WEPP-Predicting water erosion using a process-based model

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In 1940, A. W. Zingg published an equation expressing the effect of slope steepness and length on soil erosion, to be followed a year later by D. D. Smith's paper (1941) that included a conservation practice factor and a tolerable soil loss limit based on the loss of soil fertility. This research began a scientific approach to managing a tract of land so that erosion was less than some tolerable amount. This technology was further developed by the addition of a soil factor by Browning et al. (1947) and by the Musgrave equation (1947). In 1961, the Universal Soil Loss Equation was released, followed by revisions in 1965 and 1978. In 1992, RUSLE-The Revised Universal Soil Loss Equation (Renard et al. 1991, 1997) was released. In 1993, RUSLE was implemented by NRCS. A Window-based RUSLE, with a graphical user interface is planned for release in 1997.

WEPP is a project to develop a fundamentally based soil erosion prediction technology. It was initiated in 1985, included a strong research program to develop specific technology needed for WEPP, and was organized around a team of research scientists and user agency personnel. WEPP includes the products of 25 ARS (Agricultural Research Service) locations, and contributions from NRCS (Natural Resource Conservation Service), Forest Service, Bureau of Land Management, at least 10 Universities, and many international scientists. Land uses represented include croplands, forestlands and rangelands.

The WEPP model was released in 1989. From 1989 to 1995, WEPP underwent considerable revision and testing. A DOS-based interface was developed. The improved WEPP model, supported by the results of a comprehensive testing program and a national soil and climate database, was released for general use in 1995 at a WEPP/WEPS (Wind Erosion Prediction System) symposium held in conjunction with the 1995 Soil and Water Conservation Society International Meeting in Des Moines, Iowa. WEPP is to be updated early in 1997 with fixes to errors discovered in implementation and testing. WEPP is planned for release in late 1997 with a multi-platform, Windows-based, graphical user interface. In 1998, a multi-platform, Windows based, graphical user interface release is planned for WEPP, RUSLE, WEPS, and RWEQ (Revised Wind Erosion Equation).

What is WEPP?

WEPP is a computer model for predicting soil erosion and sediment delivery from fields, farms, forests, rangelands, construction sites and urban areas. It embodies the fundamental concept described by Ellison in 1947 that erosion is a process of detachment and transport. These concepts have previously been expressed in models, but none were developed to the extent as they have been in WEPP. WEPP is designed to work at a farmer's desk or in a district conservationist's office, as a consultant's tool, or for about any use by any person who may need to know how much soil is detached on and delivered from or to a site. Sediment delivery is modeled in WEPP with channels and impoundments on and leading from fields. Channels may include grassed waterways, other small channels on fields, or road ditches. Impoundments may be small reservoirs, impoundment terraces, or small pondage areas above culverts, silt fences or straw bales.

WEPP is a daily simulation model. Every day the hydrologic status of the land is computed-including soil moisture content, evaporation and transpiration. The biomass is also computed daily, including residue cover, root mass, dead root mass, buried biomass, above ground live biomass, leaf area index and canopy height and cover. If rain or snow melt occurs, or irrigation water is applied, infiltration and runoff are computed. If runoff occurs, then detachment of soil by rain, irrigation and runoff in rills is computed. Transport and deposition are also calculated. The detachment due to rain or irrigation drops is called interrill erosion, while detachment by flowing water in small channels (rills) is called rill erosion. WEPP can estimate the contribution to total soil loss due to interrill erosion and rill erosion. WEPP can also estimate erosion in waterways and ephemeral gullies and sediment delivery to channels from fields. WEPP can also estimate deposition on fields and in channels. WEPP can estimate deposition in terrace channels and grassed waterways.

WEPP does not predict classical gully erosion, erosion processes in continuously flowing

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streams such as stream bank sloughing, tillage erosion or mass wastage.

Much of WEPP deals with the status of the land and above and below ground live and dead biomass. WEPP components include crop growth routines adapted from EPIC, dead biomass decomposition routines identical in concept with those in RUSLE and WEPS, and the latest applicable infiltration and hydrologic science, including winter hydrology. Hydrology drives the erosion process as modeled in WEPP, so valid hydrologic modeling is critical for WEPP.

WEPP simulates real conditions on a daily basis, producing information that can meet many needs. For example, WEPP can be used to generate recurrence interval information on daily runoff volumes, peak rates, sediment detachment, deposition, sediment delivery and sediment concentration. In nature, no two days are ever identical with regard to climate, growth, soil moisture and residue. WEPP models this variety in nature, providing realistic simulations of what is happening in the area of runoff and soil erosion on a field. WEPP has already been used to analyze the effect of global climate change on soil erosion (Nearing and Nicks 1997; Savabi et al. 1993).

WEPP requires extensive climate, soil, plant and tillage, management and topographic databases. Currently, a soil database is available for the dominant phase of nearly every soil in the U.S., and can easily be generated for most other phases. The climate database is available for every area of the U.S. except for some mountainous regions. The daily climate input needed to run WEPP includes 4 characteristics of rainfall (amount, duration of rainfall, the ratio of the peak intensity to average intensity and the time at which the peak intensity occurred), solar radiation, maximum and minimum temperature, dew point temperature and wind velocity and direction-a total of 10 values for every day. A database and program has been developed that can generate an input climate data set for any point in the country, unless it is in a mountainous region. It can generate a climate data set of 100 years in seconds on most personal computers. WEPP includes databases for most field operations and most crops that are grown in the U.S. The topographic database can be very sophisticated, or quite simple, depending on the needs of the simulation. The management database represents the timing and description of field operations.

The total WEPP package includes the model, databases, user manual, technical documentation, validation data sets and a user interface. The user interface sets up and controls model operation, allowing the user to build and select input files and to select the form of the output desired.

Why WEPP?

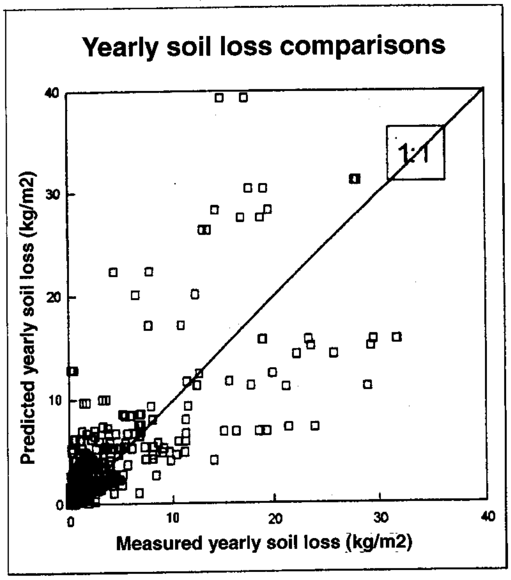
Soil erosion prediction through the 1960s was mostly concerned with selection of conservation practices to control soil erosion, and that is still a major use of erosion prediction in 1997. However, our customers now have many other needs. Putting into place a fundamentally-based erosion prediction technology was driven by our customers needs–the USLE technology could not meet those needs because of its empirical nature. The development and implementation of WEPP was made possible by the experience with other models using similar fundamentally-based technology (Meyer and Wischmeier 1969) and the ubiquity of the personal computer.

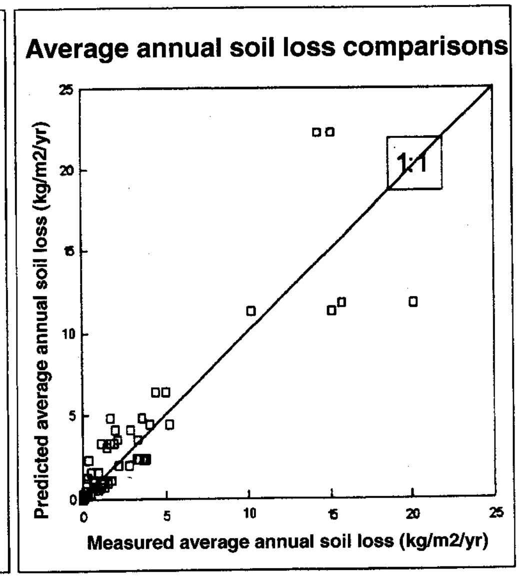
The need to predict offsite-sediment delivery and onsite-deposition of sediment have increased rapidly, and for some federal agencies, these are more important than the detachment of soil. Soil erosion prediction has become a regulatory tool, and it is difficult to support the use of present technology in this context. Increasingly, erosion and sediment delivery estimates for non-rainfall conditions, irrigation and snowmelt, are required. There are numerous questions related to frequency information about soil erosion and sediment delivery. Some of these might be, what is the probability that a contractor can complete a construction job with no erosive events; what are the probabilities that a terrace will fill with sediment in a given period of time; what is the likelihood that a natural rainfall study will produce the data needed to make a judgment on the efficacy of a control practice in a 5 year period? WEPP is designed to produce the answers needed in each of the areas above.

Fundamentally based-technology driven by hydrology is a significant step forward. While it was long recognized that there were significant interactions among all the factors in the USLE, many of these were ignored so that the technology could be used (W. H. Wischmeier, personal communication). A question not answered by USLE technology, is what is the interaction of soil and the slope steepness and length (LS) factor in the USLE. The same LS factor is used for all soils, yet, a high sand soil might have a lower runoff volume and rate causing the LS factor to be lower for a sandy soil having high infiltration rates. On the other hand, since a sandy soil is more easily detached, the LS factor might actually increase. Previously, we had to hypothesize about these effects and test these hypotheses using very limited data sets. WEPP can sort out these complex interactions. The answer to the question above is that it depends on how much clay is in the sandy soil, how steep is the slope, how deep is the soil, how wet is the climate, what are the storm characteristics, when do these storms occur, what plant is grown,

Figure 1. (Left) shows yearly values of measured and WEPP predicted soil loss for data from Table 1

Figure 2. (Right) shows average annual values of measured and WEPP predicted soil loss for data from Table 1





how deep does it root, what tillage system is used, plus perhaps dozens of others-some important and some not so important. WEPP has the power to consider these factors in estimating soil erosion and sediment delivery.

The ability to consider these factors in soil erosion brings a power to the prediction of erosion never before available routinely at the field level. When WEPP is implemented at the field level, the user will be able to make erosion and sediment delivery predictions that consider the characteristics of each individual site. From a regulatory viewpoint, this is required if the technology is to meet the basic tests of fairness.

Testing and applications

Testing of WEPP is critical to its acceptance and application. This has been a high priority since the project began. Dozens of studies have been and are being conducted in the U.S. and around the world to evaluate WEPP for local conditions. In most cases, WEPP has performed satisfactorily.

One of the major areas of testing has been the comparison of measured with predicted soil loss from USLE type plots and small watersheds. The USLE type plots constitute a valuable erosion data set that was used in the development of the USLE and in its maintenance. Generally, only daily values of soil loss were measured and then only for natural rainfall. Additionally, winter runoff and soil losses were frequently not measured. WEPP has not been tested on all the available data from USLE type runoff plots, but the testing is continuing.

The major federal agency that is presently applying WEPP is the U.S. Forest Service. The Forest Service, along with the Natural Resource Conservation Service and the Bureau of Land Management of the Department of Interior, has been an active partner in WEPP since the day the project was initiated, and has carried on an extensive research program directed toward meeting forest needs. Since WEPP was released in 1995, the Forest Service has had an active program of transferring WEPP technology to National Forests and to their partners through a continuing series of workshops. They have also been actively applying the model to specific problem areas. Some of those are described below.

WEPP testing on USLE plot data

Comparisons were made between WEPP predictions and measured data from natural runoff and erosion plots located at 9 U.S. sites with USLE type plots (Table 1). The cropping

Table 1. Measured and predicted values for average yearly and average annual soil loss for 9 locations having USLE type runoff plots

Note: Soil loss was predicted by the USLE (Risse et al. 1993), RUSLE (Rapp 1994) and WEPP. The data used for the USLE and RUSLE comparisons were identical, and the WEPP comparison used a sub-set of the larger data.

		USLE	RUSLE	WEPP
Yearly soil loss	Number of samples	1638	1638	544
	Avg. measured soil loss, (t/ha)	35	35	28
	Avg. predicted soil loss, (t/ha)	32	32	31
Avg. annual soil loss	Number of samples	206	206	64
	Avg. measured soil loss, (t/ha/yr)	35	35	28
	Avg. predicted soil loss, (t/ha/yr)	31	31	31

Table 2. Total runoff and sediment yields for the small watershed studies

Watershed	Total runoff (mm) for selected events		Sediment yield (t/ha) For selected events		Number of years of record	Total number of selected events
	Measured	Predicted	Measured	Predicted		
Chickasha C5, OK	320	309	4.27	3.81	4	34
Coshocton 109, OH	25	26	1.99	1.02	11	4
Coshocton 130, OH	49	30	0.036	1.11	7	6
Coshocton 191, OH	20	20	0.055	0.035	11	3
Holly Springs 1, MS	3409	2820	64.7	153.7	8	237
Holly Springs 2, MS	3576	2658	65.9	121.8	8	241
Holly Springs 3, MS	2858	2600	94.0	141.6	8	241
Riesel SW-12, TX	1086	940	—	3.88	6	57*
Riesel W-12, TX	833	860	15.77	9.61	6	117
Riesel W-13, TX	879	920	10.38	8.05	6	83
Tifton Z, GA	403	332	6.67	8.31	8	46
Watkinsville P-1, GA	596	567	53.9	67.6	11	33
Watkinsville P-2, GA	377	359	17.40	18.18	3	21
Watkinsville P-3, GA	518	614	9.74	8.51	11	35
Watkinsville P-4, GA	529	541	5.96	7.50	10	36

*Sediment data were not available for the SW-12 watershed

and management ranged from fallow to continuous meadow. Locations included Presque Isle, ME, Holly Springs, MS, Watkinsville, GA, Castana, IA, Bethany, MO, Morris, MN, Madison, SD, Guthrie, OK and Geneva, NY. The period of record ranged widely for locations, but some data were collected as early as 1931 (Bethany, MO) and as late as 1980 (Holly Springs, MS). Input files were constructed for soils, topography, climate, and management using information from the original field data sheets. Predictions were made using procedures recommended in the WEPP User Summary.

Figures 1 and 2 show the results in terms of yearly and average annual soil loss. Yearly soil loss values are the total measured or predicted soil loss for a specific year, while average annual is the average of the yearly measured or predicted values for the years for that particular plot. Table 1 presents some overall statistics of the fit of the WEPP model, as well as the USLE and RUSLE. A portion of these plot data were used in the statistical analysis which led to the development of both the USLE and RUSLE (Wischmeier and Smith 1978; Renard et al. 1991, 1997). WEPP was not calibrated directly on these data, however, some of the temporal adjustments to the WEPP Green and Ampt effective hydraulic conductivity values are based in part on these data (Risse et al. 1995; Zhang et al. 1995a,b). The soil erodibility values for the WEPP analysis are based on the WEPP erodibility estimation equations, which were developed independently of these data (Flanagan and Nearing 1995). Generally, WEPP, the USLE and RUSLE predicted very similarly. Note that these studies did not use the same data sets. WEPP generally used a subset of the USLE and RUSLE data sets.

Ghidey and Alberts (1996) recently reported on testing of WEPP on eleven years of data from USLE type plots on a claypan soil. Tillage treatments included fallow, conventional plowing, chisel plowing and no till, crops were continuous corn and soybeans. WEPP generally did a good job of predicting runoff volumes, with soil loss generally overestimated.

WEPP predictions were evaluated for seven storms that accounted for over 80% of the total measured soil loss during the 11 year period for the conventionally tilled plots of Ghidey and Alberts (1996). For these storms for continuous corn, WEPP overestimated runoff 3% and underestimated soil loss 13%. For continuous soybeans, WEPP overestimated runoff 11% and soil loss 28%. As shown in figures 3 and 4, WEPP provided excellent predictions of runoff and soil loss for these large storms over a considerable range of storm sizes.

WEPP testing on watershed data

Measured data from 15 small (0.34 to 5.14 ha) watersheds (Table 2) at six U.S. locations were compared to runoff and sediment yield estimates using WEPP. The average period of record for the data was 9 years. WEPP performed very well on the small watershed sites. Average annual runoff ranged from a measured low of about 2 mm/yr to a maximum of over 400 mm/yr. Sediment yield ranged from about .007 t/ha/yr to over 8 t/ha/yr. Soils ranged from a silty clay to a sandy loam and management included conventional and no-till, as well as meadow. These 6 sites represent tremendous diversity, yet WEPP did a nice job of accounting for this as shown by the predictions of runoff and sediment delivery in Table 2.

The testing of WEPP does reveal some areas that need improvement. At Holly Springs, the consistent overestimation of sediment delivery has shown a need to improve the silage routines in WEPP. The over prediction of sediment delivery is attributed to an overestimation of the

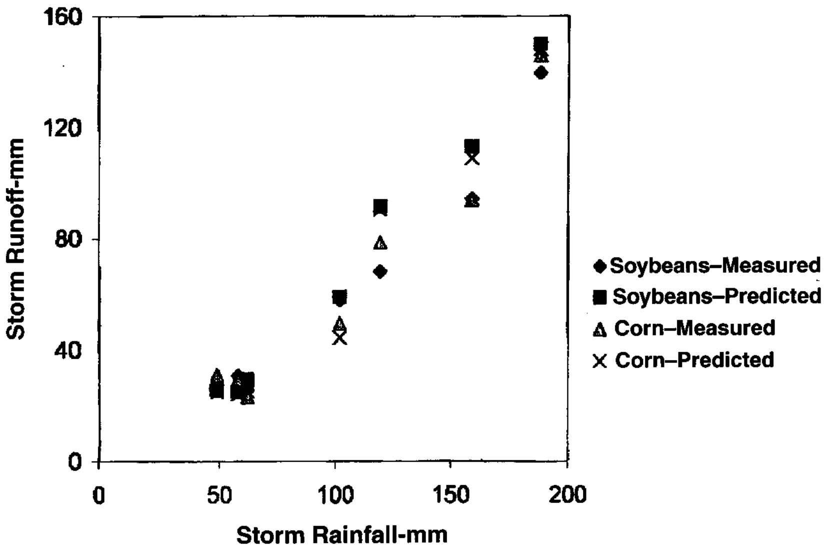


Figure 3. Measured and predicted runoff vs rainfall for continuous corn and soybeans, conventionally tilled for a midwestern claypan soil (data from Ghidey and Alberts 1996)

amount of material removed when corn was harvested for silage.

The Coshocton watersheds produced small amounts of sediment. Except for one watershed, predicted and measured runoff and sediment loss compared very favorably.

Forest applications

Forest lands experience the same erosion processes as agricultural and range lands. However, the processes that dominate are different. In northwestern forests, and to a lesser extent, in high-elevation eastern forests, snow melt processes tend to dominate hydrologic events. There is almost no erosion from undisturbed forests, but disturbances can lead to erosion rates similar to those observed on agricultural lands. The main disturbances are roads, fires and logging operations. In many forest watersheds, roads account for up to 90 percent of the sediment delivered to forest rivers and streams, the major concern in forested watersheds. WEPP provides a sediment yield estimate, the information generally needed in forest watershed analysis.

The U.S. Forest Service has focused research on roads and harvest areas, providing erodibility values for these conditions and a better understanding of the dominant erosion processes in forests. The Forest Service has modified WEPP mountain climate station data to more accurately describe higher elevation climates for some field applications of WEPP. They are also developing a technology to allow a user to access a wider range of climate records, including NRCS SNOTEL data, to improve high-elevation climate generation.

WEPP has been successfully applied to siting of roads and to the design of practices to reduce offsite delivery of sediment in forests. In a sensitive high elevation watershed in Wyoming, WEPP identified the critical road segments, and mitigation measures were developed only for those segments, economically controlling sediment delivery to a trout stream. WEPP was also applied to a road in an Idaho watershed where over half the sediment was estimated to come from less than 15 percent of the road, allowing mitigation measures to focus only on those critical segments. In another application in Utah, WEPP was used to evaluate the impact of graveling a road on the overall watershed sediment budget. The estimated impact of graveling was to reduce sediment delivery from the road to channels by up to 80 percent, as past measurements had indicated (Burroughs and King 1989).

The flow path that runoff follows along the road surface can play a major role in determining erosion rates. On a road with a well-drained surface, runoff water will leave the surface before there is sufficient flow depth to initiate rilling. When the surface flattens due to traffic, the path length increases, rilling starts and erosion can increase by more than five times the initial rate (Elliot and Hall 1997). There are complex relationships among road topography, hillside topography and climate in determining how much, if any, sediment is transported from a road across a forest buffer zone to a stream channel (Morfin et al. 1996). WEPP allows the study of roads a segment at a time to determine which parts of a road are the main contributors to off-site sedimentation. WEPP appears to model the process well and to give reasonable results compared to field observations.

WEPP model enhancements

As with any new computer technology, a few bugs have surfaced. Winter hydrology routines had an incorrect rate coefficient for snow melt, and soil moisture content during the winter period was incorrectly updated. Fixes will be released with other corrections in the spring of 1997.

Updated file builders for soils and management and an improved climate file builder allowing weather data smoothing between stations have been developed and will be released in the spring of 1997. Use of interpolated generated weather will provide for more consistent predictions of precipitation, runoff, and erosion from location to location within a county or state. There are also some minor problems in the impoundment and channel routines that have been corrected and will be included in the new release.

The interface requires a complete overhaul. The present interface was developed before the Windows environment was fully developed. The hardware and software industries have made major advances in recent years, and the development of a Windows-based user-centered interface is underway. Watch the WEPP website for a prototype WEPP Windows interface by the end of 1997. The screens that are under development can be viewed on the WWW site now. This interface is a part of the common effort by all ARS erosion modeling teams (RUSLE, RWEQ, WEPS, and WEPP) to develop a common interactive graphic users interface.

There are some problems that need to be addressed in WEPP. Currently, when erosion rates are high, typically for conventionally tilled long and steep slopes, rill depths can be unrealistically high, particularly on farmed fields where a layer at the bottom of the most recent tillage may limit erosion depth. On bare construction slopes that have not been tilled or where fills are deep, the estimated erosion depths would be better estimated. In cases where erosion rates seem unreasonably high, the slope length may need to be reduced. This is an area of the WEPP model that will be improved in the future.

The cropping parameters for WEPP are complex and difficult to estimate. Additional efforts are needed to parameterize crops for the entire U.S. For example, soybeans grown in Minnesota have different parameters than those grown in Mississippi, presently estimation of these parameters is difficult. Outside the United States the soil and climate information is often difficult to obtain. WEPP testing has revealed the need to allow more flexibility in representing silage cutting and to represent weed growth. An additional enhancement is needed to model residue additions. Continual improvements are needed to maintain any model, and WEPP is no exception.

What's ahead for WEPP?

There are 5 areas important to the future of WEPP: 1) Interface development, 2) Maintenance, 3) Improvement, 4) Implementation, and, 5) Commonality with other natural resource models. Each of these are necessary if WEPP is to fulfill its promise of ushering in a new technology for prediction of soil erosion and sediment delivery. Here is what we're doing or plan to do in each of these areas.

Interface Development. Major work is underway to replace the current DOS-based interface with a Windows-based interface that will be easier to install and use. This work is proceeding in concert with the other ARS erosion models-WEPS, RUSLE and RWEQ. Additionally, the Forest Service is developing an interface for WEPP for its new UNIX network.

Maintenance. WEPP has a maintenance team in the National Soil Erosion Research Laboratory charged with assisting with model use, maintaining model access and fixing model errors. WEPP will remain available, with supporting information and databases, on the WWW. Automated help will be further automated. Humans are available for support also.

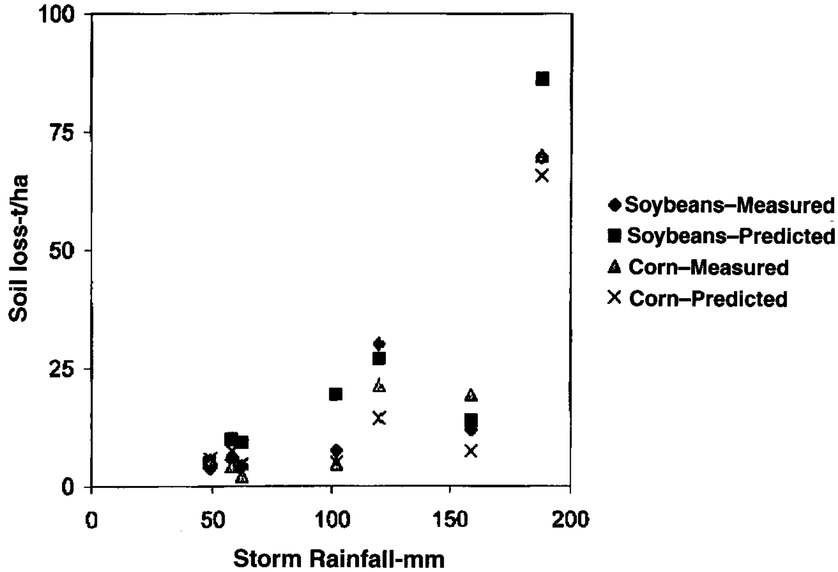


Figure 4. Measured and predicted soil loss vs rainfall for continuous corn and soybeans, conventionally tilled, for a midwest claypan soil (data from Ghidey and Alberts 1996)

Considerable scientific power is also available outside the National Soil Erosion Research Laboratory to apply and maintain WEPP.

Improvements. There are areas within the model that need enhancement-such as the silage and weed growth options identified above. These improvements will be made based on their priority and as resources are available. Partnering with others with specific expertise will be important in improving WEPP.

Implementation. The Forest Service is implementing WEPP. The NRCS will also implement WEPP, as will other federal agencies and other users. Considerable training will be required. Implementation requires testing and needed improvements will be identified during the process. The total replacement of USLE technology will take several years.

Commonality. Commonality among ARS natural resource models for science, databases and interfaces has been identified as a high priority need. Most daily simulation models have very similar components. There are immense benefits to having common science and common databases, both to the developers and the agency that supports them, and to the users of the technology. Testing, verification, validation, maintenance and training costs would be reduced. More attention needs to be given to having identical components and databases for natural resource models.

ARS has developed a number of natural resource models. We expect WEPP to be an important member of a suite of ARS natural resource models for use by city, county, state and federal action agencies, farmers, ranchers, students, consultants and others. We expect these models to eventually use a common interface and common, readily available data sets. These technologies must operate under a broad range of operating systems and hardware.

WEPP was developed to replace the Universal Soil Loss Equation. It is important to recognize that replacing older technology is not a trivial task. It took nearly 20 years for the USLE to replace the Musgrave equation, and they were quite similar. We are moving rapidly to the widespread use of personal computers for many analyses using modern technology. Today, a ten year old child can design a city on a computer using SIM-CITY. How long will it be before the sophisticated natural resource management tools that we have developed will be used in that child's classroom?

WEPP availability

The WEPP model is most easily accessible via the World Wide Web. The WEPP home page is http://soils.ecn.purdue.edu:20002/~wepp/wepp.html.

The WEPP model and information are also available via file transfer protocol (ftp). An inquiry to WEPP@ecn.purdue.edu will elicit a set of instructions for obtaining WEPP via ftp. Templates for WEPP forest applications described in Elliot and Hall (1997) are available by ftp from forest.moscowfsl.wsu.edu/water/WEPP.

The WEPP model and supporting information are also available on a CD-ROM. More than 2000 have been distributed, and are available by sending an e-mail request to WEPP@ecn.purdue.edu.

Materials available on the WWW and the CD-ROM include the model, the DOS interface, climate and soils databases, default cropping and management databases, documentation and user guides and some training materials. The CD-ROM also includes an additional set of educational video clips. The WWW site contains frequently asked questions (FAQ) with answers.

Another page on the WWW is devoted to WEPP fixes-errors in the model that have been fixed or improvements in the interface. E-mail to WEPP@ecn.purdue.edu will elicit a response to assist users in whatever way necessary. Generally, questions and answers are provided by the point of first contact. Occasionally additional scientific help is needed.

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