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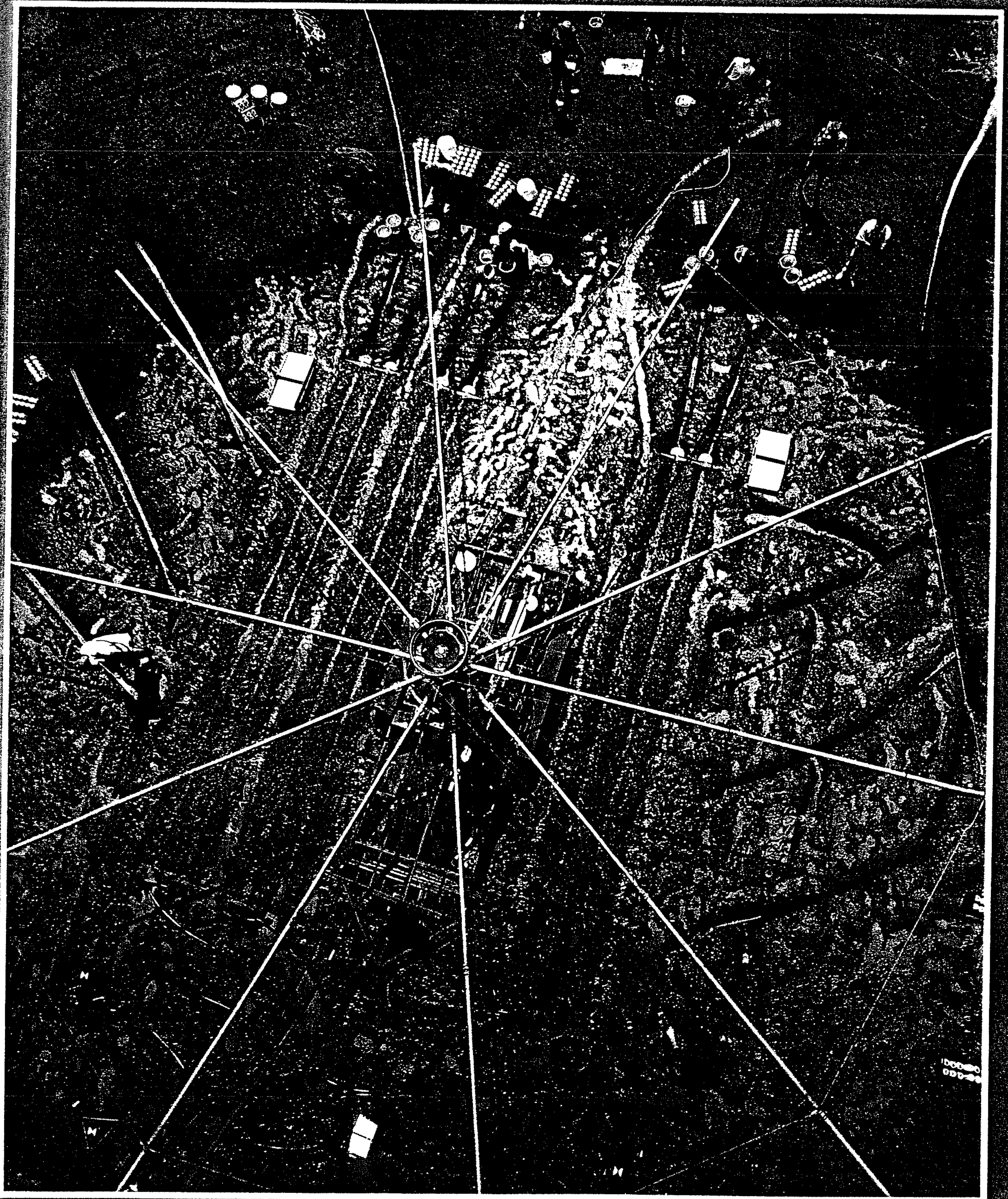
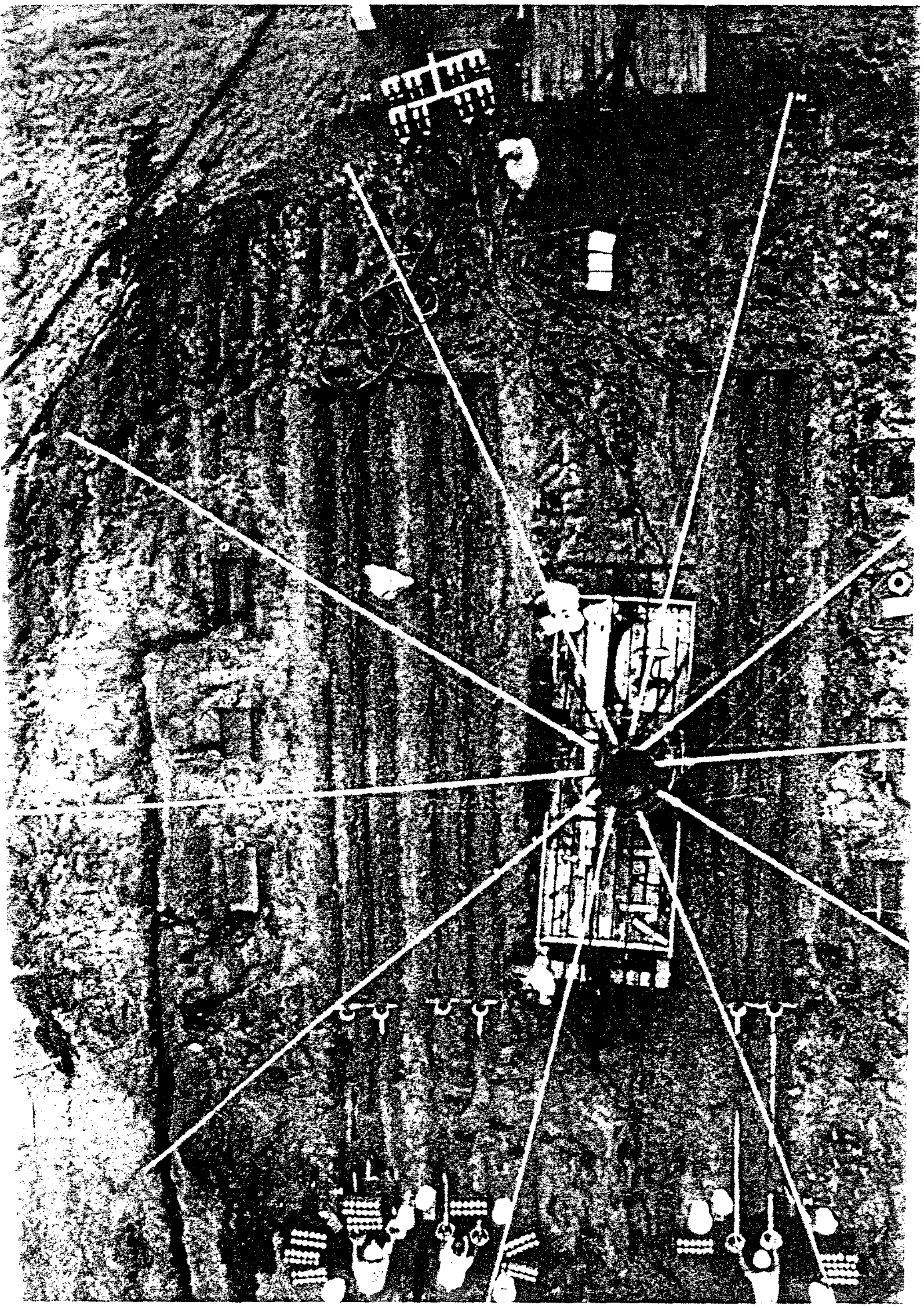


WEPP
A new generation of erosion prediction technology

By John M. Laflen, Leonard J. Lane, and George R. Foster



EROSION prediction is the most widely used and most effective tool for soil conservation planning and design in the United States. Because it is impossible to monitor the influence of every farm and ranch management practice in all ecosystems under all weather conditions, erosion predictions are used to rank alternative practices with regard to their likely impact on erosion. These erosion predictions are thus an essential part of soil conservation programs in the United States.

The prediction of soil erosion by water has played an important role in the use, management, and assessment of land, not only in the United States, but in most regions of the world. The major tool has been the universal soil loss equation (USLE) developed by Wischmeier and Smith (*10, 11*).

USLE is a factor-based equation. The soil erosion process is quantified and approximated by a series of factors. Each factor may quantify one or more processes and their interactions. The equation has served and continues to serve our needs in erosion prediction well. However, like most technology that is at least 30 years old—with components that are similar to those derived nearly 50 years ago—there are some shortcomings. As our understanding of the erosion process improves, the limitations of the technology embodied in the USLE become more apparent. A major limitation is the effort needed to apply the USLE to new crops and management techniques and the inability to satisfactorily apply the USLE to different situations than those for which it was developed.

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Over the past several decades, the USLE has been used to predict soil erosion by water and to select soil conservation measures and management practices. While it has been used successfully in the United States and, in fact, the world, it does have limitations. In 1985, one outcome of a workshop held in Lafayette, Indiana, was the recognition that the ability existed, with some well-targeted research, to develop a new generation of erosion prediction technology that was based on our current understanding of erosion processes and that this technology could be applied at the same level and for the same uses, as well as new uses, as the current USLE technology.

Following that workshop, the U.S. Department of Agriculture (USDA) initiated a 10-year research and development effort to replace the USLE with improved erosion prediction technology. In 1986, four federal agencies agreed to develop and implement this new generation of erosion prediction technology. The agencies were the Agricultural Research Service (ARS), the Soil Conservation Service (SCS), and the Forest Service in USDA and the Bureau of Land Management (BLM) in the U.S. Department of the Interior. The Water Erosion Prediction Project (WEPP) was the result of this initiative and was designed as a three-phase project.

The first phase of the project, technology development, lasted from 1985 until 1989. This phase delivered a prototype or research model computer program to SCS, the Forest Service, and BLM for initial testing and evaluation. A critical component was the completion of crucial research related to soil erodibility and flow hydraulics on cropland and rangeland.

Phase two, testing and refinement, was scheduled for 1989 to 1992. This phase of the project is designed to finish development of all versions of WEPP, to complete user interfaces for most versions, and to make refinements and correct problems identified during the testing and evaluation.

Phase three, implementation and training, is scheduled for 1992 to 1995. This phase will be a user responsibility; the main tasks will be installing the computer programs in the thousands of user locations, developing data bases, developing quality control and quality assurance procedures, and providing training and evaluation.

Major milestones in the project to date have been the development of a set of user requirements (*3*), documentation of the project (*1, 7, 8*), and delivery of the first computer program version in August 1989 (*9*). The technology is to be ready for use by action agencies in 1992, and SCS is expected to fully implement it by 1995.

WEPP is to be implemented on a personal computer. The target computer will have a 80386 microprocessor with math coprocessor and a UNIX operating system. It will also be available for other users operating in nearly any computing environment. One of the specifications in the development of WEPP has been that it be capable of evaluating an alternative management system within one minute. The technology has to be usable and parameterized for the soils, crops, topographies, and management systems to which it might be applied.

WEPP is a simulation model with a daily time step. For every day, plant and soil characteristics important to the erosion process are updated. When rainfall occurs, the characteristics of the plants and soils are considered in determining if a runoff event occurs. If runoff is predicted to occur, the model computes soil detachment, transport, and deposition at frequently spaced points along the profile and, depending on the version used, in channels and small reservoirs.

Versions of WEPP

WEPP is to be delivered in three versions: profile, watershed, and grid. The profile version is the direct replacement for the USLE, with the added ability to estimate sediment deposition on a slope. It was this version that was delivered in August 1989. Work is underway to incorporate new components into this version. Considerable testing and evaluation will be required before final release in 1992.

The watershed version will apply to a "field-size" watershed. It includes the profile version to estimate sediment delivery to channels. It will apply to watersheds having one or more areas where the profile version applies; plus, it will compute sediment transport, deposition, and detachment in small channels. It will also compute sediment deposition in small impoundments. The watershed version might be used on a terraced field; to compute sheet, rill, and ephemeral gully erosion on a watershed; and calculate delivery of sediment to and from a small reservoir at the outlet of a watershed.

The grid version will apply to an area whose boundaries do not coincide with watershed boundaries. Such an area might be broken up into several small areas, called elements, and within each element the profile version applied. The grid version also will deal with the sediment transport from element to element and with the delivery of sediment from the area through one or more discharge points.

WEPP, in all versions, is intended to apply to field-size areas, a fairly ambiguous limitation. It is intended to be ambiguous, for the limitation in area is really more a limitation of processes considered. Erosion processes in WEPP are limited to sheet and rill erosion and to erosion occurring in channels where detachment is due to hydraulic shear. This excludes erosion in classical gullies or continuously flowing streams. Hence, in some cases, such as a highly erodible loessial area, the maximum size might be less than a section (640 acres). On the other hand, for some rangeland or cropland areas, maximum size might be several sections. The upper limit depends on the erosion and hydrologic processes that may occur.

Erosion processes in WEPP

Ellison (*2*) indicated that soil erosion is a process of detachment and transport. We would add that deposition also is an erosion process. This process, as well as detachment and transport is included in WEPP. The essence of WEPP is a procedure to quantify these three processes. The quantification of these processes occurs in the erosion component in WEPP.

WEPP uses the rill-interrill concept of describing sediment detachment (*4*). Interrill erosion is the detachment and transport by raindrops and very shallow flows, such as occur on row sideslopes. Rill erosion is the detachment by flowing water.

Rill erosion is estimated as a linear function of excess hydraulic shear. Interrill erosion is estimated as a function of interrill slope and of the square of rainfall intensity, modified by surface cover and crop canopy.

The Yalin sediment transport equation (*15*) is used to estimate sediment transport in channels and rills. Deposition in flowing water is computed on the basis of sediment load; transport capacity, as computed by the Yalin equation; and the fall velocity of the transported sediment. Deposition in impoundments is computed similarly to that in the CREAMS model (*12*).

Hydrologic processes in WEPP

The erosion process is a direct result of the forces and energies developed in hydrologic processes. The impact and magnitude of these forces are affected by the characteristics of the plants above and below the soil surface, the characteristics and status of the soil at and below the surface, the topography of the land, and the mass and characteristics of material in contact with the soil surface. Most important parts of the hydrologic cycle are represented by the hydrology in WEPP.

Hydrologic processes in WEPP are represented by several components. WEPP contains a climate component, an infiltration component, and a winter component dealing with frozen soils and snow accumulation and melt.

The climate component in WEPP uses either generated or measured climatic variables, including storm rainfall amount and duration, ratio of peak rainfall intensity to average rainfall intensity, time that peak intensity occurs, daily maximum and minimum temperature, wind velocity and direction, and solar radiation. These climate variables are used in estimating duration, peak rate, and total amount of runoff, including that generated by snow melt; plant growth, including live biomass above and below the soil surface; decomposition of above and below ground biomass; and soil water content of the various soil layers.

Infiltration in WEPP is based on the Green and Ampt equation (*5*), with ponding considered. Infiltration is a two-stage process. That which occurs when there is no ponding on the surface is equal to the rainfall intensity. When there is surface ponding, infiltration is computed as a function of matric potential, cumulative infiltration, and saturated hydraulic conductivity. Rainfall excess is the difference between rainfall intensity and infiltration rate. Runoff rates are computed by kinematic routing (*6*) of the excess rainfall.

The winter component deals with soil frost, snowmelt, and snow accumulation. It draws heavily on the climate component. When frost is present, it computes daily frost and thaw depth, water balance of the frozen soil, and infiltration capacity of the soil. When snow is present, it also computes snowmelt, surface runoff, and infiltration for use in the water balance and deep percolation components.

Plant growth and residue processes

WEPP contains plant growth and residue decomposition components to accurately estimate the plant and residue status above and below the soil surface. Clearly, plant status has a major impact on rainfall energy reaching the soil surface and on soil water status, which directly affects runoff volumes. There are considerable direct and interactive effects of plant status that can only be captured by a crop growth component. Additionally, above and below ground live and dead biomass has a major impact on the soil erosion process, and effective methods of controlling soil erosion almost always include management of plants and their living or dead biomass.

Both cropland and rangeland plant growth and residue amounts and decomposition are considered in WEPP. Canopy cover and height, mass of live and dead below and above ground biomass, leaf area index and basal area, and residue cover are estimated on a daily basis. Information about dates and kinds of various farming operations are input to the model. Many annual and perennial crops, management systems, and operations that may occur on cropland and rangeland have been parameterized. Major efforts are underway to paramaterize many of those remaining.

Water use processes

WEPP also updates soil water status on a daily basis. Knowledge of the water balance is crucial in estimating infiltration and surface runoff volumes, the driving force in detachment by flowing water in rills and channels. The water balance and percolation component quantifies these processes.

The water balance component uses information from the climate component (precipitation, temperature, and solar radiation), the plant growth component (leaf area index, root depth, and residue cover) and the infiltration component (infiltrated water volume). The water balance component computes the status of the soil water on a daily basis at each of the designated layers in the soil and computes the percolation below the lowermost layer.

The water component estimates daily potential evapotranspiration and soil and plant evaporation. It also receives values for infiltration of melted snow from the winter component. These values are needed to compute the daily soil water status and deep percolation.

Hydraulic processes

The hydraulic component of WEPP computes the hydraulic shearing forces exerted on the soil surface by surface runoff. The hydraulic shearing forces are required for the rill erosion computations in the erosion component.

The procedure uses information about surface runoff volumes, hydraulic roughness, and approximations of runoff duration and peak rate to apply the kinematic wave equations for runoff on a plane. A particular problem is the representation of various strips on a slope, such as for stripcropping. Depending on many factors, it is possible to have runoff on one strip and not on another strip. Runoff might occur near the top of a slope because of a particular crop or soil. When it drains into a lower strip, runoff might stop and then occur again on some lower strip. This requires the use of several approximations to the kinematic wave equations.

In nature, the hydraulic shearing force occurs in rills. To compute the shearing force in a rill, the flow depth and rill shape must be estimated. The rill spacing determines the flow rate in a rill—a necessity in computing flow depth. In WEPP the rill spacing was estimated at three feet based on studies of a number of different soils (Gilley, 1989, personal communication). Rills are assumed to be rectangular. Based on these assumptions and with the kinematic wave equations and their approximations, shearing force along a slope can be computed.

Soil processes

Many processes that directly affect soil erosion take place in and on the soil. These processes are considered in the soil component of WEPP.

The soil component of WEPP provides to the hydrology component several variables important to the estimation of surface runoff rates and volumes and the estimation of infiltration and percolation. The soil component of WEPP deals with temporal changes in soil properties important in the erosion process and quantifies the impact of many factors, including mankind's activities, on many soil and surface variables.

The soil component of WEPP maintains a daily accounting of the status of the soil and surface variables. These variables include random roughness, ridge height (an oriented roughness), bulk density, saturated hydraulic conductivity, and the soil erodibility parameters of rill and interrill soil erodibility and critical hydraulic shear.

The soil component considers the effect of tillage, weathering, consolidation, and rainfall on soil and surface variables. Tillage effects are expressed in bulk density, roughness, ridge height, and residue cover in the soil component. Baseline rill soil erodibility and critical hydraulic shear values for a freshly tilled condition are adjusted to other conditions by consolidation because of wetting and drying. Additional adjustments to interrill erodibility are made based on live and dead roots in the upper 6 inches of the soil and to rill erodibility because of incorporated residue in the upper 6 inches of the soil. Rainfall effects on bulk density of freshly tilled soils are estimated in the soil component.

Soil erodibility values are computed either internally or externally to WEPP. Past efforts to model the erosion processes have used USLE relationships for estimating soil erodibility. A major component of the WEPP effort has been extensive field studies (*1, 11*) to develop the technology to predict erodibility values for WEPP from soil properties. In addition, a number of other relationships were developed that are helpful in parameterizing the process-based model.

The power of WEPP

WEPP will have the capability to provide answers important to new and old natural resource issues. It will be able to give farmers and conservationists better information on where to locate conservation practices on specific fields to achieve one or more goals. These goals might be a reduction of soil erosion, reduction of soil loss, or a reduction of sediment deposition at the foot of a slope. WEPP will have the potential to provide better information to help solve problems whose solutions lacked scientific estimates.

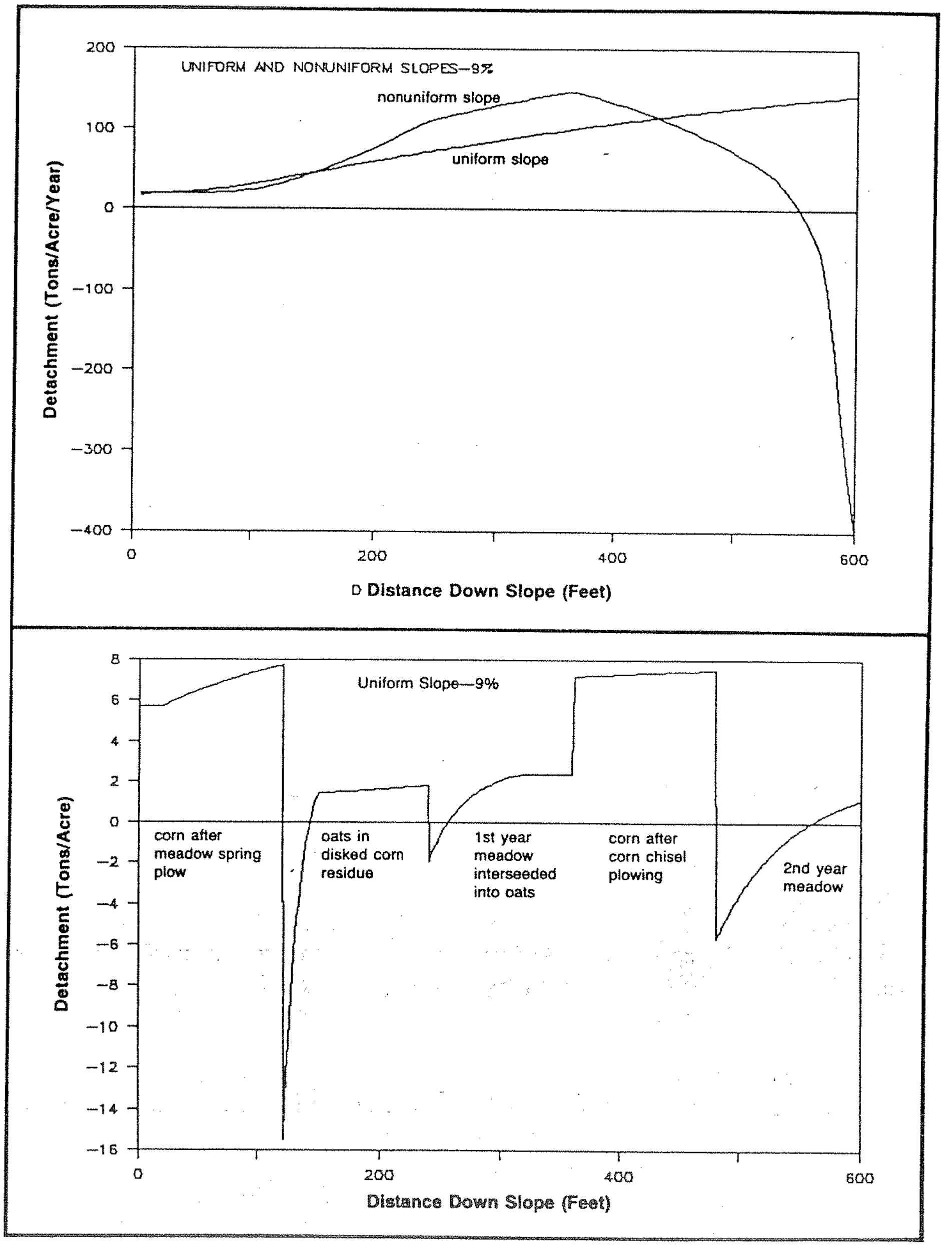
The power of WEPP is illustrated in the accompanying figures. In the first, WEPP is applied to a uniform and a nonuniform slope, both with an average nine percent slope. The slope is maintained in a continuous fallow condition and has a length of 600 feet. The values shown are average annual values for detached (or deposited if detachment is negative) soil at points along the slope. The data were generated using a 15-year climate data set for Des Moines, Iowa, as computed by WEPP for a silt loam soil. The WEPP climate generator (*10*) was used to generate the 15-year climate data set.

Detachment rates increased down the slope until deposition occurred on the nonuniform slope. The nonuniform slope was convex on the upper end and concave on the lower end. Because of the deposition on the nonuniform slope, there was less sediment delivered from the nonuniform slope than from the uniform slope. However, there were considerably higher rates of detachment in the steep areas for the nonuniform slope than for the uniform slope. The ability to accurately predict where detachment and deposition occur will be quite helpful in siting conservation practices to effectively meet conservation and resource protection goals. Individual storm values also could have been presented because the same information would be computed for every runoff event during that 15-year period of weather.

The second figure shows the results of a single storm simulation to illustrate the power of WEPP. The uniform nine percent slope was divided into five 120-foot-wide strips planted to a corn-corn-oats-meadow-meadow rotation. For this analysis, there is never a corn strip adjacent to another corn strip. Meadow is spring plowed, disked, and planted for the first year of corn; chisel plowing and disking are used to prepare a seedbed for the second year of corn. Corn stalks are disked before seeding to oats. Alfalfa is interseeded into the oats. Typical yields and hay cuttings were assumed.

The variation of detachment down the slope is intriguing. There is deposition at the upper end of the alfalfa strips and at the upper end of the oat strip. However, the uppermost strip and corn strip are subject entirely to detachment, as expected. The detachment that does occur on the oats and alfalfa strips is at a lower rate than on the

WEPP analysis (top) showing the effect of slope shape on average annual sediment detachment on a uniform and nonuniform 9 percent slope. Negative values indicate deposition. The nonuniform slope is an S-shaped slope with a concave portion on the upper end, a steep portion in the middle, and a convex portion on the lower end. The bottom figure is another WEPP analysis of the effect of crop strips on sediment detachment downslope on a uniform 9 percent slope. Results are from a single large storm in late spring for a silt loam soil in central Iowa.



corn strips, which is also expected.

A constant rate of detachment is shown at the upper end of the first 120-foot-long strip, followed by a gradual increase in detachment to the lower end of that strip. The rate of detachment at the upper end is that due to interrill erosion. When the detachment rate begins to increase on that strip is the point at which the hydraulic shear of the flowing water exceeds the criticial hydraulic shear. The detachment rate for interrill erosion would be lower for a smaller storm, with the point at which rill erosion begins being further down hill. Values of all rates of detachment are affected by storm size, soil erodibility, position on slope, and tillage and cropping at and above the position on the slope. Additionally, relative rates of detachment for one storm may be much different for other storms and much different for an average over a long period of time.

For a severe storm, runoff departing a corn strip might have high sediment concentrations and, if alfalfa was in the next lower strip, deposition might occur in the upper end of the strip with low levels of detachment in the remainder of the strip. When the runoff leaves the alfalfa strip, it would have a low sediment concentration with a great ability to detach soil, particularly if the next lower strip is corn.

The information in the second figure is computed for each storm, so extensive analyses are possible for a continuous simulation. While such analyses might not be made for most cases, they could be performed where special needs exist. Other information also is available, including daily crop growth and water balance parameters.

Additional information that will be of great use in evaluating off-site effects of land treatment are the size distribution and specific area of the sediment delivered to the bottom of the slope. These are calculated for both the average annual case and every individual storm. This information is vital to predicting the downstream transport of sediments and in computing chemical loss from farm fields. The WEPP technology likely will be a part of many water quality models.

The power of WEPP will allow researchers and policymakers to delve into issues of natural resource management that have not been addressed. The issue of a tolerable soil loss value surely will be addressed again now that we can identify rates of detachment on portions of a slope. The interaction of treatment with topography will be addressed more fully. Eventually, we will reevaluate the effect of erosion on soil productivity. As with the USLE, we can now only visualize a few of the issues where WEPP will be important.

Summary

WEPP represents a departure from factor-based erosion prediction technology to a new process-based technology. As new studies are conducted and more computer power becomes available, WEPP will provide a basis for inserting improved process descriptions and parameter values that will provide improved technology for prediction of soil erosion. The WEPP effort is serving as a guide in developing other technology in the natural resource area for action agencies and other users of prediction technology in the natural resource area.

The WEPP effort has been and continues to be a multi-step process, as follows:

1. Development of a user-requirements document that gave the specifications of the prediction technology to be produced.
2. Evaluation and targeting of critical research to be accomplished before the technology could be used.
3. Identification of a core team of scientists to produce the various components of the technology.
4. Development of an operational computer program with interface that would make it possible to develop and manage the necessary input data files and to use the technology at the SCS field office level and at the various other levels needed by other action agencies and other users.
5. Development and completion of an implementation plan that includes validation and testing of the portion of WEPP that computes soil erosion and evaluation and testing of the user-friendly components of the operational computer program.

WEPP today is largely on schedule for delivery of the technology in 1992 to action agencies for use at the field office level. The transition to WEPP will require considerable effort by action agencies to develop the necessary local data bases so the technology can be used for all of the conditions and situations envisioned when the project was initiated. Considerable training of personnel will be required. These remain as the largest obstacles to the implementation of WEPP.

As with USLE, WEPP is intended to be a living technology that provides the framework for a technology for a long period of time. During its lifetime, we would expect new science to be developed and used in WEPP. We would also expect modification from time to time to meet new needs for erosion prediction technology, insofar as possible, given the WEPP framework for erosion prediction. We would also expect that new generations of technology for resource management will be developed that will replace WEPP in the years ahead.

The power of WEPP holds great promise for addressing important natural resource issues in ways that they need to be addressed but in the past could not be because of limitations in the predictive technology. Surely, new answers and policies will emerge that will benefit the American people and others for years to come.

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