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SHALLOW LAND BURIAL OF LOW LEVEL WASTES

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USE OF CREAMS MODEL IN EXPERIMENTAL DESIGNS FOR SHALLOW
LAND BURIAL OF LOW LEVEL WASTES

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ABSTRACT

A state-of-the art model developed by the U. S. Department of Agriculture called CREAMS (A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems) is used to simulate the hydrologic processes in soil and rock covers at shallow land waste disposal sites. Application of the CREAMS model in management of soil moisture and percolation at waste disposal sites is discussed for diverse topsoil-backfill-cobble-gravel trench cap designs tested at different field scales.

INTRODUCTION

The ability to accurately model shallow land burial facility performance is important for monitoring, regulation and evaluation of these facilities. The predictive capability of a model is a criterion the Nuclear Regulatory Commission (NRC) uses to accept or reject a license application for a low level waste disposal site. 10CFR part 61 requires that modeling analyses provide a reasonable assurance that the disposal site will meet NRC performance objectives. Hydrologic characterization of the site is required.

These regulations have required the application of hydrologic models to compute a water balance for the surface and near-surface areas of shallow land burial facilities. The CREAMS model has been successfully applied in waste management to simulate waste site configurations that minimize soil erosion of trench caps into underlying buried wastes.¹

This paper discusses the application of the CREAMS model in several low level waste burial scenarios at different field scales. Observed and CREAMS calculated soil moisture values are compared for various topsoil-backfill-cobble-gravel configurations.

THE CREAMS MODEL

The CREAMS model was originally developed in 1978 by the U. S. Department of Agriculture to evaluate non-point source pollution from agricultural lands.

However, the CREAMS model, described in a USDA Conservation Research Report,² has been successfully applied to shallow land burial systems in arid and semiarid areas of the West.³

The CREAMS model is a continuous simulation model to predict water balance. The model has hydrology, erosion and chemistry components. The water balance concept and hydrology component of CREAMS are briefly described because they are important in this application.

Figure 1 illustrates the water balance at a shallow land burial site. It depicts the interactive nature of surface and near surface water balance dynamics at shallow land burial facilities. The water balance for one-dimensional movement of water in the soil profile is described by the equation:

$$\frac{ds}{dt} = P - Q - ET - L$$

where $\frac{ds}{dt}$ = time rate change in soil moisture

P = precipitation

Q = runoff

ET = evapotranspiration

L = seepage or percolation

t = time

CREAMS uses this equation to calculate the water balance of the soil profile to the plant rooting depth.

The hydrologic component predicts runoff and infiltration and maintains a soil water balance by simulating ET and percolation. This component has two options: (1) a daily rainfall-runoff model based on the Soil Conservation Service runoff equation⁴ and (2) an infiltration model based on the Green and Ampt infiltration equation.⁵ The daily option is applied herein.

Lane and Nyhan¹ described the hydrologic component of CREAMS as follows:

"The soil profile, to the plant rooting depth, is represented by up to seven layers each with a representative depth or thickness and a water storage capacity. The evapotranspiration calculations are based on a procedure developed by Ritchie and include soil evaporation estimates and plant transpiration estimates based on a leaf area index. Flow through the root zone is computed using a soil storage-routing technique based on the depth of the soil profile, the existing soil water content, and the saturated hydraulic conductivity. Although this procedure only computes saturated flow or percolation below the root zone, a soil water balance is maintained.

Soil water storage in each of seven layers is subject to evapotranspiration (ET) losses based on the rooting depth and the water use rate in the surface layer. The result is an estimate of ET as a function of the total rooting depth and as a function of the roots in each soil layer."

EXPERIMENTAL FACILITY

Model simulations were performed at experimental facilities of varying field scales at the Los Alamos Engineered Waste Burial Facility, Los Alamos, New

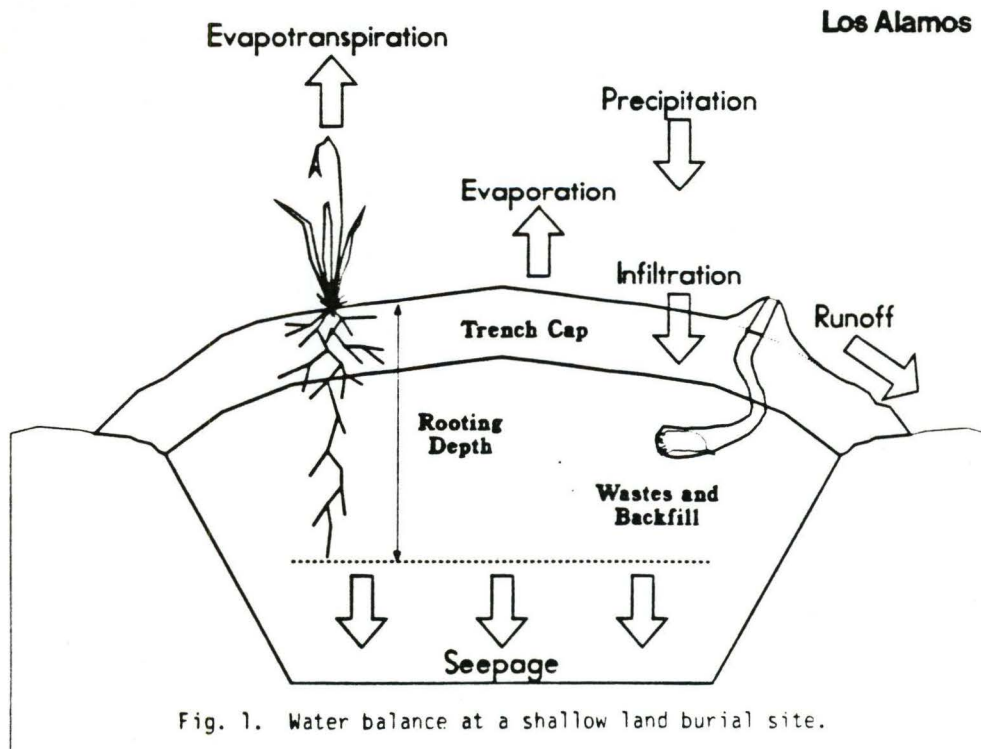
Mexico. Soil moisture measurements were made in controlled experiments in caissons nearly at full field scale and at one field site in an actual shallow-land waste disposal site. Additional detail is given in a Los Alamos National Laboratory Report.⁶ Data from two experimental caissons, each 304.8 cm diameter and 609.6 cm deep is presented. One caisson contained topsoil and crushed tuff; the second was filled with a mixture of topsoil, cobble and gravel. The field site was decommissioned in 1948 and has laid fallow for 32 years (Area B). Experimental field plots at Area B are 40 m x 40 m. Various combinations of topsoil, backfill, gravel and cobble were monitored at each site (See Figures 2-5).

DATA

Observed soil moisture data was obtained for the 1982-4 period using a Campbell Pacific Model 503 neutron moisture gauge. Location of soil moisture measurements for each site are given in Table I. The two soil moisture measurements (at two depths) taken on each plot were averaged.

CREAMS input parameters were obtained from field data (e.g. climatic data and topographic factors) or estimated from previous applications of CREAMS to shallow land burial systems at Los Alamos (e.g. control variable, leaf area index, soil characteristics). Input parameters for the hydrologic component of CREAMS are given in TABLE II. Site characteristics -- topsoil, precipitation, vegetable cover and slope -- are detailed in TABLE III.

A rooting depth of 60 cm was assumed for the caisson and Area B sites. CREAMS predicts average soil moisture over the rooting depth. At each site this value was compared with the linear average of two neutron probe soil moisture measurements.



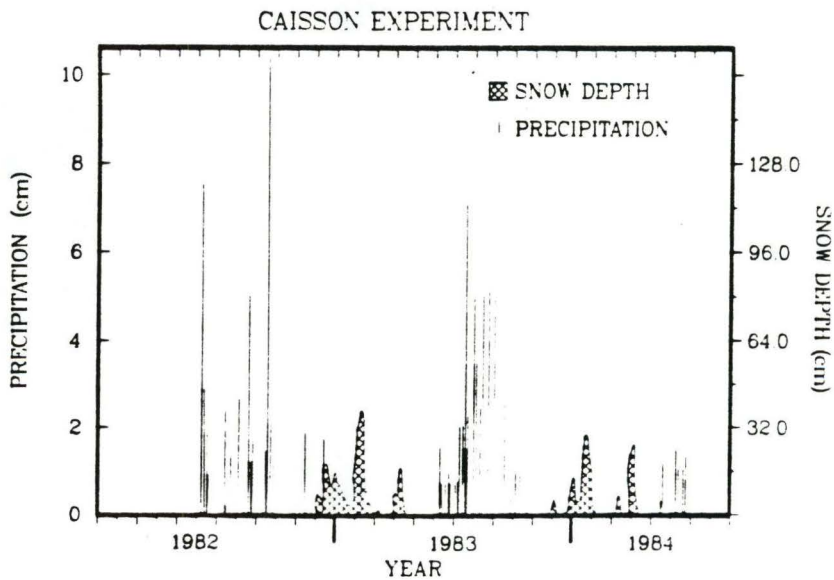
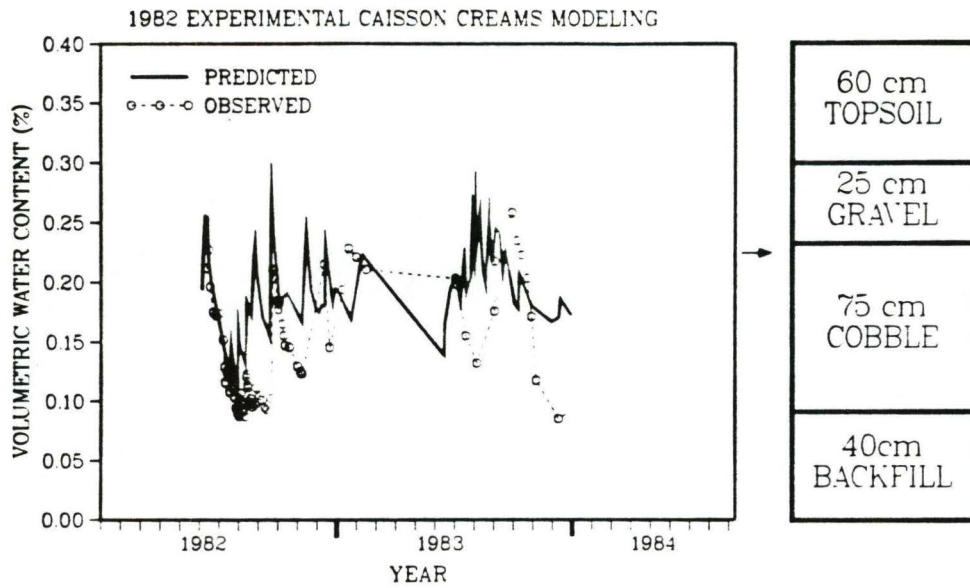


Fig. 3. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given Area B control profile (top right).

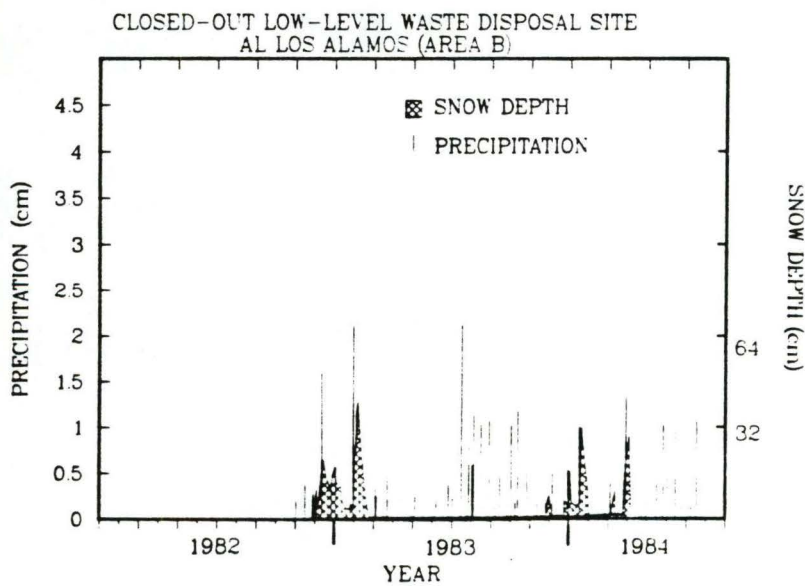
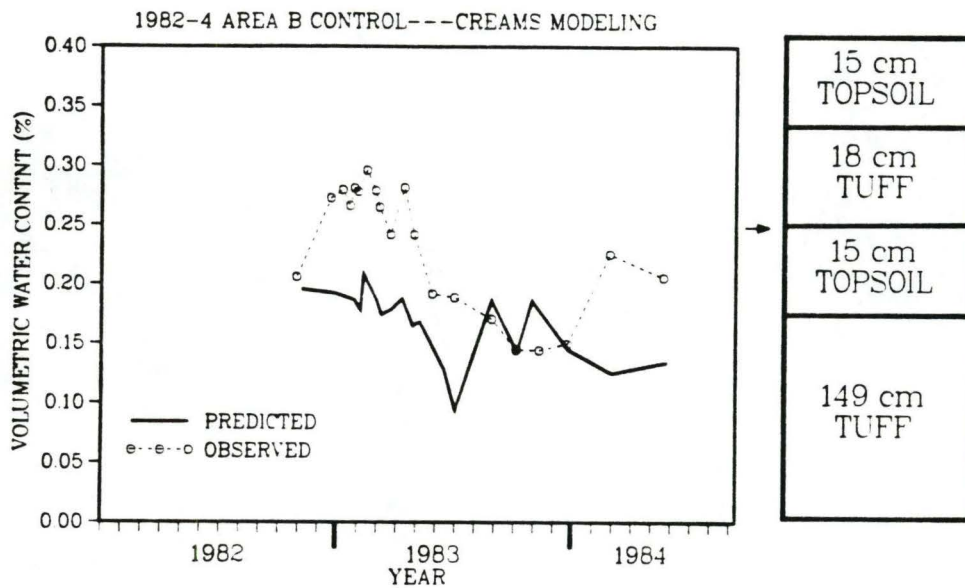


Fig. 4. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given Area B control profile (top right).

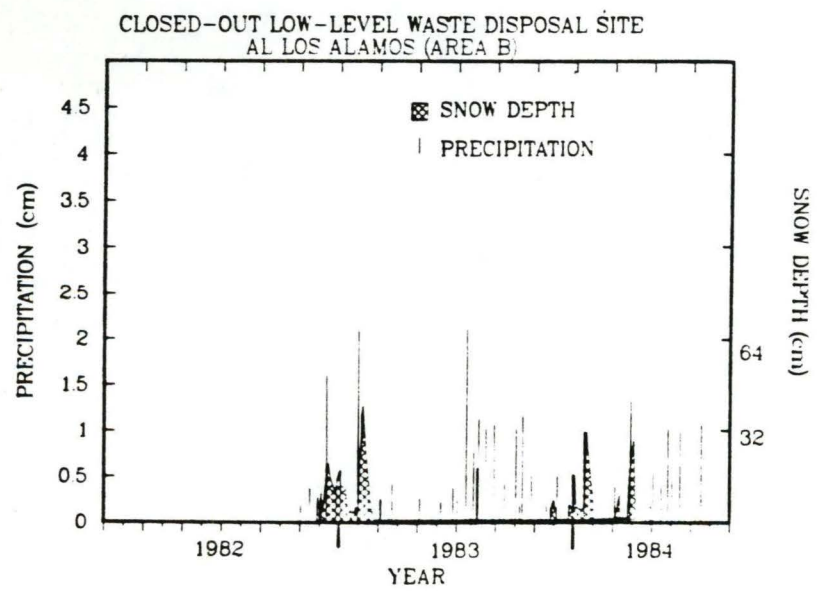
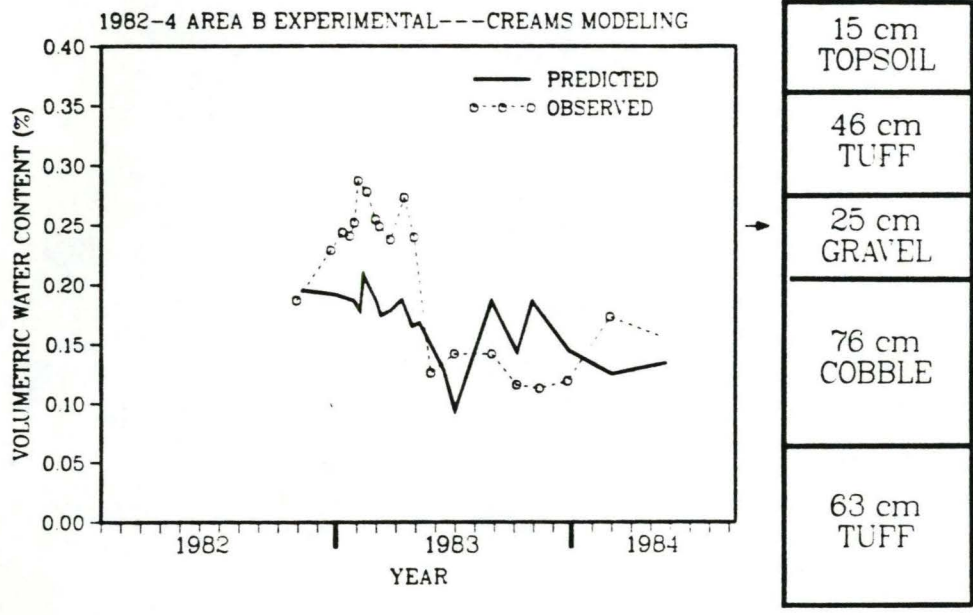


Fig. 5. CREAMS simulation of volumetric water content (top) and observed precipitation and snow depth (bottom) for given Area B experimental profile (top right).

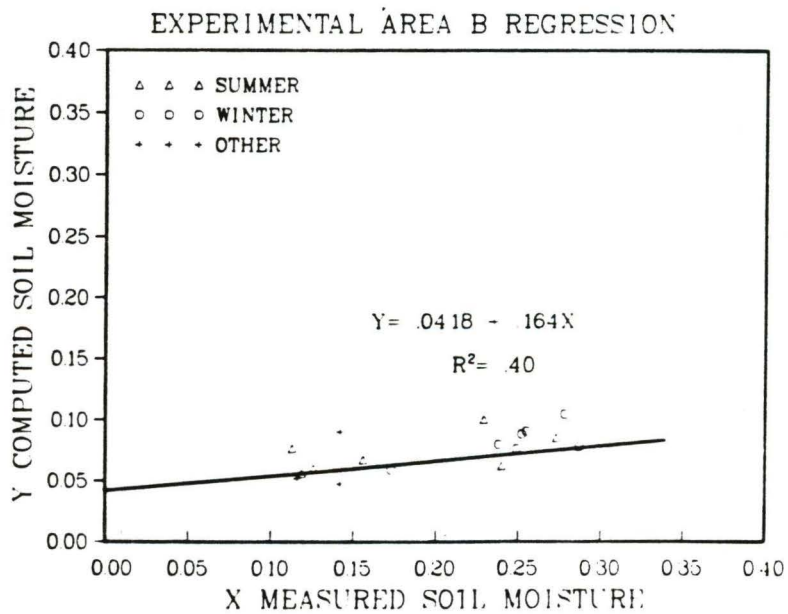
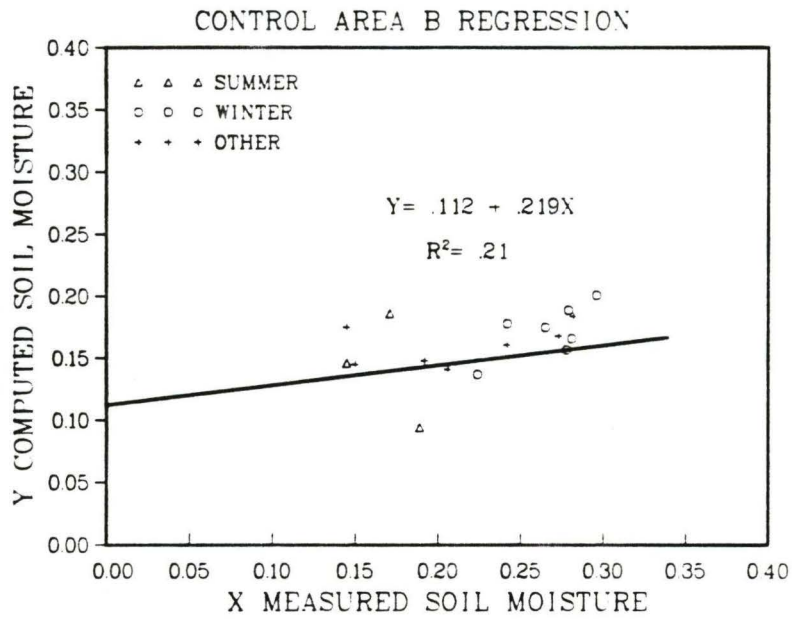


Fig. 7. Relationship between measured and CREAMS-predicted soil moisture for Area B.

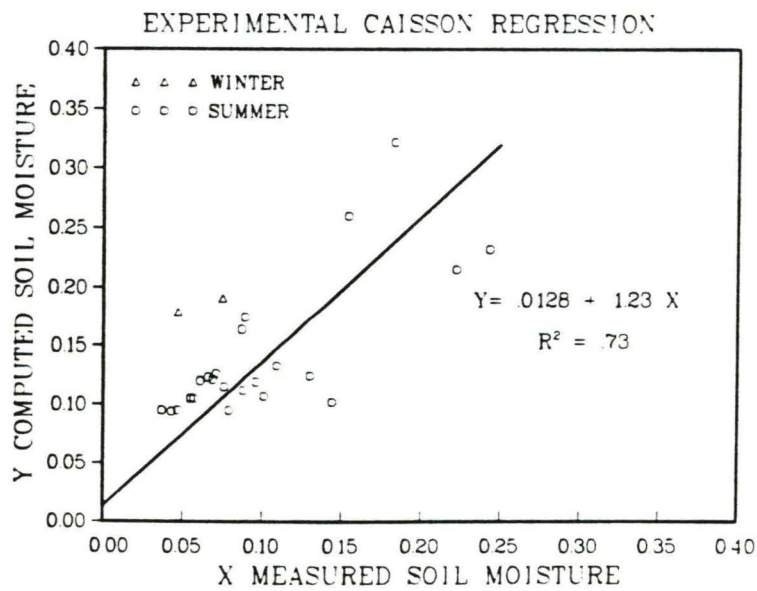
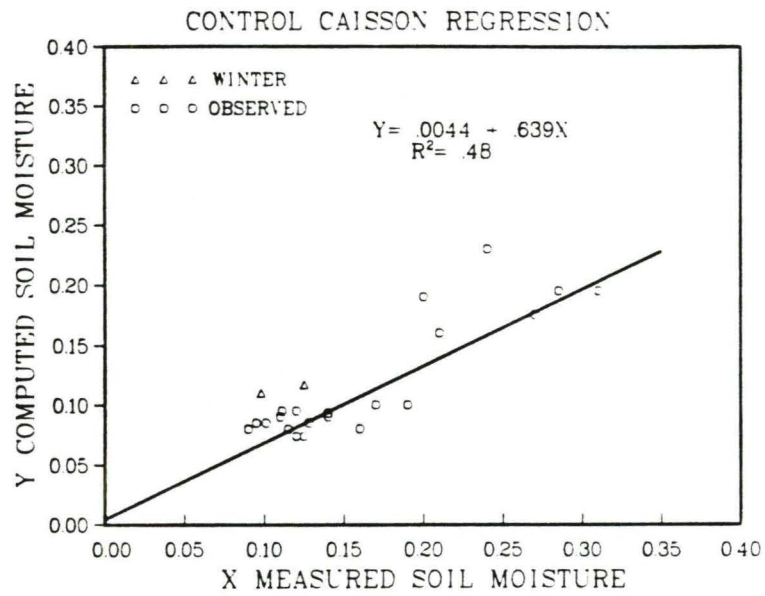


Fig. 6. Relationship between measured and CREAMS-predicted soil moisture for caissons.

TABLE I

RESULTS AND DISCUSSION

ation of neutron probe soil moisture
asurements averaged for comparison
with CREAMS predictions

	Depth from soil surface (cm)
ontrol and mental)	20, 50
ontrol mental)	23, 53 18, 48

The observed soil moisture averaged over the rooting depth and CREAMS-simulated soil moisture is presented for two field scales in Figures 2 to 5. Daily precipitation and snow data is also included in these figures. Supplemental moisture was added to the caissons bringing the annual precipitation to about 175 cm/yr (as opposed to about 75 cm/yr for natural precipitation). An annual precipitation of that magnitude at Los Alamos has a probability of occurring about once every 100 years.

Generally, at both sites, observed increases in topsoil moisture are correlated with periods of snow cover (although caissons were irrigated). During the summer growing season soil moisture is relatively constant or decreases slightly, despite the occurrence of summer precipitation. Figures 2 to 5 show that the CREAMS model predicts observed soil moisture best in the summer and fall; maximum divergence between observed and predicted soil moisture occurs in the winter with snow cover, snowmelt and freeze/thaw. The two main descriptors of the plant component, leaf area index (LAI) and rooting depth, are estimated and therefore may be subject to significant uncertainties.

The caisson data (Figures 2 and 3) shows the closest agreement of field data and model predictions. CREAMS simulates the major increases and decreases in soil moisture. The observed soil moisture on the experimental and control caissons is very comparable, except for spring 1983, when the experimental volumetric soil moisture is approximately .05 units higher than the control plot. This may result from the soil/rock barrier design serving as a capillary barrier preventing the downward flow of water. Previous studies⁶ have shown that the moisture content of topsoil over a rock barrier often measures several volume percent higher than topsoil moisture over a tuff barrier.

At the larger field scale of Area B there is more variability between the observed and CREAMS-predicted soil moisture (see Figures 4 and 5). However, CREAMS still tracks increases and decreases in soil moisture. The greatest discrepancies between observed and predicted soil moisture occur in the winter.

Generally, CREAMS has been shown to better predict soil moisture under more humid conditions where flow is dominated by gravity.⁷ Under drier conditions, where capillary forces become important, CREAMS modeling of soil moisture is less accurate. LAI values for the alfalfa and barley on the caissons site are derived from agricultural application of CREAMS, and contain less uncertainty than LAI estimates for the native grasses found on Area B.

The correlation between observed and computed soil moisture for the caissons and Area B are shown in Figures 6 and 7 respectively. Correlation coefficients for caisson data for the experimental and control plots are respectively .73 and .48. The correlation coefficients for Area B data are considerably lower than those for the caisson data -- .40 and .21 for experimental and control plots respectively. These results show that CREAMS predicts soil moisture better (lower R²) for the experimental plots. It also indicates that for Area B less than 50 percent of the variation in observed soil moisture is explained by CREAMS.

TABLE II

Input Parameters for Hydrologic Component of CREAMS

Parameter	Caissons	Area B
<u>Parameter Estimates</u>		
Number of Layers	85	85
Effective Saturated Hydraulic Conductivity (cm/hr)	.06	.10
Soil Evaporation Parameter	3.0	3.0
Porosity (voids)	.46	.46
Field Capacity	.20	.20
Wilting Point	.10	.085
<u>ed Parameters</u>		
Moisture Fraction Killed at Field Capacity	.30	.316
Plant Available Soil Water Storage Capacity		
<u>ative Parameter Estimates</u>		
Leaf Area Index		
Plant Rooting Depth (inches)	24	24
Winter Cover Factor	1.0	0.85
<u>ographic Data</u>		
Watershed Area (acres)	1.0 (unit)	
Watershed Length-Width Ratio	1.0	1.0
Channel Slope	0.0	0.048
Soil Water Storage Capacity gives initial for 3 soil layers		
1982	.647	.694
1983	.694	.694
1984	.430	.456
1985	.456	.456
1986	.456	.456
1987	.456	.456

index values are input by Julian Date

1	36	72	108	144	180	216	252	288	324	355
C	.44	.88	.90	.90	1.55	3.0	.30	.30	0.14	0.0
C	.06	.30	.30	.30	.30	.27	.50	.50	.50	0.0

TABLE III

Site Characteristics

istics	Sites	
	Caissons	Area B
60 cm		15 cm
ion	Natural (75 cm) plus supplemental irrigation (103 cm)*	natural
cover	0% 1982-barley 1983-alfalfa	2-3% native grassmix

1 precipitation simulates a water year a 100 year return period.

The simulation results demonstrate that agreement between CREAMS predicted and observed soil moisture increases with (1) winter snow cover and snowmelt; (2) increasing field scale; and (3) more complex soil, backfill, cobble, gravel configurations.

The CREAMS model has several shortcomings. The model averages soil moisture over the rooting zone. Observed data was collected with a neutron probe at one to three discrete points over the rooting zone; these values were averaged and compared with model predicted values. Water content typically does not increase linearly with depth; these data are therefore not representative and may be causing some of the discrepancy between observed and predicted soil moisture.

The CREAMS model simplifies soil physics, introducing potential sources of error into the simulation results. First, CREAMS assumes a linear relationship to describe the change in hydraulic conductivity with soil moisture content in the topsoil. Secondly, percolation does not begin until the soil water content in the rooting zone reaches field capacity. Thirdly, CREAMS models water movement as a wetting front; however, fingering occurs with flow through cobble or gravel. Fourthly, CREAMS does not consider the effects of frozen soil, snow or snowmelt on the water balance. Finally, CREAMS does not consider lateral soil water movement.

The leaf area index (LAI) values used in CREAMS are estimates; actual LAI measurements are scarce. LAI influences evapotranspiration predictions. In the CREAMS model, small changes in evapotranspiration can cause large changes in runoff and percolation. Hence it is important to have accurate LAI data to minimize modeling error.

Even though the CREAMS model has shortcomings as discussed here, the results of this application suggest that CREAMS is useful for estimating the water balance of diverse topsoil-backfill-cobble-gravel systems.

FUTURE CONSIDERATIONS

The results presented here suggest that consideration of the effects of frozen soil and snowmelt on the water balance should be incorporated into CREAMS. Secondly, since the CREAMS model has only recently been applied to waste disposal sites under arid and semi-arid conditions, additional research is required to quantify model parameters (especially LAI and rooting depth) under these conditions. Thirdly, rock barriers have been shown to act as capillary barriers preventing downward flow of water. Whether CREAMS can accurately model soil moisture throughout a soil/rock intrusion barrier design requires further investigation. Finally, lateral subsoil movement of soil water toward and through the wastes below the trench cap should also be considered.

Research designed to answer several of these questions is currently in progress. USDA-ARS is revising the CREAMS model to account for frozen soil, snowmelt, and lateral water movement. Several

experiments being conducted at the Los Alamos Engineered Waste Burial Facility and similar experiments in conjunction with USDA-ARS at Tombstone, Arizona, and Boise, Idaho will provide information on parameter values for arid and semi-arid areas in the West.

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