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Indexing Current Watershed Conditions Using Remote Sensing and GIS

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ABSTRACT

Two objectives of the Sierra Nevada Ecosystem Project (SNEP) were to evaluate the current condition of watersheds in the Sierra Nevada and to identify physical processes such as soil erosion that effect watershed health and sustainability. In response to this request for a resource inventory an indexing or screening model has been developed that produces both an Natural Erosion Potential (NEP) and Sedimentation Hazard Index (SHI) which are indicators of the "current cumulative condition" in watersheds of the Sierra Nevada.

The goal of the study undertaken here is to design and test a methodology using geographic information systems (GIS) and remote sensing to rank watersheds prone to soil erosion and locate specific sites where stream sedimentation is likely to occur. One hundred and thirty-four watersheds on the Eldorado National Forest (ENF) were analyzed and ranked using a method which selects the parameters of slope, cover, and soil detachability that were assumed to be the most significant contributors to soil erosion, given uniform climatic conditions. Threshold values established for these parameters provided the link to locations where there is a high probability of sediment reaching the watercourse.

Correlation with US Forest Service equivalent roaded acres (ERA) and cumulative watershed effects (CWE) work previously completed and in progress on the ENF was positive when compared to NEP and SHI rankings created by this model. Additional correlation opportunities yet to be implemented using change detection techniques with Landsat TM imagery, spectral mixture analysis (SMA) with high resolution AVIRIS imagery, and the identification of large rock outcrops are expected to improve results. The model described here gives the resource manager a tool which can be used to quickly screen proposed CWE assessment areas and focus both human and financial resources on potential "hot spots." Once located, the cumulative effects benefit of a specific mitigation opportunity may be evaluated as to its cost and to the watershed improvement that it provides.

Keywords: cumulative effects; erosion; watersheds; resource management; forest management; forest roads; erosion control mitigation.

EXECUTIVE SUMMARY

HR 5503 and HR 6013 both requested assessments and inventories, by an independent group of scientists, to evaluate the current condition, health and sustainability of the Sierra Nevada. In order to insure these ecosystems are healthy and sustainable both agency and private land owners must be able to exchange cumulative effects information about their individual activities accurately, quickly and in similar formats. The assumption that a readily available, standardized, data set capable of producing information for a diverse group of scientists was erroneous.

Watersheds represent distinct topographic units and the understanding of there health and condition cannot be limited by ownership. Current condition is the culmination of all cumulative past events and the ecosystems response to those events whether natural or management induced. Implementation of management strategies may be unique to ownership; however, in order to account for mitigation activities in mixed ownership watersheds, when assessing for CWE, all disturbance activities must be calculated. The accuracy of assessments of this nature are dependent on the quality of the data base being utilized, and the lack of a homogeneous soil layer for either the study region or any of the sub-regions has severely hindered the progress of this work. A standardizes soils and disturbance history data base is needed that will provide resource managers, both public and private, the information they need for economically and environmentally sound decision making.

Soil erosion is one of the processes specifically mentioned in HR 6013 for evaluation. The susceptibility of soils and their underlying geologic units to mass failure and rill and gully erosion are part of this process. A healthy watershed, as defined here is an area of land, having the structure and density of forest stands to support a diverse wildlife population. In addition it has the natural stability of geology and soils to maintain the contribution of eroded sediments, reaching streams, at a level where natural hydrologic processes, balances the ability of the system to both store and transport these sediments without degrading aquatic habitats.

The model constructed for this study identifies sites with high potential for producing sedimentation. The hypothesis is that risk of erosion is a function of slope, soil detachability and bare unprotected ground. The risk of erosion becoming sediment is increased as a function of road location in proximity to streams and decreases in the presence of riparian vegetation buffers near streams.

This model yields a relative ranking for each Cal-Water planning watersheds without the need of extensive field surveys. Information is generated which ranks watersheds: one, in order of their natural sensitivity or their inherent erosion potential and two, predicting the probable origins of sediment to be used as guides for future mitigation activity. Its results are: significantly less costly to produce, objectively generated, easily updated, responsive to changes in elevation and precipitation conditions and minimize data corruption. Predicting the potential for erosional of a given unit area of land is the objective of this methodology it is intended to index “current condition”, or “watershed health”, for individual planning watersheds relative to their neighbors and given similar climatic conditions. It has been designed as a primary screening tool and environmental accounting system which provides objectively generated data to decision makers.

Because this study is a screening process which attempts to focus the resource managers attention on the most acute problem areas, potential sedimentation is its’ primary consideration. This tool allows the manager to optimize both environmental and economic investment strategies by locating those areas which have the greatest impact on cumulative watershed effects and selecting the mitigation which is most cost effective. Thinking of this as an environmental accounting system allocates resources to those projects which have the most immediate impact on cumulative effects.

INTRODUCTION

<u>Congressional Authorization and Mandate</u>

Although, The Sierra Nevada Ecosystem Study Act of 1992, HR 6013 was not passed because of House adjournment, the bill requested the inventory of watersheds to evaluate their condition and to identify physical processes that affect watershed health and sustainability. Soil erosion is one of the processes specifically mentioned for evaluation. In a January 19, 1993, House Committee on Natural Resources Chairman George Miller sent a letter to US Forest Service (USFS) Chief Dale Robertson, that further defined the intent of Congress after the passage of, The Conference Report for Interior and Related Agencies 1993 Appropriation Act, HR 5503. He said "In order for this (assessment) effort to succeed and be credible it is imperative that an independent panel of scientists with expertise in a variety of forest disciplines be appointed to work with the many knowledgeable experts within the USFS... As this study will be conducted in a relatively short time frame, we do not expect that the panel will be gathering data from the field, but will compile existing information from the number of agencies and organizations involved in forest research in the Sierra Nevada range." It is likely that this statement assumes a readily available data set at resolutions, formats, and in units capable of producing combined information for a diverse group of scientists. The letter further states, "This study should provide the Congress with the comprehensive data needed to make important policy decisions concerning future management of the Sierra Nevada forests. It is our hope ... we can identify management alternatives that will assure the long-term health and sustainability of these forest ecosystems." This statement implies that scientists similar to the science team involved in the Sierra Nevada Ecosystem Project (SNEP) will be successful in determining the current "health" of these forest ecosystems and, from this base of information, generate a variety of management scenarios that will ensure their sustainability.

In 1995 after the 192nd Congress revised Committee assignments, newly appointed USFS Chief Jack Ward Thomas received correspondence prioritizing the Committee's expectations of SNEP's efforts and restated some specific products that were anticipated. As in previous correspondence and legislation, lands systems inventories, watershed health condition assessments, and insights into processes were high priorities. Management scenarios are to be formulated based on the results of the SNEP assessments, once more stressing the importance of understanding current watershed condition.

Sustainability of forest ecosystems in both the eastern and western United States depends on understanding the "current cumulative condition." In order to gain this understanding at a regional scale one must have information on what resource elements are present and how are they distributed, regardless of ownership. Providing this information in a standard format or as a standard tool to all consumers is an appropriate role of government. Congressional authorization of matching funds for resource unit inventories regardless of land ownership, and incentives for public-private data collection and exchange programs are options that should stimulate the development of these tools. Resource managers need these tools to do their jobs and this is an opportunity to equitably share the costs of data preparation.

Regional Background

Years of grazing, mining, road building, home construction and logging disturbances as well as fire, land slides and plant disease in the California Sierra Nevada has modified forest ecosystems. Present remote sensing technology provides for understanding, monitoring and in some cases quantifying these natural and management induced perdition such as soil loss, changes in vegetative cover, and the consequences of habitat disturbance. There are, however, very few predictive ecosystem models that use spatial and temporal remote sensing data to infer current watershed condition or ecosystem health. Comparison of current condition on a watershed by watershed basis allows us to index ecosystems relative to each other. An accurate indexing methodology is a valuable tool when allocating resources for CWE mitigation or adjudicating disturbance rights among landowners in mixed ownership watersheds.

The methodology presented here assesses the ecosystem, as defined by watershed boundaries, for natural erosion potential and sedimentation hazards. It presents parameters for ecosystem assessment and an accounting system to track and recalculate a watershed condition index. Data on the amount of ground cover, bare soil, soil detachability or sensitivity to erosion as well as slope are used to quantify the ecosystem's sensitivity to accelerated erosion and sedimentation. Geographic information system (GIS) layers of slope, soil type, soil detachability and disturbance history data are integrated to spatially display current relative watershed condition and to focus attention on locations which may be at greater risk of producing sedimentation.

Both national and state environmental quality acts (NEPA and CEQA) require cumulative effects assessment for all projects on private, state, and federal land. Definitions of cumulative effects vary and there are no universally accepted techniques for their measurement or monitoring. Our inability to objectively quantify cumulative effects and the absence of standards for comparison has created difficulty for regulatory agencies. This model aids resource managers and their regulators in objectively analyzing ecosystem complexities with particular regard for cumulative and synergistic impacts of human activity and natural processes.

With the advent of GIS technology spatial analysis procedures are available to quantify both present and historic physical features and land use practices on a landscape basis. From the rates of change in these features, as determined by GIS interpretations of aerial and space imagery, habitat improvement or degradation and habitat potential may be inferred. This model includes several GIS layers that, when analyzed together, provide a more objective view of ecosystem condition.

METHODS

Model Description

In response to the request for resource inventory information by the House Committee on Natural Resources, an indexing or screening model has been developed that produces both an Natural Erosion Potential (NEP) and Sedimentation Hazard Index (SHI) which are indicators of the “current cumulative condition” in the watersheds of the Sierra Nevada. For the purposes of this study a healthy watershed is defined as an area of land, having the structure and density of vegetative stands to support a diverse wildlife population, and having the natural stability of geology and soils to maintain the contribution of eroded sediments reaching streams at a level where natural hydrologic processes balance the ability of the system both to store and transport these sediments without degrading aquatic habitats. In this paper, “erosion” is defined as the detachment and transport of soil particles and “sedimentation” is the deposition of soil particles into the aquatic habitat.

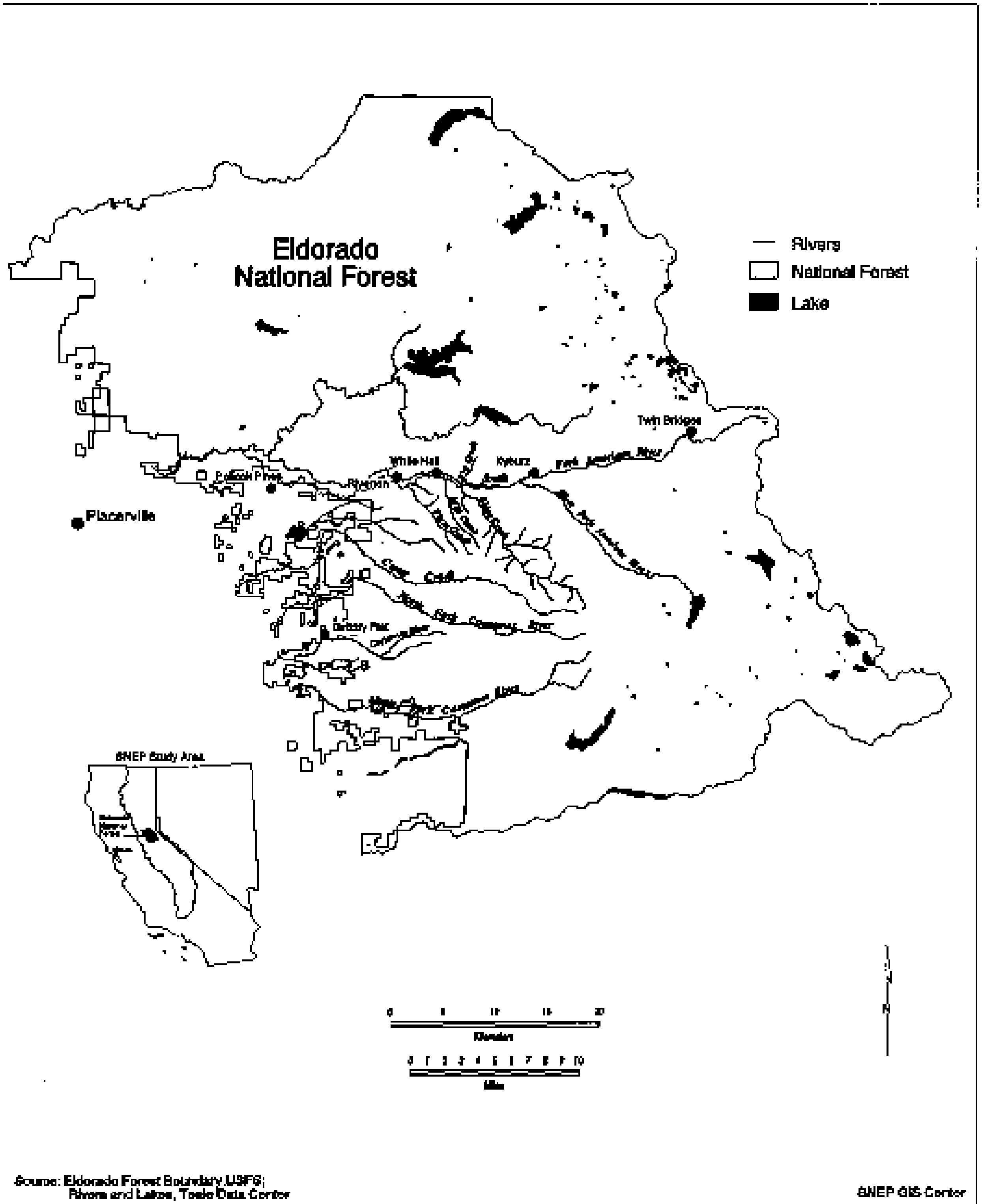


Figure 1 Sierra Nevada Ecosystem Project Study Area Map and Eldorado National Forest

The methodology proposed herein is similar to USFS Region 5's current "equivalent roaded acres" (ERA) method of CWE analysis which has been evolving on the Eldorado National Forest (ENF) since the mid 1980s (Kuehn and Cobourn 1989) (Carlson and Christiansen 1993). However, results from early versions of ERA were considered subjective, difficult to reproduce, and expensive to develop. After two years of compiling data to run the ERA process, it was apparent that a screening model could be developed using remote sensing and GIS that could cut costs and give reliable, objective information.

Watershed characteristics that are used here to assess the relative health of watersheds include an estimate of their natural sensitivity to erosion, and an analysis of the location and number of roads, to allow prediction of probable origins of sediment. The model yields a relative ranking for each watershed without extensive field surveys and because it is spatially explicit it may be used to guide future mitigation activity. Advantages of the model include: lower dollar costs to produce, objective generation, capacity to be easily updated, responsiveness to changes in elevation and precipitation conditions, and less data corruption because minimal staff (one or two individuals) is required to process data.

Because this present model is a screening tool, it focuses on initial soil forming and erosional processes. The susceptibility of soils and geology to mass failure, and rill and gully erosion are part of this process. If the field resources manager is to have a practical tool for watershed assessments, that tool must be based on simple concepts and built around readily available or easily acquired information. The method proposed here requires the user to have access to Landsat imagery, and a limited knowledge of soils, geomorphology, and ecology. Doing hierarchical analysis, first using a screening tool, followed by more data intensive and quantitative procedures allows managers to identify and prioritize both analytical and restoration activities.

USLE and the Use of Erosion Risk Parameters

For this indexing methodology the slope, cover, and soil detachability parameters of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) were chosen to characterize a watershed's natural susceptibility to erosion. These parameters were chosen because: the data needed to calculate USLE are generally available for large areas of the Sierra Nevada, and while not perfect, the USLE has been applied world wide. In the United States, the USLE has a record of predicting soil loss within $\pm 0.5 \text{kg/m}^2$ 84 % of the time (Wischmeier and Smith 1978). Only the Morgan et al. (1984) model has a better record but only when all the soil properties are based on local field measurements (Morgan 1986) thereby limiting its predictive capability when local data are not available. Morgan's model also uses the same basic parameters adopted here from USLE. USLE and Revised USLE (RUSLE) are erosion-prediction models that express the interrelationships among slope, slope length, cover, and soil detachability (McCool et al. 1987). RUSLE differs from USLE primarily in the algorithms used to generate the individual factors; in addition RUSLE has been adopted for computer use. The formula $A = R\ K\ L\ S\ C\ P$ remains the same, only the coefficients change: A is the computed soil loss, R is the rainfall erosivity factor from runoff, K is the soils detachability or erodibility factor, L is the length of slope, S is the steepness or angle of slope factor, C is the farming or cover-management factor at or near the soil surface, and P is the supporting practice generally associated with farming or grazing (Renard et al. 1994). The USLE equation and the parameters that support it are based on the experience of thousands of field observations that can be arranged into four primary categories affecting erosion. They are: the effects of rainfall on erosion which in the equation are represented by R, the detachability of the soil unit represented by K, slope and topography represented by LS, and the land-use-management practices represented by CP.

Because surface and rill erosion are the primary erosional forces at work in the Central Sierra (Lewis and Rice, 1989) K, S, and C were selected as the three parameters to use in this study when calculating current watershed condition. Each of these parameters has a range of values across each watershed, K-factor for instance ranges from 0.10 to 0.46 for the ENF soils (USDA Forest Service 1985, USDA Forest Service 1991, USDA Soil Conservation Service 1961, USDA Soil Conservation Service 1974). Regardless of slope, soils with K-factor above 0.28 are observed to rill and gully more easily than soils at 0.24 and below (personal observations). The RUSLE does not set risk threshold values for these parameters; however other studies, which will be discussed at length later, suggest logical or intuitive points at which to begin setting threshold values. Thus the initial threshold values came from field experience, the literature, as well as current state and federal regulation.

While the contribution of mass failure to erosion and sedimentation are acknowledged to be significant problems in California's Coast Range, surface erosion and gullying, particularly related to road construction and road use, are the greatest contributors to sedimentation in the Sierra Nevada. Lewis and Rice in their 1989 Critical Sites Erosion Study reviewed 1104 timber harvest plans (THP's) looking for erosion problems. Of the 418 considered in the Sierra Nevada only eight had critical sites (an area of at least two acres where 200 cubic yard or more of erosion volume had been moved) This compared with the Coast Range where 33 sites were critical and 130 questionable out of 499 considered. They found road related problems to be the major contributor to sedimentation in both regions. After visiting 29646 acres in the Sierra Nevada compared to 24232 acres in the Coast Range the Sierra portion of the study was halted because the problems on the coast were more acute. While their study recognizes mass failures of all kinds to be the most significant problem for the Coast Range, surface and gully erosion were the problems most often encountered in the Sierra Nevada. This model points to locations where the potential for problems is high. The potential for mass failure and gullying is greater on soils with high detachabilities and increases as slope get steeper.

Inherent in the use of GIS and remote sensing is the ability to quickly modify your input parameters while seeking higher correlation's of one data set with another. Work done on the ENF by their hydrology and resource groups provided such an opportunity for comparison. This study used watershed boundaries mapped by the State of California's Department of Forestry and Fire Protection in a Data Dictionary project known as "Cal-Water". Cal-Water defines their smallest watershed unit as a Planning Watershed and give it the acronym (CWPWS) (Brandow 1995). The dates of several Landsat images provide points-in-time where conditions in the watershed may be assessed as confined by these CWPWS boundaries.

Interrill and Rill Erosion Processes

Hillslope erosion, a common process in land management, is broken into two segment's: interrill and rill. Each has different susceptibilities to physical and mechanical change. Interrill erosion can be generated by raindrop splash on unprotected soil, by overland flow and sheet wash (Morgan 1986). Rill erosion represents processes where the concentration of water on the slope creates a cutting force. Rills concentrate flow down slope and transport sediment from interrill and rill areas. Many erosion models describe soil detachment by the force of flowing water as a linear function of flow shear stress or energy typically called "critical shear" (Nearing et al. 1994). The Water Erosion Prediction Project (WEPP) model developed for use by the USDA-Natural Resources Conservation Service (NRCS) and the Bureau of Land Management on agricultural and range land uses the equations:

$$D_i = K_i \; I^2 \qquad (1)$$

for interrill processes: where D_i is the rate of interrill sediment delivery to rills, K_i is an interrill erodability parameter, and I^2 is the average rainfall intensity integrated over the duration of rainfall excess. And:

$$D_c = K_r(\tau - \tau_c) \qquad (2)$$

for rill and interrill detachment where D_c is the detachment capacity of clear water flow, K_r is the soil's rill erodibility, τ is the shear stress of the flow, and τ_c is the soil's critical hydraulic shear strength (Nearing et al. 1994). The first equation is an empirical relationship developed after intensive-rainfall simulations (Meyer 1981; Singer and Walker 1983). Kirkby and Morgan (1980) state that sediment yields from interrill areas are relatively low compared to rill erosion processes as described in the second equation. Each equation requires sequential analysis for detachment and transport phases. While WEPP does not yet support forest lands or road related erosion problems it is an event driven model and may provide the soil movement linkage to a Eco-hydrologic model currently being developed by Ustin and Wallendar (SNEP Rpt. 1995 Vol. III).

Model Use of GIS

The method employed here is similar to pre-GIS geographic map overlaying techniques where clear acetate sheets scribed with information at one spatial and temporal scale, such as the distribution of vegetation in the central Sierra Nevada in 1929, are overlain by other maps which have information from a different time period or a different spatial arrangement such as, a 1994 vegetation and land use map for the central Sierra Nevada. In this system both of these sheets are fixed to a base map which contains information, such as topography, streams, and soils common to both overlays. In order to see and begin to understand the relationships between the aggregate information, we analyze the composite, often assigning new values or classifications to the data in the form of similar clusters, which may be called polygons, or at a single point, which in this study is called a cell. Using a commercial GRID raster based GIS computer program all of our data is distributed over a matrix where the smallest block, the cell, approximately 0.22 acres has the dimensions of 30 meters on each side. This fine scale allows large numbers of attribute variables such as soil, slope, vegetation and so on, to be viewed individually or simultaneously in very rapid order for a single cell or a cluster of cells speeding the analysis process. Every major attribute, soil for instance may have dozens or hundreds of variables which describe the soil at a specific location. One data base or many may support our understanding of a fixed point on the ground. GIS provides a means of mathematically searching for relationships between data layers and their attribute's that might not be apparent to our eyes and may have been missed using earlier techniques.

Model Hypothesis

If a healthy watershed is determined by the degree to which physical processes and biological responses are at equilibrium, then excessive erosion and sedimentation suggest system instability and declining health. The hypothesis for this model is: risk of erosion is primarily a function of steep slopes, high soil detachability, and bare unprotected ground. Further, the risk of erosion becoming sedimentation increases where roads are close to streams and is decreased by the presence of a riparian vegetation buffer near stream banks. Using ARC/INFO GRID as well as available soil and topographic data, these four critical parameters are plotted from GIS and Landsat Thematic Mapper (TM) imagery. Slope, soil detachability or K-factor, ground cover, and proximity of roads to streams all become parameters of the model.

Literature Review for Selected Parameters

Slope

Wischmeier and Smith (1978) are generally credited with originating the USLE (Renard et al. 1994) while it was not created for use on steep forested slopes its principles do apply to the model being created here; i.e. soil loss increases much more rapidly than runoff as slopes get steeper. They also state that the logarithm of runoff from row crops was linearly and directly proportional to the percent slope. Further, neither good meadow sod nor smooth bare surfaces had any significant effect on this relationship. They did note, however, that as conditions became extremely wet the effect of slope on runoff was reduced (Wischmeier and Smith 1978). Their equation to evaluate their slope S is:

$$S = 65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065 \qquad (3)$$

where θ is the angle of the slope. They found that using the sine as opposed to the tangent of the slope gave the equation greater accuracy, especially as slopes became steeper than 20 % (Wischmeier and Smith 1978). Angle of slope in contrast to length of slope is a more important consideration when setting threshold parameters for erosion potential or measuring soil loss (Renard et al. 1994). As an example, a 10 % error in slope angle yields a 20 % error when computing soil loss with the USLE. The RUSLE, however, halves these errors as well as being sensitive to short slope interrill erosion and freeze-thaw phenomenon (Renard et al. 1994). While slope length is important in calculating runoff velocities and amounts of soil loss, it cannot be measured accurately with current GIS techniques and therefore has been justifiably omitted as a screening risk parameter at this time.

An important objective of this study was to provide a basic screening module for uses in other resource assessment models. The first iteration of this model set the slope threshold value at steeper than 50% gradient because it fell between the limits of tractor and cable yarding methods for logging permitted under California and Washington State Forest Practice Rules and was the standard used by McKittrick (1994). One project objective was to produce regional slope information from digital elevation models (DEMs) and to produce a GIS layer of slope distributions where a variety of slope classes could be tested. The DEMs available at the time through US Geological Survey (USGS) did not have fine enough vertical resolution for the needs of this model and the eco-hydrologic model being developed concurrently by Ustin and Wallendar (SNEP 1995 Vol. III). As an interim step Georgia Pacific Corporation provided digital 40 ft contour maps, developed from 200 foot DEMs, for the Camp Creek and Clear Creek study area. In October of 1994, the combined efforts of the USFS and USGS finished the production of 30m DEMs for the SNEP study area. These DEMs are the basis for the slope maps and coverages used in this model and analysis.

Current USFS timber sale contracts require that cable yarding systems be utilized when slopes exceed 35%. Because of imprecise ways of measuring slope over large areas, the range of slopes from 35%-40% has been used as a general rule to separate areas of cable yarding from tractor operations and hence slopes greater than 40% became the threshold setting for the second model run (Christiansen 1995). The model is interactive with the parameter threshold selections so that alternative slope classes may be tested in the future.

Soil Detachability or K-Factor

There have been many attempts to develop simple indexes of erodibility using either soil properties determined in the laboratory or the response of soil to flowing water or wind (Morgan 1986). Bryan (1969) and Singer et al. (1978) argue for aggregate stability as the most efficient index of erodibility. However, those data depend heavily on information about soil chemistry. Soil detachability rating, or K-factor, is more easily obtained from existing soil surveys and therefore more likely to be used by resource managers because of availability. A K-factor indicates the susceptibility of soils to sheet and rill erosion and is calculated primarily on the basis of texture, structure, and permeability. Percent very fine sand, sand, silt, and organic matter are the key components modified by the percent of rock fragments. Values range from 0.2 to 0.69 with increasing susceptibility to erosion (Morgan 1986).

The effect of organic matter on K-factor rating, however, adding additional complexity should not be passed over lightly. Mitchell and Bubenzer's (1980) work in The effects of organic matter on K-factor, Table 1 shows how increases in percent organic matter change K-factor for a variety of soil textures. Increases in organic matter generally increase soil stability and reduce detachability. In that case, the K-factor is improved at an increasing rate as organic matter is increased. However, the addition of organic material has a decreasing effect as soil textures grade from light, sandy to heavy, clay. Table 1 from Mitchell and Bubenzer 1980 and is not for field use.

Table 1 The Effects of Organic Matter on K-Factor

Texture Class	K-factor <0.5% Org	K-factor 2% Org	% Change 75	K-factor 4% Org	%Change 50
Sand	0.05	0.03	40	0.02	33
Fine sand	0.16	0.14	13	0.1	29
Very fine sand	0.42	0.36	14	0.28	22
Loamy sand	0.12	0.1	17	0.08	20
Loamy fine sand	0.24	0.2	17	0.16	20
Loamy very fine sand	0.44	0.38	14	0.3	21
Sandy loam	0.27	0.24	11	0.19	21
Fine sandy loam	0.35	0.3	14	0.24	20
Very fine sandy loam	0.47	0.41	13	0.33	20
Loam	0.38	0.34	11	0.29	15
Silt loam	0.48	0.42	13	0.33	21
Silt	0.6	0.52	13	0.42	19
Sandy clay loam	0.27	0.25	7	0.21	16
Clay loam	0.28	0.25	11	0.21	16
Silty clay loam	0.37	0.32	14	0.26	19
Sandy clay	0.14	0.13	7	0.12	8
Silty clay	0.25	0.23	8	0.19	17
Clay		0.13-0.29			

An estimate for an unknown K value from soil properties can be calculated from the regression equation:

$$K = 2.8 * 10^{-7} M^{1.14} (12 - a) + 4.3 * 10^{-3} (b - 2) + 3.3 * 10^{-3} (c - 3) \qquad (4)$$

where M, the particle size parameter, = % silt + % very fine sand * 100 - % clay; a is the percent organic matter; b is the soil structure code (very fine granular, = 1; fine granular, = 2; medium or coarse granular, = 3; blocky, platy, or massive, = 4); c is the profile permeability class (rapid, = 1; moderate to rapid, = 2; moderate, = 3; slow to moderate, = 4; slow, = 5; very slow, = 6) (Lal and Elliot 1994).

Calculating K in the field from the effects of running water is a more complex process but it is the basis of the mass of empirical K-value measurements taken from around the country over several decades (Wischmeier and Smith 1978). In the field, K is not only a function of texture, structure, and permeability but is highly influenced by S (slope gradient) and L (slope length). As an index of erodibility this complex inter-relationship is what makes the use of K-factor so promising. RUSLE provides for modeling complex slope and slope-length relationships (Renard et al. 1994). Topographic factors influence predicted erosion rate because longer, steeper, slopes yield greater volumes of soil during events of equal rainfall intensity (McCool et al. 1987; Wischmeier and Smith 1978). Lal and Elliot (1994) suggest that these differences are the result of increased rill erosion rates as runoff increases with longer slopes and the cutting force of water increases with increased gradients. To model this phenomenon, they propose:

$$L = \left[\frac{i}{22}\right]^{m} \qquad (5)$$

where L is the slope length factor; m the exponent, is 0.2 for slopes < 1%, 0.3 for 1% to <3%, 0.4 for 3.5% to <4.5% and 0.5 for slopes > 5%; and i is the slope length in meters; and s is the slope %;

And, for slopes (S) less than 4 m long:

$$S = 3.0\ (\sin(\theta))^{0.8} + 0.56 \qquad (6)$$

For slopes greater than 4 meter long, and s < 9 %:

$$S = 10.8 \sin(\theta) + 0.03 \qquad (7)$$

For slope greater than 4 meter long, and s $\geq$ 9 %:

$$S = 16.8 \sin(\theta) - 0.50 \qquad (8)$$

where: θ is the field slope (= $\tan^{-1}$(s/100). Equations of this nature provide for the creation of more dynamic threshold values for slope and K-factor as the accuracy and resolution of DEMs improve. Equation (3) will be used along with equation (4) in this study to generate an erosion hazard rating (EHR) on a cell by cell bases in the next iteration of the model. K-factor is currently being calculated for the Stanislaus National Forest (SNF) using equation (4). The current cell size used by the GIS, is 30x30 m with this course minimum resolution slope length for erosion prediction models cannot be measured accurately enough to adjust the K-factor by redefining the mapping unit boundaries.

Soil Data Origins

K-factor information and a soils data base were acquired from the ENF and Georgia Pacific Corporation. Their data base included USFS very detailed 5 acre minimum mapping unit size Order 2 soil survey and a twenty acre unit size Order 3 as well as SCS Order 3 surveys for Eldorado and Amador Counties which were mapped at a 10 to 15 acre minimum map unit.

Watershed analysis using this model had to be limited to areas where complete digital soils data bases exist or could be quickly constructed. The time necessary to digitize soil maps and develop attribute tables for the entire SNEP study area limited the opportunity to expand this study.

Soil mapping units on the national forest are usually composed of several soil series having similar properties (USDA Forest Service 1985, USDA Forest Service 1991, USDA Soil Conservation Service 1961, USDA Soil Conservation Service 1974). Descriptions of physical, chemical, and engineering properties were entered into a data base and matched with the SCS versions for similar series. This information provided standard textures, permeability, and moisture-holding capacities so that the hydrologic flow and vegetation evapotranspiration models would have a consistent medium within soil mapping units and across soil-survey boundaries. The physical, chemical, and engineering properties and the unit name were taken from the series which made up the largest percentage of the combined unit. Effort would have been made to divide further the soil series by percentage contribution within the units but the component series were not spatially located. Since mapping units cross many cells and a unit may represent as many as six soil series, it was not appropriate to give each cell a fractional proportion of all soil-unit values. K-factor was taken from county and national forest Order 3 Surveys and where necessary, applied to the ENF's Order 2 mapping.

The threshold setting of 0.28 is in the range of K-factors selected to separate moderate and high erosion hazard ratings by the Washington State Board of Forestry in their Board Manual: Standard Methodology for Conducting Watershed Analysis (1993), results from the Boise National Forest (Megahan et al. 1981), and information obtained from personal observations. As an assumption for this model the attributes for the series occupying the largest area were entered into the data base. It was also assumed that if a series had a K-factor of 0.28 or greater for any horizon, that series would be considered over threshold. Likewise if any series within a unit had a K-factor in excess of 0.28, the entire unit was included in the high K-factor layer because significant sedimentation problems are often associated with relatively small areas especially where road construction exposes deeper and at times less well consolidated horizons (Rice 1993). Soil series with K-factors from 0.28 to 0.47 became the GIS high K-factor layer and each cell in the model exceeding 0.28 received a value of one. While the Washington State experience will vary from that the Sierra Nevada because of steepness of slope and climatic differences many of its watershed assessment methods are considered standards and are recommended for adoption by the California Division of Forestry and Fire Protection and others (Pete Cafferata personnel communication 1995)(Berg et al. 1995).

Cover

Bare ground, the most elusive parameter to measure, was identified and quantified in several ways using Landsat TM imagery. While Landsat imagery has been found acceptable for mapping vegetation and identifying bare ground at this scale (Roberts 1993), it must be recognized that all imagery and photography represent a single moment in time. Forest environments, at this latitude, typically regain vegetative cover sufficient to reduce erosion hazards within one or two seasons after disturbance (personal observation). Selective harvest methods, including small patch cuts, practiced by most commercial timber operators in mid-elevations of the central Sierra Nevada. These leave sufficient slash and understory vegetation after harvest to limit rain drop impact as a serious cause of soil detachment and transport (Euphrat 1992). Singer and Blackard (1978) working with rainfall simulators on Sierran foothill and forest soils, found that soil losses did not begin to decrease until mulching levels reached 50 % cover. However, reasonable protection was noted by Shaxson (1981) with 40 % cover. Contact cover, that which touches the soil, prevents soil loss from raindrop impact while micro diversions add roughness and reduce erosion by sheet flow. In earlier work, Wischmeier and Meyer (1973), Lal (1977), and Foster and Meyer (1975) found that the rate of soil loss decreased exponentially with increase in area covered by mulch. Laflen and Colvin (1981) expressed this with the equation:

$$MF = e^{-a.RC} \qquad (9)$$

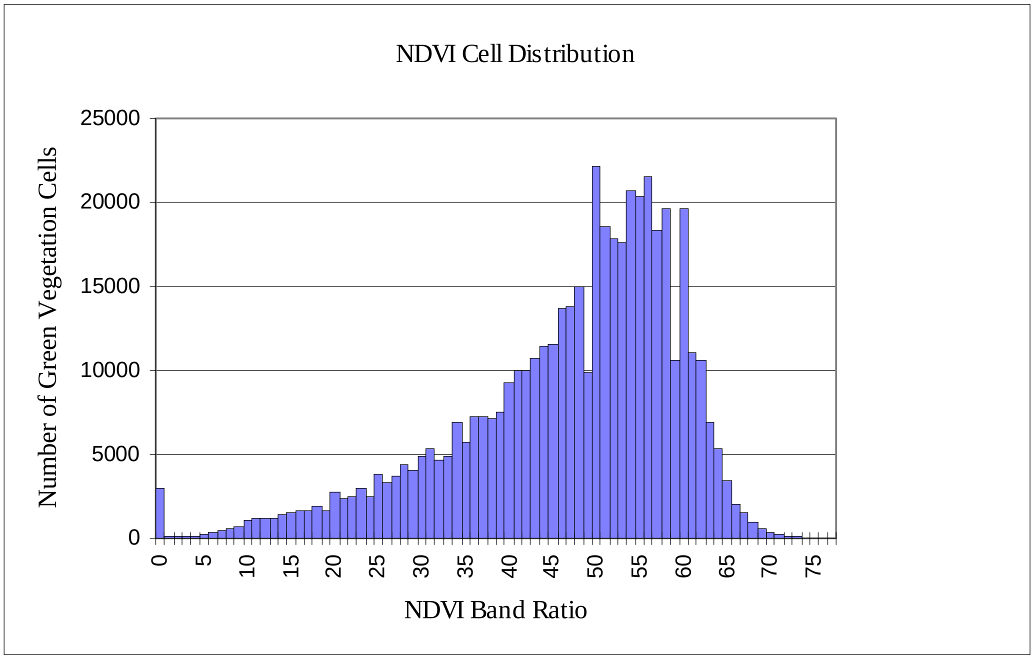
where MF is defined as the ratio of soil loss with mulching to the loss without mulching, RC is the percentage residue or mulch cover, and a ranges in value from 0.03 to 0.07. Later Hussein and Laflen (1982) found that this exponential relationship worked only for rill erosion and that the rate of erosion on interrill areas decreased linearly with increasing cover. When multiplied by the C-factor of the USLE, the protective effects of mulching are included in its calculation (after Morgan 1986).

Clear-cuts and brushfield conversions may have as many as three separate disturbances prior to replanting. Each of these operations reduce cover until all natural protection has been eliminated (personal observation). For this reason it is useful to continue to monitor bare ground for short-term changes annually or bi-annually.

Calculation of Normalized Difference Vegetation Index

Landsat's TM imagery is made up of seven bands of spectral information. These bands register spectral reflectance from specific wavelengths of visible and near-infrared energy (Lillessand and Kiefer 1987). The wavelength band used here were selected because they are the most commonly used for identifying vegetation, soil and rock types, and are standard remote-sensing technology (Avery and Berlin 1992). Bands 3 and 4 are most widely used to distinguish various types of vegetation while band 5 in combination with band 4 is more widely used to enhance bare soil and rock features.

Ratios of these bands have been used to help separate vegetative from non-vegetative reflectance and to guide the classification of soil and geology. The Normalized Difference Vegetation Index (NDVI) is a ratio where the near-infrared (NIR) band (band 4) minus the red band (band 3) are divided by the sum of NIR + red. When displayed as a histogram the NDVI values for a scene allow separation of the non-green reflectance from green reflectance. Cells which have no vegetation green reflectance are assumed to be bare ground. The goal was to identify cells where more than 40% of the ground was bare and had neither an overstory for interception, nor litter for contact mulching. All cells below 20 on the NDVI ratio band 4/3 were classified as bare ground or rock as shown in NDVI/NDSI Ratio, Figure 1. Cells greater than 35 were considered completely vegetated and became background. Using the Normalized Difference Soil Index (NDSI) ratio band 5/4, cells below 20 were also considered bare soil or rock. When the two ratios are combined, the NDVI cells greater than 20 and the NDSI cells less than 25 equate to a transition where bare ground or rock is likely to have dry grass or logging slash present. These differences are given values and the resulting ARC/INFO coverage represents these values in different colors. With unique Universal Transverse Mercator (UTM) positions for the bare and part-bare cells, site visits were made by navigating to these locations via the GPS unit. Calculation of the actual amount of bare ground and litter at each site is continuing via step point transects.



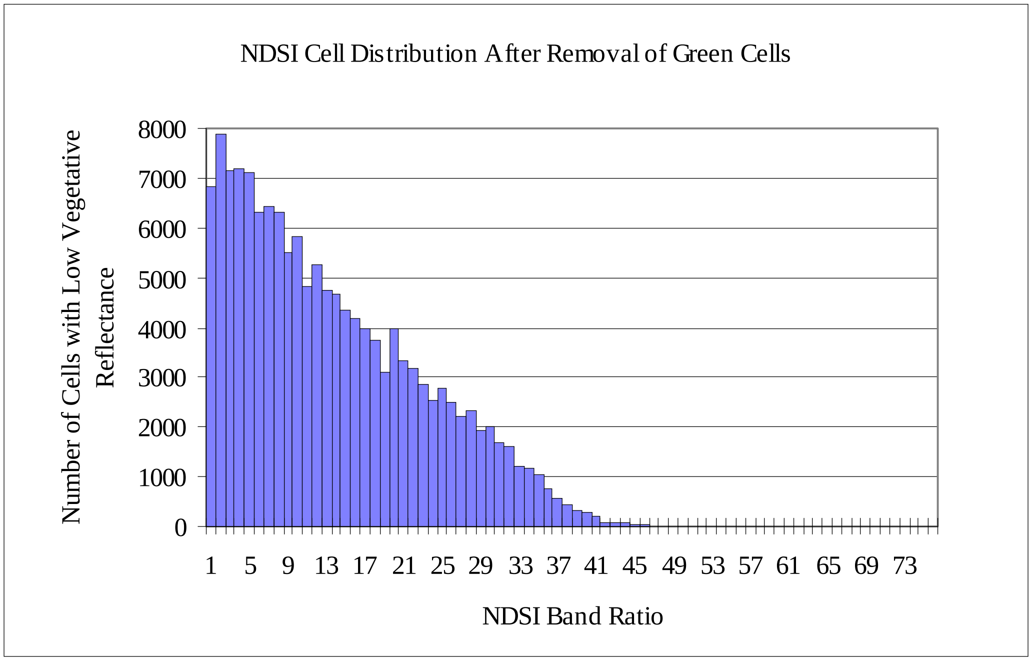


Figure 2 Support for Bare Ground Assumptions Using NDVI and NDSI Ratios From 1994 Landsat TM Image

Modified NDVI/NDSI ratios provide an array of spectral features and do not always identify the bare ground features correctly. In some cases what is classified as bare ground is soil exposed after logging, or an over-grazed meadow. In other cases it is bedrock such as granite outcrops, or volcanic lahar ridges common in many of the high elevation watersheds. When using TM imagery it is difficult to differentiate among the latter three conditions. At present this model does not distinguishing between bare soil and bare rock surfaces however this distinction is expected to be made easier with Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) imagery, soon to be available for Camp and Clear Creeks (see Figure 1 and Plate 3). In the interim rock outcrops mapped as an attribute of the soil surveys provide a method for distinguishing rock out crops large enough to be mapped.

Change Detection Method of Identifing Areas of Disturbance

Large clear-cuts, two-to-three acre patch cuts, some log landings, borrow pit, mine spoil piles, and major natural disturbances, such as fires and landslides are easily distinguished using TM imagery. The current limitations on bare ground identification are image resolution and cells-value averaging. These limitations make the identification of bare areas less than 100 X 100 feet in size difficult. "Change detection," techniques such as those pioneered by Pacific Meridian Resources (Green et al. 1993), while confined by the same resolution restrictions, are able to detect disturbance from selective harvesting easily because the green bands of the spectrum are included and the changes in canopy closure suggests disturbance below. Change detection uses two registered Landsat TM images taken at different times. Color enhancement is added to those areas where the vegetation or surface cover has been altered (Green et al. 1993, Lachowski et al. 1994, Maus et al. 1992). Timber-harvest boundaries and property lines in particular become more easily detected and quantifiable.

Spectral Mixture Analysis Application to Bare Ground Predictions

Spectral Mixture Analysis (SMA) (Adams et al. 1986) is another image-analysis technique which was tested in this study on all the ENF watersheds to determine the location of bare ground or partially bare ground cells . The hypothesis was that SMA will improve the accuracy of identifying cells with mixed spectral features where a portion of the cell is more than 40% bare. If successful an SMA analysis would add to the amount of bare ground identified and help to improve the analysis limitations of the Landsat TM imagery with its 30m resolution.

Very few cells in any scene represent the pure spectra of a single feature such as a 100% vegetation or 100% bare ground. Most cells reflect a combination of spectral signatures. Mixing spectra of pure known features, called end members, until a simulation of the target cell spectra is achieved has been done by many others Smith (1990); Ustin et al. (1993); Ustin et al. (1995). Each cell in an image is broken down into its component pure spectra. It is assumed that the spectra for a cell which is 50 % tree and 50 % bare ground will appear as a linear addition of one-half the tree spectrum, plus one-half the soil spectrum (Ustin et al. 1995).

For this study, a number of end members were analyzed before three were chosen. Because of the unique contrast between volcanic-soil spectra and granitic or metasedimentary-soil spectra, I assumed that I could compensate for the changes in geology by adjusting the soil end member as elevation increased from west to east. In this area of the central Sierra Nevada, granitic rocks have been intruded into sediments forming metamorphic rocks. Volcanic mudflows from the Sierran crest have capped the granitic and metamorphic rocks. Subsequent glaciation and erosion have stripped away much of the volcanic rock leaving a mosaic of soil parent material at high elevations where volcanic flows and granite outcrops predominate. Mid-elevation rock outcrops are generally granitics and metamorphics in the stream channels and volcanics on the ridge tops with an occasional metasedimentary outcrop at mid-slope. (see theEldorado NF Geology of Soil Parent Material, Plate 1)

Using a granitic soil spectrum for stream channels and high elevation basins, volcanic soil spectrum for ridge tops in the mid-elevations, and metasediment soil spectrum for mid-slopes in the middle elevations an attempt was made to stratify the TM scene in order to identify more bare ground cells. Soil samples representing these three parent materials had been collected in the field, processed and analyzed for their spectral reflectance. While the soil spectra were distinct and easily distinguished from each other in laboratory samples the spectra for volcanic soils were not distinguishable from dry grass in the TM image. Grasses mature later in the season from low elevation to high elevation. Hence adjusting the soil end members for changes in elevation was not used in the last iteration of this analysis. The technique may still have some validity if attempted on an image acquired early in the season when all the grasses are green. SMA TM images with their limited number of spectral bands do not appear to have the same reliability separating soil, rock, and non-green vegetation in the near-infrared wavelengths as do AVIRIS images (Ustin 1995). The work of matching soil color to spectral signature and ultimately to soil parent material continues to engage many soil scientists and remote sensing specialists (Escadafal et al.1988, 1989, Fernandez 1987, Huete 1986, 1991, Melville and Atkinson 1985).

Initial Parameter Thresholds

In order to rank watersheds for comparison, erosion and sedimentation hazard risks are quantified. Each of the parameters described above is assigned a threshold value which becomes the bases for this quantification. These thresholds are pointers to potential erosion. Values for each watershed cell are assigned by the number of thresholds: slope, cover, and detachability, exceeded within that cell. Given normal precipitation conditions for the central Sierra Nevada, it is assumed that each parameter or risk factor has about the same probability of causing erosion. The GIS does not count the cell until the parameter value in that cell exceeds the established threshold. Each time a parameter threshold is exceed a “1” is tabulated for that cell. A cell value may be 0, 1, 2, or 3 as seen in Cell Value Calculation, Table 2 below where the seven possible combinations of parameters and their corresponding values are displayed.

Table 2 Cell Value Calculation

	Possible combinations of parameters over threshold.						
Parameter	Slope	K-factor	Cover	Slope+ K-factor	Cover+ K-factor	Slope+ Cover	Slope+ K-factor+ Cover
Value	1	1	1	2	2	2	3

Threshold Values

Here risk thresholds are defined as slopes in excess of 40 %, soils with K-factors (detachability ratings) higher than 0.28 and cells with more than 40 % bare soil no surface cover (Elwell and Stocking 1974). These threshold values were derived from the soil literature (Wischmeier and Smith 1978; Rose 1994; Stocking 1994), from current USFS limits for tractor and cable yarding, and from the California and Washington State Forest Practice Rules. Along with the intensity of precipitation, these three parameters are dynamically interactive, with each contributing to "critical shear," detachment as previously defined and transport of soil both individually and collectively. For example, bare, highly detachable soils are not as erodible at slopes of 0 % to 5 % as they are at 15% to 35 %; conversely, bare, steep slopes are not as erodible when soil textures have low detachability values such as clays, as they are when soils are highly detachable, like very fine sandy loams see Table 1 (Mitchell and Bubenzer 1980; Kirkby and Morgan 1980). As we gain more experience in using this model, the threshold values will be changed and further refined into a continuous scale, and the influences of other external factors such as climate and elevation will be added. Adding these factors allows us to predict the potential for rain-on-snow events thereby increasing the model's sensitivity to natural and management perturbations.

Parameters over threshold have been quantified and analyzed for each CWPWS to provide a comparative index which, when examined along with the proximity of roads to streams and total area of disturbance, ranks these watersheds by their percentage of area over threshold. The model calculates a current condition ranking on a "most-healthy to least-healthy" scale as judged by the percent of the watershed which exceeds each threshold or combination of thresholds. Examples of these combinations may be reviewed in Table 8, Results and Discussion.

Soils Data Base and Derived Map Products

This analysis draws from three primary sources of information: slope is derived from a 30 meter digital elevation model (DEM) produced by the US Geological Survey, bare ground is derived from a 1994 Landsat Thematic Mapper satellite image, and the soils information are found in four soil surveys form the ENF and the US Natural Resources Conservation Service (NRCS). The soils data base attributes in particular had to be constructed by gleaning information from the survey data such as engineering properties from one table and physical/chemical properties from another. A number of derived products have been crafted from this source including Eldorado NF Geology of Soil Parent Material, Plate 1. Here the soil parent material and particular geologic formations are used to group soils that have similar erosion characteristics. This map provides foresters and resource managers with a ready reference of spatial information by basic geologic group and soil series.

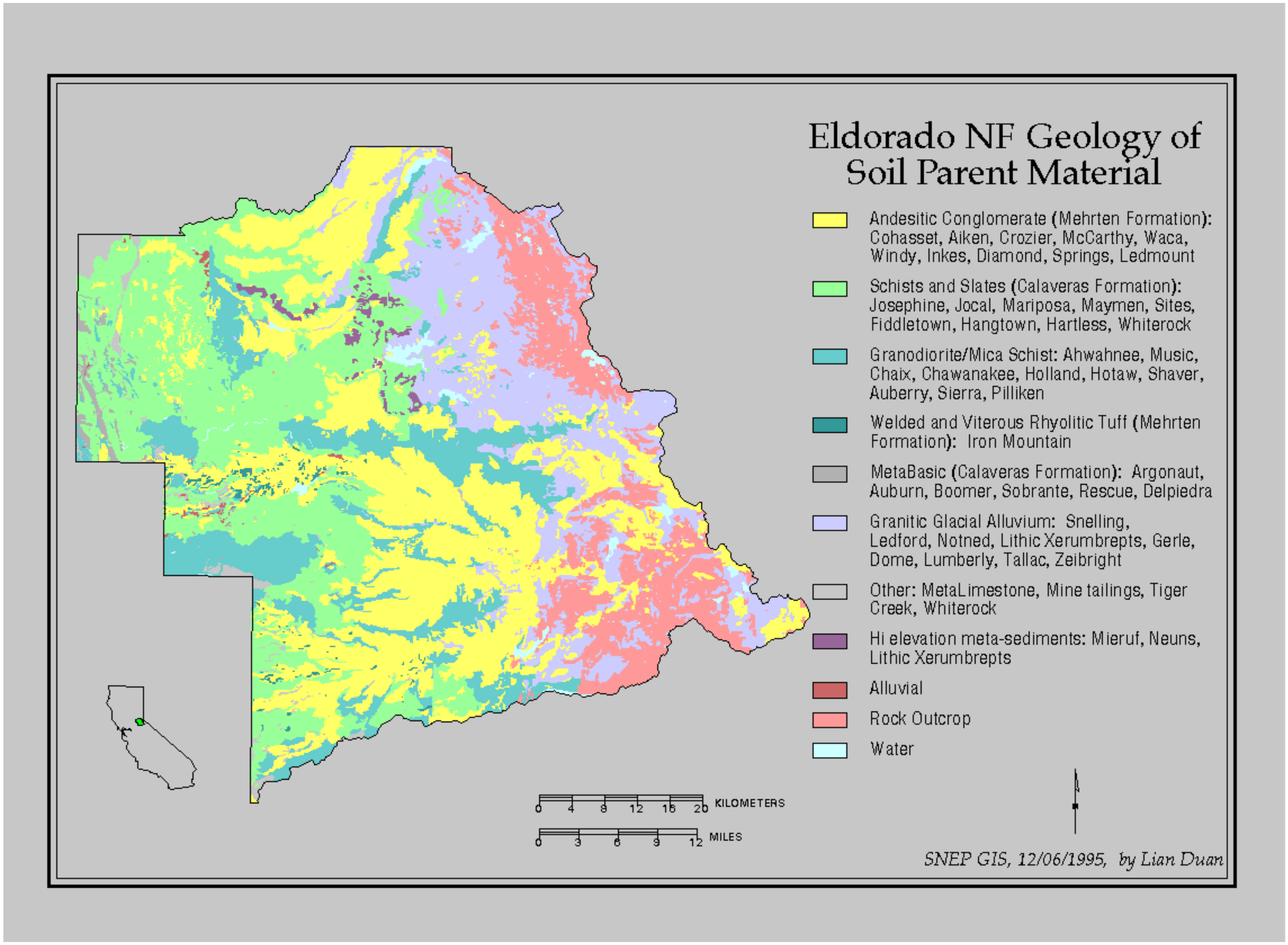


Plate 1 Eldorado NF Geology of Soil Parent Material

Natural Erosion Potential Calculation

NEP is an index of stability or resilience, predicting an unmanaged watershed's ability to withstand erosion causing events. As seen in Eldorado NF Natural Erosion Potential, Plate 2 and in Lower Camp Creek Cells Over Threshold, Table 3 this model operates on Boolean logic: when a cell's value exceeds any threshold it is assigned a one; conversely, if the feature being assessed is less than the threshold, the cell value is assigned a zero. Cell value accuracy is a function of grid size. Using the best available information 30X30m DEMs in the case of slope means that the angle formed using one cell's centroid elevation when compared to the centroid value of its neighbors either does or does not exceed the threshold. Each parameter has its own data layer in the GIS. Again referring to Table 2 when two thresholds are exceeded for the same cell, each cells value remains one and the combination of those cells has a value of two. Likewise, for the combination of all three thresholds being exceeded in the same cell the value of that cell becomes three. In the worst case every cell could have a value of three.

In order to calculate percent NEP multiply three times the number of cells in a watershed this becomes the maximum potential NEP watershed value. The present watershed value is generated by counting the total number of cells over threshold in the composite GIS layers. The total number of cells exceeding thresholds, divided by the maximum potential for the watershed, times 100, becomes the relative watershed score or %NEP. The NEP for the whole national forest, graphically projected is found on "Eldorado NF Natural Erosion Potential" Plate 2: where K-factor, Bare ground and Slope are column headings and the presence of a "1" indicates the parameter is over threshold. If a "1" is present in more than one column it is interpreted as an increased erosion risk up to a value of three (See Table 2 for further explanation).

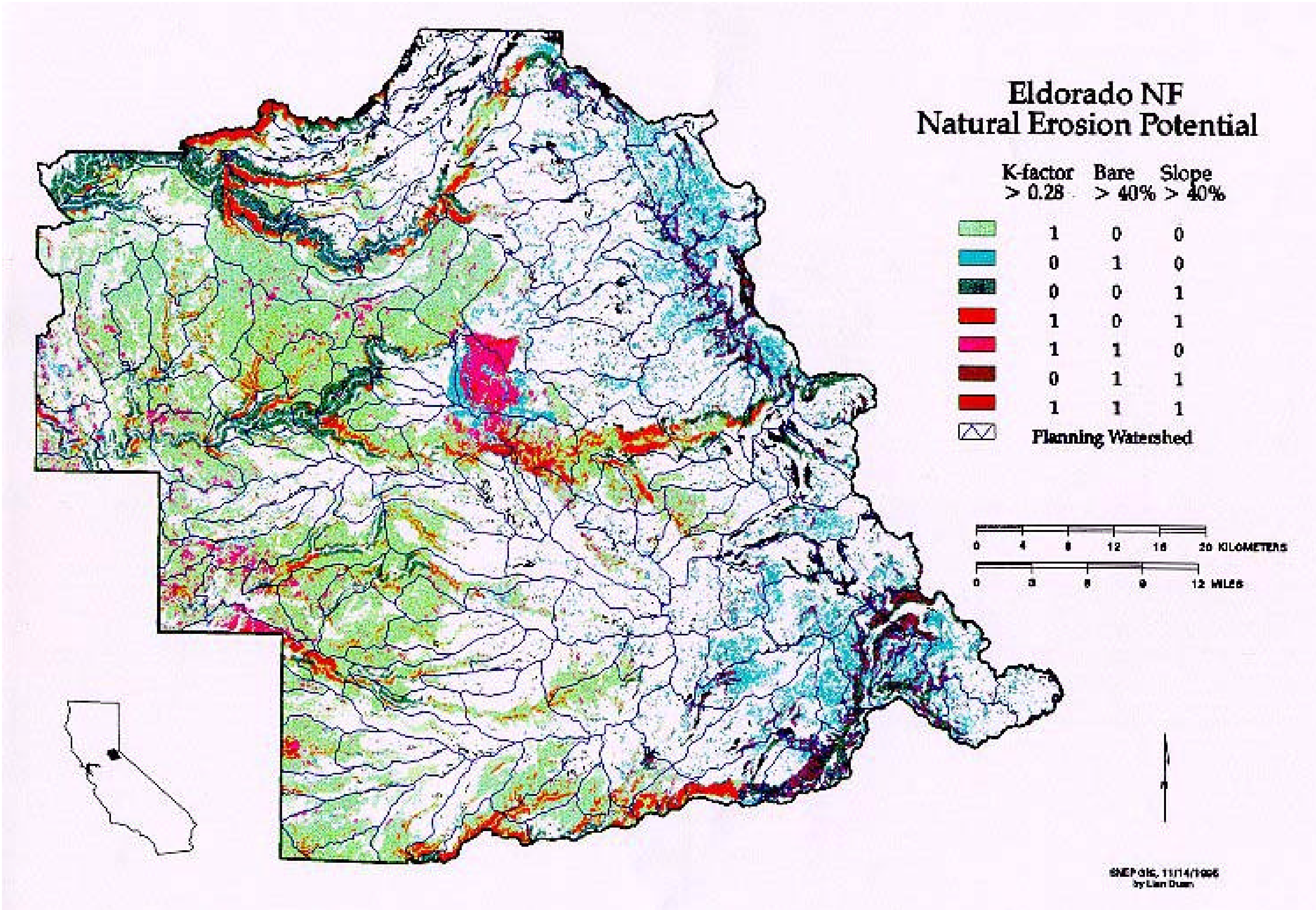


Plate 2 Eldorado NF Natural Erosion Potential

On a computer monitor Plate 2 can be blown-up so that individual 30 X 30m cells may be located and reviewed for soil, slope or bare ground attributes. Even at a very small scale this map provides sufficient spatially explicit information to make reasonable visual watershed comparisons and guide additional assessment work. Each watershed is given an attribute table which provides the user with specific information about the parameters being evaluated. These attribute tables on either a watershed or parameter bases may be accessed to add or edit data.

Camp Creek Area Natural Erosion Potential, Plate 3 is the type of map product that is used for field assessment work and is the basis for the tables used to calculate the ranking of every cell and aggregated up to planning watershed or river basin. Roads and stream buffers are shown so that areas of special concern, may be reviewed for possible mitigation opportunities e.g., the Fry Creek watershed, in red and in the upper center of Plate 3. Fry Creek Data Interpretation, Table 6 is an example of one of the data tables which is built for every watershed. The Interpretation column has been added for reader assistance. The digital version of ENF Watersheds with Acres Over Threshold, The digital version of Table 9, Eldorado National Forest Watershed Ranked by Acres Over Threshold provides acreage data on 21 separate combinations of parameters over threshold. Access to these data may be gained through computer programs such as Arc/View. Cells over threshold and their corresponding acreage's are summed at the bottom of the columns. Values are not duplicated when thresholds are combined. Maps similar to Plate 3, Camp Creek Area Natural Erosion Potential were used in the field to validate the parameter data. Both individual cells and clusters of cells were targeted and found for examination using global positioning systems (GPS) equipment.

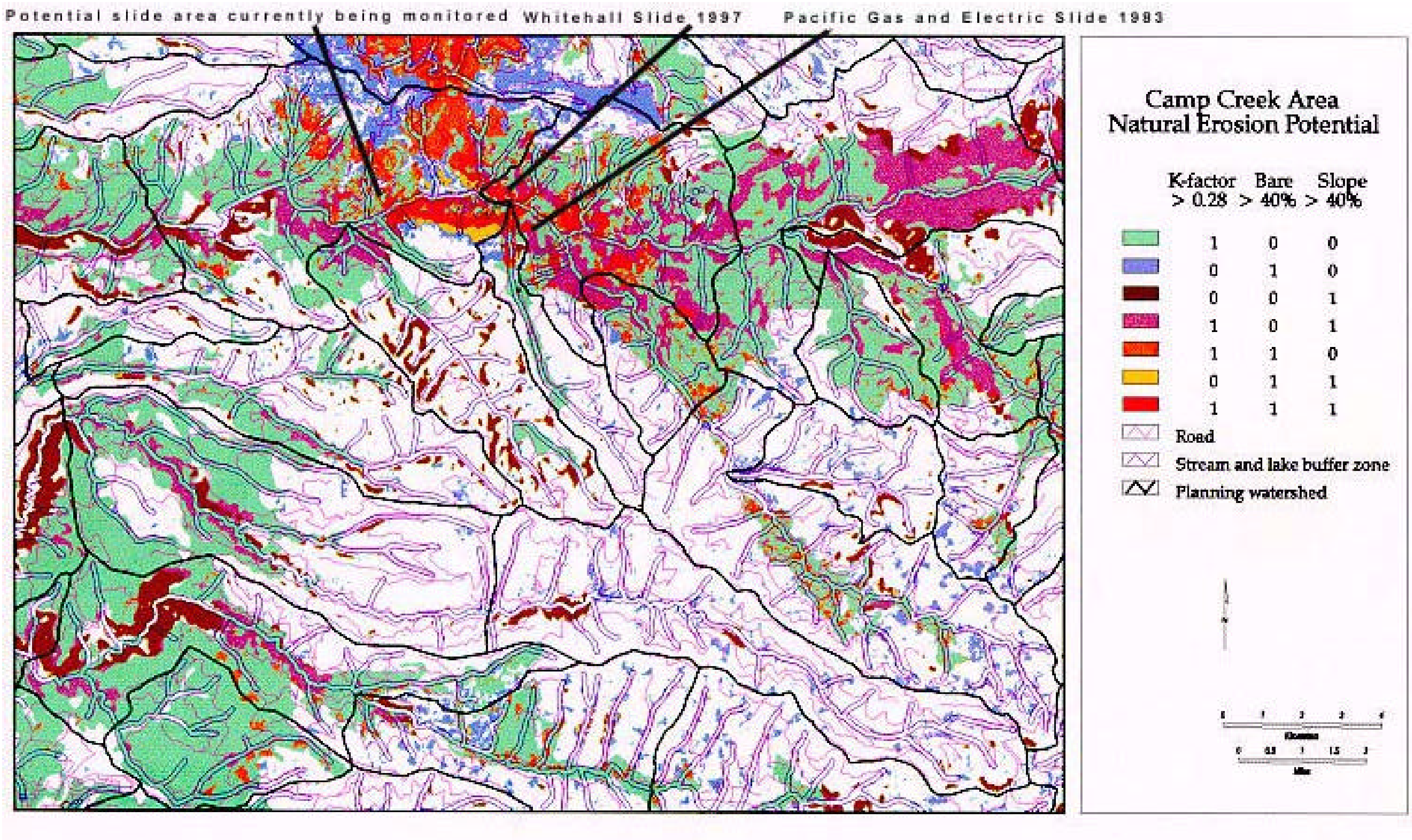


Plate 3 Camp Creek Area Natural Erosion Potential

Percent Sedimentation Hazard Index Calculation

Although NEP reflects a watershed's natural stability, sedimentation hazard index (SHI) focuses on the potential to upset that stability through road construction and maintenance practices. Stream sedimentation is often the result of a very small erosional failure becoming a very large CWE disturbance (Megahan et al. 1991; Rice 1993). SHI seeks to micro-analyze a stream buffer zone by identifying areas at risk, predicting points most likely to fail, and reflecting reductions in its index numbers as road segments are abandoned, rocked or paved.

As defined earlier, a healthy watershed is one in which the natural stability of geology and soils maintains the contribution of sediments at a level where natural hydrologic processes balance the ability of a system to both store and transport these sediments without degrading aquatic habitats. If vegetation and debris in stream buffers trap and stabilize incoming sediments, how wide must these buffers be to protect habitat of aquatic and terrestrial species while permitting access to managed lands? Erman et al. (1977; 1983) looked at stream buffer widths and the impacts on benthic organisms. He found the population count and species diversity of these organisms was an indicator of the conditions of the habitat but only as it pertains to aquatic species. Buffers originally thought to be adequate to meet the needs of invertebrates and to prevent or minimize sedimentation may not be adequate to maintain stream organic inputs or provide for the needs of mammals and riparian species (Kattelmann, 1996). Because this study is a screening process attempting to focus the resource manager's attention on the most acute problem areas, potential sedimentation is its primary consideration. In that regard, roads which fall within 60 m (197 feet) of a perennial stream become the target of GIS querying. Cells fully located in the buffer between a road and stream that exceed any of the thresholds are tagged. Where multiple thresholds are exceeded in the same cell, the magnitude of severity ensures that management attention will be focused on that location. Parameters exceeding thresholds for cells within a 60 m buffer zone along perennial streams and adjacent to roads are calculated in the same manner as for NEP except that the maximum potential SHI value becomes the total number of stream buffer cells where roads are present, times three. Actual SHI is made up of those cells over threshold, within the stream buffer where roads are present. Dividing the potential into the actual, yields the %SHI in the same manner as %NEP was generated (see Tables 4 and 5). These new values are the most critical of the process because they reflect the increased probability that sedimentation will occur at a location under specified conditions. The cells which potentially will cause problems are noted and are uniquely identifiable. Therefore, they can be monitored and/or mitigated. Maps of roads, stream buffers, watershed boundaries, and parameters over threshold are produced along with the tables so that graphical comparisons can be made and checked in the field. Camp Creek Area Sedimentation Hazard Index Plate 4 emphasizes the fact that the occurrence of cells over threshold inside stream buffers is limited. This limitation points to locations where increased sedimentation should be expected and to critical areas which should be monitored.

NEP and SHI Analysis Applied to the Camp Creek Case Study Area

NEP and SHI results for all CWPWS have been tabulated individually and are summarized in Appendix 1. Table 3 provides an example of watershed 532.23011 Lower Camp Creek Planning Watershed, which is a portion of the Camp and Clear Creeks case study (McGurk et al. 1995). The percent NEP and SHI are calculated from the cell totals; however, reading the values parameter by parameter yields additional information. The watershed area measured via GIS for the Camp Creek segment being analyzed is 46448 cells, (calculation not shown) at 0.22 acres per cell this portion of the watershed area is approximately 10330 acres. The maximum potential NEP for this example is 3 X 46448 or 139344. Assume that each combination of cells is unique and that cells are not counted twice: to interpret the last row where one cell is high K-factor, bare, and >40% slope we see that the cell is not in a stream buffer or beside a road because there are 1's in the first three columns and 0's in the last two. In the first row 10 bare ground cells were found inside the stream buffer with a road present. In the second row 444 cells where roads are inside the stream buffer and the soils there have K-factors above 0.28. In the third row 16 cells are bare with a high K-factor and adjacent to a roads. The calculations of NEP and SHI for this watershed are found in Tables 4 and 5.

Table 3 Lower Camp Creek Planning Watershed Cells Over Threshold

Cal-Water Planning Watershed ID	Number of cells over Threshold	Cells with K-factor > 0.28	Cells with > 40% bare ground	Cells with slopes >40%	Cells inside a 60m stream buffer	Cells inside a 60m stream buffer with a road
532.23011	602	0	0	0	1	1
532.23011	10	0	1	0	1	1
532.23011	444	1	0	0	1	1
532.23011	16	1	1	0	1	1
532.23011	2541	0	0	0	1	0
532.23011	917	0	0	1	0	0
532.23011	21	0	0	1	1	0
532.23011	398	0	1	0	0	0
532.23011	60	0	1	0	1	0
532.23011	19	0	1	1	0	0
532.23011	12663	1	0	0	0	0
532.23011	2618	1	0	0	1	0
532.23011	1988	1	0	1	0	0
532.23011	139	1	0	1	1	0
532.23011	64	1	1	0	0	0
532.23011	7	1	1	0	1	0
532.23011	1	1	1	1	0	0

Table 3 above is a typical ARC/INFO table where: Columns represent the data for each threshold parameter covered there is a 1 in the row if there is data, 0 if there is not. The number of cells exceeding each threshold or thresholds is found in the “Number of cells over threshold” column. A 1 in the “Cells inside a 60 m stream buffer column” indicates that the cells counted were also inside a stream buffer. If there is a 1 in the “Cells inside a 60 m stream buffer with a road” column it means the number of cells shown are over threshold and adjacent to roads. Each cell is identifiable and may be found using via GPS coordinates.

Table 4
Natural Erosion Potential (NEP) Calculations for Lower Camp Creek

Parameter	Total Cells Over Threshold
Bare Ground	468
Bare G + High K	87
High K-factor	15725
High K + Slopes	2127
Slopes over 40%	938
Bare G + Slopes	19
Bare G + Slopes + High K	1
Total cells over threshold =	19365

Lower Camp Creek NEP calculation 46448 WS cells * 3 = 139344 maximum potential NEP

19365/139344 X 100 = 13.9% NEP

Table 5 Sedimentation Hazard Index (SHI) Calculation for Lower Camp Creek

Only for cells inside the stream buffer and adjacent to roads.

Parameter	Total cells Over Threshold
Bare Ground	10
Hi K-factor	444
Bare G + High K	16
	470

1072 (total cells in stream buffers and adjacent to roads) * 3 = 3216 maximum potential SHI

470 / 3216 X 100 = 14.6% SHI

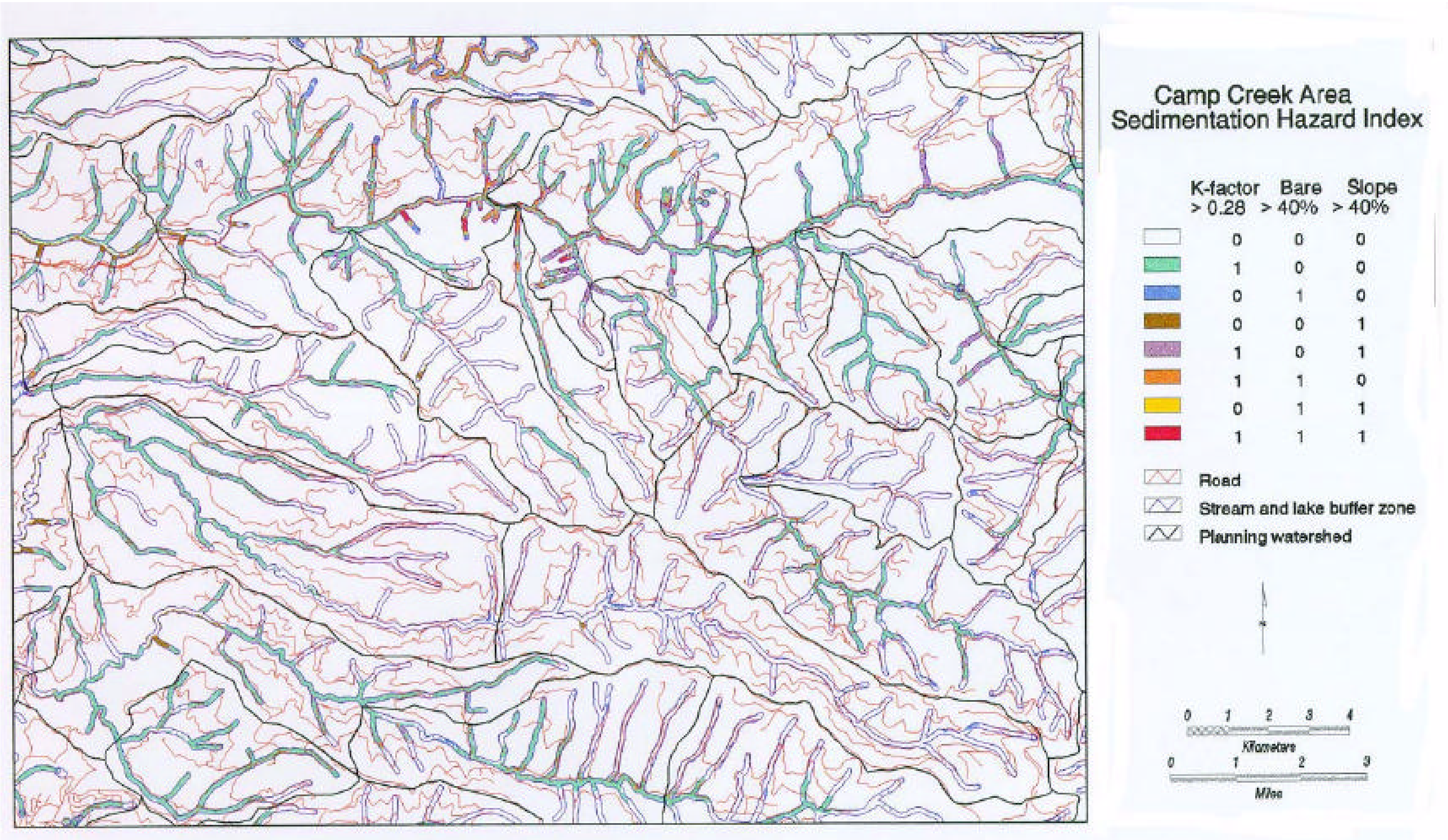


Plate 4 Camp Creek Area Sedimentation Hazard Index

Table 6 Fry Creek Data Interpretation

Number of cells	Total Acres	% of Watershed	Soil K-factor >0.28	Bare Ground >40%	Steep Slopes >40%	Stream Buffer	Road in Steam Buffer	Interpretation
28535	6345	100	0 *	0	0	1123 acs	134 acs	6345 acres is the watershed 1120 in stream buffers and 134 with roads in the buffers.
420	93	1.5	0	0	0	1	0	93 acres of stream buffer under threshold without roads.
81	18	0.3	0	0	0	1	1	18 acres of stream buffer under threshold with roads.
380	84	1.3	0	0	1 *	0	0	84 acres of slopes >40% outside of stream buffers and without roads.
17	4	0.1	0	0	1	1	0	4 acres of slopes >40% in the stream buffer.
1363	303	4.8	0	1	0	0	0	303 acres of bare ground outside the stream buffer without roads.
14	3	0	0	1	0	1	0	3 acres of bare ground inside the stream buffer but without roads.
13	3	0	0	1	1	0	0	3 acres of bare, steep area outside the stream buffer and without roads.
8916	1982	31.2	1	0	0	0	0	1982 acres of high K-factor soils outside of stream buffers or roads.
2697	600	9.5	1	0	0	1	0	600 acres of Hi-K soils in stream buffers.
404	90	1.4	1	0	0	1	1	90 acres of Hi-K soils in stream buffers and beside roads.
5131	1141	18	1	0	1	0	0	1141 acres of Hi-K and steep lands outside of stream buffers or roads.
765	170	2.7	1	0	1	1	0	170 acres of Hi-K and steep lands inside stream buffers without roads.
18	4	0.1	1	0	1	1	1	4 acres of Hi-K and steep lands inside stream buffers with roads.
2334	519	8.2	1	1	0	0	0	519 acres of Hi-K and bare lands outside of stream buffers or roads.
420	93	1.5	1	1	0	1	0	93 acres of Hi-K and bare lands inside stream buffers without roads.
97	22	0.3	1	1	0	1	1	22 acres of Hi-K and bare lands inside stream buffers with roads.
1358	302	4.8	1	1	1	0	0	302 acres of Hi-K, bare and steep lands outside of stream buffers or roads.
112	25	0.4	1	1	1	1	0	25 acres of Hi-K, bare and steep lands inside of stream buffers without roads.
3	1	0	1	1	1	1	1	1 acre of Hi-K, bare and steep land inside of stream buffers with roads.
			4949 acs	1271 acs	1734 acs	1123 acs	134 acs	

* "0" Means no data in the "number of cells" column for this parameter. "1" means the number of cells shown in the "number of cells" column are the cells, acres, or percent over threshold for this parameter or combination of parameters.

Watershed Assessment Terminology

The application of the NEP and SHI methodology was limited to the Eldorado National Forest and to those CWPWS's that were completely within the national forest because of data limitations for areas beyond the national forest boundaries. Table 8, features 27 of 177 watersheds reviewed for this work. There were differences in watershed boundaries selected by the Forest Service and Cal-Water. These differences were reconciled by consolidating Cal-Water watersheds in some cases and Forest Service watersheds in others. The consolidating process yielded 120 watersheds with enough data to compare. Only 76 of the USFS watersheds had complete data which was directly compatible with the study model. However all 120 watersheds had the USFS generated Natural Sensitivity Index (NSI). Designed by Kuehn in 1989 for CWE analysis on the ENF this indexing system considers both hillslope and in-channel hydrologic and erosional processes. Soils, stream channel conditions, geomorphic instability, drainage density and precipitation regimes are all part of the NSI calculation. NSI is used to generate a watershed's Threshold of Concern or (TOC) (USDA-FS, 1987a). TOC relates to the percent of Equivalent Roaded Acres (ERA) which is a watershed ranking by the amount and type of land disturbance within a watershed. TOC for a watershed is determined by the NSI number where < 15 is very low and > 65 is very high. For watersheds with very low NSI numbers the TOC will range from 18 - 20% ERA. Meaning that 20% of the watershed may be disturbed before significant cumulative effect occurs. Likewise watersheds with very high NSI numbers have lower TOC's and as little as 10% ERA may trigger significant CWE.

Table 7 Relationship of Natural Sensitivity Index to Equivalent Roaded Acres and Threshold of Concern
(from Carlson and Christiansen 1993)

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

RESULTS AND DISCUSSION

Watersheds represent distinct topographic units and the understanding of their health and condition cannot be limited by ownership. "Current condition" is the product of all past events and the ecosystems' response to those events, both natural and management induced.

Implementation of management strategies may be unique to ownership, however, in order to account for mitigation activities in mixed ownership watersheds, when assessing CWE, all disturbances must be considered.

Standardization of Soil Data Collection and Data-Base Management

The accuracy of assessments of this nature is dependent on the quality of the data being used. The lack of a continuous and consistent digital soil map, standardized labeling and common physical descriptions, for the SNEP study area as well as adjacent national forests, has severely hindered progress of this work. The fact that there are no standardized mapping, labeling, analytical processing, or report formats between national forests from the same Region is further complicated in that soil surveys completed by the Soil Conservation Service (SCS) (a.k.a. Natural Resources Conservation Service NRCS) and the State of California Soil-Vegetation Survey are at different scales and have varying standards.

Given the emphases placed on accuracy of the assessment process and the proposed future needs for precise inter-agency and public-private monitoring protocols, standardized data-base resource information to support varied geographic information systems (GIS) is imperative. Watershed names, identification numbers and boundaries as well as soils and geology information should be collected, standardized, maintained and disseminated by a single agency to federal, state, local, and private consumers. Such an approach would be consistent with CWE issues of both the National Environmental Protection Act (NEPA) and the California Environmental Quality Act (CEQA).

Model Limitations

This model does not calculate soil movement it directs attention to those areas where management activity has a high likelihood of detaching soil particles and making them available for transport. Predicting soil loss with mathematical models continues to challenge soil scientists and engineers because of the vast number of variables and the wide range of data needs. Some models predict accurately for time steps of a few minutes but are confined by scale and cannot be applied to large areas (Morgan 1986). Screening models, while simple in concept, are designed to identify problem locations. Assessment models must predict with greater accuracy and thus are used to quantify severity of erosion under various land management options (Morgan 1986). McGurk and Berg (1995) applied the Water Yield and Sediment Model (WATSED) (USDA Forest Service 1991) model for determining sedimentation to Clear and Camp Creeks and found it both data and labor intensive. Doing hierarchical analysis, first using a screening tool, followed by more data intensive and quantitative procedures allows managers to identify and prioritize both analytical and restoration activities.

Determining rates of erosion and volumes of sediment moved requires sophisticated models and extensive amounts of empirical data. Models of that caliber typically require twenty to thirty years of data to test and validate. Although these models are reasonably successful in characterizing annual processes, they have difficulty in predicting erosion on a localized area from a single storm event. Scale also has a great influence on model selection and the accuracy of the output. Modeling large basins requires significantly different data demands than modeling a small field or the impact of a single raindrop. Although much theoretical work has focused on the latter, it is difficult to scale these findings up to a watershed or region (Nearing et al. 1994).

Model Comparison With USFS Outputs

One of the highest Forest Service NSI and TOC rankings is that of Fry Creek (see Table 8). Fry Creek is a tributary of the South Fork of the American River its ground cover was burned in the 1993 Cleveland Fire. It has steep slopes and highly detachable soils. This model calculated Fry Creek as one of its highest risk watersheds with NEP and SHI ratings of 41.7% and 35.5 % respectively. Fry Creek is approximately 6346 acres in area its NSI and %TOC are 183 and 138%. A TOC of 138% indicates that this watershed is significantly over the US threshold and that further unmitigated disturbance may result in considerable harm to the ecosystem. The erosion hazard rating (EHR) Risk Nr for this watershed, as seen in the seventh column of Table 8, is 5: extreme. Table 8 is one example of the type of data that may be extracted from the model. Here using percent allows for relative scaling when comparing a 2,000 acre watershed with a 13,000 acre watershed. Table 9 uses the same base cell data generated from ARC/INFO to compare the acres over threshold in these same watersheds.

Table 8 Twenty-Seven Eldorado National Forest Watersheds with the Highest Sedimentation Hazard Indes and Their Corresponding Natural Sensitivity Index and Threshold of Concern Rankings

CPWS ID Nr Cal-Water Planning watershed ID number	Cal-Water watershed Name	CPWS Acs Cal-Water planning watershed acres	NSI Natural Sensitivity Index	% TOC Threshold of concern	% ERA Equivalent roaded acres	EHR RiskNr Erosion Hazard Rating Nr	%NEP Natural Erosion Potential	%SHI Sedimentation Hazard Index	% Rd acs Roaded acres	%SB/Rd Roaded acres inside stream buffers
514.33021	Peavine Creek	11,510	60	125.0	15	5	40.9	38.6	10.5	11.4
514.35021	Fry Creek	6,346	183	138.0	13.8	5	41.7	35.5	9.1	11.9
514.32010	Gaddis Creek	8,684	81	106.0	10.6	5	35.2	34.6	8.2	9
532.60051	Beaver Creek	2,464	95	100.0	10	5	31.7	34.6	8.2	9.5
514.33035	Camp Seven	4,248	291	70.0	7	3	32.4	34.4	6.1	5.3
514.32012	Brush Creek	5,132	37	36.4	5.1	2	36.6	34.0	10.2	7.7
532.23043	Clear Creek	2,896	34	61.3	9.8	3	28.1	32.2	10.3	14.1
514.33030	Little Silver Creek	8,604	28	68.1	10.9	3	30.6	32.0	9.6	11.3
514.35050	Twenty-five Mile Cyn	10,972	138	129.0	12.9	5	33.6	31.6	9.6	10.8
532.60061	W Panther Creek	5,853	79	104.0	10.4	5	26.1	30.2	11.3	9.9
532.23042	Middle Butte	2,925	160	53.0	5.3	2	31.1	29.8	6.2	3.2
514.36033	Middle Creek	4,735	119	50.0	5	3	24.5	29.8	7.0	6.9
514.32022	Whaler Creek	10,209	91.3	62.0	6.2	3	29.7	29.4	11.5	11
532.23033	North Canyon	3,541	25	23.1	3.7	1	29.5	28.8	10.0	15.3
514.32011	Slab Creek	5,493	114	43.0	4.3	2	32.3	27.9	11.0	8.6
532.23062	Clear Creek	6,840	28	50.0	8	2	28.0	27.7	13.1	14.5
514.32031	Bear Creek	5,358	59	68.3	8.2	3	28.1	27.4	12.6	16
514.32013	Slab Creek Res	5,723	174	51.0	5.1	2	28.7	26.8	9.8	6.1
514.35022	Mill Creek	2,178	61	117.5	14.1	5	11.5	24.9	8.6	8.1
514.35051	Grays Canyon	8,308	173	51.0	5.1	2	31.2	24.6	9.0	5.7
514.43033	Zero Spring	8,212	220	30.0	3	2	34.8	24.5	6.0	4.2
514.32015	Iowa Canyon	5,107	41	95.0	13.3	4	18.2	24.5	14.2	10.9
514.32021A	AWS1	13,502	94	34.0	3.7	2	25.1	24.4	10.3	0
532.24012	Cat Creek	5,655	93	138.0	13.8	5	14.4	23.9	10.7	13.8
532.23032	Van Horn Creek	7,516	77	64.0	6.4	3	26.5	23.8	10.2	12.3
514.35052	Soldier Creek	3,414	52	103.3	12.4	5	17.6	23.5	9.3	13.4
532.23051	Camp Creek	10,140	92	66.0	6.6	3	29.9	23.3	7.4	3.9

See Eldorado National Forest Watershed Statistics, Appendix 1 for a complete listing.

Table 9 ENF Watersheds Ranked by Acres Over Threshold

Cal-Water Planning Watershed ID Nr	Cal-Water Planning Watershed Name	Cal-Water Planning Watershed Total Acres	Slope >40% No Stream Buffer No Road Acs	Slope >40% in Strm Buff With Rd Acs	>40% Bare Gd In Stm Buff No Rd Acs	>40% Bare Gd In Stm Buff With Rd Acres	Hi-K Soil No Stm Buff No Rd Acres	Hi-K Soil In Stm Buff With Rd Acres	Hi-K+Steep In Stm Buff No Rd Acres	Hi-K+Bare In Stm Buff No Rd Acs
514.33021	Peavine Ck	11510	40.9	2.2	311.1	27.6	1423.3	44.9	0.2	547.2
514.35050	Twentyfive Mile Cyn	10972	366.9	3.1	67.4	8	2754.9	115.2	40	154.1
514.34031	Union Valley Res	11288	34.5	0.2	975	8.4	1632.9	26.7	0.7	134.3
532.23062	Clear Ck	6840	59.6	0	13.8	1.8	2709.8	96.7	6.2	97.8
514.35021	Fry Ck	6346	84.5	0	3.1	0	1982.5	89.8	170.1	93.4
514.32030	Traverse Ck	9378	184.1	0	60.5	9.8	4634.4	137.4	0	86.5
514.32024	Redbird Ck	8228	696.8	4.2	18.5	2.4	4345.6	149	8.2	78.5
532.24041	Lower Perry Ck	4801	144.5	2.2	6.7	1.3	1478.8	25.6	8	68
532.23070	Long Ravine	4952	214.6	0	49.1	0	2340.9	61.6	17.8	55.6
514.35030	Upper Alder Ck	9233	91.6	0	76.7	18.2	778	38.2	1.3	55.4
514.43040	Upper Pilot Ck	9543	21.3	0	33.4	1.3	5385.3	56.7	7.8	52.5
532.23072	Squaw Hollow Ck	2414	0	0	0.2	0.2	1165.1	54.5	0	47.4
514.33032	Onion Ck	3358	31.8	0	0	0	2155	15.3	5.1	45.1
514.32040	Big Sailor Ck	9835	70.7	0	94.7	9.6	2593	74.7	1.6	43.4
532.23031	Mid-Upr. NF Cos. R	6247	73.2	0	43.8	6.7	745.3	36.9	6	39.1
514.44021	Lower SF Rubicon R	6676	606.6	0	28	4.2	607.7	8.7	16.2	36.2
514.32041	Kelsey Cyn	6687	1043.7	1.3	115.2	10.2	1264.9	45.4	12	35.6
514.32032	White Rock Ck	10831	2143	8	44.2	4.9	2854.1	88.9	34.5	35.6
532.23061	Jackass Ck	6047	150.3	0	13.3	3.6	2497	28	3.8	34.5
514.32010	Gaddis Ck	8684	0.4	0	2.2	0	6411	117.6	25.3	32.7
514.32031	Bear Ck	5358	73.4	0	6	1.3	3468	123.8	0.4	31.8
514.31022	Cold Springs Ck	1480	0	0	6.9	0.7	693.7	19.6	0	29.8
514.36030	Bark Shanty Cyn	5371	14.2	0	28.9	2.4	1802.1	31.4	12	29.1
532.23050	Jenkinson Lake	3057	2.4	0	81.4	0	595.9	12.9	0	29.1
514.33030	Little Silver Ck	8604	93.8	6	37.4	3.8	5499.4	136.5	8.4	26.7
532.23051	Camp Ck	10140	1771	0	15.1	1.1	4409.4	31.4	30.5	21.6
514.35022	Mill Ck	2178	18.5	0	6	0	223.5	16	7.1	21.1
532.23043	Clear Ck	2896	0	0	0	0	1770.1	52.5	0	20.7
532.23060	Butte Ck	5420	123.8	1.1	4.7	0.2	3433.5	46.9	1.3	20.5

See Eldorado National Forest Watershed Statistics, Appendix 1 for a complete listing.

Frequency distribution results of the models watershed ranking

In Figure 2, Distribution of Cells Over Threshold for Twenty-seven Eldorado National Forest Watersheds with High NEP where twenty-seven watersheds with high NEP's were selected. There was a concern that the effects of the various parameters selected to determine watershed sensitivity might not be evenly distributed across the study area. In order to review that, parameters from the 27 watersheds were graphed. While high K-factor and Steep Slopes have the greatest influence on NEP, bare ground is dominant in several cases leading to the conclusion that one factor does not overshadow all others. Frequency distributions of watershed rankings, Figure 4 examines how this model compares with USFS indexes distributions. These histograms for each index suggest that the NEP/SHI data are more evenly distributed across all the watersheds than the USFS comparisons. Figure 3 compares both Natural Erosion Potential (NEP) and Equivalent Roaded Acres (ERA) indexing methods. %NEP is the percent Natural Erosion Potential, NSI is the USFS natural sensitivity index, % SHI is the percent Sedimentation Hazard Index, TOC is the USFS threshold of concern, % Rd Acs is the percent of watershed in roads 30m wide, and ERA is the USFS percent of the watershed which has been disturbed.

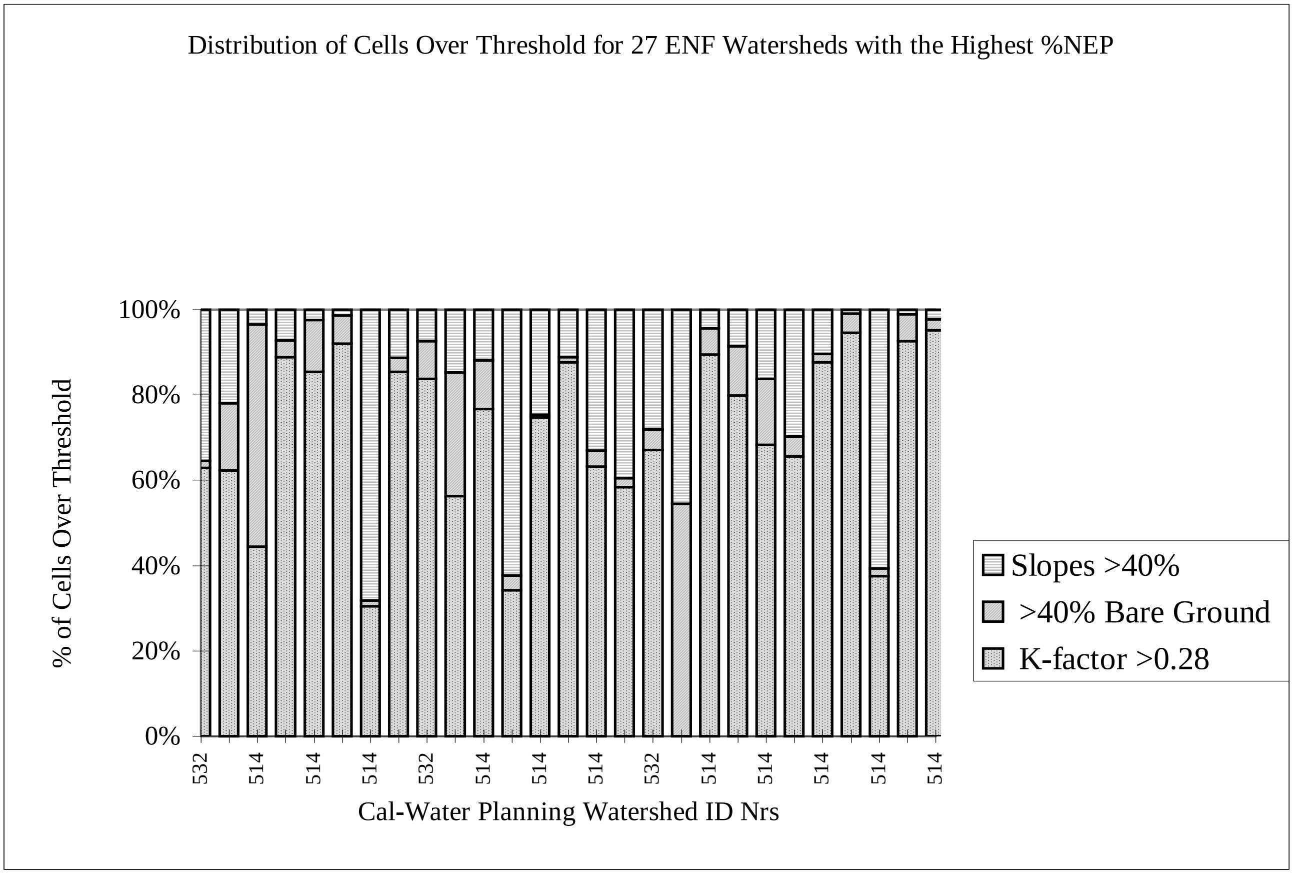


Figure 3 Distribution of Cells Over Threshold for 27 ENF Watersheds with the Highest %NEP

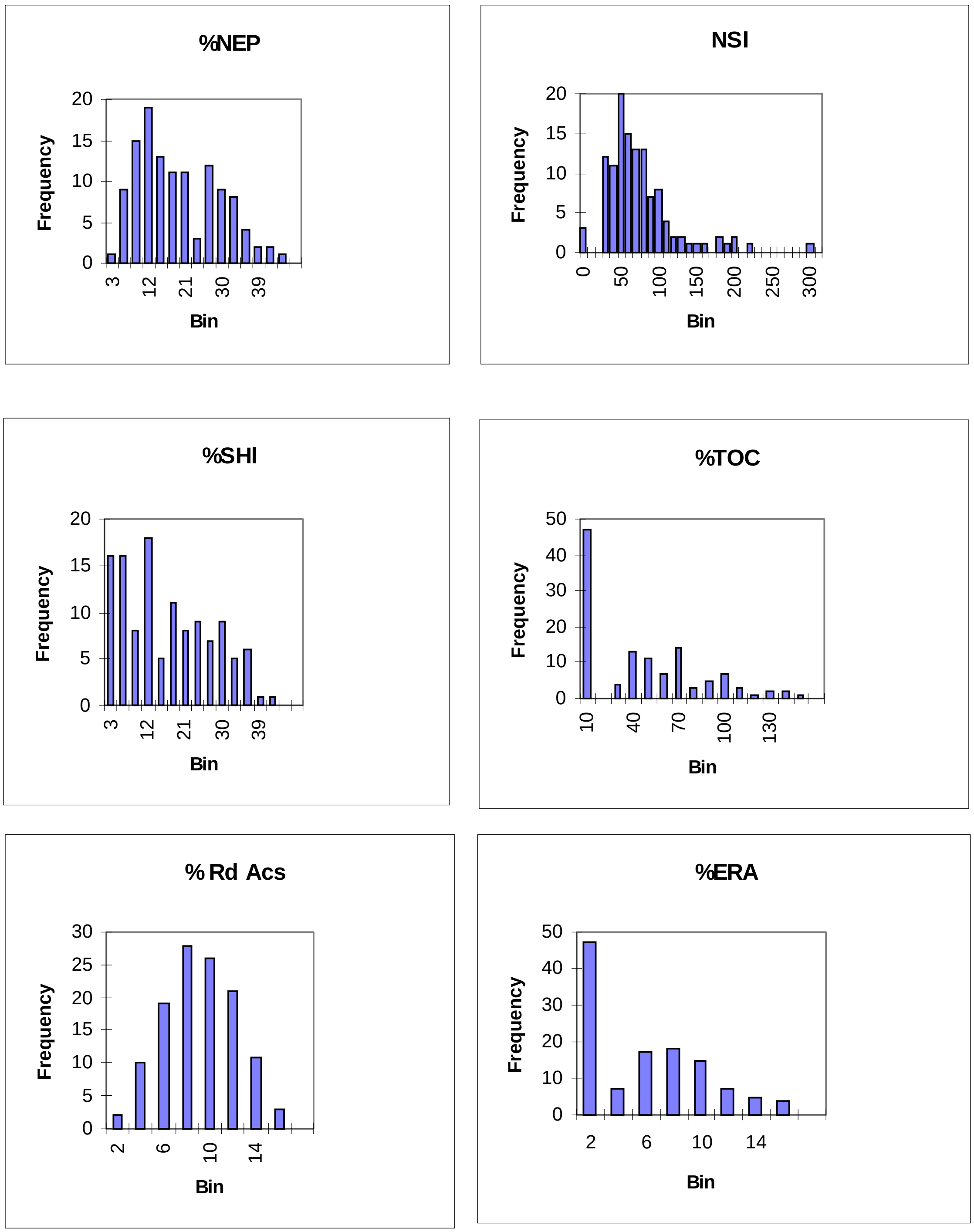


Figure 4 Frequency Distribution of ENF Watershed Rankings

Model Construction Time and Proposed Uses

After the soil data base was constructed, 177 CWPWS were reviewed and 134 analyzed for natural erosion potential and sedimentation hazards using approximately 10 days of GIS and analysis time. Positive correlation with the Eldorado National Forest's natural sensitivity index and equivalent roaded acres methodology provides significant encouragement to continue refining this model and expanding its application to other portions of the Sierra Nevada Ecosystem Project study area. NEP and SHI rankings may be modified by testing mitigation alternatives which include the surfacing and abandonment of road segments in areas over erosion parameter threshold. While this model is relatively easy to apply, and cost effective, it is a screening tool and is proposed for use in the allocation of human resources. Pre-assessment screening with NEP and SHI provide resources managers with information to guide selection of watersheds for more focused CWE analysis. Modeling the NEP and SHI response to various mitigation options allows the optimization of mitigation budgets.

Correlation Comparisons

The correlation coefficients, r, are positive for the four major indexes: USFS's NSI, ERA, and this model's NEP and SHI. The correlation between NEP and NSI is 0.54. Between SHI and TOC it is 0.44 and between SHI and ERA it is 0.34. The model has been run once, hence ground truthing to calibrate its prediction will continue. Finding that 54% of the variation in NSI ranking is explained by the variation in NEP is encouraging considering the difference in these methodologies, and with limited field validation. Calibration for large areas of exposed bedrock as in high elevation watersheds, precipitation isohyets and their influence on areas of high rain-on-snow potential, as well as change detection analysis will further improve the correlation between these two NEP and ERA watershed assessment methods. The ERA method of analysis is likewise an evolving technique requiring large commitments of personnel time in both the field and disturbance history research. Because of frequent opportunity for human bias the objectivity of the ERA method is often questioned.

Table 10 Correlation Coefficients, r, for the NEP and SHI Model Output

	NSI	ERA	TOC
NEP	0.54	0.19	0.33
SHI	0.43	0.34	0.44
RdAcs	-0.12	0.47	0.42
StBufAc	-0.29	0.37	0.24

	NSI	TOC	ERA
NSI		0.1865*	0.0698*
TOC	0.1978*		
ERA	0.0617*	0.9220*	

	NEP	SHI	RdAcs
NEP		0.8948	0.1491
SHI			0.3724
RdAcs		0.3724	
StBufAc	-0.1159	0.0405	0.6276

Where: NEP is the natural erosion potential, SHI is the sedimentation hazard index, RdAcs are this models roaded acres, StBufAc are acres within the stream buffer. NSI is the USFS natural sensitivity index, ERA is the USFS equivalent roaded acres, and TOC is the USFS threshold of concern. * = USFS data available only for comparison of 77 watersheds, all others had data from 120 watersheds.

<u>Correlation using watershed improvement needs reports</u>

Several validation methods were conceived and applied to the NEP and SHI data to analyze better the results of the watershed ranking. Thorough sampling continued into the Fall of 1995 and other data sets that were used in previous or concurrent assessments are being actively sought.

Both the ENF and Georgia Pacific Corporation collect and maintain reports of Watershed Improvement Needs (WIN) where opportunities to improve CWEs through mitigation are recorded. Reviewing 333 of these reports for the watersheds being studied yielded a correlation coefficient of 0.2 when total WINs for 114 watersheds were compared to the percent of the stream buffer that is roaded. While this fact has limited statistical significance, no other significant correlationís were observed. Attempts to correlate NSI, %ERA, %TOC, %NEP, and % RdAcs were all negative. The assumption that WINs represented randomly gathered data that were distributed evenly across all watersheds was false (Christiansen 1995). As a matter of practice, both industry and USFS road crews routinely repair problem spots eliminating the need for work requests or WIN reports. Table 10 contains the WIN report data reviewed. Each group of data collectors focused its attention primarily on lands belonging to or managed by their separate entities.

Table 11 Tabulation of Watershed Improvement Needs (WIN) Forms for the 24 ENF Watersheds Receiving the Most Reports

ENF Watershed ID Nr	Cal-Water planning watershed Nr	Cal-Water planning watershed name	USFS watershed improvement rpts	GP watershed improvement rpts	Total watershed improvement rpts
2236	532.23031A	AWS6	37	0	37
2176	532.2301	Camp Cr	30	0	30
4013	514.43032	Big Grizzly Cyn	19	0	19
1121	532.6006	E Panther Creek	7	7	14
1011	532.60063	Little Tiger Creek	0	12	12
1001	532.60064	Mill Creek	0	11	11
1211	532.60051	Beaver Creek	3	7	10
2471	532.24012	Cat Creek	9	0	9
3325	514.3505	Twentyfive Mile Cyn	6	3	9
2246	532.23032	Van Horn	7	0	7
3143	514.3202	Brass Cr	7	0	7
3355	514.35021	Fry Creek	7	0	7
2136	532.23021	Sly Park Creek	1	5	6
2456	532.2402	McKinney Creek	6	0	6
3336	514.3504	Plum Creek	5	1	6
3736	514.3603	Bark Shanty Cyn	5	1	6
3916	514.35017(A)	AWS3	6	0	6
1111	532.60061	W Panther Creek	0	5	5
3116	514.32015	Iowa Canyon	5	0	5
3133	514.32022	Whaler Creek	5	0	5
3386	514.3503	Upper Alder Creek	3	2	5
4123	514.4301	S F Long Canyon	5	0	5
4123+4143A	514.4301	S F Long Canyon	5	0	5

Pending correlation with other erosion potential assessments

The work of McKittrick (1994) using a GIS model to classify the erosion potential of private forested watersheds in northern California is currently being reviewed for additional comparisons. Integrating McKittrick's use of precipitation and geology will improve the NEP/SHI model. Other SNEP science team members are currently completing sensitive watershed assessments which will eventually be compared to the NEP/SHI results. Change detection analysis mentioned earlier (Maus et al. 1992, Green et al. 1993, Lachowski et al. 1994) allows more precise measurements of moderate cumulate disturbance such as selective timber harvesting and road construction. Using this technique to calculate the bare ground parameter requires the calibration and analysis of several images registered to the same location. Using change detection is expected to improve the indexing correlation with that of the ERA method this work will take place as Post-SNEP research.

Results of Cover Typing and Location Validation

In order to validate the TM band ratio and SMA techniques used here, selected bare ground sites were visited in the field. A Trimble Pathfinder Pro-exel Global Positioning System (GPS) was used in the field to locate the bare ground cells defined in the image, and to fix the position of additional data-collection points. Post-SNEP research will continue to evaluate the ease of use and accuracy of the various methods of bare-ground identification. This assessment has demonstrated that features as small as log landings 30 to 40 meters square (10,000 to 15,000 ft^2) are identifiable when their locations coincide with the matrix of the TM image.

In addition, the thresholds set to estimate vegetative crown closure appear effective. In the areas where field work has been conducted, young plantations with sparse weeds and some bare ground between the trees were easily distinguished. However, other plantations, along Darlington Creek, a tributary of Camp Creek, for example where broad leaf shrubs dominate the area between trees, did not appear on the coverage because their green reflectance was over the threshold. This suggests that the bare ground threshold is reasonable and distinct.

Field checking has revealed that many logging landings, one-quarter to one-half acre in size, used for storage and loading of logs, are easily identified as bare ground. Others, however, which are equal in size, aspect, and surrounding vegetation are not visible in the TM data. One explanation is cell registration. The resolution of Landsat imagery is about 30 m on a side. Values within a cell are averaged across the surface and, in the case of spectral reflectance, the averaged spectrum is reported. When cell boundaries directly register or match with the boundary of a feature on the ground, such as a landing, bare ground is easily detected. However, if the cell boundary falls across the middle of a landing and captures an equal amount of green vegetation, it is likely that the average spectral value will be considered green and not bare.

Other opportunities to influence the NEP/SHI are available through planting or seeding and mulching of bare areas. The Fry Creek watershed has 5614 cells or 1248 acres that could be considered for treatment. This number includes all those cells or combinations of cells that are bare and exceed other thresholds. It includes many areas already planted in trees which are not yet tall enough to provide a closed canopy. Bare rock outcrops and heavily grazed meadows also give the spectral signature of bare ground or bare ground covered with non-green vegetation. Many of these conditions cannot be mitigated. When they can be, however, those cells so mitigated are deducted from the number of cells over threshold and the NEP and SHI indexes are re-calculated. This system allows resource managers to optimize both environmental and economic-investment strategies by locating those areas which have the greatest impact on CWE and selecting the mitigation which is most cost effective. Thinking of this as an environmental accounting system permits one to allocate resources to those projects which have the most immediate impact on the net reduction of cumulative effects.

Model Directed Mitigation

After reviewing the results of the screening analysis and making an on-the-ground inspection of potential hazards, one of the first questions to be asked is, "what are the mitigation opportunities here?" It is not possible to change a soil's K-factor but one can consider abandoning or surfacing roads when they are located adjacent to streams and on soils that are highly detachable or combined with, steep slopes, and bare ground. In the Fry Creek example Table 6 (read down column 8, Road in Stream Buffer, where there is a 1 read across to column 1, Number of cells, and sum the cell numbers), 603 cells (add cells from column one when there is a "1" in column eight), 134 acres or 61 hectors of roads within stream buffers represent opportunities for possible CWE mitigation and each cell can be located by its coordinates. Finding these cells, via GPS, portable computer, and GIS programs provides for immediate optimization of mitigation alternatives based on the recalculation of SHI. Some high risk cells will become candidates for road abandonment, road surfacing, culvert replacement or fill-slope ripraping. The current cumulative condition of the watershed can be evaluated and improved as soon as steps are taken to reduce these risks. Abandoning a portion of road within a stream buffer, on steep bare ground, and where the soils are highly detachable reduces the denominator in the formula thereby reducing the percent SHI. It will also reduce the percentage of the watershed exceeding thresholds and, if it does not improve the watershed's ranking relative to others, it will at least allow for additional management to take place without excessive risk.

Other opportunities to influence the NEP or SHI are available through planting or seeding and mulching of bare areas. The Fry Creek watershed has 5716 cells, 1271 acres or 578 hectors that could be considered for this treatment. The number includes all those cells or combinations of cells that are bare and exceed other thresholds. It includes many areas already planted in trees which are not yet tall enough to provide a closed canopy where their green spectral reflectance exceeds the threshold. Bare rock outcrops and heavily grazed meadows also give the spectral signature of bare ground or bare ground covered with non-green vegetation such as logging slash or litter. Some of these conditions cannot be mitigated or may not need treatment. When they can be, however, those cells so mitigated are deducted and the NEP and SHI indexes are re-calculated. This system allows resource managers to optimize both environmental and economic-investment strategies by locating those areas which have the greatest impact on CWE and selecting the mitigation which is most cost an environmentally effective. Thinking of this as an environmental accounting system permits one to allocate resources to those projects which have the most immediate impact on the net reduction of cumulative effects.

Camp Creek Case Study and Cumulative Watershed Effects Comparison

In order to develop and test hydrologic process tools for CWE analysis models the SNEP Science Team and the Hydrology Working Group selected Camp Creek and Clear Creek in Eldorado County as sites for intensive case studies. Two teams worked on the study. One team built the traditional conceptual hydrologic model using locally available data and air photo analysis (McGurk and Berg 1995). The other team built a spatially-explicit eco-hydrologic model using 30-m DEMs, Landsat imagery, and an extensive ecological unit inventory data base (Ustin et al. 1995). The two teams are working to predict the hydrologic responses to land use changes in a forested and an urbanized watershed. Their tools will also be used to model several land-use scenarios being developed by the SNEP Science Team.

The development of the NEP and SHI screening methodology began in Camp and Clear Creeks because of the availability of data for that area. Early review of the screening-technique's output suggested that a thorough evaluation of this technique needed to be attempted on a much larger area. The ENF was selected also because of data availability and the fact that the soils data base, created to aid the eco-hydrologic modeling efforts, could easily be expanded to cover the rest of the ENF.

A Cumulative Effects Analysis of Upper Camp Creek

An existing study for the area titled "A Cumulative Off-site Watershed Effects Analysis for the Upper Camp Creek Watershed USFS #2176" (Carlson and Christiansen 1993) was completed in June of 1993 by the ENF staff using ERA and it found 9.3 % of the watershed to be disturbed. The Threshold Of Concern (TOC) range for this portion of the watershed had been set at 12 to 14 % ERA. This means that when cumulative disturbance of exceeds 14 % of the watershed area, there could be adverse CWE to the aquatic resources in this portion of Camp Creek. If management activities such as timber harvesting proceeded without sufficient mitigation, significant environmental damage could result.

Some Analytical Limitations of this Model and Remote Sensing and GIS Tools

Based on the NEP/SHI scores from Tables 3, 4, and 5, Camp Creek does not appear to be in a sensitive condition; a finding which is consistent with Forest Service calculations for NSI and ERA found in Table 8. One of the advantages of using a data format like that in Cell Counts for Parameters Over Threshold Lower Camp Creek, Table 3 is that it is a practical guide to management opportunities for mitigation of problems affecting the watersheds "current cumulative condition," or "health," as seen from a sedimentation or erosion control point of view. While steep slopes and high K-factor soils cannot be changed managing the use of these areas can become more sensitive. Mitigation of these conditions takes place through road surfacing, relocation or abandonment along with continuous seeding and mulching after operations. The Cal-Water Project, has divided Camp Creek into three segments two inside the ENF and the most westerly segment outside the Forest. The two most easterly segments have been named Lower and Upper Camp Creek by the ENF but the 1993 CWE analysis refers to the entire area as Upper Camp Creek which has lead to some confusion.

As an example of how the NSI, ERA, NEP, and SHI ranking methods may miss important findings the following anecdote is offered. During several trips into the watershed, with Science Team members and other experts on the SNEP staff the validity of the ENF CWE analysis was questioned because the watershed from the ground appears to be a healthy ecosystem. Many of the major logging haul roads in the watershed are paved or rocked and the areas of steep slopes and highly detachable soils are limited in comparison to neighboring basins. Large areas of old-growth forest in the center of the watershed, well-stocked plantations that were previously harvested clear-cuts, and nearly closed canopy in areas that had been selectively logged, all suggest a healthy condition. Appearances indicate that if this basin is near TOC, elements other than those normally measured by ERA might be making significant contributions to watershed sensitivity.

Access to the heart of Upper Camp Creek is provided by paved road directly from Highway 50 via Sly Park Reservoir and Iron Mountain Road, which connects with another trans-Sierra Nevada highway, Route 88. Water, that features numerous gentle stretches along Camp Creek and its tributaries, as well as no prohibition to stream-side camping, attract many visitors and their off road vehicles (ORVs) to this area every weekend (Richardson, 1994 SNEP Vol. III). Intense use has created tens of miles of ORV trails. These trails which lack drainage or erosion controls have made a significant contribution of sediment to Camp Creek. NEP and SHI techniques may detect disturbance from ORV use, however if these trails are under a closed forest canopy and in the riparian zone they may have overwhelming impacts on aquatic habitat without triggering the screening indices. Only an expensive and time consuming stream channel survey will identify these kinds of watershed impacts. Both Camp Creek and Rock Creek have sustained similar riparian degradation form heavy ORV use (Swanson et al. 1993, USDA Forest Service 1995). Public policy concerning recreational access to, and use of, riparian zones needs to be examined.

CONCLUSIONS

After the soil data base was constructed 177 CWPWS were reviewed and 134 analyzed for NEP and SHI using approximately 10 days of GIS and analysis time. There were positive correlation with the ENF's NSI and ERA methodology which are not objective scientifically based assessments. With an emerging field of study such as CWE even a low r square value suggests that the results are not random and therefore provides significant encouragement to continue refining this model and expanding its application to other portions of the SNEP study area (Berg et al. 1995, Menning 1995, SNEP Vol III). NEP and SHI rankings may be modified by testing mitigation alternatives which include the surfacing and abandonment of road segments in areas over erosion parameter threshold. While this model is relatively easy to apply, and cost effective, it is a screening tool and is proposed for use in the allocation of human resources. Pre-assessment screening with NEP and SHI provide the resources managers with information to guide selection of watersheds for more focused CWE analysis. Modeling the NEP and SHI response to various mitigation options allows the optimization of mitigation budgets.

Need for Public-Private Cooperation

The structure of SNEP provided for many work groups with specific interests, one of the most important conclusions of the Hydrology Group is the extreme need for standardized digital tools such as a soils data base and disturbance histories. These will help to provide resource managers, both public and private, the information they need for economically and environmentally sound decision making. To do accurate CWE analysis which will contribute to making the Sierra Nevada ecosystem sustainable, both public and private land owners must be able to exchange information about their individual activities accurately, quickly, and in similar formats. Data base programs like ORACLE may be the type of mechanism to provide data, but it will require a commitment of Congress to fund the building of a data-base. As an example, recent revisions of the California Forest Practice Act mandated the development of Sustained Yield Plans by September 1996. These plans must address CWE's. However, currently there is no digital source of information which identifies and locates previous timber harvest activity on federal land. Furthermore, a standardized digital soils layer which covers entire watersheds on both sides of the national forest boundary does not exist. This kind of information is critical for accurate CWE assessments and monitoring of outcomes of any management scenarios. Sustainability of forest ecosystems in both the eastern and western United States depends on understanding the "current cumulative condition." In order to gain this understanding at a regional scale one must have information on what resource elements are present and how are they distributed, regardless of ownership.

The most productive elevation range in the Sierra Nevada for the west side Ponderosa Pine dominated mixed conifer forests is between 3000 and 6000 feet. Historically these lands have been in private ownership. Generally, there are large blocks of commercially owned timberland in this range and there is a steady encroachment of residential uses advancing west to east as well as both north and south of all major access routes. Because the drainage of the western Sierra Nevada is east to west most, major watersheds have their headwaters at elevations above 6000 feet, where Federal ownership predominates. Watershed analysis, especially for cumulative effect, must consider natural and management disturbances along a continuum of private residential, commercial timberland, and national forest lands.

Thirty-six percent of the nearly twenty-nine million acres in the SNEP study area are privately owned. These private lands are relatively evenly dispersed in "mixed ownership watersheds." The natural boundaries of many mixed ownership watersheds often cross the administrative boundaries of the national forests and divide a watershed for analysis purposes. As an example, there might be one-third of a watershed inside the national forest, and two-thirds outside, half of which is held by large land owners and half held in small lots for residential use or investment. While each land-holding group may have extremely different management plans, all agencies and private operators need a standardized data base in order to calculate the combined impacts of their land use histories and from which to project their combined future activities.

Re-establishing National Forest Boundaries

National forest boundaries were established many decades ago prior to ecosystem management and watershed analysis. Today's GIS analytical environment operates more effectively when boundaries are defined along major drainage divides. Currently the Tahoe National Forest (TNF), ENF, and SNF are divided along the channels of sub-basins. Therefore, the SNF shares the North Fork of the Mokelumne River with the ENF and the ENF shares the Middle Fork of the American River with the TNF. Inter-forest and forest-industry watershed management could be made more efficient if national forest boundaries were moved to the ridges dividing these major basins.

As public and private resource managers move toward ecosystem management and watershed analysis, the location of boundaries between national forests must be called into question. Ridge tops are now the division between analysis units and should become administrative boundaries. When each national forest is allowed to adopt its own naming and numbering conventions, and boundary lines for watersheds, and soil mapping units, chaos follows when cross-agency and inter-agency assessments are required. With multiple agencies and private landowners needing to share data for CWE studies, delays caused by differences in naming conventions and formats are expensive and unnecessary.

Model Expansion and Improvement

As standardized and integrated soils data bases are completed for other portions of the Sierra Nevada and as DEMs of higher resolution become available, a Sierra Nevada regional NEP and SHI analysis could be run and re-run periodically to evaluate the impacts of residential development, fire, timber harvest, and other regionally important phenomenon that can be observed from space. Although this model will continue to be evaluated and validated, effects of additional elements such as climate, rain-on-snow, and geology will be tested to improve model performance. High-elevation basins are important and sensitive even if unmanaged; however, their contribution to the sediment load is not potentially as high as lower-elevation areas that are heavily managed. Therefore the problem of separating bare rock outcrops from bare exposed soil will be an important element of future NEP models.

Adjudication of “Disturbance Rights” in CWE Limited Watersheds

An accurate indexing methodology is a valuable tool when allocating resources for watershed improvement or adjudicating “disturbance rights” between landowners. Predicting the erosional potential for a given unit area of land is the objective of this methodology; it is intended to index current cumulative condition for individual planning watersheds relative to their neighbors given similar climatic conditions. It was designed as a primary screening tool and environmental accounting system that provides objective information for decision makers.

The adjudication of logging rights has not yet been implemented in mixed ownership watersheds but when watersheds become, “cumulative effects limited” or over TOC, to the extent that management operation must be modified. My model provides the basis for the selection of mitigation projects that will improve the cumulative condition of the watershed as well as locating those areas which should be avoided or managed with informed sensitivity.

With these tools, decisions about road location and abandonment, skid trail layout, as well as recreation and grazing practices may be reviewed on local or regional scales and provide information to be used when balancing ecosystem health and cumulative watershed effects with human need in order to maintain all systems in sustainable condition.

LIST OF ACRONYMS

ARC/INFO	A geographic information system developed Environmental Systems Research Institute, Inc. ESRI. Primarily for workstation use.
ARC/INFO GRID	A geographic information system tool used to analysis spatially distributed data in a matrix or raster format.
Arc/View	A geographic information system program used to display coverage's developed on either ARC/INFO or ARC/INFO GRID. Primarily for PC use.
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer a NASA research tool which collects 220 bands of spectral data simultaneously.
AWSI	Associated USFS watershed assembled to match CWPWS boundaries.
BLM	Bureau of Land Management
CDF	California Division of Forestry and Fire Protection
CEQA	California Environmental Quality Act
Change Detection	A technique using images taken at different times registered to the same location. Color enhancement differentiates areas on the ground that have changed form areas that have not changed.
COUNT	An ARC/INFO term which related to the sum of the cell in a particular query.
CWE	Cumulative watershed effects the total impact of past, present, and foreseeable activities in a watershed.
CWPWS	Cal-Water planning watersheds the boundaries defined by the California Department of Forestry and Fire Protection.
DEM	Digital elevation model a matrix draped over a landscape which reflects the topography of the surface.
EHR	Erosion Hazard Rating an index of a soils susceptibility to disturbance.
ENF	Eldorado National Forest
ERA	Equivalent Roaded Acres one method of calculating CWE for a watershed. It equates all disturbance to acres of roaded surface.
FSWSID	Forest Service watershed identification numbers are not the same as the Cal-Water numbers nor are the boundaries
GIS	Geographic Information System a method of organizing and analyzing information about a landscape both spatially and temporally.
GP	Georgia Pacific Corporation
GPS	Global Positioning System an instrument used to find or fix the users location on the ground.
GPWIN	Georgia Pacific Corporation watershed improvement needs forms used to inventory and monitor potential problems on Company lands.
ID	Identification
Interrill	An area between rills normally susceptible to sheet or surface erosion.
K-factor	K is the soils detachability or erodibility factor

Landsat TM	Thematic Mapper images taken by satellites and used for many resource based monitoring functions.
NDSI	Normalized Difference Soil Index a method of ratio satellite reflectance date to enhance our identification of soils versus vegetation.
NDVI	Normalized Difference Vegetation Index a measure of the greenness of vegetation.
NEP	Natural Erosion Potential a product of this study which indexes a watersheds natural stability based on the amounts of bare, steep and highly erodible soils present.
NEPA	National Environmental Protection Act
NIR	near-infrared a portion of the electromagnetic spectrum used to identify vegetation.
NRCS	Natural Resources Conservation Service. Agenciy name changed from Soil Conservation Service (SCS).
NSI	USFS Natural Sensitivity Index derived from soil, stream channel, and climate assessment used to define a watersheds natural stability.
ORACLE	A data base management program.
ORV	Off Road Vehicle
Rill	A linear void caused by erosion having less than 1 square foot of crossection, when it exceed 1sq/ft it becomes a gully.
RUSLE	Revised Universal Soil Loss Equation a method of calculating erosion losses. Used mainly on mid-western agricultural soils.
SB	Stream Buffers any distance one wishes to set on either side of a stream.
SCS	Soil Conservation Service (USDA) currently Natural Resources Conservation Service (NRCS).
SHI	Sedimentation Hazard Index a product of this study which indexes the impact of management and road systems adjacent to flowing streams.
SMA	Spectral Mixture Analysis a statistical method of using spectral reflectance of selected features to suggest how much of each feature is contained in mixed cell or pixel.
SNEP	Sierra Nevada Ecosystem Project
SNF	Stanislaus National Forest

The following are acronyms used frequently in this paper:

TNF	Tahoe National Forest
TOC	USFS Threshold Of Concern based on NSI and normally falling between 10 and 20 % ERA.
USDA	United States Department of Agriculture
USDA-FS	United States Department of Agriculture Forest Service
USDA-NRCS	United States Department of Agriculture Natural Resources Conservation Service formerly the Soil Conservation Service
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USFS	US Forest Service
USGS	US Geological Survey

USLE	Universal Soil Loss Equation a method of calculating erosion losses. Used mainly on mid-western agricultural soils.
USWIN	USFS Watershed Improvement Needs watershed improvement needs forms used to inventory and monitor potential problems on federal lands.
UTM	Universal Transverse Mercator
WATSED	Water Yield and Sediment Model a model which predicts amounts of soil loss in forest and range watershed of Montana. A CWE model for use in mixed ownership's.
WEPP	Water Erosion Prediction Project is a distributed parameter, continuous simulation, erosion prediction model developed by several federal agencies for use in watersheds of moderate slope steepness.

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Appendix 1 Eldorado National Forest Watershed Statistics

Eldorado National Forest 120 Watershed Comparisons of NSI, ERA, TOC, NEP, and SHI

							Natural Sensivity and Natural Erosion Potential Comaprison for 120 Eldorado National Forest Watersheds			
CPWS ID Nr Cal-Water Planning watershed ID number	Cal-Water watershed Name	CPWS Acs Cal-Water planning watershed acres	NSI Natural Sensitivity Index	% TOC Threshold of concern	% ERA Equivalent roaded acres	EHR RiskNr Erosion Hazard Rating Nr	%NEP Natural Erosion Potential	%SHI Sedimentation Hazard Index	% Rd acs Roaded acres	%SB/Rd Roaded acres inside stream buffers
514.31010	N F Webber Creek	6376	44	0.0	0	0	15.6	9.6	12.2	10.5
514.31011	S F Webber Creek	4916	30	0.0	0	0	12.3	14.9	20.1	17.3
514.32010	Gaddis Creek	8684	81	106.0	10.6	5	8.2	35.2	34.6	9
514.32011	Slab Creek	5493	114	43.0	4.3	2	11.0	32.3	27.9	8.6
514.32012	Brush Creek	5132	37	36.4	5.1	2	10.2	36.6	34.0	7.7
514.32013	Slab Creek Res	5723	174	51.0	5.1	2	9.8	28.7	26.8	6.1
514.32014	Long Canyon	2876	69	149.0	14.9	5	14.3	20.5	19.2	5.7
514.32015	Iowa Canyon	5107	41	95.0	13.3	4	14.2	18.2	24.5	10.9
514.32022	Whaler Creek	10209	90	62.0	6.2	3	11.5	29.7	29.4	11
514.32023	One Eye Creek	4521	66	75.0	7.5	3	12.4	26.8	21.6	12.4
514.32030	Traverse Creek	9378	36	0.0	0	0	12.3	25.7	27.1	12.3
514.32031	Bear Creek	5358	59	68.3	8.2	3	12.6	28.1	27.4	16
514.33010	Lyons Creek	11306	42	49.3	6.9	2	5.0	13.5	8.8	7.4
514.33020	Ice House Res	6175	49	0.0	0	0	6.7	7.5	7.3	3.6
514.33021	Peavine Creek	11510	60	125.0	15	5	10.5	40.9	38.6	11.4
514.33030	Little Silver Creek	8604	28	68.1	10.9	3	9.6	30.6	32.0	11.3
514.33031	Sugar Pine Creek	10713	103	87.0	8.7	4	5.0	26.0	17.3	6.4
514.33032	Onion Creek	3358	27	0.0	0	0	5.7	36.0	39.3	3.5

514.33033	Jay Bird Canyon	1643	50	58.6	8.2	2	11.3	6.7	3.2	17.6
514.33034	Round Tent Canyon	2403	61	60.8	7.3	3	6.9	10.8	6.8	16.3
514.33035	Camp Seven	4248	291	70.0	7	3	6.1	32.4	34.4	5.3
514.34010	Jones Silver Creek	6150	65	7.5	0.9	1	3.4	14.6	10.5	2.5
514.34011	Table Rock	10084	41	39.3	5.5	2	8.4	5.2	4.9	7.8
514.34020	Lawrence Lake	5234	60	4.2	0.5	1	1.6	14.2	2.7	1.9
514.34021	Bassi F Silver Creek	8290	50	29.3	4.1	1	3.5	8.4	3.4	5.1
514.34022	Big Siver Creek	6725	59	39.2	4.7	2	4.7	6.2	1.2	5.9
514.34030	Tells Creek	5899	30	41.9	6.7	2	6.8	4.3	4.7	9
514.34031	Union Valley Res	11288	57	80.8	9.7	4	8.8	18.9	18.2	2.9
514.35010	Pyramid Creek	6051	91	0.0	0	0	2.6	26.8	15.8	2.7
514.35012	Aspen Creek	6675	44	0.0	0	0	5.9	14.4	2.5	11.3
514.35013	Sayles Canyon	4237	62	0.0	0	0	4.1	11.3	2.2	8.5
514.35014	Strawberry Creek	7418	54	33.3	4	2	5.1	11.1	2.8	5.5
514.35016	Cody Creek	2437	46	0.0	0	0	5.9	6.9	2.2	10.6
514.35018	Station Creek	2275	43	0.0	0	0	7.0	7.1	0.5	5.2
514.35020	Carpenter Creek	9215	79	0.0	0	0	7.9	31.5	25.2	8.4
514.35021	Fry Creek	6346	183	138.0	13.8	5	9.1	41.7	35.5	11.9
514.35022	Mill Creek	2178	61	117.5	14.1	5	8.6	11.5	24.9	8.1
514.35030	Upper Alder Creek	9233	45	72.9	10.2	3	10.2	10.0	11.6	15.3
514.35031	North Creek	2717	55	0.0	0	0	6.6	3.9	1.5	8.9
514.35032	Lower Alder Creek	2209	192	100.0	9	5	11.1	30.2	20.3	7.8
514.35040	Plum Creek	5466	69	94.0	9.4	4	6.5	11.0	9.2	7.6
514.35050	Twentyfive Mile Cyn	10972	138	129.0	12.9	5	9.6	33.6	31.6	10.8
514.35051	Grays Canyon	8308	173	51.0	5.1	2	9.0	31.2	24.6	5.7
514.35052	Soldier Creek	3414	52	103.3	12.4	5	9.3	17.6	23.5	13.4
514.36010	Emigrant Creek	8742	72	0.0	0	0	4.9	10.7	5.6	6
514.36011	Kirkwood Creek	2306	90	0.0	0	0	6.0	14.8	10.4	7.5
514.36012	Caples Creek	9212	67	0.0	0	0	4.0	13.2	5.0	6.2
514.36013	Silver Lake	9691	87	0.0	0	0	4.7	13.9	6.4	5.6
514.36014	Oyster Creek	5400	83	0.0	0	0	3.2	10.4	1.1	4.9
514.36020	North Tragedy Creek	4781	38	47.9	6.7	2	1.9	12.4	8.0	1.9

514.36021	Sherman Canyon	6262	142	0.0	0	0	7.6	4.5	3.9	9.8
514.36022	Mule Canyon	3505	54	49.2	5.9	2	8.9	9.7	9.7	12.2
514.36023	Matin Creek	3253	72	38.0	6	2	7.2	5.6	4.9	8.4
514.36030	Bark Shanty Cyn	5371	94	80.0	9.9	4	8.8	19.9	15.1	9.9
514.36031	Girard Creek	2067	58	91.7	11	4	10.0	10.9	11.0	18.5
514.36032	Long Canyon	3597	45	0.0	0	0	6.3	9.1	3.6	8.2
514.36033	Middle Creek	4735	119	50.0	5	3	7.0	24.5	29.8	6.9
514.36034	Beanville Creek	2343	123	0.0	0	0	7.7	25.8	21.1	7.6
514.41020	Missouri Canyon	11451	109	44.0	4.4	2	9.6	18.8	11.9	6.5
514.41030	Canyon Creek	8807	51	52.5	6.3	2	12.5	21.5	19.3	11.6
514.43010	S F Long Canyon	6375	39	0.0	0	0	7.8	5.7	1.3	7.1
514.43011	N F Long Canyon	4244	49	0.0	0	0	7.9	7.1	1.0	9.6
514.43012	Long Canyon	11700	110	82.0	8.2	4	6.4	19.0	9.3	3.7
514.43013	Wallace Canyon	8347	44	59.3	8.3	2	9.4	10.1	7.9	10.6
514.43020	Stony Creek	11933	72	34.0	3.4	2	7.7	18.7	10.8	6.2
514.43021	Little Deer Creek	2727	45	0.0	0	0	13.9	6.7	4.5	22.4
514.43032	Big Grizzly Cyn	4321	64	95.8	11.5	4	9.3	17.8	19.1	9.6
514.43033	Zero Spring	8212	220	30.0	3	2	6.0	34.8	24.5	4.2
514.43040	Upper Pilot Creek	9543	22	92.5	14.8	4	6.7	26.8	21.3	5.6
514.43041	Lower Pilot Creek	9818	73	0.0	0	0	8.9	34.6	30.0	5.3
514.44010	Gerle Creek	7943	38	35.7	5	2	6.6	7.1	7.7	8.1
514.44011	Rocky Basin Creek	6584	47	37.9	5.3	2	6.0	6.3	3.8	4.7
514.44012	Loon Lake	5141	38	5.0	0.7	1	4.8	6.8	10.7	2.7
514.44020	Up S F Rubicon River	10127	28	38.8	6.2	2	6.5	6.1	1.5	4.6
514.44021	Lwr S F Rubicon River	6676	90	62.0	6.2	3	9.7	15.2	6.6	9
514.45022	Rockbound Lake	4434	102	0.0	0	0	4.4	18.3	13.3	5.9
514.45023	Phipps Creek	11722	0	0.0	0	0	2.7	19.5	13.5	5.6
514.45024	Lake Schmidell	8249	0	0.0	0	0	3.5	22.7	10.7	6
532.23010	Upper Camp Creek	8716	51.4	65.0	7.6	3	12.4	2.6	1.9	13.6
532.23011	Lower Camp Creek	10330	41.3	27.9	3.9	1	11.2	15.5	15.1	16.6
532.23021	Sly Park Creek	6275	42	0.0	0	0	7.7	11.0	9.6	11.1
532.23022	Hazel Creek	1755	33	0.0	0	0	7.7	8.5	10.9	4.3

532.23032	Van Horn Creek	7516	77	64.0	6.4	3	10.2	26.5	23.8	12.3
532.23033	North Canyon	3541	25	23.1	3.7	1	10.0	29.5	28.8	15.3
532.23040	North Steely Creek	6857	28	46.3	7.4	2	11.7	14.2	16.5	16.7
532.23041	String Canyon	6964	73	0.0	0	0	12.2	27.5	23.3	8.6
532.23042	Middle Butte	2925	160	53.0	5.3	2	6.2	31.1	29.8	3.2
532.23043	Clear Creek	2896	34	61.3	9.8	3	10.3	28.1	32.2	14.1
532.23050	Jenkinson Lake	3057	36	0.0	0	0	9.6	10.1	11.2	4.4
532.23051	Camp Creek	10140	92	66.0	6.6	3	7.4	29.9	23.3	3.9
532.23062	Clear Creek	6840	28	50.0	8	2	13.1	28.0	27.7	14.5
532.24010	Anderson Canyon	3252	72	64.0	6.4	3	7.3	10.3	16.2	3.1
532.24011	Prothro Creek	9263	83	0.0	0	0	11.7	16.7	17.2	13.2
532.24012	Cat Creek	5655	93	138.0	13.8	5	10.7	14.4	23.9	13.8
532.24013	Shingle Mill Creek	9609	60	83.3	10	4	11.7	9.5	9.6	10.8
532.24014	Crystal Mine	4493	92	47.0	4.7	2	9.9	16.3	18.6	7.2
532.24020	McKinney Creek	3005	29	39.4	6.3	2	8.6	4.6	3.4	18.6
532.24021	Dogtown Creek	6799	63	50.0	6	2	8.3	17.1	15.7	7.2
532.24022	Middle Dry Creek	3383	33	54.4	8.7	2	13.6	3.8	1.7	24.5
532.24030	Sopiago Creek	7699	43	85.0	11.9	4	12.7	9.8	11.6	11.7
532.24040	OConnor Gulch	2623	193	0.0	0	0	7.8	42.2	34.4	1.8
532.24060	Oregon Gulch	5742	22	62.5	10	3	11.1	13.2	12.4	9.4
532.60040	Bear River	7838	80	0.0	0	0	2.9	15.2	4.8	3.3
532.60041	Tragedy Creek	4736	78	0.0	0	0	2.8	13.3	0.0	1.4
532.60042	Corral Flat	3633	58	0.0	0	0	4.2	5.5	0.6	4.6
532.60043	Bear River Res	7659	32	31.9	5.1	2	8.1	6.2	3.3	4.7
532.60050	Rattlesnake Creek	6639	93	0.0	0	0	7.0	16.4	5.9	9.7
532.60051	Beaver Creek	2464	95	100.0	10	5	8.2	31.7	34.6	9.5
532.60060	E Panther Creek	5463	47	68.6	9.6	3	9.2	24.8	18.1	11.4
532.60061	W Panther Creek	5853	79	104.0	10.4	5	11.3	26.1	30.2	9.9
532.60063	Little Tiger Creek	7394	24	0.0	0	0	10.1	17.3	17.7	11.4
532.60064	Mill Creek	8005	61	0.0	0	0	8.3	16.5	15.4	11.4
514.32021A	AWS1	13502	94	34.0	3.7	2	10.3	25.1	24.4	0
514.32032(A)	AWS2	19057	71	0.0	0	0	11.6	28.9	29.2	0

514.35017(A)	AWS3	13698	63	0.0	0	0	5.7	18.1	9.7	0
514.43031A	AWS4	14221	123	32.0	3.2	2	5.1	23.9	22.2	0
514.45024A	AWS5	19971	0	0.0	0	0	3.0	20.8	12.3	0
532.23031A	AWS6	13728	53	62.5	7.5	3	8.5	8.4	9.9	0
532.60017A	AWS7	21307	74	0.0	0	ukn	2.9	24.4	17.7	0
532.60031A	AWS8	13760	69	0.0	0	0	4.2	11.9	3.6	0

Eldorado National Forest Watersheds with Acres Over Threshold

Cal-Water Planning Watershed ID Nr	Cal-Water Planning Watershed Name	Cal-Water Planning Watershed Total Acres	Slope >40% No Stream Buffer No Road Acs	Slope >40% in Strm Buff With Rd Acs	>40% Bare Ground No Stm Buff No Rd Acs	>40% Bare Gd In Stm Buff No Rd Acs	>40% Bare Gd In Stm Buff With Rd Acres	>40% Bare + Steep Gd No Stm Buff No Rd Acs	Hi-K Soil No Stm Buff No Rd Acres	Hi-K Soil In Stm Buff No Rd Acs	Hi-K Soil In Stm Buff With Rd Acres
514.31010	NF Webber Ck	6376	203.9	0.2	231.5	11.6	0.7	8.7	947	231	38.9
514.31011	SF Webber Ck	4916	64.3	0.2	266.4	14.5	2.4	0.2	1308.3	132.7	52.5
514.31012	China Ck	4562	28	0.9	168.1	12.2	1.1	0	1990.9	329.5	39.6
514.31020	Ringold Ck	1061	6.4	0	33.4	5.1	0.7	0	555	54	17.6
514.31021	Hangtown Ck	418	4.2	0	43.8	2.2	0	1.6	82.7	5.1	3.6
514.31022	Cold Springs Ck	1480	0	0	108.5	6.9	0.7	0	693.7	141.6	19.6
514.32010	Gaddis Ck	8684	0.4	0	4	2.2	0	0	6411	1170.7	117.6
514.32011	Slab Ck	5493	389.3	1.6	6.7	0.9	0	5.6	2373.8	656.2	70.7
514.32012	Brush Ck	5132	42.5	1.1	0	2	0.2	0	3659.7	720.2	55.8
514.32013	Slab Ck Res	5723	2186.6	24.9	7.6	42	0.4	16.9	1214.5	217	31.1
514.32014	Long Cyn	2876	286.2	0	13.8	3.1	0.2	0.2	1080	97.8	14.2
514.32015	Iowa Cyn	5107	185.2	0.2	28.5	3.6	0	0	1654.3	280.2	59.1
514.32020	Brass Ck	6089	72.9	0	20.5	0.7	0	0	2539.5	627.7	79.4
514.32021	Bald Mtn Cyn	7413	495.2	0.9	17.8	0.7	0	3.1	3529.1	869.6	60.9
514.32022	Whaler Ck	10209	438.9	2.4	15.6	0.4	0	3.1	6177.3	1039	138.7
514.32023	One Eye	4521	222.6	1.6	22	0.7	0	1.3	2262.9	495	65.8
514.32024	Redbird Ck	8228	696.8	4.2	54	18.5	2.4	2.9	4345.6	836.3	149
514.32030	Traverse Ck	9378	184.1	0	154.5	60.5	9.8	0.7	4634.4	791.6	137.4
514.32031	Bear Ck	5358	73.4	0	5.3	6	1.3	5.8	3468	581.9	123.8

514.32032	White Rock Ck	10831	2143	8	201.4	44.2	4.9	109.4	2854.1	494.5	88.9
514.32040	Big Sailor Ck	9835	70.7	0	965	94.7	9.6	18.7	2593	504.7	74.7
514.32041	Kelsey Cyn	6687	1043.7	1.3	308.4	115.2	10.2	236.4	1264.9	236.1	45.4
514.32050	Georgetown Ck	2575	0	0	0.7	0	0	0	17.3	0.4	0.2
514.33010	Lyons Ck	11306	649	1.8	2177.9	309.7	28.2	670.2	0.4	0	0
514.33020	Ice House Res	6175	100.9	0.4	884.3	147.2	9.6	13.6	138.1	34	1.1
514.33021	Peavine Ck	11510	40.9	2.2	2464.5	311.1	27.6	99.4	1423.3	308	44.9
514.33030	Little Silver Ck	8604	93.8	6	75.8	37.4	3.8	36	5499.4	971.7	136.5
514.33031	Sugar Pine Ck	10713	1561.6	6.7	635	114.5	14.2	73.2	4071.5	684.2	37.1
514.33032	Onion Ck	3358	31.8	0	7.1	0	0	0.4	2155	447.1	15.3
514.33033	Jay Bird Cyn	1643	10.5	0.2	19.1	1.6	0	0	160.1	58.7	3.3
514.33034	Round Tent Cyn	2403	140.3	0	127.4	1.3	0.2	2.9	317.7	67.1	7.8
514.33035	Camp Seven	4248	2036.5	0.9	2.9	16.7	0	57.1	1004.1	129	33.1
514.34010	Jones Fk Silver Ck	6150	299.7	0	1549.1	221.5	6.9	307.5	0	0	0
514.34011	Table Rock	10084	158.1	0	987.7	96.7	12	18.5	143.4	22.2	6.4
514.34020	Lawrence Lake	5234	196.8	0	1372.6	237.9	1.3	207	0	0	0
514.34021	Bassi Fk Silver Ck	8290	718.4	0	908.1	115.8	4.9	171.9	0.2	0	0
514.34022	Big Siver Ck	6725	312	0	649.5	50	2	65.8	76.3	0	0
514.34030	Tells Ck	5899	63.1	0.2	607.7	59.1	11.8	0.4	2.4	0	0
514.34031	Union Valley Res	11288	34.5	0.2	557.7	975	8.4	3.6	1632.9	204.3	26.7
514.35010	Pyramid Ck	6051	825.6	0	1603.4	758.2	22.7	777.3	0	0	0
514.35012	Aspen Ck	6675	1377	0	878.7	72.9	9.3	196.8	0	0	0
514.35013	Sayles Cyn	4237	384.9	0	640.6	38.9	2.9	183.4	0	0	0
514.35014	Strawberry Ck	7418	1500.9	0.7	674.4	17.1	3.6	92.3	0	0	0
514.35015	Rocky Cyn	4215	945.2	0	409.8	16.5	5.8	63.8	54	4.7	0.9
514.35016	Cody Ck	2437	100.1	0	343.3	16.2	2.7	14	0	0	0
514.35017	Forni Ck	9483	1254.3	0	1047.5	46.9	2.4	107.6	967.2	229.9	20
514.35018	Station Ck	2275	234.8	0	191.2	3.3	0.2	0.9	17.8	15.8	0
514.35020	Carpenter Ck	9215	499.8	0.4	173.4	10.2	0.9	8.9	2482.1	529.2	48.2

514.35021	Fry Ck	6346	84.5	0	303.1	3.1	0	2.9	1982.5	599.7	89.8
514.35022	Mill Ck	2178	18.5	0	129.4	6	0	9.1	223.5	112.7	16
514.35030	Upper Alder Ck	9233	91.6	0	753.1	76.7	18.2	9.8	778	312	38.2
514.35031	North Ck	2717	80.3	0	211.5	30	1.8	0.2	0	0	0
514.35032	Lower Alder Ck	2209	2.7	0	70.5	6	1.8	0	662.4	181.7	12.9
514.35040	Plum Ck	5466	587.9	0.2	66	2.4	0.4	4	562.3	181.7	13.1
514.35050	Twentyfive Mile Cyn	10972	366.9	3.1	1202.5	67.4	8	150.5	2754.9	851.4	115.2
514.35051	Grays Cyn	8308	1685.9	1.3	30.9	21.1	0.2	16.7	2885.7	416.7	38.9
514.35052	Soldier Ck	3414	20.9	0.4	49.6	2.7	0.4	3.1	1368.3	204.8	40
514.36010	Emigrant Ck	8742	750	0.9	1328.1	197	18.2	226.6	0	0	0
514.36011	Kirkwood Ck	2306	625	0	189.4	30	6.2	80.9	0	0	0
514.36012	Caples Ck	9212	1301.9	1.1	1654.7	289.3	12	179	0	0	0
514.36013	Silver Lake	9691	612.8	0	2466.8	347.1	20.5	285.9	0	0	0
514.36014	Oyster Ck	5400	623.5	0	758.4	81.2	1.1	94.5	0	0	0
514.36020	North Tragedy Ck	4781	173.9	0	1182.9	206.6	3.8	103.8	0	0	0
514.36021	Sherman Ck	6262	92.3	0	656.6	59.1	10.9	4.2	0	0	0
514.36022	Mule Cyn	3505	20.9	0	172.5	11.3	3.6	0	533.9	105.8	9.6
514.36023	Matin Ck	3253	40.7	0	119.6	12.2	0.9	10.9	173.9	61.4	3.3
514.36030	Bark Shanty Cyn	5371	14.2	0	212.3	28.9	2.4	0	1802.1	356.6	31.4
514.36031	Girard Ck	2067	25.8	0	166.3	18.5	7.8	0.2	268.6	52.3	11.6
514.36032	Long Cyn	3597	41.4	0	318.6	17.1	2.4	1.1	468.9	91.6	1.8
514.36033	Middle Ck	4735	293.1	0	57.6	10	0	9.1	1275.2	219.2	27.8
514.36034	Beanville Ck	2343	8.7	0	30.7	0.9	1.3	0	1035.9	250.1	8.9
514.41010	Mad Cyn	1282	849.4	3.8	0	1.3	0	0	105.6	0	0
514.41012	Dardanelles Ck	6372	3147.8	2.2	32.2	40.5	0.4	11.3	528.7	40.2	1.1
514.41020	Missouri Cyn	11451	2017.8	8	53.4	3.6	0	10.9	3447.3	289.5	36.5
514.41030	Cyn Ck	8807	78.7	1.6	48.9	4.2	0.9	0	4075.7	856.7	101.2
514.41040	New Orleans Gulch	1597	5.8	0	0	0	0	0	8.9	0	0
514.41041	Gas Cyn	569	0	0	0.4	0	0	0	0	0	0

514.42012	French Meadow Res	647	115	0	12.5	0.4	0	1.1	0	0	0
514.42013	Chipmunk Ck	4456	841.4	1.1	77.2	6.4	1.8	2	29.8	15.1	0.2
514.42030	Big Mosquito Ck	3768	1200	4.2	59.4	4	0.2	11.8	102.7	46	0
514.42031	Brushy Cyn	6455	510.1	0.7	187.4	14.9	0.4	0.7	772.7	176.1	8.4
514.43010	SF Long Cyn	6375	879.6	0.9	145.9	20.2	1.6	3.6	0	0	0
514.43011	NF Long Cyn	4244	731.3	0	119	10.2	1.8	13.1	0	0	0
514.43012	Long Cyn	11700	2669.1	2	127.6	15.1	2.4	80.7	911.6	212.1	10.7
514.43013	Wallace Cyn	8347	515.4	0	397.6	26.2	6.7	7.1	825.8	222.4	18.5
514.43020	Stony Ck	11933	1888.4	5.1	129	46.9	0.4	48.5	1522.7	338	15.6
514.43021	Little Deer Ck	2727	147.9	0.2	206.8	10.2	4.9	0.7	90.7	34.9	7.3
514.43030	Lawyer Trail	7149	1919.5	2.9	28.5	14.7	0.2	15.3	1081.7	227.9	10.7
514.43031	Little Grizzly Cyn	7072	2382.5	0	51.1	10.5	0	28.7	1141.5	113	0.4
514.43032	Big Grizzly Cyn	4321	256.1	0	205	6.9	2	1.1	1139.8	189.7	21.3
514.43033	Zero Spring	8212	3932.5	24.2	5.6	8.2	0.9	45.8	1118.6	180.5	7.3
514.43040	Upper Pilot Ck	9543	21.3	0	133	33.4	1.3	3.1	5385.3	974.1	56.7
514.43041	Lower Pilot Ck	9818	440.5	0	0.2	1.8	0	0	6651.6	1015.7	60
514.44010	Gerle Ck	7943	279.9	0	1249.8	96.7	20.9	30.5	0	0	0
514.44011	Rocky Basin Ck	6584	288.6	0	481.2	76.3	4	66.3	129.9	6.4	0
514.44012	Loon Lake	5141	155.4	0.9	631.5	165.9	12.5	40	0	0	0
514.44020	Upper SF Rubicon R	10127	411.3	0	1077.7	112.3	2.4	107.8	9.6	0.4	0
514.44021	Lower SF Rubicon R	6676	606.6	0	228.8	28	4.2	2.2	607.7	191.2	8.7
514.45013	Hell Hole Res	7156	1746.8	4.9	322.4	342.4	7.3	156.3	156.3	57.8	2.4
514.45020	Barker Ck	3232	1011.2	1.1	340.9	54.9	3.6	513.2	0	0	0
514.45021	Miller Ck	4403	351.5	0	1087.5	210.6	3.6	255.3	0	0	0
514.45022	Rockbound Lake	4434	232.8	0	1669	222.4	17.3	152.1	0	0	0
514.45023	Phipps Ck	11722	675.1	0.7	4265.6	508.7	30.9	654.2	0	0	0
514.45024	Lake Schmidell	8249	1144.4	1.8	2104.5	247.3	17.6	1007.9	0	0	0
532.23010	Upper Camp Ck	8716	205.9	0.7	396.9	56.3	8.2	3.1	2.4	0	0
532.23011	Lower Camp Ck	10330	203.9	0	88.5	13.3	2.2	4.2	2815.6	582.1	98.7

532.23021	Sly Park Ck	6275	207	0	150.1	2.9	0.2	8.7	1027.7	311.5	27.3
532.23022	Hazel Ck	1755	40	0	67.6	8.2	0	0.7	207	56.9	3.6
532.23030	Leek Spring Valley	7481	113	0	641	44	6.4	8.2	193	130.3	15.1
532.23031	Mid-Upper NF Cosumnes	6247	73.2	0	472.5	43.8	6.7	16.7	745.3	329.7	36.9
532.23032	Van Horn Ck	7516	712.9	0.2	140.5	3.3	0.4	6.9	2962.1	541.9	81.8
532.23033	North Cyn	3541	0	0	21.6	0	0.2	0	2340.9	402	69.4
532.23040	North Steely Ck	6857	84.3	1.3	32.5	2.9	0.4	0	2013.8	455.2	74.7
532.23041	String Cyn	6964	13.1	0	23.3	0.7	0	0	4331.4	596.6	57.8
532.23042	Middle Butte	2925	540.8	0.4	7.1	4.4	0	9.3	1351.2	181	7.8
532.23043	Clear Ck	2896	0	0	6.9	0	0	0	1770.1	263.5	52.5
532.23050	Jenkinson Lake	3057	2.4	0	51.4	81.4	0	0	595.9	88.5	12.9
532.23051	Camp Ck	10140	1771	0	60.5	15.1	1.1	20.2	4409.4	488.3	31.4
532.23060	Butte Ck	5420	123.8	1.1	8.7	4.7	0.2	0	3433.5	448.7	46.9
532.23061	Jackass Ck	6047	150.3	0	130.5	13.3	3.6	9.8	2497	336.2	28
532.23062	Clear Ck	6840	59.6	0	292.2	13.8	1.8	6	2709.8	626.6	96.7
532.23070	Long Ravine	4952	214.6	0	77.8	49.1	0	32.2	2340.9	490.3	61.6
532.23072	Squaw Hollow Ck	2414	0	0	73.4	0.2	0.2	0	1165.1	188.8	54.5
532.24010	Anderson Cyn	3252	82.5	0	294.8	31.4	1.1	14.5	369.3	87.2	3.3
532.24011	Prothro Ck	9263	309.1	1.1	457.6	26.2	5.1	5.3	2528.6	483.4	72.9
532.24012	Cat Ck	5655	2.9	0	279.7	8.2	0.7	0	1259.4	382.7	73.8
532.24013	Shingle Mill Ck	9609	91.2	1.1	143.2	13.8	1.8	0.9	1303.9	486.5	39.4
532.24014	Crystal Mine	4493	726.4	0.4	31.6	6.9	0.4	13.8	664.8	197.9	24
532.24020	McKinney Ck	3005	85.4	0	97.4	13.8	2.9	3.1	96.7	77.6	5.3
532.24021	Dogtown Ck	6799	377.6	0.4	139.4	12.7	1.6	1.6	1743	406.5	29.4
532.24022	Middle Dry Ck	3383	23.3	0.4	81.4	8	0.7	0	164.1	55.8	5.3
532.24030	Sopiago Ck	7699	272.4	1.1	37.4	2.9	2.4	0	1372.6	372.2	41.6
532.24040	OConnor Gulch	2623	222.1	0	4.7	5.3	0	8.2	949.4	198.3	6.4
532.24041	Lower Perry Ck	4801	144.5	2.2	199.2	6.7	1.3	19.6	1478.8	178.1	25.6

532.24042	Upper Perry Ck	1243	0	0	33.6	0	0	0	786.9	118.3	2.7
532.24060	Oregon Gulch	5742	178.1	0	66.9	1.8	0.2	0	1424.8	358	27.1
532.24061	Farnham Ck+C118	5887	2.4	0	131.2	13.1	2.7	0	2901.9	467.6	66.9
532.24062	Cedar Ck	4572	9.3	0.7	86.9	2.4	0.4	0.2	1220	333.3	26.2
532.24063	John Schell Mine	7590	164.5	0	186.8	7.6	0.7	2	2669.8	452	40.2
532.40010	Ashland Ck	8229	2	0	127.9	27.1	0	0	4427.2	733.5	5.1
532.40011	Pioneer Ck	3531	0.7	0	23.8	7.1	0.7	0	2334.5	320	15.6
532.40020	SF Dry Ck	1389	3.1	0	17.8	0	0	0	511.2	35.1	2.9
532.60012	Upper Deer Ck	5183	342.2	0	593.7	89.6	6.9	84.3	0	0	0
532.60013	Lower Deer Ck	5624	236.8	0	1175.8	177.9	2	156.3	0	0	0
532.60014	Deadwood Cyn	6411	1371.5	0	1862	311.3	1.8	787.6	0	0	0
532.60016	Upper Summit Ck	12557	1382.8	0.2	2428.1	499.4	19.1	1461.5	0	0	0
532.60017	Lower Summit Ck	8750	1879.3	0.4	2335.3	359.5	16.5	1607.8	0	0	0
532.60020	Ladeux Meadow	4960	468	3.8	1983.4	245.9	5.6	269.9	0	0	0
532.60021	Fourth of July Cyn	3923	1535.8	0	379.3	78.5	0.2	694.4	0	0	0
532.60022	Jelmini Ck	4360	775.6	0	481.8	22.5	0	849.6	0	0	0
532.60023	Tanglefoot Cyn	6643	1001.5	4.9	508.3	138.1	4.9	277.7	169.9	34.2	13.8
532.60030	Upper Cole Ck	5828	385.1	0	1429.5	259.5	1.6	438.5	0	0	0
532.60031	Middle Cole Ck	7932	295.7	0	1039.9	192.3	7.6	155.6	33.6	2.2	0
532.60032	Lower Cole Ck	3498	166.1	0	107.6	10.7	2	116.3	888.1	249.9	20
532.60040	Bear R	7838	207.7	0	2214.6	395.8	6.2	365.1	0	0	0
532.60041	Tragedy	4736	54.3	0	1517.3	205.7	0	63.1	0	0	0
532.60042	Corral Flat	3633	62.7	0	436.3	54.3	0.4	24.7	0	0	0
532.60043	Bear R Res	7659	229.7	0.4	681.7	250.1	7.6	52	107.4	8.4	0
532.60050	Rattlesnake Ck	6639	334.4	2.2	372.4	56	7.3	145.2	912.1	270.4	5.1
532.60051	Beaver Ck	2464	8.7	0	10.2	0.2	0	0	1528.2	236.1	24.2
532.60052	Camp Ck	5087	713.1	0.4	35.8	5.1	0	9.3	1742.8	239	18.2
532.60060	East Panther Ck	5463	260.6	0.2	56.7	6.4	1.1	4.7	1671.4	313.3	32.9
532.60061	West Panther Ck	5853	152.8	0	71.4	0.7	0	0.9	2904.3	609	69.4

532.60062	Panther Ck	4137	284.8	0	6.4	4.4	0	2.2	1127.5	337.7	21.3
532.60063	Little Tiger Ck	7394	145.9	2.4	34.2	1.8	0.2	1.6	1976.5	446.5	63.1
532.60064	Mill Ck	8005	36.9	0.2	86.3	2.7	0.9	1.1	2296.9	539	51.8