductivity of the GCL at which it outperforms a 1 m thick compacted clay liner with a hydraulic conductivity of $2x10^{-8}$ cm/s. It is seen that for the cases examined this typically occurs for a GCL hydraulic conductivity of between about 10^{-11} and 10^{-10} cm/s.

Based on the maximum allowable increase in chloride concentration permitted by the MOEE's 'Reasonable Use' Policy, the fourth design may be acceptable at all the GCL hydraulic conductivities examined, and the third design may be acceptable for GCL hydraulic conductivities less than 4 x 10^{-10} cm/s. For dichloromethane the fourth design would require a GCL hydraulic conductivity less than 4 x 10^{-11} cm/s, and the third design would require a GCL hydraulic conductivity less than 1.3 x 10^{-11} cm/s.

Discussion and Conclusions

Some regulators (eg. MOEE, 1993b) require that when assessing the potential impact of a landfill on an underlying aquifer, the service life of the engineered systems must be considered. When composite liners are utilized the service life of the geomembranes must also be considered, in addition to the service life of the leachate collection systems. The service life of the geomembrane for barrier systems involving only primary liners has a much greater effect than for systems involving both primary and secondary systems.

Although the geomembranes and geosynthetic clay liners are engineered components, there is still uncertainty regarding their hydraulic conductivity and effective diffusion coefficients. Since the hydraulic conductivity of a well installed geomembrane is very low, the migration process is primarily diffusive and relatively insensitive to the effective hydraulic conductivity of the geomembrane over the range examined. However, after the geomembrane fails the contaminant transport is controlled by advection and for a composite liner incorporating a GCL, the hydraulic conductivity of the GCL becomes the key factor controlling impact (similarly, of course, with a compacted clay liner it would be the hydraulic conductivity of the clay that would control impact).

This paper demonstrates that even with relatively long service lives (more than a hundred years), consideration of the finite service life of components of the engineered systems can have a profound effect on the estimated impact for a modest sized landfill (approximately 12.5 m average waste thickness); the effect could be expected to be greater for a larger landfill. It is concluded that reasonable uncertainty regarding the service life of engineered systems should be considered when evaluating the potential impact and the health and safety risks associated with proposed waste disposal facilities.

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