United States
Environmental Protection
Agency

Research and Development

Hazardous Waste Engineering
Research Laboratory
Cincinnati OH 45268

EPA/600/S2-87/050 Apr. 1988

EPA

Project Summary

Verification of the Hydrologic Evaluation of Landfill Performance (HELP) Model Using Field Data

P. R. Schroeder and R. L. Peyton

The study described was conducted to verify the lateral drainage component of the Hydrologic Evaluation of Landfill Performance (HELP) computer model using laboratory drainage data from two large-scale physical models of landfill liner/drainage systems. Drainage tests were run to examine the effects that drainage length, slope, hydraulic conductivity and depth of saturation have on the lateral drainage rate. The drainage results were compared with HELP model predictions and numerical solutions of the Boussinesq equation for unsteady, unconfined flow through porous media.

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).

Purpose and Scope

This study was performed to verify Version 1 of the Hydrologic Evaluation of Landfill Performance (HELP) model using existing field data. Mathematical simulations of 20 landfill cells at seven sites across the United States were made using the HELP model and were compared to measured field data. Measurements of leachate drainage were available from all 20 landfill cells, while data on runoff were available only from about half of the cells. Measurements of percolation were available only from one cell and no data on evapotranspiration were available. These landfills included a wide variety of conditions for which the HELP model was tested. The cells ranged in size from 0.04 to 24 acres and the simulation periods ranged from 2.5 to 8 years. This report summarizes the results of these simulations and evaluates the verification that has been achieved. In addition, the report presents a sensitivity analysis for the input parameters used in the HELP model and a review of landfill design regulation and guidance in light of the results of the verification studies and sensitivity analysis.

The HELP model was developed to help hazardous waste landfill designers and evaluators estimate the magnitudes of components of the water budget and the height of water-saturated soil above barrier soil layers (liners). This quasi-two-dimensional, deterministic computer-based water budget model performs a sequential daily analysis to determine runoff, evapotranspiration, percolation, and lateral drainage for the landfill (cap, waste cell, leachate collection system, and liner) and obtain estimates of daily, monthly, and annual water budgets. The model does not account for lateral inflow or surface runon.

The HELP model computes runoff by the Soil Conservation Service (SCS) runoff curve number method. Percolation is computed by Darcy's law, modified for unsaturated flow. Lateral flow is computed by a linearization of the Boussinesq equation, and evapotranspiration is determined by a method developed by Ritchie. The vertical percolation and evapotranspiration components of the HELP model originated with the Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model. The development presented here, however, reflects a significant advance beyond the CREAMS model in both of these areas.

In the course of the development of any model, provisions should be taken to verify that the model accurately represents reality. Laboratory tests have been performed to verify the lateral drainage portion of the HELP model, but prior to this study the other portions of the model had only been calibrated and not verified. This report presents the results of efforts to verify the model using existing data collected at landfills, test cells, and lysimeters.

This study consists of three parts. The main part is an attempt to verify the model using existing data. The purpose of this part was to assess the adequacy of the model to simulate reality and to validate the use of the model to evaluate designs (generally with minimum information). The second part of this study is a sensitivity analysis of the principal input parameters used in the HELP model. The purpose of this part was to determine which parameters need to be well-defined and what are the likely effects of a change in the value of a parameter. This analysis also provided much insight for interpreting and explaining the verification results. The third part of the study consists of an evaluation of the technical guidance developed to support the regulations regarding design and operation of a landfill. The purpose of this part was to examine the results of the laboratory and field verification studies and the sensitivity analysis to determine whether the technical guidance was practicable and achieved its objectives (particularly that of minimizing potential percolation through the liner at the base of the landfill) in the best practicable manner.

Field Verification

Comparisonswere performed between simulations and measured field data for seven sites:

(1) *University of Wisconsin-Madison.* From 1970 to 1977, eight large lysimeter cells filled with either shredded or unprocessed refuse were monitored for surface runoff and leachate production. The general purpose of the study was to determine the effect on landfill performance of shredding the refuse prior to placement and covering the refuse with a soil layer.

(2) *Sonoma County, CA.* A solid waste stabilization project was sponsored by the U.S. Environmental Protection Agency and Sonoma County, California from 1971 to 1974. The purpose of the project was to investigate the stabilization of solid waste in five municipal sanitary landfill test cells by analyzing leachate, gas, temperature, and settlement parameters and to determine the effect on solid waste stabilization of applying excess water, septic tank pumpings, and recycled leachate. Leachate production was measured for all five cells and runoff was measured from three of the cells.

(3) *Boone County, KY.* Two field-scale test cells and three small-scale cells were studied from 1971 to 1980 in Boone County, Kentucky under the sponsorship of the U.S. Environmental Protection Agency. The study objectives were to evaluate the amount and characteristics of leachate, the composition of gases, the temperature conditions, the settlement of the cells, the clay liner efficiency, and to compare the behavior between the field-scale and small-scale cells. The data collected from one of the field-scale cells was used in this study.

(4-6) *Brown, Eau Claire, and Marathon Counties, WI.* The State of Wisconsin Bureau of Solid Waste Management has reported on the geologic setting, major design features, construction experience, leachate production and operational performance of these three large landfills in Wisconsin. These landfills were started between 1976 and 1980; however, none of these landfills has yet been completely filled and capped so that each data set reported thus far represents the conditions of a continuously expanding landfill. For example, at any given time, the cover could range from the daily cover of a 6-inch-thick blanket of sand or silty clay to a final cover of clay and topsoil.

(7) *Niagara Falls, NY.* Since 1976, a chemical waste management company has filled and capped three landfill cells in Niagara Falls, NY. The surface areas of the cells range from 2 to 5 acres. Records of leachate pumpage have been kept from 1983 and indicate annual withdrawals ranging from 1 to 11 inches. An evaluation of the performance of the facility during 1984 was reported to the USEPA Region II by Recra Research, Inc.

The data used in the simulations were obtained from a variety of sources. In most cases, daily rainfall and monthly temperature data were obtained from the nearest National Oceanic and Atmospheric Administration weather station. Solar radiation values stored in the HELP model were used for all simulations. Model input values for design data and soil and waste characteristics were determined from published reports describing the construction and operation of each landfill. In general, the information available on soil and waste characteristics, surface vegetation, runoff curve numbers, or evaporative depths was descriptive and sketchy, not quantitative; therefore, extensive use was made of default values stored in the HELP model.

The measured data used for comparison with the HELP model simulations were primarily lateral leachate drainage volumes. Measured runoff data was available from 11 landfill cells. Barrier soil percolation was measured at one landfill, although its suitability for model verificaiton was limited. The measured data from very similar cells at the same landfill varied greatly from cell to cell. For four practically identical cells the range in total runoff was about 50 percent of the mean total runoff, and for lateral drainage the range was greater than 100 percent of the mean.

Runoff

Measured runoff data existed for eight cells at the University of Wisconsin and for three cells at Sonoma County, CA. Runoff was overpredicted for five cells by an average of 30 percent of the measured runoff, and underpredicted for six cells by an average of 20 percent of the measured runoff. Overall, runoff was overpredicted by 3 percent. Following these initial simulations, the curve numbers were varied to determine their effect on the overall model prediction of landfill performance. Five simulations were improved by a change in curve number—all had originally underpredicted runoff.

For the three cells at Sonoma County, it was obvious that the evapotranspiration and/or soil characteristics were controlling runoff volume and not the curve number. Because of this close interaction, it was difficult to assess the accuracy of the curve number method in the HELP model based on the field data in this report. However, the predicted runoff volumes appear overall to be in reasonable agreement with the measured results.

A comparison of measured and predicted runoff on a monthly basis for the University of Wisconsin cells indicated that the assumptions used in the HELP model for snowmelt runoff may not be appropriate. The model stores all precipitation on the surface when the mean daily temperature interpolated from the mean monthly temperature is below freezing. When this mean daily temperature rises above freezing, the precipitation is allowed to either run off or infiltrate. Since mean daily temperatures are computed in the HELP model based on mean monthly temperatures which are generally below freezing in Wisconsin for several consecutive months, no runoff was predicted by the HELP model during the winter. Instead, a large runoff volume was predicted during April of each year when temperatures warmed. This compared to measured results which showed significant runoff throughout the winter without an excessively large runoff in April. This discrepancy probably contributed to the overprediction of runoff for several cells.

Evapotranspiration

No suitable evapotranspiration field data from landfill sites was found for model testing. This was not unexpected due to the complexities involved in collecting this type of data. Yet, evapotranspiration is typically the single largest outflow component of the landfill system; therefore, small changes in evapotranspiration can have major impacts on volumes of lateral drainage and barrier soil percolation.

For those cells which had runoff data available, a surrogate variable for evapotranspiration was identified, and comparisons were made between measured and predicted results. The variable consisted of the sum of the water balance components which were not directly measured. In the case of the University of Wisconsin cells, the variable was the sum of evapotranspiration and change in moisture storage, ET+DS. For the Sonoma County cells, it was the sum of evapotranspiration, change in moisture storage, and percolation, ET+DS+PERC. The ET+DS variable was found to be underpredicted by an average of 4 percent of the measured values, whereas the ET+DS+PERC variable was underpredicted by an average of 25 percent. It is obviously rather complex to discern the meaning of these results since evapotranspiration, change in moisture storage, and percolation are all interrelated. The evidence suggests that values chosen for evaporative depths may have been too small.

Lateral Drainage and Percolation

Since measurements of barrier soil percolation volumes and leachate ponding depths were not available, the lateral drainage and barrier soil percolation submodel could only be evaluated using measured leachate collection data. One exception was the Boone County, KY cell where barrier soil percolation volumes were measured. However, the configuration of the clay liner and percolation collection pipe was such that vertical percolation did not actually occur; rather, the percolation flow paths were forced to converge radially toward the collection pipe. The attmept to simulate this percolation using the HELP model resulted in an overprediction of approximately 35 percent.

Lateral drainage was overpredicted by 10 percent of the measured drainage in two cells where very high leachate collection rates were observed. In three cells where very small quantities of leachate were collected, lateral drainage was underestimated by 97 percent of the measured drainage, although this difference only amounted to 1.4 inches per year. Of the remaining nine cells, lateral drainage was overpredicted by an average of 4 percent of the measured drainage in five covered cells and overpredicted by an average of 53 percent of the measured drainage in four permanently uncovered cells with a weathered waste surface that supported dense vegetation. Small errors in the hydraulic conductivities of the cover soils can cause large differences in the leachate production when the leachate production is small. Also the overpredictions may have been partially related to the manner in which the HELP model estimates unsaturated hydraulic conductivities. To linearly relate unsaturated hydraulic conductivity to moisture content between field capacity and saturation tends to overpredict unsaturated hydraulic conductivity. Thus, moisture is routed more quickly through the evaporative zone, contributing to larger leachate volumes and smaller evapotranspiration volumes.

The poor reproductions of lateral drainage for the uncovered cells at the University of Wisconsin and the three cells without subsurface liquid addition at Sonoma County were probably caused by poor estimates of the hydraulic conductivity of the surface layer. The field results could be reproduced by adjusting only the hydraulic conductivity of the surface layer by less than a factor of 10, within the range of its probable value. This result is understandable since cumulative lateral drainage is dependent on two main factors: the rate of infiltration into the lateral drainage layer and the rate of percolation through the liner beneath the drainage layer. The rate of percolation was very small in these cells; therefore, the rate of infiltration was the source of error.

Summary

The lack of adequate site description and measured water budget components affected the verification study in two ways. First, the lack of descriptive landfill information required the frequent use of default values in the HELP model which introduced additional uncertainty into the verification. Second, the lack of water balance overflow measurements limited the number of HELP outflow predictions that could be verified. These limitations restricted the ability of the study to isolate and test mathematical characterizations of specific physical processes, such as soil mositure storage and routing, evapotranspiration demand and its distribution through the soil profile, unsaturated vertical drainage, and details of the apportioning of leachate production between lateral drainage to collection systems and vertical percolation through the clay liner.

In addition, the variable degree of field measurement precision and reliability presented challenges in interpreting the data which did exist. None of the field data used in this report were collected specifically for verifying the HELP model; therefore, the field data were not always consistent with the needs of this study. For instance, the data available for the three largest landfills were collected while they were simultaneously undergoing expansion. In other cases, there was large variability in measured results between otherwise identical landfill cells. In general, the error in estimates of water budget components were much smaller than the variability in the field measurements for similar landfill cells. These results are very good in light of the fact that the precipitation data used in this study, which is known to be spatially highly variable, were not measured at most of the landfill sites. All of this required a significant amount of engineering judgment in interpreting the data for the HELP model comparisons.

Although a detailed verification of specific model components was not always possible, the data did confirm the model's overall utility in estimating a landfill water balance even without extensive knowledge of specific landfill characteristics. This was an important finding since the HELP model is typically used without a large amount of detailed landfill information.

The following conclusions are made. The field data verified the utility of the HELP model for estimating general landfill performance. However, not all model components were well tested due to the limited field data available. It is concluded that a laboratory and field monitoring program explicitly designed for HELP verification would be necessary for further refinement of specific model components. In addition, studies are needed to examine lateral drainage and percolation for small infiltration rates and flow through synthetic liners and in leakage detection of double liner systems.

The overall data base of long-term water budget measurements at landfills is poorly organized and too small to continually advance the state of the art in understanding landfill leachate generation and migration. More extensive monitoring activities are required to fill this gap.

Improvements to the HELP model are warranted in the areas of snowmelt, winter runoff, unsaturated hydraulic conductivities, and the selection of evaporative depths based on the results of this study.

Sensitivity Analysis

A sensitivity analysis of the HELP model was performed to examine the effects of the major design parameters on components of the water budget for landfills. The analysis examined the effects of cover design, topsoil thickness, topsoil characteristics, vegetation, runoff curve number, evaporative depth, drainable porosity, plant available water capacity, hyhdraulic conductivity, drainage length, and liner slope on the water budget. Hydraulic conductivity values for the topsoil, lateral drainage layers and clay liners are the most important parameters in determining the water budget components. These parameters are particularly important in estimating the percolation through the landfill. Other design parameters tend to affect the apportionment between runoff, evapotranspiration and lateral drainage from the cover.

The interrelationship between parameters influencing the hydrologic performance of a landfill cover in the HELP model is complex. It is difficult to isolate one parameter and exactly predict its effect on the water balance without first placing restrictions on the values of the remaining parameters. With this qualification in mind, the following general summary statements are made.

The primary importance of the topsoil depth or thickness is in controlling the extent or existence of overlap between the evaporative depth and the head in the lateral drainage layer. Surface vegetation has a significant effect on evapotranspiration from soils with long flow-through travel times (low hydraulic conductivity) and large plant available water capacities; otherwise, the effect of vegetation on evapotranspiration is small. The general influence of surface vegetation on lateral drainage and barrier soil percolation is difficult to predict outside the context of an individual cover design. Clayey soils yield greater runoff and evapotranspiration, and less lateral drainage and barrier soil percolation. Simulations of landfills in colder climates and in areas of lower solar radiation are likely to show less evapotranspiration and greater lateral drainage and barrier soil percolation. An increase in the runoff curve number will increase runoff and decrease evapotranspiration, lateral drainage, and barrier soil percolation. As evaporative depth, drainable porosity or plant available water increase, evapotranspiration tends to increase while lateral drainage and barrier soil percolation tend to decrease; the effect on runoff is varied.

The sensitivity analysis shows that the ratio of lateral drainage to percolation is a positive function of the ratio of K_D/K_P and the average head above the liner. However, the average head is a function of Q_D/K_D and L/α. The quantity of lateral drainage, and therefore also the average head, is in turn a function of the infiltration. Therefore, the ratio of lateral drainage to percolation increases with increases in infiltration, and the ratio of K_D/K_P for a given drain and liner design. The ratio of lateral drainage to percolation for a given ratio of K_D/K_P increases with increases in infiltration and decreases in L/α. The percolation and average head above the liner are positive functions of the term L/α.

Review of Technical Guidance

The information from the sensitivity analysis and the verification results were used to evaluate RCRA landfill design guidance and regulation. This evaluation showed that saturated hydraulic conductivity is the most important design parameter for minimizing percolation. Care should be taken to recommend the highest hydraulic conductivity that is commonly available for drainage media. Similarly, the lowest saturated hydraulic conductivity practically obtainable should be used as guidance for soil liners. Changes in other design parameters yield much smaller effects on percolation or leakage volumes if the values of these parameters are kept in a reasonable range.

P. R. Schroeder and R. L. Peyton are with U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180.

***Robert Landreth** is the EPA Project Officer (see below).*

The complete report, entitled "Verification of the Hydrologic Evaluation of Landfill Performance (HELP) Model Using Field Data," (Order No. PB 87-227 518/AS; Cost: $18.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

☆U. S. GOVERNMENT PRINTING OFFICE: 1988/548-158/67117

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EPA/600/S2-87/050