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Project Summary

Estimating Leachate Production from Closed Hazardous Waste Landfills

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Hazardous wastes disposed of in landfills may continue to drain for several years after site closure. Leachate sources include waste fluids as well as precipitation trapped in the landfill during construction and operation. Waste fluids may be released via barrel degradation and subsidence and/or compression of waste materials. Water may also continue to enter the landfill through structural faults. Predictions of rates and amounts of leachate produced can be developed if the hydraulic parameters and/or specific-yield values for the hazardous waste and backfill materials are known.

A literature search showed that limited hydraulic parameters and specific-yield information are available. Unit-gradient and specific-yield modeling approaches were evaluated for use at hazardous waste landfills. Specific yield was determined for three data sets: one collected by a commercial hazardous waste landfill operator and provided by the state regulatory agency, one collected by the authors at a hazardous waste site located in New York State, and one developed from physical models where drum arrangement, void volume, and soil type were varied.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Leachate levels rise in closed hazardous waste landfills as waste materials dewater and as precipitation trapped during construction and operation drains under gravitational influences. This leachate collects on top of the liner and is pumped or drained by gravity via leachate collection systems. Under regulations developed pursuant to the Resource Conservation and Recovery Act (RCRA), the depth of leachate in the cell above the liner should not exceed one foot (approximately 30 cm). Should the cover or liner not be functioning properly, additional fluid may enter the landfill. When leachate in the cell lies above the 30-cm standing level, operators will be required to pump or drain the cell until the guideline level has been achieved. If models can be developed to estimate the fluid drainage rate from a properly functioning closed landfill, deviations from the predicted leachate drainage rate may be used as indicators of cover or liner performance.

Previous work on leachate production from municipal solid waste landfills has emphasized the concept of field capacity to determine the amount of leachate produced. Field capacity is defined as the amount of water retained by a porous material after gravity drainage ceases and downward water movement becomes negligible; therefore, in closed landfills where the waste is saturated, field capacity refers to the moisture content after the landfill has drained. Hence, the maximum volume of fluid that may drain from a closed landfill is the difference between the saturated porosity and the field capacity and is denoted as the specific yield or drainable porosity. The specific yield, therefore, is essential in determining the total amount of leachate that may be drained from a landfill.

Procedures

This project was divided into three main tasks: 1) assess the availability of data concerning the hydraulic properties of waste and backfill material, 2) review the conceptual models applicable to investigating the drainage characteristics of wastes and soil in a landfill environment, and 3) select and test an appropriate conceptual model to estimate leachate production from typical hazardous waste landfills.

Waste Properties

Information on hydraulic properties of wastes and soil drainage were found in the literature from a wide range of disciplines (e.g., chemical, civil, agricultural, and geotechnical engineering; biology; geology; soil physics; and soil chemistry). A comprehensive literature review was made using computer-assisted data bases. The data bases included NTIS (for government research reports), COMPENDEX (for engineering documents), and BIOSIS (for biological and environmental publications). Key words, such as landfill, drainage, landfill cells, liner, leachate, conductivity, and permeability were used to identify titles and abstracts applicable to this study. In addition, owners and operators of hazardous waste landfills were contacted to determine their disposal techniques and types of waste forms handled at the facility. Results of this literature review are summarized in Table 1.

Conceptual Models

Simplifying the assumptions about the complexity of leachate flow through the wastes was necessary in order to model the behavior of hazardous waste landfills. The two major assumptions made for this analysis were that 1) all liquid flow is vertical and 2) the hydraulic properties of the waste materials are uniform throughout the landfill.

The first major assumption that reduces the flow geometry from three dimensions to a one-dimensional (1-D) analysis is dictated by the increased complexity and computational costs associated with 2-D and 3-D flow models. Although landfills are 3-D in nature, the assumption of flow only in the vertical direction may be valid for landfills of regular geometry receiving uniform areal recharge. The assumption may not be valid in landfills where surface soils (covers or daily backfill) or surface slopes result in increase of runoff in certain areas of the landfill and ponding of precipitation in others. In addition, horizontal hydraulic gradients at the landfill sidewalls or the presence of a shallow water table may produce significant components of horizontal flow.

The second major assumption of uniform hydraulic properties ignores the effects of the heterogeneity of the waste. Typical hazardous waste landfills in the United States handle a wide variety of solid wastes ranging from contaminated soils and sludges in bulk form to drummed waste and polychlorinated biphenol-contaminated transformers. In addition, soil material is often placed between the layers of drums to allow vehicle movement within the landfill cell during operation. Modes of deposition of the wastes range from neat upright or horizontal placement of drums and careful mapping of their location to haphazard disposal of drums and containers by dragline or overhead crane. Bulky waste material is often dumped and spread by bulldozer or front-end loader.

In performing this project, the focus was not on a complete description of fluid movement throughout the cell, but on that amount of fluid draining to the leachate collection system. The effect of the leachate collection system is to average the local drainage from various portions of the cell. In similar problems of agricultural drainage, simplified models of flow mechanisms can be employed because the details are lost in the process of averaging over large areas. As a result of a review of the available research on flow in hazardous waste cells, two types of modeling approaches were chosen for application: unit gradient and specific yield.

The unit gradient approach is applicable to soil or bulk waste cells (i.e., those cells receiving a uniform, soil-like waste material). Such wastes might be found at private generator/disposer sites where cells are used strictly for a specific kind of waste. These waste types would be expected to behave like soils, and drainage from these materials has been analyzed as such.

The second approach is for landfill cells that may not contain primarily soil-like material. Currently, many commercial waste sites dispose of drummed, solidified waste. Leachate will be stored in the large voids between the drums as well as in the pore spaces of any back-filled soil. In most cases, the large voids will contain the most leachate. Under drainage conditions, these large voids will easily dewater, leaving the leachate in the back-filled soil behind. The concept of free-draining pore spaces (voids) can be used to model fluid drainage in drum disposal cells.

Using the assumption that the porous material has sufficient time to drain to near equilibrium, the specific yield is given by the following equation:

$$Sy = \frac{Q}{LFV}(100) \qquad (1)$$

where Sy is the specific yield, Q (m^3) is the amount of leachate pumped out of the landfill, and LFV (m^3) is the volume of landfill drained.

The models evaluated represent simplified conceptual models of hazardous waste landfills. Under actual field conditions, no one model may be completely applicable. The models chosen are designed for use under a variety of landfill configurations and waste types. Table 2 (see page 6) outlines the key points of the models and the typical data needed for their application.

Selected Methodology

The models described were incorporated into a methodology or decision tree analysis that may be used to estimate the leachate production from a closed landfill. Figure 1 shows the major components of the decision tree analysis. This analysis is designed to be applicable to a wide variety of closed landfill cells. The methodology begins with the first question of: What type of wastes are in the landfill? Based on discussions with operators and regulators, landfills were found to be composed of 1) primarily bulky, soil-like waste (e.g., fly ash, contaminated soil, metal hydroxide sludges), 2) drummed or containerized waste with small amounts of backfilled soil, and 3) mixtures of bulky and drummed waste. All subsequent analysis in the methodology requires that this information be known. The second question is How much leachate (saturated thickness) lies above the landfill liner? RCRA guidelines state that the level of leachate shall not exceed 1 foot (approximately 30 cm) above the liner. Once these questions have been

Table 1. *Reported Hydraulic and Geotechnical Properties of Hazardous Wastes*

	Saturated parameters			Partially saturated parameters					Consolidation parameters			
Waste type	K_{SAT} (cm/s)	Porosity	Compacted density (kg/m^3)	K(θ)	θ(H)	θRES	Field Capacity	Grain size data	C_v (cm^2/s)	E(σ)	% Vol reduction	Shear strength data
Municipal waste		50%					45%					
Municipal waste			340.0				10-14%					
Papermill sludge	1.0×10^{-4} 1.0×10^{-8}											
Flue Gas Desulfurization (FGD) sludge	1.0×10^{-4} 1.0×10^{-6}									X		X
Solvay soda ash sludge			2.71*					X	2.87#	X		X
FGD sludge		46-57%	1040-1280					X		X		X
Municipal waste							20-35%			X		
FGD sludge	1.0×10^{-2} 1.0×10^{-5}		2.72-2.52*						0.75-1.05#			X
Lead/zinc mill tailings	3.4×10^{-6} 5.0×10^{-5}	41-57%	2.88-3.02*					X				
Uranium mill tailings	2.2×10^{-4}	44%	1.63**									
Municipal waste				X	X		30-40%					
Uranium mill tailings												
Coarse	6.3×10^{-3}	43.3%	1.48-1.57**	X	X	7.6%		X				
Medium	2.3×10^{-3}	45.8%	1.28-1.50**	X	X	9.0%		X				
Fine	6.7×10^{-7}	66.0%	0.90-1.10**	X	X	31.0%		X				
Fly ash	8.3×10^{-3} 5.0×10^{-2}		0.99-1.50**	X X	X X							
Municipal waste							Bulk density versus field capacity data					
Municipal waste			287.0				28.6%					
Spent oil shale										X		X
Municipal incinerator residue	$4.1\text{-}6.9 \times 10^{-5}$											
Phosphate tailings	1.2×10^{-4} 2.0×10^{-5}											
Coal mine wastes	1.4×10^{-3} 7.22×10^{-5}											
Waste clays from phosphate mining	1.0×10^{-4} 1.0×10^{-8}								$1.0\text{-}6.0 \times 10^{-4}$			
Fly ash/soil mixture	1.0×10^{-3} 1.5×10^{-6}											
Red mud (aluminum tailings)	$1.2\text{-}20 \times 10^{-7}$								$0.09\text{-}6.9 \times 10^{-2}$			

*—particle density **—bulk density
#—compression index X—data not readily available

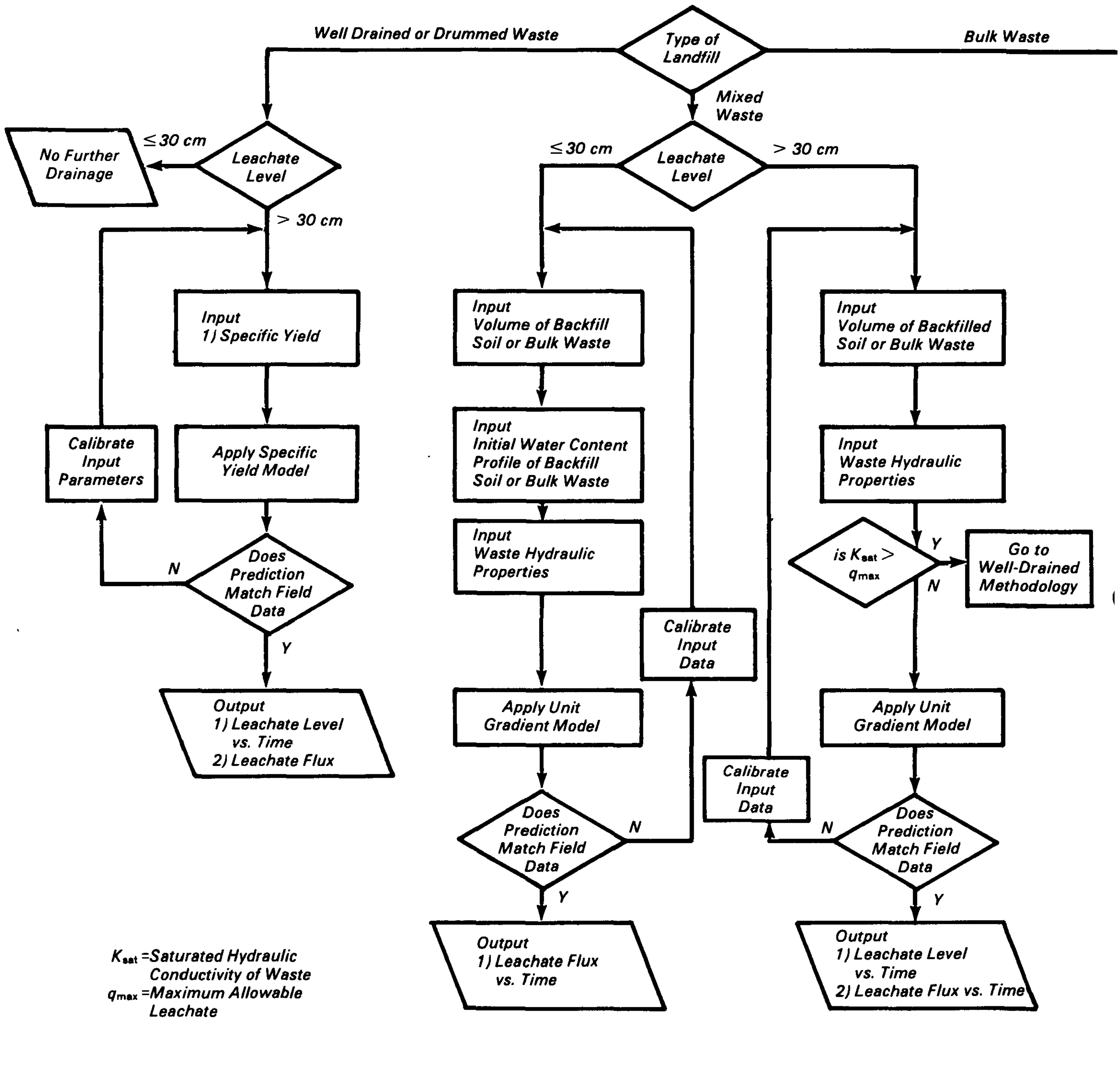
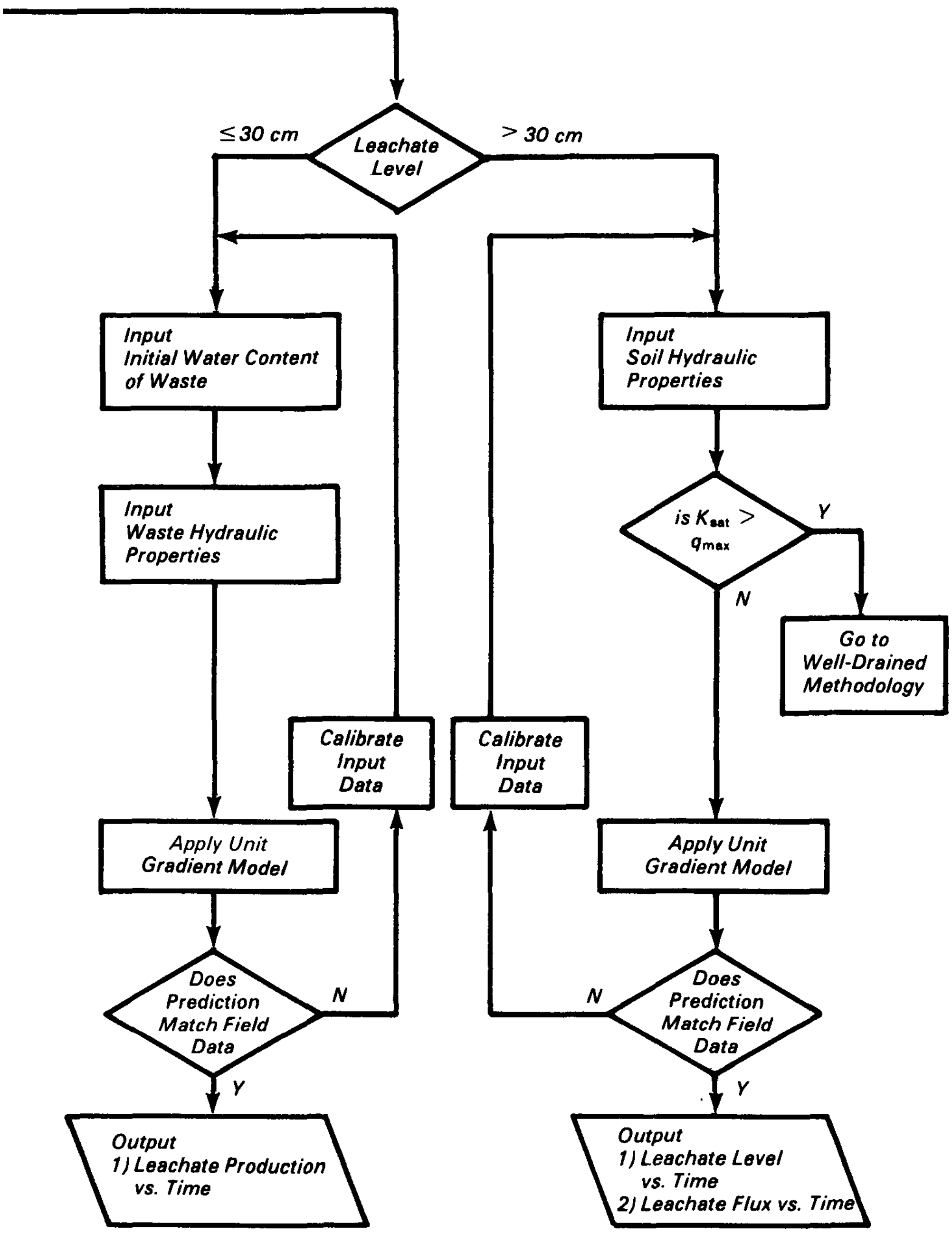


Figure 1. *Decision tree analysis to determine leachate production from closed landfills.*



answered, data must be assembled on the hydraulic properties of the waste. The properties needed for the analysis depend on the answers to the first two questions.

After the landfill parameters have been identified, the user must decide whether the initial flow rates predicted by either model will exceed the capacity of the leachate collection and treatment system. This decision is based on a comparison of the leachate flux (saturated hydraulic conductivity • head • area) of the waste to the designed leachate collection/treatment capacity. If the leachate flux of the landfill exceeds the capacity of the system, then the leachate production rate will be limited by the system capacity. If this product is less than the system capacity, the production rate will be controlled by the hydraulic properties of the waste. At this point in the decision tree, the proper model is applied to the site data, and leachate production is predicted. If field data on leachate production are available, these are compared to the predicted results and the model may be calibrated to better predict long-term leachate production.

Discussion

In this study, specific yield was determined for three data sets: one collected by a commercial hazardous waste landfill operator and provided by the state regulatory agency; one collected by the authors at the Glen Falls, New York site; and one developed from physical models where drum arrangement, void volume, and soil type were varied.

Commercial Site

The commercial site cells are excavated in native clay and lined with both compacted clay and flexible membrane liners. Data collected for one of the cells at the site were analyzed. The cell is divided into five subcells; each subcell is hydraulically separated using clay berms to allow for the segregation of specific materials.

The data collected by the site operators consisted of daily leachate level measurements in standpipes for each subcell and monthly total leachate volumes pumped from each cell. Two leachate levels were recorded for each day for each subcell; the level before pumping and the level measured immediately after pumping stopped. Leachate levels were measured in standpipes using a weighted string, and pumping

Table 2. Summary of Conceptual Models

Model	Application	Resulting Data
Unit Gradient		
a) deep water table	*Bulk waste forms, known hydraulic properties, uniform initial water content profile, deep landfill*	*Drainage flux versus time, water content profile versus time*
b) shallow water table	*Same as above except shallow landfill*	*Drainage flux versus time, water content profile versus time*
Specific Yield	*Unknown hydraulic properties, drummed or rapidly draining waste forms*	*Leachate level versus time*

volumes were measured using totalizing flow meters.

Specific yield was calculated over two time periods. The first time period was from September 1982 to September 1983, the second from October 1983 to January 1984. The first of these periods reflects the time during which a temporary cover was in place. The second period is after final cover placement. Cover integrity and collection system efficiency can be determined by examining data from these time periods.

Using Equation 1, the results of these analyses indicate that the specific yield was 6.6% during the first time period and 11.0% during the second time period. The increase in specific yield (after the final cover was installed) tends to indicate that the temporary cover was as effective in reducing infiltration as the final cover.

Glen Falls Site

An existing hazardous waste site in New York State was selected for installation of an automated water level recorder to help determine a typical specific yield value for mixed waste. The automated water level recorder was used to determine the changes in water level associated with leachate removal. This waste site had an ineffective clay cap, which was scheduled for replacement during the summer of 1985. The liner was constructed from two layers of clay separated by gravel with a leak detection system located in the gravel. No detectable leakage from the waste site had occurred. At the end of August 1984, a leachate level of 3.6 m was observed above the top clay liner. The leachate level was monitored as leachate was removed from the waste site in 25.0 m^3 increments.

The calculated specific yield for the Glen Falls Site was 18.0%. However, calculation of the precipitation entering the wastes through the cover indicates that as much as 52% of the leachate pumped may have been contributed by sources outside of the landfill. This being the case, the specific yield would decrease to 8.0% for the Glen Falls Site.

Physical Models

Physical models were constructed to represent various configurations of hazardous waste and backfill materials. Drum arrangement, void volume, and soil type were evaluated by simulating a section of landfill containing 8 to 10 drums, each 0.21 m^3 in volume, and backfill soil material. For each physical model constructed, the drum volumes and large interdrum void spaces were calculated. Drainage was measured by continuously weighing the entire model. Drainage rates from the physical model were restricted by the outflow pipe conductivity and the soil column flow resistance. Drainage rates at any time were determined as a function of the outflow pipe resistance, treatment-dependent soil resistance, and hydraulic head of the saturated soil column in the model.

The specific yield for the entire tank measured for each treatment is dependent on the presence of large void space, soil volume available for drainage, soil drainage characteristics, and the amount of soil column discontinuties introduced by large void spaces. Values are presented in Table 3 for total drainage, drum volume, void volume, specific yield, maximum drainage rate, and time required for the drainage rate to decrease below an arbitrarily chosen flux of 5.46×10^{-4} cm/s for each treatment. Calculation of specific yield for all treatments was based on Equation 1 where Q is the average leachate volume drained from that treatment and LFV is the filled volume of the tank.

Conclusions and Recommendations

Based on the results of the research, it is apparent that numerical and analytical models are either too complex or require characterization data that are not currently available. Even the application of the specific yield model requires generally unavailable information about the volumes of drainable large voids, specific yield or water retention, and hydraulic conductivity values for the backfill material and the volume of nondraining solids at hazardous waste landfills.

Very few values of specific yield have been reported for either nonhazardous or hazardous waste sites. Estimates of specific yield can be determined from single withdrawals of leachate from a waste site if care is taken to account for possible infiltration of precipitation or changes in barometric pressure during measurements of leachate levels. It is highly recommended that leachate levels be monitored with an automatic data collection system for several days before and after each leachate withdrawal. The data collection system should also record barometric pressure, temperature, and precipitation data.

The effect of drum arrangement, void volume, and soil type on specific yield were examined in a physical model. Values of specific yield were shown to be most sensitive to the presence of large voids. The effects of soil type on drainage rates and specific yield were also observed; fine soil retained more water and had lower drainage rates. The presence of nondraining solids generally reduced the drainage rate.

Because useful information is currently not available for existing hazardous waste sites it is recommended that a protocol be established that requires careful characterization of waste sites as they are built. Because site failure is always a possibility, site characterization information describing all aspects of waste form, placement, and burial should be part of the site history. Only if landfill design and waste handling information is available, can reasonable predictions of leachate production be made without extensive assumptions or potentially dangerous site characterization investigations to estimate the specific yield of the hazardous waste landfill under study. It is

Table 3. Physical Model Results

Treatment	Average Drainage (kg)	Drum Volume (m^3)	Large Void Volume (m^3)	Specific Yield Tank	Maximum Drainage Rate (cm/s)	Time Elapsed Until Drainage Falls Below 5.46×10^{-4} cm/s (min)
Sand, No Drums	987.2	-0-	-0-	0.24	4.46×10^{-2}	105
Sand, Single Layer, No Voids	430.2	2.08	-0-	0.11	1.74×10^{-2}	47
Sand, Vertical, Voids	666.0	1.87	0.35	0.17	2.90×10^{-2}	37
Sand, Vertical, No Voids	536.4	1.87	-0-	0.13	2.06×10^{-2}	50
Sand, Single Layer, Voids	1130.5	2.08	0.77	0.28	6.52×10^{-2}	26
Sand, Double Layer, No Voids	467.4	1.98	-0-	0.12	2.38×10^{-2}	51
Loamy Sand, Single Layer, No Voids	238.8	2.08	-0-	0.06	8.92×10^{-3}	202
Loamy Sand, Single Layer, Voids	1125.0	2.08	0.90	0.28	4.67×10^{-2}	38

recommended that a new research effort be initiated to define acceptable construction and as-built reporting criteria for all new hazardous waste landfill construction. Once the reporting criteria are established, procedures for prediction of leachate production can be developed for use by landfill operators and regulatory agencies.

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***Jonathan G. Herrmann** is the EPA Project Officer (see below).*
The complete report, entitled "Estimating Leachate Production from Closed Hazardous Waste Landfills," (Order No. PB 86-207 503/AS; Cost: $11.95, subject to change) will be available only from:
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