USE OF A STATE OF THE ART MODEL IN GENERIC DESIGNS OF SHALLOW LAND REPOSITORIES FOR LOW-LEVEL WASTES

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ABSTRACT

A state of the art model is described for simulating hydrologic and soil erosion processes at shallow land waste disposal sites. Applications of the model in waste site selection and in the management of waste disposal sites are discussed relative to minimizing soil erosion of trench caps and percolation of soil water through trench caps into underlying buried wastes.

INTRODUCTION

The increasing volume of radioactive wastes produced each year in the United States is of major concern in that new, and acceptable, sites will be required for the disposal of such wastes. New burial sites need to be selected in a wide range of field environments, and actual or anticipated problems with closed shallow land burial sites must be also corrected.

Currently, the most popular method of disposing of low level radioactive wastes is shallow land burial. Burial trenches vary in size from the 4.6-m deep, 3.0 × 15 m disposal pit at Oak Ridge National Laboratory to Chem-Nuclear's 6.1-m deep, 30 × 300 m trench at Barnwell, South Carolina. After the waste materials are added to these burial trenches, current management practices range from just backfilling the trench to more elaborate plans involving installation of multilayered trench caps and revegetation programs.

Once the burial trench receives its final cover, several environmental processes start influencing the trench's configuration and integrity. Although hydrology is only one component of this total effect, water is the principal element: it causes surface erosion, percolates through the wastes, carries contaminants, and is an uncontrolled natural input. Each climatic region and physiographic site has its own characteristics that affect the surface and subsurface response of the waste trench system differently.

Acceptable management practices for such a wide range of waste burial environments would logically involve maintaining cover integrity by minimizing erosion rates and by minimizing percolation of water through the trench cover into underlying waste materials. However, erosion, surface runoff rates, soil moisture in the cover material, and seepage or percolation through the cover are all strongly interrelated variable at any waste disposal site. Thus, a procedure is needed to evaluate soil erosion and water balance within a soil cover profile, based on long term climatic data.

Several factors point up the need for a mathematical model to simulate these hydrologic processes at a waste disposal site. A simulation model is needed because hydrologic processes at a disposal area can't always be measured due to cost limitations and the difficulty of making appropriate measurements. A generic modeling approach can accommodate the wide range of disposal site climatic, soil hydrologic, and vegetative cover characteristics, as well as the effects of having disposal trenches of varying sizes. Long-term hydrologic behavior of a site can be studied in a simulation model which can come closer to matching the service lives of a waste trench than short-term experimentation at a site. The simulation model can be used as a tool to evaluate existing cover systems and to suggest remedial actions for a faulty disposal site. Finally, the model can be used to develop a predictive capability for a site and to develop generic designs of shallow land waste repositories.

More specifically, the simulation model should analyze the hydrologic processes affecting trench cover integrity: runoff, infiltration, percolation, evapotranspiration, soil moisture, and erosion. Because these processes are interrelated, a water balance should be maintained in the simulation model, and on a continuous basis, since climatic variables are continuously changing.

In response to these needs, we have applied a reasonably simple simulation model to these waste management challenges. The model is intended to be useful without extensive calibration and data collection to estimate parameter values.

BRIEF OVERVIEW OF THE CREAMS MODEL

Several procedures or models are available to estimate infiltration, runoff, erosion, and sediment yield. Knisel[1] summarized several of these and described the hydrology, erosion, and chemistry components used in each as well as their intended scale of application. Each of these models have their strengths and weaknesses and application in which they are expected to perform well.

In 1978 the U.S. Department of Agriculture recognized the need to develop improved, physically based, mathematical models to evaluate nonpoint source pollution from agricultural lands. A group of some 50 scientists were assigned to the taks of developing a field-scale model including hydrology, erosion, and chemistry components.[2] The resulting model, entitled CREAMS, A Field Scale Model for **C**hemicals, **R**unoff, and **E**rosion from **A**gricultural **M**anagement **S**ystems, was described in a USDA Conservation Research Report.[3]

Because the CREAMS model was developed using state-of-the-art technology, we feel that it has potential for applications in waste management. Many of the physical factors and management options involved in nonpoint processes on agricultural lands are common in waste management, particularly in shallow land burial of waste material. Therefore, we briefly describe the hydrology and erosion/sediment yield component of the CREAMS model.

The Hydrologic Component

The hydrologic component consists of two options. The first, a daily rainfall model based on the Soil Conservation Service runoff equation[4] and the second, an infiltration model based on the Green and Ampt infiltration equation.[5] These options are discussed in detail by Smith and Williams.[6]

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[7] 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.

In summary, the hydrologic model predicts runoff and infiltration and maintains a soil water balance by simulating ET and percolation. In addition, estimates of runoff volumes and rates are used in the erosion/sediment yield component to compute sediment transport capacity. Results of model testing and validation for surface runoff, evapotranspiration, and percolation are summarized by Smith and Williams.[6]

The Erosion/Sediment Yield Component

The erosion/sediment yield component computes detachment, sediment transport, and deposition on a storm-by-storm basis. Inputs from the hydrologic component include rainfall erosivity, runoff volume, and a maximum runoff rate for each storm. Sediment is routed through overland and concentated flow (channel) areas.[8-10]

Slope length, steepness, and shape are used to construct representative slopes for overland flow. Interrill and rill detachment rates are computed using runoff volume and peak rate together with a modification of the Universal Soil Loss Equation (USLE) which is described by Wischmeier and Smith.[11] Sediment routing is by particle size classes using a modified form of the Yalin[12] sediment transport equation for primary particles and soil aggregates.

The concentrated flow element computes erosion, sediment transport, and deposition in natural channels, grassed waterways, terrace channels, and diversion channels. The spatially varied flow equations (increasing discharge) were normalized and solved for a variety of flow conditions. Third order polynomials were fitted to these solutions and are used to compute friction slope as a function of position along the channel. Channel erosion is computed using an excess shear stress equation and the modified Yalin equation is used to compute transport capacity.

In summary, the erosion/sediment yield model computes erosion, transport, and deposition of sediment in overland flow and in concentrated flow. Gross erosion and sediment yield are computed by sediment particle size classes. Results of model testing and validation are summarized by Foster et al.[8] and Foster et al.[9]

Scientific Basis and Source Material

The scientific basis for the CREAMS model is documented in the recent Conservation Research Report No. 26.[3] This report consists of three volumes. Volume I, model documentation, describes each model component and includes a sensitivity analysis. Volume II, user manual, describes model applications and presents material to aid in the selection of appropriate parameter values. Volume III, supporting documentation, provides additional data and explanatory material.

Basic source material providing the basis for the components included in the CREAMS model are summarized in Table I. The original formulations are described in the references listed in Table I and subsequent modifications are described in Volume I of Conservation Research Report No. 26.[3]

TABLE I

BASIC SOURCE MATERIAL FOR THE CREAMS MODEL

PROCESS	COMMENTS	REFERENCES
Surface Runoff		
Option 1	Daily rainfall model Modified SCS procedure	SCS (4) Williams and LaSuer (13)
Option 2	Breakpont rainfall model Modified Green & Ampt infiltration equation	Green and Ampt (5) Smith and Parlange (14)
Evapotranspiration	Soil evaporation Plant transpiration	Ritchie (7)
Percolation	Daily percolation below the root zone	Williams and Hann (15) Smith and Williams (6)
Sheet & Rill Erosion	Modified USLE	Foster, Meyer, and Onstad (16) Wischmeier and Smith (11)
Sediment Transport and Deposition	Modified for particle size distributions in overland and open channel flow	Yalin (12) Einstein (17)
Channel Erosion	Excess shear equation for cohesive soil	Foster et al. (9) Lane and Foster (18)
Impoundments	Sediment deposition in ponded water	Laflen et al. (19)

APPLICATIONS

The CREAMS model has several potential applications in waste management research. The simulation model could be used to aid in the selection of waste disposal sites using a land resource approach as illustrated by Knisel.[2] Once a specific location for a waste disposal site was selected, CREAMS simulation studies could be used to screen management alternatives involving soil properties, slope steepness, slope length, vegetative cover and depth of cover materials, in an effort to control site erosion and percolation below the cover material. Remedial actions for problems at operational and abandoned waste sites could be suggested using model simulation results. For example, the CREAMS model, which computes actual and potential plant transpiration, could estimate actual and potential herbage yield,[20] which could then be related to minimizing trench cover erosion and maximizing plant transpiration of soil water in the trench cap.

Although the state-of-the-art technology previously described is intended for applications across broad climatic regions, the focus of the paper is on the semiarid regions of the western United States. More specifically, one major use of CREAMS has involved rangeland and waste burial trench configurations, rather than the traditional agricultural systems commonly studied with this model.

Example Application

To illustrate an application of CREAMS we considered the water balance and soil loss for a particular soil and climate. Climatic inputs for Los Alamos, New Mexico were collected, including mean monthly temperature and solar radiation, as well as daily rainfall for the 20 year period 1951-1970. Hydrologic conditions with various cover profiles consisting of Hackroy soil[21] plus backfill with and without vegetative cover (a sparse stand of rangeland grasses or a dense alfalfa cover) were simulated for a uniform slope 22 m long with a slope steepness of 5%.

The results of three simulation studies to evaluate the influence of vegetative cover on site hydrologic processes are shown in Fig. 1. Average annual values for precipitation, evapotranspiration, seepage, and runoff are shown for each simulation. For the bare soil study, the evapotranspiration values represent soil evaporation only, while for the vegetated plots the evapotranspiration values represent soil evaproation and plant transpiration. This figure shows that as plant density increases on the 91 cm trench cap covering the wastes, evapotranspiration increases at the exprense of runoff and percolation. The plot shows that having a dense vegetative cover on a trench cover results in more than a six-fold decrease in runoff and a nine-fold decrease in seepage over that found in the bare soil profile.

We used the erosion/sediment yield output of CREAMS to study the influence of land steepness on soil loss from the trench cover. The results of several 20 year simulations are shown for a bare soil profile in Fig. 2, where the average annual soil loss rate is shown as a function of land slope of the trench cap. These simulation results show that increasing the slope from 2% to only 10% results in greater than a nine-fold loss of topsoil in an average simulation year. This implies that only a

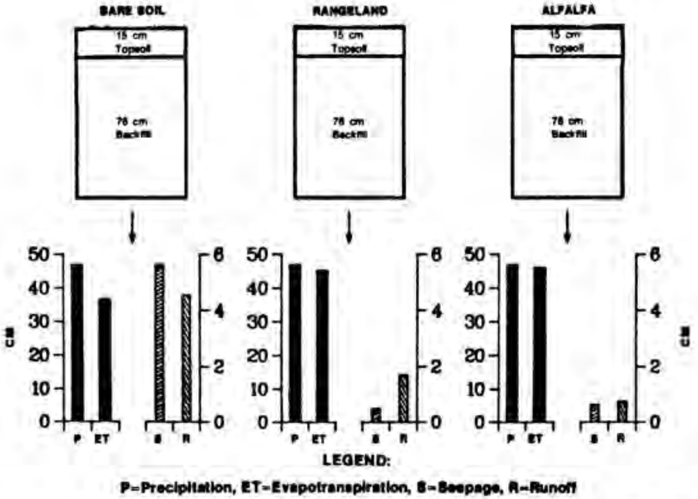

Fig. 1. CREAMS 20 Year Simulation: Average annual hydrologic values for soil profiles with different plant covers.

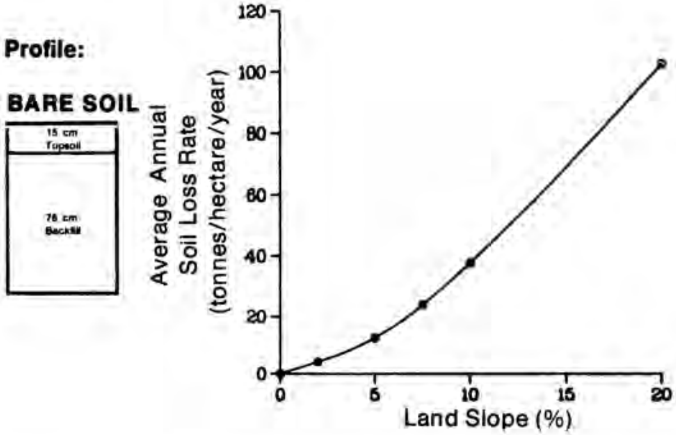

Fig. 2. CREAMS 20 Year Simulation: Average annual soil loss rate for trench covers with varying land slopes.

five-fold increase in the land slope of a trench cap could result in a nine-fold enhancement of its erosion, and thus, a potential nine-fold decrease in its service life.

Another management alternative at a disposal site might involve placing a clay liner within the trench cap to minimize percolation of water through the cap and to act as a biobarrier (see Hakonson, White, and DePoorter, "Field Evaluation of Natural Materials to Limit Biological Intrusion of Low-Level Waste Site Covers," Low-Level Waste Regulation and Safety Assessment session of this symposium). Practical decisions would have to be made concerning the thickness of such a clay layer and what would happen to hydrologic processes in the trench cap if roots penetrated the clay layer. Figure 3 shows the results of three 20-year simulations using a trench cap with a 5% land slope and vegetated with a sparse range grass cover. Average annual hydrologic values are first presented for a profile without a biobarrier, and with plant roots distributed throughout the profile; for a profile with a 30 cm clay biobarrier effective in limiting rooting depth to 46 cm; and finally a profile with a 30 cm clay layer in which plant roots penetrate the 31 cm clay layer and the underlying 46 cm of backfill. These simulation results demonstrate that although a 30 cm clay biobarrier does eliminate percolation through the trench cover, average annual runoff is predicted to increase by 64-68% whether or not the plant roots penetrate the clay biobarrier. This effect is caused by the decreased rainfall infiltration rate of the clay layer.

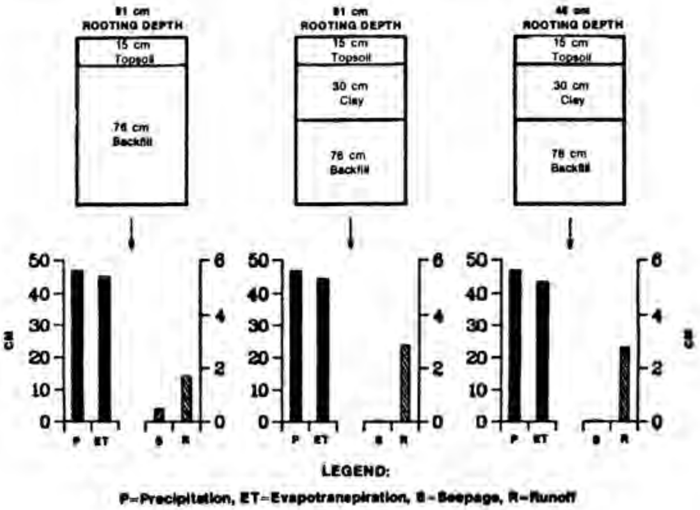

Fig. 3. CREAMS 20 Year Simulation: Average annual hydrologic values for trench caps with range grasses and biobarriers.

FUTURE CONSIDERATIONS

Since most of the use of CREAMS has traditionally been in humid regions with agricultural applications, additional research is required to quantify the model parameters under semiarid conditions and under unique profile conditions containing biobarriers and wick systems. In addition, a length-to-width ratio for a drainage area is used to estimate peak runoff rates: this empirical relationship should be tested for areas a small as a waste trench occupies. An additional consideration might involve consideration of lateral subsoil movement of soil water toward and through the wastes below the trench cap, not just vertical movement of soil water through the trench cap.

Several experiments designed to answer several of these questions are currently in progress at the los Alamos Engineered Waste Burial Facilly described at this symposium last year.[22] In addition, similar experiments are being planned in conjunction with USDA-ARS at Tombstone, Arizona and Boise, Idaho. These experiments should provide information on parameter values at locations representative of large areas of the western United States.

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