CHAPTER 14.

Methods Used for Analyzing the Cumulative Watershed Effects of Fuel Management on Sediment in the Eastern United States

Daniel A. Marion, J. Alan Clingenpeel

Previous chapters have described how various resource systems within a watershed can experience cumulative effects from fuel management activities like prescribed burning. As noted before, a cumulative effect is "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative effects can result from individually minor but collectively significant actions taking place over a period of time" (40 C.F.R. § 1508.7).

A cumulative watershed effect is any cumulative effect that involves water movement through a landscape, either because water-related resources are affected or because a change in watershed processes generates the effect (Reid 2010). Because sediment production and movement affect water-related resources and are tied to water movement, a cumulative sediment effect is clearly a cumulative watershed effect.

Reid (2010) has identified the expectations for cumulative effect analysis that Federal courts have expressed in recent decisions that involved two Federal agencies—National Forest System of the Forest Service (U.S. Department of Agriculture) and the Bureau of Land Management (U.S. Department of the Interior)—after reviewing 62 district and appellant court decisions issued from 2000 to 2005. Some of these expectations are unaffected by which method is chosen to analyze sediment cumulative effects. However, others would be affected by what method is chosen or the content of the documentation for a given method (table 1).

For eastern national forests (Forest Service Southern and Eastern Regions), a technical guide (Tetra Tech 2002) provides the sanctioned strategy for determining if a cumulative watershed effect assessment is needed. The guide provides a step-by-step decision process (after MacDonald 2000) for conducting a cumulative watershed effect analysis and for determining the "level of effort" to be applied for a given situation. Five effort levels are identified depending on the degree of controversy involved, the linkages between activities and resources of concern, and the risk to those resources; with level 1 being the lowest effort and level 5 the highest. The guide does not specify that any particular analysis method be used at a given level; rather the analyst is expected to select the method most appropriate given the resource concerns and level of effort required.

Table 1. Legal expectations for cumulative effect analyses from 65 Federal court decisions, 2000 to 2005 involving the Forest Service (U.S. Department of Agriculture) or the Bureau of Land Management (U.S. Department of the Interior) (Reid 2010); and ways that the analysis method can affect the user's ability to address these expectations

Expectation number	Expectation	Does the analysis method …
1	The area potentially affected by cumulative effects must be identified.	… allow the user to define an analysis area that includes all relevant individual effects, represents the processes and linkages by which a cumulative effect could result, and includes the location of resources or entities that could be affected?
2	The impact of the proposed project must be identified.	… consider both direct and indirect impacts of the new project activities on the resource of concern? Are results for the project clearly distinguished from other results and evaluated over a relevant time period?
3	The expected impacts of other individual actions in the past, present, and foreseeable future must be identified.	… list past, present, and foreseeable future actions (and their related impacts) in sufficient detail that they can be compared to those predicted for the proposed action?
4	The expected cumulative effect from the individual actions must be identified.	… determine the aggregate impact resulting from the combined individual impacts of past, present, and future actions?
5	Current and future impacts should be interpreted relative to naturally occurring conditions.	… define a baseline case upon natural conditions that would be expected to exist if no changes had occurred in the past? Can results from this case be compared to those for the past, present, and future conditions, and the proposed project?
6	Model validity for the present applications must be demonstrated.	… have documented tests of cumulative predictions using conditions similar to those now being analyzed?
7	Model shortcomings must be disclosed.	… have documentation that identifies the scientific reasoning used and any methodological assumptions, data gaps, or other problems that could affect prediction accuracy?
8	Reasoning behind significance interpretations must be stated.	… provide an interpretation of results significance to the resource of concern? If so, is the justification for this interpretation available in the documentation?
9	Effectiveness of mitigation must be evaluated.	… demonstrate how impacts are reduced if mitigation is necessary to lessen impacts to acceptable levels?

Understanding the difference between a "method" for evaluating a cumulative watershed effect and the cumulative watershed effect analysis itself is important. The method is a tool used to predict how a specific watershed feature or process (such as stream temperature or sediment yield) will respond to a proposed activity; whereas the analysis uses these predictions to assess how a resource of concern (such as water quality or a freshwater mussel population) will be affected. The methods are a necessary first step to the analysis, but they do not constitute the cumulative watershed effect analysis itself, and the reader should keep this difference clearly in mind. Our review will focus largely on the methods in use, but we will briefly describe how outputs from these methods have been used in past analyses. The eastwide technical guide (Tetra Tech 2002) is recommended for those wishing a more comprehensive discussion of how the results from the analysis methods should be incorporated into a cumulative watershed effect analysis.

The purpose of this chapter is to describe the methods currently being used to conduct cumulative watershed effect analyses of fuel management projects within the forest lands of the Eastern United States and to evaluate how well they provide the information needed to meet legal expectations. To determine what methods are being used, we contacted soil scientists, hydrologists, and other specialists from all national forests within the Eastern United States who might be involved with such analyses.

We also contacted a limited number of resource specialists within environmental agencies of Eastern States who were recommended to us. While our survey indicates that cumulative watershed effect analysis of fuel-management projects is presently limited to Federal forest lands, the methods we discuss below could be used for any forest lands in the Eastern United States. Currently, the only cumulative watershed effect issue related to fuel management that is being analyzed is sediment; therefore only methods addressing sediment are covered. Moreover, although many techniques are available for managing fuel loads, prescribed fire is the one most commonly used; and is the technique, along with its concomitant fireline construction and use, that occasions cumulative watershed effect analyses most frequently in the Eastern United States. We limit our review to those methods that have been employed since 2000.

The remainder of this chapter is organized as follows. First, we review the methods currently being used to assess possible cumulative sediment effects from fuel management practices. Second, we discuss how well the methods provide the information required to meet the legal expectations identified by Reid (2010). Lastly, we identify several issues that should be considered in developing future models for assessing cumulative sediment effects.

Analysis Methods Used in Eastern United States

Based on our survey of resource specialists, we found that the sediment analyses conducted in eastern national forests have several features in common. The responses from these specialists indicate that sediment is the only cumulative watershed issue related to fuel management that is being addressed in environmental analysis documents. The fuel-management practices of greatest concern are fireline construction and prescribed burning. The reasons why sediment is a primary concern can be found in chapter 12. Within eastern national forests, sediment analyses have most often been done during the forest planning process, and only rarely as part of project assessments. Sediment cumulative watershed effect analysis has not yet been applied to wildfires.

Past cumulative watershed effect applications for fire in eastern national forests seem to fall into just two effort levels—based on the eastwide technical guide (Tetra Tech 2002)—and employ similar methods within each level. Level 2 applications occur most often and result when sediment concerns are low and existing protection or mitigation methods are considered sufficient to address any concerns. Level 4 applications occur when concerns are moderate to high and existing controls may not be sufficient. Level 2 applications use a "narrative analysis" that describes the extent and potential severity of potential sediment effects, reviews the relevant literature on fire effects on sediment production, and states conclusions as to likelihood of a sediment effect and the effectiveness of proposed mitigation measures. For level 4 situations, "hazard rating models" are used to assess sediment effects. Hazard rating models use measured or categorized input variables that are mathematically manipulated (based on some conceptual or empirical model) to compute the combined effect of these variables on a response variable (in this case, sediment). Hazard rating models differ from deterministic models—such as the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing 1995)—in several ways. Perhaps the most important difference is that the rating model output is explicitly recognized as not representing a real amount; rather it is interpreted as an index value that can be used to compare different action scenarios and rate the potential risk of occurrence (high, moderate, or low). Although a number of models, both hazard rating and deterministic, have been developed over the years to assess the cumulative effects associated with fuel management activities (Elliot and others 2010), the only two models currently being used specifically for fuel management effects in the Eastern United States are the Erosion and Sediment Yield (EASY) model and the Aquatic Cumulative Effects (ACE) model. Both of these models produce outputs that are labeled as "sediment," however the documentation for both models states that these values are not to be considered physical quantities, but rather are relative values to be used in comparing alternatives and judging relative risks.

Narrative Analysis

The use of narratives to assess cumulative watershed effects from fuel management practices is common in the forest plans of eastern national forests as well as in project level analyses. These narratives vary widely in detail and content, with sediment being the predominant concern. Conclusions are often based on professional opinion and the implementation of mitigation practices. Because of the wide range in detail and content of this method type, we did not attempt to evaluate narratives or assess how well they addressed the expectations listed in table 1.

Hazard Rating Models

As noted above, the two hazard rating models currently being used in eastern national forests to assess sediment cumulative watershed effects related to fuel management are the EASY[1] and ACE[2] models. Both models predict the amount of erosion and sediment yield that will occur based on conditions within an analysis area. Erosion, also called soil loss, is the detachment and displacement of soil material from the ground surface. Sediment yield is the amount of eroded material that moves across the land surface, reaches a stream channel, and is transported as stream sediment to a given outlet point downstream. Erosion is typically expressed as a volume per unit area per unit time (tons per acre per year) whereas sediment yield is generally expressed as a total volume per unit time (tons per year).

Both the EASY and ACE models are applied using the same general procedure:

1. Delineate the analysis area, which is the total land area addressed by the analysis, including the area that will be directly affected by the activity prompting the analysis effort, plus all upstream and downstream areas that may contribute to or be affected by the possible effect being considered. Because both the EASY and ACE models predict sediment yield for entire drainage basins, the analysis area boundary is typically delineated using the one or more basins that encompass all of these land areas. Separate analyses can be done when multiple basins are used.
2. Identify all condition types within the area for the past, present, or future (proposed) scenario being analyzed. The condition type is a classification of the land-use activity or site conditions occurring or proposed over a contiguous land area. Examples include undisturbed forest land, forest area with a specific silvicultural practice applied (such as a clearcutting or shelterwood), road area, cropland, orchard, pastureland, urban land, or abandoned land. The classifications used vary somewhat between the models, but both models require an inventory of the existing condition types within the analysis area. Increasingly, this is accomplished using relevant Forest Service geographic information system (GIS) datasets for Forest Service lands and spatial data sets like National Land Cover Data (U.S. Department of the Interior U.S. Geological Survey 1992) and Topologically Integrated Geographic Encoding and Referencing (U.S. Census Bureau 2006) datasets for other lands.
3. Compute the total erosion from all condition types.
4. Compute the total sediment yield at the outlet of the area.
5. Repeat steps 2 through 4 for all project alternatives.
6. Interpret the sediment hazard associated with all project alternatives.

Details on how the analysis area is delineated, condition types are identified, erosion and sediment yield are computed, and results are interpreted for both the EASY and

[1] Hansen, William F.; Henderson, Jerry; Law, Dennis. 1994. Erosion and sedimentation yield background information using the Sumter National Forest Plan process records. 25 p. plus unpaged materials Unpublished paper. U.S. Department of Agriculture Forest Service, Francis Marion and Sumter National Forests, Columbia, SC.

[2] Clingenpeel, J. Alan; Crump, Michael A. 2005. A manual for the aquatic cumulative effects model. 42 p. Unpublished paper. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.

ACE models are given in the following sections. Differences between the two models are also noted.

The EASY Model

The EASY model has been used on the Francis Marion and Sumter National Forests since the late 1980s to evaluate potential sediment impacts from existing or proposed conditions. A Microsoft Excel® spreadsheet program[3] is used to compute the model outputs from input data. To apply the EASY model to any area other than the Francis Marion and Sumter National Forests, the spatial data for all relevant condition types would have to be compiled for the new area.

Analysis area delineation

Analysis areas are determined by the user; the EASY model places no restrictions on how large or small the area may be. Past applications have used areas up to 50,000 acres. Analysis areas generally correspond to watershed boundaries, but not always. On coastal areas, the terrain is very flat and watershed boundaries are difficult to discern with confidence, thus analysis areas there have not always been constrained to match watersheds. Past decisions have been based on what was deemed appropriate for the potentially affected terrain and the project being analyzed.

Condition type determinations

For Forest Service lands, land areas for each existing or proposed condition type are obtained from Forest Service GIS datasets or relevant planning documents. Past applications have estimated the length of new or existing firelines from sample data when GIS data were not available. For other forest lands, existing conditions are determined by manual measurements from GAP imagery (South Carolina Cooperative Fish and Wildlife Research Unit 1993) or aerial photographs. The EASY model distinguishes several different condition types related to fire. Burned areas are classified as a site-preparation burn, dormant-season burn, or growing-season burn—with the latter two used for either fuel reduction or wildlife improvement. Firelines are classified as either hand or bulldozer constructed. Wildfire burns are not included, but could be classified using the existing types that best match the wildfire severity and suppression activities.

Erosion and sediment yield computations

For each condition type, the soil loss is computed using

$$SL_i = area_i \times A_i \times t_{r_i} \qquad (1)$$

where

SL_i = soil loss (tons) from the ith condition type for the recovery period

$area_i$ = total area (acres) of the ith condition type in the analysis area

A_i = erosion rate (tons per acre per year) for the ith condition type with the given soil region

t_{r_i} = recovery period (years) for the ith condition type.

The EASY erosion rates are calculated for each condition type using equation (2):

$$A_i = R_{ave} SL_{ave} K_{ave} \left(\frac{C_{low} + C_{ave}}{2} \right) \qquad (2)$$

[3] Hansen, W.F. [Undated]. [Untitled]. Spreadsheet. Available from the Francis Marion and Sumter National Forests, 4931 Broad River Road Columbia, SC 29212.

where for the *i*th condition type

R_{ave} = average rainfall factor

SL_{ave} = average slope length factor

K_{ave} = average erosivity factor

C_{low} = low cover type factor

C_{ave} = average cover type factor[4]

Equation (2) is a variation of the Universal Soil Loss Equation (USLE) model (Wischmeier and Smith 1978) and primarily uses factor values developed by Dissmeyer and Stump (1978) for large soil regions throughout the South. Dissmeyer and Stump (1978) determined low, high, and average factor values for a variety of condition types (including burned forest land) in each soil region. The low, high, and average values are interpreted by Dissmeyer and Stump (1978) as those that would result from "minimum," "heavy," and "average" impacts, respectively, to a given land area. The values given in Dissmeyer and Stump (1978) are mean annual values for the entire recovery period for each condition type. The recovery period was the time (in years) it took for the values to return to pre-disturbance levels. Recovery rates vary from 1 to 2 years for most vegetation removal practices, to the entire analysis period for roads. Dissmeyer and Stump (1978) provide computational procedures and a map showing the soil regions and tables listing the low, average, and high factor values and their related erosion rates.

Although values for most of these factors are taken from Dissmeyer and Stump (1978), some were estimated based on available research and consultation with relevant specialists (see footnote 1). Users can readily change the erosion rates provided by the EASY model if they have more specific data for their analysis area.

In applying the EASY model, it is assumed that all cover type values fall somewhere between the low (C_{low}) and average (C_{ave}) values given by Dissmeyer and Stump (1978); therefore the model uses the simple average of these two values in computing a representative erosion rate for each condition type [equation (2)]. This assumption is based on the reasoning that current practices are not as disruptive to the groundcover as those measured by Dissmeyer and Stump (1978); thus the typical response should fall within the lower part of the range (see footnote 4).

Soil losses from forests not managed by the Forest Service are included in the analysis, but are assumed to be constant over the analysis period and the same for all planning alternatives.

The total sediment yield is the product of the total predicted erosion and the sediment delivery ratio (DR) for the analysis area [equation (3)].

$$Yield = DR \times \sum_i SL_i \qquad (3)$$

Sediment delivery is the integrated result of the various processes between onsite erosion and downstream sediment yield, whereas the sediment delivery ratio is the ratio of total yield at the basin outlet to total erosion within the basin (Walling 1983). Sediment delivery ratio values have been determined two different ways in the past, depending on the spatial scale of the model application. For coarse spatial scales, a single delivery ratio value has been determined for each of the three landforms that make up the Francis Marion and Sumter National Forests: Appalachian Mountains, 0.38; Piedmont, 0.34; and Coastal Plain, 0.1.

The sediment delivery ratio values for the Appalachian Mountains and Piedmont were determined by Goddard (see footnote 1), while the value for the Coastal Plain is assumed to be 10 percent. This assumption is based on the estimated delivery ratio for third- and fourth-order basins in the Appalachian Mountains and Piedmont that is reduced by 30 percent for the lower drainage density in the lower Coastal Plain (U.S. Department of the Interior Forest Service 2006). For finer spatial scales (such

[4] Personal communication 2007. William Hansen, Hydrologist, Francis Marion and Sumter National Forests, 4931 Broad River Road Columbia, SC 29212.

as individual projects or timber sales), individual delivery ratio values are determined from Roehl's (1962) model using basin area.

Results interpretation

The EASY analysis produces estimates of total soil loss and sediment yield for each condition type and total sediment yield for each analysis area and planning alternative (fig. 1). The spreadsheet can be modified by the user in any way desired to show how sediment yields vary between alternatives, condition type, land ownership, time period, or other categories of interest. The model does not include explicit direction on how to interpret the sediment yields; it is expected that the results will be presented and interpreted in whatever form is most appropriate for the problem at hand. Past applications on the Francis Marion and Sumter National Forests have presented EASY model results in a number of ways. One common approach has been to compute sediment yields for similar analysis units and to then judge the potential impacts between alternatives by the relative differences in their predicted sediment totals. A second method has been to compare the magnitude of sediment concentrations between alternatives. Sediment concentration is computed for the analysis area over the entire recovery period using an assumed mean water yield (based on local data) and the predicted sediment yield value for each alternative. A third method has been to determine the sediment yield value for the analysis area that is judged to be the worst case, and assume that impacts in other areas will be less than the worst-case value.

One concern with the EASY model is the way sediment delivery ratio values are often applied. Sediment yields are generally computed for each condition type within an analysis area (fig. 1). While this produces mathematically accurate results, it is nonetheless conceptually incorrect. Sediment delivery ratio values provided by Roehl (1962) and others are based both on the *total* erosion produced within the entire catchment [$\sum_i SL_i$ in equation (3)] and the *total* drainage area for the catchment. Applying delivery ratio values to the erosion produced from an area that covers only a portion of a drainage basin implies accuracy that is unsupported by Roehl (1962). This problem in no way invalidates the past analyses using the EASY model since

$$DR \times \sum_i^n SL_i = DR[SL_1] + \cdots + DR[SL_n] \tag{4}$$

However, we recommend that sediment yields only be listed for entire watersheds in future applications.

The ACE Model

The ACE model for the Ouachita and Ozark-St. Francis National Forests[5] is the most current version of a cumulative watershed effect model that has evolved since 1990. Previous versions[6 7 8] differ in certain components of the model, but the overall methodology has remained fairly constant. The model runs through a Microsoft Excel® workbook file. Spatial data for current conditions (the compilation date varies by area) have been compiled for all fifth-level hydrologic units on the National

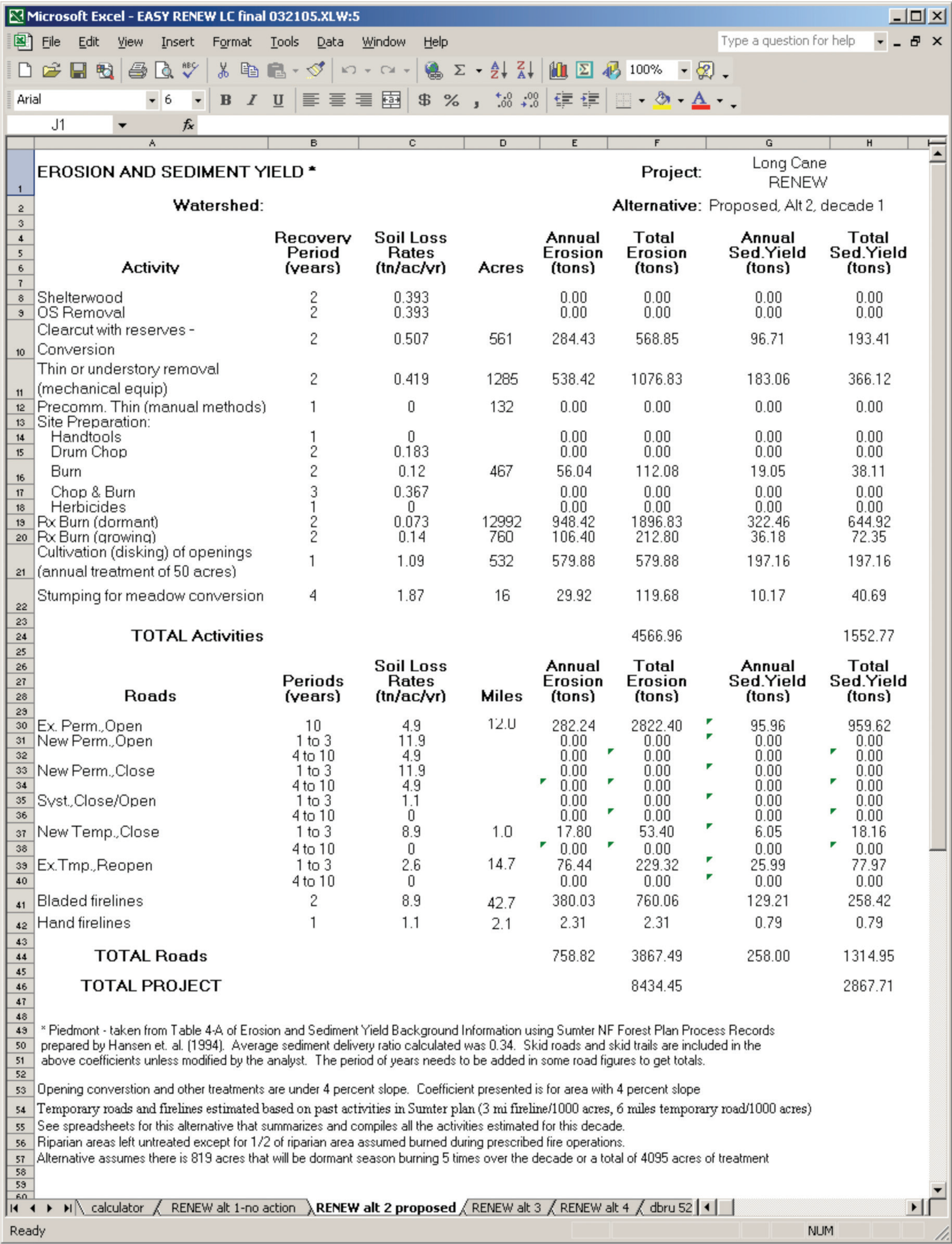
---

[5] Clingenpeel, J.A. [Undated]. [Untitled]. CD-ROM of model and spatial data for the Ouachita and Ozark-St. Francis National Forests. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.

[6] Clingenpeel, J.A. 2003. Sediment yields and cumulative effects for water quality and associated beneficial uses (process paper for forest plan revisions). 39 p. Unpublished paper. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.

[7] Clingenpeel, J.A.; Mersmann, T. 1999. Cumulative effects analysis for water quality and associated beneficial uses-national forests in Mississippi. Unpublished paper. 20 p. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.

[8] U.S. Department of Agriculture Forest Service. 1990. Cumulative impacts analysis-water quality and associated beneficial uses, Ouachita National Forest, Arkansas–Oklahoma. 13 p. Unpublished paper. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.



EROSION AND SEDIMENT YIELD *

Project: Long Cane RENEW

Watershed:

Alternative: Proposed, Alt 2, decade 1

Activity	Recovery Period (years)	Soil Loss Rates (tn/ac/yr)	Acres	Annual Erosion (tons)	Total Erosion (tons)	Annual Sed.Yield (tons)	Total Sed.Yield (tons)
Shelterwood	2	0.393		0.00	0.00	0.00	0.00
OS Removal	2	0.393		0.00	0.00	0.00	0.00
Clearcut with reserves - Conversion	2	0.507	561	284.43	568.85	96.71	193.41
Thin or understory removal (mechanical equip)	2	0.419	1285	538.42	1076.83	183.06	366.12
Precomm. Thin (manual methods)	1	0	132	0.00	0.00	0.00	0.00
Site Preparation:							
Handtools	1	0		0.00	0.00	0.00	0.00
Drum Chop	2	0.183		0.00	0.00	0.00	0.00
Burn	2	0.12	467	56.04	112.08	19.05	38.11
Chop & Burn	3	0.367		0.00	0.00	0.00	0.00
Herbicides	1	0		0.00	0.00	0.00	0.00
Rx Burn (dormant)	2	0.073	12992	948.42	1896.83	322.46	644.92
Rx Burn (growing)	2	0.14	760	106.40	212.80	36.18	72.35
Cultivation (disking) of openings (annual treatment of 50 acres)	1	1.09	532	579.88	579.88	197.16	197.16
Stumping for meadow conversion	4	1.87	16	29.92	119.68	10.17	40.69
TOTAL Activities					4566.96		1552.77

Roads	Periods (years)	Soil Loss Rates (tn/ac/yr)	Miles	Annual Erosion (tons)	Total Erosion (tons)	Annual Sed.Yield (tons)	Total Sed.Yield (tons)
Ex. Perm.,Open	10	4.9	12.0	282.24	2822.40	95.96	959.62
New Perm.,Open	1 to 3	11.9		0.00	0.00	0.00	0.00
	4 to 10	4.9		0.00	0.00	0.00	0.00
New Perm.,Close	1 to 3	11.9		0.00	0.00	0.00	0.00
	4 to 10	4.9		0.00	0.00	0.00	0.00
Syst.,Close/Open	1 to 3	1.1		0.00	0.00	0.00	0.00
	4 to 10	0		0.00	0.00	0.00	0.00
New Temp.,Close	1 to 3	8.9	1.0	17.80	53.40	6.05	18.16
	4 to 10	0		0.00	0.00	0.00	0.00
Ex.Tmp.,Reopen	1 to 3	2.6	14.7	76.44	229.32	25.99	77.97
	4 to 10	0		0.00	0.00	0.00	0.00
Bladed firelines	2	8.9	42.7	380.03	760.06	129.21	258.42
Hand firelines	1	1.1	2.1	2.31	2.31	0.79	0.79
TOTAL Roads				758.82	3867.49	258.00	1314.95
TOTAL PROJECT					8434.45		2867.71

* Piedmont - taken from Table 4-A of Erosion and Sediment Yield Background Information using Sumter NF Forest Plan Process Records prepared by Hansen et. al. (1994). Average sediment delivery ratio calculated was 0.34. Skid roads and skid trails are included in the above coefficients unless modified by the analyst. The period of years needs to be added in some road figures to get totals.

Opening converstion and other treatments are under 4 percent slope. Coefficient presented is for area with 4 percent slope

Temporary roads and firelines estimated based on past activities in Sumter plan (3 mi fireline/1000 acres, 6 miles temporary road/1000 acres)

See spreadsheets for this alternative that summarizes and compiles all the activities estimated for this decade.

Riparian areas left untreated except for 1/2 of riparian area assumed burned during prescribed fire operations.

Alternative assumes there is 819 acres that will be dormant season burning 5 times over the decade or a total of 4095 acres of treatment

Figure 1. Example of EASY model output showing the cumulative watershed effect analysis of sediment for one proposed fuels management alternative. (Source: Hansen, William F.; Henderson, Jerry; Law, Dennis. 1994. Erosion and sedimentation yield background information using the Sumter National Forest Plan process records. 25 p. plus unpaged materials Unpublished paper. U.S. Department of Agriculture Forest Service, Francis Marion and Sumter National Forests, Columbia, SC.)

Forests in Alabama, Chattahoochee-Oconee National Forest, Cherokee National Forest, Daniel Boone National Forest, Sumter National Forest, National Forests in Mississippi, Ouachita and Ozark-St. Francis National Forests, and Jefferson National Forest; and for all sixth-level hydrologic units on the Ouachita and Ozark-St. Francis National Forests.

Analysis area delineation

The ACE model is designed to be applied at the fifth-level hydrologic unit (approximately 39 to 386 square miles) for forest planning efforts and sixth-level hydrologic unit (approximately 4 to 39 square miles) for project level analysis (see footnotes 1 and 9). Unlike the EASY model, where users can bound the analysis area however they choose, the ACE model computes sediment yields for these two scales only. At the project level the user simply selects the sixth-level hydrologic unit or units that contain the project areas and the model analyzes the entire area within each selected unit.

Condition type determinations

The data sources used to compile condition types for the ACE model are described in Clingenpeel and Crump (see footnote 1). Forest Service GIS data were used to determine condition type, road, land ownership, and ecoregion type for Forest Service lands within each fifth- or sixth-level hydrologic unit. Topologically Integrated Geographic Encoding and Referencing data from 1995 (U.S. Census Bureau 2006) were used to determine road types and lengths on forests not managed by the Forest Service. Condition types outside Forest Service lands were classified using 1992 data from the National Land Cover Data (U.S. Department of the Interior U.S. Geological Survey 1992). The slope class that each condition type fell within was determined by deriving slope class polygons using ArcView®'s GIS Spatial Analysis 2.0a extension (ESRI 2001) and 100-foot digital elevation models. Ecoregion, condition type, slope class, and ownership layers were then overlaid and rasterized on a 100-foot grid using ESRI's ArcView® 3.2 so that each grid cell was assigned a single value based on the combined layers present in the cell. Total areas for each combination type were then computed using the grid cells for each fifth- or sixth-level hydrologic unit. A similar overlay analysis was done to determine total length of road types by ecoregion and ownership by hydrologic unit.

The ACE model uses four condition types related to fire: fuel reduction and site preparation burns (for areas), fireline constructed, and fireline reconstructed. No distinction is made for type of fire (prescribed versus wildfire), preburn vegetation cover, or vegetation growing period.

Erosion and sediment yield computations

The ACE model uses an overall computational process that is similar to the EASY model [equation (1)]; however there are several important differences in how erosion rates are determined and applied. Whereas the EASY model uses the factor values, the ACE model uses the actual erosion rates for each condition type provided by Dissmeyer and Stump (1978). More precisely, the ACE model uses the "average" rate determined by Dissmeyer and Stump (1978) for slopes less ≤35 percent, and the "high" rate for slopes >35 percent. Although this probably overestimates erosion associated with Forest Service activities, the higher erosion rates compensate for steeper slopes and management practices on other lands "that may not have the same standards as Forest Service lands"—where erosion rates are presumed to be higher (see footnote 9). The basis for erosion rates from burned areas is a second difference: Where measured rates are lacking (such as the Ouachita Mountains), the ACE model assumes burned areas erode at twice the rate of comparable undisturbed forest areas.[9] The length of the recovery period and how erosion rates vary during this period is still a third difference. For

[9] Personal communication. Various dates. J. Alan Clingenpeel, Hydrologist, U.S. Department of Agriculture Forest Service, Ouachita National Forest, P.O. Box 1270, Hot Springs, AR 71902.

forested areas, the ACE model assumes that all burned areas recover fully after 1 year and all harvested areas recover after 3 years. The decrease in erosion rates during the second and third years after harvest is based upon past research and field observations within the Ouachita National Forest (see footnote 1).

Soil loss from sample agricultural (such as pasture land or cultivated cropland) and urban condition types (SL_{nf}) was determined using the WEPP model (Flanagan and Nearing 1995). Representative soil characteristics from the WEPP database were applied to morphologic data (ecoregion, area, and slope) for each area of agricultural and urban condition type with a given hydrologic unit to compute the soil loss from each area (see footnote 1).

Total sediment yield from non-road areas (SY_{nr}) within a hydrologic unit is computed by summing the soil loss values computed for all forest and nonforest condition types, and multiplying this value by the sediment delivery ratio given by Roehl (1962) for the basin area [equation (5)].

$$SY_{nr} = DR \times (SL_f + SL_{nf}) \quad (5)$$

Still another important difference with the ACE model is how sediment from road areas was determined. The WEPP model (Elliot 2004) was used to compute representative sediment yield values (tons per mile) for roads, firelines, and all-terrain vehicle trails within each ecoregion based on sample data from each (see footnote 1). Separate yields were computed for each combination of usage type (road, all-terrain vehicle trail, or fireline), surface type, and maintenance level that occurs. Note that these are sediment yields, not soil loss values. The WEPP model includes a channel routing algorithm for estimating how much eroded sediment is delivered to and moves through the channel to the mouth. Total sediment yield from roads (SY_r) for an analysis area is determined by multiplying the appropriate unit yield value (SL_{r_i}) times the length of road by surface type and maintenance level (l_i), and summing these for all road types/maintenance levels within the hydrologic unit [equation (6)]

$$SY_r = \sum_i l_i \times SL_{r_i} \quad (6)$$

where

i = the given road type and maintenance level.

A more detailed explanation of how road sediment yields were modeled is given in Clingenpeel (see footnote 9).

Total sediment yield from the analysis area is the sum of road and non-road sediment yields [equation (7)].

$$SY = SY_{nr} + SY_r \quad (7)$$

The ACE model is designed to require a minimum of user input. Areas for all condition types and existing roads are already determined for each sixth-level hydrologic unit. Erosion rates for all condition types have also been computed and compiled for each hydrologic unit. The user is only required to input any road types not previously captured, the various areas and condition types associated with the project alternatives being analyzed, and an assumed rotation age for private forest lands. Once these data are entered, the ACE model computes sediment yields for past, present, and proposed future conditions within each hydrologic unit. To compute the past condition sediment yield, the model assumes undisturbed forest cover over the entire basin. Present sediment yield is based on conditions existing as of when the spatial data were compiled (1992 for the Ouachita and Ozark-St. Francis National Forests), plus any updates for roads. The condition types for nonforest lands are assumed to remain constant between the compilation date and the analysis date; whereas forest land condition types have their erosion rates adjusted based on recovery or new harvest disturbances during this intervening period. The future sediment yield is based on conditions proposed in each alternative plus assumptions about harvesting on private forest lands. The ACE model also provides a routine that takes into account erosion mitigation efforts on roads that reduce soil losses (for example, through road obliteration or closure).

Unlike the EASY model, the ACE model only computes the total sediment yield of the past, present, and future scenarios for the first year of implementation of the proposed project. For condition types with erosion rates that decrease over time (or "recover"), the model uses the rates appropriate for the implementation year. For the future scenario, all proposed activities are assumed to occur during the first year of implementation. For example, a proposed project with new road construction, harvesting, and burning is modeled in ACE as if all of these activities occur in the first year. While recognized as inaccurate for most situations, this assumption eliminates the need to know the year in which each activity will occur and provides something of a "worst case scenario" by forcing all effects into a single year (see footnote 1).

Results interpretation

The ACE model presents its results in a standard format which the user cannot modify. An example of the summary page, which displays the model results, is given in figure 2. The summary displays the total areas for each condition type under Forest Service or other management, road lengths and densities, and the total sediment yield from road and non-road areas under the past, present, and future scenarios. Lastly, the model displays ratings of relative risk to aquatic biota from sediment for each alternative.

The risk ratings show the significance of sediment effects relative to the beneficial use—providing aquatic habitat—common to all streams draining Forest Service lands. These risk ratings (also called watershed condition ranks) are based on the percent increase in sediment yield over what is predicted for the past (undisturbed forest) condition (fig. 2). Percent increases are listed for the current combination of condition types, and the combinations associated with each proposed alternative. In addition, the risk ratings for the current condition and all alternatives are also listed. These ratings were determined for each Arkansas ecoregion from bivariate analysis of various fish community metrics and predicted sediment increases using the ACE model. Based on the rationale of Terrell and others (1996), this analysis identifies when sediment increase—despite the influence of other habitat factors—becomes a limiting factor for fish population numbers. This analysis was used to establish criteria for rating the condition of fish communities given current sediment levels, and the hazard posed by potential sediment increases from proposed projects. A similar analysis was used to develop risk ratings for four ecoregions outside Arkansas: the Coastal Plain, the Central Appalachian/Western Allegheny, the Piedmont, the Blue Ridge, and the Ridge and Valley (see footnote 9).

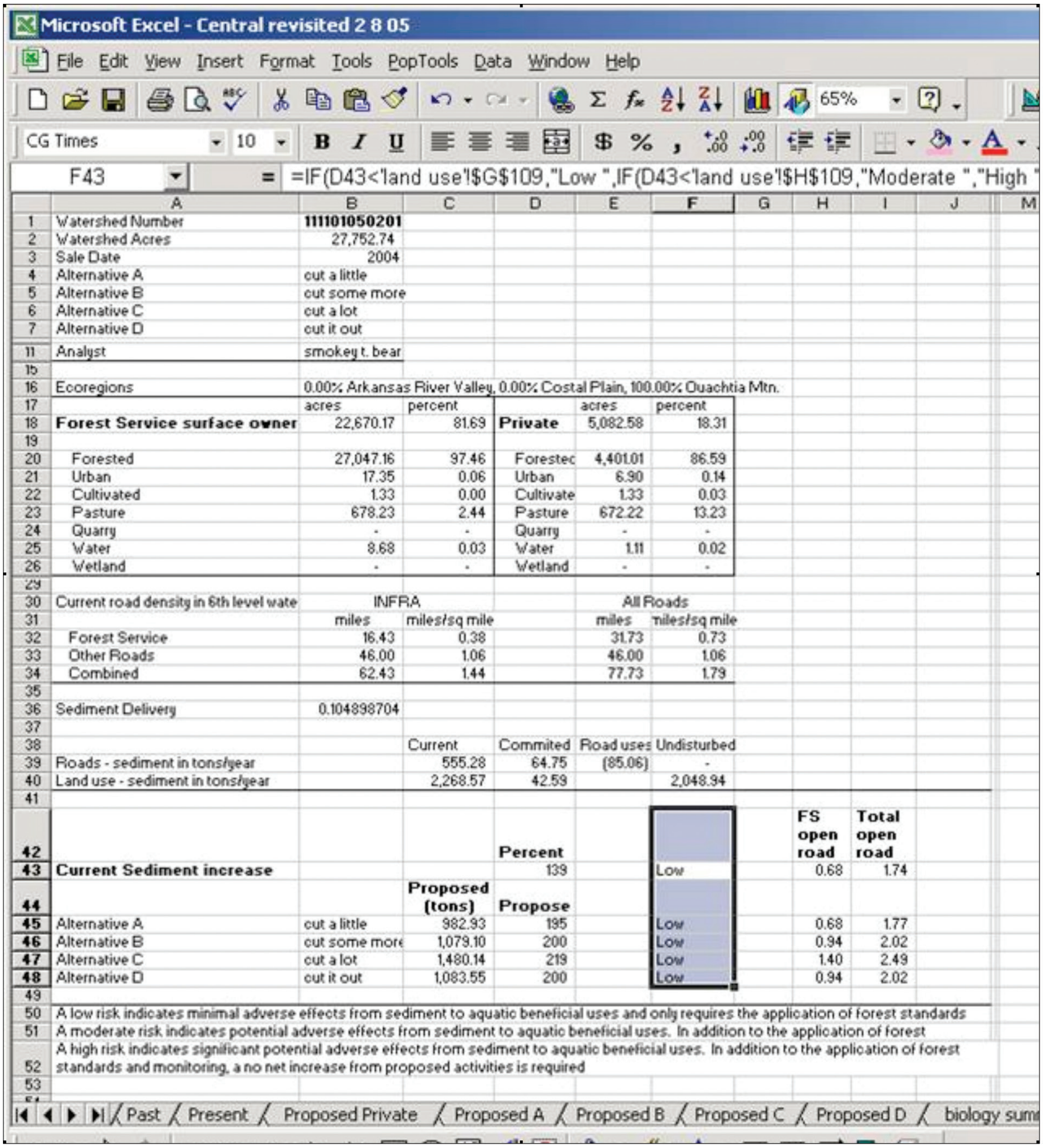
Discussion of Current Methods

Both the EASY and ACE models are based on specific analytical procedures, compute a variety of outputs, and provide supporting documentation. Following is a comparison of how well these procedures, outputs, and documentation provide the information needed to meet the legal expectations for cumulative watershed effect analysis as identified by Reid (2010) and as summarized in table 1.

Model Features

Analysis area identification

The EASY and ACE models are very different in how the analysis area is identified. The EASY model imposes no constraints on the user; the analysis area can be whatever size the user deems appropriate. One advantage of this approach is that the user can model at a series of catchment sizes to better determine the scale at which the cumulative effect becomes insignificant. A disadvantage is that the user would also have to compile the spatial data at each analysis scale, as the model itself does not provide these



	A	B	C	D	E	F	G	H	I
1	Watershed Number	111101050201							
2	Watershed Acres	27,752.74							
3	Sale Date	2004							
4	Alternative A	cut a little							
5	Alternative B	cut some more							
6	Alternative C	cut a lot							
7	Alternative D	cut it out							
11	Analyst	smokey t. bear							
15									
16	Ecoregions	0.00% Arkansas River Valley, 0.00% Costal Plain, 100.00% Ouachita Mtn.							
17		acres	percent		acres	percent			
18	**Forest Service surface owner**	22,670.17	81.69	**Private**	5,082.58	18.31			
19									
20	Forested	27,047.16	97.46	Forestec	4,401.01	86.59			
21	Urban	17.35	0.06	Urban	6.90	0.14			
22	Cultivated	1.33	0.00	Cultivate	1.33	0.03			
23	Pasture	678.23	2.44	Pasture	672.22	13.23			
24	Quarry	-	-	Quarry	-	-			
25	Water	8.68	0.03	Water	1.11	0.02			
26	Wetland	-	-	Wetland	-	-			
29									
30	Current road density in 6th level wate	INFRA			All Roads				
31		miles	miles/sq mile		miles	niles/sq mile			
32	Forest Service	16.43	0.38		31.73	0.73			
33	Other Roads	46.00	1.06		46.00	1.06			
34	Combined	62.43	1.44		77.73	1.79			
35									
36	Sediment Delivery	0.104898704							
37									
38			Current	Commited	Road uses	Undisturbed			
39	Roads - sediment in tons/year		555.28	64.75	(85.06)	-			
40	Land use - sediment in tons/year		2,268.57	42.59		2,048.94			
41									
42				**Percent**				**FS open road**	**Total open road**
43	**Current Sediment increase**			139		Low		0.68	1.74
44			**Proposed (tons)**	**Propose**					
45	Alternative A	cut a little	982.93	195		Low		0.68	1.77
46	Alternative B	cut some more	1,079.10	200		Low		0.94	2.02
47	Alternative C	cut a lot	1,480.14	219		Low		1.40	2.49
48	Alternative D	cut it out	1,083.55	200		Low		0.94	2.02
49									
50	A low risk indicates minimal adverse effects from sediment to aquatic beneficial uses and only requires the application of forest standards								
51	A moderate risk indicates potential adverse effects from sediment to aquatic beneficial uses. In addition to the application of forest								
52	A high risk indicates significant potential adverse effects from sediment to aquatic beneficial uses. In addition to the application of forest standards and monitoring, a no net increase from proposed activities is required								
53									

Figure 2. Example of ACE model output showing the summary sheet for the sediment cumulative watershed effect analysis for an entire fuels management project. (Source: Clingenpeel, J. Alan; Crump, Michael A. 2005. A manual for the aquatic cumulative effects model. 42 p. Unpublished paper. U.S. Department of Agriculture Forest Service, Ouachita National Forest, Hot Springs, AR.)

data. Although this approach does provide maximum flexibility, it also provides no guidance as to what spatial scale may be too small or too large for accurate results. The ACE model limits the analysis area to either fifth- or sixth-level hydrologic units; scales that were thought to be appropriate for forest planning (see footnote 9) and project planning (see footnote 1), respectively. The user has no ability to vary from these two options; however, most of the spatial data have already been compiled and the user only has to compile data for updates to the current condition types and the proposed actions. Thus, the EASY and ACE models provide different advantages and disadvantages with respect to analysis flexibility and data compilation requirements.

Identification of impacts from proposed action

Both models identify the sediment impact from proposed actions, and present these results in similar ways. The ACE model uses a separate sheet within the Excel® workbook for each alternative to list the areas associated with each proposed action (such as seed-tree harvest, fuel reduction burn, or fireline construction) and predicted soil losses associated with each action. The EASY model produces the same results, but the format depends on how the user chooses to present the data. The main difference between the two models is that the ACE model only computes sediment for the first year and assumes all actions are implemented during that year; whereas the EASY model computes sediment over multiple years after project implementation. The length of time modeled with EASY typically depends on the longest recovery period associated with the condition types involved.

Identification of past, present, and future impacts

Both models have the ability to predict sediment impacts from past, present, and future actions, however, only the ACE model currently does so explicitly. The ACE model computes sediment yields for past, present, and proposed future scenarios, and displays the results on separate sheets within the workbook. The EASY model typically uses the present scenario as a no-action alternative, and it displays this alternative along with all proposed future scenarios in separate tables or sheets. The EASY model does not compute sediment values for an assumed past situation that would represent natural sediment production. However, it would be a relatively simple matter to revise the model to do this based, for example, on the assumption of uniform natural forest cover. Both models also provide ways for predicting sediment from areas burned during past wildfires, site preparation, or fuel reduction burns; although they differ in the erosion rates used and recovery period lengths.

Identifying effects

The two models identify sediment cumulative watershed effects in very similar ways. They both list the relevant condition types either occurring within or proposed for the analysis area, compute the total erosion associated with each type, and the total sediment yield for present and proposed future scenarios. Both models include the ability to model expected changes in sediment yield from assumed actions on private lands in assessing future scenarios.

Interpretation of impacts relative to naturally occurring conditions

The ACE model provides an explicit comparison of cumulative sediment effects under natural conditions, whereas the EASY model does not. The ACE model estimates natural (past) sediment yield by assuming a uniform forest cover, computes the percent increase in sediment yield for the present and each proposed future scenario, and lists the relative risk ratings based on these predicted increases. The EASY model does not provide an estimate of natural sediment yields. Past applications of the EASY model have compared future to present—not past—sediment yields, and based risk interpretations on this comparison. As noted earlier, it would not be difficult to revise the EASY model to produce predictions for an assumed natural scenario and thus satisfy this expectation.

Demonstration of Model Validity

No direct validation of the EASY model output has been done. This could be accomplished by comparing measured sediment yields before and after some activity like prescribed burning in a basin, and determining how well the change compares with that predicted by the model. Another approach would be a treatment/control design wherein two basins are used that are similar in every way except that one experiences the activity (such as burning), and their sediment yield differences are compared to model predictions.

A less direct approach to model validation would be to validate the model components (soil loss and sediment yield). To our knowledge, no direct validation of the erosion rates given in Dissmeyer and Stump (1978) has been done, nor have the sediment delivery ratios of Roehl (1962) been validated. A later modification of the USLE by Dissmeyer and Foster (1984) was validated against observed sediment yield data from four plots (0.22 to 0.32 acre) and 35 small basins (0.5 to 2.5 acres) located in the Coastal Plain and Piedmont regions of the South (Dissmeyer and Foster 1984). This later model was similar to that used by Dissmeyer and Stump (1978)—the difference being in how the combined C and P factors in the two models were determined—and produced sediment yields very close to those observed ($R^2 = 0.90$). However, the EASY model is typically applied over much larger areas than those used in validating the Dissmeyer and Foster (1984) model.

Like the EASY model, the ACE model output has not been directly validated, nor has the soil loss component based on Dissmeyer and Stump (1978), or the sediment delivery component based on Roehl's (1962) sediment delivery ratios. Soil loss predictions based on WEPP have been validated for several types of forest (Elliot 2001, Elliot and Foltz 2001), nonforest (Laflen and others 2004, Soto and Díaz-Fierros 1998), and road (Grace 2005, 2007; Elliot and Tysdal 1999) conditions, but not for areas within the Ouachita and Ozark-St. Francis National Forests. Although the risk ratings have not been independently tested, they are based on actual fish collections from 178 different locations within the Arkansas ecoregions that encompass the Ouachita and Ozark-St. Francis National Forests (see footnote 1). The size of this sample and the fact that these data were collected within the same ecoregions as those undergoing assessment lends support to the assumption that the functional relationship proposed between the relative abundance of fish assemblages and predicted sediment yields is real.

Disclosure of model shortcomings

The available documentation for both models lacks a thorough discussion of the shortcomings of the data sources, computation processes, and assumptions used to evaluate sediment CWEs. The current documentation of both models focuses on providing sufficient information to users so that they can understand how the model works and how to use it. Users are left to determine for themselves how well the reasoning behind the model stands up to current scientific knowledge, how complete are the data sources, and what counterarguments could be made to challenge the validity of each model.

Reasoning behind significance interpretations

The two models take very different approaches to how significance is interpreted and justified. The ACE model provides an explicit procedure for interpreting model results by relating predicted sediment yields to relative abundance of fish assemblages. The method by which the relationship between predicted sediment yield and relative abundance, and how the risk levels are determined is explained in the model documentation (see footnotes 1 and 9). In contrast, the EASY model does not provide explicit interpretation of model outputs; rather it is expected that the user will decide how best to interpret the results based on each project's circumstances. Past applications of the EASY model have interpreted model results by comparing the percentage increases in sediment yield and by evaluating relative differences in sediment concentration, but these comparisons are not part of the standard model output. Although users bear the responsibility of justifying how they interpret the EASY model results, they have the flexibility to tailor the interpretation process to best meet the needs of each analysis.

Mitigation Effectiveness

This expectation could be addressed outside of whatever method is used to assess sediment cumulative watershed effects; however, a model could provide a very straightforward way of demonstrating mitigation effectiveness. Of course, the same expectation for demonstrated validity would apply to modeling mitigation as applies to all other aspects of a cumulative effects model (table 1, expectations 6 and 9). The ACE model currently incorporates a limited capacity to calculate the effects of mitigation on erosion from proposed alternatives. The lengths of new or existing roads and off-highway vehicle or equestrian trails that are proposed to be closed, obliterated, or have only controlled use can be entered as part of an alternative; and the model will reduce soil losses computed for these areas based on the lower erosion rates. The EASY model also provides for reducing soil losses from temporary roads by specifying them to be closed after the activities requiring them are completed. Past EASY applications have also included additional condition types to assess the effects of closing trails, reconstructing roads to higher standards, and improving road surfacing (see footnote 4); although these refinements are not included in the model documentation.

Future Modeling Issues

As our knowledge grows and our technology improves, there will be an ongoing need to periodically revisit and improve whatever models are used to assess sediment cumulative watershed effects. This need seems self evident and requires no further comment. What we think is worthy of comment are several issues related to sediment modeling because they significantly influence how future models will work and who will use them. These are often the issues that are set aside or overlooked in the urgency to develop and implement tools that are needed immediately. We may have overlooked other issues concerning assessment of cumulative watershed effects, but what we think is more important is that these issues be considered up front in future modeling efforts.

Appropriate Spatial and Temporal Scales

In setting out guidance for how to accomplish a cumulative watershed effect analysis, the Council on Environmental Quality (1997) notes that choosing the appropriate geographic scale is critical. The choice of an appropriate temporal scale is, no doubt, of equal importance. The chosen scales should set the boundaries for the space and time within which a cumulative watershed effect will occur. A number of factors require consideration when choosing the spatiotemporal scales. These include the spatial magnitude and location of past, present, and future disturbances; how long it takes for ecosystems to recover from disturbances; how individual impacts might accumulate, feedback upon, or negate each other; the location and extent of the resource prompting the analysis; and the processes translating impacts through time and space (Tetra Tech 2002). Given the number and complexity of factors, the choice of the appropriate spatiotemporal scale for analysis will likely be unique for each situation (Bunte and MacDonald 1999). Furthermore, the situation, not the model, should determine the choice. Unfortunately, this is often not the case. Practical considerations have led to a single scale or two being selected and used for all situations. A major consideration behind the single-scale decision is the difficulty in compiling the spatial data for all condition types. Despite the widespread availability of GIS software, we still seem to lack the ability to readily generate the needed spatial data at any chosen spatial scale and output these data into existing sediment models. Another consideration that affects the time scale selected is the increased model complexity required to deal with activities scheduled over multiple years. No doubt these are significant challenges; however, they must be addressed if our models are to allow the selection of appropriate temporal and spatial scales based on the situation.

Effects of Natural Disturbances

The inclusion of natural disturbances deserves more attention in future models. Models like EASY and ACE that use mean erosion rates are very limited in their ability to account for sediment produced by infrequent natural events, especially those, like hurricanes or wildfires, that affect extensive areas. Moreover, mean erosion rates, while believed to represent erosion produced over long time periods—50 years in the case of Dissmeyer and Stump (1978)—are generally derived from plot studies conducted over a limited number of years. The impact of severe storms is very likely not well represented within these values; thus estimates of sediment yield from undisturbed and disturbed areas may well be too low. Possibly these underestimates are proportional and thereby do not change interpretation of model results—the point is that we do not know. Future models will hopefully address more accurately the range of erosion amounts and how these are affected by natural disturbance processes.

Impact of Past Human Activities

One issue that is particularly relevant to modeling sediment cumulative watershed effects in the Eastern United States is the impact of past human activities on current sediment dynamics. In many forested areas, the combination of highly erosive soils with abusive land-use practices beginning with European settlement and continuing through the early 1900s produced extensive areas of severely eroded terrain and massive sediment storage within drainage systems (Trimble 1974). Although improved practices and extensive reforestation have reduced soil loss significantly, a legacy of oversteepened slopes, compacted soils, and stored sediment remains in many areas, and can dramatically affect sediment production. Future models need to provide the capability to deal with such historical influences where necessary, and model users must be careful to consider and account for these influences when appropriate.

Balancing Accuracy and Practicality

Future models, like EASY and ACE, will be developed through compromises between model accuracy and application practicality. Such compromises do not invalidate the use of such models. None of the legal expectations noted by Reid (2010) mandate use of a "perfect" or even "state-of-the-science" model; rather the courts expect that the analysis address the concern at relevant spatiotemporal scales, that the analysis and interpretations be reasonably thorough and scientifically defensible, that methodological validity be demonstrated, and that methodological shortcomings be disclosed. Therefore, our objective should be to produce the best model we can given the resources we have available. Resources would go farther if future models could be designed so that when new understanding emerges about erosion processes or sediment routing, the relevant model components could be revised without disrupting the unaffected components. Such models would require less resource investment over time and reduce the need to start from scratch to just those times when changes in the science or technology make such a decision desirable.

Deterministic versus Lumped-Parameter Models

While lumped-parameter models like ACE and EASY may serve as satisfactory interim solutions for those areas where they can be validated, the future in sediment models probably lies in deterministic models. Deterministic models, like WEPP, provide both theoretical credence to the processes being modeled and a modeling structure that facilitates both computer programming and incremental refinements. In contrast, lumped-parameter models like USLE and its descendants are easier to program and require fewer data inputs, but they lack a direct theoretical basis and therefore must be validated through numerous empirical trials. The choice between deterministic and lumped-parameter models seems to us less a question of model accuracy than investment efficiency. If we have captured the relevant process mechanics correctly in a deterministic model, then scientific theory holds that these processes should function in the same manner at different locations. Testing is necessary to build confidence, but such testing should produce a model that is more broadly applicable because the process mechanics have been improved by making them more robust to input variations. In contrast, when testing shows lumped-parameter models to be inaccurate, all that can generally be done is to apply calibration factors that fine tune the model to the specific situation being tested, but produce no improvement for model applications elsewhere.

As they prove themselves, deterministic models should require less testing over time because we can better evaluate how changing environmental factors might affect model outputs as we better understand which factors most affect model behavior. This is more difficult with lumped-parameter models in which several environmental variables are often combined into a single factor (such as cover type) and it remains uncertain how variation in one or more variables might affect the combined influence of the lumped factor. Adopting deterministic models will likely come with a cost, however: it will require that model users have sufficient scientific knowledge to use them effectively.

User Competence

Our assessment of these two models, plus our discussions with the model developers, leads us to question the ability of nonspecialists to adequately use these or other models for any but the most simple and straightforward applications. Both the EASY and ACE models were developed to facilitate evaluating sediment cumulative watershed effects for a variety of forest management projects that occur at varying spatio-temporal scales. Furthermore, these models were developed in part with the hope that personnel with adequate training—but not necessarily a background in sediment sciences—could use these models to perform sediment CWE sediment cumulative effects analyses. Most of the legal expectations identified in table 1 do not necessarily require improved skill on the part of the model user; they could be met through revisions to modeling procedures or improvements to model documentation. For example, expectations 2 to 5, and 9 in table 1 could be addressed by revising the current calculations and formats with both EASY and ACE. Items 7 and 8 could be addressed through more thorough model documentation. Item 6 (demonstrating model validity) would require some rigorous program of testing and analysis to assess model accuracy and to justify the accuracy standards that are chosen as being acceptable; however, such work would only have to been done where models have not been validated, standards are elevated, or new knowledge emerges to challenge past assumptions.

Conceivably, these improvements could all be made without requiring more knowledge or skill on the part of the user. However, the choice and justification of an appropriate analysis area (expectation 1 in table 1) can only be made by someone who understands the science of sediment processes, how these are affected by past and present land-use practices, how these processes are affected by the spatial and temporal scales at which they are evaluated, and how sediment is linked to other resources. The analyst must also appreciate how well we can actually model sediment and what that accuracy means in terms of our ability to judge the severity of cumulative sediment effects, because he or she will be the primary person interpreting the model results and defending the conclusions drawn from these results. It is unrealistic to expect that anyone without this knowledge and skill could apply and interpret these models effectively.

Conclusions

Sediment appears to be the only concern related to cumulative watershed effects from fuel management being addressed in environmental analysis documents prepared by eastern national forests. Two types of analysis methods have been used: narrative analysis and hazard rating models. Narrative analysis is used when the level of concern is low and a discussion of the given environmental situation, the relevant scientific literature, and why the analyst thinks sediment effects are unlikely is deemed sufficient to meet legal expectations. Hazard rating models are employed when the level of concern is high. Two models are currently in use; the EASY model and the ACE model. Both models produce predictions of sediment yield at the outlet point of a watershed based on the condition types present or hypothesized. The models use the same general procedural steps, compute erosion for forest areas using similar data sources, and provide outputs for comparing alternatives. They primarily differ in how the analysis area is determined, how they compute nonforest and road erosion, and how results are interpreted. Both models provide much of the information needed to meet the legal expectations identified by Reid (2010), but both suffer from lack of validation.

Future models for evaluating sediment cumulative watershed effects will have to overcome current operational constraints that limit the ability to tailor analysis area delineation and spatiotemporal scale selection to the particular circumstances of each project. To improve their practicality, future models should be designed with updating and revision in mind. Although models like EASY and ACE may suffice in the near term for those regions where they can be validated, deterministic models would seem to offer a more efficient way to develop more broadly applicable tools to assess sediment cumulative watershed effects. Lastly, all analysis methods are merely tools that can only be applied effectively by practitioners who have the necessary scientific training to understand the strengths and limitations of the methods they employ.

Acknowledgments

We wish to thank our many colleagues in the Southern and Eastern Regions of the National Forest System who responded to our survey and answered our followup questions. We are grateful to John Potyondy, Leslie Reid, Bill Elliot, Sandra Litschert, and Pat Fowler for their insightful review comments. We particularly thank William F. (Bill) Hansen for his extensive help in providing materials on the EASY model, answering our questions, sharing his thoughts on modeling needs, and reviewing this chapter.

Literature Cited

Bunte, Kristen; MacDonald, Lee. 1999. Scale considerations and the detectability of sedimentary cumulative watershed effects. Tech. Bull. 776. New York: National Council for Air and Stream Improvement. 326 p.

CEQ. 1997. Considering cumulative effects under the National Environmental Policy Act. Washington, DC: Council on Environmental Quality. 64 p.

Dissmeyer, George E.; Foster, George R. 1984. A guide for predicting sheet and rill erosion on forest land. Tech. Publ. R8-TP 6. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 40 p.

Dissmeyer, George E.; Stump, Richard F. 1978. Predicted erosion rates for forest management activities and conditions sampled in the Southeast. [Atlanta]: U.S. Department of Agriculture Forest Service, State and Private Forestry, Southeastern Region. 26 p.

Elliot, W.J. 2001. Comparing RUSLE to WEPP cropland and rangeland formats. In: Ascough, J.C., II; Flanagan, D.C., eds. Soil erosion for the 21st century: Proceedings of the international symposium. ASAE Publ. 701P0007. St. Joseph, MI: American Society of Agricultural Engineers: 388–391.

Elliot, W.J.; Foltz, M. 2001. Validation of the FS WEPP interfaces for forest roads and disturbances. In: An engineering odyssey: 2001 ASAE annual international meeting. ASAE Pap. 01-8009. St. Joseph, MI: American Society of Agricultural Engineers. 16 p.

Elliot, W.J.; Tysdal, L.M. 1999. Understanding and reducing erosion from insloping roads. Journal of Forestry. 97(8): 30–34.

Elliot, William; Hyde, Kevin; MacDonald, Lee; McKean, James. 2010. Tools for analysis. In: Elliot, W.J.; Miller, I.S.; Audin, L.J., eds. Cumulative watershed effects of fuels management in the Western United States. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 246–276.

Elliot, William J. 2004. WEPP Internet interfaces for forest erosion prediction. Journal of the American Water Resources Association. 40(2): 299–309.

ESRI. 2001. ArcGIS spatial analyst: advanced GIS spatial analysis using raster and vector data. Redlands, CA: Environmental Systems Research Institute. 13 p.

Flanagan, D.C.; Nearing, M.A., eds. 1995. USDA – water erosion prediction project: hillslope profile and watershed model documentation. NSERL Rep. 10. West Lafayette, IN: USDA-ARS National Soil Erosion Research Laboratory. [Various pagination].

Grace, J.M., III. 2005. Application of WEPP to a Southern Appalachian forest road. In: 2005 ASAE annual international meeting. ASAE Pap. 052016. St. Joseph, MI: American Society of Agricultural Engineers. 10 p.

Grace, J. McFero, III. 2007. Modeling erosion from forest roads with WEPP. In: Proceedings: Environmental connection 07, conference 38. Steamboat Springs, CO: International Erosion Control Association: 12 p.

Laflen, John M.; Flanagan, Dennis C.; Engel, Bernard A. 2004. Soil erosion and sediment yield prediction accuracy using WEPP. Journal of the American Water Resources Association. 40(2): 289–298.

MacDonald, Lee H. 2000. Evaluating and managing cumulative effects: process and constraints. Environmental Management. 26(3): 299–315.

Reid, Leslie M. 2010. Understanding and evaluating cumulative watershed impacts. In: Elliot, W.J.; Miller, I.S.; Audin, L.J., eds. Cumulative watershed effects of fuels management in the Western United States. Gen. Tech. Rep. RMRS-GTR-231. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station: 277–298.

Roehl, J.W. 1962. Sediment source areas, delivery ratios, and influencing morphological factors. IASH Comm of Land Eros, Pub. 59: 202–213.

Soto, Benedicto; Díaz-Fierros, Francisco. 1998. Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by the WEPP model. Catena. 31: 257–270.

South Carolina Cooperative Fish and Wildlife Research Unit. 1993. South Carolina 27-class land cover. http://www.dnr.sc.gov/GIS/gap/gapdata.html. [Date accessed: March 22, 2007].

Terrell, J.W.; Cade, B.S.; Carpenter, J.; Thompson, J.M. 1996. Modeling stream fish habitat limitations from wedge-shaped patterns of variation in standing stock. Transactions of the American Fisheries Society. 125(1): 104–117.

Tetra Tech. 2002. Eastwide technical guide: assessing and managing cumulative watershed effects. [Place of publication unknown]: U.S. Department of Agriculture Forest Service, Eastern and Southern Regions; contract GS-10F-0076K. [Various pagination]

Trimble, Stanley Wayne. 1974. Man-induced soil erosion on the southern Piedmont, 1700-1970. Ankeny, IA: Soil Conservation Society of American. 180 p.

U.S. Census Bureau. 2006. Topologically integrated geographic encoding and referencing TIGER/Line files. http://www.census.gov/geo/www/tiger/tiger2006se/tgr2006se.html. [Date accessed: March 22, 2007].

U.S. Department of Agriculture Forest Service. 2006. Environmental assessment—prescribed fire on the Francis Marion National Forest, South Carolina. Cordesville, SC: Francis Marion National Forest. 84 p.

U.S. Geological Survey. 1992. National land cover data, product description. http://eros.usgs.gov/products/landcover/nlcd.html. [Date accessed: March 22, 2007].

Walling, D.E. 1983. The sediment delivery problem. Journal of Hydrology. 65: 209–237.

Wischmeier, W.H.; Smith, D.D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agric. Handb. 537. Washington, D.C.: U.S. Department of Agriculture. 58 p.