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Compiled by:

D. E. Large, Oak Ridge Operations, Department of Energy
R. S. Lowrie, Oak Ridge National Laboratory
L. E. Stratton, Oak Ridge National Laboratory
D. G. Jacobs, Evaluation Research Corporation

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COVER INTEGRITY IN SHALLOW LAND BURIAL OF LOW LEVEL WASTES: HYDROLOGY AND EROSION

L. J. Lane and J. W. Nyhan
Environmental Science Group
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Applications of a state-of-the-art technology for simulating hydrologic processes and erosion affecting cover integrity at shallow land waste burial sites are described. A nonpoint source pollution model developed for agricultural systems has been adapted for application to waste burial sites in semiarid and arid regions. Applications include designs for field experiments, evaluation of slope length and steepness, evaluation of various soil types, and evaluation of vegetative cover influencing erosion rates and the water balance within the soil profile.

INTRODUCTION

To evaluate a broad range of cover systems for waste burial sites a procedure is needed to simulate, based on long term climatic data, soil erosion and water balance within the soil cover profile. To maintain cover integrity, erosion rates should be less than the soil tolerance level required to maintain a soil profile above the buried waste material. Moisture flux below the cover profile should be minimized to minimize leaching into the waste material. Because sediment transport rates are strongly related to surface runoff rates and because seepage or percolation below the cover material is strongly related to soil moisture in the cover material, it is necessary to simulate a water balance.

Therefore, to analyze the hydrologic processes affecting cover integrity, procedures are needed to estimate runoff, infiltration, percolation, evapotranspiration, soil moisture, and erosion. Because these processes are related and are functions of the climatic inputs, a continuous simulation model is required to maintain an accurate water balance.

In response to these needs we have applied a reasonably simple simulation model that incorporates fundamental principles of hydrology, hydraulics, erosion, deposition, and sediment transport mechanics. The model is intended to be useful without calibration or collection of extensive data to estimate parameter values. Therefore, established relationships, such as the Soil Conservation Service Runoff Equation and the Universal Soil Loss Equation, were modified and used in the simulation model.

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 [e.g., see Table 1, p. 147, Knisel (1)]. Each of these models have their strengths and weaknesses and applications 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 task of developing a field-scale model including hydrology, erosion, and chemistry components (2). The resulting model, entitled CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, 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 concentrated flow (channel) areas (8,9,10).

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, Lane, and Knisel (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 1. The original formulations are described in the references listed in Table 1 and subsequent modifications are described in Volume I of Conservation Research Report No. 26 (3).

APPLICATIONS

Although the state-of-the-art technology described earlier is intended for applications across broad climatic and land resource regions, the emphasis in this paper is on semiarid regions of the western United States. As parameters for the CREAMS model were, for the most part, derived for cultivated agricultural lands, less information is available for rangelands in the

Table 1. 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)

West. However, many of the physical processes are common to humid and semiarid areas. Therefore, the CREAMS model can be used in experimental design. For example, simulation studies can be used to reduce the number of factors to be evaluated by field experiments. The experimentally evaluated factors could be limited to those showing gross differences between humid and semiarid areas.

Site Selection

As the model can be used to estimate soil erosion and water balance in the soil profile, it can be used to aid in site selection. That is, estimates can be made based on site-specific climatic, soils, and vegetation data but also using generalized information within land resource areas as defined by soils, topography, climate, and land use. This approach was illustrated by Knisel (2) in a schematic of water balance for selected locations in the United States.

Screening Management Alternatives

Management alternatives might include soil properties, slope steepness, slope length, vegetative cover (such as plant seeding and maintenance), and depth of the cover material. Based on simulation studies, initial screening of combinations of these factors could suggest viable management alternatives to control erosion and percolation below the cover material. For example, at a given location with known climatic features and soil erodability, maximum slope steepness (to prevent erosion in excess of the tolerance values) could be determined as a function of slope length and vegetative cover.

Remedial Actions

Erosion rates and soil water balance can be estimated to evaluate existing systems and to rank or select proposed remedial control systems. The soil loss criterion can be used to rank the proposed remedial action systems with respect to erosion and the percolation criterion can be used with respect to soil water penetration. By simulating on a continuous basis, based on long term climatic records, systems can be evaluated with respect to the interactive criteria of soil loss and percolation.

Finally, the ratio of actual to potential transpiration can be related to the ratio of actual to site potential herbage yield (20). This suggests that the CREAMS model, which computes actual and potential plant transpiration, can be used in vegetation studies at semiarid waste burial sites. Yield estimates together with soil water estimates can be used in plant establishment and maintenance studies.

Example

To illustrate an intended application of the model we considered soil loss and the water balance for a particular soil and climate. Characteristics of the input data for the example are summarized in Table 2. Climatic inputs consisted of mean monthly temperature and solar

Table 2. Characteristics of soil, vegetation, climate, and topography for the example application.

ITEM	CHARACTERISTICS	COMMENTS
Climatic Inputs	Average monthly temperature Average monthly solar radiation Daily precipitation	Observed data at Los Alamos, NM
Cover Material	Top soil: 15 cm, sandy loam Backfill: 76 cm, crushed tuff	Nyhan et al. (21) provide descriptions
Vegetation Cover	Bare soil Short range grasses Alfalfa pasture	
Topography	Uniform, 22 m slope length	Standard erosion plot dimensions

radiation for Los Alamos, New Mexico and recorded daily rainfall at Los Alamos for the 20 year period 1951-1970. The cover profile consisted of 15 cm of a sandy loam topsoil and 76 cm of sandy backfill material. Vegetation varied from none (bare soil), to sparse rangeland grasses, to a dense alfalfa cover. Simulations were made for a uniform slope 22 m long with a slope steepness of 5%.

The results of the simulation study are summarized in Table 3. The values shown in Table 3 represent average annual values for the three vegetation conditions. The ET values represent the estimated average annual evapotranspiration. For the bare soil this represents soil evaporation only, while for the surfaces with vegetative cover the ET values represent soil evaporation and plant transpiration. The influence of vegetative cover on the soil water balance is illustrated by the data shown in Table 3. As the density of vegetative cover increases, evapotranspiration increases at the expense of runoff and percolation. This is because the infiltration rate is increased by vegetation, but, at the same time, evapotranspiration is increased. Although more precipitation infiltrates, more water is transpired: the result is less runoff and less percolation. The actual relationships between these processes is dependent upon the climate, soils, and vegetation characteristics and are thus somewhat site specific.

The last row in Table 3 is the ratio of soil loss for the particular vegetation cover to soil loss from the bare soil surface. These data illustrate, under the assumed conditions, the relative influence of vegetative cover in reducing erosion and sediment transport. The primary mechanisms involved in this example are reduced raindrop impact at the soil surface decreasing the interrill erosion, increased soil stability decreasing the rill erosion, and reduced runoff and increased hydraulic roughness which reduce the sediment transport capacity in overland flow.

Although the dense cover provided by alfalfa would significantly reduce the erosion and sediment transport rates, this example is probably unrealistic under climatic conditions at Los Alamos. Analysis of potential evapotranspiration rates under an alfalfa cover and actual rates (reduced due to limiting soil water) suggests that it would be difficult to establish and maintain a dense alfalfa cover without supplemental irrigation.

Table 3. Summary statistics for the influence of vegetative cover on soil loss and water balance for the example application. Average annual values in mm for 20 year simulation.

	mm		
ITEM	BARE SOIL	RANGELAND	ALFALFA
Precipitation	468	468	468
ET	367	451	460
Runoff	46	17	7
Percolation	56	5	6
Soil loss[1]	0.78	0.073	0.002
Relative soil loss[2]	1.00	0.094	0.0022

[1]Based on an assumed bulk density of 1.6. Does not include channel erosion. Uniform 5% slope, 22 m in length.
[2]Ratio of soil loss under vegetative cover to soil loss from bare soil.

FUTURE CONSIDERATIONS

Although the CREAMS model can be directly applied to the problem of cover integrity at shallow land burial sites, additional research is required to quantify the model parameters under semiarid conditions. Also, additional research is needed to quantify parameters under unique conditions such as wick systems or plant and soil water barriers installed within the cover soil profile. Toward this end, experiments are being planned at Los Alamos, New Mexico, Tombstone, Arizona, and Boise, Idaho. These experiments should provide information on parameter values at locations representative of large areas of the western United States.

DISCUSSION

The CREAMS model, although developed for agricultural systems, appears to explain many of the physical processes important in maintaining the cover integrity at shallow land waste burial sites. An example application, at a semiarid waste disposal site, illustrates typical applications. Even though the CREAMS model, in its present form and with existing parameter values, can be applied to the cover integrity problem, improved estimates might be obtained by experimentally determining parameter values under semiarid conditions.

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