Stochastic Simulations for Risk-Based Performance Assessments of Long-Term Cover Systems

Clifford K. Ho, Stephen W. Webb, and Bill W. Arnold
Sandia National Laboratories
Albuquerque, New Mexico
(505) 844-2384
ckho@sandia.gov

Abstract—The design of landfill covers for contaminated waste sites at DOE complexes has been largely governed by prescriptive criteria (e.g., maximum permeability), which are intended to minimize the amount of water that can contact the waste and leach contaminants to the water table. However, these guidelines are not site-specific and may not address important features, events, and processes at the site that may contribute to the risk of groundwater contamination and human exposure to contaminants. This paper presents a risk-based performance-assessment method that incorporates uncertainty and variability for important parameters at each site. In addition, changes in the environmental setting (e.g., precipitation, temperature) and aspects impacting the cover design (e.g., liner integrity, bio-intrusion) are considered for long time periods (~1000 years). Regulatory requirements regarding groundwater contamination or human exposure can be used as the performance metrics for the stochastic simulations, and alternative cover designs can be compared in the analyses. A preliminary example is provided using the Monticello, Utah, disposal site, which employs a long-term cover system for uranium mill tailings. The water percolation reaching the uranium mill tailings is used as the performance metric. Uncertainty distributions of the most important parameters (e.g., liner integrity, parameters affecting evapotranspiration, hydraulic conductivity) are sampled in a stochastic Monte Carlo analysis. The resulting cumulative distribution function of the percolation is used to determine risk, and these results are also compared to deterministic results to illustrate the importance of including uncertainty and variability.

Introduction—Long-term cover systems are needed at DOE complexes to assist in isolating contaminants and waste that have migrated into the subsurface near landfills, waste disposal sites, and high-level waste tanks. Currently, landfill-cover design guidelines, such as those stated in the Resource Conservation and Recovery Act (RCRA), do not consider site-specific influences such as climate and the evolution of hydrologic processes on long-term performance. Caps designed to meet RCRA performance standards may fail under certain conditions, resulting in adverse migration of contaminants. In addition, traditional design methods for covers often rely on deterministic models of flow and transport processes that neglect the uncertainty and variability inherent in the model parameters and processes that may influence the predicted performance of the covers.

To meet the long-term needs of designers, regulators, and involved stakeholders, a probabilistic, risk-based performance-assessment approach is being developed for the selection, design, modeling, and monitoring of long-term covers. This approach will consider regulatory requirements, environmental setting (e.g., climate change), site-specific FEPs (features, events, and processes), engineering design parameters, and long-term verification and monitoring requirements. The integrated development between performance-assessment models and engineering will reduce costs in the long run by eliminating poor design choices (from a risk-based analysis) and by optimizing site-characterization efforts through sensitivity analyses of system components. Long-term monitoring can also benefit from the models and methods we develop by focusing on the key parameters and processes that are identified in the performance-assessment calculations as being most important to long-term performance.

Approach—An integrated approach for probabilistic, risk-based performance assessments of long-term cover systems is being developed for end-users. The approach consists of two primary tasks: (1) develop and implement a software tool that can integrate all relevant component models of the performance assessment and (2) develop and implement subsystem component models of relevant processes for long-term cover systems (e.g., infiltration through the cover, source-term release, unsaturated-zone radionuclide transport, saturated-zone radionuclide transport, exposure pathways, etc.). The first task develops the framework to assess and evaluate alternative cover designs based on probabilistic, risk-based calculations that address uncertainties within the system. The second task evaluates site-specific processes that influence long-term performance. Models are implemented and developed to provide input (cumulative distribution functions, response surfaces, discrete data, etc.) to the integrated performance-assessment model.

The FRAMES software developed at Pacific Northwest National Laboratory is being used to integrate the various subsystem component models, from source-term release to exposure. The software allows the development of a conceptual site model through drag-and-drop icons that represent subsystem models. The icons are arranged and connected to represent various pathways of contaminant transport and human exposure. By double-clicking the icons, the user can choose from an inventory of models for that subsystem component. Additional subsystem models developed by the user can also be added to the inventory.

Demonstration, Results, and Discussion—The disposal site at Monticello, Utah, was chosen as a demonstration site to develop and illustrate the performance-assessment approach for long-term covers. The disposal site, located in southeast Utah, is a permanent repository for 2.5 million cubic yards of low-level radioactive uranium mill tailings and contaminated soil. The present climate is "sub-humid," with an average annual precipitation of 15 inches and an average annual temperature of 46 ºF. The cover design consists of four primary layers: (1) a topsoil layer to allow vegetative growth and evapotranspiration; (2) a lateral drainage sand layer; (3) a geosynthetic membrane; and (4) a compacted clay barrier layer (Figure 1).

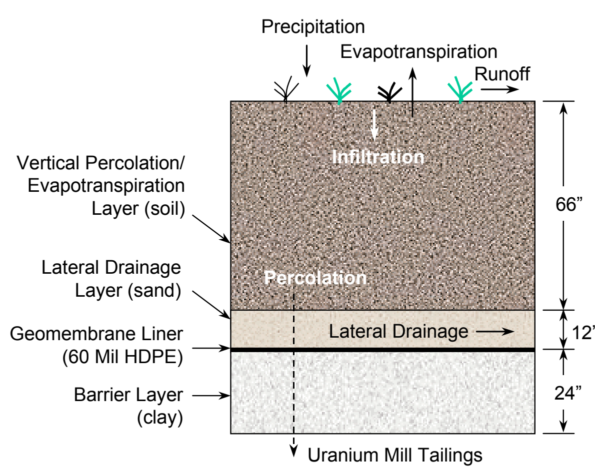

Figure 1. Conceptual model of percolation through the cover at the Monticello disposal site.

Analyses to date for this demonstration have focused on the amount of water that can penetrate the cover and contact the waste. The performance metric for this example is therefore the percolation flux through the cover; subsequent analyses will consider the total-system performance, which will be evaluated against other risk-based performance metrics (e.g., groundwater concentration, dose, health impacts, etc.). The HELP v. 3.07 (Hydrologic Evaluation of

Landfill Performance) code was used to simulate the amount of percolation penetrating through the cover. Uncertainty distributions were developed for key parameters that significantly impact percolation. Parameter distributions were obtained from a number of sources. Present-day climate data were obtained from the National Oceanic and Atmospheric Administration (Owenby and Ezell, 1992), and hydrologic data were obtained from Daniel B. Stephens and Associates (1993). Joint probability distributions for hydrologic parameters (K_{sat}, α, N) were obtained from the literature (Carsel and Parrish, 1988), and several HELP parameters such as wilting point and field capacity were determined from these distributions if actual data were not available. Preliminary estimates of parameter distributions (e.g., precipitation, temperature) for future climate scenarios were obtained from Waugh and Petersen (1994).

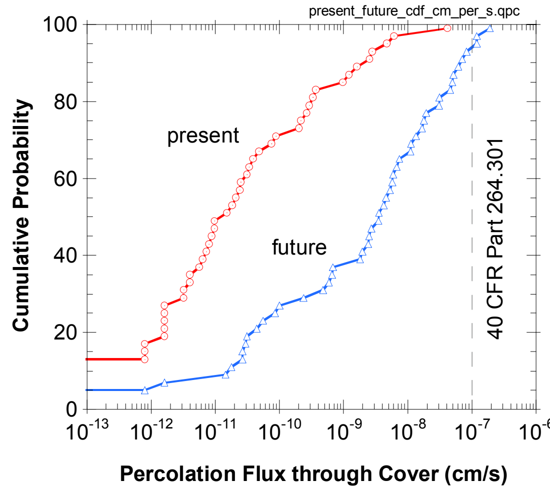

Figure 2. Cumulative probability plot of simulated percolation flux through the cover.

Results of the Monte Carlo simulations using the HELP code are presented as a cumulative probability in Figure 2 for both present-day and future conditions. The simulations for future conditions included additional uncertainty in input parameters such as precipitation, temperature, and integrity of the geomembrane liner. Results show that the uncertainty in the input parameters cause a large range in the percolation through the cover (5-6 orders of magnitude). The performance of the cover under future conditions is seen to be worse (higher percolation through the cover) because of the potential for increased precipitation and a degraded geomembrane liner. However, the cumulative distributions for both present-day and future conditions are generally below the maximum hydraulic conductivity value of $1x10^{-7}$ cm/s as prescribed in 40 CFR 264.301. The probabilistic results shown in Figure 2 indicate that there is no risk under present-day conditions that the percolation through the cover will exceed the regulatory requirement for maximum hydraulic conductivity, but this risk increases to approximately 5% for future conditions (we assume a unit gradient, making the percolation flux and hydraulic conductivity equivalent).

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

Carsel, R. F. and R. S. Parrish, 1988, Developing joint probability distributions of soil water retention characteristics, *Water Resources Research*, Vol. 24, No. 5, pp. 755-769.

Daniel B. Stephens and Associates, Inc., 1993, Laboratory analysis of soil hydraulic properties of Monticello remedial action project samples, Albuquerque, New Mexico.

Owenby, J. R. and D. S. Ezell, 1992, Monthly station normals of temperature, precipitation, and heating and cooling degree days 1961-90 Utah, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Asheville, NC.

Waugh, W. J. and K. L. Petersen, 1994, Paleoclimatic data application: long-term performance of uranium mill tailings repositories, in Proceedings of "Climate Change in the Four Corners and Adjacent Regions: Implications for Environmental Restoration and Land-Use Planning," CONF-9409325, Grand Junction, CO, Sep. 12-14, 1994.