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WATERSHED PLANNING and ANALYSIS IN ACTION

Proceedings of the Symposium sponsored by the Committee on Watershed Management of the Irrigation and Drainage Division of the American Society of Civil Engineers in conjunction with the ASCE Irrigation and Drainage Conference in Durango, Colorado

in cooperation with the
American Geophysical Union
American Water Resources Association
Illinois State Water Survey
Society for Range Management
U.S. Army Corps of Engineers
U.S.D.A Agricultural Research Service
U.S.D.A Forest Service
U.S.D.A Soil Conservation Service

Durango, Colorado
July 9-11, 1990

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Published by the
American Society of Civil Engineers
345 East 47th Street
New York, New York 10017-2398

spillways. The major features of the model are the ability to 1) delineate areas of detachment and deposition on a hillslope or along a channel reach, 2) account for the effects of management and land use on the erosion process, and 3) account for the effects of backwater on detachment, transport, and deposition processes within channels.

Introduction

The USDA Water Erosion Prediction Project (WEPP) watershed version is an extension of the WEPP profile version computer model (Lane and Nearing, 1989). Both models provide erosion prediction technology based on fundamentals of infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. The models provide several important advantages over existing erosion prediction technology including the ability to 1) estimate spatial and temporal distributions of soil loss and sediment yield at any point on a hillslope or within a watershed, 2) account for the affects of management and land use on the erosion process, and 3) be applied beyond the range of conditions for which they were validated.

The basic concepts guiding the development of the WEPP watershed model are that sediment yield from a watershed is the result of detachment, entrainment, transport, and deposition of sediment on overland (rill and interrill) flow areas and channel flow areas. The movement of suspended sediment on rill, interrill, and channel flow areas is based on a steady state solution to the sediment continuity equation (Foster and Meyer, 1972). The erosion and deposition calculations are physically based in that the basic equations are derived from the equations of motion and momentum. Empirical relationships and approximations of physical processes are used to reflect those processes which influence erosion and deposition but which are too complex or varied, either spatially or temporally, to be represented by a simple differential equation. Thus, subprocesses which significantly influence the erosion and deposition processes (rainfall, runoff, crop growth, tillage operations) are represented at a level of complexity commensurate with the erosion and deposition calculations.

The development of the subprocess components of the WEPP watershed model was constrained by two factors. First, the solution of the erosion and deposition equations used in the WEPP models are for steady state conditions. Thus, in terms of the hydrology subcomponent, only the steady state discharge, duration of runoff, and flow shear stress are needed. Second, the models are intended to be used by action agencies such as the Soil Conservation Service as a replacement of the Universal Soil Loss Equation. Because of this, model execution time was a major factor to be

Water Erosion Prediction Project (WEPP) Watershed Model: Hydrologic and Erosion Calculations.

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Abstract

The Water Erosion Prediction Project (WEPP) watershed model is a distributed continuous simulation model developed to compute the spatial and temporal distribution of erosion and deposition within small agricultural watersheds. The model is made up of three major components; hillslope, channel, and impoundment. The hillslope component calculates rainfall excess by the Green and Ampt infiltration equation, peak runoff rate by a method based on a semi-analytical solution of the kinematic wave equation for overland flow, interrill erosion as a function of soil detachment by raindrop impact, sediment delivery to rill flow areas by broad sheet flow, and rill erosion as a function of the flow's ability to detach sediment, sediment transport capacity, and the existing sediment load in the flow. Channel infiltration is calculated by either the Green and Ampt or a transmission loss equation. Watershed peak discharge rate is calculated by a method based on a semi-analytical solution of the kinematic wave equation. Flow depth and hydraulic shear stress along the channel are computed by regression equations based on a numerical solution of the steady state spatially varied flow equation. Detachment, transport, and deposition within permanent channels or ephemeral gullies are calculated by a steady state solution to the sediment continuity equation. The impoundment component computes deposition within terrace impoundments and stock tanks, and sediment delivery through

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considered in developing the hydrology and hydraulic algorithms needed for the erosion and deposition calculations. Simplifications and approximations of the runoff process were included if they resulted in a decrease in accuracy in the sediment yield output of less than 10%.

The model simulates the erosion process on three types of landforms; hillslopes, channels, and impoundments. Hillslopes are defined as areas on which broad sheet and rill flow occur. Channels are defined as ephemeral gullies, established channels, or concentrated flow areas within which backwater occurs. Impoundments are defined as areas in which flow is retained temporarily or permanently by a man-made structure.

Hillslope Hydrology and Erosion

The controlling variables which affect hillslope erosion are rainfall intensity, runoff duration, peak flow rate, and flow shear stress. The controlling parameters are those which define infiltration characteristics, surface roughness, soil erodibility, and topography. A complete description of how management and land use influence the controlling parameters is contained in the WEPP Hillslope Profile Model User Documentation (Lane and Nearing, 1989).

The primary purpose of the hillslope hydrology component is to supply the erosion calculations with peak discharge, duration of runoff, and flow shear stress. Infiltration is computed using a formulation of the Green and Ampt (Chu, 1978) equation for the case of unsteady rainfall. Rainfall excess is defined as the difference between rainfall and infiltration during the period when the infiltration rate is less than the rainfall rate. Peak discharge at the bottom of the hillslope is estimated by either an semi-analytical solution to the kinematic wave equation for a single plane (Eggert, 1987) or regression equations derived from the kinematic solution for a range of slope steepness and lengths, surface roughness coefficients, soil textural classes, and rainfall distributions (Hernandez et al., 1989). For the case of strip cropping (cascading planes), peak discharge is estimated using the concept of the equivalent plane as described by Hernandez et al. (1989) along with the semi-analytical solution of the kinematic wave equation or the regression equations described above. An effective runoff duration used to calculate event sediment yield is defined as the runoff volume divided by the peak rate of flow.

Flow shear stress varies downslope as a function of the rill bed slope and hydraulic radius. The rill hydraulic radius is computed assuming a downslope linear increase of discharge within a rectangular rill. Because the rill geometry changes with distance, the distribution of flow shear on the hillslope reflects the spatial variation of slope gradient, allowing for identification of zones of detachment and deposition on a hillslope.

Soil erosion is described on overland flow areas as 1) interrill detachment of soil particles by raindrop impact and sediment transport by sheet flow (interrill delivery rate), and 2) rill detachment, transport, and deposition of soil particles by concentrated flow (rill erosion and sedimentation). Interrill delivery rate is described as a rate process proportional to the square of rainfall intensity and includes parameters to account for the effects of ground cover, canopy cover, and interrill erodibility (Lopes et al., 1989). Transport of detached soil particles by sheet flow occurs only during periods of rainfall excess. Thus, rainfall occurring during periods when infiltration capacity is greater than rainfall intensity does not contribute to interrill detachment and transport. Rill detachment and deposition are described as rate processes proportional to the difference between the flow's ability to transport detached sediment-transport capacity and the existing sediment load in the flow. Net soil detachment in rills occurs when hydraulic shear stress exceeds critical shear stress and when sediment load is less than sediment transport capacity (Lopes et al., 1989). Net deposition occurs when sediment load is greater than sediment transport capacity. Sediment transport capacity is calculated as a function of the distance downslope using a simplification of the Yalin equation (Finkner et al. 1989) A new particle size distribution is computed each time the rill flow is routed through a deposition region and at the end of the hillslope. A sediment enrichment ratio based on specific surface area is calculated at the end of the hillslope using a procedure developed by Foster (1980).

Channel Hydrology and Erosion

The channel erosion and deposition calculations are similar to those of the hillslope with the major differences that 1) only entrainment, transport, and deposition by concentrated flow are simulated and 2) the flow shear is calculated based on the spatially varied flow equations. As in the case of the hillslope, the primary purpose of the channel hydrologic and hydraulic calculations is to provide flow peak, duration and shear stress for calculation of detachment, transport, and deposition of sediment within the channel network. The channel component follows a similar logic to those of the hillslope; infiltration or transmission losses, estimation of watershed peak discharge, calculation of flow shear stress, and detachment, transport and deposition of soil material.

The model offers two options to compute channel infiltration; the Green and Ampt equation or a transmission loss equation (Lane, 1983). The Green and Ampt equation is used when the channel is within a developed soil as is the case with an ephemeral gully or grassed waterway. The transmission loss equation is used for those channels which have alluvial beds characterized by high loss rates. Peak discharge at the watershed outlet is estimated by a semi-analytical solution of the kinematic wave equation for a single channel (Stone and Shirley, 1990) or an approximate method similar to that of the WEPP profile model.

Hydraulic shear stress is calculated using regression equations developed by Foster (1980) which approximate the spatially varied flow equations (Chow, 1959). A control section is assumed at the channel outlet and can be described by a critical depth, a depth discharge relationship, or normal depth. Given a control section, the regression equations are applied at distance increments upstream from the control section assuming subcritical flow for the entire length of the reach.

Channel erosion is based on a steady state sediment continuity equation similar to that used for the hillslope model. Sediment load in the channel is a function of the incoming sediment load from upstream reaches and adjacent overland flow areas and the ability of the flow to detach soil particles or channel bed material. The flow detachment rate is proportional to the difference between the flow shear stress exerted on the bed material and the transport capacity of the flow. Net detachment will occur when the flow shear stress exceeds the critical shear stress of the soil or bed material and when the sediment load is less than the transport capacity. Net deposition will occur when the sediment load is greater than the transport capacity. For the channel erosion computations, the channel reach is divided along its length into segments which are determined by changes in the channel characteristics (surface roughness, critical shear, etc.) or on the contributing hillslope areas. Within ephemeral gullies, detachment is assumed to occur initially from the channel bottom until it reaches a nonerodible layer (usually the primary tillage depth). Once the channel reaches this boundary, the channel begins to widen and the erosion rate decreases with time until the flow is too shallow to cause detachment. The ephemeral gully cross sectional geometry is updated after each storm that causes detachment in order to estimate channel hydraulics for subsequent storms.

Impoundment Hydrology and Erosion

The impoundment component is similar to the one used in CREAMS model (Foster et al., 1980) and estimates deposition and sediment yield from terrace and reservoir impoundments. Terrace impoundments are defined to drain between runoff events while reservoir impoundments retain water. In both cases, the main sedimentation process in the impoundment is deposition. The amount of deposition is a function of the time available for sediment to settle. The impoundment terrace routines compute the fraction of each particle size class that leaves the impoundment as a function of the particle size distribution of the incoming sediment, the depth of water in the pond and the diameter of the outlet pipe.

Limitations

The WEPP watershed version is intended to be used on small agricultural watersheds in which the sediment yield at the outlet is significantly influenced by hillslope processes. Model application is constrained by the following limitations of application of the model apply; 1) no partial area response, 2) no headcutting, 3) no bank sloughing, and 4) no perennial streams.

Summary

The WEPP watershed version model is a distributed, continuous, small agricultural watershed erosion model. Its intended purpose is to simulate the effects of management practices and land use on the spatial and temporal variability of the erosion process within a watershed system. Hillslope erosion processes are described in terms of interrill detachment by raindrop impact and sediment delivery to rill flow areas, and sediment detachment, transport, and deposition on rill flow areas. Channel erosion process are described in terms of detachment, transport and deposition occurring within man-made farm conveyance channels, ephemeral gullies, and alluvial channels. The spatial distribution of detachment and deposition processes within the watershed system is identified from the description of slope variations on both the hillslope and channel systems.

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