Projected Long-term Infiltration Rates Through a Degraded Multi-layer Soil/Geosynthetic Closure Cap

J.R. Luellen[1], J.M. Brydges[2], and W.T. Frederick[3]

Abstract: As part of an evaluation of closure alternatives for a radioactively-contaminated facility, the Hydrologic Evaluation of Landfill Performance (HELP) Model was used together with published leakage equations to predict the long-term hydraulic performance of a (degraded) multi-layer soil/geosynthetic closure cap. Because the HELP Model does not account for the effects of aging on the integrity of a geomembrane (a component of the proposed cap), a review of environmental and geomechanical degradation processes that could detrimentally affect the hydraulic performance characteristics of the geomembrane was conducted, and possible effects of these processes on geomembrane properties were estimated. Long-term leakage rates through two different types of defects, which are predicted to occur in the geomembrane as a consequence of these degradation processes, were calculated. An evaluation of the possible effects of degradation processes on other components of the cap was also conducted. HELP Model simulations were conducted using different geomembrane quality input parameters to duplicate the previously calculated leakage rates through the composite barrier layer of the cap. Results of the simulations and calculations indicate that, for the cap investigated in this study, the HELP Model underpredicted long-term percolation rates through the cover barrier components, compared to rates projected using the leakage equations.

One of the closure alternatives being considered for certain areas of a radioactively-contaminated site includes construction of a multi-layer soil/geosynthetic cap following decontamination of impacted facilities within the selected areas. Stakeholders reviewing this closure alternative expressed a concern regarding the possible detrimental effects of degradation mechanisms on the long-term performance of the hydraulic barrier components of the proposed engineered cap. To further evaluate the potential impacts of degradation mechanisms on long-term infiltration rates through the cap, possible degradation mechanisms were identified, and potential consequences of those degradation mechanisms on long-term performance of the cap were estimated. A series of infiltration modeling simulations and analytical calculations were conducted to estimate potential long-term percolation/leakage rates through the degraded cap. The proposed closure cap, approximately 8.5 acres in size, has cover slopes inclined between 5 percent (top deck) and 20 percent (side slopes). The cap would consist, from top to bottom, of the following components:

- A 1.22-m (48-in) thick vegetative soil layer (layer thickness based on estimated frost penetration depth);
- A 0.46-m (18-in) thick granular filter/drainage layer;
- A polyethylene geomembrane (assumed to be a 60 mil thick high density polyethylene [HDPE] membrane);
- A geosynthetic clay liner (GCL), approximately 0.006-m (0.25-in) thick;
- A 0.91-m (36-in) thick compacted clay layer; and
- A 0.46-m (18-in) thick cobble bio-barrier layer (over a compacted engineered base layer).

[1] Sr. Project Scientist, URS Corporation, Orchard Park, NY, USA, Ph 716.675.7130, Fax 716.675.7137, jon_luellen@urscorp.com (corresponding author)
[2] Environmental Engineer, URS Corporation, Orchard Park, NY, USA, Ph 716.675.7130, Fax 716.675.7137, jason_m_brydges@urscorp.com
[3] Project Hydrogeologist, URS Corporation, Orchard Park, NY, USA, Ph 716.675.7130, Fax 716.675.7137, bill_frederick@urscorp.com

An evaluation was conducted to assess the potential impacts of various environmental and geomechanical degradation mechanisms on the long-term hydraulic performance of the cap. The following studies provided useful information on the effects of ion-exchange transformation, freeze-thaw processes, and wetting/drying cycles on the hydraulic conductivity of a geosynthetic clay liner (GCL): Badu-Tweneboah et. al. (1999), studies by Engloffstein (1997), James et. al. (1997), Melchior (1997), Shan and Daniel (1991), Hewitt and Daniel (1997), Boardman and Daniel (1997), and Kraus et. al. (1997). Smith (1999), Daniel and Koerner (1992), Albrecht and Benson (2001), and several other studies also provided useful information for this evaluation by describing the effects of various environmental/geomechanical processes on the hydraulic conductivity of compacted clay liners and other soil layers (See **References** below). Based on this evaluation, time-dependent, "degraded" hydraulic parameters were estimated for each cover layer component and then used as input variables for both the modeling simulations and infiltration (leakage) calculations.

The HELP Model, Version 3.07 (Schroeder et. al., 1997; Schroeder and Peyton, 1995) was used to estimate future percolation rates through the degraded cap and predict future infiltration-induced head buildup levels on top of the geomembrane within the proposed cap. The HELP Model was selected for this study based on the site's climate (average annual precipitation ³ 0.91 m [36 in] per year) and the relative simplicity of using this model. The HELP Model simulates cap hydraulic performance for a time period of up to 100 years. For additional conservatism, a potentially wetter climatic regime was manually generated and incorporated into the HELP Model climate input data set. For the leakage computations, equations published by Giroud (1997) were used to estimate the rate of water flow through the composite geomembrane/GCL barrier system of the cap due to defects in the geomembrane, including both circular-shaped defects and infinitely long cracks (i.e., environmental stress cracks) at various times during the postclosure period. Flow rates through both types of defects were calculated and summed (as appropriate, depending on the age of the cap) over the entire cap area to estimate total long-term percolation rates through this composite barrier. Procedures similar to those reported by Badu-Tweneboah et. al. (1999) were used in these calculations. Initial (average and peak) hydraulic head values used in the equations for head over the top of the geomembrane (about 0.0127 m [»½ in] and 0.3 m [»1 ft], respectively) were derived from the HELP Model. Estimated leakage rates through the geomembrane/GCL at year 0, at about year 300 after closure, and beyond 300 years after closure, were calculated. To make comparisons between the HELP Model and Giroud equations, additional HELP Model simulations were conducted using the same hydraulic parameters that were used in the leakage calculations for each cap layer and each postclosure time period considered.

Results of comparing the modeling simulations and Giroud equation calculations indicate that, for all postclosure time periods after which cracking of the geomembrane begins, in order to obtain identical predicted percolation rates through the GCL, it is necessary to increase the number of (circular) defects per acre for the geomembrane in the HELP Model (beyond the recommended default values specified in the user guide). In addition to this modification, other (parallel) changes needed to be made in the other cap layer parameters. These changes in geomembrane characteristics, together with the other modifications made to the other cap layer parameters, resulted in higher [presumably more accurate] percolation rates through the cap than would have been predicted using a conventional steady-state HELP Model approach (as summarized in Table 1 and Figure 1 below).

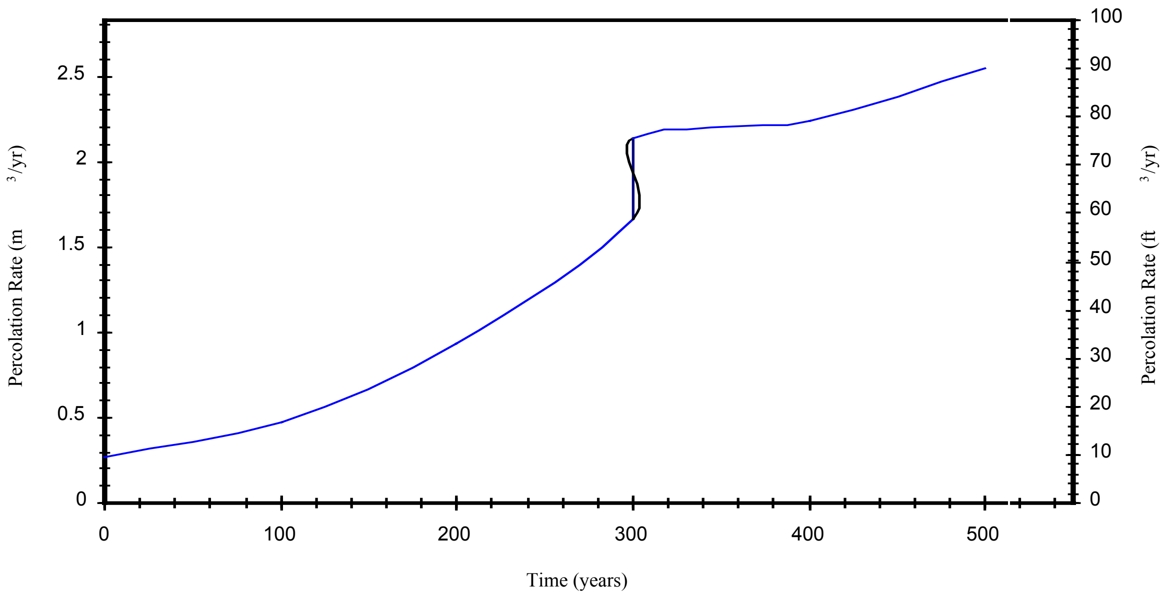
Table 1 - Calculated Long-Term Leakage Rates
Through Geomembrane/GCL Composite Barrier Cap Component

Number of Years After Cap Construction	Estimated Leakage Rate Through Geomembrane/GCL Barrier Component	
0	Average Leakage Rate 0.27 m^3/yr (9.7 ft^3/yr)	Worst-Case Leakage Rate 16.1 m^3/yr (569 ft^3/yr)
_ 300	Average Leakage Rate 2.1 m^3/yr (75.7 ft^3/yr)	Worst-Case Leakage Rate 107 m^3/yr (3,780 ft^3/yr)
_ 300	Average Leakage Rate 2.5 m^3/yr (90 ft^3/yr)	Worst-Case Leakage Rate 115 m^3/yr (4,066 ft^3/yr)

Figure 1

Calculated Average Percolation Rate

Through Progressively Degraded Membrane/GCL



Results of this case study indicate that when projecting the potential long-term hydraulic performance of engineered multi-layer soil/geosynthetic caps, all of the following factors should be considered: (1) the effects of geomembrane aging and other degradation processes on long-term geomembrane hydraulic barrier efficiency; (2) the effects of progressive changes in the hydraulic properties of the various other cap layers (e.g., lateral drainage layer, GCL, etc.) on hydraulic performance; and (3) the effects of changes in hydraulic head buildup on the geomembrane component of the cap on leakage rate. The results of this study can be applied to similar engineered barrier systems when assessing long-term hydraulic performance.

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