Contributions of RUSLE2 to TMDL Development

Seth Dabney[1], Daniel Yoder[2], Ken Renard[1]

[1]USDA-ARS National Sedimentation Laboratory, P.O. Box 1157, Oxford, MS 38655; PH (662) 232-2975; FAX (662) 281-8642, email:seth.dabney@ars.usda.gov
[2]Department of Biosystems Engineering & Soil Science, University of Tennessee, 2506 E.J. Chapman Drive, Knoxville, TN 37996; PH (865) 974-7116; FAX (865) 974-4514, email:dyoder@utk.edu
[3]USDA-ARS (retired) Southwest Watershed Research Center, 2000 E. Allen Rd. Tucson, AZ 85719; PH (520) 647-2986; FAX (520) 670-5550, email: ken.renard@ars.usda.gov

ABSTRACT

RUSLE2 is a robust and computationally efficient conservation planning tool that estimates soil, climate, and land management effects on sheet and rill erosion and sediment delivery from hillslopes, and also estimates the size distribution and clay enrichment of sediment delivered to the channel system. RUSLE2 is supported by extensive databases maintained by the USDA-Natural Resources Conservation Service. It is commonly accessed through a graphical user interface (GUI) running in a Windows environment, but is also a dynamic-link library (DLL) version that uses the same scientific code and can interact with other computer programs through an application programming interface (API). In addition to average annual erosion and sediment delivery, recent enhancements give RUSLE2 the ability to predict a representative runoff event sequence for a particular location, soil, management, and user-specified return period that can be coupled with a channel erosion and routing model. These features make RUSLE2 applicable to TMDL modeling.

INTRODUCTION

A Total Maximum Daily Load, or TMDL, is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards (http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm). Water-borne sediment is the contaminant most commonly of concern to TMDLs because of both its direct impact on waterways and aquatic habitat, and its role in the transport of other contaminants. The Revised Universal Soil Loss Equation, version 2 (RUSLE2) is conservation planning tool that provides estimates of runoff and sediment delivery from one-dimensional hillslope profiles (<300 m long). It is applicable to all land uses where runoff is generated by rainfall excess. RUSLE2 program can be very useful for estimating the relative impacts of various management alternatives on sediment delivery to concentrated flow channels. For comprehensive TMDL

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development, the results of RUSLE2 should be linked with other programs that consider sediment generation and routing through the stream channel system.

The Universal Soil Loss Equation (USLE) on which RUSLE2 is based has the following equation structure (Wishmeier and Smith, 1978):

$$A = R K L S C P \quad [1]$$

where A is the computed soil loss per unit area; R is the rainfall and runoff factor; K—the soil erodibility factor--is the soil loss rate per rainfall erosion index unit for a specified soil under Unit Plot conditions; L and S are the slope length and steepness factors; C is the cover and management factor; and P is the support practice factor, representing the fractional reduction of soil loss due to a support practice like contouring, stripcropping, or terracing. In the USLE, the terms on the right hand size of equation [1] were independent and constant. The L, S, C, and P factors are dimensionless ratios relating the erosion of a particular management condition to Unit Plot conditions: 9% steepness, 22.1 m long slope, managed with continuous fallow on plots tilled up and down slope. Under unit plot conditions, therefore, the L, S, C, and P factors are all equal to 1.

RUSLE2 uses the same terms, but all except the slope steepness factor now vary on a daily bases and they are not independent of each other (Renard et al., 2011). As in the USLE, soil detachment is assumed to be linearly related to rainfall erosivity, which is supported by a vast empirical body of evidence. Despite this commonality, RUSLE2 goes far beyond USLE in several respects that make it a powerful tool for TMDL development based on sediment yield from landscapes under alternative management scenarios.

RUSLE2 INNOVATIONS

Climate Descriptions

RUSLE2 climate databases include monthly averages for precipitation, temperature, and erosivity density (erosivity per unit rainfall, MJ ha^{-1} h^{-1}, a measure of rainfall intensity), plus the location's 10-year 24-h precipitation amount ($P_{10\ year,24\ h}$). The erosivity density concept was developed during the preparation of the 30-year averages of climate parameters. Because erosivity density is the ratio of rainfall erosivity to rainfall depth, its monthly values become stable with fewer years of data than do average values of rainfall depth or erosivity individually. The RUSLE2 monthly erosivity density values are directly proportional to the average monthly 30-min rainfall intensity (USDA-ARS, 2008) and thus reflect seasonal variation in rainfall intensity at a location.

Soil Descriptions

Soils are described in RUSLE2 using the same information needed by the USLE: texture, inherent organic matter (under fallow management), soil hydrologic class with and without subsurface drainage, time to consolidation after tillage, and the

tolerable soil loss value. The K factor may be specified by the user or calculated from either the traditional nomograph suitable for agricultural soils or a modified nomograph considered more suitable for disturbed areas such as construction sites. The K factor is adjusted by RUSLE2 based on temperature and rainfall values relative to values at a central reference location (Columbia, MO). Under unfrozen conditions, the same soil will have a higher K factor for cooler or wetter conditions. This adjustment to K applies both between different locations and between different seasons at one location. These variations reflect the tendency for increased runoff and resulting increased erosion from unit plots when the soils are likely to be wet. K factors are reduced during winter periods when soils are likely to be frozen.

Land Management Descriptions

RUSLE2 management descriptions comprise combinations of field operations reflecting all ways in which those operations change the area from Unit Plot conditions. Field operations specify the dates and nature of all field operations such as grading, tillage, planting, and harvest or grazing events that affect the land surface, vegetations, residues, and mulches. Vegetation descriptions provide the growth characteristics of all crops or vegetations grown, while residue descriptions include all relevant impacts of residues coming from those plants or from mulch additions. RUSLE2 uses the information contained in the management description to determine effects on the L, C, and P factors through numerous variables tracked or calculated, including residue biomass in the soil, surface residue cover, surface roughness, canopy cover, Manning's roughness, and the runoff curve number (Renard et al., 2011). A recent innovation has been the addition of a new perennial vegetation growth model that improves estimates of runoff and erosion from lands used for hay or grazing (Dabney and Yoder, 2012). The new science allows a single vegetation to be grown for periods up to several years, and the model automatically adjusts growth and residue creation in response to harvest and residue management operations.

Transport Capacity and Deposition

One major difference between USLE or RUSLE1.04 (Renard et al., 1997) and RUSLE2 was the addition of process-based equations for sediment transport capacity and deposition (USDA-ARS, 2008). This development allows RUSLE2 to compute sediment deposition where sediment load exceeds transport capacity on hillslope concavities, in impoundments, or on hydraulically rough surfaces (Fig. 1). With this enhancement, the definition of a RUSLE2 hillslope includes depositional areas and extends from the top of the hill to where the flow path encounters a concentrated flow channel (waterway, gully, terrace channel, or ditch). Hillslopes are almost always less than 300 m long. A RUSLE2 profile (Fig. 1) consists of topographic, soil, and management layers, each of which may be segmented to reflect changes in slope steepness, soil, or management. RUSLE2 predicts detachment to occur in five particle size classes, including sand, silt, clay, and two aggregate sizes whose properties are a function of the soil clay content. Since soil type may vary within a single profile, RUSLE2 places all sediment into a predetermined set of 20 sediment size bins. Deposition of each sediment class is calculated separately, allowing RUSLE2 to compute enrichment of fines in sediment delivered to the channel system.

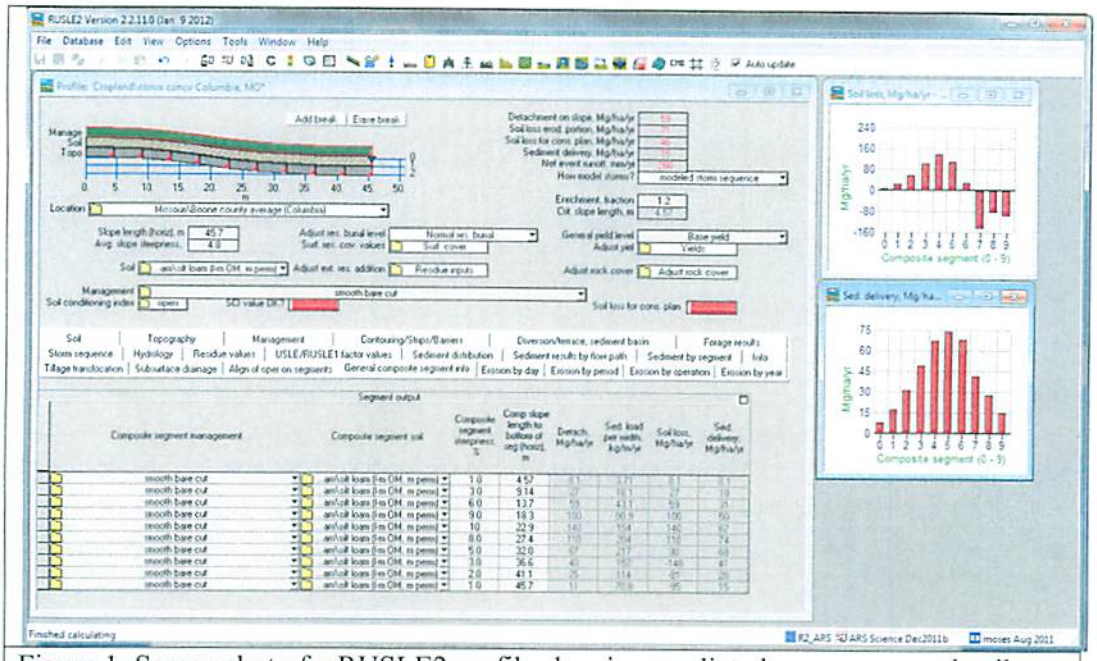

Figure 1. Screen shot of a RUSLE2 profile showing predicted average annual soil erosion and sediment delivery for a complex 10-segment profile with a silt loam soil on a smooth bulldozer blade cut surface in central Missouri. Note the net deposition on the last three segments. The sediment yield for the last segment matches that reported for the entire profile and represents sediment delivered to the channel, represented by a blue triangle graphic at the bottom of the hillslope.

This enrichment is reported in terms of an enrichment ratio, defined as the ratio of the sediment specific surface area to the specific surface area of the base soils being eroded. This enrichment ratio is correlated with enrichment in clay, organic matter, or phosphorous content that may be important for development of other TMDLs.

Runoff Estimation

Since it was first released (Foster et al., 2000; Foster et al., 2003), RUSLE2 has internally calculated a curve number (CN) using information contained in the climate, soil, and management databases. Consequently, users do not need to estimate a CN, and CN values are automatically adjusted to reflect differences in soil, management, and yield. Recently, RUSLE2 was enhanced to adjust the CN to reflect seasonal changes in antecedent water content and erosivity density, and to use the results to estimate average monthly runoff, the number of runoff events per year, and the scale parameter of a gamma distribution describing the population of runoff events (Dabney et al., 2011). Under the assumption that the maximum runoff event will occur during the month with greatest predicted runoff, and using a user-specified return period to specify the size of that event, procedures coded into RUSLE2 create a representative runoff event sequence that closely matches the erosion impact of the original RUSLE2, which assumes some erosion every day. This storm sequence both speeds up the erosion calculation and creates the more realistic runoff inputs needed to drive a process-based ephemeral gully or stream channel erosion model (Fig. 2).

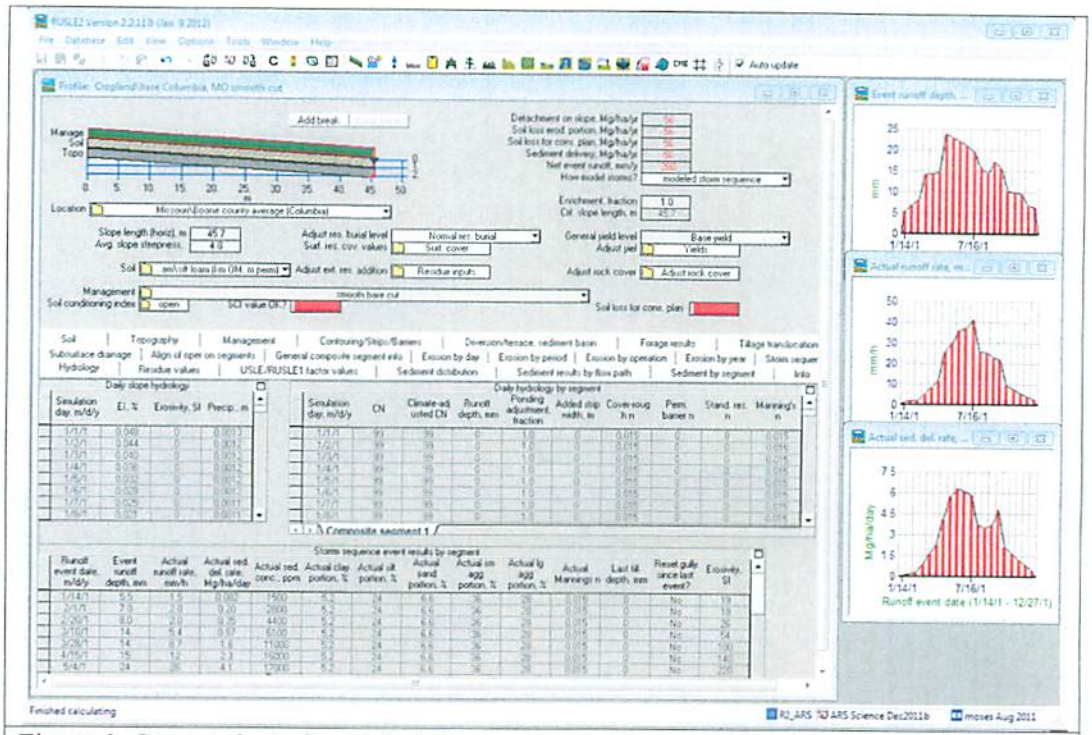

Figure 2. Screen shot of modeled storm sequence for a profile with a smooth bulldozer bare cut soil surface in central Missouri. Results indicate a total runoff of 280 mm from 990 mm of rainfall. The largest runoff event, with a 1-yr return period, is 24 mm and occurs on May 23. The hydrology outputs and sediment characteristics provide the inputs needed to drive any process-based ephemeral gully or channel erosion model. Note that on this linear slope with the same average length and steepness used for the convex-concave profile in Fig. 1, the average erosion rate is lower but the sediment delivery to the channel is higher than with the more complex profile shape.

USDA-NRCS RUSLE2 DATABASE

A strength of RUSLE2 as a tool for TMDL development is the extensive database that has been developed by the USDA-NRCS. This database includes climate descriptions for every county in the U.S., with additional subdivisions in 11 western states where within-county elevation differences greatly affect rainfall amounts. Similarly, there are soils descriptions for every county in the U.S., reflecting information from 3100 soil surveys. Land management scenarios are organized in the database into Crop Management Zones (Fig. 3). Each scenario is created by combining operation descriptions (e.g., grading, tillage, planting, applying materials, or harvest), vegetation descriptions (describing growth over time), and residue descriptions (decomposition and biomass/cover relationships). As of January 2011, the NRCS database contained over 29,000 management scenarios composed of combinations of about 600 tillage and field operation records, 1400 vegetation records, and 140 residue records. At that time, it also contained about 600 support

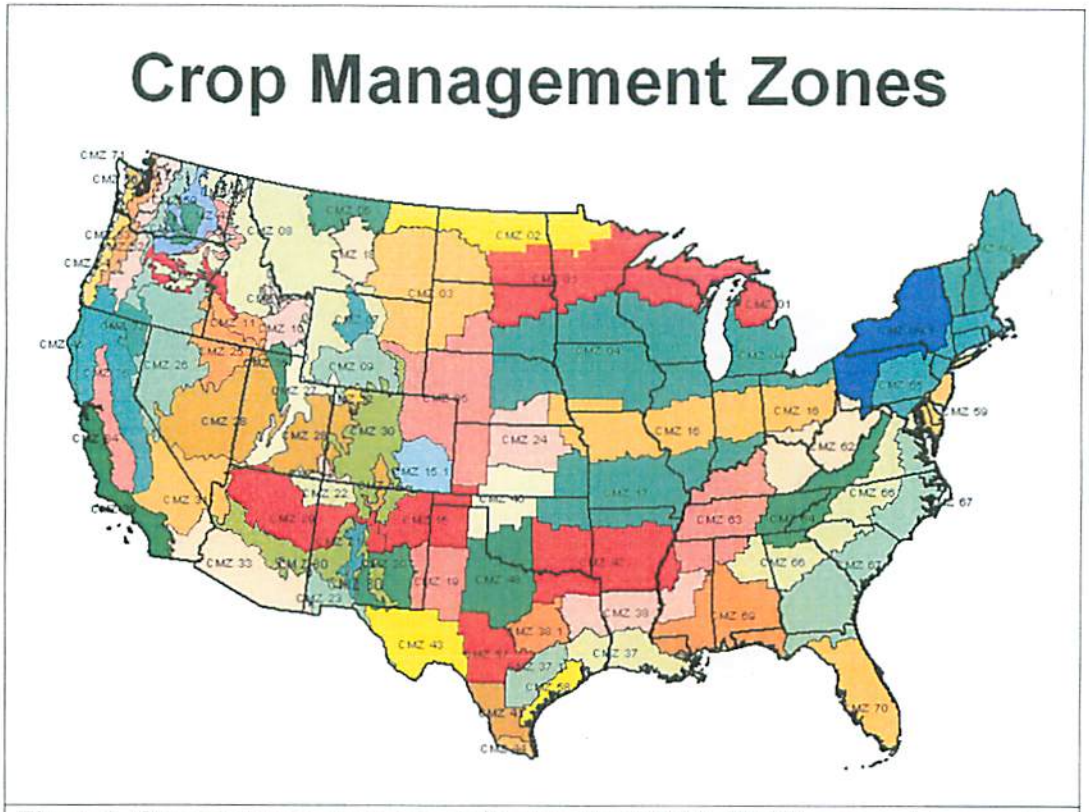

Figure 3. Crop management zones, defined by the USDA-NRCS, are used to organize RUSLE2 land management descriptions including all crop, residue, and operations descriptions important to each region.

practice choices comprising contour systems, hydraulic element systems (diversions, terraces, impoundments), and strip-barrier systems. When downloading the NRCS database (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm), one first downloads a base database containing all the vegetation, operation, residue, and support practice records for the nation, and then downloads the climate, soils, and crop management records specific to the area of interest.

The database describing conservation practices applicable to construction sites is less well developed than that for cropland applications (Tyner et al., 2011). Nevertheless, RUSLE2 is a land use-independent model and has been widely used for conservation planning on construction sites by engineers, planners, reviewers, inspectors, and developers. Yoder et al. (2007) described enhancements made to the RUSLE2 interface and databases to facilitate this application. These enhancements include database descriptions of management practices such as mulches, blankets and vegetations, devices or structures such as permeable barriers (e.g., silt fences, straw bales, fiber rolls, compost socks, etc.) and sediment basins, and combination techniques such as vegetative filter strips. A major advance in results reporting was the definition of an "accounting period," the period of interest during which the construction planner is responsible for controlling sediment delivery from a site.

Though the definition is flexible, in the example cited in Yoder et al. (2007), the accounting period begins with the first soil disturbing field operation and ends with the application of permanent erosion protection, defined as either application of a semi-permanent non-erodible surface (pavement, landscape fabric and cover, sod, etc.) or a specified period of growth of a perennial vegetation. The default for this specified growth period is 60 days during which the average air temperature was above 1.7°C, thereby giving no growth credit for periods when vegetation is dormant. This approach gives the planner an incentive to keep the accounting period short, to reduce erosion and delivery during that period, to plan construction during non-erosive periods, and to plant cover when it will grow, all of which are good conservation planning practices.

RUSLE2 INTERFACES

Stand alone versions of the model and database are controlled through a flexible graphical user interface (GUI) operating in Microsoft Windows©. This interface controls the appearance of RUSLE2 through the "user template" and controls how much freedom the user has to see or change variables through an "access level." In the screenshots presented in Fig. 1 and 2, three text fields are displayed at the bottom right of the screen. The first, "R2-ARS" is the current access level. The second, "ARS Science 2011b" is the active template. The third, "moses Aug 2011" is the name of the active database. Novice RUSLE2 users should use a simple template because the complexity of a template like that used in Fig. 1 and 2 may be overwhelming. These templates are completely configurable, and a broad range of complexities are already available. Trained users may also create custom templates to meet the needs of particular applications, such as TMDL development.

In many applications it is desirable to have an intermediate value (e.g., the percent soil cover) or runoff or erosion estimates that can be used as an input to another program with some other purpose. The calculation engine, scientific routines, and database objects can be accessed through an application programming interface (API) that allows another computer program to send inputs to and receive results from a dynamic-link library (DLL) version of RUSLE2. This DLL uses the same scientific code as the GUI and therefore gives the same answers. Other programs can make additional calculations using this information. Current programs and systems that use the RUSLE2 DLL include: the Purdue Manure Management Planner (http://www.agry.purdue.edu/mmp/), the Wisconsin SNAP-PLUS nutrient management planning system (http://www.snapplus.net/), the AGREN 2-D erosion calculator (http://www.agreninc.com/projects.php?proj=15), the DOE sustainable residue harvesting calculator (Muth and Bryden, 2012), the USDA-NRCS Natural Resources Inventory (http://cssm.iastate.edu/natlresinv/), and the USDA-NRCS Conservation Delivery Streamlining Initiative (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/about/cdsi).

ARS and NRCS versions of the model

The RUSLE2 model is jointly developed by USDA-ARS, the University of Tennessee, and the USDA-NRCS. The most recently released version is usually available at the ARS website (http://www.ars.usda.gov/Research/docs.htm?docid=6038). The official NRCS version and database are available from the NRCS web site (http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm). Because the NRCS version is used many times each day in field offices nationwide to develop conservation plans and determine program eligibility, it is critical that the version and databases are consistent and controlled. Therefore, the NRCS only adopts a new version after it is thoroughly tested. Databases are strictly controlled at regional and national levels, and access levels restrict the ability of users to alter values. The ARS version is updated more frequently and access levels giving users more power to see and control variables are available. Currently, the version available from the NRCS web site was released in 2006 and the version available from the ARS web site was released in 2010 and includes the new hydrology (Dabney et al., 2011) and perennial vegetation science (Dabney and Yoder, 2012). New releases are planned by both NRCS and ARS for 2012, and at that point the same model will be available from both web sites, although there will continue to be differences in templates and access levels included with each version.

DISCUSSION

RUSLE2 can be a valuable aid to TMDL development because it provides a robust way of estimating runoff and sediment delivery from hillslopes to the channel system. Due to the extensive available database, it can be used throughout the country with no calibration. While an individual one-dimensional hillslope profile is the fundamental unit over which RUSLE2 computes erosion and sediment delivery, there are two additional views in the stand-alone GUI that may facilitate TMDL development. One is the "plan view" in which multiple hillslopes can be defined and given weights so that an effective average erosion or sediment delivery rate can be calculated for a non-uniform area of interest. The second alternative is the "worksheet view" in which numerous combinations of management and support practices can be compared for a single hillslope characterized by a single set of climate, soil, and topographic properties. The worksheet view is very convenient for comparing management alternatives and selecting those that achieve specific conservation goals.

RUSLE2 can also be a valuable component of a comprehensive dedicated TMDL tool in a GIS environment. A water body or segment large enough to need a TMDL, or a watershed composed of many such segments, will receive runoff from numerous hillslopes. RUSLE2 can be accessed through its API to provide hillslope runoff and sediment yields information, and those results can then be coupled with additional models to route and estimate sources and sinks of sediment in a larger watershed context. For example, while RUSLE2 can predict deposition of sediment in low-gradient channels and impoundments, it cannot currently estimate gully or stream channel erosion, which are frequently important sources of sediment for TMDLs. With recently added technology RUSLE2 can predict the number of runoff events,

the statistical distribution of runoff event depths, and can generate a representative runoff event sequence that is suitable for linkage with a channel erosion model. Because effects of land management changes are buffered by sediments stored in channel systems and flood plains, RUSLE2 by itself cannot provide comprehensive TMDL estimates. RUSLE technology is embedded in some watershed models such as AnnAGNPS (http://go.usa.gov/KFO) that, coupled with a stream channel model like CONCEPTS (http://www.ars.usda.gov/Research/docs.htm?docid=5453), can provide the basis for comprehensive watershed TMDL development (Simon et al., 2002).

CONCLUSIONS

RUSLE2 is a well developed computer model designed to estimate erosion and sediment delivery at sites where runoff producing precipitation events occur. This technology has an extensive history of development and use on farms and ranches. The technology has also been used extensively for planning roadside protection and soil movement in strip mining activities. Efforts to extend RUSLE2 technology are continuing.

Accurate development of sediment TMDLs must deal with the complexity of sediment generation and transport processes through watersheds, which include erosion and deposition on the hillslopes, delivery to channel systems, and sediment generation or deposition within the channel system itself. In general, however, the goal of a TMDL is development of management alternatives that reduce sediment delivery to the channel system, and RUSLE2 is perfectly suited to that task because most management alternatives are implemented on the hillslopes. RUSLE2's value for this type of planning is enhanced by its flexibility in modeling almost any situation, ease of use, accurate results without calibration, and extensive databases reflecting almost any climate, soil, and management alternative in the US and protectorates.

RUSLE2's availability as a DLL makes the databases and calculated values within RUSLE2 available for more complicated programs that can model channel processes while using RUSLE2 estimates of sediment and runoff delivered from the hillslopes.

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