ESTIMATING SEDIMENT YIELD FROM RANGELAND WITH CREAMS[1/]

G. R. Foster L. J. Lane[2/]

ABSTRACT

The erosion/sediment yield component of CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, may be used to estimate sediment yield from small rangeland watersheds. The component operates on a storm-by-storm basis using rainfall erosivity, runoff volume, and a characteristic runoff rate. It applies to a broad range of management practices and considers the influence of topographic features on erosion and deposition along concave, convex and complex slopes; deposition by backwater at field outlets; and erosion and deposition in natural and constructed waterways. Enrichment of the sediment by fines is computed when the model computes deposition. Validation studies have shown that the model gives reasonable results for agricultural areas with little or no calibration.

INTRODUCTION

CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (USDA, 1980), may be used to estimate sediment yield from small rangeland watersheds. The model has three separate components: (i) hydrology, (ii) erosion/sediment yield, and (iii) chemistry. The hydrology component estimates runoff amount, peak runoff rate, and storm erosivity using data for daily, hourly, or breakpoint rainfall. Runoff estimates from daily rainfall are based on the SCS curve number method and those from hourly or breakpoint rainfall are based on a modification of the Green-Ampt infiltration equation (Smith and Williams, 1980). The chemistry component describes the movement of soluble and sediment-adsorbed plant nutrients (Frere et al., 1980), pesticides, herbicides, and other similar chemicals (Leonard and Wauchope, 1980) from field-sized areas.

1/ Contribution of the USDA- Science and Education Administration-Agricultural Research, Lafayette, Indiana in cooperation with the Purdue University Agricultural Experiment Station, West Lafayette, Indiana. Purdue Journal No. 8511.

2/ Hydraulic Engineer, USDA, and Associate Professor, Agricultural Engineering Department, Purdue University, West Lafayette, Indiana; and Hydrologist, USDA, Southwest Rangeland Watershed Research Center, Tucson, AZ.

The erosion/sediment yield component of CREAMS (Foster et al., 1980c) was orginally developed for agricultural fields but has sufficient generality to apply to rangelands, disturbed forest areas, construction sites, and surface mines. The component also applies to a broad range of conservation practices including conservation tillage, rotations, contouring, stripcropping, terraces, grassed waterways, and small impoundments. It considers the influence of topographic features on erosion and deposition along concave, convex, and complex slopes; deposition by backwater at field outlets; and erosion and deposition in natural and constructed waterways. The model has overland flow, concentrated flow, and impoundment components to represent the major hydrologic, hydraulic, erosion, deposition, and sediment transport processes on field-sized areas. Both absolute and relative erosion and sediment yield estimates for a specific site and practice are reasonably accurate (Foster et al., 1980a; Foster and Ferreira, 1981). Parameter values require little or no calibration, and their selection is relatively easy (Foster et al., 1980b). Since the model uses runoff volume, rainfall erosivity, and a characteristic runoff rate to compute an average sediment concentration for each storm, computer time required to simulate a record of 20 or more years of individual storms is much less than that required by a similar fully dynamic model that time-steps through each storm.

BASIC RELATIONSHIPS

The model computes detachment, sediment transport, and deposition on a storm-by-storm basis. Quasi-steady flow is assumed, and sediment is routed through overland flow and concentrated flow areas.

The basic equation of the model is for continuity and is given by:

$$dq_s/dx = D_L + D_F \qquad [1]$$

where q_s = sediment discharge, x = distance, D_L = rate of lateral inflow of sediment, and D_F = rate of detachment or deposition by flow. Rate of deposition D_d is given by:

$$D_d = \alpha(T_c - q_s) \qquad [2]$$

where T_c = transport capacity and the coefficient α is given by:

$$\alpha = a\, V_s/q \qquad [3]$$

where a = 0.5 for overland flow and 1.0 for concentrated flow, V_s = fall velocity of a sediment class, and q = rate of runoff. Sediment transport capacity is estimated with the Yalin equation (Yalin, 1963; Foster and Meyer 1972) modified for nonuniform sediment (Foster et al., 1980c). Flow hydraulics are computed with the Manning equation, and shear stress is distributed between ground cover and the soil according to sediment transport theory. The shear stress acting on the soil is that portion of the total shear stress that is responsible for sediment transport.

Sediment is assumed to be detached as a mixture of several classes of primary particles and aggregates. The model computes the segregation of the classes and enrichment of fines during deposition (Foster et al., 1980d).

Detachment on overland flow areas is computed separately for interrill erosion, which is principally by raindrop impact, and rill erosion, which is principally by flow, by using a modification of the Universal Soil Loss Equation (Wischmeier and Smith, 1978; Foster et al., 1977; Foster et al., 1980b). Detachment by concentrated flow in waterways is computed with an excess shear-stress type equation where the critical shear stress is a function of soil type, tillage, and recency of tillage (Foster et al., 1980b). Deposition in small impoundments where outflow is controlled by an orifice is described with an exponential relationship that is a function of sediment fall velocity, impoundment geometry, infiltration within the impoundment, and orifice diameter (Foster et al., 1980c).

APPLICATION TO RANGELANDS

The erosion/sediment yield component of CREAMS can be applied to small rangeland watersheds. The same general size limitations that apply on cultivated agricultural areas also apply on rangelands. Watershed areas are limited in size by the assumption of uniform rainfall and runoff. Soil, cover, and topography may vary along the slope, but not laterally within the watershed. The channel network is represented by a simple main channel or a main channel and several, similar contributing channels analogous to a terrace channel system or furrows in row crops contributing to an outlet channel. The size of the area to which the erosion/sediment yield component of CREAMS applies varies with the situation, but 100 acres is a general upper limit.

The model can be used to evaluate erosion and sediment yield under current conditions and under proposed alternative managment practices such as different grazing intensities, different types and percentages of vegetative cover, and different surface roughnesses and soil disturbances from mechanical treatments such as root plowing. CREAMS can also describe the influence of slope shape, especially its effect on deposition on concave slopes and increased erosion on steep portions of convex slopes, and the variation in erosion and deposition due to changes in soil, cover, and roughness along a slope. The model can also be used to estimate erosion or deposition in waterways or channels within small watersheds. The effects of spatially varied flow in channels is simulated to account for the influence of changes in channel slope, increase of flow rate in the downstream direction, and localized flow controls at the outlet that cause backwater. Such controls can significantly reduce transport capacity, causing a great reduction in sediment yield due to deposition by the backwater immediately upstream of the control.

An advantage of CREAMS for application to Western rangeland is that it more accurately estimates erosion and sediment yield for individual storms than does the Universal Soil Loss Equation. This is especially important because a very few, even one or two, storms can dominate annual erosion for many Western sites. CREAMS is also more accurate than the USLE for surfaces where transport capacity limits sediment yield because CREAMS treats transport separate from detachment, while the Universal Soil Loss Equation lumps these two separate processes together.

Application of CREAMS to rangeland is not without difficulty because values for some parameters are either unknown or have not been validated for certain conditions. For example, soil erodibility factor values have not been measured for many Western soils. Also, the effects on erosion processes of erosion pavement and clumped, isolated vegetation have not been evaluated. Critical shear stress and channel erodibility factor values are not readily available for natural channels in rangelands. However, CREAMS is a state-of-the-art erosion model. These same difficulties exist with other erosion models (Foster, 1981) that might be used. New parameter values specifically for rangelands can readily be used in CREAMS as soon as research defines them.

SUMMARY

The erosion/sediment yield component of CREAMS, a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems, with elements for overland flow, concentrated flow, and small impoundments, can be used to estimate erosion and sediment yield from rangelands. It operates on a storm-by-storm basis using rainfall erosivity, runoff volume, and a characteristic runoff rate. Sediment is routed downslope using equations for continuity, detachment or deposition, and sediment transport capacity. Sediment is assumed to be composed of both primary particles and aggregates.

Validation studies have shown that the model can give reasonable results for agricultural conditions with little or no calibration. The same is expected for rangelands, particularly after research more precisely defines parameter values for soil erodibility, erosion pavement, and other features unique to Western rangelands.

REFERENCES

Foster, G. R.
1981. Modeling the soil erosion process. In: Hydrologic Modeling of Small Watersheds. C. T. Haan, ed. Amer. Soc. of Agric. Engr. St. Joseph, MI. (In press).

Foster, G. R. and V. A. Ferreira
1981. Deposition in uniform-grade terrace channels. In: Proc. of ASAE Confer. on Crop Production with Conserv. in the 80's. Amer. Soc. of Aric. Engr. St. Joseph, MI. pp. 185-197.

Foster, G. R., L. J. Lane, and W. G. Knisel
1980a. Estimating sediment yield from cultivated fields. In: Proc. of Watershed Management Symposium. Amer. Soc. of Civil Engr. pp. 151-163.

Foster, G. R., L. J. Lane, and J. D. Nowlin
1980b. A model to estimate sediment yield from field-sized areas: Selection of parameter values. In: CREAMS - A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems.

Vol. II: User Manual. Conserv. Research Report No. 26. USDA-Sci. and Educ. Admin. pp. 193-281.

Foster, G. R., L. J. Lane, J. D. Nowlin, J. M. Laflen, and R. A. Young
1980c. A model to estimate sediment yield from field-sized areas: Development of model. In: CREAMS - A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. I: Model Documentation. Conserv. Research Report No. 26. USDA-Sci. and Educ. Admin. pp. 36-64.

Foster, G. R. and L. D. Meyer
1972. Transport of soil particles by shallow flow. Trans. of the ASAE 15:99-102.

Foster G. R., L. D. Meyer, and C. A. Onstad
1977. A runoff erosivity factor and variable slope length exponents for soil loss estimates. Trans. of the ASAE 20:683-687.

Foster, G. R., W. H. Neibling, S. S. Davis, and E. E. Alberts
1980d. Modeling particle segregation during deposition by overland flow. In: Proc. of Hydrologic Transport Modeling Symposium. Amer. Soc. of Agric. Engr. St. Joseph, MI. pp. 184-195.

Frere, M. H., J. D. Ross, and L. J. Lane
1980. The nutrient submodel. In: CREAMS - A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. I: Model Documentation. Conserv. Research Report No. 26. USDA-Sci. and Educ. Admin. pp. 65-87.

Leonard, R. A. and R. D. Wauchope
1980. The pesticide submodel. In: CREAMS-A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. I: Model Documentation. Conserv. Research Report No. 26. USDA-Sci. and Educ. Admin. pp. 88-112.

Smith, R. E. and J. R. Williams. 1980. Simulation of the surface water hydrology. In: CREAMS - A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. I: Model Documentation. Conserv. Research Report No. 26. USDA-Sci. and Educ. Admin. pp. 13-35.

U. S. Department of Agriculture (USDA). 1980. CREAMS - A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Conserv. Research Report No. 26. Sci. and Educ. Admin. 643 pp.

Wischmeier, W. H. and D. D. Smith. 1978. Predicting Rainfall Erosion Losses. Agriculture Handbook No. 537. USDA-Sci. and Educ. Admin. 58 pp.

Yalin, Y. S. 1963. An expression for bed-load transportation. J. of the Hydraulics Division, Proc. of the ASCE 89:221-250.