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LA-UR -87-2855

CONF-870859-14

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TITLE: DEVELOPMENT OF AN ARID SITE CLOSURE PLAN

LA-UR--87-2855

DE87 014755

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SUBMITTED TO: Proceedings of the Ninth Annual DOE Low-Level Radioactive Waste Management Conference, Denver, Colorado, August 25-27, 1987

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DEVELOPMENT OF AN ARID SITE CLOSURE PLAN

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ABSTRACT

The purpose of this task is to develop a prototype plan for the effective closure and stabilization of an arid low-level waste disposal site. This prototype plan will provide demonstrated closure techniques for a trench in a disposal site at Los Alamos based on previous NLLWMP-sponsored SLB field research both at the Los Alamos Experimental Engineered Test Facility, and at two waste disposal areas at Los Alamos.

The accuracy of modeling soil water storage by two hydrologic models, CREAMS and HELP, was tested by comparing simulation results with field measurements of soil moisture in eight experimental landfill cover systems having a range of well-defined soil profiles and vegetative covers. Regression analysis showed that CREAMS generally represented soil moisture more accurately than HELP simulations.

Precautions for determining parameter values for model input and for interpreting simulation results are discussed. A specific example is presented showing how the field-validated hydrologic models developed in this endeavor can be used to develop a final prototype closure plan.

INTRODUCTION

If we examine the ecosystem processes that influence site closure and long-term site performance with potential impact on dose to man (Figure 1), we note that water and soil dynamics, as influenced by physical and biological factors, account for most of the performance-related problems. For example, erosion associated with the runoff from a trench cap can breach the cap and expose waste to the biosphere. Consequently, erosion rates on the cap must be within tolerances that leave the cap intact over the 100-200 year life of the LLW disposal facility. Likewise, water that infiltrates into the trench cap can accumulate in the trench (bathtub effect) and/or percolate in association with solutes into groundwater. Percolation also enhances subsidence of the trench cap as a result of decomposition of bulky waste in the trench. Finally, both plants and animals, in addition to playing an important role in water balance, can penetrate into the waste and transport radionuclides to the ground surface as a result of root uptake and/or burrowing activities.

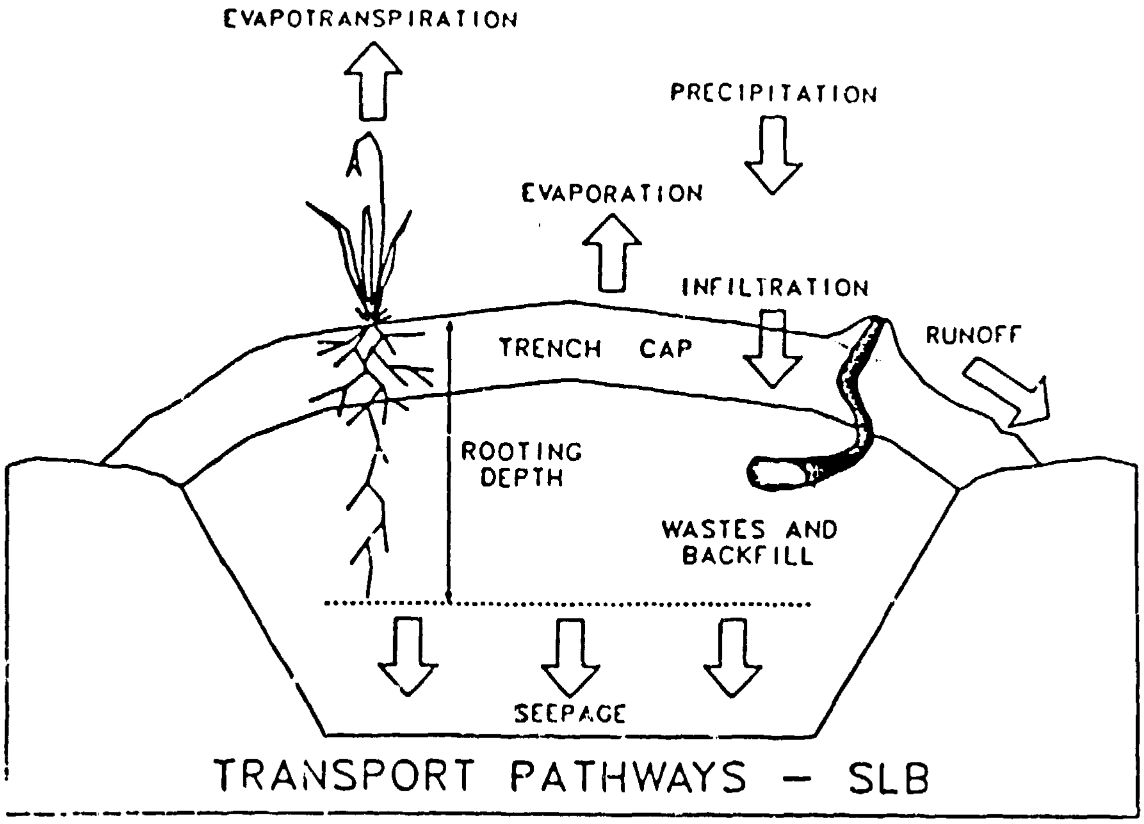

FIGURE 1. Hydrologic processes effecting shallow land burial sites.

Although trench cap configurations are usually arbitrarily chosen, the major point that this paper is making is that SLB design characteristics such as trench cap thickness do not have to be arbitrarily chosen. Hydrologic models are frequently used to estimate or predict water balance components in agricultural and rangeland watersheds (Lane and Stone 1983, Lane et al. 1984, Lane and Barnes 1987), or to aid in designing reclamation projects for surface mining or landfill operations (Hakonson et al. 1982, Nyhan et al. 1984). The choice of a model depends on the specific need, the data available, and the perceived accuracy of the simulation results. Comparisons between models for a wide range of site conditions, and tests of the accuracy of the simulated results are necessary for an informed choice. Few such studies on commonly used models have been presented.

In this study, the USDA model CREAMS (Knisel 1980) and the EPA model HELP (Schroeder et al. 1983) were used to simulate soil water storage in eight experimental landfill cover systems over a two-year period. These models are widely used in the management of agricultural lands and hazardous waste landfill systems. The methods of parameterizing the models are discussed. Field data on soil moisture and vegetation leaf area indices are presented for the various cover treatments. Soil moisture values predicted by each model are compared with field data, and the accuracy of each model assessed. An example of how the CREAMS model can be used to optimize trench cap configurations at Los Alamos, NM is then presented.

BACKGROUND

The CREAMS model (a Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed and intended for modeling field-scale agricultural systems (Knisel 1980). The model has been used in several areas of waste management research in semi-arid climates, including erosion studies (Nyhan and Lane 1982), water balance and primary production of desert shrubs (Lane et al. 1984) and landfill cover design (Hakonson et al. 1982, Nyhan et al. 1984). Both CREAMS and HELP have been tested in a limited way with respect to percolation of water below a surface rooting zone, but not in any detail with respect to the effects of native plant cover on soil water storage.

CREAMS was used in the daily rainfall-runoff mode to obtain a complete water budget (estimates of runoff, evapotranspiration, percolation and soil-water storage, or water content in the soil column to the depth of the rooting zone) on each day that there was a precipitation event; using the simplified water balance equation:

$$\frac{ds}{dt} = P - Q - ET - L \qquad (1)$$

where ds/dt = time rate of change in soil moisture, P = precipitation, Q = runoff, ET = evapotranspiration, and L = seepage or percolation. Monthly and annual water budgets are also obtained. The model is one-dimensional, calculating the process of vertical transport of water in the soil column using a seven layer representation of the profile from the surface extending through the rooting zone of the vegetative cover. Initial responses to precipitation are calculated on a daily time-step using a modification of the Soil Conservation Service (SCS) curve number model (Knisel 1980).

An alternative model, HELP (Hydrologic Evaluation of Landfill Performance) is presented as being directly applicable to most landfill designs. In contrast to the purely one-dimensional character of CREAMS, the HELP model permits quasi-two-dimensional modeling of soil water movement by including lateral flow simulation in drainage layers. Precipitation inputs are modeled one-dimensionally down to the depth of lateral drainage layers or impermeable membrane liners. Lateral flow out of drainage layers is treated separately. The infiltration routine is similar to that used in CREAMS, and there are changes (claimed to be improvements) in the treatment of percolation and evapotranspiration. The model is interactive and user-friendly, with default climatic and soils data available for many regions in the U. S. Default estimated vegetation data is also available to the user. Alternatively, the user can specify parameter values specific to the site being modeled.

Both models require data on soil characteristics, seasonal vegetation characteristics and soil cover design as input. Monthly mean temperatures, mean monthly solar radiation values, and daily precipitation inputs are also required.

MATERIALS AND METHODS

The study area was a closed low-level radioactive waste disposal site ("Area B") located at Los Alamos National Laboratory in north-central New Mexico. Area B (Fig. 2) has a generally uniform 5% slope and southeast aspect. Remediation treatment in 1982 resulted in three distinct soil profiles being installed across the site (east, west and cobble-gravel). Eight experimental plots were established on the site, distributed on the three soil profiles as shown in Figure 2. The topsoil used in the construction of the Area B landfill cover remedial treatment is a local Hackroy sandy clay loam (Nyhan et al. 1978). The crushed Bandelier tuff used as an overburden to the waste material can be classified as a sandy loam. East and west control profiles differ in the amount of sandy clay loam in the profile. The west profile is more typical of landfill covers at Los Alamos, having about 15 cm of topsoil over 85 cm of crushed tuff. The east profile has a much higher amount of topsoil (sandy clay loam) mixed into the profile as a result of reconstruction in 1982, and thus the east soil profiles have significantly higher water holding capacity than the west soil profile. The "biobarrier" profile has a layer of cobble and gravel (as a barrier to capillary moisture flow and biointrusion) overlain by 45 cm of crushed tuff and 15 cm of topsoil.

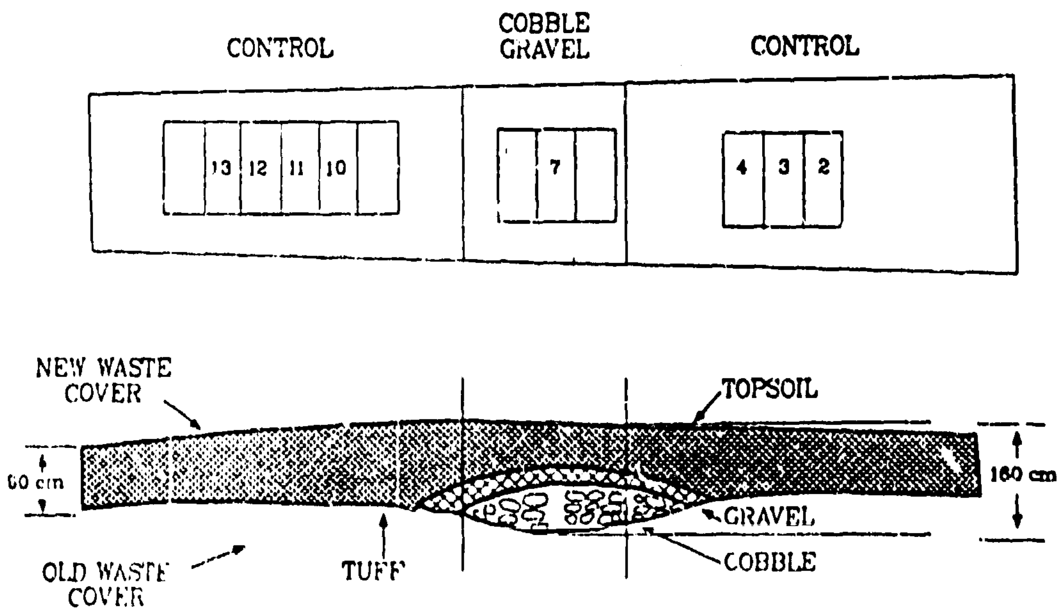

Figure 2. Plan view and cross-section of study site, Area B. Vegetation covers are: bare (plots 12, 13), grass (plots 4, 12), shrubs (plots 3, 7, 11) and 1/5 density shrubs (plot 10).

Each plot was 8 by 24 m (25 by 80 ft), oriented parallel to the slope. The vegetative cover treatments included bare, grass and shrub covers (Table 1). The "bare" treatment was weeded frequently to remove all standing live vegetation, resulting in a variable vegetative cover during the summer months. The grass covers were weeded to remove forbs and seedling shrubs. Shrub plantings of rabbitbrush (Chrysothamnus nauseosus subsp. latisquameus (Gray) H. & C.) were established in 1984 at two densities: dense at 2.15 plants/m^2, and sparse at 0.43 plants/m^2. These covers were weeded to remove grasses and forbs.

Table 1. Plot numbers for each cover and soil profile treatment at Los Alamos Area B site.

	Soil Profile		
Cover Treatment	East Control	West Control	Biobarrier
Bare	2	13	
grass/forbs	4	12	
rabbitbrush, dense	3	11	7
rabbitbrush, sparse		10	

Throughout the year, soil moisture distribution with depth was measured with a neutron moisture probe (Campbell Pacific Nuclear Corp. Model 503, Pacheco, CA) via access tubes at three or four locations per plot. The measurement frequency was not great enough to follow each precipitation event and thus data represent average trends in soil moisture.

Plant Parameters

Hydrologic models require estimates of leaf area index (LAI) and rooting depth as input for calculating utilization of soil moisture by the vegetative cover. LAI data are commonly available only for crop species or grass covers. In order to extend CREAMS and HELP modeling strategies to native plant covers, it was necessary to develop nondestructive methods that allowed frequent estimates of LAI during the year without disturbing the vegetative cover on the plots.

Shrubs

A regression relationship was developed relating shrub crown dimensions and crown volume to total shrub biomass and total crown leaf area. Rabbitbrush shrubs of various sizes were harvested, both on the experiment site from areas planted specifically for harvest purposes, and from naturally occurring stands in other areas on Los Alamos National Laboratory lands. Prior to harvest, crown dimensions (crown height, greatest diameter D_1, and diameter D_2

perpendicular to D_1) were measured to the nearest cm. Three subsamples of actively growing twigs were taken from the crown, and the rest of the crown was separated into actively growing leaves and twigs (current season), and secondary (older) twigs and branches. The subsamples were separated into leaves and twigs and projected area of each portion determined using a leaf area meter (LI-COR, Inc., Model 3050, Lincoln, NE). The subsamples and the rest of the shrub's crown portions were then dried at 75°C for 48 h, and weighed. Specific leaf mass, SLM (gm cm^{-2}), was calculated for each subsample, the mean computed for each shrub harvested and an overall mean computed for all shrubs sampled (Table 2). The dry leaf mass as a fraction of dry mass of current growth was determined and total crown leaf area estimated for each shrub. Several regression models relating crown biomass and leaf area to crown volume and crown dimensions were used. Tests showed that the highest correlation coefficients were obtained using spherical crown volume as the independent variable of crown architecture in the regression models (Fig. 3).

Table 2. Mean values, standard error (S.E.) and sample size (n) of specific leaf mass (SLM, g/cm) and leaf mass as percent of total aboveground biomass (LM, %) for rabbitbrush and mixed grasses.

	Mean Value	S.E.	n
rabbitbrush			
SLM	0.0169	0.0013	33
LM	0.499	0.021	33
mixed grass			
SLM	0.0243	0.0021	122
LM	0.424	0.023	104

Using the relationships developed, total biomass and leaf area indices were periodically estimated for the plots with rabbitbrush cover. Shrub individuals were randomly selected on each plot, and the canopy dimensions recorded. A mean spherical crown volume for the plot was computed, and biomass and leaf area index estimated using the regression relationships and planting densities.

Grass

Regression relationships were developed between visually estimated percent cover and total aboveground dry biomass on the bare and mixed grass plots as follows. On each sampling date, quadrats (25 x 50 cm) were laid out randomly on each plot. The locations were selected so as to sample over the range of grass canopy cover on the site. For each quadrat, the percentage of

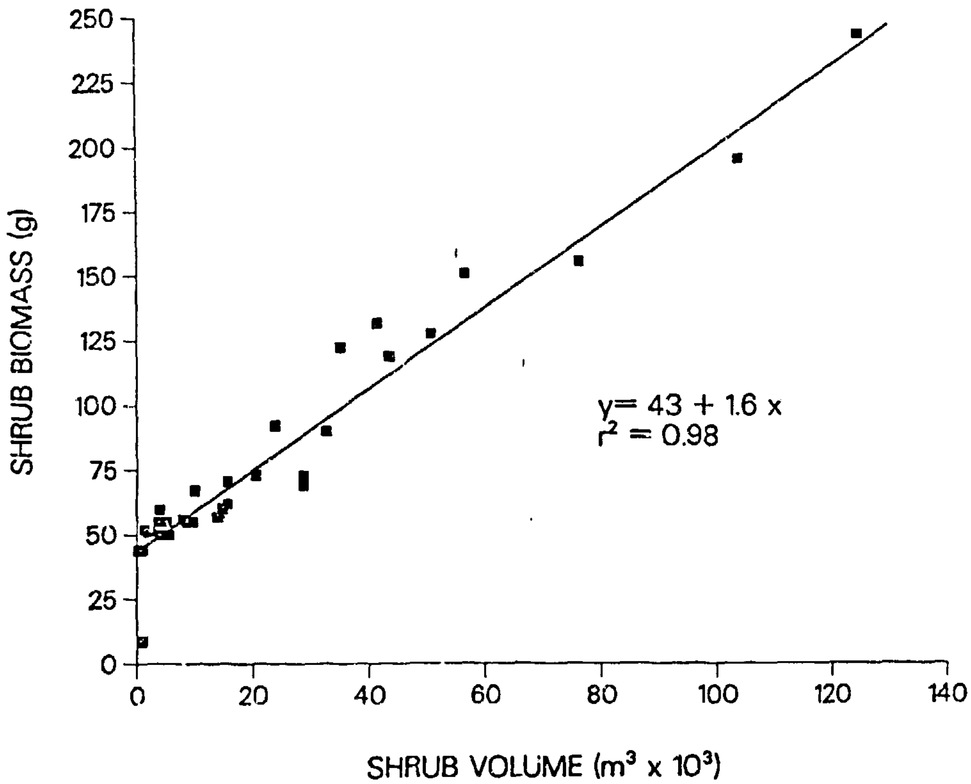

Figure 3. Relationship between crown volume and total above-ground biomass of rabbitbrush.

ground covered by the grass canopy was estimated (percent cover). All standing biomass in the quadrat was clipped and bagged, and taken to the laboratory for sorting. Each sample was separated into green leaf, green stem, and standing dead fractions. Projected area was measured on the green fractions. All fractions were dried at 75°C for 48 h, and then weighed. Biomass per unit ground area, leaf biomass as a fraction of total biomass (LB) and specific leaf mass (SLM, or mass of dry leaf per unit leaf area) were determined for each quadrat sample.

Several regression relationships between biomass and percent cover were developed and tested for the effect of time of harvest, plot location, or vegetative cover. Statistical analysis showed that effects of vegetative cover (bare versus grass) and plot locations were not significant. Neither time of harvest, vegetative cover, nor plot location had a significant effect on the overall SLM or LB. Time of harvest had a significant effect and data were analyzed by month to give four linear regression equations. In the final analysis, it was found that use of the monthly regression equations had an insignificant effect on actual LAI estimates for each plot, and in the following discussion, the overall linear regression equation was used (Fig. 4). To estimate the changes in LAI during the growing season, percent cover was estimated on each of a series of either 50 or 100 randomly placed quadrats on each plot. The overall regression equation was used to estimate average total biomass, and LB and SLM used to calculate LAI.

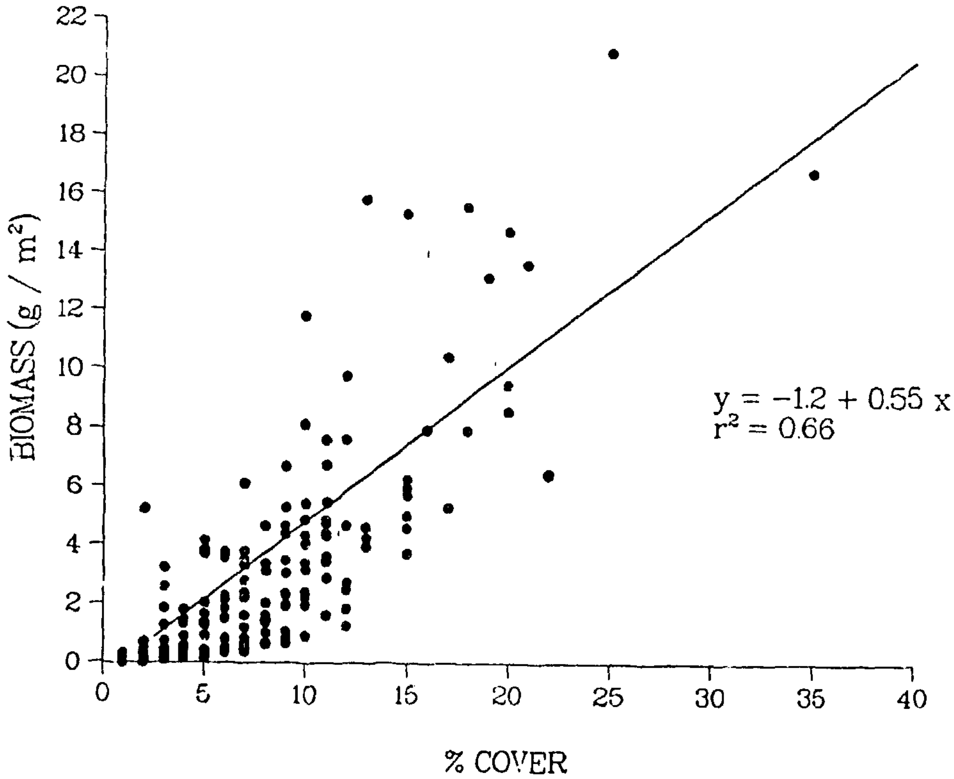

Figure 4. Relationship between canopy cover and total above-ground biomass of mixed grasses at Area B.

Modeling Studies

The modeling studies were conducted in two phases. Initially, a series of CREAMS simulations were conducted to optimize values of hydrologic soil parameters. Secondly, CREAMS and HELP simulations were conducted on all experimental scenarios using the optimized parameters and, for HELP only, using the model's default values.

Lane (1984) gives a range of possible values for each soil parameter required for CREAMS (saturated hydraulic conductivity, bare soil evaporation, porosity, field capacity and wilting point). The optimum values were chosen by initially conducting a series of simulations to explore the capability of the models to reproduce observed profile averaged soil moisture trends from 1983 to 1985 on the west control plot 11 which had a dense rabbitbrush cover, a standard landfill cover soil profile, and a two-year record of soil moisture measurements prior to the start of the study (Nyhan et al. 1986).

The basic structure and initialization of the model was established using known site specific data, actual daily precipitation totals for 1983-1985, and 20 year averages of air temperature and solar radiation for Los Alamos. LAI in 1983 and 1984 was estimated so as to agree with observed seasonality in growth patterns and LAI levels attained by herbaceous weeds in 1985. For 1985, estimates of LAI were based on field measurements on shrubs and herbaceous weeds. Instead of using recommended values for soil hydrologic parameters of the appropriate soil texture classes represented on our site (Knisel 1980, Lane 1984, Schroeder et al. 1984), several simulations tested the effects of varying the parameters over the reported ranges on predicted average soil moisture content.

First, average values of certain soil parameters (saturated hydraulic conductivity, field capacity and wilting point) were used as recommended by Lane (1984) and Schroeder et al. (1984) for the soil texture classes represented in the plot 11 soil profile. Second, the ranges suggested for the soil texture classes (Lane 1984) were tested. Third, the effect of using the measured saturated hydraulic conductivities of the specific soils on the site (Abeele 1984) was tested. Finally, after determining which parameter values maximized the fit between observed and predicted retention and drainage of soil water, the curve number was adjusted to obtain the best possible representation of infiltration of precipitation from summer storm events.

The performance of CREAMS in predicting soil moisture on plot 11 at Area B was assessed at each step. The observed field values were averaged over three measurement depths (20, 40 and 60 cm) and over four locations on the plot to give one mean soil moisture value for each measurement time. Best fit of the predicted to the observed soil moisture patterns was assessed by the standard technique of regression analysis with aim of maximizing the correlation coefficient (r^2) and optimizing the slope and intercept of the regression line to approach the equal value line (Pathak et al. 1984). The parameters that produced the optimum CREAMS simulation (summarized in Table 3) were the minimum saturated hydraulic conductivity of any layer (RC=2.5×10^{-8} m/s for Hackroy sandy clay loam); and the average field capacity (19%) and average wilting point (8%) for sandy loam. The curve number used for the SCS representation of infiltration and runoff was 95, which results in 95% of precipitation becoming runoff, and 5% infiltrating into the soil profile. These same parameters were used to initialize a 3 year simulation of plot 11 data using the HELP model (version 1).

The optimum CREAMS simulation and the corresponding HELP simulation as well as observed field data are shown in Figure 5. When the predicted and observed soil moisture were compared point for point by regression analysis, large differences (under or over-predictions) were observed. Using the correlation coefficient as a measure of overall goodness of fit, only a portion of the variation in soil moisture is explainable by the algorithms in the models (23% for CREAMS, 34% for HELP). This implies that a large proportion of the variability in soil moisture results from processes either poorly represented or absent in the models. In both models, water transport from the surface zone (2 to 5 cm) to the layers below is a simple power function of soil water storage in the surface zone. Percolation below the rooting depth does not occur unless storage plus inflow exceeds field capacity. These simplifications of the soil hydrologic system, which undoubtedly contribute to the reduced accuracy of predictions on a daily time-step basis, may be less important if monthly or quarterly totals of water balance components are used to assess model performance. It is very clear that HELP grossly underestimates

Table 3. Optimized parameters for CREAMS simulation of soil water storage on plot 11.

Soils: 0 to 15 cm, Sandy clay loam (SCL)
16 to 75 cm, Sandy loam (SL)

Rooting Depth: 76 cm (30 in.)

SCS curve number: 95

Slope: 5%

Area: 0.40 ha (1 acre)

Soil Parameters:
Saturated hydraulic conductivity:
SCL 2.5×10^{-8} m/s (0.0035 in/hr)

Porosity: SCL 0.46
SL 0.46

Field capacity: SCL 0.34
SL 0.19

Wilting point: SCL 0.15
SL 0.08

average soil moisture to the depth of the rooting zone throughout the 3 year simulations. This is due in part to the apparently excessive ET estimates predicted by HELP which result in soil moisture depletion to a very low level.

RESULTS AND DISCUSSION

Leaf Area Indices

The estimated LAI value for 1985 and 1986 are summarized in Figures 6-8. The high spring rains of 1985 resulted in a dense growth of cool season grasses and forbs on all plots. After weeding in June 1985, LAI dropped and from that time, the plots were kept weeded as much as possible. In those cases where cover was not measured directly after weeding, a LAI value of 0.01 on the bare plots was assigned to the postweeding date.

Shrub LAI was not very different between the three densely planted plots by the end of 1986 (0.68 to 0.78). Plot 10, with 1/5 the density of shrubs, had about 1/3 the LAI of the densely planted plots, and a larger average size per individual.

Soil Moisture

Differences in soil moisture retention by the three profiles can be seen by comparing average soil moisture (20-60 cm depths) on plots with similar

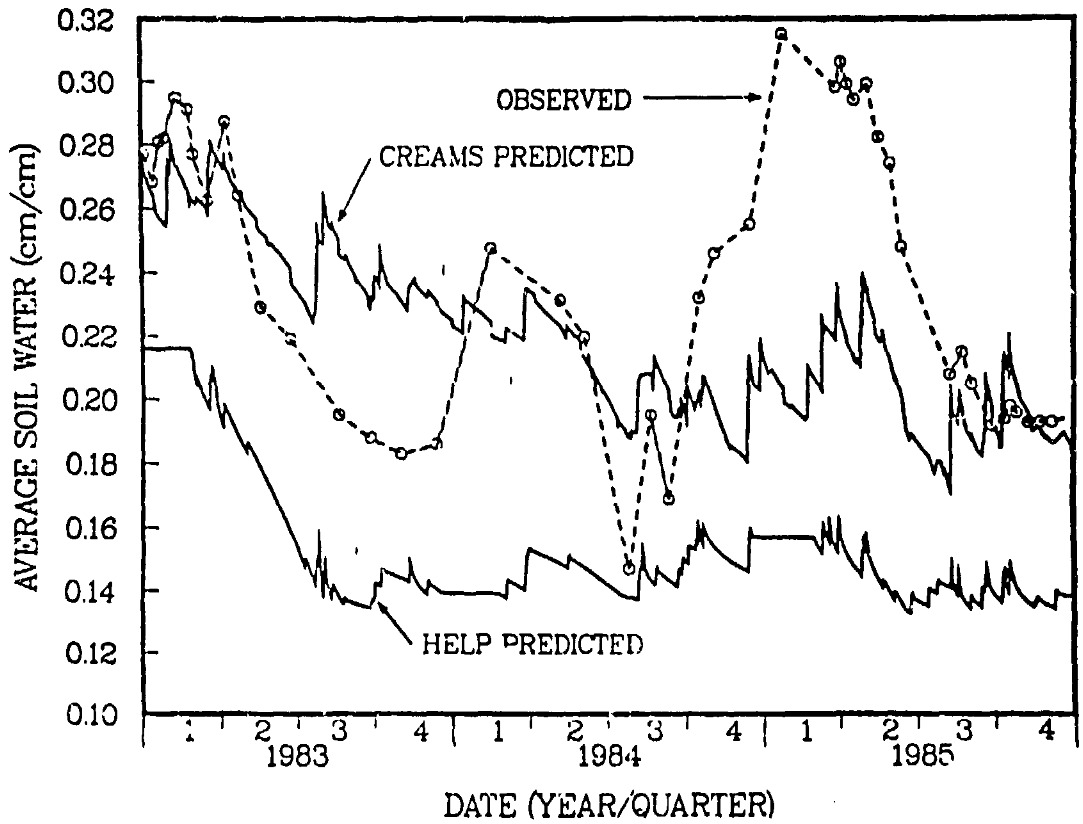

Figure 5. Observed average soil moisture (20, 40 and 60 cm depths) and average soil moisture predicted by CREAMS and HELP simulation of plot 11 scenario (1983-1985).

vegetative covers (Figs. 9-11). Under all three vegetative covers (bare, grass and dense shrubs) it is readily apparent that the east profile (high percent sandy clay loam) retained more soil moisture throughout the year than the west profile which is predominantly crushed tuff overlain with a thin layer of sandy clay loam topsoil. The cobble-gravel profile was consistently drier than either the east or west profile. This was most likely due to lateral drainage of soil moisture above the gravel layer as well as to more complete water extraction by the plant roots in the shallower soil profile above the cobble-gravel layer.

The effect of vegetative cover can be assessed by comparing plots with similar soil profiles. In both the comparisons, soil moisture was lowest beneath a shrub vegetative cover. On the east plots, it is also apparent that in the profile under the shrub cover soil moisture started to decrease in May 1985 when the temperature had risen and the plants started to grow actively and thus transpire water actively.

This decrease in soil moisture continued through September 1985, with the result that average soil moisture was about 2/3 the values measured on the grass and bare plots. Although soil moisture increased on all plots with spring snow melt and again with summer rains in 1986, the soil moisture on the shrub plots never recharged to the levels observed on grass and bare plots.

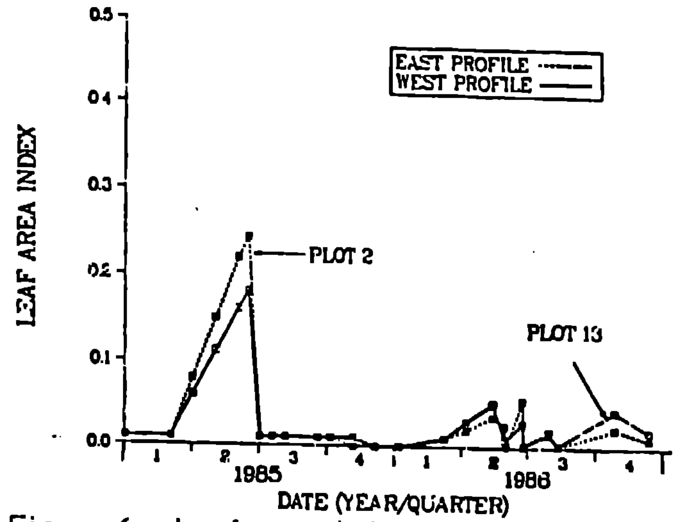

Figure 6. Leaf area indices estimated on bare soil cover plots in 1985 and 1986.

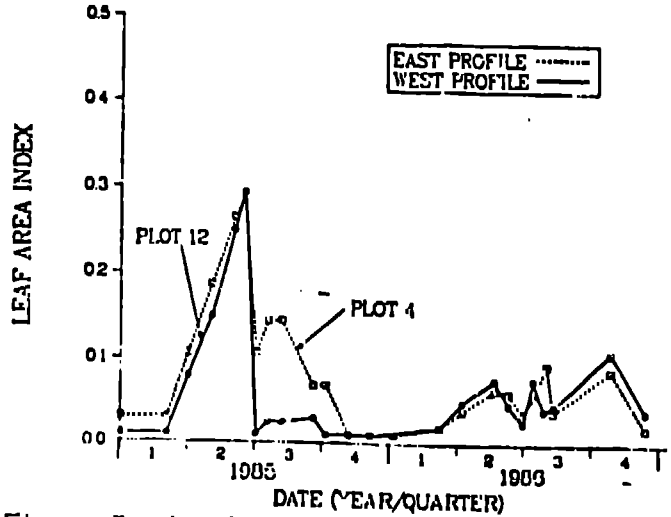

Figure 7. Leaf area indices estimated on grass cover plots in 1985 and 1986.

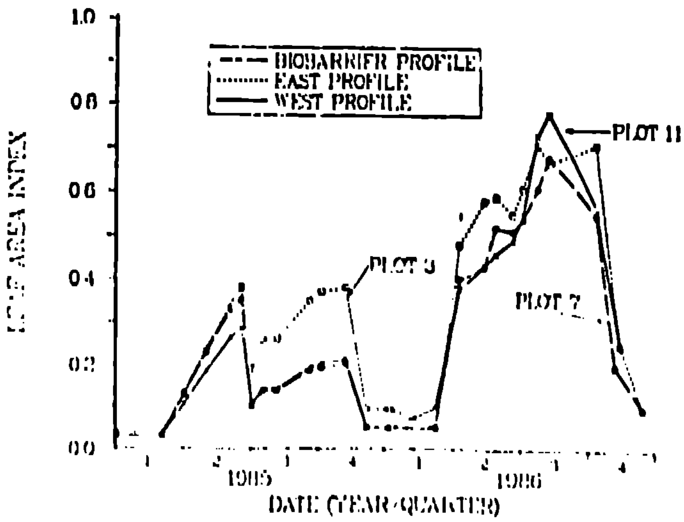

Figure 8. Leaf area indices estimated on shrub cover plots in 1985 and 1986.

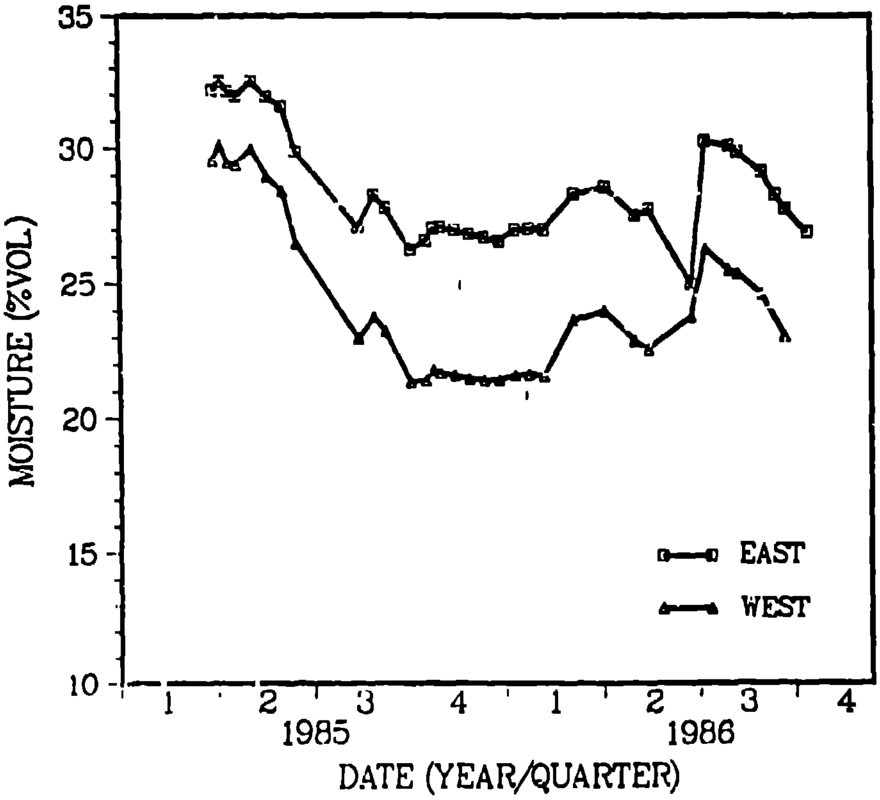

Figure 9. Soil moisture (average 20, 40 and 60 cm depths) in bare soil plots with different soil profiles.

Spring precipitation levels were higher than usual in 1985, resulting in a very high soil water content on all plots in early Spring 1985. Winter 1985-86 was also drier than usual and the general downward trend in soil water storage continued until the summer monsoon rains began in 1986. June had exceptionally high rainfall, September through November had higher than normal rainfall, and soil water recharge is apparent in most plots.

At the end of the 1986 growing season, soil moisture on shrub plots was several percent (by volume) below grass and bare treatments. The soil moisture averages are for the 20, 40 and 60 cm measurement depths. Since the neutron moisture probe has a measurement sphere-of-influence of up to 20 cm radius in soil, a conservative estimate is that the average of the three measurements represents 0 to 70 cm of soil depth. Using this soil depth, the total soil water storage was calculated at the approximate start and end of the growing seasons for 1985 and 1936. The differences between the treatments on the east control profile suggest that after 2 years, ET from the shrub cover resulted in 6.9 cm less water stored in the shrub soil profile than in the bare profile, and 3.6 cm less water than in the grass profile. Similar trends were noted on the west plots.

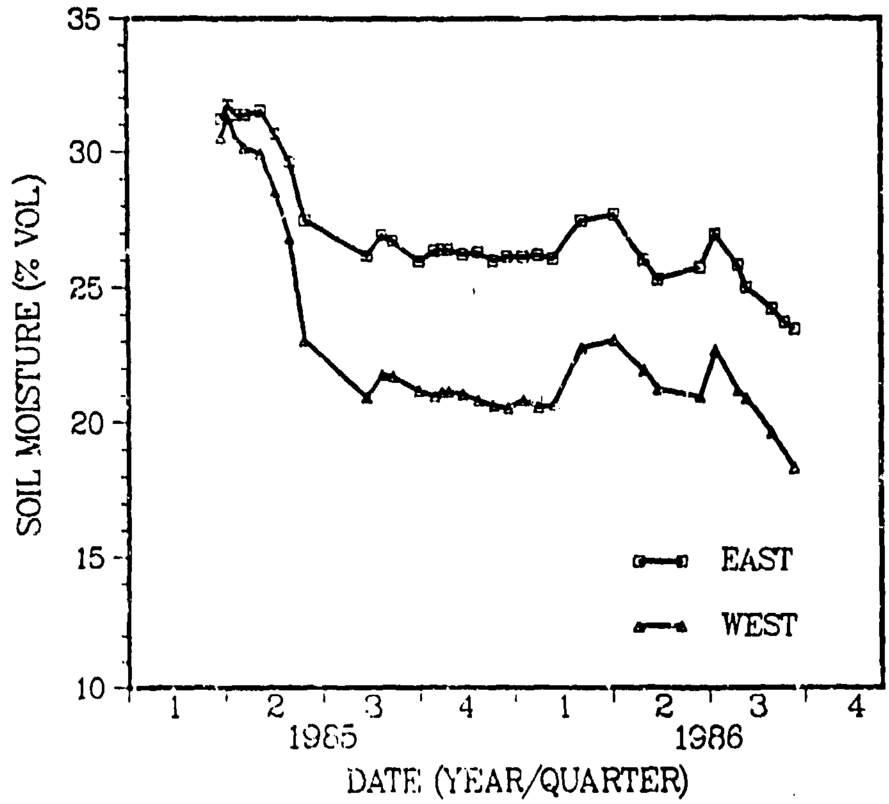

Figure 10. Soil moisture (average 20, 40 and 60 cm depths) in dense grass plots with different soil profiles.

Prediction of Soil Moisture

The overall predictive power of each model was tested by assessing what percentage of the variability in the observed data was explained by model predictions in two year simulations on all soil/vegetation combinations. For CREAMS runs, the optimized parameter values for soil hydrologic properties were used. For HELP runs, simulations were first performed using the CREAMS optimized values, and then repeated using the default values supplied by the HELP model. Each plot had soil profiles with varying percentages of sandy clay loam and sandy loam soils. For each plot, profile values for hydrologic parameters were calculated as weighted averages of the optimum field capacities and wilting points already determined. The driving variable was 1985 and 1986 daily precipitation totals. The first field measurement of 1985 was used to initialize profile soil moisture in CREAMS simulations. LAI data specific for each plot was used (Figs. 6-8).

The overall predictive power of each model was assessed by a linear regression analysis of predicted versus observed average soil moisture over all plots (Fig. 12). For the CREAMS model, the values are well clustered about the equal values line. The variability is high, and only 62% of the variability in the observed soil moisture values is explained by the algorithms of

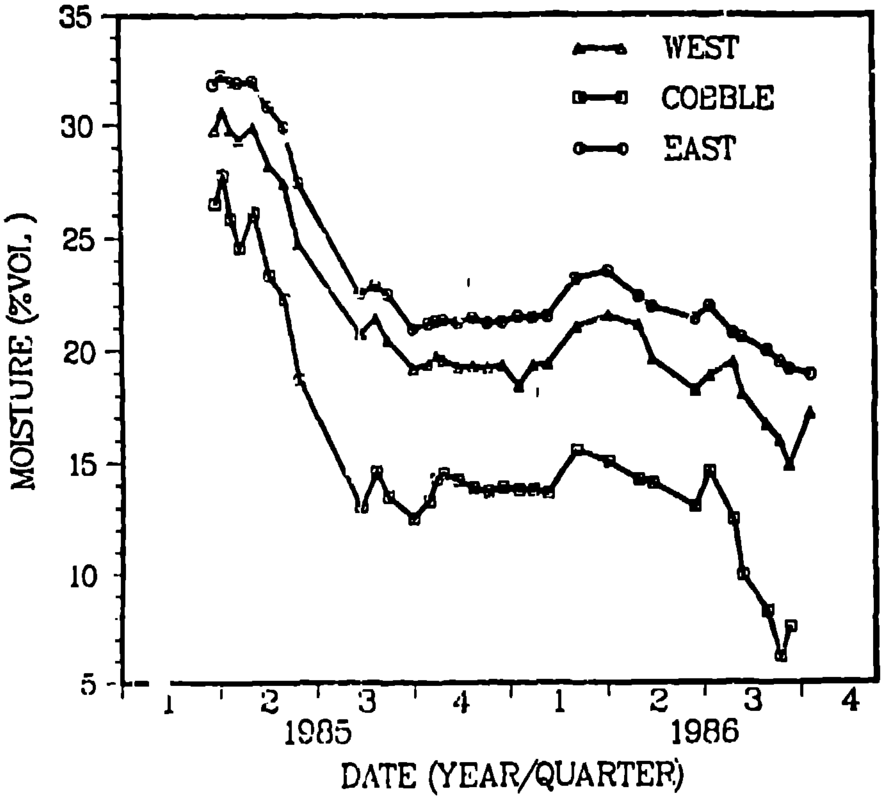

Figure 11. Soil moisture (average 20, 40 and 60 cm depths) in shrub plots with different soil profiles.

the model. Nonetheless, over a wide diversity of soil profiles and plant covers, the model predicts soil moisture with acceptable accuracy.

In contrast, the overall regressions of the HELP predicted soil moisture values shows that neither the CREAMS optimized soil parameters nor the default soil parameters gave acceptable estimates of soil moisture. The CREAMS-optimized parameters resulted in excessively low estimates of soil moisture regardless of precipitation events. The use of default values for parameters raised the average level of predicted soil moisture, but there was still a serious lack of correspondence between observed and predicted soil moisture, as suggested by the small slope of the regression line (0.33). The range of soil moisture was severely restricted compared to observed values, with HELP underestimating soil moisture when field soil moisture was high, and overestimating moisture when field soil moisture was actually low. It is noteworthy that HELP did not allow soil moisture to decrease below about 14%, regardless of the profile composition or the time since precipitation. In addition, soil water recharge was significantly below what was actually observed in the field. The necessity for considering the correlation coefficient (r^2), the slope and the intercept of the regression line, and the proximity of the line to the equal values line in evaluating the model predictions can be seen by comparing the two HELP regressions. The optimized

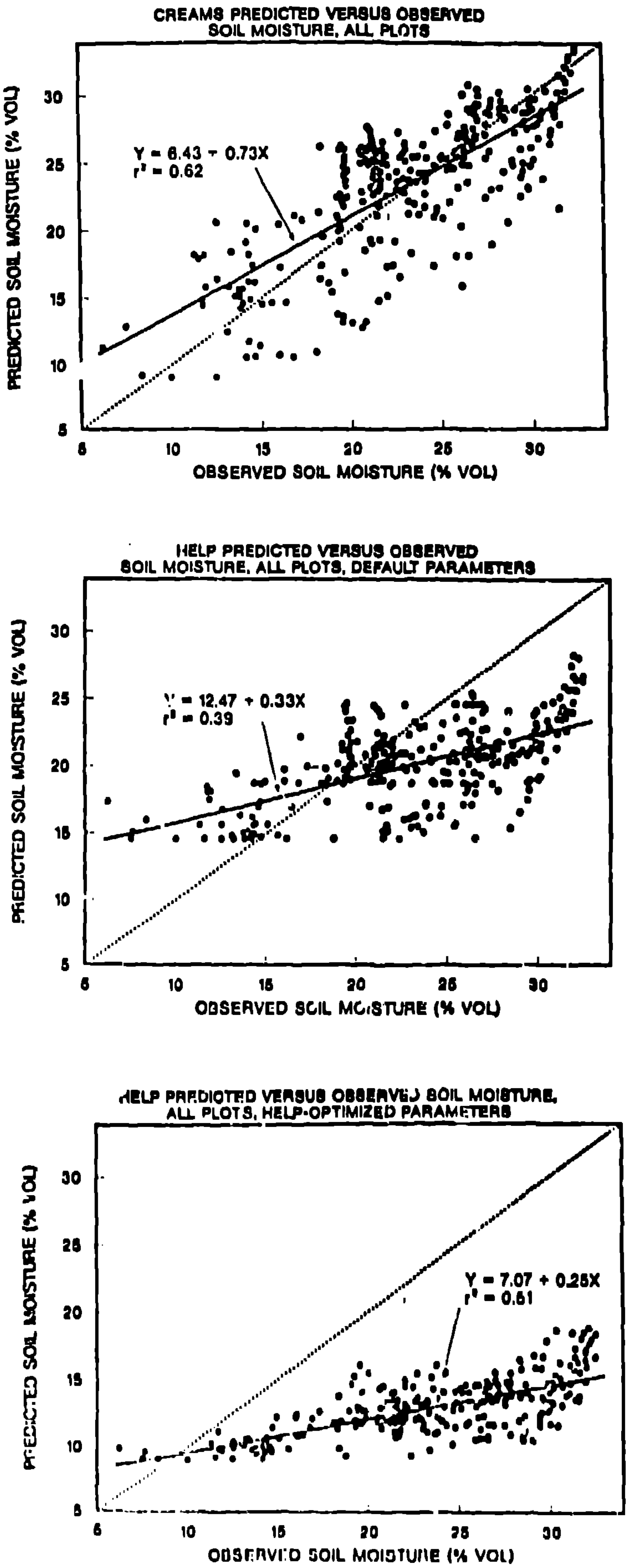

Figure 12. Regression relationships between observed average soil moisture and soil moisture predicted by CREAMS, HELP using default parameters and HELP using optimized parameters.

values produced a regression with a higher overall correlation coefficient (r^2 = 0.51) and a lower intercept value (both indicative of good fit), but had lower slope than the regression of default parameter runs. In addition, inspection of the regression plot shows that the predicted values are far from the equal values line, and that the higher correlation coefficient is the result of some model-produced extreme restriction of the range of values produced.

These results suggest several areas of research which would be fruitful to pursue. The west plots have a more clearly stratified soil profile, consisting of crushed tuff and a thin layer of top soil. This combination in no way represents a natural soil. The crushed tuff is a finely-ground, sterile, compacted layer, which does not support vigorous plant growth. Presumably, plant roots do not penetrate this layer well. The topsoil layer is easily erodible, and there is a sharp boundary between the layers. Abrupt discontinuities in the soil profile will possibly result in lateral flow of subsurface water. Such processes are not accounted for by either model. In contrast, the east plots generally had much more topsoil in the profile, and more closely resembled agricultural soils. It would be advantageous to examine the hydrologic properties of constructed, artificial soil profiles in greater detail. Neither CREAMS nor HELP is likely to be able to represent the movement of water in constructed profiles without more accurate assessment of soil properties and better representation in the models of water extraction processes by plants.

With respect to the vegetative cover, the LAI estimates on shrub and bare covers were more accurate than on the grass covers. Field measurements on grass covers were found to have high errors associated with them, even after doubling the number of samples from 50 to 100. Methods of estimating LAI are tedious, time-consuming, and relatively inaccurate, and there are few data published in the literature. Development of relationships between LAI and easily measured parameters (e.g canopy cover) for individual species are needed. For grasses, the need is obvious.

Previous tests of CREAMS modeling of soil water storage (Devaurs 1985) showed that the accuracy of predictions of soil water storage decreased with the field scale of the study and with increasing artificiality of the soil profile. Similar conclusions were reached by Pathak et al. (1984) who found that agreement between observed and simulated runoff decreased as watershed size and soil heterogeniety increased. Both these studies reported correlation coefficients of the regression relationship between observed and predicted parameter values of 0.21 to 0.76, similar to the range in this study. In addition, the slopes of the regression lines were from 0.91 to 0.49 (Pathak et al. 1984) and 0.16 to 0.22 (Devaurs 1985), indicating that the tendency of CREAMS to underestimate the dynamic range in seasonal soil water storage is also reflected in an underestimate of the range of runoff volumes. The wide range in r values and regression line slopes reported in these studies and the present study shows that the absolute values of predicted water balance components may be accurate only under certain conditions, such as relative uniformity of soils and slopes.

SUMMARY AND DEVELOPMENT OF PROTOTYPE CLOSURE PLAN

Simulations of the different scenarios were made using the CREAMS and HELP models. Parameter values for soil hydrologic characteristics were optimized using data for a shrub plot for which there was a four-year record of soil moisture (two years prior to the start of the experiment plus two years during this study). Optimization was performed by varying values within recommended ranges for hydraulic conductivity, field capacity, wilting point and curve number and then performing a linear regression analysis between observed and predicted soil moisture over a three year period. The process was repeated until it was apparent which combination of parameter values resulted in the highest correlation coefficient (indicating the least amount of scatter in values), the slope of regression line closest to 1.0 (indicating a dynamic range in predicted values that most closely approximates the variability observed in the field) and an intercept closest to 0.0 (indicating an absolute value of soil moisture values most closely resembling the observed values).

The optimization exercise made it very obvious that values for these parameters derived from laboratory studies may be very different from values in the field. In addition, the process of constructing a landfill cover may greatly change the effective value of such parameters compared to values for soils under more natural conditions. As noted by Hartley (1984), the accuracy of a simulation result depends on the precision with which the parameters can be evaluated. Field evaluation of soil hydrologic parameters would greatly increase the absolute accuracy of the modeling results.

Simulations of all treatment scenarios were performed for a two year period with CREAMS (using optimized soil parameters), and with HELP (using optimized soil parameter values and also again using the default parameter values as supplied by the HELP model). Predictions of soil moisture using the CREAMS model more closely resembled the measured soil moisture over a range of soil and vegetation treatments than predictions obtained using the HELP model using either set of soil parameter values. The HELP model produced predicted values for soil moisture closer to observed values when default soil parameter values were used than when using the CREAMS-optimized values. Simulations of the east profile treatments were more accurate than those of the west profile treatments. This may be because the east profiles more closely resembled a natural soil profile than the west profiles. Treatments with shrub or bare covers were more accurately modeled than treatments with grass covers.

The CREAMS model should be used with several precautions. Actual values for soil hydrologic parameters will undoubtedly produce better results than values assumed on the basis of soil texture class. However, the use of approximate values may still produce useful comparisons between different land management scenarios, and may well indicate with good accuracy the relative results of design scenarios.

Nonetheless, we can use CREAMS to optimize configurations of specific cap materials. For example, an important variable in the design of an SLB trench cap is the thickness of the cap material. Optimizing water storage capacity of the cap where it can be pumped back to the atmosphere by evapotranspiration, provides a potentially effective means of preventing percolation. The potential effect of increased trench cap thickness in site closure designs on various components of the water balance for both vegetated and the bare soil conditions is illustrated in Figure 13. If we focus on seepage or percolation as a function of increasing cap thickness, we see that increasing thickness had little effect under bare soil conditions, but as thickness increased to about 1 m, seepage below the vegetated surface reached a minimum dictated by a plant rooting depth of 1 meter. Further increases in cap thickness had little effect on seepage because the plant roots could not exploit the deeper regions.

Using this approach we will evaluate closure designs with and without partial gravel covers for erosion control, as well as rock biointrusion barriers. This will be done for meteorological conditions to encompass the average (Figure 13) and record wet years, as well as for various vegetative covers. The cost effectiveness and practicality of various designs will be evaluated with the help of our site operator, who will have a major input into the selection of a final closure design.

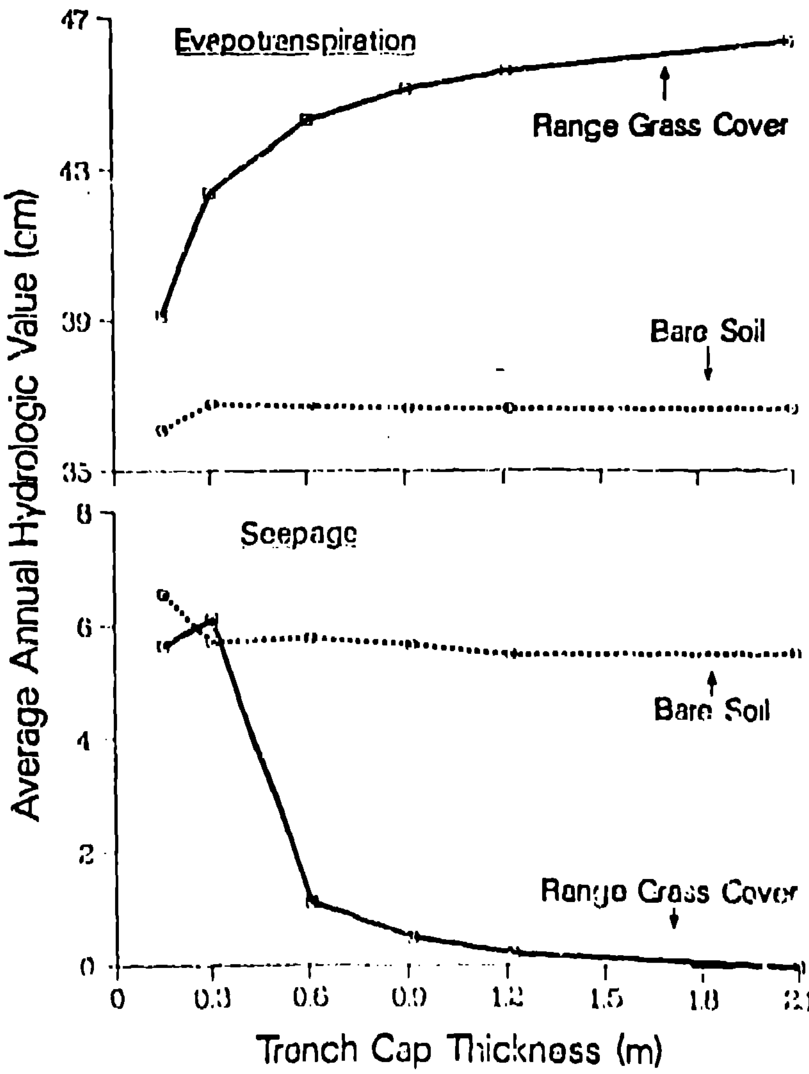

Figure 13. Predicted average annual hydrologic values as a function of sandy-loam trench cap thickness at Los Alamos, NM, 1951-1970.

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