EXPERIMENTAL EVALUATION OF 'HELPQ' LEACHEATE GENERATION AND QUALITY

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ABSTRACT. This study describes the verification of the Hydrologic Evaluation of Leachate Production and Quality (HELPQ) computer program using physical model comparisons. HELPQ facilitates the design of confined disposal facilities (CDFs) of contaminated dredged material by estimating leachate production rates and leachate quality. To verify the HELPQ model results, physical models of CDFs were constructed and experiments conducted. The quantity of leachate produced and the salinity results from the physical models were compared with the HELPQ model predictions. Salinity concentrations were used as a basis of water quality comparison between the physical models and HELPQ. The results indicate that the HELPQ model overestimated the leachate rates, as well as the salinity concentrations. The relative percent error between the HELPQ and physical models were 19% for the cumulative leachate collected and 23% for the cumulative mass of salt collected.

INTRODUCTION

The use of mathematical models requires field verification before they can be reliably applied to predict field situations. Unfortunately, contaminant data from CDFs are not available for verification of a numerical model that predicts leachate generation rates and quality over time. Hence, physical models may be used to verify certain aspects of the numerical model. Moreover, the dependence on salinity of the adsorption/desorption of contaminants in dredged material solids allows numerical models be verified for the leaching of salt as well as contaminants.

Objective of the Study

The main objective of this study is to verify the leachate generation rates, and concentrations produced by the HELPQ computer program (Aziz and Schroeder 1998) through the use of physical models. The specific objectives are:

(i) development, construction, and testing of a physical confined disposal facility model to predict the leachate quantity and quality in a dynamically similar prototype;
(ii) simulation of leachate generation and concentrations in CDFs using the HELPQ program; and
(iii) comparison of the physical and numerical models.

BACKGROUND AND RELATED WORK

Contaminated dredged material is often placed in a CDF to control the environmental impacts of the disposed material. Myers, et al. (1989) state that when contaminated dredged material is placed in a CDF, contaminants may become mobilized to form leachate that can be transported to the site boundaries by seepage. This occurrence can create the potential to contaminate adjacent surface and groundwaters. To predict and simulate contaminant movement in CDFs, it is necessary to implement mathematical models that incorporate site-specific hydrology, leachate production and transport mechanisms, and leachate quality data.

Water routing models in porous media based on mass balance are available to estimate leachate generation. Schroeder et al. (1994) developed a model for the U.S. Environmental Protection Agency (EPA) to compute the hydrologic water balance at and below the surface of landfills. The model, the Hydrologic Evaluation of Landfill Performance (HELP), is a quasi-two-dimensional, deterministic water budget model that uses soil, climatological, and design data to predict daily, monthly, and annual values of leachate generation. Since the model was developed for evaluating landfill performance, it offers additional features that are useful in CDF performance evaluation (Aziz and Schroeder, 1998). These features include the use of sand or gravel layers for lateral drainage and leachate collection, as well as clay and geomembrane layers for liners to minimize leachate migration. These features of the HELP model are used for the water balance components of HELPQ.

Numerical Modeling

Leaching can be defined as the interphase transfer of contaminants from waste material solids to the pore water surrounding the solids and the subsequent transport of these contaminants by pore water seepage. Therefore, leaching is an interphase mass transfer combined with porous media fluid mechanics.

HELPQ facilitates the design of CDFs of contaminated dredged material by estimating leachate production rates and leachate quality. This model was developed based on contaminant mass balance and utilizes the principle of conservation of mass as it applies to the sediment solids, the percolating fluid (leachate), and the contaminants dissolved in the fluid. The results of laboratory data analysis (Brannon et al.

1990) indicate that the desorption isotherms for estuarine sediments do not have a general trend similar to the traditional constant partitioning coefficients observed in fresh water sediments. The data, however, indicate that several contaminants behave in a manner related to their salt concentrations. It is therefore important to verify that the salinity is correctly being routed through the HELPQ model.

The hydrologic modeling for contaminant routing in the soil profile is composed of balancing the water budget at the ground surface and then routing the infiltrated water and the available contaminants throughout the soil profile. The HELP model is used for surface water hydrology, infiltration, and drainage in the soil. Contaminant routing in the soil profile relies heavily on the results of the subsurface water routing performed by the HELP model. Routing of contaminants begins after vertical drainage, lateral drainage, and soil moisture contents are computed. In lateral drainage layers, contaminants may leave the layer laterally to a drain, and hence outside the CDF, thus reducing the amount of contaminant entering the barrier soil liner and eventually contaminating the groundwater. When lateral drainage layers are used, lateral drainage occurs above the barrier soils. Therefore, lateral drainage in the contaminant routing model is taken into consideration in the mass balance for contaminants at the bottom of lateral drainage layers. The net result is a decrease in the amount of contaminants that may percolate into the underlying barrier soil.

Model output includes contaminant concentrations in the CDF profile, contaminant concentration and mass releases through the bottom of the CDF, and contaminant masses captured by leachate collection systems. The model also produces the salinity concentration of the leachate at every time step.

Physical Modeling

Physical models can provide insight to many engineering problems and provide a method of verifying numerical models. Physical models offer several advantages to the engineer (Sill 1980). These advantages include flexibility, visualization, and less dependence on empirically determined coefficients than numerical models. Physical models, when compared to numerical models, suffer several disadvantages as well. Physical models can be costly to construct, often require large amounts of floor space. and may also be very time consuming to the researcher. In contrast, an existing numerical model can give results much quicker than a physical model. Therefore, it is ideal to have a numerical model and a physical model to verify the accuracy of the data collected.

To collect accurate data in any type of physical model study, dynamic, geometric, and kinematic similitude must exist between the model and prototype. Geometric similarity is present when the scale of the geometry between the prototype and model is equal in all directions. Kinematic similarity exists when the motions of homologous particles in the model and the prototype lie at homologous points at homologous times. Dynamic similitude exists when homologous particles in the model and prototype experience similar net forces at homologous times. To actually achieve these similitudes, the model would have to be an exact duplicate of the prototype and the study would not be feasible.

PHYSICAL MODEL DEVELOPMENT AND EVALUATION

There were several steps in the development and evaluation of the physical model. This included selecting a suitable scale for the model, choosing proper model components that would be representative of an actual CDF, model construction, and lastly an analysis of the physical model.

The model components and scales were chosen to produce prototype values that were representative of a typical CDF. A time scale of one prototype year being equivalent to thirty minutes in the model was chosen along with a geometric scale of 1:25. The size of the model was based on convenience, and is 432 mm in length by 102 mm wide by 457 mm deep.

With the geometric scale being set at 1:25, the model would be representing a vertical slice of a confined disposal facility cell with the following dimensions: 10.80 meters long by 2.55 meters wide by 11.43 meters deep. Sand was used for the dredged material layer, aquarium gravel was used for the lateral drainage layer, and the barrier soil layer was constructed using a mixture of kaolin clay and sand. The hydraulic conductivity, porosity, and initial moisture content of each layer were all determined prior to model construction.

Precipitation Simulation

To verify the mathematical model, the same conditions that were entered into the mathematical model were incorporated into the physical model. One of the most important factors to be established was the amount of precipitation entering the model and the time at which it enters. To use the time scale that was previously chosen, low flow rates are required. A peristaltic pump, which provided the constant low flow rates desired, was used. A Masterflex 30 rpm pump drive was used in conjunction with two different pump heads, which allowed two simulations to be carried out concurrently. The two pump heads chosen produced flow rates of 84 mL/min and 26 mL/min.

Precipitation was dispersed over the surface of each model using a plastic tray with a pattern of drill holes. To prevent ponding in the tray, an initial quantity of precipitation was instantaneously added to the tray at the same moment that the pumped precipitation was added. This initial volume (500 mL) would thus initiate flow through all of the holes and would maintain an even flow distribution for the period of precipitation. The initial volume of water and the pumped precipitation were converted to depths and scaled to prototype values, using the geometric and time scales. The results were used as input for the mathematical model.

Leachate Quality

The electrical conductivity of the leachate was used as a gage of the leachate quality. The electrical conductivity is a measure of the ability of a solution to carry electric current. It is dependent on both the temperature of the solution and the total concentration of ionized substances dissolved in the solution. The electrical conductivity in the models was measured using a Corning Check Mate, model M90, conductivity probe.

The contaminant used in the dredged material of the model CDF was table salt. A salt calibration curve was determined to find the concentration of salt needed to achieve the initial electrical conductivity desired throughout the dredged material.

To achieve the desired initial electrical conductivity in the dredged material layer, the water added to reach the saturation moisture content was contaminated with a known quantity of salt. To determine the amount of water to add to reach the saturation moisture content, the volume of sand required to bring the depth to the desired level was calculated and then multiplied by the porosity.

Model Testing

The following steps were performed for testing the model.

1) The amount of water required to reach the saturation moisture content was measured into a large bucket. An additional measured quantity of salt was then added. An electrical conductivity reading of the "contaminated" water was then recorded.

2) The pore water was added to the model instantaneously and allowed to percolate until it reached the lateral drainage layer. During this time, the precipitation tray was placed atop the model and 1500 mL beakers were placed to collect the leachate.

3) The starting time of the experiment occurred when the front moving through dredged material reached the top of the lateral drainage layer. At this time, the initial precipitation of 500 mL, as well as the pumped precipitation were added to the tray simultaneously.

4) The leachate was collected in beakers and the time that each full beaker was replaced was recorded. This process was continued until the leachate quality within the beaker reached a pre-determined average value of less than 5 µS.

5) At this point, the pumped precipitation was stopped and the tray was removed. The model was then allowed to drain without precipitation for a time equal to approximately two leachate collection intervals.

At the conclusion of each physical model test, the leachate data recorded included the volume, electrical conductivity, and temperature of the leachate that were collected for each time interval.

The volume of leachate collected was scaled to prototype values using the geometric scale of 1:25. The electrical conductivity measurements were converted to salinity concentrations through the use of the salt calibration curve. The mass of salt that was collected was determined by multiplying the salt concentration by the volume of leachate collected for that time interval.

COMPARISON OF PHYSICAL AND HELPQ MODELS

Data from the physical experiments were compared to the results of simulations using the HELPQ model. The input for HELPQ includes scaled geometry and time.

HELPQ Input

Sixteen rainfall files were created representing each of the physical model tests. This was accomplished by converting the total precipitation added to the physical model into a depth and scaling this value to prototype value. These depths were then converted to daily rainfall amounts and were entered into the HELPQ model. The HELPQ simulation was conducted for a time period equivalent to the duration under each experiment was conducted. Therefore, each model has a time over which precipitation was applied and a time in which drainage due to gravity alone occurred.

Since the physical model tests were run in short periods of time (approximately three hours), it was assumed that there was no evapotranspiration. To achieve an evapotranspiration of zero, the most important factors to be entered into the HELP model are the wind speed and relative humidity. The wind speed was set at zero and the relative humidity was set at 100 percent, simulating an evapotranspiration rate of zero. It was also necessary to set the solar radiation to zero.

The hydraulic conductivity that was entered into HELPQ was found from the scaling relationships. The values of field capacity and wilting point that were entered in HELPQ were chosen from the default values (of typically encountered soils) in the program which were the closest to the soil that was being modeled. This was accomplished by comparing the hydraulic conductivity and porosity to default values in the model. The initial moisture content of the dredged material in the physical model was at saturation. To ensure that the proper flow characteristics were modeled, the saturation value for the dredged material layer was used as the initial moisture content in HELPQ. The wilting point value was used as the initial moisture content for the lateral drainage layer. In the physical model, the initial moisture content was the room dry moisture content, which is essentially zero.

HELPQ requires the user to define various geometric parameters of the CDF. These include the maximum drainage length, which was specified to be 35 feet, found by using the geometric scaling relationship. The slope of the drain was set at 2 %, which corresponds to the slope found in the physical model.

Within the HELPQ program, it is necessary to enter the contaminant data to be routed for each of the layers of the CDF. This data included are the leachate initial salinity, in parts per thousand. The value that was used for this parameter corresponded to the initial concentration of the pore water in the physical model.

The contaminant routing model was then executed. The program output consisted of the monthly values of lateral drainage collected and the salinity of the leachate.

Data Analysis

Plots were developed comparing the HELPQ model to the physical model in terms of cumulative lateral drainage versus time. Plots were also developed for the mass of salt collected versus time in order to compare the quality of the leachate produced from each model. The plots contain the data obtained from the physical model without dead space considered, the physical model with dead space considered, and the HELPQ results. These plots are shown below.

The comparison of the models indicates that the HELPQ over predicts both the quantity and quality of leachate collected. It was therefore necessary to consider the influence of dead space (fraction of permanent volume that does not mix with the influent concentration) within the physical model, as only a small portion of the model was actually being affected by the precipitation, due to the precipitation tray configuration.

Sensitivity Analysis. Sensitivity analyses were performed on HELPQ to determine what effects the field capacity and porosity had on the cumulative mass of salt collected. It was determined that the field capacity did not have an effect on the results. Yet, the porosity, η, did have a measurable effect on the results when values of 0.4, 0.5, and 0.67 were used for the dredged material layer. The cumulative mass of salt collected is the greatest when η equals 0.67, and is lowest when η equals 0.40. The HELPQ results more closely fit the physical model results for this study when η is in the range of 0.4 to 0.5. It is therefore important that the researcher measure the value of porosity as accurately as possible.

CONCLUSIONS

The conclusions of this study can be summarized as:

(i) HELPQ over predicts the quality and quantity of leachate discharging from the lateral drainage component as compared to the results of physical models;

(ii) the HELPQ results are more comparable to the laboratory results when considering dead space within the physical model; and

(iii) the sensitivity analysis on the values used in HELPQ indicate that the results are very sensitive to porosity and negligibly effected by the field capacity of the media.

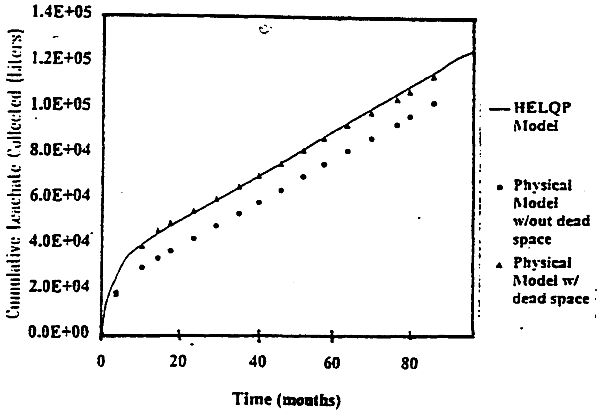

Figure 1. Total leachate collected for Model 14 (Low Flow).

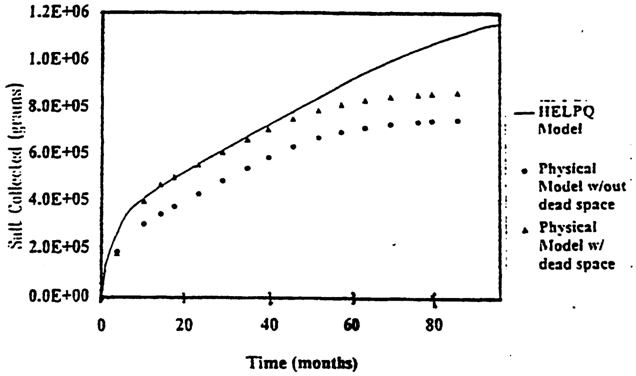

Figure 2. Total salt collected for Model 14 (Low Flow).

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