**TABLE 15: Issues and Corrective Actions, Grazing**

| G-1 | |
|---|---|
| Issue | a) See P-7.<br><br>b) Previous standards and guides (S&G's) used to monitor grazing utilization in riparian areas were inconsistent from Forest to Forest and were not found to provide reliable results in terms of rangeland health.<br><br>c) Many Rangeland Environmental Analyses and Allotment Management Plans (AMPs) are out of date and/or insufficient. |
| Corrective Action | a) See P-7.<br><br>b) Forest Plans in the Sierra Nevada were modified by the new Standards & Guidelines (S&G's) from the Sierra Nevada Forest Plan Amendment. The new S&G's will provide better consistency for monitoring and protecting riparian areas across the Sierra Nevada.<br><br>c) There has been a change in Regional and National priorities to increase the emphasis on completing Rangeland Environmental Analyses and AMPs. New direction is being adopted Regionally and Nationally. This review process will include water quality specialists and is expected to maintain conditions where they are good and improve conditions where they are not.<br><br>d) Since 1999, the Region has been implementing a Range Monitoring Program to assess long-term rangeland condition and trends. The program will also provide ecological classifications and quantitative condition scorecards for meadows, which will provide a basis for range conservationists, wildlife biologists, hydrologists, soil scientists, and fisheries biologists to assess meadow conditions and evaluate whether management changes are necessary. |
| Status | a) See P-7.<br><br>b) Implementation of new grazing standards in the Sierra Nevada is ongoing.<br><br>c) Implementation of new direction emphasizing Rangeland Environmental Analyses and AMPs will begin in 2005. As a result, a marked increase in the number of completed Rangeland Environmental Analyses and updated AMPs is expected over the next 5 years.<br><br>d) The Region continues to implement its Range Monitoring Program. Preliminary ecological classifications have been developed based on results from 785 permanent plots. Scorecards to rate ecological condition for the sampled meadows are expected in 2005. Subsequently, these results will be used to inform management decisions regarding grazing in different meadows (see Section 3.9). |
| Priority | 1 |

### 2.5.6. Prescribed Fire

Prescribed fire BMPs were highly effective (98%) when they were implemented. However, implementation rates were not particularly high during the 1992-2002 monitoring period (77%) and declined between the first and second monitoring periods (79% and 74%, respectively). While elevated effects on water quality were extremely rare (1, <1%), additional focus on implementation of these BMPs is necessary because this activity is being conducted more often than in the past. Additional details are provided in Table 16.

**TABLE 16: Issues and Corrective Actions, Prescribed Fire**

| **F-1** | |
|---|---|
| Issue | BMP implementation rates for prescribed fire declined between the first and second monitoring periods, from 79% to 74%. With additional use of this tool, implementation of these BMPs is becoming increasingly important. |
| Corrective Action | a) Through a variety of means (e.g., formal direction, program reviews, site visits), the Regional Office will direct forests to place additional emphasis on these BMPs, both in project planning and implementation. Forest Earth Scientists will increase participation in the planning of prescribed fire projects.<br>b) These practices will be emphasized during BMP training sessions.<br>c) Additional monitoring will be focused on this activity.<br>d) Continued implementation of the recently adopted RWQCB timber harvest waivers is expected to improve BMP implementation for this activity, since it requires interdisciplinary review of projects. |
| Status | a) Fuels program reviews are scheduled to occur on the Los Padres and Tahoe national forests in 2005.<br>b) BMP training will occur on each Forest by the end of 2006.<br>c) Monitoring targets for this activity were increased in 2004.<br>d) Fuels projects are continuing to be implemented under the new timber waiver. |
| Priority | 1 |
| | |

### 2.5.7. Mining

As described previously, results associated with much of the mining data are not yet available. Only qualitative results were available for mining operations associated with locatable minerals (M26). Based on these results, there appear to be no significant problems associated with implementation of these BMPs. Only one site (1%) had water quality effects ranked as elevated. Nonetheless, the effectiveness of these BMPs requires some improvement. Specific issues are described in Table 17.

**TABLE 17: Issues and Corrective Actions, Mining**

| **M-1** | |
|---|---|
| Issue | Approximately 15%-19% of mining sites associated with locatable minerals have evidence of erosion or sediment delivery from dumps, excavations, and fillslopes. |
| Corrective Action | a) The Regional Office will emphasize these BMPs during reviews of the mining program.<br><br>b) The Regional Office and forests will prioritize legacy sites for restoration according to their risks and opportunities available to address them. Forests will pursue external funding to supplement appropriated funds.<br><br>c) Effective July 23, 2004, the Regional Office requires permit administrators to be certified or to operate under someone that is certified. This is expected to prevent the recurrence of legacy problems by improving the quality of permit administration for locatable minerals.<br><br>d) Forests will visit each mining operation at least once per year and identify, track, and resolve potential water quality issues at those sites. |
| Status | a) The Regional Office will conduct reviews of mining operations on at least three national forests in 2005.<br><br>b) The 2005 budget advice from the Regional Office will direct forests to prioritize mining sites for restoration and pursue external funding opportunities to supplement appropriated funds.<br><br>c) Effective July 23, 2004, the Regional Office requires permit administrators to be certified or operate under someone that is certified.<br><br>d) The FY 2005 budget advice will also direct forests to visit all mining operations at least once per year. The highest priority (top one-third) sites will be visited with mining permittees. All needed corrective actions at each site will be documented and tracked to completion by the forests. |
| Priority | 2 |

| M-2 | |
|---|---|
| Issue | See E-6. |
| Corrective Action | See E-6. |
| Status | See E-6. |
| Priority | 2 |
| | |

### 2.5.8. Vegetation Management

The vegetation management program performed very well from 1992 to 2002. Implementation rates were high from 1992 through 2002 (87%) and improved between the first and second monitoring periods. Effectiveness rates were also high (89%) and remained so throughout the composite monitoring period. Only one (<1%) vegetation management site had effects on water quality that were classified as elevated. No issues or corrective actions were identified for this program.

# 3. RELATED MONITORING PROGRAMS

Besides the BMPEP Onsite Evaluations described in Section 2, the USFS has implemented several complimentary monitoring programs, many of which include an instream monitoring component. These programs, described below, use a variety of approaches to address different water quality and aquatic ecosystem monitoring questions at different spatial and temporal scales. Issues addressed by these programs include validation of BMP effectiveness, evaluation of compliance with regulatory standards, assessment of conditions and trends in water quality and aquatic resources, and development and validation of models for assessing cumulative watershed effects (CWE).

## *3.1.Regional Bioassessment Program*

The USFS has developed one of five scientifically valid bioassessment programs in the State (SWRCB 2002). This program is intended to: 1) biologically classify streams in the Region according to macroinvertebrate communities; and 2) assess water quality conditions and trends in these ecosystems. Two separate, complimentary approaches have been pursued to achieve these objectives. The first is development and application of a Regional multivariate bioassessment model based on the River Invertebrate Prediction and Classification System (RIVPACS) approach. The second is development and application of sub-Regional Benthic Indices of Biotic Integrity (B-IBI), which use multi-metric methods.

### 3.1.1. Multivariate Methods

Through a partnership with Utah State University, the USFS developed a RIVPACS model that is applicable on national forests and surrounding lands throughout California. RIVPACS is a standard method of bioassessment in Great Britain and Australia and is increasingly being used by Federal and State agencies in the western United States (Hawkins 2003a and 2003b).

RIVPACS-type water quality assessments are conducted by comparing taxa expected to occur at a site under relatively undisturbed conditions (E) to those that are actually observed at the site (O). These models have been demonstrated to detect biological impairment from land use activities in watersheds up to approximately 10,000 acres in size. Expected taxa are predicted by multivariate statistical models based on invertebrate data and other physical and chemical parameters collected from high quality "reference" streams. The O/E ratio is the proportion of taxa measured at a site to those that should occur in the absence of significant anthropogenic disturbance. Consequently, O/E ratios near a theoretical mean of 1.0 represent high biological integrity and values significantly less than 1.0 indicate possible impairment (Hawkins 2003a and 2003b).

A complete RIVPACS model was developed in 2004 based on samples from 176 reference sites on national forests and national parks in California (Figure 23). The following site variables were found to be strongly correlated with the observed biological communities and are consequently used as predictor variables in the model: elevation, average number of wet days per year, latitude, sampling date, watershed area, average annual precipitation, longitude, and alkalinity. Based on these predictor variables and macroinvertebrate data, O/E scores were calculated for reference sites (Figures 24). The model was found to be accurate (i.e., mean of 1.01 compared to a theoretical mean of 1.0) and precise (standard deviation = 0.14) compared to RIVPACS-type models developed for other areas (Hawkins 2003a and 2003b).

The model was then tested against 52 test (i.e., potentially impaired) sites and was shown to discriminate between reference and test sites (Figures 25 and 26). Beyond this development and testing, the model has been applied as part of the monitoring component of the Heavenly Valley TMDL Implementation Plan (Section 3.9). It is also being applied, along with the B-IBI described in Section 3.1.2, as part of a University of California, Santa Barbara monitoring project on the Los Padres National Forest.

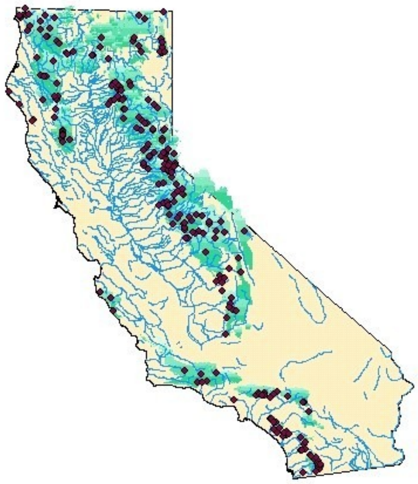

**Figure 23. Distribution of 176 reference sites on national forests and national parks in CA.**

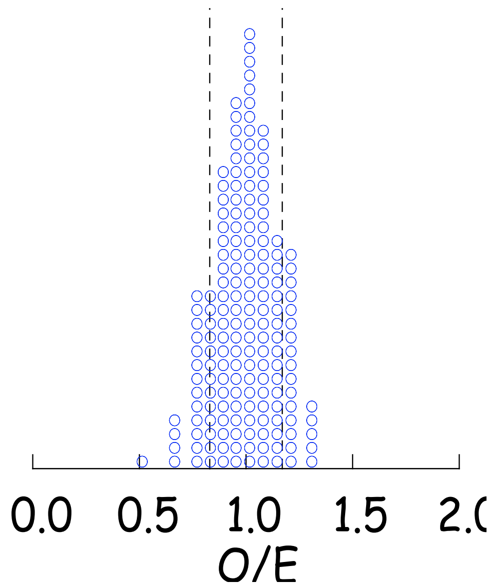


**Figure 24. Frequency Distribution of Reference Site O/E values (from Hawkins 2003b)**

Mean = 1.01, Standard Deviation = 0.14

$10^{th}$ and $90^{th}$ percentiles (dashed lines) are often used as thresholds to infer impairment.

$10^{th}$ percentile = 0.83, $90^{th}$ percentile = 1.17

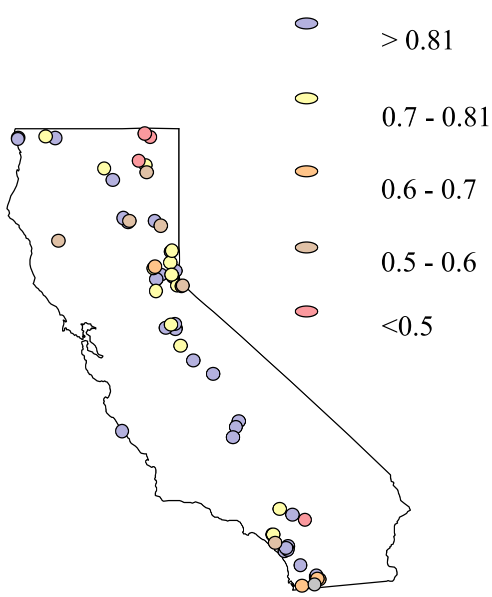


**Figure 25. O/E Values for Test Sites (from Hawkins 2003b)**

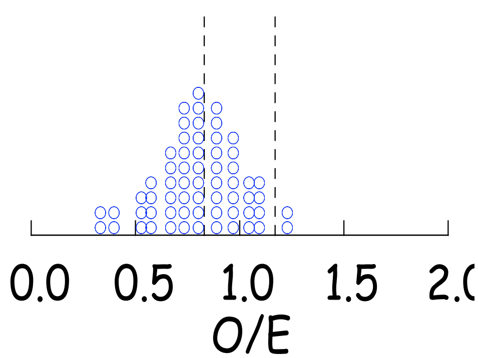


**Figure 26. Frequency Distribution of Test Site O/E Values (from Hawkins 2003b)**

Mean = 0.81, Range = 0.33 – 1.25.

60% of test sites were not reference quality based on $10^{th}$ and $90^{th}$ percentile thresholds.

### 3.1.2. Multimetric Methods

To compliment this multivariate approach to bioassessment, the USFS collaborated with the California Department of Fish and Game (CDFG), the San Diego Regional Water Quality Control Board, and the U.S. Environmental Protection Agency to enhance an existing preliminary Benthic Index of Biotic Integrity (B-IBI) for the southern California coastal region (Ode et al. 2004). While different field protocols were used to collect samples, results obtained from sites at which both protocols were used were found to be strongly and consistently correlated. Consequently, data from 56 sites on national forests were combined with data from 220 other sites in Southern California to produce a final B-IBI (Figure 27). The distribution of B-IBI scores from the sites used to develop the model is shown in Figure 28a. Once the model was developed, it was validated against an independent dataset of reference and test sites. As shown in Figure 28b, this validation effort demonstrated the model's ability to discriminate between populations of reference and test watersheds.

Besides producing an analytical tool that compliments the Regional RIVPACS model, this study demonstrated that there is promise for a more unified statewide bioassessment program in California. Specifically, the results suggest that integration of disparate datasets may be possible. This would overcome what the SWRCB (2002) considers to be the single largest barrier to an integrated program.

In the future, the USFS plans to pursue additional opportunities for data integration and refinement and development and application of B-IBI throughout its lands in California.

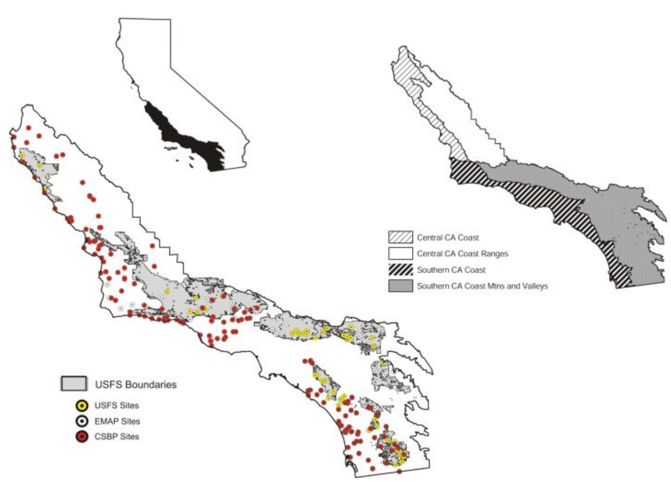


Figure 27. Distribution of sites used to produce a B-IBI for Southern Coastal CA (from Ode et al. 2004)

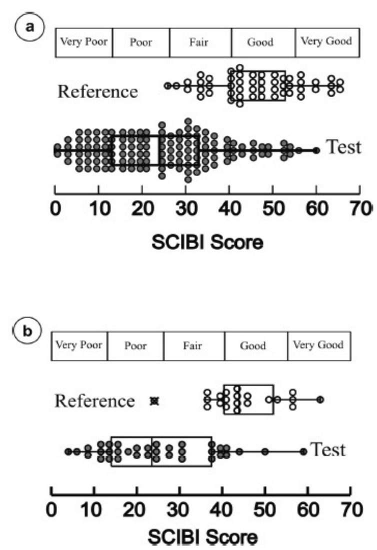


Figure 28. Distribution of B-IBI scores for the datasets used to (a) develop and (b) validate the model (from Ode et al. 2004)

### *3.2. Northern Province Administrative Study*

The USFS Pacific Southwest Regional Office and the University of California, Berkeley signed an agreement in 2003 for the first of a planned five-year study to evaluate cumulative watershed effects (CWE) and BMP effectiveness on the Klamath National Forest (KNF). Scientists from USFS Pacific Southwest Research Station (PSW) are also participating in this investigation.

The objectives of the study are to:

- Evaluate whether existing KNF erosion models can be used to explore the influence of sediment supply on stream channel conditions.
- Assess whether empirical relationships and digital elevation models can successfully delineate the spatial extent of channel types and median grain sizes throughout the study watersheds.
- Determine how biologically significant properties of different types of channels respond to changes in coarse and fine sediment supply.
- Verify whether biomonitoring with macroinvertebrates is an effective tool for detecting altered channel conditions resulting from changes in sediment supply.
- Validate the degree to which road management BMPs are effective in protecting beneficial uses of water.

In the CWE portion of this study, habitat conditions and macroinvertebrates are being sampled in 20 or more reaches located in KNF watersheds with significantly different rates of current and past anthropogenic alterations of natural sediment supply regimes. Assessments of condition will be made by comparing stream channel attributes observed in the field to those predicted using an analytical reference condition model (Power et al. 1998). This model, which predicts channel attributes using well-established physical principles and theoretically and empirically based knowledge of watershed and stream channel processes, is expected to control for some of the significant variability that naturally occurs between different streams. This portion of the study will also further evaluate the existing USFS RIVPACS model (Section 3.1). Specifically, this study will assess whether it can be used to detect the biological effects of increased sediment supplies to streams. In addition, two new multivariate models will be developed specifically for the Klamath region. The first new model will use physical habitat estimates from the analytical reference condition model and other field data to predict macroinvertebrate community composition at future test sites. The second model will predict macroinvertebrate communities based on predominant species traits (e.g., body size, presence of protective cases) observed in channels of varying habitat quality.

The BMP effectiveness component of this study is using measurements of sediment delivery, channel morphology, and macroinvertebrates in a before-after control-impact (BACI) study design to evaluate the degree to which USFS road management BMPs protect beneficial uses of water. The study is focused on road decommissioning and storm-proofing projects on KNF.

More details regarding this study can be found in May et al. (2004). Since the study was initiated in the summer of 2004, results are not yet available.

### 3.3. Northwest Forest Plan Aquatic Riparian Effectiveness Monitoring

The USFS and the Bureau of Land Management are jointly implementing the Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Plan (AREMP). It is intended to characterize the ecological condition of watersheds, streams, and riparian areas on federal lands covered under the Northwest Forest Plan (NWFP). This includes the Mendocino, Shasta-Trinity, Six Rivers, Modoc, and Klamath national forests in California. AREMP will assess present watershed conditions, track trends in watershed condition over time, and report on the NWFP's effectiveness across the region. Although its focus is on characterizing ecosystem status and trend, AREMP will also supply information useful in determining causal relationships (Reeves et al. 2001).

Key questions to be addressed by AREMP include (Reeves et al. 2001):

1. Are the key processes that create and maintain habitat conditions in aquatic and riparian systems intact?
   - What is the status of upslope processes as indicated by vegetation, roads and stream crossings, and landslides in the watershed?
   - What is the status of riparian processes as indicated by vegetation composition, structure and diversity, roads and stream crossings, and floodplain connectivity?
   - What is the status of in-channel processes as indicated by pools, sediment flux, substrate, water temperatures, large structure in the channel, and rates of channel movement?
   - What is the status of the fauna as indicated by fish, amphibians, and macroinvertebrates?

2. Has the distribution of these and other key indicators shifted in a direction indicating improved or degraded habitat and biotic condition?
   - How does the aggregate quality of the key indicators used to evaluate watershed condition change through time under the Northwest Forest Plan?
   - Are current management practices at the site and watershed scales attaining the Aquatic Conservation Strategy objectives?

Over a five-year period, a total of 250 watersheds will be sampled in Washington, Oregon and northern California within the NWFP area. Watershed conditions are being assessed by analyzing indicator values using a decision support model that incorporates physical, chemical, and biotic relationships developed by provincial and regional experts. Figure 29 shows the sites in California that have been or will be sampled as part of AREMP. Additional details, including a 2002 Annual Report can be found at: http://www.reo.gov/monitoring/watershed/index.htm.

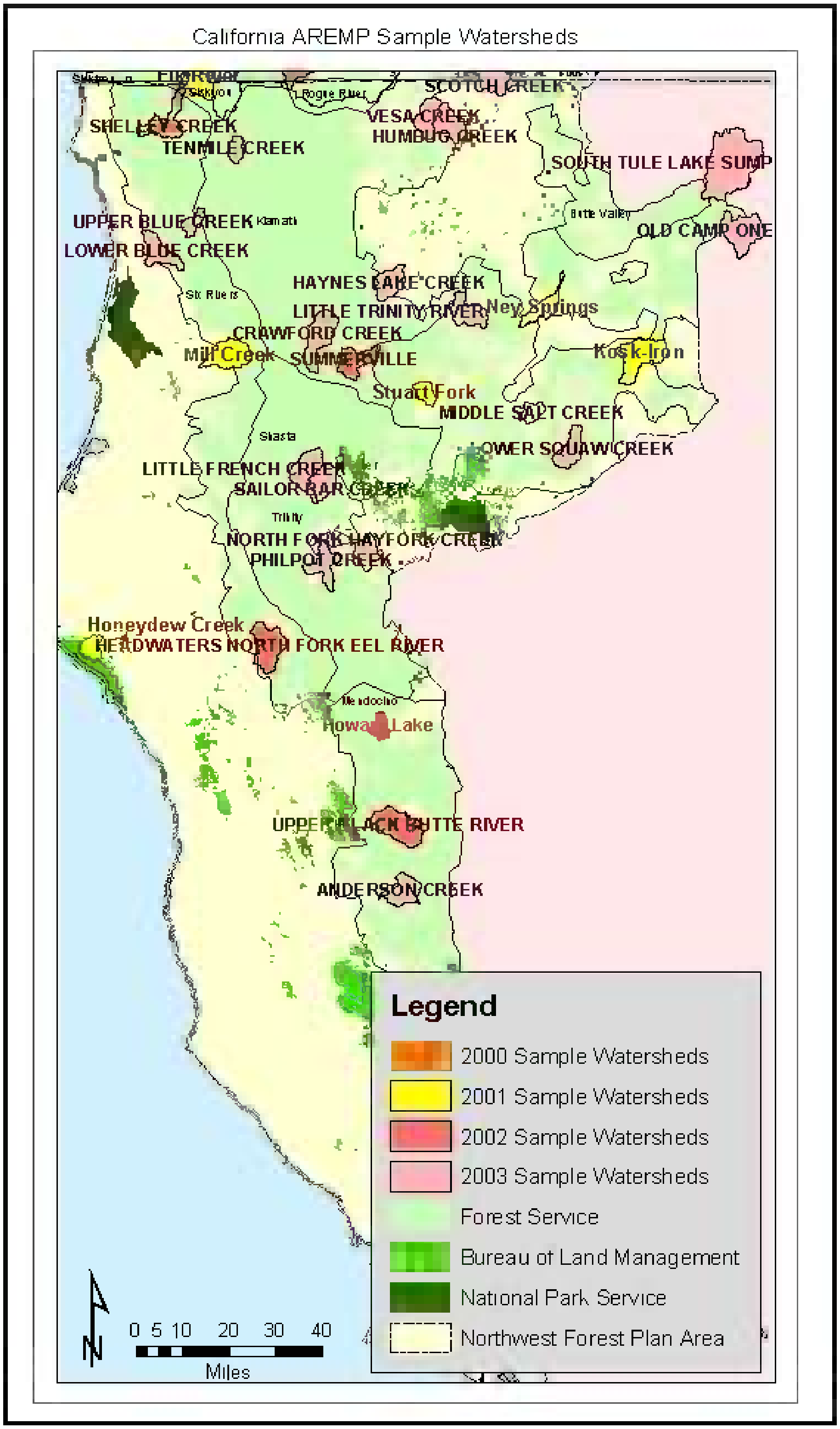


**Figure 29. AREMP Sample Watersheds in California.**

## *3.4. Cumulative Watershed Effects in the Central Sierra Nevada*[10]

Since 1999, the USFS and the California Department of Forestry and Fire Protection have funded Colorado State University (CSU) to investigate cumulative watershed effects (CWEs) in the Central Sierra Nevada. The USFS objectives are to develop flexible, user-friendly, GIS-based models to predict changes in flow, sediment production, and ultimately, sediment delivery for watersheds ranging from approximately ten to several hundred square kilometers.

### 3.4.1. Field Investigations

Field investigations in support this effort have focused on (1) quantifying sediment production and sediment delivery from timber harvest, roads, wild and prescribed fires, off-road vehicles, and undisturbed areas; (2) quantifying the year-to-year variability in sediment production; and (3) determining the effect of key site variables such as elevation, slope, percent cover, soil type, and contributing area on sediment production rates.

Sediment production rates are being measured with sediment fences. Ninety-one fences were constructed in the 1999. Since the working hypothesis was that roads and severely burned areas would generate more sediment than other sources, CSU installed 27 sediment fences at the outlets of road drainage structures (e.g., waterbars, rolling dips, and cross-relief culverts), 36 sediment fences at the outlets of waterbars on skid trails, 7 sediment fences on rills and gullies draining off-highway vehicle (OHV) trails, 15 sediment fences on hillslopes burned by prescribed fires, 3 fences on hillslopes burned by a high-severity wildfire, and 3 fences on minimally-disturbed hillslopes (Table 18).

There was considerable variability in sediment production rates between the different land uses within the first wet season. The median sediment production rate from roads was 0.2 kg $m^{-2}$, or nearly an order of magnitude higher than any of the other sources (Figure 30). The sediment production rates within a given land use generally were highly skewed, with a few sites producing the majority of the sediment from that land use. Hence the mean sediment production rate from roads was 0.9 kg $m^{-2}$, or nearly five times the median value. In comparison, the mean sediment production rate was 0.1 kg $m^{-2}$ from skid trails, 0.4 kg $m^{-2}$ from ORV trails, and just 0.001 kg $m^{-2}$ from minimally disturbed sites. When the burned sites were separated by burn severity, the sites burned at high severity had a mean sediment production rate of 1.1 kg $m^{-2}$ (n=3), or approximately 1,000 times greater than the mean value of 0.001 kg $m^{-2}$ from sites burned by prescribed fire (n=15).

Native surface roads produced 10-50 times more sediment than rocked roads. Skid trails on Holland soils produced an average of 0.9 kg $m^{-2}$ (n=2) of sediment, and this was significantly more than the mean value of 0.04 kg $m^{-2}$ for the skid trails on all other soil types (n=34).

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[10] This section is a slightly edited version of MacDonald et al. (2004).

| Table 18. Number of sediment fences by land-use type for each of three wet seasons. | | | |
|---|---|---|---|
| | Wet season | | |
| **Land-use type** | **1999-2000** | **2000-2001** | **2001-2002** |
| Roads | 27 | 47 | 66 |
| Skid trails | 36 | 48 | 10 |
| OHV | 7 | 7 | 7 |
| Fire | 18 | 18 | 3 |
| Undisturbed | 3 | 3 | 0 |
| Total: | 91 | 123 | 86 |

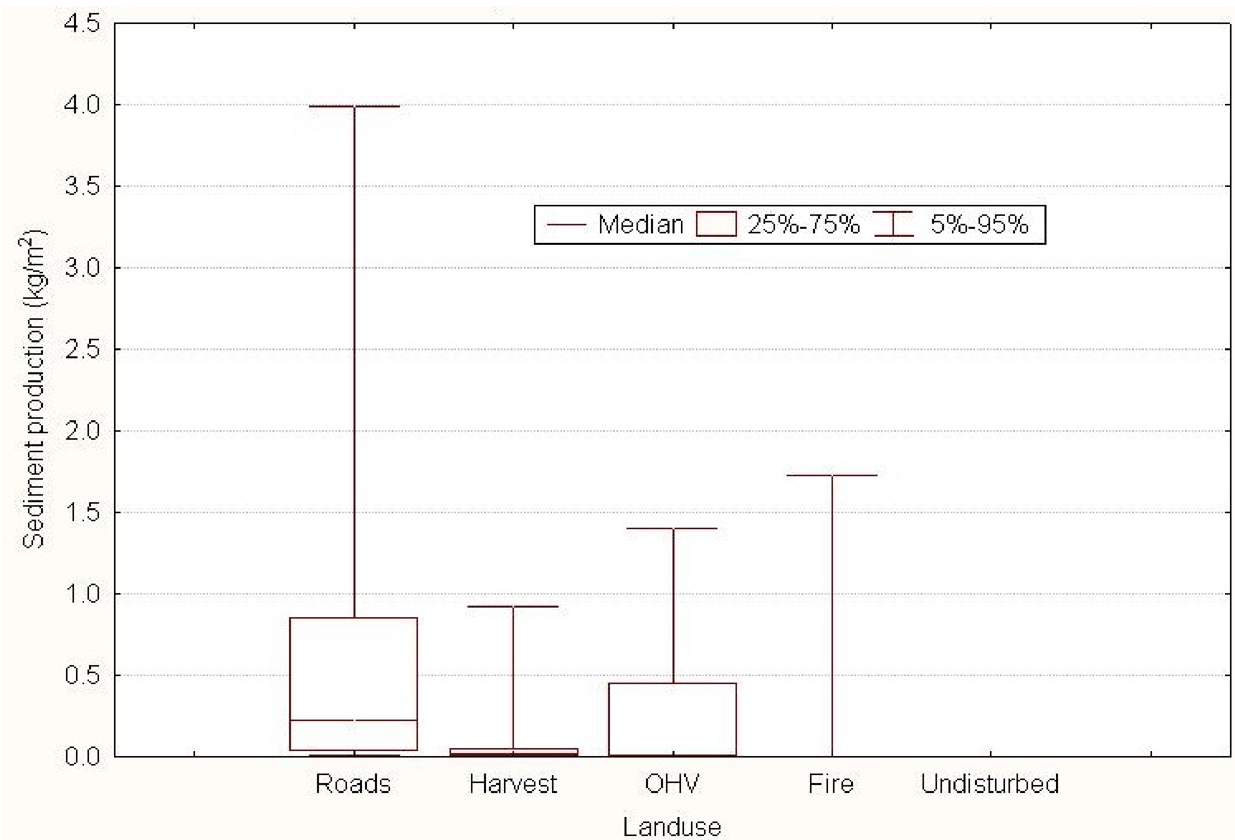


Figure 30. Sediment production by dominant land use for the 1999-2000 wet season.

Results from the first wet season supported the initial hypothesis and, consequently, efforts in the second and third years focused on sediment production from unpaved roads. Although it was not possible to add additional sediment fences on areas burned at high severity, the number of fences on roads increased from 27 in the first year to 47 in the second year and 66 in the third year (Table 18). Since some of the lower-producing sites were not monitored in all three years, a total of 300 fence-years of data have been collected.

Sediment production rates from roads in the second and third wet seasons were only 10-30% of the values measured in the first wet season (Figure 31). The sediment production rates for skid trails, OHV trails, burned sites, and undisturbed areas showed a similar decrease. The largest decline was for the three sites burned at high severity, where the second year sediment production rates were an order of magnitude lower than in the first year, and the third year rates were another 70% lower than the second year rates. This decrease is attributed primarily to the increase in vegetative cover, as this has been shown to be the largest control on post-fire sediment production rates in other areas.

The decline in sediment production rates in the second and third seasons for the other land uses generally can be attributed to differences in the magnitude and type of precipitation. Total precipitation in the first wet season was 45% higher than the second wet season and 22% higher than in the third wet season. Perhaps more importantly, storms in the second and third wet seasons generally were colder than in the first wet season, so the rainfall erosivity was approximately 90% higher in the first wet season than in the second and third wet seasons. The larger and more persistent snowpack at most of our sites apparently protected the surface from rainsplash erosion and may also have slowed any overland flow.

Taken together, the three years of data confirm that roads, high-severity wildfires, OHV trails, and certain skid trails were the dominant sediment sources at the hillslope scale. Sediment production rates were highly variable between sites within a year as well as between years. Multivariate analyses indicate that the dominant controls on road sediment production include road contributing area (A), road gradient (S), annual erosivity ($E_A$), and road surfacing (rock vs. native surface; T). An empirical model containing these variables explained 54% of the variability in annual road sediment production. It was also found that road segments receiving runoff from adjacent rock outcrops produced four times more sediment than comparable segments unaffected by rock outcrops. The observed variations in sediment production rates between sites and between years show the difficulty of developing accurate predictive models for CWEs.

In 2003 and 2004, the USFS funded CSU to expand this fieldwork to other parts of the Sierra Nevada. Specifically, these methods will be used as part of a study to evaluate the effects of fire and fuels treatments on hillslope erosion rates, water quality, and aquatic and riparian ecosystems in the Kings River watershed (Section 3.4). These methods are also being employed to quantify road erosion rates on the Lassen National Forest.

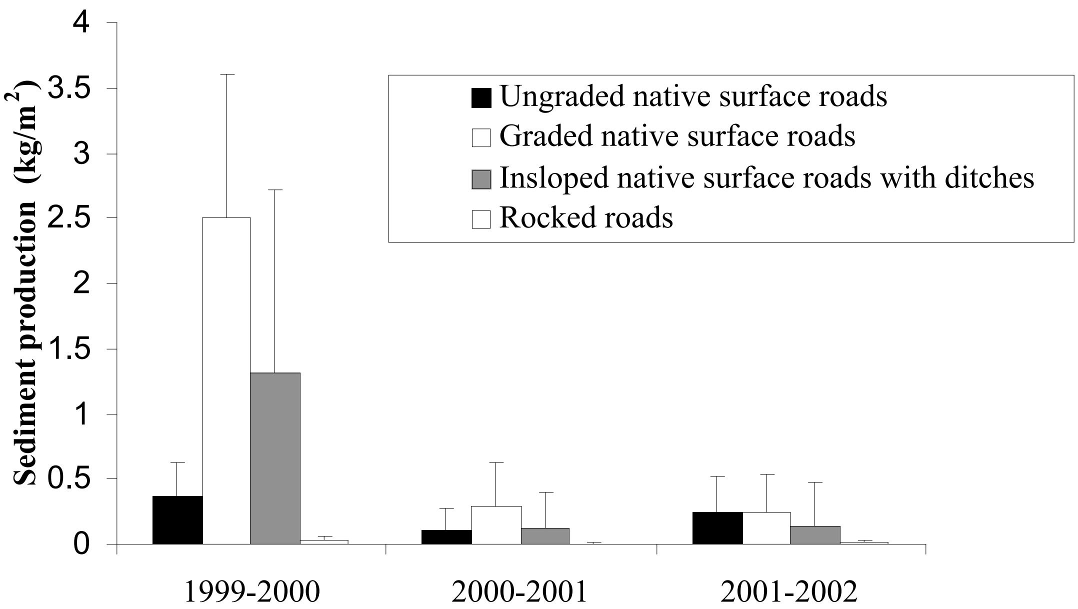


Figure 31. Magnitude and inter-annual variability in sediment production rates for various road drainage types and surfaces. Bars represent one standard deviation.

### 3.4.2. CWE Model Development

The goal of the modeling component of this study is to develop flexible, user-friendly, GIS-based models to assess CWE that better represent environmental processes and are validated to a greater degree than some commonly used tools, yet are simpler and less data intensive than complex physically-based models.

The first objective is to explicitly separate the procedures used to assess changes in flow from changes in sediment production. A second goal is to utilize the capability and greater sensitivity of spatially-explicit models, while still recognizing basic data limitations and the desire for models that can be easily applied by a range of users. The final objective is to provide users with the flexibility to change values and recovery rates to better represent their local conditions. A modular approach is being employed, so that new procedures can be added as these are developed or different issues arise.

A flow model, DELTA-Q version 1.0, was completed in June 2003. This model calculates changes in runoff based on activities such as forest harvest and fires (http://www.cnr.colostate.edu/frws/people/faculty/macdonald/macdonald.html). It estimates catchment-scale changes in high, median, and low flows resulting from changes in forest cover due to timber harvest or fires. Changes can be calculated in absolute terms or as a percentage. The input data are GIS layers representing the extent, type, and years of the different activities. Users determine the flows of interest and select values for the change in flow for each activity type and the time to hydrologic recovery. Help files provide data from an analysis of changes in flow from 26 paired-watershed studies (Austin 1999). Each model run calculates the change in flow over the chosen time period for one activity layer. The model sums the changes in flow from multiple runs using different activity layers to obtain a total change in flow for the area of interest. Tables of the individual and total changes in flow over time can be exported as text files for plotting, report preparation, or other analyses.

The second model is the FORest Erosion Simulation Tool (FOREST), and in its first iteration this is designed to calculate changes in surface erosion resulting from forest harvest, unpaved roads, and fires. The explicit separation of changes in flow and surface erosion will help users to recognize the different magnitudes of change and different recovery periods for these two different types of CWE. Once FOREST is released, work will begin on a third model to route the sediment produced on hillslopes into and through stream networks.

As in the case of DELTA-Q, the input data for FOREST are one or more GIS coverages with the activities of interest. There are separate procedures for calculating sediment production from linear features (e.g., roads) and from polygons. The modular structure means that FOREST provides the user with several options for calculating sediment production rates, depending on data availability and the desired level of complexity.

For roads and other linear features, the options within FOREST include fixed sediment production rates per unit road length for each road type and empirical models (e.g., Luce and Black, 1999). Alternatively, users can run a set of simulations outside of FOREST using models such as the Water Erosion Prediction Project (WEPP, http://forest.moscowfsl.wsu.edu/fswepp/). Depending on the data available and the desired level of complexity, users can stratify their roads layer and then use FOREST to assign spatially-explicit values to the different road segments.

The polygon module is used to calculate sediment production rates from activities such as forest harvest or fires. The required input is one or more polygon coverages that include the type(s) of disturbance and year of each activity. Users assign first-year sediment production rates to each activity and a time period for erosion rates to return to background levels. At this stage, a linear recovery is assumed, although users can also specify no recovery, as might be the case for unpaved roads with continuing usage. An additional polygon coverage can be used to adjust sediment production rates for factors such as fire severity, soil type, or elevation.

To help users, FOREST provides a lookup table of published post-fire erosion rates. Alternatively, the user can use programs such Disturbed WEPP to calculate sediment production rates and bring these in to FOREST. In contrast to DELTA-Q, FOREST converts vector data to raster data in order to perform raster-based calculations. Model outputs include sediment production grids for each year as well as a summary table of sediment production rates over time for the areas of interest. When FOREST is run on multiple layers of overlapping activities, the results can be combined into a grid to show maximum sediment production rates for the time period of interest.

The raster-based approach of FOREST will facilitate the development of proposed modules to deliver the sediment into and through the stream network. Given the data limitations and uncertainties in predicting sediment transport, we expect that the sediment delivery models modules will use a combination of empirical data and relatively simple algorithms based on key variables such as slope and drainage area. The final step will be to test the validity of these CWE models against data from a range of managed and relatively unmanaged watersheds.

## *3.5.Kings River Experimental Watershed Project*

The USFS Pacific Southwest Regional Office and USFS Pacific Southwest Research Station (PSW) are implementing the Kings River Experimental Watershed (KREW) Project, an adaptive management project on the Sierra National Forest (http://www.fs.fed.us/psw/programs/snrc). Key cooperators include the University of California (Santa Barbara), the University of Nevada, Colorado State University, and California State University (Fresno). The objectives of the project are to evaluate the effects of mechanical thinning and prescribed fire on key ecosystems processes and conditions, including those associated with aquatic environment.

Key aquatic resource questions being addressed are:

- What is the variability in the physical, chemical, and biological characteristics of headwater stream ecosystems and their associated watersheds, with and without vegetative treatments (e.g., thinning, prescribed fire)?
- What width and range of treatments for riparian buffers are most effective in maintaining and restoring aquatic, riparian, and meadow physical, chemical, and biological conditions?
- Over short and long time scales, how do fuels treatments affect erosion rates and soil health and productivity?

The study is being conducted in eight 50-100 hectare watersheds (Figure 32). Two of these watersheds will be thinned, two will be burned, two will be thinned and burned, and two will serve as controls (no treatments). Since this study is intended to represent the effects of typical fuels reduction projects conducted in the southern Sierra, they will be conducted according all management direction applicable to the Forest (e.g., standards and guidelines, BMPs). Consequently, the study will validate the degree to which USFS BMPs are effective in protecting water quality and aquatic ecosystems.

KREW is conducting a wide array of measurements that will provide a basis for observing and modeling the effects of fuels treatments. They will characterize meteorology, vegetation, fuel loading, soil characteristics, hillslope sediment production and delivery from different land types and disturbances, stream flow and sediment yield, stream channel morphology, macroinvertebrates, food webs, stream channel microclimate, streamflow, shallow soil, and precipitation chemistry.

A draft study plan is expected in 2005 and will be made available to interested parties for review. Baseline data analysis will also begin in 2005.

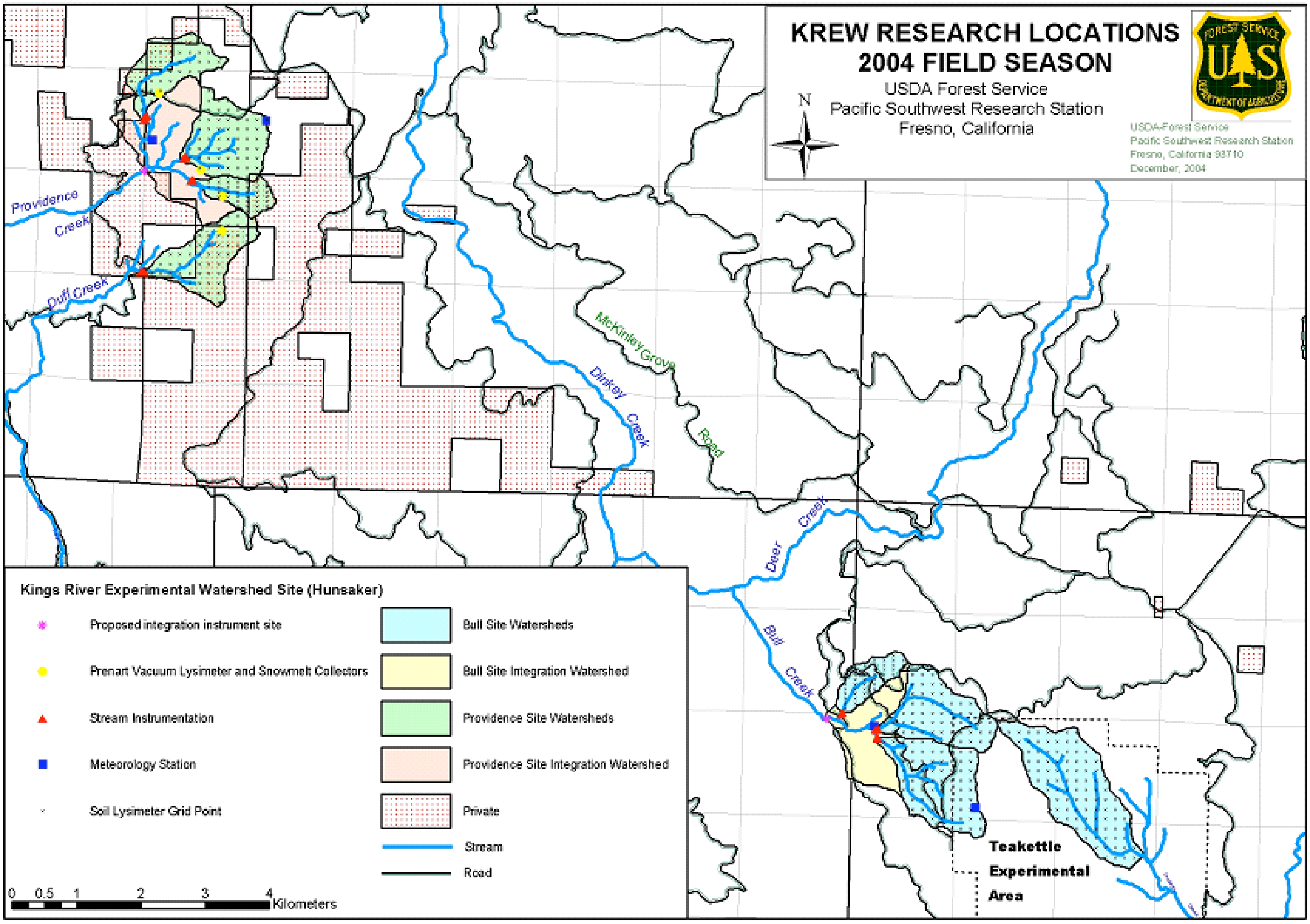


Figure 32. KREW Study Watersheds on Sierra National Forest

## *3.6.Herger-Feinstein Quincy Library Group Forest Recovery Act Monitoring*

The Herger-Feinstein Quincy Library Group Forest Recovery Act (HFQLG) is being implemented on the Lassen, Plumas, and Tahoe national forests. HFQLG projects are intended to reduce fire hazards, improve forest heath, and provide economic stability. A comprehensive monitoring program has been developed to: 1) provide information useful to mangers applying the principles of adaptive management; 2) assist the public in gauging the success of resource management activities; and 3) assess the effectiveness of the resource management activities in achieving resource objectives (USFS 2002).

This program includes stream monitoring to determine how stream channel and riparian attributes in the HFQLG project areas change over time. This includes those with areas with the highest intensity of activities. The approach is to track changes in stream attributes, as measured by Regional Stream Condition Inventory (SCI) protocols (USFS 2004) in randomly selected "treated" sub-watersheds relative to changes in randomly selected "reference" watersheds. Measured attributes include macroinvertebrates, large woody debris, stream temperature, bankfull width and depth, substrate composition, channel cross sections, gradient, entrenchment ratio, habitat type, pool tail fines, number of pools, pool depths, streambank stability, stream shading, stream shore water depth, and streambank angle (USFS 2004).

A total of 14 sample reaches per year are selected for before and after project sampling. Selected sites may be vegetation management or riparian restoration projects. The intent is to select reaches below areas where a substantial amount of activity will occur. Samples from each stream type (based on channel types and ecological region) will be consolidated to give average values for each attribute and then compared to data from similar reference streams.

Comparisons will include: 1) attributes before and after project implementation; 2) attributes from "treated" streams with reference streams (by channel type); and 3) assessment of temporal variation by comparing reference attributes collected in difference years. Post-project sampling for some projects will begin during the 2004 field season. Consequently, results from this monitoring are not yet available.

## *3.7.Heavenly Valley TMDL*

In January 2003, a stream monitoring plan was submitted to the Lahontan Regional Water Quality Control Board by the Lake Tahoe Basin Management Unit in accordance with the *Water Quality Control Plan Amendments for the Heavenly Valley Total Maximum Daily Load* (Lahontan RWQCB 2003*)*. As outlined in the plan, the following parameters have been and will continue to be monitored: stream flow and suspended sediment, physical habitat attributes described in the Region 5 Stream Condition Inventory (SCI) Handbook (USFS 2004), and macroinvertebrates.

Target conditions for these attributes, as defined in the TMDL implementation plan, are:

- *instream sediment loads:* maximum 58 tons/year (5-year rolling average)
- *SCI attributes*: improving trends in channel morphology over time
- *Pfankuch channel stability rating*: increasing trend over time from "poor-fair" to "good"
- *macroinvertebrate community health*: improving trends in benthic invertebrate community metrics over time, approaching conditions in Hidden Valley Creek.

SCI attributes and macroinvertebrates are being monitored at three sites on Heavenly Valley Creek and compared to data from two sites in Hidden Valley Creek, a reference stream. The USFS has proposed that the RIVPACS model described in Section 3.1 be used as one of several methods for evaluating macroinvertebrate community trends in Heavenly Valley Creek (e.g., compare O/E trends in Heavenly Valley Creek with respect to those in Hidden Valley Creek).

To enable these comparisons, baseline O/E ratios were calculated for each of the five monitoring sites. All three Heavenly Valley sites had O/E scores greater than two standard deviations (sd=0.19) from the mean reference site score (O/E = 1.01). Consequently, the model provided addition evidence to support the listing of these sites as impaired. The model also supported the presumption that Lower Hidden Valley is a reference site (O/E = 0.97). However, the model did not predict the Upper Hidden Valley site to be in reference condition (O/E = 0.45).

There are several reasons why the model may have predicted the site to be impaired, even if its presumed reference state were true. The Upper Hidden Valley site is intermittent, but the reference site streams used to build the RIVPACS model are mostly perennial. This could explain why the observed taxa were so much lower than predicted at the Upper Hidden site. Moreover, such high elevation sites were not well represented among the reference sites used to develop the RIVPACS model (only nine out of 136 sites (<7%) were over 9,000 feet).

A system for calculating and applying multi-metric Index of Biotic Integrity (IBI) scores to Heavenly Valley data remains to be developed. As previously described, the USFS collaborated with other agencies in the development of a B-IBI for southern California. Provided funding is available, future work will likely focus on development of B-IBIs in the Sierra Nevada.

### *3.8.Herbicide Monitoring*

USFS Pacific Southwest Region has conducted water quality monitoring of herbicides since 1991. Eight forests have monitored for glyphosate, five have monitored for triclopyr, and nine have monitored for hexazinone. Bakke (2001) synthesized the results of these studies and they are summarized below.

Glyphosate and triclopyr were rarely detected in surface water, as expected from their chemical characteristics (Table 19). Detections were associated with use within riparian areas or poor implementation of BMPs. Hexazinone has been detected numerous times in both surface and ground water, which is also expected based on its characteristics. If label direction and BMPs are followed, detected amounts of hexazinone are usually less than 10 parts per billion (ppb).

**Table 19 – Water quality monitoring of Region 5 herbicide projects, 1991 – 2000**

| Herbicide | Total Samples | With No Detectable Residues | 0-10 ppb | 11-30 ppb | 31-50 ppb | 51-100 ppb | 101-600 ppb | Maximum observed concentration [11] |
|---|---|---|---|---|---|---|---|---|
| Glyphosate | 104 | 103 | 0 | 1 | 0 | 0 | 0 | < 25 ppb |
| Triclopyr | 43 | 30 | 12 | 0 | 0 | 1 | 0 | 82 ppb |
| Hexazinone | | | | | | | | |
| - Surface water | 580 | 245 | 301 | 16 | 4 | 8 | 6 | 600 ppb |
| - Groundwater | 103 | 78 | 25 | 0 | 0 | 0 | 0 | 2.1 ppb |

[11] Where limit of detection (LOD) may be higher than a reported concentration, the maximum has been listed as "less than" (<) the LOD.

#### 3.8.1.1. Hexazinone

There were no detectable levels of hexazinone in 245 of 580 samples (42%) of the surface water samples. Of the samples with detectable levels, 90% were below 7 ppb and 95% were below 15 ppb. Effects to aquatic insects and fish are not expected until levels greatly exceed 1,000 ppb and the current EPA Health Advisory level (HA) is 400 ppb.

For groundwater, 78 of 103 samples (76%) showed no detections of hexazinone. Almost all (95%) detections in groundwater were at levels very near limits of detection (<1 ppb) and the highest level detected was 2.1 ppb in very shallow lysimeter holes (2 feet deep). Once hexazinone is in shallow groundwater, lateral movement can be extensive (e.g., hexazinone was detected approximately 450 feet down gradient from one treated unit). Together, results from surface and groundwater data imply that hexazinone in groundwater can be a source of surface water contamination over a long period of time, regardless of implementation of BMPs to directly protect surface water.

#### 3.8.1.2. Glyphosate

There were no detections of glyphosate in water associated with reforestation projects, except those ascribed to sample contamination. Glyphosate was detected in only one of twelve samples associated with noxious weed treatments in the riparian zone. The detected concentration of 15 ppb is below any level of concern for human health or aquatic resources.

#### 3.8.1.3. Triclopyr

The few detections of triclopyr not associated with accidental or erroneous applications in water were all less than 2.4 ppb. These levels are below any aquatic levels of concern. The detection that resulted in the highest level of triclopyr (82 ppb) was caused by the absence of an untreated buffer on an ephemeral stream. This concentration does not represent a substantial risk of harm to humans or the environment. Monitoring results suggest that untreated streamside buffers of greater than 15 feet in width reduce risk of water contamination to near zero.

## *3.9.Range Monitoring*

The Region initiated a comprehensive Range Monitoring Program in 1999. Objectives, methods, and results of this study are described in detail in *USFS Region 5 Range Monitoring Report* (Weixelman et al. 2003) and are summarized here.

The purpose of the program is to monitor long-term trends in range conditions across the Region by establishing permanent plots on key sites. The project will provide critical information needed to inform management decisions regarding grazing. Specifically, it will develop an ecological classification of rangelands based on vegetation, soils, and hydrology and quantitative scorecards for assessing meadow conditions and trends.

A total of 785 plots on key range sites have been established throughout the Region since 1999: 572 rooted frequency plots in meadows, 79 rooted frequency plots in annual grasslands, and 134 "green line" and cross section plots. To date, preliminary ecological classifications have been developed based on statistical analysis of data from the 785 permanent plots. Initial scorecards to rate ecological condition for monitored sites are expected in 2005. Data from twenty-four sites established in 1999 and reread in 2003 is currently being analyzed to evaluate possible short-term trends.

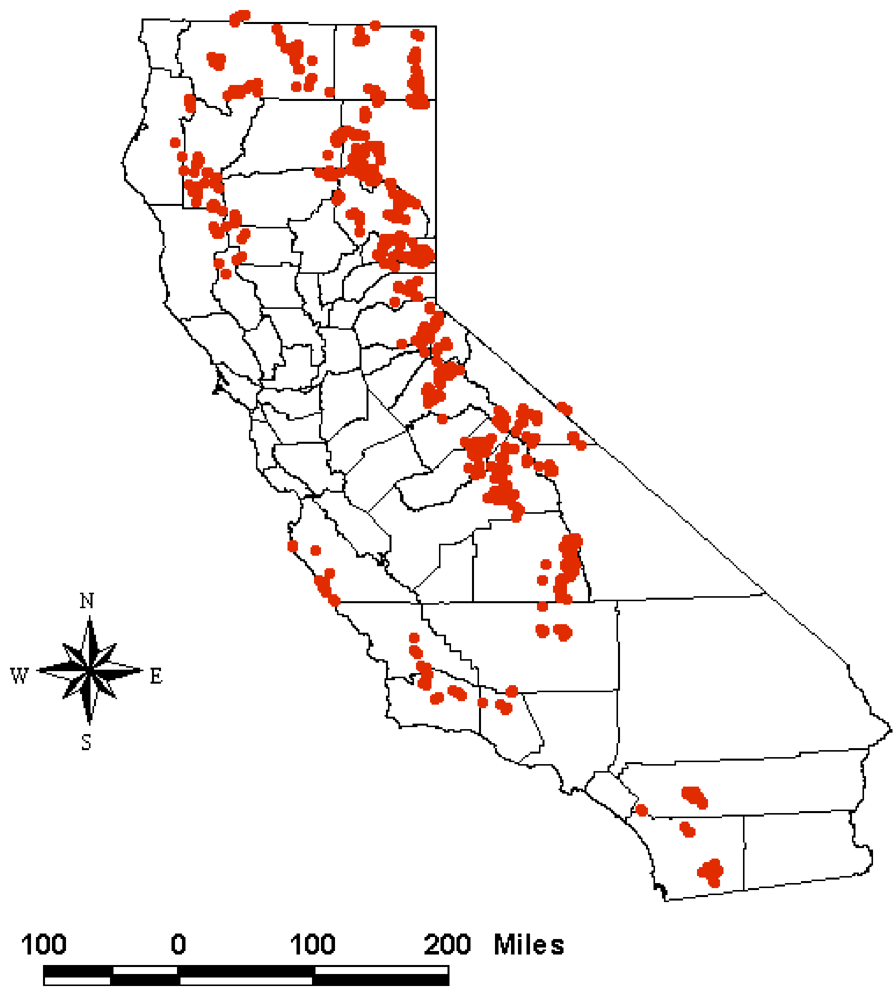


Figure 33. Distribution of all 785 range monitoring plots established from 1999 through 2003 across Region 5.

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# *Water Quality Protection on National Forests in the Pacific Southwest Region: Best Management Practices Evaluation Program, 2003-2007*

*USDA Forest Service*
*Pacific Southwest Region*
*September 19, 2009*

**Water Quality Protection on National Forests in the Pacific Southwest Region: Best Management Practices Evaluation Program, 2003-2007**
**USDA Forest Service**
**Pacific Southwest Region**

## ***Executive Summary***


The USDA Forest Service Pacific Southwest Region (USFS) Best Management Practices Evaluation Program (BMPEP) included 2,861 randomly-selected onsite evaluations of Best Management Practice (BMP) implementation and effectiveness between 2003 and 2007. For the 5-year reporting period, 86% of Best Management Practices (BMPs) were rated as implemented and 89% were rated as effective. Among implemented BMPs, 93% were rated effective.

Of the 2,861 on-site evaluations used for this report, 98% indicated no significant adverse impacts on water quality. Only 8% of the onsite evaluations indicated any measurable potential or actual adverse impacts on water quality.

Many of the BMPs rated as ineffective were ineffective owing to lack of implementation rather than shortcomings in the BMPs. Improved implementation of BMPs is the single most useful step that can be taken to improve water-quality protection on national forests in California.

Several BMPs were not highly effective even when implemented, and can be revised to improve protection of water quality. These include BMPs for developed recreation sites, road stream crossings, and water source development.

Several BMPs have been 95 to 100% effective when implemented, including almost all BMPs for timber harvests, vegetation management, and prescribed fire. Given the documented performance of these BMPs, effectiveness monitoring of these protocols can be reduced in the future in order to focus on areas where improvement is needed.

BMP implementation and effectiveness have improved slightly in comparison to results for 1992 to 2002 (Staab, 2004), and the number of BMPEP evaluations has increased. BMP implementation on national forests in California was within the range of results reported in previous studies on private lands in the western United States.

Measures planned to improve protection of water quality on national forest system lands in the Pacific Southwest Region include implementation checklists for all projects with ground disturbance, annual reviews of national forest watershed staffing, revision of selected BMPs that have relatively low effectiveness when implemented, modification of the BMPEP scoring procedures, and adoption of a new regional water-quality monitoring program.

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***Introduction***

California depends on water produced in forested watersheds. Almost all forest management activities have potential to affect water quality. The implementation of appropriate forest management measures is therefore critical to protection of the state's water resources.

The national forests in California were established under the Organic Act of 1897, which states that a primary purpose of the national forests is to "secure favorable conditions of water flows." All national forests in California are managed by the USDA Forest Service (USFS). The USFS Pacific Southwest Region (Region 5) manages roughly 20,000,000 acres (fig. 1) in 18 national forests that produce about 45% of the state's water. Results for small areas of the state within the Siskiyou and Humboldt-Toiyabe National Forests are not included in this report because these forests are administered by other USFS regions.


***Figure 1: Locations of national forests within the Pacific Southwest Region in California***

The federal Clean Water Act gives the authority to regulate water-quality protection to the states. In California, this authority rests with the State Water Resources Control Board and 9 Regional Water Quality Control Boards. In 1981, the State Water Resources Control Board entered into a management agency agreement (MAA) with the USFS that designated the USFS as the water-quality management agency for national forest lands in California. This agreement obligates the USFS to incorporate Best Management Practices (BMPs) for protection of water quality into land and resource management activities and to monitor their implementation and effectiveness, which has been accomplished since 1992 using the BMP Evaluation Program (BMPEP; USFS, 2000; USFS, 2002). Although changes in state law have affected the status of the MAA, it remains in effect. A strategy to modify the agreement is currently being negotiated.

This report presents the results of the BMPEP for the national forests in the Pacific Southwest Region for 2003 to 2007. Onsite evaluations are the foundation of the BMPEP and are therefore the focus of this report. This report temporally extends the analysis of BMPEP monitoring results for 1992 to 2002 (Staab, 2004).

BMP effectiveness can be affected by weather conditions. BMPs that are adequate for mild or moderate rainfall, snowmelt, and runoff conditions may not be appropriate for more extreme conditions. A general evaluation of hydrologic stress during the 2003 to 2007 reporting period can be made based on streamflow records published by the U.S. Geological Survey (http://ca.water.usgs.gov). Streamflow stations with long, but variable, periods of record were used to compare unregulated annual peak streamflows during the 5 years of the 2003 to 2007 reporting period with the highest annual peak flows for the periods of record. Seven stations were selected throughout the state to represent the areas included within the national forest system (Table 1a). Results are shown in Table 1b. Annual peak streamflows at the 7 stations during 2003 to 2007 ranged from 0% to 100% of the period-of-record maximums. In general, peak flows were high during 2006 (3 to 100% of maximum flows) and low in 2007 (0 to 29% of maximum flows). These results indicate that the 2003 to 2007 reporting period was not extreme in terms of precipitation or runoff, but represents a reasonably wide range of conditions that can be considered a "fair test" of BMP effectiveness.

**Table 1a: U.S. Geological Survey streamgages used to represent hydrologic conditions on national forests during the 2003 to 2007 study period**

| Station number | Stream | National forests | Period of record (POR) | POR peak streamflow (cfs) | POR water year |
|---|---|---|---|---|---|
| 11532500 | Smith River | Six Rivers, Klamath, Mendocino | 1932-2007 | 228,000 | 1965 |
| 11402000 | Spanish Creek | Modoc, Lassen, Plumas | 1934-2007 | 22,100 | 1997 |
| 11427700 | Duncan Canyon | Tahoe, Eldorado, Stanislaus | 1961-2007 | 3,650 | 1965 |
| 10336780 | Trout Creek | LTBMU | 1961-2007 | 615 | 2006 |
| 11189500 | South Fork Kern R. | Sierra, Sequoia, Inyo | 1914-2007 | 28,700 | 1967 |
| 11143000 | Big Sur River | Los Padres | 1951-2007 | 10,700 | 1978 |
| 11015000 | Sweetwater River | Angeles, San Bernardino, Cleveland | 1957-2007 | 3,890 | 1967 |

**Table 1b: Annual peak streamflows during water years 2003 to 2007 at selected USGS streamflow gaging stations, expressed as percentages of the maximum recorded peak streamflows during the station periods of record (http://ca.water.usgs.gov)**

| Station number | Stream | %, 2003 | %, 2004 | %, 2005 | %, 2006 | %, 2007 |
|---|---|---|---|---|---|---|
| 11532500 | Smith River | 26 | 36 | 38 | 53 | 29 |
| 11402000 | Spanish Creek | 19 | 30 | 18 | 57 | 12 |
| 11427700 | Duncan Canyon | 15 | 15 | 32 | 85 | 23 |
| 10336780 | Trout Creek | 23 | 9 | 32 | 100 | 10 |
| 11189500 | South Fork Kern R. | 23 | 1 | 7 | 6 | 0 |
| 11143000 | Big Sur River | 33 | 17 | 22 | 39 | 6 |
| 11015000 | Sweetwater River | 1 | 22 | 75 | 3 | 0 |
| Average | | 20 | 19 | 32 | 49 | 12 |

***Objectives***

The objectives of this report are to:

1. Summarize onsite evaluations of BMP implementation and effectiveness.
2. Summarize observations of adverse effects on water quality from BMP evaluations.
3. Identify BMPs that can be improved to benefit water quality.
4. Identify BMPs that are highly effective in protecting water quality.
5. Compare results to other recent BMP monitoring studies in California
6. Describe a new BMPEP scoring protocol scheduled for implementation in 2010.
7. Present recommendations for improving BMP implementation and effectiveness.

***Methods***

Onsite evaluations are used to assess both BMP implementation and effectiveness. Implementation evaluations determine the extent to which planned water quality protection measures were actually put in place on project sites. Effectiveness evaluations determine the extent to which the practices met their water-quality protection objectives.

There are 29 onsite evaluation protocols used to assess the implementation and effectiveness of most of the 96 individual BMPs, or groups of closely related BMPs. BMPEP protocols for major categories of land and resource management activities are summarized in Table 2. A more detailed list of protocols and associated BMPs is provided in Appendix A. References in this report to BMP implementation and effectiveness results for the 29 onsite evaluation protocols refer to the groups of BMPs evaluated by each protocol, rather than individual BMPs. Additional details can be found in *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program (BMPEP) User's Guide* (USFS, 2002) and *Water Quality Management for National Forest System Lands in California* (USFS, 2000; http://www.fs.fed.us/r5/publications/).

Onsite evaluation protocols are applied to both randomly and non-randomly selected project sites. The numbers of random evaluations to be completed each year are assigned to the national forests by the regional office, based on: 1) the relative importance of the BMP in protecting water quality in the Region; and 2) the management activities most common on the individual Forest (for example, range management on the Modoc National Forest, recreation on the Angeles National Forest). Forests supplement these randomly selected sites with additional sites based on local monitoring needs, such as those prescribed in environmental compliance (NEPA) documents. Although all data collected with onsite evaluations are entered into the regional BMPEP data base, only data from onsite evaluations made at randomly selected sites are presented in this report.

**Table 2- BMPEP Onsite Evaluation Protocols and associated BMP's for major categories of land and resource management activities on national forest system lands in California**

| **Land and resource management activity** | **BMPEP protocols (USFS, 2002)** | **BMPs (USFS, 2000)** |
|---|---|---|
| Timber | T01 to T07 | 1-8, 1-10, 1-11, 1-12, 1-13, 1-14, 1-15, 1-16, 1-17, 1-18, 1-19, 1-20, 1-21, 1-22, 1-25, 5-3 |
| Roads (Engineering) | E08 to E20 | 2-1 to 2-5, 2-7 to 2-12, 2-14, 2-16 to 2-27 |
| Recreation | R22, R23, and R30 | 4-4 to 4-6, 4-9, 4-10 |
| Grazing (Range) | G24 | 8-1 to 8-3 |
| Fuels (Prescribed fire) | F25 | 6-2 and 6-3 |
| Mining | M26 and M27 | 3-1 to 3-3, 2-18 |
| Vegetation Management | V28 and V29 | 5-1, 5-2, 5-4 to 5-6 |

Procedures for onsite evaluations vary greatly, but the overall approach for each onsite evaluation is consistent. For BMP implementation, evaluators are asked a variety of specific questions intended to determine whether the project was executed on the ground, as planned and described in project documents. A range of possible scores is allocated to each question, depending on its relative importance and the degree to which particular requirements are met (whether the project exceeds, meets, departs slightly, or departs substantially from requirements). Scores for all implementation questions are then summed and compared to a predetermined threshold (inference point) to conclude whether the applicable BMPs were implemented. BMP effectiveness is determined based on indirect measures of water quality protection, including observations (for example, evidence of sediment delivery to channels) and quantitative measurements (for example, amount of ground cover, percent of stream shade). A scoring system similar to that used for BMP implementation is used to determine BMP effectiveness. All evaluations are scored automatically after entry into the regional BMPEP data base. Therefore, field evaluators do not necessarily know whether BMPs will be considered implemented or effective at the time of the onsite evaluation.

This scoring approach results in a 2 x 2 matrix, in which BMPs are placed into 1 of 4 categories: implemented and effective, implemented, but not effective, not implemented, but effective, not implemented and not effective. Evaluations rated as not implemented but effective indicate that under the conditions prevailing between the project activity and the effectiveness monitoring, the prescribed BMPs were not necessary to protect water quality.

BMPEP monitoring is conducted at the hillslope scale and does not include direct monitoring of beneficial uses in streams. BMPs scored as "ineffective" therefore represent potential, rather than actual, impairment of beneficial uses by a given activity.

In addition to the implementation and effectiveness questions, field evaluators qualitatively estimate the degree, duration, and spatial extent of any existing or potential adverse water-quality impacts associated with the evaluated BMPs (the evaluations do not distinguish between existing and potential impacts, and references to adverse water-quality effects in this report apply to both actual and potential impacts). Each protocol includes guidelines for rating activities in 1 of 3 categories corresponding to insignificant (unmeasurable), minor, and significant levels of adverse impacts. If adverse impacts are noted, the impacts are classified into 1 of 3 duration levels (less than 5 days, more than 5 days but less than one season, and more than one season) and 1 of 3 spatial extent levels (hillslope scale, stream reach scale, and drainage basin scale).

BMPEP implementation and effectiveness scoring problems may affect results for several protocols included in this report. These problems, as well as steps underway to correct them, are discussed in detail in Appendix B. This report uses results as they were stored in the regional BMPEP data base as of June 28, 2008, with the exception of Table 6, which uses data retrieved on September 18, 2008. The field evaluations of adverse water-quality effects (degree, duration, and spatial extent) are independent of the scoring protocols and are therefore useful as indicators of BMP performance for all protocols regardless of scoring procedures.

## ***Results and Discussion***

A total of 2,861 onsite evaluations were conducted in the Pacific Southwest Region during fiscal years 2003 to 2007 using 29 monitoring protocols (Tables 3 and 4). The average number of evaluations per year during the 2003 to 2007 period was 572, which is a significant increase from the average of 357 evaluations per year for the 1992 to 2002 period (Staab, 2004).

Based on implementation and effectiveness scores for the evaluations, each onsite evaluation was classified into 1 of 4 categories, as described above. The total number of

BMPs considered implemented is the sum of the "implemented and effective" and "implemented, but not effective" evaluations. The total number of BMPs considered effective is the sum of the "implemented and effective" and "not implemented, but effective" evaluations. BMPs were considered to be effective even where not implemented if no evidence of water-quality impairment was observed. Unless otherwise noted, BMPs reported as effective in this report include both implemented and non-implemented BMPs that were considered to be effective based on lack of evidence for water-quality impairment.

Of the total of 2,861 BMPs evaluated for the 29 protocols, 2,467 (86%) were rated as implemented and 2,533 (89%) were rated as effective (note that the number of evaluations reported in Table 3 sums to only 2,854 owing to slight differences between annual and study-period totals in the data base; results reported here include the entire 2,861 evaluations). Implementation ranged from 81% in 2003 to 89% in 2007 (Table 3). Effectiveness ranged from 86% in 2003 to 90% in 2007 (Table 3). Both implementation and effectiveness improved between 2003 and 2007. The generally higher peak flows experienced in 2006 (Table 1b) do not appear to have reduced BMP effectiveness for the region as a whole. Of the 2,467 BMPs that were implemented, 2,284, or 93%, were effective (Table 4).

**Table 3: BMPEP evaluations conducted at national forests in the Pacific Southwest Region, 2003 to 2007**

| Year | Number of forests reporting results | Number of evaluations completed | % Implemented | % Effective |
|---|---|---|---|---|
| 2003 | 14 | 597 | 81 | 86 |
| 2004 | 14 | 452 | 88 | 89 |
| 2005 | 11 | 495 | 88 | 90 |
| 2006 | 13 | 532 | 87 | 90 |
| 2007 | 16 | 778 | 89 | 90 |

Among individual monitoring protocols, BMP implementation ranged from 0 to 100%, with an average of 84% (Table 4). BMP effectiveness ranged from 57 to 100%, with an average of 88% (Table 4). Among implemented BMPs, effectiveness ranged from 69 to 100%, with an average of 93% (Table 4). Eight protocols (T03, T05, T06, E18, E19, F25, M27, and V28) achieved 100% effectiveness among implemented BMPs. Eight protocols (E08, E09, E13, E16, E20, G24, R22, and R23) had effectiveness less than 90% among implemented BMPs. The remaining 12 protocols had effectiveness ranging between 90 and 99% among implemented BMPs (M26 had no implemented BMPs and was therefore not included).

To better summarize the results of the BMP monitoring, protocols were grouped into 6 major land-management activities (Table 5). Among the major activities, implementation ranged from a low of 24% for mining to a high of 98% for vegetation management.

Effectiveness, expressed as a percentage of the total number of BMPs evaluated, ranged from a low of 73% for recreation to a high of 98% for fuels management. Effectiveness, expressed as a percentage of implemented BMPs, ranged from 82% (recreation) to 100% (fuels management and mining).

Effectiveness of implemented BMPs was high, indicating that the BMPs are accomplishing their objective of protecting water quality. The greatest opportunities for improving protection of water quality appear to be in increased implementation, particularly for recreation and mining activities.

BMPEP results for each of the 18 national forests in the region are summarized in Table 6. BMP implementation ranged from 77 to 93%. BMP effectiveness ranged from 74 to 97%. Among implemented BMPs, effectiveness ranged from 77 to 99%.

Overall, 92% of the BMPs evaluated for this report were considered to have no potential or actual adverse impacts on water quality (Table 7). An additional 1% were considered to have insignificant adverse impacts. A total of 6% had minor adverse impacts, and only 2% had significant adverse impacts (percentages total to 101% due to rounding). The percentage of onsite evaluations associated with measurable potential or actual adverse impacts on water quality is the sum of the evaluations with minor and significant impacts, or 8% of all evaluations. The percentages of onsite evaluations reporting measurable impacts on water quality ranged from 0 to 21% among the 29 BMPEP protocols (Table 7).

Among the 2,861 onsite evaluations analyzed for this report, 98% had no significant impacts to water quality (Table 7). The difference between this percentage and the total implementation percentage of 86% indicates that for 12% of the evaluations, BMPs were not implemented as they should have been, but under prevailing conditions were not needed to protect water quality. This result does not excuse lack of implementation, but does indicate that implementation failures do not necessarily result in significant adverse impacts to water quality.

Adverse water-quality impacts that persisted for 5 or more days were reported for 6% of the onsite evaluations, and 3% of the evaluations reported impacts that extended to stream channels. The difference between the percentage of evaluations reporting impacts that extended to stream channels (3%) and the percentage of evaluations with measurable potential or actual adverse impacts (8%) indicates that most of the measurable adverse impacts were potential rather than actual.

**Table 4: Implementation and effectiveness of BMPEP protocols for all national forests in the Pacific Southwest Region, 2003 to 2007**

[IE, implemented and effective; NIE, not implemented but effective; INE, implemented but not effective; NINE, not implemented and not effective; IMP, implemented; EFF, effective; IMP EFF, effectiveness expressed as a percentage of implemented BMPs]

| Protocol | Number of Evaluations | % IE | % NIE | % INE | % NINE | % IMP | % EFF | % IMP EFF |
|---|---|---|---|---|---|---|---|---|
| T01 | 206 | 91 | 3 | 4 | 1 | 96 | 94 | 95 |
| T02 | 224 | 86 | 12 | 0 | 2 | 86 | 97 | 99 |
| T03 | 45 | 40 | 49 | 0 | 11 | 40 | 89 | 100 |
| T04 | 278 | 94 | 4 | 1 | 1 | 94 | 98 | 99 |
| T05 | 42 | 93 | 7 | 0 | 0 | 93 | 100 | 100 |
| T06 | 24 | 100 | 0 | 0 | 0 | 100 | 100 | 100 |
| T07 | 33 | 85 | 6 | 6 | 3 | 91 | 91 | 93 |
| E08 | 309 | 72 | 10 | 10 | 7 | 82 | 83 | 88 |
| E09 | 252 | 77 | 4 | 12 | 8 | 89 | 80 | 86 |
| E10 | 184 | 88 | 5 | 6 | 1 | 94 | 93 | 94 |
| E11 | 173 | 89 | 5 | 2 | 3 | 91 | 94 | 97 |
| E12 | 25 | 96 | 0 | 4 | 0 | 100 | 96 | 96 |
| E13 | 82 | 63 | 13 | 18 | 5 | 82 | 77 | 78 |
| E14 | 71 | 86 | 6 | 6 | 3 | 92 | 92 | 94 |
| E15 | 35 | 80 | 3 | 6 | 11 | 86 | 83 | 93 |
| E16 | 51 | 53 | 10 | 20 | 18 | 73 | 63 | 73 |
| E17 | 45 | 82 | 7 | 2 | 9 | 84 | 89 | 97 |
| E18 | 1 | 100 | 0 | 0 | 0 | 100 | 100 | 100 |
| E19 | 6 | 83 | 17 | 0 | 0 | 83 | 100 | 100 |
| E20 | 37 | 81 | 0 | 16 | 3 | 97 | 81 | 83 |
| R22 | 114 | 50 | 7 | 23 | 20 | 73 | 57 | 69 |
| R23 | 34 | 56 | 12 | 9 | 24 | 65 | 68 | 86 |
| R30 | 120 | 70 | 19 | 5 | 6 | 75 | 89 | 93 |
| G24 | 98 | 79 | 2 | 15 | 4 | 94 | 81 | 84 |
| F25 | 190 | 87 | 11 | 0 | 2 | 87 | 98 | 100 |
| M26 | 41 | 0 | 80 | 0 | 20 | 0 | 80 | -- |
| M27 | 13 | 100 | 0 | 0 | 0 | 100 | 100 | 100 |
| V28 | 67 | 99 | 0 | 0 | 1 | 99 | 99 | 100 |
| V29 | 61 | 90 | 3 | 7 | 0 | 97 | 93 | 93 |
| Total | 2,861 | | | | | | | |

**Table 5: BMP implementation and effectives for major activities on national forests in the Pacific Southwest Region, FY 2003-2007**

| Activities | Protocols | BMPs Implemented (% of total) | BMPs Effective (% of total) | BMPs Effective (% of implemented) |
|---|---|---|---|---|
| Timber | T01 to T07 | 90 | 96 | 98 |
| Roads | E08 to E20 | 88 | 85 | 90 |
| Recreation | R22, R23, and R30 | 73 | 73 | 82 |
| Grazing | G24 | 94 | 81 | 84 |
| Fuels | F25 | 87 | 98 | 100 |
| Mining | M26 and M27 | 24 | 85 | 100 |
| Vegetation Management | V28 and V29 | 98 | 96 | 97 |

**Table 6: BMPEP results for national forests in the Pacific Southwest Region, 2003 to 2007**

| National Forest | Number of BMPEP evaluations | % BMPs Implemented | % total BMPs effective | % implemented BMPs Effective |
|---|---|---|---|---|
| Angeles | 26 | 85 | 81 | 77 |
| Cleveland | 32 | 91 | 81 | 83 |
| Eldorado | 164 | 91 | 97 | 99 |
| Inyo | 120 | 78 | 74 | 81 |
| Klamath | 242 | 90 | 96 | 99 |
| Lake Tahoe Basin | 208 | 90 | 87 | 90 |
| Lassen | 362 | 91 | 91 | 94 |
| Los Padres | 147 | 84 | 77 | 80 |
| Mendocino | 55 | 93 | 93 | 94 |
| Modoc | 11 | 91 | 82 | 90 |
| Plumas | 364 | 83 | 86 | 92 |
| San Bernardino | 59 | 80 | 97 | 98 |
| Sequioa | 204 | 82 | 86 | 89 |
| Shasta-Trinity | 304 | 82 | 88 | 97 |
| Sierra | 53 | 77 | 91 | 98 |
| Six Rivers | 179 | 85 | 91 | 95 |
| Stanislaus | 121 | 91 | 88 | 91 |
| Tahoe | 210 | 88 | 90 | 94 |

Results in Table 7 indicate that the protocols most likely to be associated with measurable adverse water-quality effects (percentages of BMPs with measurable effects higher than 15%) are R22 (developed recreation sites), E09 (road stream crossings), and E16 (water source development). These protocols also were found to have relatively low effectiveness when implemented (Table 4). The BMPs evaluated with these protocols are high priorities for revision.

Six protocols had no evaluations with measurable water-quality effects, and an additional 11 protocols had 5% or less of their evaluations with measurable water-quality effects (Table 7). These include all the timber harvesting BMPs except T07 (meadow protection), and all vegetation management and prescribed fire BMPs. The BMPs for these protocols can be considered highly effective at protecting water quality.

Results presented in this report can usefully be compared to previous USFS regional monitoring results to determine if BMP implementation and effectiveness have improved. For the 1992 to 2002 period, overall BMP implementation was 85%, and for implemented BMPs, overall effectiveness was 92% (Staab, 2004). Results for 2003 to 2007 presented in this report are slightly higher for both implementation (86%) and effectiveness (93% of implemented BMPs).

Results of this report can also be compared with previous studies of BMPs on privately owned forest lands in the Western states (Table 8). Results are only roughly comparable because the BMPs, evaluation procedures, and scoring procedures vary. Only implementation results are presented in Table 8 owing to substantial differences in methods for evaluating effectiveness. BMP implementation success on national forests in the Pacific Southwest Region during 2003 to 2007 was within the range of the results of these previous studies.

### ***Recommendations***

1. Increased implementation of BMPs would clearly improve the performance of the USFS in protecting water quality in California. The USFS intends to achieve improvements in implementation through the following actions:

   a. In addition to random BMPEP evaluations, the USFS will require the completion of implementation checklists for all projects on national forests in the Pacific Southwest Region that involve ground disturbance. BMP implementation checklists are part of the proposed USFS regional monitoring plan (see item 5. below and Appendix C), which will be put into effect when formally approved by the State Water Resources Control Board as part of the renegotiation of the MAA.
   b. Forest staffing will be reviewed annually by the USFS regional office and when appropriate, recommendations will be made to national forests that need additional personnel for BMP implementation review.
   c. Training in BMPEP monitoring and inter-forest BMPEP reviews will be coordinated by the USFS regional office.

d. The USFS regional office will review BMPEP protocols and forms to determine where revisions are needed so that BMP implementation language and intent is more clearly defined for evaluators. This, along with training described above, should reduce evaluator variation and error in understanding the intent of each BMP.

2. BMPs evaluated using several BMPEP protocols were found to be effective even when implemented for less than 90% of the evaluations. These protocols include 5 engineering protocols, 2 recreation protocols, and one grazing protocol. The BMPs evaluated by these protocols therefore will be reviewed and revised to improve their effectiveness after consideration of scoring problems (see item 4. below).

3. Several BMPEP protocols achieved 100% effectiveness among implemented BMPs. These included 3 timber harvest, 2 engineering, one fire, one mining, and one vegetation management protocol. The high level of effectiveness indicates that the BMPs are performing well when implemented. The USFS will reduce BMPEP effectiveness evaluation targets for these protocols to allow watershed staff to focus on higher monitoring priorities (see item 5. below).

4. The USFS will implement the Frazier scoring protocol beginning with BMPEP evaluations for 2009 (see appendix B).

5. The USFS will implement the Pacific Southwest Regional water-quality monitoring plan (appendix C) when approved by the State Water Resources Control Board as a component of the revised Management Agency Agreement.

**Table 7: BMP onsite evaluations on national forests in the Pacific Southwest Region associated with measurable adverse effects on water quality, 2003 to 2007**

| BMPEP Protocol | % BMPs with measurable actual or potential adverse effects on water quality | % BMPs w/ effects that persisted for 5 or more days | % BMPs w/ effects that extended to a stream |
|---|---|---|---|
| T01: Streamside Management Zones (SMZs) | 3 | 3 | 3 |
| T02: Skid Trails | 1 | 2 | 0 |
| T03: Suspended Yarding | 2 | 4 | 0 |
| T04: Landings | 1 | 1 | 1 |
| T05: Timber Sale Administration | 0 | 0 | 0 |
| T06: Special Erosion Control & Revegetation | 4 | 0 | 0 |
| T07: Meadow Protection | 9 | 9 | 6 |
| E08: Road Surface, Drainage & Slope Protection | 11 | 12 | 6 |
| E09: Stream Crossings | 15 | 14 | 9 |
| E10: Road Decommissioning | 2 | 2 | 0 |
| E11: Control of Sidecast Material | 5 | 3 | 2 |
| E12: Servicing and Refueling | 0 | 0 | 0 |
| E13: In-Channel Construction Practices | 6 | 4 | 7 |
| E14: Temporary Roads | 1 | 3 | 1 |
| E15: Rip Rap Composition | 6 | 9 | 3 |
| E16: Water Source Development | 18 | 22 | 16 |
| E17: Snow Removal | 0 | 0 | 2 |
| E18: Pioneer Road Construction | 0 | 0 | 0 |
| E19: Restoration of Borrow Pits & Quarries | 0 | 0 | 0 |
| E20: Protection of Roads During Wet Periods | 14 | 14 | 8 |
| R22: Developed Recreation sites | 21 | 22 | 9 |
| R23: Location of Stock Facilities in Wilderness | 9 | 9 | 0 |
| R30: Dispersed Recreation | 8 | 8 | 7 |
| G24: Range Management | 11 | 11 | 6 |
| F25: Prescribed Fire | 1 | 1 | 1 |
| M26: Mining Operations (Locatable Minerals) | 12 | 10 | 5 |
| M27: Common Variety Minerals | 0 | 0 | 0 |
| V28: Vegetation Manipulation | 1 | 1 | 1 |
| V29: Revegetation of Surface Disturbed Areas | 5 | 5 | 2 |
| Total | 8 | 6 | 3 |

**Table 8: Implementation results from selected previous studies of BMP implementation on private forest lands in Western states**

| Authors | State | Study Period | Type of BMPs | % Implemented |
|---|---|---|---|---|
| Brandow and others, 2006 | California | 2001-2004 | Roads | 96 |
| Brandow and others, 2006 | California | 2001-2004 | Watercourse crossings | 83 |
| Cafferata and others, 2002 | California | 1996-2001 | Roads | 93 |
| Cafferata and others, 2002 | California | 1996-2001 | Skid trails | 95 |
| Cafferata and others, 2002 | California | 1996-2001 | Landings | 94 |
| Cafferata and others, 2002 | California | 1996-2001 | Watercourse crossings | 86 |
| Cafferata and others, 2002 | California | 1996-2001 | Stream protection zones | 98 |
| Ice and others, 2004 | Idaho | 2000 | Forest Practice Rules | 92 |
| Ice and others, 2004 | Montana | 2002 | Forest Practice Rules | 96 |
| Ice and others, 2004 | New Mexico | unspecified | Forest Practice Rules | 75 |
| Ice and others, 2004 | Oregon | unspecified | Forest Practice rules | 96 |
| Ice and others, 2004 | Wyoming | Not much | Forest Practice Rules | 91 |

***Summary***

The BMP implementation and effectiveness results presented in this report indicate that the USFS Pacific Southwest Region BMP program was generally successful in protecting water quality between 2003 and 2007. The number of BMP evaluations has increased since 2002, and rates of implementation and effectiveness have improved.

Of the 2,861 on-site evaluations used for this report, 98% indicated no significant adverse impacts on water quality. Only 8% of the onsite evaluations indicated any measurable potential or actual adverse impacts on water quality.

Many of the BMPs rated as ineffective were ineffective owing to lack of implementation rather than shortcomings in the BMPs. Improved implementation of BMPs is the single most useful step that can be taken to improve water-quality protection on national forests in California.

Several BMPs were not highly effective when implemented, and can be revised to improve protection of water quality. These include some BMPs for developed recreation sites, road stream crossings, and water source development.

Several BMPs have been highly effective when implemented, including almost all BMPs for timber harvests, vegetation management, and prescribed fire. Given the documented performance of these BMPs, effectiveness monitoring of these protocols can be reduced in the future in order to focus on problems.

BMP implementation and effectiveness have improved slightly in comparison to results for 1992 to 2002 (Staab, 2004), and the number of BMPEP evaluations has increased. BMP implementation on national forests in California was within the range of results reported in previous studies on private lands in the western United States.

Measures planned to improve protection of water quality on national forest system lands in the Pacific Southwest Region include implementation checklists for all projects with ground disturbance, annual reviews of national forest watershed staffing, revision of selected BMPs that have relatively low effectiveness when implemented, modification of BMPEP scoring procedures, and adoption of a new regional water-quality monitoring program.

## ***References***


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## APPENDIX A: BMPEP Onsite Evaluation Protocols and associated BMP's

| BMPEP Onsite Evaluation Protocols | BMPs Evaluated |
|---|---|
| T01: Streamside Management Zones (SMZs) | ▪ SMZ Designation (1-8)<br>▪ Streamcourse and Aquatic Protection (1-19)<br>▪ Slash Treatment in Sensitive Areas (1-22) |
| T02: Skid Trails | ▪ Tractor Skidding Design (1-10)<br>▪ Erosion Control on Skid Trails (1-17) |
| T03: Suspended Yarding | ▪ Suspended Log Yarding in Timber Harvesting (1-11) |
| T04: Landings | ▪ Log Landing Location (1-12)<br>▪ Log Landing Erosion Control (1-16) |
| T05: Timber Sale Administration | ▪ Erosion Prevention & Control Measures During Timber Sale Operations (1-13)<br>▪ Erosion Control Structure Maintenance (1-20)<br>▪ Acceptance of Timber Sale Erosion Control Measures Before Sale Closure (1-21)<br>▪ Modification of Timber Sale Contract (1-25) |
| T06: Special Erosion Control & Revegetation | ▪ Special Erosion Prevention Measures on Disturbed Land (1-14)<br>▪ Revegetation of Areas Disturbed by Harvest Activities (1-15) |
| T07: Meadow Protection | ▪ Meadow Protection During Timber Harvesting (1-18)<br>▪ Slash Treatment in Sensitive Areas (1-22)<br>▪ Tractor Operation Limitation in Wetlands and Meadows (5-3) |
| E08: Road Surface, Drainage & Slope Protection | ▪ Erosion Control Plan (2-2)<br>▪ Stabilization of Road Slope Surfaces and Spoil Disposal Areas (2-4)<br>▪ Road Slope Stabilization Construction Practices (2-5)<br>▪ Control of Drainage (2-7)<br>▪ Construction of Stable Embankments (2-10)<br>▪ Maintenance of Roads (2-22)<br>▪ Road Surface Treatments to Prevent Loss of Materials (2-23) |
| E09: Stream Crossings | ▪ General Guidelines for Location and Design of Roads (2-1)<br>▪ Stabilization of Road Slope Surfaces and Spoil Disposal Areas (2-4)<br>▪ Road Slope Stabilization Construction Practices (2-5)<br>▪ Control of Road Drainage (2-7) |

| | | |
|---|---|---|
| | | ▪ Construction of Stable Embankments (fills) (2-10)<br>▪ Stabilization of Road Slope Surfaces and Spoil Disposal Areas (2-4) |
| E10: Road Decommissioning | | ▪ Obliteration or Decommissioning of Roads (2-26) |
| E11: Control of Sidecast Material | | ▪ Control of Sidecast Material During Construction & Maintenance (2-11) |
| E12: Servicing and Refueling | | ▪ Servicing and Refueling of Equipment (2-12) |
| E13: In-Channel Construction Practices | | ▪ Controlling in-Channel Excavation (2-14)<br>▪ Diversion of Flows Around Construction Sites (2-15)<br>▪ Bridge and Culvert Installation (2-17) |
| E14: Temporary Roads | | ▪ Stream Crossings on Temporary Roads (2-16)<br>▪ Obliteration or Decommissioning of Roads (2-26) |
| E15: Rip Rap Composition | | ▪ Specifying Rip Rap Composition (2-20) |
| E16: Water Source Development | | ▪ Water Source Development Consistent with Water Quality Protection (2-21) |
| E17: Snow Removal | | ▪ Snow Removal Controls to Avoid Resource Damage (2-25) |
| E18: Pioneer Road Construction | | ▪ Timing of Construction Activities (2-3)<br>▪ Constraints Related to Pioneer Road Construction (2-8)<br>▪ Timely Erosion Control Measures on Incomplete Road and Stream Crossing Projects (2-9)<br>▪ Disposal of Right-of-way and Roadside Debris (2-19) |
| E19: Restoration of Borrow Pits & Quarries | | ▪ Regulation of Streamside Gravel Borrow Areas (2-18)<br>▪ Obliteration or Decommissioning of Roads (2-26)<br>▪ Restoration of Borrow Pits and Quarries (2-27) |
| E20: Protection of Roads During Wet Periods | | ▪ Traffic Control During Wet Periods (2-24)<br>▪ Management by Closure to Use (7-7) |
| R22: Developed Recreation sites | | ▪ Control of Sanitation Facilities (4-4)<br>▪ Control of Solid Waste Disposal (4-5)<br>▪ Assuring that Organizational Camps Have Proper Sanitation and Water Supply Facilities (4-6)<br>▪ Protection of Water Quality Within Developed and Dispersed Recreation Areas (4-9)<br>▪ Location of Pack and Riding Stock Facilities and Use in Wilderness, Primitive, and Wilderness Study Areas (4-10) |
| R23: Location of Stock Facilities in Wilderness | | ▪ Location of Pack and Riding Stock Facilities and Use in Wilderness, Primitive, and Wilderness Study Areas (4-10) |
| G24: Range Management | | ▪ Range Analysis and Planning (8-1), Grazing |

| | | |
|---|---|---|
| | | Permit System (8-2), Rangeland Improvements (8-3) |
| F25: Prescribed Fire | | ▪ Consideration of Water Quality in Formulating Fire Prescriptions (6-2)<br>▪ Protection of Water Quality from Prescribed Burning Effects (6-3) |
| M26: Mining Operations (Locatable Minerals) | | ▪ Water Resources Protection on Locatable Mineral Operations (3-1)<br>▪ Administering Terms of BLM-Issued Permits or Leases for Mineral Exploration and Extraction on NFS Lands (3-2) |
| M27: Common Variety Minerals | | ▪ Administering Common Variety Mineral Removal Permits (3-3)<br>▪ Regulation of Streamside Gravel Borrow Areas (2-18) |
| V28: Vegetation Manipulation | | ▪ Soil Disturbing Treatments on the Contour (5-1)<br>▪ Slope Limitations Mechanical Equipment Operation (5-2)<br>▪ Disposal of Organic Debris (5-5)<br>▪ Soil Moisture Limitations for Tractor Operations (5-6) |
| V29: Revegetation of Surface Disturbed Areas | | ▪ Revegetation of Surface Disturbed Areas (5-4) |
| R30: Dispersed Recreation | | ▪ Control of Sanitation Facilities (4-4)<br>▪ Control of Solid Waste Disposal (4-5)<br>▪ Assuring that Organizational Camps Have Proper Sanitation and Water Supply Facilities (4-6)<br>▪ Protection of Water Quality Within Developed and Dispersed Recreation Areas (4-9)<br>▪ Location of Pack and Riding Stock Facilities and Use in Wilderness, Primitive, and Wilderness Study Areas (4-10) |

## APPENDIX B: BMPEP SCORING PROCEDURES, PROBLEMS, AND PLANNED IMPROVEMENTS

BMPEP evaluations are conducted in the field using forms specific to each protocol. Each form consists of questions for implementation and effectiveness. Questions are answered with numbers ("raw" scores) that indicate the degree to which implementation or effectiveness was achieved. Low numbers indicate successful implementation and effectiveness, while high numbers indicate poor performance. Implementation questions are usually answered with numbers ranging from 1 to 4, with a score of 2 signifying acceptable implementation. Similarly, effectiveness questions are usually answered with numbers ranging from 1 to 3, with a score of 2 indicating acceptable effectiveness (some questions are yes/no answers, see discussion below). For both implementation and effectiveness responses, scores higher than 2 indicate standards were not met, and scores of 1 indicate that standards were exceeded (meaning that BMP performance was better than expected).

After the questions are answered on the form, the answers are entered into the Regional BMPEP data base and a weighted score is assigned to each response. Weighted scores were developed by a regional team of experienced hydrologists and fisheries biologists based on the potential for effects on water quality related to each question and response. The weighted scores were designed to result in an overall evaluation score of roughly 100 for a worst-case outcome.

The evaluations are automatically scored in the BMPEP data base using the sums of the weighted scores for all responses. The determinations of implementation and effectiveness depend on comparing the sums of the weighted implementation or effectiveness scores to pre-set inference points (IPs). High scores indicate poor performance, so a sum of weighted scores that is at or above the IP is rated as "not implemented" or "ineffective." A sum below the IP is rated as "implemented" or "effective."

A weighted-score sum equivalent to a "raw" score of 2 on all questions is minimally acceptable performance, so the IPs should be roughly equal to a sum of weighted scores corresponding to "raw" scores of 2, plus 1. Poor performance on one question (score of 4), however, can be offset by superior performance on another question (score of 1), so an evaluation that included a major BMP departure could still be rated as implemented and effective. Also, because the evaluations are scored based on weighted scores, some responses affect the overall score more than others. In practice, most IPs have been set to values corresponding to the sums of the minimally successful weighted scores plus roughly 10 points, to allow for minor departures without "failing" the entire evaluation. However, documentation of the IP determination process is incomplete, and identifying the correct IP for some protocols is problematic.

Over the 17 years during which the BMPEP data base has been in use, several problems with this scoring procedure have arisen owing to changes in the BMPEP field forms and questions. Questions and weighted scores were changed or added in the data base, but the IPs were not updated to correspond to the newer scores. As a result, 2 BMPEP protocols (E15, E20) could potentially have been scored as implemented or effective when their actual performance was substandard, and 3 BMPEP protocols (T03, E13, R22) could have been scored as not implemented or ineffective when their performance was adequate or better. The number of incorrectly scored evaluations, if any, is not known, and can be determined only by an examination of the individual evaluation forms. In addition, 3 BMPEP protocols have multiple questions in the data base that correspond to a single question on the field form, and the correct IPs cannot be determined (E10, E18, and M26).

To address these problems, a new scoring procedure was developed in 2004 by a regional BMPEP task group that included Stanislaus National Forest hydrologist Jim Frazier, Lassen National Forest Fisheries Biologist Ken Roby, and Regional Hydrologist Brian Staab. The revised procedure has since been known as the "Frazier protocol" (attached below). This protocol does not use IPs, but instead rates BMPs as successful or not based on whether individual responses indicate departures. This system is much easier to use and understand, but it was never incorporated into the BMPEP due to lack of funding. Regional funds adequate to support the change in scoring procedure were made available in 2008, and an Enterprise Team has been contracted to make the scoring procedure change.

An initial comparison of the existing pass-fail IP-based scoring system and the Frazier 3-level protocol was made using data from 2,832 evaluations made between 2003 and 2007 and retrieved in September, 2008. The Frazier protocol rated fewer evaluations as implemented and effective (Table B-1), but also fewer as not implemented and not effective (Table B-2), because the new protocol has a third possible score of "at risk" that does not count toward either implementation/effectiveness or lack of implementation/effectiveness. The existing scoring system rated 86% of the evaluations as implemented and 86% as effective. The Frazier protocol rated 81% of the evaluations as implemented and 71% as effective. The existing scoring system rated 14% of the evaluations as not implemented and 13% as not effective. The Frazier protocol rated 5% of the evaluations as not implemented and 10% as not effective. For the BMPEP protocols that had questionable scores using the IP-based system (T03, E10, E13, E15, E18, R22, M26; noted in ***bold italics*** in Tables B-1 and B-2 below), the Frazier protocol scores are considered a more reliable indicator of implementation and effectiveness.

**Table B-1: BMPEP implementation and effectiveness success for 2003 to 2007 scored under the existing IP-based system and the proposed Frazier protocol**

**[imp; implemented; eff, effective; results in *bold italics* indicate BMPEP protocols with scoring problems using the IP system]**

| **Protocol** | **Number of evaluations** | **IP scoring, % imp** | **IP scoring, % eff** | **Frazier scoring, % imp** | **Frazier scoring, % eff** |
|---|---|---|---|---|---|
| T01 | 201 | 91 | 89 | 92 | 89 |
| T02 | 223 | 86 | 97 | 91 | 89 |
| ***T03*** | ***45*** | ***89*** | ***40*** | ***89*** | ***87*** |
| T04 | 277 | 94 | 98 | 93 | 90 |
| T05 | 42 | 93 | 100 | 90 | 79 |
| T06 | 24 | 100 | 100 | 96 | 92 |
| T07 | 33 | 91 | 91 | 70 | 64 |
| E08 | 309 | 82 | 83 | 75 | 53 |
| E09 | 252 | 89 | 80 | 76 | 50 |
| ***E10*** | ***184*** | ***73*** | ***93*** | ***85*** | ***67*** |
| E11 | 173 | 91 | 94 | 51 | 50 |
| E12 | 25 | 100 | 96 | 88 | 80 |
| ***E13*** | ***82*** | ***82*** | ***77*** | ***82*** | ***82*** |
| E14 | 35 | 86 | 83 | 77 | 69 |
| ***E15*** | ***35*** | ***86*** | ***83*** | ***77*** | ***69*** |
| E16 | 51 | 73 | 63 | 73 | 86 |
| E17 | 45 | 84 | 89 | 76 | 76 |
| ***E18*** | ***1*** | ***100*** | ***100*** | ***0*** | ***0*** |
| E19 | 6 | 100 | 83 | 67 | 83 |
| ***E20*** | ***37*** | ***97*** | ***81*** | ***78*** | ***51*** |
| ***R22*** | ***114*** | ***73*** | ***57*** | ***84*** | ***82*** |
| R23 | 34 | 65 | 68 | 56 | 32 |
| G24 | 98 | 94 | 81 | 83 | 41 |
| F25 | 190 | 87 | 98 | 81 | 83 |
| ***M26*** | ***41*** | ***0*** | ***59*** | ***73*** | ***54*** |
| M27 | 27 | 100 | 48 | 74 | 85 |
| V28 | 67 | 99 | 99 | 96 | 90 |
| V29 | 61 | 97 | 93 | 82 | 74 |
| R30 | 120 | 87 | 85 | 74 | 77 |
| **Average** | **--** | **86** | **86** | **81** | **71** |

**Table B-2: BMPEP implementation and effectiveness failures for 2003 to 2007 scored under the existing IP-based system and the proposed Frazier protocol**

**[imp; implemented; eff, effective; results in *bold italics* indicate BMPEP protocols with scoring problems using the IP system]**

| **Protocol** | **Number of evaluations** | **IP scoring, % not imp** | **IP scoring, % not eff** | **Frazier scoring, % not imp** | **Frazier scoring, % not eff** |
|---|---|---|---|---|---|
| T01 | 201 | 4 | 6 | 4 | 3 |
| T02 | 223 | 14 | 3 | 3 | 5 |
| ***T03*** | ***45*** | ***11*** | ***60*** | ***2*** | ***4*** |
| T04 | 277 | 6 | 2 | 3 | 4 |
| T05 | 42 | 7 | 0 | 0 | 2 |
| T06 | 24 | 0 | 0 | 0 | 0 |
| T07 | 33 | 9 | 9 | 6 | 3 |
| E08 | 309 | 18 | 17 | 6 | 14 |
| E09 | 252 | 11 | 20 | 5 | 24 |
| ***E10*** | ***184*** | ***27*** | ***7*** | ***4*** | ***7*** |
| E11 | 173 | 9 | 6 | 8 | 3 |
| E12 | 25 | 0 | 4 | 0 | 4 |
| ***E13*** | ***82*** | ***18*** | ***23*** | ***4*** | ***1*** |
| E14 | 35 | 14 | 17 | 6 | 17 |
| ***E15*** | ***35*** | ***14*** | ***17*** | ***6*** | ***17*** |
| E16 | 51 | 27 | 37 | 16 | 12 |
| E17 | 45 | 16 | 11 | 2 | 4 |
| ***E18*** | ***1*** | ***0*** | ***0*** | ***0*** | ***0*** |
| E19 | 6 | 0 | 17 | 0 | 0 |
| ***E20*** | ***37*** | ***3*** | ***19*** | ***3*** | ***24*** |
| ***R22*** | ***114*** | ***28*** | ***44*** | ***5*** | ***9*** |
| R23 | 34 | 35 | 32 | 15 | 59 |
| G24 | 98 | 6 | 19 | 0 | 28 |
| F25 | 190 | 13 | 2 | 4 | 5 |
| M26 | ***41*** | ***100*** | ***41*** | ***7*** | ***17*** |
| M27 | 27 | 0 | 52 | 4 | 0 |
| V28 | 67 | 1 | 1 | 1 | 3 |
| V29 | 61 | 3 | 7 | 2 | 7 |
| R30 | 120 | 13 | 15 | 8 | 20 |
| **Average** | **--** | **14** | **13** | **5** | **10** |

# *R5 BMPEP Scoring Rule Set*

***By Jim Frazier***

***April 13, 2004***

## *Implementation*

**Pass**

- All rating items are 1 or 2, and/or < ½ of rating items are 3, and none is 4 (example: if there are 5 rating items: 2 are 3's and the rest are 1 or 2)

*At Risk*

- ***½ of rating items are 3, and none is 4 (example: if there are 5 rating items: 3 are 3's and the rest are 1 or 2)***

*Fail*

- ***All rating items are 3's, or any rating item is a 4***

## *Effectiveness*

*Pass*

- All rating items are in column 1, or combination of column 1 and 2 with <1/2 of the rating items in column 2

*At Risk*

- >= ½ of the rating items are in column 2 with no more than 1 rating item in column 3 (example: if there are 6 rating items, at least 4 are in column 2 and not more than 1 in column 3)

*Fail*

- 2 or more rating items are in column 3, or any rating in column 3 is a "sediment to channel" rating item

Note: Columns 1-3 as described above go from left to right on the evaluation form

**APPENDIX C: DRAFT version 1.6 , USDA Forest Service Pacific Southwest Region Water Quality Monitoring Plan, September 29, 2008**

A comprehensive and regionally consistent water-quality monitoring program is needed to guide water-quality protection programs on national forests in the Pacific Southwest Region. This draft plan proposes a program that is intended to meet the needs of the Region as well as the State Water Resources Control Board and the Regional Water Quality Control Boards for water-quality information. When finalized, this plan will serve as the monitoring component of the Regional Water Quality Management Plan. This version of the draft plan incorporates suggestions from the staffs of the State and North Coast Regional Boards.

**Criteria**

The program must include the following:

1. A scientifically valid approach to data collection and analysis.
2. Early detection of water-quality problems associated with current management activities.
3. Follow-up monitoring to ensure correction of known deficiencies and to evaluate long-term effectiveness of water-quality protection measures.
4. Conjunctive hillslope and in-channel monitoring ("nested" monitoring) to evaluate linkages between BMP effectiveness and effects on beneficial uses.
5. Evaluation of trends in beneficial uses in receiving waters downstream of forest management activities, including waters listed as impaired under section 303(d).
6. Assessments of water quality in relatively pristine reference streams for comparison with listed and potentially listed impaired waters.
7. Targeted monitoring of high-risk projects.
8. Flexibility in program scope to ensure that the program can be accomplished with available Forest Service resources.

**Program Management**

1. The monitoring program will be a regional program coordinated by the Regional Office and conducted by the national forest staffs.
2. Monitoring targets will be made based on regional priorities, rather than being evenly distributed among forests.
3. Annual targets for all monitoring activities will be set by the Regional Office and communicated to the State and Regional Boards. Targets will be changed as necessary to reflect changes in funding and staffing.
4. Funding to support monitoring will be allocated based on assigned targets.
5. Watershed staff will be used to conduct monitoring to the extent possible, but monitoring may also be conducted by other trained USFS personnel.

**Proposed Plan**

This plan will rely on existing well-documented monitoring methods. Hillslope monitoring for management activities will use Best Management Practice Evaluation Program (BMPEP, U.S. Forest Service, Pacific Southwest Region, 2001) protocols. In-channel monitoring will follow Stream Condition Inventory (SCI, U.S. Forest Service, Pacific Southwest Region, 2002) protocols.

**A. Hillslope monitoring of current management activities and corrective actions**

1. All projects will have administrative implementation monitoring using a "checklist" approach. This monitoring will be conducted by USFS project staff (timber, range, recreation, etc.) and will be coordinated and reviewed by the Forest Hydrologists. Administrative implementation monitoring will be the primary systematic means for early detection of potential water-quality problems, and will be completed early enough to allow corrective actions to be taken, if needed, prior to the onset of the first winter after project implementation.
2. The BMPEP, with random site selection, will continue to be the primary means of assessing the effectiveness of water-quality protection for current projects on NFS lands at the hillslope scale.
3. Effectiveness monitoring for BMPEP protocols that have consistently scored 95% or higher for 5 consecutive years at the Regional level will be reduced to allow efforts to focus on implementation, retrospective, and beneficial-use monitoring.
4. Corrective actions will be taken in response to recommendations made the previous year to address water-quality protection, and these actions will be documented in annual BMPEP reports.
5. Follow-up monitoring for sites that were not rated as fully implemented or effective the previous year will be conducted, and results will be presented in annual BMPEP reports.
6. All projects in "high risk" watersheds that are at or above thresholds of concern for cumulative watershed effects, as determined by the Equivalent Roaded Area model, or in watersheds with 303(d) listed impaired waters, will have non-random BMPEP effectiveness monitoring.
7. National forests will conduct road patrols to the extent allowed by weather, safety, and road conditions during and after major storms to detect and correct road drainage problems that could affect water quality.

**B. Retrospective hillslope monitoring of past management activities**

1. Sample pools will be developed for timber, engineering, and grazing projects completed in the past 5 years that were rated as effective as part of the random BMPEP monitoring.
2. Projects will be selected randomly for retrospective BMPEP effectiveness evaluations.
3. Results of retrospective monitoring will be compared to original BMPEP effectiveness scores to determine if BMPs remained effective over a period of years.

## C. Representative in-channel beneficial-use monitoring

The purpose of in-channel monitoring of beneficial uses is to determine whether BMPs collectively are effective in protecting water quality at the watershed scale. Effectiveness will be assessed by monitoring trends in channel characteristics that affect beneficial uses and by comparing channel characteristics of streams downstream of intensively managed areas with those in pristine watersheds (the paired watershed approach).

Because USFS resources are limited, monitoring will be restricted to a relatively small number of sites. Therefore, monitoring sites will need to be carefully selected to represent large landscapes within the national forest system. Detecting downstream channel changes related to upstream activities is problematic (MacDonald and Coe, 2006), so monitoring sites will be located on headwaters streams. Paired monitoring sites (intensively managed and pristine) will be selected to have similar valley segment and stream reach characteristics (Bisson and others, 2006).

1. Fixed long-term locations for SCI surveys will be selected by the forest hydrologists and Regional Office in cooperation with the State and Regional Board staffs to represent areas of similar landform, geology, climate, and vegetation.
2. SCI sites will be selected to minimize variability in channel type.
3. SCI sites will be stratified based on watershed condition class (I, II, III), with approximately one-third of the selected watersheds in each condition class.
4. SCI surveys will be made near the mouth of each selected watershed at least once every 5 years and as soon as possible following major (RI>10 year) floods. Roughly 20% of the watersheds will be surveyed each year, on average.
5. If SCI results indicate adverse impacts to channels from management activities in watersheds in condition class II or III, restoration plans will be developed and implemented. Adverse impacts will be inferred by comparison with SCI results for watersheds in condition class I.
6. Non-random "nested" BMPEP evaluations for all current management activities will be conducted within the selected watersheds. Implementation and effectiveness results will be compared to SCI results.
7. For watersheds 303(d) listed for water temperature, SCI water-temperature monitoring will be conducted for at least one full snow-free season. In addition, effective shade will be monitored using Solar Pathfinders.
8. Sites will be removed from or added to the sample pool as needed by the Regional Office in consultation with the State and Regional Boards.

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# STORM-PROOFING FOREST ROADS

by

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**ABSTRACT:** Erosion and mass wasting associated with forest roads systems is a common and important accelerated sediment source in many mountainous watersheds. Road-related sediment production includes storm-triggered episodic fluvial erosion and landsliding, as well as the chronic production and delivery of fine sediment from the road alignment. Sediment produced and delivered by both mechanisms has been identified as detrimental and, in some cases, limiting to salmonid production and recovery throughout the Pacific Northwest.

Storm-proofing and winterizing are two pro-active methods for minimizing erosion rates and sediment delivery from forest road systems. Both storm-proofing and winterizing require the identification and quantification of on-going correctable erosion as well as potential erosion problems that have not yet developed. Winterizing is a road maintenance activity, whereas storm-proofing involves either upgrading (and maintaining) roads to current design standards, or temporarily or permanently decommissioning them to prevent future erosion and sediment delivery to streams.

Storm-proofing is a five step program beginning with a quantitative inventory of future sediment sources and ending with the implementation of either road upgrading or decommissioning tasks. Roads and sites within roads can be prioritized for storm-proofing implementation using a quantitative methodology for prediction of treatment cost-effectiveness. Data from three relatively high sediment yield watersheds in northern California are used to provide an example of storm-proofing inventory information, prescription development and implementation costs and priorities. Guidelines for storm-proofed roads are outlined.

KEY WORDS--Roads, erosion control, sediment sources, storm-proofing, winterize, landslide, gully, stream crossings, decommission, upgrade

## INTRODUCTION

Roads and road-related activities need not threaten the natural biological productivity and water quality of streams in a watershed if they are properly located, designed, constructed and maintained. However, poor road building and maintenance practices can cause excess runoff, damaging erosion, and lead to sedimentation in downstream areas which can pollute water supplies, increase flooding potential, accelerate stream bank erosion and trigger landsliding. Salmon and trout eggs laid in stream gravels can become buried and suffocate, pools and other fish habitat can be lost, and other aquatic life may be threatened or killed. Poor road construction and maintenance practices can also damage riparian vegetation and result in increased summer water temperatures and loss of food and cover for fish and other wildlife.

## ROAD EROSION AND ITS CONTROL

Roads are a major source of erosion and sedimentation on many managed forest and ranch lands in the Pacific Northwest. Compacted road surfaces increase the rate of runoff, and road cuts intercept and bring groundwater to the surface. Ditches concentrate storm runoff and can transport sediment to nearby stream channels. Culverted stream crossings can plug, causing fill washouts or gullies where the diverted streamflow runs down nearby roads and hillslopes.

Roads built on steep or unstable slopes may trigger landsliding which deposits sediment in stream channels. Filling and sidecasting redistributes slope mass, road cuts remove slope support, and construction can alter soil pore water pressures, all of which may trigger landsliding. Unstable road or landing sidecast materials can fail, often many years after they were put on steep hillslopes. Excessive winter and summer traffic can generate fine sediment that is delivered to local streams. Lack of inspection and maintenance of drainage structures and unstable road fills along old, abandoned roads can also result in accelerated fluvial erosion, mass wasting, and sediment delivery to stream channels.

### Correctable and Preventable Accelerated Erosion

Road-related erosion can be classified as occurring in two general forms: 1) episodic mass wasting and fluvial erosion, triggered by intense winter or summer rainfall events, and 2) chronic or persistent fine sediment contributions, generated by surface erosion processes along the road prism. Episodic fluvial erosion and mass soil movement (landsliding) are the two types of geomorphic processes which can most efficiently deliver large quantities of sediment to stream channels.

Fluvial erosion includes rills and gullies caused by stream flow and concentrated runoff, as well as bank erosion in the vicinity of stream crossings. One of the most damaging sources of fluvial erosion is from streams which are diverted out of their natural channels when stream crossing culverts on roads become plugged or their capacity is exceeded (Hagans and Weaver, 1987). For example, stream diversions at logging road stream crossings have been found to be the overwhelming, leading cause of sediment production from abandoned, unmaintained roads in the 280 $mi^2$ Redwood Creek watershed of northern California

(Weaver et al. 1995, Hagans et al. 1986). Diverted waters can create large, complex gully systems or trigger off-site landslides which are responsible for greatly increased rates of watershed sediment production and yield, and enlarged (gullied) natural stream channels. These hillslope processes, in turn, lead to further off-site impacts including aggradation and stream channel widening. Most episodic road-related erosion occurs during relatively short-lived, large magnitude storms that trigger widespread watershed erosion and sedimentation. These conditions are easily identified in the field and corrected through relatively inexpensive reshaping of the road prism and stream crossing.

Recent detailed inventories of over 800 $mi^2$ of forest land and 1,500 miles of logging road have also revealed preventable landsliding to be a significant future source of accelerated sediment production and yield to fish-bearing streams in many managed watersheds. Road-related landslides may contribute from 10% to over 80% of the basin-wide road-related sediment production and yield. The relative importance of landslides as a sediment source depends on a variety of factors, including geology, natural slope stability, road location and road construction methods.

Road-related landslides typically occur on steep, unstable terrain, such as inner gorge slopes where roads cross stream and river canyons. Landslides which might otherwise occur as a result of road-related activities (construction, maintenance, reconstruction, etc.) can often be prevented by both planning (avoidance of steep or unstable terrain) and mitigation (the use of special construction techniques (e.g., full bench roads, no sidecasting, spoil endhauling) or the excavation of unstable materials). Many road-related landslides, especially potential fill failures, can be identified and prevented before they occur through straight forward excavation.

Unlike many road-related landslides, potential landslides within harvest units cannot be effectively prevented by the application of post-harvest mitigation measures. Such “in-unit” landslides, which might be triggered by harvesting or yarding activities, are best prevented through pre-harvest identification and mitigation or avoidance. This is a planning procedure that is prescribed and implemented during the timber harvest review process (PWA 1998 and PWA 1999).

Sediment Source Investigations

Sediment source inventories can be employed to determine the relative magnitude or importance of each road-related erosional process in a watershed. For example, the distribution of past road-related sediment sources along 206 miles of forest roads, over the last 50 years, in three inventoried watersheds in northern California is depicted in Table 1. In these watersheds, over 60% of past sediment delivery originated from gullies caused by stream diversions (26%) and road and landing fill failures (37%). The remaining 37% of sediment delivery was attributed to stream crossing washouts, stream bank erosion immediately above and below crossings sites, and cutbank failures. The relative importance of each road-related sediment source can vary dramatically between watersheds, depending on both natural and management-related factors.

Sediment source inventories such as these describe the occurrence and importance of

Table 1. Past road-related sediment delivery, by sediment source, along 206 miles of forest road in three northern California watersheds.

| Watershed | Water-shed area ($mi^2$) | Road length (mi) | Road density ($mi/mi^2$) | Number of sites (#) (past erosion) | Stream crossing Washout[1] ($yds^3$) | Gullies[2] (fillslope/ hillslope/ road) ($yds^3$) | Streambank and channel erosion ($yds^3$) | Road fill failure ($yds^3$) | Road cutbank failure ($yds^3$) | Total yield[3] ($yds^3$) | Unit yield ($yds^3/mi$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Jordan Creek** | 4.8 | 34 | 7.1 | 237 | 9,690 | 26,190 | 13,970 | 28,360 | 15,930 | 94,140 | **2,769** |
| **Bear Creek** | 8.0 | 39 | 4.9 | 186 | 11,525 | 31,170 | 2,210 | 51,530 | 35,170 | 131,605 | **3,375** |
| **Elk River** | 22.4 | 133 | 5.9 | 602 | 14,950 | 24,410 | 10,190 | 37,250 | 1,290 | 88,090 | **662** |
| **Totals** | 35.2 | 206 | 5.9 | 1,025 | 36,165 (12%) | 81,770 (26%) | 26,370 (8%) | 117,140 (37%) | 52,390 (17%) | 313,835 (100%) | |
| **Unit sediment yield ($yds^3/mi$)** | | | | | 176 | 397 | 128 | 569 | 254 | 1,523 | |

[1] Significantly underestimated due to frequent road repair and stream crossing reconstruction through time (volume could be 10% to 50% greater).
[2] Most gully erosion is caused by stream diversions at stream crossings.
[3] Does not include road-related hillslope failures which are "associated" with the road, but which may not be "caused" by the road's presence. Also does not include surface erosion.

past erosion in watersheds. Such inventories are useful and relatively straight forward, as gullies and landslides can be identified and directly measured in the field. However, to prevent or reduce future accelerated sediment production and delivery from forest road systems, it is necessary to identify and measure (predict) expected fluvial erosion and mass wasting before it occurs (Table 2). Results of "forward looking" forest road inventories throughout northern California and southern Oregon suggest a typical range of 100 to 800 cubic yards of potential (future) sediment delivery from all sources of road-related fluvial erosion and landsliding, on average, for every mile of road (Table 3). Steep and unstable watersheds may exhibit future yields approaching 2,500 $yds^3/mi$. Even in watersheds which have experienced substantial past road-related erosion, estimated future sediment loss from the road system can still be substantial.

In high yield watersheds, where mass wasting and fluvial erosion is significant, chronic fine sediment production and delivery may represent less than 10% of road-related erosion. In highly stable watersheds, fine sediment from roads and ditches can account for 50%, or more, of the accelerated road-related erosion over many years. Although volumetrically not as large a source of sediment as episodic fluvial

Table 2. Sites of future road-related sediment delivery along 206 miles of forest road in three northern coastal California watersheds.

| Watershed | Jordan Creek | | Bear Creek | | Elk River | | Total | |
|---|---|---|---|---|---|---|---|---|
| **Area (mi²)** | 4.8 | | 8.0 | | 22.4 | | 35.2 | |
| **Road length (mi)** | 34 | | 39 | | 133 | | 206 | |
| | | | | | | | Total yield[2] | |
| **Road-related sediment source[1]** | Sites (#) | Future yield[2] (yds³/mi) | Sites (#) | Future yield[2] (yds³/mi) | Sites (#) | Future yield[2] (yds³/mi) | (yds³/ mi) | (% of total) |
| **Stream crossings[3]** | 54 | 622 | 82 | 627 | 308 | 1,366 | 1,103 | 64% |
| **Mass wasting (road fills)** | 62 | 1,413 | 55 | 774 | 139 | 329 | 592 | 34% |
| **Ditch relief culverts (gullies)** | 19 | 16 | 15 | 9 | 52 | 15 | 14 | 1% |
| **Other** | 10 | 34 | 4 | 11 | 42 | 9 | 13 | 1% |
| **Total** | 145 | **2,085** | 156 | **1,421** | 541 | **1,719** | **1,723** | **100%** |
| **Chronic road surface erosion[4] (mi; % network)** | 2.1 (6 %) | | 5.5 (14 %) | | 18.7 (14 %) | | 26.3 (13%) | |

[1] Includes only sites that have been recommended for road-related erosion prevention work (storm-proofing).
[2] Future sediment yield from sites if they are left untreated.
[3] At stream crossings with a diversion potential, future gully erosion is difficult to predict. A minimum estimate of the stream crossing volume was used as a predicted value for this table. This value is probably low, perhaps by an order of magnitude.
[4] Miles of road ditch (% of road network) which currently drain directly into stream crossing culverts.

erosion or mass wasting, processes which are responsible for the chronic delivery of potentially damaging fine and suspended sediment from roads and bare soil areas can also be easily identified and cost-effectively treated.

## Storm-Proofing and Winterizing Forest Road Systems

Storm-proofing and winterizing are two pro-active methods for minimizing erosion rates and sediment delivery from forest road systems. Each process involves specific inventory and inspection procedures and schedules, methods for problem identification and developing treatment prescriptions and implementation procedures (PWA 1990). Storm-proofing is the act of performing erosion control and erosion prevention activities which will protect a road, including its drainage structures and fills, from serious episodic erosion during a large storm and flood and from chronic erosion during intervening periods. It is a procedure that minimizes future maintenance and reconstruction costs while at the same time preventing erosion during the stressing hydrologic events (storms and floods). Winterizing forest roads is one element of an effective road maintenance program that is applied to temporary, seasonal and all-weather roads. It is an annual activity that involves erosion

Table 3. Summary road erosion inventory and sediment yield data for selected, inventoried watersheds in Oregon and northern California.

| Watershed | | Watershed area ($mi^2$) | Road length (mi) | Road density ($mi/mi^2$) | Future yield ($yds^3$) | Unit yield ($yds^3/mi$) |
|---|---|---|---|---|---|---|
| Shaw Creek | Eel River, CA | 4 | 18 | 4.5 | 9,200 | 511 |
| Jordan Creek | Eel River, CA | 5 | 34 | 7.1 | 70,890 | 2,085 |
| Bear Creek | Eel River, CA | 8 | 39 | 4.9 | 55,419 | 1,421 |
| McGarvey Creek | Klamath River, CA | 9 | 68 | 7.8 | 164,800 | 2,441 |
| Pine Creek | Klamath River, CA | 21 | 104 | 5.0 | 45,400 | 437 |
| Elk River | Humboldt Bay, CA | 22 | 133 | 5.9 | 228,627 | 1,719 |
| Tish Tang Creek | Trinity River, CA | 31 | 74 | 2.4 | 17,100 | 231 |
| Dumont Creek | S. Umpqua River, OR | 31 | 114 | 3.6 | 12,020 | 106 |
| Mill Creek | Trinity River, CA | 50 | 177 | 3.5 | 137,200 | 775 |
| New River | Trinity River, CA | 277 | 175 | 2.0 | 32,400 | 185 |
| **Totals** | | **460** | **936** | **2.0** | **773,056** | **826** |

prevention and erosion control work on a road in preparation for winter rains and normal winter stream flow.

## STORM-PROOFING FOREST ROADS

In most upland forest watershed assessments, logging roads are initially singled out in a “forward-looking” sediment source analysis both because the road network provides ready access for heavy equipment to treat potential work sites, and because roads have been identified throughout the region as serious, treatable sediment sources themselves (Swanson and Dyrness 1975, Reid 1981, Weaver et al.1981, Frissell and Liss 1986, Farrington and Savina 1977, LaHusen 1984, Hagans et al. 1986, and Pacific Watershed Associates (PWA) 1994a,b). Stream crossings, log landings, oversteepened sidecast and road fills built in "suspect" geomorphic locations are prime areas where cost-effective erosion prevention projects can keep large quantities of sediment from entering streams and being transported to important spawning and rearing areas (Weaver et al. 1987b, Harr and Nichols 1993).

Storm-proofed forest roads fall into one of two categories: 1) upgraded and maintained, or 2) decommissioned. Good land stewardship requires that all roads designated as part of an active, driveable road network be regularly inspected, winterized and maintained to protect water quality, regardless of how frequently they are used. When the need for a road diminishes, it is rarely sufficient to close the road by simply abandoning it or by putting up barricades or a gate. Post management erosion can only be minimized if the road is proactively closed by “hydrologic decommissioning”.

A variety of factors, including future mainten-ance costs, predicted erosion, and anticipated level or frequency of use, will dictate whether or not a road should be storm-proofed by upgrading to current standards, or by decommissioning (either permanently or temporarily). Decommis-sioning is done by fully excavating stream crossings, by excavating potentially unstable fill material that might fail and deliver sediment to local stream channels during winter storms, and by providing permanent improvements to road surface drainage that make the former road "hydrologically invisible".

Steps to road storm-proofing

Developing an erosion prevention plan and storm-proofing a forest road system involves several discrete steps. These include:

1. problem identification (through inventory and assessment),
2. problem quantification (determination of future yield in the absence of treatment),
3. prescription development (both heavy equipment and labor-intensive),
4. cost-effectiveness evaluation and prioritization of treatment sites, and
5. implementation.

It is necessary to follow an organized, systematic series of steps in assessing road systems for future erosion and sediment delivery. Only then can you ensure that erosion control and erosion prevention work will treat those sources of future erosion and sediment yield that could be effectively controlled for the lowest expenditure. Although a common practice, it is generally not cost-effective to take a shot-gun approach, where problem areas are randomly identified and treated without regard to their importance in overall watershed health or to our ability to cost-effectively control or prevent stream sedimentation.

**Phase 1 -** Road-related problems in a watershed are typically identified through analysis of historic aerial photographs and field inventories. As the first step, an ***air photo analysis*** of the watershed is conducted to identify all the roads that were ever constructed in the watershed, whether they are currently maintained and driveable, or are now abandoned and overgrown with vegetation. When possible, historic photographic coverage from a number of years (perhaps one or two flights per decade) are selected to "bracket" major storms in the watershed. This analysis leads to the construction of detailed land use and erosion history maps for the watershed, including road location, road construction history and landslide history.

A ***preliminary transportation plan*** is developed for the watershed at this time, outlining the best long term permanent and seasonal road network needed to manage natural resources. This phase is conducted using data from the air photo analysis and employing the knowledge of land owners and managers familiar with the existing road network and plans for future land management. During this phase, efforts are made to delineate which roads pose high risk of episodic or chronic sediment production and delivery, or high long term maintenance costs, which might make them candidates for temporary or permanent decommissioning.

**Phase 2 -** Phase two of the watershed sediment source assessment involves field inventories and site analyses to identify and quantify future erosion prevention sites. Detailed inventories of all maintained and abandoned road systems are used to identify and determine future contributions of sediment to the stream system, and potential treatment sites. This generally includes all stream crossings, all potentially unstable road and landing fills, all road segments which exhibit surface erosion and sediment delivery and all other sources of contributing erosion. The most critical areas and road systems identified during the air photo analysis are inventoried and evaluated in the greatest detail. For the detailed field assessment, acetate overlays are attached to 9" x 9" aerial photographs and used to record site location information as it is collected in the field. A computer database (data form) is then developed and more detailed information is collected for each site of potential sediment yield identified in the field (Weaver and Hagans 1996).

During the field inventory of existing and potential erosion sources, a more detailed analysis of each significant site is performed. This step includes an analysis of the most effective and cost-effective erosion prevention and/or erosion control work that could be applied to each of the sites recommended for treatment, including all sites classified as having a high, moderate or low priority for treatment (Table 4). Once sites are identified and quantified, prescriptions for erosion control and erosion prevention are developed for each major source of treatable erosion that, if left untreated, would likely result in sediment delivery to streams. Prescriptions identified during the field inventory include types of heavy equipment needed, equipment hours, labor intensive treatments required, estimated costs for each work site and expected sediment savings.

Sites are then prioritized for treatment based on a cost-effectiveness analysis that determines the cost of implementing the proposed erosion prevention treatment against the calculated benefit to the stream system (volumetric sediment savings)(Table 4). *The cost-effectiveness of treating a work site is defined as the average amount of money spent to prevent one cubic yard of sediment from entering or being delivered to the stream system* (Weaver and Sonnevil, 1984). Unit cost-effectiveness of all proposed treatments can be expressed as $/yd$^3$ (dollars spent per cubic yard of sediment "saved"). By using this methodology, a variety of different techniques and proposed projects can be compared against each other using the same criteria: reducing accelerated erosion and keeping eroded sediment out of the watershed's streams. In this way, a prioritized listing of proposed road storm-proofing and erosion prevention treatments can be developed for each road and for the watershed road network as a whole. The preliminary transportation plan is then revised and finalized following this field inventory phase and roads are subsequently targeted either for upgrading (and continued maintenance) or decommissioning (temporary or permanent closure).

To be considered for priority storm-proofing treatment, a site should typically exhibit: 1) potential for significant (>25 yds$^3$) sediment delivery to a stream channel (with the potential for transport to a fish-bearing stream), 2) a high or moderate treatment immediacy and 3) a predicted cost-effectiveness value averaging no more than about \$15/yd$^3$, and preferably closer to \$5-\$7/yd$^3$, or less (Table 5). Other criteria may be important in selecting watersheds or roads for treatment, including the occurrence of domestic water supplies, listed aquatic species or other valuable or sensitive downstream resources. Treatment cost-effectiveness analysis is often applied to a group of sites (rather than on a single site-by-site basis) so that only the most cost-effective groups of projects are undertaken

Table 4. Sites recommended for erosion prevention (storm-proofing) treatments in three northern coastal California watersheds.

| **Watershed** | **Jordan Creek** | | **Bear Creek** | | **Elk River** | | **Total** | |
|---|---|---|---|---|---|---|---|---|
| **Area (mi$^2$)** | 4.8 | | 8.0 | | 22.4 | | 35.2 | |
| **Road length (mi)** | 34 | | 39 | | 133 | | 206 | |
| **Treatment Immediacy[1] (priority)** | Sites (#) | Future yield[2] (yds$^3$) | Sites (#) | Future yield[2] (yds$^3$) | Sites (#) | Future yield[2] (yds$^3$) | Sites (% total) | Future road-related yield[2] (% total) |
| **High** | 9 | 15,920 | 19 | 8,630 | 41 | 31,150 | 8% | 14% |
| **High/moderate** | 165 | 20,430 | 40 | 11,140 | 100 | 48,830 | 36% | 20% |
| **Moderate** | 50 | 15,010 | 58 | 11,830 | 205 | 94,730 | 37% | 30% |
| **Moderate/low** | 33 | 17,680 | 23 | 21,530 | 125 | 39,140 | 21% | 20% |
| **Low** | 37 | 1,840 | 16 | 2,060 | 72 | 14,820 | 15% | 5% |
| **Sub-total** | 145 | **70,880** | 156 | **55,190** | 543 | **228,670** | **100%** | **89%** |
| **Chronic road surface erosion[4] (yds$^3$ delivered)** | | 3,595 | | 9,410 | | 32,000 | Total = 45,000 | 11% |
| **Total (yds$^3$)** | | **74,475** | | **64,600** | | **260,670** | **399,745** | **100%** |

[1] Treatment immediacy (priority) based on likelihood of erosion, expected delivery volume and predicted treatment cost-effectiveness. All inventoried sites were classified into one of the five categories.
[2] Future sediment yield if sites and road surfaces are left untreated.
[3] Fine sediment contribution from the road alignment assumes 20 ft width with a 15' cutbank; surface lowering of 0.1 ft per decade (for 50 years); and 50% delivery to streams. Total yield per decade averages 2.5% of future yield from inventoried sites, or 12.5% of total estimated site yield for 50 year period.

(Table 5). Cost-effectiveness analysis assures that the greatest benefit is received for the limited funding that is typically available for erosion prevention, watershed protection and restoration projects.

Types of Storm-Proofing Treatments

Effective storm-proofing of forest road systems must incorporate both erosion control and erosion prevention work. ***Erosion control*** practices for steep forested lands impacted by logging and road building have been thoroughly tested and evaluated and are applicable for most steepland areas (NPS 1992, Sonnevil and Weaver 1981, Weaver and Sonnevil 1984, Weaver et al. 1987a, Harr and Nichols 1993, PWA 1994c). Projects which provide for ***erosion prevention*** are generally the most cost-effective means of protecting fish habitat and entail the recognition and treatment of potential sediment sources before they become contributors to sediment yield.

Table 5. Storm-proofing treatment costs, sediment saved and erosion prevention cost-effectiveness, Mill Creek watershed, California.

| Treatment area (50 $mi^2$) | Number of inventoried sites | Number of sites recommended for treatment | Predicted treatment cost ($) | Volume of sediment "saved" ($yds^3$) | Treatment cost-effectiveness ($\$/yd^3$ saved) |
|---|---|---|---|---|---|
| 1 (Tribal) | 37 | 22 | $72,600 | 32,000 | 2.27 |
| 2 (Tribal) | 89 | 43 | $89,200 | 33,600 | 2.65 |
| 3 (Tribal) | 67 | 26 | $29,800 | 9,300 | 3.20 |
| 4 (Tribal) | 121 | 51 | $25,950 | 14,800 | 1.75 |
| 5 (Tribal) | 36 | 17 | $28,900 | 6,100 | 4.74 |
| 6 (Tribal) | 75 | 32 | $45,600 | 13,900 | 3.28 |
| 7 (Tribal) | 90 | 41 | $33,900 | 21,400 | 1.58 |
| 8 (USFS) | 241 | 46 | $15,200 | 6,100 | 2.49 |
| **Totals** | **756** | **278** | **$ 341,150** | **137,200** | **2.49** |

If a watershed sediment assessment is done well, the logical final step will be for skilled equipment operators, laborers and erosion control specialists to immediately implement those projects deemed most cost-effective and most beneficial to long term watershed health and the protection of fisheries resources.

Road storm-proofing includes both road upgrading techniques as well as road decommissioning practices. The criteria listed in Figure 1 can be used as a general guide to assist field personnel in determining whether or not a forest road meets the criteria which define road storm-proofing.

**Road upgrading -** In most managed watersheds, some roads are typically needed to provide for long term resource management, for administrative access, for fire control and for other purposes. Roads which are best suited for retention need to be identified in the transportation planning process for each sub-watershed. They are typically, but not exclusively, located on stable terrain, where the risk of fluvial erosion, stream crossing failure, storm damage and mass soil movement (landsliding) is lowest. Each retained road is then upgraded, as necessary, to make them largely self-maintaining or requiring low levels of maintenance.

A variety of "upgrading" techniques are available to make these stable, well located roads as "storm-proof" and resilient to large storms and flood flows as is possible. The goal of road upgrading is to strictly minimize the contributions of fine sediment from roads and ditches to stream channels, as well as to minimize the risk of episodic erosion and sediment yield when large magnitude, infrequent storms and floods occur. On retained roads, the most important road storm-proofing techniques include:

**The following general criteria identify common characteristics of "storm-proofed" roads. Minor exceptions to these "guidelines" can occur at specific sites within a forest road system.**

**Stream crossings**

- no unculverted fill or log crossings of stream channels (unless they are rocked fords)
- each stream has its own drainage structure (with minor exceptions)
- diverted streams are returned to their original (natural) channels (with local exceptions)
- stream crossing culverts and bridges are sized for 50-year flow (at minimum), including debris
- existing 15" or 18" stream crossing culverts can be retained if they show no signs of being undersized or prone to plugging
- stream crossings have no diversion potential (functional critical dips are in place at stream crossings - with local exceptions)
- low plugging potential or adequate trash barrier to protect culvert inlets from plugging
- culverts are placed at base of fill or steep enough to transport debris and discourage plugging
- downspout or energy dissipation installed if outlet is eroding or flow discharges on road fill
- culvert inlet, outlet and bottom are open and in sound condition
- fills with very deep headwalls (deeper than backhoe reach) should have emergency overflow culvert installed higher in fill if they exhibit high or moderate plugging potential or are undersized for the 50-year flow
- inboard and outboard fillslopes are stable
- bridges have stable, non-eroding abutments and do not significantly restrict 50-year flood flow
- road surfaces and ditches are "disconnected" from streams and stream crossing culverts (general 50' maximum ditch and road surface length feeding directly to streams - exceptions can occur where ditch drain would discharge on unstable road fill that cannot be removed or stabilized)
- decommissioned roads have all stream crossings completely excavated to original grade (local exceptions where complete, permanent armoring is used to prevent erosion of fill)

**Road and landing fills**

- unstable and potentially unstable road and landing fills that could deliver sediment to streams are excavated (removed)
- excavated spoil is placed in locations where eroded material will not enter a stream
- excavated spoil is placed where it will not cause a slope failure or landslide

**Road surface drainage**

- ditches are drained frequently by functional rolling dips or ditch relief culverts
- minimum new ditch relief culvert size of 18" (existing 12" and 15" culverts are ok if they are functioning problem-free)
- outflow from ditch relief culverts does not discharge to streams (additional drainage structures are needed if outlet gullies have formed and flow discharges to a stream)
- gullies (including those below ditch relief culverts) are dewatered to the extent possible
- road surfaces and ditches are "disconnected" from streams and stream crossing culverts (general 50' maximum ditch length feeding directly to streams - exceptions can occur where a ditch drain would discharge onto unstable road fill that cannot be removed or stabilized)
- ditches do not discharge (through culverts or rolling dips) onto active or potential landslides
- decommissioned roads have permanent road surface drainage and do not rely on ditches

Figure 1. Characteristics of storm-proofed roads.

Table 6. Recommended storm-proofing treatments along roads in the Jordan Creek watershed, Humboldt County, California.

| Treatment | No. | Comment | Treatment | No. | Comment |
|---|---|---|---|---|---|
| **Install critical dip** | 14 | To prevent stream diversions | **Outslope road** | 2 | Outslope 750 feet of road to improve surface drainage |
| **Install culvert** | 2 | Install a cmp at an unculverted fill | **Clean ditch** | 3 | Clean 240 feet of ditch |
| **Replace culvert** | 8 | Upgrade an undersized cmp | **Install ditch relief culvert** | 1 | Install ditch culverts; use rolling dips if possible |
| **Excavate soil** | 105 | Fillslope & crossing excavations; 59,576 $yds^3$ | **Install rolling dips** | 59 | Install rolling dips to improve road drainage |
| **Add culvert downspout** | 10 | Installed to protect the fillslope from erosion | **Remove ditch (outslope road)** | 1 | Remove 150 feet of inboard ditch |
| **Install wet crossing** | 2 | Install a rocked rolling dip or armored fill | **Other** | 9 | Miscellaneous treatments |
| **Rock road surface** | 1 | Rock road surface using 750 $ft^2$ of rock | **None** | 124 | No treatment recommended |

1) stream crossing upgrading (especially culvert up-sizing and elimination of stream diversion, replacing large high risk culverts with bridges, and replacing culverted fills with hardened fords in areas where debris torrenting is common or can be expected), 2) removal of unstable sidecast and fill materials from steep slopes, headwater swales, and along road approaches to deeply incised stream channels, and 3) the application of drainage techniques to improve dispersion of road surface runoff. Standard road upgrading techniques are well documented and illustrated in the literature (eg., "*Handbook for Forest and Ranch Roads,*" PWA 1994c). As an example, Table 6 describes the range of storm-proofing treatments recommended along 34 miles of road in the 4.8 $mi^2$ Jordan Creek watershed.

Fine sediment contributions from roads, cut banks and ditches in watersheds are minimized by utilizing seasonal closures for hauling and travel, road surfacing, converting ditched insloped roads to outsloped alignments (especially at and near the approaches to stream crossings), adding rolling dips to drain and disperse road surface runoff, and adding rolling dips or ditch relief culverts immediately adjacent stream crossings (to reduce extension of the drainage network and eliminate ditch contributions to sediment yield (Wemple 1994)).

**Road decommissioning -** In the past, unneeded or high maintenance roads were often abandoned and allowed to "return to nature". Forest roads may have been abandoned because they were no longer needed, or because they cross unstable areas, require excessive maintenance or caused

Table 7. Roads prioritized for decommissioning, McCready Gulch watershed, Humboldt County, California (roads listed in descending order of future unit sediment yield).

| Road Name[1] | Length (mi) | Future yield[2] ($yds^3$) | Unit yield ($yds^3$/mi) | Comment |
|---|---|---|---|---|
| 612 | 0.45 | 4,240 | 9,400 | Inner gorge spur road on main stem channel contains two very large Humboldt (log) crossings |
| 603 | 0.80 | 6,580 | 8,200 | Midslope spur road above main tributary contains numerous mid-size Humboldt log crossings |
| 606 | 0.31 | 2,270 | 7,300 | Inner gorge spur road above main tributary with 6 medium size sites |
| 607 | 0.56 | 4,040 | 7,200 | Inner gorge spur road on main tributary with 15 sites (6 crossings and 9 fillslope instabilities) |
| 600 | 1.26 | 8,540 | 6,800 | Lower slope and inner gorge road with 30 sites (16 crossings; 5 over 500 $yds^3$) |
| 601 | 0.28 | 1,465 | 5,200 | Inner gorge dead end spur road with 3 good sized Humboldt log crossings) |
| 605 | 0.31 | 1,155 | 3,700 | Inner gorge and midslope spur road to main tributary. Possible connector road. |
| 602 | 0.59 | 1,805 | 3,100 | Inner gorge road paralleling and immediately adjacent main stem McCready Gulch. Poor location. |
| 609 | 0.53 | 1,560 | 2,900 | Midslope spur road with two large sites (1 crossing and 1 fill failure) |

[1] All roads in this list had been abandoned since the late 1970s.
[2] Estimated future delivery of sediment to streams, typically from failing (eroding) stream crossings and fillslope failures, assuming no erosion prevention treatments are undertaken.

persistent environmental damage. If a road is not going to be inspected and maintained for one or more seasons, it should be storm-proofed by temporary decommissioning. If it is poorly located, overly expensive to maintain, or causes unacceptable environmental damage, it is a candidate for permanent decommissioning.

Decommissioning essentially involves "reverse road construction," except that full topographic obliteration of the road bed is not normally required to accomplish sediment prevention goals. In order to protect the aquatic ecosystem, the goal is to "hydrologically" decommission the road; that is, to minimize the adverse effect of the road on natural hillslope and watershed hydrology and slope processes.

Roads which are of low relative priority for decommissioning include those which follow low gradient ridges, roads traversing large benches or low gradient upland slopes, and roads with few or no stream crossings. Even though some routes might be relatively easy and inexpensive to permanently close, they may not be high priority candidates for decommissioning because their closure would do little to protect the downstream aquatic ecosystem. Estimating the future sediment yield and treatment cost-effectiveness of projects along all roads will help identify which roads in the watershed are truly the best targets for decommissioning (Table 7).

Based on potential threats to the aquatic ecosystem, a variety of roads qualify as "best-candidates" for decommissioning. These often include roads built in riparian areas, roads with a high potential risk of sediment production (such as those built on steep inner gorge slopes and those built across unstable or highly erodible soils), roads built in tributary non fish-bearing canyons where stream crossings and steep slopes are common, roads which have high maintenance costs and requirements, and abandoned roads.

## CONCLUSION

In many steepland watersheds, the most serious immediate and potential impact to the aquatic system is related to accelerated sediment production and yield. Storm-proofing forest roads is a forward-looking process that involves the identification, quantification, prescription, prioritization and treatment of potential (future) erosion problems, as well as on-going erosion that could delivery sediment to streams. The highest yielding sites along forest roads often include vulnerable stream crossings, fill slopes and road surfaces.

Road storm-proofing techniques, including both upgrading and decommissioning, involve the application of tested erosion prevention and erosion control practices. Erosion prevention entails identifying and preventing erosion before it has occurred and is typically less expensive and more effective than trying to control erosion once it has begun. Predicting cost-effectiveness allows a variety of proposed treatments to be compared and prioritized throughout a watershed when funds for restoration and protection work are limited. In general, heavy equipment will perform most of the significant and cost-effective erosion prevention and erosion control work for storm-proofing road networks. Only the most cost-effective hand labor practices are then used for subsequent revegetation and erosion control.

Storm-proofed roads share a number of basic, predictable characteristics that can be identified by field inspection (Figure 1). Once roads and road systems are inventoried and treated to meet these “guidelines,” chronic and episodic accelerated sediment delivery from the road system will be minimized. Annual and winter storm inspections of the storm-proofed road should be sufficient to identify any new problems which may need attention. In practice, where aquatic resources are at risk, storm-proofing projects need only treat those sediment sources which would otherwise deliver sediment to the stream system. Landowners may also desire that non-yielding sites be identified and prescribed during the inventory process. These treatments target road integrity and passage, and are considered a part of normal maintenance and winterization tasks.

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COUNCIL OF WESTERN STATE FORESTERS

## *A Report from the*

## *Council of Western State Foresters*

# *Forestry Best Management Practices for Western States:*

### *A summary of approaches to water quality implementation and effectiveness monitoring*

June 1, 2007


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## About the Council of Western State Foresters

Established in 1967, the Council of Western State Foresters (CWSF) is a nonpartisan organization of state, territorial, and commonwealth foresters of the Pacific Islands and Western United States. State Foresters are responsible for forest management on state and private lands, including assistance to landowners as well as wildfire and forest health protection services. The members of the CWSF include the 23 State and Pacific Island Foresters of the West.

## Mission

Our mission is to promote science-based forest management that serves the values of society and ensures the health and sustainability of western forests.


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## Objectives

The objective of this report is to provide an overview of forestry BMP implementation and effectiveness monitoring for states represented by Western Water Resources Committee of the Council of Western State Foresters. Specifically, this paper lists the western states which have active, organized BMP monitoring programs that gather information regarding (1) whether BMPs are being implemented and (2) if BMPs are effectively limiting non-point source pollution from forestry operations. An overview of forestry BMP programs for each state and territory are discussed and a summary of each state's efforts is then presented in Table 1. Forestry BMP monitoring activities for the southern and northeastern regions of the U.S. are also discussed for comparison points. Broad observations of forestry BMP monitoring efforts are then summarized in the concluding section. This report illustrates the progress that western states have made in ensuring forestry activities are practiced in such a way that they maintain the highest levels of water quality. Every effort was made to gather the most current data; however, more current data for some states could have been created since the last data call used to inform this report.

## Background

Since the 1970s, non-regulatory forestry Best Management Practices (BMPs) in the western U.S. have provided guidance as minimum water quality protection standards for forestry operations. In 1987, Congress amended the Clean Water Act and added Section 319 to address non-point sources of pollution. Section 319 directed all States to develop non-point source pollution plans to address pollution of this nature; however, silvicultural activities were exempt from needing BMP permits for usage and reporting. This directive led western states to develop forestry BMP programs administered within the respective regulatory and non-regulatory frameworks of each state (see Table 1). Additionally, this directive allowed western states to develop their own unique forestry BMP programs. Most western states have initiated forestry BMP implementation and effectiveness monitoring efforts, while a few have not (see Table 1).

## Individual State Reviews

### *Alaska*

BMP implementation monitoring in Alaska is mandatory in order to demonstrate the effectiveness of BMPs in meeting water quality standards. Annual meetings are held by Alaska's Department of Natural Resources to identify the need for increased effectiveness when monitoring projects and potential means for funding. The recommendations from the annual meetings are then reviewed by the AK Board of Forestry. BMP compliance monitoring is conducted on all current timber harvest operations that are subject to the *Forest Resources and Practices Act*. Because these monitoring efforts are part of on-going inspections of harvesting operations, monitoring data is collected on a continual basis. The monitoring efforts are coordinated by the division training officer. BMP effectiveness monitoring data is collected periodically by specific monitoring reports. *Compliance Monitoring Score Sheets* are completed for harvest activities during the routine inspections of timber harvesting operations on state, other public, and private timber lands. Scores range from 1 – 5. A score of '1' represents that an attempt was rarely made to implement the BMP when it was applicable to a harvest activity and the BMP was applied in a manner that was ineffective in achieving the desired result. A score of '5' indicates that the BMP was consistently implemented when it was applicable to a harvest activity and the BMP was applied in a manner that was effective in achieving the desired result. Upon completion of the score sheets, the *Field Inspection Reports* are then completed.

### *Arizona*

The use of Best Management Practices in Arizona is voluntary; consequently, the state has no forestry BMP guidelines. As commented in Ice et al. (2004), "Forestry is generally ranked a low-priority water quality issue in the state" (p. 145). In fact, "Silviculture was not even listed as a probable source of stress to Arizona streams in the draft 2000 [*National Water Quality Inventory*] 305(b) report" (Ice et al. 2004 p. 145). Thus, a review of forestry BMP implementation or effectiveness has never been conducted in Arizona.

### *California*

Under California's *Forest Practice Act* (FPA), which was adopted in 1973 and implemented in 1975, Timber-harvesting Plans (THPs) must be submitted to the California Department of Forestry and Fire Protection (CDF) for review of compliance with the FPA and the *Forest Practice Rules* (FPRs). In 1984, *Forest Plan Rules* (FPRs) were certified by the State Water Resources Control Board as *Best Management Practices* under Section 208 of the *Federal Clean Water Act.* Additionally, the State Water Resources Control Board certified FPRs as BMPs with the condition that a monitoring and assessment program be implemented (Cafferata & Munn 2002).

By 1989, the California State Board of Forestry and Fire Protection (BOF) formed an interagency task force, later known as the Monitoring Study Group (MSG), to develop a long-term monitoring program "that could test the implementation and effectiveness of FPRs in protecting water quality" (Cafferata & Munn 2002 p. 4). This monitoring program has been funded by CDF since 1990. Cafferata & Munn (2002) state, "The primary goal of the MSG's monitoring program has been to provide timely information on the implementation and effectiveness of forest practices related to water quality for use by forest managers, agencies, and the public" (p. 4). The MSG also has a long-term monitoring program that tests the effectiveness of FPRs and provides oversight to CDF in implementing the program.

In recent years, there have been a number of factors, such as the new requirements by the Regional Water Quality Control Boards for monitoring of Timber Harvesting Plans (THPs), which have significantly increased forestry-related water quality monitoring in California (Cafferata & Brandow 2006). More specifically, in the past ten years, many of the monitoring efforts have focused on learning more about the implementation and effectiveness of FPRs in protecting California's water quality.  Two long-term monitoring programs, for example, which assess FPRs implementation and effectiveness, are the *Hillslope Monitoring Program* (HMP) and the *Modified Completion Report* (MCR).

The *Hillslope Monitoring Program* began in 1996 and ran until 2002 when funding was no longer available.  The purpose of the HMP was to determine if *Forest Practice Rules* were adequately protecting beneficial uses of water associated with commercial timber operations on nonfederal lands.  Field inspections were conducted by independent contractors for 295 THPs. Data was prepared by CDF in a final report in 2002.  Similar to the HMP, the *Modified Completion Report* (MCR) monitoring program also focused on looking at implementation rates and effectiveness of FPRs.  However, unlike the HMP, this program was considered more cost-effective because it utilized CDF Forest Practice Inspectors rather than independent contractors to collect onsite monitoring information.  Implemented from 2001 to 2004, data was collected on a random selection of 281 completed THPs (12.5% of total Plans).  Also, based on the results from the HMP, high risk and highly sensitive parts of the Timber-harvesting Plan were sampled (i.e., roads, crossings, and watercourse and lake protection zones).  Comparable to the findings in the HMP, compliance with FRPs was high and FRPs were found to be highly effective when properly implemented.

Currently, CDF has approximately 70 Forest Practice Inspectors, who have jurisdiction on both private forest lands, approximately 7,000,000 acres, and Demonstration State Forests, approximately 71,000 acres.  In order to determine compliance with the FPA and FPRs, Forest Practice Inspectors are responsible for conducting pre-harvest inspections, active harvest inspections, and completion inspections.  The CDF inspectors can also perform erosion control period inspections up to three years after harvest completion.  The inspectors can apply enforcement where needed, including writing Notices of Violation and Citations (both criminal and civil).

In addition to the HMP, MCR, and the Forest Practice compliance inspection program, there are several cooperative in-stream monitoring projects that also assess the effectiveness of FPRs.  For example, the *Caspar Creek Watershed Study* provides long-term hydrologic information (such as hydrologic changes, sediment production, and erosion impacts) from logging and road construction in managed second-growth conifer forests.  The project is a cooperative effort between the USFS Pacific Southwest Research Station and CDF, which has been collecting data for more than four decades.  Additionally, California is also required to report monitoring information to the Regional Water Boards.  Timber companies, such as the Pacific Lumber Company, also have initiated in-stream and road-related monitoring.

Today, the CDF and MSG are developing a new *Interagency Mitigation Monitoring Program* (IMMP).  The concept of IMMP "is that monitoring developed and performed jointly by the staff members of the affected agencies will produce a product that is useful to and accepted by each of the affected agencies" (Cafferata & Brandow 2006 pp. 3-4).  The pilot program began in July 2006 and is looking specifically at watercourse crossing.

### *Colorado*

Colorado adopted new voluntary BMPs for forest operations in 1998. To date, the state has not developed a formal program for BMP monitoring. As Ice et al. (2004) comment, "The state has used anecdotal feedback on BMP implementation…but has not conducted a formal survey to determine implementation" (p. 149). However, Colorado is currently working on developing a statewide BMP audit, which may be initiated in the fall of 2007.

### *Hawaii*

Although forestry BMPs have been used in Hawaii for a few years, no monitoring programs have been established that evaluate BMP implementation and effectiveness. However, the state is currently working on a 15-year program, which will be implemented statewide in 2013, that proposes to link forestry programs, BMPs, and education and training programs to water quality goals. Contained in *Hawaii's Coastal Nonpoint Pollution Control Program Management Plan* (CNPCP), the state proposed to develop mechanisms to ensure that the appropriate BMPs are used in forestry operations. Currently, Hawaii requires BMPs to be incorporated into Forest Stewardship contracts and leases of State lands for forestry operations. Because commercial forestry operations have only recently expanded in Hawaii, the state is gathering more information to determine the appropriate BMPs needed to ensure that the management measures in the CNPCP are implemented statewide.

### *Idaho*

In order to evaluate the implementation and effectiveness of forestry BMPs, Idaho is required, under the Idaho Non-point Source Management Plan, to conduct on-site reviews of timber harvest activities. Idaho's BMP monitoring program is the responsibility of the Idaho Department of Environmental Quality (DEQ), who coordinates and chairs the statewide Forest Practices Water Quality Audit (FPWQ Audit). The main purpose of the FPWQ Audit is to assess the application and effectiveness of forestry BMPs, as described by the *Idaho Forest Practices Act* (FPA) (McIntyre et al. 2005). The audits are one of the key steps "in the process to determine if forest practices are being implemented and maintained, and if water pollutants are being effectively controlled" (McIntyre et al. 2005 p. 8).

FPWQ Audits began in 1984 and have been conducted every four years, with the most recent audit in 2004. During intervening years, the Idaho Department of Lands (IDL) conducts on-going informal BMP audits. Audits are conducted by the FPWQ Compliance Audit team, which is comprised of a representative from IDL and from DEQ. The IDL's Forest Practices Program Manager has participated on every audit team, and personnel from IDL have also assisted with the audits by collecting data for the representatives.

The BMP monitoring procedure is developed and documented in a work plan that is written specific to the purpose and objectives of each given audit. In the 2004 FPWQ Audit, for example, the audit team proposed objectives that assessed the extent to which the FPA Rules were implemented and effective, as well as recommend rule and administrative procedure revisions to the FPA Rules. Timber sales in the 2004 audit were randomly selected based on three criteria: 1) they occurred on unstable geologic types; 2) they bordered or encompassed at least 500 feet of a Class I stream; and 3) they were inspected previously by agency foresters with a final report. 27 timber-harvesting sites were audited for compliance, with four of these sites audited for effectiveness. McIntyre et al. (2005) state, "The 2004 audits addressed the FPA requirements for timber harvest and road construction and maintenance, and focused on specifications for retaining shade, leaving trees, and providing fish passage" (p. vi). The findings of the audits were then reported to the Idaho Governor, the Forest Practices Steering Committee, the Forestry Practices Act Advisory (FPAA) Committee, and the Idaho Board of Land Commissioners. The report also went to the Idaho Board of Environmental Quality and the IDL.

In addition to the state's monitoring program, a private forest products corporation is also analyzing BMP effectiveness. Initiated in 1990, The Potlatch Corporation and cooperators are evaluating the effectiveness of state forest practices rules in the Mica Creek Watershed in northern Idaho.

### *Kansas*

The use of Best Management Practices in Kansas is voluntary. Consequently, no BMP monitoring program is in place. However, voluntary BMPs are promoted through watershed foresters.

### *Montana*

Montana's water quality protection program for forestry involves a combination of regulatory and non-regulatory approaches that are implemented through the Forestry Division of the Department of Natural Resources and Conservation (DNRC). Since the 1970's, non-regulatory Forestry Best Management Practices (BMP) have provided guidance as minimum water quality protection standards for forestry operations. Several legislative actions in the late 1980's resulted in a more standardized process for BMP implementation. The *BMP Notification Law* (76-13-101 MCA) requires private landowners to notify the DNRC prior to harvesting timber. DNRC then provides forestry BMP information and technical assistance on how to apply the BMPs. An interdisciplinary technical workgroup with members representing a broad range of forestry interests within the state provides oversight to DNRC for BMP development and program implementation.

Montana also has a regulatory *Streamside Management Zone Law* (77-5-301 307 MCA) that prohibits certain forest practices within a defined buffer zone along stream channels and lakes where improper practices have the potential to result in erosion, water quality problems, and degradation.

Since the early 1990's, DNRC has been monitoring forest practices for BMP and SMZ implementation and effectiveness through a biennial statewide BMP audit process. The most recent forestry BMP audit process was completed in 2006. The audits were conducted by interdisciplinary teams with members representing natural resource specialists, forest industry, conservation interests, and private forest landowners. The teams evaluated 49 BMP practices and 12 SMZ practices at each of 45 sites distributed across the state by geographical region. The sites represented logging operations conducted since 2003 where timber harvest and related activities had the greatest potential for impacting water quality. The results show that across all ownerships, BMPs were properly applied 96% of the time and were effective in protecting soil and water resources 97% of the time. In addition, SMZ practices were applied 98% of the time with 99% effectiveness. The results for 2006 are similar to audit results from the past several audit cycles and show a significant improvement in implementation and effectiveness from the early 1990's. The audit findings and recommendations were summarized in a comprehensive report (Rogers 2006) and presented to the Montana legislature.

### *Nebraska*

The use of Best Management Practices in Nebraska is voluntary; consequently, there is no monitoring BMP program is in place.

### *Nevada*

The *Nevada Forest Practices Act* (FPA) regulates all silvicultural activities in Nevada. Under the FPA, a timber harvest permit and a performance bond are required; in which applicable forest practice rules are outlined. The Nevada Division of Forestry is responsible for reviewing the permit and bond, as well as for providing the harvest operator with oversight and guidance to BMP implementation. Silviculture BMPs in Nevada are voluntary.

The vast majority of commercial timber-harvesting throughout Nevada's portion of the Sierra Front ended in the 1970s. Today, commercial harvest projects are infrequent. However, if there is a commercial timber sale, then BMPs are implemented through the FPA permit process and are visually monitored for effectiveness. Monitoring data is only collected on a project specific basis during the project period.

Since the 1970s, the U.S. Forest Service has acquired some of the private timberlands. More recently, the remaining true timbered private lands have been incrementally converted to high value urban development. When forested private lands are converted to urban land uses, a Timberland Conversion Permit is required (under the FPA), which mandates that BMPs for site erosion control are in place until the development is complete.

Nevada's Division of Environmental Protection (NDEP) is responsible for surface and ground water quality throughout the state, and does surface water quality monitoring on a regular basis. NDEP has a state BMP manual, which was developed in the early 1990s. Currently, NDEP is working on a statewide protocol for BMP monitoring; however, no completion date has been set.

Pinyon-juniper woodlands occupy the majority of Nevada's remaining forested lands. Recently, they have become the focus of a growing biomass industry coupled with fuels reduction projects. As noted in Ice et al. (2004), "An emerging issue is the development of BMPs for harvesting pinyon-juniper forests for biomass recovery and to restore wildlands" (p. 154).

### *New Mexico*

Best Management Practices in New Mexico are state regulations that are outlined in the *New Mexico Forest Harvest Guidelines*. Upon completion of a timber sale, the unit is inspected by the New Mexico Forestry Division. If the sale unit passes inspection, then the inspection form (referred to as the '208 form') is sent to the New Mexico Environment Department. The Environment Department's surface water quality bureau monitors TMDL; however, the results of the timber sale are not specifically monitored because they are a non-point source. Nevertheless, based on the inspection reports, Ice et al. (2004) estimate implementation of the regulations to be 75% (p. 154). Violations of the regulations can result in administrative and/or criminal penalties. Currently, a statewide database for the inspections is planned. Ice et al. (2004) comment that upon completion of the database, New Mexico will "explore opportunities" to test BMP effectiveness (p. 154).

### *North Dakota*

The *Landowner Assistance State Priority Plan* and the *North Dakota Forestry Best Management Practices* define North Dakota's BMP program. The BMP program is tied to the delivery of technical and financial assistance to landowners. Every five years a landowner's Forest Management Plan is reviewed and their property is assessed to see if it is in compliance with Forest Stewardship Program guidelines. The responsibility for BMP monitoring rests with the Staff Forester of the North Dakota Forest Service. Field assessments are performed by the Forest Resource Management Team, which is made up of six employees (including the Staff Forester).

The North Dakota Forest Service also offers financial incentives programs. As an eligibility requirement a landowner must sign an agreement with the NDFS that states that they will maintain the practice for ten years. All of the BMP programs in the state are voluntary. Consequently, a landowner can chose to remove a practice at any time. However, if they do so prior to the completion of the 10-year maintenance period they must pay back the cost-of-practice establishment.

North Dakota relies heavily on cooperating agency personnel and contract foresters to perform BMP monitoring efforts. Currently, the U.S. Forest Service is initiating the Forest Stewardship Program Monitoring efforts, which will allow for data to be more formally collected and provide an avenue for integrating BMP monitoring on a larger scale.

### *Oregon*

The Oregon Department of Forestry (ODF) regulates all forestry operations on Oregon's nonfederal land. Private forests are subject to water protection rules outlined in the *Oregon Forest Practices Act* (adopted in 1971). The *Oregon Forest Practices Act* also applies to state-owned forestlands, but state forests are also subject to an additional aquatic conservation overlay contained in the *Oregon State Forests Northwest Management Plan*. It is clearly mandated in the FPA that monitoring and evaluating water protection rules are necessary in order "to increase the level of confidence of all concerned that the rules will maintain and improve the condition of the riparian vegetation and waters of the state over time" (*Oregon Forest Practice Rules*, January 2006, Chapter 628, p. 42). Additionally, the Board of Forestry is required to meet its statutory

obligation, in which the Board "shall establish best management practices and other rules applying to forest practices as necessary to insure that to the maximum extent practicable non-point source discharges of pollutants resulting from forest operations on forestlands do not impair…water quality" (*Oregon Forest Practices Rules*, January 2006, Chapter 628, p. 87). Therefore, both the state and private forests' programs have an active BMP program that assesses BMP implementation and effectiveness monitoring for forestry operations.
ODF's *Forest Practices Monitoring Program* (FPMP) "provides scientific information for adapting regulatory policies, management practices, and volunteer efforts on non-federal lands" (ODF 2002 p. 1). The FPMP was established in 1988, updated in 1994, and then revised again in 1998. The FPMP is responsible for monitoring the implementation and effectiveness of water protection rules on an annual basis. Monitoring efforts are conduct with ODF personnel as well as through cooperative agreements with universities, large private landowners, federal researchers, and other organizations. Monitoring data is collected on a project-by-project basis by using specific questions that illustrate issues or concerns with particular BMPs. The questions were drawn from a previous monitoring strategy, *Oregon Plan for Salmon and Watersheds Workplan*, the Forest Practices Advisory Committee final report, and citizen and stakeholder input in 1994 and 2000. The findings and recommendations from the monitoring efforts are then reported to the Board of Forestry.

Because the Board of Forestry has authority to develop and enforce statewide rules, the Board believes that this continued monitoring is necessary to provide feedback about the adequacy of the rules and how to improve them (Ice et al. 2004 p. 154). Since the rules are subject to revisions based on monitoring data and best available science, the rules have undergone many changes with the most recent changes occurring in 1994 and 1995.

There are several current projects on both state and private forestlands that look at BMP compliance and effectiveness. In 1998, for example, the private forests program conducted a comprehensive BMP compliance monitoring study, which was implemented during the 1999 and 2000 field season. The goal of the study was to identify the level of forest operations in compliance with forest practice rules and to identify if adjustments to administration of the program are needed. Units were surveyed by a former Forest Practices Forester as either 'compliant' or noncompliant'. A total of 13,506 BMP applications were reviewed on a total of 189 harvest operations. While compliance was relatively high (96.3%), the results of the study will now be used to assist with future monitoring, education, and training to reduce the incidences of noncompliance (Cathcart et al. 2005 p. 1). An example of Oregon's BMP effectiveness monitoring efforts is the Riparian Function and Stream Temperature effectiveness monitoring study, which evaluates stream temperature and riparian condition before and after timber-harvesting. The study was initiated in 2002 and is scheduled for completion in 2012. Over the ten years, reports will be completed in 2006 (baseline), 2007 (one-year post harvest), 2009 (three-year post harvest), 2011 (five-year post harvest), and a final report and recommendations in 2012.

There are also several watershed studies on state and private forestlands that examine the implementation and effectiveness of water protection rules. The Hinkle Creek Paired Watershed Study and Demonstration Area is a ten year project funded through the Watersheds Research Cooperative in the College of Forestry at Oregon State. The four watersheds in the project area, which are owned by Roseburg Forest Products, will be harvested in compliance with forest practice rules. Stream discharge and water quality will then be monitored to assess BMP effectiveness. Another watershed monitoring project that evaluates the effects of harvesting activities is the Trask River project. Currently, the study design is being developed. Once implemented, this 15-year study will evaluate the effects of forest management at stream headwaters, as well as evaluate the effects of timber-harvesting downstream.

***South Dakota***

Best Management Practices for South Dakota were established by the state in 1980. South Dakota revised their BMPs in 1993 and 2003, in which both revisions were then adopted in the *South Dakota Non-point Source Pollution Management Plan*. Despite the fact that BMP compliance is voluntary, timber harvest operators, wood products industries, and land managers have made a commitment to implement BMPs. In fact, in 2001, the Black Hills Forest Resource Association (BHFRA) began a financial and technical partnership with the South Dakota Department of Environment and Natural Resources (DENR) for voluntary monitoring, evaluation, and training for BMP implementation (Everett 2004 p. 1). The first timber sale field audits to evaluate BMP compliance were conducted in 2001.

In 2004, training workshops and field audits were conducted by the BHFRA and BENR, in which seven timber sales were audited for BMP application and effectiveness. A diverse team of private and public sector resource professionals conducted the audits. Using a well-established system of rating criteria, a consensus-based approach was used to evaluate BMP compliance. Based on the 2001 and 2004 trainings and audits, it was recommended that the audits and training occur on a three-year cycle.

***Utah***

Prior to 2001, timber-harvesting activities in Utah went “largely unchecked due to the lack of information related to the location of these activities” (Gropp 2006 p. 9). In 1982, the state conducted the first statewide assessment of forest practices, in which field surveys were conducted on 55 timber sales. It was concluded that silviculture was not a significant non-point source pollutant because approximately 90% of the timber being harvested was on federal land (Gropp 2006 p. 10). From 1982 to 2002 no field audits were conducted that examined silvicultural impacts and their relationship to non-point source pollution. However, in response to Utah’s *Non Point Source Management Plan for Silvicultural Activities* (1998) and the *Utah Forest Practices Act* (FPA) (2001), the *Forest Water Quality Guidelines (FWQG) Monitoring Program* was developed. The objectives of the *FWQG Monitoring Program* “are to develop and implement a forest water quality monitoring and evaluation program, and to demonstrate the application of the FWQG as being effective in reducing non-point source pollution and protecting forest, soil and water resources” (Gropp 2006 p. 6). This monitoring program functions within a voluntary, non-regulatory framework.

The FPA requires operators to register with and notify the Division of Forestry, Fire and State Lands (FFSL) of their timber harvest plans. This notification of intent (NOI) is the key to Utah’s monitoring efforts, in that it provides the FFSL with contact information and location of timber-harvesting activities. In addition, the FPA requires the FFSL to provide technical assistance and education to the landowners and operators. Upon receiving an NOI, the FFSL must give landowners and operators information on Utah's FWQG.

During the period 2002-2005, the FFSL conducted post-harvest field audits on 40 sites that evaluated FWQG application and effectiveness. Six teams, each comprised of at least a two-person team (usually an Area Forester or Area Manager and an administrative staff person and/or a Forest Management program manager), carried out the monitoring efforts. Additionally, landowner(s) and operator(s) were encouraged to participate during the audit process. The audits are based primarily on "visual assessments and professional judgment" and decisions are based on "consensus among audit team members" (Gropp 2006 p. 6). The current monitoring direction corresponds directly to the number of NOIs received (i.e., for every NOI received a FWQG audit will be conducted unless permission by the landowner is denied). Thus, the state attempts to conduct field audits for 100% of all timber sales on state and private lands.

It was concluded that the FWQG monitoring process was "a positive and productive approach to dealing with a complex issue" (Gropp 2006 p. 38). Therefore, "It is anticipated that FWQG audits will be conducted on a continuous, on-going basis with accompanying reports being produced on a three-year cycle" (Gropp 2006 p. 11).

### *Washington*

The *Washington Forest Practices Act* was enacted in 1974 to achieve public resource protection and a viable forest industry. The act established the Forest Practices Board which has the responsibility of developing rules to achieve the goals of the act. The original *Forest Practices Rules* were adopted in 1974 and implemented in 1975. The *Forest Practices Rules* apply to all nonfederal forest lands and are regulated by the State of Washington Department of Natural Resources (DNR) to achieve protection of public resources. The rules have been modified several times and the current *Forest Practices Rules* were adopted in July 2001.

The *Forest Practices Rules* are generally very prescriptive in nature to achieve the desired goals and outcomes of the act. The *Forest Practices (FP) Board Manual* provides practical guidance to the landowners, operators, foresters, tribal participants, other interested parties and agency regulators to assist in implementing the rules. Some of these *FP Board Manual* Sections contain a mixture of best management practices (BMPs) elements, practical examples, and instructions to help landowners apply the rules to their ownership on the landscape. Because the FP Rules are so prescriptive, the DNR does not maintain a list of the BMPs that could be used to meet the rule requirements. Therefore we do not have an evaluation process to determine effectiveness of them.

The latest rule adoption included Compliance Monitoring as an element of the FP Rules. The Department conducts compliance monitoring per WAC 222-08-160 (4) which states "*The department shall conduct compliance monitoring that addresses the following key question: 'Are forest practices being conducted in compliance with the rules?' The department shall provide statistically sound, biennial compliance audits and monitoring reports to the board for consideration and support of rule and guidance analysis.*"

In 2006 the Compliance Monitoring Program was implemented to assess how well landowners were implementing the *Forest Practices Rules*. The expectation is that the program will cover all operational rules over time. DNR in collaboration with participants from Washington State departments of Ecology, Fish and Wildlife, along with Tribal volunteers reviewed 97 randomly selected forest practices applications covering 278 forest practice activities. These samples were generated from a population of over 6,000 applications submitted annually. Selection criteria consist of activities related to riparian harvest and roads as these two rule groups have the most potential for impact to public resources.

The results of the 2006 field reviews of the 278 activities reviewed are:

a. 224 of the 278 site specific activities (81%) are in compliance.
   Breakdown of the two rule groups:
   i. 93 of the 126 Riparian activities statewide (74%) are in compliance
   ii. 131 of the 152 Road activities statewide (86%) are in compliance.

All decisions for compliance verses out of compliance are made in the field by the review group using professional judgment based on their understanding of the rule element.

The program is currently reviewing applications to complete this biennial cycle requirements. In July 2007 rules for Small Forest Landowners with 20 acres or less to harvest, and Alternate Plans will be added to the existing list of rules being reviewed. For more information see the Compliance Monitoring website at
http://www.dnr.wa.gov/forestpractices/compliancemonitoring/

***Wyoming***

Wyoming's BMP standards for forestry operations were developed in a cooperative effort between the Wyoming Department of Environmental Quality, the Wyoming State Forestry Division, and the U.S. Environmental Protection Agency. There is no law or regulation that requires compliance with these BMP standards. Although the standards are voluntary, forest managers are committed to full BMP implementation.

Using an interdisciplinary team, field audits were first conducted on twelve timber sites in 2000 and 2001. Each audit rated 42 separate practices, for both BMP application and effectiveness. The results of the 2000-2001 field audits allowed for common mistakes and areas of confusion to be identified. Training was also conducted during this time. The combination of auditing and training has allowed Wyoming to develop a self-monitoring system, in which forest managers are able to highlight common mistakes in BMP application during training sessions. In order to maintain Wyoming's system of continuous improvements, field audits were conducted again in 2004. 42 practices were examined at six timber sites, and each practice was rated on BMP application and effectiveness. The field audits were conducted over the course of one week, with the audit team spending one-half day on each timber sale. As a result of the audit findings, forestry BMPs were updated in 2004, and further training was scheduled for July 2005. The next round of audits is scheduled to occur in 2006 and training in 2007. Additionally, the state's forestry BMP Handbook, which is used as a training reference, will be updated to accurately reflect the state BMPs by 2007.

***Territories and Commonwealths of the Pacific Islands***

*No information was available for the Pacific Island Territories and Commonwealths.*

## Conclusion

The purpose of this paper is to provide a preliminary assessment of forestry BMP monitoring efforts by the states represented by the Council of Western State Foresters. The information presented can help us to understand the implementation and effectiveness of forestry BMPs in meeting water quality objectives in the West. In summary, each of the states that have assessed implementation of BMPs (eight out of 17 states) indicated BMP compliance to be relatively high. The implementation rates ranged from 75% to 97%. Additionally, the states that have conducted BMP effectiveness monitoring (nine out of 17 states) have shown that BMPs, when properly implemented, are effective in protecting water resources.

In 2004, the Water Resources Committee of the National Association of State Foresters (NASF) conducted a survey that examines state non-point source pollution control programs for silviculture. This survey compiled information that could be beneficial in looking at methodologies used by states in the west. Also, the future needs for progress in non-point source control programs was assessed in this report. The specific results of the surveys could provide insightful information for further analysis of forestry BMP monitoring efforts in the western U.S.

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## Table 1: Brief summary of forestry non-point source control programs for states represented by the CWSF.

| State | Does the state have established BMPs for silviculture? | Are these BMPs regulatory? | When were the current BMPs developed and revised? | Has the state done monitoring for BMP implementation? | Has the state done monitoring for BMP effectiveness? | Brief summary of recent BMP monitoring programs. |
|---|---|---|---|---|---|---|
| **AK** | Y | Y | developed: 2000<br>revised: 2004 | Y | Y | ▪ BMP compliance monitoring in Alaska is conducted on all current timber harvest operations that are subject to the Forest Resources and Practices Act. Because these monitoring efforts are part of on-going inspections of harvesting operations, monitoring data is collected in a continuous basis using Compliance Monitoring Score Sheets. Upon completion of the score sheets, Field Inspection Reports are then completed. |
| **AZ** | N | n/a | n/a | n/a | n/a | ▪ The state has no forestry BMP guidelines; therefore, a review of forestry BMP implementation and monitoring has never been conducted. |
| **CA** | Y | Y | developed: 1974<br>revised: 2006 | Y | Y | ▪ The Hillslope Monitoring Program ran from 1996-2002. The purpose of the program was to determine if Forest Practice Rules were adequately protecting beneficial uses of water associated with timber operations on nonfederal land. Field inspections were conducted by independent contractors for 295 timber-harvesting plans.<br>▪ The Modified Completion Report monitoring program was implemented from 2001 to 2004. Its purpose was also to assess BMP compliance and effectiveness. Field inspections were conducted by CDF Forest Practice Inspectors for 281 timber-harvesting plans.<br>▪ Currently, the state is developing an Interagency Mitigation Monitoring Program, which will specifically look at watercourse crossings. The pilot program began in July 2006.<br>▪ The Forest Practice Inspection and Enforcement Program, which began in 1975, monitors compliance with BMPs (California Forest Practice Rules) and special mitigations contained in site-specific Timber Harvest Plans. Records are kept of inspections, Notice of Violations, and other enforcement actions. |

| State | Does the state have established BMPs for silviculture? | Are these BMPs regulatory? | When were the current BMPs developed and revised? | Has the state done monitoring for BMP implementation? | Has the state done monitoring for BMP effectiveness? | Brief summary of recent BMP monitoring programs. |
|---|---|---|---|---|---|---|
| **CO** | Y | N | developed: 1998 | N | N | ▪ To date, the state has not developed a formal program for BMP monitoring. However, Colorado is currently working on developing at statewide BMP audit, which may be initiated in the fall of 2007. |
| **HI** | Y | N | developed: 1998 | N | N | ▪ Although forestry BMPs have been in place in Hawaii for a few years, no monitoring programs have been established that evaluate BMP implementation and effectiveness. Contained in *Hawaii's Coastal Nonpoint Pollution Control Program Management Plan* (CNPCP), the state proposed to develop mechanisms to ensure that the appropriate BMPs are used in forestry operations. Currently, Hawaii requires BMPs to be incorporated into Forest Stewardship contracts and leases of State lands for forestry operations. Because commercial forestry operations have only recently expanded in Hawaii, the state is gathering more information to determine the appropriate BMPs needed to ensure that the measures in the CNPCP are implemented statewide. |
| **ID** | Y | Y | developed: 1975<br>revised: 2006 | Y | Y | ▪ Forest Practices Water Quality Audits (FPWQ Audits) are the process that Idaho uses to determine if forest practices are being implemented and if they are effective at controlling water pollutants. This monitoring program is the responsibility of the Idaho Department of Environmental Quality. FPWQ Audits began in 1984 and have been conducted every four years, with the most recent audit in 2004. During the intervening years, the Idaho Department of Lands conducts on-going, informal audits. |
| **KS** | Y | N | developed: 1995 | N | N | ▪ Kansas has no BMP monitoring program in place. |
| **MT** | Y | N | developed: 1987<br>revised: 2004 | Y | Y | ▪ The Montana Department of Natural Resources and Conservation has been monitoring BMP compliance and effectiveness biannually since 1990. The most recent audit report was completed in 2006. |
| **NE** | Y | N | developed: 2000 | N | N | ▪ Nebraska has no BMP monitoring program in place. |
| **NV** | Y | N | developed: 1994 | N | N | ▪ Nevada has no BMP monitoring program in place. Currently, Nevada's Division of Environmental Quality is working on a statewide protocol for BMP monitoring; however, no completion date has been set. |

| State | Does the state have established BMPs for silviculture? | Are these BMPs regulatory? | When were the current BMPs developed and revised? | Has the state done monitoring for BMP implementation? | Has the state done monitoring for BMP effectiveness? | Brief summary of recent BMP monitoring programs. |
|---|---|---|---|---|---|---|
| **NM** | Y | Y | developed: 2002 | N | N | ▪ Timber sale units are inspected upon completion of harvesting. However, the results of the timber sale are not specifically monitored. Nevertheless, based on inspection reports, BMP implementation can be estimated. Currently, a statewide database of inspections is planned, which could allow for BMP effectiveness to be tested; yet no projects are presently being planned. |
| **ND** | Y | N | developed: 1997 | N | Y | ▪ Every five years a landowner's Forest Management Plan is reviewed and their property is assessed to see if it is in compliance with the Forest Stewardship Program guidelines. However, no formal monitoring efforts that specifically assess BMP compliance have been made.<br>▪ The state relies heavily on cooperating agency personnel and contract foresters to perform BMP monitoring efforts. Currently, the U.S. Forest Service is initiating the Forest Stewardship Program Monitoring efforts, which will allow for data to be more formally collected and provide an avenue for integrating BMP monitoring on a larger scale. |
| **OR** | Y | Y | developed: 1972<br>revised: 2003 | Y | Y | ▪ The Oregon Department of Forestry's Forest Practices Monitoring Program is responsible for monitoring the implementation and effectiveness of water protection rules on an annual basis. This program was established in 1988, updated in 1994, and then revised again in 1998. |
| **SD** | Y | N | developed: 1993<br>revised: 2004 | Y | Y | ▪ In 2001, the Black Hills Forest Resource Association began a financial and technical partnership with the South Dakota Department of Environment and Natural Resources for voluntary monitoring, evaluation, and BMP implementation training. The first timber sale field audits to evaluate BMP compliance were conducted in 2001. In 2004, training and field audits were conducted on seven timber sales. Based on the 2001 and 2004 trainings and audits, it was recommended that the audits and training occur on a three-year cycle. |
| **UT** | Y | N | developed: 2001<br>revised: n/a | Y | Y | ▪ In response to Utah's Non Point Source Management Plan for Silvicultural Activities (1998) and the Utah Forest Practices Act (FPA) (2001), the Forest Water Quality |

| State | Does the state have established BMPs for silviculture? | Are these BMPs regulatory? | When were the current BMPs developed and revised? | Has the state done monitoring for BMP implementation? | Has the state done monitoring for BMP effectiveness? | Brief summary of recent BMP monitoring programs. |
|---|---|---|---|---|---|---|
| | | | | | | Guidelines (FWQG) Monitoring Program was developed. The objectives of the FWQG Monitoring Program are to develop and implement a forest water quality monitoring and evaluation program, and to demonstrate the application of the FWQG as being effective in reducing non-point source pollution. During 2002-2005, the Division of Forestry, Fire and State Lands conducted post-harvest field audits on 40 sites that evaluated FWQG application and effectiveness. It is anticipated that FWQG audits will be conducted on a continuous, on-going basis with accompanying reports being produced on a three-year cycle. |
| **WA** | Y | Y | developed: 1974<br>revised: 2004/05 | N | N | The state has recently begun a compliance monitoring program started in 2006. The results of the 2006 field reviews of the 278 activities reviewed are:<br>b. 224 of the 278 site specific activities (81%) are in compliance.<br>Breakdown of the two rule groups:<br>i. 93 of the 126 Riparian activities statewide (74%) are in compliance<br>ii. 131 of the 152 Road activities statewide (86%) are in compliance.<br><br>All decisions for compliance verses out of compliance are made in the field by the review group using professional judgment based on their understanding of the rule element.<br><br>For more information see the Compliance Monitoring website at http://www.dnr.wa.gov/forestpractices/compliancemonitoring/ |
| **WY** | Y | N | developed: 1998<br>revised: 2003 | Y | Y | ▪ Field audits to assess BMP application and effectiveness were first conducted on 12 timber sales in 2000 and 2001. Field audits were conducted again in 2004. The next round of audits is scheduled to occur in 2006. |

**Y-Yes N-No**

# POST-TREATMENT EROSION OF DECOMMISSIONED

# FOREST ROAD STREAM CROSSINGS

by

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A Thesis

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# ABSTRACT

Post-Treatment Erosion of Decommissioned Forest Road Stream Crossings

Sarah Wilson

Forest road decommissioning projects have increased in number over the last two decades. The goal of this study is to provide information which can help to focus restoration efforts on the most cost-effective use of technique and treatment. To pursue this goal, I examined the strength of several variables which may control erosion rates, and evaluated the relative importance of the type of erosion each variable affects. This study explores the relationship between the physical characteristics of twenty excavated forest road stream crossings and the post-excavation erosion at each of those crossings. The study areas were located in northwest California, at sites within Headwaters Reserve, Six Rivers National Forest, and Klamath National Forest.

Channel incision erosion contributed the greatest portion, 93 percent, of total post-treatment crossing erosion. In 16 of the 20 study crossings, channel incision accounted for all of the total post-treatment erosion. Post-treatment erosion from excavated banks contributed approximately seven percent of the total post-treatment erosion volume. The most significant independent variable in explaining the depth of post-treatment channel incision was watershed size. Watershed area explained 79 percent of the variation in channel incision depth within the Wildcat Formation, and 90 percent of the variation in observed post-treatment incision in two sandstone formations (Wildcat and Yager). Similarly, stream power was found to explain 65 percent of the variation in channel incision in the Wildcat Formation, and 56 percent of the variability in channel incision depth in the two sandstone formations.

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# INTRODUCTION

Roads exist in forest landscapes for a variety of purposes, including providing access for land management, outdoor recreation, fire suppression, and timber harvest. Depending on the purposes of a road, it may be used daily, seasonally, or in the case of some timber extraction access roads, only for a short period every 20 to 30 years.

The effects of roads on their environment range from ecological to hydrologic (Luce and Wemple 2001). Many of the road-related impacts occur at sites where roads intersect the channel network. Major effects of forest road stream crossings include decreased upstream and downstream access for fish, decreased passage of sediment and wood, and an increased risk of failure and mass wasting (Switalski et al. 2004).

Weaver and Hagans (2000) found that roads contribute a significant amount of sediment to forest waterways, and recommended that they be decommissioned when no longer in use. Fisheries biologists identified roads as a key culprit in salmonid habitat degradation, and also recommend the removal of problem roads (Spence et al. 1996).

Land owners and managers may choose to decommission a road for regulatory or scientific reasons.  There is also economic incentive to choose road decommissioning over long-term maintenance. Proper maintenance of a forest road is a large commitment of time and money, and even with proper and conscientious care, chronic problems with water quality can still occur (Weaver and Hagans 1994). Managers strive to achieve the optimal balance between cost and benefit, between risk of failure and the cost of prevention. However, according to the USDA Forest Service (Copstead 1997), more than half of the forest roads constructed in the last 50 years are not adequately maintained in a usable condition.

There is the risk of dramatic environmental impact in cases of stream crossing failure. Debris slides and torrents are always a potential risk during storms (Wemple et al. 2001), and a debris torrent delivered from upstream of a road crossing has the potential to quickly clog even a relatively large-sized culvert. During high flow culverts may become clogged with branches, logs, whole trees and other assorted debris. A clogged culvert can rapidly lead to a partial or total failure of the crossing structure. Diverted water may flow across the road surface, eroding the adjacent road prism. Even if the misplaced flow does not further erode the hillside it runs across, the volume of sediment from the eroded road crossing can be great (Wemple et al. 2001).

In the Pacific Northwest, many salmonid populations are already in jeopardy. Potential pulses of sediment into fish-bearing streams (or their tributaries) pose a great risk to the fishes' health and ability to reproduce (Newcombe and MacDonald 1991, Servizi and Martens 1992, Shaw and Richardson 2001). Based on the seriousness of this threat and on the increasing cost of maintaining non-decommissioned roads, both private and government agencies are decommissioning roads determined not to be needed in the near future. The National Park Service and the US Forest Service both receive annual funding for this process (Madej 2001).

When a forest road is decommissioned it is often in response to a change in the use of the forest in that area. In this case the cost of the road removal must be included in the cost of the new forest management plan (Niemi and Whitelaw 1999). Road removal treatments vary according to the goals and desired permanence of the decommissioning.

A road may be decommissioned only temporarily, as in the case of a logging road leading to a timber unit which will not be harvested again for 20 years or more. Some projects remove the road permanently, such as in the Headwaters Forest Preserve. In this case, land that was previously used for timber harvest has changed ownership and has been designated a preserve. In the Headwaters Forest Preserve and in Redwood National Park, some roads are converted to trails during the decommissioning process. This provides access for both outdoor recreation and future research (Morrison and Dunklin 1998).

Road decommissioning projects intended to control or prevent erosion consist of primary and secondary treatment activities. Primary treatment is the physical removal of potentially erodible fill materials, and secondary treatments protect the areas disturbed by the primary activities (Bundros et al. 1981).

Primary treatments are intended to restore the natural (pre-road) route and timing of surface and sub-surface flow in the watershed. Restoring the natural flow of water as much as possible decreases the risk that road material will become saturated and undergo mass wasting (Walder and Bagley 1999). The road surface can also be decompacted or “ripped” to increase infiltration through the road bed (Luce 1997). The former road surface is commonly outsloped, inboard ditches are filled, and unstable downslope fill is removed.

An important part of road decommissioning is the treatment of any stream crossings. Fill dirt, wood, and culverts are removed, and the operators excavate the crossing down to the natural streambed (Coffin 2000). Finding the natural streambed after it has been buried for years or decades is made more difficult by the fact that original streambed materials were often pushed out of the way during road construction to create a smooth, more stable base for the culvert (Morrison and Dunklin 1998). Every excavated stream crossing is a potentially large source of sediment to the stream, so it is critical that the fill be removed completely from the channel (Walder and Bagley 1999).

Once the crossing has been excavated, various secondary erosion control measures are commonly applied to the bankslopes and channel (Morrison and Dunklin 1998, Weaver and Hagans 2000):

1. Straw may be applied to bare soil to shield soil particles from rain and help prevent surface erosion.
2. Whole hay bales may be used as check dams within very small streams or swales where surface flow may tend to concentrate. Bales of hay can also be placed on large areas of bare soil (Weaver and Hagans 1994).
3. Large pieces of wood from trees cut during the decommissioning process and from excavated crossings can be applied to cover bare soil and to break up any surface flow across the exposed soil. The wood also provides shade and moisture to insects, birds, mammals and young vegetation (Morrison and Dunklin 1998).
4. Wood pieces may also be chipped and then applied to bare soil, providing a large amount of surface coverage. Wood chips also protect soil particles from raindrops, helping prevent surface erosion.
5. The streambed can be fortified with large cobbles and even small boulders to prevent channel erosion and incision during the winters after treatment.
6. Grass seeding can be used to provide stability for bare soil. However, this technique is not suitable for all areas, especially on slopes which are very

steep (greater than 45 degrees), and in areas which experience high winds or other processes which would remove the grass seed before it could take root (Weaver and Hagans 1994).

7. Trees may be planted on excavated bankslopes to provide stability with the strength of their root networks when the trees are older.

Additional treatments, such as the construction stream grade control structures, are generally found in larger crossings. Secondary erosion control treatments are widely used. They are also expensive to apply, and not necessarily cost-effective (Weaver and Hagans 2000). All decisions on whether or not to apply secondary erosion control measures are made in accordance with the judgment, protocols, and the budget of the decommissioning agencies. Consequently, treatments can vary widely even among excavated crossings which have similar site characteristics.

When stream crossings are excavated during road decommissioning, channel incision is a common post-treatment response. Pacific Watershed Associates (2005) found that 95 percent of the stream crossings surveyed had some degree of channel incision. Incision can be caused by several post-treatment conditions. Crossings which acted as sediment barriers in the past, causing sediment accrual upstream, are susceptible to post-treatment incision, as are crossings which were incompletely excavated. Stream crossings with culverts are particularly susceptible to incision because culverts provide grade control when the stream channel has already undergone some incision before decommissioning. Post-treatment incision results directly in sediment delivery to the stream, and can also cause bank over-steepening, which leads to failures and additional sediment input (Castro 2003).

Stream power expresses the ability of a stream to do work, generally the transportation of bed materials. Analysis of data from 207 stream crossings decommissioned over a period of seventeen years revealed that a surrogate for stream power, watershed area multiplied by slope of the channel, and the total volume of material excavated from each crossing were the only two significant predictors of the volume of post-treatment erosion (Madej 2001). Klein (1987) found that erosion in excavated stream crossings was directly correlated with stream power, and inversely correlated with the percentages of large material in the streambanks and woody debris in the streambed.

Cook and Dresser (2007) examined 262 excavated stream crossings within Six Rivers National Forest and found that 40 percent of post-treatment erosion was from stream channel adjustment, with 60 percent resulting from sideslope failures. They did not find stream power to be a good predictor of post-treatment erosion, but found storm history during the first winter after decommissioning to be an effective predictor when combined with the total amount of fill excavated from a given stream crossing. Average post-treatment erosion was found to be approximately 4.5 percent of the total fill excavated, with relatively large crossings having a smaller percentage of erosion compared to the volume of material removed during decommissioning.

While stream crossing channel incision is a common post-treatment response to road decommissioning, Klein (2003) determined bank failure to not be a major erosional process in his study of sixty-five excavated stream crossings. Although road removal and stream crossing excavation are widely practiced by both government agencies and private landowners, there has been a lack of research on the effects of decommissioning

(Switalski et al. 2004). Luce (2002) called research on the effectiveness of restoration efforts “critical.”

As in any environmental rehabilitation project, planners and managers strive to obtain the maximum benefit from each restoration dollar. The research needs expressed by other scientists, and the drive to achieve the most benefit from each restoration dollar, provided the motivation for this study.

Land managers must have feedback on the usefulness of common techniques when decommissioning a stream crossing. The goal of this project was to identify physical characteristics of excavated stream crossings which have the greatest potential influence on post-treatment erosion. These crucial variables may be site characteristics such as rock type and watershed size, or management-related factors such as slope of excavated banks and channels and application of secondary erosion control treatments.

The results of this study contribute information which may be used in the development of guidelines for land managers to identify conditions at stream crossings that could aggravate erosion, and then adapt decommissioning techniques to address those conditions. To focus restoration efforts on the most cost-effective use of technique and treatment, it is necessary to quantify the strength of possible controlling variables, as well as the relative importance of the type of erosion each variable affects. Tailoring decommissioning methods to address specific erosion risk factors, based on characteristics of the area, would make the decommissioning process more cost-effective, so that each dollar spent can be used for the best possible effect.

# METHODS

To acquire access permits and select the stream crossings for this study, I contacted the Bureau of Land Management and the United States Forest Service. Each agency provided maps and directions to roads which had been decommissioned one to two years previously. The only crossings eliminated from the study were small swales, which did not meet the selection criterion of having clearly separate and identifiable channel bed and banks. Due to the high rate of local re-vegetation and presumed speed of channel adjustment in streams to be studied, study sites were limited to those treated one to two years before the study. Klein (2003) suggested that half of all long-term post-treatment erosion occurs during the first year after decommissioning.

Assessment of post-treatment channel adjustment was performed on 20 excavated stream crossings from six decommissioned roads. Two roads with a total of nine crossings are in Klamath National Forest, one road with three crossings is located in Six Rivers National Forest, and three roads with a total of eight crossings are within Headwaters Forest Reserve in Northern California (Figure 1).

Stream crossings in this study shared the following characteristics:

1. crossing had clearly identifiable, separate channel bed and banks
2. no fish or amphibians were observed at any site
3. channel slopes ranged between 4 and 15 degrees
4. stream channel widths were between 0.3 to 2.1 meters
5. watershed areas for the study crossings ranged from 0.018 to 0.435 $km^2$

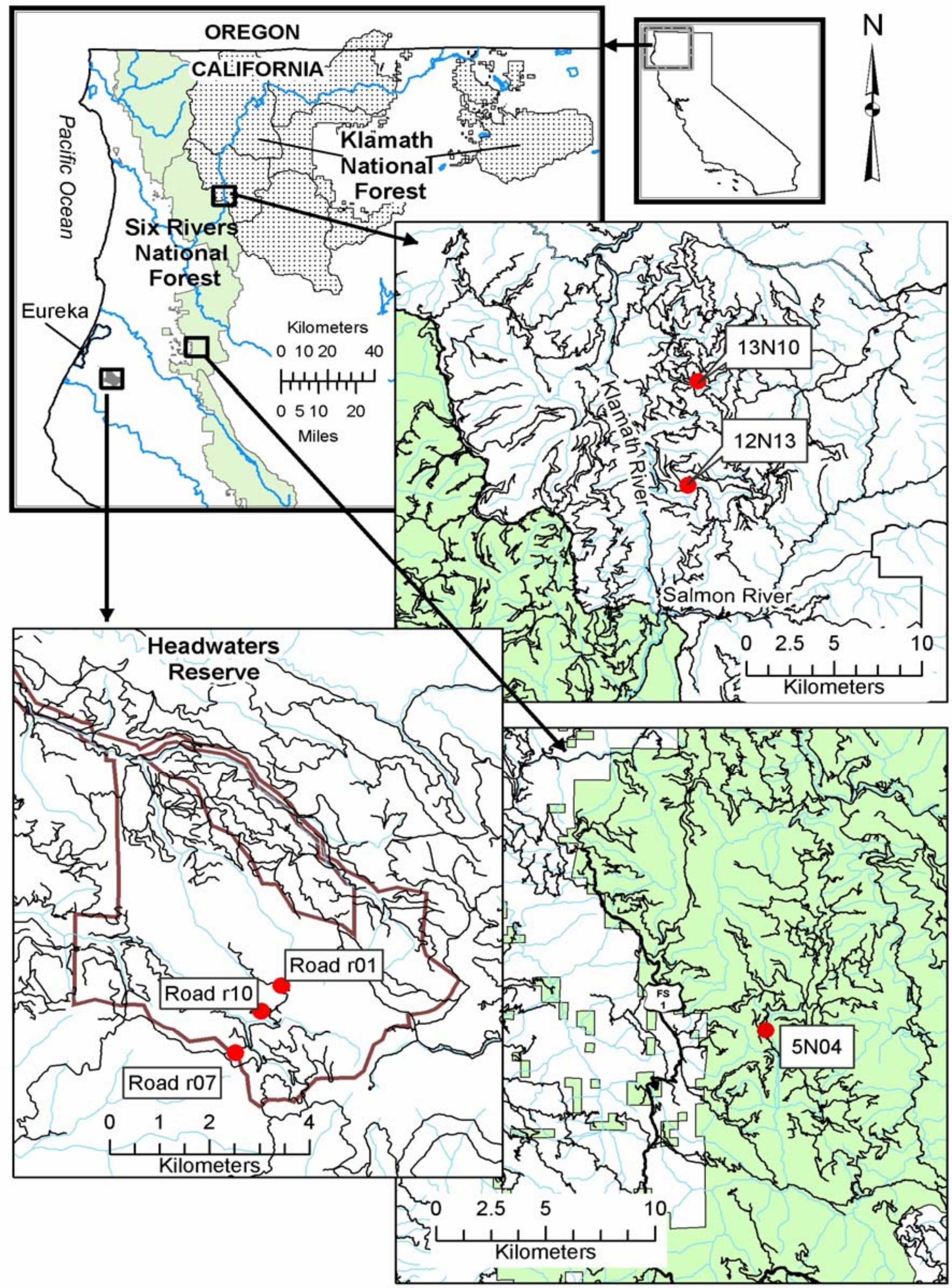


Figure 1. Location of study roads in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest.

Stream crossings included in this study were located on four different bedrock types (Table 1). In Klamath National Forest, the nine crossings studied were in decomposed granitic rock, which is relatively soft and susceptible to erosion. The three study crossings within Six Rivers National Forest are in the Galice Formation. Young (1978) characterized the Galice formation as an interbedded, very fine to coarse-grained metagraywacke. The rock type at the three study crossings within this formation is an incompletely metamorphosed, medium grained rock which Young described as low-grade semischist.

In the Headwaters Forest Reserve, data were collected at eight crossings on three roads, r01, r07 and r10. Six of the crossings in the Headwaters Reserve were in the Wildcat Formation, which consists of soft sandstone, siltstone, and claystone. These soft rocks are subject to erosion after disturbance to the vegetation cover, such as during the road decommissioning process. Two of the study crossings in the Headwaters Reserve were within the Yager Formation, which in this area consists of hard sandstone.

Some sections of Headwaters roads r01 and r10 were constructed right along the border between Wildcat and Yager Formations. This decision may have been to utilize the strength of the Yager Formation for road placement, while taking advantage of the relative ease of excavation of Wildcat Formation material. The boundary between the two rock formations may have also produced a break in the natural (pre-road) topography, making that location desirable for road construction.

The watershed size of each study crossing ranged from 0.02 to 0.44 square kilometers (Table 1). The smallest watersheds were located within Headwaters Reserve and the largest in the Klamath National Forest.

Table 1. Physical characteristics of study crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Forest, Road, Crossing | Rock Type | Forest Type | Age of Excavation (yrs) | Watershed Area ($km^2$) | Watershed Spring-Fed? |
|---|---|---|---|---|---|
| Headwaters r01, 3 | Wildcat Formation | redwood | 2 | 0.06 | no |
| Headwaters r01, 2 | Wildcat Formation | redwood | 1 | 0.02 | no |
| Headwaters r01, 1 | Wildcat Formation | redwood | 1 | 0.02 | no |
| Headwaters r07, 3 | Wildcat Formation | redwood | 2 | 0.05 | no |
| Headwaters r07, 2 | Wildcat Formation | redwood | 2 | 0.04 | no |
| Headwaters r07, 1 | Wildcat Formation | redwood | 2 | 0.02 | no |
| Headwaters r10, 2 | Yager Formation | redwood | 2 | 0.05 | no |
| Headwaters r10, 1 | Yager Formation | redwood | 2 | 0.12 | no |
| Klamath 12N13, 5 | Decomposed Granite | mixed tanoak | 1 | 0.08 | no |
| Klamath 12N13, 4 | Decomposed Granite | mixed tanoak | 1 | 0.08 | no |
| Klamath 12N13, 3 | Decomposed Granite | mixed tanoak | 1 | 0.12 | no |
| Klamath 12N13, 2 | Decomposed Granite | mixed tanoak | 1 | 0.20 | no |
| Klamath 13N10, 5 | Decomposed Granite | tanoak | 2 | 0.08 | yes |
| Klamath 13N10, 4 | Decomposed Granite | tanoak | 2 | 0.35 | yes |
| Klamath 13N10, 3 | Decomposed Granite | tanoak | 2 | 0.44 | yes |
| Klamath 13N10, 2 | Decomposed Granite | tanoak | 2 | 0.19 | no |
| Klamath 13N10, 1 | Decomposed Granite | tanoak | 2 | 0.12 | no |
| Six Rivers 5N04, 3 | Galice Formation | mixed tanoak | 2 | 0.19 | no |
| Six Rivers 5N04, 2 | Galice Formation | mixed tanoak | 2 | 0.15 | no |
| Six Rivers 5N04, 1 | Galice Formation | mixed tanoak | 2 | 0.21 | no |

The vegetation at the study sites has historically been predominantly coniferous forest. Each decommissioned road used in this study has been used for timber extraction in the past. Tanoak forests at the study sites within Six Rivers and Klamath National Forests are successional stages following the harvest of Douglas-fir and other conifers (Table 1). The climate of the study areas is often referred to as Mediterranean. Summers are dry, and winters are relatively mild but with high precipitation.

Data were collected between July and September of 2004. The age of excavation of each study site was one or two years, so each site had experienced precipitation either during water year 2004 only, or during both 2003 and 2004. Precipitation during those years was relatively close to the long-term average, with 2003 slightly above average and 2004 slightly below average (Table 2).

For this study each crossing was divided into two areas: 1) the excavated stream channel; and 2) the right and left excavated banks, which form a continuous slope from the historical road surface down to the channel (Figure 2). Post-treatment erosion from excavated crossings fell into two main categories: channel erosion and erosion from the banks. Bank erosion was further divided into gully erosion and bank failures (Figure 3). Total volume of material from each type of erosion was calculated from measurements of each erosion feature's length, mean width, and mean depth (Table 3). The vertical depth of channel incision was measured from the break in slope at the bottom of the excavated stream bank, to the top of the native channel material.

Measurement of void spaces left by erosion features is consistent with the methods of Madej's (2001) study of erosion following forest road removal. Stream channels were excavated to a simple configuration. The generally accepted protocol

Table 2. Precipitation at study areas in Headwaters Forest Reserve, Six Rivers National Forest, and Klamath National Forest during water years 2003 and 2004.

| Study Area: Rain Gage Location | Water Year | Precipitation | Percent of Average |
|---|---|---|---|
| Klamath Forest: Salmon River | 2003 | 132 cm | 121% of 50-yr avg. |
| | 2004 | 99 cm | 90% of 50-yr avg. |
| Six Rivers Forest: Willow Creek | 2003 | 149 cm | 106% of 30-yr avg. |
| | 2004 | 131 cm | 93% of 30-yr avg. |
| Headwaters Forest: Arcata | 2003 | 135 cm | 111% of 30-yr avg. |
| | 2004 | 105 cm | 87% of 30-yr avg. |


Figure 2. Excavated stream crossing (Klamath National Forest road 13N10, crossing 1, August 18, 2004).

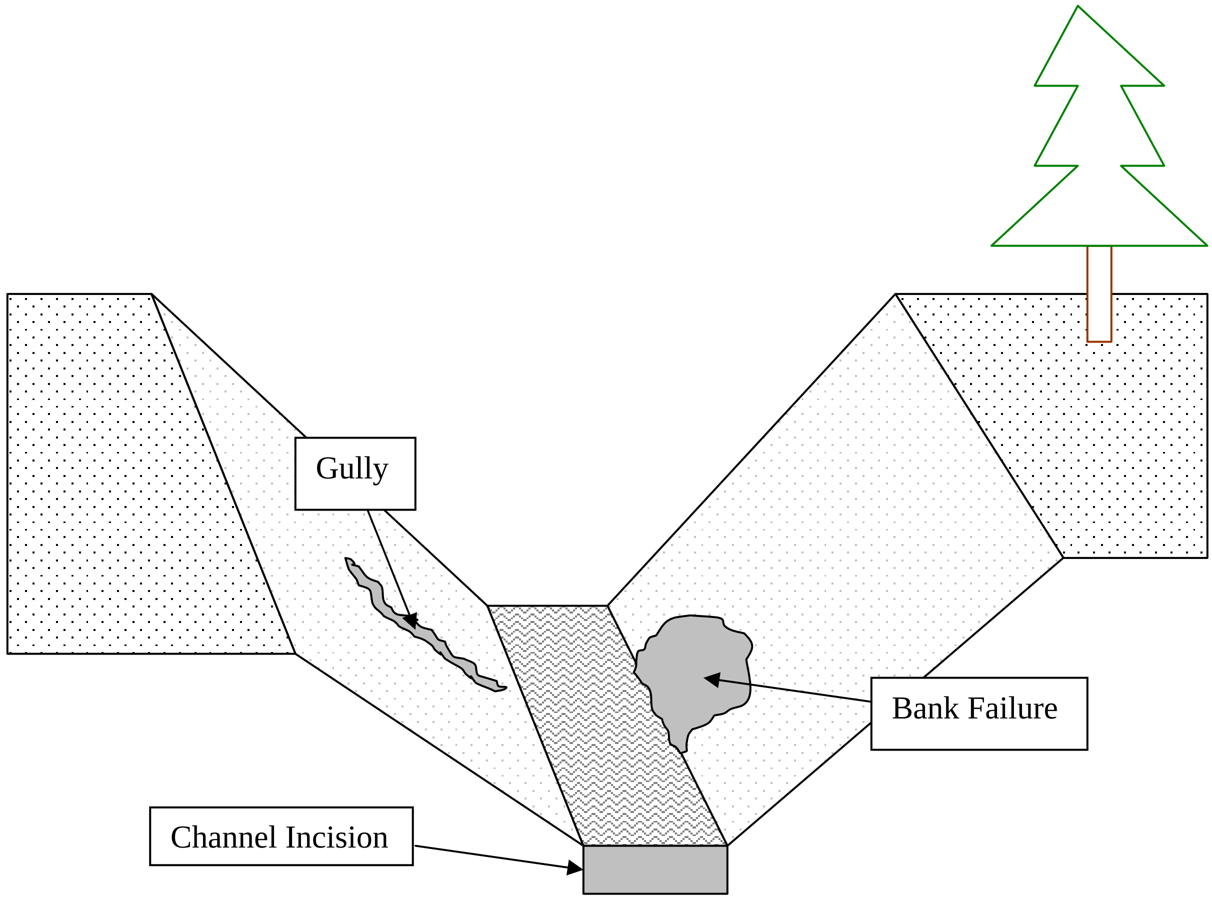


Figure 3. Post-treatment erosion types.

Table 3. Sample data collection sheet.

Klamath National Forest
Road 12N13, Crossing 5
Data Collected Summer 2004
Decommission Age: 1 year
Rock type: Decomposed Granite
Secondary erosion control (on banks): straw
Secondary erosion control (in channel): none apparent

| LEFT BANK | | RIGHT BANK | | CHANNEL | |
|---|---|---|---|---|---|
| slope (deg.) | 36 | slope (deg.) | 34 | slope (deg.) | 15 |
| surface area ($ft^2$) | 1512.00 | surface area ($ft^2$) | 1931.00 | length of crossing (ft | 75 |
| surface erosion ($ft^2$) | none | surface erosion ($ft^2$) | none | channel width (ft) | 1.5 |
| gully volume ($ft^3$) | 12.50 | gully volume ($ft^3$) | 0.00 | excavated width (ft) | same |
| failure volume ($ft^3$) | 135.00 | failure volume ($ft^3$) | 82.50 | incision depth (ft) | 0.8 |

GEV (Gully Erosion Vol.) + BFV (Bank Failure Vol.) = TVBE (Total Vol. Bank Erosion)
(12.50 + 0.00) + (135.00 + 82.50) = 230.00 $ft^3$

Channel (length x width x incision depth) = TVCE (Total Vol. Channel Erosion)
75.00 x 1.50 x 0.80 = 90.00 $ft^3$

TVBE + TVCE = TVEC (Total Vol. Erosion at Crossing)
230.00 + 90.00 = 320.00 $ft^3$

included construction of a straight channel profile with little or no complexity, and banks which sloped from the channel up to the former road location with no changes in slope (Pacific Watershed Associates 2005).

Sediment from the erosion void spaces was assumed to be delivered to the stream system, as no re-deposition from erosion features in the stream crossing was visible at any of the study crossings. This is important to note because bank material re-deposited in the channel could lead to double counting the volume of sediment eroded from a crossing: first as bank erosion and then again as channel incision.

Site descriptions and measurements were recorded in the field at each excavated stream crossing in the study. The underlying rock type at each crossing was determined from geologic maps, and confirmed at each crossing in the field. The width of the active stream channel, the streambed showing evidence of “use” by water since excavation, was measured with a tape to one tenth of a foot (0.03 meters). If the active channel did not take up the entire width of the excavated channel, the excavated width was also measured with a tape to one tenth of a foot (0.03 meters). The gradient in degrees of the streambed was measured in the field with a hand level at each crossing. The slope in degrees of each excavated bank was also measured in the field with a hand level. Although natural stream banks vary in slope along the length of a stream, the excavated banks produced during the stream crossing decommissioning process are of uniform slope. The slope is uniform both along the length of the excavation, and from the historical road surface down to the stream channel.

The length of the excavated streambed through each crossing, and the surface dimensions of each excavated bank were also measured with a tape to the nearest foot

(0.3 meters). Post-treatment erosion features were categorized into three types: channel incision, gully erosion, and stream bank failure. Width and depth of each erosion feature were measured in at least three places using a tape to one tenth of a foot (0.03 meters). Measurements were then averaged and multiplied by the total length of the feature. Notes were made at each crossing on the presence and type of secondary erosion control measures used in the streambed and on stream banks. The surface area of each excavated bank was recorded so that the total volume of surface erosion could be calculated.

To determine the watershed area of each crossing, I delineated the contributing watershed area on 7.5" USGS topographic maps, transferred those watersheds to digital form onscreen using ArcMap (version 9.1), and then calculated the areas using ArcMap's CalcArea script.

## Data Analysis

Post-treatment erosion data were analyzed using the analysis package within Microsoft Excel. For the channel erosion data, correlation was performed on each set of dependent and independent variables (described below) to determine whether there was a relationship between the variables. Student’s t-test was used to determine whether or not there was a relationship between the dependent and independent variables. Finally, for each set of dependent and independent variables determined by the t-test to have a significant relationship, I then performed a simple (linear) regression to quantify the nature of that relationship.

The total volume of erosion at a crossing (*TVEC*) is the sum of the total volume of bank erosion (*TVBE*) and the total volume of channel erosion (*TVCE*).

$$TVEC = TVBE + TVCE$$

The total volume of channel erosion (*TVCE*) is the product of channel length through the crossing (*L*), the width of the active channel (*W*), and the vertical depth of channel incision (*D*) (Figure 3).

$$TVCE = (L * W * D)$$

The width of the stream channel is determined by a combination of factors including precipitation, watershed area and underlying rock type. Length of the excavated crossing is determined only by the width of the road crossing which was removed. To avoid having a dependent variable with some of the same components as the independent variables, I selected the depth of channel incision rather than the total volume of channel erosion as the dependent variable for channel erosion.

The following site characteristics were the independent variables tested for correlation with depth of channel incision.

1. Slope of the excavated channel. Although excavated slope is determined by trying to match the slope of the upstream and downstream channel, there may still be a relationship between slope and post-treatment incision.
2. Watershed area.
3. Stream power. The product of watershed area and the slope of the excavated channel was used as a surrogate for stream power.

Since the age of excavation of the study crossings is not a continuous variable like the independent variables above, only the comparison of means (t-test) was performed. Six of the excavated crossings were one year old at the time of observation, and 14 of the crossings had been excavated for two years.

Within the potential relationship between watershed size and the depth of channel incision, I also tested for relationships within two categories. The first category was the rock type at each crossing. The crossings in this study are located within four rock types: 1) Wildcat Formation, 2) Yager Formation, 3) decomposed granite, and 4) Galice Formation. Three of nine crossings in decomposed granite have watersheds which are spring fed. The presence of springs may alter the relationship between watershed size and amount of water which will pass through the excavated crossing following a given precipitation event by providing additional or differently-timed flow. Therefore, only crossings without springs were included in the correlation analyses.

The second category was the type of secondary erosion control method used in each excavated channel. Secondary channel erosion treatments observed at the study crossings were put into four categories: 1) straw; 2) wood, including whole logs and stumps excavated from within the crossing; 3) rock, ranging in size from cobbles to small boulders; and, 4) no apparent treatment. Other studies (Madej 2001, Klein 1987) have shown stream power to be a significant factor in predicting post-treatment erosion, so I also tested for a correlation between stream power and channel incision within each rock type.

Bank erosion was divided into two types for this study: gully erosion and erosion due to bank failure. The total volume of bank erosion (*TVBE*) is the sum of gully erosion volume (*GEV*) and bank failure volume (*BFV*).

$$TVBE = GEV + BFV$$

Once the data were collected, the sample size of sites which had gully or bank failure erosion was very small: only three of 40 streambanks had gullying, and four of 40 banks had erosion due to bank failure. Although statistical analysis of such small sample size is not appropriate, relationships between site characteristics and bank erosion may still be visible when the data are presented visually. The dependent variables (volume of gully erosion, and the volume of erosion due to bank failure) on each bank were plotted against each of the following independent variables:

1. The slope of each excavated bank.
2. Length of each excavated bank. Measurements made to determine the surface area of each bank were used to calculate an average length of bank from the historic road surface to the edge of the channel. This average length is an index to compare the distance surface water may travel down each of the excavated banks.
3. Watershed area.

Since it is reasonable that the small, near-vertical banks created by channel incision could destabilize the excavated bank above them, the volume of erosion due to bank failure was also plotted against depth of channel incision.

# RESULTS

The two largest volumes of post-treatment erosion occurred within Galice Formation schist, at crossings two and three of road SR 5N04 (Table 4). The erosion volume from the two sites was 91.67 $m^3$, nearly half (48 percent) of the total erosion from all 20 crossings. The third largest total erosion volume (21.57 $m^3$) was at road HW r10, crossing one, within Yager Formation sandstone. All three sites had erosion from their banks and channels, but most of the eroded volume was from channels. These sites also represent the three largest volumes of channel erosion.

Erosion from the banks was seven percent of total erosion volume in this study. Four bank failures occurred at three crossings, contributing 91 percent (11.71 $m^3$) of total bank erosion (Table 5). One bank failure, on the right bank of crossing three of Six Rivers' road 5N04, accounts for 44 percent of bank failure erosion volume. Gully erosion volume was only 1.14 $m^3$, nine percent of total bank erosion. Out of 20 study crossings only four had either type of bank erosion. Two of these, crossing five of road K 12N13 and crossing one of road HW r10, had both bank failure and gully erosion.

Channel widths at the study crossings ranged from 0.30 to 2.13 meters, excavated channel lengths ranged from 9.1 to 30.5 meters, and channel incision varied between 0.00 and 0.91 meters (Table 6). Only two study crossings, crossing one of Headwaters Forest road r01 and crossing three of Klamath Forest road 12N13, had no incision. These crossings were both one year old at the time of survey. Site characteristics which may have had an impact on depth of post-treatment incision at each crossing are presented in Table 7.

Table 4. Total volume of post-treatment erosion at twenty excavated study crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Forest, Road, Crossing | Rock Type | Age of Excavation (yrs) | Watershed Area ($km^2$) | Watershed Spring-Fed? | Total Vol. Channel Erosion ($m^3$) | Total Vol. Bank Erosion ($m^3$) | Total Vol. Erosion at Crossing ($m^3$) |
|---|---|---|---|---|---|---|---|
| Headwaters r01, 3 | Wildcat Formation | 2 | 0.06 | no | 12.10 | none | 12.10 |
| Headwaters r01, 2 | Wildcat Formation | 1 | 0.02 | no | 1.70 | none | 1.70 |
| Headwaters r01, 1 | Wildcat Formation | 1 | 0.02 | no | none | none | none |
| Headwaters r07, 3 | Wildcat Formation | 2 | 0.05 | no | 4.82 | none | 4.82 |
| Headwaters r07, 2 | Wildcat Formation | 2 | 0.04 | no | 1.25 | none | 1.25 |
| Headwaters r07, 1 | Wildcat Formation | 2 | 0.02 | no | 0.93 | none | 0.93 |
| Headwaters r10, 2 | Yager Formation | 2 | 0.05 | no | 1.17 | none | 1.17 |
| Headwaters r10, 1 | Yager Formation | 2 | 0.12 | no | 20.89 | 0.67 | 21.57 |
| Klamath 12N13, 5 | Decomposed Granite | 1 | 0.08 | no | 2.55 | 6.51 | 9.06 |
| Klamath 12N13, 4 | Decomposed Granite | 1 | 0.08 | no | 1.55 | none | 1.55 |
| Klamath 12N13, 3 | Decomposed Granite | 1 | 0.12 | no | none | none | none |
| Klamath 12N13, 2 | Decomposed Granite | 1 | 0.20 | no | 4.02 | none | 4.02 |
| Klamath 13N10, 5 | Decomposed Granite | 2 | 0.08 | yes | 0.89 | none | 0.89 |
| Klamath 13N10, 4 | Decomposed Granite | 2 | 0.35 | yes | 6.37 | none | 6.37 |
| Klamath 13N10, 3 | Decomposed Granite | 2 | 0.44 | yes | 1.95 | none | 1.95 |
| Klamath 13N10, 2 | Decomposed Granite | 2 | 0.19 | no | 9.85 | none | 9.85 |
| Klamath 13N10, 1 | Decomposed Granite | 2 | 0.12 | no | 14.66 | none | 14.66 |
| Six Rivers 5N04, 3 | Galice Formation | 2 | 0.19 | no | 30.12 | 5.10 | 35.22 |
| Six Rivers 5N04, 2 | Galice Formation | 2 | 0.15 | no | 55.88 | 0.57 | 56.45 |
| Six Rivers 5N04, 1 | Galice Formation | 2 | 0.21 | no | 7.13 | none | 7.13 |

Table 5. Total volume of bank erosion at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Forest, Road, Crossing | Rock Type | Age (yrs) | Water-shed Area ($km^2$) | Secon-dary Erosion Control | Bank | Index of Bank Length (m) | Slope of Bank (deg) | Gully Erosion Vol. ($m^3$) | Bank Failure Vol. ($m^3$) | Total Vol. Bank Erosion ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Headwaters, | Wildcat | 2 | 0.06 | | l | 11.9 | 36 | 0.00 | 0.00 | 0.00 |
| r01, 3 | Formation | | | straw | r | 8.6 | 34 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Wildcat | 1 | 0.02 | straw, | l | 10.9 | 24 | 0.00 | 0.00 | 0.00 |
| r01, 2 | Formation | | | wood | r | 8.2 | 18 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Wildcat | 1 | 0.02 | straw, | l | 9.0 | 25 | 0.00 | 0.00 | 0.00 |
| r01, 1 | Formation | | | wood | r | 10.6 | 20 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Wildcat | 2 | 0.05 | straw, | l | 3.0 | 33 | 0.00 | 0.00 | 0.00 |
| r07, 3 | Formation | | | wood | r | 2.5 | 32 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Wildcat | 2 | 0.04 | straw, | l | 6.4 | 32 | 0.00 | 0.00 | 0.00 |
| r07, 2 | Formation | | | wood | r | 10.3 | 32 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Wildcat | 2 | 0.02 | straw, | l | 8.6 | 32 | 0.00 | 0.00 | 0.00 |
| r07, 1 | Formation | | | wood | r | 8.6 | 30 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Yager | 2 | 0.05 | straw, | l | 16.3 | 30 | 0.00 | 0.00 | 0.00 |
| r10, 2 | Formation | | | wood | r | 15.7 | 28 | 0.00 | 0.00 | 0.00 |
| Headwaters, | Yager | 2 | 0.12 | straw, | l | 7.0 | 29 | 0.22 | 0.45 | 0.67 |
| r10, 1 | Formation | | | wood | r | 12.2 | 35 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 1 | 0.08 | | l | 8.5 | 36 | 0.35 | 3.82 | 4.18 |
| 12N13, 5 | Granite | | | straw | r | 9.8 | 34 | 0.00 | 2.33 | 2.33 |
| Klamath, | Decomposed | 1 | 0.08 | straw, | l | 3.2 | 37 | 0.00 | 0.00 | 0.00 |
| 12N13, 4 | Granite | | | wood | r | 4.8 | 28 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 1 | 0.12 | | l | 16.1 | 38 | 0.00 | 0.00 | 0.00 |
| 12N13, 3 | Granite | | | wood | r | 14.4 | 38 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 1 | 0.20 | | l | 11.9 | 28 | 0.00 | 0.00 | 0.00 |
| 12N13, 2 | Granite | | | wood | r | 9.6 | 28 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 2 | 0.08 | | l | 4.0 | 23 | 0.00 | 0.00 | 0.00 |
| 13N10, 5 | Granite | | | straw | r | 4.3 | 23 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 2 | 0.35 | | l | 10.5 | 30 | 0.00 | 0.00 | 0.00 |
| 13N10, 4 | Granite | | | straw | r | 7.9 | 27 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 2 | 0.44 | | l | 8.0 | 23 | 0.00 | 0.00 | 0.00 |
| 13N10, 3 | Granite | | | straw | r | 4.8 | 28 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 2 | 0.19 | | l | 9.3 | 27 | 0.00 | 0.00 | 0.00 |
| 13N10, 2 | Granite | | | straw | r | 9.9 | 30 | 0.00 | 0.00 | 0.00 |
| Klamath, | Decomposed | 2 | 0.12 | straw, | l | 6.4 | 40 | 0.00 | 0.00 | 0.00 |
| 13N10, 1 | Granite | | | wood | r | 6.3 | 27 | 0.00 | 0.00 | 0.00 |
| Six Rivers, | Galice | 2 | 0.19 | | l | 4.3 | 35 | 0.00 | 0.00 | 0.00 |
| 5N04, 3 | Formation | | | straw | r | 4.2 | 25 | 0.00 | 5.10 | 5.10 |
| Six Rivers, | Galice | 2 | 0.15 | trees | l | 8.2 | 40 | 0.57 | 0.00 | 0.57 |
| 5N04, 2 | Formation | | | planted | r | 8.9 | 42 | 0.00 | 0.00 | 0.00 |
| Six Rivers, | Galice | 2 | 0.21 | trees | l | 5.4 | 33 | 0.00 | 0.00 | 0.00 |
| 5N04, 1 | Formation | | | planted | r | 3.3 | 34 | 0.00 | 0.00 | 0.00 |

Table 6. Total volume of channel erosion at twenty excavated stream crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Forest, Road, Crossing | Channel Length (m) | Channel Width (m) | Depth of Channel Incision (m) | Total Volume of Channel Erosion ($m^3$) |
|---|---|---|---|---|
| Headwaters r01, 3 | 29.0 | 0.91 | 0.46 | 12.10 |
| Headwaters r01, 2 | 24.4 | 0.46 | 0.15 | 1.70 |
| Headwaters r01, 1 | 23.8 | 0.30 | 0.00 | 0.00 |
| Headwaters r07, 3 | 21.6 | 0.49 | 0.46 | 4.82 |
| Headwaters r07, 2 | 26.8 | 0.61 | 0.08 | 1.25 |
| Headwaters r07, 1 | 25.0 | 0.30 | 0.12 | 0.93 |
| Headwaters r10, 2 | 25.3 | 0.30 | 0.15 | 1.17 |
| Headwaters r10, 1 | 25.0 | 0.91 | 0.91 | 20.89 |
| Klamath 12N13, 5 | 22.9 | 0.46 | 0.24 | 2.55 |
| Klamath 12N13, 4 | 18.6 | 0.37 | 0.23 | 1.55 |
| Klamath 12N13, 3 | 30.5 | 0.61 | 0.00 | 0.00 |
| Klamath 12N13, 2 | 21.6 | 0.61 | 0.30 | 4.02 |
| Klamath 13N10, 5 | 9.1 | 0.46 | 0.21 | 0.89 |
| Klamath 13N10, 4 | 13.7 | 1.52 | 0.30 | 6.37 |
| Klamath 13N10, 3 | 14.0 | 0.91 | 0.15 | 1.95 |
| Klamath 13N10, 2 | 17.7 | 1.83 | 0.30 | 9.85 |
| Klamath 13N10, 1 | 22.6 | 2.13 | 0.30 | 14.66 |
| Six Rivers 5N04, 3 | 23.2 | 2.13 | 0.61 | 30.12 |
| Six Rivers 5N04, 2 | 28.7 | 2.13 | 0.91 | 55.88 |
| Six Rivers 5N04, 1 | 17.1 | 1.83 | 0.23 | 7.13 |

Table 7. Independent variables which may have affected channel incision at the study crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Forest, Road, Crossing | Channel Slope (deg) | Age of Excavation (yrs) | Watershed Area ($km^2$) | Stream Power Surrogate Variable | Rock Type | Secondary Channel Erosion Control | Depth of Channel Incision (m) |
|---|---|---|---|---|---|---|---|
| Headwaters r01, 3 | 17 | 2 | 0.06 | 1.08 | Wildcat Formation | wood | 0.46 |
| Headwaters r01, 2 | 15 | 1 | 0.02 | 0.34 | Wildcat Formation | straw | 0.15 |
| Headwaters r01, 1 | 11 | 1 | 0.02 | 0.19 | Wildcat Formation | straw | 0.00 |
| Headwaters r07, 3 | 18 | 2 | 0.05 | 0.88 | Wildcat Formation | none | 0.46 |
| Headwaters r07, 2 | 22 | 2 | 0.04 | 0.78 | Wildcat Formation | none | 0.08 |
| Headwaters r07, 1 | 13 | 2 | 0.02 | 0.26 | Wildcat Formation | wood | 0.12 |
| Headwaters r10, 2 | 4 | 2 | 0.05 | 0.19 | Yager Formation | wood | 0.15 |
| Headwaters r10, 1 | 8 | 2 | 0.12 | 0.99 | Yager Formation | none | 0.91 |
| Klamath 12N13, 5 | 15 | 1 | 0.08 | 1.19 | Decomposed Granite | none | 0.24 |
| Klamath 12N13, 4 | 12 | 1 | 0.08 | 0.95 | Decomposed Granite | rock | 0.23 |
| Klamath 12N13, 3 | 12 | 1 | 0.12 | 1.41 | Decomposed Granite | rock | 0.00 |
| Klamath 12N13, 2 | 12 | 1 | 0.20 | 2.37 | Decomposed Granite | none | 0.30 |
| Klamath 13N10, 5 | 13 | 2 | 0.08 | 1.01 | Decomposed Granite | none | 0.21 |
| Klamath 13N10, 4 | 14 | 2 | 0.35 | 4.86 | Decomposed Granite | rock | 0.30 |
| Klamath 13N10, 3 | 14 | 2 | 0.44 | 6.09 | Decomposed Granite | rock | 0.15 |
| Klamath 13N10, 2 | 8 | 2 | 0.19 | 1.50 | Decomposed Granite | rock | 0.30 |
| Klamath 13N10, 1 | 12 | 2 | 0.12 | 1.45 | Decomposed Granite | rock | 0.30 |
| Six Rivers 5N04, 3 | 8 | 2 | 0.19 | 1.49 | Galice Formation | wood | 0.61 |
| Six Rivers 5N04, 2 | 12 | 2 | 0.15 | 1.78 | Galice Formation | none | 0.91 |
| Six Rivers 5N04, 1 | 12 | 2 | 0.21 | 2.51 | Galice Formation | none | 0.23 |

Results of correlation analyses between the depth of channel incision and the independent variables at all 20 sites are contained in Table 8. Only age of excavation has a statistically significant correlation with depth of post-treatment incision. Mean depth of channel incision at sites which were two years old (0.37 m) is significantly higher than at sites which were one year old (0.15 m) at time of measurement (Figure 4). Since it is not appropriate to perform a regression analysis on an independent variable with only two categories (the age of all sites was either one or two years), the correlation and comparison of means was the final analysis performed on this set of variables.

Correlation analyses between independent variables and channel incision within rock types were performed (Table 9). Channel incision depth is not correlated with watershed area when the crossings within all rock types were analyzed together (Figure 5). However, depth of channel incision increases significantly with increasing watershed area at the six sites within Wildcat sandstone formation (Figure 6). The correlation between the depth of channel incision and watershed area is even stronger when the eight crossings within both sandstone formations are analyzed together (Figure 7).

Watershed size versus depth of channel incision was also tested for correlation within secondary erosion control method applied (Table 10). At the sites where any method of secondary erosion control had been used, post-treatment channel incision is positively correlated with watershed area (Figure 8). Regression analysis shows that this relationship is weak as watershed size explains only 35 percent of variation in post-treatment incision.

Table 8. Results of correlation of independent variables with channel incision at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Dependent Variable | Independent Variable | *r* | *t* | critical *t* | Reject H0 for correlation? |
|---|---|---|---|---|---|
| Channel Incision Depth | Channel Slope | -0.208 | -0.902 | 1.734 | no |
| Channel Incision Depth | Age of Excavation | 0.399 | 1.845 | 1.734 | yes |
| Channel Incision Depth | Watershed Size | 0.131 | 0.561 | 1.734 | no |
| Channel Incision Depth | Stream Power | 0.321 | 1.312 | 1.771 | no |

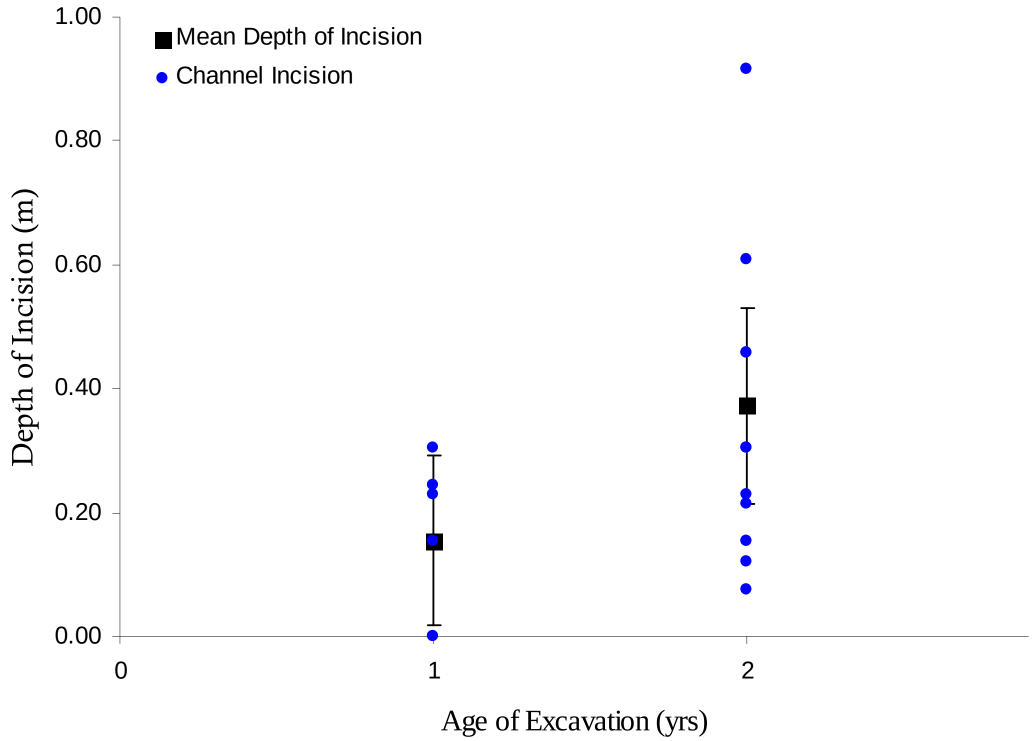


Figure 4. Distribution and mean depth of channel incision, with 95 percent confidence intervals, versus age of excavation, at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

Table 9. Results of correlation of independent variables with channel incision within rock types at the study crossings in Headwaters Forest Reserve and Klamath National Forest, Summer 2004.

| Dependent Variable | Independent Variable | *r* | *t* | critical *t* | Reject H0 for correlation? |
|---|---|---|---|---|---|
| Channel Incision Depth within the Wildcat Formation | Watershed Size | 0.889 | 3.893 | 2.132 | yes |
| Channel Incision Depth within Sandstone Formations | Watershed Size | 0.946 | 7.175 | 1.943 | yes |
| Channel Incision Depth within Granite | Watershed Size | 0.361 | 0.774 | 2.132 | no |
| Channel Incision Depth within the Wildcat Formation | Stream Power Surrogate Variable | 0.803 | 2.696 | 2.132 | yes |
| Channel Incision Depth within Sandstone Formations | Stream Power Surrogate Variable | 0.748 | 2.759 | 1.943 | yes |
| Channel Incision Depth within Granite | Stream Power Surrogate Variable | 0.279 | 0.581 | 2.132 | no |

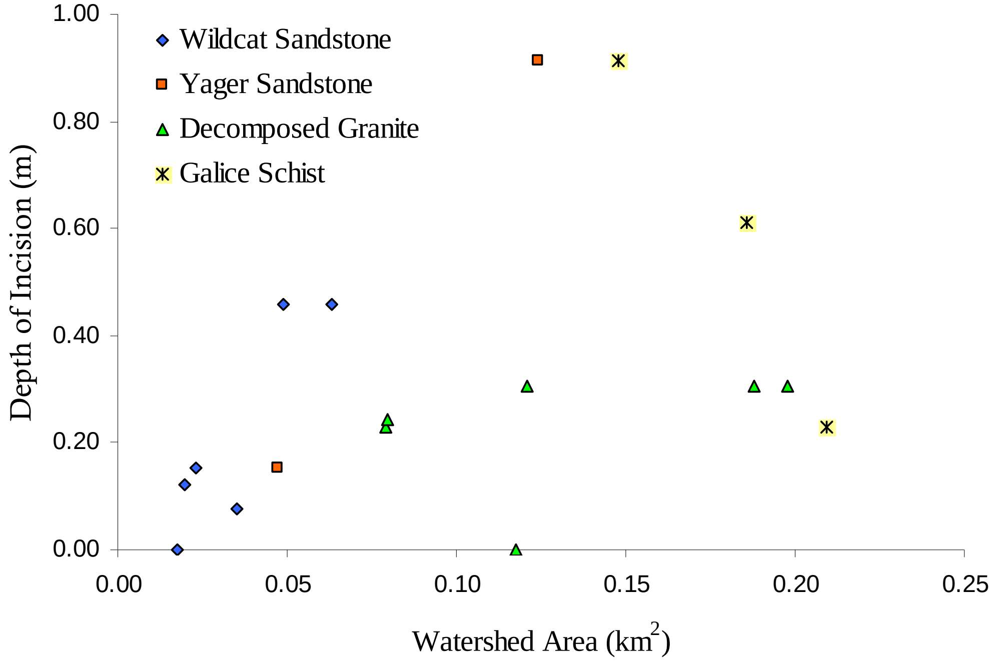


Figure 5. Channel incision versus watershed size by rock type at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

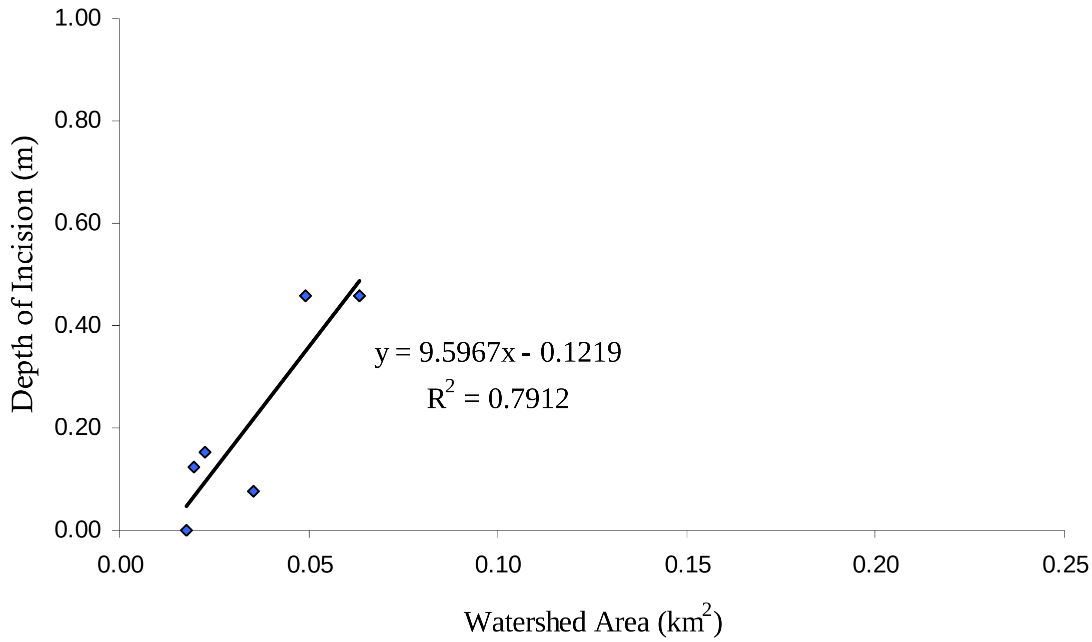


Figure 6. Channel incision versus watershed size at excavated crossings within the Wildcat formation in Headwaters Forest Reserve, Summer 2004.

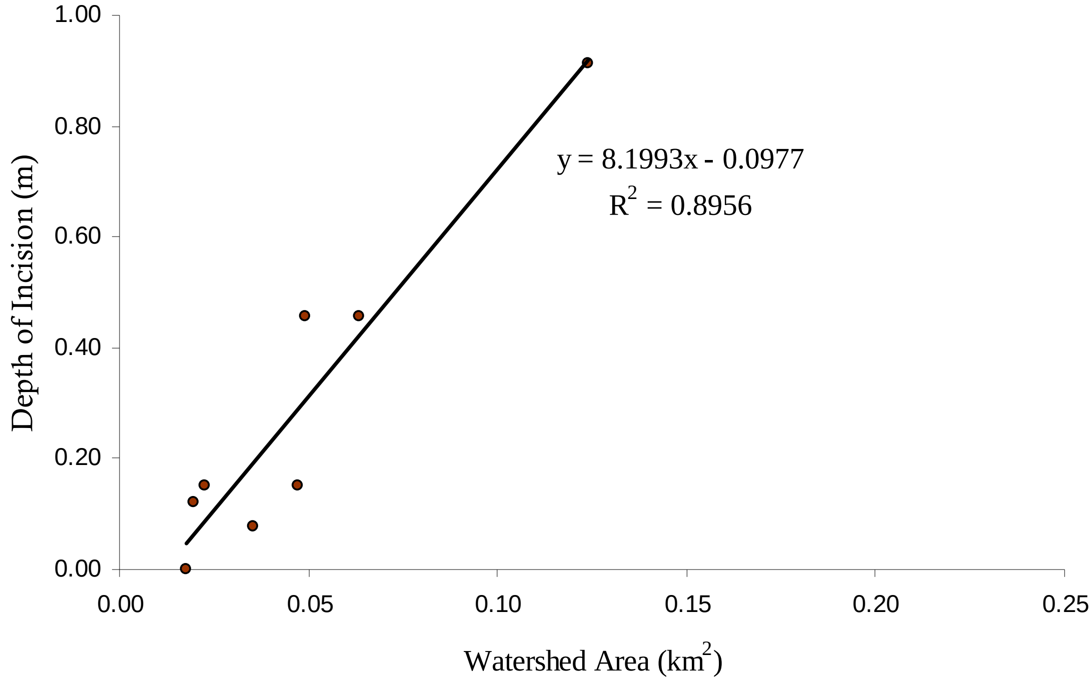


Figure 7. Channel incision versus watershed size at excavated crossings within the Wildcat and Yager sandstone formations in Headwaters Forest Reserve, Summer 2004.

Table 10. Results of correlation of independent variables with channel incision within secondary erosion control treatments at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

| Dependent Variable | Independent Variable | *r* | *t* | critical *t* | Reject H0 for correlation? |
|---|---|---|---|---|---|
| Channel Incision Depth with Any Method of Secondary Erosion Control | Watershed Size | 0.591 | 2.073 | 1.860 | yes |
| Channel Incision Depth with No Secondary Erosion Control Applied | Watershed Size | 0.167 | 0.380 | 2.015 | no |
| Channel Incision Depth with Rock as Secondary Erosion Control | Watershed Size | 0.324 | 0.485 | 2.920 | no |
| Channel Incision Depth with Wood as Secondary Erosion Control | Watershed Size | 0.876 | 2.569 | 2.920 | no |

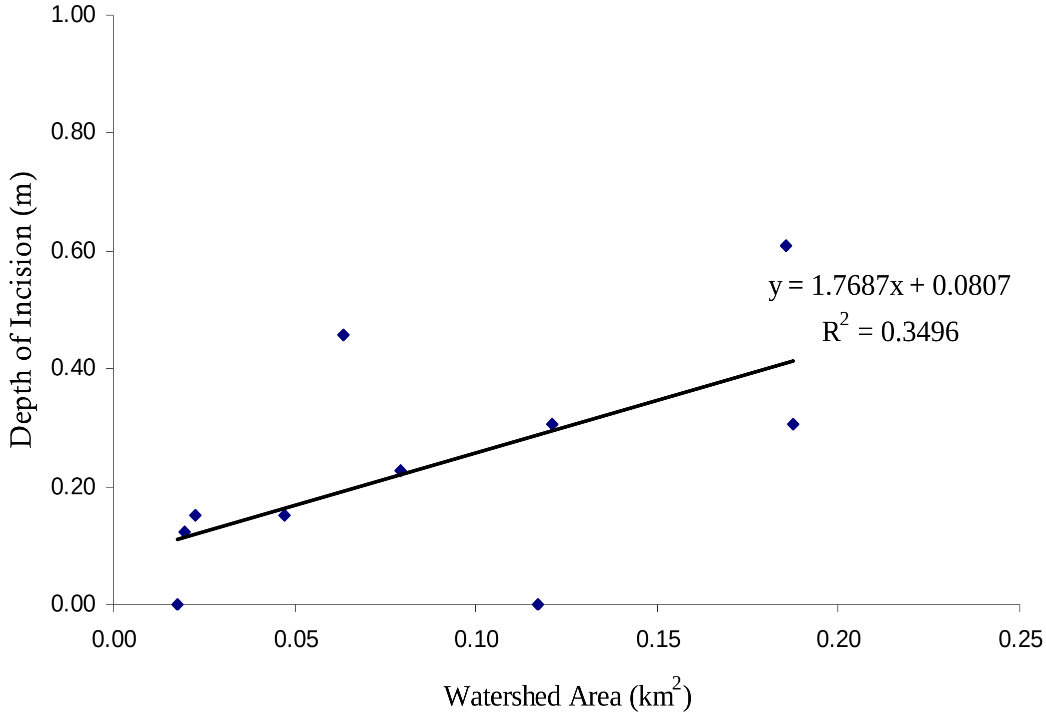


Figure 8. Channel incision versus watershed size with secondary erosion control measures applied, excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

The stream power surrogate variable used in this study is the product of watershed area and channel slope. Although watershed size alone was also tested for correlation with channel incision, other studies found stream power to be a significant predictor of post-excavation erosion (Madej 2001, Klein 1987). I also tested for a correlation between stream power and channel incision within each rock type.

Channel incision was not significantly correlated with the stream power surrogate variable within all four rock types together (Figure 9). Although the correlations were not as strong as between channel incision and watershed area (Figures 6, 7), stream power was positively correlated with post-treatment incision at the six sites within the Wildcat sandstone formation (Figure 10), and at the eight sites within the Wildcat and Yager sandstone formations (Figure 11).

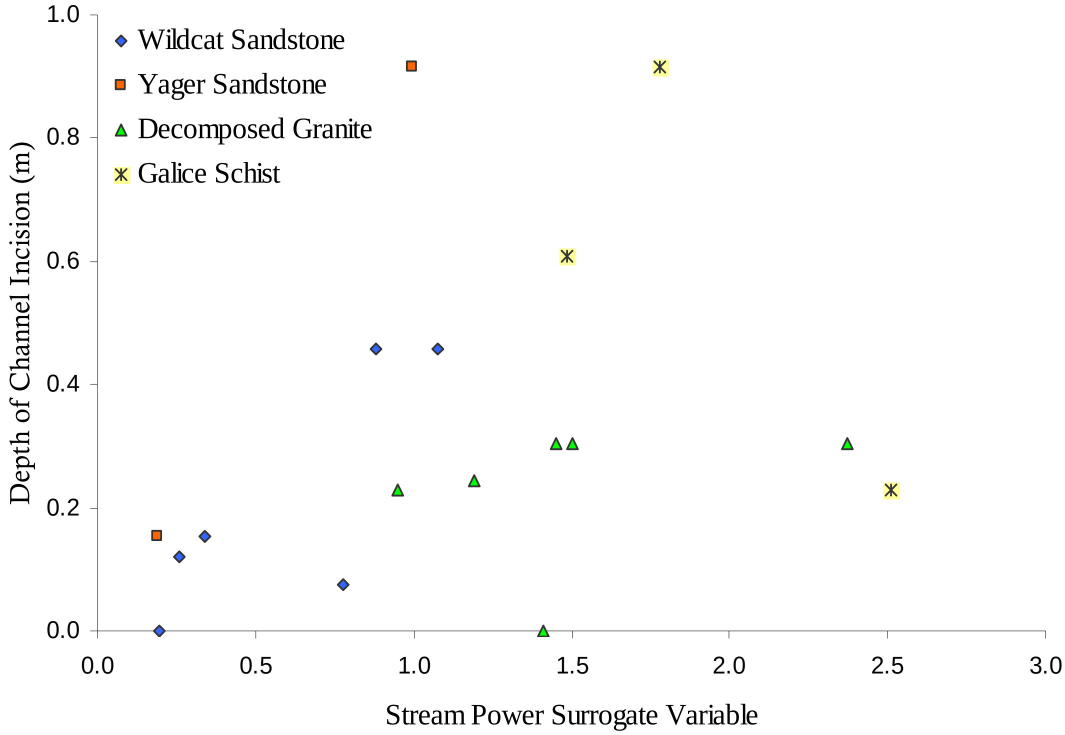


Figure 9. Channel incision versus stream power by rock type at excavated crossings in Headwaters Forest Reserve, Klamath National Forest, and Six Rivers National Forest, Summer 2004.

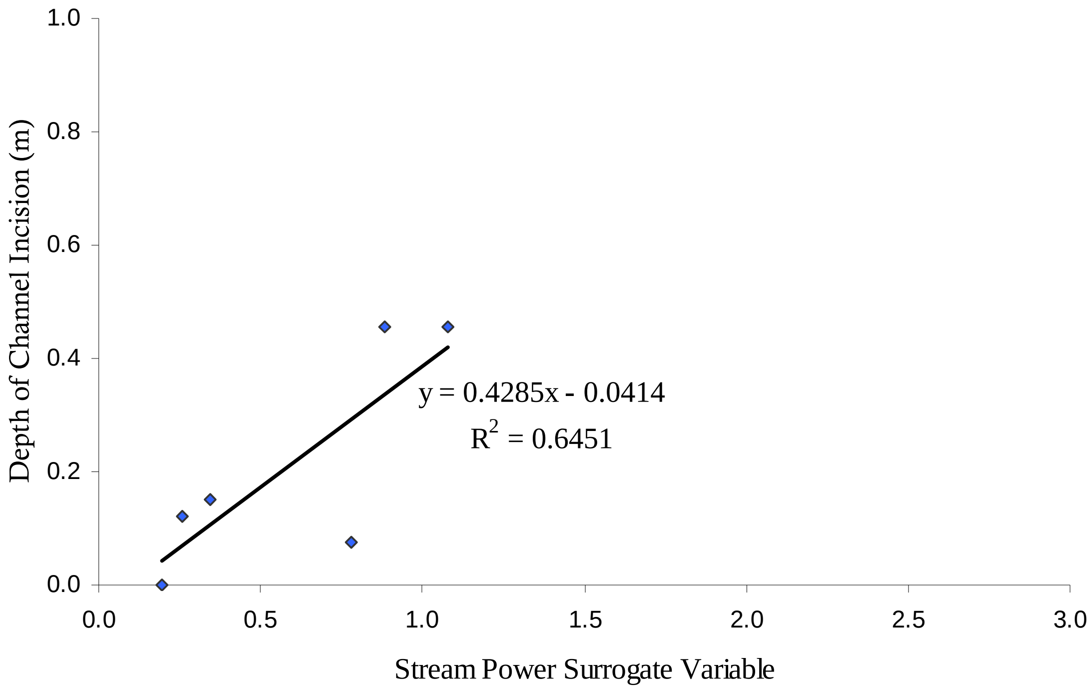


Figure 10. Channel incision versus stream power at excavated crossings within the Wildcat formation in Headwaters Forest Reserve, Summer 2004.

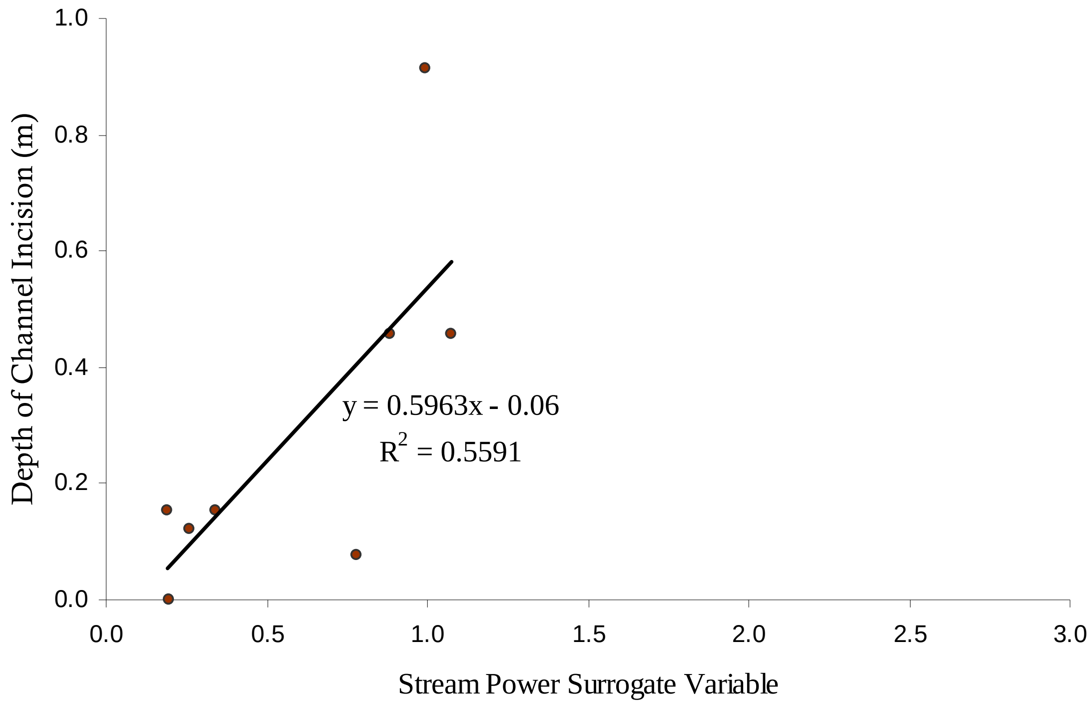


Figure 11. Channel incision versus stream power at excavated crossings within the Wildcat and Yager sandstone formations in Headwaters Forest Reserve, Summer 2004.

# DISCUSSION

The two largest volumes of post-treatment erosion occurred at sites within the Galice schist formation, suggesting that Galice material is less stable and less resistant to erosion than the sandstones and granite at other study sites. The third largest volume was at a crossing within the Yager sandstone formation. All three crossings had been excavated for two years when the data were collected. Although bank erosion was not a large percentage of total erosion at the crossings, each had erosion from both the channel and the banks. These three crossings may have been less stable than the others in this study, and therefore more susceptible to large scale failure had they not been decommissioned.

The total volume of erosion from the banks, bank failure volume and gully erosion volume, was relatively small (11.82 $m^3$). Bank erosion represented only seven percent of the total volume of eroded material measured in this study. Additionally, the majority of the yield (11.61 $m^3$) came from two crossings. This is consistent with Klein (2003) who studied 65 stream crossings in the Mattole River basin in northern California, where bank failure was not a major portion of post-treatment erosion. At the three sites with gully erosion, total gully volume did increase with increasing bank slope, bank length, and watershed size. The sites where gully erosion occurred were in the top two-thirds of the sample bank slopes, suggesting that with a larger sample size a significant relationship may exist between these two variables. Gully and bank failure erosion both occurred at sites in Headwaters, Six Rivers, and Klamath forests, and within Yager Formation sandstone, decomposed granite, and the Galice Formation.

The distribution of bank failure erosion volume versus independent variables on the four stream banks where failures occurred did not show any statistical relationship. There were no correlations between gully erosion or bank failure erosion and any of the secondary bank erosion control treatments applied to the study sites.

The greatest portion of total post-treatment erosion was contributed by channel incision, a volume of 180 $m^3$ (93 percent of total eroded material). In 16 of 20 study crossings, erosion due to channel incision accounted for all of the total post-treatment erosion. These results are consistent with the results of Pacific Watershed Associates' (2005) study on stream crossing erosion following road decommissioning. In that study 95 percent of stream crossings surveyed had some degree of channel incision. Land managers seeking to maximize return on their erosion control dollars might use this information to focus more on erosion control measures in channels, rather than on excavated banks.

Analysis of the post-treatment channel erosion data showed that the only significant independent variable in explaining the depth of post-treatment channel incision across all rock types was the age of site excavation. A factor which might be complicating the analyses of age as a predictive variable is the relationship between site age and site location. For example, all sites in Six Rivers National Forest are on a road which was two years old at the time of the study. This one road also represents all the sites located within the Galice Formation. Based on these compounding factors, researchers conducting future studies of this type might choose to restrict their study to sites of the same age, and within the same geologic formation.

Correlation analysis did not reveal a relationship between post-treatment channel incision and watershed size when the data from all twenty sites were analyzed together. However, analysis by rock type did reveal statistically significant relationships within the Wildcat Formation, and within the Wildcat and Yager sandstone formations together. Watershed area explained 79 percent of the variation in channel incision depth within the Wildcat Formation. Within the two sandstone formations, watershed area explained 90 percent of variation in post-treatment incision.

The lack of a uniform relationship between post-treatment incision depth and watershed size across all rock types could be due to inconsistencies in decommissioning technique. Among the study sites, the Wildcat and the Yager sandstone formations were found only in the Headwaters Forest Reserve. Klamath National Forest contained all sites in decomposed granite, and Six Rivers National Forest contained all sites in the Galice Formation schist. Forest-specific factors, such as different operators hired to perform the stream crossing excavations, or differences in precipitation type and amount of peak flows, could be responsible for obscuring an underlying relationship between dependent and independent variables.

At the ten sites where secondary erosion control was applied to the channel, depth of post-treatment channel incision increased with watershed area. Correlation analysis did not show a relationship between channel incision and watershed area within each type of secondary erosion control when analyzed separately, so secondary erosion control methods were not directly compared. A factor which may be affecting the results of the analysis is the preference for different secondary erosion control treatments in different areas. The sites in Klamath National Forest had only rock or no secondary erosion control treatment in the channel. Crossings in Six Rivers National Forest had either wood or no treatment applied. Headwaters Forest Reserve stream channels were treated with either straw, wood, or no treatment.

The stream power surrogate variable (the product of channel slope and watershed area), was not significant in predicting post-treatment channel incision for all the study sites together. Analysis by rock type did show significant relationships within the Wildcat Formation, and within the Wildcat and Yager sandstone formations together, just as in the relationship between channel incision and watershed size. Stream power explained 65 percent of the variation in channel incision depth within the Wildcat Formation, and 56 percent of the variation in the depth of post-treatment incision in the Wildcat and Yager Formations combined.

These results match well with other locally conducted research. Madej (2001) found that the surrogate for stream power, watershed area multiplied by slope of the channel, and the total volume of material excavated from each crossing were the only two significant predictors of the volume of post-treatment erosion from excavated stream crossings. Klein (1987) stated that stream power was of “primary importance” in explaining the variation in post-treatment channel incision at his study sites.

The correlation analysis of channel incision depth versus stream power within decomposed granite did not indicate a relationship between the two variables. Depth of channel incision was fairly consistent at four of the five crossings in this rock unit, ranging between 0.22 and 0.31m, while the value of the stream power surrogate varied from 1.0 to 2.4. One of the five decomposed granite sites fell outside this range, having a stream power value of 1.4 but no channel incision. This site, Klamath road 12N13 crossing 3, was the only site in decomposed granite with cobbles as the secondary erosion control treatment. Three of the five had no apparent secondary erosion control in the channel, and one had larger boulder-sized rock. Although this sample size is very small, it is possible that the cobble was an effective treatment at preventing channel incision. Boulders, lacking any smaller size rocks between them, may have been as ineffective at preventing channel scour and erosion as no treatment at all.

Secondary erosion control measures are difficult to study due to the discretionary nature of their use in the field. Because of the cost of purchasing, transporting and applying treatments, operators may naturally use them sparingly. Sites which the operator or project manager perceives as being more likely to have significant post-treatment erosion are more likely to have secondary erosion control treatments applied.

No evidence of surface erosion was seen at any of the study crossings. The presence of evenly distributed straw and other secondary bank erosion control treatments at the crossings indicated that surface erosion was not likely a significant percentage of the total erosion from excavated crossings. This observation is consistent with those of other forest road erosion studies in the Pacific Northwest (Madej 2001). Pacific Watershed Associates (2005) evaluated decommissioned roads and also found that, due to the high rate of revegetation in coastal areas, surface erosion was a minor component of post-treatment erosion.

Identifying the factors most likely to influence post-treatment erosion allows project managers to focus both their efforts and their budgets on the most rewarding techniques for their project area. The more cost-effective this type of restoration effort becomes, the greater the benefit for our natural resources.

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Appendix A. Headwaters Forest road r01, crossing 3 photo, September 15, 2004.

Appendix B. Headwaters Forest road r01, crossing 3 data, September 15, 2004.

Headwaters
Road r01, crossing 3
Data Collected 9/15/04
Years Since Decommissioning: 2
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.06

Secondary erosion control on banks: straw
Secondary erosion control in channel: small logs

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 192.87 | 304.16 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 29.0 | 0.9 | 1.2 | 36 | 34 | 17 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.5 | 12.10 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 12.10 |

Appendix C. Headwaters Forest road r01, crossing 2 photo, September 15, 2004.

Appendix D. Headwaters Forest road r01, crossing 2 data, September 15, 2004.

Headwaters
Road r01, crossing 2
Data Collected 9/15/04
Years Since Decommissioning: 1
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.02

Secondary erosion control on banks: small logs, stumps, straw
Secondary erosion control in channel: straw

| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|---|---|
| | | 6.22 | 7.62 | 0.0 | 0.00 |

| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
|---|---|---|---|---|---|
| 24.4 | 0.5 | 0.5 | 24 | 18 | 15 |

| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
|---|---|---|---|---|---|
| 0.2 | 1.70 | 0.0 | 0.0 | 0.0 | 0.00 |

| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |

| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 1.70 |

Appendix E. Headwaters Forest road r01, crossing 1 photo, September 15, 2004.

Appendix F. Headwaters Forest road r01, crossing 1 data, September 15, 2004.

Headwaters
Road r01, crossing 1
Data Collected 9/15/04
Years Since Decommissioning: 1
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.02

Secondary erosion control on banks: logs, slash, straw, stumps
Secondary erosion control in channel: straw

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 7.43 | 6.60 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 23.8 | 0.3 | 0.3 | 25 | 20 | 11 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |

Appendix G. Headwaters Forest road r07, crossing 3 photo, September 4, 2004.

Appendix H. Headwaters Forest road r07, crossing 3 data, September 4, 2004.

Headwaters
Road r07, Crossing 3
Data Collected September 4, 2004
Years Since Decommissioning: 2
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.05

Secondary erosion control on banks: straw, logs
Secondary erosion control in channel: none apparent

| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|---|---|
| | | 66.89 | 48.31 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 21.6 | 0.5 | 0.5 | 33 | 32 | 18 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.5 | 4.82 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 4.82 |

Appendix I. Headwaters Forest road r07, crossing 2 photo, September 4, 2004.

Appendix J. Headwaters Forest road r07, crossing 2 data, September 4, 2004.

Headwaters
Road r07, Crossing 2
Data Collected September 4, 2004
Years Since Decommissioning: 2
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.04

Secondary erosion control on banks: straw, some excavated wood
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 299.61 | 172.80 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 26.8 | 0.6 | 0.6 | 32 | 32 | 22 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.1 | 1.25 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 1.25 |

Appendix K. Headwaters Forest road r07, crossing 1 photo, September 4, 2004.

Appendix L. Headwaters Forest road r07, crossing 1 data, September 4, 2004.

Headwaters
Road r07, Crossing 1
Data Collected September 4, 2004
Years Since Decommissioning: 2
Rock Type: Wildcat Formation
Watershed Area ($km^2$): 0.02

Secondary erosion control on banks: straw, some excavated wood
Secondary erosion control in channel: none apparent (two stumps left in excavated channel)

| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|---|---|
| | | 6.50 | 6.27 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 25.0 | 0.3 | 0.3 | 32 | 30 | 13 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.1 | 0.93 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.93 |

Appendix M. Headwaters Forest road r10, crossing 2 photo, September 5, 2004.

Appendix N. Headwaters Forest road r10, crossing 2 data, September 5, 2004.

Headwaters
Road r10, Crossing 2
Data Collected September 5, 2004
Years Since Decommissioning: 2
Rock Type: Yager Formation
Watershed Area ($km^2$): 0.05

Secondary erosion control on banks: straw, logs
Secondary erosion control in channel: some logs from the banks fallen into channel

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 303.42 | 378.02 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 25.3 | 0.3 | 0.3 | 30 | 28 | 4 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 1.17 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 1.17 |

Appendix O. Headwaters Forest road r10, crossing 1 photo, September 5, 2004.

Appendix P. Headwaters Forest road r10, crossing 1 data, September 5, 2004.

Headwaters
Road r10, Crossing 1
Data Collected September 5, 2004
Years Since Decommissioning: 2
Rock Type: Yager Formation
Watershed Area ($km^2$): 0.12

Secondary erosion control on banks: straw, logs
Secondary erosion control in channel: none apparent

| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|---|---|
| | | 238.76 | 166.67 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 25.0 | 0.9 | 0.9 | 29 | 35 | 8 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.9 | 20.89 | 11.9 | 0.1 | 0.2 | 0.22 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 2.4 | 0.6 | 0.3 | 0.45 | | 0.45 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 21.57 |

Appendix Q. Klamath Forest road 12N13, crossing 5 photo, July 24, 2004.

Appendix R. Klamath Forest road 12N13, crossing 5 data, July 24, 2004.

Klamath
Road 12N13, Crossing 5
Data Collected July 24, 2004
Years Since Decommissioning: 1
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.08

Secondary erosion control on banks: straw
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 179.40 | 140.47 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 22.9 | 0.5 | 1.0 | 36 | 34 | 15 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 2.55 | | | | 0.35 |
| | | 50 | 0.5 | 0.5 | |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 5.5 | 1.5 | 0.5 | 3.82 | | 6.51 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.9 | 3.4 | 0.8 | 2.34 | | 9.06 |

Appendix S. Klamath Forest road 12N13, crossing 4 photo, July 24, 2004.

Appendix T. Klamath Forest road 12N13, crossing 4 data, July 24, 2004.

Klamath
Road 12N13, Crossing 4
Data Collected July 24, 2004
Years Since Decommissioning: 1
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.08

Secondary erosion control on banks: branches, straw
Secondary erosion control in channel: boulders

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 65.96 | 45.89 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 18.6 | 0.4 | 1.2 | 37 | 28 | 12 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 1.55 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 1.55 |

Appendix U. Klamath Forest road 12N13, crossing 3 photo, July 24, 2004.

Appendix V. Klamath Forest road 12N13, crossing 3 data, July 24, 2004.

Klamath
Road 12N13, Crossing 3
Data Collected July 24, 2004
Years Since Decommissioning: 1
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.12

Secondary erosion control on banks: branches
Secondary erosion control in channel: cobbles

| RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|
| 416.86 | 368.55 | 0.0 | 0.00 |

| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
|---|---|---|---|---|---|
| 30.5 | 0.6 | 0.6 | 38 | 38 | 12 |

| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.00 |

| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |

| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |

Appendix W. Klamath Forest road 12N13, crossing 2 photo, July 24, 2004.

Appendix X. Klamath Forest road 12N13, crossing 2 data, July 24, 2004.

Klamath
Road 12N13, Crossing 2
Data Collected July 24, 2004
Years Since Decommissioning: 1
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.20

Secondary erosion control on banks: branches, trees planted
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 161.84 | 214.88 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 21.6 | 0.6 | 0.9 | 28 | 28 | 12 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.3 | 4.02 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 4.02 |

Appendix Y. Klamath Forest road 13N10, crossing 5 photo, August 18, 2004.

Appendix Z. Klamath Forest road 13N10, crossing 5 data, August 18, 2004.

Klamath
Road 13N10 , Crossing 5
Data Collected August 18, 2004
Years Since Decommissioning: 2
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.08

Secondary erosion control on banks: straw
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 32.89 | 29.45 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 9.1 | 0.5 | 0.5 | 23 | 23 | 13 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 0.89 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.89 |

Appendix AA. Klamath Forest road 13N10, crossing 4 photo, August 18, 2004.

Appendix BB. Klamath Forest road 13N10, crossing 4 data, August 18, 2004.

Klamath
Road 13N10 , Crossing 4
Data Collected August 18, 2004
Years Since Decommissioning: 2
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.35

Secondary erosion control on banks: straw
Secondary erosion control in channel: small boulders

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 79.25 | 110.37 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 13.7 | 1.5 | 1.5 | 30 | 27 | 14 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.3 | 6.37 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 6.37 |

Appendix CC. Klamath Forest road 13N10, crossing 3 photo, August 18, 2004.

Appendix DD. Klamath Forest road 13N10, crossing 3 data, August 18, 2004.

Klamath
Road 13N10 , Crossing 3
Data Collected August 18, 2004
Years Since Decommissioning: 2
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.44

Secondary erosion control on banks: straw
Secondary erosion control in channel: small boulders

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 48.59 | 79.15 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 14.0 | 0.9 | 0.9 | 23 | 28 | 14 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 1.95 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 1.95 |

Appendix EE. Klamath Forest road 13N10, crossing 2 photo, August 18, 2004.

Appendix FF. Klamath Forest road 13N10, crossing 2 data, August 18, 2004.

Klamath
Road 13N10 , Crossing 2
Data Collected August 18, 2004
Years Since Decommissioning: 2
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.19

Secondary erosion control on banks: straw
Secondary erosion control in channel: boulders/cobbles (only part way across)

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 125.51 | 121.89 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 17.7 | 1.8 | 1.8 | 27 | 30 | 8 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.3 | 9.85 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 9.85 |

Appendix GG. Klamath Forest road 13N10, crossing 1 photo, August 18, 2004.

Appendix HH. Klamath Forest road 13N10, crossing 1 data, August 18, 2004.

Klamath
Road 13N10 , Crossing 1
Data Collected August 18, 2004
Years Since Decommissioning: 2
Rock Type: Decomposed Granite
Watershed Area ($km^2$): 0.12

Secondary erosion control on banks: straw, slash
Secondary erosion control in channel: some small boulders

| RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
|---|---|---|---|
| 115.20 | 116.64 | 0.0 | 0.00 |

| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
|---|---|---|---|---|---|
| 22.6 | 2.1 | 2.1 | 40 | 27 | 12 |

| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
|---|---|---|---|---|---|
| 0.3 | 14.66 | 0.0 | 0.0 | 0.0 | 0.00 |

| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |

| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.00 | | 14.66 |

Appendix II. Six Rivers Forest road 5N04, crossing 3 photo, August 22, 2004.

Appendix JJ. Six Rivers Forest road 5N04, crossing 3 data, August 22, 2004.

Six Rivers
Road 5N04, Crossing 3
Data Collected August 22, 2004
Years Since Decommissioning: 2
Rock Type: Galice Formation
Watershed Area ($km^2$): 0.19

Secondary erosion control on banks: straw
Secondary erosion control in channel: some logs

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 78.04 | 58.71 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 23.2 | 2.1 | 2.1 | 35 | 25 | 8 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.6 | 30.12 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 5.10 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 4.6 | 1.5 | 1.2 | 5.10 | | 35.22 |

Appendix KK. Six Rivers Forest road 5N04, crossing 2 photo, August 22, 2004.

Appendix LL. Six Rivers Forest road 5N04, crossing 2 data, August 22, 2004.

Six Rivers
Road 5N04, Crossing 2
Data Collected August 22, 2004
Years Since Decommissioning: 2
Rock Type: Galice Formation
Watershed Area ($km^2$): 0.15

Secondary erosion control on banks: few trees planted
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 232.26 | 216.00 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 28.7 | 2.1 | 2.1 | 40 | 42 | 12 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.9 | 55.88 | 12.2 | 0.3 | 0.2 | 0.57 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 56.45 |

Appendix MM. Six Rivers Forest road 5N04, crossing 1 photo, August 22, 2004.

Appendix NN. Six Rivers Forest road 5N04, crossing 1 data, August 22, 2004.

Six Rivers
Road 5N04, Crossing 1
Data Collected August 22, 2004
Years Since Decommissioning: 2
Rock Type: Galice Formation
Watershed Area ($km^2$): 0.21

Secondary erosion control on banks: few trees planted
Secondary erosion control in channel: none apparent

| | | | | | |
|---|---|---|---|---|---|
| | | RB surf area ($m^2$) | LB surf area ($m^2$) | bank lower (m) | bank surf. erosion ($m^3$) |
| | | 57.14 | 83.61 | 0.0 | 0.00 |
| length (m) | channel width (m) | bottom width (m) | left bank slope (deg) | right bank slope (deg) | channel slope (deg) |
| 17.1 | 1.8 | 1.8 | 34 | 33 | 12 |
| downcut depth (m) | total vol. downcut ($m^3$) | total gully length (m) | mean gully width (m) | mean gully depth (m) | total vol. gully ($m^3$) |
| 0.2 | 7.13 | 0.0 | 0.0 | 0.0 | 0.00 |
| LB failure length (m) | LB failure width (m) | LB failure depth (m) | LB failure vol. ($m^3$) | | bank failure vol. ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 0.00 |
| RB failure length (m) | RB failure width (m) | RB failure depth (m) | RB failure vol. ($m^3$) | | total erosion volume ($m^3$) |
| 0.0 | 0.0 | 0.0 | 0.00 | | 7.13 |

# COMPOSITION OF THE SUSPENDED LOAD

# AS A MEASURE OF STREAM HEALTH

CAL FIRE CONTRACT WITH HUMBOLDT STATE UNIVERSITY SPONSORED PROGRAMS FOUNDATION 1.22-1757

FINAL REPORT FEBRUARY 27, 2009

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## PROJECT SUMMARY:

Objectives of this exploratory research were: 1) to characterize the contribution of size-specific and total concentrations of organic and inorganic components to the suspended load during high and low flow periods in 4 streams in coastal northern California; and 2) to evaluate relationships between composition and nutritive quality of the suspended load with feeding efficiency and condition of salmonid fishes and the abundance of their invertebrate prey. In addition, we conducted laboratory feeding trials to evaluate the effects of suspended sediment concentration, organic: inorganic particle ratios, and their interaction on feeding rates of juvenile steelhead trout. Two levels of suspended sediment concentration (producing turbidities of approximately 25 and 50 NTU's), and three levels of organic: inorganic particle ratios (25,50, and 75% organic suspended sediments) were tested.

Suspended sediments, macroinvertebrates, and salmonids were sampled from 200-m reaches in North Fork Caspar and South Fork Caspar creeks (Caspar Creek basin in Mendocino County), and Little Lost Man and Upper Prairie creeks (Redwood Creek basin in Humboldt County) in three high flow and three low flow periods from October 2002 through December 2003. Stream sites differed in size and in riparian vegetation and land use history, and were chosen to represent a range of discharge and suspended load conditions.

Masses of organic and total suspended sediments (mg/L) were greater at high than at low flows. Within the size particle range of > 0.7 - 1µm , but not in the >1 µm – 1mm range, flow categories also affected both mass and percentage of organic suspended sediments. However, in the >1 µm – 1mm range, total suspended sediments were greater at high than low flows. Mass and percentage of organic sediments (total or by particle size class) did not detectably differ among the 4 streams or with a site*flow interaction. The total suspended load was moderately predicted by turbidity, but the addition of the percentage of organic particles did not improve the model fit. The percentage of organic suspended sediments was weakly correlated with turbidity. The contribution of algal particles, indexed by chlorophyll *a* concentration in suspension, to the suspended load was greatest in the reach where canopy coverage was least, but did not differ between high and low flow periods. In contrast, microbial respiration associated with organic sediments was greater at low than at high flows, but did not differ among sites.

Macroinvertebrate biomass was not predicted by mass or percentage of organic sediments. Biomass of filtering collectors was modestly positively related to chlorophyll concentration of the suspended load. The interaction of site and flow also affected the biomass of filtering collectors. At high flows, filtering collector abundance was greatest in the most pristine of the

sites (Upper Prairie Creek). The percentage of drifting macroinvertebrates (drift/ benthic + drifting invertebrates), by mass, was modestly related to the suspended load of organic particles, but not to the total suspended load.

Gut fullness and feeding activity of juvenile salmonids were not affected by mass or percentage of organic suspended sediments, and they did not detectably vary among sites or high and low flows. Underwater observations were made of at least some feeding activity at each site on each of the sampling dates, at turbidities ranging from 4 – 123 NTU, although salmonids available for observation were much more sparse at higher turbidities. Condition of coho salmon at the end of the overwinter period did not differ among sites. In lab feeding trials, individual steelhead consumed twice as many prey under low than high suspended loads, but differing fractions of organic particles within the suspended load did not affect their efficiency of prey consumption.

Although this study failed to detect a response by salmonid fishes or their invertebrate prey to the organic component of the suspended load, it is premature to dismiss the potential importance of organic sediments in affecting stream biota for at least two reasons. First, organic sediments provide food for filtering and gathering-collector invertebrates that are often common in fish diets. Second, because organic particles weigh less than do inorganic particles of the same size, organic particles likely contribute differentially to turbidity, which may affect both fish feeding efficiency and in-stream primary production. Biotic response is likely better revealed in time-integrated sampling than in small numbers of point samples of the suspended load. We recommend continued study of biotic response to organic and inorganic components of the suspended load, and inclusion of the organic fraction of the sediment load in analyses of suspended-sediment concentrations conducted for stream monitoring programs.

## ACKNOWLEDGEMENTS:

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# INTRODUCTION

For over three decades, geologists, hydrologists and stream ecologists have shown significant interest in suspended load in running waters (e.g. Waters 1995). Physical scientists have focused on development of sediment-rating curves and estimation of sediment yields, often as an indicator of changing land uses (e.g. Beschta 1996). Over the same period, the interest of stream ecologists on sediments has often focused on the role of suspended sediments in water quality degradation, for example its deleterious impacts on biological communities (e.g. Waters 1995). However, stream ecologists have also studied the beneficial roles of the suspended load, or its surrogate turbidity) in providing basal resources to fluvial food webs and as the major pathway of organic matter transport that links upstream and downstream reaches (Minshall et al. 1983, Minshall et al. 1985, Wallace et al. 2006 ). The organic carbon portion of turbidity has been modeled, along with other components, as nutrient spiraling, in which materials are continuously taken up by stream biota, released, and transported downstream (e.g. Webster and Patten 1979, Webster and Valett 2006). Differences in the focus of studies on suspended load between physical and biological scientists have resulted in very different methodologies. In most cases, physical scientists have removed organic components in suspended load samples by ashing or chemical digestion, and they have discarded data on the organic fraction (ash- free or carbon digested). However, stream ecologists, while concentrating on the importance of the organic fraction of suspended load as a food resource for aquatic macroinvertebrates, have discarded information on the mineral fraction (ash or digestion residue). When data are reported on suspended load, derived from turbidity readings, it is seldom made clear whether reported values have been “corrected” for the organic fraction or whether, as is the usual case, both inorganic and organic components of the sample are combined as dry mass.

Failure to distinguish between organic and inorganic components of the suspended load or to consider the full suite of information present in suspended sediment samples has hindered full understanding of sediment dynamics as it affects stream health and reflects watershed condition (e. g. Minshall 1996). For example, because organic sediments remain in suspension longer than do similarly sized inorganic particles, and therefore ultimately contribute more to turbidity, they may have a greater overall effect on light reduction. An increased proportion of suspended organic sediments would be expected to reduce light penetration to the stream bottom over a longer period and could result in decreased primary production This could lead to a loss of macroinvertebrate scrapers that feed on periphytic algae. At the same time, an increased proportion of organic suspended sediments, in the appropriate size range and of sufficient quality, may benefit filter-feeding invertebrates (filtering collectors; Wallace and Merritt 1980, Benke et al. 1984). Deposition of organic sediments may enhance food resources for the gathering collectors, which feed within the benthos. Along with some scrapers, filtering and gathering collectors are often important prey items in the diets of juvenile anadramous and resident salmonids and other drift-feeding fishes. At present, the net effect of suspended organic: inorganic ratios on prey availability for fish is not known. Apart from effects on fish through their food base, the effect of an increased percentage of suspended organic sediments on light attenuation would also directly impact fish because of reduced visibility that would impact their feeding efficiency and feeding rate (Sweka and Hartman 2001a). This in turn could result in depressed growth rate of the fish (e.g. Barrett et al. 1992, Sweka and Hartman 2001b).

The particle size distribution of the suspended load (turbidity) is another important attribute that usually is not explored in analyses of suspended sediments. The majority of organic particles transported by most streams during baseflow conditions are < 50 µm in diameter (Sedell et al 1978, Naiman and Sedell 1979a & b, Wallace et al 1982), although in some cases, seston particle size varies with stream size. Wallace et al. (1982) showed that smaller headwater streams draining forested areas have larger median seston particle sizes than larger rivers downstream. While particle size composition of the mineral sediment portion provides insight into sediment transport hydraulics and likely sediment source areas, the particle size distribution and qualitative nature (e.g. microbial activity and relative amounts of plant, animal, and detrital material) of the constituents of the organic fraction of the suspended load may predict the response of macroinvertebrate filtering or gathering collectors. The organic fraction of the suspended load, or seston, is generally composed of fine particulate organic matter (FPOM) in the size range of > 0.45 µm to < 1000 µm (1 mm), with size fractions sometimes further subdivided into categories of medium-large (250 – 1000 µm), small (100-250 µm), fine (45-100 µm), very fine (25-45 µm), and ultrafine (0.45-25 µm). FPOM originates from a variety of sources, including mechanical breakdown of larger particles, animal consumption, microbial processes, flocculation of dissolved organic matter, and terrestrial inputs (Wotton 1984). The source and nutritional value of FPOM varies among size fractions. Generally, bacterial cells fall within the ultrafine fraction, macroinvertebrate feces within fine or larger fractions, algal detritus in the small fraction, and small leaf fragments within the medium-large fraction (Bisson and Bilby 1998). Small filtering collectors, such as blackflies (Diptera: Simuliidae), philopotamid caddisflies (Trichoptera), and certain chironomids (Diptera) such as *Rheotanytarsus*, are not selective of the quality of seston that they harvest, but select food only on the basis of particle size (Cummins and Klug 1979). For example, the majority of particles ingested by larval blackflies are < 10 µm (Merritt et al. 1982), on the component of the seston that is most nutritionally consistent and abundant component (Wallace et al. 1982). Other filtering collectors, including hydropsychid caddisflies (Trichoptera), feed on particles several hundred or larger micrometers, in a seston range that is more nutritionally variable . Evidence exists that this group may exhibit selectively capture larger particles (Edler and Georgian 2004, Brown et al. 2005). Inasmuch as the suspended load reflects the smaller particle component of the bed load, attributes of the organic fraction may also affect the response of the gathering collectors. We suggest that separation of suspended load material into inorganic and organic fractions, and detail on the particle size distribution of both fractions, together with qualitative aspects of the organic fraction, would provide a far greater resolution of physical and biological conditions relevant to juvenile salmonids and their prey base in a watershed than is currently available.

Objectives of this research were: 1) to characterize the contribution of size-specific and total concentrations of organic and inorganic components to the suspended load during high and low flow periods in 4 streams in coastal northern California; and 2) to evaluate relationships between composition of the suspended load with feeding efficiency and condition of salmonid fishes and the abundance of their invertebrate prey. Suspended sediments, macroinvertebrates and salmonids were sampled from two stream sites each within the Caspar Creek (Mendocino County), and Redwood Creek (Humboldt County) basins in coastal northern California over a two year period.

# METHODS

## STUDY SITES

Study sites within the Caspar Creek basin included North Fork Caspar Creek and South Fork Caspar Creek. These are tributaries in the headwaters of the 21.7km$^2$ Caspar Creek basin, situated within the Caspar Creek Experimental Watersheds in the Jackson Demonstration State Forest. Study sites within the 725 km$^2$ Redwood Creek basin included Upper Prairie Creek (UPC) and Little Lost Man Creek (LLM). Both sites are within the Prairie Creek watershed, which is tributary to Redwood Creek within the lower third of the basin. Upper Prairie and Little Lost Man creeks are within the boundaries of Redwood National and State Parks. Study sites were selected that were fish-bearing, for which records of continuous water discharge and periodic suspended load were available, and that offered the opportunity to explore effects of riparian composition and catchment area on composition of the suspended load. The North and South Forks of Caspar Creek are of equivalent catchment area, but differ in that riparian composition is dominated by second growth conifers in the North Fork and by red alder (*Alnus rubra*) and other hardwoods in the South Fork. The catchment areas of Little Lost Man and Upper Prairie creeks are each approximately twice as large as those of the North and South Forks of Caspar Creek, with riparian vegetation dominated by old-growth conifers. Salmonid fishes in each creek included steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). In Little Lost Man and Upper Prairie creeks, cutthroat trout (*Oncorhynchus clarkii*) were also found within the reaches.

Both the Caspar Creek and Redwood Creek basins are within a geologic province characterized by some of the highest rates of erosion in the United States (Brown and Ritter 1971, Milliman and Meade 1983). High erodibility results from inherently weak rock units situated in a tectonically active area with a Mediterranean climate (Nolan et al. 1995). In both basins, extensive timber harvest activities have accelerated naturally high rates of erosion. Both basins are underlain by rocks of the Franciscan assemblage. Dominant rock types in Caspar Creek are well consolidated marine sedimentary sandstone with intergranular clay, silt, and feldspatic sandstone (Cafferata and Spittler 1998). In Redwood Creek, the Grogan fault bisects the basin, juxtaposing sedimentary rocks to the east against metamorphic rocks to the west (Pitlick 1995).

Forest vegetation in Caspar Creek and the lower Redwood Creek drainage is dominated by coast redwood (*Sequoia sempervirens*) and Douglas-fir (*Pseudotsuga menzieii*), with an understory of evergreen huckleberry (*Vaccinum ovatum*), Pacific rhododendron (*Rhododendron macrophyllum*), and sword fern (*Polystichum munitum*). Virgin forest in the Caspar Creek basin was extensively logged in the late 1800's; logging of second-growth began in the 1960's. The entire watershed of South Fork Caspar Creek was selectively harvested and tractor yarded in 1971-1973. The watershed of North Fork Caspar Creek was clearcut logged (46%) in large patches during 1989-1991. Commercial timber harvest in the Redwood Creek basin did not begin until the 1930's (Best 1995). Twenty percent of the basin, nearly all of it within Redwood National and State Parks, remains as uncut virgin forest. Of the two Redwood Creek sites, Upper Prairie Creek is the most pristine, as Little Lost Man Creek contains evidence of an historical debris flow.

Sites in both basins lie within a predominantly maritime climate with warm, dry summers and cool, wet winters. Average annual precipitation is 120 cm (Caspar Creek) and 170 cm (Prairie Creek State Park), with most occurring as rainfall between October and April. This study was conducted from October 2002 through December 2003, during water years that experienced average precipitation based on a 70-y record at Prairie Creek Redwoods State Park. Recurrence intervals for peak flows in Little Lost Man Creek were 2 and 25 y for water years (Oct 1 – Sep 30) 2002 and 2003, respectively. Recurrence intervals for peak flows in the Caspar Creek drainage were 1.5 and 2.5 y respectively for these same years.

A 200-m study reach was established in each stream within the vicinity of previously established gauging stations. At each site, stream gradient over lengths of about 30 bank full widths and one to three cross sections were surveyed using standard surveying equipment. Percent canopy cover was measured at each cross section with a spherical densitometer. Dominant overstory riparian vegetation type and substrate size categories (following Cummins 1964) were estimated by visual inspection. Site characteristics are described in Table 1.

## FIELD SAMPLING

Each study reach of Upper Prairie Creek, Little Lost Man Creek, North Fork Caspar Creek and South Fork Caspar Creek was sampled six times between October 2002 and December 2003, with 3 sampling events during times of low flows (< 1 cfs in North and South Fork Caspar Creeks, < 4 cfs in Little Lost Man Creek, and ≤ 10 cfs in Upper Prairie Creek), and 3 sampling events during higher flows (Table 2). A sampling event included collections of the suspended load, benthic and drifting macroinvertebrates, and juvenile salmonids. Underwater observations by snorkeling were also made of salmonid feeding behavior.

The suspended load at the time of biological sampling was measured from water samples collected with a 1-liter Horizontal Beta Plus™ grab sampler. Water samples were collected at 0.6 depth within the thalweg at three randomly chosen locations within the 200-m reach.

Current velocity at each location was measured with a Marsh-McBurney™ digital flowmeter. After collection, a sample was poured into a sealed, black 1-liter container that was continuously stirred with a magnetic stirrer to keep particles in suspension. Turbidity (NTU), chlorophyll *a* (mg/L, measured as fluorescence), and dissolved oxygen (DO, in mg/L), were measured with a YSI 6600™ sonde. DO measurements were tracked over a 5-min period to estimate microbial respiration, expressed as $O_2$-mg · $L^{-1}$· $min^{-1}$, from reductions in DO concentrations. Each sample was separated into inorganic and organic fractions. The organic fraction was decanted off, and the two fractions were placed in containers with distilled water added to bring volumes back to 1 liter. Samples were re-suspended with the magnetic stirrer, and DO and turbidity were again measured. Water samples were shielded from ambient light sources with black plastic sheeting and continuously stirred with an enclosed battery powered magnetic stirrer during measurements. Samples were saved on ice in a cooler, and brought to the lab for analysis of the mass of organic and inorganic fractions and particle sizes.

Suspended sediment samples were analyzed at the Soil Sciences Laboratory on the Humboldt State University campus to measure ash-free dry mass (AFDM) of size-specific organic and inorganic fractions of the suspended load. Particles > 1mm in diameter were removed by filtering a sample through a 1 mm sieve. Samples were then filtered through pre-weighed 1.0 µm and 0.7 µm glass fiber filters using a vacuum pump, and filters were oven-dried at 50 °C for 24 h, dessicated for 24 h, and weighed on an analytical balance (± 1 µg). Dry-weighed samples and filters were ashed in a muffle furnace at 550 °C, rewetted with distilled, deionized water to restore waters of hydration, and oven-dried (50 °C for 24 h), dessicated (24 h), and weighed on an analytical balance. Masses obtained provided measures of AFDM of the organic load (dry mass – ash mass) and inorganic load (ash mass) for each particle size range (>0.7 – 1 µm, and >1-1000µm), in mg/L . The choice of particle size ranges was constrained by availability of filter sizes.

Macroinvertebrates were sampled with a collection device designed by Cummins and Wilzbach to separately sample drifting and benthic macroinvertebrates from the same location (Fig. 1). The sampler was a square plexiglass box (0.18 $m^2$) with a center divider. A 5 cm flange around the outside of the box and a 2.5 cm flange on the bottom of the center divider had an attached layer of foam that provided a seal with the substrate when the box was in sampling position. The front of the box had a large panel of 250 µm mesh screening to allow current to pass through both sides of the box and out two ports, one on each side at the rear of the box. Each port was fitted with a cylinder onto which a 250 µm mesh, 1-m long drift net was fitted. Wing deflectors positioned on the front of the box increased flow through the front mesh panels. Two partitioning samplers were positioned within a reach on each sampling event, with drift nets attached that collected drift for a 1 hr period at dusk. Current velocity was measured at the mouth of the drift net ports at the end of the sampling period. After 1 h, the nets (n = 4) were removed and the contents of each washed onto a 250 µm sieve. Samples were transferred to a sample container, labeled, and preserved with 70% ethanol. Drift nets were then repositioned on the sampler, and the bottom sediments enclosed on each side of the partitioning sampler were disturbed, including hand washing the cobbles, to dislodge invertebrates into the attached nets (n = 4). The sampling device allowed for replicated comparison of drift and benthos collected from the same confined area, with the first set of nets collecting animals drifting from the known area of bottom, and the second set representing animals that did not drift during the drift-sampling period. Preserved animals were returned to the laboratory, where they were sorted under a dissecting microscope, identified, measured, and assigned to functional feeding groups of scrapers, shredders, predators, filtering collectors and gathering collectors following the designations in Merritt et al. (2008). Taxonomic resolution was at the level of genus where possible, or higher levels. Individual body lengths were converted to estimates of dry mass using taxon-specific relationships based on unpublished data of Cummins and Wilzbach (Appendix B).

To assess the feeding activity of salmonid fishes, we snorkeled each 200 m reach for a 30 minute period during daylight hours. Microhabitats (e.g. pools) that were found to hold two or more salmonids were observed for 3-minute periods each. Individuals were enumerated and the total number of prey captures observed by all individuals within a microhabitat during an observation session was recorded to determine mean prey captures per individual per minute. Individuals were not identified to salmonid species during the observations.

Following the period of underwater observation, juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) within each reach were captured with a backpack electro-shocker to collect a sample of individuals for assessment of fish condition and diet analysis by gastric lavage. Reaches were not systematically sampled. Rather, our goal was to obtain at least 10 fish for diet analysis from each of the six sampling events, and at least 50 individuals for assessment of fish condition during sampling events in October 2002 and June 2003. Condition measured in October provided an indication of growth potential during low flows of the previous summer, while condition measured in June suggested growth potential during the previous winter and spring high flow periods. Following capture, fish were anaesthetized with Alka-Seltzer™ tablets prior to measuring fork length to the nearest mm, and wet mass to the nearest 0.01g. Gut contents were sampled by gastric lavage, and fish were returned to the site of capture after they had recovered from $CO_2$ anaesthesia and handling. Gut contents were collected on a 250 µm mesh sieve, preserved in 70% ethanol, and returned to the laboratory for sorting and identification. Macroinvertebrates in gut contents were identified, measured, and classified by functional feeding group under a dissecting microscope. Diet samples from steelhead and coho salmon were pooled for analysis. Coho salmon dominated the salmonid assemblage in each site, comprising 65% (n = 216), 83% (n = 315), 58% (n = 390), and 86% (n = 297) of salmonid numbers in North Fork Caspar, South Fork Caspar, Little Lost Man, and Upper Prairie creeks, respectively.

## DATA ANALYSIS

Suspended sediment composition was characterized by a) organic and inorganic mass, and b) the percentage of organic particles by mass. The effects of site (n = 4), flow category (low and high), and the interaction of site and flow on response variables were analyzed by 2-way ANOVA for each particle size category (0.7-1µm and 1 – 1000 µm) and the total sediment sample . To meet assumptions of normally distributed variables, organic and inorganic mass were $\log_{10}$ transformed, and the percentage of organic particles was transformed with an arcsine square root transformation. As land use managers are often interested in the ability of turbidity to predict the suspended sediment load, we explored the relationship between turbidity and total suspended sediment concentration by linear regression. Turbidity and total suspended sediment concentration were $\log_{10}$-transformed. We also evaluated the correlation between turbidity and percentage of organic suspended sediments, and asked whether the addition of percentage of organic sediments improved the fit of the predictive model for suspended sediment concentration.

Nutritional quality of the suspended sediment load for stream macroinvertebrates was assessed by comparing effects of site and flow on a) microbial respiration per gram of organic sediment, and b) chlorophyll *a* concentration. We compared microbial respiration per liter on organic and inorganic fractions of the suspended load with a paired t- test. Chlorophyll *a* concentrations were examined in relation to canopy coverage of the reaches. We evaluated the correlation between microbial respiration and chlorophyll a concentration of suspended sediments to test the hypothesis that the relationship between allochthonous (i.e. respiration) and authochthonous (i.e. chlorophyll) energy sources in flowing water ecosystems is inverse (Cummins and Wilzbach 2008).

Macroinvertebrate response variables included biomass, in $g/m^2$, of filtering collectors, all collectors (filtering + gathering collectors), scrapers, and all macroinvertebrates, and the percentage of drifting invertebrates by mass (drifting/ drifting + benthic invertebrates). Functional group biomass variables were log-transformed to meet normality assumptions; the percentage of drifting invertebrates was arcsine-transformed. We tested hypotheses that biomass of filtering collectors and other functional feeding groups could be predicted by mass (log-transformed) and percentage of organic suspended particles (arcsine-transformed) using least-squares linear regression. We also evaluated relationships between biomass of filtering collectors and nutritional quality (microbial respiration and chlorophyll content) of the suspended load. Effects of site, flow, and a site*flow interaction on biomass of functional groups and all macroinvertebrates were analyzed by 2-way ANOVA. We analyzed relationships between the percentage of drifting invertebrates with the total suspended load and with the organic suspended load.

Fish response variables included a) feeding activity, measured as number of prey captures per minute per individual; b) gut fullness, measured as mg invertebrates in gut contents per gram of fish; and c) fish condition. Relationships between gut fullness and feeding activity with turbidity, mass of organic suspended sediments, or percentage of organic suspended sediments were analyzed by least-squares linear regression. Effects of site and flow were analyzed using 2-way ANOVA. Differences in fish condition among sites and sampling dates were analyzed by comparing slopes and intercepts of log-transformed length-weight regressions. Analyses of fish condition were restricted to coho salmon, as sample sizes of steelhead from some sampling events were too small to be legitimately analyzed.

## FLUME EXPERIMENT OF FISH FEEDING EFFICIENCY

The effect of suspended sediment concentration and organic: inorganic particle ratios on feeding rates of juvenile steelhead trout were measured in short-term feeding trials conducted in artificial stream channels located outdoors at the Humboldt State University (HSU) fish hatchery. Trials were conducted at two levels of suspended sediment concentration, and three levels of organic: inorganic ratios. Suspended sediment concentrations were high (averaging 0.54 mg/L, SD = 0.38), producing turbidities ranging between 44-67 NTU; or low (averaging 0.22 mg/L, SD = 0.11), producing turbidities ranging between 24-31 NTU. Organic to inorganic particle ratios varied as 0.75 to 0.25, 0.50 to 0.50, and 0.25 to 0.75 by dry mass. Each treatment combination was replicated 5 times (number of trials = 30). During a feeding trial, live invertebrate prey were introduced to an experimental arena containing a solitary trout. The number of prey captured and consumed by the trout during a 3-minute period was determined.

Five artificial channels used for feeding trials were each 9 m long, 0.41 m wide, and 0.19 m deep. Each channel had a reservoir with a submersible pump that re-circulated filtered water derived from Fern Lake, which supplies freshwater for the hatchery facility. Ambient water temperatures ranged from 14-16 ° C during the trials. The channels were covered with 1 cm mesh plastic screening to exclude the introduction of plant debris and terrestrial invertebrates from the surrounding vegetation. Feeding trials were conducted within a 1.5 m section of each channel, which was bounded with 3 mm mesh screening at the upstream and downstream end. Velocity through the experimental section was 8.0 cm/s.

Turbidity was created in the channels by introducing mixtures of inorganic and organic particles. Clay (bentonite) < 62 µm in diameter was used as the source of inorganic particles and alder leaf fragments were used as the source of organic particles. Organic particles were prepared from leached and dried leaves that were ground to pass through a 62 µm sieve. Pumps that re-circulated the water in the flumes maintained the particles in suspension and the resulting turbidity (NTU) was continuously measured with a YSI™ 6600 sonde throughout a feeding trial.

Juvenile steelhead used in the experiments were provided by the HSU hatchery, and ranged in size from 85 to 97 mm fork length (mean = 90 mm; SD = 3). Fish were held without food in the artificial channels at 14-16 ° C during a 5-day acclimation period prior to the beginning of trials. Pilot studies established that the trout began feeding on live *Gammarus* after a 5 day period. Each fish was used in only one feeding trial. During a trial, fish were offered live amphipods (*Gammarus* sp.). Amphipods were collected from Prairie Creek (Redwood National and State Park near Orick, CA) and cultured in aquaria at the HSU hatchery. Mean body length of *Gammarus* used in feeding trials was 5 mm (SD = 0.3).

Feeding trials were conducted between 0700-900 h in August 2003. Sixty amphipods were introduced to a channel in groups of 5-10 individuals at the beginning of a trial. Prey were released into the upstream end of the experimental section of a channel, and they drifted in the water column through the section. At the termination of a trial, each test fish was captured and its stomach contents were sampled by gastric lavage to determine the number of *Gammarus* ingested. Feeding activity of the fish was also filmed using an Aqua-View ™ underwater camera connected to a videorecorder.

Number of prey captured by the steelhead during trials was subjected to a two-way analysis of variance having two levels of suspended sediment concentration (low, high), and three levels of percentages of organic particles (25,50, and 75%). Effects were determined to be significant at the 0.05 significance level.

## RESULTS

### CHARACTERIZATION OF THE SUSPENDED LOAD

Mass of both total and organic suspended sediments differed between low and high flow periods ($F_{1,16}$ = 9.42, $P$ = 0.01 for total suspended sediments; $F_{1,16}$ = 4.87, $P$ = 0.04 for organic seston), but not among sites or the interaction of site and flow (all $P \geq 0.50$). Concentrations of organic and inorganic components were greater during high than low flows. Total suspended sediments averaged 6.7 mg/L (SD = 3.7, n = 12) at low flows among the 4 sites, and 19.5 mg/L (SD = 14.5, n = 12) at high flows. Organic seston averaged 3.17 mg/L (SD = 3.01, n = 12) during low flows, and 9.22 (SD = 7.92, n = 12) at high flows (Fig. 2). Neither site nor flow had a detectable effect on the (arcsine-transformed) percentage of organic sediments by mass (all $P >$ 0.3). The percentage of suspended sediments composed of organic particles averaged 53% (SD = 34, n = 24), over a range extending from 0.3 to 100%.

Response of total and organic suspended sediments to flows differed among size classes. In the particle size range of 0.7 µm – 1.0 µm, flows affected both mass and percentage of organic particles ($F_{1,16}$ = 5.09, $P$ = 0.04 for mass and $F_{1,1,6}$ = 5.48, $P$ = 0.03 for percentage organics). Concentrations of organic seston were greater during high than low flow periods (average = 0.42mg/L, SD = 0.32, n =12 at low flows, and 1.35 mg/L, SD = 2.05, n = 12). Within this size range, organic particles averaged 40% (SD = 29) of the total suspended load by mass at low flows, and 70% (SD = 37) of the total load at high flows. Neither site nor site*flow interaction were significant (all $P \geq 0.22$). Within the particle size range of >1.0 µm – 1.0 mm, neither mass nor percentage of organic particles were affected by flow period, site, or their interaction (all $P \geq 0.18$). However, effects of flow (but not site or a site*flow interaction) were significant for total suspended sediments ($F_{1,1}$6 = 12,04, $P < 0.01$). At low flows, total suspended sediments in this larger size class averaged 5.20 mg/L (SD = 3.97, n = 12); at high flows, total suspended sediments averaged 15.29 mg/L (SD = 9.16, n = 12).

Partitioning of the suspended load between size classes was similar between organic and inorganic sediments. Mass of inorganic sediments in the size range of >1.0 µm – 1.0 mm (mean = 4.93 mg/L) was greater than in the size range of 0.7 µm – 1.0 µm (mean = 1.96) (2-tailed paired t test, t = 2.71, df = 23, $P$ = 0.01). Mass of organic sediments the size range of >1.0 µm – 1.0 mm averaged 5.31 mg/L, and was greater than the mass in the range of 0.7 µm – 1.0 µm (mean = 0.88) (t = -4.46, df= 23, $P < 0.01$).