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Calibration and Testing of Simulation Models for Evaluation of Trench Cap Designs

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ABSTRACT

A prototype decision support system (PDSS) using multi-objective decision theory and embedded simulation models is being developed to evaluate landfill cover designs for low-level radioactive waste disposal sites. To evaluate the performance of the PDSS, the simulation models, which are used to parameterize the decision model when data are not available, must be calibrated and tested. The two linked simulation models embedded in the PDSS are the HELP (hydrologic evaluation of landfill performance) and CREAMS (chemicals, runoff, and erosion from agricultural management systems) models. Data from a field demonstration study at Hill Air Force Base were used to calibrate the simulation models. The models were calibrated using water balance and erosion parameters for two alternative designs, a control soil cover and a modified USEPA Resource Conservation and Recovery Act design. Simulations were run using the calibrated model parameters for a 200-yr period to evaluate the long-term performance of the models. The progressive annual average for all of the output parameters was within the 95% confidence limits of the long-term mean by Year 60 for both of the cover designs evaluated. The results of the calibration and long-term evaluation of the simulation models were reasonable for the length of the data set. To fully validate and test the simulation models, other data sets of landfill covers in a variety of climates are needed.

A PROTOTYPE DECISION SUPPORT SYSTEM (PDSS) is being developed to evaluate alternative trench cap designs for shallow landfill waste disposal sites. The major components of the PDSS are simulation models, a decision model, default data bases, input file generators, output interpreters, and a system driver (Paige et al., 1996). The intended uses of the PDSS are: (i) to aid the risk manager (user) in selecting the parameters needed by the simulation models for different capping alternatives, and (ii) to use the output of the simulation models as input to the decision model to choose the most appropriate trench cap design for a given situation. The ability to evaluate the environmental and economic effects of a particular trench cap design often requires the use of sophisticated models. These models simulate the availability and movement of water, the potential for contaminant transport, and the long-term viability of the cap, as well as the immediate and long-term economic costs. To use these models as management rather than research tools, a framework around the simulation model is being developed to aid the risk manager in evaluating alternatives and supporting decisions. Included in the framework for the PDSS are: (i) a method to quickly determine realistic parameters of the model for a given location by linking it to a database and, (ii) a structured output of the simulation models to help the decision maker–risk manager decide on the proper course of action.

The decision model component of the PDSS, based on multi-objective decision making theory, evaluates a suite of alternatives using a set of decision criteria (e.g., percolation, erosion, cost) selected by the decision maker or determined by federal regulation. Scoring functions (Wymore, 1988) are used to scale the decision criteria to a common unitless 0 to 1 scale. The scoring functions are parameterized using the annual values of the conventional design or practice for each decision criteria (Yakowitz et al., 1992). The annual average of the conventional design automatically scores 0.5 as the baseline value. The alternative designs are then scored relative to the conventional using their annual average value for each decision criteria. The importance order of the decision criteria can be determined either by the decision model, using the slope of the scoring function, or by the user. The total composite scores for each of the alternatives for a given importance order are determined by an optimization technique and then ranked by their composite scores (Yakowitz et al., 1993). The alternative with the highest composite score is considered to be the *best* alternative among those being considered, given the importance order of the decision variables. A more detailed explanation of the decision model and the PDSS is given in Paige et al. (1996).

In the absence of actual field observations and data, a computer simulation model is used to predict the values of the decision criteria for a given site. The simulation models incorporated in the PDSS are the HELP (hydrologic evaluation of landfill performance) (Schroeder et al., 1988) model (version 2), which is used to simulate the trench cap water balance, and the CREAMS (chemicals, runoff, and erosion from agricultural management systems) (Knisel, 1980) model, which is used to simulate erosion of the trench cap. The two simulation models are linked so that the HELP model generates the hydrology file used by the CREAMS erosion model.

The ability to simulate the hydrology and erosion processes of a trench cap both in the short and long term is important for assessing the viability of alternative designs. The primary objective of the study was to calibrate and test the simulation models used in the PDSS to evaluate trench cap designs. The HELP and CREAMS simulation models were calibrated and tested using data from the Hill Air Force Base, Layton, UT, trench cap demonstration study (Hakonson et al., 1994). Long-term simulations using the calibrated model parameters were

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Abbreviations: PDSS, prototype decision support system; HELP, hydrologic evaluation of landfill performance; CREAMS, chemicals, runoff, and erosion from agricultural management systems; ET, evapotranspiration; FML, flexible membrane liner; SWRRB, simulator for water resources in rural basins; LAI, leaf area indices; CN, curve number; Hill AFB, Hill Air Force Base; RCRA, Resource Conservation and Recovery Act; CV, coefficient of variation.

run to evaluate the long-term performance of the models and to test the ability of the models to respond to the long-term variability in climate.

The results of both the model calibrations and the long-term simulations are presented herein. Descriptions and limitations of the simulation models, the field site, and the data used in the study are given. The method of model calibration and optimization and the results are discussed. Finally, the results of the long-term simulations are presented and evaluated.

SIMULATION MODELS

The HELP model is being used in the PDSS because it is easy to parameterize and is recommended by the USEPA for solid waste landfill design (Schroeder et al., 1984; U.S. Dep. of Energy, 1990). The model was developed by the U.S. Army Corps of Engineers Waterways Experiment Station for the USEPA Hazardous Waste Engineering Research Laboratory. HELP is a quasi–two dimensional model that uses climatologic, soil, and design data and calculates the infiltration, surface runoff, evapotranspiration (ET), soil moisture storage, lateral drainage, and percolation in a shallow landfill system with up to 12 different layers. The model simulates water flow within three different soil layer types: vertical percolation, lateral drainage, and barrier soil layers with or without a flexible membrane liner (FML). The HELP model cannot simulate capillary barriers. Both default (USDA soil classes) or user-specified soil characteristics can be used in designing the landfill system and include the following soil properties: porosity, field capacity, wilting point, saturated hydraulic conductivity, and initial soil water content. The program accepts both manual and default climate data and includes WGEN, the synthetic weather generator developed by the USDA-ARS (Richardson and Wright, 1984), which computes daily precipitation, temperature, and solar radiation values for a given location. Temperature and solar radiation values are used in the HELP snowmelt and evapotranspiration calculations. HELP also includes the vegetative growth model from SWRRB (simulator for water resources in rural basins) (Arnold et al., 1989) to calculate daily leaf area indices (LAI) used in the ET calculations. The surface runoff is estimated using a modified Soil Conservation Service curve number (CN) method. Version 2 of the HELP model is currently being used in the PDSS. Version 3 was released in late 1994 after this evaluation was conducted.

The overland flow erosion component of CREAMS has been added to the HELP model to simulate trench cap erosion. The erosion component of CREAMS can be used to predict sediment yield and particle composition of the sediment on a storm-by-storm basis for a given trench cap design. The overland flow erosion component requires an erosion parameter file and the input of hydrologic variables for each runoff event simulated by the HELP model. The erosion parameter file includes: the surface geometry (e.g., area, slope, flow length) and the soil surface and cover characteristics. The principal erosion outputs from the overland flow component are sediment load, soil loss per unit area, and the concentration of up to five particle sizes.

Hill Air Force Base Trench Cap Study

Four shallow landfill trench cap designs were installed at Hill Air Force Base (Hill AFB) and their performance was monitored for a 4-yr period (Hakonson et al., 1994). There are three basic cover designs: a control soil cover, a modified USEPA RCRA (Resource Conservation and Recovery Act) cover, and two versions of a Los Alamos design. The Los Alamos designs contain erosion control measures, an improved vegetation cover to enhance evapotranspiration, and a capillary barrier to divert the downward flow of water. Because the HELP model is unable to simulate flow through a capillary barrier, the Los Alamos trench cap designs were not used in this study. The two trench cap design configurations used in this study are presented in Fig. 1. The control soil cap consists of 90 cm of soil over 30 cm of a gravel drainage layer. The modified RCRA design consists of 120 cm of soil, 30 cm of sand (lateral drainage layer), 60 cm of compacted clay (hydraulic barrier), 30 cm of a gravel drainage layer, and did not contain the USEPA recommended FML. A porous geotextile (Mirafi 600X)[1] was used to separate the layers in all of the cover designs. The surface and all of the underlying layers of the covers have a 4% slope.

The trench caps were instrumented to measure their performance with respect to controlling hydrology and erosion. Daily precipitation data were measured using tipping bucket rain gauges linked to data loggers. Cumulative precipitation data were also collected, measured approximately every 2 wk, and recorded about 17% higher precipitation at the experiment site than the tipping bucket gauges. Lateral flow and percolation out of the gravel drainage layer were also measured daily using tipping buckets connected to a data acquisition system, and then into cumulative flow collectors that served as backup. Soil moisture (measured with a neutron probe moisture meter), surface runoff, and sediment yield were measured approximately bimonthly. Evapotranspiration was estimated for each trench cap by solving the water balance equation over an approximate 2-wk time interval:

$$\mathrm{ET} = P - L - I - R - dS$$

where ET is evapotranspiration (cm), P is precipitation (cm), L is percolation (cm), I is barrier lateral flow (cm), R is runoff (cm), and dS is the change in soil moisture (cm). The annual water balance for all 4 yr for both trench caps are presented in Fig. 2. Evapotranspiration is the largest component of the water balance for both covers for all 4 yr.

The decision criteria used in the decision model for evaluating the cover designs are: runoff (including lateral flow), evapotranspiration, percolation (leachate produc-

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[1] The USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

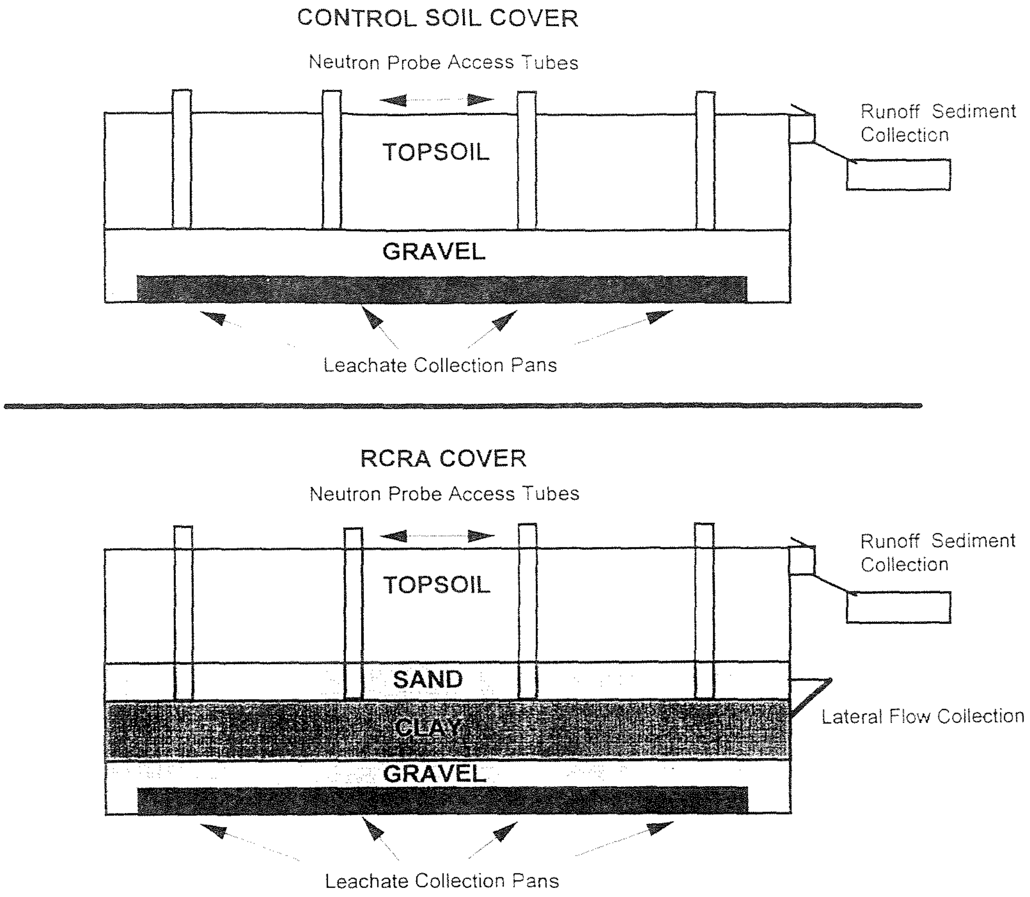

Fig. 1. Side view of two of the trench cap designs from Hill Air Force Base, Layton, UT (not to scale).

tion), sediment yield, and cost. Runoff, evapotranspiration, and percolation are important criteria for evaluating the ability of a trench cap design to control the movement of water into a waste site. The main objective of the trench cap is to minimize the production of leachate. This may be accomplished by maximizing any of the following three parameters: runoff, evapotranspiration, or lateral flow. Sediment yield is an important criterion for evaluating the long-term integrity of the trench cap. Cost will always be an important criterion in selecting options for remediating contaminated sites. The economic objective is to minimize costs while satisfying technical and regulatory constraints.

Calibration

Procedures (Water Balance)

Calibration of the HELP 2 simulation model was performed using the annual water balance for the control and modified RCRA trench caps from the Hill AFB study (Fig. 2). Due to the approximately biweekly time step used to collect the soil moisture, runoff, and sediment data, daily calibrations of the simulation models were not possible. Inconsistencies within the monthly water balance, i.e., negative evapotranspiration, were found due to errors in measurement associated with the soil moisture data. The monthly water balance and its associated error are presently being evaluated at Colorado State University (Ron Warren, 1994, personal communication). The daily precipitation collected at the site, as well as the soil properties and cover characteristics, were used to parameterize the simulation models. The simulations were run for the full 4 yr of precipitation data; however, only the last 3 yr of the simulation period were used for the calibration. The first year (1990) was not used in the calibration process to allow 1 yr for the newly constructed trench caps to settle and equilibrate.

Both default and measured parameters were used to calibrate the HELP model for the control soil cap. The input parameters for the calibrated (optimized) control soil and modified RCRA trench caps are presented in Tables 1 and 2. Precipitation data from Hill AFB, monthly mean temperatures, and latitude and longitude were used in the HELP input generator to simulate daily temperature and solar radiation data. For the control cap, the model was optimized for observed total annual runoff and percolation. To optimize for the annual percolation through the cover, the saturated hydraulic conductivity and the water storage capacity of the soil layer were adjusted. Saturated hydraulic conductivity is the most sensitive parameter affecting the water balance in landfills (Schroeder and Peyton, 1987), as well as the HELP model. The values for the soil texture and hydraulic properties were determined by analysis of soil core samples taken from one of the Los Alamos design plots at Hill AFB. The soil layer was defined as a compacted

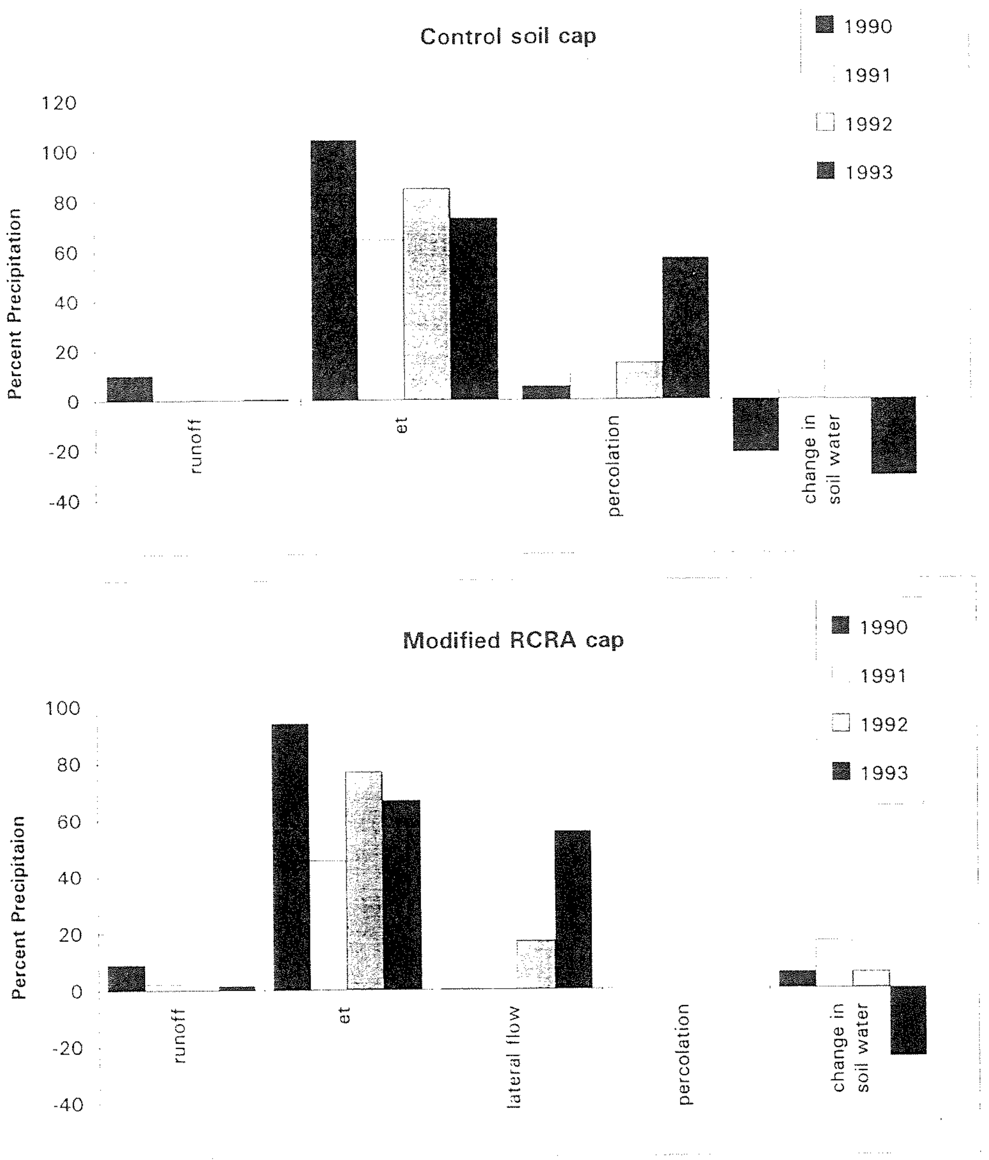

Fig. 2. Measured annual water balance as percent of precipitation for the control and modified RCRA trench caps.

vertical percolation layer with a fine sandy loam texture. There was a large variation in the saturated conductivity values determined from the soil cores (three orders of magnitude). The average saturated hydraulic conductivity of the 15 soil cores was 5 × 10^{-6} cm/s, with a maximum conductivity of 2.7 × 10^{-4} and a minimum of 1.2 × 10^{-7} cm/s. The optimum value for the hydraulic conductivity for the control soil cap calibration was 1.9 × 10^{-4} cm/s, which is less than the maximum value of the soil cores but approximately two standard deviations higher than the average. The annual runoff was optimized by adjusting the CN. The initial soil moisture was determined by neutron probe soil moisture measurements. The model allows the user to determine the maximum LAI that will be used by selecting the quality of the vegetation on the cover. For the control cover, *poor grass* was selected, maximum LAI of 1.0, based on the cover characteristic measurements of 0.55 and 0.88 made in June 1992 and September 1993, respectively (Hakonson et al., 1994).

As with the control cover, both default and measured parameters were used to calibrate the HELP model for the modified RCRA cap design. The precipitation, temperature, and solar radiation input files used for calibrat-

Table 1. Optimized input model parameters for the control soil cap.

Model parameter	Inputs
Vertical percolation layer	
Hydraulic conductivity	1.9 × 10^{-4} cm/s
Porosity	0.3000 cm^3/cm^3
Field capacity	0.2000 cm^3/cm^3
Permanent wilting point	0.0700 cm^3/cm^3
Initial soil moisture	0.2000 cm^3/cm^3
Curve no.	85
Evaporative depth	20 cm
Plant cover	Poor grass (max. LAI = 1)

Table 2. Optimized input model parameters for the modified RCRA cap.

Model parameter	Inputs
Vertical percolation layer	
Hydraulic conductivity	3.5×10^{-4} cm/s
Porosity	0.3000 cm^3/cm^3
Field capacity	0.2600 cm^3/cm^3
Permanent wilting point	0.0800 cm^3/cm^3
Initial soil moisture	0.2000 cm^3/cm^3
Lateral drainage layer	
Hydraulic conductivity	2.5 cm/s
Porosity	0.4170 cm^3/cm^3
Field capacity	0.1800 cm^3/cm^3
Permanent wilting point	0.0200 cm^3/cm^3
Initial soil moisture	0.0200 cm^3/cm^3
Soil barrier layer	
Hydraulic conductivity	9.0×10^{-8} cm/s
Curve no.	86.2
Evaporative depth	25 cm
Plant cover	Poor grass (max. LAI = 1)

ing model parameters for the control soil cap were used for the modified RCRA cap.

The soil properties were more difficult to parameterize for the modified RCRA cover due to the interaction between the soil layers in the model. The modified RCRA cap was optimized for observed total annual runoff, percolation, and lateral drainage. As with the control cap, the top layer was defined as a compacted vertical percolation layer; however, the field capacity and wilting point values were increased slightly. The saturated hydraulic conductivity was increased during optimization to 3.5×10^{-4} cm/s. This was necessary to increase the infiltration into the plot. These soil parameters are slightly higher than those used for the control cover. However, since the properties were never directly measured, it is hard to estimate the associated errors in the parameters.

The hydraulic conductivity of the lateral drainage layer was a fitted parameter. The hydraulic conductivity was increased significantly to: (i) approximate the lateral flow measured in the field, and (ii) to decrease the infiltration of water into the clay barrier layer since the HELP model automatically saturates the clay layer. The large volume of lateral drainage from the modified RCRA cap (23 cm in 1993) was most likely affected by the porous geotextile along the interface between the clay barrier and the lateral drainage layer. The porous geotextile both increases the lateral flow along the interface and decreases the infiltration into the clay barrier. Version 2 of the HELP model does not simulate porous geotextiles. To account for the effects of the geotextile on both the lateral drainage and the infiltration into the clay layer in the modified RCRA plot, the saturated hydraulic conductivity for the 30 cm sandy soil was defined as 2.5 cm/s, and the storage capacity was increased by adjusting the porosity, wilting point, and field capacity. As with the control soil cap, *poor grass* with a maximum LAI of 1.0 was used based on the measured characteristics of the vegetation cover. Hakonson et al. (1994) calculated LAI of 0.55 in 1992 and 0.84 in 1993.

The compacted clay barrier (defined as a barrier soil liner in the HELP model) was also difficult to parameterize. For the entire 4-yr period during which the soil covers were monitored, there was little or no drainage out of the modified RCRA cover, except for 6.8×10^{-4} and 2.8×10^{-3} cm during the spring of 1992 and 1993. The clay barrier was not saturated when installed. According to proctor tests during plot construction, a saturated hydraulic conductivity of only 1.0×10^{-6} cm/s (instead of the desired 1.0×10^{-7} cm/s) was achieved. The actual hydraulic conductivity was never measured. The HELP model automatically saturates the barrier soil liner and does not let the user change the field capacity or wilting point parameters. The effect on the outcome of the model is that once there is a hydraulic head on top of the clay layer and if no FML is present, percolation will occur out of the bottom of the plot. The hydraulic head on top of the clay layer is necessary to simulate the lateral flow in the drainage layer. To model what actually happened in the field, the saturated hydraulic conductivity was decreased to 9.0×10^{-8} cm/s. It is speculated that this value is probably closer to the actual hydraulic conductivity of the clay layer since: (i) it was

Table 3. Difference between measured annual values and HELP predicted values for the control soil cover at Hill AFB.

Water balance variable	Measured	%	Predicted	%	Difference	% Difference
	cm	precip.	cm	precip.	% precip.	
1991						
Precip.	53.72	100.00	53.70	100.00	–	–
Runoff	1.50	2.79	1.14	2.14	−0.64	−24
Perc.	9.09	16.93	17.09	31.84	15.0	88
ET	34.70	64.58	34.64	64.53	0.27	0
Soil water†	8.43	15.70	0.81	1.49	−14.65	−90
1992						
Precip.	39.09	100.00	39.26	100.00	–	–
Runoff	0.10	0.26	0.25	0.63	0.37	150
Perc.	5.79	14.81	10.84	27.62	12.81	87
ET	33.30	85.18	28.47	72.50	−12.68	−15
Soil water†	−0.10	−0.26	−0.30	−0.75	0.49	200
1993						
Precip.	41.78	100.00	41.85	100.00	–	–
Runoff	0.25	0.61	0.61	1.49	0.88	144
Perc.	23.80	56.96	10.49	25.08	−31.88	−56
ET	30.66	73.37	32.18	76.88	3.51	5
Soil water†	12.93	−30.94	−1.44	−3.44	27.50	−111

† The change in soil water storage.

not saturated when installed, and (ii) it was subjected to further compaction when the additional soil layers were added.

Results and Discussion (Water Balance)

For the control soil cap, using only default model input parameters HELP overpredicted the ET by approximately 30% and underpredicted the percolation through the cover by approximately 95% each year. The model results for the 3-yr period using the calibrated–optimized parameters reduced the relative estimation error in ET for all 3 yr, and for percolation in 2 of the 3 yr. Measured and predicted values for the 1991 to 1993 water balance for the control soil cap are expressed as a percent of precipitation (Table 3). Both the relative estimation error, the percent difference between the measured and predicted values, and the difference as a percent of precipitation and are presented. For the application in the PDSS, we are interested in the ability of the model to predict the distribution of the water balance.

The differences between the measured and predicted values could be influenced by a number of different factors. Only 3 yr of annual data were used for the calibration, and there was a large variance (53%) in precipitation for the period. Runoff and ET had the least amount of bias for the 3-yr period, but runoff makes up only a small portion of the water balance. The greatest error estimation was for the percolation out of the bottom of the cover in 1993. Most of the 23.8 cm (9.37 inches) of percolation in 1993 occurred in the spring as a result of snowmelt; snowmelt is not easily simulated in the HELP model.

For the modified RCRA cap, default model input parameters used to simulate the modified RCRA design resulted in approximately 48% overprediction of ET, 150% of runoff, and an approximately 97% underprediction of lateral flow. The model results from the calibrated–optimized input parameters for the RCRA cap decreased the overall relative estimation error. The measured and predicted values for the modified RCRA cover for the 1991 to 1993 period are presented in Table 4. Percolation was overestimated by the HELP model as one would expect, but by < 0.5 cm each year. As with the control cover, the largest underprediction, −29% bias in the lateral drainage, was most likely due to snowmelt in the spring of 1993. The large decrease in the measured change in soil water content in 1993 for both plots was not accounted for in the model. Since the *measured* soil moisture and ET values have more associated uncertainty, more importance was placed on predicting the percolation, lateral flow, and runoff measurements for both of the plots.

Procedures (Erosion)

The CREAMS overland flow erosion component was calibrated for both cap designs using the storm date, precipitation, and runoff determined by the calibrated HELP model. These data are used along with an erosion parameter input file to model the surface erosion and calculate sediment yield. The erosion parameter file includes the surface geometry and the soil surface characteristics. The surface geometry characteristics used in the erosion parameter file were the same for both designs: a 41 m^2 area with a flow length of 9 m and a 4% slope. Based on the soil core samples, the particle size distributions for both covers were defined as 10% clay, 65% silt, and 25% sand. Other model input parameters included a contour factor of 1, indicating no contours and a Manning's *n* of 0.5. A soil erodibilty factor of 0.35 and soil loss ratio 0.20 were used. These input parameters are based on tables from *Agriculture Handbook No. 537* (Wischmeier and Smith, 1978), but were also found to be the optimal values.

Table 4. Difference between measured annual values and HELP predicted values for the modified RCRA cover at Hill AFB.

Water balance variable	Measured	%	Predicted	%	Difference	% Difference
	cm	precip.	cm	precip.	% precip.	
1991						
Precip.	53.72	100.00	53.70	100.00	–	–
Runoff	1.14	2.13	0.84	1.57	−0.56	−26
Lat. drain	19.00	35.37	17.25	32.11	−3.26	−9
Perc.	0.00	0.00	0.28	0.51	0.51	0.28‡
ET	24.59	45.77	34.36	63.98	18.21	40
Soil water†	8.99	16.73	0.99	1.84	−14.89	−89
1992						
Precip.	39.09	100.00	39.26	100.00	–	–
Runoff	0.05	0.13	0.13	0.32	0.19	160
Lat. drain	6.70	17.15	11.23	28.60	13.45	68
Perc.	0.00	0.00	0.28	0.69	0.69	0.28‡
ET	30.12	77.06	27.86	70.99	−6.07	−8
Soil water†	2.21	5.65	−0.22	−0.59	−6.24	−110
1993						
Precip.	41.78	100.00	41.85	100.00	–	
Runoff	0.71	1.70	0.43	1.02	−0.68	−40
Lat. drain	23.32	55.80	11.10	26.53	−29.27	−52
Perc.	0.00	0.00	0.28	0.64	0.64	0.28‡
ET	27.94	66.87	31.80	75.96	9.09	14
Soil water†	−10.18	−24.37	−1.73	−4.16	20.21	83

† The change in soil water storage.

‡ The difference between predicted and measured.

Table 5. Measured and predicted sediment yield values for the control soil cap and the modified RCRA cap.

Year	Control soil cover			Modified RCRA cover		
	Measured	Predicted	% Difference	Measured	Predicted	% Difference
1991	94.17	174.16	185	142.31	151.91	110
1992	0.00	21.53	21†	0.00	21.77	21†
1993	21.28	77.99	366	10.26	86.84	846
Total	115.45	273.68	237	152.56	260.82	171

† The difference between predicted and measured.

Results and Discussion (Erosion)

The measured and predicted sediment yield for both trench caps for the 3-yr calibration period are presented in Table 5. The sediment yield for both plots is overpredicted for all 3 yr. Most of the erosion for both trench caps occurred in 1991. This was most likely due to the time necessary for the establishment of the vegetative cover and equilibration of the soil cover. The large variation in measured annual sediment yield from 1991 to 1993, with the minimal change in runoff, made it difficult to accurately predict the sediment yield using the same input parameters for all 3 yr. The sediment yield for the control cap is overpredicted by approximately 2.4 times, and for the modified RCRA cap by 1.7 times for the 3 yr. Both the measured and the predicted values are well below the federal regulation for landfill covers of 4400 Kg/ha per year (USEPA, 1989).

LONG-TERM SIMULATIONS

Risk managers are interested in assessing the long-term performance of a trench cap design for a particular site. Trench caps are designed and installed to last hundreds of years. The decision model in the PDSS uses the annual average value of the decision criteria (runoff, lateral flow, ET, percolation, and sediment yield) for each of the alternatives to evaluate the designs. The annual average, maximum, and minimum of the conventional design are used to parameterize the scoring functions in the decision model (Paige et al., 1994).

To evaluate the long-term performance of the Hill AFB trench cap designs, the calibrated HELP and CREAMS models were run for a 200-yr simulation. The model input parameters were not modified or updated, except for soil moisture, which is automatically updated by the HELP model. The model assumes that the cover is maintained as required by federal regulation (U.S. Dep. of Energy, 1990). The weather generator CLIGEN (Nicks and Lane, 1989) was used to generate a 200-yr precipitation record for the Hill AFB site; WGEN in the HELP model cannot simulate more than 20 yr of precipitation. The 200-yr simulation was run in 20-yr periods, the maximum allowable in the HELP model, with an overlap of 5 yr to alleviate the affects of the initial soil moisture conditions on the results of the model. The progressive annual mean for each of the decision criteria was compared with the 200-yr (long-term) mean to ascertain when the annual average would approach the 95% confidence interval of the long-term average within a 200-yr period. The time needed for the progressive annual mean to approach the long-term mean was used as an indicator of the time period necessary to run a simulation model to predict a long-term average for a specific climate. This is especially important for the PDSS, which uses the average annual values of the decision criteria to parameterize the scoring functions and to determine the scores for the alternative designs.

The long-term averages determined from the 200-yr simulations for each of the trench cap designs plotted against the progressive annual mean (Fig. 3 and 4). By Year 48, the annual mean precipitation for both soil designs was well within the 95% confidence limits of the 200-yr mean. For the 200-yr period, the maximum annual precipitation was 62 cm and the minimum was 18 cm. The annual average percolation for the control soil cover was initially higher than the 200-yr mean; however, it was well within the confidence intervals of the long-term mean by Year 60. The annual percolation varied from 1.8 to 20.4 cm. Annual average ET, which had a maximum annual total of 47.2 cm and a minimum of 16.6 cm, was within the 95% confidence limits of the long-term mean by Year 29. By Year 85, the progressive annual average for ET was approximately equal to the long-term mean with little variability. The progressive annual average for both runoff and sediment yield for the control soil cover (Fig. 3) showed much more variability from the long-term mean than the other decision variables. This is partly due to the annual variability from 0 to 11.8 cm of runoff, and 0 to 13.5 kg of soil loss during the 200-yr period. The coefficients of variation (CV) for runoff and sediment yield for the 200-yr period are 321 and 423%, respectively.

The resulting long-term graphs for the modified RCRA design decision criteria (Fig. 4) are similar to the results for the control design. The long-term precipitation used for the modified RCRA design is the same data that were used for the control design. The annual percolation out of the bottom of the clay barrier layer varied from 0.245 to a maximum of 0.274 cm (CV of 1.64%), but the annual average was not within the 95% confidence limits of the long-term mean until Year 60. Evapotranspiration showed little or no variation from the long-term mean and stabilized at Year 29. The progressive annual average for runoff and sediment yield displayed similar behavior for the modified RCRA cover as for the control soil cover, but at slightly lower values. This is to be expected due to the similar soil surface characteristics and different calibration values. The annual lateral drainage varied from 2 cm to a maximum of 20.8 cm (CV of 40%; Fig. 4). The annual average was within the 95% confidence limits of the long-term mean by Year 60, but still showed some variability until Year 140 of the simulation period.

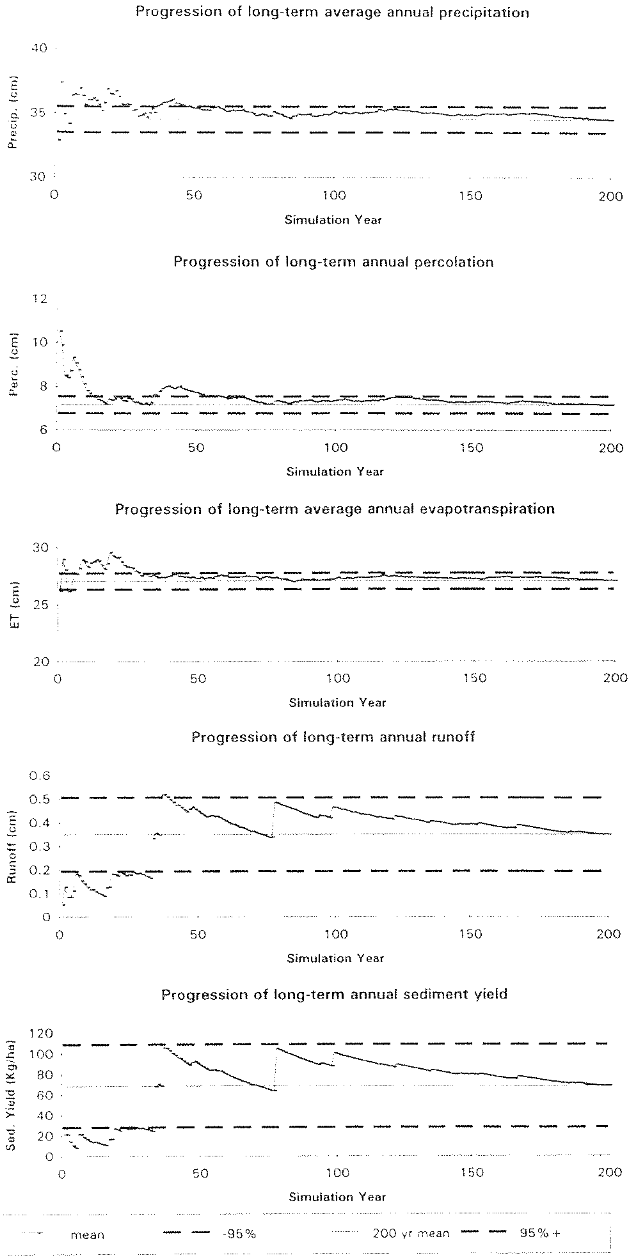

Fig. 3. Progression of long-term average annual values for the control soil cap compared with the long-term mean.

With the exception of runoff and sediment yield, the annual mean for all of the decision variables approached the long-term mean well before the end of the simulation period. The long-term means for the runoff and sediment yield criteria still seem reasonable due to: (i) the relatively small scale compared with the amount of precipitation, and (ii) the large variability within the runoff and sediment yield predicted values.

CONCLUSIONS

Simulation models are used in the Prototype Decision Support System (PDSS) to predict the long-term performance of a trench cap design. The HELP and CREAMS models were selected because they simulate the decision variables necessary to evaluate landfill covers, and the HELP model is recommended by the USEPA. The Hill AFB data set is not long enough to conduct a full calibration and validation of the simulation models. However, the results of the annual calibrations of the two models were reasonable for the 3 yr of field data available. The predicted values followed the annual trends in the field data and were often within 15% of the measured values

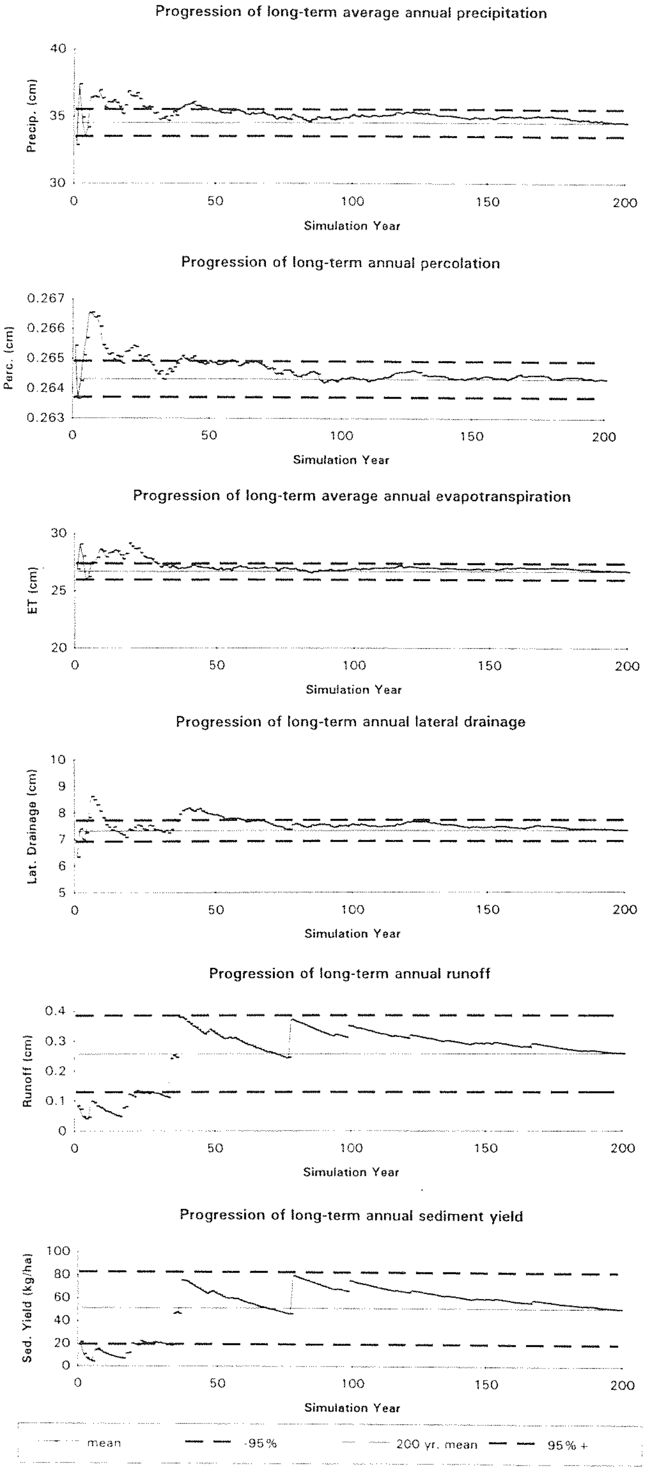

Fig. 4. Progression of long-term average annual values for the modified RCRA cap compared with the long-term mean.

relative to the annual precipitation. The largest bias when comparing observed and predicted values was an underestimation of the percolation out of the control cover in 1993. This was primarily a result of the HELP model's inability to effectively simulate spring snowmelt.

The long-term stability and performance of the simulation models are important when predicting the long-term performance of trench cap designs. The ability of the simulation models to predict long-term average values that are representative of a design and a climate is especially important for the PDSS, which uses the annual average, maximum, and minimum values predicted by the simulation models to parameterize the decision model. For both models, the progressive annual averages approached the long-term means within 60 yr of the 200-yr period. The results for the sediment yield predicted by the CREAMS model followed the runoff results from the HELP model as expected. The progressive annual average of the water balance variables from the HELP model reflected the variability in the progression of the annual average precipitation. The greatest variance in the long-term simulation results was in runoff and sediment yield for both designs as demonstrated in the results for the progression of the long-term averages.

The PDSS is a tool for risk managers to select the *best* trench cap design for a specific site. It is important that the ability of the potential designs to minimize contaminant transport be discerned by the PDSS. For this study, the HELP model was able to differentiate between the two designs, which is very important for use in the decision model. The model was able to predict the relative magnitudes of the terms in the water balance equation for the two designs considered, and differentiate between the designs in terms of their ability to minimize percolation. The modified RCRA cover did eliminate/minimize percolation for the 3 yr simulation period, whereas the control cover did not. To fully validate and test the PDSS and its embedded simulation models, other data sets of landfill covers for waste disposal sites in a variety of climates are needed.

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