RUSLE revisited: Status, questions, answers, and the future

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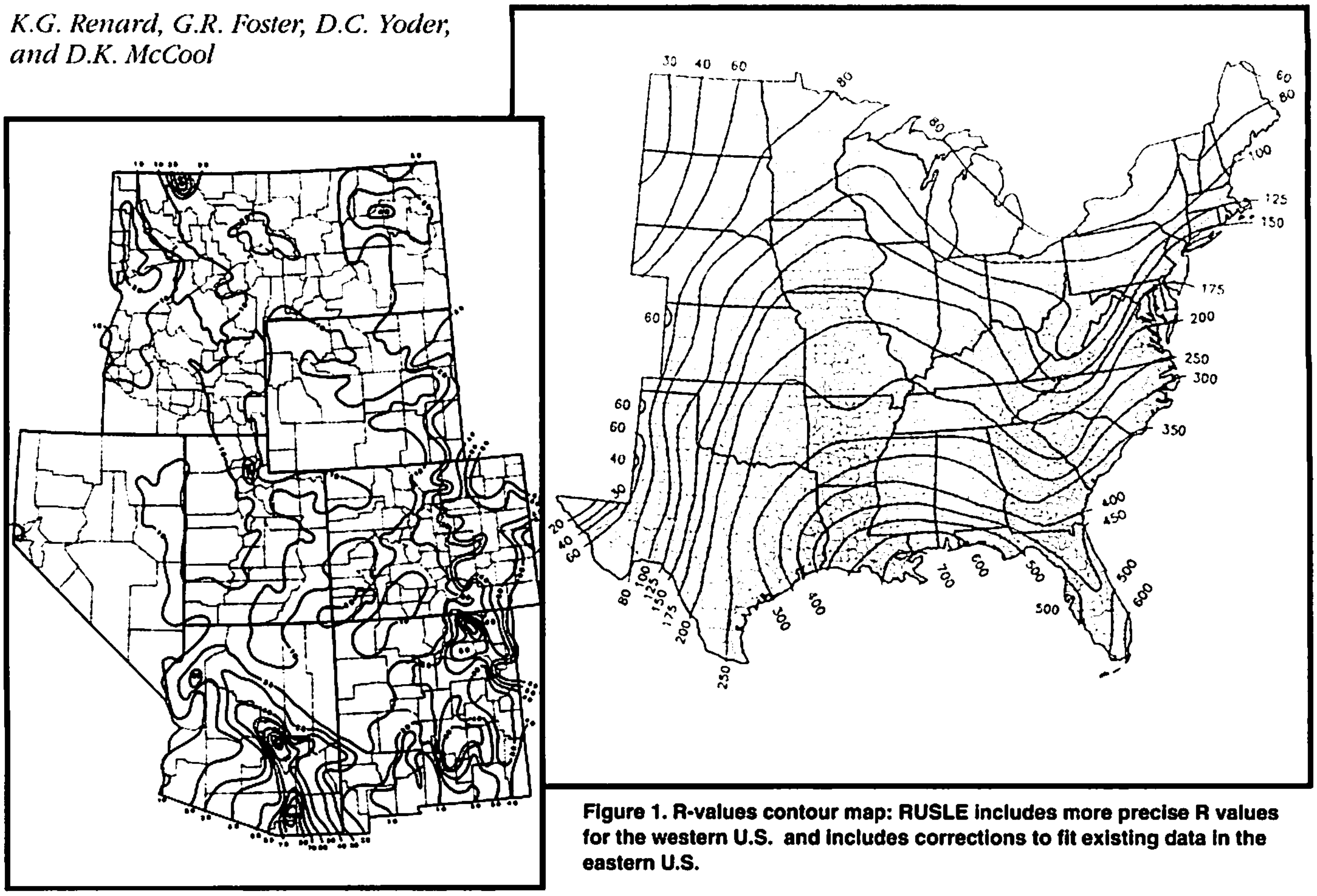

Figure 1. R-values contour map: RUSLE includes more precise R values for the western U.S. and includes corrections to fit existing data in the eastern U.S.

RUSLE, the Revised Universal Soil Loss Equation, is a modern erosion prediction and conservation planning tool based in large part on the USLE (Universal Soil Loss Equation) and its supporting data, but also including major improvements and updates. Differences between RUSLE and the USLE were described in some detail in earlier articles (*11,12*). This report will describe changes in RUSLE since the time of those articles, and proposed future changes in RUSLE technology. In addition, the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) has recently made the decision to implement RUSLE as its official erosion prediction and conservation planning tool (*13*). This article will answer questions concerning RUSLE's implementation and use.

RUSLE description

General description of RUSLE. RUSLE uses the same fundamental structure as did the USLE (*15*):

$$A = R \cdot K \cdot LS \cdot C \cdot P \quad (1)$$

where

- A = predicted soil loss (tons acre^{-1} year^{-1})
- R = climate erosivity ([hundreds of ft-tons] inch acre^{-1} hr^{-1} year^{-1})
- K = soil erodibility measured under standard unit plot conditions (tons hour [hundreds of ft-tons]$^{-1}$ in^{-1})
- LS = dimensionless factor representing the effect on erosion of slope length and steepness
- C = dimensionless factor for cover and management
- P = dimensionless factor for conservation support practices, such as contouring, stripcropping, terraces, deposition, etc.

The four major factors affecting interrill and rill erosion are therefore represented in this empirical relationship, with climate ero-

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FILE    EXIT    HELP    SCREEN

          Rotational C: general inputs TEST 0.26
                      city code: 38001    PHILADELPHIA  PA
      adjust for soil moisture depletion: 1
      % surface covered by rock fragments:0
     surface cover function; B-value code:1
          number of years in the rotation:8

                                  #   Crop

                                    1 alfalfa 1st year
                                    2 alfalfa 2nd year
                                    3 alfalfa established
                                    4 corn

                              F3 When Questions Answered

Tab  Esc  F1   F2  F4   F6   F9   PgUp PgDn Home End
FUNC esc  help clr cont call info pgup pgdn 1st  last
```

```
FILE    EXIT    HELP    SCREEN

Rotational C: field operations TEST 0.26

  1/4 crop: alfalfa 1st year senescence code: 2
  Date    Field Operation    Res. Add (#/A)   New Growth Set
  3/30/1  chisel (3 in. twist)
  4/5/1   disk; tandem
  4/6/1   harrow (tine)
  4/10/1  drill; conventional
  6/30/1  hay harvest        600              alf. 1st yr regrowth
  8/15/1  hay harvest        450              alf. 1st yr regrowth
  9/30/1  hay harvest        450              alf. 1st yr sen clrso

                              F3 When Questions Answered

Tab  Esc  F1   F2  F4   F6   F9   PgUp PgDn Home End
FUNC esc  help clr cont call info pgup pgdn 1st  last
```

Figure 2. RUSLE keeps track individually of every residue added to the field, and calculates cover and decay relationships. This demonstrates tillage operations which incorporate some of the previous corn crop residue and residue added following hay harvest. The values in the Res. Add. column indicated the amount of residue added to the surface by each operation.

sivity represented by *R*, soil erodibility by *K*, topography by *LS*, and land use and management by *C* and *P*. The basic regression equation structure of the USLE (*15*) was derived from thousands of plot-years of data under both natural and simulated rainfall. This linkage is maintained in RUSLE, though some of the factors have been broken down further to allow for better definition and more accuracy of prediction.

Table 1. Summary of the differences between the USLE and RUSLE (adapted from [13]).

Factor	Universal Soil Loss Equation (USLE)	Revised Universal Soil Loss Equation (RUSLE)
R	Based on long-term average rainfall conditions for specific geographic areas in the U.S.	Generally the same as USLE in the Eastern US. Values for Western States (Montana to New Mexico and west) are based on data from more weather stations and thus are more precise for any given location. RUSLE computes a correction to R to reflect the effect of raindrop impact for flat slopes striking water ponded on the surface.
K	Based on soil texture, organic-matter content, permeability, and other factors inherent to soil type.	Same as USLE but adjusted to account for seasonal changes such as freezing and thawing, soil moisture, and soil consolidation.
LS	Based on length and steepness of slope, regardless of land use.	Refines USLE by assigning new equations based on the ratio of rill to interrill erosion, and accommodates complex slopes.
C	Based on cropping sequence, surface residue, surface roughness, and canopy cover, which are weighted by the percentage of erosive rainfall during the six crop stages. Lumps these factors into a table of soil loss ratios, by crop and tillage scheme.	Uses these subfactors: prior land use, canopy cover, surface cover, surface roughness, and soil moisture. Refines USLE by dividing each year in the rotation into 15-day intervals, calculating the soil loss ratio for each period. Recalculates a new soil loss ratio every time a tillage operation changes one of the subfactors. RUSLE provides improved estimates of soil loss changes as they occur throughout the year, especially relating to surface and near-surface residue and the effects of climate on residue decomposition.
P	Based on installation of practices that slow runoff and thus reduce soil movement. P factor values change according to slope ranges with some distinction for various ridge heights.	P factor values are based on hydrologic soil groups, slope, row grade, ridge height, and the 10-year single storm erosion index value. RUSLE computes the effect of stripcropping based on the transport capacity of flow in dense strips relative to the amount of sediment reaching the strip. The P factor for conservation planning considers the amount and location of deposition.

The differences between RUSLE and USLE are represented in Table 1. As was described in some detail in earlier publications on RUSLE (*11, 12*), it represents a significant improvement over USLE technology in calculation of each of the factors.

R factor. RUSLE includes more precise R values for the entire western half of the United States, and includes corrections, more refined smoothing, and filling of gaps for the Eastern United States. Corrections are also made for the reducing erosion effect of raindrops falling on ponded water. In the cropland areas of the northwestern wheat and range region, an equivalent R factor has been developed to reflect runoff from frozen and partially-thawed soils.

K factor. USLE researchers realized that inherent soil erodibility varies with time as a function of soil loosening by freeze-thaw cycles, and by reconsolidation due to moisture extraction during the growing season. RUSLE includes such an effect. The temporal *K*-value reflects higher soil moisture in the spring and thus greater runoff. The temporal *K* correction is not used on areas west of 105° latitude.

LS factor. The effect of topography on erosion varies depending on whether the erosion is primarily interrill erosion, rill erosion, or a combination of the two. It was also found that the USLE relationship did not fit well for data from steep slopes. Both of these problems are corrected in RUSLE. The new relationships also apply to slope lengths less than 15 ft., whereas USLE does not. In addition, a special topographic equation is used on cropland in the northwestern wheat and range region to describe rill erosion from thaw-weakened soil.

C factor. Application of this technology is made substantially more flexible by dividing the C factor into a series of subfactors (reflecting prior land use, crop canopy, surface cover, and surface roughness), allowing finer division of the data. An additional term is included to reflect antecedent soil moisture in the northwestern wheat and range region.

P factor. RUSLE brings in a mixture of empirical and process-based erosion technology to provide a better measure of the effect of contouring and stripcropping on erosion. With stripcropping, the *P* factor for conservation planning is computed based on amount and location of deposition.

Recent changes in RUSLE. More recent changes in RUSLE technology have been driven by specific needs and requests from users. These changes have undergone thorough testing by USDA, Agricultural Research Service (ARS), SCS personnel, and other users. These changes are included in the latest RUSLE version to be certified and released by the SWCS and includes:

R factor. A slight redrawing of the eastern U.S. R-value contour maps to more closely fit existing data, and more refined calculation of the effect of ponded water on the erosivity of rainfall on soils in locations with intense storms.

K factor. More accurate erodibility nomograph calculations.

C factor. Restructuring of the *C*-factor inputs to provide more flexibility in describing cropping systems, and especially conservation tillage systems or those involving forages in rotations (*17*).

P factor. Refinement of the routines to calculate the contouring effect (*5*), completely new process-based routines to determine the effect of stripcropping, and a more complete set of routines to handle conservation practices used on rangelands.

Recent changes in RUSLE technology have been driven by specific needs and requests from users.

RUSLE reflects research since Agricultural Handbook 537 (*15*). In addition, RUSLE is a computer model and allows much more comprehensive use of research results.

Status of RUSLE

Why RUSLE keeps changing. As occurs with most software packages, RUSLE has undergone several changes since it was first released by SWCS in December of 1992. RUSLE SWCS1.03 was released in January of 1994 and is largely an update with correction of earlier computer "bugs." After the release of RUSLE SWCS1.03, ongoing research and development of RUSLE by ARS, SCS, and others identified improvements in RUSLE for no-till, pasture, land tilled after long periods without tillage, and manure applications. These improvements were developed from analysis of a large, comprehensive database on no-till cropping and data from several locations on the effect of incorporated manure on soil loss. Version SWCS1.04, to be released in April 1994, incorporates these scientific improvements, and this version also provides an easier way to model manure and sludge applications than did previous versions.

There has been objection to model updates, based on the argument that an erosion prediction tool must be completely stable and unchanged if it is to be used. We admit that changes in RUSLE do cause problems. Sometimes, consistency between soil loss estimates is more important that the estimated values. For example, evaluating trends in soil loss requires that the same version be used in the computations because changes could be the result of model differences rather than actual changes in soil loss. If two farmers have their soil loss values computed for very similar situations, they expect the same results. If changes in computed soil loss values favor a client having their soil loss recomputed each time a new version is released, a considerable work load will be generated for field personnel.

Though very important, this argument must be balanced against several other factors. First, farmers and others impacted by erosion prediction technology deserve reasonable access to the state of the art, which changes as new data are collected and model relationships are refined. Though many think of the USLE as being described completely in the *Agriculture Handbooks 282* and *537* (*14, 15*), it was being continually updated by additions and revisions developed by the ARS, SCS, and other agencies. Some of the major improvements made between and after formal releases of the USLE have been the development of the erodibility nomograph, development of the subfactor method for woodlands and other land uses, development of values for construction sites and conservation tillage, and improved P factor values for terraces and contouring. Some of these improvements were rapidly adopted. Others were not, such as improved slope steepness relationships published in 1988.

Changes in RUSLE have sometimes been driven by this need to include new science. An example of such change is the incorporation of a new residue decomposition routine. The simple model currently in RUSLE works well, but this technology is developing rapidly, and a better one will probably be proposed and adopted in the future. Other examples would include better ways of representing particular bits of difficult data. One of the changes between versions SWCS1.03 and SWCS1.04 will be to split the effect of buried residue from the effect of roots, as the data seem to show such a difference.

Another evolutionary change evident in RUSLE has been to incorporate new features suggested by users. For example, in early RUSLE development, users expressed little interest in modeling manure injection, yet this change has been recently requested and will be incorporated into version SWCS1.04. These evolutionary changes occur with many products, and are especially common in the commercial software industry, as evidenced by the frequent release of new versions of popular word-processing programs.

Next, as with most complex computer programs, RUSLE contains errors. The number of different possible combinations of inputs is astronomical, and testing by the program developers almost invariably misses some combination of inputs that will cause problems. These errors must be corrected as they arise.

The general approach that we have chosen is to release new versions at about six-month intervals; with the exception of major technology changes that might occur once every two years, data files would not require changing with each revision. With this approach, most changes are transparent to the user.

Adoption and implementation of RUSLE by user groups. As was mentioned, RUSLE was adopted by SCS in late 1992 as its erosion prediction tool, with plans to proceed with implementation as quickly as possible. Since RUSLE does a better job than the USLE of reflecting the value of surface residue, this decision was received enthusiastically by the popular farm press (*1, 2, 4, 16*). Problems with collecting the required information, ensuring internal consistency within the data files and compatibility with the model has made an unprecedented large task. Improvements in RUSLE such as having model "incorporated" residue for no-till, separating the effect of roots from the effect of residue on erosion, and simplifying the procedure for analyzing the manure injection into soil have also been made. These improvements will be in the next release of RUSLE, SWCS1.04.

The SCS is working on incorporating the RUSLE computer program into its new Field Office Computing System (FOCS), which will allow for easy access to the required input information and which will make RUSLE compatible with other SCS computer programs. This process is well under way.

RUSLE training and distribution. The ARS has been the lead agency in the development of RUSLE and is responsible for its science. The ARS is charged with transferring the technology to potential users, but it has neither the structure nor the personnel required to provide and support a computer program available to multiple users. ARS therefore joined into a Cooperative Research And Development Agreement (CRADA) with the Soil and Water Conservation Society (SWCS), giving the SWCS the sole right to distribute the technology.

In exchange, the SWCS has developed training books, videos, and complete training sessions. Perhaps more importantly, the SWCS has also begun a peer review process of the model and its databases through two Certification Committees. These fill much the same role as the editorial staff and reviewers of journal articles, providing an objective and scientifically-sound basis for certifying the model and databases as state-of-the-art. Such a certification does not mean that the model is perfect, but rather that it performs as expected, and gives good results under all tested conditions.

Future of RUSLE

Following the development and release of RUSLE version SWCS1.04, work will begin on another version (SWCS2.0), which uses the same RUSLE erosion prediction technology, but which applies it in a more straightforward yet flexible way.

There were several reasons behind the decision to proceed with this new approach, the first of which is historical. When the update of the USLE began in 1985, the intent was to continue to use it in "paper form." At that time, personal computers were much less powerful than they are today, and they were not readily available to SCS field personnel. By the target date of 1987, much of the background was completed, and a computer program had been developed to solve the C-factor equations. There was a debate at that time over whether to continue to develop a "paper updated USLE", or to develop a Revised USLE implemented as a computer program. The compromise that was struck was to have the computer program retain the structure of the USLE factors, giving the user the option of either using RUSLE in "paper" form or on a computer program. The resulting RUSLE based on the USLE "paper" structure is awkward to use. The input does not flow naturally. Many of the factors are interrelated, and jumping back and forth between them causes technical and computer problems.

RUSLE SWCS 2.0...will provide a powerful tool for conservation in the rest of the world.

However, with the computer resources that are now widely and reasonably available, the need to have a "paper" version of RUSLE no longer exists. Version 2.0 will use a graphical interface in a hierarchical fashion that will be significantly easier to use. It will have the look and feel of a modern computer program.

A second reason for a RUSLE SWCS 2.0 is that most of the world is interested in using it in metric units, rather than in its current English unit form. If a program is designed from the beginning with this in mind, it is easy to build into the program not only the capability of accepting different units of measure, but even different languages. This will serve well not only in the United States, but will also provide a powerful tool for conservation planning in the rest of the world.

The major difference between USLE and RUSLE is for conservation tillage systems, and especially for no-till.

The main reason for the new version, however, is that the RUSLE erosion prediction power is not being fully used by the current version. This is most apparent in the calculation of how the RUSLE factors change with time. The *K*, *C*, and *P* factors each change with time, and the value of each for a specific time period is weighted by the percentage of rainfall erosivity occurring during that period. These averaged values are then multiplied at the end of the rotation in the basic soil loss calculation. This approach misses the interaction between the factors. For example, if the soil is highly erodible (high *K*) at the same time that it is without cover (high *C*) and not under any conservation practice (high *P*), the soil loss from that time period should be very high, significantly affecting the annual average. Preliminary calculations show that this can cause changes in calculated soil loss of ±25 percent of the current calculated value. Though this is the primary example, there are other cases where the current "paper" RUSLE structure has significantly limited its potential as an erosion prediction or conservation planning tool.

How does RUSLE compare with USLE?

The adoption of a particular erosion prediction technology by an agency or organization depends on several factors in the context of the intended application. These factors include scientific and technical adequacy, ease of use, availability of expertise, input data, computers, other resources needed to use the technology, and policy considerations. Frequently the developers of RUSLE are asked to comment on the scientific and technological merits for immediate adoption of RUSLE. Alternatives include continued use of the USLE and not adopting RUSLE while awaiting the release of the Water Erosion Prediction Project (WEPP) model. WEPP will be the end product of a major development effort currently underway by the ARS, SCS, USDA-Forest Service, the USDI-Bureau of Land Management, and others (*6, 8, 9*).

RUSLE or USLE? RUSLE is scientifically superior to the USLE. Examples of why this is so include the following:

USLE erosivity calculations in the western U.S. were based on the use of a very few weather stations to develop a relationship between the *R* factor and the 2-yr frequency 6-hr duration rainfall event. In contrast, erosivity values in RUSLE are based on analysis of data from over 1,000 weather stations.

K values computed by RUSLE are weighted based on their temporal distribution during the year. In the east, the difference between the weighted *K* value and the USLE K value can be more than 20 percent.

The *S* factor in RUSLE was derived from a far more extensive data analysis than was the slope relationship in the USLE. Data from not more than five locations was reported as being considered in the derivation of the USLE *S* factor, whereas data from about 15 locations were analyzed to derive the RUSLE *S* factor. Differences between the S factors are significant at slopes of about 6 percent and for slopes greater than 20 percent. At a 6 percent slope, the RUSLE *S* factor is 0.68, while the *S* factor value for the USLE is 0.57, a 16 percent difference. At a slope of 30 percent (which is not uncommon on rangelands and construction sites), the RUSLE *S* factor value is 4.33, while the USLE value is 6.78, for a difference of 57 percent.

The *L* factor for a 1,000 ft long slope on a 0.5 percent grade is 0.11, while the USLE value is 0.15, a 27 percent difference.

Differences between *C* factor values for the USLE and RUSLE are not great for conventional tillage systems except for crop stage 4, the period between harvest and primary tillage. For example, the USLE uses a soil loss ratio of 0.07 for 80 percent cover during this period, whereas RUSLE uses a value of 0.047. The net result is that RUSLE computes a *C* factor for a conventional corn crop in Columbia, Missouri, of 0.24 whereas the USLE uses a value of 0.28. Part of the reason is the lower soil loss ratio during crop stage 4. Soil loss ratios for other parts of the year in RUSLE are backed up by data collected from 10 locations in the 1960s, the last set of data that covered a 10-yr period and which provided a sufficient data base to average out year to year variations. Those data showed a soil loss ratio of 0.12 for crop stage 3, the period from 75 percent canopy to harvest, whereas the USLE uses a value of 0.2. This period covers a significant period of the erosive rains in many locations, including 42 percent of the total annual erosivity experienced at Columbia. RUSLE computes a value of 0.17, which may be too high as well, but closer to the experimental data than the USLE value.

The major difference in computed soil loss is for conservation tillage systems, and especially for no-till. The USLE uses a C factor value of about 0.1, whereas RUSLE computes a *C* factor value of 0.026, resulting in a USLE over-estimate of almost 300 percent. RUSLE values have been validated against data collected from more than 60 studies, while the values for conservation tillage used in the USLE appear to be based on data from not more than five studies.

Using the subfactor approach for calculating *C* factor with RUSLE, it is possible to compute soil loss, given basic crop data not available when the USLE was completed (*16*). Furthermore, the *C* factors can be calculated for a variety of crop yields if there is information available on the tillage impacts on surface random roughness and the residue incorporation. Because these data are available in the RUSLE databases, the ensemble of *C* factors can be greatly expanded over those previously available in the USLE.

A similar situation exists with regard to analysis of data for the effect of contouring and strip cropping. For the case of contouring and strip cropping, the USLE factor values appear to be based on data from about five studies, whereas data from more than 15 studies were utilized to develop RUSLE relationships.

RUSLE or WEPP? Comparison of RUSLE with WEPP is somewhat more difficult, as the approaches used by these models are so different. First, WEPP is being developed to incorporate far more complex technology than was ever intended with RUSLE. Because of its process-based approach, WEPP can deal with erosion and sedimentation problems from a holistic field setting, being able to consider deposition, ephemeral gully erosion, sediment yield, and spatial and temporal variations. Both models can be used to compute interrill and rill erosion for conservation planning. Externally, both models can even look the same to the user. WEPP will, however, require a greatly expanded database, and more computer resources, including storage media, memory, and time to run. The importance of these differences to the user remains to be seen.

WEPP requires more data on weather, plants, soils, and tillage operations than does RUSLE. Another key difference between the two models is that large plot experiments can be conducted and the data used directly in RUSLE, without giving thought to erosion processes. In WEPP, erosion processes are more process-based, requiring more basic experiments in order to isolate the fundamental erosion processes and determine WEPP parameter values. In addition, full scale plot experiments are still needed to produce data that can be used to validate WEPP.

Simplicity has its appeal, in spite of the raw computing power that is readily available to solve very complex models (*3, 7, 10*). Process-based models like WEPP potentially have much more power than an empirical, process-lumped model like RUSLE. That power also gives it far more ways to generate erroneous output than does the simple approach. Though the simple approach may not always give a perfect result, in most cases it will be realistic, especially if its empirical parameter values are routinely updated to incorporate the experience of users. If experience with runoff models is any guide, RUSLE may well continue to be chosen over WEPP for the routine situations where interrill and rill erosion predictions are normally made.

Whether you should wait for WEPP or proceed with RUSLE depends on your erosion prediction needs.

Whether you should wait for WEPP or proceed with RUSLE depends on your erosion prediction needs. If you are currently making erosion predictions with the USLE, by all means implement RUSLE. RUSLE is proven technology that is available for use, and the data files and instructions provided allow you to apply RUSLE to every condition where the USLE can currently be applied.

Even though WEPP will be released in March 1995, experience with RUSLE, CREAMS, and EPIC indicates that some time will be needed to fully "shake down" the WEPP model before it is ready for routine use in the field. Therefore, in all likelihood WEPP will not be operational at the current level of confidence in RUSLE until 1997 or later. For example, the values that RUSLE computed in 1991 are very nearly the same as the values being computed by the present RUSLE. However, three years later, RUSLE is just beginning to be implemented in a major way. Such a maturation period could be even longer for WEPP, as its model is more complicated.

The choice between RUSLE and WEPP will to some degree be a "marketplace" decision. If RUSLE is adequate, and can be implemented and used with less costs than WEPP, it may very well continue to be used. WEPP clearly is the more powerful model, but whether the increased power will be realized in specific applications remains to be proven. If experience with other hydrologic models is a guide, WEPP may not be much better, for the more frequently-occurring situations. For example, even though very elaborate hydrologic models are available to compute peak runoff rate, the simple and empirical rational method continues to be widely used. It may only be in the extreme conditions that WEPP will consistently outperform RUSLE as well as applications where sediment yield is required from a complex watershed.

A key factor to RUSLE usage beyond the introduction of WEPP may be how long it will be supported either by a government agency like the SCS or ARS, or by commercial vendors. Certainly ARS seems committed to giving its emphasis to process-based modeling approaches such as WEPP. We don't envision a major future investment in RUSLE by the research community. RUSLE is mature technology, but it should not be written off prematurely on that basis. The subfactor approach for estimating *C* and use of fundamental erosion processes in the strip cropping *P* factor have shown that empirical methods can be combined with erosion theory to capture the best of both the empirical and the process-based worlds.

Summary

The Revised Universal Soil Loss Equation (RUSLE) is now in the final stages of implementation by the USDA, Soil Conservation Service and by other land management agencies. There have been some changes in the model originally published in the *Journal of Soil and Water Conservation* in 1991. The changes are summarized here, and important differences between RUSLE and the USLE are described.

We also show that RUSLE is scientifically superior to the USLE in many respects and that these are good reasons to use RUSLE now rather than waiting for the implementation of new, evolving process-based erosion prediction models.

Finally, the RUSLE developers answer some of the more common questions about the technology. In addition, plans are presented for some of the packaging and technology corrections that will be made in future program versions, allowing for further model streamlining, for easier usage, and for developing a metric version for international use.

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