Chapter 11. HILLSLOPE EROSION COMPONENT

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11.1 Introduction

The main objective of the Water Erosion Prediction Project is to develop a new generation of erosion prediction technology. The purpose of this chapter is to describe the erosion model used in the WEPP hillslope profile technology. The governing equations for sediment continuity, detachment, deposition, shear stress in rills, and transport capacity are presented. The normalized forms of the equations and parameters, the means for characterizing downslope spatial variability, and solution methods are discussed. Information on the channel erosion routines is presented in Chapter 13.

11.2 Governing Equations

11.2.1 Sediment Continuity Equation

The WEPP hillslope profile erosion model uses a steady-state sediment continuity equation to describe the movement of sediment in a rill:

$$\frac{dG}{dx} = D_f + D_i \qquad [11.2.1]$$

where x represents distance downslope (m), G is sediment load ($kg \cdot s^{-1} \cdot m^{-1}$), D_i is interrill sediment delivery to the rill ($kg \cdot s^{-1} \cdot m^{-2}$), and D_f is rill erosion rate ($kg \cdot s^{-1} \cdot m^{-2}$). Interrill sediment delivery, D_i, is considered to be independent of x, and is always positive. Rill erosion, D_f, is positive for detachment and negative for deposition. For purposes of model calculations, both D_f and D_i are computed on a per rill area basis, thus G is solved on a per unit rill width basis. After computations are complete, soil loss is expressed in terms of soil loss per unit land area.

Interrill erosion is conceptualized as a process of sediment delivery to concentrated flow channels, or rills, whereby the interrill sediment is then either carried off the hillslope by the flow in the rill or deposited in the rill. Sediment delivery from the interrill areas is considered to be proportional to the product of rainfall intensity and interrill runoff rate, with the constant of proportionality being the interrill erodibility parameter, K_i. The interrill erodibility parameter is adjusted for various temporally changing factors (See Section 7.10.2 in Chapter 7). The function for interrill sediment delivery also includes a factor for soil roughness impacts. The interrill functions are discussed in detail below.

Net soil detachment in rills is calculated for the case when hydraulic shear stress exceeds the critical shear stress of the soil and when sediment load is less than sediment transport capacity. For the case of rill detachment

$$D_f = D_c \left(1 - \frac{G}{T_c}\right) \qquad [11.2.2]$$

where D_c is detachment capacity by rill flow ($kg \cdot s^{-1} \cdot m^{-2}$), and T_c is sediment transport capacity in the rill ($kg \cdot s^{-1} \cdot m^{-1}$). When hydraulic shear stress of the rill flow exceeds the critical shear stress for the soil, detachment capacity, D_c, is expressed as

$$D_c = K_r(\tau_f - \tau_c) \qquad [11.2.3]$$

where K_r ($s \cdot m^{-1}$) is a rill erodibility parameter, τ_f is flow shear stress acting on the soil particles (Pa), and τ_c is the rill detachment threshold parameter, or critical shear stress, of the soil (Pa). Rill detachment is considered to be zero when flow shear stress is less than the critical shear stress of the soil. The rill erodibility and critical shear stress are also adjusted within the WEPP model as a function of temporally-varying factors, as discussed in Sections 7.11.2, 7.11.3, and 7.11.5 of Chapter 7.

Net deposition in a rill is computed when sediment load, G, is greater than sediment transport capacity, T_c. For the case of deposition

$$D_f = \frac{\beta\, V_f}{q}\,(\,T_c - G) \qquad [11.2.4]$$

where V_f is effective fall velocity for the sediment ($m \cdot s^{-1}$), q is flow discharge per unit width ($m^2 \cdot s^{-1}$), and β is a raindrop-induced turbulence coefficient. For situations of rain drops impacting rill flows, β is assigned a value of 0.5 in the WEPP model, while for other cases such as snow melting or furrow irrigation, β is assigned a value of 1.0.

11.2.2 Hydrologic Inputs

The four hydrologic variables required to drive the erosion model are peak runoff, P_r ($m \cdot s^{-1}$), effective runoff duration, t_r (s), effective rainfall intensity, I_e ($m \cdot s^{-1}$), and effective rainfall duration, t_e (s). These variables are calculated by the hydrology component (see Chapter 4) of the WEPP model which generates breakpoint precipitation information and runoff hydrographs. To transpose the dynamic hydrologic information into steady-state terms for the erosion equations, the value of steady-state runoff, P_r, is assigned the value equal to that of the peak runoff on the hydrograph. The effective duration of runoff, t_r, is then calculated to be the time required to produce a total runoff volume equal to that given by the hydrograph with a constant runoff rate of P_r. Thus, t_r is calculated as

$$t_r = \frac{V_t}{P_r} \qquad [11.2.5]$$

where V_t is the total runoff depth for the rainfall event (m). Effective rainfall intensity, I_e, which is used to estimate interrill soil loss, is calculated from the equation

$$I_e = \frac{\int I\; dt}{t_e} \qquad [11.2.6]$$

where I is the breakpoint rainfall intensity ($m \cdot s^{-1}$), t is time (s), t_e is the total time during which the rainfall rate exceeds infiltration rate (s), and the integral is evaluated over the time t_e.

11.2.3 Flow Shear Stress

Shear stress of rill flow is computed at the end of an average uniform profile length by assuming a rectangular rill geometry. The uniform profile is defined as a profile of constant or uniform gradient, $\bar{S}$, that passes through the endpoints of the profile. The shear stress from the uniform profile is used as the normalization term for hydraulic shear along the profile as discussed below. Rill width, w (m), may either be input by the user or may be calculated using Eq. [10.7.1].

Depth of flow in the rill is computed with an iterative technique using the Darcy-Weisbach friction factor of the rill, the rill width, and the average slope gradient. Hydraulic radius, R (m), is then computed from the flow width and depth of the rectangular rill. Shear stress acting on the soil at the end of the uniform slope, τ_{fe} (Pa), is calculated using the equation

$$\tau_{fe} = \gamma R \sin(\alpha) \left(\frac{f_s}{f_t}\right) \qquad [11.2.7]$$

where γ is the specific weight of water ($kg \cdot m^{-2} \cdot s^{-2}$), α is the average slope angle of the uniform slope, f_s is friction factor for the soil, and f_t is total rill friction factor. The ratio of f_s / f_t represents the partitioning of the shear stress between that acting on the soil and the total hydraulic shear stress, which includes the shear stress acting on surface cover (Foster, 1982).

11.2.4 Sediment Transport Capacity

Sediment transport capacity, as well as sediment load, is calculated on a unit rill width basis. Sediment load is converted to a unit field width basis when the calculations are completed. The transport capacity, T_c, as a function of flow shear stress is calculated using a simplified transport equation of the form

$$T_c = k_t \, \tau_f^{3/2} \qquad [11.2.8]$$

where τ_f is hydraulic shear acting on the soil (Pa), and k_t is a transport coefficient ($m^{0.5} \cdot s^2 \cdot kg^{-0.5}$). Transport capacity at the end of the slope is computed using a modification of the Yalin (1963) equation.

The Yalin equation for nonuniform sediment was described by Foster (1982). Those equations have been modified in two ways, with the objective in both cases to better represent differences in transport capacity as a function of soil particle size characteristics. These modifications are based on extensive testing of the WEPP model for a large range of different soil types and measured field erosion data.

For the application of the Yalin equation as described by Foster (1982), sediment transport capacity for each of the particle size classes of the soil are summed to obtain the total sediment transport capacity of the soil. Using this method there were only small differences in the computed sediment characteristics, which were limited to differences in the density and diameter of the large and small aggregates. In other words, two soils with vastly different sediment size distributions, but with essentially the same size and density of aggregates, would have little difference in total sediment transport capacity. The modification included in WEPP uses a weighted average of the sediment transport capacity for each particle size class, where the weighting function is the mass fraction of sediment within each class.

Even with the first modification to the Yalin transport summation, observed transport capacities for the very sandy soils under shallow-flow, field conditions were less than the computed values. An empirical adjustment function was developed for soils with sand contents greater than 50% based on extensive testing of the model on different soil types. The adjustment factor is computed as:

$$tcadjf = 0.3 + 0.7\, e^{-12.52\,(sand\, -\, 0.5)} \qquad [11.2.9]$$

where *sand* is the fraction of sand in the surface soil for the current overland flow element (OFE). *tcadjf* is limited to a minimum value of 0.30.

In Eq. [11.2.8] the coefficient, k_t, is calibrated from the transport capacity at the end of the slope, T_{ce}, using the method outlined by Finkner et al. (1989). A representative shear stress is determined as the average of the shear stress at the end of the representative uniform average slope profile and the shear stress at the end of the actual profile. The representative shear stress is used to compute T_{ce} using the modified Yalin (1963) equation and k_t is then determined from the relationship given in Eq. [11.2.8]. Differences between the simplified equation and the modified Yalin (1963) equation, using the calibration technique, are minimal (Finkner et al., 1989).

11.3 Normalizations

11.3.1 Normalized Parameters

The erosion computations are made by solving nondimensional equations and then redimensionalizing the final solution. By nondimensionalizing, shear stress and transport capacity can be written as polynomials of x. Thus, the solutions to the detachment and deposition equations are more readily obtained and require less computational time. Conditions at the end of a uniform slope through the endpoints of the given profile are used to normalize the erosion equations. Distance downslope is normalized to the slope length, i.e., $x_* = x/L$. The slope at a point is normalized to the average uniform slope gradient and is expressed as

$$s_* = a\ x_* + b \qquad [11.3.1]$$

where a and b are calculated from slope input data describing the hillslope. Note that a and b need not be, and usually will not be, constant over an entire slope length. Eq. [11.3.1] for a given set of a and b values describes a simple slope shape, either convex, concave, or uniform, depending on whether the value of a is positive, negative, or zero. The profile input to the model is processed in such a way as to describe the hillslope in sections of simple slope shapes, and to calculate a and b values for each section.

Shear stress as a function of downslope distance is normalized to shear stress at the end of the uniform slope, τ_{fe}. The function for shear stress vs. downslope distance is derived using the Darcy-Weisbach uniform flow equation and the assumption that discharge varies linearly with x, hence,

$$\tau_f = \gamma \left[\left(\frac{P_r}{C}\right) x\ s \right]^{2/3} \qquad [11.3.2]$$

where C is the Chezy discharge coefficient ($C = (8g/f_t)^{1/2}$), and s is the slope ($m \cdot m^{-1}$) at the location x. Thus the normalized shear stress acting on the soil, τ_* (where $\tau_* = \tau_f/\tau_{fe}$), using Eq. [11.3.1] and [11.3.2] and assuming that γ, P_r, and C are constant on the hillslope, is

$$\tau_* = (a\ x_*^2 + b\ x_*)^{2/3} \qquad [11.3.3]$$

Sediment load normalized to transport capacity at the end of the uniform slope is

$$G_* = \frac{G}{T_{ce}} \qquad [11.3.4]$$

Transport capacity normalized to transport capacity at the end of the uniform slope is

$$T_{c*} = \frac{T_c}{T_{ce}} \qquad [11.3.5]$$

Since T_{ce} is equal to $k_{t1}\ \tau_{fe}^{3/2}$, using Eq. [11.2.8] and [11.3.3], then

$$T_{c*} = k_{t1}\ \tau_*^{3/2} = k_{tr}\ (a\ x_*^2 + b\ x_*) \qquad [11.3.6]$$

where k_{tr} is the ratio of k_t (from Eq. [11.2.8]), as calibrated by Finkner et al. (1989), to k_{t1}, the value of the transport coefficient for the uniform representative profile.

The model has four erosion parameters; one for interrill erosion, two for rill erosion, and one for rill deposition.

11.3.2 Rill Detachment Parameters

The parameters for rill detachment are η and τ_{cn} given by

$$\eta = \frac{L\ K_{radj}\ \tau_{fe}}{T_{ce}} \qquad [11.3.7]$$

and

$$\tau_{cn} = \frac{\tau_{cadj}}{\tau_{fe}}. \qquad [11.3.8]$$

In these equations K_{radj} and τ_{cadj} are the adjusted rill erodibility and critical hydraulic shear of the soil as defined in Chapter 7. The adjusted values take into account various factors such as soil consolidation, residue, and freeze-thaw effects. The adjustment factors for each modeled effect are multiplied by the baseline rill erodibility (K_b) and critical shear stress (τ_{cb}) to obtain the adjusted values in Eq. 11.3.7 and 11.3.8. See Section 7.11 in Chapter 7 for a full description of the equations for the baseline rill erodibility parameters and the adjustment factors.

11.3.3 Interrill Erosion Parameter

The interrill erosion parameter, θ, is given by

$$\theta = \frac{L\ D_i}{T_{ce}}\ \frac{t_e}{t_r} \qquad [11.3.9]$$

where

$$D_i = K_{iadj}\ I_e\ \sigma_{ir}\ SDR_{RR}\ F_{nozzle}\ \left(\frac{R_s}{w}\right) \qquad [11.3.10]$$

in which K_{iadj} is adjusted interrill erodibility, I_e is effective rainfall intensity ($m{\cdot}s^{-1}$), σ_{ir} is the interrill runoff rate ($m{\cdot}s^{-1}$), SDR_{RR} is a sediment delivery ratio which is a function of the random roughness, the row side-slope and the interrill sediment particle size distribution, F_{nozzle} is an adjustment factor to account for sprinkler irrigation nozzle impact energy variation, R_s is the spacing of the rills (m), and w is the rill width (m). Equations for baseline interrill erodibility and various adjustment factors are presented in Chapter 7, Section 7.10.

The interrill sediment delivery ratio, SDR_{RR}, is computed as a function of the random roughness of the soil surface, the fall velocity of the individual particle size classes of sediment, and the particle size distribution of the sediment. This method is an adaptation of the method suggested by Foster (1982). The procedure involves three steps. First, an interrill roughness factor is computed based on a functional representation of Table 8.4 from Foster (1982), i.e., the interrill roughness factor is a function of random roughness of the soil surface. This factor is not allowed to be outside the limits of zero to one in value. The second step involves calculating a sediment delivery ratio for each of the five WEPP particle size classes as a function of the interrill roughness factor and the fall velocity of the size class. These relationships were developed for WEPP from Table 8.5 from Foster (1982). The third step is to simply take a weighted average of the sediment delivery ratio for each particle size class, weighted by the mass fraction of sediment in each class, to obtain the sediment delivery ratio for the entire sediment. The values predicted for sediment delivered in each size fraction are also used in the updating of the flow sediment size classes at the end of each detachment region and beginning of each deposition region (see Eq. [11.5.3]).

The sprinkler irrigation nozzle impact energy factor, F_{nozzle}, is a dimensionless parameter that is assigned a value of 1.0 for all simulations which exclude sprinkler irrigation. For simulations in which water is applied to the soil surface through sprinkler irrigation, the user may enter a value for F_{nozzle}, normally between 0.0 and 1.0, to account for the differing impact energy and erosivity of water drops from sprinkler nozzles. For days on which natural rainfall occurs, F_{nozzle} is set to the default of 1.0 within the model. The WEPP interface and the User Summary document provide detailed information on how to estimate this parameter.

11.3.4 Rill Deposition Parameter

The nondimensional deposition parameter, ϕ, is given by

$$\phi = \frac{\beta \, V_f}{P_r} \qquad [11.3.11]$$

The equations derived by Foster et al. (1985) are used to compute the diameter, specific gravity, and fractions of the particle classes primary clay, silt and sand, and large and small aggregates as a function of primary sand, silt, and clay fractions and organic matter content of the surface soil horizon. The effective diameter is computed from

$$d_{eff} = e^{\left(\frac{1}{\sum_{i=1}^{3} f_{\det i}} \sum_{i=1}^{3} f_{\det i} (\log[d_i]) \right)} \qquad [11.3.12]$$

where d_{eff} is effective diameter (m), d_i is particle diameter of size class i, and $f_{\det i}$ is the fraction of detached sediment in size class i. An effective value for particle specific gravity is calculated in an identical manner, substituting S_g for d values in the above equation. The use of this equation is still under evaluation and future refinements of the WEPP technology may include changes to this lumped function or implementation of a different procedure which uses characteristics of all particle size classes for computation of deposition.

11.3.5 Normalized Erosion Equations

The model solves the normalized sediment continuity equations. For the case of detachment the normalized equation is

$$\frac{dG_*}{dx_*} = \eta \, (\tau_* - \tau_{cn}) \, (1 - (\frac{G_*}{T_{c*}})) + \theta \qquad [11.3.13]$$

where η, τ_{cn}, and θ are the normalized detachment parameters given by Eq. [11.3.7], [11.3.8], and [11.3.9], and G_*, T_c, and τ_* are the normalized functions of x_* given by Eq. [11.3.3], [11.3.4], and [11.3.6]. Eq. [11.3.16] is solved using a Runge-Kutta numerical method.

The normalized deposition equation is

$$\frac{dG_*}{dx_*} = (\frac{\phi}{x_*}) \, (T_{c*} - G_*) + \theta \qquad [11.3.14]$$

where ϕ and θ are normalized erosion parameters and G_* and T_{c*} are functions of x_* presented in the above section. Eq. [11.3.17], with substitutions for the normalized terms, has a closed-form solution.

11.3.6 Sediment Yield

Normalized sediment load, G_*, is converted to actual load on a per unit width basis by the formula

$$G = G_* \, T_{ce} \left(\frac{w}{R_s} \right) \qquad [11.3.15]$$

where G is in terms of $kg \cdot s^{-1}$ per unit width. Total load for the entire storm event is obtained by multiplying the load per unit time by the effective storm runoff duration, t_r.

11.4 Downslope Variability

The WEPP erosion model calculates soil loss for cases involving downslope variability such as surface roughness cover and canopy differences, soil type, and surface runoff rates. The model does this by dividing the hillslope into homogeneous overland flow elements and treating each element as an independent hillslope with added inflow of water and sediment equal to that coming from the upslope overland flow element. The flow elements may have complex topography, but within each element all other properties are considered homogeneous.

Finkner et al. (1989) presented the method for calculating dimensionless shear stress and transport capacity for the case of added inflow of water onto an overland flow element. Non-dimensional shear stress becomes

$$\tau_* = (A \, x_*^2 + B \, x_* + C)^{2/3} \qquad [11.4.1]$$

where

$$A = \frac{a}{(q_{o*} + 1)} \qquad [11.4.2]$$

$$B = \frac{(a \, q_{o*} + b)}{(q_{o*} + 1)} \qquad [11.4.3]$$

and

$$C = \frac{b \, q_{o*}}{(q_{o*} + 1)} \qquad [11.4.4]$$

In the above equations, q_{o*} is nondimensional influx of water onto the overland flow element given by

$$q_{o*} = \frac{q_o}{P_r \, L} \qquad [11.4.5]$$

where q_o $(m^2 \, s^{-1})$ is the inflow of water at the top of the element. Non-dimensional transport capacity for the case of added inflow of water becomes

$$T_{c*} = k_{tr} \, (A \, x_*^2 + B \, x_* + C) \qquad [11.4.6]$$

Solutions of the detachment and deposition equations for the case of strips remain similar as for the case of no inflow except that the boundary conditions for inflow of sediment change to account for sediment influx at the top of the strip. The form of the deposition equation and its analytic solution also changes slightly. The denominator of the first term on the right side of Eq. [11.4.4] becomes $x^* + q_o^*$. Calculation of water and sediment from the strip act as boundary conditions for the next strip downslope.

11.5 Sediment Enrichment

Sediment enrichment refers to the mass fraction increase of the more chemically-active fine sediment particles (silt, clay, and organic matter) due to selective deposition of coarser sediment. The WEPP model predicts the particle size distribution and composition of detached sediment based on the primary sand, silt, clay, and organic matter content of the *in situ* soil (Foster et al., 1985). When flow is routed through a deposition region, a new particle size distribution must be computed.

Eq. [11.3.14] was solved for G_* for the case of added inflow, since the solution had to be general enough to perform with the downslope variability possible in the model. The solution is:

$$G_* = (x_* + q_{o*})^{-\phi}\left[\frac{\phi k_{tr} A}{\phi + 2}(x_* + q_{o*})^{\phi + 2} + \frac{(\phi k_{tr} B + \theta - 2k_{tr} A \phi q_{o*})}{\phi + 1}(x_* + q_{o*})^{\phi + 1} + k_{tr}(A q_{o*}{}^2 - B q_{o*} + C)(x_* + q_{o*})^{\phi}\right]$$

$$+ K(x_* + q_{o*})^{-\phi} \qquad [11.5.1]$$

The constant of integration, K, was obtained by imposing the boundary condition at the upper edge of a deposition region. At this point, $x_* = x_{u*}$ and $G_* = G_{u*}$, and K is:

$$K = (x_{u*} + q_{o*})^{\phi}\left[G_{u*} - \frac{\phi k_{tr} A}{\phi + 2}(x_{u*} + q_{o*})^2 - \frac{\phi k_{tr} B + \theta - 2k_{tr} A \phi q_{o*}}{\phi + 1}(x_{u*} + q_{o*}) - k_{tr}(A q_{o*}{}^2 - B q_{o*} + C)\right] \qquad [11.5.2]$$

A more detailed description of the equation development and solution can be found in Flanagan and Nearing (1990).

Equations [11.5.1] and [11.5.2] are solved for the 5 individual particle size classes at $x_* = x_{e*}$, the end of the deposition region. A total exiting load is computed, and fractions exiting the region are calculated. A check is performed to insure that mass is conserved within each size class, so that the amount of a particle type predicted to be leaving a region cannot exceed that entering plus the interrill contribution in the region. If exiting load in a class is too high, the excess load is distributed among the other classes.

Several of the equation variables have to be partitioned among the particle classes. The deposition parameter, ϕ, is computed for each class using Eq. [11.3.17] with a fall velocity for the class found using the class diameter and specific gravity. The interrill erosion parameter, θ, is multiplied by the fraction of each class in detached sediment. The transport coefficients A, B, and C are proportioned for each particle class based on the fractions of transport capacity computed using the modified Yalin (1963) equation when the shear stress at the end of the slope is the average of the shear stresses calculated using the actual end slope and the average slope.

G_{u*} is multiplied by the current sediment fractions in the flow at the point on the profile where deposition is predicted to begin. As sediment is routed downslope through detachment and deposition regions, the fraction of each particle size class is updated. At the top of the first deposition region on a hillslope the incoming sediment fractions are the same as those for the detached sediment. At a subsequent deposition region, the fractions of sediment exiting the detachment region above are computed using:

$$f_{out}(i) = \frac{f_{in}(i)\ G_{in\,*} \ + \ \left(f_{detr}(i)\ G_{rill\,*} + f_{deti}(i)\ G_{ir\,*} \right)}{G_{out\,*}} \qquad [11.5.3]$$

where $f_{out}(i)$ is the fraction of a size class leaving the detachment region (entering the next deposition region or exiting an overland flow element), $f_{in}(i)$ is the fraction in the flow determined at the end of the previous deposition region, $f_{detr}(i)$ is the fraction of detached rill sediment for a size class, $G_{rill\,*}$ is the portion of the sediment load leaving the detachment region contributed from rill detachment, f_{deti} is the fraction of the delivered interrill sediment for a size class, $G_{ir\,*}$ is the portion of the sediment load leaving the detachment region contributed from interrill sediment delivered to the rill channels, and $G_{in\,*}$ is nondimensional sediment load at the end of the previous deposition region, and $G_{out\,*}$ is nondimensional sediment load at the end of the current detachment region or overland flow element.

At the end of each overland flow element an updated sediment size distribution is computed using Eq. [11.5.3], and then an enrichment ratio of the specific surface area is also calculated using:

$$ER = \frac{SSA_{sed}}{SSA_{soil}} \qquad [11.5.4]$$

where ER is enrichment ratio, SSA_{sed} is the specific surface area of the sediment ($m^2 g^{-1}$), and SSA_{soil} is the specific surface area of the *in situ* soil ($m^2 g^{-1}$) (USDA, 1980). The specific surface area of the sediment is computed using:

$$SSA_{sed} = \sum_{i=1}^{5} f_{out}(i) \left[\frac{frsnd(i)\, ssasnd + frslt(i)\, ssaslt + frcly(i)\, ssacly}{1 + frorg(i)} \ + \ \frac{frorg(i)\, ssaorg}{1.73} \right] \qquad [11.5.5]$$

where $frsnd(i)$, $frslt(i)$, $frcly(i)$, and $frorg(i)$ are the fractions of sand, silt, clay, and organic matter comprising each particle class, respectively, and *ssasnd*, *ssaslt*, *ssacly*, and *ssaorg* are the specific surface area for sand, silt, clay, and organic carbon, respectively. Values for the specific surface area used in the model computations were 0.05, 4.0, 20.0, and 1000.0 $m^2 \cdot g^{-1}$ of sand, silt, clay, and organic carbon, respectively, as used in the CREAMS model (Foster et al., 1980).

The specific surface area of the surface soil is computed using:

$$SSA_{soil} = \frac{orgmat\ ssaorg}{1.73} + \frac{sand\ ssasnd \ + \ silt\ ssaslt \ + \ clay\ ssacly}{1 \ + \ orgmat} \qquad [11.5.6]$$

where *sand*, *silt*, *clay*, and *orgmat* are the fractions of sand, silt, clay, and organic matter in the surface soil, respectively.

Typical values for enrichment ratios are between 1.0 and 3.0, though the range can be from 0 to greater than 8. Some high silt soils have ratios less than 1.0 due to deposition of aggregates containing large amounts of clay and organic matter which increases the less chemically-active primary silt fraction. The procedure described here does not address the problems that occur when multiple overland flow elements composed of different soil types are input. Each element will possibly have aggregates of different sizes and composition, which will mix with the incoming sediment from the previous element. This could affect enrichment ratio values since the specific surface area of the soil is for the current flow element, and the actual sediment may have arrived from somewhere upslope and have an entirely different composition. In practice this may not be a serious problem if the various soil types present are not greatly different in composition, or if there is a region of significant detachment in each flow element.

11.6 Summary

The WEPP erosion model uses a steady-state sediment continuity equation as the basis for describing the movement of suspended sediment in a rill. Like other recent erosion models, such as the one used in CREAMS (Foster et al., 1981), the WEPP erosion model calculates erosion from rill and interrill areas and uses the concept that detachment and deposition rates in rills are a function of the portion of the transport capacity which is filled by sediment. Unlike other recent models, the WEPP erosion model partitions runoff between rill and interrill areas and calculates shear stresses based on rill flow and rill hydraulics rather than sheet flow (Page, 1988).

The model presented here does not rely on USLE relationships for parameter estimation. Erodibility parameters are based on the extensive field studies of Laflen et al. (1987) and Simanton et al. (1987) which were specifically designed and interpreted for the erosion model. Adjustments due to cropping-management effects are directly represented in the model in terms of plant canopy, surface cover, and buried residue effects on soil detachment and transport. These adjustments are made possible with the plant growth and residue decomposition routines in the WEPP model. Finally, because the WEPP erosion routines make use of daily water balance and infiltration routines which are spatially varied, the model can calculate erosion for the case of nonuniform hydrology on hillslopes.

11.7 References

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11.8 List of Symbols

Symbol	Definition	Units	Variable
A	coefficient for shear stress	NOD	ainf
B	"	NOD	binf
C	"	NOD	cinf
C	Chezy discharge coef.	$m^{0.5} \cdot s^{-1}$	chezch
$clay$	fraction of clay in surface soil	NOD	clay
D_c	detachment capacity of rill flow	$kg \cdot s^{-1} \cdot m^{-2}$	-
D_f	rill erosion rate	$kg \cdot s^{-1} \cdot m^{-2}$	-
D_i	interrill sediment delivery rate	$kg \cdot s^{-1} \cdot m^{-2}$	detinr
d_{eff}	effective particle diameter	m	diaeff
d_i	diameter of particle class	m	dia
ER	enrichment ratio of specific surface area	$m^2 \cdot m^{-2}$	enrato
$f_{deti}(i)$	mass fraction of detached interrill sediment for a sediment class	NOD	fidel
$f_{detr}(i)$	mass fraction of detached rill sediment for a sediment class	NOD	frac
$f_{in}(i)$	sediment mass fraction at top of detachment region	NOD	frcflw
$f_{out}(i)$	sediment mass fraction at end of detactment region or end of flow element	NOD	frcflw
f_s	friction factor for soil	NOD	frcsol
$frcly\,(i)$	fraction of clay in particle class *i*	NOD	frcly
$frorg\,(i)$	fraction of organic matter in particle class *i*	NOD	frorg
$frslt\,(i)$	fraction of silt in particle class *i*	NOD	frslt
$frsnd\,(i)$	fraction of sand in particle class *i*	NOD	frsnd
F_{nozzle}	sprinkler nozzle energy adjustment factor	NOD	nozzle
G	sediment load	$kg \cdot s^{-1} \cdot m^{-1}$	-
G_*	sediment load normalized to T_{ce}	NOD	load
$G_{in\,*}$	normalized sediment load at top of detachment region	NOD	lddend
$G_{ir\,*}$	normalized portion of sediment load leaving a detachment region that originated from interrill sediment delivery to rills	NOD	intlod
$G_{out\,*}$	normalized sediment load at end of deposition region or end of flow element	NOD	ldtop
$G_{rill\,*}$	normalized portion of the sediment load leaving a detachment region that originated from detachment in the rill channels	NOD	rillod
G_{u*}	normalized sediment load at top of deposition region	NOD	ldtop
I_e	effective rainfall intensity	$m \cdot s^{-1}$	effint
K_i	interrill soil erodibility	$kg \cdot s \cdot m^{-4}$	ki
K_{iadj}	adjusted interrill soil erodibility	$kg \cdot s \cdot m^{-4}$	kiadjf*ki

K_r	rill erodibility parameter	$s \cdot m^{-1}$	kr
K_{radj}	adjusted rill erodibility	$s \cdot m^{-1}$	kradjf*kr
k_t	transport coefficient	$m^{0.5} \cdot s^2 \cdot kg^{-0.5}$	kt
L	slope length	m	slplen
$orgmat$	fraction of organic matter in surface soil	NOD	orgmat
P_r	peak runoff rate	$m \cdot s^{-1}$	peakro
q	flow discharge per unit width	$m^2 \cdot s^{-1}$	-
q_o	inflow of water at top of an OFE	$m^2 \cdot s^{-1}$	qin
q_o^*	nondimensional inflow of water at top of an OFE	NOD	qostar
R	hydraulic radius	m	hydrad
R_s	average rill spacing	m	rspace
$\bar{S}$	average slope gradient	$m \cdot m^{-1}$	avgslp
SDR_{RR}	interrill sediment delivery ratio	NOD	intdr
SSA_{sed}	specific surface area of exiting sediment	$m^2 \cdot g^{-1}$	sumssa
SSA_{soil}	specific surface area of surface soil	$m^2 \cdot g^{-1}$	ssasol
$sand$	fraction of sand in surface soil	NOD	sand
$silt$	fraction of silt in surface soil	NOD	silt
$ssacly$	specific surface area of clay	$m^2 \cdot g^{-1}$	ssacly
$ssaorg$	specific surface area of organic carbon	$m^2 \cdot g^{-1}$	ssaorg
$ssaslt$	specific surface area of silt	$m^2 \cdot g^{-1}$	ssaslt
$ssasnd$	specific surface area of sand	$m^2 \cdot g^{-1}$	ssasnd
T_c	sediment transport capacity in rill	$kg \cdot s^{-1} \cdot m^{-1}$	-
T_{ce}	sediment transport capacity at end of slope	$kg \cdot s^{-1} \cdot m^{-1}$	tcend
T_{c*}	transport capacity normalized to transport capacity at end of uniform slope	NOD	tcap
t_e	total time during which the rainfall rate exceeds infiltration rate	s	effdrr
t_r	effective runoff duration	s	effdrn
$tcadjf$	transport capacity adjustment for sandy soils	NOD	adjtc
V_f	effective fall velocity of sediment	$m \cdot s^{-1}$	veleff
V_t	total runoff depth	m	runoff
w	rill channel width at end of OFE	m	width
x	distance down slope	m	-
x_*	normalized downslope distance	NOD	xinput
α	slope angle of the uniform slope gradient	*radians*	-
β	coefficient reflecting raindrop-induced turbulence	NOD	beta
γ	specific weight of water	$kg \cdot m^{-2} \cdot s^{-2}$	gamma
η	dimensionless rill erosion parameter	NOD	eata
ϕ	dimensionless deposition parameter	NOD	phi
θ	dimensionless interrill erosion parameter	NOD	theta
σ_{ir}	interrill runoff rate	$m \cdot s^{-1}$	qi
τ_*	normalized shear stress	NOD	shear
τ_c	rill detachment threshold parameter (critical shear stress)	Pa	shcrit
τ_{cn*}	dimensionless critical shear parameter	NOD	tauc
τ_f	flow shear stress	Pa	-
τ_{fe}	shear stress acting on soil at end of uniform slope	Pa	shrsol

Note - *NOD* stands for nondimensional variable.