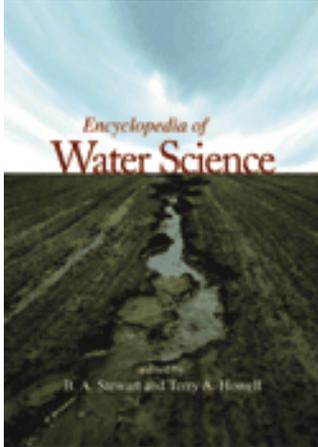


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Erosion Prediction

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INTRODUCTION

Soil erosion prediction models play an important role both in meeting practical needs of soil conservation goals and in advancing the scientific understanding of soil erosion processes. They are used to help land managers choose practices to reduce erosion rates. Erosion prediction models are used for erosion assessment and inventory work to track temporal changes in erosion rates over large areas. Erosion models are also used for engineering purposes, such as predicting rates of sediment loading to reservoirs. Increasingly, governments are using erosion models and their results as a basis for regulating conservation programs. Models are used wherever the costs or time involved in making soil erosion measurements are prohibitive.

In selecting or designing an erosion model, a decision must be made as to whether the model is to be used for on-site concerns, off-site concerns, or both. On-site concerns are generally associated with degradation or thinning of the soil profile in the field, which may reduce crop productivity. Conservationists refer to this process as "soil loss", referring to the net loss of soil over only the portion of the field that experiences net loss over the long term (excluding deposition areas). Off-site concerns, on the other hand, are associated with the sediment that leaves the field, which we term here "sediment yield".

CHOOSING AND USING AN APPROPRIATE EROSION PREDICTION MODEL

Models fall into two broad categories: material and mathematical (also known as "formal") (Fig. 1).^[1] Material models are physical representations of the system being modeled, and may be either iconic or analog. Iconic models are physical models that are composed of the same types of materials as the system that is being modeled, but simpler in form. In the case of soil erosion, a rainfall simulator applied to a field or laboratory plot of soil is an example of an iconic model. Analog models are also physical models, but are

composed of substances other than those of the system being modeled. A classic example is the use of electrical current for modeling water flow. Analog models are not commonly used for soil erosion studies.

Mathematical models of soil erosion by water are usually either empirical or process based (Fig. 1). The first models of soil erosion were empirical, which means that they were developed primarily from statistical analysis of erosion data. The prime example of the empirical model is the Universal Soil Loss Equation (USLE).^[2-4] More recent models have been based on equations that describe the physical, biological, and chemical processes that cause or affect soil erosion.^[5] It is important to understand that process-based models also possess a major empirical component, in the sense that the constitutive equations use parameters based on experimental data.

Choosing how to manage land, from the practical perspective, is often a matter of choosing between an array of potential management options. Often, therefore, what we need to know is not necessarily the exact erosion rate for a particular management option to a high level of accuracy, but rather we want to know how the various options stack up against one another. Choosing which model to use then becomes a matter of 1) what type of information we would like to know, and 2) what information (data) we have for the particular site of application. If we have an interest in off-site impacts, then we probably want to choose a process-based model that will provide estimates of the sediment leaving the hillslope or watershed. If we have an interest in obtaining auxiliary information about our choice of management strategy, such as soil moisture or crop yields, we might also decide to use a process-based model that provides such information. On the other hand, if data are limited for the situation to be modeled, then a simple empirical model might be the best option.

THE UNIVERSAL SOIL LOSS EQUATION

The prime example of an empirically based model is the USLE, which was developed in the United States

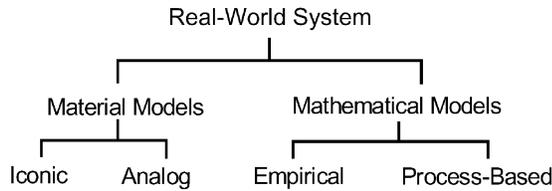


Fig. 1 Model classification. (Adapted from Ref.^[1].)

during the 1950s and 1960s.^[2,3] This equation has been adapted, modified, expanded, and used for conservation purposes throughout the world.^[6-8]

The USLE was originally based on statistical analyses of more than 10,000 plot-years of data collected from natural runoff plots located at 49 erosion research stations in the United States, with data from additional runoff plots and experimental rainfall simulator studies incorporated into the final version published in 1978.^[4] The large database upon which the model is based is certainly the principal reason for its success as the most used erosion model in the world, but its simplicity of form is also important:

$$A = RKLSCP \quad (1)$$

where A (tons/ha/yr) is the average annual soil loss over the area of a hillslope that experiences net loss, R (MJ mm/hr/ha/yr) is the rainfall erosivity, K (tons hr/MJ/mm) is the soil erodibility, L (unitless ratio) is the slope length factor, S (unitless ratio) is the slope steepness factor, C (unitless ratio) is the cropping factor, and P (unitless ratio) is the conservation practices factor. The USLE predicts soil loss and not sediment yield. The word erosivity is used to denote the driving force in the erosion process (i.e., rainfall in this case) while the term erodibility^[9] is used to note the soil resistance term.^[9] These two terms are not interchangeable. The model predicts the “average annual soil loss:” it was not intended to predict soil loss for storms or for individual years.

The key to understanding the dimensional units for the USLE lies with the definition of rainfall erosivity and the concept of the “unit plot”. Wischmeier^[10] found for the plot data that the erosive power of the rain was statistically best related to the total storm energy multiplied by the maximum 30-min storm intensity. Thus, we have the energy term (MJ) multiplied by the intensity term (mm/hr) in the units of R , both of which are calculated as tons per hectare and per year. The unit plot was defined as a standard of 9% slope, 22.13 m length, tilled and left fallow (cultivated for weed control). Most of the early erosion plots were 1.83 m (6 ft) wide. A length of 22.13 m (72.6 ft) and a width of 1.83 m (6 ft) resulted in a total area of 1/100 of an acre. Prior to the days of calculators and computers this was obviously a convenient value for

computational purposes. The K value was defined as A/R for the unit plot. In other words, erodibility was the soil loss per unit value of erosivity on the standard plot. The remaining terms, L , S , C , and P , are ratios of soil loss for the experimental plot to that of the unit plot. For example, the C value for a particular cropped plot is the ratio of soil loss on the cropped plot to the value for the fallow plot, other factors held constant.

The USLE reduced a complex system to a quite simple one for purposes of erosion prediction. There are many complex interactions within the erosional system that are not, and cannot be, represented within the USLE. On the other hand, for the purposes of general conservation planning and assessment, the USLE has been, and still can be, used with success.

THE REVISED USLE: RUSLE1 AND RUSLE2

The USLE was upgraded to the revised universal soil loss equation (RUSLE1) during the 1990s^[11] and evolved to the current RUSLE1.06c released in mid-2003.^[12] RUSLE1 is land-use independent and applies to any land use having exposed mineral soil and Hortonian overland flow; RUSLE2 was also released in mid-2003, and is also land-use independent.^[12]

Both RUSLE1 and RUSLE2 are hybrid models that combine the existing index with equations process-based equations. RUSLE2 expands on the hybrid model structure and uses a different mathematical integration than does the USLE and RUSLE1. Both RUSLE1 and RUSLE2 are computer based, and have routines for calculating time-variable soil erodibility, plant growth, residue management, residue decomposition, and soil surface roughness as a function of physical and biological processes.

PROCESS-BASED MODELS

Various process-based erosion models have been developed in the last 10 yr including EUROSEM in Europe,^[13] the GUEST model in Australia,^[14] and the WEPP model in the United States.^[15,16]

Process-based (also termed physically based) erosion models attempt to address soil erosion on a relatively fundamental level using mass balance differential equations for describing sediment continuity on a land surface. The fundamental equation for mass balance of sediment in one dimension on a hillslope profile is given as:

$$\partial(cq)/\partial x + \partial(ch)/\partial t + S = 0$$

where c (kg/m³) is the sediment concentration, q (m²/sec) is the unit discharge of runoff, h (m) is the

depth of flow, x (m) is the distance in the direction of flow, t (sec) is time, and S [kg/(m²sec)] is the source/sink term for sediment generation. Eq. (2) is exact. It is the starting point for development of physically based models. The differences in various erosion models are primarily: 1) whether the partial differential with respect to time is included, and 2) differing representations of the source/sink term, S . If the partial differential term with respect to time is dropped, then the equation is solved for the steady state, whereas the representation of the full partial equation represents a fully dynamic model. The source/sink term for sediment, S , is generally the greatest source of differences in soil erosion models. It is this term that may contain elements for soil detachment, transport capacity terms, and sediment deposition functions. It is through the source/sink term of the equation that empirical relationships and parameters are introduced.

The disadvantage of the process-based model is complexity. Data requirements are greater, and every new data element provides the opportunity to introduce uncertainty. Model structure interactions are also large.

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