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Modeling Aquatic and Riparian Systems, Assessing Cumulative Watershed Effects, and Limiting Watershed Disturbance

ABSTRACT

Cumulative Watershed Effects often have severe impacts on the condition of aquatic and riparian systems. Under the auspices of the Sierra Nevada Ecosystem Project (SNEP) we have adapted a cumulative watershed effects accounting system to model forest stand response to fire and timber harvest activities. This system is intended to help us (1) address effects of sedimentation; (2) limit possible losses of aquatic biodiversity; (3) account quantitatively for the total amount of cumulative watershed effects; and (4) limit cumulative watershed effects that may accrue as a result of management activities or natural events such as wildfire. The Equivalent Roaded Area (ERA) strategy, which we have adapted, is described in this paper. Examples are provided to contrast and illustrate a traditional approach of calculating cumulative effects using ERA values with our modification of this method. The modified ERA system has been adapted to more accurately depict the effects of fire intensities, steepness, and grazing. In addition, we use a two-zoned buffer system with an emphasis on the biological components of cumulative effects. At the same time, we have eliminated the use of site-specific information about watersheds and their susceptibility to cumulative effects since this information has not been developed for the entire Sierra Nevada.

This buffer model differs from many others in that it is designed to protect *site-specific* biological effects rather than *downstream* physical effects such as sedimentation. To achieve this goal of local protection of in-stream organisms and systems less activity is allowed the closer one moves to streams. In addition, buffer sizes increase with adjacent slope steepness and decrease with stream size. As a result, buffers are largest in steep headwaters areas.

INTRODUCTION

The Sierra Nevada Ecosystem Project was commissioned by Congress in 1993 to assess the health of the ecosystems of the Sierra Nevada and to evaluate “management strategies to maintain the health and sustainability of these ecosystems while meeting human needs” (SNEP 1994). The importance of late-successional forests and watersheds was emphasized in numerous letters from Congress and in a bill considered by the Agriculture Committee of the House that became, in part, the model for the SNEP assignment. That bill, as an example, requested,

> ...recommendations of alternative management strategies to protect and enhance each ecosystem of the Sierra Nevada forests and the resources thereof, including the watersheds and late-successional forests and their dependent and associated species, including a determination of whether late-successional reserves are necessary for the maintenance of the health of the Sierra forest ecosystems and if such reserves are necessary, what lands should be included in such reserves.
>
> (section (5) (A) of HR 6013)

Sierra Nevada Ecosystem Project:Final report to Congress, Addendum. Davis: University of California, Centers for Water and Wildland Resources, 1996.

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The assessment of Sierra Nevada ecosystems has revealed a number of problems with achievement of health and sustainability including: (1) decline in the amount and complexity of late-successional forest in the commercial forest types, especially mixed conifer and east-side pine; (2) declines in aquatic biodiversity and existing and potential threats to riparian-associated species; and (3) existing and potential difficulties from watershed disturbance (SNEP, volume II). Also, there may be increased threat of severe fire in some forest types from the build-up in fuels and decrease in fire periodicity, although opinions vary about the degree of that increase.

Franklin, et al. (1996), have proposed and evaluated the potential for a number of different conservation strategies for late-successional forests. These conservation strategies all involve increasing the general extent and complexity of late-successional forests in the Sierra, with varying degrees of human intervention through prescribed fire and mechanical treatment (timber harvest and road building) to accelerate development of late-successional characteristics and reduce the threat of fire.

Goals and strategies designed to deal with the different problems identified potentially influence and impact each other. As an example, mechanical treatment to improve late-successional / old-growth (LS/OG) forest rank, decrease fuel loads, and/or produce timber can impact riparian areas and watersheds. Cattle grazing can have a similar effect. Aquatic goals for riparian zones can affect the amount of LS/OG forest and the state of corridors between Areas of Late-Successional Emphasis ("ALSE," see Franklin, et al. 1996).

Thus, we have built a policy analysis model that emphasizes the analysis of strategies for late-successional forests in fire-dominated landscapes, but that can also accommodate goals and strategies for riparian areas and watersheds (Sessions, et al. 1996). This model can also accept goals for, or limits on, timber harvest and grazing and limits on budgets.

The purpose of this paper is to explain our approach to the measurement and control of cumulative watershed effects in the strategic policy analysis that we have undertaken of forests, fire, and watersheds. The analysis of this strategy is limited to the federal lands in the Sierra with the exception of a narrow margin of private lands in watersheds along the federal boundary. The legal constraints and opportunities for extending this strategy to private lands in the Sierra have not been closely examined.

I THINKING ABOUT AQUATIC AND RIPARIAN ECOLOGICAL SYSTEMS[1]

Aquatic and riparian systems are easily affected by management activities on surrounding lands. Individual events or cumulative effects can have severe effects on aquatic life, channel condition, species using riparian habitat, and water quality. For these reasons, riparian systems often receive special protection from activities that might affect them. The riparian zone protection scheme we are using in the SNEP forest stand projection model (see Sessions, et al. 1996) has been designed according to four principles. First, a stream needs natural or near-natural energy and nutritional inputs to sustain its biological functions. Second, some plant and animal communities rely on the forest adjacent to streams. Third, small streams are more affected by hillslope activities than are larger streams. A headwaters aquatic system, for example, is small in relation to the zone that influences it. Compared to a larger stretch of stream further down the system the small amount of water in a headwaters system is easily affected by even small effects on surrounding lands. Fourth, the likelihood of disturbance resulting in discernible in-stream effects increases as adjacent slopes become steeper. Therefore, stream protection should increase as adjacent slopes increase in steepness.

The aquatic and riparian management protection scheme developed by D. C. Erman, N. Erman, L. Costick and S. Beckwitt has three spatial components designed to accommodate the four principles described above (see Kondolf, et al. 1996; Kattelmann and Embury 1996). The C*ommunity Influence Region,* the first region, is the area in which plants, animals and other organisms dependent upon the area adjacent to the water live or spend time. *Obligate* species such as beavers and dippers, and *transients,* such as bats and other predators, are species for which this zone is critical.

The second component is an *Energy Influence Region.* This area, which extends as far from the stream as the height of the tallest tree when tree cover is present, includes all the habitat necessary for the community influence region plus all the area that contributes energy and nutrients to the aquatic system. Recruitment of leaves and snags into the stream, for example, usually originate within the length of one tree height. Included in the functions of this zone are the recruitment of woody debris and shading canopies. Changes in flow and temperature are considered to result from disturbances in the Energy Influence Region due to the filtering and buffering capacity of the near-stream area.

These first two zones are based in convergent ways of thinking about ecosystems. The first is rooted in *community ecology* in which the organisms and their structure in biological communities is examined, and the second in *ecosystem ecology*—the study of flows of energy and materials between organisms and other components of the system. In this protection strategy both approaches are considered.

The third part of the system, the *Land Use Influence Region*, includes the area in which land use activity will influence stream conditions and the functioning of the community influence and energy influence regions. Influences include concentrations of nutrients above baseline levels, increased sedimentation, and changed microclimate. The width of the Land Use Influence region varies according to the probability of disturbance to a stream as a function of hill slope and/or hazardous soil and geologic conditions.

In this riparian protection scheme different levels of disturbance and tree removal would be permitted in each region. In the Community Influence Region, for example, a

[1] *For a full description of the SNEP approach to thinking about aquatic and riparian systems please refer to Kattelmann and Embury 1996*

strict limit on activity would exist—very little disturbance would be allowed and generally a mature forest would be established as the goal. The Energy Influence Region would have varying degrees of activity allowed including selective removal of canopy. Finally, the Land Use Influence Region would allow more management activity to occur. Uplands, beyond the third region, would be managed even more permissively with respect to the range and intensity of possible activities allowed.

At the scale of the entire Sierra Nevada, we do not have the capacity to determine the precise widths of each of these zones for every stretch of stream in each watershed. Actual land management would require gathering additional site-specific information that could be used to determine these buffer distances. As a result, we have organized these three ecological regions into two riparian management zones for SNEP's modeling efforts. These zones are discussed more fully below.

The theory that stream buffers should get larger as streams get smaller contrasts with traditional stream buffers (see Moyle, et al. 1996; Kattelmann and Embury 1996). The state Forest Practice Rules, for example, have stream buffers that get successively smaller as streams become smaller (§916.5 California Forest Practice Rules; Menning, et al. 1996). This system differs from many others in that it is designed to protect *site-specific* biological effects rather than just *downstream* physical effects such as sedimentation. This is an important distinction, because those who criticize a buffer system wider in headwater areas almost always cite downstream effects as the reason for having larger protective buffers downstream. The approach described in this paper was designed to focus less on sediment transport to other areas (in which case, larger, downstream waters may need more protection) than on biological effects which may be more significant in small water bodies. Small waterbodies have a lower volume to influence-area ratio and so dilute effects less readily than do larger water bodies (see Moyle, et al. 1996; Kattelmann and Embury 1996). These smaller waterbodies also have less developed aquatic fauna/flora and tend to be *allochthonous* (depending on biological inputs from *outside* the system). Downstream waters are more likely to have more trophic levels, more developed flora and fauna, and often tend to be *authochthonous* (depending on *internal* cycling of nutrients/resources). As a result of these considerations, we have chosen to use a buffer system that protects locations where biota are most susceptible to small changes in land use: steep slopes and headwater areas.

II CUMULATIVE WATERSHED EFFECTS

Cumulative watershed effects (CWE) are those impacts accruing from more than one incident or activity that have combined to affect a stream or riparian area. Cumulative watershed effects often result from the combined effects of localized physical problems such as landslides, failed culverts, or poorly drained road sections, in conjunction with unique weather phenomena such as extreme storms (Ziemer, personal communication). Thus, most direct sources of cumulative effects are local in space and time. Indirect and dispersed sources of cumulative effects, such as large harvested areas and reduced forest density throughout a watershed, have more subtle effects. Cumulative watershed effects as they relate to land management are typically considered non-point sources.

In assessing cumulative effects one must consider the *past*, *present* and possible *future* activities that may contribute to watershed disturbance. Often, the magnitude of the effects of the activities tapers off with time. As a clear cut forest grows back, for example, revegetation may reduce the extent of bare soil surface and resulting erosion. As a result, the subsequent transport of sediment into a stream will decrease and nutrient cycling may increase (see Berg, Roby and McGurk 1996).

The kinds of physical impacts that may occur in an aquatic system as result of watershed disturbance include sedimentation, gravel embeddedness, pool filling, aggradation, bank cutting, bank mass wasting, downcutting, scouring, debris jamming, canopy reduction, changes in peak flows, and temperature changes (California Department of Forestry and Fire Protection 1994). In addition, biological effects may include riparian and aquatic habitat loss, decreases in in-stream biodiversity, organic debris effects, loss of spawning habitat and changes in species composition.

Scales of analysis: watersheds

A hierarchical system of watersheds has been developed by the California Department of Forestry and Fire Protection (CDF) in conjunction with federal and state agencies and private interests. This system of standardized watersheds, known as the CalWater watershed system, includes from largest scale down, seven nested scales of analysis (figure 1).

Figure 1: CalWater hierarchical watershed system

- State of California;
  - Hydrologic Regions / Basin (e.g. West slope of Sierra);
    - Hydrologic Units (e.g., American River);
      - Hydrologic Areas (e.g., Rubicon River tributary to American River);
        - Hydrologic Sub-area (100,000—300,000 acres: e.g., headwaters of Rubicon);
          - Super Planning Watersheds (averaging 50,000 acres); and
            - Planning Watersheds (3,000-10,000 acres).

(Brandow 1994)

While cumulative watershed effects can occur and may be detected at any scale, the effects are most discernible in the watershed where they occurred. Sedimentation due to high densities of dirt roads in riparian areas, or nutrient changes affecting in-stream biodiversity, for example, may be detectable at the scale of a hydrologic unit. If such effects are detected, however, they are certainly discernible at a local level in the watersheds where the activity is taking place. Effects at the local level are likely to be greater since downstream waters are diluted by inflow from other tributaries.

In addition to the local occurrence and impacts of cumulative effects in small watersheds the factors that affect system susceptibility to cumulative effects vary at a local scale as well. Slope, soil condition and detachability, parent material, vegetation cover, and microclimate all vary significantly enough that analyses of cumulative effects and the likelihood of their occurrence typically are examined at the scale of a small watershed.

Most cumulative watershed effects in the Sierra are analyzed at the local level for these reasons. The planning watershed level is the scale at which the California Department of Forestry and Fire Protection (CDF) requires assessments of cumulative watershed effects when timber harvest plans (THP) or Sustained Yield Plans are filed for timber-related activities on private lands (Menning, Johnson & Ruth 1996). The Forest Service usually measures impacts in similar size watersheds and typically uses the same boundaries as the CalWater system described above. Larger scales of analysis sometimes are considered, but activities are only constrained at the local level of planning watersheds.

In this project, we have chosen to model cumulative watershed effects resulting from projected management actions at the small-scale level of planning watersheds. Because management actions anticipated in the SNEP modeling effort—such as timber harvest, recreational trail use, and prescribed fire—are typically located in individual late successional/old growth (LS/OG) polygons (see Sessions, et al. 1996), and these polygons are similar in scale to planning watersheds, cumulative effects are assessed in LS/OG polygons. Frequently, these LS/OG polygons straddle ridgelines and may contain parts of several watersheds. Effects, however, are allocated to parts of individual watersheds within these polygons. The use of cumulative effects analysis in each local polygon allows for a more realistic and site-specific simulation of vegetation management and the resulting impacts than have other forest stand modeling efforts.

All further analyses discussed in this report are described at this scale, either in CalWater planning watersheds, or in LS/OG polygons.

Regulatory use of cumulative effects analysis to constrain watershed activity

The Federal Water Pollution Control Act (commonly called the Clean Water Act or CWA) entrusts the state with the role of ensuring water quality within the constraints of detailed federal legal requirements and approval. A solid case history demonstrates that the state can set water quality standards for the federal government on water quality & cumulative watershed effects under the authority of the CWA. Best management practices (BMP) of the federal agencies do not supersede the state's authority and water quality boards' regulatory authority even when Memorandums of Understanding (MOU) or Management Agency Agreements (MAA) have been signed. Thus, the federal land management agencies (Bureau of Land Management, National Park Service, Forest Service, and Fish & Wildlife Service) must meet state water quality requirements while performing forest management activities. In contrast, this state authority over federal lands in water quality is not paralleled by state forestry laws and regulations administered by the California Department of Forestry and Fire Protection (CDF). These state forestry laws are strictly limited to the non-federal lands.

The state's authority over water quality extends over all lands in the state but the actual means of administration are different for the federal agencies and non-federal land owners. The Regional Water Quality Control Boards' (RWQCB) strategies for protecting water quality are primarily *performance oriented* and not *prescriptive* (Menning, Johnson and Ruth 1996). State law, in fact, precludes the agencies from stating how effects must be avoided (California Porter-Cologne Act). The RWQCBs determine what water quality levels must be met but they will not state specifically *how* those standards must be met. When permits are required for discharge, or any activity with probable effects on aquatic systems, the regional boards can accept or deny proposals based upon the likely impact on declared downstream beneficial uses. In making these rulings the RWQCBs can require mitigation or minimization but cannot say how a project must be done.

CDF approaches—Non-federal forested lands

On non-federal forested lands the primary authority for assessing and regulating cumulative watershed effects derives from the state Forest Practice Rules administered by the California Department of Forestry & Fire Protection (CDF). Probable cumulative watershed effects are reviewed when a Timber Harvest Plan (THP) is filed. They also will be considered when Sustained Yield Plans (SYP) are reviewed. In the Sierra, the Lahontan or Central Valley Regional Water Quality Control Board (RWQCB) is called in on consultation with CDF for pre-harvest inspections and, sometimes, post-harvest inspections (personal communications with Yee, Blatt, and Caffereta 1995).

The state Board of Forestry (BOF) has established rules for meeting water quality standards but the Board does not have prescribed methods of determining attainment of the standards. Additionally, while there are some quantitative standards described in the Forest Practice Rules (§912.9, 932.9, 952.9 and Technical Rule Addendum #2), CDF and the appropriate RWQCB perform qualitative visual inspections and usually do not take actual measurements—on occasion, stream temperatures and shade cover data are collected. While standards for water quality do exist in the RWQCB Basin Plans no specific assessment method for cumulative effects has been defined by either of the RWQCBs or CDF. Many methods are allowed, including Equivalent Roaded Area assessments (ERA) and general narratives. The actual form of assessment used is up to the Registered Professional Forester (RPF) who works on the THP or SYP (see Menning, Johnson & Ruth 1996).

Federal lands

While the state has been invested with the authority to regulate the federal agencies under the CWA on federal land this regulatory function has largely been deferred back to the federal government with the understanding that the federal agencies will take actions embracing state and regional water quality standards. Federal agencies can set stricter standards for water quality but must at least meet state standards.

Best Management Practices (BMP) and acceptable levels of watershed disturbance are developed cooperatively between the federal agencies, the State Water Resources Control Board (SWRCB) and the US Environmental Protection Agency (EPA) while these agencies develop a Management Agency Agreement (MAA). On Forest Service land the agreements between the SWRCB and the federal agency state that BMPs will be used to assess, monitor and predict cumulative watershed effects. Currently, the preference of Forest Service Region Five in California is to apply the ERA method developed in the Region (described below; also, see Berg, Roby and McGurk 1996). The net result is that through cooperative agreements the Forest Service defines its own regulations and methods for assessment and is responsible for monitoring itself for compliance.

Modification of plans based on activity in watersheds

The Forest Service does not have to consider the role of adjacent private lands when writing a programmatic EIS as long such an analysis is performed when a site-specific action is considered. Under its own guidelines the Forest Service must consider cumulative effects on adjacent non-federal lands when a site-specific action is proposed. The Region 5 Soil and Water Conservation Handbook states the best available information must be found and used, and in the absence of any information a worst case scenario must be assumed (USDA Forest Service 1988).

On the Eldorado National Forest the staff has amended several timber sales a number of years after the sales were completed partially due to concerns over cumulative watershed effects. Some of the watershed analyses showed current impacts were too high to proceed as originally planned. Watersheds had been affected by higher than expected levels of harvest on private lands during the years intervening the timber sales and the proposed harvests. As a result, the Forest Service had limited ability to maintain watershed quality and continue with planned management while remaining below thresholds of disturbance. In conjunction with other concerns, the Forest Service amended the sales to avoid lawsuits that might have enjoined harvesting due to violations of the Forest Service's own water quality standards.

Cases such as this may occur in watersheds that have a mix of federal and private ownership and where Forest Service lands are in a less-disturbed condition than adjacent private lands. This can also happen when the Forest Service, with its stricter cumulative watershed effects standards, is more constrained by the cumulative impacts than are adjacent private landowners. In such a case, the Forest Service might determine it must change or postpone planned activities on federal lands in the watershed to avoid exceeding a threshold of concern (TOC). In contrast, private interests may set higher allowable levels of activity in the watershed. If CDF with the private cumulative effects analyses then activity affecting the watershed may occur on those lands. If private lands do have higher thresholds more harvesting and road building may be planned on the private portion of the watershed. This additional activity in the watershed would continue to constrain the Forest Service.

On some National Forests in the Sierra Nevada the cumulative watershed effects analysis methods are not spatial. In other words, the methodology does not differentiate between sources near the stream and those far upslope. The Forest Service does can escape from this problem, however. If a timber sale or other management activity will violate a Threshold of Concern in a watershed (TOC, described below), the Forest Service is not strictly required to prevent the activity. If a calculated TOC would be slightly breached by a timber sale in the uplands, for example, the sale might be allowed to proceed based on its position far from the stream.

Cumulative Watershed Effects Assessment Methods

Many sources of direct cumulative effects, as discussed above, are local in space and time and subject to stochastic events such as storms which trigger or magnify impacts. Means of assessing risks of cumulative effects, however, may be based on expected likelihoods of events occurring across entire portions of landscape. As a result, risks may be determined to be high, but cumulative effects *may* or *may not* occur, and their magnitude, if they do occur, are variable. Similarly, a low risk rating does not mean that cumulative effects will not occur (Ziemer personal communication; Reid 1993; Berg, Roby & McGurk 1996). In sum, cumulative effects and the magnitude of their effects are difficult to predict. A number of different methods of assessing cumulative effects have been developed to attempt to deal with this complex arrangement of causes and effects. These methods are discussed in Berg, Roby & McGurk (1996) and are summarized here (also, see Reid 1993).

Qualitative assessments

The California state Forest Practice Rules provide an example of how cumulative effects analysis may be performed (State of California: Forest Practice Rules, §912.9 Cumulative Impacts Assessment Checklist) but there is no required method (§1091.6 Forest Practice Rules). Acceptable methods include the ERA approach described below, other developed analyses of cumulative watershed effects, and a separate checklist provided separately by CDF (California Department of Forestry 1994). With the exception of the ERA method, each of these approaches is essentially *qualitative*. They require the professional judgment of the Registered Professional Forester, and where available, information on the past, present, and expected future watershed-disturbing activities, but no *quantitative* measures or thresholds are established.

Quantitative Methods

Practitioners of the Equivalent Clear-cut Area (ECA) method attempt to link harvest activity to changes in water yield. ECA does not, however, consider for other kinds of activity on the landscape. A second method, the Klock Watershed Cumulative Effects Analysis (KWCEA) is a hybrid method developed for the Northwest focused on sedimentation and surface erosion. Only timber harvest and roads are considered and the method is generally unproven.

A third method, the R-1/R-4 Sediment-Fish Model, focuses more narrowly on fish survival as a function of sediment input. Sediment yields are determined for areas affected by fire, logging and roads. The relationships that form the basis of this model are specific to the area on the Idaho Batholith for which it was developed. Its relevance to the Sierra is unknown. A fourth method, the Water Resources Evaluation of Non-point Silvicultural Sources (WRENSS) allows for quantitative evaluation of changes in flow, sediment and temperature. A number of qualitative assessments can also be made. WRENSS can be used to assess road and harvest activities, but not fire.

Fifth, Limiting Factor Analysis (LFA) focuses on the variables that limit coho smolt populations in the Pacific Northwest. Such an analysis is of limited use for the Sierra Nevada. Sixth, the U.S. Environmental Protection Agency developed the Synoptic Approach to assess cumulative impacts to wetlands. This method allows for comparison of impacted wetlands sites. Similar to LFA, its range of application is limited in the Sierra.

Several watershed-wide expert analysis systems are available as well. The Washington State Watershed Analysis (WWA) requires intensive on-site investigation by teams of experts. The assessments are partially quantitative but mostly qualitative. WWA is intended to help define likely sources of major local cumulative effects that can impact larger water systems. A ninth method, the Forest Ecosystem Management Assessment Team's Watershed Analysis (FEMAT-WA) operates at a large scale and is less an accounting procedure than a watershed review process. Similar to WWA, many elements of the FEMAT-WA are qualitative in nature and of questionable use in a range-wide evaluation. The Idaho Forest Practices Method, the tenth discussed here, has recently been developed and is focused on timber-harvest related activities, not including grazing, mining and recreation. The applicability of this system to the Sierra has not yet been evaluated fully.

Within the last decade, Region 5 of the Forest Service developed the Equivalent Roaded Area (ERA) approach in order to grapple with the difficulty of assessing cumulative watershed disturbance in a consistent fashion. The potential for impact from any of a number of different activities—roads, fire, harvest site preparation, recreation, and silvicultural system used—is measured in a common currency, an area of bare road surface, and evaluated in the context of the susceptibility of the watershed to cumulative effects. Although the ERA method is better designed to identify areas of risk than to predict exact effects, ERA evaluations have been linked to some impacts such as in-stream invertebrate biodiversity (McGurk and Fong 1995). Various approaches to using ERA have been implemented throughout the National Forests in the Sierra Nevada. This method is describe in greater detail below.

A new Forest Service approach being developed to assess Cumulative Watershed Effects

No system of assessing cumulative effects is fully satisfactory. Region 5 of the Forest Service is currently developing a new two-tiered method of assessing cumulative watershed effects to address many of these concerns. The new system, which may be implemented in the next few years, splits cumulative effects assessments into aquatic (in-stream) and terrestrial (land disturbance) components. This requires considerable site-specific information about land disturbance, vegetation, and stream channel condition. For the purposes of this analysis, this method requires more information about each watershed than is currently available.

The Equivalent Roaded Area (ERA) approach to Cumulative Watershed Effects

Of the many methods available to assess cumulative watershed effects we have selected the Equivalent Roaded Areas (ERA) approach. Like any accounting system designed to measure impacts ERA has advantages and disadvantages. A number of drawbacks do exist with the ERA approach. First, a fully-implemented ERA system requires more site-specific information than is currently available for the Sierra. Second, ERA does not predict effects with precision and has tenuous linkages between activities in upland areas and in-stream effects. Third, the evaluation of recovery over time is more linked to the causes of effects than to the effects themselves. Fourth, ERA describes a level of risk but does not offer an index of actual effects. In sum, ERA is essentially an evaluation of risk due to management activities and not an outright prediction of the magnitude or exact location of cumulative effects or of their rates of recovery.

Although the ERA system is imperfect, it is the most useful model for limiting and evaluating the effects of our management strategies for a number of reasons. First, the ERA method provides a quantitative accounting and analysis system. Our forest stand modeling efforts have most of the necessary data as inputs to the process, and the outputs of this analytical system can be used to estimate probable effects of multiple management activities dispersed in time and space. Second, ERA analyses have been correlated with some ecological measures of in-stream effects (McGurk and Fong 1995, described below). Third, there are some theoretical bases for linking ERA to measures of effects. Fourth, ERA is considered a legally legitimate and commonly used method of assessing cumulative watershed effects at both the state and federal levels in the Sierra Nevada. Fifth, ERA allows for

Table 1: ERA coefficients as originally developed for the Eldorado N. F.

Activity or Impact	**Years since impact**					
	1	2	5	10	20	50
I. Transportation system						
A. System & non-system roads and landings						
1. good drainage	1.0	1.0	1.0	1.0	1.0	1.0
2. poor drainage	1.5	Fixing road during problems associated with ditches, culverts, etc.: coefficients return to 1.0				
3. diversion potential	2.0	Same comment as above				
B. Abandoned roads and landings	1.0	0.9	0.9	0.8	0.8	0.8
C. Trails (recreational)	1.0	1.0	1.0	1.0	1.0	1.0
D. Ripped and obliterated roads and landings	0.4	0.3	0.3	0.2	0.1	0.1
II. Silvicultural system						
A. Tractor (includes impact due to skid trails)						
1. Clearcut and seed tree	0.25	0.24	0.20	0.15	0.10	0.08
2. Shelterwood	0.22	0.20	0.15	0.10	0.10	0.08
3. Overstory removal	0.20	0.16	0.12	0.10	0.10	0.08
4. Sanitation / Salvage	0.15	0.10	0.08	0.05	0.05	0.04
5. Selection / Thinning	0.15	0.12	0.10	0.08	0.08	0.08
B. Cable						
1. Clearcut	0.15	0.14	0.10	0.05	0	0
2. Overstory removal	0.10	0.06	0.02	0	0	0
C. Helicopter						
1. Clearcut & seed tree	0.10	0.09	0.05	0.02	0	0
2. Overstory removal	0.05	0.05	0.05	0	0	0
3. Sanitation / Salvage	0.02	0	0	0	0	0
4. Selection / Thinning	0.05	0.02	0.01	0	0	0
III. Site preparation method						
A. Mechanized						
1. Pile & Burn	0.15	0.12	0.10	0.05	0.05	0.05
2. YSM Tractor	0.10	0.08	0.05	0.03	0.03	0.03
3. YSM cable	0.05	0.02	0	0	0	0
4. Crush / Chip	0.04	0.02	0.02	0.02	0.02	0.02
B. Non-mechanized						
1. Broadcast burning L-M	0.08	0.05	0.02	0	0	0
2. Hand pile & burn	0.05	0.02	0	0	0	0
3. Lop & scatter slash	0	0	0	0	0	0
C. Herbicides	0	0.05	0	0	0	0
D. Rip / obliterate skid trails	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
E. Hand grubbing	0.10	0.05	0	0	0	0
F. Disc (not plowed)	0.07	0.05	0.02	0	0	0
IV. Wildfire						
A. Crown (0-10% CC)	0.30	0.30	0.20	0.10	0.05	0
B. High intensity (10-40% CC)	0.18	0.15	0.10	0.05	0	0
C. Moderate intensity (40-60% CC)	0.05	0	0	0	0	0
D. Low intensity (60+% CC)	0	0	0	0	0	0

(Kuehn and Cobourn 1989, Carlson and Christiansen 1993) greater consideration of the effects of fire than do most other models. Sixth, the model has been implemented in the Sierran National Forests and data is available for comparison purposes.

Region 5 of the Forest Service originally developed the ERA approach to assess channel destabilization. Over time the system has been broadened to include a number of other cumulative impacts sources and effects. Because susceptibility to cumulative effects varies with soil condition, climate and other factors, coefficients linking activities to effects may be developed uniquely in different geographic regions. In the Sierra Nevada each National Forest has its own Equivalent Roaded Area method with unique coefficients (see Berg, Roby and McGurk 1996). We have chosen to work most closely with the Eldorado ERA system due to the recommendation of specialists in the field and Forest Service personnel involved in cumulative effects analyses. These experts considered it to be one of the best developed and tested systems in the Sierra.

Before initiating any activity creating cumulative impacts the ERA method is used to determine the current condition of the watershed and to evaluate the natural sensitivity of that watershed to cumulative effects. A threshold of concern (TOC, explained more fully below) is established and if the TOC ranks below the measure of current condition (%ERA) planned projects are postponed, mitigated or eliminated. Either the watershed must recover sufficiently before new activities can occur or the watershed must have some of its features such as roads and harvest areas restored.

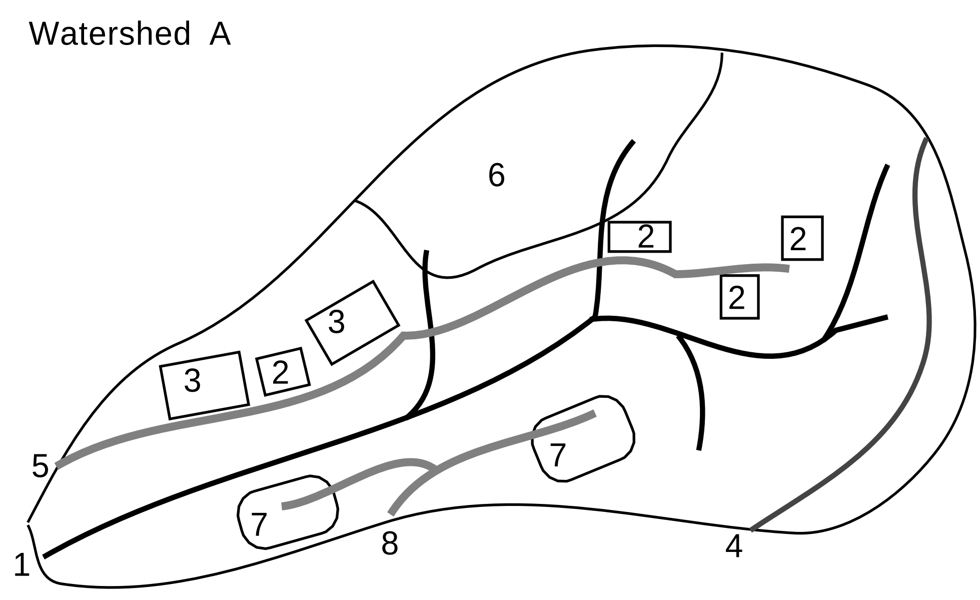
As a quantitative accounting method the ERA approach also may be used to determine the additional risk or effect an activity might contribute if the planned action were implemented. This accounting allows for better planning before project implementation to lessen, if necessary, possible adverse effects. If high or very high risks are found, then there must be a much more thorough investigation of the current condition of the watershed. If the model's results are validated the project is allowed to proceed only if effects are reduced to acceptable levels.

A CWE example: Applying the ERA method

In the CWE analysis, each watershed-disturbing activity is measured in a common currency: a dirt road with good drainage, one acre in total surface area. According to the Eldorado National Forest Cumulative Off-Site Watershed Effects (CWE) Analysis Process guide "a road surface is considered to be the most extreme type of disturbance in terms of increasing or concentrating water flows and sediment production" (Carlson and Christiansen 1993). A dirt road surface is given an ERA value of 1.0 and all other activities and impacts are measured in this currency relative to these roads.

Each watershed-disturbing activity has a coefficient based upon the type of activity and the amount of time since that activity occurred (table 1 below). A clearcut, for example, has a coefficient of 0.25 for the first year which tapers off over time to 0.08 in the fiftieth year. A maintained road starts at 1.0 and remains that way unless restored or abandoned.

Figure 2: Eldorado ERA Method: example of an ERA calculation for a watershed



These coefficients were developed by the Eldorado National Forest (Kuehn and Cobourn 1989) and have been modified by the Forest for more recent use source (Carlson and Christiansen 1993). The revised method determines coefficients with a best fit regression on coefficients from the earlier source. The Eldorado's new coefficients are fit to a continuous curve, start off higher and recover more quickly in time.

All coefficients are based on the assumption of full implementation of Best Management Practices. Each year, the success of BMP implementation is assessed and reported to the regional office. In 1994, for example, the Forest Service found approximately 85% effectiveness in implementation of BMPs on the Eldorado National Forest (Christiansen, personal communication 1995).

Within each watershed the total number of acres is determined. Next, the total number of acres of each kind of activity is calculated. For example, a certain length of road, multiplied by its average width, would has a net area. This area is multiplied by the road coefficient (1.0) to attain the net ERA of roads. Likewise, the acres of 5-year old shelterwood cuts are tallied and multiplied by the coefficient for 5-year old shelterwood cuts (0.15). This process is repeated for each activity in the watershed. These products are summed and divided by the total number of acres in the watershed. A net %ERA is the result. As an example, let us consider a typical watershed, Watershed A (figure 2).

Watershed A (features described below in Table 5) will have all of its current and historical impacts evaluated in order to determine the current %ERA. This value is determined by using the equation,

%ERA = {(miles of roads * road width) *
(coefficient for roads) +
(acres of activity j) *
(coefficient for activity j) + ...+
(acres of activity n) *
(coefficient for activity n)}

To see an example of this method review results in table 3.

An ERA assessment typically includes several components. First, as described above, is an assessment of current roaded equivalence. This assessed value is called the *%ERA*. A watershed, for example, might be found to have 12% ERA disturbance, or 6.8% as in this example.

Second, each watershed is evaluated for its susceptibility to disturbance. This part, the *Natural Sensitivity Index* (NSI), is calculated for each watershed using soils, slope, channel classification, precipitation regime, and a few other variables (see Costick 1996).

Third, each NSI is then converted to a *Threshold of Concern* (TOC) based upon ranges of sensitivity. The more sensitive to disturbance the watershed, the lower its threshold of concern. For example, an NSI score of 13 is considered very low and corresponds to a high threshold of concern: 18-20% ERA. In other words, since the watershed is relatively resistant to impact more land can be disturbed without exceeding thresholds. In contrast, a watershed with a high NSI score such as 55 is high risk and a low TOC is established: 10-12%.

For the Eldorado National Forest this correspondence is demonstrated in Table 2.

Table 2: Natural Sensitivity Index (NSI) and linkage to Threshold of Concern (TOC)

NSI	Sensitivity	TOC
<15	Very low	18-20% ERA
16-35	Low	16-18% ERA
36-50	Moderate	14-16%
51-65	High	12-14%
>65	Very high	10-12%

(Carlson & Christiansen 1993)

Table 3: Eldorado ERA Method: Features of Watershed A (3500 acres)

#	description	extent (acres)	coefficient (from tab. 1)	total ERA
1	Stream			
2	Clearcut—100 acres, 2 years old	100	0.24	24
	pile and burn tractor treatment	100	0.12	12
3	Overstory removal—200 acres, first year	200	0.20	40
	broadcast burn	200	0.08	16
4	Recreational trail—total area (length X width), 3 acres	3	1.0	3
5	Road System—good drainage, 20 acres	20	1.0	20
6	Crown fire—5 years old, 500 acres (flame length 14')	500	0.2	100
7	Clear cut & seed tree cut—300 acres, 50 years old	300	0.08	24
8	Ripped and obliterated road—10 acres, 50 years old	10	0.1	1
total		**1433**		**238**
%ERA calculation		**238 ERA / 3500 total Acres = 6.8%**		

Table 4: Eldorado Natural Sensitivity Index (NSI) coefficients and calculations

NSI Attributes	**Total Acres in category**	**Index Factor**	**Index Total** (product of prev. columns)
I. Attributes Affecting Runoff Processes A. Horton Overland Flow 1. Rock Outcrop		1.0	
2. Hydrologic Soil Group D		0.8	
3. Hydrologic Soil Group C		0.4	
B. Saturation Overland Flow 1. Wet meadows		1.0	
2. Ponds		1.0	
3. Streamside Management Zones		1.0	
II. Attributes affecting sediment delivery A. Erosion from highly erosive soils 1. Soils prone to gully erosion		1.0	
2. Soils with a very high EHR (includes altered/eroded phases)		0.5	
B. Erosion from mass wasting 1. All active forms of mass wasting		8.0	
2. Inner gorge		2.0	
C. Channel Erosion 1. Aggradation		1.0	
2. Degradation		1.0	
3. Lateral scour and bank erosion		4.0	
Subtotals for Natural Sensitivity Attributes			a. Sum of products above

III. Drainage basin and channel morphology affecting sediment routing processes	Index Factor				
	Low	Moderate	High	Extreme	
A. Relief ratio (feet/feet)	0.9	1.0	1.1	1.2	coefficient selected from the left
B. Drainage density	0.9	1.0	1.1	1.2	ditto
C. Precipitation regime (snow, rain, rain/snow)	0.8	1.0	1.2		ditto
D. Channel classification 1. Rosgen: % length by sensitivity	%	%	%	%	often this data is not available and coefficient 1 is used here
Index value					ditto
2. Pfankuch: % length by sensitivity	%	%	%	%	ditto
Index value					ditto
Product for Channel morphology attributes					b. Product of coefficients immediately above
Weighted percentage of Watershed classified sensitive	(Sum of Part II: 'a') /		(Total Acreage) =		c.
Natural Sensitivity Index (NSI)	(answer from 'c') x		(product of sect. III:'b') =		
Threshold of Concern (TOC)					from table 2

(Carlson & Christiansen 1993. This table is currently being modified by the Eldorado National Forest)

When a TOC has been established for a watershed it is compared to the current condition of the watershed (%ERA). First, if the *current* watershed condition (%ERA) exceeds the TOC, existing management activities in the watershed must be eliminated or postponed until the area is sufficiently recovered, restored, or mitigated. As shown in table 1, the effects of various activities taper off with time, so activities might be allowable after some time has passed and the effects of current CWE sources have declined. The ERA calculation serves a second purpose which is to determine whether a *proposed* activity will result in an ERA level below the TOC. If the ERA level exceeds the TOC, the activity might be altered to lessen its impact and could then be allowed. If either the current condition (%ERA) or proposed activity (calculated ERA) exceeds the TOC one option is to restore features in the watershed such as roads, thereby reducing overall %ERA.

In contrast to situations in which activity should not be allowed, ERA analysis may reveal that certain activities can proceed without risk of watershed disturbance. A watershed with a high TOC and a low %ERA, for example, is in sufficiently good condition to allow further activity in the watershed without exceeding disturbance limits.

In the case of Cat Creek, shown at the top of Table 5, the threshold of concern (10) is below the current %ERA (13.8). Correspondingly, the watershed risk factor is rated, “very high.” No further management activity producing cumulative effects will likely occur in this watershed before some CWE sources in the watershed are restored through natural processes or an intensive restoration effort. An exception occurs if the project is determined to be of little consequence based on site-specific evaluations. Other watersheds listed in the table have current %ERA levels below the threshold of concern. From a cumulative effects perspective, more activity would be allowable in these watersheds as long as the new activities do not cause the thresholds to be exceeded.

Table 5: An example of Cumulative Watershed Effects analysis on the Eldorado National Forest

(Analyses of the current condition of watersheds in the Sierran National Forests, including the Eldorado National Forest, are at various stages of completion. The following data are informal and unpublished and are provided here as an example, they are not final).

Cosumnes Basin Watershed: Cumulative Watershed Effects Risk Determination					
Watershed name	**Total Acres**	**NSI**	**TOC**	**Risk**	**‘95 %ERA**
Cat Creek	5571	93	10	Very High	13.8
Van Horn	1206	116	10	Medium	6.4
Sopiago	7701	43	14	High	11.9
Upper Camp	8320	52	12	Medium	7.8
Upper North Fork Cosumnes	13858	53	12	Medium	7.5
Scott	5736	22	16	Medium	10.0
Clear	2869	32	16	Medium	9.8
Middle Dry	3414	33	16	Medium	8.7
Dogtown	6834	63	12	Medium	6.0
Middle Middle Fork Cosumnes	9665	60	12	High	10.0
McKinney	3037	29	16	Low	6.3
Upper Steely	7028	28	16	Low	7.4
Lower Middle Fork Cosumnes	4454	92	10	Low	4.7
Lower Camp	10166	92	10	Medium	6.6
Anderson Canyon	3328	72	10	Medium	6.4
Lower North Fork Cosumnes	2926	160	10	Medium	5.3
Pleasant Valley	6960	28	16	Medium	8.0
Darlington	480	41	14	Low	4.3
Middle Camp	9590	42	14	Low	3.9
Big Canyon	3515	25	16	Low	3.7
Jenkinson Res.	2944	36	14		
Hazel Creek	1738	33	16		
Sky Park Creek	6438	42	14		
Big Pebble	755	32	16		
Middle North Fork Cosumnes	6278	70	10		
Lower Steely	6977	73	10		
L. Lower Middle Fork Cosumnes	2513	193	10		
Upper Middle Fork Cosumnes	9218	83	10		
Average	**5483**		**12.9**		**7.4**

(Christiansen, Eldorado National Forest, Personal Communication)

III A MODIFIED APPROACH TO MODELING CWE WITH ERA

Adaptation of the three ecological regions into the model's two riparian zones

The aquatic and riparian system developed by D. C. Erman, N. Erman, L. Costick and S. Beckwitt (Discussed in Section I of this paper, and reported in Kondolf, et al. 1996, and Kattelmann and Embury 1996) is being incorporated into the SNEP policy analysis in two zones. An inner tier, called the "green" zone, merges the first two regions described in the first section of this paper—Community Influence and Energy Influence regions. The height of one tree is approximated by designating the width of this area as 150 feet on each side of the stream. The outer tier, corresponding to the Land Influence Region, is represented in this model's variable-width "grey" zone. While the width of this outer tier should depend on soils information and slope, our analysis is using only slope data since a complete soils coverage for the entire Sierra is not currently available.

In these policy analyses, ERA goals and limits are expressed in two ways. First, disturbance limits based on the ERA approach of assessing watershed disturbance constrain road building and harvest-related management activities within each riparian zone in the various management strategies (see Sessions, et al. 1996). Second, late-successional goals for the forest in each zone are set using the LS/OG rank system developed by Franklin and Fites (1996).

Rules for determining the buffer widths of the variable "grey" zone

Buffer calculations assume streams are without associated wetlands or aquatic habitats that would expand beyond the narrowly defined "streambank" zone. Consideration of such habitats in our model would require collection of additional information on the extent of the wetland and would development of new rules for computing the buffer. While this important information for site-specific management it is not available at the Sierra-wide scale of SNEP analysis and would probably have a marginal effect on model outputs. For these reasons all streams are considered to be confined to their banks.

The minimum width of a outer riparian buffer (grey zone) is *150 feet*. This distance is a first approximation of the distance needed to provide a supply of terrestrial energy sources, large wood, and a minimum amount of habitat for riparian-dependent species. In no case would the grey zone be smaller than the green zone.

Buffer width is determined based on this weighted slope average (see Kondolf, et al. 1996; Kattelmann and Embury 1996):

$$\text{Buffer zone (ft)}=(150)e^{(1+\text{slope})}$$

Steepness of the slope perpendicular to stream segments is determined by calculating a weighted average of five slope segments generated from Digital Elevation Model (DEM) data. These segments, in 30 m increments, stretch out to five units (150 m) from the watercourse. The zone closest to the stream is weighted 5, the next is 4, and so on until the most distant slope segment being weighted 1 in order to emphasize that slope closest to the stream has the greatest effect. Slope is used in decimal form of percentage. An 18% slope, for example, would be 0.18.

If soil and geological hazard data (k) values of detachability are available for the particular forest being modeled, then the exponential portion is modified by $e^{(1+s+K-sK)}$. Subtraction of the probability cross-product is a common correction term to multiple probability-type exponential functions, for example, two forms of population mortality.

ERA limits in the different zones

Why this model does not use a traditional Threshold of Concern (TOC)

Due to a lack of geomorphologic and soils information current data is insufficient to determine traditional Natural Sensitivity Indices and corresponding Thresholds of Concern (TOC) for each CalWater Planning Watershed in the Sierra Nevada. If thresholds of concern had been developed by the Forest Service or other agencies for each watershed in a consistent fashion we could use this data. Since the federal agencies have not yet completed these analyses, however, we decided to treat the landscape in a slightly more uniform fashion. Because SNEP is not attempting to develop a comprehensive management plan but is attempting to paint a broad picture of the current state of the Sierra and assess different strategies projected into the future, a looser approach, which does not consider site-specific sensitivity data from each individual watershed, has been deemed acceptable by the team. The mean result of many watersheds should be similar to an actual analysis of many watersheds averaged. Hence, for modeling purposes, activity will be limited by standard ERA limits (ERAL), and not TOCs established for each watershed as is done by the Eldorado National Forest.

Limits on Watershed Disturbance being considered in this modeling effort

The ERA method, as implemented by the Eldorado National Forest, is non-spatial. No distinction is made between impacts that are close to the stream and those far away that probably have less effect on in-stream conditions. Unfortunately, little research has been done to link %ERAs to in-stream conditions for *entire* watersheds. Studies that have attempted to link ERA levels from entire watersheds—including uplands—to in-stream conditions have not found distinct and consistent relationships.

A series of studies by D. C. Erman with his students and colleagues were recently re-analyzed by McGurk and Fong (1995) and a positive correlation was found between %ERA levels within 100 meters of first and second order streams and in-stream invertebrate diversity. The ERA system used is comparable to the one being adapted from the Eldorado National Forest for use in this model (McGurk, personal communication 1995). In McGurk and Fong's analysis, a %ERA of fifteen percent inside the 100m buffer strip represents the point at which the Shannon-Weaver Biodiversity Index for in-stream invertebrate diversity drops by 50%. The index begins dropping noticeably around 5% ERA.

Based on this finding, we developed the spatially-sensitive tiered riparian buffer system described in this paper that is used to analyze ERA impacts first in the inner "green" zone, second in the "grey" zone, and third in the uplands of the watershed. This system serves two vital functions. First, this approach more closely approximates the aquatic and riparian ecological regions described in Section I than does the traditional ERA approach. Second, the system allows better consideration of the distance between a road, fire, or harvest and the stream that the activity might affect with respect to McGurk and Fong's finding (1995). Our vegetation dynamics model can then limit activity in watersheds or LS/OG polygons with an allowable ERAL in each of these three zones.

Aquatic and riparian systems are most influenced by activity close to the stream itself. Hence, the strictest limits on watershed disturbance are in this inner green zone. An intermediate ERAL is set for the grey zone and a more permissive ERAL is established for the outer zone. As a result of McGurk and Fong's analysis, we have established an initial ERAL for the green zone of 5%. The green zone is 150 feet, or approximately 46%, of the 100m buffer assessed in the McGurk and Fong analysis. An intermediate limit of 10% has been established for the broader grey zone and 15% has been set for the uplands.

On the Plumas and Eldorado National Forests the green zone occupies 13% of the landscape, the grey zone 33% and the uplands contain the remaining 54% (see Sessions, et al. 1996). With ERALs as described above—5%, 10%, 15%—in the three zones, the overall average %ERA across the forest is 12%.

In comparison, the Eldorado National Forest has TOCs—the equivalent of the ERAL we are using—averaging 12.0% for entire watersheds. The watersheds range from 10 to 18% with very few watersheds across the entire forest rated higher than 14% (Data were supplied by Eldorado National Forest which determined TOCs for ninety-one of 153 watersheds).

In preliminary analyses of SNEP projections of harvest management the ERA limits (ERAL) were found to greatly constrain the range of possible outcomes (see Sessions, et al. 1996). In order to explore a wide range of forest policies, we therefore examined several ERAL sets with different limits. Three different ERAL sets are analyzed to determine the degree to which they affect the quantity of roads, timber harvest and other activities in the watershed. The second set of limits, meant to simulate more permissive timber harvest activities as might exist on private lands, is 5% higher in each zone: 10%, 15% and 20%. Across the entire forest these limits would average 17% per watershed. The third ERAL set, intended to simulate a very protective strategy, has limits of 5%, 5% and 10%. These limits were examined on all watersheds in the Eldorado and Plumas National Forests where they average 7.7%.

ERA coefficients also were modified by the SNEP project. We added a grazing coefficient (Table 6, part V), revised fire coefficients to reflect ground fire intensity instead of canopy coverage remaining (Table 6, part IV), and added a steepness factor of 1.5 for transportation systems on slopes over 40% (Table 6, part I; see Sessions, et al. 1996).

Assumptions about private lands

Many watersheds along the Forest boundary contain a mix of ownerships. In these cases, federal land management may be limited due to cumulative effects from harvest activities on private lands. The opposite is possible, as well, but is probably the exception.

SNEP has little information about the current condition of private lands in the Sierra Nevada. Many federal land managers involved in assessing cumulative effects, however, feel that private lands are significantly more impacted than federal lands. Since SNEP has little direct data on watershed disturbance on private lands we are making some educated assumptions.

For the current condition on the *upland* regions of non-federal lands we are assuming an average ERA coefficient of 0.20. This assumed coefficient could result from any of a number of probable ERA coefficient combinations. For example, an ERA coefficient of 0.20 could be derived from an average condition of a 20 year old mechanized pile and burn operation (rated 0.05 after 20 years) combined with a 20 year old overstory removal harvest (0.10) and a background road density of 1/20th acre of road per acre. Similarly, an ERA coefficient of 0.20 per acre could represent an uniform condition of an overstory removal operation (0.20) with no other effects. Several scientists and managers familiar with the Eldorado ERA method think these assumptions represent a crudely appropriate assessment of conditions in the uplands in private lands. In comparison, the analysis above, of the second proposed ERAL set, yields an average ERA of 17% on the National Forest lands if ERALs are set at 10%, 15% and 20%.

The California Forest Practiœ Rules provide for more protection for aquatic and riparian systems than for the uplands (see Menning, Johnson & Ruth 1996). Since much of the private land acreage in the Sierra is commercial timberlands these rules apply to harvest activities on these lands. The more restrictive nature of the riparian rules are estimated to prohibit activities that would exceed a %ERA of 10%. The exception would be where roads historically were built in the narrow riparian zone before regulations constrained the development of roads in these sensitive regions.

Table 6: SNEP ERA coefficients based on Kuehn and Cobourn (1989)

Activity or Impact	**Years since impact**					
	1	2	5	10	20	50
I. Transportation system	*(multiply road coefficients by 1.5 when slope is > 40%)**					
A. System & non-system roads and landings						
1. good drainage	1.0	1.0	1.0	1.0	1.0	1.0
2. poor drainage	1.5	Fixing road during problems associated with ditches, culverts, etc.: coefficients return to 1.0				
3. diversion potential	2.0	Same comment as above				
B. Abandoned roads and landings	1.0	0.9	0.9	0.8	0.8	0.8
C. Trails (recreational)	1.0	1.0	1.0	1.0	1.0	1.0
D. Ripped and obliterated roads and landings	0.4	0.3	0.3	0.2	0.1	0.1
II. Silvicultural system						
A. Tractor (includes impact due to skid trails)						
1. Clearcut and seed tree	0.25	0.24	0.20	0.15	0.10	0.08
2. Shelterwood	0.22	0.20	0.15	0.10	0.10	0.08
3. Overstory removal	0.20	0.16	0.12	0.10	0.10	0.08
4. Sanitation / Salvage	0.15	0.10	0.08	0.05	0.05	0.04
5. Selection / Thinning *(Selection/Thinning as modified by SNEP)*	*Due to the absence of clearcuts in the SNEP model, heavy selection cuts are projected. Coefficients vary between 0.08 and 0.2 based on the amount of timber removed. These coefficients taper off over time (see Sessions, et al. 1996)*					
B. Cable						
1. Clearcut	0.15	0.14	0.10	0.05	0	0
2. Overstory removal	0.10	0.06	0.02	0	0	0
C. Helicopter						
1. Clearcut & seed tree	0.10	0.09	0.05	0.02	0	0
2. Overstory removal	0.05	0.05	0.05	0	0	0
3. Sanitation / Salvage	0.02	0	0	0	0	0
4. Selection / Thinning	0.05	0.02	0.01	0	0	0
III. Site preparation method						
A. Mechanized						
1. Pile & Burn	0.15	0.12	0.10	0.05	0.05	0.05
2. YSM Tractor	0.10	0.08	0.05	0.03	0.03	0.03
3. YSM cable	0.05	0.02	0	0	0	0
4. Crush / Chip	0.04	0.02	0.02	0.02	0.02	0.02
B. Non-mechanized						
1. Broadcast burning L-M	0.08	0.05	0.02	0	0	0
2. Hand pile & burn	0.05	0.02	0	0	0	0
3. Lop & scatter slash	0	0	0	0	0	0
C. Herbicides	0	0.05	0	0	0	0
D. Rip / obliterate skid trails	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
E. Hand grubbing	0.10	0.05	0	0	0	0
F. Disc (not plowed)	0.07	0.05	0.02	0	0	0
IV. Wildfire *as modified by SNEP*	*(multiply fire coefficients by 1.5 when slope is > 40%)**					
A. *flame length ≥12’*	*0.2 in period 1*	*0.075 in period 2*	*0.025 in period 3*	*0 in period 4*		
B. flame length ≥8’	*0.102 in period 1*	*0.025 in period 2*	*0 in period 3*			
C. flame length ≥4’	*0.005 in period 1*	*0 in period 2*				
*V. Grazing in flat riparian areas**	*0.0133*	*0*	*0*	*0*	*0*	*0*

(based on Kuehn and Cobourn 1989; also see Carlson & Christiansen 1993)

* All the items in italics—selection harvest, grazing coefficients and corrections for slopes over 40%—are SNEP modifications to the Eldorado method based on (1) meetings of cumulative watershed specialists convened by the Sierra Nevada Ecosystem Project in May, 1995, and (2) subsequent analyses by Sessions, et al. (1996).

In an analysis of road densities in the inner "green" riparian zone on private lands within the Eldorado and Plumas National Forest boundaries we found that roads contributed approximately 1.7% to %ERA in these non-federal inner riparian zones. Assuming that %ERA in riparian zones is high where there are roads located near the stream and very low where roads are not placed in the riparian zone we have assigned different %ERA contributions to these differently impacted riparian zones. In riparian areas with roads within 150 feet of the stream the model assumes a %ERA of 18% based on the following data: roads represent an average 30 foot strip within the 300 foot buffer, or 10% (coefficient 0.10); typical low-level harvest activity such as selection harvests contribute about 8% (0.08) for a total of 18% (coefficient of 0.18). In riparian areas without roads within 150 feet of the stream we assume an average selection harvest %ERA of 8% (coefficient of 0.08) from an average background of 50 year old selection and thinning harvest.

In sum, for private lands, we assume an average %ERA within the inner riparian zone of 18% if there is a road within this zone; 8% if no road is present; and in the uplands we assume a uniform 20%.

An example of a Cumulative Watershed Effects analysis using the modified ERA method

In contrast to the non-spatial ERA calculation provided earlier, SNEP's analysis explicitly takes into account the location of watershed-disturbing activities relative to the riparian zones. For example, In this case the ERA ranges from 7.3% in the upland areas to 6.8% in the grey zone to 5.5% in the inner green riparian zone. Thus, our approach allows us to consider the proximity of sources of cumulative effects in relation to the streams they affect. We can use this method to both assess current condition, as we have in this example, or to determine whether future activities will exceed thresholds. In this case we might specify that future activities must occur in the uplands and not in either of the riparian zones.

Figure 3: SNEP ERA Method: calculation of ERA with inner and outer riparian zones

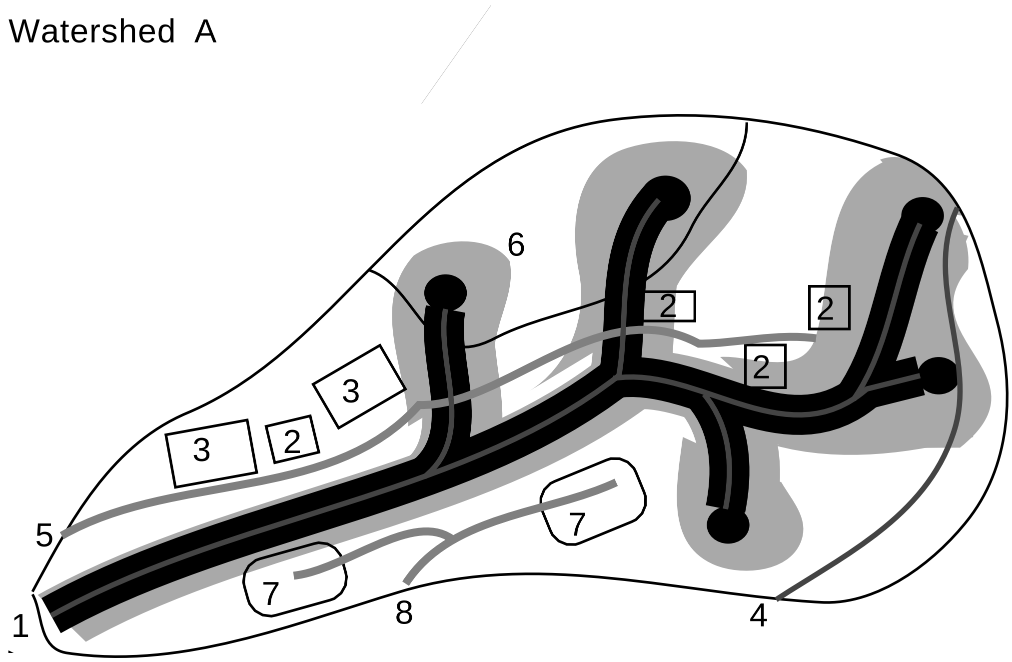


Table 7: Modified ERA Method: Inner riparian "green zone"—500 acres

#	description	extent in this zone (acres)	coefficient (table 1)	total ERA
1	Stream			
2	Clearcut—100 acres, 2 years old	15	0.24	3.6
	pile and burn tractor treatment	15	0.12	1.8
3	Overstory removal—200 acres, first year	0	0.20	0
	broadcast burn	0	0.08	0
4	Recreational trail—total area (length X width), 3 acres	0	1.0	0
5	Road System—good drainage, 20 acres	2	1.0	2
6	Crown fire—5 years old, 500 acres (flame length 14')	100	0.2	20
7	Clear cut & seed tree cut—300 acres, 50 years old	0	0.08	0
8	Ripped and obliterated road—10 acres, 50 years old	0	0.1	0
total		**132**		**27.4**
%ERA calculation		**27.4 ERA / 500 acres = 5.5%**		

Table 8: Modified ERA Method: Outer riparian "gray zone"—1000 acres

#	description	extent in this zone (acres)	coefficient (from tab. 6)	total ERA
1	Stream			
2	Clearcut—100 acres, 2 years old	45	0.24	10.8
	pile and burn tractor treatment	45	0.12	5.4
3	Overstory removal—200 acres, first year	5	0.20	1
	broadcast burn	5	0.08	0.4
4	Recreational trail—total area (length X width), 3 acres	1.5	1.0	1.5
5	Road System—good drainage, 20 acres	6	1.0	6
6	Crown fire—5 years old, 500 acres (flame length 14')	200	0.2	40
7	Clear cut & seed tree cut—300 acres, 50 years old	30	0.08	2.4
8	Ripped and obliterated road—10 acres, 50 years old	0	0.1	0
total		**337.5**		**67.5**
%ERA calculation		**67.5 / 1000 = 6.8%**		

Table 9: Modified ERA Method: Uplands—2000 acres

#	description	extent (in acres)	coefficient (from tab. 6)	total
1	Stream			
2	Clearcut—100 acres, 2 years old	40	0.24	9.6
	pile and burn tractor treatment	40	0.12	4.8
3	Overstory removal—200 acres, first year	195	0.20	39
	broadcast burn	195	0.08	15.6
4	Recreational trail—total area (length X width), 3 acres	1.5	1.0	1.5
5	Road System—good drainage, 20 acres	12	1.0	12
6	Crown fire—5 years old, 500 acres (flame length 14')	200	0.2	40
7	Clear cut & seed tree cut—300 acres, 50 years old	270	0.08	21.6
8	Ripped and obliterated road—10 acres, 50 years old	10	0.1	1
total		**963.5**		**145.1**
%ERA calculation		**145.1 / 2000 = 7.3%**		

IV SUMMARY

The SNEP policy analysis team has considered a number of Cumulative Watersheds Effects analysis methods and has chosen to adopt and modify the ERA approach because this method (1) is a useful accounting system for tallying and limiting disturbance within watersheds; (2) has been tested and implemented in the Sierra Nevada by federal agencies and has been approved for use by the state of California; (3) has been linked to in-stream levels of biological diversity; (4) allows for spatially-sensitive consideration of watershed-disturbing events; and (5) permits inclusion of road, fire, slope and grazing factors in assessing cumulative effects. Although our application of the modified ERA method is imperfect and lacks site-specific information about the natural sensitivity of watersheds, it allows us to model a large-scale region—a range of mountains as large as the Sierra—and can help allocate and limit management activities to individual watersheds within that large area.

In addition, this ERA methodology sets up a new approach to riparian buffers, breaking from the traditional approach of having larger buffers as the stream gets larger. The approach in this model is rooted in the theory that as streams get smaller the zone that influences them grows larger. Such a strategy should help to ensure that (1) streams get functional energy and nutritional inputs from riparian zones; (2) riparian habitat is maintained for transitory and obligate species; (3) steeper slopes are more protected from timber-harvest activity; and (4) in-stream aquatic biodiversity is minimally impacted.

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