However, smaller first order crenulations still commonly drain into inboard ditches, which divert the water to crossings, resulting in gullying at the outlet or failure of the road fill. Improvements to standard practices over those used in "the legacy era" are readily apparent. Perhaps the most disturbing of the legacy era's road practices are older culvert installations with shot-gun outlets that impede or prevent up or downstream fish migration, and crossings that directly or indirectly divert natural watercourses down the roads and onto hillslope locations when plugged.

ANADROMOUS FISH PRODUCTIVITY

The 1998-1999 Garcia River spawning survey report identified four steelhead spawning-run strength indicators. These consisted of: (1) the number of steelhead observed per mile of spawning survey, (2) the number of redds observed per mile of stream, or total redd area, (3) steelhead carcass counts, and (4) peak live steelhead counts. The number of steelhead carcasses found during spawning surveys is very low relative to the number of fish that spawn, and therefore, provides little useful information. Peak live counts could provide a reasonable index for the spawning populations, but only if the amount of stream surveyed each year is similar or, ideally, the same streams are surveyed each year. In the past, because of access conditions, there has been considerable change between years in which streams were surveyed, as well as the length of survey segments.

To determine a baseline condition for the steelhead run on the Garcia River, one could simply refer to the results of the 1998-1999 survey where 1.2 live fish per mile of spawning survey were observed, or alternatively, where 6.3 redds per mile of stream were observed (Maahs, 1999). A single year of spawning data, however, does not account for variability between years and provides a very limited basis for establishing a baseline condition. Two other recent years of spawning survey data are available for sections of the Garcia River, these being 1995-1996 and 1996-1997 (Maahs, 1996; 1997). For those two years, the number of live steelhead observed per mile of stream survey, for the February - April period, was 3.3 and 3.6, respectively, while the number of redds per mile was 12.2 and 13.4, respectively. Therefore, the average baseline indicator for the Garcia River steelhead run would be 2.7 live steelhead per mile of survey, or alternatively, 10.6 redds/mile of stream, stated as a 3-year average.

An alternative baseline is the total redd area for the February through April survey period. For example, in 1998-1999, there was an estimated 297 sq. meters of redds constructed in survey areas. Although only a single example was found in an initial review of the literature regarding the amount of area utilized by a female steelhead for spawning purposes (Shapovalov and Taft, 1954), this approach could be used to estimate the steelhead population. Shapovalov and Taft (1954) observed a single 60 cm female steelhead construct redds over a 60 sq. ft. area, which is equal to about 5.5 sq. meters, suggesting that about 53 female steelhead spawned in the 297 sq. meters of redd area surveyed within the Garcia River watershed.

The 1995-1996 and 1996-1997 Garcia River steelhead abundance indices can be compared to steelhead abundance in two other Mendocino County coastal streams: Caspar Creek and Ten Mile River (Maahs, 1996; 1997). Spawning surveys in the much smaller Caspar Creek watershed found 1.1 live steelhead observed per mile of survey in both these years, with redd densities nearly identical at 4.5 and 4.6 per mile for the same two years, respectively. For tributaries of Ten Mile River, live steelhead counts were 0.26 and 0.29 per mile in 1996 and 1997 and redd densities were 3.3 and 11.3, respectively. This limited information suggests that the steelhead run in the Garcia River is relatively strong compared to other Mendocino County streams.

No coho salmon were found in two out of three years that spawning surveys were conducted in the Garcia River watershed. While these surveys did not occur throughout the watershed, they did cover many of the areas coho would be expected. In 1996-1997, the total coho population within five of the major Garcia River tributaries was estimated to be between 7 and 9 fish (Maahs, 1997). These population counts indicate that the Garcia River coho run is in a very precarious state and is on the brink of extinction, if it has not already occurred.

Finally, any use of spawning information as a baseline must also consider that angling regulations were changed starting in the 1998-1999 season. In prior years, sportsman could keep up to two steelhead per day, but starting in the fall of 1998, all steelhead caught by sportsmen had to be released. The impact of this change on the 1998-1999 run, as well as future runs, may be difficult to quantify, but there should be an increase in the proportion of the steelhead run which is able to reach its spawning grounds. This regulation, besides resulting in the release of hooked steelhead, has also significantly reduced the total fishing effort (Marty Scribner, North Coast Angler, Fort Bragg, CA, personal communication). Future steelhead spawning abundance estimates should take into account the effect of this reduced fishing pressure whenever a reference is made to abundance indices developed for years prior to the 1998-1999 spawning run.

Besides spawning survey information, little other information is available to characterize the population levels of Garcia River salmonids. The MCRCD investigated the utilization of outmigrant traps to estimate the population of salmonid smolts, but this was determined to be unfeasible within the budgetary constraints of the GRIMP and landowners were unwilling to take on this expense. Currently, there are few funding sources available to conduct fish monitoring and assessment work, and unless there are significant increases made to state agencies or other entities, even the continuation of spawning surveys in the Garcia River is unlikely to occur.

SUMMARY OF HABITAT CONDITIONS MONITORED

Table 15 summarizes the baseline monitoring data collected on the Garcia River tributaries in 1998-99.

Table 15. Summary of baseline conditions for Garcia River tributaries, 1998-1999.							
Study	**Bed**	**Woody**	**Gravel Quality**		**STCs**	**Shading**	**Canopy**
Reach	**Gradient**	**Debris**	**% Fines**	**Permeab.**	**% Road**	**July Data**	**Density**
		Volume	**dry-sieved**	**(cm/hr)**	**Related**	**(%)**	**(%)**
		(m^3/ha)	**(<0.85 mm)**				
1	1.9	69	9.7	1883	60	64.5	56.5
2	5.9	553	n/a	n/a	67	88.8	82.1
3	1.1	197	9.8	2515	0	63.9	50
4	0.9	179	8.8	4876	2	81.5	60.6
5	1.2	43	8.4	1708	70	58.9	31
6	3.7	159	4.9	1914	29	76	72.5
7	2	112	10.8	1861	0	76.5	73.4
8	0.9	333	6	3964	55	60.7	52.7
9	1.6	543	10.1	2158	57	69.9	78.8
10	2.2	213	7.1	5002	75	47.1	33.8
11	2.4	741	5.7	3312	33	83.2	88.1
12	2.9	335	n/a	n/a	17	83.5	84.4
Study	**Water Temperature Data, deg F**					**Habitat**	**Fish**
Reach	**Peak Temp**	**MWAT**	**MWAT**	**MWAT-- 7 Day**	**MWAT -- 7 Day**	**Pools/mi**	**Steelhead**
	Recorded	**Weekly**	**Weekly**	**Moving Daily**	**Moving Daily**	**>2 ft Deep**	**Redds/Reach**
	1999	**Max**	**Ave**	**Max Temp**	**Ave Temp**		**Mile**
1 ds	79.2	76.5	68.2	76.8	68.2	40.4	3
2 ds	59.6	58.6	57.5	58.7	57.7	6.3	0
3 us	58.6	58.2	56.3	58.4	56.6	19.8	NA
4 ds	69.4	68.2	64.3	68.2	64.9	36.5	12.6
5 ds	81.1	79.8	71.3	79.9	71.3	12.7	22
6 us	66.3	65.2	62.2	65.2	63	11.1	42.4
7 us	59.4	58.4	57.2	58.4	57.2	0	NA
8 us	79.5	77.2	69.8	77.3	69.8	18	0.9
9 ds	61.1	60	57.7	60	58.1	22.6	16.5
10 us	78.3	76.3	69.4	76.4	69.6	27.3	4.6
11 ds	58	57.6	56.3	57.6	56.6	26	22.2
12 ds	60.8	59.8	57.2	59.8	57.7	7.9	NA
ds = downstream reach; us = upstream reach							
Downstream reaches were used unless there was missing data or anomalous factors.							

Large woody debris loading was found to be highest in tributaries 11, 2, and 9. The percentage of fine sediment found in stream gravels was lowest in tributaries 6, 11, and 8. Gravel permeabilities were highest in tributaries 10, 4, and 8. Shading and canopy were highest in tributaries 2, 12, and 11. Water temperatures were lowest in the coastal tributaries 11, 7, 3, 2, 12, and 9. Deep pool frequency was highest in tributaries 1, 4, and 10. Steelhead redd density was greatest in tributaries 6, 11, and 5.

REVISITING THE MONITORING OBJECTIVES

PURPOSE OF THIS SECTION

The goals and objectives of any monitoring project should be periodically reviewed to determine whether, and to what extent, its objectives can be met (MacDonald et al., 1991). A critical examination of this project toward meeting its objective is appropriate at this point. This section (1) reintroduces the study objective in light of the past, present and future; (2) investigates the benefits and limitations inherent to numeric target-conditions assessment; and (3) underscores the conclusions of preliminary, pilot and related projects, which suggested that valid conclusions about influences of Forest Practice Rules cannot be drawn until on-the-ground hillslope conditions are tracked downhill to the instream tributary study-reaches sampled under the GRIMP.

GARCIA RIVER WATERSHED IMP OBJECTIVES

"The primary objective of this plan is to test the capability and effectiveness of the California Forest Practice Rules to protect determined beneficial uses, in this case, the salmonid fishery of the Garcia River. A secondary objective is to create a long-term monitoring data set whereby the Garcia River can be compared to other neighboring rivers in the development of a regional standard. The third, and perhaps most important objective, is to understand the Garcia River watershed and reduce its overall sediment load through adaptive management" (Euphrat et al., 1998).

Instream and hillslope disturbances resulting from forest practices have been linked to adverse conditions in the freshwater habitats of salmonids. "Legacy" era conditions (pre-Z'Berg-Nejedly Forest Practice Act of 1973) are widely cited as the cause of dramatic increases in soil erosion on hillslopes and sedimentation of rivers (Hagans and Weaver, 1987; Cafferata and Spittler, 1998), as well as other manifestations in rivers in California and the Pacific Northwest. Linkages between forest practices and aquatic dysfunction are acknowledged by ecologists, geomorphologists, loggers, foresters, environmentalists, regulatory agencies, and the public. The experimental design put forth in the GRIMP assumes that these legacy-era disturbances largely generated the conditions observed in 1998 and 1999, when baseline conditions were monitored. The notion that present channel conditions are largely controlled by the legacy era disturbances was reported by Knopp's (1993) findings in several North Coast watersheds. Present-day Forest Practice Rules have greatly improved on-the-ground methods used to access and harvest timber.

Timely efforts by the North Coast Regional Water Quality Control Board compiled many references from the research literature and have reported them in the form of numeric targets for instream conditions supporting optimal salmonid reproductive success (NCRWQCB, 2000). These targets are useful in evaluating the Garcia River baseline condition in relation to optimal instream conditions. The Garcia River Instream Monitoring Project was designed to determine if the FPRs are now providing adequate protection of salmonid habitat through the use a set of uniformly applied habitat measurements over time.

Determining whether FPRs can or do control whether a stream trends toward or away from target conditions will be difficult or impossible to answer unless broad assumptions or expanded efforts to link current channel conditions with hillslope conditions are made.

LINKING CONDITIONS INSTREAM TO CONDITIONS UPSLOPE

Pilot projects are an investment made to provide preliminary, practical guideposts prior to implementation of a full-blown project. Another useful application is to critically evaluate whether the project will meet its intended goal based on the initial design once initial monitoring data is obtained (MacDonald et al., 1991). However, it appears that at least one of the recommendations made by several studies was not incorporated into the GRIMP. An early report on FPR effectiveness monitoring by the Board of Forestry's Monitoring Study Group clearly recommended that instream monitoring coincide with upslope monitoring to link disturbances with instream effects (BOF, 1993). The instream monitoring component conducted by Rae (1995) concluded that a combination of hillslope monitoring along with instream monitoring would improve the understanding of how upslope activities affect channel conditions. It seems to this author to be critical that local hillslopes be examined in order to determine whether and to what extend the application of FPRs controlled problematic hillslope conditions resulting from timber harvesting activities. Yet this sort of assessment was omitted in the design of the Garcia River Instream Monitoring Plan.

The current Hillslope Monitoring Program traces timber harvest disturbances downhill to the receiving waterways, but does not determine downstream channel and habitat conditions. The BOF's Hillslope Monitoring Program interim report (BOF, 1999), not surprisingly, concluded, "Recent timber operations cannot be linked to current instream channel conditions based on results from the Hillslope Monitoring program because the project evaluated FPR effectiveness on hillslopes, not in the stream channels."

So without an upslope monitoring component within the subwatersheds sampled linked to instream conditions, results of Garcia River instream monitoring will be limited to comparisons of: 1) long-term trend data collected in the Garcia River basin, and 2) instream target conditions set by the North Coast Regional Water Quality Control Board. The latter approach is straight forward and useful for monitoring trends in channel conditions toward or away from the ideal channel condition. However this approach alone reflects an unsubstantiated assumption that post-1974 FPRs have a controlling influence on instream habitat conditions. In fact, this assumption was refuted by Knopp (1993). Without an effort to describe localized hillslope conditions adjacent to monitoring reaches, this target based analysis approach can tell us nothing about how, if, where, or when forest practices or FPRs control channel conditions.

It is questionable whether the Forest Practice Rules can be evaluated from the channel without exploring linkages to hillslope disturbances (Michael J. Furniss, USFS, Six Rivers National Forest, personal communication). The channel receives and interprets the entirety of watershed processes, delivered from all directions from the present as well as the past, natural and forest-practice related impacts alike. If forest practices of today are to be singled out for their effect on channel conditions, then some effort must be made to isolate them relative to the other forces that act on the channel. These forces include legacy conditions, natural background conditions, and the effects of non-compliance with FPR requirements.

Extracting Present FPR-based Activities from Past, "Legacy Era" Conditions Prior to FPRs

Extracting present conditions from the past is important in that the GRIMP objectives focus on effects of present timber harvest activities, rather than those from the legacy period. It is a difficult undertaking, but if seriously considered, then perhaps a "space-for-time substitution" on landscapes is a practical solution for the separation of legacy and present conditions (Dr. Tim Lewis, Forest Science Project, Arcata, CA, personal communication). This would require an investigation into the sub-watersheds of the Garcia River tributaries monitored to establish timber-harvest histories and their year of occurrence. The ultimate objective would be to relate the instream conditions monitored with a period of timber harvest history. This is important to discern whether the instream conditions are a result of legacy conditions only (no timber harvest for approximately 100 years), or those resulting from timber harvest activities before the modern Forest Practice Rules were enacted (no timber harvest since the passage of the Z'Berg-Nejedly Forest Practice Act of 1973), or the result of timber harvest since the mid-1970's. Then a reorganization of the data into these groups would enable an analysis group-by-group to indicate whether instream conditions have improved as a result of improved timber harvest practice rules. Even with considerable effort, however, the sample size of each group may be too small to glean a result. If that strategy is employed, then reviewing the basin history described in The Garcia River Watershed Enhancement Plan (Monschke and Caldon, 1992) is recommended reading. Timber harvest records could be examined from the records located in CDF offices.

THE USE OF INSTREAM NUMERIC TARGETS CONDITIONS TO ASSESS FPRS

Channel form-related indices that identify healthy stream habitat have been adopted by NMFS, and PACFISH (reported in Reid and Furniss, 1998) and by the NCRWQCB (Mangelsdorf, 1997). Achieving the recommended target habitat conditions in the Garcia and other salmon and steelhead rivers may be essential to increase the population of sustainable anadromous fisheries. If this were to be the intended mechanism with which to evaluate conditions in Garcia River tributaries, than this goal would have been clearly stated in the Garcia River Instream Monitoring Plan, but it was not. Data gatherers and analysts would have been encouraged or required to collect data and state their findings in the same numeric units used in quantifying the numeric targets. In this way, comparisons to the numeric targets would have been straight forward.

Several of the instream features measured during the baseline GRIMP are, however, comparable to the numeric targets, or, healthy stream indicator conditions. Comparing the existing baseline condition to the targets will help to evaluate the current habitat quality in the various Garcia tributaries. Future monitoring measurements should reveal positive trends toward these ideals or negative trends away from them. Positive trends would suggest FPRs are working and negative trends would suggest they are not working, but exceptionally large storm events will complicate this process (Madej, 1999).

If the FPRs are beneficial in reducing limiting factors on salmonid productivity, then fish productivity would be expected to improve (assuming that freshwater habitat conditions are currently limiting anadromous fish populations). The NCRWQCB and a team of technical specialists representing local, state, and federal agencies identified potential limiting factors for subbasins in the Garcia River watershed. They are as follows (Mangelsdorf, 1997):

Tributary	Potential Limiting Factors
North Fork	**Poor access, embededdness, pool depth, pool frequency, LWD, fine sediment**
Lee	**Pool depth, pool frequency**
Inman	**High temperature, limited pool depth, pool frequency, LWD, fine sediment**
Pardaloe	**High temperature, pool depth, pool frequency, instream complexity, fine sediment**
Rolling Brook	**Limited pool depth, pool frequency, fine sediment**
South Fork	**Access, pool depth, pool frequency, instream complexity, fine sediment**
BlueWaterhole	**High temperature, pool depth, pool frequency, fine sediment**
Fleming	**Access, pool depth, pool frequency, fine sediment**
Whitlow	**Pool depth, instream complexity**

Fine Sediment Targets: Current and target conditions for sediment were identified by the NCRWQCB as follows for the Garcia River TMDL (Mangelsdorf, 1998):

- For stream gravel percent fines <0.85 mm in Class I watercourses, the present condition was determined to be 20.6% (wet sieve) with the target set at 14%.
- The present conditions for fines <6.5 mm were estimated to be 45% and the numeric target was set at 30%.

These are useful targets for effectiveness monitoring. While the TMDL does not state whether targets were quantified for dry or wet sieved gravel, a review of the data used to develop the target clearly indicates that the target refers to wet sieve data. As stated previously, dry sieving methods are more accurate, but indicate a smaller proportion of fines than the same gravel sample sieved wet, which includes water weight. Wet sieving is more common because no time is required for drying the gravels.

Other Targets: The NCRWQCB refers to threshold sedimentation levels for several instream conditions, which may be useful in evaluating the sediment-related baseline or future conditions. Too little large woody debris indicates reduced habitat quality, but no threshold levels were quantified. While no numeric target was stated, instream summer water temperatures should not exceed the preferred range for anadromous fish growth: 12-14, 12-14, 10-13 degrees Celsius for chinook, coho, and steelhead, respectively (Mangelsdorf, 1997).

Parameter	**Habitat Impact**
Embeddedness > 25%	Spawning is limited
Sediments <0.85mm B diameter[3] >14% of riffle	Embryo development is limited
Sediments <6.5mm B diameter > 30% of riffle	Fry emergence is limited
Average pool depth < 4 feet	Rearing is limited
Average pool frequency < 40%	Rearing is limited
Average V* > 21%	Channel stability is limited
Average D_{50} particle size < 69 mm	Channel stability is limited

Statistical Considerations: Unbiased conclusions are most appropriately developed if acceptable rates of change toward targets are stated clearly and early in the process (definitely prior to any subsequent monitoring). If data analysis concludes that acceptable rates of change in the target directions are met, then the FPRs could be determined adequate at conserving fish habitat. However, natural fluctuation or variation could be mistaken for a trend toward or away from targets that have nothing to do with FPR effectiveness (Dr. Howard Stauffer, USFS Pacific Southwest Research Station, Arcata, CA, personal communication).

Complicating Factors:

(1) The desired numeric target conditions are not entirely known for the suite of parameters measured under the IMP (such as LWD).

(2) Schools of thought are divided as to whether healthy habitat form or healthy watershed function is needed by salmonids. The concept of dynamic equilibrium suggests that undesirable forms of habitat are part of the larger sequence of events that sustain salmonids over time across landscape mosaics and food-chain substitutions.

[3] The B axis is the intermediate axis on a pebble, the A axis has the widest diameter.

(3) Meaningful points of knowledge about what makes habitat inaccessible or inhospitable include some items that do not have targets and were not considered as potentially limiting candidates, including:
   - road-related migration barriers
   - high and unnatural levels of predation
   - lack of off-channel habitat for refuge from high winter storm flows
   - duration and frequency of exposures to high water temperature and/or turbidity
   - cumulative watershed effects

(4) Some limiting factors are instream signals of unidentified disturbance upslope. Without implementing a hillslope monitoring component within the same watershed as the instream component, tracking the effects of FPRs from source to signal is not feasible. Some of the driving variables and biological links thought to be controlled by FPRs include:
   - road-related hydrological connections that deliver a high proportion of fines via gullying/landsliding/chronic surface erosion
   - depleting the riparian corridor, which increases water temperatures by solar exposure
   - harvesting trees in the riparian corridor or on the hillslope that would have been recruited to instream locations, generating accumulations of large woody debris and instream cover
   - destruction of off-channel habitat by utilizing heavy equipment in riparian zones

What is a Healthy Fishery?

An old-timer from Oregon once said that it doesn't require an extensive monitoring program to determine whether a healthy salmon fishery exists. What is required is simply modest olfactory sensors in the nose because a healthy fishery smells of rotting fish carcasses in spawning season. On that basis along with a more technical fishery report (Maahs, 1999), it can be said that the Garcia coho fishery is not presently healthy, nor has it been for a number of years. However the steelhead fishery appears strong in the Garcia. There has not been a precise or quantitative description of a healthy fishery, however (SRP, 1999).

DISECTING THE PRIMARY OBJECTIVE AND CREATING HYPOTHESES

The objective statement can be used as a broad hypothesis that is divisible into smaller alternate hypothesis components for testing through direct experimentation, results of past experimentation, and by logical argument (Platt, 1964). Or, if the hypothesis were restated as "the FPRs work and allow fisheries recovery," then, the following decision table might be utilized (Dr. Fred Euphrat, Forest Soil and Water, Healdsburg, CA, personal communication).

Population of salmonids	FPRs are effective	FPRs are ineffective
Decrease	Unknowns in control of fish	FPRs may be at fault
Increase	FPRs allow watershed processes to support fish	FPRs irrelevant, unknown factor improves fishery

Smolts are Better than Spawners at Indicating Watershed Health

Spawning adult counts represent both watershed and ocean productivity. A better test of a watershed's ability to produce healthy fish would be survival from incubation to a 1+ smolt length of 18 cm for steelhead. Smolt fitness is a primary watershed-controlled limiting factor, in that a steelhead smolt smaller than 18 cm in length is less likely to return as an adult to spawn (Dr. William Trush, Humboldt State Univ., Arcata, CA, personal communication). Testing watershed conditions with respect to average smolt length requires an outmigrant trap measuring smolt length, or, perhaps, using scale samples from spawning adults to indicate how large smolts are at outmigration to the ocean. This metric provides a logical mechanism whereby the entirety of channel conditions is measured by smolt length. While this would not identify how FPRs impact channel conditions, it would address how well the watershed is producing fish. Without direct measures of fish production, we must assume that the combined elements of the GRIMP are a suitable proxy for evaluating fish conditions (Dr. Fred Euphrat, personal communication). This is a substantial assumption.

Ocean and Climatic Factors Beyond Control of the Forest Practice Rules

Certainly there is a major problem with either (or both) the freshwater or ocean conditions currently affecting salmon and steelhead. Coho salmon have not been found in the Garcia River basin for several years and have been decreasing in many California North Coast basins, as corroborated by the recent listings under the federal Endangered Species Act. Steelhead have also been recently listed in some basins, but appear stronger in the Garcia. There is evidence supporting the concept that ocean conditions, a large and mostly unknown influence, may be controlling distribution or limiting these fish in this portion of their range (Mantua et al., 1996; Francis, 1993; Beamish and Bouillion, 1993; Anderson, 1995). One hypothesis is that a cyclic division between the Alaska and California currents determines whether the northern or southern ranges of salmon are productive, but not both (Pearcy, 1992). Thus there remains a possibility that ocean conditions or some other factor is controlling anadromous fish populations over and above watershed conditions. If so, even ideal freshwater habitat conditions in each of the life stages might not bring the fish back to sustainable populations. However, when and if ocean currents reverse to favor the southern ranges (10-40 year cycles), then watershed processes and disturbance rates could become primary limiting factors (if they are not already).

CONCLUSIONS OF ANALYSIS FOR THE PRIMARY OBJECTIVE

It appears unlikely that instream experimental design will be able to test the effects of the FPRs from the channel unless target conditions are used, a useful but oversimplified notion with several assumptions. Instead, testing whether the FPRs are protecting the anadromous fishery should be linked to an upslope monitoring program to fairly and accurately determine what works and what does not. Without this upslope component, the connection between upslope activities and instream conditions remain unknown.

FACTORS COMPLICATING THE PRIMARY OBJECTIVE

While conceptually simple, the primary GRIMP objective requires understanding, distributing, and quantifying the effects of timber harvest practices on instream conditions that limit anadromous fishes. This leads to underlying difficulties that include: (1) upslope disturbances caused by timber harvest activities have not been traced, or linked, directly to habitat in the channel; (2) exactly what habitat features protect the anadromous cold-water fishery, and exactly what watershed processes maintain them is not entirely understood; (3) "legacy" era disturbances dominate current channel conditions in highly and moderately disturbed channels (Knopp, 1993); and (4) whether habitat conditions, watershed function, or ocean conditions are primary limiting factors has not been determined.

SECONDARY OBJECTIVES

A Data Set for Long Term Instream Monitoring

Baseline conditions should be reexamined for a variety of objectives. Data resulting from the instream monitoring program will be freely available to the public, public agencies, industrial timberland owners, etc. It will provide opportunities for comparative research with other streams in the region, and will allow further research for any imaginative researcher with interest in this area.

The Garcia River Conditions as a Regional Standard

The regional standard concept was introduced as a means to compare rivers in terms of their instream conditions (Dr. Fred Euphrat, personal communication). The conditions in the Garcia are not ideal and how these conditions could be used as a reference to other streams has not been identified.

Reducing Overall Sediment Loads through Adaptive Management

This objective requires an approach for implementation that has not been clearly identified. Perhaps the first step is to provide landowners with a list of items to address--that are meaningful and feasible (Dr. Fred Euphrat, personal communication). As a starting point, it is recommended that landowners inspect their roads during or just after substantial rainstorms to determine the adequacy of road drainage structures and the ability of stream crossings to provide for fish passage (Weaver and Hagans, 1994).

QUALITY ASSURANCE AND QUALITY CONTROL

INTRODUCTION

The Quality Assurance and Quality Control component of the project was included to ensure that data collection efforts were implemented as envisioned by the Instream Monitoring Plan (IMP). A secondary role was to encourage reevaluation of the ability of the experimental design to determine whether the IMP and its data will meet its objectives. A discussion of the practical limitations of the IMP is presented in the previous section entitled "Revisiting the GRIMP Objectives."

DATA COLLECTION

Quality assurance recommendations set forth in the GRIMP by Euphrat et al. (1998) included a sampling framework in designated stream reaches and listed the desired qualifications of the staff implementing the sampling. The procedure employed by the MCRCD consisted of: (1) hiring qualified resource professionals to collect the data; (2) using explicit contract language to facilitate communication of mutual expectations regarding fees, protocol and task, level of precision required, and deliverable products; (3) hiring a Quality Assurance/Quality Control Hydrologist to insure IMP data would meet the needs of a long-term monitoring program; and (4) relying on the Garcia River Project Manager to manage each subcontract. For each of these roles, the MCRCD hired independent subcontractors having at least a masters level education and/or considerable experience.

The Quality Assurance Hydrologist's duties included: coordinating activities with the MCRCD's Garcia Project Manager, organizing a panel to select and refine recommended protocols, meeting with subcontractors to affirm field methods prior to data collection, and reviewing draft subcontractor reports. Identification and review of protocols and field methods prior to data collection was considered a priority. Intentions of the subcontractor were to be approved by the Project Manager and Quality Assurance Hydrologist prior to any data collection, but this was not always accomplished.

Subcontractors for each protocol were asked to attend two meetings prior to gathering data to establish consensus in: (1) selection and refinement of the parameter protocol, and (2) agreement on the proper field methods. Meetings were initially targeted to include consulting watershed specialists, but this was found to be problematic to schedule with available funding. Attendees included the subcontractor (often a specialist), neighboring landowners (industrial and non-industrial timberland owners), the Project Manager, and the Quality Assurance Hydrologist. Together, this group invested approximately half a day to identify and/or edit a proposed protocol, gain more complete understanding, and accept a unified protocol for implementing the parameter in question across ownerships. A smaller group invested a second half-day to work through field methods to be employed during data collection. This day also improved efficiency by introducing subcontractors to the location of the streams and their best access points.

The team approach to preliminary acceptance of protocols and field methods proved to be a wise quality assurance procedure. This preliminary review substantially reduced field costs over those expended to determine the status of contracted work, facilitated identifying and resolving gray areas before implementation began in the field, helped to maintain good relations with the subcontractors, and was more successful in conveying the intent behind each protocol task than the contract language. This was especially true where subcontractors had an interest in the monitoring effort that went beyond compensation, such as an applied interest in the data.

QUALITY REVIEW OF THE DATA

The Quality Assurance Hydrologist targeted a 25 percent sample of subcontractor work for quality control review, amounting to three of 12 survey reaches. The goal of this review was to observe whether or not subcontractor work met the terms of the contract and the goals of the IMP. An effort was made to identify the sample randomly to get a representative, unbiased view of contracted fieldwork to grade quality and identify problems.

Study Reach Establishment

Problems identifying reach and plot boundaries were anticipated, and contract language was developed to avoid a poor selection by requiring submittal of maps identifying each study reach and a timeline for work agreed to by the Project Manager before implementation. However, a full set of study reach maps was not received until after the contract term expired, which denied their utility for other subcontractors and left evaluation by the MCRCD or others out of the question. A considerable amount of the survey work was completed before the “preliminary site visit” was made with the subcontractor. The subcontractor did not wait for approval for monitoring sites and located them assuming approval.

Upon examining the first plots, issues were raised by the Quality Control Hydrologist to the Contract Manager that plots were too narrow to allow channel migration during the study and that bankfull widths were not estimated properly, which had impacts on the plot length criterion.

Longitudinal and Cross-Sectional Profiles

Determining bankfull width in the field is generally acknowledged as difficult on the North Coast, and fundamental differences of opinion existed. The survey subcontractor consistently identified much narrower bankfull channels than did the LWD subcontractor, with the Quality Control Hydrologist somewhere in between the two estimates. A San Francisco based regional estimate of bankfull width was applied from tables in Dunne and Leopold (1978) to further evaluate the estimates of bankfull width, both on the plots themselves and on the criterion of establishing reach lengths equivalent to 10 or 20 bankfull widths (see Table 3). This information indicated all of the survey subcontractor's estimates and most of those by the LWD subcontractor were too narrow. One result of a narrow cross-section was that in one tributary, original cross-sections intended to represent a width equal to three bankfull channels had endpoints that were wetted by a bankfull event. The site with the narrowest width was corrected, but the problem generally persists in most study sites. Thalweg and cross-sectional profiles did not fully satisfy sample design, generally accepted methods for long term channel monitoring, or the terms set forth in the contract in that:

(1) Multiple plots were individually shorter than recommended to satisfy statistical and hydrological assumptions (20 bankfull widths), but when summed, the overall reach length went beyond 20 bankfull widths. Because plots were not continuous nor connected, hydrological and statistical assumptions based on the 20-bankfull width sample were not met. A request to link the plots by a single measure of gross elevation change was not provided for most streams.

(2) The minimal cross-section widths may not accommodate flooding and/or channel migration.

(3) Soil benchmarks used to establish elevations recorded at rebar pins are likely to fluctuate, which means the benchmark elevations cannot be relied on to determine streambed aggradation/degradation, either in cross-section or thalweg profile.

(4) Truly permanent monuments, such that reach and plot relocation can be expected in five to 20 years, was generally not achieved (this was partially corrected by the MCRCD staff).

(5) Staff gauges were located at a distance from cross-sections, which precluded their use for gauging stream flows.

Secondary, less serious deficiencies included: (1) a lack of "closing the loop" on thalweg profiles negated the ability to provide an estimate of measurement errors, such that real geomorphic scour or aggradation is recognizable from that error (Madej, 1999; Harrelson et al., 1994; Scott McBain, McBain and Trush, Arcata, CA, personal communication); and (2) no installation of flagging at regular intervals, so that the same positions within the plot could be measured separately by each following parameter's subcontractors. Negotiations with the subcontractor were initiated, but without additional payments, the subcontractor was unwilling make corrections.

As a result, the MCRCD Board of Directors withheld partial payment of invoiced work and used these funds to install more permanent monuments for elevational benchmarks outside flood-prone areas. These monuments are ½ inch rebar in 4-foot lengths driven into the soil and capped with yellow plastic. Distance, azimuth, and elevation to the first thalweg measurement were measured at most of these points. These are the minimum procedures recommended by Harrelson et al. (1994) that were referenced by Euphrat et al. (1998) and by Scott McBain (personal communication). The MCRCD's follow up efforts were courtesy of EPA's Garcia River restoration implementation program and will correct some elements of the cross-section and thalweg profiles and improve plot relocatability. However, without completely resurveying and linking all plots in terms of elevation and distance, some cross-section and thalweg profile data may be unusable in comparing initial surveys with later ones.

Canopy and Shading

Reports for five tributaries were completed in late summer 1998, but the remaining creeks were not measured until the return of the leaves in 1999. A single sampling season would have afforded a more uniform sampling condition at baseline measurement (which is usually an assumption of baseline measurements). In this case, we have assumed that no changes in independent variables affecting canopy and shading occurred between summer 1998 and summer 1999.

Water Temperature

Initial sampling began in August 1998, after most summer water temperatures had already peaked. All data loggers were redeployed in May through October 1999. Air temperature loggers were recommended by the subcontractor but were not implemented. The two-year data set may be useful in estimating general variability of non-peak water temperatures. Other than this utility, the 1998 effort may be insignificant in establishing baseline conditions and perhaps the late start should have deterred the investment.

Large Woody Debris

Various LWD protocols were examined and discussed in a pre-data collection meeting. The selected protocol borrowed from a combination of methods from the Fish, Farm and Forests Communities Forum Field Protocols Handbook[4], from previous Caspar Creek LWD studies (O'Connor and Ziemer, 1989; Surfleet and Ziemer, 1996), and from procedures utilized by Mendocino Redwood Company and Campbell Timberlands Management, Inc. (formerly Georgia-Pacific Corp.) industrial forestland managers. This survey also incorporated riparian stand classification elements from the Washington Department of Natural Resources' Watershed Analysis Riparian Function Module (WDNR, 1995), along with the California Department of Fish and Game's Wildlife Habitat Relationships (WHR) vegetation classification system. The data and report includes an inventory of the existing LWD over 10 cm in diameter and 2 meters in length, and a recruitment estimate based on the density of "fresh wood" presumed to have had 0-3 years residence time in the channel.

The subcontractor for this work also recommended that if the LWD data is analyzed in terms of volume per unit area, the unequal area of sample plots will require a statistical data transformation using a ratio estimator (O'Connor, 2000). LWD is traditionally expressed as volume per unit area of stream channel or by weight per length of stream channel. The bankfull width identified and utilized by the LWD subcontractor was consistently and considerably wider than that estimated by the subcontractor who established the cross-section measurements, illustrating the degree of variability of this measurement and its dependence on the individual's methodology for determining bankfull stage (Table 3).

Spawning Surveys

Spawning surveys were conducted from the first week in December 1998 through the fourth week in March 1999 in tributaries and some portions of the mainstem Garcia River. No coho redds, live coho, or coho carcasses were observed during the survey. However, the literature indicates that adult coho spawn in late fall and early winter in their southern zone and coho salmon were identified in Mendocino County tributaries in November 1998 (Jerry Wall, Salmon Restoration Association, Fort Bragg, CA, and Charlotte Morrison-Ambrose, NMFS, Santa Rosa, CA, personal communication). This raises the possibility of coho activity in the Garcia in November, prior to the onset of the survey.

No redds of any kind were found during the first week in December, suggesting that either there was no coho activity prior to December, that redds built by coho before the survey were washed out prior to the first week in December, or that coho tributaries were not sampled. In any case, future surveys should begin in early fall so that no potential coho activity is overlooked.

Gravel Quality in Bulk Samples and Permeability

Initially, all gravel measurements were to be made in abandoned salmonid redds because redd construction is known to alter the composition of fines in spawning substrate. McNeil bulk gravel composition results are notoriously variable, indicating the GRIMP would benefit from as many bulk samples as possible to accurately represent the mean proportions and variability of gravel size classes. The subcontractor for these measurements worked with the Project Manager and Quality Assurance Hydrologist to estimate the most efficient sample size that accurately represented the sample population within the available budget. This evaluation showed that when the constraint of sampling abandoned redds was included, an insufficient number of sample sites were generated. Instead of mixing spawned gravel sites with non-spawned gravel sites, a decision was made to exclude spawned sites from the primary data set to limit expected variation.

Permeability samples were to be taken at any known redd site located in the study, but this element was not implemented due to time constraints, despite the fact that gravel sampling took place well after salmonid emergence, and in most tributaries, spawning sites were still evident by streambed features and flagging left by spawning survey crews. These omissions took place even though it was discussed in pre-data-collection meetings, and the Quality Assurance Hydrologist was present during much of the data collection.

Analysis of bulk gravel data from the Garcia River tributaries indicated lower percent intergravel fines than was expected from a river basin impaired by excessive fine sediments. This is due to differences resulting between processing dry-sieved samples and wet sieved samples. Dry-sieved GRIMP baseline gravel results cannot be directly compared with wet-sieved results produced from previous studies, due mostly to water weight gained with wet sieving.

Measurement variability is best controlled by sieving dried gravels to remove the mass attributable to water, without requiring correction. The literature suggests using air or oven drying in a laboratory, sorting into size classes by passing the sample through a series of sieves, and weighing

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[4] See the Fish, Farm and Forests Communities Forum web page at www.humboldt.edu/~fffc.

each size class's collection. The subcontractor's budget (and that of the entire GRIMP) precluded transporting gravel samples to a laboratory, but considerable effort was made to ensure that all samples were air-dried by spreading the samples uniformly on separate tarps and turning them such that all sides were exposed to the sun, heat, and air. Samples prepared in this manner appeared dry, and no particles adhered to one another upon sieving. Once dry, the entire sample was weighed and its weight entered on a field form for that sample. This was followed by sieving and weighing of each size class. A final sum of weights by size class was compared to the initial sample weight to test for gross gain or loss in mass. The argument remains, however, that some water weight may have remained in the "dry" samples. If so, the intergravel percent fines reported would reflect both fines and water, such that the true and unknown net fraction of fines alone would reflect an even lower percent than those reported.

Turbidity Sampling

Turbidity was not formally adopted into priority parameters intended to be included in the GRIMP. Nonetheless, its value as an immediate response variable was recognized. A preliminary attempt at turbidity measurement was made by MCRCD staff and members of the spawning survey crew during winter 1998-99, with the loan of a turbidometer from the Mendocino County Water Agency. Problems that unfolded included: (1) staff gauges were not always located at cross-sections, resulting in limited gauge height data to relate to water samples, and (2) as winter progressed and high flows were encountered, five staff gauges washed out or were so damaged that gauge heights could not be determined. On one tributary, the staff gauge was too short and was overtopped in high flows, while on another, the staff plate was not installed until February. Even with these problems, the resulting turbidity and flow data was informative. But a quantitative investigation requires sampling in high flow conditions where a discharge rating curve is maintained. A greater commitment in effort would be required to deliver a successful turbidity monitoring program, yet it is perhaps the signal most appropriate to the needs of this study.

Sediment Transport Corridors

The STC survey was the only parameter utilized in the GRIMP capable of linking cause and effect. This parameter and protocol were introduced by Forest Soil and Water (Euphrat et al., 1998). The only previous reports or reviews of the procedure known to have occurred are in the personal experiences of Dr. Euphrat and Dr. O'Connor. Difficulties quantifying STCs and repeating this survey were expected.

Quantifying STC length, width, and depth from the field observations is needed to obtain volume estimates for eroded material. Accuracy within an order of magnitude is likely from the existing data, but finer precision will not be available until more accurate field measurements can be made. This may be achieved by having a team of two in the field, rather than one, and by more carefully accounting for width and depth variations in individual STCs.

Sediment delivered to a fish-bearing channel is one of the most obvious impacts on the stream. When roads alter topographic and subsurface drainage patterns, fresh scars can appear on the landscape that are recognizable as STCs – usually gullies and landslides. Although not included in the STC protocol, the STC analysis could have included density of gullies, landslides, bank failures, and tributaries, perhaps stratified by road density in the plot or sub-watershed.

Repeatability of this survey may not be a problem, even if individual STCs are not relocated. The protocol is similar in nature to the LWD survey, where the particular pieces of wood may not be relocated due to washing out or burial by sediment, but an increase or decrease in wood per mile, or a change in rate is discernable. In contrast, relocatability suggests that a future person or team repeats the survey from plot 1 through plot 4, attempting to locate those STCs found initially to determine whether they are visible and whether their length, width, and depth has increased or decreased. STCs may not be relocated due to healing and revegetating or lack of experience in the surveyor. There was a definite trend towards identifying more STCs with experience.

STC density and rate of development may be more informative than precise estimates of the volume of sediment they deliver. If so, it would be more useful to determine whether the density of STCs increases with time than an effort to relocate each STC identified in 1999.

Pebble counts

In response to public comments during the review of the draft GRIMP, pebble counts were added to the list of parameters to be monitored, and this sampling work was conducted during spawning gravel quality sampling. However, this data has not been analyzed and was submitted as raw data only because the analysis was not specifically included in the original scope-of-work.

CONCLUSIONS FROM QUALITY ASSURANCE METHODS

Recovery from unacceptable methods is not always possible, and the GRIMP experience suggests that it is far more productive, efficient, and realistic to work out problems before they are implemented rather than attempting to solve them later. Pre-data collection investments in Quality Assurance were highly effective at solving problems before surveyors began field work and presumably saved money. Consensus building at each stage reduced probabilities of future contesting of data, fostered support and goodwill among diverse landowners, and maintained good relations with subcontractors. Most importantly, many issues were resolved before they became problems. Critical personnel should attend a scooping meeting to review experimental design and meet to compare and contrast protocol options. Attendees should include representatives from the sponsoring organization, contracting organization, and subcontractors. In the field, a separate meeting should include these same individuals as well as field people collecting the data. Consensus building between those involved increased understanding of expectations such that fewer surprises resulted, thereby avoiding potential problems both for protocol development (office setting) and protocol implementation (field setting). In the one problematic contract, no such preliminary meeting took place.

Contractual Methods

A signed written contract can clarify mutual expectations of tasks, deliverable products, and compensation. It is the main source of documentation and leverage for resolving disputes. If contract language is carefully articulated to clearly convey deliverables, and if the contract is revisited to ensure its applicability throughout its life, then problems can be taken care of through arbitration, mediation, or in court. This does not necessarily assist in fixing poor quality data. The 10% withholding provision is useful when additional expenses are required for corrective work. The primary problem encountered in implementing the GRIMP was failure by subcontractors to carry out some portion of the scope-of-work specified in contract, although in some cases, the task descriptions were not as clear as they should have been. Once the work was completed, subcontractors were unwilling to go back and collect missing data or refine their work. Problems with property access and starting GRIMP implementation later than expected exacerbated this situation by forcing decisions to allow subcontractors to use short-cuts to keep progress at a reasonable pace.

Field Methods

When conflicts arise, they should be worked out in the field as soon as possible to the satisfaction of the Quality Assurance person. Utilizing the Quality Assurance person as a field technician can also conserve resources for both the subcontractor and contracting organization. However, it may be unrealistic to expect this person to fully project himself/herself into both roles unless sufficient field time is allocated to successfully undertake both tasks.

Resolving Problematic Issues - Whose Role?

Contracts are typically negotiated and administered by the Project Manager. This person takes the lead when dealing with the subcontractor over tasks described in the contract. When the Quality Assurance role is assigned to a different individual, the responsibility for resolving problems resides somewhere in between. If direct negotiation between the Quality Assurance Hydrologist and the subcontractor is inappropriate, some mechanism must be included to illuminate and solve problems so that the investment in identifying problems is not wasted. If issues are raised but not addressed, funds spent to ensure quality are wasted in the mildest case. In the worst case, the integrity of the program is at risk. Whether the QA/QC representative is empowered to remedy problems or not, he/she should document all problems in writing when they are first identified and, if necessary, forward them up to all rungs in the ladder empowered to negotiate the contract. If verbal communications fail, the written document stating the problem provides a record of when the problem was brought to the subcontractor's attention and the measures proposed for resolution.

COSTS IN DEVELOPMENT AND IMPLEMENTATION

BUDGETED AND ACTUAL EXPENSES

The dollar amount of the contract between CDF and the MCRCD for developing and implementing the Garcia River Instream Monitoring Project totaled $173,880. The budgeted expenses and actual costs are detailed in Table 16. Upon completion, the project was over budget in Establishing Plots and Surveying Profiles, Quality Assurance/Quality Control, and Project Management. The approximate dollar amount extended to this project from other sources is $9000.00, funded mostly through EPA's 319H Garcia River restoration implementation project.

Table 16. Estimated and Actual Expenses for IMP Development and Implementation.

Task	Budgeted Expense ($)	Actual Expense ($)
Develop Instream Monitoring Plan	33779	33733
Establish Plots and Survey Profiles	20453	21420
Water Temperature	7174	7174
Riparian Canopy	2808	2808
Large Woody Debris	15075	15075
Spawning Survey	9998	10000
Sediment Transport Corridor	3500	3500
Gravel Quality	36678	36687
Quality Assurance and Control*	5829	9315
Project Management**	15905	11788
Overhead	22680	19988
Equipment		2393
TOTAL	173879	173881
* included some aspects of project management		
** approximate over-budget expense not paid by CDF		9000

BEST PARAMETER PERFORMANCE

Riparian Canopy and Water Temperature

Riparian canopy and water temperature were the most cost-effective measurement parameters. Water temperature is dependent on canopy in smaller streams and is a biological link that shows the importance of canopy closure/shading in cooling stream waters. As baseline parameters, both are simply quantified and understood, and for utility in fisheries assessment, canopy closure and maximum temperature are useful data metrics. The models developed by Hines and Ambrose (2000) successfully predicted coho absence from elevated stream temperatures according to duration and magnitude of exposure in cool water refugia. Therefore, canopy and temperature are biologically significant parameters that can be affected by forest practices along the WLPZ (watercourse and lake protection zone). Harvesting the riparian canopy reduces stream shading, potentially elevating stream water temperatures and increasing duration of elevated stream water temperatures, which can be used to predict the absence of one threatened anadromous fish species within its range.

Sediment Transport Corridors

Sediment transport corridors identified links between road disturbances and hillslope erosion. Surveys of second and third order tributaries revealed that fine sediment eroded from upslope locations was usually either flushed from the tributary and transported to the mainstem, or was mixed into the bedload substrate so that its presence was not observed. Quantitative measurements used to obtain baseline data and subsequent monitoring could be improved. Most critical and recurring STCs were road crossing diversions, ditch relief drainage structures, waterbar outlets, and roadway diversions.

Large Woody Debris Recruitment Rate

The species and recruitment rate of wood entering the system was a sub-element of this parameter, but may be the most important parameter linking watershed process to ideal habitat form features that can be directly controlled by the FPRs. That is, because we believe juvenile and perhaps adult salmonids rely on the cover and pool features created by LWD, it is important to know if we are building our in-channel wood or causing depletion. Determining only fresh recruitment species and rate would substantially reduce costs by quantifying only freshly down wood by species and volume. However this would omit pre-existing LWD in relation to the habitat present.

Gravel Quality and Permeability

Gravel measurements and analysis were the most costly elements of the GRIMP. Bulk gravel samples are notoriously costly to measure and require many samples because of variability, so this was not surprising. However, the gravel permeability protocol that directly measures the rate at which water passes through spawning gravel took much less time and was relatively inexpensive. Permeability measurement has a potential to replace the more laborious McNeil technique that requires removing one cubic foot of gravel and then determining its particle-size distribution. The link between stream biology and particle size is the clogging of gravels by fines that prevents the flow of water through the gravel. Permeability is a more direct measurement of these phenomena. However, its utility awaits further testing to determine criteria for predicting survival-to-emergence, a concept that has already been quantified for percent fines. Sampling permeability alone is an emerging goal if survival-to-emergence can be predicted directly by permeability.

Channel Morphology via Longitudinal Thalweg and Cross-sectional Profiles

The longitudinal thalweg profile is best used to investigate trends of channel aggradation, downcutting, and pool filling. Cross-sections are useful for identifying the relationship between the bed, banks, and floodplains. It is difficult to determine the cost-effectiveness of these factors individually because they were budgeted and invoiced together. Costs could be reduced without sacrificing data integrity by measuring one or two cross-sections per plot. Longitudinal profiles are classic elements of a stream survey and can be used to produce a great deal of graphical information about bed elevations and channel complexity (i.e., more “bumps” mean more complexity and more diverse habitat).

PREPARING A COST EFFECTIVE, REALISTIC MONITORING PROJECT

All parameters could have been implemented at less cost if a staff of employees were trained by specialists and then conducted measurements for $15-$20 per hour. Instead, highly skilled resource professionals were generally compensated between $20 and $40 per hour for this work. Using lower cost technicians would have allowed measurements of additional parameters such as V* or a committed turbidity measurement effort. Tradeoffs in quality of data are anticipated but not known.

Project Management requires a larger budget than was allotted, by about 25%. Perhaps a reduction in overhead budget could reasonably be reapportioned to project management. Participating in collaborative, pre-protocol meetings with project managers, landowners, technical peers, and other concerned parties prevented problems as opposed to attempting time consuming and less effective resolutions, thereby reducing project management time. Reexamination of project objectives in light of the plan and parameters cannot happen too often.

FUTURE MONITORING AND STUDY MAINTENANCE

FUTURE MONITORING

Monitor Hillslope Conditions in Hydrologic Units Sampled Under the GRIMP

To adequately answer the primary objective of the GRIMP, hillslope and instream conditions should be monitored in the same hydrologic unit. Moreover, disturbances identified in the hillslope component should be traced to the channel where any physical changes to the receiving channel could be reported. When a change in the physical condition is related to salmonid requirements, then a biological link connects the source with the signal and the problem. Without these links, possible conclusions regarding FPR effectiveness over time cannot reveal where the problems lie.

Because instream baseline conditions have been established, a hillslope component can now be applied to the Garcia River in subwatersheds where aquatic conditions were monitored under the GRIMP. The BOF's hillslope monitoring procedures have been well developed, tried, and tested, so that its protocols are well defined. Hillslope monitoring should be conducted in the hydrologic units of the GRIMP as soon as possible to establish hillslope baseline conditions, and then remeasured following THP operations in each of the hydrologic basins. In particular, hillslope monitoring for FPR effectiveness should be conducted following significant stressing storm events.

Link Harvest Related Disturbances to Measured Instream Conditions

Causal mechanisms thought to begin with timber harvest-related activities (such as road construction) go through a series of linkages before affecting fish-related beneficial uses in the channel (such as accumulation of fines in spawning gravel, reduction in fry feeding due to chronic turbidity, filling of pools, and reducing available off-channel habitat by roading a flood plain). The GRIMP has established baseline conditions for some fish habitat indicators, but did not consistently establish their links to causal mechanisms due to a lack of explicit recommended methodologies, and a separation of instream from upslope monitoring. However, the potential still exists to determine these links to instream parameters if the project is expanded to include monitoring of upslope activities in the monitored subbasins and tracking process mechanisms to the receiving channel downstream. The GRIMP has identified several streams that would serve as ideal locations to conduct simultaneous hillslope and instream monitoring.

The objectives of future monitoring could include:

(1) Determine long-term trends in the measured habitat parameters.
(2) Link beneficial fish uses with channel conditions, and channel conditions with upslope disturbances, and upslope disturbances with forest practices, and forest practices with FPRs.
(3) Quantify the range of ecologically acceptable watershed disturbances.
(4) Determine whether the application of FPRs effectively limits watershed disturbances to the level established in (3).

Plan for Use of Target Conditions and Measure Parameters by Same Methods and Units

The Garcia River can now be used as a baseline data set for testing FPRs, as the measured habitat conditions are reevaluated in the future. Continued monitoring of instream parameters without upslope monitoring will test instream conditions against target conditions identified as beneficial for the fishery. Some such targets were identified by the NCRWQCB in its TMDL process (U.S. EPA, 1998), as well as NMFS and Pacfish (reported in Reid and Furniss, 1998). If this is the desired plan for analysis, then all future monitoring should measure conditions in the same units as they are expressed in the targets. Whether a few or the entirety of parameters measured are selected in answering the monitoring question, a directional trend toward fish-friendly targets and acceptable rates of improvement for each parameter should be determined before another round of data is collected. Identifying the acceptable direction and rates of trends ahead of time will enable unbiased conclusions to be drawn (Dr. Howard Stauffer, personal communication).

STUDY MAINTENANCE

In visiting stream reaches and plots over the last two years, it became clear that more than one marker is needed for each plot and that, while flagging is the most visible marker, it is quite temporary in nature. Flags and driven rebar were the contracted methods for establishing reaches and plots boundaries. We suggest that all reaches and plots be revisited in the very near future to apply “flashers” or aluminum tree tag markers at each end of the reach and in plot boundaries. Cement monuments with an inset steel carriage bolt are also desirable to facilitate relocation by a magnetic detector (Scott McBain, personal communication; Harrelson et al., 1994).

It would be advisable to examine study reaches one to two years after establishment to insure markers can be relocated based on study reach maps and written descriptions. Someone other than the person who originally installed the study reach should conduct this task to insure accuracy and utility in maps and descriptions. The ability to relocate study reaches, plot boundaries, and benchmarks is essential if all or some of the IMP parameters are to be revisited. The objective of this task would be to either confirm that plot boundaries can be identified, or to remedy situations onsite so that plots and study reaches can be relocated in perpetuity or at least in the next round of monitoring.

Remeasuring Schedule to Encapsulate Change in Watershed Conditions

For LWD and channel morphology, conditions are unlikely to change in a significant manner until a 30-year to 100-year storm is experienced (Euphrat et al., 1998). Other parameters change more quickly. The GRIMP recommends a remeasuring schedule based on a time-scale that reflects the expected rate of change for each parameter. A conceptual framework for developing a re-monitoring schedule is presented in Table 17, based on a table which was included in the Instream Monitoring Plan (Euphrat et al., 1998). It is suggested that parameters such as LWD loading, channel cross-sections, and thalweg profiles be remeasured following geomorphically significant flood events, while other parameters such as water temperature, fish surveys, and turbidity be remeasured seasonally and/or annually. A precise remeasurement schedule remains to be developed for the Garcia River watershed.

Table 17. Time scale of watershed response: potential remeasurment schedule (after Table 5-3, Euphrat et al., 1998).

Condition Measured	Seasonal Response	Annual Response	Management Response	Geomorphic Event Response (>30 yr)
Turbidity	x	x	x	
Temperature	x	x	x	
Gravel composition		x	x	
Gravel permeability		x	x	
Cross-section profiles			x	x
Longitudinal thalweg profiles			x	x
Riparian canopy	x	x	x	
Large woody debris			x	x
Sediment transport corridors	x	x	x	x
Fish surveys	x	x	x	

CONCLUSIONS[5]

A COMPREHENSIVE BASELINE OF INSTREAM CHANNEL CONDITIONS WAS ESTABLISHED

The baseline conditions identified by this monitoring program describe many features of Garcia River tributaries, including: water temperature, riparian canopy and shading, pool depth and frequency, spawning gravel composition and permeability, LWD loading, spawning adults, and sediment transport corridors. Although coho salmon appear to be virtually gone from the basin, the steelhead population in the Garcia watershed appears to be strong relative to other streams in Mendocino County (Maahs, 1999). Large woody debris is entering these systems at a relatively rapid rate, although it is composed of multi-species and is of smaller dimensions than the longer lasting old-growth redwood seen in persistent pools in the South Fork of the Garcia, Mill Creek, and other tributaries (O'Connor, 1999).

Water temperatures in the coastal tributaries were adequately cool so that coho presence is predicted based on temperature alone. Riparian canopy was well-correlated to water temperatures, corroborating the concept that a decrease in canopy increases water temperatures. The correlation between canopy and water temperature in the Garcia River basin is credited to Project Manager Michael Maahs, who had just plotted the data on the last day prior to his untimely death in March 2000.

Permeability monitoring was tested to describe spawnable substrate. This method may replace the more costly and more variable bulk sampling done throughout the region if a reliable relationship between permeability and salmonid egg survival to emergence can be developed (McBain and Trush, 2000). Currently, permeability can be considered an index of gravel quality. Another new protocol, the STC (sediment transport corridor), was tested in this program. This procedure tracks hillslope disturbances from their source and identifies some consequences in the stream. The STC procedure was the only sediment-related parameter that linked management-related sources to a channel signal. STC identified problems linked to forest practices were mostly road-related diversion gullies and landslides (Barber, 1999).

The author summarized the baseline data collected during the Instream Monitoring Project for Board of Forestry and Fire Protection's Monitoring Study Group (MSG) in June 2000. The presentation brought excellent reviews and commendations by the diverse group. It appears that the public, industrial timberland owners, and the resource agencies see long-term value in this project, where there was an intensive baseline collection of instream conditions within multiple tributaries of a single river basin. This is further reflected in the dollars contributed by EPA for this purpose. As a result, the MSG made a firm recommendation to CDF to explore avenues to: 1) follow through on future monitoring to identify trends, even if upslope linkages are not identified; 2) provide funding for this future monitoring, 3) act on recommendations to revisit the plot boundaries in the field and increase the permanency of markers to ensure that plot boundaries may be relocated, and 4) determine hillslope linkages.

HILLSLOPE CONDITIONS WERE NOT INVESTIGATED

Hillslope conditions and forest practices were not evaluated as to their effects on channel condition. Instream conditions reflect responses to watershed processes working on landscapes created in both the present and the past, and they reflect both natural and management related disturbances. Separating the effects of the Forest Practice Rules from past and present, and from hillslope to channel in the watershed mosaic requires focusing on how timber harvest effects are routed to the channel and how they effect the fish. Therefore by omitting a hillslope investigation tied directly to the channels monitored, the present GRIMP is unable determine the effects of timber harvest practices on instream conditions.

Except for the Sediment Transport Corridor Component, the GRIMP did not establish linkages from channel conditions monitored to activities on hillslopes where forest practices most often occur. Therefore this report recommends an additional investment in Garcia River watershed hillslope monitoring to determine the nature and extent to which upslope disturbances are connected to the channel and to relate in-channel effects to needs of the fish.

Without the hillslope link, monitoring instream trends, particularly toward or away from "target channel conditions," will be the practical approach to experimental design used to determine whether the Forest Practice Rules are effective at conserving the coldwater fishery in the Garcia. This requires assumptions in that: (1) instream conditions are controlled by FPRs--but this assumption is refuted by Knopp's (1993) work; (2) target channel conditions represent those

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[5] Please also see the following section, Recommendations, for a concise list of conclusions.

desired by salmonid fishes; and (3) watershed processes control fish productivity--but this assumption ignores the significance of ocean conditions during most of the fish's life, from smolt to adult.

Monitoring fish themselves is problematic because they respond to channel and watershed conditions as well as ocean conditions, predation, disease, etc. Yet, if we do not monitor the fish we lose the most important indicator of fish health, the fish! We must admit that we are not conscious of everything that affects salmonids (Reid and Furniss, 1998). Food web dynamics involved with instream temperature and turbidity may play a greater role than previously credited (Sommarstrom, 1997; SRP, 1999). Finally, Knopp (1993) concluded that legacy disturbances continue to dictate channel conditions of today in moderate or highly disturbed watersheds, which suggests that the current FPRs cannot control instream channel conditions (particularly in regard to coarse sediment and LWD loading). If so, then restoration from legacy conditions, improvements in grazing and agricultural practices, etc., will be required before stream channel conditions in the Garcia can be controlled by application of Forest Practice Rules. Some such work has been undertaken.

SURVEY PLOTS AND STREAM REACHS ARE SMALLER THAN PLANNED

Unfortunately, the plot boundaries were set by the first subcontractor, without input from MCRCD or its staff, or anyone else. While avenues to keep this from happening were incorporated into the contract language, the deficiencies brought forward by the Quality Control Hydrologist were ignored by the sub-contractor and the project manager. So, narrow plot boundaries persist which are not permanently benchmarked. Disconnected plots with several hundred feet between plots remain without measurements describing the elevation gained between the upper end of one plot and the lower end of the next. This may impart a statistical problem, in that the samples (plot lengths) may be too small to yield sound conclusions.

Therefore, recommendations include extending plot widths to valley walls, initiating plot and reach reconnaissance to more permanently mark each plot and reach, and an investigation into whether the plot layout is hydrologically and statistically valid. Further, it is recommended that future studies either empower the quality control person to negotiate with the surveyors to ensure the work meets the goal, or to merge the quality control position with contract manager.

Since the tributary codes have been released, each tributary has a baseline collection of its own to allow independent monitoring in the future. Further, THPs from the past and present can be utilized to interpret findings in the channel, and linkages between hillslope conditions and the channel can be made by any individual with legal access to the land.

RECOMMENDATIONS

(1) The goals, objectives, and baseline data of the GRIMP should be reviewed by a multi-disciplinary review team that includes a statistician, hydrologist/geomorphologist, fisheries biologist, and a forester.

(2) A list of pertinent literature that identifies previous work in FPR effectiveness monitoring should be developed for use with future projects. This should include reports documenting preliminary investigations evaluating FPR effectiveness monitoring.

(3) Monitoring of instream conditions should be linked to hillslope monitoring within the same sub-watershed to identify and establish critical linkage mechanisms between upslope activities and channel response.

(4) Future monitoring should include habitat measurements for each numeric target, with field methods equivalent to those recommended by the numeric target providers. Measurement units should be duplicated by the monitoring parameter so that comparisons are as straight forward as possible.

(5) Landowner access requirements should be finalized before project implementation begins.

(6) If data privacy constraints prevent achieving an objective, either the objective should be revised or the privacy constraint must be lifted.

(7) No objective should be planned without also creating a procedure for implementation.

(8) The reasons for not implementing recommendations from a preliminary investigation should be explained.

(9) A position or committee should be established to regularly check progress toward achieving objectives.

(10) Continue spawning surveys annually.

(11) Follow Table 16 for remeasuring channel conditions.

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Sediment Production and Delivery from Roads in the Sierra National Forest, California

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Abstract. Unpaved roads are often a major source of sediment in forested watersheds, but few areas have data on the magnitude and variability of road sediment production. Over the past four wet seasons we have been measuring road sediment production from 29-40 unpaved road segments in the southern Sierra Nevada of California. These data provide a relatively unique opportunity to quantify the effects of climate, elevation, and other site factors on road sediment production. The study area includes the mid-elevation Providence Creek watersheds(1485-2005 m) and the higher elevation Bull Creek watersheds(2050-2420 m) in the Sierra National Forest. Annual sediment production is being measured with sediment fences placed immediately below road drainage outlets. The overall mean sediment production for the 71 fence-years of data from native surface roads is 0.50 kg m^{-2}, but mean annual values have varied from 0.017 kg m^{-2} in a dry year to 1.1 kg m^{-2} in a year when precipitation was 60% above average. Values from individual segments vary from zero to a maximum of 6.6 kg m^{-2} yr^{-1}. Sediment production generally increases with the product of road segment area times segment slope (R^2=0.22; p<0.0001) and with the amount of bare soil on the active road surface (R^2=0.14, p=0.01). After normalizing by slope, sediment production decreases with increasing elevation (R^2=0.16; p=0.0005). This decrease is attributed to the increased proportion of snow relative to rain, as peak snowmelt rates are only about 30% of peak rainfall rates, snowflakes generate no splash erosion, and the more frequent snow cover reduces rainsplash during rain-on-snow events. We are now extending this project to measure road sediment production and delivery rates in a lower-elevation (850 m to 1200 m) basin. We hypothesize that sediment production rates will be higher, despite the lower total precipitation, as most of the precipitation should fall as rain. The collection of road erosion data from three elevation zones will allow us to quantify the effect of climate change and the associated shift from rain to snow on road sediment production rates in the southern Sierra.

Road Sediment Production and Delivery: Processes and Management

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Abstract. Unpaved roads are often considered to be the predominant sediment source in forested catchments. In steep, wet climates roads can cause a 10- to 300-fold increase in the landslide erosion rate, and this increase is due to the effects of roads on hillslope flow paths and the structural integrity of hillslopes. The proportion of sediment that is delivered to the stream will generally be very high for road-induced failures in hollows and inner gorge landforms, and much lower for planar hillslope failures. The pulsed input of sediment from road-induced landsliding can greatly alter stream channel habitat and morphology.

Unpaved roads can increase sediment production rates by more than an order of magnitude as a result of road surface erosion. The high surface erosion rate stems from the generation of surface runoff from the highly compacted road travelway, the lack of surface cover, and the availability of fine sediment due to traffic and road maintenance procedures such as grading. Sediment delivery to streams occurs primarily at road-stream crossings and secondarily by road-induced gullies. The proportion of the road network that is connected to the stream network is primarily a function of mean annual precipitation (R^2=0.9), and is increased by about 40% in the absence of any engineered drainage structures. The chronic input of the fine sediment from roads can have adverse effects on freshwater aquatic ecosystems as well as coral reefs.

Our present understanding of road surface erosion processes is good, but our models to predict road surface erosion and landsliding are much better for relative than absolute predictions. Climate change can greatly increase road-induced landslides and road surface erosion by increasing the magnitude of large storm events and increasing the amount of rain relative to snow. Extensive field surveys also show that relatively few road segments typically generate most of the road-related increases in sediment yields. Road surface erosion, the risk of road-induced landslides, and road sediment delivery can be greatly decreased by improved road designs and maintenance practices. Hence the greatest needs are to develop and provide land managers with the tools for identifying high-risk segments, and then to make the necessary investments in road reconstruction and restoration.

1. Introduction

Sediment production and delivery in steep, forested catchments is typically dominated by low frequency, high magnitude erosion events such as landslides or debris flows. These occur against a background of relatively low sediment production and delivery rates (Reeves et al., 1995; Kirchner et al., 2001). In unmanaged catchments the pulses of surface erosion and mass wasting are driven by storms, fires, and earthquakes (Benda and Dunne, 1997; Miller et al., 2003). Aquatic species are adapted to these periodic disturbances, and periodic erosional events may be necessary to sustain long-term ecosystem diversity and productivity (Reeves et al., 1995).

Unpaved roads are one of the most common types of man-induced disturbances. Roads induce surface runoff and can alter subsurface flow on hillslopes, and this can affect the magnitude and timing of surface runoff (Jones et al., 2000; Wemple et al., 2001; Wemple et al., 2004). By exposing the soil surface and increasing and concentrating runoff, surface erosion can be greatly increased on each of the different parts of the road prism (i.e., cutslope, travelway, and fillslope) (Figure 1). The surface runoff from roads also can initiate gully erosion below the road prism. Roads also can increase landsliding on road cutslopes, fillslopes, and hillslopes by altering flowpaths as well as altering the strength, loading, and pore water pressures on hillslopes (Reid and Dunne, 1984; Megahan et al., 1991; Megahan et al., 2001; Wemple et al., 2001).

The magnitude and relative dominance of these different road erosion processes is driven by variations in climate, geology, physiography, road design, road construction, and road maintenance practices (Jones et al. 2000, Wemple et al. 2001). As such, there can be considerable variation in the type, magnitude, and frequency of road-related sediment production within and between regions. Hence the objectives of this paper are to: 1) describe the underlying processes of road sediment production from surface erosion and landsliding; 2) compare road sediment production rates from surface erosion and landslides in different environments; 3) compare the delivery and potential off-site effects of road-related sediment from surface erosion and mass movements, respectively; and 4) indicate the extent to which best management practices (BMPs) can minimize road sediment production and delivery.

2. Sediment Production from Forest Roads

2.1. Surface Erosion from Forest Roads

The high infiltration rates and dense vegetative cover on most undisturbed forested hilllslopes means that surface runoff is relatively rare and hillslope erosion rates are very low. In contrast, unpaved roads can increase surface erosion rates by two or more orders of magnitude relative to undisturbed hillslopes (MacDonald and Coe, 2007). Over the past two decades research in a variety of environments has led to a relatively good understanding of road runoff and erosion processes.

The first key point is that road travelways are highly compacted and have very low infiltration rates (typically less than 5.0 mm hr^{-1}) (Reid and Dunne, 1984; Luce and Cundy, 1994; Loague and Kyriakidis, 1997; Luce, 1997; Ziegler and Giambelluca, 1997). This results in the generation of infiltration-excess (Horton) overland flow even during small rainfall events (Ziegler and Giambelluca, 1997). In addition, road cutslopes can intercept transient hillslope groundwater (i.e., subsurface stormflow) when the height of the cutslope exceeds the depth to the water table (Ziegler et al., 2001b) (Figure 2). The interception of subsurface stormflow (SSF) is threshold dominated, as SSF only occurs when precipitation exceeds 25-50 mm under wet antecedent conditions (Weiler et al., 2005). In some cases the interception of SSF can account for more than 90% of the road surface runoff (LaMarche and Lettenmaier, 2001; Wemple and Jones, 2003).

The amount and energy of surface runoff determines the erosive force applied to the road prism by overland flow (Luce and Black, 1999). The road prism can be broken into different process domains for surface erosion based on the interaction of flowpath length (L), which largely controls the amount of runoff, and slope (S), which is the primary control on the energy of the runoff. On road cutslopes and road fillslopes the slope can be very steep (Figure 1), but the limited slope length limits the amount of flow accumulation and hence the potential for hydraulic erosion. As a result, road cutslope and fillslope erosion is primarily through rainsplash (if there is not much cover), sheetwash, and rill erosion if the slope length allows sufficient runoff accumulation. The limited data suggests that cutslope erosion is usually much less than the erosion from the road travelway (Ramos-Scharrón and MacDonald, 2007).

Figure 1. A picture of a reconstructed outsloped native surface road on a highly erodible, weathered granodioritic hillslope in northern California, USA. The road prism is comprised of the cutslope, travelway, and fillslope, and the arrows show the potential length of overland flow for each of these pathways. Note how the rill networks on the travelway concentrate the road surface runoff before it is discharged onto the fillslope. The extensive rilling is due to poor compaction during road reconstruction.

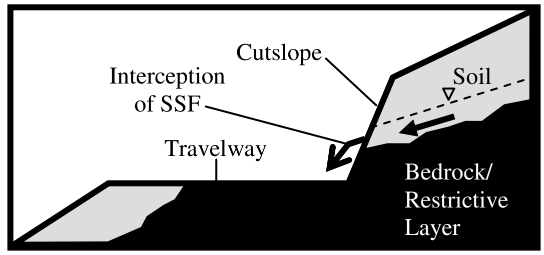

Figure 2. Schematic showing how subsurface stormflow (SSF) along the soil-bedrock interface can be intercepted by a road cutslope to create overland flow (modified from Ziegler et al., 2001b). from clearcut hillslopes (Sidle and Ochiai, 2006).

The slope of the travelway is usually limited to about 10-12% in order to facilitate traffic and maximize safety, but runoff can accumulate along the travelway unless it is strongly outsloped or insloped (Figure 1). Detailed road surveys indicate that the average road segment length is about 50-70 m for forested areas in the western U.S. In many cases road runoff is prevented from running off the travelway by wheel ruts, and this can result in extensive rill or gully erosion on the road surface. Inboard ditches also collect and concentrate runoff with a resulting risk of ditch incision and widening. Road fillslopes below road drainage outlets (i.e., relief culverts, rolling dips, and waterbars) are subject to the greatest erosive forces because they are steep and the potentially large volume of runoff draining to that point (Figure 2). The large volumes of water from longer road segments also can induce gully erosion below drainage outlets (Montgomery, 1994; Wemple et al., 1996). Gully erosion can be particularly severe when roads divert stream channels at road-stream crossings, and route the streamflow down the road or onto hillslopes.

The erodibility of the road prism varies as result of time since construction, maintenance activites (i.e., grading), soil texture, ground cover, and traffic (Luce and Black, 2001a; Ramos-Scharrón and MacDonald, 2005; Ziegler et al., 2001a). Rainsplash erosion on roads is common due to the relative lack of vegetative cover, and can account for up to 38-48% of total sediment production on freshly disturbed road travelways (Ziegler et al., 2000). Rainsplash erosion is highest on the road travelway, since this portion of the road prism is most frequently disturbed by traffic and typically has less vegetative cover than the adjacent cutslopes and fillslopes (Figure 1).

Sediment production rates for cutslopes, travelways, and fillslopes are highest immediately after road construction, with erosion rates declining rapidly within 1-2 years (Megahan, 1974). Fine-textured soils are the most susceptible to surface erosion, with siltier soils producing 4-9 times more sediment than soils dominated by sand or gravel (Luce and Black, 1999; Sugden and Woods, 2007). Soils with higher rock content are more resistant to erosion and these soils typically have lower erosion rates (Sugden and Woods, 2007).

Table 1. Surface erosion rates for the travelway, cutslope, and fillslope for different study locations in megagrams (10^6 grams) per hectare of road per year. Assuming an average road density of 4 km km^{-2} and an average road width of 6 m, these rates would apply to 2.4% of the catchment area. On this basis, multiplying these sediment production rates by 0.024 allows a direct comparison with the sediment production rates from road-induced landslides in Table 2. Data compiled by Carlos Ramos-Scharrón.

Study location	Portion of road prism	Sediment production rate (Mg ha^{-1} yr^{-1})	Reference
North Carolina, USA	Travelway	1143	Lieberman & Hoover, 1948
North Carolina, USA	Travelway	7110	Hoover, 1952
Idaho Batholith, USA	Travelway	73	Megahan & Kidd, 1972
Idaho Batholith, USA	Travelway	20	Megahan, 1975
Washington, USA	Travelway	4.8 – 66	Wald, 1975
Southeast, USA	Travelway	8 -120	Dissmeyer, 1976
North Carolina, USA	Travelway	37	Simons et al., 1978
Northeast Oregon, USA	Travelway	0 – 7	Buckhouse & Gaither, 1982
Northwest Washington, USA	Travelway	1 – 1010	Reid & Dunne, 1984
North Carolina, USA	Travelway	0.3 - 52.4	Swift, 1984
Western Washington, USA	Travelway	52	Bilby, 1985
Idaho Batholith, USA	Travelway	23 - 76	Vincent, 1985
New Zealand	Travelway	0 – 113	Fransen et al., 2001
Poland	Travelway	98	Froehlich, 1991
Australia	Travelway	50 – 90	Grayson et al., 1993
Oregon Coast Range, USA	Travelway	1.8 – 37	Luce and Black, 1999
U.S. Virgin Islands	Travelway	0.46 – 74	MacDonald et al., 2001
U.S. Virgin Islands	Travelway	74	Ramos-Scharrón & MacDonald, 2005
Sierra Nevada CA, USA	Travelway	0.002 - 40	Coe, 2006
North Coast CA, USA	Travelway	0.5 – 46	Barrett & Tomberlin, 2008
Georgia, USA	Cutslopes	26 – 108	Diseker & Richardson, 1962
Oregon, USA	Cutslopes	153 – 370	Wilson, 1963
Oregon, USA	Cutslopes	75 - 105	Dyrness, 1970; 1975
Idaho Batholith, USA	Cutslopes	150 - 165	Megahan, 1980
New Guinea	Cutslopes	1050	Blong & Humphreys, 1982
New South Wales, Australia	Cutslopes	36 - 58	Riley, 1988
South Island, New Zealand	Cutslopes	52 - 152	Fahey & Coker, 1989; 1992
Idaho Batholith, USA	Cutslopes	0.1 - 248	Megahan et al., 2001
Idaho Batholith, USA	Fillslopes	107	Bethlahmy & Kidd, 1966
Idaho Batholith, USA	Fillslopes	12	Megahan, 1978
South Island, New Zealand	Fillslopes	1 - 12.0	Fahey & Coker, 1989; 1992

Vegetative cover can protect the soil against surface erosion, and erosion from cutslopes and fillslopes decline over time as they revegetate. Road travelways and inboard ditches are subjected to maintenance activities such as grading, and this removes the surface cover and can greatly increase the supply of easily-erodible sediment. Recent studies have shown that grading can increase erosion rates from 70% to more than an order of magnitude relative to ungraded roads (Luce and Black, 2001b; Ramos-Scharrón and MacDonald, 2005). Surface erosion rates decline exponentially to a baseline erosion rate following initial construction or grading, and this rapid decline is due to the rapid depletion of the readily erodible material and the subsequent armoring of the road prism (Megahan, 1974). (Megahan, 1974; Ziegler et al., 2001). Higher traffic levels increase the supply of fine material, and this is a major reason why traffic can increase sediment production rates by 2-1000 times (Reid and Dunne, 1984; Ramos-Scharrón and MacDonald, 2005). Dry ravel from steep cutslopes can provide sediment to an inside ditch and the road travelway and thereby sustain higher surface erosion rates.

The variations in rainfall, soil texture, traffic, and other controlling factors mean that road surface erosion rates vary over several orders of magnitude (Table 1). Both empirical and physically-based road surface erosion models have been developed, and these typically include key variables such as precipitation or rainfall erosivity, road slope, road area or length, road surface slope, soil texture, time since grading, and traffic. Unfortunately it is still very difficult to accurate predict road surface erosion for several reasons. First, many of these variables interact (e.g., traffic simulataneously affects infiltration rates, road surface cover, and the amount of erodible material on the road surface). Second, the road surface characteristics and drainage patterns can be verydynamic as wheel ruts develop or waterbars break down. Third, most road erosion models only account for erosion due to infiltration-excess overland flow, even though the interception of SSF can be an important source of road surface runoff (e.g., Wemple and Jones, 2003). Fourth, detailed road survey data need to be collected to predict surface erosion rates for each road segment. Finally, the paucity of validation studies for road surface erosion models means that the models are most useful for predicting relative rather than absolute road surface erosion rates.

2.2. Landslide Erosion from Forest Roads

Forest roads increase landsliding by disrupting the balance of driving and resisting forces acting upon and within hillslopes. As shown in Figure 3, road-related increases in landsliding are commonly attributed to: 1) oversteepening and/or overloading of downslope areas by road fills; 2) removing support for unstable hillslopes by undercutting road cutslopes; and 3) and concentrating road surface runoff onto potentially unstable portions of the road fillslope and lower hillslopes (Benda et al., 1998; Sidle and Ochiai, 2006).

Landsliding from roads can exceed natural landsliding rates by one to two orders of magnitude (Table 2). Sediment production rates from road-induced landslides are also an order of magnitude higher than from clearcut hillslopes (Sidle and Ochiai, 2006).

Road-induced landsliding is generally only an issue in relatively steep terrain, with most road-initiated failures occurring on hillslopes greater than 31-39˚ (i.e., 60-80%) (Chatwin, 1994; Montgomery, 1994; Benda et al., 1998; Veldhuisen and Russell, 1999). Landslides initiated from fillslopes are typically larger

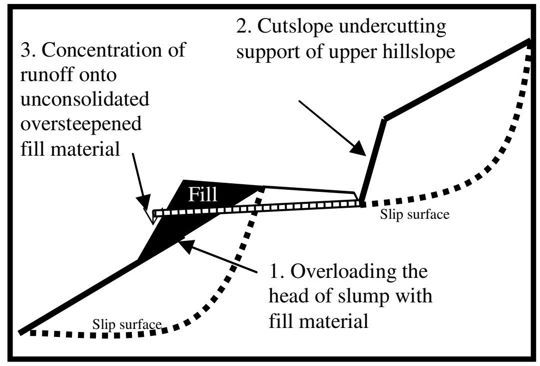

Figure 3. Schematic showing how a road increases the likelihood of landsliding (modified from Benda et al., 1998).

than those initiated from cutslopes (Wemple et a., 2001). Fill material is particularly unstable when it is placed on slopes greater than 35˚ and on unstable landforms such as colluvial hollows and inner gorges (Chatwin, 1994; Benda et al., 1998). Fillslope failures are more likely on cut-and-fill roads and can be largely eliminated by the more costly approach of full bench construction (Figure 4). This design excavates a bench into the hillslope that is equal to the entire width of the travelway (Figure 4), but the trade-off is that this generates a much higher cutslope.

Cutslope failures are a common occurrence in steep areas as a result of the oversteepened hillslopes (Figure 3). By reducing the support at the toe of unstable features (i.e., undercutting), cutslopes can increase the likelihood of rotational sliding. The potential for oversteepening, undercutting unstable features, and intercepting subsurface stormflow is greatest on fully benched roads because of the increased cutslope height (Figure 4). Cutslopes also

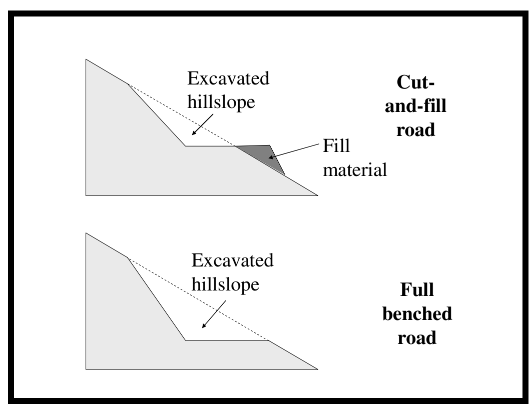

Figure 4. Schematic showing how different road designs affect slope stability. (a) A cut-and-fill road attempts to balance the amount of excavation with the amount of fill necessary to create the desired road width. (b) A full benched road requires more extensive excavation and a higher cutslope, but the excavated material is removed rather than being placed on the hillslope.

Table 2. Sediment production rates from road-induced landslides in different forested areas (modified from Sidle and Ochiai, 2006).

Study Location	Sediment production rate ($Mg\ ha^{-1}\ yr^{-1}$)	Increase over natural rate (times)	Reference
Coastal SW British Columbia, Canada	3.8	27	O'Loughlin, 1972
Western Oregon Cascades, USA	34	30	Swanson and Dryness, 1975
Western Oregon Cascades, USA	202	337	Morrison, 1975
Oregon Coast Range, USA	21	50	Swanson et al., 1977
South Island, New Zealand	28		Mosely, 1980
Western Oregon Cascades, USA	21.2	44	Marion, 1981
Oregon Klamath Mountains, USA	36	64	Amaranthus et al., 1985
North Coast California, USA	64		Weaver et al., 1995
North Coast California, USA	15		Rice, 1999

expose the hillslope to weathering, which can progressively decrease the strength of the hillslope materials. A downslope or fillslope failure also can be initiated if a cutslope slide plugs the inside ditch and the road runoff is then directed onto a fillslope or hillslope (Wemple et al., 2001).

In many cases the increase in landsliding due to roads is a result of the hydrological changes rather than just the overloading, steepening, or undercutting of hillslopes (Sidle and Ochiai, 2006). Roads increase the amount of surface runoff and concentrate this flow. When this water is routed onto fillslopes or hillslopes this can greatly decrease their stability as a result of both the additional weight and the increase in pore water pressures. The decrease in permeability between the cutslope and the compacted road surface also can decrease the stability of the cutslope by increasing pore water pressures at the base of the cutslope (Dutton et al., 2005).

In the Pacific Northwest (USA), landslides can occur on steep slopes (i.e., >31˚) when road lengths of 60-130 m discharge overland flow below the outlets of drainage structures (Montgomery, 1994). Roads crossing steep midslopes have a high likelihood of intercepting subsurface stormflow, and cutslope and fillslope landslides are particularly common along midslope roads (Figure 5) (Wemple et al., 2001; Sidle and Ochiai, 2006). Midslopes are also common locations for unstable landforms such as colluvial hollows (Dietrich et al., 1993), and road drainage routed into colluvial hollows increases their likelihood of failure. Culverts at road-channel crossings can plug or overtop during storms, leading to catastrophic failure of the road fill and the initiation of debris flows (Furniss et al., 1998).

The prediction of road-related landsliding is difficult given the stochastic nature of landslide initiation, variability in road design and construction, and the inability to represent many of the causal processes for road-landslide interactions. Slope stability models such as SHALSTAB and SINMAP are useful for predicting the relative risk of failure and as landscape stratification tools. For management purposes these spatially-explicit estimates must be followed by field-based slope stability assessments to better identify the risk for a specific area and determine the best way to minimize the risk of road-related landslides.

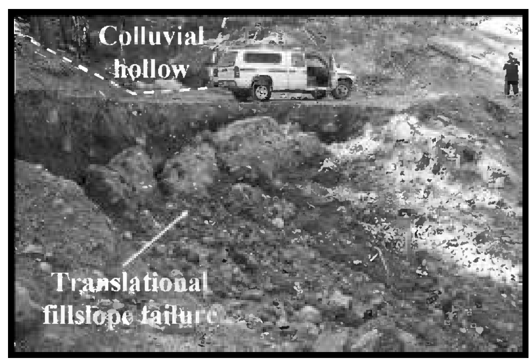

Figure 5. A translational fillslope failure directly below a colluvial hollow. Colluvial hollows concentrate SSF, so placing fill material in these landforms can increase the likelihood of landsliding.

3. Sediment Delivery from Forest Roads

3.1. Sediment Delivery from Road Surface Erosion

The delivery of road-related surface erosion is of particular concern because it is generally fine-grained (sand sized or smaller) (Ramos-Scharron and MacDonald, 2005), and this material is particularly detrimental to many organisms (Waters 1995). Connectivity refers to the proportion of roads that drain directly to streams or other water bodies.

Surveys indicate that the proportion of connected roads is strongly controlled by road location, road design, and the factors that control the amount of road runoff. In the western U.S. road-stream crossings account for 30-75% of the connected road length (Wemple et al., 1996; Bowling and Lettenmaier, 2001; La Marche and Lettenmaier, 2001; Coe, 2006). It follows that road sediment delivery is highly dependent on stream density, as this affects both the number of road-stream crossings and the proximity of the roads to the stream channel network.

The delivery of road runoff and sediment to streams generally decreases as the distance between a road and a stream increases. The high infiltration rates and high surface roughness of most forested hillslopes means that buffer strips can be quite effective at trapping road-related sediment. If the road runoff is dispersed, the sediment from road surface erosion rarely travels more than 30 m on vegetated hillslopes (Megahan and Ketcheson, 1996; Brake et al., 1999; Coe, 2006). However, if the road runoff is concentrated into a single drainage outlet, the runoff and sediment can induce gullying and travel 3-4 times further than when it is dispersed (Megahan and Ketcheson, 1996; Coe, 2006).

The development of gullies as a result of concentrated runoff is the second most important mechanism for road-stream connectivity, as 9-35% of the total road length can be connected to the channel network via this process (Wemple et al., 1996; Croke and Mockler, 2001; Coe, 2006). Since longer road segments result in more runoff and more erosive power below road drainage outlets, roads with inadequate drainage are much more likely to induce gullies and be connected to the stream channel network that roads with dispersed or more frequent drainage. Modeling studies have suggested that road-stream connectivity will increase with the amount of intercepted subsurface flow (Bowling and Lettenmaier, 2001; La Marche and Lettenmaier, 2001), but there are not yet enough field studies to verify this relationship.

A meta-analysis of the available data indicates that road-stream connectivity is a relatively simple function of annual precipitation and the presence of engineered drainage structures (Coe, 2006). The empirical predictive equation developed from 11 studies in different parts of the world is:

$$C = 12.9 + 0.016P + 39.5M \qquad (1)$$

where C is the percent of road length or road segments that are connected to the channel network, P is the mean annual precipitation in millimeters, and M is a binary variable with 0 representing roads with drainage structures, and 1 representing roads without drainage structures (R^2=0.92; p<0.0001). This predictive equation indicates the importance of precipitation in controlling both the amount of runoff and the density of the stream network. The binary variable indicates that well-designed roads with regular drainage will decrease road connectedness and hence road sediment delivery by at least 40%.

The connectivity between roads and streams is important because any increase in fine sediment loads will adversely affect water quality, macroinvertebrate populations, fish habitat, salmonid populations, and the health of coral reefs (Everest et al., 1987; Waters, 1995; Suttle et al., 2004; Ramos-Scharron and MacDonald, 2007). For macroinvertebrates, an increase in fine sediment deposition from roads will: decrease taxa richness and abundance; decrease the abundance and richness of sensitive taxa such as *Ephemeroptera*, *Plecoptera*, and *Tricoptera*; and increase the number of oligochaetes and burrowing chironomids (Waters, 1995). These macroinvertebrate changes will adversely affect the amount and type of prey available to high-value fisheries. Large increases in fine sediment and substrate embeddedness can adversely affect spawning and rearing habitat, decrease juvenile fish growth, and feeding efficiency (Everest et al., 1987; Suttle et al., 2004).

3.2. Sediment Delivery from Road-Related Landslides

The downstream delivery of road-induced landslides is dependent on their location relative to the channel network, road design, and the travel distance of the failure (MacDonald and Coe, 2007). Road-failures initiated in colluvial hollows have a higher likelihood of delivering sediment to the channel network because these areas are located directly above first-order channels (Figure 6). Similarly, road-related failures in inner gorge landforms have a high probability of delivering sediment to streams because these areas are typically very steep and the slopes feed directly into the stream channels that carved these features (MacDonald and Coe, 2007). Landslides from roads crossing steep midslopes also are likely to deliver sediment to the channel network because hillslopes are steep, roads frequently cross low-order channels, and there is a high potential for intercepting subsurface (Wemple et al., 2001). Sediment delivery is also high when flood flows overtop road-channel crossings and initiate landslides on the fillslopes at a crossing (Furniss et al., 1998) (Figure 7).

Figure 6. Road-induced debris flows in northwest Washington state, USA. The debris flows initiated in the colluvial hollows on the upper road were triggered by road runoff, and these triggered the failures at the road-stream crossings on the lower road. This sequence has been defined as a “disturbance cascade” (Wemple et al., 2001). The road was built prior to the implementation of best management practices and large fill volumes were placed within colluvial hollow and inner gorge landforms (WA DNR, 1983).

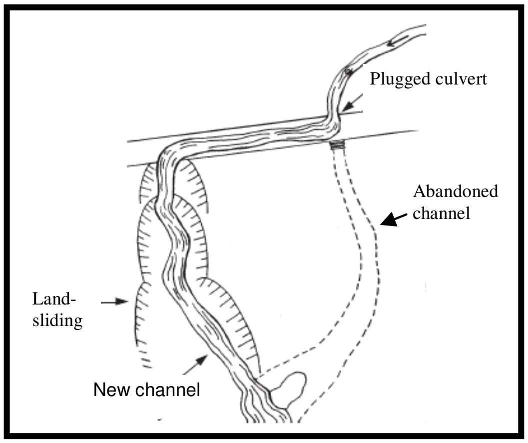

Figure 7. Schematic showing how a plugged culvert or other crossing failure can cause severe erosion by diverting water onto a road. When this water leaves the road it can cause gullying and/or landslides. Culvert failures due to overtopping or plugging with sediment and woody debris are common when the culvert diameter is less than the active channel width, the culvert is not set to the stream grade, or the culvert is poorly aligned with the stream channel (taken from Keller and Sherar, 2003).

The delivery of sediment from road-related landslides also depends on the road design. Sediment from cutslope landslides is more likely to be delivered to the stream network if the sediment is deposited into an inside ditch it than on the road travelway (Wemple et al., 2001). Fillslope slides have a much higher likelihood of delivering sediment to the channel network, and in the western U.S. 50% of the fillslope slides delivered sediment to the channel network after a large flood event (30-100 year recurrence interval). Fillslope slides are also more likely to initiate debris flows than cutslope slides (Wemple et al. 2001), and debris flows almost always deliver sediment into the channel network (MacDonald and Coe, 2007).

Road-induced landslides deliver both fine and coarse sediment (i.e., >2 mm) to the channel network. The episodic delivery of this sediment can induce debris flows, debris fans, valley terrace formation, channel avulsion, increased bedload transport, channel aggradation, substrate fining, channel widening, and pool infilling (MacDonald and Coe, 2007). These sediment-induced changes in channel morphology can increase downstream flooding and bank erosion by reducing the channel capacity, and also can adversely affect water quality and fish habitat (MacDonald and Coe, 2007).

In summary, roads not only induce landslides at a very high rate relative to forests or clearcuts, but they also have a greater potential to deliver this sediment to the stream network. In the Oregon Coast Range in the western USA, road-induced mass failures traveled on average three times farther than the mass failures in a mature forest. The combination of a much higher mass-failure rate and a higher sediment delivery means that road-induced mass failures can increase the amount of sediment being delivered to the channel network by nearly five times relative to mature forests (May, 2002).

4. Management Implications

The effective mitigation of road-related sediment production and delivery is dependent upon the dominant road erosion process and the proper selection and implementation of best management practices (BMPs). Without sufficient knowledge of the relevant road erosion processes, managers are more likely to treat the symptoms rather than the underlying cause.

Road surface sediment production can be reduced by improving road drainage, as this will decrease the amount of accumulated runoff and the erosive force applied to the road prism. Road drainage can be improved by increasing the frequency of road drainage structures such as waterbars, rolling dips, or cross-relief culverts. Guidelines for the spacing of drainage structures are typically based on the erodibility of the soil and the gradient of the travelway, with drainage spacing decreasing when travelway gradient and soil erodibility increases (Figure 8). Empirical regional spacing guidelines can be developed by observing the length and gradient of road necessary to initiate rill erosion (Figure 8), as sediment production increases significantly when the dominant surface erosion process transitions from rainsplash and sheetwash to rill erosion. Outsloping the travelway at a gradient of 3-5% towards the fillslope will further decrease the flowpath length and help minimize sediment production.

Surface erosion from roads also can be minimized by increasing the resistance of the road prism to the erosive forces of rainsplash and overland flow. Rocking the travelway can reduce sediment production by more than an order of magnitude (Coe,

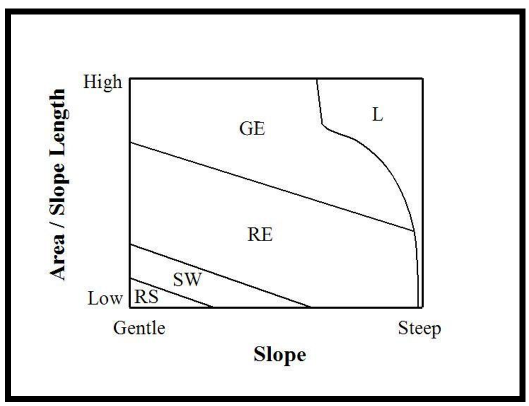

Figure 8. Conceptual process domains for rainsplash erosion (RS), sheetwash erosion (SW), rill erosion (RE), gully erosion (GE), and landsliding (L) as a function of flowpath slope gradient and the amount of runoff as a function or flowpath area or length. The effectiveness of BMPs can be maximized through knowledge of these process domains.

2006). The addition of groundcover (e.g. mulching) to cutslopes and fillslopes have proven to be effective in decreasing sediment production (Megahan et al., 1991; Megahan et al., 2001). Placing energy dissipators such as rocks or logging slash below road drainage outlets can greatly reduce surface erosion on the fillslopes. Grading of the road travelway should be minimized, and the need for grading can be avoided if adequate drainage is put in place and wet weather driving is restricted. Grading of inboard ditches also should be avoided unless absolutely necessary.

The same concepts can be applied to reduce the delivery of road surface erosion to the channel network. The delivery of road surface erosion is best prevented by draining the road travelway frequently before road-stream crossings (i.e., disconnecting). Rocking the remaining portion of the travelway that drains directly to the road-stream crossing will further minimize sediment delivery (Figure 9). Gully initiation below drainage outlets can be prevented by frequently draining the road and by placing energy dissipators below the outlets (Figure 9).

In areas dominated by road-related landsliding, road surface erosion may only represent 1-10% of total road-related sediment production (see Tables 1 and 2). In these instances priority should be given to avoiding road-related landsliding.

Many slope stability issues can be avoided during the road design phase by: 1) minimizing the length of road on steep and unstable hillslopes; 2) minimizing road width on steep midslopes; 3) minimizing the crossing of channels or convergent areas; and 4) laying out the road to fit hillslope topography (Sidle and Ochiai, 2006). Roads crossing slopes greater than 60-70% should be fully benched. If fill placement is necessary during construction, then the fill should be free of large organic material and should be compacted in successive layers of 0.2-0.3 m (Sidle and Ochiai, 2006).

On existing roads, fillslopes in excess of 70% should be removed or pulled back to a gradient of less than 70% (Benda et al., 1998). Priority should be given to treating steep fillslopes on roads adjacent to stream channels or roads crossing unstable landforms with a high likelihood of delivering sediment to the channel network (e.g., colluvial hollows, inner gorges). If fill removal is not feasible, then a retaining wall may be necessary to stabilize the fill. If cutslopes have undercut support for the upper hillslope then rock buttressing of the toeslope may be necessary (Chatwin, 1994).

It should be clear that improving road drainage is a critical to reducing preventing road-related landslides**.** Road runoff should not be drained onto unstable fillslopes or onto unstable areas such as colluvial hollows, inner gorges, or the scarps of deep-seated landslides. Outsloping can help to drain the road, but is generally not feasible when the travelway gradient exceeds 8-12%. In some cases road runoff has to be collected in an inside ditch so that the road runoff is not directed onto potentially unstable fillslopes or hillslopes. This will concentrate runoff and increase surface erosion in the ditch in exchange for reducing the likelihood of road-induced landslides.

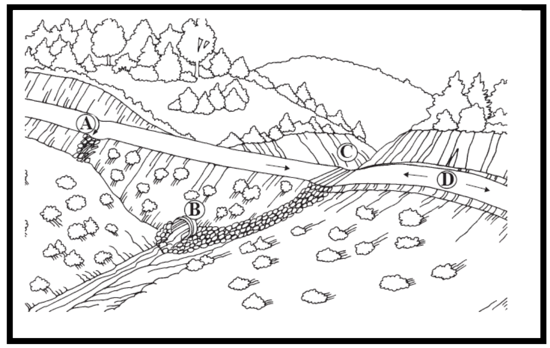

Figure 9. Schematic showing a road-stream crossing designed to minimize sediment delivery. Much of the road can be disconnected by draining the road runoff at point A. Armoring the fillslope at this point prevents gullying below the road. An armored dip at point C prevents fill erosion if the culvert (point B) becomes plugged and water flows across the road**.** Rocking the travelway should be rocked between points A and D will greatly reduce road surface erosion and the delivery of sediment to the stream (from Keller and Sherar, 2003).

Landsliding and gullying at road-stream crossings can be prevented by minimizing the potential for stream diversion. If possible, armored low water crossings should be used instead of culverts, as culverts can overtop or become plugged obstructed by sediment and debris during storm events. Culvert diameter should be greater or equal to the bankfull channel width so that culvert plugging is minimized (Cafferata et al., 2004). If the potential for stream diversion exists, an armored dip should be installed to route the diverted streamflow back into the channel (Figure 9).

The effective mitigation of road sediment impacts also will depend upon the resource of concern. For example, some aquatic species may be more sensitive to chronic rather than episodic erosion. In this case, priority should be given to minimizing road surface erosion, even though road-related landsliding may produce the most sediment. Due to the episodic nature of landsliding, improvements in resource conditions from landslide mitigation treatments may not be realized for years or decades.

5. Conclusions

Roads are important, chronic sources of runoff and sediment. This sediment is generated by both surface erosion and road-induced landslides. The surface erosion comes primarily from the road travelway as a result of rainsplash, sheetwash and rilling. Road surface erosion rates are highly variable, and depend on the contributing area, slope, precipitation intensity, soil type, soil rock content, and traffic. This sediment is delivered to the stream channel network primarily at road-stream crossings. Mean annual precipitation appears to be the primary control on road-stream connectivity.

Road-induced landslides can generate more sediment in some steep, humid areas than road surface erosion. An understanding of the process domains for road runoff and erosion is essential for reducing road sediment production and delivery. A range of best management practices have been developed to reduce road sediment production and delivery. In general it is easier to reduce road surface erosion than the number and size of road-induced landslides.

6. Acknowlegements

A series of graduate students have and are working on road erosion and delivery issues in California, Colorado, and the U.S. Virgin Islands, and we would specifically like to thank Don Anderson, Rob Sampson, Carlos Ramos-Scharron, Zamir Libohova, Ethan Brown, Abby Korte, Matt Welsh, Allison Stafford, and Andrew Donnellycolt. We also would like to thank the U.S. Forest Service, National Park Service, U.S. Geological Survey, California Department of Forestry, and other agencies for their support, and colleagues too numerous to name for their ideas and contributions.

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DRAFT

Summary Report

Erosion Prevention Planning Project for County Roads and Roads in the Soquel Demonstration State Forest, in the Soquel Creek Watershed, Santa Cruz County, California

prepared for

Santa Cruz County Resources Conservation District and the California Department of Fish and Game

by

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April, 2003

Summary Report

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Summary Report+

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Introduction

The Soquel Creek is one of the more productive and restorable anadromous fish streams within Santa Cruz County. The Soquel Creek drains directly to the Pacific Ocean in Capitola, California (Figure 1). This watershed is one of the major streams in the county that currently supports native populations of Coho salmon and Steelhead trout.

Pacific Watershed Associates (PWA) was contracted by the Santa Cruz County Resource Conservation District and the California Department of Fish & Game (CDFG) to complete a sediment source assessment and prepare a prioritized erosion prevention plan for Santa Cruz County roads and California Department of Forestry (CDF) roads within the Soquel Creek watershed. This project was funded by an SB271 restoration grant administered by the California Department of Fish and Game (CDFG) and the Santa Cruz County Resources Conservation District (Contract # 091902-01). This project was specifically aimed at identifying future erosion sources that are impacting, or could impact, fish bearing streams and to develop prescriptions aimed at reducing sediment input to the watershed. The report has been divided into two different parts in order to differentiate the treatments and costs for Santa Cruz County paved roads (Part 1) from the unpaved forest roads in the CDF Soquel Demonstration State Forest (Part 2).

Soquel Creek Watershed Assessment

Perhaps the most important element needed for long term restoration of salmon habitat, and the eventual recovery of salmonid populations is the reduction of accelerated erosion and sediment delivery to the stream channel system. In relation to reducing the effects of urbanization, past and current land management practices on sediment production, this summary report describes the erosion assessment and inventory process that was employed in the Soquel Creek watershed. It also serves as a prioritized plan-of-action for cost-effective erosion control and erosion prevention treatments for roads within the watershed. When implemented and employed in combination with protective land use practices, the proposed projects are expected to significantly contribute to the long term protection and improvement of salmonid habitat in the basin. The implementation of erosion control and erosion prevention work is an important step toward protecting and restoring watersheds and their anadromous fisheries (especially where sediment input is a limiting factor to fisheries production, as is the case for the Soquel Creek).

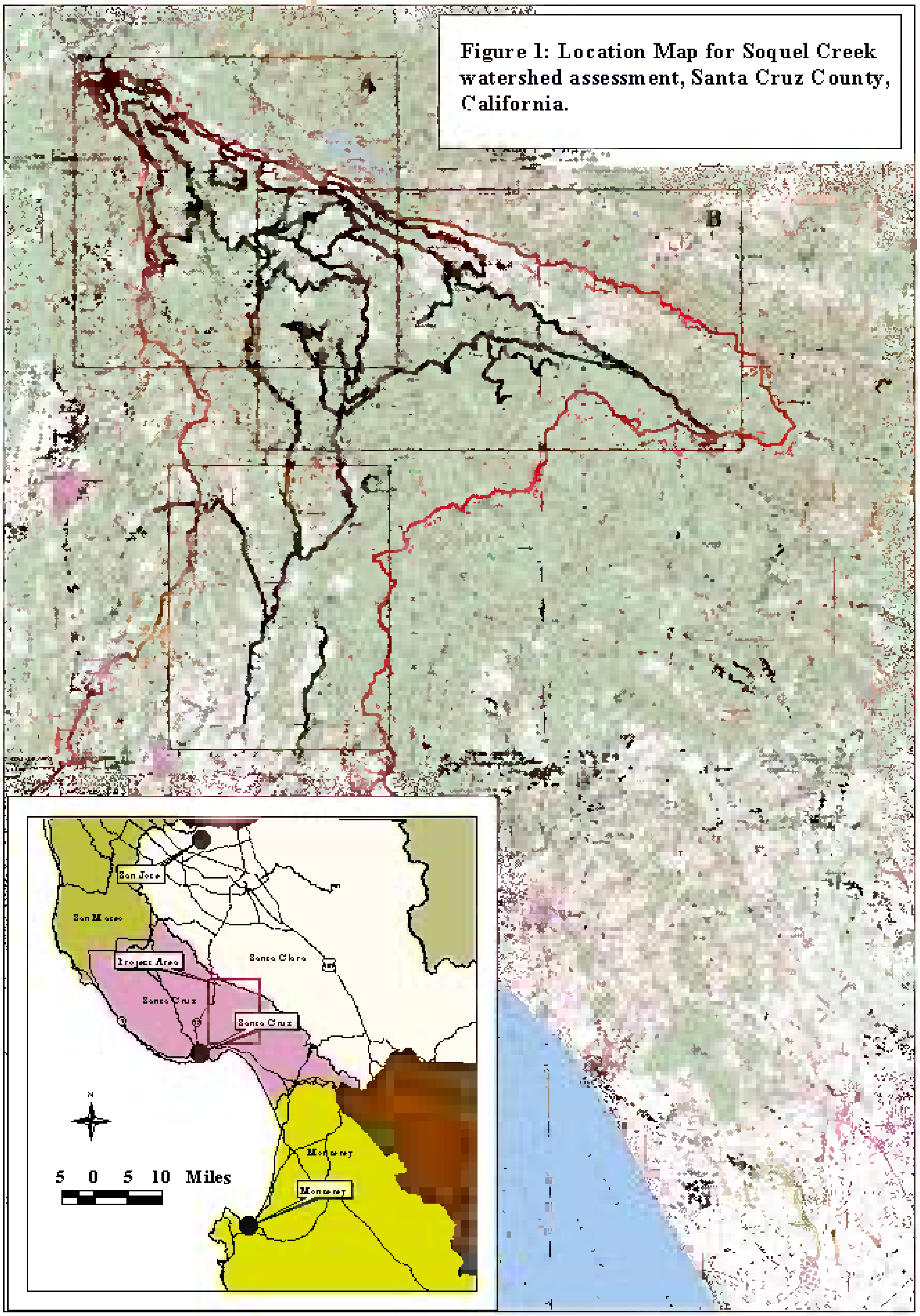

Figure 1: Location Map for Soquel Creek watershed assessment, Santa Cruz County, California.

Road systems are perhaps the most significant and most easily controlled sources of anthropogenic sediment production and delivery to stream channels. The Soquel Creek is underlain by erodible and potentially unstable geologic substrate, and field observations indicate that roads have been, and continue to be, a significant source of accelerated sediment production and delivery in the watershed. In the Soquel Creek, as in many other coastal watersheds, excess sediment input to stream channels during large rainfall events is perhaps one of the most significant factors affecting salmonid populations. Chronic sediment inputs to the channel system, from roads, driveways and other bare soil areas, are also thought to be important contributors to impaired habitat and reduced salmonid populations.

Unlike many watershed improvement and restoration activities, erosion prevention and "storm-proofing" of road systems has an immediate benefit to the streams and aquatic habitat of the basin. It helps ensure that the biological productivity of the watershed's streams is not impacted by future human-caused erosion (or that such impacts are minimized), and that future storm runoff can cleanse the streams of accumulated coarse and fine sediment, rather than depositing additional sediment from managed areas. Sites targeted as high, moderate or low treatment immediacy in the Soquel Creek watershed have been identified as priority sites for implementation so that road fill failures, undersized stream crossing culverts, stream crossing washouts, ditch relief gully erosion, stream diversions and chronic cutbank and ditch sediment delivery do not degrade the stream system or salmonid habitat.

The assessment identified all recognizable current and future sediment sources from roads identified on Santa Cruz County and CDF Soquel Demonstration State Forest roads within the watershed. The combined field inventories identified future sediment sources from just over 82.0 total miles of Santa Cruz County maintained roads and CDF Soquel Demonstration Forest roads. The primary objective of the road upgrading recommendations that have been prepared, is to implement hydrologically effective, erosion control and erosion prevention work on sites that were identified as a part of this field inventory. This assessment is also intended to be used as a tool for basin wide planning in which the ecological impacts of specific roads and drainage structures can be balanced against the limited financial resources available for capital improvements aimed at reducing the potential for sediment production and delivery.

Part 1 and Part 2 Project Description

The watershed assessment included two parts; 1) Part 1, an inventory of all Santa Cruz County roads and 2) Part 2, an inventory of all CDF Soquel Demonstration State Forest roads in the Soquel Creek watershed. The watershed assessment process consisted of distinct project elements. These included: 1) a field inventory of all stream crossings and ditch relief culverts on the County maintained roads, 2) a comprehensive inventory of all stream crossings on the County maintained roads with 3 x 1 channel dimensions or a stream crossings with 24" diameter culvert or greater, 3)a complete inventory of all potential future road-related sediment sources along 18.2 miles of Soquel Demonstration State Forest roads 4) data base analysis to evaluate road segments and prioritize site specific treatments, 5) preparation of a final report of findings that outlines a prioritized restoration plan that can be used either to directly implement some or all of the recommended improvements, or to apply for grant funding for implementation.

A composite map of the road system in the watershed was developed from GIS base maps provided by CDF and Santa Cruz County Public Works Department (Map 1). The composite map depicts the County and CDF road network in the watershed and was used as the base map for showing the location of sites with potential for future erosion and sediment delivery to the stream system.

Field work began in January 2003 and by March 2003, 82.0 miles of inventoried roads had been inventoried and evaluated. In Part 1, County maintained roads inventoried in the assessment are as follows: Deerfield Road, Glen Haven Road, Highland Way, Laurel Glen Drive, Miller Hill Cutoff, Morrell Road, Mount Bache Drive, Old Santa Cruz Highway, Soquel-San Jose Road, Shultes Drive, Skyland Drive, Skyview Terrace, Spanish Ranch, Stetson Road, Redwood Lodge Road, Olive Springs Drive and Mount Charlie. In Part 2, all Soquel Demonstration State Forest roads were inventoried in the assessment. Technically, this assessment was neither an erosion inventory nor a road maintenance inventory. Rather, it was an inventory of sites where there is a potential for future sediment delivery to the stream system that could impact fish bearing streams in the watershed. All the roads were inspected by trained personnel and all existing and potential sediment delivery sites were identified and described.

In Part 1, inventoried sites on the Santa Cruz County roads consisted exclusively of stream crossings and associated road connectivity. All stream crossings were mapped on a mylar overlay over a 1:12,000 scale topographic map. The database form filled out for each inventoried site contained questions regarding the site location, likeliness of plugging, ditch length activity and if the stream crossing has the potential for diversion. In addition, all stream crossings on the County road that currently have a 24" culvert or a minimum channel dimension of three feet wide by one foot deep (3 x 1), were inventoried with a more comprehensive database form. This data form included tape and clinometer surveys of the road prism, and an evaluation of such factors as erosion potential, the nature and magnitude of existing and potential erosion problems, the likelihood of erosion and a recommended treatment to upgrade the road to reduce the risk of failure and eliminate the site as a future source of sediment delivery. Sites, as defined in this part of the assessment, include locations where there is direct evidence that future erosion or mass wasting could be expected to deliver sediment to a stream channel. Sites of past erosion were not inventoried unless there was a potential for additional future sediment delivery. Similarly, sites of future erosion that were not expected to deliver sediment to a stream channel were not included in the inventory, but were mapped on the field maps during the assessment. This subset of stream crossing sites is presented in the tables 2-6.

In Part 2, inventoried sites in Soquel Demonstration Forest generally consisted of stream crossings, potential and existing landslides related to the roads, gullies below ditch relief culverts and long sections of uncontrolled road and ditch surface runoff which currently discharge to the stream system. For each identified existing or potential erosion source, a database form was filled out and the site was mapped on a mylar overlay over a 1:12,000 scale topographic map (Figure 2).

The erosion potential and potential for sediment delivery was estimated for each major problem site or potential problem site. The future volume of sediment expected to be eroded and delivered to streams was estimated for each site. The data provides quantitative estimates of how much material could be eroded and delivered in the future, if no erosion control or erosion prevention work is performed. In a number of locations, especially at stream diversion sites, actual sediment loss could exceed field predictions. All sites were assigned a treatment priority, based on their volume, rate of erosion and potential to deliver sediment to stream channels in the watershed as well as the cost-effectiveness of the proposed treatment.

In addition to the database information, tape and clinometer surveys were completed on virtually all stream crossings. These surveys included a longitudinal profile of the stream crossing through the road prism, as well as two or more cross sections. The survey data was entered into a computer program that calculates the volume of fill in the crossing. The survey allows for an accurate and repeatable quantification of future erosion volumes (assuming the stream crossing was to wash out during a future storm) and/or excavation volumes that would be required to complete a variety of road upgrading and erosion prevention treatments (e.g., culvert installation, culvert replacement, etc.).

Part 1: Roads Inventory Results for County Roads

All stream crossings- Approximately 63.8 miles of County maintained roads were inventoried for future erosion sources and sediment delivery within the Soquel Creek watershed. A total of 285 stream crossings were identified on 63.8 miles of Santa Cruz County roads in the Soquel Creek watershed (4.5 stream crossings/mile) (Table 1). From a total 285 stream crossings identified 235 of these are culverted crossings, 47 are fill crossings (stream crossings with no drainage structure), and 3 are bridges. Two hundred forty five (245) or 86% of the County stream crossings have a diversion potential and 63 (22%) are currently diverting. Two hundred one (201) (71%) have a high, high-moderate, or moderate plug potential. Ninety five (95) stream crossings currently receive active ditch transport and sedimentation from the inboard ditch. Of the total 235 culverted stream crossings identified in the Soquel Creek County road assessment 182 or 78% are currently undersized for the 100-year storm flow.

Large crossing subset - From the 285 identified stream crossings, a separate subset of the larger stream crossings (these with a channel dimension greater then three by one (3 x 1) and/or a stream with a 24" diameter culvert or greater) were inventoried utilizing a more comprehensive dataform. Inventoried future erosion sites identified along the County roads were treated as future upgrade sites, where stream crossings were to be “designed” for the 100-year stream flow, the potential for stream diversion is to be eliminated or reduced, and the potential for future erosion and sediment delivery is minimized. Only future road-related erosion and sediment delivery from County road stream crossings in the Soquel Creek watershed were inventoried in this part of the assessment (Part 1).

A total of 127 sites with channel dimensions greater then three by one (3 x 1) and/or a stream crossing with a 24" diameter culvert or greater were identified along 63.8 miles of road with the potential to deliver sediment to streams. Of these, 125 sites were recommended for some type of erosion control and erosion prevention treatment. All of the sites are classified as stream crossings (Table 2).

Table 1. Stream crossings identified in the assessment of County roads, Santa Cruz County, California.

Stream crossing types	Total # of sites	# of sites with a channel greater than 3 x 1	Stream crossings with a diversion potential (#)	Streams currently diverting	Stream crossings likely to plug (plug potential rating = high or moderate)	Stream crossings with active ditch transport (ditch transport = high or moderate)	Culvert appear undersized
Culvert crossings	235	123	199	18	201	59	182
Fill crossings	47	2	45	45	N/A	35	N/A
Bridge crossings	3	2	1	0	N/A	1	N/A
Total stream crossings	**285**	**127**	**245**	**63**	**201**	**95**	**182**
Total ditch relief culverts	357	-	-	-	-	-	-

Site Types

Stream crossings - The subset of 127 of the largest stream crossings inventoried in Part 1 of the Soquel Creek assessment, included 123 culverted crossings (including metal pipes, cement box culverts and arched culverts), 2 unculverted fill crossings, and 2 bridges. An unculverted fill crossing refers to a stream crossing with no formal drainage structure to carry the flow through or beneath the road prism. Most unculverted fill crossings are located at small Class III streams that exhibit flow only in the larger runoff events. These unculverted fill crossings are currently diverting and directed down the inboard ditch to another culvert.

Approximately 129,967 yds^3 of future road-related sediment delivery in the Soquel Creek assessment area could originate from erosion at or associated with County stream crossings, if the crossings were to completely wash out (Table 2). This amounts to nearly 85% of the total expected future sediment yield from the road system, excluding mass wasting processes (which could be substantial). Not all these stream crossings can be expected to fail and wash out, but over long periods of time many of the largest crossings will experience repeated episodes of partial erosion, stream diversion or complete failure. The rate of failure will be higher for those stream crossings that are not designed to current 100-year storm discharge standards.

Figure 2. Road erosion inventory data form used in the Soquel Creek watershed assessment

*ASAP*___ **P W A R O A D I N V E N T O R Y D A T A F O R M** (3/03 version) ***Check***____

GENERAL	**Site No:** ________	GPS:	Watershed:		CALWAA:		
Treat (Y,N):	Photo: ______	T/R/S:	Road #:		Mileage: ___________		
	Inspectors:_______	Date: ________	Year built:______	Sketch (Y):			
	Maintained	Abandoned	Driveable	Upgrade	Decommission	Maintenance	
PROBLEM	Stream xing	Landslide (fill, cut, hill)	Roadbed (bed, ditch, cut)	DR-CMP	Gully	Other	
	Location of problem (U, M, L, S)	Road related? (Y)	Harvest history: (1=<15 yrs old; 2=>15 yrs old) TC1, TC2, CC1, CC2, PT1, PT2, ASG, No		Geomorphic association*:* Streamside, I.G., Stream Channel, Swale, Headwall, B.I.S.		
LANDSLIDE	Road fill	Landing fill	Deep-seated	Cutbank	Already failed	Pot. failure	
	Slope shape: (convergent, divergent, planar, hummocky)			Slope (%) ______	Distance to stream (ft) __________		
STREAM	CMP	Bridge	Humboldt	Fill	Ford	Armored fill	
	Pulled xing: (Y)	% pulled ______	Left ditch length (ft) ___________		Right ditch length (ft) ___________		
	cmp dia (in) ______	inlet (O, C, P, R)	outlet (O, C, P, R)	bottom (O, C,P, R)	Separated?		
	Headwall (in) ____	CMP slope (%) _____	Stream class (1, 2, 3)	Rustline (in)			
	% washed out ____	D.P.? (Y)	Currently dvted? (Y)	Past dvted? (Y)	Rd grade (%) ________		
	Plug pot: (H, M, L)	Ch grade (%) _____	Ch width (ft) _____	Ch depth (ft) ____			
	Sed trans (H, M, L)	Drainage area (mi^2) _________					
EROSION	E.P. (H, M, L)	Potential for extreme erosion? (Y, N)		Volume of extreme erosion (yds^3): 100-500, 500-1000, 1K-2K, >2K			
Past erosion...	Rd&ditch vol (yds^3) (yds^3)___________	Gully fillslope/hillslope (yds^3)__________	Fill failure volume (yds^3) _________	Cutbank erosion (yds^3)__________	Hillslope slide vol. (yds^3) ____________	Stream bank erosion (yds^3) __________	xing failure vol (yds^3) _________
	Total past erosion (yds) __________	Past delivery (%) __________	Total past yield (yds) _________	Age of past erosion (decade)_______			
Future erosion...	Total future erosion (yds) __________	Future delivery (%) __________	Total future yield (yds) _________	Future width (ft) _________	Future depth (ft) ________	Future length (ft) _______	
TREATMENT	Immed (H,M,L)	Complex (H,M,L)	Mulch (ft^2)				
	Excavate soil	Critical dip	Wet crossing (ford or armored fill) (circle)		sill hgt (ft) ___	sill width (ft) _______	
	Trash Rack	Downspout	D.S. length (ft) ________	Repair CMP	Clean CMP		
	Install culvert	Replace culvert	CMP diameter (in) _____	CMP length (ft) _______			
	Reconstruct fill	Armor fill face (up, dn)	Armor area (ft^2) _______	*Clean or cut ditch*	*Ditch length (ft)* _________		
	Outslope road (Y)	*OS and Retain ditch (Y)*	*O.S. (ft)* ____________	*Inslope road*	*I.S. (ft)* _____	*Rolling dip*	*R.D. (#)* __
	Remove berm	*Remove berm (ft)* _____	*Remove ditch*	*Remove ditch (ft)* __________		*Rock road - ft^2* ________	
	Install DR-CMP	*DR-CMP (#)* ________	Check CMP size? (Y)	Other tmt? (Y)	No tmt. (Y)		
COMMENT ON PROBLEM:							
EXCAVATION VOLUME Total excavated (yds^3) _______ Vol put back in (yds^3) _______ Volume removed (yds^3) ________							
	Vol stockpiled (yds^3)	Vol endhauled (yds^3) __	Dist endhauled (ft) _____	Excav prod rate (yds^3/hr) _________			
EQUIPMENT HOURS	Excavator (hrs) ___	Dozer (hrs) ___	Dump truck (hrs) ______	Grader (hrs) ________			
	Loader (hrs) _____	Backhoe (hrs) ______	Labor (hrs) _______	Other (hrs) ______			
COMMENT ON TREATMENT:							

Table 2. Site classification and potential future sediment delivery from the inventoried subset of large stream crossings, in the Soquel Creek watershed, Santa Cruz County, California.

Site Type	Number of sites or road miles	Number of sites or road miles to treat	Future yield (yds^3)	Stream crossings w/ a diversion potential (#)	Streams currently diverted (#)	Stream culverts likely to plug (plug potential rating = high or moderate)
Stream crossings	127	125	129,967	100	4	105
Persistent surface erosion[1] (paved)	18.6	18.5	23,538	N/A	N/A	N/A
Totals	**127**	**125**	**153,505**	**100**	**4**	**105**

[1] Assumes road is paved and volumes of surface erosion are from cutbanks areas.
Erosion rates were identified by observing the pedistoling, erosion and exposed bare areas on cutbanks. In the field the cutbanks were rated as having a high, moderate or low cutbank surface retreat rate. Rates of erosion per decade are 0.3', 0.2', 0.1' per decade respectively.

The most common problems which lead to erosion at stream crossings include: 1) undersized culverts that do not have the capacity to pass flood flows, 2) culverts that are plugged by debris or are highly likely to plug, 3) stream crossings with a diversion potential and 4) fillslope gully erosion at the culvert outlet. The sediment delivery from stream crossing sites is always classified as 100% because any sediment eroded at the crossing site is then delivered directly to the stream channel. Even sediment which is delivered to small ephemeral streams will eventually be transported downstream to fish-bearing stream channels.

At stream crossings, the largest volumes of future erosion can occur when culverts plug or when potential storm flows exceed culvert capacity (i.e., the culvert is undersized or prone to plugging) and flood runoff spills onto or across the road. When stream flow goes over the road's fillslope, part or all of the stream crossing fill may be degraded and washed away. Alternately, when flow is diverted down the road, either on the road bed or in the ditch (instead of spilling over the fill and back into the same stream channel), the crossing is said to have a "diversion potential" and the road bed, hillslope and/or stream channel that receives the diverted flow can become deeply gullied or destabilized. These hillslope gullies can be quite large and can deliver significant quantities of sediment to stream channels. Alternately, diverted stream flow which is discharged onto steep, potentially unstable slopes can also trigger large hillslope landslides. Of the 125 stream crossings inventoried recommended for treatment in the Soquel Creek watershed, 100 (80%) have the potential to divert in the future and 4 streams are currently diverted at stream crossing sites (Table 2). The worst scenario is for the culvert to plug and the stream crossing to wash out or the stream to divert down the road in a major storm. These road and stream crossing conditions are easily recognizable in the field and have been identified on all inventoried roads in the Soquel Creek watershed.

Approximately 98% (n=125) of the largest stream crossings inventoried in the Soquel Creek assessment area will need to be upgraded for the roads to be considered "storm-proofed." For example, 83% of the existing culverts have a "moderate" to "high" plugging potential and nearly 79% of the stream crossings exhibit a diversion potential (Table 2). Because most of the roads were constructed many years ago, culverted stream crossings are typically under-designed for the 100-year storm flow. At stream crossings with undersized culverts or where there is a diversion potential, corrective prescriptions have been outlined on the data sheets and in the following tables.

Preventative treatments include such measures as installing critical culverts (overflow pipes) at selected stream crossings to prevent stream diversions, installing larger culverts wherever current pipes are under-designed for the 100-year storm flow (or where they are prone to plugging), installing culverts at the natural channel gradient to maximize the sediment transport efficiency of the pipe and ensure that the culvert outlet will discharge on the natural channel bed below the base of the road fill, installing debris barriers or trash racks to prevent culvert plugging, installing flared inlets to increase culvert capacity and/or adding downspouts to prevent future outlet erosion.

Chronic surface erosion- In the Soquel Creek assessment area, we measured approximately 18.6 miles of, cutbank and/or road ditch (representing 29% of the total inventoried road mileage) which currently drain directly to streams and deliver cutbank, ditch and/or road runoff and fine sediment to stream channels. These roads are said to be "hydrologically connected" to the stream channel network. This does not include spur roads and driveways that also contribute runoff and sediment to the County roads and their drainage structures. When these roads are being actively maintained and used for access, they represent a potentially important source of chronic fine sediment delivery to the stream system.

Of the 18.6 miles of connected cutbank and/or road ditch 18.5 miles have been recommended for erosion control and erosion prevention treatment. From the 18.5 miles of "connected" road segments, we calculated approximately 23,538 yds^3 of sediment could be delivered to stream channels in the Soquel Creek watershed over the next 20 years if no efforts are made to change road drainage patterns. This will occur through a combination of 1) cutbank erosion delivering sediment to the ditch triggered by dry ravel, surface erosion, cutbank landslides and brushing/grading practices, 2) inboard ditch erosion and sediment transport, and 3) erosion of exposed portions of the road edge and turnouts during wet weather periods.

Relatively straightforward erosion prevention treatments can be applied to upgrade road systems to prevent fine sediment from entering stream channels. These treatments generally involve dispersing road runoff and selectively disconnecting road surface and ditch drainage from the natural stream channel network. Road surface treatments include the installation of sediment basins, berm breaks, and/or additional ditch relief culverts.

Treatment Priority

An inventory of future or potential erosion and sediment delivery sites is intended to provide information which can guide long range planning, as well as identify and prioritize erosion prevention and erosion control. Not all of the sites that have been recommended for treatment have the same priority, and some can be treated more cost effectively than others. Treatment priorities are evaluated on the basis of several factors and conditions associated with each potential erosion site. These include:

1) the expected volume of sediment to be delivered to streams (future delivery - yds^3),
2) the rate of erosion,
3) the potential or "likelihood" for future erosion (erosion potential - high, moderate, low),
4) the "urgency" of treating the site (treatment immediacy (high, moderate, low),
5) the ease and cost of accessing the site for treatments, and
6) recommended treatments, logistics and costs.

The ***erosion potential*** of a site is a technical evaluation of the likelihood that erosion will occur during a future storm event. Erosion potential is an estimate of the potential for additional erosion, based on field observations of a number of local site conditions. Erosion potential was evaluated for each site, and expressed as "High", "Moderate" or "Low." The evaluation of erosion potential is a subjective estimate of the probability of erosion, and not an estimate of how much erosion is likely to occur. It is based on the age and nature of direct physical indicators and evidence of pending instability or erosion. The likelihood of erosion (erosion potential) and the volume of sediment expected to enter a stream channel from future erosion (sediment delivery) play significant roles in determining the treatment priority of each inventoried site (see "treatment immediacy," below). Field indicators that are evaluated in determining the potential for sediment delivery include such factors as slope steepness, slope shape, distance to the stream channel, soil moisture and evaluation of erosion process. The larger the potential future contribution of sediment to a stream, the more important it becomes to closely evaluate its potential for cost-effective treatment.

Treatment immediacy (treatment priority) is a professional evaluation of how important it is to "quickly" perform erosion control or erosion prevention work. It is also defined as "High", "Moderate" and "Low" and represents both the severity and urgency of addressing the threat of sediment delivery to downstream areas. An evaluation of treatment immediacy considers erosion potential, future erosion and delivery volumes, the value or sensitivity of downstream resources being protected, and treatability, as well as, in some cases, whether or not there is a potential for an extremely large erosion event occurring at the site (larger than field evidence might at first suggest). If mass movement, culvert failure or sediment delivery is imminent, even in an average winter, then treatment immediacy might be judged "High". Treatment immediacy is a summary, professional assessment of a site's need for immediate treatment. Generally, sites that are likely to erode or fail in a normal winter, and that are expected to deliver significant quantities of sediment to a stream channel, are rated as having a high treatment immediacy or priority.

Evaluating Treatment Cost-Effectiveness

Treatment priorities are developed from the above factors, as well as from the estimated cost-effectiveness of the proposed erosion control or erosion prevention treatment. Cost-effectiveness is determined by dividing the cost ($) of accessing and treating a site, by the volume of sediment prevented from being *delivered* to local stream channels. For example, if it would cost $5000 to treat an eroding stream crossing that would have delivered 500 yds^3 (had it been left to erode), the predicted cost-effectiveness would be $10/$yds^3$ ($5000/500$yds^3$).

To be considered for priority treatment a site should typically exhibit: 1) potential for significant (>25-50 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 favorable cost-effectiveness value. 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 sites or projects are undertaken. Typical measures of treatment cost-effectiveness for forest and ranch roads are not directly comparable to values which might be developed for the treatment of public roads, such as those on the County roads in the Soquel Creek watershed. Here, the costs for treatments are typically much higher, and the resulting cost-effectiveness values will be less favorable.

Cost-effectiveness can be used as a tool to prioritize potential treatment sites throughout a watershed (Weaver and Sonnevil, 1984; Weaver and others, 1987). It assures that the greatest benefit is received for the limited funding that is typically available for protection and restoration projects. Sites, or groups of sites, that have poor cost-effectiveness values relative to other sites in the watershed, or are judged to have a lower erosion potential or treatment immediacy, or low sediment delivery volumes, are less likely to be treated as part of the primary watershed protection and "storm-proofing" program. These sites should be addressed during future road reconstruction or when heavy equipment is performing routine maintenance or restoration at nearby, higher priority sites.

Types of Prescribed Heavy Equipment Erosion Prevention Treatments

Roads can be storm-proofed by one of two methods: upgrading or decommissioning (closure) (Weaver and Hagans, 1999). Upgraded roads are kept open and are inspected and maintained. Their drainage facilities and fills are designed or treated to accommodate or withstand the 100-year recurrence interval storm. All inventoried roads in the Soquel Creek watershed have been prescribed for upgrading treatments. The characteristics of storm-proofed roads, including those which are upgraded are depicted in Figure 3.

Road upgrading involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially culvert up-sizing to accommodate the 100-year storm flow and debris in transport, and to eliminate stream diversion potential) and the application of drainage techniques to improve dispersion of road surface runoff. Road drainage techniques include berm removal, berm breaching, and/or the installation of ditch relief culverts. The goal of all treatments is to make the road as "hydrologically invisible" as is possible.

Heavy equipment conducting stream crossing culvert upgrades will utilize two different methods to install new pipes. Methods are dependent on the depth of road fill at the stream crossing site. For a stream crossing that has a <8' deep road fill, a trench will be excavated. The new pipe will be installed and the crossing excavation will be back filled with an aggregate concrete slurry.

FIGURE 3. CHARACTERISTICS OF STORM-PROOFED ROADS

The following abbreviated criteria identify common characteristics of "storm-proofed" roads. Roads are "storm-proofed" when sediment delivery to streams is strictly minimized. This is accomplished by dispersing road surface drainage, preventing road erosion from entering streams, protecting stream crossings from failure or diversion, and preventing failure of unstable fills which would otherwise deliver sediment to a stream. Minor exceptions to these "guidelines" can occur at specific sites within an inventoried road system.

STREAM CROSSINGS

- ✔ all stream crossings have a drainage structure designed for the 100-year flow
- ✔ stream crossings have no diversion potential (functional critical dips, emergency overflow pipes or other preventative structures are in place)
- ✔ stream crossing inlets have low plug potential (trash barriers & graded drainage)
- ✔ stream crossing outlets are protected from erosion (extended, transported or dissipated)
- ✔ culvert inlet, outlet and bottom are open and in sound condition
- ✔ undersized culverts in deep fills (> backhoe reach) have emergency overflow culvert
- ✔ bridges have stable, non-eroding abutments & do not significantly restrict design flood
- ✔ fills are stable (unstable fills are removed or stabilized)
- ✔ road surfaces and ditches are "disconnected" from streams and stream crossing culverts
- ✔ decommissioned roads have all stream crossings completely excavated to original grade
- ✔ Class 1 (fish) streams accommodate fish passage

ROAD AND LANDING (TURNOUT) FILLS

- ✔ unstable and potentially unstable road, landing and turnout fills are excavated (removed) or structurally stabilized
- ✔ 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

- ✔ road surfaces and ditches are "disconnected" from streams and stream crossing culverts
- ✔ ditches are drained frequently by functional rolling dips or ditch relief culverts
- ✔ outflow from ditch relief culverts does not discharge to streams
- ✔ gullies (including those below ditch relief culverts) are dewatered to the extent possible
- ✔ ditches do not discharge onto active or potential landslides
- ✔ decommissioned roads have permanent road surface drainage and do not rely on ditches

Approximately 90% of the road fill that is excavated for the new culvert installation will be endhauled away from the site. The remaining 10% of fill will be backfilled and compacted to create a bed for the new pipe. Estimated excavator and backhoe times are based on an excavation production rate that is determined by the complexity of the work site. Dump trucks will endhaul spoil to a temporary storage areas located at predetermined County road locations where there is available space in safe and stable locations.

Once the new pipe is set at or close to the natural channel gradient, a cement truck will haul slurry material to backfill the excavated crossing. Each trench crossing will be backfilled with a slurry to ensure a hardened surface that will not settle after the new pipe installation is completed. Cement trucks can haul 10 yds^3 of slurry and are able to backfill at a rapid 10 yds^3 in 10 minutes. Costs for the cement truck are based on the cost of the material delivered to the average work site. Several cement trucks will be utilized at once and may be required to deliver up to 90 cubic yards of slurry to backfill a larger trench crossing. The crossing then will be capped with new pavement whose surface area is based on the width and length of the trench excavation. The crossing will then be swept with a mechanical broom. To finish the treatment, guard rails will be re-installed, stripping will be repainted and any excavated reflectors will be replaced.

For crossings >8' deep and fill depths beyond the reach of an excavated trench, a non-trenched excavation will be applied. To install a new pipe at the natural channel gradient, a deep crossing will require the excavator to open up a crossing completely to safely allow room for laborers to replace or install the pipe deep in the fill. The excavation will require sideslopes be excavated back at a 1:1 slope (at least). This differs significantly from a typical trenched excavation. Approximately 100 yds^3 of clean, dry fill material will be stockpiled on-site and the remaining road fill will be endhauled to the temporary storage yard. The new pipe will be installed using the locally stockpiled spoils for a compacted bed. The remaining excavation will then be backfilled with quarry fill at a delivered cost of \$13.50/yds^3 of new fill.

As a general rule, large volume stream crossings that were classified as under designed (undersized) by at most 12" of culvert diameter were prescribed to be retained (as long as the existing culverts were in good overall condition) and upgraded so a failure would not wash out the entire crossing. Overflow pipes, flared inlets and trash racks were applied to protect the culverted fill, extend the life of the under sized pipe and to enhance the flow capacity of the pipe.

Recommended Treatments

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of potential sources of road-related sediment delivery. Table 3 and Maps 4A, 4B and 4C outline the treatment priorities for all 125 inventoried “large” stream crossings that have been recommended for treatment in the Soquel Creek watershed. Of the 125 sites 70 (56%) were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 99,350 yds^3. Fifty two (52) sites (42%) were listed with a moderate or moderate-low treatment immediacy and these account for nearly 50,402 yds^3 of future sediment delivery. Finally, 3 sites (2%) were listed as having a low treatment immediacy with approximately 3,753 yds^3 of future sediment delivery.

Table 3. Treatment priorities for all inventoried sediment sources on County roads in the Soquel Creek watershed assessment area, Santa Cruz County, California

Treatment Priority	Upgrade sites (# and site #)	Problem	Future sediment delivery (yds^3)
High	**23** (site #: 118, 119, 126, 168, 182, 193, 196, 200, 208, 218, 229, 247, 249, 250, 252, 257, 263, 267, 294, 298, 303, 503, 504)	23 stream crossings	32,265
Moderate High	**47** (site #: 8, 13, 16, 28, 40, 43, 49, 101, 109, 111, 120, 121, 123, 130.1, 131, 136, 169, 170, 171, 172, 177, 180, 183, 184, 186, 187, 191, 192, 210, 215, 221, 222, 230, 235, 236, 242, 244, 253, 255, 259, 264, 291, 300, 313, 314, 316, 318)	47 stream crossings	67,085
Moderate	**46** (site #: 1, 5, 10, 14, 17, 24, 34, 37, 38, 42, 46, 48, 106, 107, 110, 116, 122, 125, 128, 129, 139, 141, 142, 166, 167, 174, 205, 206, 211, 214, 217, 219, 223, 225, 233, 241, 256, 261, 266, 275, 276, 289, 296, 301, 324, 326)	46 stream crossings	45,758
Moderate Low	**6** (site #: 130, 213, 268, 281, 285, 292)	6 stream crossings	4,644
Low	**3** (site #: 104, 108, 317)	3 stream crossings	3,753
Total	**125**	**125 stream crossings**	**153,505**

Road priority - An efficient way of addressing treatment priorities is to identify high priority roads for treatment. This manner of treating sites maximizes equipment efficiency and minimizes the need to "jump around" the watershed treating only the high priority sites. Prioritizing roads is the preferred method of establishing watershed work plans for erosion prevention, and there are several ways of developing a prioritized list.

Table 4 summarizes the proposed treatments for sites inventoried on all the County roads in the Soquel Creek watershed assessment. These prescriptions include upgrading measures only where sediment savings will occur. The database, as well as the field inventory sheets, provide details of the treatment prescriptions for each site. Most treatments require the use of heavy equipment, including an excavator, loader, tractor, dump truck, roller, broom, cement truck, grader and/or backhoe.

Hand labor is required at sites needing new culverts, flared inlets, downspouts, culvert repairs, berm flumes, drop inlets, trash racks and/or for applying seed, plants and mulch following ground disturbance activities. Two types of trash racks are designed to protect the culvert inlet. An I-beam trash rack's primary function is to trap floating wood before it reaches the drainage structure. I-beam trash racks will extend across the full width of the active channel. Another type of trash rack recommended is a single deflector pole. The single pole trash rack deflects small wood flowing perpendicular with the channel and either turns the debris so that it will pass through the pipe, or catches it before it reaches the inlet. Single pole trash barriers are designed for the smallest stream channels while the I-beam trash racks are recommended for larger channels. Additional labor will be required to conduct traffic control at all work sites. Labor necessary to allow vehicles to pass through the work site with minimal delay will require a single flagman on both sides of the work site. The flaggers will be equipped with radios and stop signs and direct traffic to a single lane. Stop signs will replace flaggers during nights or hours when work will not be conducted. Longer or “blind” reaches may require the use of a pilot car.

It is estimated that erosion prevention work will require the excavation of approximately 75,246 yds^3 at 102 sites. All of the volume excavated is associated with upgrading stream crossings. A total of 5,159 yds^3 of 1.0 to 3.0 foot diameter mixed and clean rip-rap sized rock will be needed to armor seventy eight (78) outboard fill faces (Table 4). Armor is placed at the base of the outboard fillslopes of newly replaced or installed culverts at stream crossings to reduce sediment delivery and buttress the lower portion of the excavation. Rock armor is placed to prevent the newly replaced fill from slumping and/or delivering to the stream network. At four proposed treatment sites, 565 feet of ditch will require 140 yds^3 of rock armor to protect the ditch from chronic scouring, erosion and downcutting. At 92 stream crossing sites, we have recommended replacing or installing new culverts designed for the 100-year storm. Many of these culverts are not just undersized, they are showing signs of advanced deterioration. At six stream crossings, we have recommended replacing undersized culverts with arched culverts. At three stream crossings we have recommended the installation of a bridge.

At deep stream crossings where an excavator cannot reach the natural stream bottom and install a culvert at the natural channel gradient, downspouts have been prescribed to transport the stream flow beyond the road fill to the natural stream bottom. To prevent potential stream diversions, each site with a high diversion potential has been prescribed to either have an oversized pipe, critical pipe (a second overflow pipe) or to have a flared inlet to increase pipe inlet capacity. Fifty five (55) critical pipes have been prescribed at stream crossings to prevent a stream diversion (Table 4). Twenty five (25) flared inlets have been prescribed for installation to increase the inlet capacity at certain stream crossings. A minimum of 463 new ditch relief culverts are recommended for installation along the inventoried road routes to disconnect long lengths of connected ditches from natural stream channels (Table 4).

Downspouts will be attached to 406 of the ditch relief culverts, stream crossing culverts and overflow pipes to transport the ditch flow beyond the erodible uncompacted road fill and disperse

Table 4. Recommended treatments along all inventoried County roads in the Soquel Creek watershed, Santa Cruz County, California.

Treatment	No.	Comment	Treatment	No.	Comment
Install bridge	3	Install a bridge at a current undersized culvert crossing	Armor fill face	78	Rock armor to protect outboard/ inboard fillslope from erosion using 5,159 yds^3 of rock
Install CMP	1	Install a CMP at an unculverted fill	Armor ditch	4	Armor ditch for 565 feet using 140 yds^3 of rock
Replace CMP	91	Upgrade an undersized CMP	Reconstruct/ Engineer fill	6	Re-construct fill using engineered fix
Install arched culvert	6	Install arched culverts at a current CMP crossing	Rebar trash racks	12	Added to catch debris and reduce plugging potential of culvert
Install critical pipes	55	Install critical overflow pipes above already installed CMP	I beam trash rack	33	Added to catch debris and reduce plugging potential of culvert
Install ditch relief CMP	403	Install ditch relief culverts to improve road surface drainage	Add curb/ berm	48	Add 4,240 feet of curb/ berm to improve road drainage
Down spouts	406	Installed to protect the outlet fillslope from erosion	Install curb/ berm drains	75	Install drains to improve road drainage
Flared inlets	25	Install flared inlets to increase carrying capacity	Asphalt/ chip seal road surface	521	Asphalt/ chip seal road surface using 213,432 square feet
Excavate and remove soil	102	Typically fillslope & crossing excavations; excavate and endhaul a total of 75,246 yds^3	Clean CMP	1	Remove debris and/or sediment from CMP inlet
Install sediment basin	3	Install sediment basin to catch uncontrollable ditch and road surface runoff	Other	8	Other miscellaneous treatments

the flow on to less erodible native ground. A minimum of 75 new berm flumes or berm drain pipes with flared inlets will be installed on the outboard edge of the road to break up and transport road surface and inboard ditch flow. Downspout flumes and/or pipes attached to the berm breaks will be installed to transport concentrated flow beyond the road fill and disperse runoff onto native ground.

Special Considerations Related to Treatment of Problematic Priority Roads

Several roads within densely populated areas of the Soquel Creek watershed will be difficult to treat for sediment reduction and road maintenance. Field observations of off-site road length contribution note the connectivity of unpaved driveways delivering fine sediment to the stream network. These difficulties arise from inherent problems associated with road location, residents' houses, poor construction techniques and/or the hydrologic influence from adjacent driveways, county roads and state highways.

Equipment Needs and Costs

Treatments for the 125 sites identified with future sediment delivery in Part 1 of the Soquel Creek County Road assessment will require approximately 5,530 hours of excavator time and 22 hours of dozer time to complete all prescribed upgrading and erosion control and erosion prevention work (Table 5). A loader has been listed for 780 hours of work to fill dump trucks with excavated spoil, backfill stream crossings, and keep the road swept of any obstacles that might stop traffic. Approximately 8,414 hours of dump truck time has been listed for work in the basin for end-hauling excavated spoil from stream crossings and at unstable road and landing fills where local disposal sites are not available. Approximately 4,198 hours of labor time is needed for a variety of tasks such as installation or replacement of culverts, flared inlets, installation of debris barriers and downspouts, and 60 hours are for seeding, mulching and planting activities. A total of 13,462 traffic control hours have been listed for a crew of two flagmen during heavy equipment work hours. Approximately 635 hours for a roller, 502 hours for a pavement cutter and 601 hours for a mechanical broom have been listed to finish and resurface each upgraded site.

Estimated costs for erosion prevention treatments - Prescribed treatments are divided into two components: a) site specific erosion prevention work identified during the watershed inventories, and b) control of persistent sources of road surface, ditch and cutbank runoff, erosion and associated sediment delivery to streams. The total costs for road-related erosion control at all the inventoried sites with future sediment delivery to the Soquel Creek watershed is estimated at approximately $17,831,176. Of this engineered work set aside to design and build bridges, arched culverts and reinforced walls is roughly estimated at $11,627,000.

This cost is based on local Santa Cruz County engineered upgrades performed in 2001. Without the cost of the engineered structures the total cost of the project is $6,204,176 for an average cost-effectiveness value of approximately $40.42 per cubic yard of sediment prevented from entering Soquel Creek and its tributaries (Table 6). It should be noted that costs to re-pave the entire upgraded road system following implementation of the proposed storm-proofing activities are included in this table.

Overall site specific erosion prevention work - Equipment needs for site specific erosion prevention work at sites with future sediment delivery are expressed in the database, and summarized in Table 5, as direct excavation times, in hours, to treat all sites having a high, moderate, or low treatment immediacy. These hourly estimates include only the time needed to treat each of the sites, and do not include travel time between work sites, times for basic road surface treatments that are not associated with a specific "site," or the time needed for work

Table 5. Estimated heavy equipment and labor requirements for treatment of all inventoried sites with future sediment delivery on County roads, Soquel Creek watershed assessment area, Santa Cruz County, California.

Treatment Immediacy	High, High/Moderate	Moderate, Low/Moderate	Low	**Total**
Site (#)	70	52	3	**125**
Total Excavated Volume (yds^3)[1]	63,960	19,036	100	**83,096**
Excavator (hrs)	3,979	1,489	62	**5,530**
Dozer (hrs)	0	22	0	**22**
Loader (hrs)	597	183	0	**780**
Dump Trucks (hrs)	6,515	1,865	34	**8,414**
Labor (hrs)	2,739	1,384	75	**4,198**
Traffic Control (hrs)	9,476	3,790	196	**13,462**
Roller (hrs)	374	241	20	**635**
Pavement Cutter (hrs)	310	179	13	**502**
Broom (hrs)	366	221	14	**601**

[1] Total excavated volume includes permanently excavated material and a percentage of temporarily excavated materials used in backfilling upgraded stream crossings.
[2] Cement truck hours are included in the rock/slurry cost in Table 6. Total slurry used during backfilling trenched stream crossings is near 3,170 yds^3 at \$95/ yds^3 including delivery.

conferences at each site. These additional times are accumulated as "logistics" and must be added to the work times to determine total equipment costs as shown in Table 6.

The costs in Table 6 are based on a number of assumptions and estimates, and many of these are included as footnotes to the table. The costs provided are assumed reasonable if work is performed by outside contractors, with no added overhead for contract administration and pre-and post-project surveying. Movement of equipment to and from the site will require the use of low-boy trucks. Costs for this project do not include the costs to move equipment to and from the project or from site to site. The majority of treatments listed in this plan are not complex or difficult for equipment operators experienced in road upgrading. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended treatments conform to the general guidelines described in "The Handbook for Forest and Ranch Roads" prepared by PWA (1994) for the California Department of Forestry, Natural Resources Conservation Service and the Mendocino County Resource Conservation District.

Treatments were then modified from these general standards to more closely meet current County procedures and acceptable standards for paved public roads. The specific treatments outlined in this report will need to be reviewed by County DPW staff on a site-by-site basis to ensure they meet current operating practices that are in place for similar treatments. It should also be noted that approximately 90% of the road length inventoried was on paved county roads where engineers will likely need to be involved in the design of specific upgrade work. Extra costs could include safety flagging, painting, guard rails, additional design and engineering. This could add a significant cost to completing the proposed work.

Table 6 lists a total of 3,755 hours for "supervision" time for detailed pre-work layout, project planning (coordinating and securing equipment, materials and obtaining plant and mulch materials), on-site equipment operator instruction and supervision, establishing effectiveness monitoring measures, and post-project cost effectiveness analysis and reporting. It is expected that the project coordinator and/or Contracting Officer's Representative (COR) will be on-site full time at the beginning of the project and intermittently after equipment operations have begun.

Conclusion

The expected benefit of completing the erosion control and prevention planning work lies in the reduction of long term sediment delivery to Soquel Creek, an important salmonid stream. A first-step in the overall risk-reduction process is the development of a proactive plan for erosion prevention and erosion control on public roads. In developing this plan, all roads in the watershed are considered for upgrading. Not all roads are high risk and those that pose a low risk of degrading aquatic habitat in the watershed may not need immediate attention. It is therefore important to rank and prioritize roads based on their potential to impact downstream resources, as well as, their importance to the overall transportation system and to management needs.

Good land stewardship requires that roads be upgraded and maintained. The old practice of "crisis management" and treating roads only when a flooding disaster happens, is no longer considered acceptable. Road upgrading consists of a variety of techniques employed to "erosion-proof" and to "storm-proof" a road and prevent unnecessary future erosion and sediment delivery. This requires a proactive investment in the basic infrastructure of the transportation network. Erosion-proofing and storm-proofing typically consists of upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff as well as a large storm event without failing or delivering excessive sediment to the stream system. In fact, many of the drainage structures (culverts) at inventoried stream crossings are nearing the

Table 6. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on all County road inventoried sites with future sediment delivery in Part 1 of the Soquel Creek watershed assessment, Santa Cruz County, California

Cost Category[1]		Cost Rate[2] ($/hr)	Estimated Project Times			Total Estimated Costs[5] ($)
			Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	
Heavy Equipment requirements for site specific treatments	Excavator	165	3,918	1,175	5,093	840,345
	Dozer	140	22	7	29	4,060
	Dump truck	75	7,608	2,282	9,890	741,750
	Loader	140	780	234	1,014	141,960
	Broom	55	198	59	257	14,135
	Pavement cutter	140	99	30	129	18,060
	Roller	50	232	70	302	15,100
Heavy Equipment requirements for road drainage treatments	Excavator	165	1,612	484	2,096	345,840
	Dump truck	75	806	242	1,048	78,600
	Loader	140	2	1	3	420
	Broom	55	403	121	524	28,820
	Pavement cutter	140	403	121	524	73,360
	Roller	50	403	121	524	26,200
Laborers[6]		40	4,258	1,277	5,535	221,400
Traffic control laborers		30	13,462	4,039	17,501	525,030
Rock Costs: (includes trucking for 5,299 yds^3 of rip-rap sized rock and 60,362 yds^3 of clean backfill)						1,026,847
Backfill slurry costs: includes trucking and pouring for 9,724 yds^3 of backfill slurry						923,780
Culvert materials costs (24,640' of 18", 840' of 24", 2,350' of 30", 2,995' of 36", 2,010' of 42", 1,940' of 48", 670' of 54", 680' of 60", 810' of 72". Costs included for couplers, flared inlets, and elbows)						626,084
6 Arched culverts(25' x 6', 20' x 6', and 4 20' x 6') Cost for complete removal and new installation						600,000
Engineered bridge (3 100' bridges)						10,500,000
Engineer fill for 5 reinforced retaining walls						527,000
I-beam trash rack materials						2,228
I-beam trash rack welder ($60/day)						1,980
Berm drain formed flared inlets at $100/each plus 3,229' of flume drain pipe						32,525
Pavement placed with paver for 220,134 ft^2						134,462
Berm installation with berm machine ($23/ft. @ 4,240')						97,520

Cost Category[1]	Cost Rate[2] ($/hr)	Estimated Project Times			Total Estimated Costs[5] ($)
		Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	
Mulch, seed and planting materials for 3.71 acres of disturbed ground[7]					2,045
Layout, Coordination, Supervision, and Reporting[8]	75 75 75	--	--	1,700 1,700 355	281,625
Total Estimated Costs					**$17,831,176**
Total Estimated Costs without engineered upgrades					$6,204,176
Potential sediment savings: 153,505 yds^3					
Overall project cost-effectiveness: $40.42 spent per cubic yard saved[9]					

[1] Costs for tools and miscellaneous materials have not been included in this table. Costs for administration and contracting are variable and have not been included. Costs and dump truck time (if needed) for re-rocking the road surface at sites where upgraded roads are outsloped are not included. Costs for replacing excavated striping and reflectors not included.

[2] Costs listed for heavy equipment include operator and fuel. Costs listed are estimates for favorable local private sector equipment rental and labor rates.

[3] Treatment times include all equipment hours expended on excavations and work directly associated with erosion prevention and erosion control at all the sites.

[4] Logistic times for heavy equipment (30%) include all equipment hours expended for opening access to sites on maintained roads, travel time for equipment to move from site-to-site, and conference times with equipment operators at each site to convey treatment prescriptions and strategies. Logistic times for laborers (30%) includes estimated daily travel time to project area.

[5] Total estimated project costs listed are averages based on private sector equipment rental and labor rates.

[6] An additional 60 hours of labor time is added for straw mulch and seeding on upgraded stream crossings.

[7] Seed costs equal $6/pound for erosion control seed. Seed costs based on 50 lbs. of erosion control seed per acre. Straw costs include 50 bales required per acre at $5 per bale. Sixteen hours of labor are required per acre of straw mulching.

[8] Supervision time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, supervision of labor work and post-project documentation and reporting). Supervision times based on 50% of the total excavator time plus 2 weeks prior and 2 weeks post project implementation.

[9] Project cost effectiveness based on the total cost of the project without the cost for engineered upgrades (i.e. bridges, arched culverts and engineered fills).

end of their useful life. They are rusted out and beginning to fail through erosion and collapse of the fill. These will need to be replaced, and this presents an opportunity to upgrade the drainage structure with one that better meets today's higher standards. Finding adequate funding to accomplish this upgrading of the road network will be a challenging task, but one that has rewards in terms of lowered maintenance and storm damage costs, and increased protection to fish habitat and water quality throughout the watershed.

In identifying potential sediment sources along the Santa Cruz County road system, PWA employed a standardized and accepted protocol for identifying, describing and quantifying erosion problems. However, in developing recommended treatments to address the various sediment sources, we employed a modified set of prescriptions that were formulated to be consistent with paved public roads and Santa Cruz Department of Public Works (DWP) road standards. Discussions with Santa Cruz County DPW staff guided our selection of appropriate erosion prevention techniques. Recent cost figures for a suite of potential treatments were used to generate reasonable cost estimates for each of the tasks. We have provided a complete listing of our assumptions that were used to derive work times and costs for each treatment (Appendix A). These can be changed globally in the database to provide a revised treatment prescription and/or cost estimate.

County roads in upper and lower Soquel Creek watershed have been identified and prescribed for upgrading. The goal of 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 serious erosion and sediment yield when large magnitude, infrequent storms and floods occur. PWA can work with road managers to make recommendations that achieve both long term sediment delivery reduction as well as retaining the road shapes and locations.

Part 2: CDF Soquel Demonstration Forest Inventory Results

Approximately 18.2 miles of maintained roads were inventoried for future sediment sources within the California Department of Forestry Soquel Demonstration State Forest. All but one of the inventoried road-related erosion sites within the assessment area are categorized as upgrade sites - defined as sites on maintained open roads that are to be retained for access. One abandoned road has one stream crossing site that has been recommended for decommissioning. Virtually all future road-related erosion and sediment yield in the Soquel Demonstration State Forest is expected to come from three sources: 1) erosion at or associated with stream crossings (from several possible causes), 2) potential road fill failures (landslides) and 3) road surface and ditch erosion.

A total of 82 sites with sediment delivery were identified in the Soquel Demonstration State Forest (Map 3B). These sites were identified as having a high, high-moderate, moderate, moderate-low or low potential of future sediment delivery to Soquel Creek (Table 7). Sites include 57 stream crossings, 21 “other” sites and four (4) potential fill failures (landslides). From the total 82 inventoried sites, 69 (84%) have been recommended for erosion control and erosion prevention treatment. In addition, 26% of the 18.2 miles of the Soquel Demonstration Forest roads are currently connected to stream crossings and delivering fine sediment and road surface runoff to streams.

Site Types

Stream crossings - Fifty seven (57) stream crossings were inventoried on the Soquel Demonstration State Forest roads including 43 culverted stream crossings, seven (7) unculverted fill crossings, four (4) wet ford crossings, two (2) bridges and one (1) Humboldt stream crossing.

An unculverted fill crossing refers to stream crossings with no formal drainage structure to carry the flow through the road prism. Flow is carried over the road surface and is diverted down the road to the inboard ditch. The unculverted fill crossings are located at small streams that exhibit flow only in the larger runoff events. A Humboldt stream crossing (site #668) refers to a legacy redwood region logging technique where stream crossings were built with wood, fill and debris.

Forty six (46) of the 57 stream crossing sites identified in the assessment have been recommended for erosion control and erosion prevention treatment. Approximately 5,417 yds^3 of future road-related sediment yield in the Soquel Demonstration State Forest could originate from erosion at stream crossings if they are not treated (Table 7). This amounts to nearly 36% of the total expected future sediment yield from the road system. The most common problems which can lead to erosion at stream crossings include: 1) crossings with undersized drainage structures, 2) crossings with no drainage structures and 3) stream crossings with a diversion potential. The sediment delivery from stream crossing sites is always classified as 100% because any sediment eroded at the crossing site is delivered directly to the channel. Any sediment which is delivered to small ephemeral streams will eventually be delivered to downstream fish-bearing stream channels of Soquel Creek.

Table 7. Site classification and sediment yield from all inventoried sites with future sediment delivery in the Soquel Demonstration State Forest, Santa Cruz County, California.

Site Type	Number of sites or road miles	Number of sites or road miles to treat	Future yield (yds^3)	Stream crossings w/ a diversion potential (#)	Streams currently diverted (#)	Stream culverts likely to plug (plug potential rating = high or moderate)
Stream crossings	57	46	5,417	34	5	27
Other sites	21	19	270	N/A	N/A	N/A
Landslides	4	4	412	N/A	N/A	N/A
Total (all sites)	82	69	6,099	34	5	27
Persistent surface erosion[1]	5.2 miles	4.7 miles	9,133	N/A	N/A	N/A
Totals	**82**	**69**	**15,232**	**34**	**5**	**27**

[1] Assumes 25' wide road prism and cutbank contributing area, and 0.2' of road/cutbank surface lowering per decade for two decades

At stream crossings, the largest volumes of future erosion can occur when drainage structures plug or when flood runoff spills onto or across the road and diverts down the road. When stream flow goes over the fill, part or all of the stream crossing fill may be eroded. Alternately, when flow is diverted down the road, either on the road bed or in the ditch (instead of spilling over the fill and back into the same stream channel), the crossing is said to have a “diversion potential” and the road bed, hillslope and/or stream channel that receives the diverted flow can become deeply gullied or destabilized. These hillslope gullies can be quite large and can deliver significant quantities of sediment to stream channels. Alternately, diverted stream flow which is discharged onto steep, potentially unstable slopes can also trigger large hillslope landslides. Thirty four (34) stream crossings identified on the Soquel Demonstration State Forest have a diversion potential and 5 are currently diverted (Table 7). Treatment for stream crossings diversions are straight forward and require the construction of a broad “critical dip” at the down-road hinge line of the stream crossing to re-direct flow back into its natural drainage.

Forty six (46) stream crossings inventoried in the Demonstration Forest will need to be upgraded for the roads to be considered “storm-proofed.” Preventative treatments include such measures as constructing critical dips (rolling dips) at stream crossings to prevent stream diversions and installing larger culverts wherever culverts are under-designed for the 100-year storm flow (or where they are prone to plugging).

Landslides - Only those road-related landslides with a potential for sediment delivery to a stream channel were inventoried. A total of four (4) “landslides” were identified and these account for less than 3% of the total expected future sediment delivery volume (Table 7). Most of the potential landslide sites were found along the road where material had been sidecast during road construction and/or recent road maintenance grading and now show signs of instability. These sites were identified using field evidence such as road surface cracks, scarps or J-shaped trees.

The four potential landslides identified along the Soquel Demonstration State Forest roads have been recommended for erosion control and erosion prevention treatment. Potential landslides are expected to deliver nearly 412 yds^3 of sediment to Soquel Creek and its tributaries in the future if they are not treated. Correcting or preventing potential landslides associated with the forest road system is relatively straight-forward, and involves the physical excavation of potentially unstable road fill and sidecast materials. There are a number of potential landslide sites located on the road that did not, or will not, deliver sediment to streams. These sites were not inventoried using data sheets due to the lack of expected sediment delivery to a stream channel. They are generally shallow and of small volume, or located far enough away from an active stream such that delivery is unlikely to occur. For reference, all landslide sites were mapped on the mylar overlay of the field inventory maps, but only those with the potential for future sediment delivery were inventoried using a datasheet.

“Other” sites - A total of 21 “other” sites were also identified in the Soquel Demonstration State Forest (Table 7 and Map 3B). Other sites include ditch relief culverts, major springs and gullies which exhibited the potential to deliver sediment to streams. The main cause of existing or future erosion at these sites is surface runoff and uncontrolled flow from long sections of undrained road surface and/or inboard ditch. Uncontrolled flow along the road or ditch may affect the road bed integrity as well as cause gully erosion on the adjacent hillslopes. Road runoff is also a major source of fine sediment input to nearby stream channels. Gully erosion can occur below ditch relief culvert outlets due to excessive road and/or ditch contribution to the inlet. Gully erosion can also occur as a result of poor installation techniques such as shotgunned outlets or the culvert being placed too high in the fill without a functional downspout.

Nineteen (19) of the 21 “other” sites have been recommended for erosion control and erosion prevention treatment. We estimate 270 yds^3 of sediment could be delivered to streams if they are left untreated. Sediment delivery from these sites represents less than 2% of the total potential sediment delivery from sites recommended for erosion control and erosion prevention treatment.

Persistent surface erosion - We measured approximately 5.2 miles of road surface and/or road ditch (representing 29% of the 18.2 miles of the Demonstration Forest road system) which currently drain directly to streams, and delivers ditch and road runoff and fine sediment to stream channels. These roads are said to be “hydrologically connected” to the stream channel network. When they are being actively maintained and used for forest management or recreation access, they represent a potentially important source of chronic fine sediment delivery to the stream system throughout the year.

Of the 5.2 miles of road surface and/or ditch hydrologically “connected” to streams, 4.7 miles have been recommended for treatment. From these “connected” road segments, we calculated approximately 9,133 yds^3 of sediment could be delivered to Soquel Creek and its tributaries over the next 20 years if no efforts are made to change road drainage patterns (Table 7)[1]. This will occur through a combination of 1) cutbank erosion delivering sediment to the ditch triggered by dry ravel, surface erosion, rainfall, cutbank landslides and brushing/grading practices, 2) inboard ditch erosion and sediment transport, 3) mechanical pulverizing and wearing down of the road surface, and 4) erosion of the road surface during wet weather periods. Roads in the Soquel Demonstration State Forest are intermittently used for commercial forest activities.

Relatively straightforward erosion prevention treatments can be applied to upgrade road systems to prevent fine sediment from entering stream channels. These treatments generally involve dispersing road runoff and disconnecting road surface and ditch drainage from the natural stream channel network. Road surface treatments include the installation of rolling dips, road surface outsloping, road surface insloping and/or installation of additional ditch relief culverts prior to rocking road surfaces.

Recommended Treatments

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of potential sources of road-related sediment delivery. Table 8 and Map 5B and outline the treatment priorities for all 69 inventoried sites with future sediment delivery that have been recommended for treatment in the Soquel Demonstration State Forest. Of the 69 sites, 3 sites were identified as having a high treatment immediacy with a potential sediment

[1] The applied, average rate of surface lowering on cutbanks and along road beds (i.e. 0.2 feet/decade) is based on observed retreat or erosion rates in the Soquel Creek watershed, and on un-published data from sediment budget studies in the Redwood Creek watershed, Humboldt County (Redwood National Park, unpublished data).

Table 8. Treatment priorities for all inventoried sediment sources in the Soquel Demonstration State Forest watershed assessment area, Santa Cruz County, California

Treatment Priority	Upgrade sites (# and site #)	Decommission sites (# and site #)	Problem	Future sediment delivery (yds^3)
High	**3** (site #: 651, 666, 677)	**0**	3 stream crossings	1,631
Moderate High	**16** (site #: 609, 616, 618, 619, 620, 622, 625, 626, 642, 653, 659, 664, 671, 673, 675, 678)	**1** (site #: 668)	12 stream crossings, 5 other	5,229
Moderate	**20** (site #: 603, 608, 610, 611,613, 614, 623, 624, 643, 647, 649, 650, 655, 658, 663, 667, 670, 672, 674, 679)	**0**	14 stream crossings, 1 landslide, 5 other	3,847
Moderate Low	**17** (site #: 600, 601, 602, 614.1, 615, 617, 631, 632, 640, 648, 648.1, 656, 657, 662, 665, 669, 676)	**0**	9 stream crossings, 2 landslides, 6 other	2,995
Low	**12** (site #: 604, 606, 607, 612, 621, 627, 634, 636, 637, 645, 646, 654)	**0**	8 stream crossings, 1 landslide, 3 other	1,530
Total	**68**	**1**	**46 stream crossings, 4 landslides, 19 other**	**15,232**

delivery of approximately 1,631 yds^3. Seventeen (17) were listed with a high-moderate treatment immediacy and these account for up to 5,229 yds^3. Twenty (20) sites were listed with a moderate treatment immediacy and these account for 3,847 yds^3. Seventeen (17) sites were listed with a moderate-low treatment immediacy and these account for nearly 2,995 yds^3. Finally, 12 sites were listed with a low treatment immediacy and these account for approximately 1,530 yds^3 of future sediment delivery from the inventoried roads.

Table 9 summarizes the proposed treatments for sites inventoried in the Demonstration Forest. The database, as well as the field inventory sheets, provide details of the treatment prescription for each site. Most treatments require the use of heavy equipment, including an excavator, dozer, dump truck, water truck and/or grader. Some hand labor is required at sites needing new culverts, downspouts, and for applying seed, plants and mulch following ground disturbance activities.

Table 9. Recommended treatments along all inventoried roads in the Soquel Demonstration State Forest, Santa Cruz County, California.

Treatment	No.	Comment	Treatment	No.	Comment
Critical dips	24	To prevent stream diversions	Rock road surface	1	Rock road surface using 26 yds^3 road rock
Install CMP	1	Install a CMP at an unculverted fill	Outslope road	21	Outslope 6,377 feet of road to improve road surface drainage
Replace CMP	16	Upgrade an undersized CMP	Remove berm	3	Remove 698 feet of berm to improve road surface drainage
Wet crossings	5	Install rocked armored fill crossing using 50 yds^3 rip-rap	Cross road drains	1	To improve road surface drainage on abandoned road
Flared inlets	15	Install flared inlets to increase CMP carrying capacity	Install ditch relief CMP	12	Install ditch relief culverts to improve road surface drainage
Armor fill face	11	Rock armor to protect outboard/ inboard fillslope from erosion using 490 yds^3 of rock	Install sediment basin	1	Install to catch sediment and prevent fines from delivering
Install trash racks	2	Install trash rack to catch debris and reduce plugging potential of culvert	Rolling dips	104	Install rolling dip to improve road drainage
Clean CMP	2	Remove debris and/or sediment from CMP inlet	Down spouts	6	Install to protect the outlet fillslope from erosion
Excavate and remove soil	17	Typically fillslope & crossing excavations; excavate and remove a total of 1,392 yds^3	No treatment recommended	13	

A total of 24 critical dips have been recommended to prevent diversions at streams that currently have a diversion potential. A total of 17 culverts are recommended for replacement or for installation at unculverted streams. It is estimated that erosion prevention work will require the excavation of approximately 1,392 yds^3 at 17 sites. A total of 540 yds^3 of 0.5 to 3 foot diameter, mixed and clean rip-rap sized rock will be needed to armor stream crossing fillslopes and armor wet crossings. We have recommended 104 rolling dips be constructed at selected locations along the road, at spacings dictated by the steepness of the road. Twelve (12) ditch relief culverts are recommended to be installed along the Soquel Demonstration State Forest road system.

A variety of road surface treatments (such as installation of a sediment basin, berm removal, insloping and outsloping) have been prescribed to lessen erosion and fine sediment delivery from the road surface during wet winter months. One cross road drain has been recommended to reduce road surface erosion on a "hydrologically connected" spur road adjacent to a stream crossing.

Equipment Needs and Costs

Table 10 lists the expected heavy equipment and labor requirements, by treatment immediacy, to treat all the specific inventoried sites as well as the 4.7 miles of "connected" road bed and ditch. Treatments for the 69 sites identified with future sediment delivery on the Soquel Demonstration State Forest roads will require approximately 282 hours of excavator time and 328 hours of tractor time to complete all prescribed upgrading, erosion control and erosion prevention work (Table 10). Excavator and tractor work is not needed at all the sites that have been recommended for treatment and, likewise, not all the sites will require both a tractor and an excavator.

Table 10. Estimated heavy equipment and labor requirements for treatment of all inventoried sites with future sediment delivery in the Soquel Demonstration State Forest assessment area, Santa Cruz County, California.

Treatment Immediacy	Site (#)	Excavated Volume (yds^3)	Excavator (hrs)	Tractor (hrs)	Dump Trucks (hrs)	Grader (hrs)	Backhoe (hrs)	Labor (hrs)
High, High/Moderate	20	3,339	202	216	69	4	0	81
Moderate, Low/Moderate	37	965	67	99	11	11	7	73
Low	12	311	13	13	4	1	0	26
Total	**69**	**4,615**	**282**	**328**	**84**	**16**	**7**	**180**

Approximately 84 hours of dump truck time has been listed for work along the Demonstration Forest roads for end-hauling excavated spoil from stream crossings and landslides where local disposal sites are not locally available. Approximately 180 hours of labor time is needed for a variety of tasks such as installing new culverts, rock armor, filter fabric, downspouts and other miscellaneous tasks. An additional 17 hours are allocated for mulching and planting activities. A water truck will be required for 155 hours to wet down material during road surface and stream crossing upgrades.

Estimated costs for erosion prevention treatments- Prescribed treatments are divided into two components: a) site specific erosion prevention work identified during the road inventory, and b) control of persistent sources of road surface, ditch and cutbank erosion and associated sediment delivery to streams. The total costs for road-related erosion control at sites with future sediment delivery is estimated at approximately $304,410 for an average cost-effectiveness value of approximately $19.98 per cubic yard of sediment prevented from entering Soquel Creek (Table 11).

Overall site specific erosion prevention work- Equipment needs for site specific erosion prevention work at sites with future sediment delivery are expressed in the database, and summarized in Table 10, as direct excavation times, in hours, to treat all sites. These hourly

estimates include only the time needed to treat each of the sites, and do not include travel time between work sites, times for basic road surface treatments that are not associated with a specific "site," or the time needed for work conferences at each site. These additional times are accumulated as "logistics" and must be added to the work times shown in Table 10 to determine total equipment costs as shown in Table 11. The estimate includes costs for seed and mulch, rock armor, culvert materials, downspouts, filter fabric, as well as rock necessary for rip-rap and road surfacing at rolling dips and other specific locations.

The costs in Table 11 are based on a number of assumptions and estimates, and many of these are included as footnotes to the table. The costs provided are assumed reasonable if work is performed by outside contractors, with no added overhead for contract administration and pre- and post-project surveying. Movement of equipment to and from the site will require the use of low-boy trucks. The majority of treatments listed in this plan are not complex or difficult for equipment operators experienced in road upgrading operations on forest lands. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended treatments conform to guidelines described in "The Handbook for Forest and Ranch Roads" prepared by PWA (1994) for the California Department of Forestry, Natural Resources Conservation Service and the Mendocino County Resource Conservation District. Costs in Table 11 assume that the work in the watershed will be accomplished during two summers work periods using one equipment team.

Table 11 lists a total of 308 hours for "supervision" time for detailed pre-work layout, project planning (coordinating and securing equipment and obtaining plant and mulch materials), on-site equipment operator instruction and supervision, establishing effectiveness monitoring measures, and post-project cost effectiveness analysis and reporting.

Conclusion

The expected benefit of completing the erosion control and erosion prevention planning work lies in the reduction of long term sediment delivery to Soquel Creek and its tributaries, an important salmonid stream system. For this assessment, the majority of the Soquel Demonstration State Forest roads were considered for upgrading. Road upgrading consists of a variety of techniques employed to "storm-proof" a road and prevent unnecessary future erosion and sedimentation. Storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road is capable of withstanding both annual winter rainfall and runoff, as well as a large storm event, without failing or delivering excessive sediment to the stream system. The goal of road upgrading is to strictly minimize the chronic contributions of fine sediment from the road bed, cutbanks and ditches in the Demonstration Forest, as well as to minimize the risk of serious erosion and sediment yield when large magnitude, infrequent storms and floods occur.

Table 11. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on all inventoried sites with future sediment delivery in the Soquel Demonstration Forest assessment area, Santa Cruz County, California.

Cost Category[1]		**Cost Rate[2] ($/hr)**	**Estimated Project Times**			**Total Estimated Costs[5] ($)**
			Treatment[3] (hours)	**Logistics[4] (hours)**	**Total (hours)**	
Move-in; move-out[6] (Low Boy expenses)	Excavator	120	8	-	8	960
	D-6 tractor	120	8	-	8	960
Heavy Equipment requirements for site specific treatments	Excavator	165	246	74	320	52,800
	D-6 tractor	140	224	67	291	40,740
	Dump Truck	75	84	25	109	8,175
	Water truck	90	33	10	43	3,870
Heavy Equipment requirements for road drainage treatments	Excavator	165	36	11	47	7,755
	D-6 tractor	140	104	31	135	18,900
	Grader[7]	100	50	15	65	6,500
	Water truck	90	120	36	156	14,040
Laborers[8]		35	197	59	256	8,960
Rock Costs[9]: (includes trucking for 1,348 yds^3 of road rock and 540 yds^3 of rip-rap sized rock)						75,520
Culvert materials costs (540' of 18", 170' of 24", 240' of 30", 280' of 36", 130' of 42", 130' of 54", 100' of 84", Costs included for couplers, flared inlets and elbows)						41,532
Mulch, seed and planting materials for 1.1 acres of disturbed ground[10]						598
Layout, Coordination, Supervision, and Reporting[11]		75	--	--	308	23,100
Total Estimated Costs						**$304,411**
Potential sediment savings: 15,232 yds^3						
Overall project cost-effectiveness: $19.98 spent per cubic yard saved						

[1]Costs for tools and miscellaneous materials have not been included in this table. Costs for administration and contracting are variable and have not been included.

[2] Costs listed for heavy equipment include operator and fuel. Costs listed are estimates for favorable local private sector equipment rental and labor rates.

[3] Treatment times include all equipment hours expended on excavations and work directly associated with erosion prevention and erosion control at all the sites. An additional 34 hours of grader time have been added for post-treatment road grading.

[4] Logistic times for heavy equipment (30%) include all equipment hours expended for opening access to sites on maintained and abandoned roads, travel time for equipment to move from site-to-site, and conference times with equipment operators at each site to convey treatment prescriptions and strategies. Logistic times for laborers (30%) includes estimated daily travel time to project area.

[5] Total estimated project costs listed are averages based on private sector equipment rental and labor rates.

[6] Lowboy hauling for tractor and excavator, approximately 2 hours round trip for two (2) crews to work areas in the Soquel Demonstration Forest. Costs assume 4 hauls each for two pieces of equipment over the time of the project.

[7] An additional 17 hours of labor time has been added for straw mulch and seeding activities.

[8] An additional 34 hours of grader time have been added for post-treatment road grading.

[9] Volumes for re-rocking the road surface at previously rocked upgrade sites are as follows; 452 yds^3 for outsloping and insloping, 520 yds^3 for rolling dips, 340 yds^3 for new culvert installations, 10 yds^3 for new ditch relief culverts.

[10] Seed costs equal $6/pound for erosion control seed. Seed costs based on 50 lbs. of erosion control seed per acre. Straw costs include 50 bales required per acre at $5 per bale. Sixteen hours of labor are required per acre of straw mulching.

[11] Supervision time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, supervision of labor work and post-project documentation and reporting). Supervision times based on 50% of the total excavator time for site specific treatments plus 50% of the time for road drainage treatments. Plus 1 week prior and 1 week post project implementation.

Appendix A

Appendix A. Typical logistics and costs for a variety of upgrading tasks for the Soquel Creek watershed assessment.

Treatment	Equipment	Cost rate	Application rate and assumptions	Cost[1]
Inslope road and retain ditch	grader with rippers	$110/hr	500 ft/hr for 20' wide road	$220/1,000 ft
Rolling dip	dozer with rippers water truck	$140/hr $ 90/hr	1 hr each for both pieces of equipment (20'-30' wide road)	$230 each
Remove berm	grader	$100/hr	1,000'/hr (no trees on berm or in ditch)	$100/1,000 ft
Clean ditch	grader	$100/hr	1,000'/hr (no trees on berm or in ditch)	$100/1,000 ft
Rock road (1.5" - 2.0" crushed rock)	dump truck spread	$40/yd^3 delivered	4" deep x 20' wide = 244 yds^3 / 1,000 ft road	$9,760/1,000 ft
Install ditch relief culvert (assumes 40' of 18" culvert)	back hoe or excavator + laborer	$85/hr $165/hr $40/hr	8 hours each + $7.75/culvert ft + $16 coupler + $640 labor	$700 - $940 each
Ditch relief culvert removal	back hoe or excavator	$85/hr $165/hr	2 hours each (back hoe) or 1 hr excavator	$165 - $170 each
Critical dip installation	dozer with rippers water truck	$140/hr $ 90/hr	1 hr each for both pieces of equipment (20'-30' wide road)	$230 each
Install flared inlet	labor	$40/hr	4 hours	$160 + materials
Install bridge	engineer design	-	-	$3,500,000 each
Install arched culvert	engineer design	-	-	$100,000 each

Appendix A. Typical logistics and costs for a variety of upgrading tasks for the Soquel Creek watershed assessment.				
Treatment	**Equipment**	**Cost rate**	**Application rate and assumptions**	**Cost[1]**
CMP downspout installation	hand labor (18" - 24") culvert 10- 100' long excavator	$40/hr $165/hr	<40' x 24"-30" = 3 hours labor + 1 hour excavator 40'-60' x 24"-30" = 4 hours labor + 1.5 hours excavator >60' x 24"-30" = 6 hours labor + 2 hours excavator < 40 x 36"-72" = 4 hours + 1.5 hours excavator 40'-60' x 36"-72" = 6 hours labor + 2 hour excavator >60' x 36"-72" = 8 hours labor + 3 hours excavator	$285 + materials $408 + materials $570 + materials $408 + materials $570 + materials $815 + materials
Trench excavation (<8' deep road fill) and install stream crossing culvert and critical culvert	excavator labor traffic control dump truck roller broom pavement cutter cement truck	$165/hr $40/hr $30 $75/hr $50/hr $140/hr $55/hr $95/yd^3	Excavator hours = volume excavated/ excavator production rate + ½ labor time= excavator hours Traffic control = total excavator hours x 2 laborers Dump truck hours = 1 hour dump truck/ 10yds^3 to remove and endhaul spoil Roller hour = 1 hour per site Broom hour = 1 hour per site Pavement cutter hours = 2 hours per site Cement truck cost = $95/yd^3 of backfill volume	-

Appendix A. Typical logistics and costs for a variety of upgrading tasks for the Soquel Creek watershed assessment.

Treatment	Equipment	Cost rate	Application rate and assumptions	Cost[1]
Install critical culvert in excavated crossing	excavator labor	\$165/hr \$40/hr	1 hour + 2 hours labor	\$245 + materials
Ditch relief culvert downspout installation	excavator dump truck labor	\$165/hr \$75/hr \$40/hr	<20' x 18" 2 hours labor 21'-40' x 18" 3 hours labor 41'-60' x 18" 4 hours labor >60' x 18" 6 hours labor <40' x 24" 3 hours labor 41'-60' x 24" 4 hours labor >60' x 24" 6 hours labor	\$80-\$240 + materials \$120-\$240 + materials
Rebar trash rack	labor	\$40/hr	1 hour	\$40 + materials
I-beam trash rack	labor truck welder	\$40/hr \$6/hr \$60/day	5'-40' wide 20 hours labor + truck +\$60/day welder + \$4/foot I-beam	\$996-\$2000 including materials and equipment
Reconstruct fill with rip-rap	excavator dump truck	\$165/hr \$75/hr	10yds^3/hr for 1'-3' rock Dump truck times included in rock costs \$27/yds^3 of rip-rap	\$1920/ 10 yds^3 of 1'-3' rock
Engineer fill with reinforced wall	Engineered design	\$85/ 1ft^2 (face foot)	-	\$8,600-\$7,310,000
Clean CMP	labor	\$40/hr	1 hour	\$40
Armor outboard fill face	excavator dump truck	\$165/hr \$75/hr	Excavator hours= 10yds^3/hr for 1'-3' rock Dump truck times included in rock costs \$40/yd^3 of rip-rap	\$565/ 10yds^3 rip rap placed on fillface
Armor inboard fill face	excavator dump truck	\$165/hr \$75/hr	10yds^3/hr for 1'-3' rock Dump truck times included in rock costs \$27/yds^3 of rip-rap	\$435/ 10yds^3 placed on fillface

Appendix A. Typical logistics and costs for a variety of upgrading tasks for the Soquel Creek watershed assessment.

Treatment	Equipment	Cost rate	Application rate and assumptions	Cost[1]
Add berm	berm machine dump truck labor truck	$65/hr $75/hr $40/hr $6/hr	$24/foot of asphalt berm	$23/foot
Install sediment basin	backhoe Labor	$85/hr $40/hr	1-10 yds^3excavated sediment basin 4 hours backhoe 10 hours labor	$560 each
Paving	Paver	-	$50/ton 150lbs/$ft^2$ pavement is 2-4" thick	0.63/ ft^2
Install berm drain	excavator dump truck labor	$165/hr $75/hr $40/hr	6"-12" flex pipe $7.75/ft $100 flared inlet 5'-20' flex pipe 2 hours labor + 1 hour excavator + 2 hours dump truck 21'-40' flex pipe 4 hours labor + 1 hour excavator + 2 hours dump truck	$395 + materials $475 + materials
Cement truck	cement truck	$95/$yds^3$	10 /yds^3 cement truck	$950 /10$yds^3$ delivered slurry

[1] Costs are variable depending on materials costs, equipment types and rental rates, and operator experience. Culvert cost assumptions (16 gage galvanized cmp): 1" - $7.75/ft; 24" - $10.00/ft; 36" - $15.25/ft; 48" - $20.00/ft; 60" (14 gage) - $31.50/ft. Some other assumptions are listed. Some treatments (e.g., insloping road and cutting the ditch) may be performed for different rates using tractor instead of grader. Logistical costs for supervision and oversight not included in cost

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Evaluation of Road Decommissioning, CDFG Fisheries Restoration Grant Program, 1998 to 2003

submitted to

The California Department of Fish and Game

Contract #P0210559

by

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July, 2005

Evaluation of Road Decommissioning, CDFG Fisheries Restoration Grant Program, 1998 to 2003

Executive Summary

This report presents the results of our investigation, documentation, and analysis of the effectiveness of road decommissioning conducted under the California Department of Fish and Game's (CDFG) Watershed and Fisheries Restoration Grant Program (FRGP). In 2004 Pacific Watershed Associates (PWA), with funding from the California Department of Fish and Game, assessed over 51 miles of road decommissioned between 1998 and 2003 under the Fisheries Restoration Grant Program in northwestern California.

The California Department of Fish and Game, in conjunction with earth scientists and watershed restorationists, has adopted a suite of standard protocols and guidelines for road decommissioning that were developed to ensure thorough and consistent implementation of funded projects and to guarantee these projects accomplish the goals of the restoration grant program. These guidelines cover the most common erosion control and erosion prevention treatments associated with road decommissioning. Typical road decommissioning practices include the removal of all fill and associated drainage structures from stream crossings, excavation of unstable fill from the road prism and landings, and hydrologically disconnecting the road from the stream network by either decompacting and cross-draining the road surface, or reshaping the road bed.

The goal of the assessment was to determine the effectiveness of the current road decommissioning restoration techniques being employed under the FRGP. Specifically, we documented the current conditions along a modified stratified random sample of the roads that had been decommissioned under the CDFG FRGP between 1998 and 2003, and evaluated them in regards to achieving CDFG's goal of sediment reduction to anadromous fisheries streams. Quantitative site data was colleted to identify the sources and causes of post-decommissioning erosion and sediment delivery, and to differentiate between sediment sources caused by correctable implementation practices and those that were deemed "natural" and less controllable or avoidable. By identifying the most common restoration mistakes we have also developed a suite of recommendations to improve current decommissioning protocols and practices.

We evaluated 51 miles of decommissioned road (33% of the total FRGP decommissioned road length) and 449 treated sites in northwestern California between the Oregon border and the northern San Francisco Bay Area. The sample included 275 stream crossings, 111 landslides, and 63 "other" (road drainage) sites. Fifty-eight (58) percent of all the decommissioned sites we evaluated did not meet one or more of the generally accepted CDFG decommissioning protocols or standards (CDFG, 2004).

In the one-to-six year period following decommissioning, the average post-decommissioning sediment delivery for a decommissioned stream crossing was approximately 5% of the original pre-treatment average fill volume of 769 yds^3. This is consistent with other reported results. The average post-decommissioning unit sediment delivery (i.e., sediment delivery per site) for all stream crossings was 34 yd^3/site, for all landslide sites it was 1.6 yd^3/site, and for all the "other" sites it was 22 yd^3/site. There was significant variability about these mean values, but the variability appears more due to variations in site conditions and operator performance than in the length of time that has elapsed, and the storms that have occurred, since decommissioning.

Stream crossings are the most common site specific implementation targets for road decommissioning in the Fisheries Restoration Grant Program. They comprised 61% of the evaluated sites and accounted for 85% of the documented post-decommissioning sediment delivery. Fifty seven (57) percent of the inventoried stream crossings did not meet one or more of the generally accepted CDFG decommissioning protocols or standards. The average delivery volume for a stream crossing that met all CDFG protocols was 23 yd^3/site and the average delivery volume for a stream crossing that did not meet one or more of the accepted CDFG decommissioning protocols or standards was 42 yd^3/site. Post-treatment erosion and sediment delivery data from inventoried, decommissioned stream crossings strongly support the use of current CDFG standardized practices for road decommissioning.

By far the most common problem at decommissioned stream crossing sites was unexcavated fill. Channel incision, surface erosion and slumping/debris slides were the most common post-implementation erosion features associated with unexcavated fill left in the decommissioned stream crossings. Combined they make up 88% of the identified erosion sites and 91% of the post-decommissioning sediment delivery. Of the 9,322 yds^3 of measured sediment delivery at decommissioned stream crossings, 5,598 yds^3 or 60% was due to natural or relatively unavoidable causes and 3,496 yds^3 (40%) was due to operator or supervision causes. Sixty nine percent (69%) of the avoidable operator-caused erosion features were directly attributed to leaving unexcavated fill within the stream crossing.

Landslides and "other" (road drainage) sites made up 39% of our evaluated sites. Of the 111 inventoried landslide sites, 85% met all CDFG protocols and standards, and of the 63 "other" sites, 81% met all of the CDFG protocols and standards. Landslide treatments used on decommissioned roads were found to be effective in reducing the potential for failure and subsequent delivery of sediment from fillslope failures. Only 185 yds^3 of sediment delivery has occurred from all decommissioned landslides sites. The most common implementation problem associated with "other" sites was unexcavated, erodible and/or unstable fill that became saturated and failed (or eroded). Although there were only 40 inventoried "other" sites of post-decommissioning erosion, they accounted for 1,405 yds^3 of sediment delivery. The fact that many of these sites experienced significant post-decommissioning erosion and sediment delivery suggests the practice of routinely dipping (rather than excavating) swales at spring locations should be revised in favor of a more thorough treatment.

We evaluated the CDFG protocols and standards for road decommissioning based on whether or not the protocols were met, and analyzed the resulting volumes of post-decommissioning erosion and sediment delivery. Based on this evaluation we conclude: 1) The CDFG decommissioning protocols for stream crossings are effective but are not being uniformly followed at all sites; 2) The CDFG decommissioning protocols for landslides are effective and are being followed; 3) The CDFG decommissioning protocols for "other" sites are not effective and are either too vague or are not clearly understood by restorationists, and 4) The CDFG decommissioning protocols for road drainage are effective and being employed correctly. Our observations suggest that continued improvements in problem recognition, prescription development and implementation practices can further reduce post-decommissioning sediment delivery and improve the cost-effectiveness of the decommissioning work that is undertaken within the Fisheries Restoration Grant Program.

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Evaluation of Road Decommissioning, CDFG Fisheries Restoration Grant Program, 1998 to 2003

1.0 Introduction

This report presents the results of our investigation, documentation, and analysis of the effectiveness of road decommissioning conducted under the California Department of Fish and Game (CDFG) Fisheries Restoration Grant Program (FRGP). In 2004 Pacific Watershed Associates, with funding from the California Department of Fish and Game, assessed over 51 miles of road decommissioned under the Fisheries Restoration Grant Program in northwestern California between 1998 and 2003 (Map 1 Appendix A).

1.1 Purpose

The goal of the assessment was to determine the effectiveness of current road decommissioning restoration techniques being employed by CDFG in the Fisheries Restoration Grant Program. We documented the current conditions of a sample of roads decommissioned under the CDFG SB271 grant program between 1998 and 2003 and evaluated them in regards to: 1) achieving CDFG's goal of a significant reduction in long-term sediment delivery (and risk of future sediment delivery) to anadromous fisheries streams, and 2) short-term erosion and sediment delivery from the decommissioned roads.

The purpose of the inventory and analysis was to: 1) identify how much decommissioning work had been performed since the beginning of the FRGP, 2) determine which decommissioning treatment techniques have been routinely employed, 3) evaluate the short-term and long-term performance of decommissioned roads (both within the FRGP and in comparison to similar work done elsewhere on the north coast), 4) evaluate the benefits and impacts associated with road closure, and 5) identify adaptive management actions, if any, that could be employed to improve the outcome of future decommissioning work. In the analysis, we identified the most common sources of post-decommissioning sediment delivery associated with road decommissioning, including those resulting from implementation actions as well as those resulting from site variables that are largely unavoidable or unpredictable. Finally, we have provided a suite of recommendations aimed at improving the long-term effectiveness and reducing the short-term impacts of road decommissioning projects.

2.0 Organization of Report

This report is divided into 10 sections, the first 5 sections review the background and geologic setting of the CDFG road decommissioning monitoring study area. Section 6 focuses on the methodology used to inventory and assess the effectiveness (and impacts) of road decommissioning funded under the Fisheries Restoration Grant Program. Section 7 reviews the results of the study, including both the magnitude and causes of post-decommissioning erosion and sediment delivery. Section 8 discusses the results of the study in detail, and Section 9 offers conclusions and recommendations based on the study results. Section 10 contains references cited in this report

3.0 Background

A significant component of the California Department of Fish and Game's (CDFG) Fisheries Restoration Grant Program has been the treatment of anthropogenic (human caused) erosion and sediment delivery to anadromous streams where sediment has been identified as a threat to existing fish habitat or a significant limiting factor to fisheries recovery. Much of the early efforts (and funding) of this program have been focused on the identification and treatment of road-related sediment sources, because these are both significant and readily treatable (CDFG, 2004). Roads are targeted for treatment first because they often represent a disproportionate source of accelerated erosion and sediment delivery in managed wildland watersheds, and secondly, because they can be effectively treated to eliminate most sources of episodic and chronic sediment delivery (Weaver and Hagans, 1994).

In watersheds where forest, ranch or rural road systems represent a serious threat or source of ongoing sediment delivery, erosion prevention work can be accomplished to substantially reduce sediment inputs. One of the most common erosion prevention and erosion control treatments is "road decommissioning" (Weaver and Hagans, 1994; Switalski, 2004; Luce et al., 2001; Madej, 2001). Road decommissioning is employed to reduce or eliminate the erosional threat posed by a road. Decommissioning typically consists of: 1) complete stream crossing excavation, 2) excavation or stabilization or road-related landslides, and 3) permanently improving road draining through road decompaction and installation of cross-drains. When these practices are performed thoroughly and correctly they are thought to be highly effective in reducing both short-term and long-term sediment production and delivery from the road alignment. Because the treatments can also be relatively costly it is important to employ the most cost-effective practices and techniques, and to identify where improved practices can be employed to reduce costs and improve effectiveness (Weaver and Sonnevil, 1984; Weaver and Hagans, 2004).

One of the key restoration goals of road decommissioning is to minimize both short-term and long-term sediment delivery from roads to the watershed's stream system. This sediment delivery occurs by two general processes: 1) episodic erosion and sediment delivery that occurs during periods of storm runoff and flooding, and 2) chronic erosion that occurs whenever there is sufficient precipitation to result in surface runoff to stream channels. Road decommissioning is generally thought to have a significant long-term beneficial effect in reducing both these sediment production and sediment delivery mechanisms.

In the long-term, the potential volume of erosion and sediment delivery originating from a decommissioned road is much less than from a comparable road that is still intact (Weaver and Hagans 1994, Madej 2001). At the same time, it is also recognized that decommissioning treatments may result in short-term increases in erosion and sediment delivery from bare soil areas that are created during the decommissioning process. Bare soils created during decommissioning generate elevated levels of surface erosion until they revegetate and exhumed stream channels (within excavated stream crossings) experience a characteristic period of adjustment until they develop a stable longitudinal profile and cross section (Klein 2003, Madej 2001). Treating road surface runoff by reducing, spreading and dispersing surface runoff and treating potential road fill failures by direct excavation has been shown here and elsewhere to be effective at controlling both short-term and long-term post-decommissioning erosion as well as reducing (or eliminating) the risk of episodic sediment delivery from potential road-related sediment sources (Weaver and Hagans 1994).

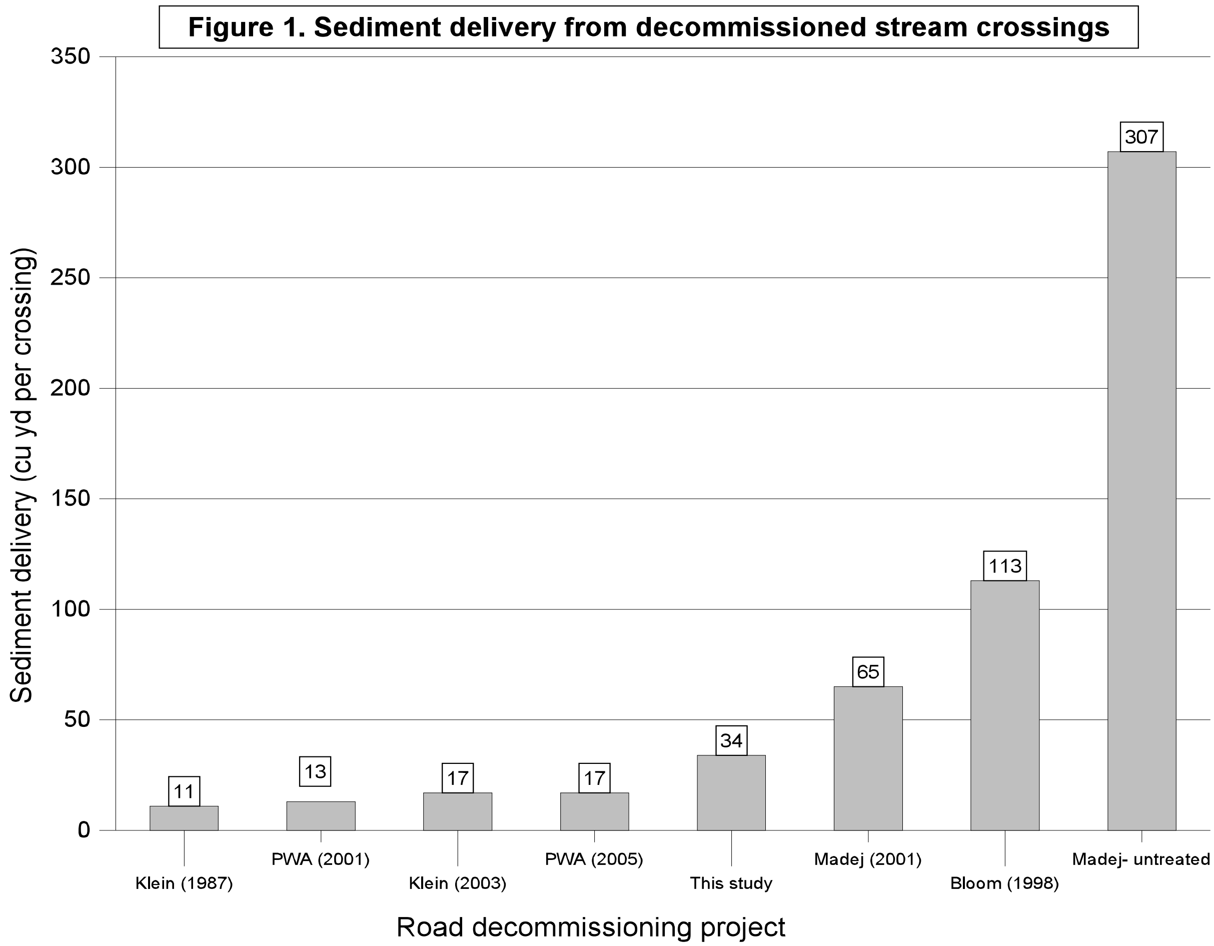
Decommissioning stream crossings along roads represents a different and more challenging type of erosion prevention treatment than controlling surface erosion or treating potentially unstable fillslopes. When they are intact, stream crossings can erode and deliver sediment through a number of erosional mechanisms. These chronic sources of sediment delivery include: 1) runoff from approaching road segments, ditches and cutbanks (termed “hydrologic connectivity”), 2) culvert outlet erosion, 3) gullying of the fill slopes (from direct runoff), and 4) soil piping (especially with Humboldt log crossings). Stream crossings can also erode during storm events and deliver sediment by: 1) culvert plugging and stream diversion, 2) culvert plugging and overtopping (washout), and 3) mass wasting of unstable stream crossing fill slopes. Complete failure (washout) of an untreated stream crossing can result in loss of the entire road fill.

4.0 Previous Studies

Results from several local studies on post-excavation road and stream crossing erosion and treatment effectiveness have been reported by Klein, 1987; Klein, 2004; PWA, 2005; Bloom, 1998; and Madej, 2001. In these studies, a common measure of the effectiveness of stream crossing decommissioning has been the volume of erosion and sediment delivery that occurs in the post-decommissioning period: the lower the delivery volumes, the more successful the decommissioning. This is sometimes represented as the volume of sediment delivery per excavated stream crossing, and other times as the ratio of measured post-decommissioning sediment delivery to the calculated “washout” volume of the unexcavated (pre-decommissioning) stream crossing fill.

Figure 1 depicts the post-decommissioning stream crossing erosion measurements that have been developed for sites within several Northern California watersheds, including volume estimates from decommissioned stream crossings from the current regional study (PWA, this study). PWA (2001, unpublished) sampled 20 excavated stream crossings in the Rowdy Creek watershed following the first full winter season and identified both channel erosion and mass wasting as important sediment delivery processes (Figure 1). Similarly, preliminary data is also included from a study of road decommissioning in the Elk River watershed (PWA, 2005). In that study, sediment delivery from 86 decommissioned sites, including 52 stream crossings, averaged 11 yds^3/site, with stream crossings generating an average of 17 yds^3/crossing (Figure 1).

Klein (1987) measured erosion from stream channel incision and bank erosion processes on relatively small stream crossings excavated in the early 1980s in Redwood National Park. Bloom (1998) inventoried 86 excavated stream crossings treated between 1980 and 1990 in the Bridge Creek watershed. Her study identified both channel adjustments and side slope failures as important sediment production mechanisms. Both authors have indicated that most post-decommission erosion at excavated stream crossings occurs during the first few years following decommissioning.



Madej (2001) expanded on Bloom's analysis and inventoried a total of 207 crossings and their associated road segments, including the 86 crossings reported by Bloom. The 207 inventoried stream crossings had been decommissioned over a period of 17 years from 1980 to 1997. The average stream crossing fill volume, before they were decommissioned, was 1,390 yds^3/crossing. However, because of the likelihood of stream diversions, Madej estimated that the potential erosion volume, had they not been excavated, would have been at least four times this volume. Most crossings produced very little erosion volume after they were decommissioned: 20% of the crossings produced 73% of the post-decommissioning erosion. At the time of the inventory, the average measured sediment delivery was approximately 66 yds^3/crossing, or about 4.8% of the pre-excavation stream crossing volume. Stream power and crossing size (volume) were found to be significant variables explaining 20% of post-decommissioning erosion at the decommissioned crossings, but a great deal of unexplained variability still existed. Madej (2001) attributed this to local site conditions.

Klein (2003) monitored and evaluated 18 of 65 decommissioned stream crossings that were excavated in 2002 in the upper Mattole watershed of Northern California. He set permanent photo points, measured post-decommissioning erosion, and monitored a select number of sites for winter storm flow turbidity during the first winter after treatment. First year sediment delivery was estimated at 15.5 yds^3/crossing, with channel scour accounting for 88% of the erosion. Headcutting of fine grained valley fill deposits upstream of two excavated crossings accounted for 16% of the total measured sediment delivery. Klein theorized that the amount of channel scour should be directly related to channel slope, but did not find this to be the case. Other site conditions were not investigated. Mass wasting of the channel sideslope accounted for only 13% of total erosion from the decommissioned crossings. Mass wasting on one crossing delivered 58% of all the measured bank slump volume, while 10 of the crossings had no sideslope failures at all.

Overall, the decommission projects show a relatively wide volumetric range of sediment delivery values from the post-treatment period, especially at sites of excavated stream crossings (Figure 1). Some of the variability in sediment delivery is likely a function of uncontrollable environmental variables, including the frequency and magnitude of storms that each site has experienced over the time period since the decommissioning work was undertaken. Some of the variability is also likely due to site variables (springs, unstable soils, etc) that might not be recognized at the time the work is undertaken (PWA, this study). However, observations and field inventory data also suggests that a portion of the variability in post-treatment erosion and sediment delivery is likely the result of an uneven application of decommissioning techniques, including poor site evaluation, improper prescription development and/or poor implementation practices. Although short-term impacts are likely to occur, the long-term erosional impacts of abandoning roads and leaving sites untreated may be dramatically higher (e.g., Figure 1).

In the current road decommissioning study we measured erosion and sediment delivery from other discrete sediment sources along the road, including landslides and gullies. Madej (2001) and PWA (2005) are the only other studies that have reported sediment delivery from road reaches and other post-decommissioning sediment sources along decommissioned roads. Madej (2001) found that most road reaches performed well and produced very little sediment. Approximately 20% of the road length produced 99% of the total erosion from treated roads, exclusive of stream crossings. Roughly 77% of the road reach sediment loss attributed to fillslope landslides and sediment delivery was estimated at 74% of eroded sediment. Unit sediment delivery from decommissioned road reaches, exclusive of stream crossings, was 1,010 yds^3/mi. Roads in lower hillslope positions had post-decommissioning sediment delivery rates over 50 times higher than those in upper slope positions.

Effective road decommissioning can provide significant benefit to a watershed's fisheries and aquatic resources by reducing anthropogenic sediment production and delivery (Leroy, 2005; Switalski, et al., 2004; Klein, 2003; PWA, in press; Luce et al., 2001; Harr and Nichols, 1993). Decommissioning can also have short-term impacts as sediment is released by erosion and channel adjustments in the immediate post-decommissioning period (Switalski, et al., 2004; Castro, 2003; Klein, 2003). The results of retrospective studies, including the present study, point clearly to certain "best management" decommissioning techniques that can be employed to minimize post-treatment channel adjustments and sediment delivery (PWA, 2004; PWA, in press; Castro, 2003; Luce, 1997; Madej, 2001; Klein, 2003; Weaver and Hagans, 1994, 1999; Weaver, et al., 1987).

Short-term effectiveness may be measured by the degree of impact (sediment delivery) caused by the decommissioning. A high quality decommissioning project should result in a minimum amount of post-decommissioning sediment delivery and associated impacts. The long-term effectiveness of road decommissioning is more correctly measured by the prevention of episodic and chronic road-related sediment delivery that would have occurred had the road not been decommissioned (Figure 1; Madej, 2001). It consists of two parts: problem recognition and effective treatment. Thus, both site variables and implementation techniques (proper recognition and treatment) can have substantial roles in determining the ultimate short-term and long-term effectiveness of road decommissioning.

Current observations and data on decommissioning work performed within and outside the CDFG Restoration Grant Program suggest that erosion and sediment delivery along decommissioned roads, using current practices and techniques, is expected and largely unavoidable, and can also be highly variable. For example, in the first year after road decommissioning post-excavation channel and side slope adjustments at 22 excavated stream crossings in the Little River watershed (a non-FRGP project) delivered 260 yd^3, or 4% of the predicted yield (washout volume) prior to treatment (PWA, unpublished report). The range in sediment delivery from individual decommissioned stream crossings varied from 0.2 to 52.2 yds^3 per site. Virtually all road decommissioning projects for which monitoring results have been reported indicate a certain level of short-term post-treatment erosion and sediment delivery, as well as a substantial long-term sediment savings (Figure 1).

The variability of post-treatment erosion and sediment delivery is sometimes large. Thus, although some post-decommissioning erosion and sediment delivery occurs at virtually all excavated stream crossings, most sites typically exhibit very little erosion (Klein, 2003). Often a few of the treated sites (especially excavated stream crossings) often generate the bulk of the eroded sediment (Madej, 2001; Klein, 2003); PWA, 2005). Likewise, in the current study, we have also found a substantial range in regional erosion and sediment delivery volumes following road decommissioning, some of which can be attributed to uncontrollable site variables (such as geologic substrate and soils) and some of which is the result of implementation practices (Figure 1).

Even in comparatively "refined" road decommissioning programs (e.g., Redwood National Park's long-established watershed restoration program) there is a relatively wide volumetric range of erosion and sediment delivery values that have been documented in the post-treatment period, especially at sites of excavated stream crossings (Figure 1)(Madej, 2001; Bloom, 1998). Some of the variability in sediment delivery is likely a function of the environmental factors and the size of storms that each site has experienced over the time period since the decommissioning work was undertaken. Although most of the erosion appears to occur in the first several years following decommissioning (Klein, 1987; 2003; Bloom, 1998), longer term delivery may approach twice the first year sediment delivery volume (Klein, 2003). Some of the variability is also likely due to site variables (springs, unstable soils, etc) that might or might not be recognized at the time the work is undertaken. However, observations also suggest that a portion of the variability in post-treatment erosion and sediment delivery, here and elsewhere, is likely the result of an uneven application of decommissioning techniques, including poor site evaluation, improper prescription development and/or improper implementation practices.

5.0 Geologic Setting

Northern California lies within a unique geologic setting and contains a complex and varied suite of rock and soil types. The portion of Northwestern California that comprises the study area, between San Francisco and the Oregon border, lies within the tectonically active translational and compressional margin of the North American plate. Since the Mesozoic Era, the geologic development of Northern California has been dominated by plate convergence between the Pacific and North American lithospheric plates. During the last 300 million years, subduction and the resulting continental accretion have welded a broad complex of highly deformed oceanic rocks to the western margin of the North American plate. These accreted rocks now comprise the Franciscan complex and the Klamath terrane, which constitute the lithologic basement of the Northcoast region.

Throughout the latest geologic period, major uplift of the coast range and erosional stripping of the regionally extensive forearc sediments has resulted, in part, from the northward migration of the Mendocino triple junction and continued subduction of the Juan de Fuca oceanic plate beneath North America. In conjunction with the northward migration of the triple junction, the stress field north of San Francisco to Cape Mendocino shifted from a compressional faulting regime (subduction), to a translational (strike-slip) faulting regime. This translational tectonic regime is now rafting large sections of the coast ranges steadily northwest along the San Andreas, Hayward/Mayacama, and Calaveras/ Bartlet Springs Fault zones. These fault systems are currently dissecting the already pulverized terranes of the Franciscan formation and are controlling the structural grain of Northwest California.

The youngest Tertiary and Quaternary marine and non-marine sediments within the region unconformably overlie the Franciscan and Klamath basement rocks on the western edge of Northern California. These sediments outcrop discontinuously within the entire study area and typically consist of partially to non-lithified sandstone, siltstone, and mudstone with minor conglomerate. Other noteworthy geologic units encountered in this study include weathered and unweathered granitic-type rocks encountered in the northern portion of the study area and multiple sites, especially in coastal regions, blanketed by deep colluvium.

Each rock type we encountered in this study has a unique erosional susceptibility primarily driven by its lithology, conditions of formation, and degree of weathering. The many different rock types encountered in this study translates to varying degrees of erosional vulnerability from one geographic location to another. See (Appendix A) for detailed descriptions of the geologic units and their erosional susceptibility.

6.0 Methods

6.1 Study Approach

The study involved revisiting and assessing (inventorying) treated road reaches and sites on selected roads decommissioned with funding under the CDFG Fisheries Restoration Grant Program. The assessment involved the following work elements:

1) Identification of all roads decommissioned with funding from the CDFG FRGP (Sampling Strategy, below).

2) Conduct a focused literature review for comparable studies evaluating the practices, benefits and impacts from road decommissioning to set the context for the findings of this study. The purpose of the review was to identify the range of expected erosion and sediment delivery associated with standard decommissioning practices, and to evaluate the importance of site specific variables and decommissioning techniques.

3) Develop one or more data forms and new database designed to include: a) pre-treatment (original data), if any, including data pertaining to existing and potential sediment sources and original treatment prescriptions, b) "as built" conditions, c) post-decommissioning erosion inventory data, and d) inventory data from new erosion sites that were not previously inventoried or implemented (i.e., missed sites).

4) Conduct a field inventory of selected decommissioned roads to: a) identify the nature and magnitude of post decommissioning sources of erosion and sediment delivery at each site and/or road reach, b) identify the causes of sediment delivery from decommissioned road reaches and determine which problems could have been identified and avoided, c) identify the most common factors associated with sediment delivery from channel side slopes, channel incision, stream bank erosion, head-cutting, and any other identifiable sediment sources at each excavated crossing, and d) evaluate those factors that appear to have been caused or been associated with measurable erosion by breaking them into implementation/operator causes and "natural" or "unavoidable" causes. .

6.2 Sampling Strategy

The overall process of site selection consisted of multiple steps designed to identify representative decommissioned roads from a wide variety of geologic settings, climatic conditions, and diverse ownerships within the study area.

6.2.1 Data acquisition

As a first step we collected all of the available CDFG FRGP implementation proposals (original grant applications), completed assessment reports, and final implementation reports that were available. The reports were cataloged and reviewed for applicability to this project and for data that described pre-decommissioning, proposed treatment and post-decommissioned conditions. The quality of the data in the documents varied.

Many of the proposals and final project reports consisted of both road upgrading and road decommissioning activities. Each project and report was evaluated to identify decommissioning elements. Road segments and treatment sites were then plotted on a GIS base-map to show their regional distribution relative to topography, geology, hydrology and ownership.

6.2.2 Geographic Segmentation

The decommissioned roads were subdivided into 11 different geographic areas (Map 2) based on the spatial distribution of decommissioning sites, the dominant local geologic bedrock type, ownerships, and available precipitation data (Appendix B: Maps 1 and 2 - for average annual precipitation data and geographic areas, respectively). This was done to assure that a representative sample was selected from most of the dominant bedrock types and land management styles (public forestry, private forestry, ranching, etc.) encountered in northwest California and to encompass a variety of climatic conditions.

6.2.3 Sampling Strategy

Because the total number of decommissioned sites was more than could be evaluated within the project scope, a sampling strategy was developed to randomly distribute the targeted evaluation sites among the geographic regions. This sampling strategy was designed to target road decommissioning projects, and sites within the projects, among the eleven geographic regions. The number of sites sampled in each region is proportional to the total number of treated sites within each region.

Step 1) Calculate the number of miles to inventory per geographic area (Table 1).

Table 1. Sample allocations by geographic area based on a 64 mile sample size

Geographic area	Number of decommissioned sites	Length of decommissioned road (mi)	% of miles	Length to inventory based on 64 mile project scope (mi)	Target inventory length (mi)
1	124	15.57	10	6.52	7
2	64	23.61	15	9.89	10
3	198	12.5	8	5.23	5
5	114	7.74	5	3.24	3
6	243	38.16	25	15.98	15
7	202	29.4	19	12.31	12
8	145	20.93	14	8.76	9
9	12	1.1	1	0.46	1
10	11	1	1	0.42	1
11	29	2.85	2	1.19	1
Totals	1142	152.86	100	64	64

1-a) Using assumptions regarding the average number of decommissioned sites per mile, travel times to the various decommissioned roads, and the average expected rate of assessment, we calculated that up to 64 of 153 miles of road (42%) decommissioned under the FRGP between 1998 and 2003 could be inventoried and analyzed for the project.

1-b) We calculated the total number of known sites, and total reported decommissioned miles of road in each geographic area using the completed assessment reports and implementation proposals. Using this information we calculated each geographic area's total known road miles decommissioned under the FRGP.

1-c) We proportioned the number of miles to inventory per geographic region calculated as a percent of the total known decommissioned miles based on a 64 mile inventory.

1-d) The final results (far right column) are the targeted number of miles proposed to be inventoried per geographic region (Table 1).

Step 2) Calculate the number of miles, per landowner type, to be assessed in all of the geographic regions.

2-a) From the reports and proposals we subdivided each geographic area into one of five landowner types (public, public park, private industrial, small private, and ranch) and determined the number of miles from each type that was represented in any given geographic area. We also calculated the percent of the total that each landowner type represented for that geographic area.

2-b) From this data we extracted a sample size for each landowner type in each geographic area.

Step 3) Determine which road segments to inventory and assess in each geographic area.

3-a) We plotted all the roads by geographic area and landowner type, divided them into segments of equal length, and assigned each segment a unique number.

3-b) We then used a random number generator to select segments of road to be inventoried in the field until the sample size target (Table 1) for each landowner type in each geographic region was reached.

Step 4) Landowner contact and road access limitations.

4-a) We contacted the landowners for each decommissioned road segment that had been selected for evaluation to secure permission for access and to determine the feasibility of accessing the desired road segment.

4-b) We re-used this protocol to re-select road segments if the landowner could not be reached or if access was unavailable due to physical constraints.

Step 5) Table 2 shows the final road segment sample allocations for the decommissioning monitoring project. The length of road correlates to the actual road length measured in the field.

6.3 Data forms

Three (3) different data forms were used in the field inventory to record all the pertinent information necessary to evaluate the effectiveness of road decommissioning practices.

Decommissioning Site Data Form - The Decommissioning Site Data Form (Appendices C, D) was designed to allow collection of detailed information pertaining to all treated sites. Treated sites include those sites that were inventoried as part of the original (pre-decommissioning) sediment source inventory, and treated sites that were not recognized in the original inventory but that were treated by the heavy equipment during decommissioning operations. Sites that were treated but not part of the original inventories had either been missed in the original sediment source field inventory or had developed signs of failure between the time of the original inventory and treatment implementation. Detailed information was collected regarding

Table 2. Inventoried decommissioned roads by geographic area and road name, CDFG decommissioning monitoring study

Geographic Area	Watershed	Road name	Road Length (mi)	Year of Decom	Pre-dominant Geology	Treated site type (#)				Post decom erosion (yds^3)	Post decom delivery (yds^3)	Unit sediment delivery (yds^3/mi)
						Stream crossings	Land-slides	Other	Total			
1	Rowdy Creek	S1110	0.86	2001	KJf	3	0	0	3	56	43	50
1	Rowdy Creek	S1130	0.38	2001	KJf	2	2	0	4	27	18	47
1	Rowdy Creek	S1200E	0.16	2001	KJf	1	0	0	1	250	250	1,563
1	Rowdy Creek	S1250	0.27	2002	KJf	4	0	0	4	247	242	896
1	Rowdy Creek	R1020	0.52	2001	KJf	5	0	0	5	56	44	85
1	South Fork Smith River	14N39A	1.76	2000	J	3	0	6	9	81	79	45
1	South Fork Smith River	16N02K	0.96	2000	J	3	0	2	5	86	86	90
1	Blue Creek	B-920	0.24	2002	J	3	2	1	6	171	170	708
1	Blue Creek	B-921	0.82	2002	J	5	1	5	11	34	33	40
1	Blue Creek	B-922-A	0.14	2001	J	2	0	0	2	16	16	114
1	Blue Creek	B-922-C	0.38	2001	J	3	1	0	4	24	24	63
1	Blue Creek	B-922-D	0.48	2001	J	1	0	2	3	15	15	31
Subtotal			**6.97**			**35**	**6**	**16**	**57**	**1,063**	**1,020**	**146**
2	Salmon River	Steinacher Road	4.23	1999	grMz	25	0	1	26	3,248	3,087	730
2	Walker Creek	46N63	3.09	2001	grMz	5	0	5	10	3,130	1,237	400
2	Walker Creek	46N61A	2.32	2001	Pz	9	2	3	14	210	178	77
Subtotal			**9.64**			**39**	**2**	**9**	**50**	**6,588**	**4,502**	**467**
3	Little River	M200-2	0.89	2001	KJf	8	16	4	28	258	213	239
3	Little River	V-1-3	0.76	2002	KJf	5	7	0	12	65	28	37
3	Little River	V-4-2	0.28	2002	KJf	3	4	1	8	28	23	82
3	Little River	X-9	0.57	2001	KJf	5	5	1	11	540	186	326
3	Redwood Creek	1050	0.24	2002	KJfs	1	0	0	1	11	8	33
3	Redwood Creek	1300	1.19	2002	KJfs	4	10	1	15	39	39	33
3	Redwood Creek	1311	0.51	2003	KJfs	3	2	0	5	49	46	51
3	Redwood Ck	1312	0.55	2002	KJfs	1	2	0	3	77	77	140
Subtotal			**4.99**			**30**	**46**	**7**	**83**	**1,067**	**620**	**124**

Table 2. Inventoried decommissioned roads by geographic area and road name, CDFG decommissioning monitoring study

Geographic Area	Watershed	Road name	Road Length (mi)	Year of Decom	Pre-dominant Geology	Treated site type (#)				Post decom erosion (yds^3)	Post decom delivery (yds^3)	Unit sediment delivery (yds^3/mi)
						Stream crossings	Land-slides	Other	Total			
4	Redwood Creek	4N09	1.06	2001	KJf	3	0	0	3	9	9	8
Subtotal			**1.06**			**3**	**0**	**0**	**3**	**9**	**9**	**8**
5	Freshwater Creek	X65.5051	1.02	1998	QTWu	4	3	5	12	144	111	109
5	Freshwater Creek	X492510	0.72	1998	QTWu	3	6	0	9	849	281	390
5	Freshwater Creek	X86	1.45	1998	QTWu	8	5	2	15	1,090	519	358
5	Salmon Creek	Road 3	0.44	2000	QTWu	2	1	1	4	534	27	61
5	Salmon Creek	Old 1000	1.34	2001	QTWu	6	8	2	16	76	70	52
Subtotal			**4.97**			**23**	**23**	**10**	**56**	**2,693**	**1,008**	**203**
6	Bull Creek	Preacher Gulch 2	1.73	1999	Ty	9	1	2	12	99	90	52
6	Bull Creek	South Prairie 2	1.83	1999	Ty	5	0	2	7	543	349	191
6	Bull Creek	Bull creek spur	3.81	2000	Ty	32	2	2	36	2,292	1,070	281
6	Bull Creek	Mill West 1	0.93	2002	Ty	7	0	1	8	155	153	165
6	Bull Creek	Mill West 6	1.49	2002	Ty	14	0	2	16	128	111	74
6	Bull Creek	Mill East 1	1.16	2001	Ty	9	0	1	10	82	80	69
6	Bull Creek	Mill East 8	1.28	2001	Ty	5	0	0	5	44	42	33
Subtotal			**12.23**			**81**	**3**	**10**	**94**	**3,343**	**1,895**	**155**
7	Upper Mattole River	Road 56	0.34	2003	KJf	9	3	1	13	82	82	241
7	Upper Mattole River	Road 57	0.4	2003	KJf	3	2	0	5	25	25	63
7	Upper Mattole River	Road 19	0.16	2003	KJf	1	3	0	4	5	5	31
7	Upper Mattole River	Road 19 spur A	0.05	2003	KJf	2	0	0	2	2	2	40
7	Mudd Creek	Mudd Creek 2	0.85	1999	KJf	9	0	0	9	54	41	48
Subtotal			**1.8**			**24**	**8**	**1**	**33**	**168**	**155**	**86**

Table 2. Inventoried decommissioned roads by geographic area and road name, CDFG decommissioning monitoring study

Geographic Area	Watershed	Road name	Road Length (mi)	Year of Decom	Pre-dominant Geology	Treated site type (#)				Post decom erosion (yds^3)	Post decom delivery (yds^3)	Unit sediment delivery (yds^3/mi)
						Stream crossings	Land-slides	Other	Total			
8	Schooner Gulch	E-019	0.56	2000	Qm	2	2	0	4	107	31	55
8	South Fork Garcia	G-005-03	1.92	2000	KJf	4	3	1	8	63	62	32
8	South Fork Garcia	G-005-01	0.56	2000	KJf	5	5	0	10	444	436	779
8	South Fork Garcia	Q LINE	1.20	2000	KJfco	4	3	0	7	585	395	329
8	South Branch NF Navarro	AR-001	1.00	2001	KJfco	3	4	4	11	134	130	130
8	Little North Fork Navarro	LNF Navarro 4	1.73	2001	KJfco	6	5	1	12	148	114	66
Subtotal			**6.97**			**24**	**22**	**6**	**52**	**1,481**	**1,168**	**168**
9	East Austin Creek	Lower walk road	0.70	2001	KJfm	6	1	2	9	38	37	53
Subtotal			**0.70**			**6**	**1**	**2**	**9**	**38**	**37**	**53**
10	Lagunitas Creek	Shafter Knoll	0.75	2002	KJf	5	0	2	7	43	39	52
Subtotal			**0.75**			**5**	**0**	**2**	**7**	**43**	**39**	**52**
11	South Fork Trinity River	28N83	0.52	2002	KJfs	3	0	0	3	28	28	54
11	South Fork Trinity River	27N25B	0.51	2002	KJfs	2	0	0	2	442	431	845
Subtotal			**1.03**			**5**	**0**	**0**	**5**	**470**	**459**	**446**
TOTALS			**51.11**			**275**	**111**	**63**	**449**	**16,963**	**10,912**	**214**

each treated site type. Site types include stream crossings, landslides and "other" sites. "Other" sites generally consisted of ditch relief culverts, springs and gullies that were derived from road surface runoff.

Information collected on the Decommissioning Site Data Form consisted of general site information including site number, previous (original) site number, road name, watershed, contractor, and general bedrock geology. Attempts were made to locate all sites that had originally been mapped in the field, and to then evaluate the decommissioning treatments that were applied. In addition, the data form included fields for detailed information pertaining to each treated site type: stream crossings, landslides and "other" sites. Treated stream crossing information included general stream characteristics, presence or absence of rock armor, location of excavated spoils, excavated channel information, including excavated channel length, grade (%), excavated channel complexity, and channel bed materials. In addition, detailed information was collected on stream crossing side slopes, including side slope grade (%), length and shape.

Data collected for treated landslides included general landslide characteristics such as landslide type, pre- and post-treatment landslide dimensions, slide excavation shape, slope gradient (%), presence or absence of rock armor, and the location of excavated spoils.

The Decommissioning Site Data Form was also used to record the specific road decommissioning treatments for each site inventoried. In addition, information was collected regarding the treatments implemented at each site and whether or not these treatments were 1) implemented as originally designed, 2) designed appropriately for the site, and 3) whether or not the treatments met California Department of Fish and Game generally accepted standardized decommissioning protocols (CDFG, 2004 - See Appendix F for generally accepted and standardized CDFG decommission protocols) .

Detailed post-treatment erosion and sediment delivery information, if any, was collected at each site inventoried. Erosion features included slumps and slides, channel incision, headcuts, gullies, rilling, surface erosion, bank erosion, and "other". Data collected for each erosion feature included: slope (%) at the erosion feature, past and/or future erosion dimensions, an estimate of sediment delivery (%), activity level of past erosion, future erosion potential, and cause of past erosion. Causes of erosion include implementation/operator and "natural" causes. Finally, if photos were taken at a treatment site, a notation was made on the sketch map for the treated site or on the photo point data table on the data form.

Implementation or operator-causes include unexcavated fill, stream undercutting, over-steepened side slopes, poor profile transition, over-steepened top of excavation, over-steepened bottom of excavation, insufficient channel width, poor channel alignment, and road drainage-related. "Natural" erosional mechanisms include unavoidable channel bed adjustments, unavoidable channel bank adjustments, some types of flow deflection, emergent groundwater, overland flow, and unstable soils/geology (Appendix F: PWA Void Measurement Protocol).

New Untreated Site Data Form - The "New Untreated Site Data Form" (Appendix C) was designed to allow collection of information on sites with past and/or future erosion and sediment delivery that were not originally inventoried and were not treated. Sites that were classified as "new untreated sites" were either not identified in the original sediment source assessment or developed after treatments were implemented. Information collected for new untreated sites included general site information, estimates of future erosion and sediment delivery, and possible road decommissioning treatments aimed at reducing sediment delivery to streams.

Road Drainage Data Form - The "Road Drainage Data Form" (Appendix C) was designed to collect specific data related to the treatment of road surface drainage on inventoried decommissioned roads. Information collected included general road shape information, and the types and extent of road surface drainage treatments that were implemented to reduce the amount of fine sediment entering streams from connected road reaches. Each road surface drainage technique (structure) was reviewed for current (post-decommissioning) connectivity. The road drainage data form also included a summary of the predominant road decommissioning techniques used on the road segment being evaluated (e.g., outsloping).

Data collected on the three road decommissioning data forms (Appendix C) was used to evaluate the effectiveness of the decommissioning. Specifically, the sites were assessed as to whether they should have been further treated or treated differently, and what possible treatments should have been implemented to reduce future erosion and sediment delivery to streams. The road reaches were evaluated to determine the hydrologic connectivity between the former road and the natural stream channel network. Finally, sites that were unrecognized, untreated or had developed after decommissioning were identified and evaluated to identify deficiencies in pre-treatment site identification or operator error during implementation work.

6.4 Assessment

The decommissioning assessment was conducted between September 2004 and February 2005. Four geologists were dedicated to the project to assure consistency in the data collection process. Continual site sheet review and weekly meetings were conducted to address issues that arose and to monitor quality control and maintain quality assurance measures.

6.5 Data Entry and GIS

Data was entered into a Microsoft Access database concurrently with data collection so any "holes" in the data could be filled while we were still inventorying in the area. Once all the data was entered, it was cross checked for completeness and internal consistency. All sites that were mapped in the field were digitized using GIS Arcview software. Once the sites were digitized the "cleaned" access database was integrated with the GIS data to facilitate interpretation of the evaluated sites, both spatially and analytically.

6.6 Generally accepted standards for road decommissioning treatments

Road decommissioning on the Northern California coast began in earnest in the late 1970s with the permanent closure of miles of former logging roads on lands within Redwood National Park (Weaver et al., 1987). Since then, techniques for road decommissioning have evolved to a fairly uniform set of prescriptions. Depending on the objective of the treatment, road decommissioning can include everything from simple decompaction, cross drain construction and stream crossing removal, to complete topographic reconstruction of the former landscape. The standardized techniques and associated costs for problem identification and road decommissioning treatments have been described elsewhere (Pacific Watershed Associates, 2004; Weaver and Hagans, 2004).

Most decommissioning on managed forest lands, such as those in north coast watersheds and elsewhere, is performed for the purpose of managing (reducing) road-related sediment production and delivery, and for reducing road maintenance requirements and costs. Unlike actively managed road systems, properly decommissioned roads need little or no maintenance. At the same time, properly decommissioned roads are also much less likely to exhibit road-related erosion and sediment delivery to the stream system, such as stream crossing washouts and stream diversions, than are maintained roads (Harr and Nichols, 1993).

Stream crossings

Generally accepted protocols for properly decommissioning stream crossings involve the permanent removal of road fill, Humboldt logs, and/or woody debris from the stream crossing by excavating fill material down to the natural (original) channel bed and sloping the excavated channel banks to a 2:1 (50%) grade, or at side slope angles that mimic the natural side slopes above and/or below the influence of the stream crossing fill. Properly decommissioned stream crossing side slopes are typically excavated with a slightly concave or straight profile shape to reduce the likelihood of slumping or sliding. In addition, stream crossing channels should be excavated with straight line profiles with little or no channel complexity (i.e., concavity or convexity) so as to reduce the chances of developing headcuts that may migrate through erodible sediment left in the excavated stream crossing. Sediment that accumulated upstream from the crossing, as a consequence of the long-term “damming” of the channel, should also be excavated and removed as a part of the crossing decommissioning. The final profile from the natural channel above the crossing, through the excavated channel, and into the natural undisturbed channel downstream from the crossing should be smooth and without abrupt grade breaks so as to minimize the occurrence of headcuts and downcutting in both the decommissioned crossing and the adjacent natural channel.

Properly decommissioning stream crossings also requires treatment of the adjacent road reaches to eliminate or strictly reduce the road and/or ditch drainage that is hydrologically connected to the crossing. Disconnecting the road and/or ditch is accomplished by outsloping the adjacent road reaches or by installing cross road drains at regular intervals along the adjacent road approaches, starting immediately adjacent the excavated stream crossing. Any springs draining to the stream crossing are disconnected from the stream by installing dips or cross road drains, or by outsloping the former roadbed.

Landslides

The generally accepted protocol for properly excavating landslides (usually potential fillslope failures) involves permanently removing unstable fill from the potential landslide feature. Landslides should be excavated with a straight line or concave slide face (downslope profile) to maximize volumetric removal of unstable materials and to reduce the likelihood future slumping or sliding. The excavation of potential landslides can involve the removal of all unstable fill or, in the case of very large landslides, the removal of unstable fill from the upper portion of the unstable slide mass. Excavating the upper portion of the landslide decreases the overall landslide mass, and as a result can reduce the landslide driving forces. This may prevent the potential landslide from failing or, because of the reduction in landslide mass, it may decrease the volume of landslide materials that eventually enter the stream.

"Other sites"
As previously mentioned, "other" sites include ditch relief culverts, gullies, springs, and related road surface and ditch drainage problems. These sites are typically caused by excessive road surface/ditch drainage and/or overland flow. Appropriate treatment for these sites involves road ripping (to increase infiltration and reduce surface runoff), road outsloping to disperse runoff, and/or and the installation of frequent cross road drains or dips to drain the road surface.

In all cases, whether excavating stream crossings or potential landslides, or treating "other" sites, all spoil materials should be placed in stable locations away from streams to prevent potential erosion and sediment delivery. Typically, spoils are placed against stable cutbanks, on the inboard edge of landings, or on the road surface, as long as the spoil has little chance of failing into streams.

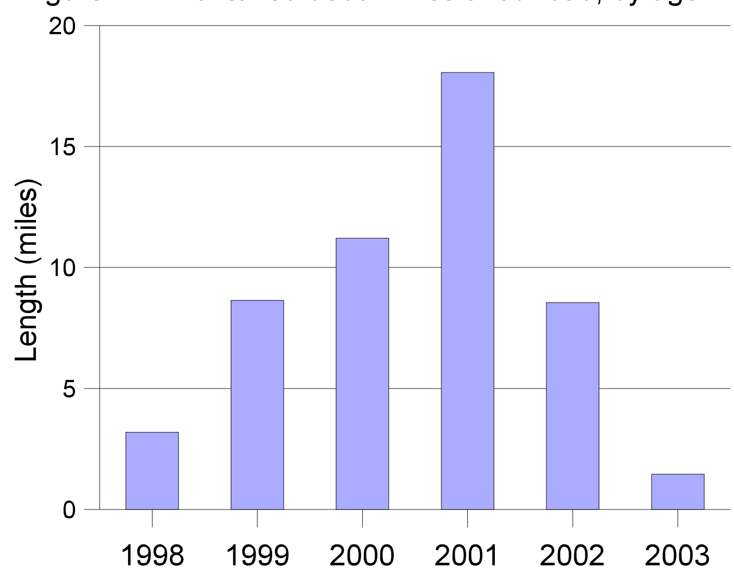
7.0 Results

7.1 Inventory Results

In the first phase of the study, over 51 miles of decommissioned roads were identified from road maps in 18 different Northern California watersheds (Table 2, Appendix B: Maps 2-40). Where it was available, pre-treatment assessment data was compiled from databases developed during the original sediment source investigations. Pre-treatment data typically consisted of general site characteristics, estimated erosion and sediment delivery, original treatment recommendations, and estimated excavation volumes for the proposed decommissioning.

The age of decommissioning for each road included in the assessment was determined from final contract reports submitted to CDFG after the completion of road decommissioning. The age of road decommissioning ranged from 1998 to 2003. Specifically, we evaluated approximately 3.19 miles (6%) of road decommissioned in 1998, 8.64 miles (17%) in 1999, 11.21miles (22%) in 2000, 18.06 miles (35%) in 2001, 8.55 miles (17%) in 2002 and 1.46 miles (3%) in 2003 (Table 2; Figure 2).

Figure 2. Inventoried decommissioned road, by age



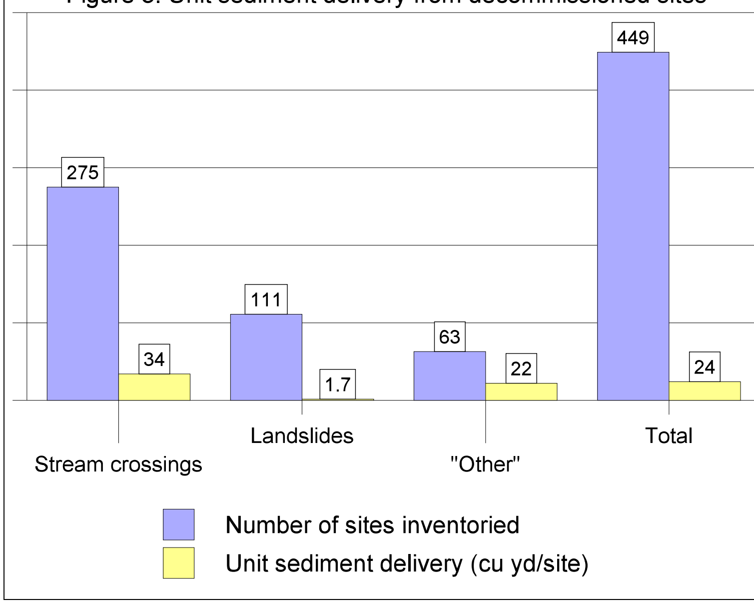
Ten different geologic bedrock types were encountered in this assessment. The predominant geology for each road was identified in the field and cross checked from one of three source maps: Ogle (1953), Jennings (1977), and McLauglin (2000). The geologic bedrock ranged from Paleozoic to Quaternary in age.

Specifically we evaluated 10.78 miles (21%) in the Central Belt Franciscan Complex (KJf), 4.78 miles (9%) in Western Klamath Mountain Terrane(J), 7.32 miles (14%) in Mesozoic Granite (grMz), 2.32 miles (5%) in Paleozoic Metamorphic rock (Pz), 3.52 miles (7%) in the South Fork Mountain Schist (KJfs), 4.97 miles (10%) in Undifferentiated Wildcat sediments (QTwu), 12.23 miles (24%) in the Yager Formation (Ty), 0.56 miles (1%) in Quaternary Marine deposits (Qm), 3.93 miles (8%) in Coastal Belt Franciscan Complex (KJfco), and 0.7 miles (1%) in Franciscan Mélange (KJfm) (Table 2). See Appendix A for detailed descriptions of all the geologic units encountered in this study.

7.2 Decommissioned Site Types

Decommissioned site types included stream crossings, landslides and "other" sites. "Other" sites included ditch relief culverts, gullies, springs, and road surface and ditch problems. From the 51.1 miles of decommissioned roads within the study area, 449 decommissioned sites were identified in the assessment, including: 275 stream crossings, 111 landslides and 63 "other" sites (Table 2, Figure 3). A total of approximately 16,963 yds^3 of post-decommissioning erosion was measured from the 449 inventoried treated sites, and approximately 10,912 yds^3 (64%) delivered to streams. Nearly 9,322 yds^3 (85%) of the past sediment delivery was accounted for at stream crossings. Approximately 185 yds^3 (2%) of past sediment delivery was measured at landslides. Finally, approximately 1,405 yds^3 (13%) of past sediment delivery was measured at "other" sites (Table 2) Unit sediment delivery from the three sites types was greatest for stream crossings (34 yds3/site) and least for landslides (1.7 yds3/site)(Figure 3).

Figure 3. Unit sediment delivery from decommissioned sites

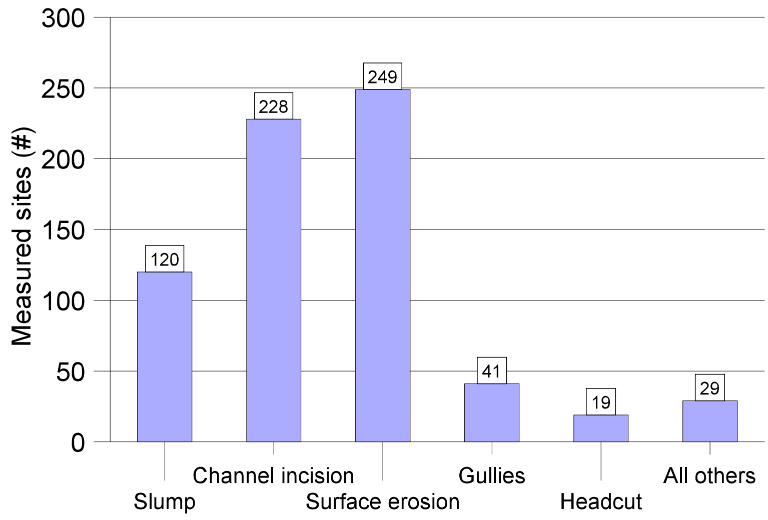


7.3 Erosion Features at Decommissioned Sites

Estimates of post-decommissioning erosion and sediment delivery at each inventoried site were delineated by erosion feature type (Figure 4). Erosion features identified at treated sites included bank erosion, channel incision, gully, headcut, surface erosion, rills, slumps, and "other" (Tables 3a-c). Each treated site type may have exhibited one or more erosion feature types. For example, an individual excavated stream crossing may have displayed a number of these erosion feature types, each of which contributed to sediment delivery at the site. All of the categorized erosion types were found at stream crossing sites. Slumps/landslides, gullies and rills, and surface erosion were identified at landslide sites. Gullies and rills, headcuts, slumps, and surface erosion were identified at "other" sites.

Six hundred eighty six (686) post-decommissioning erosion features were identified at the 449 inventoried treated sites in the study area (Tables 3a-c) including 120 slump/slides, 228 channel incision sites, 249 surface erosion sites, 41 gullies, and 19 headcuts (Figure 4). The most common erosion features identified at inventoried treated sites included slumps (17%), surface erosion (36%) and channel incision (33%). We estimated approximately 9,240 yds^3 of erosion and 3,581 yds^3 of sediment delivery from slumps, approximately 3,801 yds^3 of erosion and 3,426 yds^3 of sediment delivery from surface erosion, and approximately 2,949 yds^3 of erosion and 2,946 yds^3 of sediment delivery from channel incision. Estimated sediment delivery from channel incision, surface erosion, and slump erosion features account for approximately 91% (9,953 yds^3) of the total sediment delivery at inventoried treated sites (Tables 3a-c).

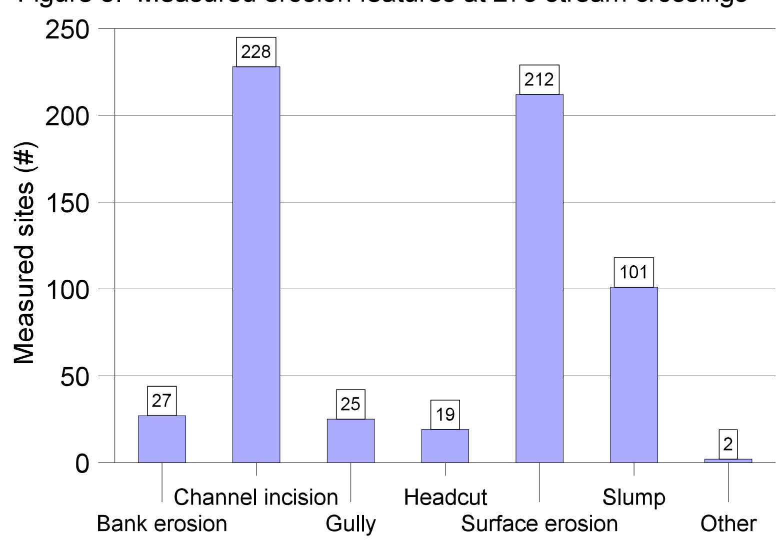
Figure 4. Measured erosion features at all 449 sites



Stream Crossings

Of the 686 erosion features identified at inventoried treated sites, 614 (90%) were identified at stream crossings, including 228 channel incision sites, 101 slump/slide features, 212 surface erosion sites, 25 gullies, 27 bank erosion sites, and 19 headcuts (Figure 5). Of the 9,322 yds^3 of sediment delivery at stream crossings, 23% (2,130 yds^3) is associated with slumps or debris slides and 32% (2946 yds^3) is associated with channel incision. In addition, approximately 36% (3,391 yds^3) of past sediment delivery at stream crossings is related to surface erosion (Table 3a) (Figure 6).

Figure 5. Measured erosion features at 275 stream crossings



Two thousand one hundred thirty cubic yards (2,130 yds^3) of past sediment delivery was associated with debris slides or slumps on the side slopes of excavated stream

Table 3a. Stream crossing post-decommissioning erosion and sediment delivery by erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried stream crossings (#)	No. of past erosion features (#)	Post-decom erosion (yds^3)	Post-decom sediment delivery (yds^3)	Unit post decom sediment delivery (yds^3/feature type)
Bank erosion	21	27	406	400	15
Channel incision	186	228	2,949	2,946	13
Gully	20	25	59	57	2
Headcut	15	19	378	378	20
Surface erosion	127	212	3,521	3,391	16
Slump	68	101	5,464	2,130	21
Other	2	2	20	20	10
Total	**--**	**614**	**12,797**	**9,322**	**15**

Table 3b. Landslide post-decommissioning erosion and sediment delivery by erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried landslides (#)	No. of past erosion features (#)	Post-decom erosion (yds^3)	Post-decom sediment delivery (yds^3)	Unit post-decom sediment delivery (yds^3/feature type)
Gully	2	3	4	4	1
Surface erosion	14	14	260	18	1
Slump	8	9	360	163	18
Total	**--**	**26**	**624**	**185**	**7**

Table 3c. "Other" sites post-decommissioning erosion and sediment delivery by erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried "other" sites (#)	No. of erosion features (#)	Post-decom erosion (yds^3)	Post-decom sediment delivery (yds^3)	Unit post-decom sediment delivery (yds^3/feature type)
Gully	13	13	106	100	8
Surface erosion	20	23	20	17	1
Slump	7	10	3,416	1,288	129
Total	**--**	**46**	**3,542**	**1,405**	**31**

crossings. One hundred seventy three cubic yards (173 yds^3) of past sediment delivery was associated with debris slides or slumps on the side slopes of treated stream crossings. Of significance, 1,815 yds^3 (93%) of the 1,957 yds^3 of past sediment delivery associated with mass wasting on the side slopes of decommissioned stream crossings was associated with side slope excavations steeper than 50% (Table 4).

Figure 6. Sediment sources at decommissioned crossings

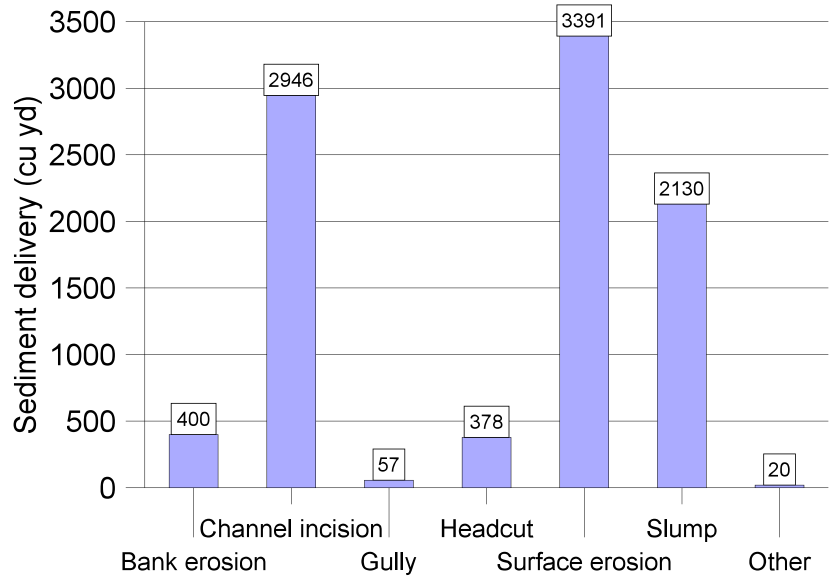


Table 4. Post-decommissioning sediment delivery from slope failures on the banks of excavated stream crossings, by slope class and slope shape, CDFG decommission monitoring study, North Coastal California.			
Slope gradient of excavated banks (%)	Excavated slope shape	No. of failures on excavated channel sideslopes (#)	Post-decommissioning sediment delivery (yds^3)
<50% (gentle)	Concave	2	7
	Convex	2	12
	Straight	9	63
	Other	2	60
Subtotal		**15**	**142**
>50% (steep)	Concave	10	35
	Convex	18	618
	Straight	52	1,161
	Other	1	1
Subtotal		**81**	**1,815**
TOTAL		**96**	**1957**

<u>Landslides</u> *(exclusive of those at decommissioned stream crossings)*

Of the 111 road-reach landslide sites assessed, 106 were classified as fillslope landslides, 3 were deep seated landslides, 1 was a cutbank slide, and 1 was a landslide that could not be categorized. Post-decommissioning erosion features identified at treated landslide sites included: 8 slumps/slides, 2 gullies, and 14 surface erosion sites (Table 3b). Seven percent (7%) of the landslide sites exhibited slumping/landsliding and 13% of the landslides exhibited surface erosion. In summary, post-decommissioning slumping/landsliding at treated landslide sites account for approximately 88% (163 yds^3) of the sediment delivery to streams, while surface erosion accounts for 10% (18 yds^3) of post-decommissioning sediment delivery (Table 3b).

<u>"Other"</u>
Of the 63 "other" sites assessed, three (3) were gullies, 11 were road surface drainage problems, 43 were springs, 4 were swales, and 2 could not be easily categorized. Post-treatment erosion features identified at treated "other" sites included: 10 slumps/slides, 13 gullies and 23 surface erosion sites. Eighteen percent (18%) of the other sites exhibited slumping/landsliding and 82% of the other sites exhibited gullies or surface erosion. Slumps/landslides at "other" sites account for approximately 92% (1,288 yds^3) of the post-decommissioning sediment delivery to streams (Table 3c).

7.4 Causes of Erosion
During the inventory of post-decommissioning erosion, the cause of erosion and the cause of each erosion feature was identified in the field. Causes of erosion included: emergent groundwater, flow deflection, natural bank adjustments, natural channel adjustments, overland flow, oversteepened fill, poor channel alignment, poor profile transition, undercutting by excavation, unexcavated fill, unstable soils/geology, road drainage, and other (Tables 5a-c).

The three most common and most volumetrically important *types of erosion* at decommissioned stream crossings included surface erosion (36% of total yield), channel incision within the excavated stream channel (32%), and slumps of the excavated stream channel side slopes (23%)(Table 3a). Post-decommissioning erosion and sediment delivery at landslide sites (13% of total yield) and at "other" sites (2%) was much less significant than that which occurred at excavated stream crossings (85%). For decommissioned landslide sites, the most common source of post-decommissioning sediment delivery was slumping of the treated unstable feature. Similarly, the most volumetrically important type of erosion and sediment delivery at "other" sites was also slumping of unstable material.

The 686 post-decommissioning erosion features were each assigned primary causes (Table 5a-c). Specifically, the causes of erosion documented included: 29 over steepened fills, 2 poor channel alignments, 2 road drainage causes, 18 poor profile transitions, 34 undercut by excavations, 122 unexcavated fills, 45 emergent groundwater causes, 117 natural bank adjustments, 21 natural channel adjustments, 238 overland flow causes, 41 unstable soils/geology, 12 flow deflections, and 5 others. Some of these causes can be attributed to natural site conditions (e.g., emergent groundwater), while others are the result of improper or avoidable implementation techniques (e.g., oversteepened or unexcavated fill).

<u>*7.4.1 Stream Crossings*</u>
In order of decreasing sediment delivery, the five most common causes of erosion at decommissioned stream crossings include: overland flow, unexcavated fill, natural bank adjustments, undercutting by excavation, and unstable soils/geology (Table 5a; Figure 7). Of the 686 causes of erosion identified at all inventoried sites along the decommissioned roads, 614 (90%) were identified at stream crossings, including: 25 over steepened fills, 2 poor channel alignments, 18 poor profile transitions, 33 undercut by excavations, 118 unexcavated fills, 21

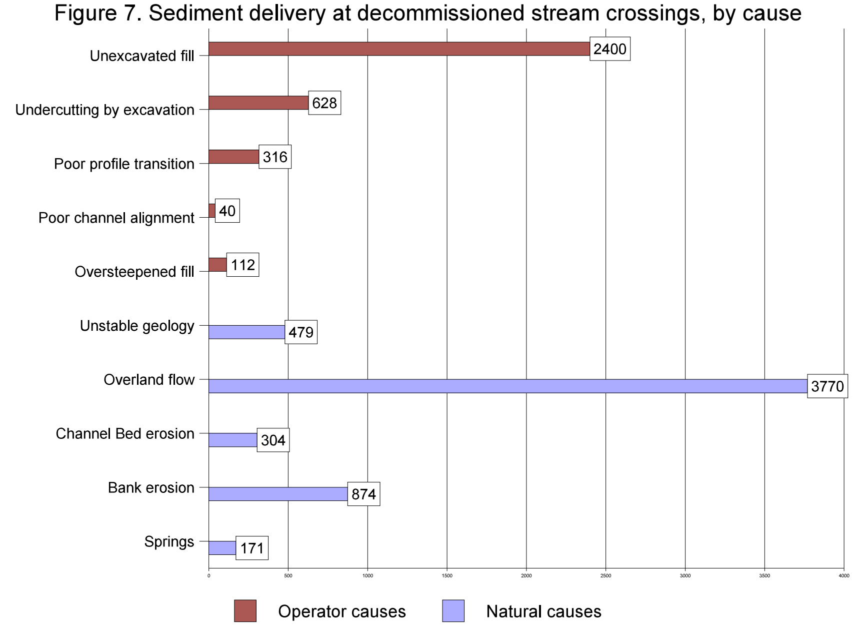
Table 5a. Stream crossing post-decommissioning erosion and sediment delivery, by cause, CDFG decommission monitoring study, North Coastal California

Cause type	Erosion cause	No .of features exhibiting erosion cause (#)	Past erosion volume (yds^3)	Past sediment delivery (yds^3)	Unit past sediment delivery (yds^3/feature)
	Emergent groundwater	21	515	171	8
	Natural bank adjustments	114	877	874	8
Natural	Natural channel adjustments	21	304	304	14
	Overland flow	210	4,491	3,770	18
	Unstable soils/geology	35	1,060	479	14
Subtotal		**401**	**7,247**	**5,598**	**14**
	Oversteepened fill	25	213	112	4
	Poor channel alignment	2	47	40	20
Operator	Poor profile transition	18	316	316	18
	Undercutting by excavation	33	806	628	19
	Unexcavated fill	118	3,939	2,400	20
Subtotal		**196**	**5,321**	**3,496**	**18**
Both	Flow deflection	12	187	186	16
	Other	5	42	42	8
Subtotal		**17**	**229**	**228**	**13**
TOTALS		**614**	**12,797**	**9,322**	**15**

emergent groundwater causes, 114 natural bank adjustments, 21 natural channel adjustments, One hundred sixteen (116) stream crossings (42%) exhibited oversteepened or head cutting top 210 overland flow causes, 35 unstable soils/geology, 12 flow deflections, and 5 others (Table 5a). In total, these produced 9,322 yds^3 of sediment delivery, or 34 yds^3/crossing or bottom transitions, although not all of them have been or are currently eroding. Of these 116 crossings, 29 (25%) were due to road construction practices, 50 (43%) were due to decommissioning practices, and 37 (32%) were due to natural causes, such as bedrock exposures.

Of the 9,322 yds^3 of sediment delivery at stream crossings, 40% (3,770 yds^3) is associated with overland flow (surface runoff) and 26% (2,400 yds^3) is associated with unexcavated fill. In addition, approximately 13% (1,178 yds^3) of sediment delivery at decommissioned stream crossings is related to natural bank and channel adjustments (Table 5a; Figure 7). Approximately 3,496 yds^3 (38% of the total post-decommissioning sediment delivery) can be directly attributed to operator or supervisor error while nearly 5,600 yds^3 (60% of the total) can

Figure 7. Sediment delivery at decommissioned stream crossings, by cause



be attributed to "natural" or unavoidable causes. This assumes that most overland flow and associated surface erosion on the long sideslopes of large decommissioned stream crossings is largely unavoidable. The remaining 2 percent could be attributable to either operator error or unavoidable adjustments, or both (Table 5a).

At decommissioned stream crossing sites, the avoidable practices of constructing over-steepened fills and undercutting of the natural channel side slopes resulted in slumps and slope failures on excavated channel sideslopes. Natural bank adjustments and unstable geology were two unavoidable causes that also resulted in sideslope failures. Significantly, excavated stream crossings with sideslopes steeper than 50% (2:1) accounted for 84% of the inventoried slumps and 93% of the sediment delivery derived from mass wasting decommissioned stream crossings (Table 4). This profound and solid relationship strongly argues for the 50% sideslope standard as a means of limiting post-excavation sediment delivery from mass wasting processes at decommissioned stream crossings.

Unexcavated fill left in the bottom of decommissioned stream crossings typically results in subsequent stream channel erosion. Channel incision is one of the most common post-decommissioning sources of erosion and sediment delivery, and it was found to be the second leading source of sediment production (overland flow was the leading source) from decommissioned stream crossings in the study area. The cause category "unexcavated fill" typically includes several situations where fill materials have not been completely excavated and removed from axis (centerline) of the decommissioned stream crossing. These might be expressed as a convex channel profile, a profile with significant "humps," or a channel bottom that was not excavated down to expose (exhume) the original, less erodible streambed materials and natural channel armor. Streamflow through incompletely excavated stream crossings quickly cuts through the remaining material resulting in immediate sediment delivery.

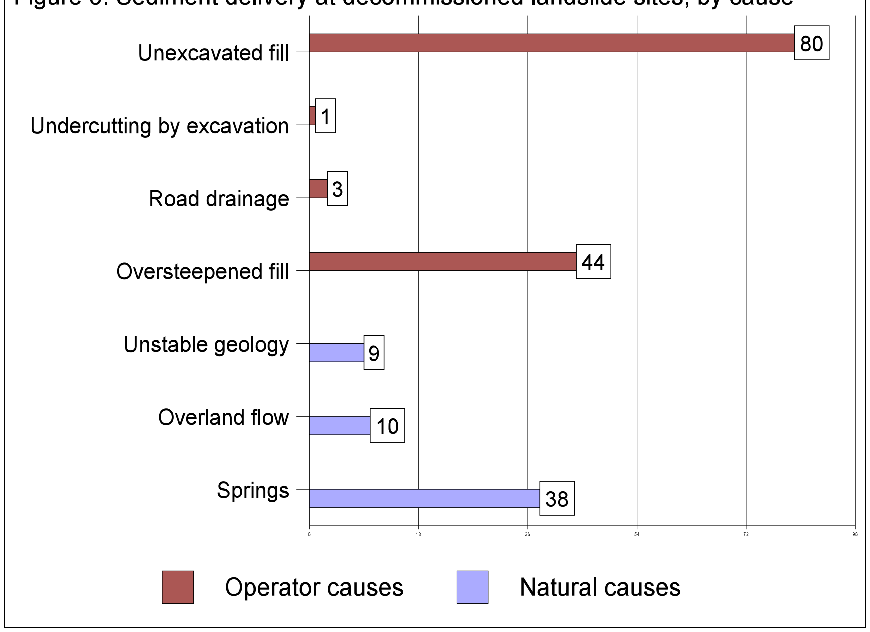
The single most important cause of post-decommissioning erosion and sediment delivery from excavated stream crossings was overland flow. Overland flow was observed to cause a number of erosion features, including surface erosion, rilling, gullying and shallow landsliding of excavated channel sideslopes. Overall, it accounted for an estimated 40% of sediment delivery from excavated stream crossings. Overland flow became more important in inland sites where hillslope revegetation was slow compared to coastal areas. In coastal environments, where revegetation is rapid, surface erosion was judged to be a minor component of post-decommissioning sediment production and delivery (PWA, 2005, Madej, 2001, Klein, 2003).

7.4.2 Landslides

Erosion at decommissioned landslide sites along the treated roads resulted in significantly less sediment delivery than that occurring at excavated stream crossings (Tables 5a, 5b). The principal causes of erosion at decommissioned landslide sites included over-steepened and unexcavated fill, emergent groundwater and unstable geologic materials. Overland flow caused 215 yds^3 of erosion, but only 5% of that volume was actually delivered to stream channels.

Landsliding was not common along decommissioned road reaches (outside of excavated stream crossings). The frequency of causes of post-decommissioning erosion at decommissioned landslide sites included: 3 oversteepened fills, 1 road fill undercut by excavation, 2 unexcavated fills, 2 road drainage causes, 1 emergent groundwater cause, 13 overland flow causes, and 4 unstable soils/geology causes (Table 5b). Again, these can be segregated into natural and operator (preventable) causes (Figure 8).

Figure 8. Sediment delivery at decommissioned landslide sites, by cause



Of the recognizable causes (Table 3b), unexcavated and oversteepened fills were the most easily avoidable source of post-decommissioning erosion and sediment delivery identified at decommissioned landslide sites (Figure 8). Thus, although unexcavated fill was identified as the leading contributor to post-decommissioning erosion at landslide sites (246 yds^3), this "correctable cause" only resulted in the delivery of 80 yds^3 of "eroded" sediment to stream channels (Figure 8, Table 5b). In general, sediment delivery from decommissioned landslide sites was low, averaging less than 30%. In contrast, and as a result of being located close to stream channels, erosion processes acting at decommissioned stream crossings had a delivery ratio of over 72% (Table 5a).

Of the 185 yds^3 of sediment delivery originating at treated landslide sites, 43% (80 yds^3) was associated with unexcavated fill and 24% (44 yds^3) was associated with oversteepened fill. In addition, approximately 21% (38 yds^3) of past sediment delivery at treated landslides was related to emergent ground water (Table 5b, Figure 8). Approximately 128 yds^3 (69% of the total delivery) can be directly attributed to operator or supervisor error (Figure 8), while 31% percent

Table 5b. Landslide post-decommissioning erosion and sediment delivery, by cause, CDFG decommission monitoring study, North Coastal California

Cause type	Erosion cause	Features exhibiting erosion cause (#)	Past erosion volume (yds^3)	Past sediment delivery (yds^3)	Unit past sediment delivery (yds^3/feature)
Natural	Emergent groundwater	1	42	38	38
	Overland flow	13	215	10	0.8
	Unstable soils/geology	4	65	9	2
Subtotal		**18**	**322**	**57**	**3**
Operator	Oversteepened fill	3	51	44	15
	Road drainage	2	4	3	2
	Undercutting by excavation	1	1	1	1
	Unexcavated fill	2	246	80	40
Subtotal		**8**	**302**	**128**	**16**
TOTALS		**26**	**624**	**185**	**7**

can be attributed to “natural” or unavoidable causes (Table 5b). Complete excavation of unstable fill materials at fillslope landslide treatment sites would have almost completely eliminated operator causes of post-decommissioning sediment delivery from mass wasting processes at decommissioned fillslope landslide sites. The generally accepted protocol for excavating deeply concave slope shapes, when treating potential fillslope landslides, is strongly supported by these inventory results.

7.4.3 “Other”

Post-decommissioning erosion and sediment delivery volumes from “other” sites was also relatively minor when compared to that originating from decommissioned stream crossings. Only 14% of the inventoried sites consisted of “other” site types, and these accounted for less than 13% of total post-decommissioning sediment delivery from all sources.

A total of 46 erosion features were inventoried at the 40 “other” sites identified along the decommissioned roads. The erosion causes identified at these sites included: 1 oversteepened fill, 2 unexcavated fills, 23 emergent groundwater causes, 15 overland flow causes, 2 unstable soils/geology causes and 3 natural bank adjustments (Table 5c). Of the 1,405 yds^3 of sediment delivery derived from decommissioned “other” sites, 72% (1,014 yds^3) was associated with emergent groundwater and 19% (271 yds^3) was associated with overland flow (Table 5c). Only 45 yds^3 (3% of sediment delivery from “other” sites) can be directly attributed to operator or supervisor error. Ninety seven (97%) percent of the sediment delivery derived from “other” sites can be attributed to “natural” or unavoidable causes (Table 5c).

Table 5c. "Other" sites post-decommissioning erosion and sediment delivery, by cause, CDFG decommission monitoring study, North Coastal California

Cause type	Erosion cause	No .of features exhibiting erosion cause (#)	Past erosion volume (yds^3)	Past sediment delivery (yds^3)	Unit past sediment delivery (yds^3/feature)
Natural	Emergent groundwater	23	2,770	1,014	44
	Natural bank adjustments	3	11	11	4
	Overland flow	15	275	271	18
	Unstable soils/geology	2	269	64	32
Subtotal		**43**	**3,325**	**1,360**	**32**
Operator	Oversteepened fill	1	172	0	0
	Unexcavated fill	2	45	45	23
Subtotal		**3**	**217**	**45**	**15**
TOTALS		**46**	**3,542**	**1,405**	**31**

7.4.4 Erosion statistics

The average past sediment delivery from the 449 inventoried sites was estimated at 24.3 yds^3 per site (Figure 3). Ninety two percent (92%) of the stream crossings exhibited post-decommissioning sediment delivery with an estimated mean of 37 yds^3 per site, a maximum of 634 yds^3/crossing, a minimum of 0.03 yds^3/crossing and a standard deviation of 82 yds^3. Fourteen (14) percent of the landslides exhibited post-decommissioning sediment delivery with an estimated mean yield of 12 yds^3 per site, a maximum of 71 yds^3, a minimum of 0.02 yds^3 and a standard deviation of 19 yds^3. Finally, 43% of the "other" sites exhibited post-decommissioning sediment delivery with an estimated mean yield of 52 yds^3 per site, a maximum of 911 yds^3, a minimum of 0.01 yds^3 and a standard deviation of 178 yds^3 (Tables 6a-c).

Table 6a. Stream crossing post-decommissioning erosion and sediment delivery statistics (n=275), CDFG decommission monitoring study, North Coastal California

Statistic	Post-decommissioning erosion (yds^3)	Post-decommissioning sediment delivery (yds^3)
Number of inventoried treated site types (#)[1]	254	254
Total delivery volume (yds^3)	12,797	9,322
Number of past erosion features associated with site type (#)	614	614
Mean volume (yds^3)	50	37
Median volume (yds^3)	10	9
Standard Deviation (yds^3)	134	82
Minimum volume (yds^3)	0.03	0.03
Maximum volume (yds^3)	1,422	634

[1] 275 stream crossings were inventoried in the field. Of the 275 stream crossings, 254 (92%) exhibited post-decommissioning erosion and sediment delivery and 15 (5%) showed no signs of post-decommissioning erosion and sediment delivery.

Table 6b. Landslide post-decommissioning erosion and sediment delivery statistics (n=111), CDFG decommission monitoring study, North Coastal California		
Statistic	Post-decommissioning erosion (yds^3)	Post-decommissioning sediment delivery (yds^3)
Number of inventoried treated site types (#)[1]	24	16
Total delivery volume (yds^3)	624	185
Number of past erosion features associated with site type (#)	26	18
Mean volume (yds^3)	24	12
Median volume (yds^3)	9	3
Standard Deviation (yds^3)	47	19
Minimum volume (yds^3)	0.03	0.02
Maximum volume (yds^3)	237	71

[1] 111 landslides were inventoried in the field. Of the 111 landslides, 24 (22%) exhibited post-decommissioning erosion and 16 (14%) delivered sediment to streams. Eighty seven (87) landslides (78%) showed no signs of post-decommissioning erosion and sediment delivery.

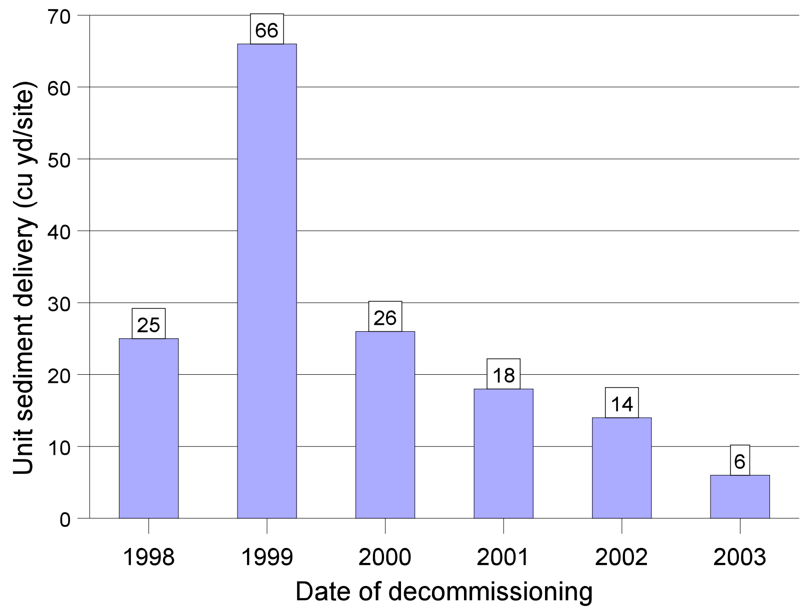
Table 6c. "Other" sites post-decommissioning erosion and sediment delivery statistics (n=63), CDFG decommission monitoring study, North Coastal California		
Statistic	Post-decommissioning erosion (yds^3)	Post-decommissioning sediment delivery (yds^3)
Number of inventoried treated site types (#)[1]	37	27
Total volume(yds^3)	3,542	1,405
Number of past erosion features associated with site type(#)	46	34
Mean volume (yds^3)	96	52
Median volume (yds^3)	2	4
Standard Deviation (yds^3)	374	178
Minimum volume (yds^3)	0.1	0.01
Maximum volume (yds^3)	2,235	911

[1] Sixty three (63) "other" sites were inventoried in the field. Of the 63 "other" sites, 37 (59%) exhibited post-decommissioning erosion and 27 (43%) delivered sediment to streams. Twenty six (26) "other" sites (41%) showed no signs of post-decommissioning erosion and sediment delivery.

7.5 Unit Sediment Delivery by Age

At every site inventoried, the age of the road decommissioning was known. Table 7 displays the erosion, delivery and unit delivery of sediment to a watercourse sorted by age of decommission. Sites that were implemented in 1998 experienced roughly 25 yds^3 of delivery per site, in 1999, 66 yds^3 of delivery per site, in 2000, 26 yds^3 of delivery per site, in 2001, 18 yds^3 of delivery per site, in 2002, 14 yds^3 of delivery per site, and in 2003, 6 yds^3 of delivery per site (Figure 9).

Figure 9. Unit sediment delivery from decommissioned sites, by age



In general, one would logically expect a greater erosional response for road decommissioning sites, including excavated stream crossings, that have been subject to long time periods and; hence, more winter floods (Klein, 2003). With the exception of roads decommissioned in 1998, this study showed a positive correlation between the age of decommissioning and post-decommissioning sediment delivery volumes. Consequently, the older the site the greater the average sediment delivery volume (Figure 9). The sites that do not fit this trend consist of the 36 sites (8% of the total number of inventoried sites) decommissioned in 1998 in the coastal environment of Humboldt Bay. Here, rapid rates of revegetation may have more than offset potentially high rates of post-decommissioning erosion that might otherwise have been expected on the poorly lithified Wildcat Formation.

A number of studies describing sediment delivery from decommissioned stream crossings have suggested that most erosion occurs in the first several years following treatment, regardless of storm intensity (Madej, 2001; Bloom, 2005; Klein, 2003; PWA, 2005). Erosion data from coastal areas appear to support this observation. In this study, the largest total volume of sediment delivery measured in the project area was from a 4.2 mile long road decommissioned in 1999. Although it was from an inland Klamath Mountain province location, the combined effect of extremely large stream crossing volumes (hence long sideslopes and great expanses of bare soil) and a highly erodible substrate of decomposed granite appears to be one of the overriding factors accounting for the elevates rates of post-decommissioning sediment delivery. This elevated sediment delivery volume likely accounts for the much of the skewed sediment delivery rates measured for 1999 road decommissioning (Figure 9, Table 7).

Table 7. Post-decommissioning erosion and sediment delivery, by date and site type, CDFG decommission monitoring study, North Coastal California							
Date of road decommissioning	Site Type (#)				Post-decommissioning		Unit sediment delivery (yds³/site)
	Stream crossing	Landslide	Other	Total	Erosion (yds³)	Sediment delivery (yds³)	
1998	15	14	7	36	2083	911	25
1999	48	1	5	54	3944	3,567	66
2000	54	16	11	81	4,148	2,141	26
2001	84	43	26	153	5,160	2,753	18
2002	56	27	13	96	1,465	1,380	14
2003	18	10	1	29	163	160	6
Total	**275**	**111**	**63**	**449**	**16,963**	**10,912**	**--**

To investigate this further, cumulative rainfall was calculated for every project location to consider the effect rainfall had on post-decommissioning erosion. We collected data that was proximal to the project area, but in some instances data was not available from proximal locations or didn't cover the exact time frame of interest. In these instances we made our best estimate of annual rainfall for the area ,and period in question, by using nearby rainfall data in conjunction with the California isohyetal map of mean annual precipitation.

Figure 10 shows a plot of cumulative precipitation versus normalized sediment delivery, by geology type. The relationship between total post-decommissioning sediment delivery and cumulative precipitation since decommissioning (an analog to "time") is weak, at best. There are many possible reasons for the lack of correlation, but the biggest contributing factor is likely the variation in the quality of work done on each road. In other words, a small amount of rainfall can cause a lot of erosion on a poorly decommissioned road and, a well decommissioned road can withstand heavy rainfall events and exhibit minimal erosion. Conclusions drawn from this study suggest there is considerable variability in the quality of work done under the CDFG Fisheries

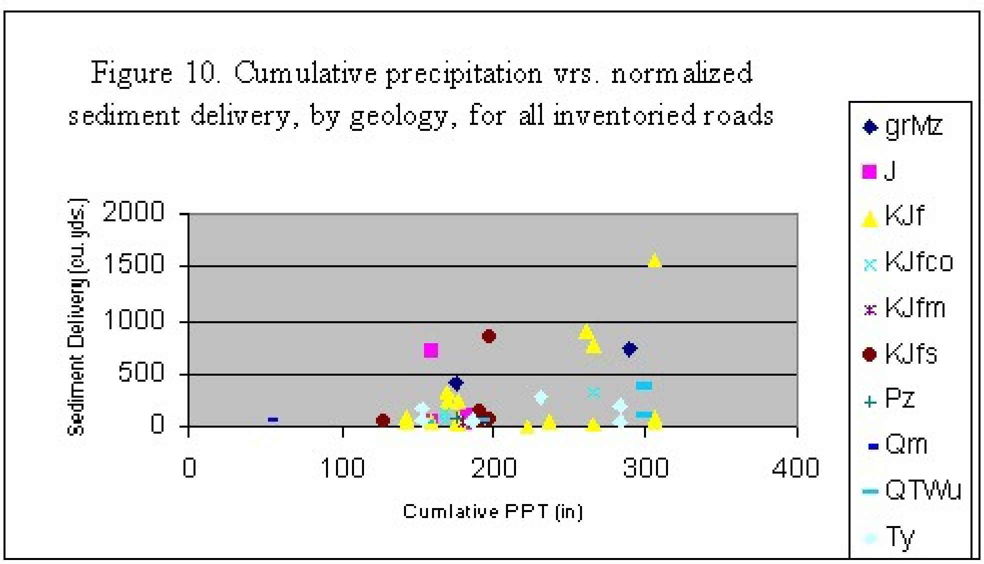


Figure 10. Cumulative precipitation vrs. normalized sediment delivery, by geology, for all inventoried roads

Restoration Grant Program, and that this factor largely explains why implementation, operator and geologic differences outweigh or mask differences in erosion due to climatic inputs (cumulative rainfall).

7.6 Unit Sediment Delivery by Geology

At every site inventoried, the geologic substrate of the area was recorded from published maps and field observations. Table 8 displays the erosion, sediment delivery and unit sediment delivery from decommissioned sites to nearby watercourses, sorted by geologic substrate. Unit sediment delivery (yds^3/site) was calculated for each geology type using the number of sites and the measured post-decommissioning sediment delivery volumes (Table 8).

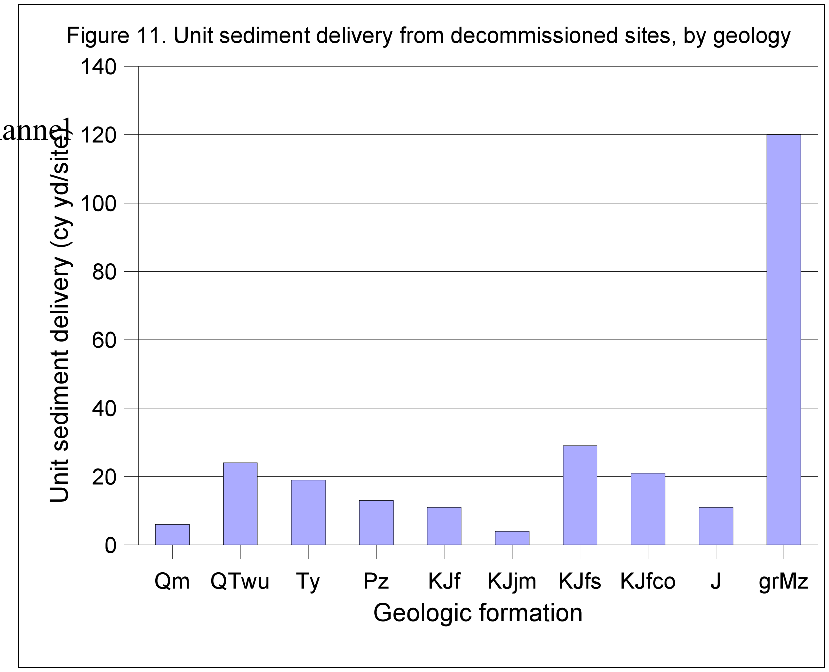
Table 8. Post-decommissioning erosion and sediment delivery, by geology, CDFG decommission monitoring study, North Coastal California

Geology	Site Type (#)				Post-decom erosion (yds^3)	Post-decom sediment delivery (yds^3)	Unit post-decom sediment delivery (yds^3/site)
	Stream crossing	Landslide	Other	Total			
Qm	1	2	0	3	92	17	6
QTwu	16	16	3	35	2,500	849	24
Ty	84	7	12	103	3,392	1,944	19
Pz	9	2	3	14	210	178	13
KJf	80	53	15	148	2,148	1,607	11
KJfm	6	1	2	9	38	37	4
KJfs	15	14	1	30	896	879	29
KJfco	14	12	5	31	882	654	21
J	20	4	16	40	427	423	11
grMz	30	0	6	36	6,378	4,324	120
Total	**275**	**111**	**63**	**449**	**16,963**	**10,912**	**24**

The unit past sediment delivery for decomposed granitic bedrock in the Klamath Mountains was exceptionally high (120 yds^3/site) compared to all other substrates (Table 8; Figure 11). Road decommissioning on this and similar highly erodible terrain likely requires special operating measures and exceptional care. Field observations of road decommissioning in the Grass Valley Creek watershed of Trinity County suggests that this is not an isolated problem, but one that merits special attention of special operating procedures (beyond the standard protocols for road decommissioning outlined in the FRGP).

7.7 Future Erosion

During the inventory of decommissioned roads and post-decommissioning erosion sites, we also made estimates of the location, nature and magnitude of future erosion that was likely to occur at each location. These estimates included the potential for future erosion, the volume of expected erosion and sediment delivery for each erosion feature. Not all the erosion features had the same potential for future erosion, and not all the features that are expected to erode will deliver



sediment to the stream channel. Examples of future erosion identified in the field inventory included: continued channel incision through unexcavated fill, continued movement and delivery from active slumps, gully widening, and continued rilling of bare soil areas, among others.

In the study area, 601 erosional features were identified as having the potential for future erosion, including 537 erosion features at stream crossings, 22 at landslide sites, and 42 features at "other" sites (Table 9a-c). From these 601 erosion features, stream crossings are expected to account for 88% of the future sediment delivery (Table 9a), landslides are expected to account for 2% (Table 9b) and "other" sites are expected to account for 9% (Table 9c).

Table 9a. Stream crossing post -decommissioning predicted future erosion and sediment delivery, by feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried stream crossings (#)	No. of future erosion features (#)	Post-decom future erosion (yds^3)	Post-decom future sediment delivery (yds^3)	Unit post-decom future sediment delivery (yds^3/feature type)
Bank erosion	22	30	534	526	18
Channel incision	161	203	2,261	2,258	11
Gully	20	24	74	72	1
Headcut	15	16	370	370	23
Surface erosion	115	192	4,295	4,149	22
Slump	52	71	4,248	2,295	32
Other	1	1	7	7	7
Total	**--**	**537**	**11,789**	**9,677**	**18**

Table 9b. Landslide post-decommissioning predicted future erosion and sediment delivery, by erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried landslides (#)	No. of future erosion features (#)	Post-decom future erosion (yds^3)	Post-decom future sediment delivery (yds^3)	Unit post-decom future sediment delivery (yds^3/feature type)
Gully	1	2	3	3	1
Surface erosion	9	9	124	9	1
Slump	9	11	636	316	29
TOTALS	**--**	**22**	**763**	**328**	**15**

Table 9c. "Other" sites post-decommissioning predicted future erosion and sediment delivery, by erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion feature	No. of inventoried "other" sites (#)	No. of future erosion features (#)	Post-decom future erosion (yds^3)	Post-decom future sediment delivery (yds^3)	Unit post-decom future sediment delivery (yds^3/feature type)
Gully	13	13	90	84	9
Surface erosion	17	20	69	29	1
Slump	5	9	2,613	886	98
TOTAL	**--**	**42**	**2,772**	**999**	**24**

Stream Crossings

Stream crossings contain 89% of the 537 predicted future erosion features at road decommissioning sites, including 30 bank erosion sites, 203 channel incision sites, 24 gullies, 16 headcuts, 192 surface erosion, 71 slumps or debris slides, and 1 "other" feature. Channel incision, surface erosion, and slumps/debris slides comprise 86% of the expected future erosion features at decommissioned stream crossings and are expected to produce 90% (8,702 yds^3)of the future delivery (Table 9a). When the expected future delivery and number of erosion features is converted to unit delivery, slumps/debris slides (32 yds^3/feature), surface erosion (22 yds^3/feature), and headcuts (23 yds^3/feature) are expected to generate the most future unit erosion (Table 9a).

Landslides

Landslides account for only 4% (22 features) of the expected future erosion features, including 2 gullies, 9 surface erosion sites, and 11 slumps or debris slides (Table 9b). Surface erosion, and slumps/debris slides make up 91% of the expected future erosion features at landslides and are expected to produce 99% (325 yds^3) of the future delivery (Table 9b). When the expected future delivery and number of future erosion features is converted to unit delivery, slumps/debris slides (29 yds^3/feature) dominate the feature types that are predicted to generate the greatest unit future erosion. All the rest of the future erosion features are expected to produce only 1 yd^3/feature (Table 9b).

"Other"

"Other" sites account for 7% (42 features) of the future erosion features that were identified in the field inventory of decommissioned roads, including 13 gullies, 20 sites of surface erosion, and 9 slumps or debris slides (Table 9c). Slumps/debris slides total 94% of the expected future erosion features at "other" sites and are expected to produce 97% (2,613 yds^3) of the future delivery (Table 9c). When the expected future delivery and number of future erosion features is converted to expected unit sediment delivery, slumps/debris slides, (98 yds^3/feature), and gullies (9 yds^3/feature), dominate the feature types that are expected to generate the most sediment. Surface erosion features are expected to produce only 1 yds^3/feature (Table 9c).

Erosion potential

Every potential future erosion site was assigned an estimated "erosion potential" (defined as the likelihood that the future erosion would actually occur) and sediment delivery ratio (%). The erosion potential for all sites that exhibit potential for future erosion was categorized into a five-tiered rating: high, high-moderate, moderate, moderate-low, and low (Tables 10a-c). Of the 537 erosion sites associated with stream crossings, 168 have a high to high-moderate erosion potential that is estimated to account for 7,210 yds^3 (75%) of future sediment delivery over approximately the next 50 years (Table 10a). Three hundred sixty nine (369) potential future erosion sites associated with stream crossings have a moderate to low erosion potential (moderate, moderate-low and low categories) that is estimated to account for 2,467 yds^3 (25%) of future sediment delivery over the next 50 years (Table 10a).

Of the 22 future erosion sites associated with landslides four (4) have a high-moderate erosion potential that we estimate will account for 109 yds^3 (33%) of future sediment delivery over the next 50 years (Table 10b). Eighteen (18) potential future erosion sites associated with landslides have a moderate, moderate-low or low erosion potential that we estimate will account for 219 yds^3 (67%) of future sediment delivery over the next 50 years (Table 10b).

Of the 42 erosion sites associated with "other" sites, 5 have a high to high-moderate erosion potential that we estimate will account for 131 yds^3 (13%) of future sediment delivery over the next 50 years (Table 10c). Thirty seven (37) potential future erosion sites associated with "other" sites have a moderate to low erosion potential that we estimate will account for 868 yds3 (87%) of future sediment delivery over the next 50 years (Table 10c).

7.8 Treatment Effectiveness

Treatment effectiveness is a measure of how effective the site decommissioning treatment was at achieving the sediment reduction goal of the program. During the inventory, we identified 275 stream crossings along the decommissioned roads in the sample, 12 of which had been left untreated. Of the 263 treated stream crossings 15 did not experience any post decommissioning erosion and sediment delivery. From geometric field measurements we calculated the average volume of potential sediment delivery at a stream crossing, before decommissioning, to be 441 yds^3, with a maximum of 4,288 yds^3 and a median of 174 yds^3 (Table 11). From our field measurements we calculated the average post-decommissioning sediment delivery to be 34 yds^3 per stream crossing, with a maximum of 634 yds^3 and a median of 8 yds^3. The average stream

Table 10a. Stream crossing post-decommissioning predicted future erosion and sediment delivery, by erosion potential and feature type, CDFG decommission monitoring study, North Coastal CA

Erosion potential	Feature type (#)								Post decom future erosion (yds^3)	Post decom future sediment delivery (yds^3)
	Bank erosion	Channel incision	Gully	Headcut	Surface erosion	Slide	Other	Total		
High	1	6	3	6	1	3	0	20	945	671
High-moderate	9	47	8	4	64	16	0	148	7,299	6,539
Moderate	13	101	7	4	95	39	1	260	3,027	2,030
Moderate-Low	7	47	5	1	26	10	0	96	460	392
Low	0	2	1	1	6	3	0	13	58	45
TOTAL	**30**	**203**	**24**	**16**	**192**	**71**	**1**	**537**	**11,789**	**9,677**

Table 10b. Landslide post-decommissioning predicted future erosion and sediment delivery, by erosion potential and feature type, CDFG decommission monitoring study, North Coastal California

Erosion potential	Feature type (#)				Post-decommissioning future erosion (yds^3)	Post-decommissioning future sediment delivery (yds^3)
	Gully	Surface erosion	Slide	Total		
High-moderate	0	2	2	4	119	109
Moderate	2	5	6	13	575	197
Moderate- low	0	1	3	4	69	22
Low	0	1	0	1	<1	<1
TOTAL	**2**	**9**	**11**	**22**	**763**	**328**

Table 10c. "Other" sites post-decommissioning predicted future erosion and sediment delivery, by erosion potential and erosion feature type, CDFG decommission monitoring study, North Coastal California

Erosion potential	Feature type (#)				Post-decom future erosion (yds^3)	Post-decom future sediment delivery (yds^3)
	Gully	Surface erosion	Slide	Total		
High	2	0	0	2	51	51
High-moderate	1	1	1	3	122	80
Moderate	6	10	3	19	1,088	725
Moderate- low	4	7	3	14	1,115	115
Low	0	2	2	4	396	28
Total	**13**	**20**	**9**	**42**	**2,772**	**999**

crossing adjustment, (calculated as the volume of post-decommissioning delivery divided by the original volume of the crossing) is 7.7 percent (Table 11). These results are skewed by two roads that experienced comparatively large volumes of post-decommissioning erosion and sediment delivery (3,087 yds^3 and 1,070 yds^3). Thus, median unit sediment delivery is less than 5 yds^3 per decommissioned crossing.

Table 11. Stream crossing pre- and post-decommissioning erosion and sediment delivery statistics (n=275), CDFG decommission monitoring study, North Coastal California.

Statistic	Pre-excavation stream crossing volume (yds^3)	Predicted stream crossing sediment delivery (wash out volume) (yds^3)	Post-decom. erosion volume (yds^3)	Post-decom. sediment delivery volume (yds^3)	Stream crossing adjustment[1] (%)
Minimum	0	0	0	0	0 %
Maximum	6,347	4288	1,422	634	15.0 %
Average	769	441	47	34	7.7 %
Median	336	174	9	8	4.6 %

[1] Stream crossing adjustment = Measured post-decommissioning sediment delivery (yds^3) / Predicted pre-excavation stream crossing washout volume (yds^3) (expressed as a percentage).

Of the 449 decommissioned sites targeted for field analysis, 10 were not found. These included 9 fillslope landslides that had been excavated along with the entire road fillslope and one small stream crossing that was nested in a series of non-erodible dipped swales. Of the 439 sites that were located, 57% (253) met all CDFG road decommissioning prescription protocols. Forty three percent (186) failed to meet one or more of the generally accepted standards for road decommissioning (Table 12; see Appendix E for generally accepted CDFG decommission protocols).

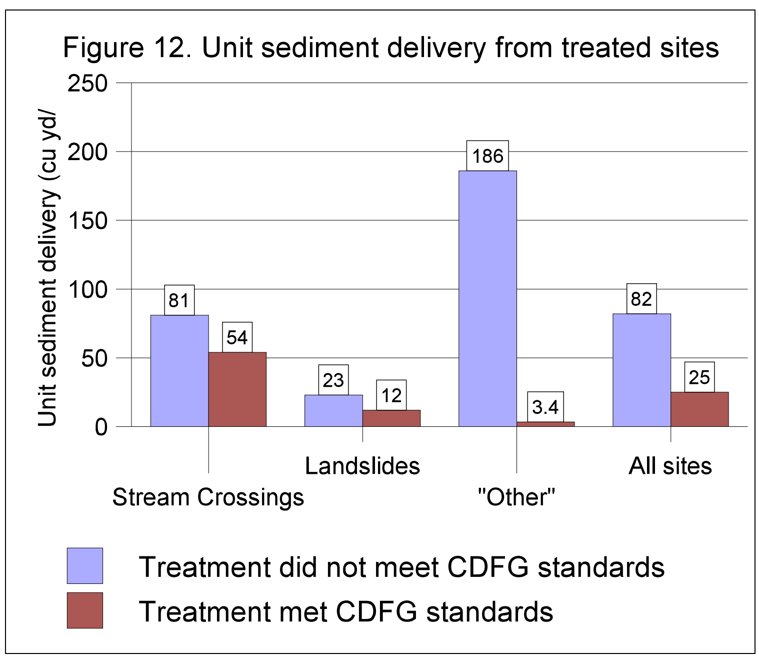
Table 12. Decommissioning treatment effectiveness, by treated site type, CDFG decommission monitoring study, North Coastal California.

Site type	Was treatment design appropriate for site?			Was the treatment implemented as prescribed?			Did the site meet all CDFG prescription protocols?	
	Yes	No	No data	Yes	No	No data	Yes	No
Stream crossing	57	12	206	58	8	209	118	157
Landslide	51	3	57	54	8	49	94	17
Other	19	4	40	19	3	41	51	12
TOTAL	**127**	**19**	**293**	**131**	**19**	**289**	**253**	**186**

At stream crossings, 118 (43%) met all CDFG road decommissioning prescription protocols, while 157 (57%) failed to meet one or more of the accepted standards for road decommissioning (Table 12). At landslide sites 94 (85%) met all CDFG road decommissioning prescription protocols and 17 (15%) failed to meet one or more of the accepted standards for road decommissioning (Table 12). At the 63 “other” sites 51 (81%) met all CDFG road decommissioning prescription protocols while 12 (19%) failed to meet one or more of the accepted standards for road decommissioning (Table 12).

The estimated total volume of past and future sediment delivery from inventoried sites decommissioned under the CDFG Program is 21,916 yds^3. Of this volume, 10,912 yds^3 (≈50%) is post-decommissioning sediment delivery that has already occurred, and 11,004 yds^3 (≈50%) is predicted as future sediment delivery (Table 13). For the sites that met all CDFG road decommissioning prescription protocols we estimate past and future sediment delivery to be 6,615 yds^3 (30%) and for sites that failed to meet one or more of the accepted standards for road decommissioning we estimate past and future sediment delivery to be 15,301 yds^3 (70%)(Table 13).

Following approved and generally accepted road decommissioning standards was found to play an important role in determining restoration effectiveness. Unit sediment delivery was calculated for past and future erosion and sorted by whether it met all CDFG road decommissioning prescription protocols (Table 13; Appendix E). For treated stream crossings we calculated 54 yds^3 of sediment delivery if it met all CDFG protocols and 81 yds^3 of sediment delivery if it failed to meet all CDFG protocols (Figure 9). For treated landslide sites we calculated 1.2 yds^3 of sediment delivery if it met all CDFG protocols and 23 yds^3 of sediment delivery if it failed to meet all CDFG protocols. For treated “other” sites we calculated 3.4 yds^3 of sediment delivery if it met all CDFG protocols, and 186 yds^3 of sediment delivery if it failed to meet all CDFG protocols (Table 13).



For all sites that were treated, we calculated 25 yds^3 of past and future sediment delivery if it met all CDFG protocols, and 82 yds^3 of past and future sediment delivery if it failed to meet all CDFG protocols (Figure 9). Thus, sites that were implemented according to generally accepted CDFG decommissioning protocols were responsible for 70% less unit sediment delivery than those sites that failed to meet one or more implementation protocols (Figure 12). This strongly argues for adherence to standard implementation protocols, unless proposed deviations can be explained and justified on the basis of local site conditions.

Table 13. CDFG protocol standards, by treated site type, CDFG decommission monitoring study, North Coastal California.

Site type	*Did the site meet all CDFG prescription protocols?*														
	Yes					***No***					***Total***				
	No. (#)	Post-decom sediment delivery (yds^3)	Unit sediment delivery (yds^3/ site)	Post-decom predicted future sediment delivery (yds^3)	Predicted unit future sediment delivery (yds^3/ site)	No. (#)	Post-decom sediment delivery (yds^3)	Unit sediment delivery (yds^3/ site)	Post-decom predicted future sediment delivery (yds^3)	Predicted unit future sediment delivery (yds^3/ site)	No. (#)	Post-decom sediment delivery (yds^3)	Unit sediment delivery (yds^3/ site)	Post-decom predicted future sediment delivery (yds^3)	Predicted unit future sediment delivery (yds^3/ site)
Stream crossing	118	2,710	23	3,609	31	157	6,612	42	6,068	39	275	9,322	34	9,677	35
Landslide	94	64	<1	57	<1	17	121	7	271	16	111	185	2	328	3
Other	51	120	2	55	1	12	1285	107	944	79	63	1,405	22	999	16
Total	**263**	**2,894**	**11**	**3,721**	**14**	**186**	**7283**	**43**	**7,283**	**39**	**449**	**10,912**	**24**	**11,004**	**25**

Table 14. Recommended treatments by problem type, CDFG decommission monitoring study, North Coastal California.

Site type	Total no. of sites (#)	No. sites requiring further treatment (#)	Treatment types									Post-decommissioning future sediment delivery if sites received further treatment (yds^3)
			Further excavation	Wider channel	Lay sideslopes back further	Rock armor	Better surface drainage treatments	Better surface erosion treatments	Grade Control	Better spoils management	Other	
Stream crossings	275	193	107	18	80	2	8	11	7	73	27	8991
Landslides	111	16	13	0	1	0	1	1	0	8	0	260
Other	63	18	11	1	1	2	2	1	0	1	3	963
TOTALS	**449**	**227**	**131**	**19**	**81**	**4**	**11**	**13**	**7**	**82**	**30**	**10,214**

7.9 Spoils Disposal

One of the generally accepted standard protocols for road decommissioning is that soil excavated from decommissioning sites be stored in a manner and location where it will not enter or re-enter a watercourse. This may require endhauling. Of the 449 treated sites in the decommissioning study, 81 (18%) of them exhibited spoil that could potentially re-enter a watercourse; 73 of those were from stream crossing excavations and 8 were from landslide excavations. The 73 associated with stream crossings, represent 27% of the total number of crossings that were treated. The 8 associated with landslide excavations represent only 7% of the total number of treated landslides. Clearly, placing excavated spoil materials next to or near the excavation site is a cost-saving measure, but can lead to future sediment delivery also. The practice of spoiling excavated materials next to decommissioned stream crossings has the greatest potential for resulting in future sediment delivery. The added expense of truck endhauling, or long-distance drifting, may be both necessary and cost-effective when compared with the potential risk of future sediment delivery.

7.10 Implementation Deficiencies

We assessed and categorized treatment deficiencies at all of the treated sites. Of the 449 treated sites, 227 (50%) would have required further treatment to meet all of the CDFG accepted protocols for road decommissioning (Table 14). Of the 275 treated stream crossings, 193 (70%) required further treatment. The most common deficiencies for stream crossings excavations included under-excavation (107 sites), inadequate channel width (18 sites), sideslopes too steep (80 sites), and poor spoil management (73 sites). Of the 111 treated landslides, 16 (14%) required further treatment. The most common deficiencies included under excavation (13 sites) and poor spoils management (8 sites). Finally, of the 63 "other" sites, 18 (29%) required further treatment. The most common deficiency was under excavation (11 sites)(Table 14).

7.11 New Untreated Sites

Some erosion and sediment delivery sites were discovered during the field inventory. Either they were not identified in the initial sediment source inventory, or had developed since the road was decommissioned. A total of 18 of these sites were identified, including 3 stream crossings, 6 landslides, 5 springs, and 4 gullies (Table 15).

Table 15. New or newly discovered untreated sites on inventoried decommissioned roads, CDFG decommission monitoring study, North Coastal California.

Site type	No. (#)	Why was site not treated? (#)			Length of "connected" road (ft)	Future sediment delivery (yds^3)[1]	Unit future sediment delivery (yds^3/site)
		Not identified pre-decom	Developed post-decom	Unknown			
Stream crossing	3	2	0	1	387	130	43
Landslide	6	0	4	2	335	5,770	962
Spring	5	1	2	2	370	135	27
Gully	4	1	3	0	100	113	28
TOTAL	**18**	**4**	**9**	**5**	**1,192**	**6,148**	**342**

[1] Future sediment delivery includes persistent surface erosion for 1,192 feet of road. Calculation of persistent surface erosion assumes 25' wide road prism and cutbank contributing area, and 0.2' of road/cutbank surface lowering over one decade. In total, persistent surface erosion only accounts for about 220 yds3 of future sediment delivery from the untreated sites.

Stream Crossings: Two of the three untreated stream crossings were not identified in the pre-decommissioning road assessment; they were not shown on maps or described in treatment prescriptions within the original assessment report or in the subsequent decommissioning proposal. It is unknown why the third site was left untreated.. Three hundred eighty-seven (387) feet of hydrologically connected road continues to deliver sediment to these three untreated stream crossings. PWA staff estimated the total future sediment delivery from these three stream crossings to be approximately 130 yds^3 (Table 15).

Landslides: Six landslides identified in our field review had not been treated during road decommissioning. Four developed in the post-decommissioning period, while the reasons for the remaining two not being treated are unknown. Three hundred thirty-five (335) feet of road remain hydrologically connected to these six sites. PWA estimates the future sediment delivery from these six landslides to be 5,770 yds^3.

Springs: Five springs were identified during our assessment, not treated during the decommission process. One of these was not identified before the treatment began and two developed post-treatment. It is not known why the final two sites were left untreated. A total length of 370 feet of road remains hydrologically connected to these untreated spring sites and the estimated future sediment delivery from these sites is 135 yds^3 (Table 15).

Gullies: Four gullies were identified in this assessment, not treated during the road decommissioning process. One of these gullies was not identified pre-treatment, and the remaining three developed following road decommissioning. A total road length of 100 feet remains hydrologically connected to these four gullies, and PWA estimates the total future sediment delivery resulting from the untreated sites is 113 yds^3.

7.12 Road Drainage

Over 41 miles of decommissioned road, along 45 different road segments, was evaluated to determine the overall road surface drainage characteristics using a specialized data form (Appendix C: Road Data Form). The data was analyzed to provide insight into the hydrologic behavior of the decommissioned roads, and the thoroughness with which road surface drainage was treated by decommissioning.

All of the inventoried roads were partially outsloped, with only localized areas of any other road drainage shape. Much of this outsloping was achieved through strategic spoils placement and light road shaping with heavy equipment. After treatment, very little of the decommissioned road surface delivered sediment to the stream system; only 3,785 feet (1.7%) of road surface remained hydrologically connected out of 41.2 miles of road evaluated. In the pre-treatment period, it is likely that hydrologic connectivity approached or exceeded 30% (12 miles). The most prevalent post-decommissioning delivery location was where the decommissioned road approaches and crosses stream channels. Here, short road segments are still locally connected and delivering fine sediment. We also documented a few other instances of individual cross-road drains, waterbars and rolling dips that were still delivering a small amount of surface runoff and fine sediment. The observed rate of surface erosion on decommissioned road surfaces is relatively low, largely due to small drainage areas and developing vegetative cover on the decommissioned roads. In addition, with only 1.7% of the road network still connected to the stream system, the volume of post-decommissioning sediment delivery from hydrologically connected road reaches comparatively negligible.

8.0 Discussion

PWA evaluated and quantified post treatment erosion at 449 sites on 51 miles of road decommissioned with funding from the CDFG SB271 Restoration Grant Program. Our results document the primary erosional mechanisms, features and causes associated with common techniques used to decommission stream crossings, landslides and road segments. Furthermore, we examined the most common, avoidable operator/supervisor mistakes as well as many other nuances associated with road decommissioning restoration activities.

8.1 Erosion Features and Causes of Erosion at Decommissioned Stream Crossings

PWA examined two hundred seventy-five (275) stream crossings. Of these, 12 were left untreated. Of the 263 treated stream crossings 15 did not experience any measurable post-decommissioning erosion and sediment delivery. The mean post-decommissioning sediment delivery at a treated stream crossing was 34 yds^3. The fact that most stream crossings experienced some post decommissioning erosion should not be interpreted as an inherent failure of the program effectiveness; in fact some erosion appears unavoidable and is to be expected at stream crossings as they adjust to their newly configured profile through the former road prism.

Erosion Features

Channel incision, surface erosion and slumping/debris slides are the most common post-implementation erosion features associated with decommissioned stream crossings. Combined they comprise 88% of the identified erosion sites and 91% of the post-decommissioning sediment delivery (Appendix G: Photos 1a, b - 4a, b).

Surface erosion, slumping/debris slides, and headcuts constitute the largest "per feature" unit sediment delivery volume (yd^3 /feature). There are likely several reasons for this: 1) 95% of the stream crossings exhibited some degree of channel incision. Some channel erosion is largely unavoidable when using heavy equipment to remove soil from a crossing and exhume a former stream channel. Typically after decommissioning there is a small amount of loose soil in the newly constructed channel that is mobilized and sorted as the channel adjusts itself to its new configuration. 2) Headcuts, although less common than channel incision, tend to be deeper and more active than is typically seen at channel incision sites. It is not uncommon for headcuts to migrate outside of the boundaries of the crossing and sometimes into the native channel upstream. Furthermore, unexcavated channel reaches above the top of the stream crossing excavation tend to headcut rapidly as the streamflow cuts through the loose sediment and the channel adjusts itself to its new configuration.

The sideslope gradient has a significant effect on the occurrence of debris slide and slump type features associated with stream crossing excavations. Table 5 shows that stream crossings typically exhibit an order of magnitude more mass wasting erosion if the side slopes are steeper than 50%. The reason for this is that slope steepness is one of the primary driving forces associated with slope stability. If the slope is composed of unexcavated or uncompacted fill materials, which typically has less cohesion and strength than the surrounding native material, the instability is likely exacerbated.

<u>Causes of Erosion</u>

There are both obvious and subtle causes associated with erosion at decommissioned stream crossings. Every crossing has a unique set of variables that determine the nature and magnitude of post-decommissioning stream crossing erosion. In many cases some of the causal factors may originate outside of the evaluated stream crossing, such as increased runoff or upstream or downstream base level changes from past land management practices. In almost all cases in this study there was a combination of causes and feature types that culminated in the overall erosion and sediment delivery measured at any given site.

In the road decommissioning inventory, we identified the primary and secondary causes of all inventoried erosion features, but in reality most erosion features have multiple or complex causes that vary in magnitude and influence for any given erosion feature. For example, a slide may have originated from undercutting of the side slope of a stream crossing; but the undercutting may have developed in response to base level lowering due to channel incision through unexcavated fill in the channel. These cascading effects can be difficult to determine and quantify, especially if the erosion is old and vegetation obscures physical observations.

Natural vs. Operator Causes - We categorized identifiable causes into "operator error" and natural or "unavoidable" causes. Of the 9,322 yds^3 of past delivery associated with stream crossings, 5,598 yds^3 (60%) was due to natural or unavoidable causes, 67% of that was due to overland flow on the sideslopes of the crossing excavations. Even on the most thoroughly mulched sideslopes of excavated stream crossings, surface erosion driven by direct precipitation and overland flow can be a significant contributor of fine grained sediment to stream channels.

Mulching was the most common erosion control technique used on the sideslopes of excavated stream crossings. Two types of mulching were observed in this study: straw mulch and slash mulch. Both have their advantages and drawbacks. Straw mulch is clearly effective at reducing rain drop erosion and is easy and inexpensive to spread. Most bare soil is initially covered after excavation. The drawback to straw mulch is that it has a short longevity; in many cases shorter than the time needed for the vegetative re-growth that will eventually fully protect the excavated surface from continued surface erosion. Slash mulch is typically used on road tread surfaces but it was also used to protect some sideslope excavations. The primary benefit to slash mulch is that once it is in place, it stays in place for a long time and the area it covers is usually protected from surface erosion. The drawbacks are that it rarely protects more than 15% of the bare soil (it is sparsely applied) and it is time consuming and expensive to spread. PWA commonly observed pedestals of soil from three to six inches tall directly below slash mulch while the rest of the surrounding soil washed away (Appendix G: Photo 5a, b).

Of the 9,322 yds^3 of past sediment delivery associated with erosion at decommissioned stream crossings, we estimated that 3,496 yds^3 (40%) was due to operator or supervision causes. Sixty nine percent (69%) of avoidable operator-caused erosion features were due to unexcavated fill within the stream crossing. The most common locations for unexcavated fill in decommissioned stream crossings were: 1) between the inboard road and the upstream natural channel, (i.e., sediment wedges backed up behind pre-existing poorly functioning (Type 2) crossings), 2) between the outboard road and the downstream natural channel, (i.e. insufficiently deep excavations at the outboard portion of the road), 3) in the channel itself (i.e. un-removed woody debris and associated sediment from old Humboldt crossings), and 4) on excavation sideslopes that were not sloped back to the gradient of the natural hillside above and below the crossing. Typically under-excavated fill leads to a multitude of erosional features including headcuts, channel incision and mass wasting of the side slopes as the channel and the sideslopes adjust to a stable configuration (Appendix G: Photos 2a,b; 4a,b; 7a,b; 8a,b).

The second most common cause of erosion at excavated stream crossings is undercutting by direct excavation. Typically, this is a result of over excavation of fill as the operator is digging into native material or bedrock. This can cause sideslope failure and an oversteepened profile through the stream crossing that commonly results in significant erosion as the stream attempts to restore itself to a stable configuration. Often, over-excavation (especially at the inboard road) causes erosion of native soil and overall lowering of the base level of the stream. This can have significant effects outside of the crossing being excavated as the newly constructed “nick point” migrates upstream. Careful evaluation and design of the stream crossing excavation boundaries and proposed excavation depths is necessary to prevent this type of erosion from occurring.

Poor profile transitions at the top and the bottom of the excavation are a third common cause of channel erosion and can lead to significant sediment delivery at decommissioned stream crossings. Poor profile transitions can be caused by leaving unexcavated fill or for other reasons including: lack of attention to detail by the operator, inexperienced operator, inadequate supervision or technical oversight, complex equipment logistics or excavation variables, or pre-existing site conditions.

Some problems encountered during decommissioning of a stream crossing are due to the original construction of the road and not associated with operator error or unavoidable erosion following decommissioning. A very common problem that could be misinterpreted as over-excavation is “beheading” of the stream during road construction. Beheading of a stream refers to the practice of cutting the inboard edge of the road deeper than the natural channel as the road is being constructed. This practice leads to an over-steepened section in the stream profile that cannot be easily corrected. It is important to recognize this during the assessment phase of the restoration work so adequate measures, such as headcut armoring, can be implemented during road decommissioning.

8.2 Erosion Features and Causes of Erosion at Decommissioned Landslides

PWA examined 111 landslides, of which 87 (78%) did not exhibit any visible post-decommissioning erosion and sediment delivery. From the 24 landslides that exhibited post-decommissioning erosion the mean sediment delivery was 12 yds^3. The fact that 78% of the landslide excavations experienced little to no post decommissioning erosion and sediment delivery testifies to the effectiveness of the practice of removing unstable fill from the outboard edge of the road to reduce mass wasting hazards (Appendix G: Photo 10a, b). Over time, continued monitoring of the decommissioned roads will allow for a longer term, more thorough evaluation of the effectiveness of landslide identification as well as techniques used to control or prevent sediment delivery from mass wasting processes.

Erosion Features

Surface erosion and slumping/debris slides are the most common post-implementation erosion features associated with landslide decommissioning. Combined they total 88% of the identified erosion features and 99% of the post-decommissioning sediment delivery. Compared to surface erosion, slumping/debris slides were far more efficient at delivering eroded sediment. Surface erosion typically has a very low delivery rate because there is usually a buffer of vegetation between the excavated surface and the closest watercourse below the site. This buffer facilitates dispersion and infiltration of the overland flow of sediment-laden water before it reaches a stream. In addition, slumps and small landslides not only have a larger erosion volume per feature; but their delivery rate is higher because the buffer zones below the excavated landslides are not as efficient at trapping sediment from mass wasting.

Erosion Causes

The causes of erosion and sediment delivery at treated landslide sites are not nearly as complex as those at treated stream crossings. Although there are multiple variables that influence erosion, typically, they are more obvious to the observer in the field. In most cases the causal factors originate at or near the landslide in question so there is a more obvious direct correlation between these factors and the erosion feature being observed.

Natural vs. Operator Causes - As with stream crossings sites, we categorized identifiable post-decommissioning erosion causes on landslide sites into "operator error" and natural or "unavoidable" causes. Of the 185 yds^3 of post-decommissioning sediment delivery associated with landslide sites, 57 yds^3 (31%) was due to natural or unavoidable causes. Most (67%) of these sites of sediment delivery were caused by emergent groundwater, typically in conjunction with unstable native soil. In most cases, the groundwater was emanating directly out of the slide area as opposed to originating off-site and subsequently affecting the slide as it made its way downhill. These types of situations, where groundwater emerges within a slide, are difficult to recognize and treat during road decommissioning, so it is important to completely excavate all road fill from a potential fillslope landslide site if it appears to be wet during most or part of the year. Signs may include springs or soil pipes, gleyed or mottled soils, and/or wet soils or perched groundwater observed during excavation.

Another significant contributor to natural or unavoidable erosion is direct overland flow of rain water. Although overland flow caused a significant portion of the post-decommission erosion measured at landslide sites, the actual amount of sediment delivered to a watercourse is very low due to dispersion and infiltration between the base of the excavation and the closest watercourse. This results in a low unit sediment delivery.

Of the 185 yds^3 of post-decommissioning sediment delivery associated with decommissioned landslide sites, 128 yds^3 (69%) was attributed to operator or supervision causes. Sixty three percent (63%) of avoidable operator-caused erosion features were due to the presence of unstable, unexcavated fill. Typically, unstable unexcavated fill was located outside of the treated areas on the right or left margins of the decommissioned (excavated) slide mass. Due to a lack of detailed information on the prescribed landslide excavation dimensions, it was frequently difficult to determine if the unexcavated, unstable fill was originally identified and targeted for excavation or if the instability developed during the post-decommissioning period.

Either way it is clearly important to examine closely the targeted and surrounding area of each proposed landslide excavation site for signs of slope instability.

Another common location for unstable, unexcavated fill was in the targeted landslide excavation itself. Usually the unstable portion of the excavated area was road fill near the axis of the slide. Field observations suggest this situation was almost always due to lack of excavation depth at the upper end of the slide. The generally accepted CDFG protocol for performing excavations of unstable and potentially unstable fillslope landslides calls for a steeply concave excavation profile. This type of excavation mimics the theoretical arcuate shape of the failure plane and results in removal of most of the unstable material, especially near the head of the failure where driving forces would otherwise be greatest.

8.3 Erosion Features and Causes at "Other" Sites

Most of the "other" sites inventoried during our survey were either springs or swales that did not meet the criteria to be classified as a stream crossing. PWA examined 63 "other" sites; 26 did not show signs of any post decommissioning erosion and sediment delivery. From the 37 "other" sites that exhibited post-decommissioning erosion the mean sediment delivery at a treated site was 52 yds^3. The fact that a high percentage of these sites exhibited significant post-decommissioning erosion and sediment delivery suggests the methods used to treat these sites should be revised.

Erosion Features

Gullying, surface erosion, and slumping/debris slides comprised all of the post-implementation erosional features associated with decommissioned "other" sites. Slumping/debris slides and gullies constituted the largest unit erosion volume per feature, with surface erosion being less significant. Typically, "other" sites were minimally treated (usually just a dip at a spring or swale) perhaps because the erosion potential of the site were not recognized as significant, or the distance to a nearby stream was though to be sufficient to prevent sediment delivery. This, in turn, translated to large amounts of erodeable fill being left which, when wet, was vulnerable to gullying and mass wasting Gullies, although less common than mass wasting features, tend to be deeper and develop more easily in the unconsolidated fill at the outboard edge of the road. It is not uncommon for fillslope gullies to migrate outside of the road prism, sometimes into native ground, which can translate into higher unit delivery volumes.

Erosion Causes

The causes of erosion and sediment delivery at treated "other" sites are not complex. Post-decommissioning erosion features are typically associated with emergent groundwater and oversteepened or unexcavated fill. As with landslides, in most cases the causative factors originate at or near the site in question so there is a more obvious direct correlation between these factors and the erosional features being observed.

Natural vs. Operator Causes - We categorized identifiable causes into "operator error" and natural or "unavoidable" causes. Of the 1,405 yds^3 of past sediment delivery associated with "other" sites, 1,306 yds^3 (93%) was primarily due to natural or unavoidable causes. Most (74%) was primarily due to emergent groundwater, typically in conjunction with unexcavated fill. In most cases field observations suggest that emergent groundwater was emanating directly out of the hillside above the site. Although emergent groundwater was the primary "natural" cause for erosional "other" sites, operator or supervisor error, such as the presence of unexcavated fill, contributed to the actual erosion and subsequent sediment delivery.

Of the 1,405 yds^3 of past sediment delivery associated with "other" sites, 45 yds^3 (3%) was primarily due to operator or supervision causes. Typically, the unstable unexcavated fill was located at the implementation site. This is usually due to the singularly common practice of dipping the road at springs or swales. This practice leaves large amounts of unprotected fill on the road where known emergent groundwater flows intermittently during the course of a normal year. Saturated fill is highly susceptible to erosion and overland flow of water, and the development of a gully or rill provides a delivery mechanism for the eroded material.

8.4 Geologic Influence on Erosion

Post-decommissioning unit sediment delivery from decommissioned sites is significantly higher when sites are located in granitic bedrock areas (Figure 11, Appendix G: Photo 1a, 1b). Restoration practitioners have observed and anecdotally maintained that post-decommissioning erosion rates in decomposing granite are higher than average, and our results quantitatively support this concept. Most granitic rocks contain minerals from the mica family, and these minerals are highly susceptible to decomposition at the earth's surface. As the mica minerals break down and decompose, the more resistant minerals (silica, feldspars) fall out of the matrix and form a granular non-cohesive, highly erodible soil. Our field observations and data suggest that even when utilizing the best management practices on decommissioned sites, granitic substrates have the potential to erode significantly more than other geologic substrates (Figure 11, Appendix G: Photo 1a, 1b). For this reason, standard operating procedures for road decommissioning in granitic terrain (where soils are non-cohesive) need to be strictly followed, or (in some cases) modified to provide proper protection to excavated stream crossings and their sideslopes.

Surface erosion rates in granular, non-cohesive soils can be extremely high; so extra measures may be required to provide complete and long-lasting protection to erodible soils. This is especially true in inland areas where rates of revegetation are slow and natural ground cover may take several years to become established. Similarly, excavated stream channels are not likely to be self-armoring, as they often are in other "harder" lithologies, thereby leading to elevated rates of channel incision, head-cutting and bank erosion. Channel armoring or other protective grade stabilization measures may be locally warranted where solid, non-erodible channel beds cannot be exhumed during decommissioning.

8.5 Time Influence on Erosion

There are many factors to consider when looking at post-decommissioning erosion and sediment delivery over time. A comparison of Tables 4a-c and Tables 10a-c demonstrates that the expected future sediment delivery is generally higher than the measured post-decommissioning sediment delivery. The primary reason for this is the time frame for which they are being evaluated. Future erosion and sediment delivery is evaluated over an estimated 50 year time span, while the maximum post-decommissioning time for our current erosion measurements is 7 years. This does however suggest that the overall rate of erosion slows over intermediate time scales.

Although PWA doesn't have unequivocal quantitative evidence suggesting the rate of erosion at decommissioned sites slows over time there are many lines of evidence that suggests it does. First, in our inventory of the decommissioned roads there were fewer expected future erosion features than there were documented past erosion features. Furthermore, many of the future erosion features are currently existing features that are expected to continue to erode, but that have probably seen their greatest erosional activity. Second, field observations suggest vegetation re-growth is continuing rapidly on all but a few road segments. As this vegetation cover continues to develop, the erosion rate for many of the existing erosion features is expected to slow dramatically. Observationally, this has been the case in areas with longer records of road decommissioning (e.g., Madej, 2001). Third, our findings suggest decreasing erosion rates over time are consistent with other observations and decommission studies on the northcoast (Madej, 2001; Bloom, 1998; Klein, 2003).

8.6 Rock Armoring

Rock armor is commonly used to protect sideslopes, channels, and unexcavated fill material at stream crossings, swales, and springs. It is usually considered an upgrade treatment for roads and is not typically used as a primary treatment for road decommissioning. Most decommissioning sites evaluated in this study did not employ rock armor, although a few did, and a few others should have. The most common use of rock armor was for protecting dipped swales and for sideslope protection and buttressing excavated stream crossing sideslopes.

Rarely did PWA observe the utilization of rock armor in compliance with the CDFG accepted standards. In cases where rock armor was improperly applied the most common mistakes observed were: improper sizing, improper quantity, and improper placement (Appendix G: Photo 11a, b).

Improper Sizing - In most instances where PWA observed the placement of rock armor, rock sizing was not done to CDFG standards. In most instances the rock was too large and was not sorted correctly to effectively protect the vulnerable area. Depending on the purpose of the rip rap, proper sizing of rock armor has two elements: 1) rock armor needs to be sized appropriately such that it will not be hydrologically transported by the watercourse or spring it is designed to protect, and 2) rock armor needs to be poorly sorted (well graded) such that small rock fill the interstitial spaces in the larger rock. This will provide a continuous, less porous blanket of rock that minimizes flow through the rock and thereby protects the underlying substrate. In other cases, rock armor can be used to buttress the slope near its toe, thereby resisting the downslope movement of a slump or small unstable mass. In this use, the mass of the rock is the protecting mechanism, and interstitial voids may not need to be filled.

Improper Quantity - In most cases where protective rock armoring was observed, the quantity was appropriate for the site conditions. The most common quantity problems observed were the use of too much rock, this can result in either diversion of low flows around the armor (flow deflection) or, at a minimum, unnecessary over-expenditure of limited funds. Proper armor quantity is critical to effective protection of fill and vulnerable crossing sideslopes. If the volume of armor is insufficient then water can exceed the boundaries of the armor and erode the material it is meant to protect (Appendix G: Photo 11a, b).

Improper Placement - Improper placement of rock armor was almost universal at the observed armor locations. The most common problems were lack of a confining shape to the armor (i.e., adequate bed and banks), and insufficient length to fully protect any remaining fill at the site (i.e., armor the entire length of the excavation). Where armor is used, proper placement is critical to the long-term success of fill-protection. If the armor is not placed correctly then water can quickly undermine or laterally cut around the protective armor, and the time and materials are wasted. There are many good references for proper armor placement including the Handbook for Forest and Ranch Roads (PWA, 1994), and Chapter 10 of the California Department of Fish and Game Fisheries Restoration Manual (CDFG, 2004). The basic elements of proper armor placement include: sufficient width, depth and concavity to confine a 100-year runoff event and sufficient size and thickness of rock armor (i.e., multiple layers of rock) to protect the underlying fill from erosion (Appendix G: Photo 11a,b).

8.7 Spoils Disposal

Spoils disposal is a critical element in determining the effectiveness of road decommissioning projects because, if not disposed of properly, eroded or failing spoil can quickly and severely degrade water quality. Soil excavated from sites needs to be stored in a place and manner such that it will not enter or re-enter a watercourse. If spoils are placed in improper locations then the eroded sediment can enter a watercourse and degrade critical fish habitat. Of the 449 treated sites, 81(18%) of them had spoil that could potentially re-enter a watercourse; 73 of those were from stream crossing excavations and eight were from landslide excavations. These represent entirely avoidable potential impacts.

The most common problematic spoil disposal location for excavated stream crossings was at the margin of the crossing, directly above the excavated side slope. From this location surface erosion or mass wasting processes can deliver spoil right back into the crossing from which it was excavated. There are two common road decommissioning practices that tend to encourage spoiling close to the margin of a stream crossing. Typically, when a road is decommissioned using the in-place outslope technique, spoil is excavated from the road fillslope and placed against the cutbank for the entire length of the road. In many cases spoils were improperly placed immediately adjacent to the excavated stream crossing, thereby perching uncompacted spoil materials above the crossing. Secondly, when excavating fill from a stream crossing, it is quicker, easier, and cheaper to move the soil the shortest distance possible. This encourages operators to place the spoils too close to the edge of the excavated crossing, rather than endhauling or pushing the spoils farther down the road.

Problematic spoil locations associated with landslides typically reflect the same issues associated with stream crossings. Either spoil was placed against the cutbank directly in line with the axis of the slide, or it was placed on the margins of the unstable area where it could either erode back into the excavated slide or trigger additional instability.

8.8 Treatment Effectiveness

Treatment effectiveness is a measure of how effective the site decommissioning treatments are at sediment reduction. Two hundred seventy-five (275) stream crossings were inventoried, of which 12 were left untreated. Of the 263 treated stream crossings, 15 did not exhibit any post-decommissioning erosion and sediment delivery. The average post-decommissioning stream crossing adjustment, calculated as the post-treatment sediment delivery divided by the estimated pre-excavation sediment delivery (washout volume), was 5%. This implies that the program has been 95% successful at eliminating long-term potential future erosion from roads targeted for decommissioning.

Unit sediment delivery was calculated for all inventoried sites and evaluated for compliance with all CDFG road decommissioning implementation protocols (Appendix E; Table 13). All site types that met a strict interpretation of the generally accepted CDFG decommissioning protocol or standard had a much lower unit sediment delivery than sites that failed to meet one or more of the protocols. Sites that met all CDFG protocol standards typically eroded less than half as much as sediment as those sites that failed to meet one or more of the CDFG standard protocols. This suggests that better adherence to all of the protocols outlined in Chapter 10 of the CDFG Manual is critical to reducing the post-decommissioning adjustments and sediment delivery observed on decommissioned roads.

8.9 Road Drainage

Most road surface sediment delivery occurred on road approaches adjacent to stream crossings. Often this was simply an unavoidable result of stream crossing excavation, but in certain areas additional cross-road drains and/or better road shaping techniques could have been implemented to prevent sediment delivery at stream crossings. Of the road drainage structures that were observed delivering sediment, it was nearly always because of their proximity to a stream crossing or to a lack of additional closely spaced drainage structures further up the road bed.

All of the roads evaluated were outsloped, albeit in different ways. Certain roads were fully re-contoured to mimic the natural hillslope, while others were ripped, outsloped with light road shaping between sites, and augmented with drainage structures such as cross road drains. Field observations suggest that there is no significant difference in the efficacy of two methods of road surface treatment to prevent sediment delivery. Overall, field observations on road drainage decommission techniques suggest that minimal erosion and sediment delivery is occurring from the decommissioned road surface between sites; and that the roads and treated road segments were hydrologically disconnected. These observations suggest that the current CDFG protocol for road surface treatment is highly effective at reducing sediment impacts to the stream system.

Standard practices of ripping, mild outsloping, and installation of cross-road drains on decommissioned road surfaces are less costly and appear to be as effective at reducing sediment impacts as is full hillside and road re-contouring. In our inventory of 51 miles of decommissioned roads, which included full re-contour, partial outslope, and rip/drain practices, PWA did not observe erosion and sediment delivery features sufficient to suggest that full recontouring should be routinely employed as a sediment control technique. Long-term monitoring of decommissioned roads, utilizing both types of treatments, will provide a better measure of their overall effectiveness at protecting anadromous streams and aquatic resources.

9.0 Recommendations

By using the unit past delivery numbers for sites that met all CDFG protocols and combining them with the sediment delivery data from sites that failed to meet one or more of the generally accepted protocols for road decommissioning we can calculate the amount of sediment that could theoretically have been saved if all sites met all protocols. By assuring strict adherence to the protocol that CDFG has outlined for its road decommissioning projects, we estimate that an additional 6,088 yds^3 of past and future sediment delivery could have been saved (prevented from being delivered) at stream crossings alone. This represents a 27% reduction in deliverable sediment for the inventoried road.

For every site that did not meet all of the CDFG prescription protocols, PWA itemized the treatments (Table 14) that would have been needed to meet current CDFG standards (Appendix E). These recommendations and inventory results can be used by CDFG project managers, restorationists, and landowners to help assure that adequate attention to detail is given to the elements of road decommissioning where the most common mistakes have been shown to occur, and where these mistakes are most likely to result in sediment delivery.

9.1 Stream Crossings

Generally accepted protocols for properly decommissioning stream crossings involves the excavation and permanent removal of road fill, Humboldt logs, and/or woody debris from the stream crossing. This is achieved by excavating down to the natural (original) channel bed with channel side slopes no steeper than 50% (2:1), or at sideslope angles that mimic the natural sideslopes upstream and downstream from the stream crossing. Post-treatment erosion and sediment delivery data from inventoried, decommissioned stream crossings strongly support these practices and standards. Properly decommissioned steam crossing sideslopes are typically excavated with a concave or straight profile shape to reduce the likelihood of slumping or sliding. In addition, stream crossing channel profiles should be excavated with straight line or concave gradients to reduce the chances of developing headcuts that may migrate through the excavated stream crossing. Two common and important sources of post-decommissioning erosion and sediment delivery from excavated stream crossings are sideslope slumps and channel incision. Both can be greatly minimized by constructing (excavating) stable, low gradient sideslopes, and by completely excavating erodible fill that was originally placed within the constructed stream crossing.

By far the most common problem at stream crossing decommission sites was unexcavated fill. The most common locations for unexcavated fill were: 1) between the inboard edge of road and the upstream natural channel, (i.e., stored sediment upstream of the former culvert inlet), 2) between the outboard edge of road and the downstream natural channel, (i.e., insufficiently deep excavations at the outboard portion of the road), 3) in the channel itself (i.e., un-excavated woody debris and associated sediment from old Humboldt log crossings), and 4) from oversteepened sideslopes that were not excavated and sloped back to at least as gentle as the gradient of the natural hillside above and below the crossing.

The second most common problem leading to sediment delivery at decommissioned stream crossings was spoil disposal. Spoil disposal is a critical element that can affect short-term and long-term road decommissioning effectiveness. Soil excavated from stream crossings should be placed in a location and in a manner such that it will not enter or re-enter a watercourse. The most common, problematic spoil location for stream crossings was at the margin of the excavated crossing, directly above the excavated sideslope.

There is no simple formula that calculates appropriate setbacks for spoils disposal at a stream crossing excavations because there are many variables acting on both erosion and the potential of sediment delivery. In most cases common sense should dictate a safe long-term storage location. Benches, broad ridges and low gradient hillslope locations are commonly appropriate for spoil disposal, provided they have been evaluated for stability and proximity to a stream channel. Endhauling may be required and should be used where necessary.

If the road approach is used for spoil disposal, and it is sloping towards the crossing, then measures should be taken to ensure that sediment generated from erosion of the spoils is not able to reach the crossing or a nearby stream. In-place outsloping should be terminated at a reasonable distance from the crossing so that spoils are not placed immediately adjacent to the crossing. The spoil generated from road fill excavations, adjacent to the crossing, should, in most cases, be endhauled rather than placed against the corresponding cutbank. Although these general procedures have existed for years, we found that they are not always implemented to their full advantage, or in all circumstances where they are necessary.

9.2 Landslides

Landslide treatments used on decommissioned roads were found to be generally effective in reducing the potential for failure, and subsequent delivery, of sediment from fillslope failures. The process consists of two components: First, the potential fillslope landslide site must be correctly identified and prescribed for treatment during the field inventory. Secondly, a sufficient volume of unstable material (preferably, nearly all of it) must be excavated from the potential landslide to reduce its potential for failure or to reduce the potential for sediment delivery. Both elements appear to have performed satisfactorily to date and additional monitoring of the decommissioned roads will allow for a longer term evaluation of these road decommissioning and mass wasting identification and prevention practices.

The generally accepted protocol for properly excavating potential fillslope landslides involves the permanent removal of unstable sidecast fill from the potential landslide feature. Field data suggests that the standard treatment protocol is appropriate. That is, potential fillslope failures should be excavated with a straight line or (preferably) steeply concave downslope profile both to reduce the likelihood of potential slumps or sliding, and to reduce the volume of the potential failure. The excavation of potential landslides can involve the removal of all unstable fill, or in the case of a larger, unstable area, the removal of unstable fill from the upper portion of the potential landslide. Excavating the upper portion of the landslide decreases the overall landslide mass, and as a result can reduce the landslide driving forces. This may prevent the potential landslide from failing, or because of the reduction in landslide mass, it may decrease the volume of landslide materials delivered to the stream when, and if, it fails.

As with stream crossings, the most common problem associated with decommissioning treatments at landslide sites was unexcavated, unstable fill. It is important that the person performing the assessment and developing treatment prescriptions for the site thoroughly investigate and delineate the extent of unstable fill associated with the existing or potential landslide, as well as the locations where excavated spoils may be disposed. Furthermore, it is equally important that the decommissioning supervisor and equipment operator thoroughly excavate unstable fill, construct a deeply concave downslope excavation profile, and store the spoil materials in a stable location. As with stream crossings, proper spoil disposal is an integral part of proper landslide decommissioning. The same general recommendations apply to spoils disposal of landslide excavations as stream crossings.

9.3 "Other" sites

The third category of sediment delivery sites, classified as "other" sites in the field inventory, typically consisted of dips at springs and swales, or other road surface drainage problems. The main characteristic almost all "other" sites have in common is copious amounts of water draining over saturated, uncompacted road fill. The most common implementation problem associated with "other" sites was unexcavated, erodible and/or unstable fill. Field observations indicate that most of these road drainage sites were treated with broad dips to constrain the flow of water to one area and to keep it from flowing down the decommissioned road. Although the areas were dipped, rarely was the fill at the outboard edge of the road thoroughly excavated or armored. Careful observations of the local groundwater and fillslope stability conditions at the site, and thorough, thoughtful corrective actions to control it are critical to reducing erosion and sediment delivery at "other" sites.

In all cases, whether excavating stream crossings or potential landslides, or treating "other" sites, all spoil materials should be placed in stable locations away from streams to prevent potential erosion and sediment delivery. Typically, spoils are placed against stable cutbanks, on the inboard edge of landings, on broad ridges or other low gradient slopes, or on the road surface as long as the spoil has little chance of eroding or falling into streams.

9.4 New Untreated Sites

Along the 51 miles of road inventoried by PWA during this study, only 18 relatively minor sites were identified as untreated. It is unknown why a number of these sites were left untreated, however in many cases the "new sites" appear to have developed after the road decommissioning had taken place. Nevertheless, there was a significant amount of sediment delivery from one landslide that developed in the post-decommissioning period, and from one landslide whose reason for being left untreated is unknown.

It appears that, apart from the landslides mentioned above, the sites that were left untreated contributed only a small amount of sediment delivery. Although it can be difficult to ascertain the existence, size and spatial extent of pending fillslope landslides on roads scheduled for decommission, it is important to identify them correctly in order to reduce future sediment impacts like those represented in Table 15.

10.0 Conclusions

1) The most common and volumetric important erosion features associated with road decommissioning under the CDFG Fisheries Restoration Grant Program are: mass wasting (either debris slides or slumps - mostly at excavated stream crossings), surface erosion, and channel incision (at excavated stream crossings).

2) The most common causative factors for inventoried erosion features were: unexcavated fill, overland flow, and emergent groundwater.

3) The most common operator or supervisor error resulting in erosion and sediment delivery at all decommission site types (stream crossings, landslides and “other” sites), was under-excavation of fill; resulting in over-steepened, perched or erodible fill in vulnerable locations.

4) Spoil disposal sites should be located further from the stream crossing site than currently practiced, or measures need to be taken to eliminate the potential for sediment delivery to a watercourse.

5) The generally accepted CDFG decommissioning protocols for stream crossings are effective; but were not followed at all sites.

6) The average post-decommissioning adjustment for a decommissioned stream crossing is approximately 5% of its original volume of 769 yds^3. Erosion at excavated stream crossings accounted for 85% of post-decommissioning sediment delivery from 51 miles of decommissioned roads in the project area, resulting in the delivery of an average of 34 yds^3 per decommissioned crossing.

7) The CDFG decommissioning protocols for landslide sites are effective and are, for the most part, followed. Post-decommissioning sediment delivery from treated landslide sites was minimal.

8) The CDFG decommissioning protocols for “other” sites are not effective and are either too vague or are not understood by restorationists. However, post-decommissioning sediment delivery from treated “other” sites was relatively minor, accounting for a total of 13% of all measured sediment delivery from inventoried sites.

9) The CDFG decommissioning protocols for road drainage are effective and are correctly applied. Full “cosmetic” road recontouring, implemented on some of the inventoried roads, was not warranted as a sediment control measure and resulted in reduced project cost-effectiveness.

10) Although locally employed, rock armor location, placement, sizing, and sorting requires better adherence to generally accepted design standards and closer supervision in order to assure its effectiveness and cost-effectiveness in road decommissioning.

11) The geologic substrate of the decommissioning region is not highly influential in controlling erosional processes, except for decomposed granite, which is particularly susceptible to surface erosion processes.

12) Approximately 58% of the sites we evaluated did not meet one or more of the generally accepted CDFG decommissioning protocols or standards. This translated into a higher unit sediment delivery for sites that did not meet protocols (43 yds^3/site) as compared to sites that did meet all CDFG protocols (11 yds^3/site)(Table 13).

Our analysis suggests that some erosion and sediment delivery from decommissioned stream crossings is largely unavoidable in all but the smallest crossings. Some measure of channel and/or sideslope adjustment is likely to occur within the excavation area of most decommissioned stream crossings. Some of this erosion is predictable and preventable, but some fraction may be unpredictable and unpreventable. Continued improvements in problem recognition, prescription development and implementation practices can further reduce post decommissioning erosion and sediment delivery while perhaps reducing costs and improving the cost-effectiveness of the decommissioning work that is undertaken within the Fisheries Restoration Grant Program.

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Appendix A

Description of Geologic Units

from:

Ogle, 1953; Jennings, 1977; and McLaughlin, R.J., 2000

Qm- Quaternary marine and non-marine sand, silt, and gravel deposits, mostly unconsolidated. This unit is very erodible because the sediments are poorly consolidated.

QTwu- (Wildcat group undifferentiated)- Marine and non-marine overlap deposits (late Pleistocene to middle Miocene). Thin-bedded to massive, weakly lithified siltstone, fine- to medium-grained sandstone, silty to diatomaceous mudstone and locally soft, scaly mudstone. Locally includes lenses of pebble to boulder size, conglomerate, carbonate concretions, and abundant molluscan fossils. Erodibilty of local bedrock is dependent on degree of lithification and the particle size distribution of the sediments which comprise the bedrock. Silt-mud-stones in the Wildcat group are less erodible than the sandstones due to their higher cohesion from the silts and clays within the rocks.

Ty- Sedimentary rocks of the Coastal Belt Franciscan Complex, Yager terrane (Eocene to Paleocene). Argillite and arkosic sandstone interbedded, thin to medium bedded; massive to thickly bedded arkosic sandstone with minor interbeds of argillite; and minor lenses of polymict boulder to pebble conglomerate. Yager terrane rocks are more indurated than Wildcat Group rocks and are less erodible.

KJfco- Sedimentary rocks of the Coastal Belt Franciscan Complex (Pliocene to Late Cretaceous). Predominantly sandstone, argillite and minor polymict conglomerate, that forms highly sheared melange and broken formation and is highly folded locally. This unit is not very erodible where the bedrock is intact. In locations where the bedrock is sheared, erodibility is enhanced.

KJf- Sedimentary rocks of the Franciscan Complex, (Cretaceous and Jurassic). Sandstone with smaller amounts of shale, chert, limestone, and conglomerate. Rocks in this unit are of low erodibility because lithologies are indurated and hard.

KJfs- Blueschist and semi-schist of the Franciscan Complex. Schist rocks are very hard and therefore of low erodibility.

KJfm- Mélange of fragmented and sheared Franciscan Complex. Mélange in this unit is weak due to the metamorphic processes that removed all rock strength; therefore erodibility is enhanced.

grMZ- Mesozoic granite, quartz monzonite, granodiorite, and quartz diorite. Most of the bedrock of this unit is readily decomposes due to physical and chemical weathering. This granular disintegration causes erosion to be enhanced when the bedrock is exposed at the ground surface. Where a soil mantle covers the bedrock, erodibility is limited.

J- Meta-sedimentary rocks of the Klamath Mountain terrane (Jurassic). Shale, sandstone, minor conglomerate, chert, slate, limestone; minor pyroclastic rocks. These rock units are not very erodible because they have undergone metamorphism; resulting in increased lithification (harder rock). The exceptions are the shale units that are slightly more erodible.

Pz- Undivided Paleozoic metasedimentary rocks. Includes slate, sandstone, shale, chert, conglomerate, limestone, dolomite, marble, phylite, schist, hornfels, and quartzite. Most bedrock in this mapped unit is strong enough to maintain a relatively low erodibility. Slate and shale units are more erodable because they are not as strong as the other rocks in this unit.

Geologic Unit	Relative Erodibility
Qm	5
Qtwu	4
Ty	3
KJfco	2
KJf	2
KJfs	2
KJfm	4
grMZ	5+
J	2
Pz	1 - 3

Appendix B

Maps 1 - 40

of

Decommissioned Roads

Appendix C

Decommission Monitoring Data Forms

Site Data Form

Road Data Form

New Untreated Site Data Form

PWA STREAM CROSSING/LANDSLIDE/OTHER DECOMMISSIONING DATA FORM (9/04 version) CHECK_____

GENERAL	Site No:	Previous site no.:	Road:	Date:	Inspectors:	Contract #:
Pre project inventory site (Y, N):	PWA site (Y, N)	Watershed:	Subwatershed:	Year of decom:		
Geographic area:	Landowner:	Contractor:	Technical Contractor:	Geology:		
Could NOT find site? (Y, N)	Suspected reason why? (comment)	Check comments? (Y, N)				

STREAM CROSSING	Stream class (1, 2, 3)	Nat. upstream Ch grade (%):	Natural upstream Ch width (100 yr flood)(ft):		
Excavated Channel info	Design TOP to Exc. TOP length (ft):	Exc. TOP to IBR length (ft):	IBR to OBR length (ft):	OBR to Exc. BOT length (ft):	Exc. BOT to Design BOT length (ft):
	Total exc. ch length (ft):	Average ch width (ft):	Excavated ch grade (%):		
	Excavated ch shape (concave, convex, straight, complex)	If complex, describe:			
	TOP transition (headcut, oversteepened, none):	Cause: (natural, construction, decommission)	BOT transition (headcut, oversteepened, none):	Cause: (natural, construction, decommission)	
	Channel bed materials (%) Rip Rap: Bedrock: Boulders: Coarse lag: Erodible material: Organic debris:				
	Base level controls? (Y, N)	% vertical drop:	Location of armor (TOP, BOT, Channel,None)	Channel armor length (ft):	
	Proper armor placement (form): (Y , N)	Proper armor size (L, S, C):	Proper armor quantity? (L, S, C):		

Excavated side slope info	**Right side slope**	IBR slope %	IBR length (ft)	IBR slope shape (CC, CV, ST)	OBR slope %	OBR length (ft)	OBR slope shape (CC, CV, ST):
		If convex: 2nd IBR slope % : IBR length (ft):			If convex: 2nd OBR slope % : OBR length (ft):		
		Fillslope armor length (ft): width (ft):		Proper armor placement (form): (Y, N)		Proper armor size (L, S, C):	
		Proper armor quantity?(L, S, C):	% bare erodible soil:	% Veg cover:	Seed/Mulch (Y, N , M)		
	Left side slope	IBR slope %	IBR length (ft)	IBR slope shape (CC , CV , ST)	OBR slope %	OBR length (ft)	OBR slope shape (CC , CV , ST):
		If convex: 2nd IBR slope % : IBR length (ft):			If convex: 2nd OBR slope % : OBR length (ft):		
		Fillslope armor length (ft): width (ft):		Proper armor placement (form): (Y, N)		Proper armor size (L, S, C)	
		Proper armor quantity?(L, S, C):	% bare erodible soil:	% Veg cover:	Seed/Mulch (Y , N , M)		
Spoil info	Are spoils perched above or have access to a stream? (Y , N):						

LANDSLIDE	Landslide type (Fillslope, Hillslope, Cutbank, Torrent, Other):	Treatment type (Excavate, Rock/Log Buttress, Retaining Structure, De-water, Vegetation, Other)			
Landslide excavation info	Dimensions of excavation (ft): L: W: D:	Dimensions of remaining fill (ft): L: W: D :			
	Excavation shape (concave, convex, straight)	Excavation gradient (%):			
	Armoring length (ft): width (ft):	% Veg cover:	% bare erodible soil:	Seed/Mulch (Y ,N , M)	
Spoil info	Are spoils perched above or have access to a stream? (Y , N):				

OTHER SITES	Other feature type (Spring, Gully, Road surface, Ditch, Cutbank, Other)	Other (specify):
IMPLEMENTATION INFO	What was the treatment? (Stream crossing excavation, Landslide excavation, Rock/Log buttress, Retaining Structure, De-water landslide, Vegetation (planting), Dip at spring, Road decompaction, Ripping, Grade control (rock, check dams), Rock armor, Cross road drains, Surface drainage structure, Road shaping (IS, OS), Other)	
Was the treatment design appropriate for the site ? (Y , N , No data)	Explain:	
Was the treatment implemented, as prescribed? (Y , N , No data)	Explain:	
Did the treatment meet standard CDFG prescription protocol? (Y, N)	Explain:	
COMMENT		

EROSION INFORMATION

GENERAL INFO				PAST EROSION INFO								FUTURE EROSION INFO							
ID #	Location	Feature	Slope (%)	w (ft)	d (ft)	l (ft)	vol (cy)	% del.	activity level (A,W,I)	Primary Cause	Secondary Cause	w (ft)	d (ft)	l (ft)	vol (cy)	% del.	Erosion Potential	Primary Cause	Secondary Cause

TREATMENT EFFECTIVENESS INFORMATION					
Should the site have been further treated (Y, N):			Should site have been treated (Y,N):		
Possible treatments (circle):	Deeper excavation	Wider channel	Sideslopes laid back further	Larger landslide excavation	Rock armor
Better surface drainage treatments	Better surface erosion treatments	Grade control	Better spoils management	Other (specify):	
Comment on most common mistakes:					

SKETCH

Photo point #	Location	View

ROAD DRAINAGE - Decommissioning "As Built" Inventory Data Form (version 9/04)

Road name					
Inspectors:					
Geographic area (#)					
Contract #:					
Watershed:					
Year of decommission:					
Landowner:					
Contractor:					
Geology:					
Road length (ft)					
Average road width (ft)					
Average road shape (IS,OS,CR,RC)[1]					
Average road grade (%)					
Steepest road grade (%)					
Water bars	Connected WB (#)				
	Connected length (ft)				
	Unconnected WB (#)				
Cross-road drains	Connected CRD (#)				
	Connected length (ft)				
	Unconnected CRD (#)				
Rolling dips	Connected RD (#)				
	Connected length (ft)				
	Unconnected RD (#)				
Miscellaneous connected length (ft)					
Ripping and decompaction (Y,N,P,U)[3]					
Seeded and/or mulched (S,M,B,N,U)[4]					
Deficiencies (ND, NR, PD, L, R)[5]					
Recommended corrections (FD, BC, RI, SP, OT)[6]					

NEW UN-TREATED SITE	Site #:	Road name:	Contract #:	Geographic area:		Watershed:	
	Stream xing	Landslide	Roadbed (bed, ditch, cut)	Spring	Gully	Other	
	Why was it not treated? (Not identified pre treatment, Developed post treatment, Unknown)						
FUT. EROSION	Future erosion (yds^3):		Future delivery (%):		Future yield (yds^3):		
CONNECTIVITY	Left length (ft):		Right length (ft):		Right (%):	Left (%):	
LANDSLIDE	Road fill	Landing fill	Cutbank	Hillslope debris slide	DS, slow landslide	Past failure	Potential failure
	Slope shape: (convergent, divergent, planar, hummocky)			Natural slope%:	Distance from toe to stream (ft):_______		
STREAM	Stream class (1, 2, 3)	Sed trans (H, M, L)	Ch grade (%):	Ch width (ft):	Ch depth (ft):		
TREATMENT	Excavate slide	Excavate crossing	Partial outslope	Complete outslope	Road rip (decompaction)		
	Cross road drains	Rock armor	Mulching	Seeding	Planting	Other	None:

Sketch

NEW UN-TREATED SITE	Site #:	Road name:	Contract #:	Geographic area:		Watershed:	
	Stream xing	Landslide	Roadbed (bed, ditch, cut)	Spring	Gully	Other	
	Why was it not treated? (Not identified pre treatment, Developed post treatment, Unknown)						
FUT. EROSION	Future erosion (yds^3):		Future delivery (%):		Future yield (yds^3):		
CONNECTIVITY	Left length (ft):		Right length (ft):		Right (%):	Left (%):	
LANDSLIDE	Road fill	Landing fill	Cutbank	Hillslope debris slide	DS, slow landslide	Past failure	Potential failure
	Slope shape: (convergent, divergent, planar, hummocky)			Natural slope%:	Distance from toe to stream (ft):_______		
STREAM	Stream class (1, 2, 3)	Sed trans (H, M, L)	Ch grade (%):	Ch width (ft):	Ch depth (ft):		
TREATMENT	Excavate slide	Excavate crossing	Partial outslope	Complete outslope	Road rip (decompaction)		
	Cross road drains	Rock armor	Mulching	Seeding	Planting	Other	None:

Sketch

Appendix D

Data Form Definitions and Explanation

Decommissioning Site Data Form
Definitions and Explanation

Front Side

GENERAL INFORMATION

Site number: The unique number assigned to the specific site being evaluated by the inspector.

Previous site number: The site number or mileage previously used to identify the site being evaluated.

Road: The name or number of the road being evaluated.

Date: The date the evaluation is taking place.

Inspectors: The initials of the individuals evaluating the decommission site.

Contract number: The California Department of Fish and Game restoration grant contract number assigned to the project being evaluated.

Pre project inventory site (yes/no): A yes/no question, was the site being evaluated, previously inventoried and prescribed a restoration treatment.

PWA site (yes/no): A yes/no question, was the site being evaluated, previously inventoried and prescribed a restoration treatment by PWA personnel.

Watershed: The name of the highest order stream draining the project area.

Subwatershed: The lowest order stream named that the work area drains to.

Year of decommission: The year the restoration project was implemented.

Geographic area: The geographic area the project falls into. (Geographic areas were assigned to clusters of restoration project sites to assure a broad suite of climactic and geologic site conditions were evaluated, see report for map).

Landowner: The current landowner of the road being evaluated.

Contractor: The heavy equipment operator that conducted the work.

Technical contractor: The contractor that managed and supervised the restoration project.

Geology: The primary geology bedrock within the restoration site.

Could not find site (yes/no): A yes/no question, could the evaluator find the restoration site.

Suspected reason why: Comment, why the site could not be found.

Check Comments: A check box to indicate that there are nuances to the site that may not be covered by the basic categories of the data form, these nuance were explained in detail on the notes and sketch of the site form.

STREAM CROSSING INFORMATION

Stream class (1,2,3): The stream classification of the stream crossing site being evaluated, based on the California Department of Forestry forest practice rules.

Natural upstream channel grade: The channel grade of the natural stream above the influence of the restored stream crossing.

Natural upstream channel width (100 yr. flood): An estimate of the channel width occupied by water during a 100 year flow event.

Natural upstream left and right bank grade: The grade of the left and right stream bank measured above the excavated stream crossing.

Excavated channel information

Design TOP to excavated TOP length: The slope distance in feet between the up stream end of the crossing excavation and the actual natural stream/fill contact.

Excavated TOP to IBR length: The slope distance in feet between the up stream end of the crossing excavation and former inboard road.

IBR to OBR length: The slope distance in feet between the former inboard road and the former outboard road.

OBR to Excavated BOT length: The slope distance in feet between the former outboard road and the down stream end of the crossing excavation.

Excavated BOT to design BOT length: The slope distance in feet between the down stream end of the excavation and the actual natural stream/fill contact.

<u>Total excavated channel length:</u> The total excavated channel length of the stream crossing being evaluated.

<u>Average channel width:</u> The excavated channel width of the crossing being evaluated.

<u>Excavated channel grade:</u> The average excavated channel grade at the restoration site being evaluated.

<u>Excavated channel shape:</u> The shape of the channel profile through the decommissioned stream crossing. Field options include:

- -Concave- an excavated surface that curves inward towards the ground.
- -Convex- an excavated surface that curves outward away from the ground.
- -Straight- a non-curving profile between the top and bottom of the excavation.
- -Complex- a stepping or otherwise non-constant grade between the top and bottom of the excavation.

If complex, describe: describe the complex channel profile through the evaluated stream crossing.

<u>TOP transition:</u> The geometry of the transition between the top of the excavation and the natural channel, "none" indicates a natural transition.

- -Headcut- An abrupt, vertical, channel elevation drop that migrates up stream through continued stream or gully erosion.
- -Oversteepened- A transition between the natural channel and the upper end of the excavation that exceeds the natural channel grade but has not developed into a head cut.
- -None- A smooth conformable transition between the natural channel and the upper end of the excavation.

<u>Cause:</u> (If the transition between the upstream end of the excavation and the actual natural stream/fill contact was a headcut or over steepened) what was the cause of the over steepened transition.

- -Natural: The geometry of the transition between the top of the excavation and the natural channel is a bedrock step or natural slope change.
- -Construction: The geometry of the transition between the top of the excavation and the natural channel was caused during construction when the road was cut deeper than the natural channel bottom at the stream crossing.
- -Decommission: The geometry of the transition between the top of the excavation and the natural channel was caused during decommission due to over or under excavation.

<u>BOT transition:</u> The geometry of the transition between the bottom of the excavation and the natural channel, "none" indicates a natural transition.

- -Headcut- An abrupt, vertical, channel elevation drop that migrates up stream through continued stream or gully erosion.
- -Oversteepened- A transition between the natural channel and the lower end of the excavation that exceeds the natural channel grade but has not developed into a head cut.

-None- A smooth conformable transition between the natural channel and the lower end of the excavation.

Cause: (If the transition between the downstream end of the excavation and the actual natural stream/fill contact was a headcut or over steepened) what was the cause of the over steepened transition.

-Natural: The geometry of the transition between the downstream end of the excavation and the natural channel is a bedrock step or natural slope change.

-Construction: The geometry of the transition between the downstream end of the excavation and the natural channel was caused during construction when the inboard road was cut deeper than the natural channel bottom at the stream crossing.

-Decommission: The geometry of the transition between the downstream end of the excavation and the natural channel was caused during decommission due to over or under excavation.

Channel bed materials: The composition of the channel bed materials in percent.

-Rip rap: purposely placed rock armoring usually over 1 foot in diameter.

-Bedrock: The native rock within the evaluated crossing

-Boulders: Natural rocks larger than .75 feet in diameter

-Course lag: rock and gravel between the size range of .75 feet and sand size particles.

-Erodible material: Fine grained material capable of being transported during the smallest stream flow

-Organic debris: Organic matter incorporated into the channel bed materials.

Base level controls (y/n): A y/n question, are there features within the channel that are controlling the base level of the stream through the crossing.

Percent vertical drop: The percent of the total vertical drop through the crossing that is controlled from the existing base level controls.

Location of armor (TOP, BOT, Channel, None): The location of purposely placed rock armor implemented during the decommission process.

Channel armor length: The length of the armor measured parallel to the channel.

Proper armor placement (y/n): Was the armor placed in the correct location and geometry.

Proper Armor Size: Was the armor size used correct for the site, (L= too large, S= too small, C= correct).

Proper Armor Quantity: Was the quantity of armor used correct for the site, (L= too much, S= too little, C= correct).

Excavated side slope information (for both right and left side slopes)

IBR slope: The side slope angle in percent measured perpendicular from the excavated channel at the previous location of the inboard road.

IBR length: The side slope length in feet measured perpendicular from the edge of the excavated channel at the previous location of the inboard road.

IBR slope shape (CC, CV, ST): The shape of the side slope excavation observed from the excavated channel to the upper edge of the crossing excavation at the previous location of the inboard road.

OBR slope: The side slope angle in percent measured perpendicular from the excavated channel at the previous location of the outboard road.

OBR length: The side slope length in feet measured perpendicular from the edge of the excavated channel at the previous location of the outboard road.

OBR slope shape (CC, CV, ST): The shape of the side slope excavation observed from the excavated channel to the upper edge of the crossing excavation at the previous location of the outboard road.

If complex second IBR slope percent: This is used when the side slope has two facets, it records the upper side slope angle in percent, measured perpendicular to the excavated channel from the break in slope between the lower side slope and the upper side slope at the previous location of the inboard road.

If complex second IBR length: This is used when the side slope has two facets, it records the upper side slope length in feet, measured perpendicular to the excavated channel from the break in slope between the lower side slope and the upper side slope at the previous location of the inboard road.

If complex second OBR slope percent: This is used when the side slope has two facets, it records the upper side slope angle in percent, measured perpendicular to the excavated channel from the break in slope between the lower side slope and the upper side slope at the previous location of the outboard road.

If complex second OBR length: This is used when the side slope has two facets, it records the upper side slope length in feet, measured perpendicular to the excavated channel from the break in slope between the lower side slope and the upper side slope at the previous location of the outboard road.

Fillslope armor length: The length of the purposefully placed armor that is protecting the side slope of the excavated stream crossing, measured in feet.

Fillslope armor width: The width of the purposefully placed armor that is protecting the side slope of the excavated stream crossing, measured in feet.

Proper armor placement (y/n): A yes/no question, records whether the armor placed to protect the side slope was correctly placed.

Proper armor size (L, S, C): Records whether the armor placed to protect the side slope was correctly sized, (L= too large, S= too small, C= correct).

Proper armor quantity (L, S, C): Records whether the armor placed to protect the side slope was volumetrically correct, (L= too much, S= too little, C= correct).

Percent bare erodible soil: The evaluators' visual estimate of the amount of erodible surface exposed on the side slope of the excavated stream crossing, recorded in percent of the total side slope area.

Percent Vegetative cover: A visual estimate of the amount of vegetative cover growing on the side slope of the excavated stream crossing, recorded in percent of the total side slope area.

Seed/Mulch (Y, N, M): A yes/no/maybe question, it records whether there is visual evidence of previous seeding or mulching.

Spoil Information

Are spoils perched or have access to a stream: A yes/no question, records whether spoils from the stream crossing excavation have been properly stored where they cannot get into a watercourse.

LANDSLIDE INFORMATION

Landslide type: This records the type of landslide that was treated at the decommissioned site being evaluated, answers are recorded as; (Fillslope, Hillslope, Cutbank, Torrent, Other)

Treatment type: This records the type of treatment that was implemented at the decommissioned site being evaluated, answers are recorded as one of the options; (Excavate, Rock/Log buttress, Retaining structure, De-water, Vegetation, Other)

Landslide excavation information

Dimensions of excavation: This records the average excavations including length, width and depth of the treated landslide being evaluated, recorded in feet.

Dimensions of remaining fill: This records the average length, width and depth of the remaining fill of the treated landslide, recorded in feet.

Excavation shape (concave, convex, straight): This records the average shape of the landslide excavation observed straight down hill from the top to the bottom of the excavation.

Excavation gradient: This records the average gradient of the landslide excavation observed straight down hill from the top to the bottom of the excavation.

Armoring length and width: This records the length and width of any rock armor used to treat the landslide being evaluated.

Percent Vegetative cover: A visual estimate of the amount of vegetative cover growing on the side slope of the excavated stream crossing, recorded in percent of the total side slope area.

Percent bare erodible soil: A visual estimate of the amount of erodible surface exposed on the side slope of the excavated stream crossing, recorded in percent of the total sideslope area.

Seed/Mulch (Y, N, M): A yes/no/maybe question, records whether there is visual evidence of previous seeding or mulching.

Spoil Information

Are spoils perched or have access to a stream: A yes/no question, records whether spoils from the stream crossing excavation have been properly stored where they cannot get into a watercourse.

"OTHER" SITES

Other feature type: This records the type of site being evaluated for all sites other than stream crossings and landslides, answers include spring, gully, road surface, ditch, cutbank, and other.

Other specify: This records the type of site if other is recorded in the "other feature type" field.

Implementation Information

What was the treatment: This records the type of treatment that was implemented at the site being evaluated, answers include (stream crossing excavation, landslide excavation, rock/log buttress, retaining structure, de-water landslide, vegetation planting, dip at spring, road decompaction, ripping, grade control (rock or check dams), rock armor, cross road drains, surface drainage structure, road shaping (inslope or outslope), and other)

Was the treatment design appropriate for the site: This records, based on decommission documentation, whether the design of the treated site was appropriate.

Was the treatment implemented as prescribed: This records, based on decommission documentation, whether the implementation of the of the treated as designed.
Did the treatment meet standard CDFG prescription protocol: This records, based on Chapter 10 of the California Department of Fish and Game Fisheries Habitat Restoration Manual, whether or not the decommissioned site meets all standard implementation protocols.

Decommissioning Site Data Form
Definitions and Explanation
(continued)

Back Side

GENERAL INFORMATION

The general information section of the back of the main data form is used to characterize unique erosional features within a particular site.

ID#: This field records a unique erosion site identification number that corresponds to a number on the sketch on the back side of the main data form. It is used to get a spatial visualization of erosion locations at any given site.

Location: This records the geomorphic location of the erosional feature in question, the field options include: Channel (CH); left bank (LB); right bank (RB); Outboard road fill (OBR); cutbank (CB); road surface/ditch (RD); upper end of excavation (TOP); lower end of excavation (BOT).

Feature: The field records the type of erosional feature being characterized, the field options include: slump/slide (SL); ch incision (CI); TOP headcut (TH); BOT headcut (BH); gully (G); rilling (R); surface erosion (SE); other (O) Bank Erosion (BE)

Slope %: This records the slope of the surface the unique erosional feature is located on, it is recorded in percent.

PAST EROSION INFORMATION

W (ft): This field records the average width of the unique erosional feature being documented, measured in feet.

D (ft): This field records the average depth of the unique erosional feature being documented, measured in feet.

L (ft) : This field records the average length of the unique erosional feature being documented, measured in feet.

Vol (cy): This field records the product of the width, length, and depth of the unique erosional feature being documented converted into cubic yards.

% delivery: This field records the percent of the volume of eroded material from the erosional feature being documented that has delivered to a watercourse.

Activity Level: This records the level of activity of the unique erosional feature being documented, the field options include:

-Active (A)- An erosional feature that is currently eroding and is likely to continue eroding in the future if nothing is done to stifle the process. Typically these are sites that exhibit continual chronic erosion such as channel incision and surface erosion.

-Waiting (W)- An erosional feature that has occurred, is currently stable, but is likely to continue eroding in distinct pulses in the future. Examples of this include slumps and landslides.

-Inactive (I)- an erosional feature that no longer poses a risk to continued erosion

Primary Cause and secondary cause: These fields record the evaluators' best judgment as to the primary and secondary causes of the unique erosional site being evaluated. The causes of erosion are categorized based on the nature of the causation. Causation categories and erosion mechanisms include:

Stream crossing or landslide excavation related –

-Unexcavated fill (UF)– This cause is recorded when the evidence suggests that unexcavated fill in either a stream crossing or road fill is the primary or secondary reason the erosion has occurred or will occur.

-Undercutting (UC)- This cause is recorded when the evidence suggests that undercutting is the primary or secondary reason the erosion has occurred or will occur. Undercutting is defined as: A process where fluvial erosion is creating a overhanging or vertical face at the base of a slope.

Stream crossing related –

-Oversteepened sideslopes (OS) - Sideslopes from an excavated stream crossing that are a residing at an angle steeper than the natural stream side sideslope angle above and below the crossing of interest.

-Poor profile transition (PT) - A stream channel gradient transition between the top of the excavation and the bottom of the excavation that is convex, stepping, or faceted.

-Oversteepened TOP (OT) - An abrupt or non-natural transition between the up hill end of the stream crossing excavation and the undisturbed channel above it.

-Oversteepened BOT (OB) - An abrupt or non-natural transition between the down hill end of the stream crossing excavation and the undisturbed channel below it.

-Oversteepened channel segment (OC) - a stream gradient transition anywhere between the top of the excavation and the bottom of the excavation that results in a channel grade steeper than the natural grade of the channel above or below the crossing, typically the result of a poorly excavated channel bottom at the crossing of interest.

-Insufficient channel width (IC) - An excavated channel that has a width smaller than the natural channel above or below the crossing.

-Poor channel alignment (PA) - An excavated channel that is not aligned properly with the natural channel above and below the crossing of interest.

Road surface drainage related –

-Road drainage (RD) – This is recorded if excessive road runoff is facilitating the erosion being documented.

-Diverted stream (DS) – This is recorded if a stream that is diverted out of its natural channel is facilitating the erosion being documented.

Natural mechanism –

-Unavoidable channel bed adjustments (NB) – The process by which loose soil and rock in a newly constructed stream channel is sorted, winnowed, and transported down stream as the channel adjusts itself to its new configuration.

-Natural channel bank adjustments (NC) - The process by which loose soil and rock in a newly constructed stream bank is sorted, winnowed, and transported down hill as the surface of the channel bank adjusts itself to its new configuration.

-Flow deflection (FD) – The process by which stream flow is deflected by an object such as a large boulder, bedrock, or fallen tree.

-Emergent water (EW) – This cause is recorded when saturated ground is a primary or secondary mechanism of failure for the erosional site in question.

-Overland flow (OF) – This cause is recorded when overland flow of water is a primary or secondary mechanism of failure for the erosional site in question.

-Unstable soils/geology (US) - This cause is recorded when unstable soils or natural bedrock is the primary or secondary cause of the failure of the erosional site in question.

Other mechanism –

-Other (O) – Any other cause is recorded as other and is specified in the comments section.

FUTURE EROSION INFORMATION

Unless defined below the future erosion information is the same as the past erosion information defined above, except it relates to future unique erosional sites as opposed to past ones.

Erosion Potential- This is a subjective call by the evaluator as to the likelihood that future erosion is going to occur. It is based primarily on geologic evidence and field conditions.

Treatment Effectiveness Information

Treatment effectiveness information refers to the overall effectiveness of the decommissioning work done at the site being evaluated.

Should the site have been further treated?- This field is circled if the site is experiencing, or may experience, erosion due to poor or improper decommissioning procedures.

Should the site have been treated? (Yes/No)- This is a yes/no question simply asking if the site should have been treated or not.

Possible treatments

Possible treatments is a list of procedures that could have been applied or applied better to eliminate or reduce the amount of post decommissioning erosion.

-Deeper excavation- This field is circled if an overall deeper excavation could have stopped or minimized the erosion of the site being evaluated.
-Wider channel- This field is circled if the excavated channel is smaller than the natural channel above and below the crossing.
-Sideslopes slope back farther (more gently) - This field is circled if the side slopes of the excavated channel are steeper than the natural channel sideslopes above and below the crossing.
-Larger landslide excavation- This field is circled if the unstable area being evaluated was not excavated thoroughly and still poses a threat of failure.
-Rock Armor- This field is circled if rock armoring could have been used to prevent or minimize erosion of the site being evaluated.
-Better surface treatments- This field is circled if better road surface runoff control was needed at the site being evaluated.
-Better surface erosion treatments- This field is circled if better surface erosion control was needed at the site being evaluated.
-Grade control- This field is circled if the site needed better channel grade control between the natural channel above and below the crossing being evaluated.
-Better spoils management- This field is circled if the spoil disposal for the site is not to CDFG standards or spoil is in any way capable of delivering to a stream.
-Other (specify)- This field is circled if there is a treatment not mentioned above that could have been implemented at the site that would have reduced or eliminated current or future erosion.

COMMENT ON MOST COMMON MISTAKES

This is a section to make comments about the most common mistakes at the site being evaluated. Typically it is used to convey nuances of the site that are not categorized in the rest of the data form. It is also used to elaborate on any of the above fields.

SKETCH

This is a section to make a map view sketch of the site, a channel profile sketch, or anything else of interest to the site being evaluated.

PHOTO POINT TABLE

This is a table to record numbers, locations, and views of digital photos taken at the site being evaluated.

Photo point #: This field records the digital number the camera assigns to the photograph.

Location: This field records the location from which the photo is taken

View: This field records a brief note describing the shot being taken.

Appendix E

California Department of Fish and Game

Generally Accepted Road Decommissioning Standards

California Department of Fish and Game

Generally Accepted Road Decommissioning Standards

STREAM CROSSINGS

Side slopes- Stream crossing side slopes should be excavated to a 2:1 angle or to an angle similar to the natural side slopes of the channel above or below the influence of the stream crossing.

Channel excavation extent- The extent of the channel excavation should be between the natural stream above the influence of the road crossing to the natural stream below the influence of the road crossing. This includes the removal of all sediment and debris that has accumulated above the crossing.

Channel profile- The profile of the stream crossing excavation between the top and bottom of the excavation should be straight or concave if no pre-existing natural features or road construction constraints preclude this profile shape. Pre-existing natural features include bedrock and large boulders. Road construction constraints include locations where the road cut has cut into and below the natural channel. The grade of the channel profile should be the same grade as the natural channel above and below the crossing.

Channel width- The width of the channel excavation should be equivalent to the dimensions of the natural channel above and below the influence of the crossing or sufficient to accommodate the 100 year recurrence interval rain runoff event.

Top and bottom transition- The transitions from the top and the bottom of the excavation to the natural stream channel should be as smooth as possible. Abrupt changes in the gradient of the profile at the top and bottom of the excavation should be avoided if possible, if this is not feasible then the transition should be as gently tapered as possible to avoid headcut potential.

Crossing road approaches- Road approaches to stream crossings should be disconnected to the maximum extent possible. Road drainage structures should be constructed as close to the crossing as possible to minimize runoff from the road tread. Road drainage structures should be spaced frequently enough to significantly reduce the likelihood of accumulated road runoff able to reach the stream.

ROAD SURFACE

De-compacting and drainage technique

Road access- Vehicle access to decommissioned roads should be adequate to prohibit all state licensed vehicles from gaining entry to the road in question.

Road de-compaction- Road de-compaction should be done on the entire length of decommissioned road. De-compaction should be done with a dozer with rippers to a depth of 15”-18”.

Road drainage feature construction- Decommissioned roads do not discharge through culverts or rolling dips. Cross road drains should be employed, and these should be constructed large enough to prohibit state licensed vehicle traffic and be designed and constructed for long-term sustainability. Drainage structures should be constructed at roughly a 30 degree skew to the road alignment to facilitate the transfer all road runoff from the road tread to the hillside.

Road drainage structure location and spacing - Road drainage structures should be placed frequently enough to disperse runoff across the hillside before it picks up enough volume and energy to connect to a stream via overland flow once the runoff is discharged off the road prism. This should be done with the intent of making the road "hydrologically invisible" in relation to the watershed. Typically road drainage structures should be spaced closer together as the distance from the road to the closest watercourse decreases. Road drainage structure localities should be selected with the intent of minimizing the likelihood of hydrologic connectivity between the road and the watershed stream network. Road drainage structures should not be placed where they will discharge onto unstable fill faces or areas where pre-existing gullies connect the road to the stream network.

Skid disconnection- All efforts to reduce the amount of runoff from skid trails connected to the decommissioned road should be taken. Cross road drains should be constructed on the skid to disperse runoff prior to its intersection with the decommissioned road. If this is not technically possible then runoff discharged from the skid should be transferred off the road in a stable location as soon as possible.

Re-contouring techniques

In place outslope- This technique is used to either fully or partially re-contour the hillside to its original configuration. The road tread where the spoil is placed should be de-compacted prior to placement of spoil. Re-contoured sections of road should be terminated far enough away from a stream crossing as to assure no potential for delivery of stored sediment to a stream crossing.

LANDSLIDES

Excavation shape and extent- Landslide excavations should include all identifiable unstable and potentially unstable fill material and side-cast. The profile shape of the excavation should be strongly concave, concave or straight in downslope profile, and rarely convex.

GENERAL

Spoil disposal- Excavated spoil should be placed in locations where it will not enter a stream.

Planting and mulching- planting and mulching is an optional treatment used to reduce surface erosion and facilitate re-vegetation.

Spring control- All springs should be identified and drained across the road as close to the source as possible. Large springs should be dipped to reduce the likelihood of erosion of the out board fill. Small springs should be cross road drained just down road from the seep. Springs directly adjacent to stream crossings should be carefully dipped to control runoff and minimize erosion.

Appendix F

Void Measurement Protocol

PWA Void Measurement Protocol

SURFACE EROSION: V_{se}= (A*$D_{avg.}$)/27*(% delivery)

Where,

V_{se}= Volume of surface erosion derived sediment delivered to a watercourse, in yd^3.

A= The area that is undergoing surface erosion, in ft^2.

$D_{avg.}$= The average depth of the surface erosion taking place in the area of interest, in ft.

% delivery= The estimated percent of the surface erosion that has or is likely to reach a watercourse.

Field estimation of past surface erosion

Estimating the area: The area undergoing surface erosion is estimated in different ways, depending on the shape of the area being eroded. If the area is generally a square shape then the X and Y axis of the square is measured using either a tape, a laser range finder, or pacing depending on which is most appropriate and the two axis are multiplied together to get an area. If the area is triangular in shape then the X and Y axis of the triangle is measured using either a tape, a laser range finder, or pacing depending on which is most appropriate and the two axis are multiplied together and divided by two to get an area. If the area is shaped other than a square or triangle it is broken into different sections composed of both squares and triangles and the above methods are used to estimate the areas of the different areas and they are summed to get a final area of surface erosion. Finally, the overall percent of the area that is actually being eroded (as would be the case in a heavily rilled fillslope) is estimated to get a final surface area.

Estimating the average depth of surface erosion: The average depth of the surface erosion is measured in two different ways, depending on the consistency of the depth of erosion over the area being assessed. If two adjacent areas have different depths of erosion then they are analyzed as two separate erosion sites. If the area being eroded has a consistent depth of surface erosion, then the depth of the erosion is measured and the percent of the area that has been lowered is estimated and they are multiplied together to come up with an average depth estimate. If the area being eroded has a multitude of different surface erosion depths then multiple steps are taken to average the depth of erosion. First the different depths of the surface erosion are categorized and the estimated percent of the whole that each category encompasses is estimated. These depths are then proportioned by their percentage and multiplied by the percent of the area that is actually being eroded to come up with an average depth of erosion.

Estimation of delivery percent: Delivery percent is a professional estimation based on available field evidence at the erosion site. It is an estimation of percent of the eroded material that has been delivered to a watercourse.

Field estimation of future surface erosion

Future surface erosion is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future surface erosion. The area measurements are estimated using the same techniques mentioned above and the depth and percent area eroded are estimated. Estimations of depth and percent area eroded are based on geomorphic phenomena and professional judgment and are estimated for a 50 year time period.

CHANNEL INCISION AND MIGRATION: $V_{ci} = (W_{avg.} * D_{avg.} * L)/27$

Where,

V_{ci}= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the channel erosion taking place in the stream channel, in ft.

$D_{avg.}$= The average depth of the channel erosion taking place in the stream channel, in ft.

L= The measured length of the channel segment undergoing erosion.

Field estimation of past channel incision and migration

The averaged width, depth and the length of channel incision are directly measured at the site by using either a tape, a laser range finder, or pacing depending on which is most appropriate. The average depth and width of the incision or migration is measured in two different ways, depending on their consistency over the length being assessed. If the depth and width of the incision or migration is consistent throughout the length of channel being assessed, then the width, depth, and length of the erosion is measured and multiplied together in the equation above to come up with an estimated erosion volume. If the depth and width of the incision or migration is inconsistent throughout the length of channel being assessed then they are estimated using one of two techniques. If the erosion width and depth increase or decrease consistently throughout the channel segment being evaluated, then the end members are averaged to get a width and depth to multiply together in the above equation. If the channel incision or migration is inconsistent throughout the channel segment being evaluated then the channel was broken into segments consisting of segments of equal depth and width and the above technique was used.

Field estimation of future channel incision and migration

Future channel incision and migration is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests channel incision is ongoing or a headcut is continuing to migrate, then the evaluator uses the geometry of the crossing and the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in the equation above.

GULLIES AND RILLS: V_g= ($W_{avg.}$* $D_{avg.}$*L)/27*(% delivery)

Where,

V_g= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the gully erosion taking place in the area of interest, in ft.

$D_{avg.}$= The average depth of the gully erosion taking place in the area of interest, in ft.

L= The measured length of the gully being investigated.

% delivery= The estimated percent of the surface erosion that has or is likely to reach a watercourse.

Field estimation of past gully and rill erosion

The average width, depth and the length of gullies and rills are directly measured at the site by using either a tape, a laser range finder, or pacing depending on which is most appropriate. The average depth and width of the gully or rill is measured in two different ways, depending on their consistency over the area being assessed. If the depth and width of the gully or rill is consistent throughout the length of area being assessed, then the width, depth, and length of the erosion is measured and multiplied together in the equation above to come up with an estimated erosion volume. If the depth and width of the gully or rill is inconsistent throughout the length of channel being assessed then they are estimated using one of two techniques. If the erosion width and depth increase or decrease consistently throughout the channel segment being evaluated, then the end members are averaged to get a width and depth to multiply together in the above equation. If the channel incision or migration is inconsistent throughout the channel segment being evaluated then the channel was broken into segments and the above technique was used.

Field estimation of future gully erosion

Future gullying and rilling is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests gullying or rilling is ongoing or a headcut is continuing to migrate, then the evaluator uses the geometry of the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in the equation above. Future estimates of active gully or rill enlargement usually fall into one of two categories: 1) features that will continue to downcut and increase in depth, and 2) features that will no longer downcut but will experience layback of its side slopes. If the future gully or rill erosion falls into the first category, then a future depth estimate is made by evaluating the geometry of the erosional feature, and the on site geomorphic evidence. If the future gully or rill erosion falls into the second category, then the future erosion is considered to be “layback” of the gully or rill sideslopes to a stable angle. An assumption of a 45 degree angle of sideslope layback, on a gully that has vertical walls, results in a future erosion volume equal to the original gully volume.

SLUMP/SLIDE: $V_s = (W_{avg.} * D_{avg.} * L_{avg.})/27 * (\% \text{ delivery})$

Where,

V_s= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the slump/slide erosion taking place in the area of interest, in ft.

$D_{avg.}$= The average depth of the slump/slide erosion taking place in the area of interest, in ft.

$L_{avg.}$= The average length of the slump/slide being investigated.

% delivery= The estimated percent of the slide volume that has or is likely to reach a watercourse.

Field estimation of past slump/slide erosion

Field estimation of past slump and landslide erosion is based on physical measurements of the boundaries of the feature being assessed. The length is measured from the crown scarp to the toe of the *surface rupture* (not to be confused with the toe of the landslide, defined here as the lower margin of the displaced material of a landslide, most distant from the main scarp). The width is measured between the scarps that define the lateral edges of the feature. The depth of the slide is measured perpendicular to the failure plane between the failure plane and the original ground surface. In all but a few cases the typical shape of a landslide does not lend itself to simple measurements of width, depth, and length to determine erosion volumes. In these cases one of two techniques can be employed (depending of the shape of the feature) to estimate the past erosion. If the slide is complex in shape then it is subdivided into different areas that have boundaries that lend themselves to reasonable estimates of average length, width, and depth. The volumes of the subdivided areas are then summed to come up with estimates of past erosion. If the feature in question is a slump or failed as a rotational feature then the volume can be calculated as a half of an ellipsoid with the equation ($V = 1/6 * \pi * L_{max} * W_{max} * D_{max}$). Once the volume of the failure is established an estimate of the percent of the eroded material that has been delivered to a watercourse is estimated and multiplied to calculate the eroded volume.

Field estimation of future slump/slide erosion

Future slump/slide erosion is based on continued erosion failure of areas that are currently undergoing instability or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests mass wasting is ongoing, then the evaluator uses the geometry of the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in one of the above equations depending of the shape of the feature.

Appendix G

Photos of common decommissioned roads and sites

LIST OF PHOTOS

Photo 1a, b	Photographs showing heavy surface erosion of stream crossing side slopes in decomposing granite bedrock
Photo 2a, b	Photographs showing an under-excavated stream crossing exhibiting bank collapse
Photo 3a, b	Photographs showing minor channel adjustments at excavated stream crossings
Photo 4a, b	Photographs showing Stream crossings exhibiting channel incision
Photo 5	Photographs showing common mulching techniques
	5a Heavy tree mulch on a steep road section
	5b Stream with straw mulch washed off of the sideslope of the excavation
Photo 6	Photographs showing good vegetative regrowth
	6a Vegetative regrowth at stream crossing
	6b Vegetative regrowth on a road surface
Photo 7a, b	Photographs showing under excavated stream crossings
Photo 8a, b	Photographs showing under excavated stream crossings
Photo 9	Photographs showing poor top transitions
	9a Poor excavation transition at top demonstrating over-excavation
	9b Poor excavation transition at top demonstrating under-excavation
Photo 10	Photographs showing stable fillslope landslide excavations
	10a Fillslope excavation with spoil endhauled to safe location
	10b Fillslope excavation with spoil stored against cutbank
Photo 11	Photographs showing common armoring mistakes
	11a Armored stream channel exhibiting minor deficiencies in sizing and placement
	11b Unnecessary armor with poor armor sizing, sorting and placement at a dip near a spring

JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
VOL. 35, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 1999

EROSION ON LOGGING ROADS IN REDWOOD CREEK, NORTHWESTERN CALIFORNIA[1]

Raymond M. Rice[2]

ABSTRACT: Road-related erosion was estimated by measuring 100 randomly located plots on a 180 km road network in the middle reach of Redwood Creek in northwestern California. The estimated erosion rate of 177 m^3 km^{-1} was contrasted with two earlier studies in nearby parts of the same watershed. A sizable proportion of the great reduction in erosion from that reported in the earlier studies is attributed to changes in forest practice rules. Those changes have resulted in better placement and sizing of culverts and, especially, to less reliance on culverts to handle runoff from logging roads.
(KEY TERMS: erosion; logging roads; forest practice rules; forest management; forest hydrology; social and political.)

INTRODUCTION

Road-related erosion has long been cited as a major source of sediment in streams draining logged areas (Anderson, 1954; Dyrness, 1967). In studies in Oregon (Swanson and Dyrness, 1975) and northwestern California (McCashion and Rice, 1983) roads were estimated to be responsible for about half of the erosion associated with timber management on terrain averaging about 43 percent slope. However, another study on the Six Rivers National Forest (the site of the McCashion and Rice study and just east of the site of this study) found that on terrain flatter than 58 percent, about 85 percent of the erosion was due to roads (Furbish, 1981). Several articles in a recent compendium of research in the Redwood Creek basin (Nolan *et al.,* 1995) identified roads and skid trails as a major cause of erosion in and upstream from the Redwood National Park. These studies, however, were mainly evaluating the consequences of road and logging practices that were in effect prior to the implementation of the Z'berg-Nejedly Forest Practice Act of 1973 (Arvola, 1976). Since the implementation of the Act forest practices related to environmental protection have, for the most part, significantly improved on private timberlands in California. It seems appropriate, therefore, to estimate the effects of current road maintenance and construction practices and contrast them with erosion associated with the earlier practices. The Redwood Creek watershed provides such an opportunity since one of the owners of timberland upstream of the Park undertook a study to estimate road-related erosion on his property since 1980. Erosion measured in that study will be contrasted with that reported in two of the earlier studies (Best *et al.,* 1995, Weaver *et al.,* 1995).

The mouth of Redwood Creek is located about 50 km (30 mi) north of Eureka California (Figure 1). The 725 km^2 (283 mi^2) watershed, which follows the Grogan Fault (Cashman *et al.,* 1995), extends 80 km (50 mi) in a south-southeasterly direction, usually not exceeding 10 km (6 mi) in width. The Grogan Fault divides the watershed into a relatively stable western side underlain mainly by the Redwood Creek Schist and a more erodible eastern side underlain by sandstones and mudstones (Cashman *et al.,* 1995). Annual precipitation ranges from about 1500 mm (60 in) at the creek's mouth near the town of Orick to about 2500 mm (100 in) in the headwaters (Harden, 1995). Descriptions of the basin typically divide it into thirds. The lower third, the Park, is dominated by redwood (*Sequoia sempervirens*). The middle third covers a transition to a Douglas-fir (*Pseudotsuga menziesii*) dominated forest with increasing amounts of oak-woodland and grasslands. That transition continues in the upper third of the basin. By 1954 about 28 percent of the middle third of the Redwood Creek watershed and 22 percent of the total watershed had

[1]Paper No. 98043 of the *Journal of the American Water Resources Association.* **Discussions are open until June 1, 2000.**
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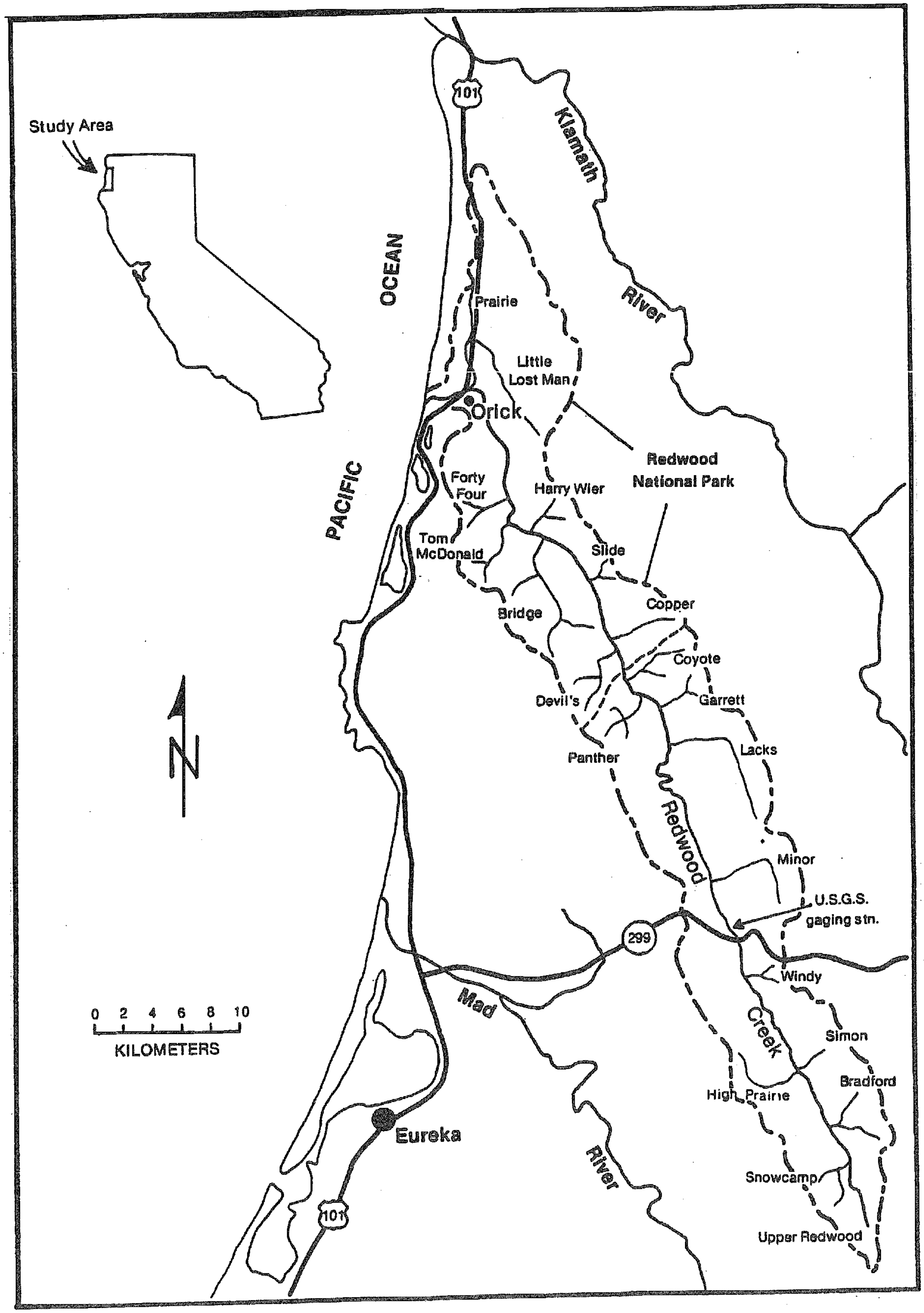

Figure 1. Redwood Creek Watershed.

been logged (Best, 1995). By 1978 those figures were 72 percent and 66 percent, respectively. By 1997 virtually all the coniferous forest outside the Park had been logged at least once.

Earlier forest practices were studied in Copper Creek (Weaver *et al.*, 1995) and Garret Creek (Best *et al.*, 1995). The current study area is north of Highway 299 mainly in the watersheds of Lacks Creek and Minor Creek (Figure 1).

The winters of 1995-1997 appear to have presented an opportunity to contrast the amount of road-related erosion before and after the implementation of the Forest Practice Act. The storms of those winters seemed severe enough that weaknesses in the present roads should have been revealed. Whatever their actual effect, the winters of 1995-1997 prompted the owner of the study area to undertake this investigation. The annual peak flows for those years ranked fourth, tenth, and sixth in the 86-year record of floods of the Eel River at Scotia, California [about 60 km (37 mi) south of the study area]. In the 44-year record of Redwood Creek at Orick the 1997 peak ranked fifth and the 1996 peak ranked eighth but 1995 only ranked 26th (Figure 2). In spite of its low ranking, it was the opinion of foresters working in the study area that 1995 was on a par with 1996 and 1997 with respect to road-related erosion. The nearest rain gage with a continuous record covering the time span of Figure 2 is in Eureka 35 km (22 mi) from the study area (Figure 1). Since there are no rainfall or runoff data from the study area it is not possible to know if these annual peaks reflect the risk of road-related erosion. Due to different locations and the vast differences in drainage areas between these two gaged watersheds and the typical area tributary to a road failure, these three winters may not have been very important with respect to road-related erosion in Redwood Creek. However, it seems more likely that within the longer, more widespread, rainfalls relevant to the Eel River and the entire Redwood Creek watershed there were localized intensities that could have caused accelerated road-related erosion in the study area. The low ranking of the 1995 Redwood Creek peak flow at Orick does cast a cloud over that assumption. The reader will have to decide how much of the differences that will be reported should be attributed to differences in weather and how much to differences in road maintenance and construction practices.

FOREST PRACTICES: 1956-1997

It is not sufficient to merely compare erosion rates on earlier roads with those measured in this study. In order for those rates to be instructive, the construction and maintenance practices must be compared. Furthermore, it will be helpful to understand the political and legislative environments that, in part, motivated forest managers to adopt various practices. Although most of the studies in Nolan *et al.* (1995) cover a time span of 1956-1980, the major change in logging road standards and the associated forest practices actually occurred in 1976. It was then that the Forest Practice Act of 1973 began to be fully implemented and the Timber Yield Tax Law, AB-1258 (Martin, 1989) was enacted. Both had profound effects on how forest properties were managed.

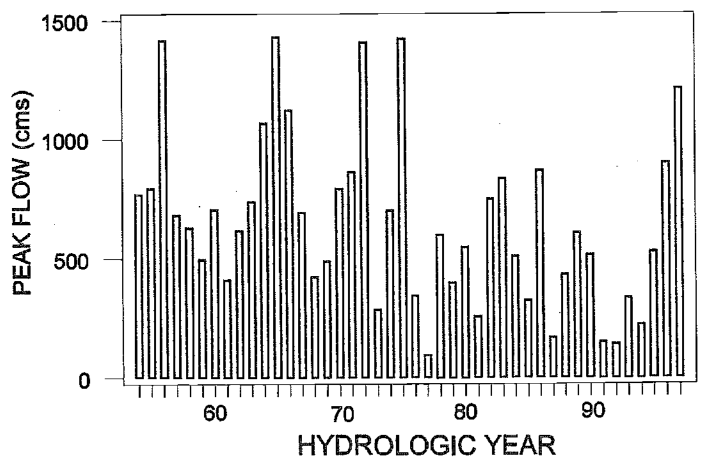

Figure 2. Redwood Creek at Orick HY-1954 to HY-1997.

Prior to the enactment of AB-1258, timber land was taxed at the value of the standing timber if the trees were more than 40 years old. With the increase in timber values that accompanied the post WW-II building boom, this tax treatment was a great incentive to logging of any timber older than 40 years. For example, in the study area during 1951-1958 practically the entire area was logged, leaving only seed trees. In the 1960s the seed trees were removed and any areas that had by then reached taxable age were cut. This practice continued into the 1970s. This history is fairly typical of the middle and upper reaches of the Redwood Creek watershed (Best, 1995). The Timber Yield Tax Law allowed for a nominal property tax but deferred tax on the value of the timber crop until it was harvested. This change permitted land owners to take a long-term view in the management of their properties. The cutting of timber that had reached maturity was based on economic and biological concerns, not on the stand having reached 40 years of age. With a more long-term view of forest management came an interest in permanent road systems to serve on-going forest management. Previously most roads were built on an ad-hoc basis to serve current logging.

The Forest Practice Act of 1973 marked a dramatic change in the level and focus of forest practice regulation by the State of California. Prior to it, although there had been forest practice legislation since 1945, regulations dealt mainly with regeneration and fire control (Arvola, 1976). The Forest Practice Act of 1973 addressed a broader range of environmental concerns which have been further enlarged in response to the California Environmental Quality Act (1970) and Section 208 of Public Law 92-500 (1972 amendments to the Federal Water Pollution Control Act). These laws, together with the Endangered Species Act, have become the vehicles by which the general public and various special interests attempt to affect forest practices. While sometimes burdensome, these laws have not been entirely at odds with the transition that has been occurring during the past half century. The timber industry has gone from utilizing virgin forests to sustained yield forestry.

The changes in practices within the study area between 1956 and 1997 are typical of most ownerships in the middle and upper reaches of Redwood Creek. Prior to 1976 practically all timber was tractor yarded downhill to roads and landings located near stream channels. This pattern of yarding timber tended to cause concentrated runoff and erosion resulting from yarding disturbances to feed into and exacerbate road-related erosion. The roads were two lane, about 8 m (25 ft) wide with occasional wider turnouts. Both alignments and grades were built to minimize road length and stress on logging trucks. Often mid-slope landings were approached with "beaver slides" (spur roads with grades as steep as 35 percent which empty trucks could scale and loaded trucks could descend under control). Most small streams were crossed using "Humboldt crossings" (i.e., cull logs laid in the channel and covered with earth). The failure of "Humboldt crossings" created most of the pre-1980 gullies encountered in this study. Roads were in-sloped and relief culverts, if used at all, were 20-30 cm (8-12 in) in diameter. After a particular road was no longer being used it was water-barred at about 100 m (300 ft) spacing and abandoned (if, in fact, any water-barring was done). All maintenance ceased with the conclusion of logging. Only one main-haul logging road in the study area was surfaced with rock. It was kept open year-round to serve a cattle operation. All other roads were reopened each spring with new fords and by rebuilding crossings that had washed out or plugged during the winter.

The most important difference in practices that has occurred since 1976 is the decreased reliance on tractors for yarding timber. Changes that have occurred in the study area are indicative of those throughout northwestern California. Currently about 35 percent of the timber harvested in the study area is skyline cable yarded. This has led to the relocation of much of the road network out of canyon bottoms to mid-slope and ridge locations. Cable yarding also creates less ground disturbance and the runoff and erosion from cable yarded areas is not so directly channeled into the road system as is the case with tractor yarding. Beginning in the mid-1980s roads in the study area were reduced in width to about 5 m (15 ft). Road grades have been reduced to less than 15 percent except for short pitches of 20 percent where necessary. Streams are crossed with bridges or culverts sized appropriately for a 50 yr. storm using empirical formulas and relief culverts are at least 46 cm (18 in) in diameter. Roads dip into and out of culverted crossings so that the fills over culverts will erode first should the culvert become blocked, preventing the stream from being diverted down the road. Culverts are installed to conform to the stream grade and entrances and outfalls are riprapped with large rock. Frequently, they are fitted with half-round down spouts. Furthermore, less than half of the road mileage in the study area is even drained by culverts. Outsloping, rolling dips, and water bars divert water off of 51 percent of the right-of-way. These changes have reduced the average drainage structure spacing in the study area to less than 37 m (120 ft). Nearly 20 percent of the present road system is surfaced for year-round use and perennially wet sections of seasonal roads are also rocked. Lastly, one man residing on the property inspects the roads throughout the rainy season and during large storms the entire field crew assists him in checking and correcting trouble spots. In addition, the entire road system was checked annually for places needing correction.

STUDY AREA

This investigation was conducted on a single 6,971 ha (17,110 ac) ownership in the middle reach of Redwood Creek, about 27 km (17 mi) inland from the Pacific Ocean. Ninety-six percent of the area lies on the east side of Redwood Creek between the mouth of Lacks Creek and Highway 299 (Figure 1). The watersheds are underlain by the Franciscan Assemblage of Cretaceous and Jurassic rocks (see descriptions in the Appendix) and range in elevation from 240 m (800 ft) to 1200 m (3,900 ft). They receive about 2000 mm (80 in) of precipitation annually, almost entirely as rain between October and April. At the time of the study about 80 percent of the ownership was in a second-growth coniferous forest – mainly Douglas-fir (*Pseudotsuga menziesii*). The addition of hardwoods – mainly Tan Oak (*Lithocarpus densiflora*) brings the total forested proportion of the study area to about 89 percent. Grasslands, brush and bare soil account for the remainder of the area.

Most of the road system evaluated in this study was originally built to support logging during 1950-1958. Consequently, roads still show evidence of erosion during the large storms in hydrologic years 1956, 1965, 1972, and 1975. Most of the system has been brought up to current standards during the past decade. The current 180 km (112 mi.) road system consists of 134 km (83 mi.) of seasonal roads, 24 km (15 mi.) of all-weather roads, 10 km (6 mi.) of jeep roads, and 11 km (7 mi.) of abandoned roads that have not brought up to current standards (see the Appendix for definition of standards). Apart from the use of the road system by logging and silvicultural crews, there is year-round use to manage cattle grazing on the property.

STUDY DESIGN

The sampling frame consisted of 1,117 road segments 0.16 km (0.1 mi.) long [the total length of logging roads in the ownership is 180 km (112 mi)]. One hundred randomly located sites were measured. The following procedure was used to eliminate observer bias in the location of plots in the field. The plots were identified as being a certain distance (to the nearest 0.1 mi) from an intersection. The field crew measured that distance using their vehicle's odometer. At that point a random distance from -80 m to +80 m (-264 ft to +264 ft) was selected. That distance was then measured from the vehicle to the near edge of the 1.5 m (5 ft) plot. The 0.16 km (0.1 mi) segment for tallying Major Events (described below) began at this point and continued in the direction from the vehicle to the plot. In theory this permitted every 30.48 cm (1.0 ft) road segment be included in our sample and therefore every drainage structure had a probability of being sampled in proportion to the length of road it drained.

Site descriptors were recorded at each location in addition to the erosion estimates (Appendix). Their purpose was to elucidate the proportion of erosion associated with various erosion mechanisms, locations, and times of occurrence. Erosion was assumed to equal the volume of the cavity left by the various mechanisms. The volume of each erosional feature was estimated by as many sets of average length, average width, and average depth as the field crew felt necessary to represent its shape. Sheet erosion was not recorded unless it left unmistakable indicators as described under Surface Sloughing in the Appendix. Only erosion deemed to have been caused by the road was recorded. Since the focus of this study was erosion and sediment sources no attempt was made to estimate delivery of sediment to a stream. The field data were collected during June and July 1997. The land owner refrained from any road maintenance on roads included in the random sample until the study data had been collected in order to avoid obliterating evidence of erosion.

Field measurements were taken in feet and converted to yd^3mi^{-1}. English units were used in the field because the crew was more familiar with them and had equipment in those units. It was hoped that by doing so the likelihood of data recording errors was lessened. The equations listed below are the metric equivalents of those used in the study. Each sample site consisted of the following three components:

The Plot. A 1.5 m (5 ft) wide swath from the top of the cut bank to the toe of the fill slope running at right angle to the road centerline. Its primary purpose was to estimate minor erosion on the cut, fill, inside ditch, and running surface.

$$\text{Plot m}^3 \times 656 = \text{m}^3\,\text{km}^{-1}$$

The Drain. Erosion related to the drainage structure conveying runoff from the Plot to a natural surface or channel. Drains included outsloping, inside ditches, rolling dips, waterbars, and culverts. The distance to be measured is clear for the last three. For outsloped roads the distance was measured to where most of the water left the road surface. The designation 'inside ditch' was used when a ditch on an abandoned road drained directly into a stream. The distance (Dist) from the Plot to the Drain was measured as an estimate of half of the spacing between drains since the average distance between the Plot and Drain will be half the average distance between drainage structures.

$$\frac{\text{Drain m}^3}{2 \times \text{Dist km}} = \text{m}^3\text{km}^{-1}$$

Major Events. The sum of the volumes of all erosional features individually displacing more than 15.3 m^3 (20 yd^3) found within a 0.16 km (0.1 mi) road segment bordered by the Plot. The much longer road segment sampled for major events was dictated by their rarity and the fact that earlier studies had found that they were a major part of the measured erosion (Rice and Datzman 1981, McCashion and Rice 1983).

$$\text{Major Events m}^3 \times 6.21 = \text{m}^3\text{km}^{-1}$$

The erosion for each sampled site was the sum of the estimated erosion of these three components.

RESULTS

Erosion Rate

The estimated erosion rate was 177 m^3km^{-1} (372 yd^3mi^{-1}) for the period 1980-1997 (Table 1). During that period the land owner only repaired existing or potential erosion sites. Routine regrading of roads was not done. The data are highly skewed (Figure 3) as is typical of erosion studies with which I am familiar (Dodge *et al.*, 1976; Furbish, 1981; McCashion and Rice, 1983; Rice and Datzman, 1981; Rice and Lewis, 1991). Twelve plots produced about half of the erosion measured. Therefore, any confidence limit based on normal theory would be unrealistic. Frequently erosion data are well fitted by a log-normal distribution. Unfortunately, the logarithms of these data have a strong left hand skew because of a number of small values (not considering nine zero erosion plots). However, the fact that similar patterns of erosion volumes have been frequently encountered (Dodge *et al.*, 1976; Furbish, 1981; McCashion and Rice, 1983; Rice and Datzman, 1981; Rice and Lewis, 1991) suggests that these results are not an anomaly and the average can be accepted with the assurance that it does represent the erosion on the road system. Although the data are based on simple random sampling they appear to give a good estimate of the erosion on the whole road network. An estimate using a stratified sample based on road standard differed from the above figure by less than one percent. Furthermore, the proportion of samples on each road standard agreed quite closely with the proportion of the network in each standard.

Thirteen plots were re-measured by a separate crew to gain some insight into possible 'bias' in the field measurements. The check plots were **chosen** (not at random), without knowledge of their erosion rates, to give a 'representative' sample of the different conditions on the road system. Although there was considerable plot-to-plot variability, the two crews' estimated average erosion rates for the 13 plots were quite close: 240 m^3km^{-1} (505) yd^3mi^{-1} and 228 m^3km^{-1} (479 yd^3mi^{-1}). Satisfaction with the relatively close agreement of these two mean erosion rates was considerably diminished when, in response to a question by a reviewer of an earlier draft of this paper, a detailed analysis was made of the source of each difference of each measurement on each of the 13 plots. The analysis revealed the considerable role that subjective measurements had in determining what was

TABLE 1. The Number of Plots Reporting Erosion Associated With Various Sites, Site Conditions, and Erosional Mechanisms (also the erosion rates and proportion of total erosion attributable to each).

	Number of Plots	Erosion m^3km^{-1}	Erosion (percent)
Erosion Site			
Five-Foot Plot	100	81	46
Major Events	100	67	38
Drainage Structure	100	28	16
Total	100	177	100
Place on Right-of-Way			
Cut Bank	64	110	63
Fill Slope)includes drain)	75	55	31
Road Surface	57	11	6
Erosional Mechanism			
Sloughing	23	53	30
Rills	24	19	11
Gullies	29	24	14
Slides	5	19	10
Slumps	11	62	35
Road Standard			
Seasonal	73	194	80
All Weather	19	146	16
Abandoned and Jeep	8	86	4
Time of Occurrence			
1997	34	6	4
1995-1997	81	92	52
1980-1997	60	78	44
No Erosion	9	0	0

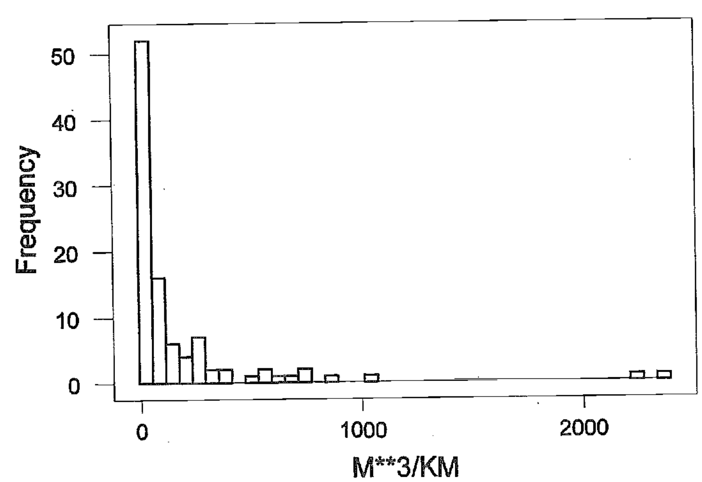

Figure 3. Number of Sites Yielding Various Amounts of Road-Related Erosion.

measured. Each of the three estimates (Plot, Drain, Major Events) had unique problems but all were affected by the determination of whether the erosion had occurred after 1979. Plot measurement differences were dominated by one plot having a high cut bank [4.42 m (14.5 ft)] on which the crews differed by 0.35 m^3 (12.2 ft^3). The next largest difference was 0.05m^3 (1.8 ft^3). The land owner's widespread use of outsloping and rolling dips was the source of much of the differences in Drain measurements. The crews had to determine whether all of the runoff on outsloped roads left the right-of-way before the dip and, if so, where (on average) did it leave? In one instance the check crew missed a culvert and consequently measured a more distant one. The crews agreed on the time of occurrence for only two of the five Major Events on the test plots. The crews volumes differed by about 8% for a large [about 153 m^3 (200 yd^3)] feature. A small slump was measured as 15.7 m^3 (20.5 yd^3) by one crew and 12.4 m^3 (16.3 yd^3) by the other causing it to be tallied by the first crew and rejected by the second.

The estimation difficulties just cited mean that the results reported here must be recognized as the product of the main crew's interpretation of the right-of-way and the volume and age of erosion features encountered. However, it is doubtful that any similar study is free of the same limitation.

Sources of Erosion

Most of the measured erosion took place on road cut banks (Table 1). Cut banks were also the site of most of the erosion by the two dominant mechanisms: sloughing and slumps. None of the site descriptors was a useful predictor of erosion. Slope had the highest correlation: 0.27. The data were plagued with over half of the sites being in one soil or geologic type or one of two types of dominant vegetation. The development of a prediction equation was not the purpose of this study but the low simple correlations suggest that such an attempt would meet with little success.

The last comparison in Table 1 deals with the estimated time of occurrence of the erosion. With some of the larger or more recent features the field crew could remember the time of occurrence. With most features, large or small, indirect evidence had to be relied upon. The sharpness of the scarps or margins was a clue to most features since weathering and animal traffic tends to break down the edges. Plants invading soil exposed by erosion are the other principal age key. Grasses and hydrophytes were usually the first invaders, appearing in the first and second post-disturbance years. Conifer seedlings, appearing in the second and later years, were the next most reliable indicators. Older erosion was usually dated by counting whorls of branches on coniferous reproduction. All of these indicators were subjectively weighted to arrive at an age determination. The three categories overlap in recognition of the uncertainty associated with such determinations. The 1997 value probably does not include all of the erosion occurring in that year. Some 1997 erosion features were likely mistaken for earlier erosion with which they were associated. The 1995-1997 category has a similar problem. Mistaking older erosion for more recent seems less likely to have been a problem. However, earlier erosion that had been corrected and obliterated by maintenance would also not be tallied. What is clear is that the most recent three years produced the majority of the road-related erosion tallied in this study. Coming on the heels of two (possibly three) years having high erosion potential (Figure 2) it is likely that the data are a fair representation of the erosion that has occurred since 1980. Whatever the truth of that assertion, the time-related errors in this study are shared with all similar investigations.

Erosion associated with drainage structures was estimated separately because earlier studies in lower Redwood Creek (Weaver *et al.*, 1995; Best *et al.*, 1995) had identified faulty stream crossings as a major source of road-related and gully erosion. Those studies estimated erosion occurring between 1956 and 1980. The roads in this study showed evidence of similar erosion having occurred prior to 1980. But, as can be seen in Table 1, the drainage structures measured in this study are associated with only 16 percent of the road-related erosion – a far cry from 80 percent as reported by Best *et al.* (1995) or about 71 percent estimated in South Copper Creek by Weaver *et al.* (1995). Nonetheless, culverts had the highest erosion rate of the drainage structures tallied in this study (Table 2).

Comparison With Other Studies

Direct comparison with the earlier Redwood Creek studies is not straightforward. Neither of the two which will be considered (Weaver *et al.*, 1995; Best *et al.*, 1995) had the same objective or experimental design as this study. All three reported erosion evident at the time of measurement with varying amounts of information about when the erosion had occurred. However, both of the other studies contained estimates of road-related erosion that occurred between 1956 and 1980. As such they provide the best available data with which to contrast erosion during that period with measurements made in this study. Both studies were part of a watershed rehabilitation program of the Redwood National Park. They aimed at estimating the magnitude and causes of erosion in

TABLE 2. Erosion Rates Associated With Various Types of Drainage Structures, Their Average Spacing, Their Contribution to Total Drain-Related Erosion, and the Proportion of Total Road Length Served.

Type	Plots (no.)	Erosion Rate (m^3km^{-1})	Spacing (m)	Erosion (percent)	Length (percent)
Out Slope	24	11	34	9	11
Rolling Dip	45	8	51	13	32
Water Bar	9	6	59	2	8
Culvert	17	96	146	59	35
Inside Ditch*	1	46	155	1	2
Other**	4	109	214	16	12

*An inside ditch that became a gully draining into a watercourse.
**Three low-water crossings and one "Humboldt crossing," all on abandoned roads.

the Park and in watersheds tributary to Redwood Creek above the Park boundary.

Weaver *et al.* (1995) were interested in gully erosion and chose nine study sites from preexisting high quality geomorphic maps to represent varying erosion rates. Detailed information was given about one of their study sites: the 246 ha (608 ac.) south side of Copper Creek about 17 km (10 mi) downstream of this study (Figure 1). Fortunately, it is the closest of their study sites to the area included in this study. It was classified as "High Yield" and was entirely underlain by the incoherent sandstone and mudstone unit of Coyote Creek (Cashman *et al.*, 1995), as were 81 percent of the plots in this study. About 73 percent of the Copper Creek site was steeper than 30 percent whereas only 56 percent of the plots in this study were steeper than 30 percent. That discrepancy may be partly due to slope measurements in this study being limited to road rights-of ways (which would tend to be on flatter terrain than the study area as a whole). Copper Creek underwent intermittent selective logging between 1959 and 1963. The remaining timber was clearcut during 1970-1971. Tractors were used for yarding during both periods. The roads were abandoned after 1971. Weaver *et al.* (1995) measured road-related erosion amounting to about 5,200 $m^3 km^{-1}$ (11,000 yd^3mi^{-1}). From the text it is clear that their estimate does not include sloughing or rills which amounted to almost 41 percent if the erosion measured in this study. Presumably, most of this erosion and that measured by Best *et al.* (1995) occurred during the large storms of hydrologic years 1972 and 1975 (Figure 2). It is likely that most of the evidence of erosion that occurred during the winter of 1965 (and also 1955 in the study by Best *et al.*) would have been obliterated by subsequent road repairs or the effects to the 1972 and 1975 storms. Neither study reports any attempt to date the erosion measured.

Best *et al.* (1995) estimated road-related erosion in the 1,080 ha (2,669 ac) Garrett Creek watershed about 10 km (6 mi) downstream from the center of this study (Figure 1). Similar to Copper Creek, it is entirely underlain by the incoherent sandstone and mudstone unit of Coyote Creek. Best *et al.* (1995) do not give specific slope data but describe a convex watershed with 30-35 percent upper slopes and 65-70 percent nearer the stream channels. Garrett Creek has three main roads. One was complete prior to 1954; one built between 1954 and 1965; and one built between 1954 and 1977. One major spur was also constructed between 1978 and 1982. They estimated 7,567 metric tons per kilometer. That rate is about 4,730 m^3km^{-1} (9,970 yd^3mi^{-1}) assuming a specific gravity of 1.6. The authors note that Copper Creek produced more erosion in a nine-year period (1971-1979) than Garret Creek did in 25 years. They attribute the difference to the fact that, unlike Copper Creek roads, Garrett Creek roads were used and sporadically maintained throughout the 25 years. They reported the average size of erosion features resulting from different causes. The smallest average size they reported was about 57 m^3 (63 yd^3) for erosion of inside ditches. From this figure it must be assumed that they too did not record any of the smaller features making up most of the erosion measured in this study.

The estimated 17 years of road-related erosion of this study (1980-1997) can be contrasted with those earlier studies although this study probably did not include as severe storms as the earlier investigations (Figure 2). The contrast with Garrett Creek, which adjoins the study area on the north, is fairly straightforward. The two study areas share common soil, geology, and climate. The only appreciable difference between the two watersheds is the presence of a sizable fraction of redwood-dominated forest in Garrett Creek. The contrast with the south side of Copper Creek is almost as good. Although it is about 17 km (10 mi.) downstream from the site of this study it is still 19 km (12 mi.) inland from the coast. It is topographically similar and underlain by the same geologic formation (KJfc) as under 81 percent of the plots in this study. Like Garrett Creek, Copper Creek had a larger redwood component in its forested areas than found in the study area.

Although the above comparisons are made to support the contention that improved forest practices have greatly reduced road-related erosion, too much importance should not be attached to the exact ratios of the pre-1980 data and the estimate in this study. There is some ambiguity concerning the length of time represented by the erosion measured in the earlier studies. However, it is safe to say that the earlier roads yielded about 20 times as much erosion as measured in this study.

DISCUSSION

The fact that 56 percent of the measured erosion was identified as having occurred in the last three years suggests that the study was timely. However, the small proportion of erosion clearly identified as having occurred in 1997 and its low rate suggests that 1995 and 1996 were mainly responsible for currently active erosion. It may be, however, that recent erosion was just more obvious. The only erosion studies that avoid this ambiguity are those which are installed immediately after a disturbance and track its effects over time. Therefore, the data reported here are comparable to that reported by the majority of studies of road-related erosion in not having a chronology based on observations spanning the time covered by the study.

Since the 1.5 m (5 ft) plot erosion and major events occurred mainly on cut banks, the estimated erosion is likely to present a smaller environmental hazard than might be assumed from the estimated erosion rate. It has been my experience that the vast majority of this eroded sediment will come to rest on the road surface where it can be dealt with in a manner that minimizes its opportunity to enter a watercourse. Deposits blocking inside ditches are removed during routine maintenance or during storm patrols, if possible. Deposits on the 51 percent of the road system that does not depend on inside ditches (out slope, rolling dip, water bar; Table 2) are left in place if they do not impede traffic.

This study confirmed the pervasiveness of bank sloughing as an important part of road-related erosion. As reported by McCashion and Rice (1983), sloughing will have to be accepted as an unavoidable cost of having roads. Fortunately, most of it occurs on cut banks and is less likely to reach a stream channel. Gullies and, to a lesser extent, rills have much higher chance of delivering sediment to a stream since they are formed by flowing water. Slides, in this study, also had a higher sediment delivery potential because about 77 percent of the slide volume measured was eroded from fill slopes. Consequently, it was more likely to have unimpeded delivery of sediment to stream channels.

The erosion rates associated with different drainage structures displayed in Table 2 suggest that this topic might warrant further investigation. Contrary to expectation, rolling dips were associated with a lesser erosion rate than out-sloping, even though they permit a greater concentration of runoff. It may be that they were used in tandem with outsloping frequently enough that their average rate was decreased by those dips being robbed of erosion even though they were the principal drainage structure associated with those plots. Of greater importance is the high erosion rate associated with culverts. Unadjusted for spacing (that is m^3 as opposed to m^3km^{-1}), the average volume of erosion per culvert is nearly 40 times higher than that of water bars, out-sloping, or rolling dips. This may be due to the fact that culverts are often also conveying runoff from other areas in addition to that from roads. It may also stem from many culverts being located in still-erodible gullies created prior to 1980. It may also be due to the random sampling including one extreme event. One site yielded almost 80 percent of all the culvert erosion. However, even with that one extreme plot removed, erosion at culverts is still more than ten times larger than that associated with other drainage structures (excluding the one inside ditch drain and the 'Other' category). The very high erosion rate of the 'Other' sample sites suggests that abandoned roads should be inventoried and erosion problems corrected.

In spite of the likely differences in erosional stress between the time period covered by the earlier Redwood Creek studies and the time period covered by this one it is highly unlikely that the differences in erosion were solely due to that cause. The erosion rate measured in this study amounted to about 3 percent of that estimated in Garrett Creek (Best *et al.*, 1995) and in South Copper Creek (Weaver *et al.*, 1995). The annual sediment load of Redwood Creek was approximately the 1.9 power of the annual peak discharge ($r^2 = 0.83$) from 1971 to 1992. If that relationship applies to erosion in the watershed the 1980-1997 erosion should have been about 40 percent of the 1956-1979 erosion. Since it was much less than that percentage it seems likely that improved forest practices played a role in reducing road-related erosion. Furthermore, both the earlier studies focused on large features, neglecting about half the erosion measured in this study. The assumption that poor road construction and maintenance was a substantial contributor to the differences between them and this study is supported by a study of road-related erosion on the adjoining Six Rivers National Forest by McCashion and Rice (1983). That investigation spanned a similar time period as the early Redwood Creek studies but estimated that road-related erosion was 188 m^3km^{-1} (395 yd^3mi^{-1}) which is close to the 177 m^3km^{-1} (372 yd^3mi^{-1}) found in this study. Road maintenance and construction standards on the Six Rivers National Forest at that time were quite comparable to those currently being employed in the study area. Disparities in culvert erosion also support the contention that differences in road standards are responsible for much of the reduction in erosion measured in this study. Both of the earlier studies report stream diversions because of blocked culverts or other stream crossings were the major cause of erosion. There were no stream diversions or blocked culverts in this study.

CONCLUSIONS

The results of this investigation suggest that changes in forest practices have greatly reduced road-related erosion in the middle reach of Redwood Creek. The estimated erosion rate was more than an order of magnitude less than that estimated in the adjacent Garrett Creek watershed (Best *et al.*, 1995) and for the south slopes of Copper Creek (Weaver *et al.*, 1995) as the result of practices employed prior to 1976. The reduction in erosion is attributable to better sizing and placement of culverts and, especially, to less reliance on culverts to handle runoff from road prisms. It is also likely the result of less reliance on tractor yarding. Cable yarding tends to isolate yarding disturbances from road rights-of-way. Since nearly 63 percent of the measured erosion occurred on cut banks and, therefore, has less direct access to the stream network, it is likely that the road system's impact on water quality will be less than might be inferred from the gross erosion rate.

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APPENDIX
EROSION MEASUREMENTS

Each erosion measurement was first identified as to location: cut, fill, road surface, or drainage structure. Next its erosional mechanism and estimated time of occurrence (1997, 1995-1997, or 1980-1997) was recorded. Finally, its dimensions were transcribed.

MECHANISMS

Surface Sloughing

This is the gradual retreat of cut or fill surfaces. On cuts it is evidenced by exposed roots (the ends of which were at the cut surface when the road cut was made) or overhanging sod where the roots of the surface vegetation has held a thin layer of soil in place as the bank beneath it retreated. On fills sloughing may be evidenced by soil deposits at the toe of the fill or by the presence of rocks, sticks, or other more resistant material protruding from the general surface (indicating that the finer soil has eroded either by water flow or dry ravel).

Rill

A rill is a clearly defined channel that is at least 0.1 ft. deep and no more than 1.5 ft. across. It also can not have a cross sectional area greater than 1.0 $ft.^2$.

Gully

A gully is a clearly defined channel made by flowing water that has a cross sectional area greater than 1.0 $ft.^2$.

Slide

All rapid incoherent mass movements will be included in this category. They range from rock falls to debris torrents depending upon the amount of water involved. Typically they are sudden in initiation and move rapidly down steep slopes (almost always slopes > 55 percent). They usually triggered by high intensity one to two day rainfall amounts (once soil moisture deficits have been satisfied in autumn or winter).

Slump

This category will include all of the more or less coherent mass movements such as block glides, slumps, and soil creep. These features are typically more deep seated than slides and, with the possible exception of block glides, are slower moving. They are also usually larger than slides. Slumps normally have a curved failure surface with a steep scarp above a cavity at the head of the movement and a depositional mound at the toe. All involve a large amount of subsurface water and respond to long duration [weeks to seasonal] rainfall amounts.

FIELD MEASUREMENTS

Plot Description Variables

- Slope – Percent
- Dominant Vegetation – Coniferous forest, hardwood forest, brush, grass, bare
- Cut Bank Height – Feet
- Cut Bank Vegetation – Bare, grass, woody plants
- Road Standard
  - Seasonal – Usually unsurfaced single lane with turn-outs
  - All-Weather Secondary – Usually most of the length is two lane; surfaced with gravel or crushed rock of moderate depth
  - Abandoned – Roads that have not been maintained since 1980
  - Jeep – Roads of such a standard that they are only passable to four-wheel drive vehicles or ATVs
- Drainage Structure
  - Type – Outslope, water bar, rolling dip, inside ditch, culvert
    - For Culverts – Diameter, condition
  - Erosion Site – Outfall, entrance, road surface

Office Measurements

- Plot Description Variables
  - Geology (from Cashman *et al.*, 1995)
    - KJfc – Incoherent sandstone and mudstone unit of Coyote Creek
    - KJfg – Transitional rocks of the Grogan Fault Zone
    - KJfr – Redwood Creek Schist
    - Qt – Terrace deposits
    - Qls – Landslide deposits

Road Age – Years since construction or major maintenance. Major maintenance would include such activities as replacing culverts, outsloping or installing rolling dips on a road previously drained in some other fashion, repairing storm damage, adding new surfacing, etc.

Soil – Types by the California Cooperative Soil-Vegetation Survey (Colwell, 1979)

Cooperative Monitoring for Turbidity and Suspended Sediment: Monitoring and Research on Three Tributaries of Elk River, California for Hydrologic Years 2004-2006

Project Completion Report for the California Department of Forestry and Fire Protection

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March 25, 2008

Abstract

Monitoring of three Elk River tributaries located in Humboldt County near Eureka, California was conducted for hydrologic years 2004 through 2006. Turbidity, streamflow and suspended sediment data were collected at three in-stream monitoring stations. The watersheds upstream of the stations differ in their management histories, but are located in close proximity to one another and have similar physiographic parameters, including size and geology. The Little South Fork Elk River watershed is comprised of mostly undisturbed, mature forest and is located completely in the Headwaters Reserve. Corrigan Creek watershed was first harvested in the 1950s and then experienced a second harvest entry in its headwaters in the early 1990s. The South Branch North Fork Elk River watershed was first harvested in the 1970s and then experienced a second harvest entry throughout its entire watershed in the early 1990s. This combination of management history allows evaluation of suspended sediment inputs on a virtually undisturbed watershed and tracking of possible declines in suspended sediment loads with road rehabilitation efforts in the two managed basins.

Data collected at these stations for all three hydrologic years has been compiled and placed on a DVD for more complete analyses by other entities. Data from hydrologic year 2004 have been summarized by Manka (2005), but data from the second and third years have only been qualitatively described to date. Hydrologic year 2005 and 2006 data indicate that sediment yield for the undisturbed watershed was substantially higher in the second and third years when compared to the values observed during the first year. Turbidity values exceeded 400 Formazine Nephelometric Units (FNUs) in year two and three, while in the first year, turbidity never exceeded 74 FNU. Additionally, the data show the effects of poor road maintenance on downstream turbidity and the benefits of road upgrading work for improving water quality in the Corrigan Creek watershed. Turbidity values were high after a section of road contributed sediment into the stream, but were reduced after correction of the problem.

Introduction

Increased suspended sediment in streams impacts both the physical and biological function of stream systems. Physically elevated suspended sediment can change the configuration of course and fine bed sediments which can fine the stream bed. This fining of the streambed can be detrimental to salmonids by reducing inter-gravel flow of oxygen to developing embryos and by entombing alevins (Hall and Lantz 1969, Phillips et al. 1975). Salmonids are of particular concern in northern California because several threatened or endangered salmonids species are present in the region. High volumes of even fine sediment and sand can effectively reduce pool volume thereby decreasing rearing habitat for juvenile salmonids and resting pools for migrating adults (Lisle and Hilton 1992). Sedimentation can also interfere with the production and diversity of macrobenthic organisms, an important salmonid food source, by reducing hyporheic movement and eliminating the rearing space of these organisms (Spence et al. 1996). The majority of watersheds on the North Coast of California have been listed as impaired due to excessive sediment under Section 303d of the Clean Water Act (Fitzgerald 2004).

In response there has been a great deal of effort in monitoring suspended sediment on the North Coast from private and government sources. However, in many cases the layout of the stations does not allow for the testing and contrast of issues, as they are often on watersheds with similar management or in places where there is not much planned activities that are expected to change sediment loads.

In 2002, an opportunity was identified by Dr. Hobart Perry of Humboldt State University to monitor sediment on three tributaries of Elk River. The three tributaries were intriguing because they were similar in size and distinct in management treatment. One, Little South Fork, had virtually no harvesting or road building. The two others, Corrigan Creek and South Branch North Fork, had repeated harvest entries and a network of roads that needed rehabilitation. Rehabilitation was in the planning stages but had not occurred yet. In response, three turbidity, streamflow and suspended sediment monitoring stations were established in the lower ends of each watershed in the fall of 2003 and monitoring occurred in the winters of 2003-2004, 2004-2005 and 2005-2006. The Watershed Program at Humboldt State University was an ideal entity to initiate and continue this monitoring because one watershed is on government controlled land (the Headwaters Reserve), while the other two watersheds are on privately managed ground (Scotia Pacific).

With the first year data (2003-2004), a Masters thesis (Manka 2005; Appendix C) was produced which mostly covers the diagnostics of measuring turbidity and suspended sediment. It also reported very stark differences in terms of annual suspended loads between the three watersheds. The Little South Fork Elk River, the watershed comprised of mostly undisturbed, mature forest, had a suspended sediment yield of 6 tons/km^2. The two managed watersheds were considerably higher. Corrigan Creek had a sediment yield of 59 tons/km^2 and the South Branch North Fork Elk River watershed had a suspended sediment yield of 121 tons/km^2 during water year 2004.

The Stations

Study Sites:

The following is excerpted from Manka 2005 (Appendix C):

The three sampled watersheds are located in the Elk River watershed just south of Eureka, California (Figure 1). Elk River drains a 137 km^2 area extending from the western slope of the northern California Coast Range to Humboldt Bay. The lower watershed is divided into many private holdings and the primary land uses are *agricultural and residential. A majority of the upper watershed is owned by the Pacific Lumber Company with the exception of the 30 km^2 Headwaters Forest Reserve that is publicly owned and managed by the United States Department of the Interior Bureau of Land Management.*

The Elk River watershed is dominated by a maritime climate regime. Temperatures are moderate, and humidity remains high throughout the year. Summers are dry, and the rainy season (October through April) accounts for 90% of the total annual rainfall. The forested uplands of the Elk River watershed receive about 165 cm of precipitation per year (Hart-Crowser 2004).

Forest stands in Elk River are dominated by redwood (Sequoia sempervirens) with Douglas-fir (Pseudotsuga menziesii), true fir (Abies sp.), Sitka spruce (Picea stichensis), western hemlock (Tsuga heterophylla), incense cedar (Calocedrus decurrens), western red cedar (Thuja plicata), and madrone (Arbutus menziesii) common in some locations. Deciduous trees are uncommon outside of riparian areas and some disturbed areas where a high degree of compaction or soil loss has occurred.

The watersheds are underlain mostly by rock units of the Quaternary/Tertiary Wildcat Group, which consists of poorly compacted sandstones, siltstones, and mudstones that are highly susceptible to erosion where exposed (Knudsen 1993, McLaughlin et al. 2000). Stream channels draining areas underlain by Wildcat units are often dominated by silts and sands and have a high potential for suspended sediment loads (Hart - Crowser 2004).

Rock units of the Late Cretaceous Yager terrain are present in portions of the upper watershed, especially in stream channels and adjacent valley segments where the streams have incised through layers of Wildcat to expose the underlying Yager units. Yager units are substantially more cohesive and resistant to erosion than Wildcat units (Personal communication, J. Stallman 2004. Stillwater Sciences, 850 G Street, Arcata, CA 95521).

They consist primarily of mudstones, siltstones, shales, graywackes, and some conglomerates (Knudsen 1993, McLaughlin et al. 2000). Stream channels that have down cut into the Yager units expose material ranging from well-consolidated bedrock to cobbles and gravel (Hart – Crowser 2004).

McLaughlin et al. (2000) mapped all three watersheds as consisting primarily of rock units of the Quaternary/Tertiary Wildcat Group with stream channels that have down cut into rock units of the Late Cretaceous Yager formation in some locations. Field reconnaissance and geologic consultation suggest that stream valley down cutting into the underlying Yager unit is more extensive than that mapped by McLaughlin et al. (2000) and that the proportion of stream channel that is cut into the Yager unit is similar for all three streams.

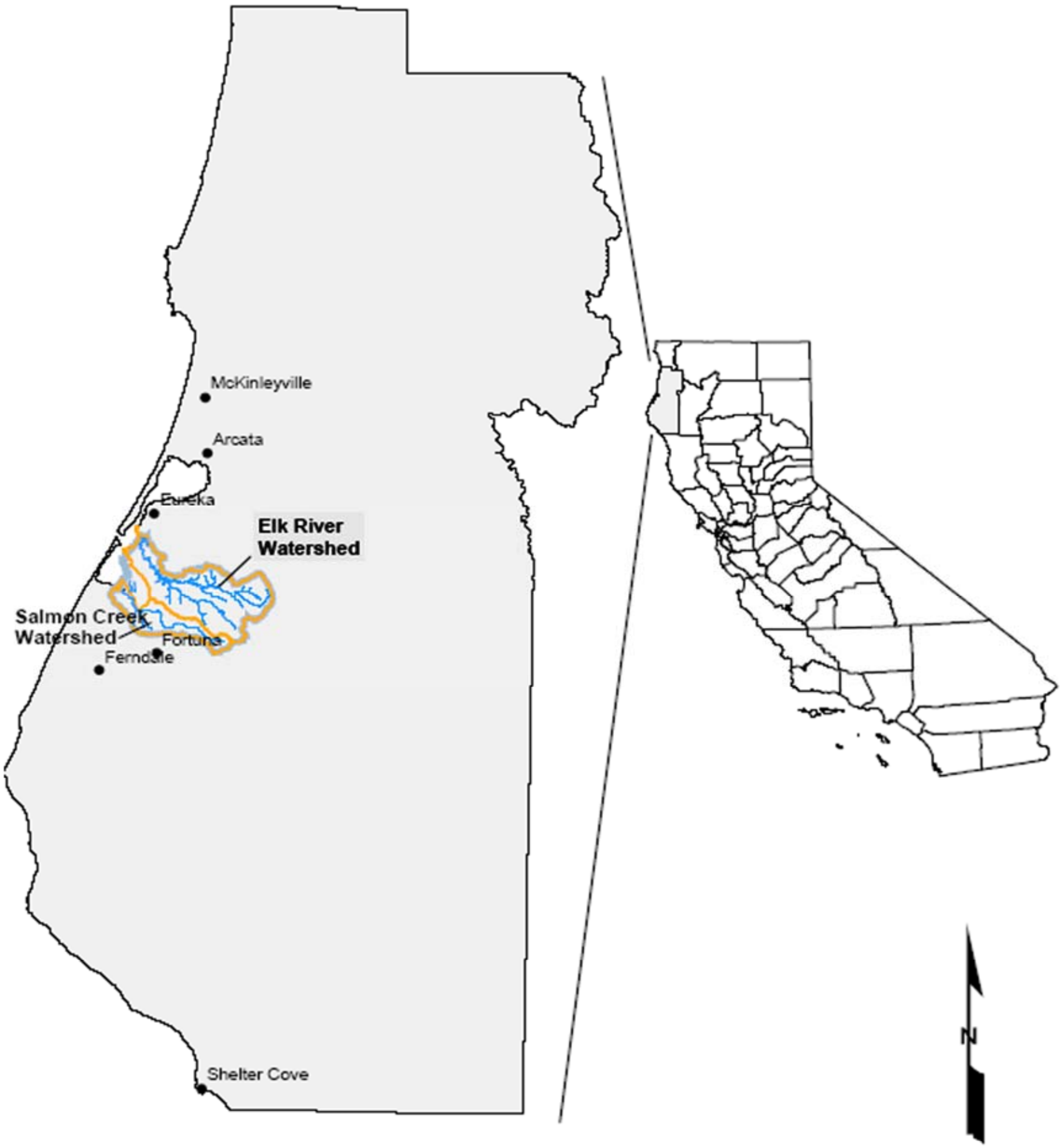

Figure 1. Elk River watershed, Humboldt County, California.

Locations of the three sampling stations in this study were selected such that the watersheds above the sampling locations were of similar physiography. All three watersheds have the same orientation to and are located the same distance from the ocean. This causes the watersheds to lie within the same isohyetal bands of average precipitation.

All three stream systems have similar watershed areas. The South Branch North Fork Elk River is the northern most system and drains an area of 4.9 km^2. Corrigan Creek drains an area of 4.0 km^2 and shares its northern watershed boundary with the southern boundary of the South Brach North Fork watershed. The Little South Fork Elk River drains an area of 3.1 km^2 and is located southwest of Corrigan Creek (Figure 2).

Lengths of stream channel per unit area that are designated as either Class 1 or Class 2 are also very similar. Class 1 and Class 2 designated stream channels are those that support fish or other aquatic species. South Branch North Fork Elk River has 1626 m/km^2 of Class 1 or Class 2 stream channel, Corrigan Creek has 1783 m/km^2, and Little South Fork Elk River has 1727 m/km^2 (Hart - Crowser 2004).

The primary difference between the three watersheds is their management histories. Most of the South Branch North Fork watershed was first harvested in the 1970s, though small areas were harvested in the 1940s and 1960s as well. A second harvest entry occurred throughout the entire watershed in the late 1980s and early 1990s consisting of partial cut and clear cut harvests with tractor yarding. The lower portion of the Corrigan Creek watershed was first harvested in the 1950s and the upper portion was first harvested in the 1970s. The upper portion experienced a second harvest entry in the late 1980s and early 1990s consisting of partial cut and clear cut harvests with tractor yarding. The lower portion of the watershed has not experienced a second harvest entry. The area above the Little South Fork Elk River sampling station has never been harvested and consists entirely of late successional, old-growth redwood forest. There were plans to conduct harvest activities in this area and a 1.6 kilometer section of road was constructed from the southern boundary of the upper watershed running adjacent to the stream channel in the early 1990s. This area of the Little South Fork watershed was included in the Bureau of Land Management's purchase of the Headwaters Forest Reserve in the mid 1990s. The road was subsequently decommissioned and a complete slope restoration including excavation of stream crossings and recontouring of hillslopes was completed in 2003.

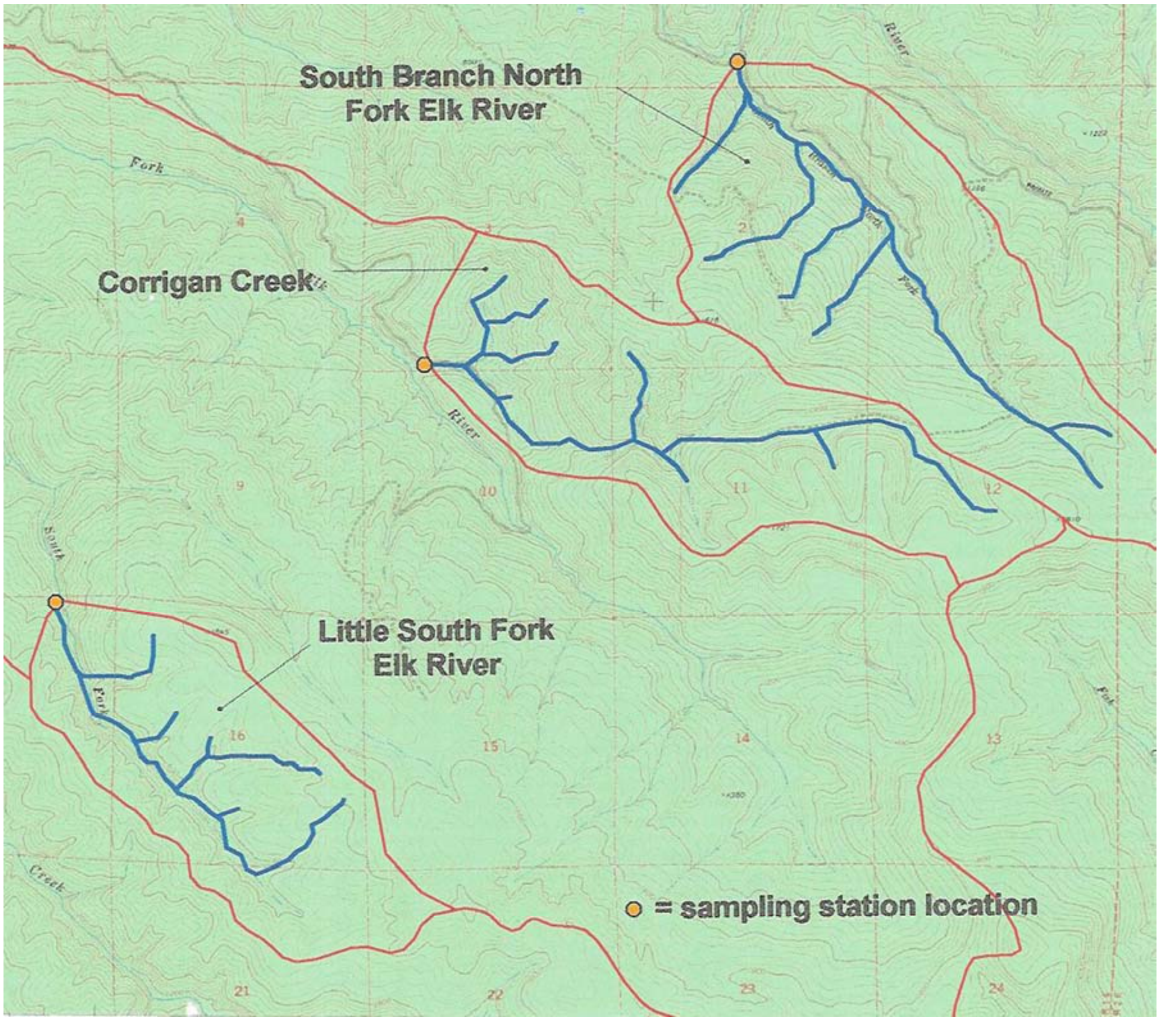

Figure 2. Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River watersheds and sampling station locations (extracted from McWhinney Creek 7.5-minute quadrangle).

Project Station Instrumentation and layout

The project utilized the turbidity threshold sampling protocol developed by Lewis and Eads (2001) to take suspended sediment samples from a pump sampler. Stations were constructed at locations on the streams that made them suitable for sediment sampling <u>and</u> stream gaging. At the sampling location, the stream had to be deep enough to fully submerge the turbidity probe. Generally pools were not used because sediment tends to settle there in a non-uniform manner depending on flow levels. Likewise riffles may create high of turbulence which can also lead to non-uniform sediment transport. The ideal location is a "run" that has relatively uniform and moderate depth, width, and bed material. This is also the ideal location to conduct stream discharge measurements. In the absence of an installed flume or weir, it was necessary to find locations that had natural downstream controls such as a log or a rock weir that serves to maintain the stage – discharge relationship throughout the range of flows.

The three suspended sediment sampling stations that were installed on Elk River all use the turbidity threshold sampling program to govern their sampling regime. The three sites all have different thresholds because of differences in turbidity ranges. All three sites use identical sampling instrumentation. Turbidity and stream water temperature is measured using a Forest Technology Systems DTS-12 turbidity probe. The units of measure for the DTS-12 are Formazine Nephelometric Units (FNU) under revised standards released by the United States Geological Survey (Anderson 2004). The uses an articulated boom that hinges laterally and downstream the probe hangs from this boom. This type of setup allows the probe to be easily displaced by logs and other debris transported during storm events without damaging it. An ISCO 3700 pump sampler is located in a small shed near each stream. The 500 mL sample bottles are filled with about 350 mL of stream water when a pump sample is triggered. The water is drawn through a 0.635 cm diameter vinyl tube that passes through the boom arm. The intake is located approximately 3 cm below the front of the turbidity probe. A Druck 1830 pressure transducer is used to monitor the water surface elevation (stage) of the stream. The pressure transducer is mounted in a 2.5 cm pipe with a perforated cap on the end to allow water in. The end of this pipe is submerged at all flows and is connected to rebar that is driven into the stream bed near the turbidity probe. This must be a fixed installation, as any movement would alter the stage reading. Each site is also equipped with a staff gage that allows a visual estimation of the water stage. The turbidity probe, the pump sampler, and the pressure transducer are all connected to a Campbell CR10X data logger which is housed inside a water proof case that is installed inside of the shed. Due to difficult access, an analog phone modem was installed at the Little South Fork site to permit remote monitoring of data and to determine when a station visit was necessary. A solar panel was installed there in order to power the site without having to transport batteries. A tipping bucket rain gage was also installed at the Little South Fork site in mid-February, 2004.

Sites were visited during and after major storm events in order to re-supply bottles, download data, check for proper functionality, clear debris interfering with the turbidity probe or pump sampler intake, clean turbidity probe optics, and conduct stream discharge measurements. Discharge was measured according to the velocity – area method (using a Marsh-McBurney Flo-Mate electronic velocity meter to measure flow velocity. Time allowing, a second discharge measurement was taken for quality control purposes.

Collected bottles were labeled and stored until they could be processed. Lab procedures for measuring suspended sediment concentration in samples followed procedures detailed in Standard Methods for the Examination for Water and Waste Water (American Public Health Association 1992). In addition to standard suspended sediment sampling procedure, all samples were first passed through a 0.0635 mm sieve to separate sands from the remaining sediments. The samples were then passed through a 1 µm (0.001 mm) pore size filter to determine the weight of fine particles (silts and clays). Every third consecutive sample whose field turbidity was greater than 200 FNU was also first passed through four additional sieves (1000, 500, 250, and 125 μm) in order to gain an appreciation for the size distribution of sediments in high concentration samples. Turbidity was measured for all lab samples using a Hach 2100 N laboratory turbidity meter. Lab turbidity data was used to cross reference field turbidity measurements in order to ensure field data quality.

Results and Discussion

Attempts were made to reduce the 2004-2005 and 2005-2006 data sets using simplified relationships for sediment load vs. turbidity relationships, as well as stage-discharge relationships. However, two entities, the North Coast Regional Water Control Board (NCRWQCB) and the Pacific Lumber Company (PALCO), plan to rework this data into a larger data set using more sophisticated methods. Rather than create a set of numbers using simplified methods that would be preliminary, refuted, and transcended by these two efforts, this report merely describes the turbidity and stage data in a qualitative way and provides all the data to both entities for their analyses.

This report briefly summarizes the 2003-2004 data reported by Manka (2005) (see Appendix C), as well as a Humboldt State University student senior project completed by Stewart and Musso (2006, included as Appendix B) who completed a preliminary analysis of 2005 and 2006 data. It also includes all stage-discharge data, instantaneous turbidity and stage data, and suspended sediment bottle sample concentrations (Appendix – DVD; described in Appendix A).

Manka (2005) reported that the relatively undisturbed watershed had an order of magnitude less sediment output than the two managed watersheds: 6 tons/km^2 vs. 59 and 121 tons/km^2 for the 2003-2004 winter season. He also determined that 75-90% of the suspended sediment load was made up of material finer than sand, and that annual relationships between sediment load and turbidity in general predicted suspended load almost as well as samples based on individual storm events.

Data from the next two years complicates some of the findings of Manka. Stewart and Musso (2006) found turbidity readings in Corrigan Creek increased relative to the South Fork of the North Fork. Also turbidity in the Little South Fork increased greatly relative to what it was in 2003-2004, meaning that its pristine values, while still likely lower than those of the managed watersheds, were not as low as first thought (Figure 3). As an example of this increase in turbidity, during 2003-2004 the highest FNU turbidity values were less than 80 FNU for the Little South Fork. During the next two years, there were several recorded values over 500 FNU (see turbidity values for the Little South Fork in Appendix – DVD). The differing relative values underscore the importance of evaluating long-term records rather than basing too much on single season records.

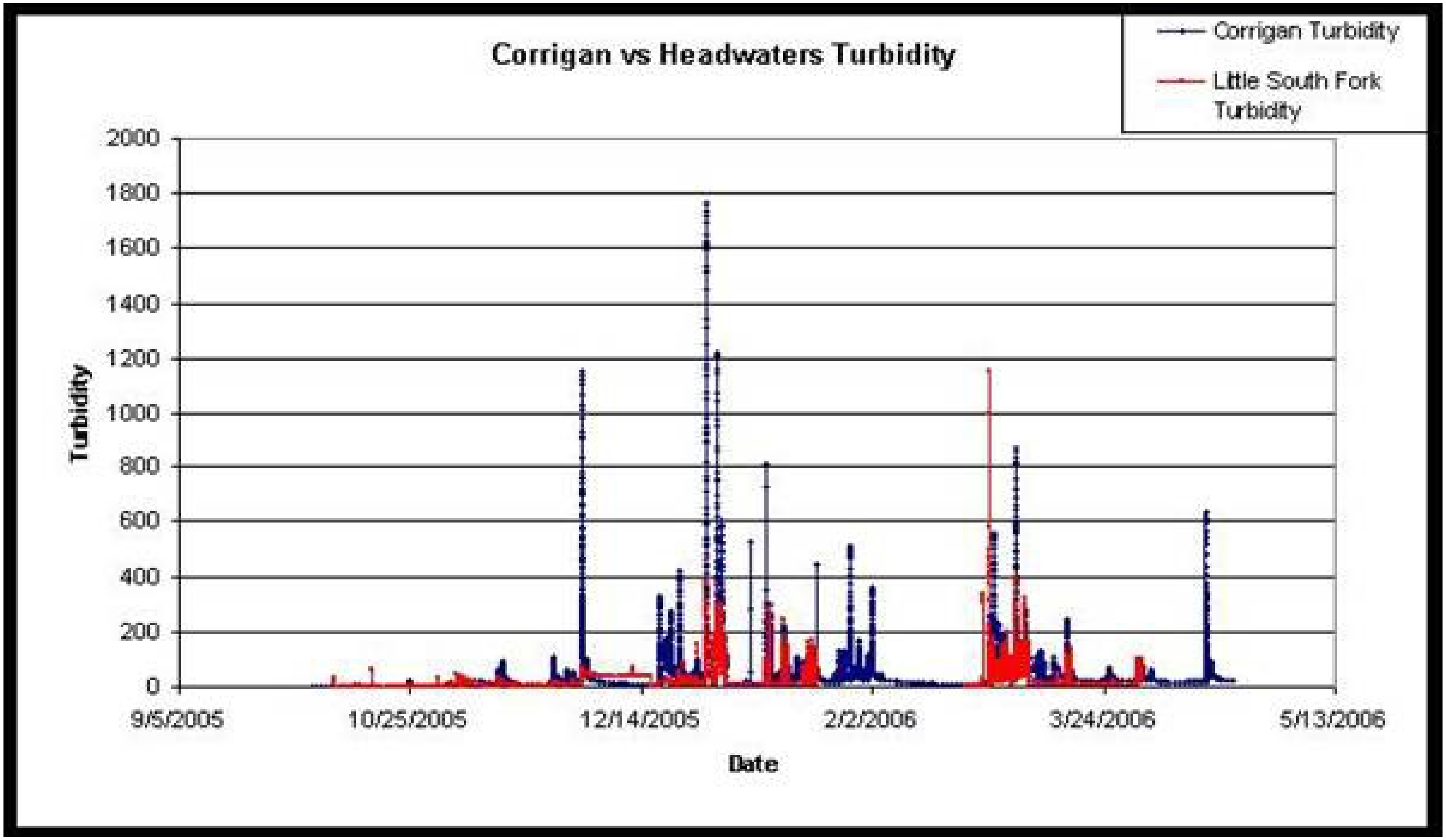

Figure 3. Comparison of turbidity between Corrigan Creek (managed) and Little S. FK. (Relatively undisturbed) for parts of the 2005 -2006 storm season (from Stewart and Musso, 2006).

Stewart and Musso (2006, Appendix B) also attempted to compare the relatively undisturbed Little South Fork with the closer of the two managed watersheds, Corrigan Creek, in terms of sediment sources using a conceptual variable source area model. By evaluating areas that were prone to surface erosion they found that there was approximately 938 m^2 (10,095 ft^2) of area that was susceptible to surface erosion vs. only 136 m^2 (1,468 ft^2) for Little South Fork. Areas that were vulnerable to surface erosion included legacy features such as old Humboldt Crossings, old road ditches and other road-related features, as well as eroding features along Corrigan Creek. They also noted that channel complexity components such as boulders and large wood were largely absent from Corrigan Creek, and that headcut erosion was occurring on Corrigan Creek but not noticed on along the Little South Fork channel. Features producing sediment such as bank failures and cut banks, as well as depositional features, were much more frequent on Corrigan Creek. Management-related features such as roads near the channel and hydrologically connected inboard ditchlines were also much more common in the Corrigan Creek drainage. Many of the features that were contributing to erosion rates on Corrigan Creek were due to past management actions and some of the features such as headcutting are secondarily related to older timber operations. Simply limiting modern day timber harvesting would only address erosion occurring at a few of these sites. In order to address a large number of sediment producing features, a watershed-based approach would have to be employed to develop erosion control measures for the most significant sites, possibly based on when they may contribute based on storm type. That is, an appropriate strategy to reduce sediment generation may be to mitigate the erosional features that contribute during low flow events.

During the Stewart and Musso (2006) study, a road maintenance problem was discovered in the Corrigan Creek watershed (late January 2006). Turbidity values spiked on Corrigan Creek during this period and then lowered after the problem was corrected during late February/March 2006, even when large storms were occurring.

Summary and Conclusions

Results for the water year 2003-2004 show an interesting difference between the three watersheds with Little South Fork having an order of magnitude less sediment output than either of the managed watersheds. In addition Corrigan Creek had about half the sediment production of North Fork of the South Fork. However, hydrologic year 2005 and 2006 data indicate that sediment yield for the undisturbed watershed was substantially higher in the second and third years when compared to the values observed during the first year. Turbidity values exceeded 400 FNUs in year two and three, while in the first year, turbidity never exceeded 74 FNU. While there is probably still a substantial difference in total yield between the Little South Fork and the other two watersheds, the differences would not be as great. These inter-annual differences illustrate the importance of having multi year records as sediment inputs can be episodic and vary greatly from year to year.

Stewart and Musso (2006) attempt to analyze source areas for the sediment that cause differences in turbidity between Corrigan Creek and Little South Fork. What they found are features due to legacy effects such as road surfaces and ditches that create fundamental differences in source between the two watersheds. Anecdotally, they also note that the Corrigan stream and near stream area lacks the complexity of Little South Fork and appears to be down cut creating different sediment dynamics along this stream. In order to get sediment values approaching Little South Fork, there would probably need to be additional activity to rehabilitate some of these conditions in addition to merely restricting current timber harvest practices. On another side note, there is an interesting sequence on Corrigan Creek where turbidity values went up probably due to poor road maintenance in that a car created ruts that discharged directly into Corrigan. After one of our student assistants reported the problem, it was corrected, and turbidity values went back down proportionally in the charts. This little sequence illustrates the benefits of road maintenance and perhaps road upgrading work for improving water quality in the Corrigan Creek watershed.

The missing data and problems listed in Appendix A illustrate the pitfalls of trying to run stations on minimal funding and the problems that can ensue. Even with these problems there are many uses for this data set. In fact, the data collected from fall 2003 to summer 2006 will only grow more valuable with the addition of the 2007 and 2008 water years that are currently being collected by others.

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Appendixes

Appendix A – Description of data sets for water years 2004-2006 for the three Elk River tributaries.

Appendix B – Stewart, R. and J. Musso. 2006. Using the variable source area concept as a tool for the comparison of instream sediment processes in the Elk River watershed. Student Senior Project (Capstone). Humboldt State University, Forestry and Watershed Management Department. Arcata, CA.

Appendix C – Manka, P. 2005. Suspended sediment yield in tributatries of Elk River, Humboldt County, California. M.S. Thesis, Humboldt State University, Arcata, CA. 91 p.

Appendix DVD – Data Sets for 2003-2004, 2004-2005 and 2005-2006 winter storm seasons for three Elk River tributaries.

Appendix A

The DVD available for this project has the complete data sets for the Elk River study. It is divided into two areas – data reduction and analysis, and field data. The data reduction and analysis folder includes a considerable amount of analyzed data, especially for the 2004 water year. For the 2005 and 2006 hydrologic years, important files include the reduced ESL (Little South Fork); ESC (Corrigan Creek) and ENS (North Fork of the South Fork) files, with names ESL Data 2005.xls etc… The names vary by stream and year but these files have all turbidity and stage data at 10 minute intervals downloaded from the data dump files which are provided in the field turbidity data section. All major files are in Microsoft Excel spreadsheets. Turbidity is in FNU and stage is in feet. Greater detail about units is given in Manka (2005). There are breaks in the turbidity and stage data that occur because of equipment malfunction. There are also shifts in stage that occur because of sediment transport dynamics. The breaks in data are self evident in the files and the stage shifts are also obvious in that they are quite large without large shifts in turbidity.

Within the field data are discharge measurements sorted into different files by tributary and year. Turbidity measurements are also sorted by tributary and year. All discharge data is provided in Excel spreadsheets in a standard format. All the information in the turbidity measurement files with the suffix xxxx.dat are collated and summarized in the Excel data files (i.e., ESL Data 2005.xls) given in the data reduction section by year and summarized above.

Information regarding pump sample bottle samples is provided in the "LabData" folder under the data reduction section. Samples from 2003-2004 and 2004-2005 have had more data reduction than the 2005-2006 samples, but there is sufficient information in the files to get the concentration for each sample that can be related back to turbidity. The samples end abruptly in spring of 2006, due to insufficient funding available to analyze the remainder of the sample bottles.

Appendix B

Stewart and Musso (2006) begins on the next page.

Appendix C

Manka (2005) follows Stewart and Musso (2006).

Using the

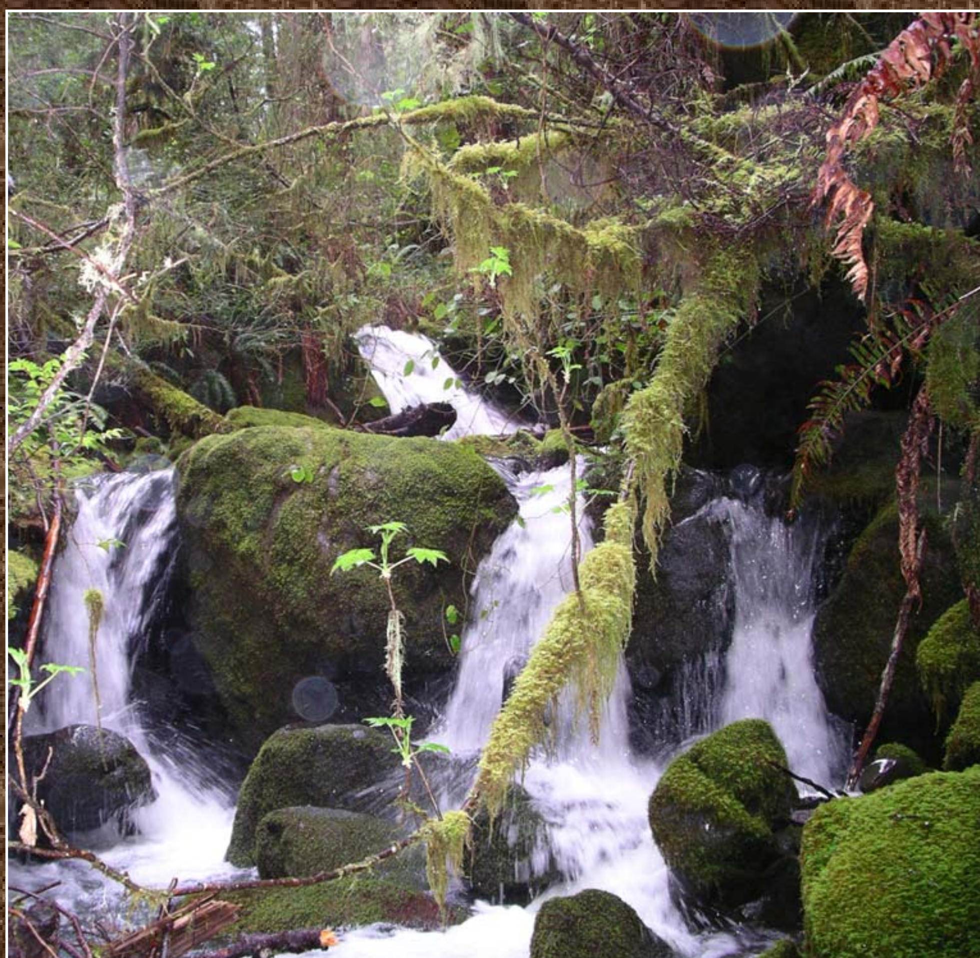
Variable Source Area Concept

as a Tool for Comparison of

In-stream Sediment Processes

in the

Elk River Watershed



Abstract

The Variable Source Area Concept was used as a tool for comparing sediment sources on two tributaries to the south fork of the Elk River. Corrigan Creek has had extensive management in its past, and is currently being managed by Pacific Lumber Company. Little South Fork is located approximately 2.5 to the southwest of Corrigan Creek, and its upper reaches (the area used for this study) have never been managed. It is currently property of the Bureau of Land Management, part of the Headwaters Reserve. Unaffiliated with this study, turbidity data and flow measurements have been taken on these streams for the past three years, and from this data it is clear that Corrigan Creek has much higher sediment loads than Little South Fork: 55.1 tons/ km^2 as compared to 6.6tons/ km^2. Investigations indicate that this magnitude of difference cannot be attributed to natural sediment sources, and therefore must be due, in part, to anthropogenic sources. Data collected showed larger frequency of in-stream sediment sources as well as sources due to management effects in Corrigan Creek. When data was analyzed it was determined that the management effects did not totally account for the difference in sediment levels, and therefore the remainder of excess sediment might be attributed to legacy effects from past management.

Introduction and Statement of Objectives

Sediment source analysis in forested watersheds provides an important indication of the connectivity of forest management practices to water quality. Many water quality regulations require and are driven by the surveys and inspections of stream sediment sources. Sediment sources may originate from two categories: natural and anthropogenic. Naturally occurring sediment sources can be a result of parent material, topography, climate, and natural disturbance regimes. Anthropogenic sediment sources are a result of human interference and can be subdivided into sources from past management (legacy effects) and sources from current management. When anthropogenic sources are added to naturally occurring sources, the increased sediment levels can adversely affect wildlife habitat, water quality and in-stream processes. A challenge in analyzing sediment sources is differentiating between sources that are naturally occurring and those that are caused by the relentless hand of humankind. The objective of this project was to develop a "quick and dirty" system of quantifying the frequency and types of stream sediment sources. This system was then used to compare sediment source areas between a managed and an unmanaged stream in hopes of differentiating between natural, legacy, and current management sources. By possibly determining the degree to which each of these categories contributed, the effectiveness of mitigation efforts may be determined.

Study Site Description

Location

Our study was located in the Elk River Watershed in Humboldt County, California (Figures 1 and 2). The Elk River watershed area is approximately 85 square miles. The Elk River is comprised of two main branches, the North Fork and the South fork. We selected two tributaries to the South Fork for our study sites. Corrigan Creek is located on Pacific Lumber Company property and Little South Fork is located on Bureau of Land Management property.

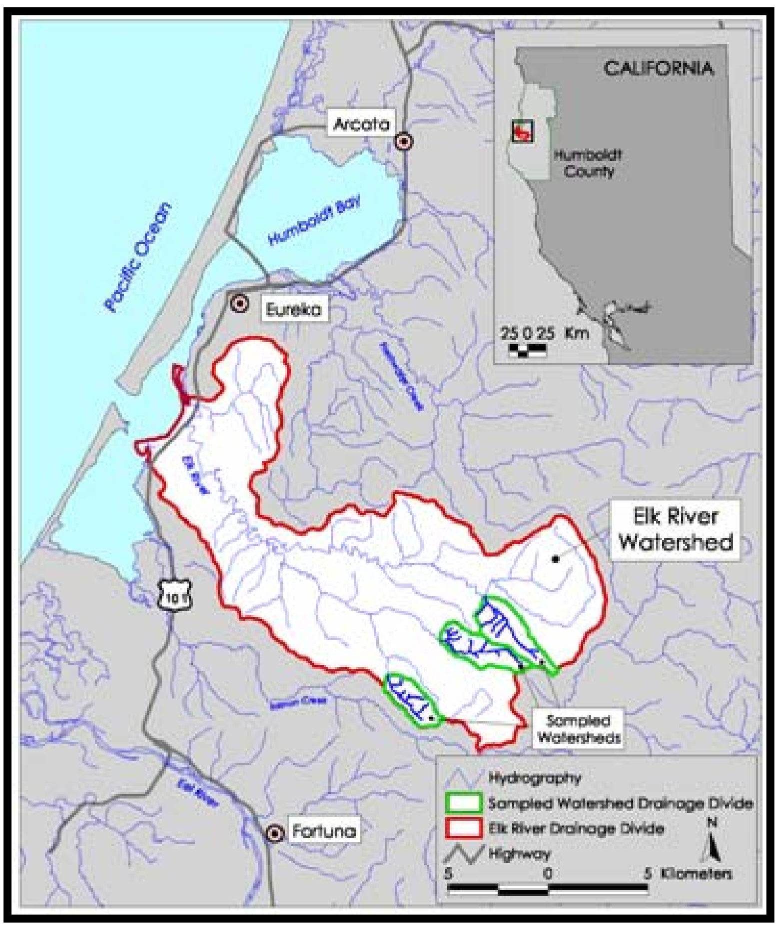


Figure 1. Elk River Watershed Location

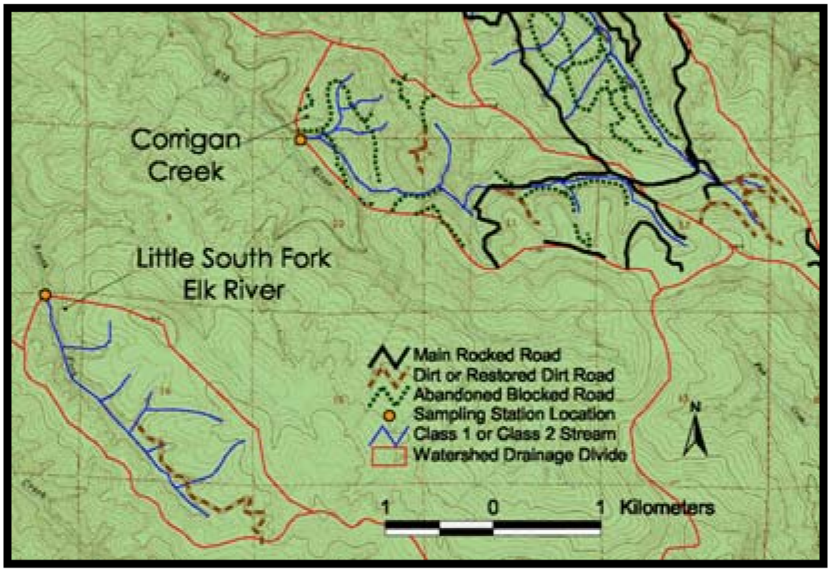


Figure 2. Little South Fork and Corrigan Creek Locations

Natural Characteristics

Corrigan Creek has a watershed area of approximately 1.9 square miles and an average stream slope of 5 percent in the area surveyed. Little South Fork has a watershed area of approximately 2.5 square miles and an average stream slope of 11 percent in the area surveyed. Both drainages have a mean annual rainfall of 65 inches per year (Hart-Crowser, 2004) and are roughly 2.5 miles apart as a spotted owl flies. As can be seen in figure 2, the surrounding topography is slightly steeper on the Little South Fork than it is on Corrigan Creek. Both streams are bedded in a geologic unit known as the Yager Formation. According to the USGS, this formation is composed of “well-indurated, massive, medium- to fine-grained graywacke sandstone, interbedded with conglomerate, siltstone or soft shale, and indurated mudstone and siltstone interbedded with biotitic graywacke and conglomerate”(USGS). However, the greater part of the watershed feeding the Little South Fork is composed of Undifferentiated Wildcat Group, consisting of “either massive, marine, fine-grained sandstone, siltstone, claystone or conglomerate” and may vary from “slightly indurated to very friable” (USGS). The Yager formation is considered a much rockier and consolidated unit, while the Wildcat formation is known for being loose and unconsolidated. Given these characteristics and the information from the geologic map, Little South Fork appears to be more susceptible to natural sediment inputs than Corrigan Creek due to its close proximity to the Wildcat Formation (Figure 3).

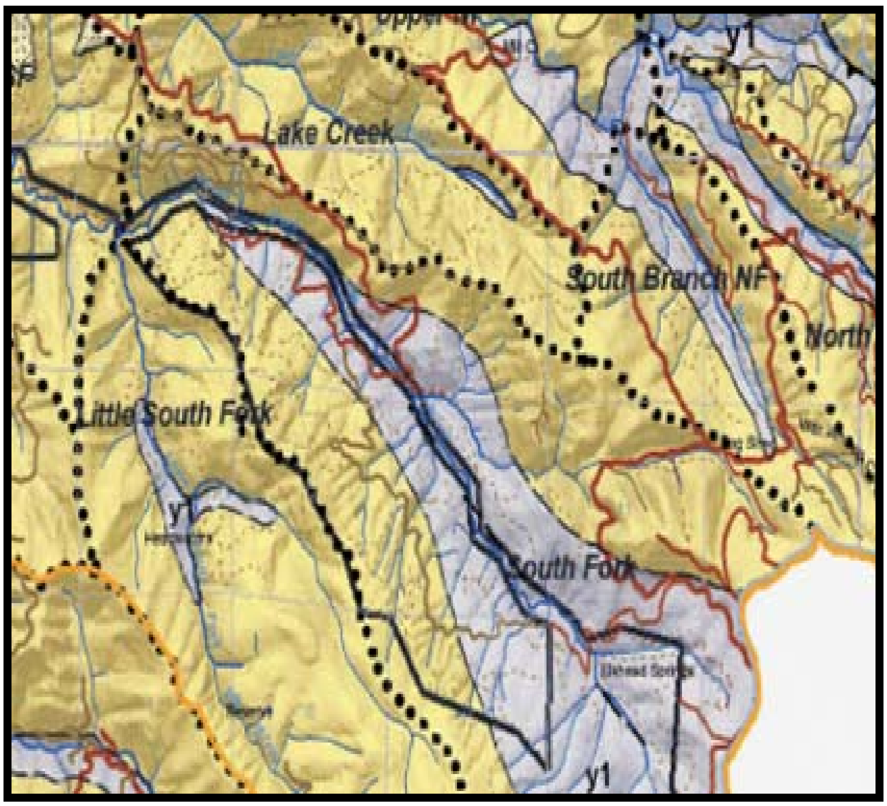


Figure 3. Geology Map (See Appendix for full map)

Anthropogenic Characteristics

Anthropogenic characteristics result from historical as well as current management practices. The lower portion of Corrigan Creek has been affected on both these levels. In the late 1940’s and early 1950’s, intensive management occurred in this watershed. As

John Oswald (CEG, PALCO) stated, the area was “rode hard and put away wet.” Although there are no written records of exactly what occurred in those years, aerial photos give a pretty good idea (Figure 4). In subsequent years there have been a number of additional entries, but due to better forest practices and the implementation of the California Forest Practice Rules, none have been nearly as devastating (Figure 5). Features reflecting these operations can be clearly seen both on the ground and on the maps. There is a relatively extensive road network around Corrigan Creek, and old landings, steam crossings, etc. can be found in multiple locations.

Figure 4. Corrigan Creek Area, 1954

Figure 5. Corrigan Creek Area, 2003

Figure 6. Little South Fork Area, 2003

The history of the upper portion of Little South Fork is quite different. The area escaped harvest during the time Corrigan Creek was logged, most likely because of its remote location and steep terrain. It was scheduled to be harvested during the early 90s, but it was purchased from PALCO and placed in the protection as a reserve by the Bureau of Land Management. A road was built by PALCO which ended near the headwaters of Little South Fork, but was decommissioned and restored in 2003 by the BLM. This road can be seen at the right of the photograph in figure 6. The Little South Fork Watershed is comprised of late seral old growth redwood, and is managed to promote and maintain its complexity by the BLM.

Water Quality Characteristics

By using time step turbidity data collected on both Corrigan Creek and Little South Fork, differences in annual sediment yields were determined by Manka for water year 2004. Corrigan Creek sediment yields for water year 2004 were 55.1 tons/ km^2, where Little South Fork was 6.6 tons/ km^2. When both sites turbidity levels are compared, it is evident that Corrigan creek has considerably large turbidity than Little South Fork (Figure 7). Discharge rating curves were established for each creek, and stream discharge for water year 2006 is compared in figure 8. Both streams show similar response times to rain events, although Corrigan Creek yields considerably more water.

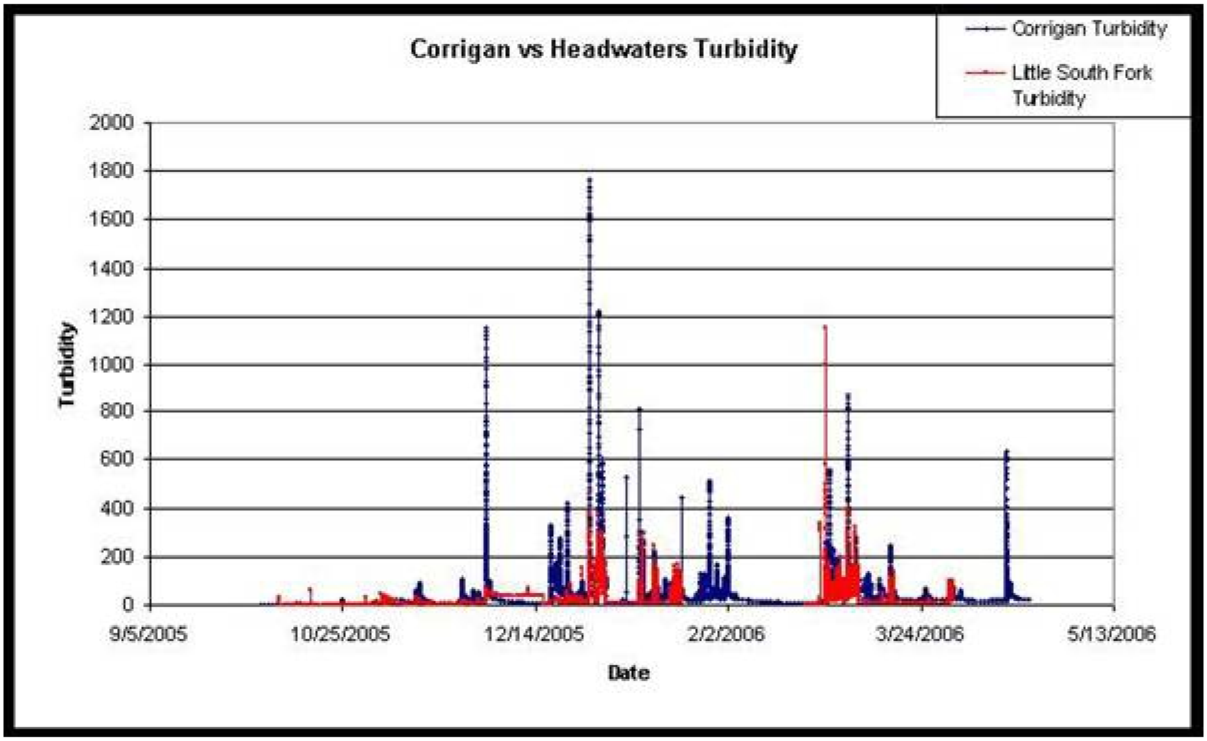


Figure 7. Corrigan Creek and Little South Fork ("Headwaters")Turbidity

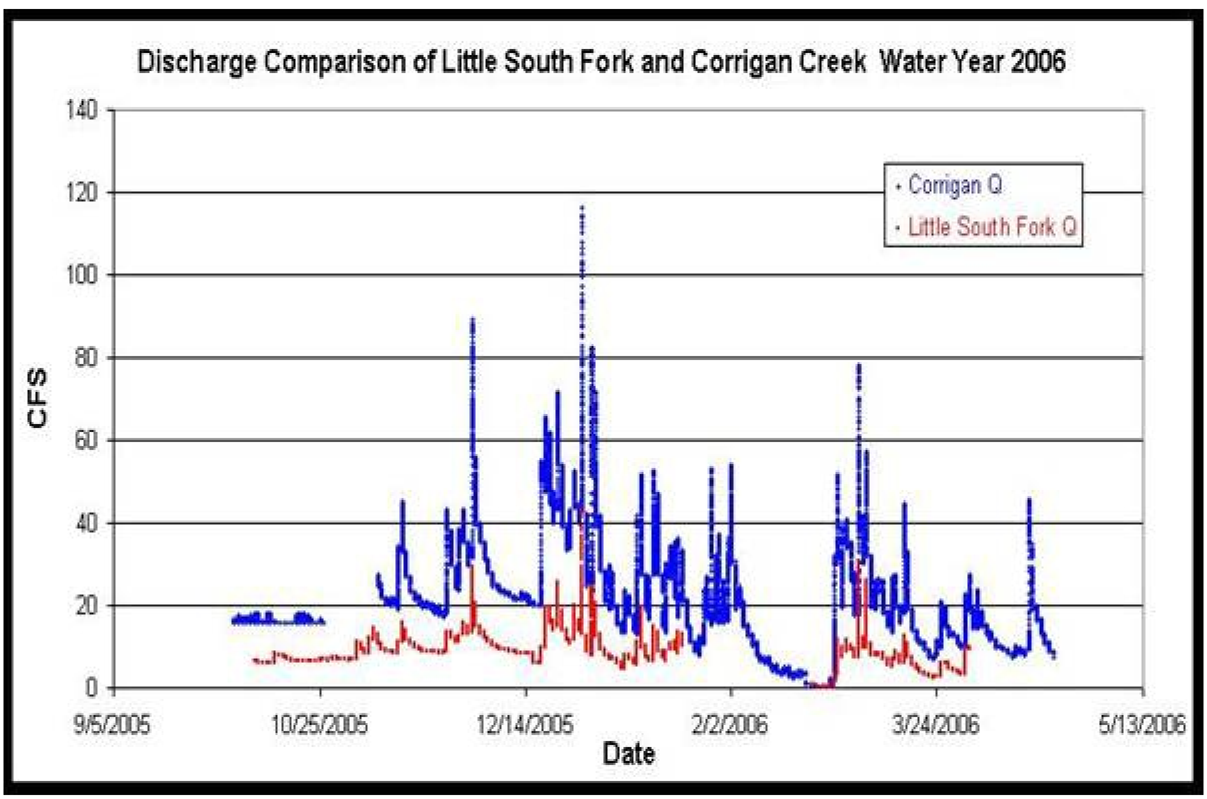


Figure 8. Corrigan Creek and Little South Fork ("Headwaters") Discharge

Methods

In developing a system that would quantify the type and magnitude of stream sediment sources, our first step was determining what factors affect the degree to which a source of sediment will actually contribute to the turbidity. We determined that the size of a feature, the erodibility of a feature and the energy applied to a feature all combine to determine the quantity of sediment that the feature can contribute. The size of the feature is effectively the surface area that is exposed, which can be easily measured.

The second two factors are more difficult to account for. The erodibility of a feature determines the ease with which particles can be entrained into the water column. The energy applied to a given feature will vary with rainfall intensity, which is reflected in the total discharge in the stream. Higher flows apply more energy to and impact a greater portion of the channel. In essence, depending on the flow level and the integrity of the feature, its level of contribution will change. In order to address this variability, we assigned each feature a degree (1-5) that would reflect both of these factors. Features that were assigned as degree 1 were those that would only contribute sediment when the stream is at its *highest* flows, and subsequently a degree 5 would be a feature which always is contributing sediment, even at the lowest flows (Figures 9 and 10).

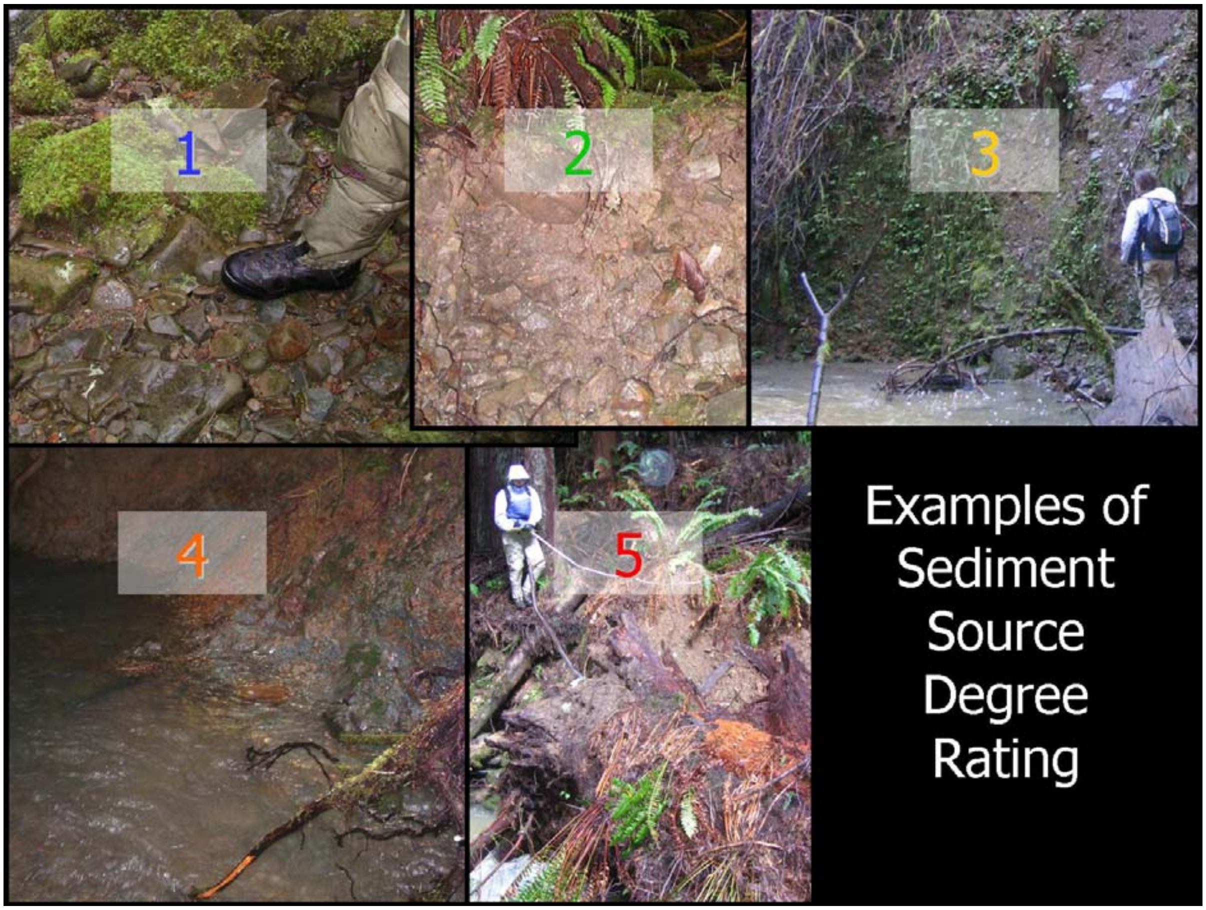


Figure 9. Examples of Degree Ratings

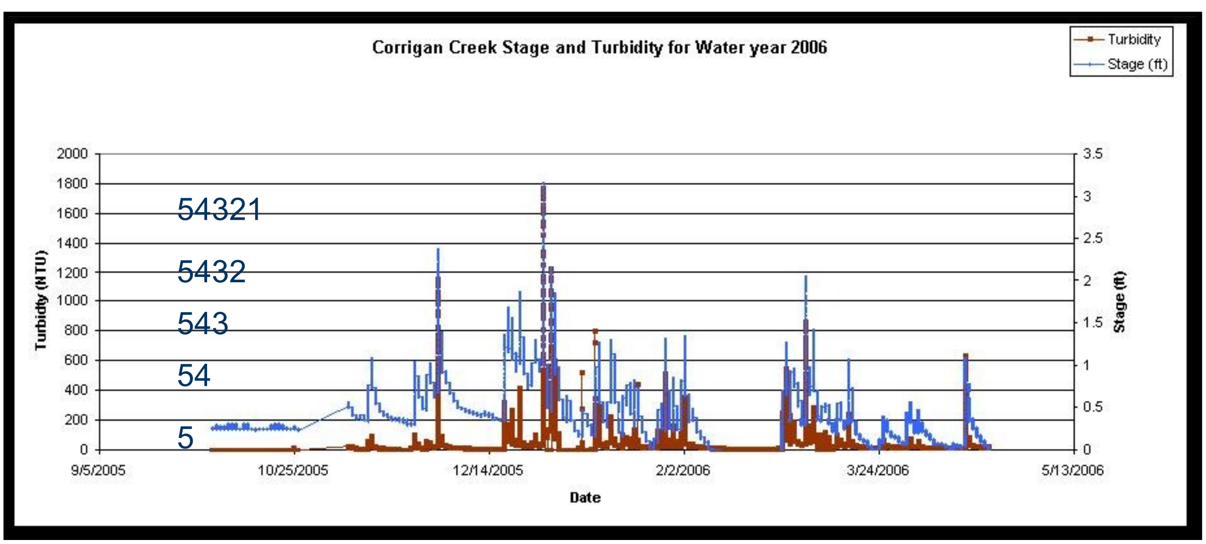


Figure 10. Conceptual Diagram of Contributing Source Areas

This concept of sediment source areas changing with varying flow levels is based on the Variable Source Area Concept (fig). The Variable Source Area Concept states that "two mechanisms are primarily responsible for quick flow response: (1) an expanding source (saturated) area that contributes flow directly to a channel and (2) a rapid subsurface flow response from upland to lowland areas" (Brooks et al., 2003).

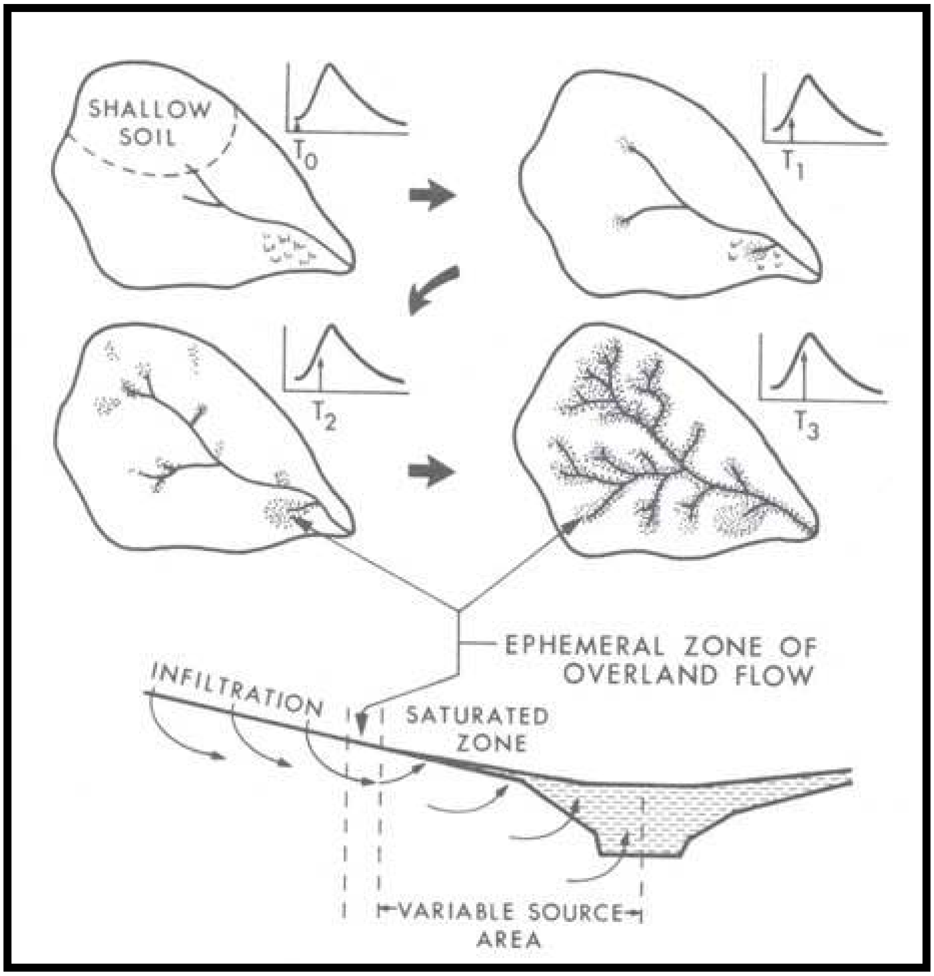


Figure 11. The Variable Source Area Concept (Brooks et al, 2003).

Sediment source surveys normally are approached with a top to bottom method of analysis. Roads, landings or other potential source areas are surveyed and subsequent source volumes are estimated. Unless the source to stream connection is traced, there is no way of knowing whether the source is actually delivering sediment to the stream. In contrast, a bottom to top approach was selected for the purposes of this study. By hiking directly up the stream channel, sediment sources were found and then traced back to their origin and categorized (1-5). This approach provided the advantage of determining all sediment sources (such as cut banks, channel adjacent landslides and small tributaries) directly within the stream channel. In addition sources from roads, landings, and large tributaries were traced to their origins. This approach also assured that the sources were actually delivering sediment into stream. Using a loggers tape, each features surface area (height and length), and the distance between features was measured. Total distance traveled upstream, and the locations of features within the stream channel were derived from these measurements (Figure 12).

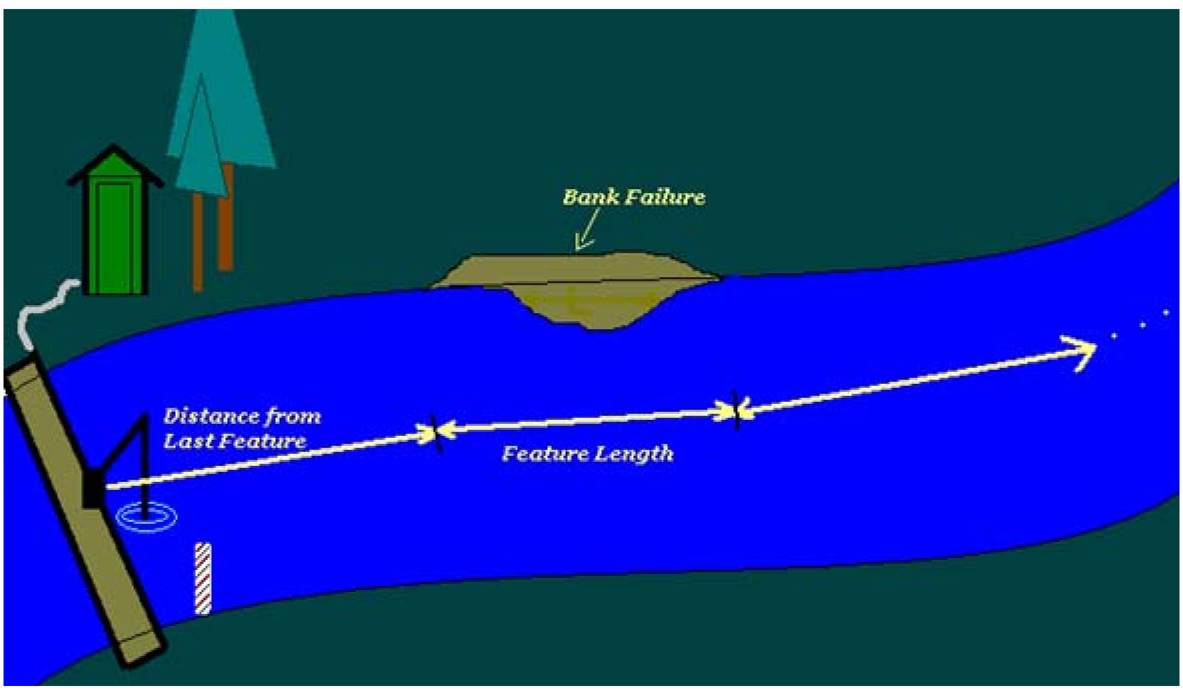


Figure 12. Conceptual Diagram of In-stream Procedure

Results and Discussion

Corrigan Creek was surveyed for a total of 2531 feet above the turbidity station. The main channel was surveyed for 1506 feet, the remaining 1025 feet were comprised of a small tributary containing an old Humboldt crossing and a diverted headwater stream. An abandoned skid road caused the headwater stream to be redirected onto a dirt road, and was then directed into the tributary. Surface areas from the Humboldt crossing and diverted stream are considered as current management sources. These are features which can be potentially removed, qualifying them as current restorable targets. Little South Fork was surveyed for 1832 feet above the station, and comprised solely of its main channel. Field surveys noted significant head cutting and cut banks on Corrigan Creek. Corrigan Creek also lacked the large boulders, cascades, pools, complexity, and stream sinuosity found on Little South Fork. Corrigan creeks steps were formed solely from log and debris jams, were Little South Forks steps and falls were the result of boulders and large rock formations. Total surface area for each stream was calculated and compared in Figure 13. Corrigan Creek shows considerably more erodable surface area than Little South Fork. Figure 14 compares the surface area by degree. Little South Fork contains a fairly even distribution between degrees 1 through 4, and contained very little degree 5.

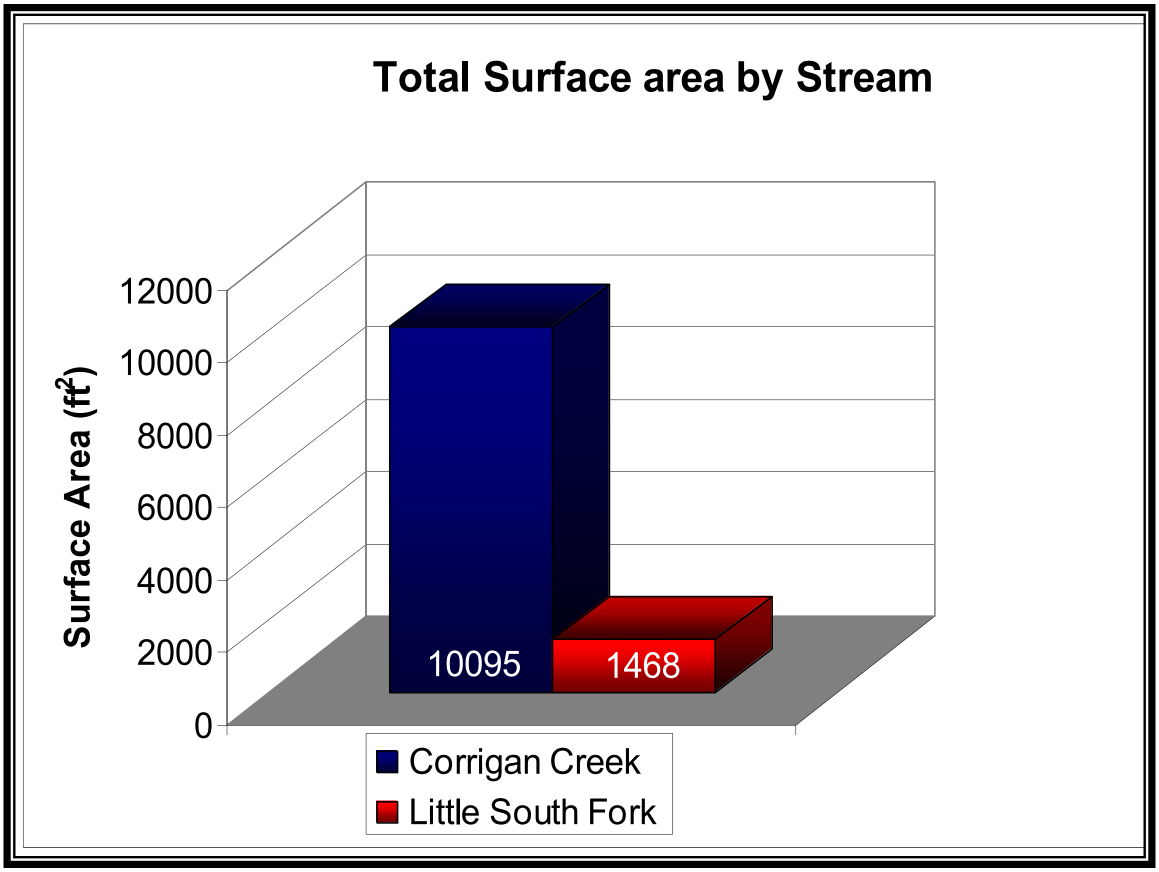


Figure 13. Total Surface Area by Stream

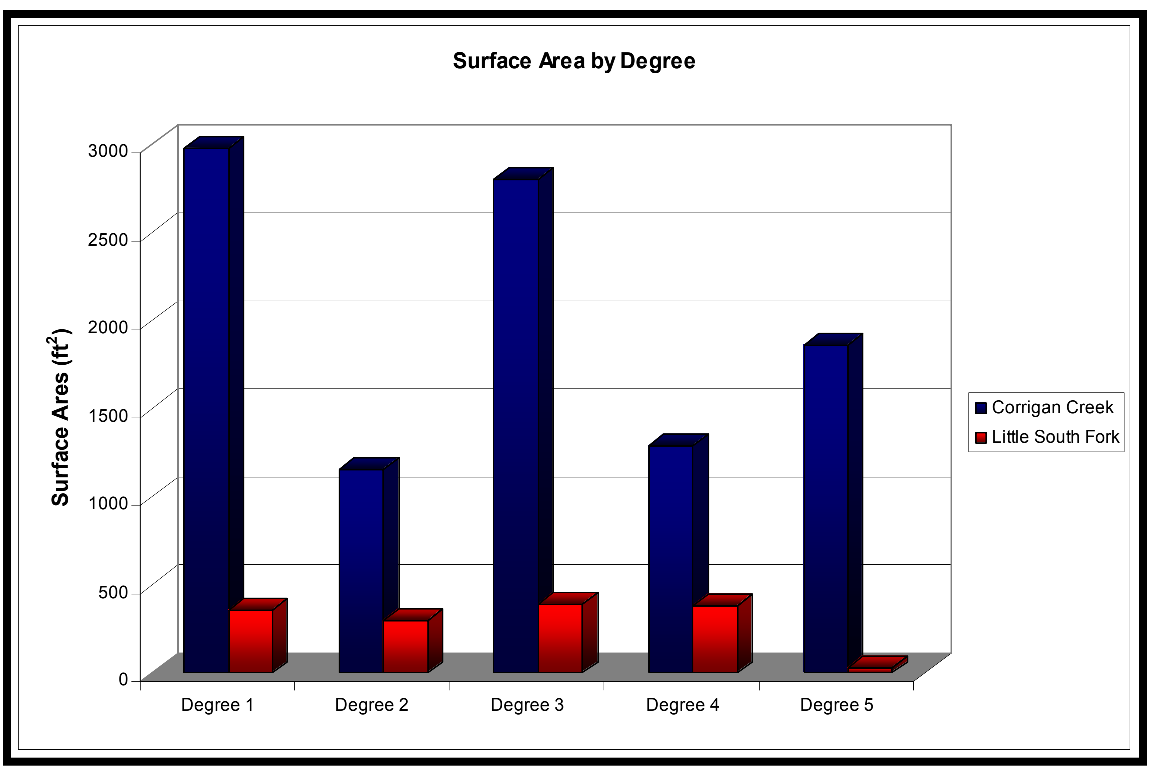


Figure 14. Surface Area by Degree

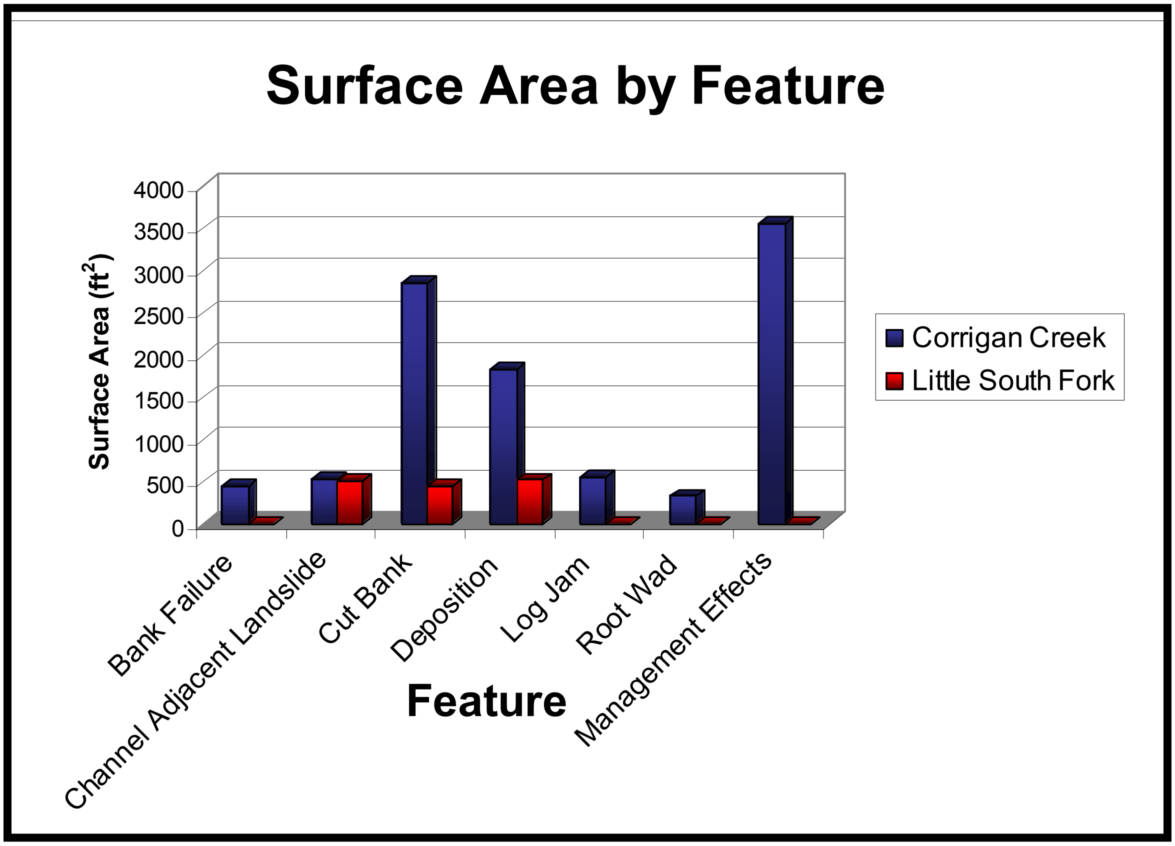


Figure 15. Surface Area by Feature

Figure 15 compared the type of features found and their surface area. Corrigan Creek contains significantly more surface area from cut banks, areas of deposition and management effects than Little South Fork. Corrigan Creek also contains surface area from log jams, root wads and bank failures. Both streams share approximately the same amount of channel adjacent landslide surface area. Figure 16 shows a comparison of cumulative sediment source areas depending on the degree of magnitude of a storm. The lowest magnitude shows only the degree 5 sources, where during the highest magnitude storm, all sources, 1 through 5, contribute. Again, Corrigan Creek has significantly more surface area contributing than Little South Fork. If the Corrigan Creek Humboldt crossing and the diverted stream source areas were restored and removed from our survey area, a considerable reduction in cumulative source area by magnitude can be seen in Figure 17.

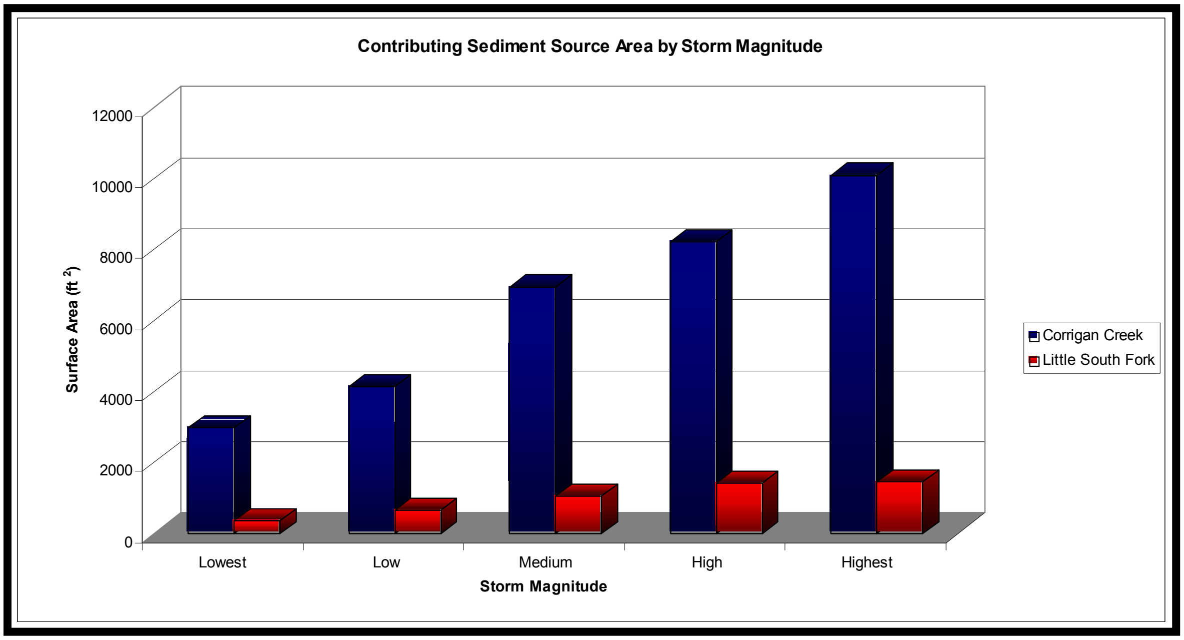


Figure 16. Contributing Sediment Source Area by Storm Magnitude

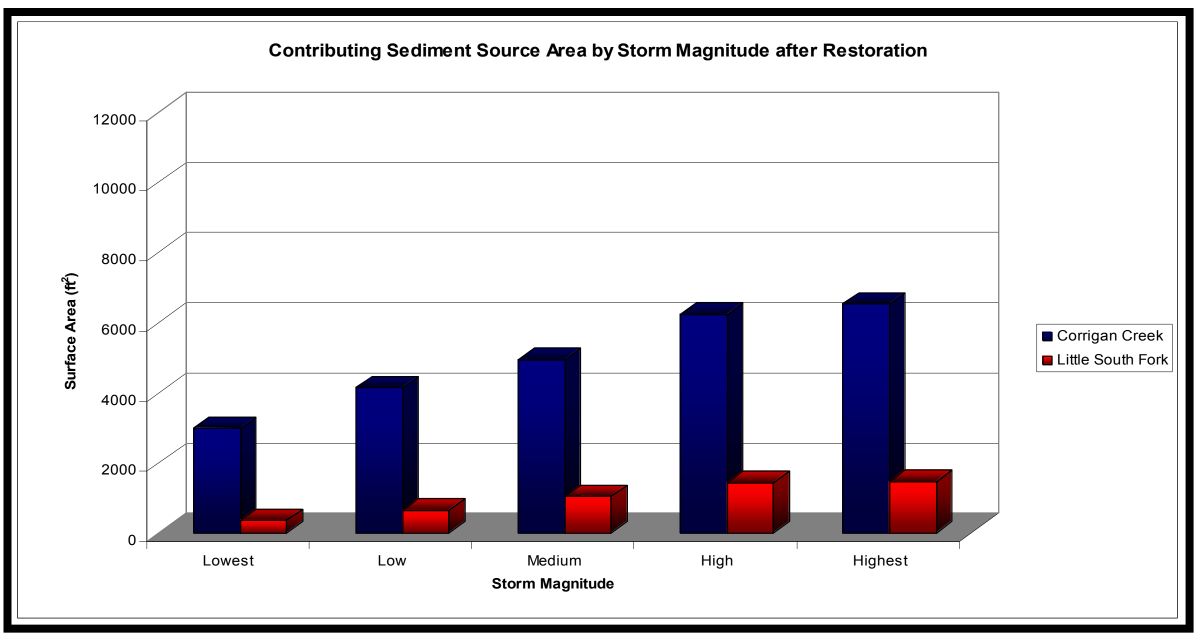


Figure 17. Theoretical Contributing Sediment Source Area by Storm Magnitude after Restoration.

Conclusions

This study revealed both disadvantages and advantages of the rating system and method of survey. Determining whether or not something is a sediment source, and rating it can be fairly subjective. We found it was difficult to guess what high flows will do during low to moderate flows. In addition, replication of source rating could be a problem. It would not be advised to compare streams surveyed by different surveyors. Finally, because of the complexity of streams, and diversity of sources, data collection, interpretation and organization were at times very tedious. Conversely, given surveyors are consistent; it is an effective method of attaining feature frequency, and comparing stream features. It is also effective at locating sources which are directly connected to a stream, and the features degree of severity. This data can be used as an aid in prioritizing restoration objectives, and reveal whether or not restoration is a feasible objective. After conducting this study, we recommend surveying the entire length of the stream would give more accurate results, especially when comparing two streams. It would be interesting to incorporate turbidity grab samples above and below features, as well as at certain points along the length of the channel. To aid in source classification, it may aid to incorporate a photo guide or pocket penetrometer to help define the erodibily of features, and possibly increase the accuracy and replicability of surveys.

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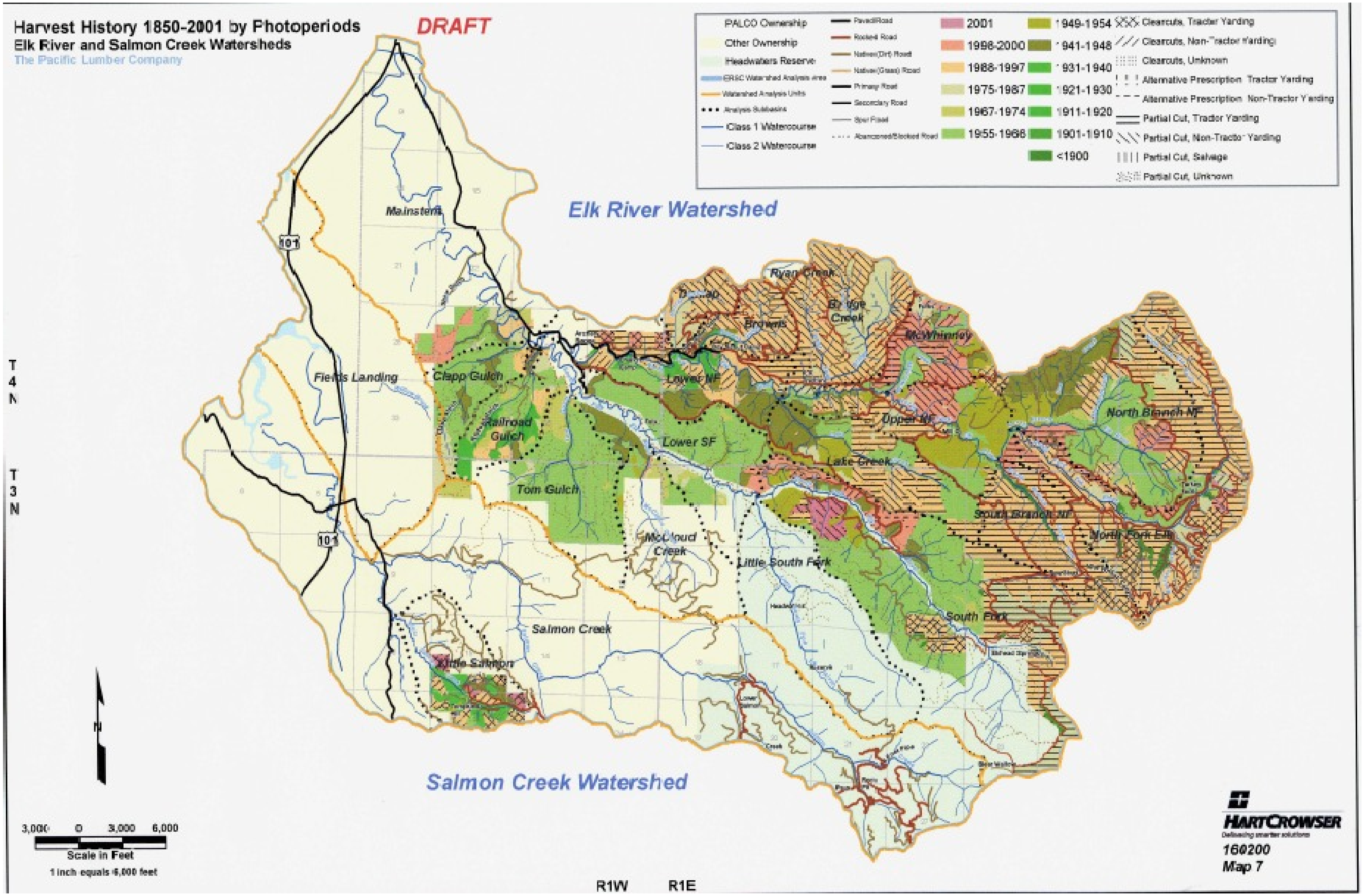
USGS McWhinney Quadrangle. Accessed via www.topozone.com.

Appendix


Harvest History 1850-2001 by Photoperiods
Elk River and Salmon Creek Watersheds
The Pacific Lumber Company
DRAFT
PALCO Ownership
Other Ownership
Headwaters Reserve
Class 1 Watercourse
Class 2 Watercourse
2001
1998-2000
1988-1997
1975-1987
1967-1974
1955-1966
1949-1954
1941-1948
1931-1940
1921-1930
1911-1920
1901-1910
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Clearcuts, Tractor Yarding
Clearcuts, Unknown
Alternative Prescription Tractor Yarding
Partial Cut, Tractor Yarding
Partial Cut, Non-Tractor Yarding
Partial Cut, Salvage
Partial Cut, Unknown
Elk River Watershed
Salmon Creek Watershed
Mainstem
Fields Landing
Clapp Gulch
Railroad Gulch
Tom Gulch
Lower SF
Lower NF
Ryan Creek
Browns
Bridge Creek
McWhinney
Upper NF
Lake Creek
North Branch NF
South Branch NF
North Fork Elk
McCloud Creek
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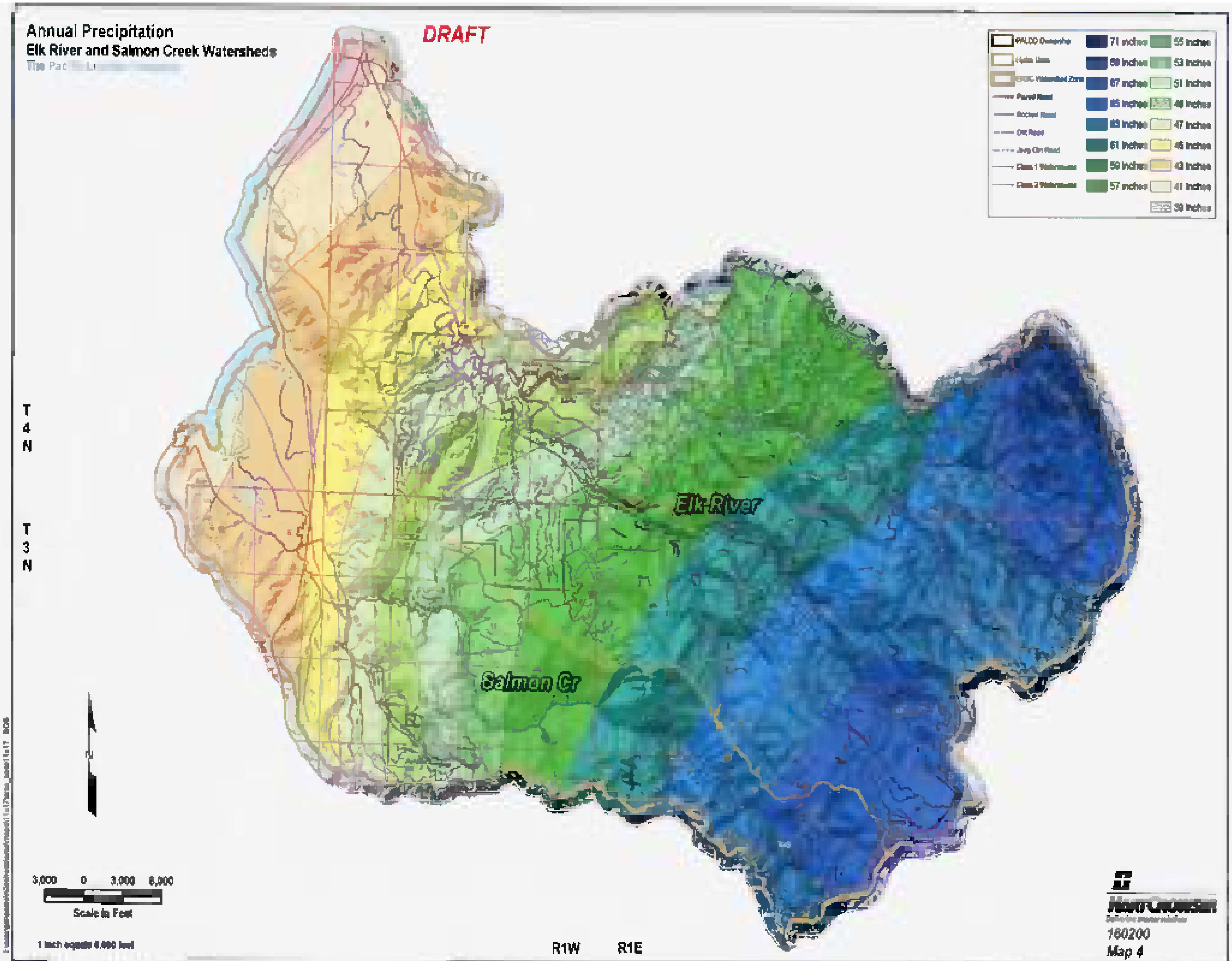
Map 7



Annual Precipitation
Elk River and Salmon Creek Watersheds
DRAFT
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67 inches
65 inches
63 inches
61 inches
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57 inches
55 inches
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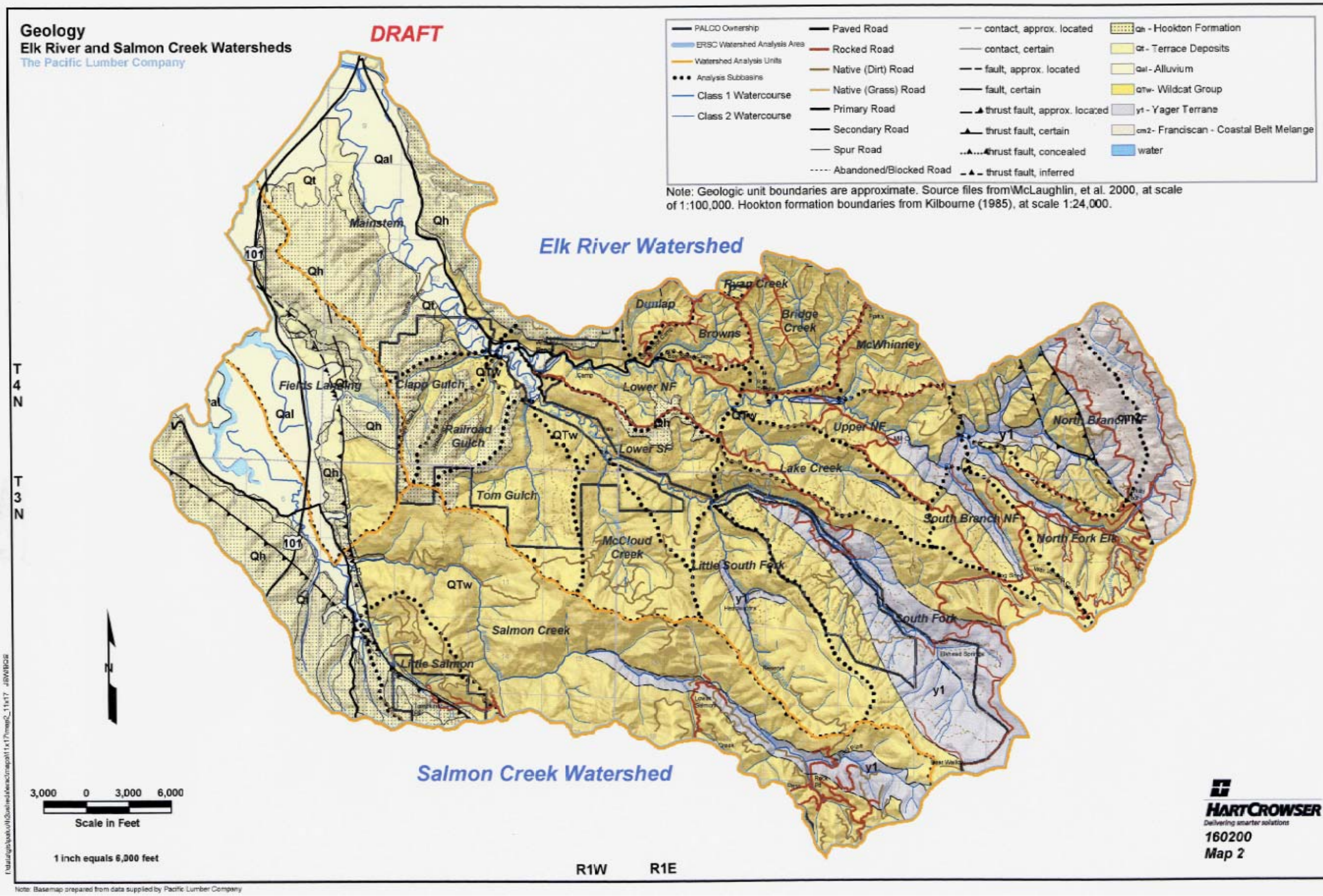
Elk River
Salmon Cr
3,000 0 3,000 6,000
Scale in Feet
1 inch equals 4,000 feet
R1W
R1E
160200
Map 4

Geology
Elk River and Salmon Creek Watersheds
The Pacific Lumber Company

DRAFT



Note: Geologic unit boundaries are approximate. Source files from McLaughlin, et al. 2000, at scale of 1:100,000. Hookton formation boundaries from Kilbourne (1985), at scale 1:24,000.

HARTCROWSER
Delivering smarter solutions
160200
Map 2

Note: Basemap prepared from data supplied by Pacific Lumber Company

SUSPENDED SEDIMENT YIELDS IN TRIBUTARIES OF ELK RIVER, HUMBOLDT COUNTY, CALIFORNIA

by

Peter Manka

A Thesis

Presented to

The Faculty of Humboldt State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

In Natural Resources: Watershed Management

August, 2005

SUSPENDED SEDIMENT YIELDS IN TRIBUTARIES OF ELK RIVER,

HUMBOLDT COUNTY, CALIFORNIA

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05-WM-564-08/01

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ABSTRACT

Suspended Sediment Yields in Tributaries of Elk River,
Humboldt County, California

Peter Manka

Turbidity threshold sampling methodology was used to estimate suspended sediment yields in three tributaries of Elk River during water year 2004. The three sampled watersheds are located in close proximity to one another and have similar physiographic parameters including size and lithology, yet differ in their management histories. The Little South Fork Elk River watershed is comprised of mostly undisturbed, mature forest; it had a suspended sediment yield of 6 tons/km^2. The Corrigan Creek watershed was first harvested in the 1950s and then experienced a second harvest entry only in its headwaters in the early 1990s; its suspended sediment yield was 59 tons/km^2. The South Branch North Fork Elk River watershed was first harvested in the 1970s and then experienced a second harvest entry throughout its entire watershed in the early 1990s. It had a suspended sediment yield of 121 tons/km^2 during water year 2004.

Particle size analysis showed that fine material (< 0.0635 mm) constituted 90 percent of the total suspended sediment load at South Branch North Fork Elk River and 87 percent of the total sediment load at Corrigan Creek. Fine material accounted for only 75 percent of the total sediment load at Little South Fork Elk River.

Suspended sediment load was estimated using a regression of the suspended sediment concentration to turbidity for individual storm events as well as for the whole year. Annual suspended sediment load estimates based on individual storm regression have the potential to be more accurate than estimates based on annual regression because

they capture variations in the suspended sediment – turbidity relationship. Variations in this relationship were observed for different storm events and also during certain components of individual storm events in this study. Differences between suspended sediment load estimates based on individual storm regression versus estimates based on annual storm regression were as large as 74 percent for individual storm load estimates and 16 percent for total annual load estimates. Variability in suspended sediment particle size, particle mineralogy, and organic content may explain the observed differences.

The severity of ill effects experienced by fish in the three streams was evaluated based on the models described by Newcombe and Jensen (1996). The observed doses (concentration × duration of exposure) of sediment in Corrigan Creek and South Branch North Fork Elk River are associated with ill effects including moderate physiological stress, moderate habitat degradation, and impaired homing in adult and juvenile salmonids, and 40-60% mortality in egg and larval stages. Fish in Little South Fork Elk River experienced lower doses of sediment that are associated with milder ill effects such as short-term reduction in feeding rate and feeding success of adult and juvenile salmonids, and major physiological stress and long-term reduction in feeding rate and feeding success of egg and larval stages.

This study examines variability in sediment yield and sediment dynamics of streams with similar physiographies and different management histories while exploring fluctuations in the suspended sediment – turbidity relationship and analyzing the potential effects of elevated sediment concentrations in these streams from a biological perspective.

ACKNOWLEDGEMENTS

Funding for this study was provided by the California State Water Resources Control Board, Region 1 - North Coast, and by McIntire-Stennis Program #134. Thanks to Bruce Gwynn and Adona White at the North Coast Regional Water Quality Control Board for their efforts in securing funding for the project and providing contract support. My deep gratitude to my committee members Dr. Andre Lehre, Jack Lewis, Dr. C. Hobart Perry, and Dr. E. George Robison for the generous contributions of their time and technical expertise. Special thanks to Ryan Stewart and Netra Khatri for their hard work and dedication in the field and in the lab. Thanks to George Pease in the Humboldt State University Forestry Department stockroom for help with providing equipment and Diane Sutherland at Redwood Sciences Laboratory for her help with GIS analysis. Thanks to Kate Sullivan at Pacific Lumber Company for facilitating access to and use of Pacific Lumber Company land, and to Robert Derby and Rich Rosen at Pacific Lumber Company for their consultation and advice. Thanks to Dave Fuller at the Bureau of Land Management for helping obtain access to and use of BLM land. Thanks to Jay Stallman at Stillwater Sciences and Sam Morrison at BLM for their geologic consultation. I am extremely grateful to my wife, Ellie, and daughter, Nehalem for their love, patience, and support.

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INTRODUCTION

Sediment yield is the total sediment outflow from a watershed per unit area over a specific period of time (e.g., $kg/km^2/yr$). The sediment load is the total amount of sediment discharge from a watershed and can be divided into two components: the suspended sediment load and the bed load. The suspended sediment load consists of fine particles such as silts, clays, and fine sands that are transported downstream in suspension. The bed load consists of larger particles such as coarse sands, gravels, cobbles, and boulders that are transported along the stream bottom. Sand-sized particles may be part of the suspended sediment load or the bed load depending on their mode of transport.

The sediment yield of a system is dependent on the geology, climate, vegetation, soils, topography, and land use of a watershed. The interaction of these variables determines not only the overall sediment yield, but also how the stream system moves and stores sediment and the resulting morphological characteristics of the stream system. Changes in any of these variables have the ability to alter the sediment regime of a stream system and thus alter the physical characteristics of the system. Potential changes in the physical characteristics of a stream include changes in: stream base level (e.g. aggradation or degradation), stream width, stream habitat units (e.g. increase or decrease in pool volume), stream sinuosity, bedforms (e.g. fining or coarsening of the stream bed), slope, and incision (Knighton 1998, Sullivan et al. 1987).

Of the factors that control the sediment yield of a system, climate and land use have the greatest potential for temporal fluctuation and are thus the factors that most commonly lead to changes in sediment regime and resultant changes in stream morphology. Reid (1993) cataloged numerous studies of sediment yield related to land use and found that sediment yields generally increased 2 to 50 times above background levels in response to road construction and logging. The highest increases were observed in systems that had poorly aligned road networks. Increases in sediment input can be larger at sites where landsliding is prevalent. Reid (1993) also observed that reduction in sediment yield was rapid after road use was discontinued and logged areas regenerated; yields measured more than five years after logging were typically less than five times greater than background levels.

The majority of watersheds on the north coast of California are listed as impaired due to excessive sediment under Section 303d of the Clean Water Act (Fitzgerald 2004). Increased sediment in streams can impact both the physical and biological function of stream systems. Salmonids are of particular concern in northern California because several threatened or endangered salmonids species are present in the region. Elevated sediment production can be detrimental to salmonids by reducing intergravel flow of oxygen to developing embryos and by entombing alevins (Hall and Lantz 1969, Phillips et al. 1975). High volumes of sediment can effectively reduce pool volume thereby decreasing rearing habitat for juvenile salmonids and resting pools for migrating adults (Lisle and Hilton 1992). Sedimentation can also interfere with the production and diversity of macrobenthic organisms, an important salmonid food source, by reducing hyporheic movement and eliminating macrobenthic rearing space (Spence et al. 1996).

Increased sediment loads in stream systems can lead to changes in stream channel morphology. Aggradation of the stream channel is a common response to increased sediment inputs. This can lead to a decrease in the volume of water that can be conveyed by the stream within its banks thereby affecting the magnitude and frequency of flood events (Knighton 1998). Channel aggradation leading to decreased channel capacity is of particular concern when there is commercial or residential development within the active flood zone.

Sediment levels are also a concern for drinking water quality. From a municipal perspective, high levels of sediment can make treatment of water to potable standards very difficult to impossible because the solids provide a medium for bacterial attachment and also serve as a protective barrier against the action of chlorine added for disinfection (Tchobanoglous and Schroeder 1985, United States General Accounting Office 1998). Private water users with shallow wells or direct diversions are rarely able to afford the technology necessary to treat heavily sediment-laden water, and their water supplies often become unusable when contaminated by high levels of sediment.

Total sediment load is important because it affects the physical nature of the stream system which in turn affects the stream biota. Many studies have addressed the adverse effects of suspended sediment on aquatic organisms and these studies suggest that the severity of the adverse effects is related to not just the total quantity of sediment or the instantaneous concentration of the sediment, but also to the duration of exposure to elevated sediment levels and also to the frequency of pollution episodes (Bisson and

Bilby 1982, Stober 1981). These studies show that adverse effects on salmonids increase with an increasing duration of exposure to elevated suspended sediment concentrations.

Duration of elevated sediment levels can also be very important because it can directly affect the quality and availability of potable water to private and municipal water users. Extended durations of highly elevated suspended sediment concentrations can cause depletion of supplies of treated drinking water and lead to shortages of potable water during periods where water quantity is abundant (United States General Accounting Office 1998).

Suspended sediment load and suspended sediment concentration duration in remote watersheds can be difficult to accurately measure given the complexities of collecting sediment data over a wide range of flow events and especially during large events when a majority of sediment is transported (Eads and Lewis 2002). Automated data collection of a parameter that can be continuously measured is necessary to effectively estimate suspended sediment loads in such systems.

Turbidity is a measure of the scattering of light by particles suspended in the water column. Turbidity can be measured on a quasi-continuous, high-frequency, time step basis, and this data can be easily stored on a data logging device for future collection. Turbidity data can then be related to the suspended sediment concentration of a limited number of physical sediment samples taken by an automated pump sampler when pre-selected turbidity thresholds are satisfied (Eads and Lewis 2002). The relationship of turbidity to suspended sediment concentration can then be applied to the continuous turbidity data to produce a continuous record of suspended sediment concentration (Lewis 2002). Unlike discharge controlled sampling systems, turbidity controlled sampling generates data for sediment pulses that may be unrelated to stream discharge, such as landslides and stream bank failures (Lewis and Eads 2001).

Turbidity is a useful surrogate for suspended sediment concentration; however, the most common unit of turbidity measurement (a Nephelometric Turbidity Unit or NTU) is not a standardized quantity and can vary widely among instruments and types of sediment (Davies-Colley and Smith 2001). Recently, efforts have been undertaken to create multiple new units of turbidity that are specific to the method by which a particular turbidity probe makes its measurement (Anderson 2004). Examples of the newly adopted units include Nephelometric Turbidity Ratio Unit (NTRU), Formazine Nephelometric Unit (FNU), Backscatter Unit (BU), Attenuation Unit (AU), and others.

The fact that turbidity measurements generated by different types of probes are not comparable and may not be recorded in the same units makes turbidity measurements on their own less meaningful. Continuous turbidity measurements become useful for the purpose of sediment load calculations when they can be correlated with physical suspended sediment samples. Use of this type of sampling methodology greatly improves the precision and utility of the data obtained.

In order to effectively manage watersheds to maintain beneficial uses it is important to understand how certain types of management activities can affect sediment dynamics. The purpose of this research is to gain insight into this relationship by observing sediment flux and sediment yield in three watersheds with similar physiography and different land-use histories. The data obtained from this study can then be used in conjunction with similar data from watersheds of varying physiography in order to better understand the role of management in watershed sediment dynamics.

The hypotheses to be tested in this study are: (a) the suspended sediment yield and the duration of elevated suspended sediment concentration increases with increasing degree of management, (b) the proportion of the suspended sediment load comprised of fine material (<0.0635 mm) increases with increasing degree of management, and (c) the sediment yield measured using individual storm regression of the suspended sediment concentration – turbidity relationship will produce different yields than estimates based on annual regression.

STUDY SITE

The three sampled watersheds are located in the Elk River watershed just south of Eureka, California (Figure 1). Elk River drains a 137 km^2 area extending from the western slope of the northern California Coast Range to Humboldt Bay. The lower watershed is divided into many private holdings and the primary land uses are agricultural and residential. A majority of the upper watershed is owned by the Pacific Lumber Company with the exception of the 30 km^2 Headwaters Forest Reserve that is publicly owned and managed by the United States Department of the Interior Bureau of Land Management.

The Elk River watershed is dominated by a maritime climate regime. Temperatures are moderate, and humidity remains high throughout the year. Summers are dry, and the rainy season (October through April) accounts for 90% of the total annual rainfall. The forested uplands of the Elk River watershed receive about 165 cm of precipitation per year (Hart-Crowser 2004).

Forest stands in Elk River are dominated by redwood (*Sequoia sempervirens*) with Douglas-fir (*Pseudotsuga menziesii*), true fir (*Abies sp.*), Sitka spruce (*Picea stichensis*), western hemlock (*Tsuga heterophylla*), incense cedar (*Calocedrus decurrens*), western red cedar (*Thuja plicata*), and madrone (*Arbutus menziesii*) common in some locations. Deciduous trees are uncommon outside of riparian areas and some disturbed areas where a high degree of compaction or soil loss has occurred.

The watersheds are underlain mostly by rock units of the Quaternary/Tertiary Wildcat Group, which consists of poorly compacted sandstones, siltstones, and

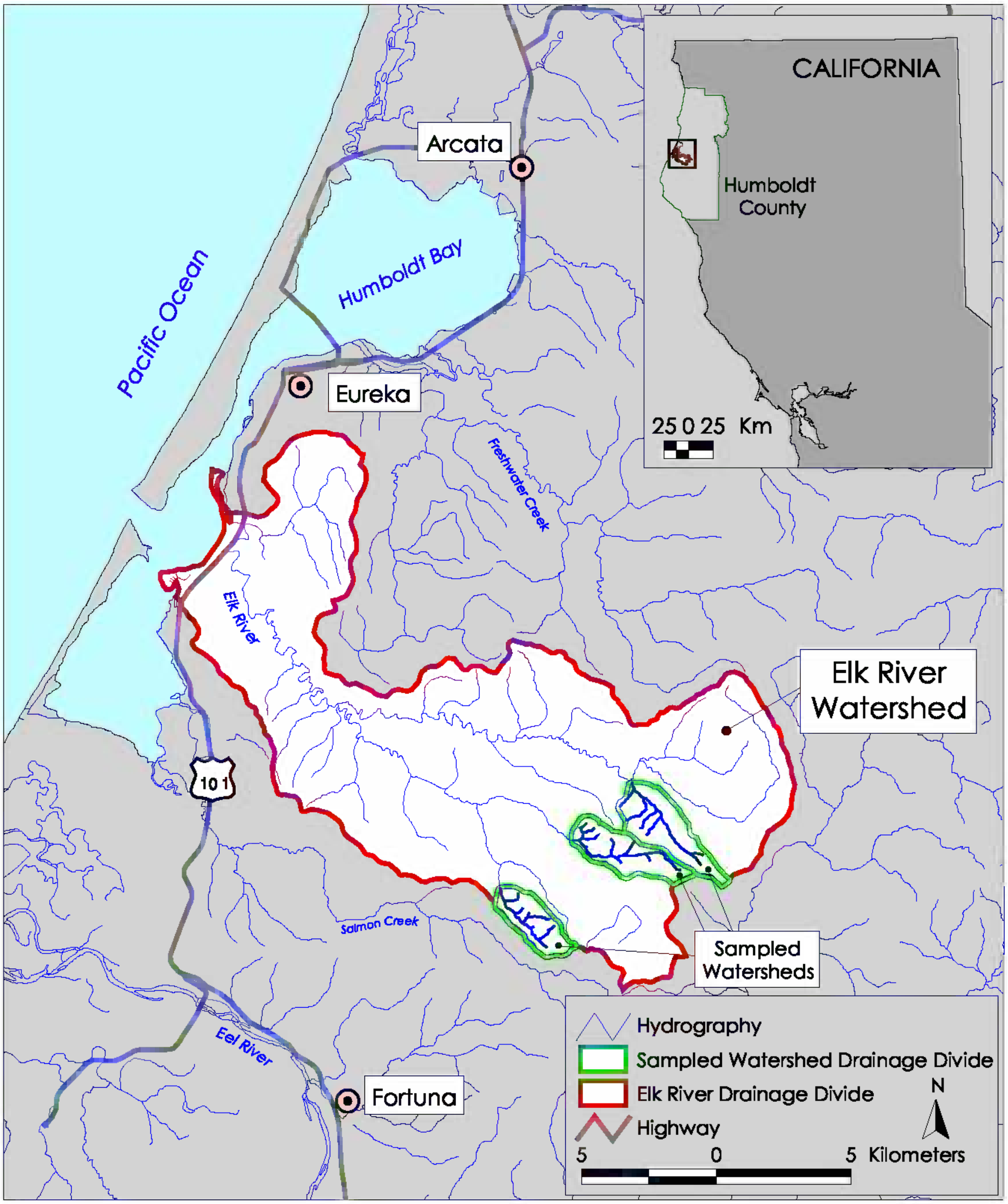

Figure 1. Elk River and sampled watersheds, Humboldt County, California.

mudstones that are highly susceptible to erosion where exposed (Knudsen 1993, McLaughlin et al. 2000). Stream channels draining areas underlain by Wildcat units are often dominated by silts and sands and have a high potential for suspended sediment loads (Hart - Crowser 2004).

Rock units of the Late Cretaceous Yager terrain are present in portions of the upper watershed, especially in stream channels and adjacent valley segments where the streams have incised through layers of Wildcat to expose the underlying Yager units. Yager units are substantially more cohesive and resistant to erosion than Wildcat units (Personal communication, J. Stallman 2004. Stillwater Sciences, 850 G Street, Arcata, CA 95521). They consist primarily of mudstones, siltstones, shales, graywackes, and some conglomerates (Knudsen 1993, McLaughlin et al. 2000). Stream channels that have down cut into the Yager units expose material ranging from well-consolidated bedrock to cobbles and gravel (Hart – Crowser 2004).

McLaughlin et al. (2000) mapped all three watersheds as consisting primarily of rock units of the Quaternary/Tertiary Wildcat Group with stream channels that have down cut into rock units of the Late Cretaceous Yager formation in some locations. Field reconnaissance and geologic consultation suggest that stream valley down cutting into the underlying Yager unit is more extensive than that mapped by McLaughlin et al. (2000) and that the proportion of stream channel that is cut into the Yager unit is similar for all three streams.

Locations of the three sampling stations in this study were selected such that the watersheds above the sampling locations were of similar physiography. All three watersheds have the same orientation to and are located the same distance from the ocean. This causes the watersheds to lie within the same isohyetal bands of average precipitation.

All three stream systems have similar watershed areas. The South Branch North Fork Elk River is the northern most system and drains an area of 4.9 km^2. Corrigan Creek drains an area of 4.0 km^2 and shares its northern watershed boundary with the southern boundary of the South Brach North Fork watershed. The Little South Fork Elk River drains an area of 3.1 km^2 and is located southwest of Corrigan Creek (Figure 2).

Lengths of stream channel per unit area that are designated as either Class 1 or Class 2 are also very similar (Figure 2). Class 1 and Class 2 designated stream channels are those that support fish or other aquatic species. South Branch North Fork Elk River has 1626 m/km^2 of Class 1 or Class 2 stream channel, Corrigan Creek has 1783 m/km^2, and Little South Fork Elk River has 1727 m/km^2 (Hart - Crowser 2004).

The primary difference between the three watersheds is their management histories. Most of the South Branch North Fork watershed was first harvested in the 1970s, though small areas were harvested in the 1940s and 1960s as well. A second harvest entry occurred throughout the entire watershed in the late 1980s and early 1990s consisting of partial cut and clear cut harvests with tractor yarding. The lower portion of the Corrigan Creek watershed was first harvested in the 1950s and the upper portion was

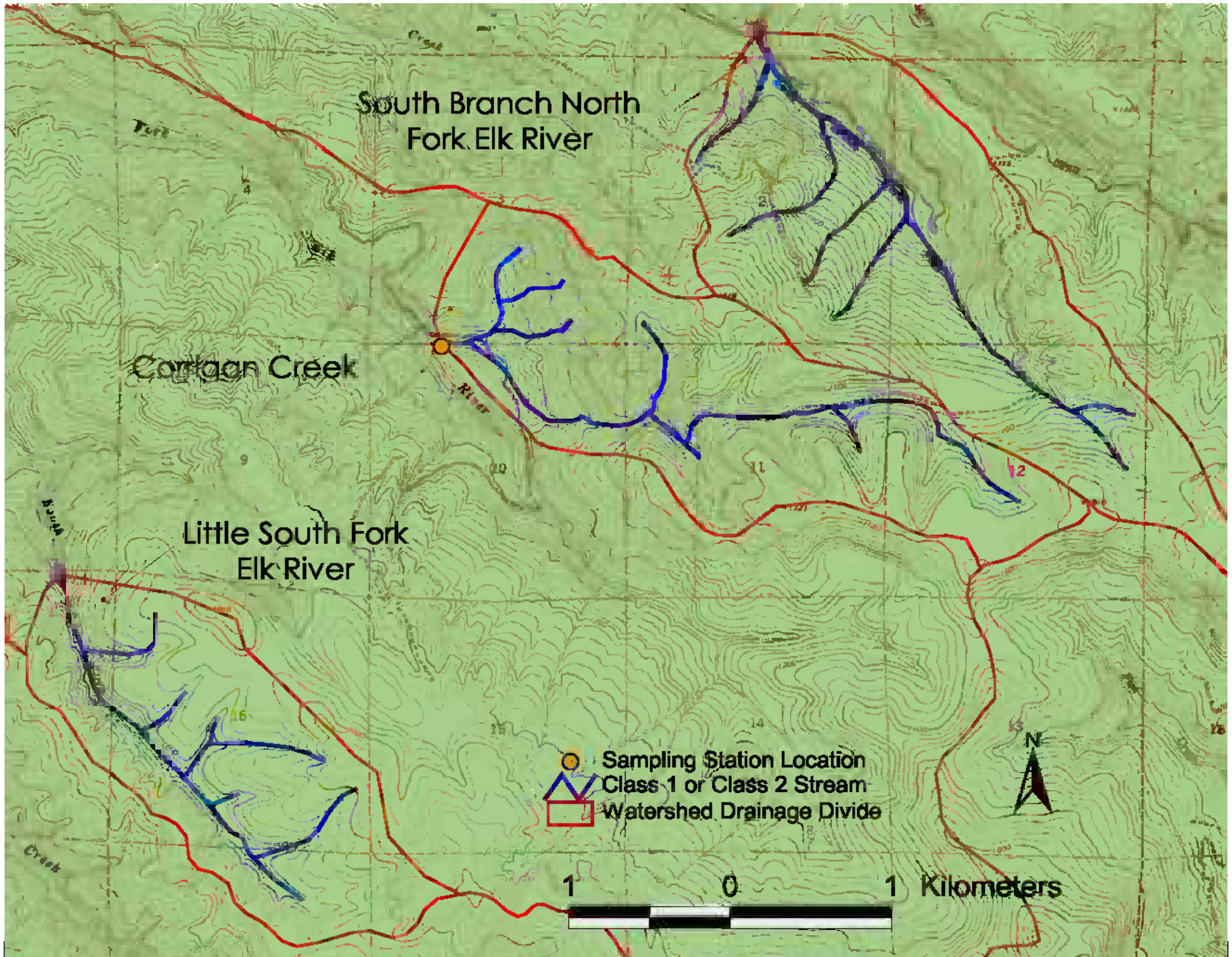

Figure 2. Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River watersheds and sampling station locations (extracted from McWhinney Creek 7.5- minute quad).

first harvested in the 1970s. The upper portion experienced a second harvest entry in the late 1980s and early 1990s consisting of partial cut and clear cut harvests with tractor yarding. The lower portion of the watershed has not experienced a second harvest entry. The area above the Little South Fork Elk River sampling station has never been harvested and consists entirely of late successional, old-growth redwood forest. There were plans to conduct harvest activities in this area and a 1.6 kilometer section of road was constructed from the southern boundary of the upper watershed running adjacent to the stream channel in the early 1990s. This area of the Little South Fork watershed was included in the Bureau of Land Management's purchase of the Headwaters Forest Reserve in the mid 1990s. The road was subsequently decommissioned and a complete slope restoration including excavation of stream crossings and recontouring of hillslopes was completed in 2003.

MATERIALS AND METHODS

Turbidity Threshold Sampling

The USDA Forest Service Redwood Sciences Laboratory in Arcata, California has developed a methodology to improve the accuracy and efficiency of suspended sediment load estimations. The turbidity threshold sampling (TTS) method uses real-time turbidity measurements to control an automated pumping sampler to collect physical suspended sediment samples over a range of turbidity values while attempting to sample all significant turbidity peaks (Lewis and Eads 2001).

The sampling thresholds are determined for each individual stream based on the range of turbidity values that are expected. These thresholds should be selected so that even small storms produce an adequate number of samples to allow creation of a relationship between suspended sediment concentration and turbidity that can be used to estimate suspended sediment concentration for the entirety of the individual storm event. The set of thresholds must also accommodate the upper limits of turbidity for a stream and be distributed such that the full range of turbidities can be sampled for a large event without exceeding 24 samples, the number of samples that the pump sampler is able to accommodate. Spacing thresholds in such a manner that their square roots are evenly spaced helps assure that both small and large events are adequately sampled (Lewis 1996). In order to improve sample coverage, different sets of thresholds are used when the turbidity is rising and falling. The number of thresholds used when the turbidity is falling is typically fifty percent greater than the number used when the turbidity is rising since the falling limb of the hydrograph is generally longer. In order to avoid sampling of turbidity spikes that may be due to non-storm-related factors (e.g., fouling of the probe or stream biota such as fish or insects), a particular threshold must be exceeded for two sampling intervals (10 minutes each) before a pump sample is collected. A user defined time period must also pass before a threshold can be reused. Sampling thresholds were adjusted numerous times at each station during the study period in order maximize sample coverage and efficiency.

Station Location

Stations were constructed at locations on the streams that made them suitable for sediment sampling and stream gaging. At the sampling location, the stream should be deep enough to fully submerge the turbidity probe at all flows. Pools are generally not suitable because sediment tends to settle there in a non-uniform manner depending on flow levels. Riffles can create a great deal of turbulence which also leads to non-uniform sediment transport depending on flow. The ideal location is a run that has relatively uniform and moderate depth, width, and bed material. This is also the ideal location to conduct stream discharge measurements. In the absence of an installed flume or weir, it is necessary to find a location that has a natural downstream control such as a log or a rock weir that serves to maintain the stage – discharge relationship throughout the range of flows. Additionally, it is desirable to find a location where a bridge can be constructed nearby for discharge measurements and depth integrated samples at discharges too large to wade. The sampling stations were constructed at locations that met these requirements on all three streams (Figures 3, 4, 5).

Station Equipment

The three suspended sediment sampling stations that were installed on Elk River all use the turbidity threshold sampling program to govern their sampling regime. The three sites all have different thresholds because of differences in turbidity ranges. All three sites use identical sampling instrumentation. Turbidity is measured using a Forest Technology Systems DTS-12 turbidity probe. Under revised standards released by the United States Geological Survey, the units of measure for the DTS-12 are Formazine Nephelometric Units (FNU) (Anderson 2004). The DTS-12 also measures water temperature.

The turbidity probe hangs from an articulated boom that hinges laterally and downstream (Figure 6). This type of articulation allows the probe to be easily displaced by logs and other debris transported during storm events without damage to the turbidity probe. The probe returns to its previous depth once the debris has passed. An articulating boom also allows the turbidity probe to move vertically in the stream channel in response to increasing and decreasing stream flow. The typical low-flow position of the turbidity probe is often less than 15 centimeters above the stream bed in order to ensure that the probe is fully submerged. As stream flow increases, drag generated by the probe and submerged portion of the boom causes the probe to be pushed further up in the water column. This movement avoids collision with the larger particles and rocks that

Figure 3. Sampling station located on Corrigan Creek.

Figure 4. Sampling station located on Little South Fork Elk River.

Figure 5. Sampling station located on South Branch North Fork Elk River.

Figure 6. Bank mounted sampling boom articulating downstream during a high flow event on Corrigan Creek.

move along the stream bed during storm events and also helps to ensure that the turbidities measured during storm events are those of the suspended load and not of the bed load. The probe can also be manually raised or lowered in response to changing flow levels. The bases of the booms at Corrigan Creek and South Branch North Fork are bank mounted whereas the boom at Little South Fork is bridge mounted (Figure 3, 4, 5, 6). Both types of installation allow the probe to articulate in the same manner. The particular installation used was determined by site-specific considerations.

An ISCO 3700 pump sampler is located in a small shed near each stream. The pump sampler can accommodate 24 water samples. The 500 mL sample bottles are filled with approximately 350 mL of stream water when a pump sample is triggered. The water is drawn through a 0.635 cm diameter vinyl tube that passes through the boom arm. The intake is located approximately 3 cm below the front of the turbidity probe.

A Druck 1830 pressure transducer is used to monitor the water surface elevation (stage) of the stream. The pressure transducer is mounted in a 2.5 cm pipe with a perforated cap on the end to allow water in. The end of this pipe is submerged at all flows and is connected to rebar that is driven into the stream bed near the turbidity probe. This must be a fixed installation, as any movement would alter the stage reading. Each site is also equipped with a staff gage that allows a visual estimation of the water stage. The staff gage is important because it provides a cross reference to determine if the pressure transducer is functioning properly.

The turbidity probe, the pump sampler, and the pressure transducer are all connected to a Campbell CR10X data logger which is housed inside a water proof case that is installed inside of the shed. A laptop computer was used to interface with the data logger, download data, and check data quality. Due to difficult access, an analog phone modem was installed at the Little South Fork site to permit remote monitoring of data and to determine when a station visit was necessary. A solar panel was installed there in order to power the site without having to transport batteries. A tipping bucket rain gage was also installed at the Little South Fork site in mid-February, 2004.

Station Visits

Sites were visited during and after major storm events in order to resupply bottles, download data, check for proper functionality, clear debris interfering with the turbidity probe or pump sampler intake, clean turbidity probe optics, and conduct stream discharge measurements. Discharge was measured according to the velocity – area method (Dingman 2002) using a Marsh-McBurney Flo-Mate electronic velocity meter to measure flow velocity. Time allowing, a second discharge measurement was taken for quality control purposes. Of the 5 quality control discharge measurements that were taken, none had a difference greater than 7 percent of the original measurement, and the average margin of difference was 4.6 percent.

All three sites have one designated low flow cross-section at which all measurements were taken. Each site also has a bridge from which discharge and depth-integrated measurements could be taken at very high flows. Field forms were completed and notes were taken during each site visit. Depth-integrated sediment samples were collected using a DH-48 sediment sampler during some station visits.

Lab Procedure

Collected bottles were appropriately labeled and stored in boxes until they could be processed. Lab procedures for measuring suspended sediment concentration in samples followed procedures detailed in Standard Methods for the Examination for Water and Waste Water (American Public Health Association 1992). In addition to standard suspended sediment sampling procedure, all samples were first passed through a 0.0635 mm sieve to separate sands from the remaining sediments. The samples were then passed through a 1 µm (0.001 mm) pore size filter to determine the weight of fine particles (silts and clays). Every third consecutive sample whose field turbidity was greater than 200 FNU was also first passed through four additional sieves (1000, 500, 250, and 125 µm) in order to gain an appreciation for the size distribution of sediments in high concentration samples. Turbidity was measured for all lab samples using a Hach 2100 N laboratory turbidity meter. Lab turbidity data was used to cross reference field turbidity measurements in order to ensure field data quality.

Sampling Period

All three stations were instrumented in the fall of 2003. Sampling began on different dates at each of the three stations, but all were fully functioning before the first storm event on December 6, 2003. To make data comparison more meaningful, all results are reported for the period of overlapping data from the three sites: November 26, 2003 through June 16, 2004. The precipitation total for this time period was 4.5 cm (6 percent) higher than the historical mean rainfall for the same period based on data from the National Weather Service rainfall station in Eureka, California for 54 years of data (Western Regional Climate Center 2005).

Data Quality

Due to the remote location of the sampling stations, some data loss was unavoidable. Data loss was typically caused by loss of battery power or insufficient data logger memory. In one instance, a tree fell on the sampling station. Stage and turbidity data for periods of lost data were reconstructed by generating regression relationships with the remaining two sites during periods of proper functionality. These data were identified in the processed data file. Fortunately, no data were lost during any of the major storm events. Subsequent analysis showed that stage and turbidity data reconstructed from the other two sites accounted for a total of 2.4 percent of the sediment load at Little South Fork Elk River. Reconstructed data accounted for only 0.06 percent of the load at Corrigan Creek and 0.9 percent of the load at South Branch North Fork.

Data loss also occurred during very short periods of time when the battery was disconnected for station service, when obviously erroneous stage or turbidity readings were registered during site work, or when the sensors were fouled by aquatic biota. These data were identified in the processed data files and replaced by linear interpolation from the point of last known valid data to the point where valid data resumed. Linear change is expected over the very short intervals typical of this type of data loss. Data restored by linear interpolation accounted for less than 0.01 percent of the total sediment load at each of the three sites.

Depth-Integrated Samples

Pumped sediment samples are taken from a fixed intake located approximately 3 cm below the upstream end of the turbidity probe. Sediment concentration can vary with depth and distance across the stream cross section. Depth-integrated samples were taken in order to calibrate the point samples to the cross-sectional mean sediment concentration. There were considerable differences between point samples and depth-integrated samples on numerous occasions. Unfortunately there was an inadequate number of samples (5 at Corrigan Creek, 7 at Little South Fork, and 10 at South Branch North Fork) to separate sampling error from bias and to justify adjustment of the load estimates. Increasing the frequency of depth integrated samples taken in future years should allow development of a stronger relationship of point to cross sectional sediment discharge that may improve the accuracy of suspended sediment load estimates.

Suspended Sediment Concentration - Turbidity Relationship

Annual suspended sediment load estimates based on turbidity are potentially sensitive to the regression model used to describe the relationship between turbidity and suspended sediment concentration. A linear model is generally adequate to describe most of the relationship, but problems are often encountered at the lower end of the relationship. There can be a significant amount of suspended material that is finer than the 1 μm filter pore size that was used to filter the sediment samples (Gippel 1989, Personal Communication, J. Lewis 2005. Redwood Sciences Laboratory, 1700 Bayview Drive, Arcata, CA 95521). In addition, there tends to be a higher percentage of organic particles at low suspended sediment concentrations (Madej 2005). Organic particles have a lower specific gravity than mineral particles and therefore produce higher turbidity values for a given mass (Gippel 1995). These factors can also lower the amount of suspended sediment that is measured for a given turbidity and cause linear plots of the relationship to have an intercept less than zero, thereby underestimating the suspended sediment load.

Quadratic models typically fit the data better than linear models, but problems similar to the linear model are encountered at the lower end of the relationship. Regression relationships using both of these models can be forced through the origin, but the quality of fit to the complete data set can suffer as a consequence. Using a best-fit quadratic relationship with a negative intercept produced a 29,346 kg smaller sediment load estimate versus a quadratic relationship forced through the origin on the South Branch North Fork data. This is a difference of approximately five percent of the total estimate.

A loess model predicts a y value for a set of equally spaced points covering the range of observed data, based on a weighted regression. It fits local first or second degree polynomials instead of forcing a simple model to fit all of the data in a sample

(Cleveland and Devlin 1988). A loess model is flexible and useful for complex data sets that have unusual points of inflection. This model solves the problem of negative predictions from models that cannot accommodate curvature near the origin. The drawback of the loess model is that it does not generate a predictive formula that can be compared to other data sets or extrapolated past the range of available data. When the loess model was used in this study, linear extrapolation was used to extend the model short distances above and below the range of the existing turbidity and suspended sediment data.

Any points that appeared to be outside the normal range of data on the suspended sediment – turbidity plots were examined to determine their validity. Plots of turbidity versus time in the range of the questionable samples were analyzed for any abnormal spikes. Particle size composition of these samples was also examined for abnormally high sand fractions. All sediment samples were determined to be valid.

RESULTS

Stage - Discharge Rating Equations

In order to make accurate suspended sediment load estimates it is important to generate a valid rating equation that describes the relationship between river stage (measured by the pressure transducer) and discharge (computed using the velocity - area method) at each gaging station. One stage and one turbidity reading are recorded by the sampling equipment at each site every 10 minutes. Linear changed in these parameters is assumed between sampling intervals. The 10 minute stream discharge computed from actual stage measurements and the rating curve is multiplied by the associated suspended sediment concentration to yield a 10 minute suspended sediment flux. These values are then summed to produce a storm or annual suspended sediment load.

Each site had between 6 and 8 discharge measurements that were used to generate the stage - discharge relationship. Due to the rapid response of the small watersheds involved in this study and the lengthy travel time to each of the sites, it was particularly difficult to obtain discharge measurements near the peaks of large storms. In addition, Elk River Road floods during large storm events making access to the sites difficult or impossible during periods of peak discharge. For these reasons it was necessary to extrapolate the stage - discharge rating curves beyond the range of discharge measurements that were obtained.

Hydraulic formulas and relationships were used in order to extend the rating curves to the level of the highest observed flows. Measurements of the water surface slope during elevated discharges were obtained in the vicinity of the gaging sites and the stream bed profile at the fixed cross sections used to collect discharge measurements was mapped. The stage of peak flows during the study period was recorded by the pressure transducer and then related to specific points at the cross sections being measured. The width, average depth, and area of flow during peak flows at the individual cross sections was then determined. Based on these parameters, the Manning equation (Knighton 1998) was used to calculate discharge at the highest recorded stages. The form of the Manning equation used is:

$$Q = (1.49/n)*R^{2/3}S^{1/2}*A$$

where:

Q = discharge (meters^3/second),

R = hydraulic radius ~ mean depth (meters),

S = water surface slope (meters/meters),

A = cross sectional area (meters^2), and

n = coefficient of roughness

The coefficient of roughness (n), however, is not a fixed value and tends to decrease as flow depth increases and proportional energy losses due to boundary friction decrease (Thorne and Zevenbergen 1985). Energy losses due to boundary friction are eventually completely overcome as flow volume increases and n subsequently remains constant. This holds true as long as the stream remains within its banks and does not rise onto the floodplain. None of the three streams rose above the banks during the study period.

Values of *n* computed from actual gaging measurements were plotted against mean depth to observe the trend in lowering of *n* values with an increase in mean depth. Such a plot for Corrigan Creek (Figure 7) shows that as mean depth increases, the coefficient of roughness decreases until the mean depth exceeds 0.3 meters, at which point *n* remains constant at 0.035. Therefore, an *n* value of 0.035 was used to calculate a discharge of 3.00 m^3/sec at the highest recorded stage at Corrigan Creek.

An identical plot was created for Little South Fork Elk River (Figure 8). Due to bedrock and large scale roughness elements present in the channel at the cross section location, the initial coefficient of roughness values were much higher. This coupled with the lack of discharge measurements at high stages (access to the Little South Fork Elk River site requires a three hour hike in addition to the hour and a half drive required to access the other two sites), explains why this relationship didn't exhibit the asymptotic behavior that was observed at Corrigan Creek. Extrapolation of the observed relationship to the predicted mean depth at the highest observed flow (0.81 meters) yielded a roughness coefficient of approximately 0.075. This value is consistent with values observed for streams of similar size and bed material (Barnes 1967) and yielded a peak flow of 2.92 m^3/second at Little South Fork Elk River.

Hydraulic geometry relationships are the resulting power function derived from plotting mean depth, width, and area of flow against discharge. These relationships can be useful in extrapolating the peak discharge of a stream. The discharge plotted against area yielded a peak flow of 3.14 m^3/second at Little South Fork Elk River and the

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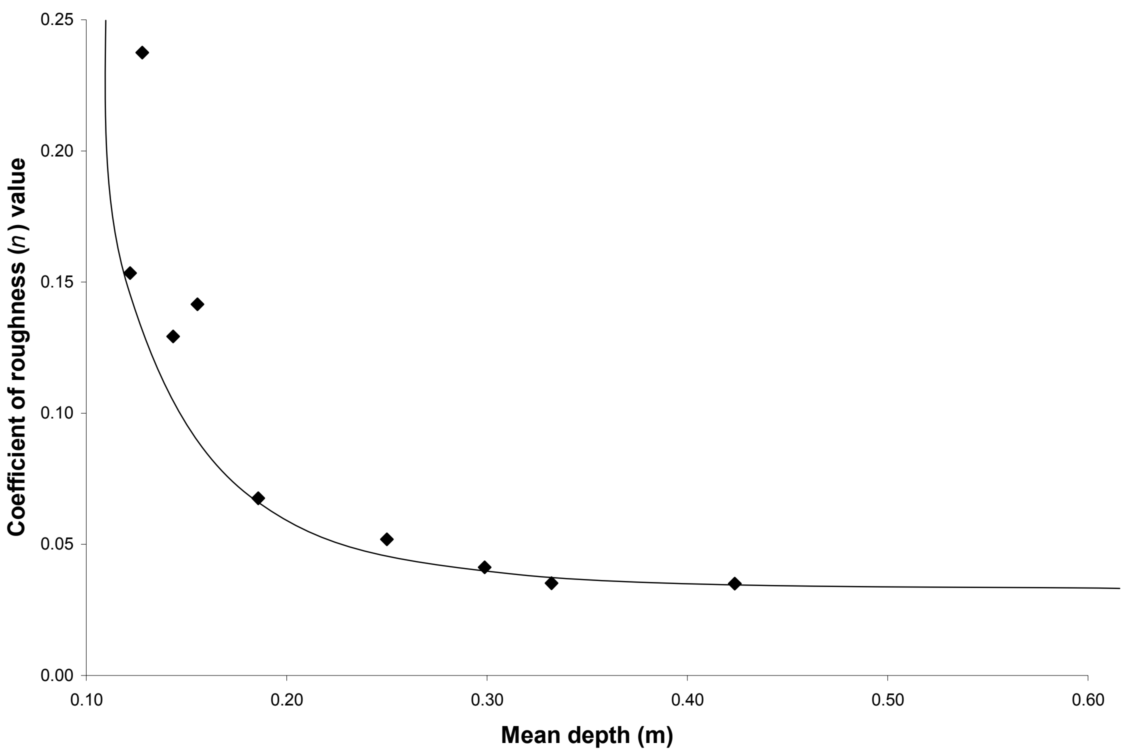

Figure 7. Computed coefficient of roughness (*n*) values against mean depth for discharge measurements at Corrigan Creek.

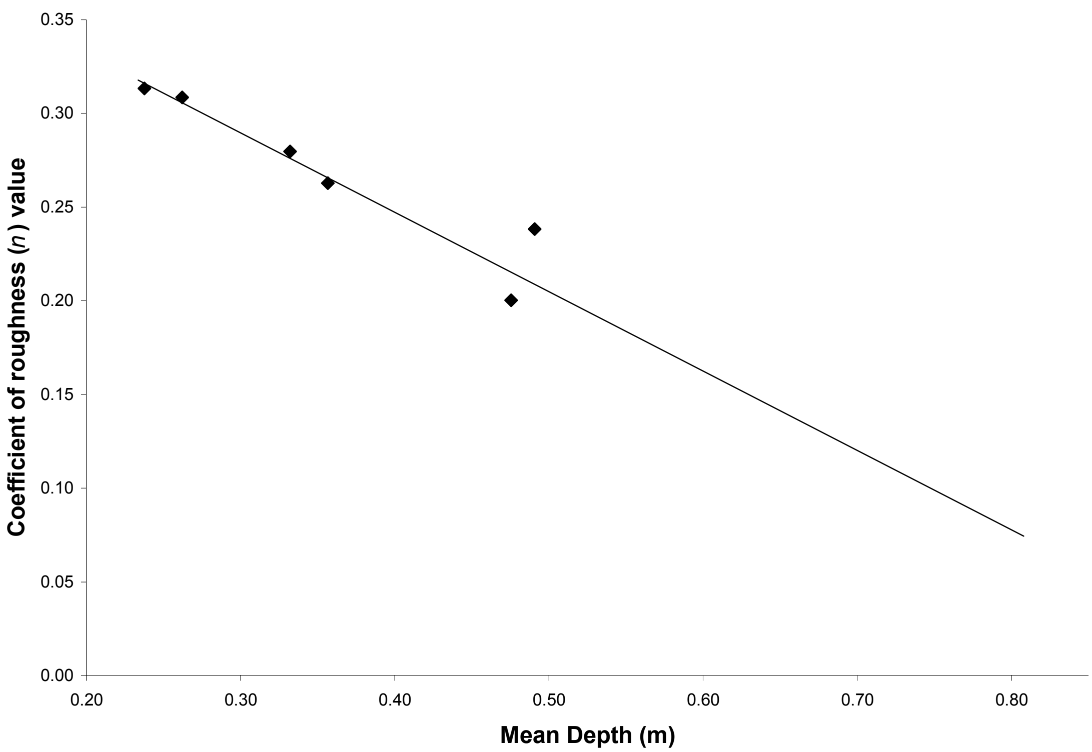

Figure 8. Computed coefficient of roughness (*n*) values against mean depth for discharge measurements at Little South Fork Elk River.

discharge plotted against the mean depth yielded a peak flow of 2.69 m^3/second. These values are roughly consistent with the peak flow estimates derived from the Manning equation.

At South Branch North Fork Elk River, there was a discharge measurement taken at a high flow that was only 0.12 meters below the highest recorded stage. The pressure transducer and staff plate were subsequently moved to a more appropriate sampling location during the summer of 2004. For these reasons, no hydraulic calculations were needed or used to predict the peak flow at this site. The rating curve was linearly extrapolated a short distance above the highest discharge measurement in order to generate the necessary peak flow data.

None of the rating curves for the three gaging locations were adequately fit by a conventional power function. There was reasonable agreement at the lower end of the curves, but peak flows were significantly over-predicted. The rating data for each of the three streams was divided into three ranges of data which were fit very well by linear regression; therefore, combinations of three linear functions were used to generate a rating curve at each of the three sites (Figures 9, 10, 11). Loess plots fit to the discharge measurement points showed very good agreement with the three linear function method, but were not used for discharge calculations because of the ease with which linear functions could be compared and altered to accommodate future potential shifts in the stage-discharge relationship. A segmented regression could also be used to combine the three linear relationships for each stream into a single continuous function (Draper and

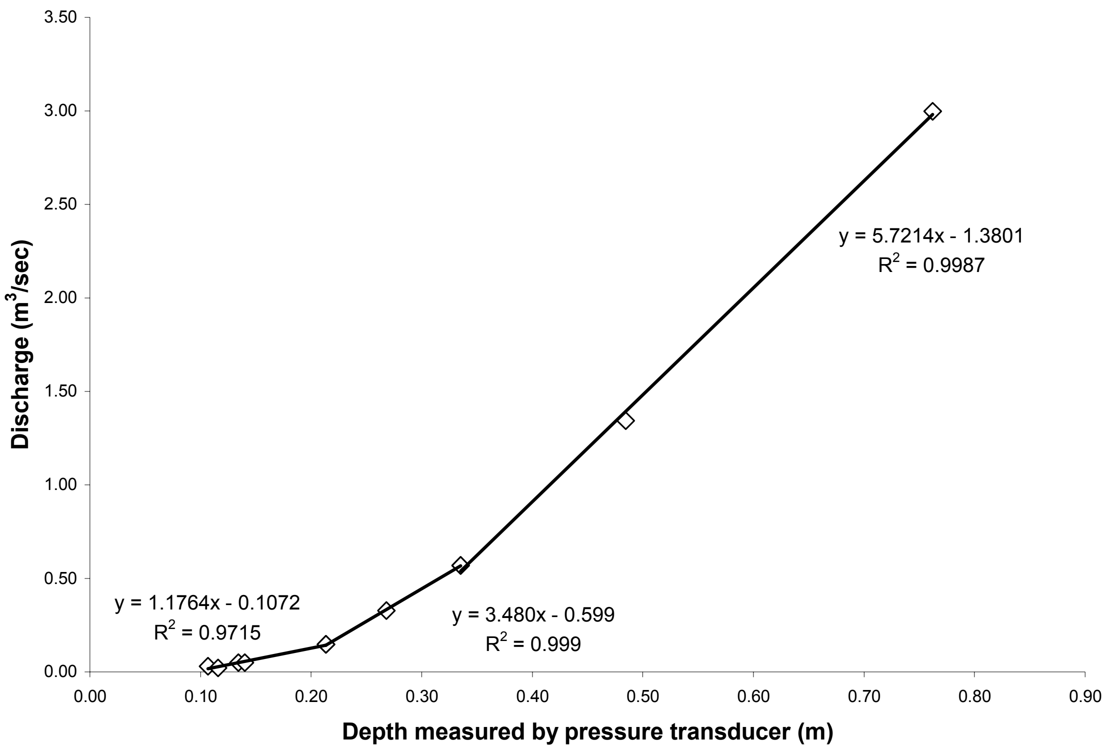

Figure 9. Three part linear discharge rating curve for Corrigan Creek.

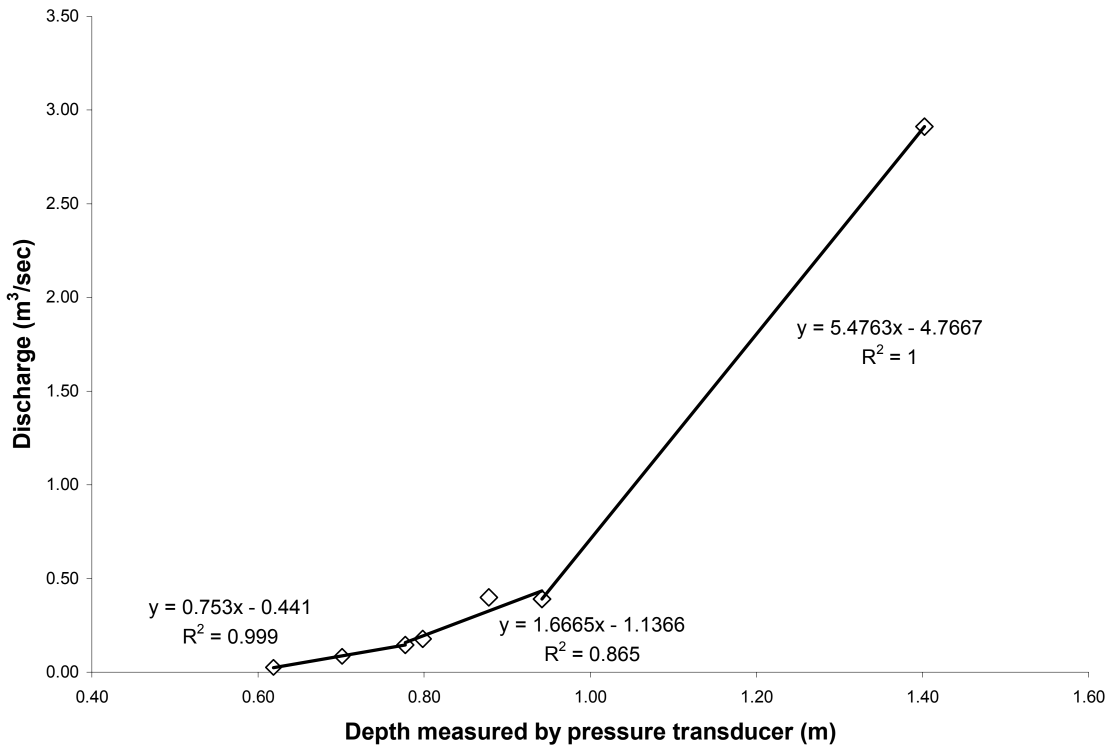

Figure 10. Three part linear discharge rating curve for Little South Fork Elk River.

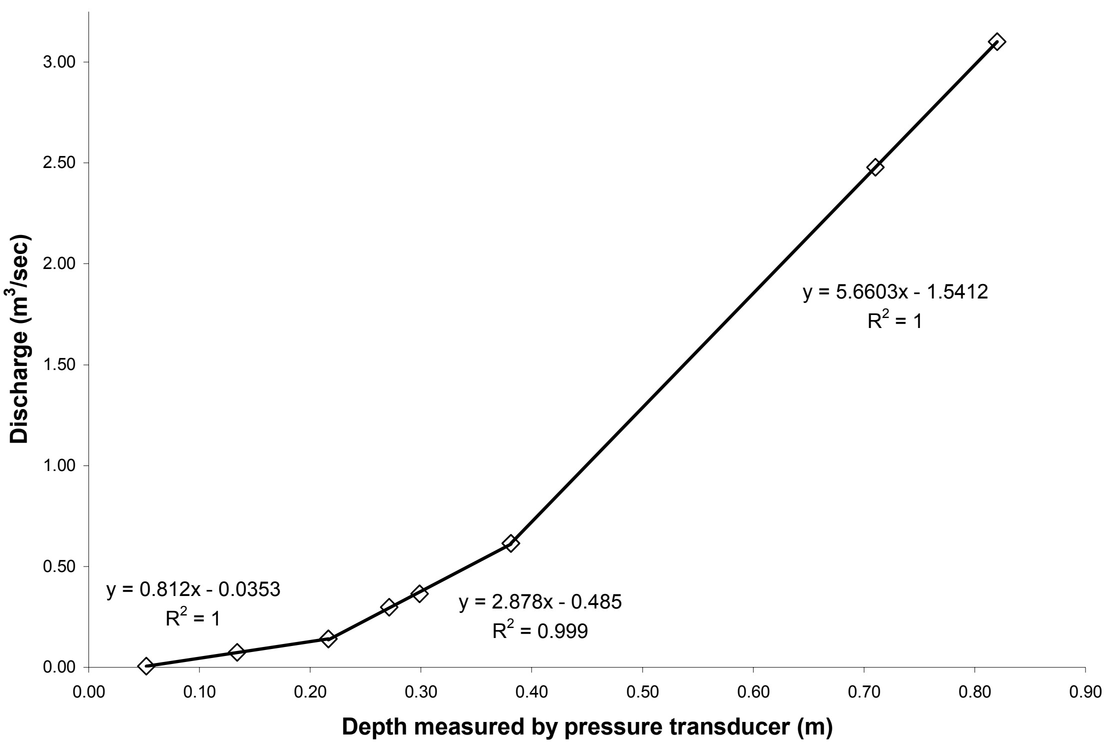

Figure 11. Three part linear discharge rating curve for South Branch North Fork Elk River.

Smith 1981). This method is suggested when creating future discharge rating curves for these sites.

Suspended Sediment Yield Estimates

A loess model was used to relate suspended sediment concentration to turbidity for the complete set of samples taken during water year 2004 at each of the 3 sites (Figures 12, 13, 14). Figures 15, 16, and 17 are the same plots with ranges constrained to 80 mg/l and 80 FNU (the range of the Little South Fork data) for comparison of the lower end of the suspended sediment – turbidity relationship. Differences in the user-defined sampling thresholds accounted for differences in the distribution of sediment samples. Little South Fork Elk River had the lowest range of turbidity values which allowed the use of low sampling thresholds (below 20 FNU). South Branch North Fork had high turbidities which necessitated use of more thresholds at elevated turbidities and allowed for very few samples below 20 FNU. Corrigan Creek had moderate turbidities which allowed for an intermediate level of sampling below 20 FNU. Specifications about the type of loess model used and the statistics associated with each of the loess plots are detailed in Table 1.

The loess model was used in conjunction with the three part linear stage - discharge rating equations for the three sites (Figures 9, 10, 11) to generate suspended sediment load estimates for each site using the R statistics software. The predicted ten minute suspended sediment concentration (mg/L) was multiplied by the predicted ten minute stream discharge (m^3/sec) and converted to produce a ten minute suspended

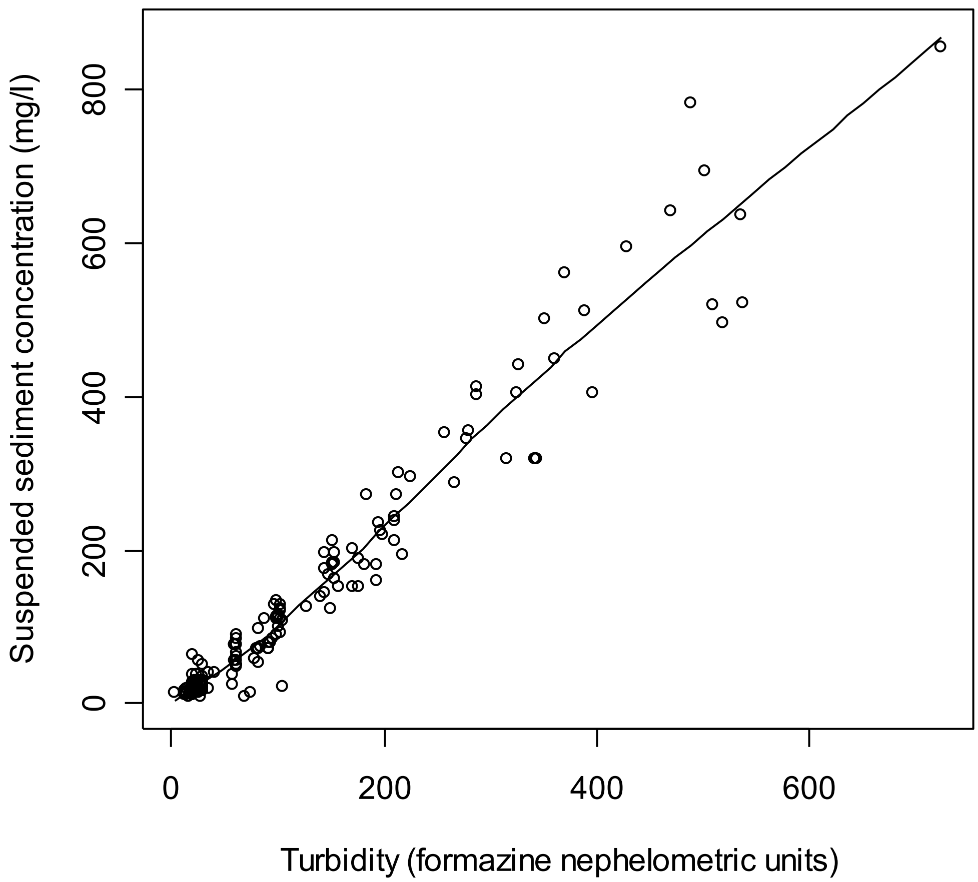

Figure 12. Loess plot of suspended sediment concentration against turbidity for Corrigan Creek.

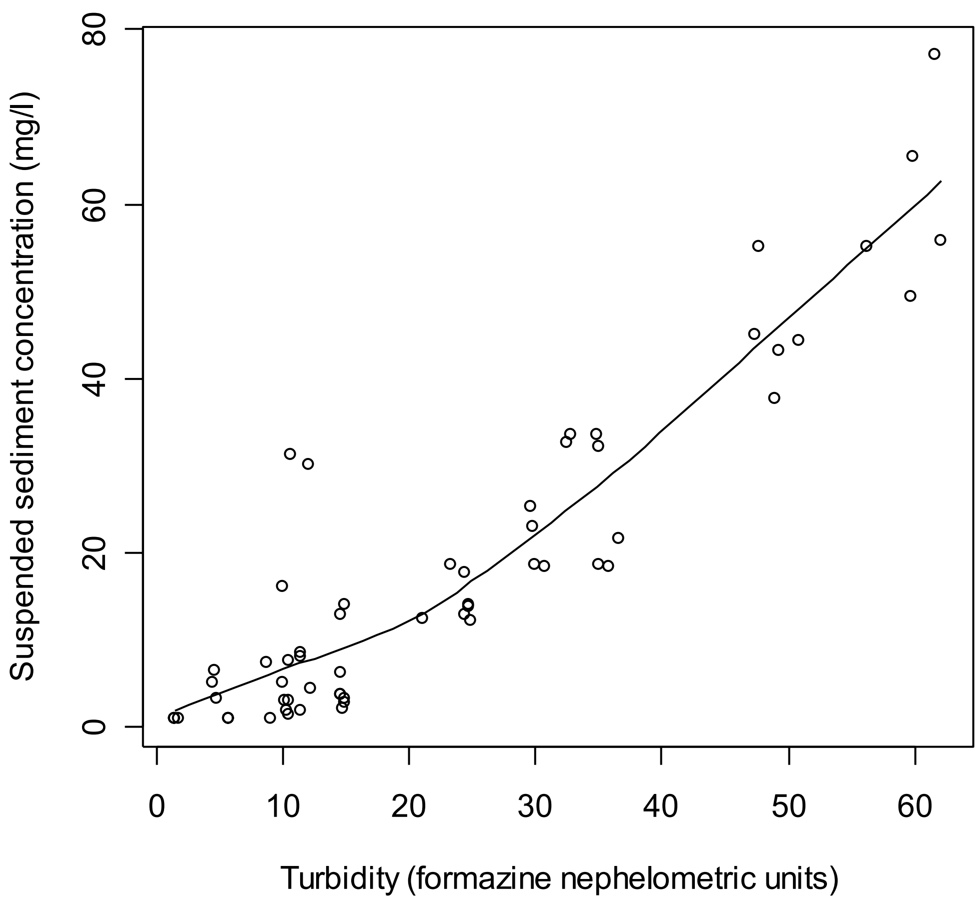

Figure 13. Loess plot of suspended sediment concentration against turbidity for Little South Fork Elk River.

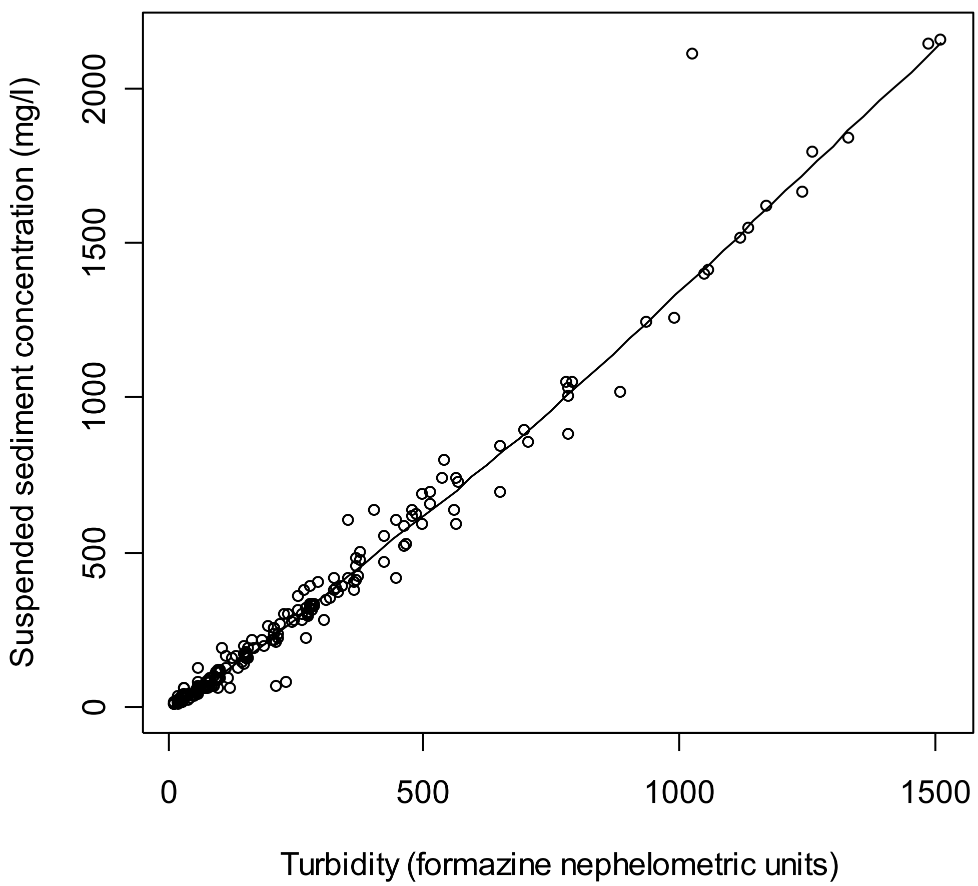

Figure 14. Loess plot of suspended sediment concentration against turbidity for South Branch North Fork Elk River.

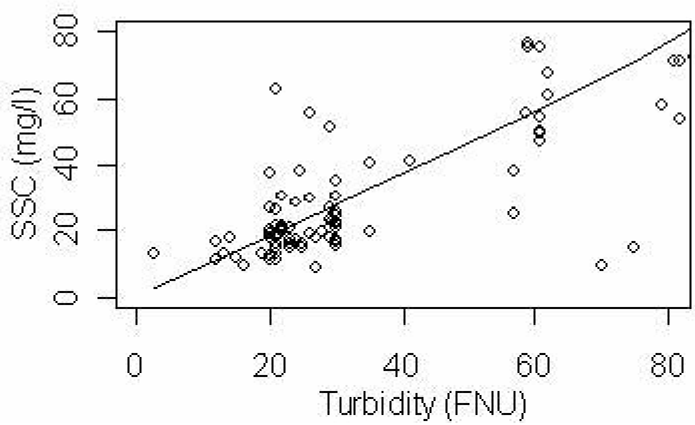

Figure 15. Low range of loess plot of suspended sediment concentration against turbidity for Corrigan Creek.

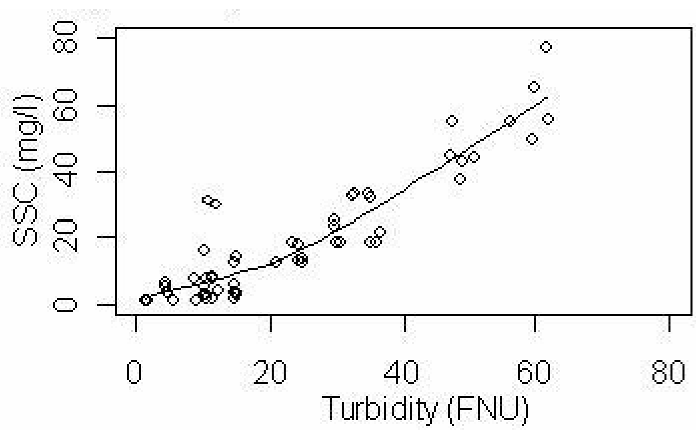

Figure 16. Low range of loess plot of suspended sediment concentration against turbidity for Little South Fork Elk River.

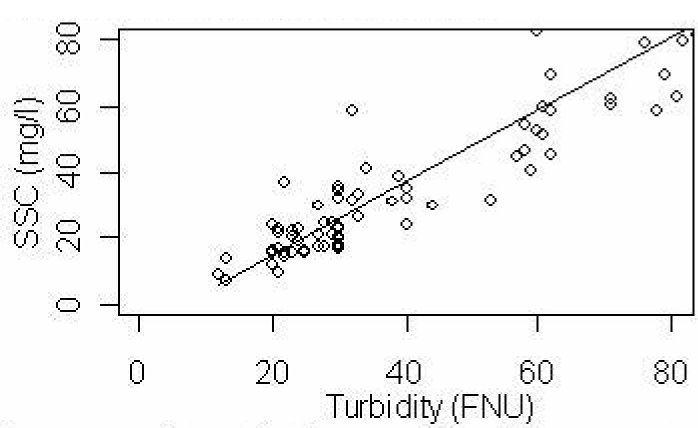

Figure 17. Low range of loess plot of suspended sediment concentration against turbidity for South Branch North Fork Elk River.

Table 1. Statistics for loess plots of suspended sediment against turbidity.

	Corrigan Creek	Little South Fork Elk River	South Branch North Fork Elk River
Plot type	Loess	Loess	Loess
Family	Gaussian	Gaussian	Gaussian
Degree	1	1	1
Span	0.67	0.67	0.67
Number of Observations	168	59	213
Residual Standard Error	36.81	7.13	65.31
Linear Extrapolation Above (mg/L)	724.00	62.16	1515.00
Linear Extrapolation Below (mg/L)	2.59	1.37	12.00

sediment discharge (kg). The entire set of 10 minute suspended sediment discharges was then summed to produce a total suspended sediment load estimate for each site. The estimated sediment load was adjusted for the drainage area above each of the stations to obtain a normalized suspended sediment yield in metric tons/km^2/year. The estimated suspended sediment yield at Little South Fork Elk River was 6.6 tons/km^2. The yield at Corrigan Creek was 55.1 tons/km^2 and the yield at South Branch North Fork Elk was 122.2 tons/km^2. These data, including the total stream discharges are summarized in Table 2.

Another method to estimate annual suspended sediment yield is to use the relationship between suspended sediment concentration and turbidity for each individual storm event to generate sediment loads for that event. This method can be of particular utility when there is a poor annual relationship between turbidity and suspended sediment concentration or when the particle sizes or composition cause the relationship to shift during different storm events or different periods of the year. Differences in rock and soil mineralogy, particle size, and the abundance of organic sediment can cause differences in the light scattering properties of the transported material and can vary the suspended sediment concentration to turbidity relationship (Gippel 1989, Gippel 1995).

The eight largest storms of water year 2004 were analyzed using individual storm regressions to generate individual storm loads. These storm events accounted for a very large percentage of the total suspended sediment load at all three sites and contributed considerably more sediment to the total load than smaller events. A storm event was

Table 2. Summary of data for overlapping sample period.

For Period of Record 11/26/03 07:20 - 06/16/04 14:50			
	Corrigan Creek	Little South Fork Elk River	South Branch North Fork Elk River
Total Discharge (m^3)	2,287,908	1,671,682	3,716,323
Watershed Area (km^2)	4.01	3.11	4.92
Unit Area Discharge (m^3/km^2)	569,914	537,867	755,200
Total Suspended Sediment Load (tons) From Annual Regression	221.1	20.4	601.5
Total Suspended Sediment Load (tons) From Individual Storm Regressions	237.1	18.0	594.7
Difference Between Estimates (tons)	16.0	-2.4	-6.8
Total Suspended Sediment Yield (tons/km^2) From Annual Regression	55.1	6.6	122.2
Total Suspended Sediment Yield (tons/km^2) From Individual Storm Regressions	59.1	5.8	120.8
Difference Between Estimates (tons/km^2)	4.0	-0.8	-1.4
Difference as a Percent of Individual Storm Regressions Estimate	6.7	-13.5	-1.1

defined as an extended period of increased stage and turbidity. A storm event concluded when the turbidity was no longer decreasing at an appreciable rate or when another storm event began.

A linear model was used for this portion of the analysis because of the limited number of points available for each storm event and the acceptability of the fit of linear functions to this data. Some storms were divided into several regressions when it appeared that there were numerous distinct relationships. In particular, different relationships were observed during some storms when turbidity was rising and falling.

Individual storm estimates obtained by this method are presented in Table 3. This table also contains the r^2 value, residual standard error, and coefficient of variation for each individual storm plot. The coefficient of variation is a statistical representation of the precision of an estimate. The coefficient of variation represented as a percentage is defined as: $100 \times \text{variance}^{0.5} / \text{estimated total load}$, where variance of the estimate is calculated as per Lewis (1996). When there are two distinct regressions to describe the turbidity – suspended sediment concentration relationship for an individual storm event, the coefficient of variation represented as a percentage is:

$100 \times ((\text{variance}_1 + \text{variance}_2)^{0.5}) / (\text{estimated total load}_1 + \text{estimated total load}_2)$

(Lewis 1996). Table 4 compares individual storm estimates generated by a loess model of the annual suspended sediment to turbidity relationship with estimates based on storm-wise linear regressions accompanied by the upper and lower boundaries of the 95% confidence interval for storm-wise linear regression estimates.

Table 3. Statistics for suspended sediment load estimates of eight largest storms of water year 2004 based on storm-wise linear regressions between suspended sediment concentration and turbidity.

Storm # and component	Date & Time Start	Date & Time End	Load Estimated Using Storm-Wise Linear Regression (kg)	Number of Sediment Samples	r^2	Residual Standard Error	Coefficient of Variation
			Corrigan Creek				
2	12/10/03 19:00	12/13/03 21:10	13,459	11	0.98	20.22	3.95
3 total	12/13/03 21:20	12/18/03 14:20	20,800	14	NA	NA	2.68
3 rising	12/13/03 21:20	12/14/03 1:00	5,953	4	1.00	10.03	1.59
3 falling	12/14/03 1:00	12/18/03 14:20	14,847	10	0.99	17.68	3.70
5 total	12/28/03 18:00	12/29/03 13:00	24,780	12	NA	NA	2.87
5 rising	12/28/03 18:00	12/29/03 6:10	8,275	5	1.00	11.59	1.83
5 falling	12/29/03 6:20	12/29/03 13:00	16,505	7	0.97	36.81	4.21
6	12/29/03 13:10	12/31/03 12:00	12,893	5	1.00	5.66	2.37
7	12/31/03 13:00	1/15/04 13:00	45,446	17	NA	NA	3.99
7rising	12/31/03 13:00	1/1/04 8:00	12,266	5	0.99	36.66	7.72
7falling	1/1/04 8:10	1/15/04 13:00	33,180	12	1.00	18.05	4.67
13	2/16/04 6:00	2/20/04 13:00	65,934	13	0.99	25.25	4.49
14	2/25/04 6:00	2/28/04 12:00	26,469	12	0.89	21.73	5.92
17	5/17/04 17:40	5/30/04 12:30	2,795	10	0.97	12.05	8.20
			Little South Fork Elk River				
2	12/10/03 19:00	12/13/03 21:10	1,378	9	0.94	4.79	7.59
3	12/13/03 21:20	12/18/03 14:20	1,770	6	0.98	3.83	9.88
5	12/28/03 18:00	12/29/03 13:00	1,519	6	0.89	6.53	9.41
6	12/29/03 13:10	12/31/03 12:00	1,727	4	0.96	1.80	5.93
7	12/31/03 13:00	1/15/04 13:00	3,246	8	0.97	4.62	14.47
13 total	2/16/04 6:00	2/20/04 13:00	4,734	10	NA	NA	7.86
13 rising	2/16/04 6:00	2/17/04 4:20	1,543	4	1.00	0.61	0.83
13 falling	2/17/04 4:30	2/20/04 13:00	3,191	6	0.93	2.27	11.66
14	2/25/04 6:00	2/28/04 12:00	1,243	4	1.00	0.34	2.51
17	5/17/04 17:40	5/30/04 12:30	109	3	0.45	8.78	87.61
			South Branch North Fork Elk River				
2	12/10/03 19:00	12/13/03 21:10	24,190	20	0.99	35.49	2.71
3 total	12/13/03 21:20	12/18/03 14:20	51,052	21	NA	NA	7.13
3 rising	12/13/03 21:20	12/13/03 23:20	8,552	5	0.96	184.25	8.14
3 falling	12/13/03 23:30	12/18/03 14:20	42,500	16	0.99	89.51	8.41
5	12/28/03 18:00	12/29/03 13:00	NA	0	0.00	0.00	0.00
6	12/29/03 13:10	12/31/03 12:00	25,679	11	0.88	76.46	13.71
7	12/31/03 13:00	1/15/04 13:00	102,301	27	0.99	40.83	2.64
13	2/16/04 6:00	2/20/04 13:00	191,348	44	0.98	53.33	2.54
14	2/25/04 6:00	2/28/04 12:00	85,977	16	0.93	25.06	3.50
17	5/17/04 17:40	5/30/04 12:30	NA	0	0.00	0.00	0.00

Table 4. Individual storm loads for the eight largest storms of water year 2004 estimated using storm-wise linear regression and loess annual regression of suspended sediment concentration against turbidity.

Storm #	Storm Load Estimated by Storm-Wise Linear Regression (kg)	Storm Load Estimated by Loess Annual Regression (kg)	Difference (kg)	Difference as a % of Estimate Using Storm-Wise Linear Regression	Coefficient of Variation for Storm-Wise Linear Regression	Lower Boundary of 95 % Confidence Interval for Storm-Wise Linear Regression (kg)	Upper Boundary of 95 % Confidence Interval for Storm-Wise Linear Regression (kg)
Corrigan Creek							
2	13,459	12,012	1,448	10.8	3.95	12,396	14,522
3	20,800	21,144	-344	-1.7	2.68	19,685	21,915
5	24,780	25,416	-636	-2.6	2.87	23,358	26,202
6	12,893	11,220	1,673	13.0	2.37	12,283	13,503
7	45,446	42,804	2,642	5.8	3.99	41,815	49,077
13	65,934	57,557	8,377	12.7	4.49	60,009	71,859
14	26,469	23,631	2,838	10.7	5.92	23,336	29,601
17	2,795	2,955	-160	-5.4	8.20	2,470	3,439
Total	209,781	193,784	15,996	7.6			
Little South Fork Elk River							
2	1,378	1,613	-235	-17.1	7.59	1,169	1,587
3	1,770	1,959	-189	-10.7	9.88	1,420	2,120
5	1,519	1,707	-188	-12.4	9.41	1,233	1,805
6	1,727	1,427	301	17.4	5.93	1,522	1,932
7	3,246	2,845	401	12.4	14.47	2,307	4,186
13	4,734	6,840	-2,106	-44.5	7.86	3,989	5,478
14	1,243	1,653	-410	-33.0	2.51	1,181	1,306
17	109	29	81	73.6	87.61	-82	301
Total	15,618	18,043	-2,426	-15.5			
South Branch North Fork Elk River							
2	24,190	22,232	1,958	8.1	2.7	22,879	25,502
3	51,052	53,276	-2,224	-4.4	7.1	43,773	58,331
5	No Data	65,239	NA	NA	NA	NA	NA
6	25,679	25,708	-29	-0.1	13.7	18,639	32,719
7	102,301	101,442	860	0.8	2.6	96,904	107,698
13	191,348	197,402	-6,054	-3.2	2.5	181,623	201,072
14	85,977	86,387	-410	-0.5	3.5	79,955	91,999
17	No Data	4,658	NA	NA	NA	NA	NA
Total	480,547	486,447	-5,899	-1.2			

The total sediment load generated by the eight largest storms as estimated by individual storm regression was added to the load estimated by annual regression for the remaining time periods. This produced an annual sediment yield estimate based on individual storm regression of 5.8 tons/km^2 at Little South Fork, 59.1 tons/km^2 at Corrigan Creek, and 120.1 tons/km^2 at South Branch North Fork (Table 2).

Figures 18, 19, and 20 are plots of the suspended sediment concentration against turbidity at all three sites. These plots contain the entire annual data set accompanied by a linear regression of this data. These plots also highlight several selected storm events and linear regressions of these events. There are obvious differences in the suspended sediment – turbidity relationships over the course of the year at Corrigan Creek (Figure 18) and Little South Fork Elk River (Figure 19). South Branch North Fork Elk River (Figure 20) shows very little variation in this relationship throughout the year.

Neither method appeared to consistently over predict or under predict the other method. Individual storm regression predicted an annual load of 2,430 kg less than annual regression predicted at Little South Fork Elk River and a load of 16,000 kg more than annual regression at Corrigan Creek (Table 4). These are considerable differences when accounting for the size of the total load, especially at Little South Fork Elk River where the difference amounted to 16 percent of the total annual load. At Corrigan Creek the difference amounted to 8 percent of the total annual load.

Annual regression predicted a load of 5,900 kg more than individual storm regression at South Branch North Fork Elk River which amounted to only one percent of

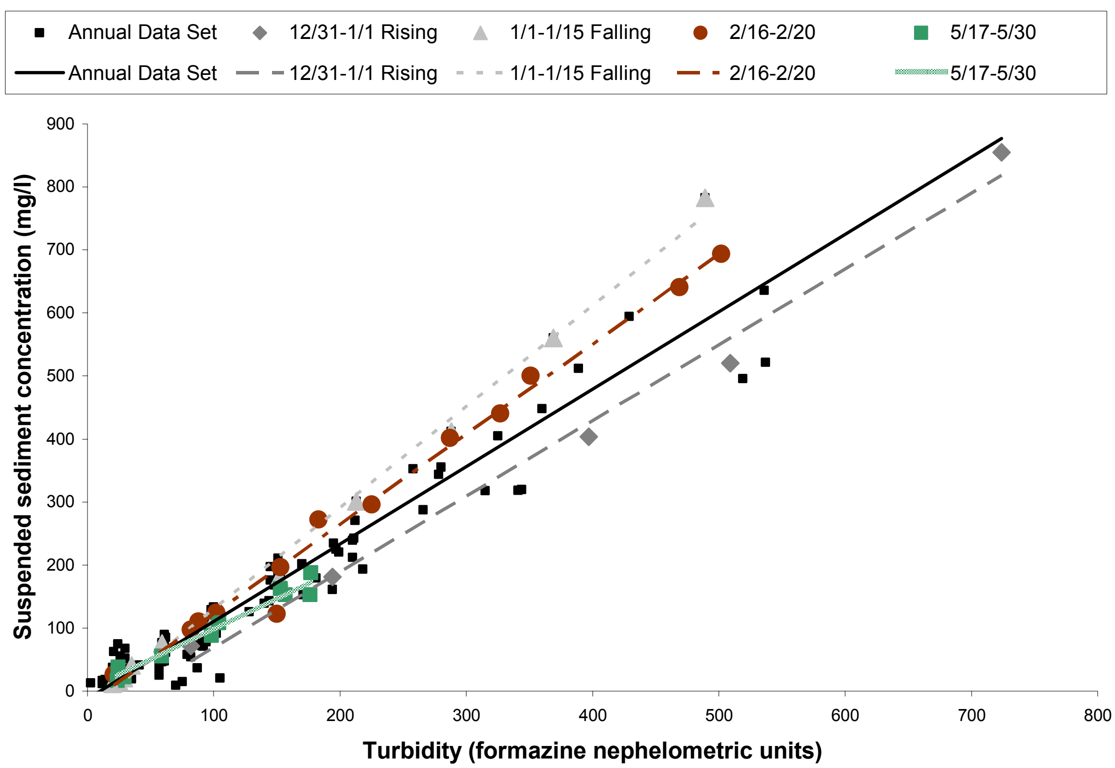

Figure 18. Suspended sediment concentration – turbidity relationship for annual data set and for selected storm events at Corrigan Creek.

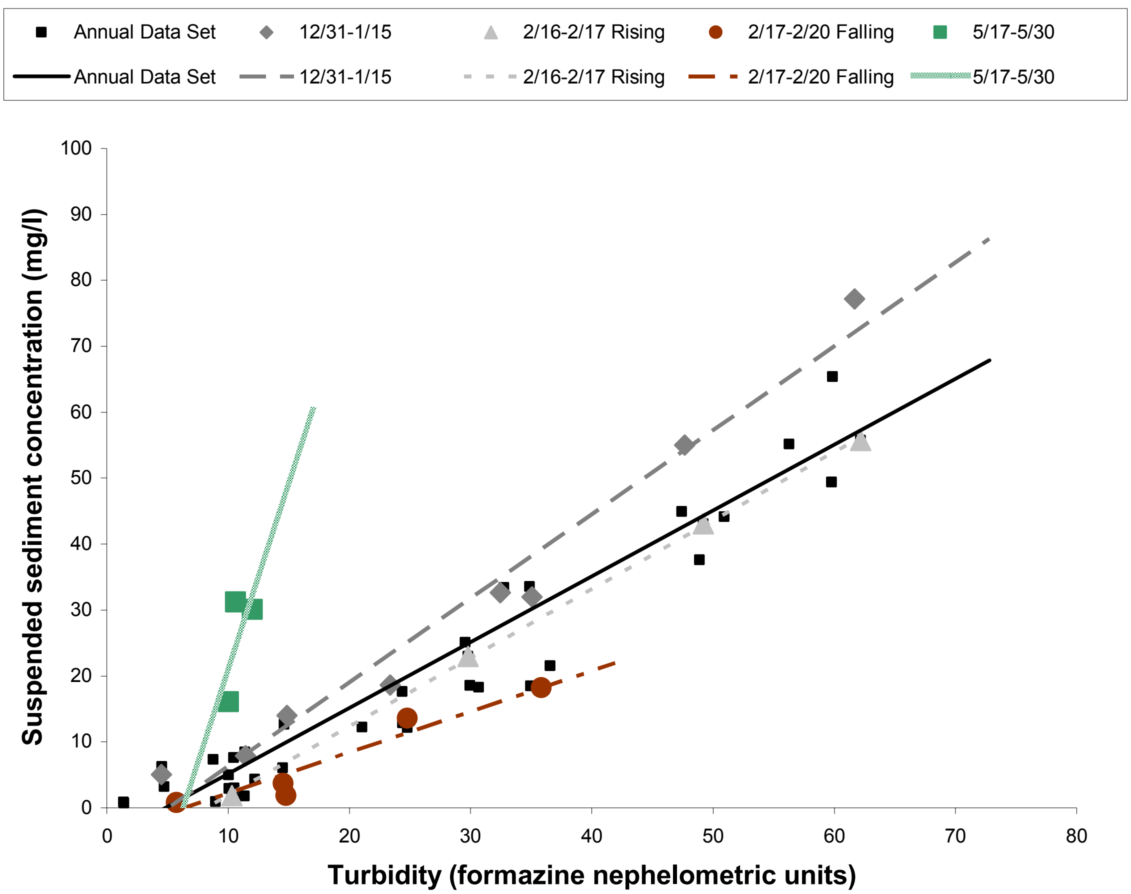

Figure 19. Suspended sediment concentration – turbidity relationship for annual data set and for selected storm events at Little South Fork Elk River.

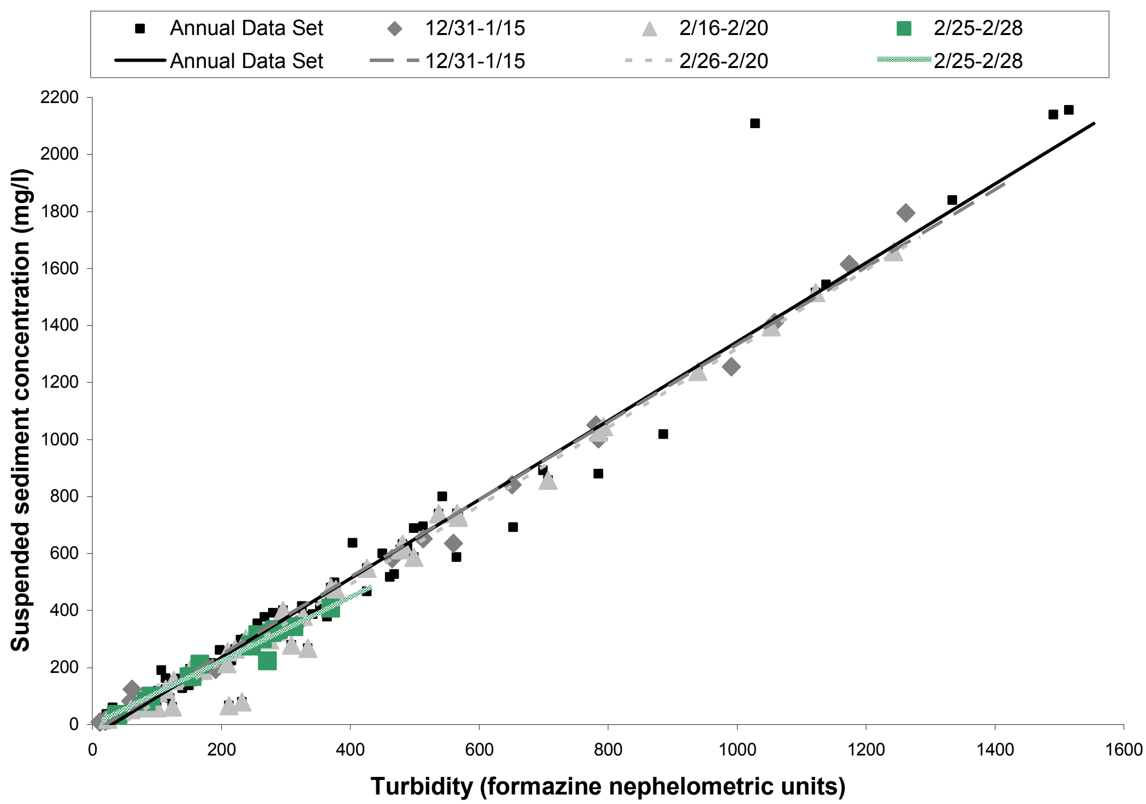

Figure 20. Suspended sediment concentration – turbidity relationship for annual data set and for selected storm events at South Brach North Fork Elk River.

the total annual load. There was, however, insufficient data for the fourth largest storm of the year to make an individual storm load prediction. This omission may have had some, but unlikely a large influence on that figure.

Particle Size Distribution

All physical sediment samples were divided into two size classes. Particles larger than 0.0635 mm are classified as sands and particles between 0.0635 mm and 0.001 mm (the pore size of the smallest filter used) are classified as fines (silts and clays). Loess models were used to compute the total suspended sediment load that moved as fines and as sands in each watershed. The total yield of both fines and sands was highest at South Branch North Fork Elk River and lowest at Little South Fork Elk River (Table 5). The percentage of the total suspended sediment load that moved as fines was similar for the two managed watersheds; 90 percent at South Branch North Fork Elk River and 87 percent at Corrigan Creek. The percentage of the total load that moved as fines was only 75 percent at Little South Fork Elk River. Figures 21, 22, and 23 show the percentage of sand observed in each sediment sample as a function of discharge at the three sampling locations. All three sites showed greater variability and higher sand fractions at lower discharges. Little South Fork Elk River had the greatest variability and the highest sand fractions throughout the range of discharges.

Every third consecutive sediment sample whose field turbidity was greater than 200 FNU was also first passed through four additional sieves; 1000, 500, 250, and 125 μm. There were 29 sediment samples that were passed through the four additional sieves

Table 5. Estimates of suspended sediment load composition and statistics for loess plots of fines and sands versus turbidity.

	Fines (0.0635 mm - 0.001 mm)			Sands (>0.0635mm)		
	Corrigan Creek	Little South Fork Elk River	South Branch North Fork Elk River	Corrigan Creek	Little South Fork Elk River	South Branch North Fork Elk River
Plot type	Loess	Loess	Loess	Loess	Loess	Loess
Family	Gaussian	Gaussian	Gaussian	Gaussian	Gaussian	Gaussian
Degree	1	1	1	1	1	1
Span	0.67	0.67	0.67	0.67	0.67	0.67
Number of Observations	168	59	213	168	59	213
Residual Standard Error	36.36	4.21	61.36	12.99	3.95	17.97
Linear Extrapolation Above (mg/L)	724.00	62.16	1515.00	724.00	62.16	1515.00
Linear Extrapolation Below (mg/L)	2.59	1.37	12.00	2.59	1.37	12.00
Total Load in Size Class (tons)	191.5	15.2	538.7	29.7	5.1	62.7
Total Yield in Size Class (tons/km^2)	47.7	4.9	109.5	7.4	1.6	12.8
Percentage of Total Suspended Sediment Load in Size Class	87	75	90	13	25	10

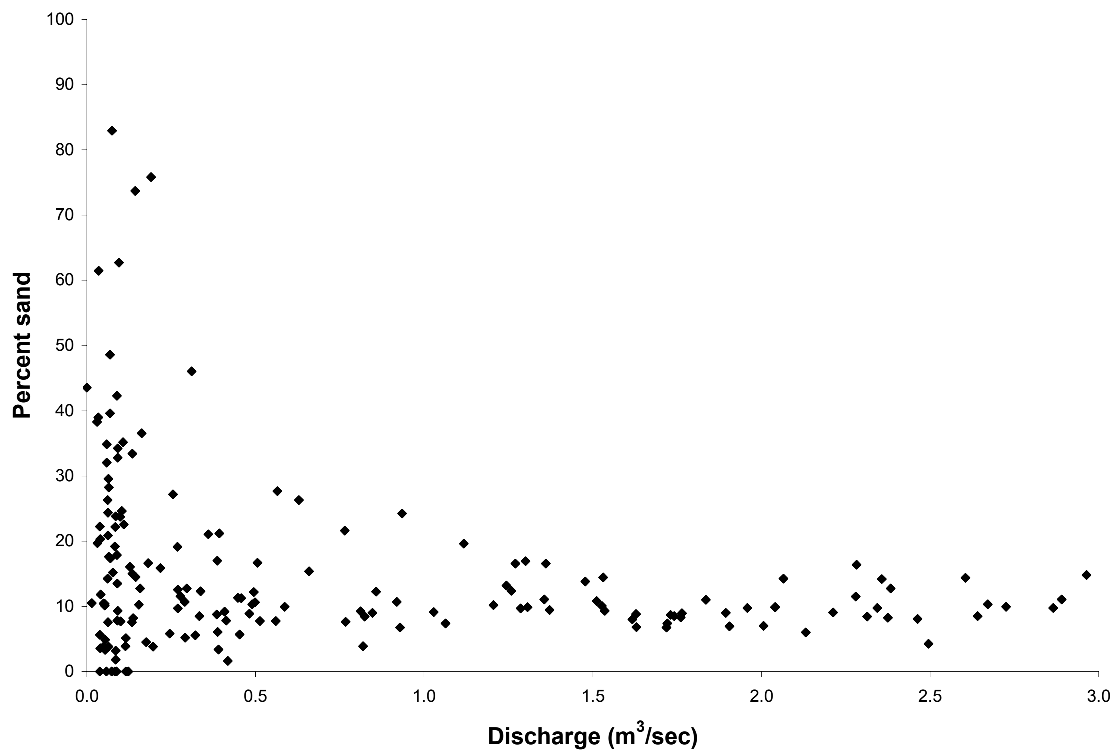

Figure 21. Percent sands as a function of discharge at Corrigan Creek.

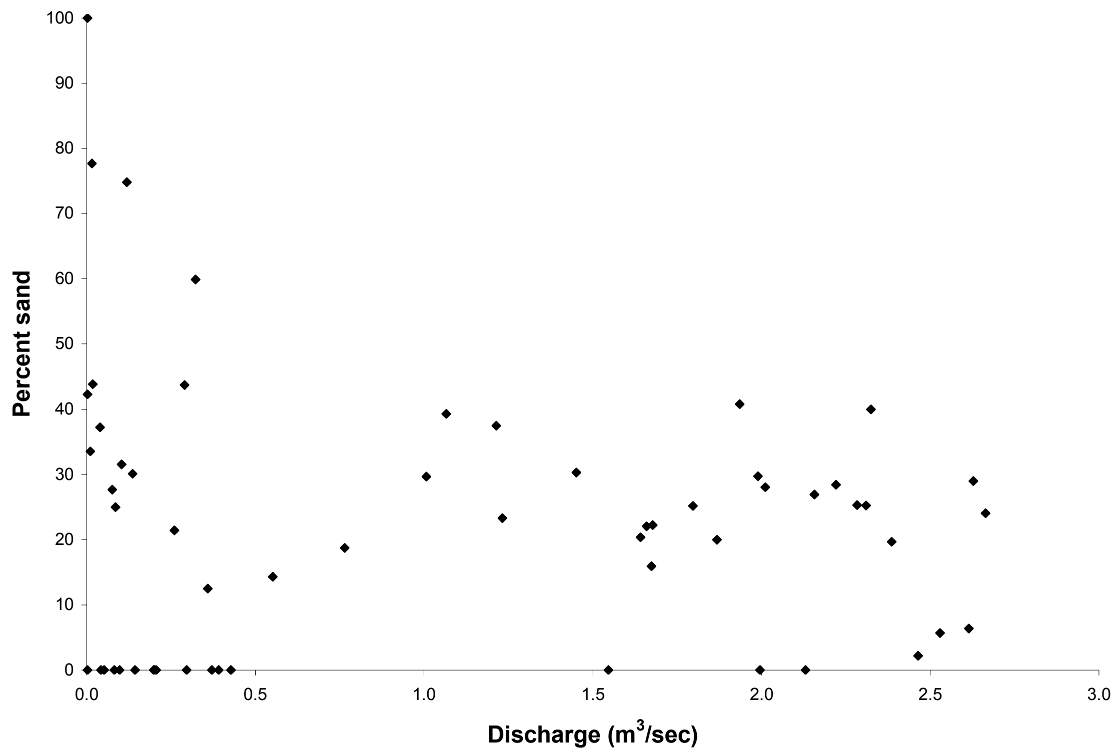

Figure 22. Percent sands as a function of discharge at Little South Fork Elk River.

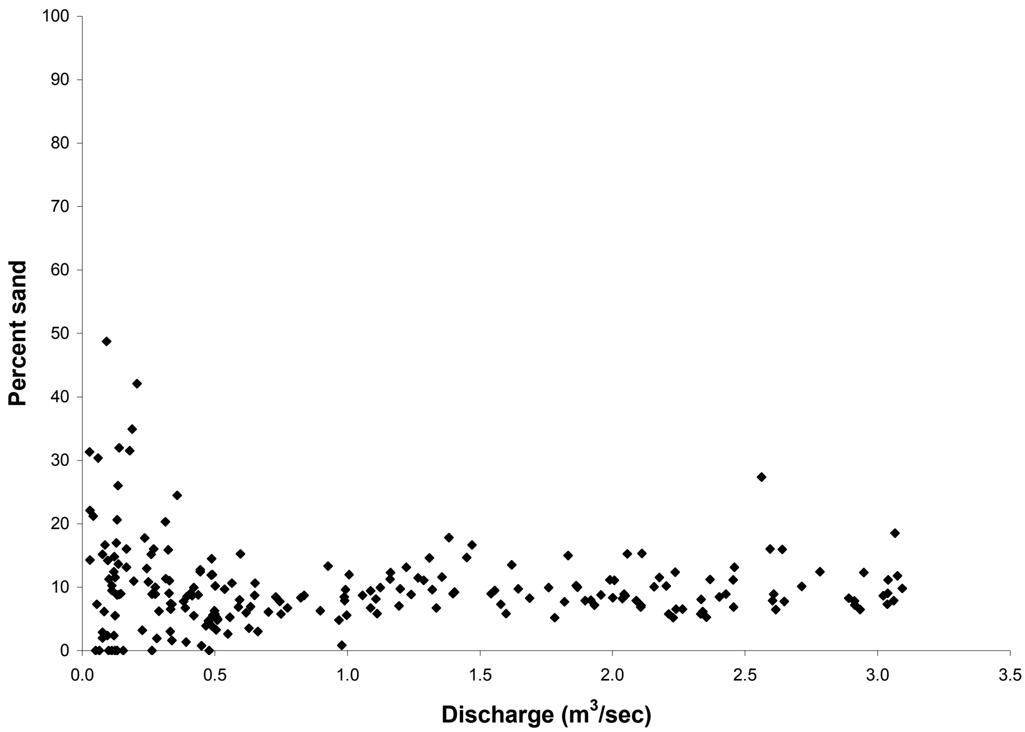

Figure 23. Percent sands as a function of discharge at South Branch North Fork Elk River.

(25 from South Branch North Fork and 4 from Corrigan Creek). Analysis of the sieve data showed no appreciable trends when plotted against time, sample suspended sediment concentration, and discharge. There was an inadequate number of samples at Corrigan Creek and Little South Fork Elk River to allow for comparison between sites.

Timing of Sediment Movement

There were 17 storm events observed during water year 2004, representing 33 percent of the study period. Hydrographs (stream discharge against time) were very similar for all three sites (Figure 24). The onset of storm events and the timing of storm peaks were nearly simultaneous at all three sites, though there were subtle differences in peak discharges and low flow magnitude. For clarity in presentation, a composite discharge was generated by averaging each of the 10 minute discharges at the three sites (Figure 25).

Sediment movement occurred primarily in several large fluxes corresponding to several large rainstorms (Figure 25). The 8 largest sediment movement events transported roughly 90 percent of the load for the entire year in 16 percent of the study period at all three stations (Figure 26). The two largest events alone moved over 50 percent of the total load at all three sites in just 9 percent of the study period. There was very little sediment movement observed outside of the defined storm events; only 2-5 percent of the total load moved during the inter-storm period. Figure 27 is a plot of the percentage of the flow frequency, flow volume, and sediment flux occurring at discharges

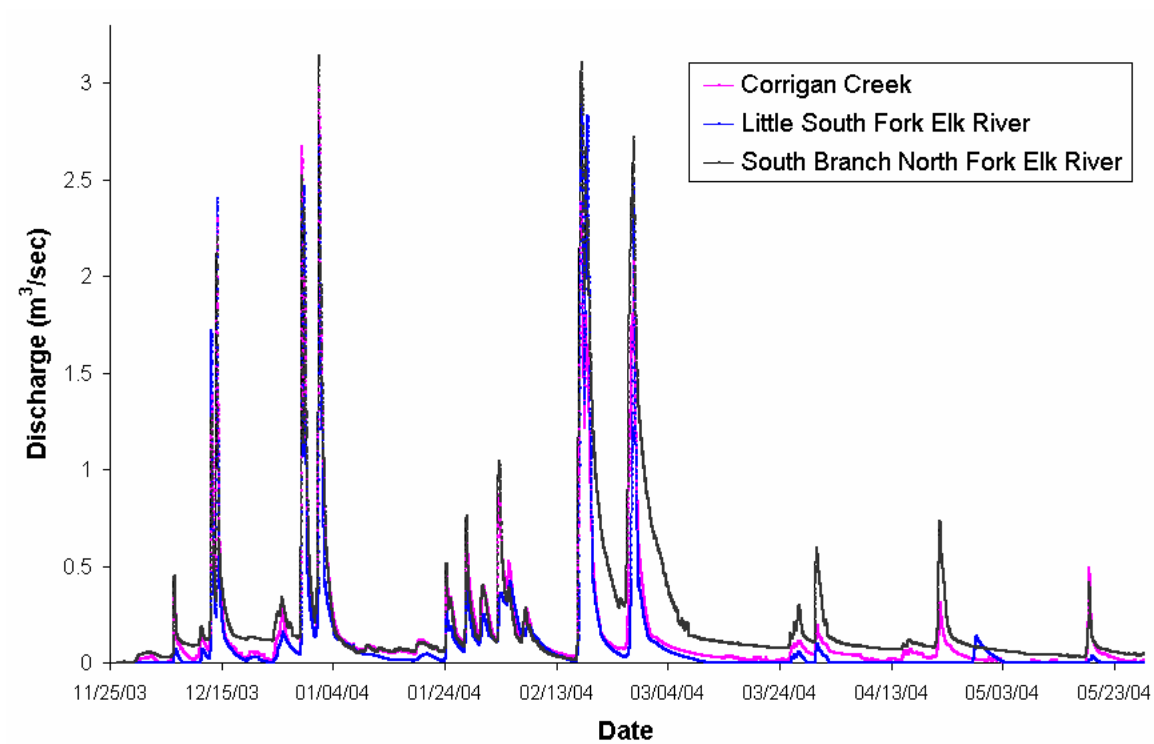

Figure 24. Hydrograph for Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River.

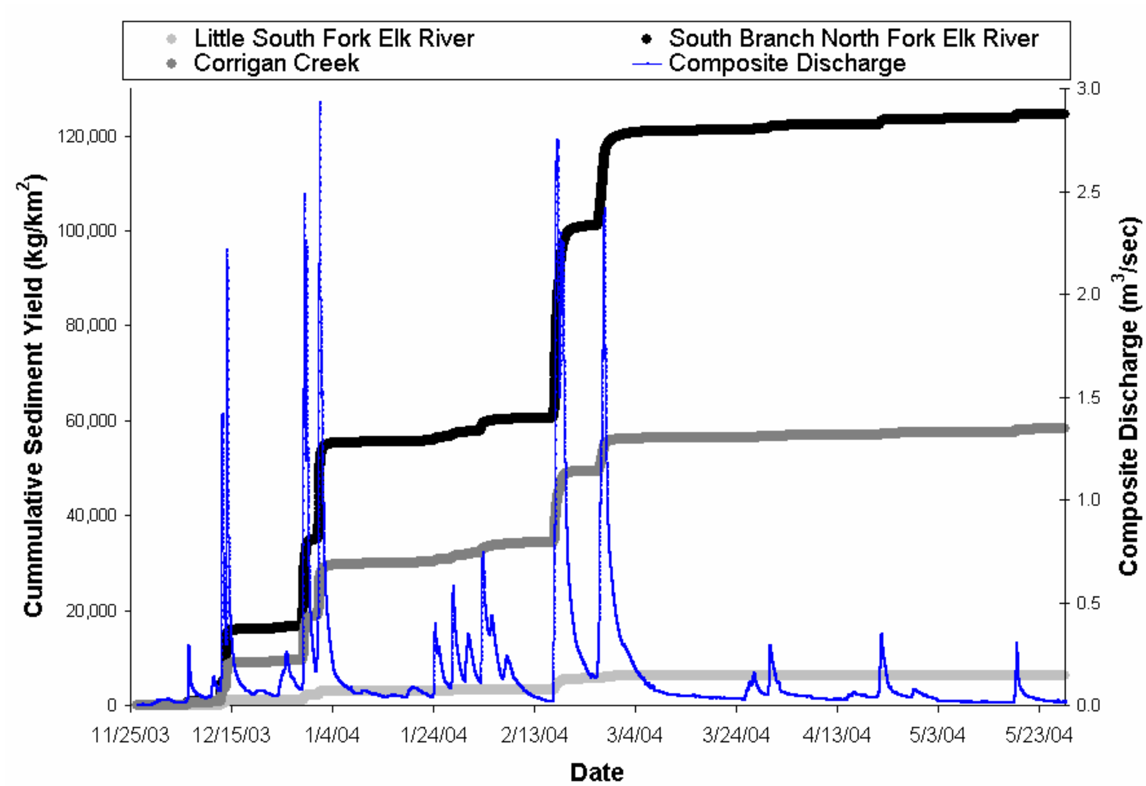

Figure 25. Sediment yield accumulation and composite discharge generated by averaging the discharges at Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River.

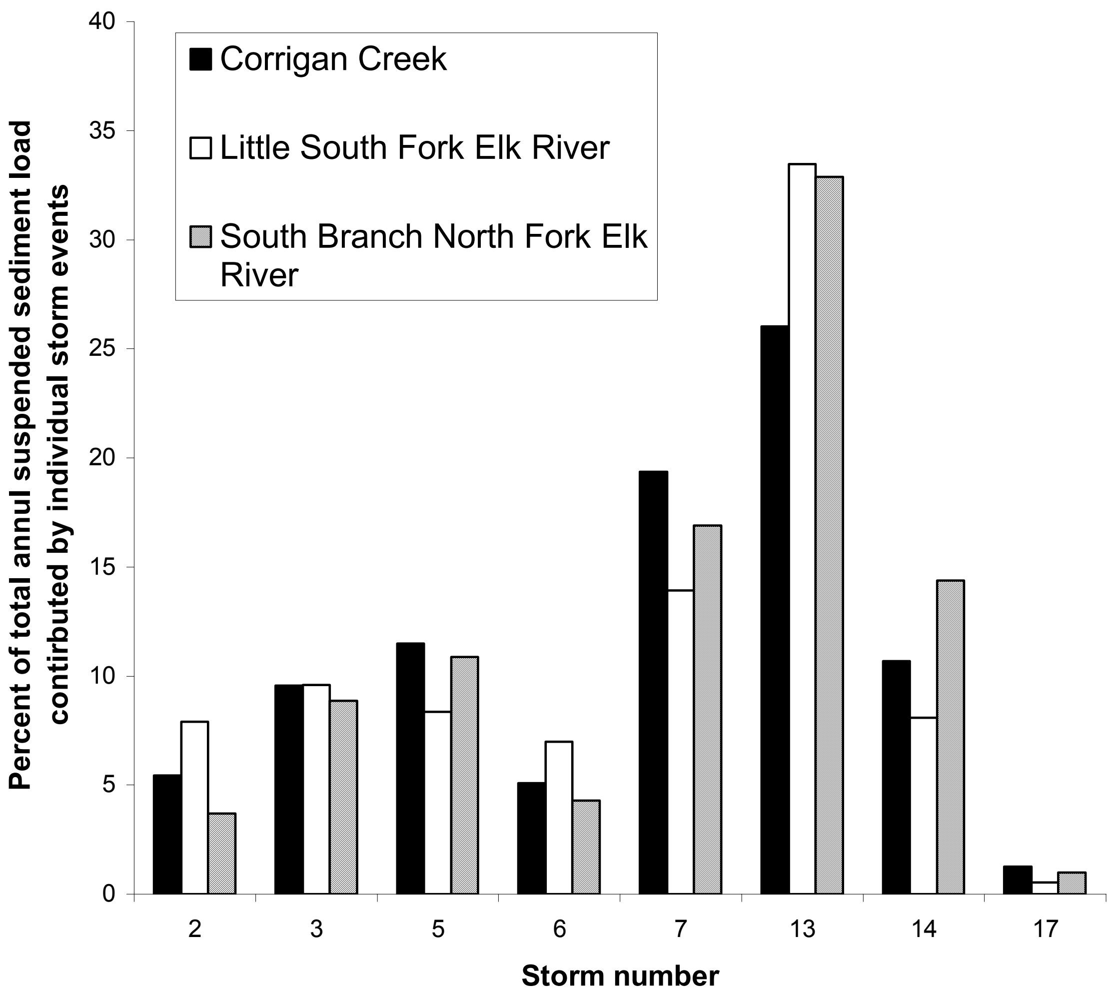

Figure 26. Percent of total annual suspended sediment load contributed by individual storm events.

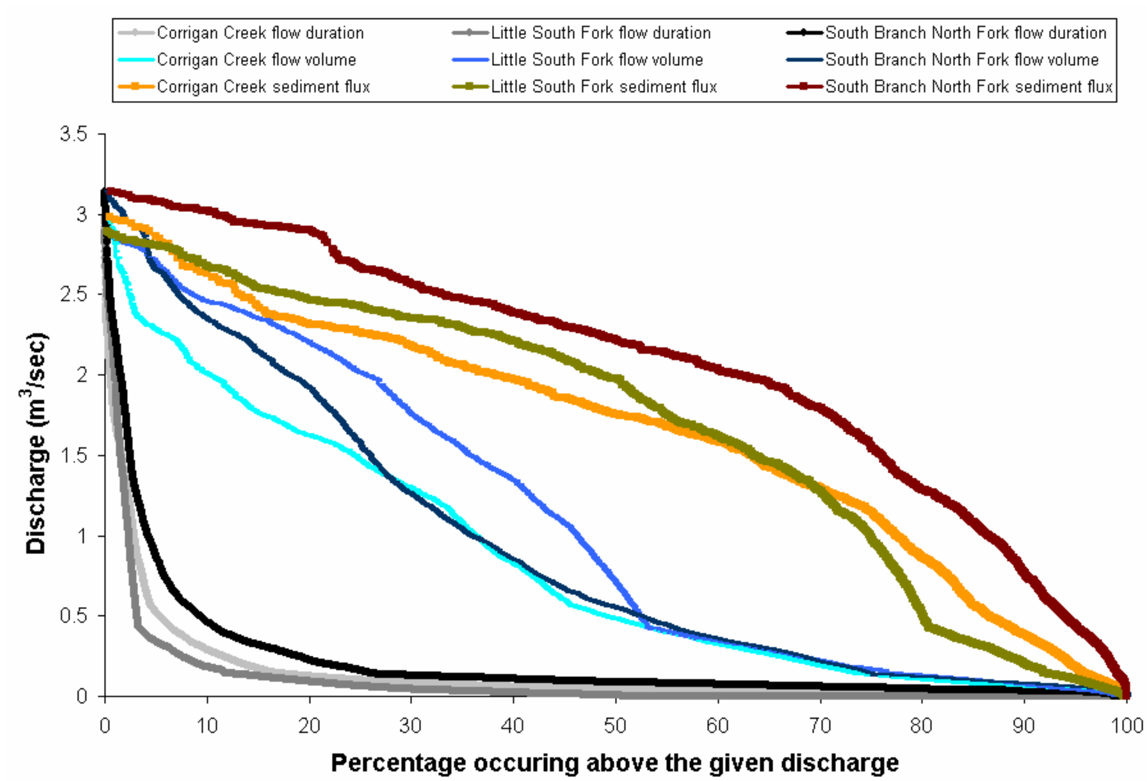

Figure 27. Flow and sediment regimes at Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River.

greater than the level indicated at all three sites. At South Branch North Fork Elk River for example, discharges greater than 1.5 m^3/sec occurred less than 5 percent of the time, but accounted for approximately 30 percent of the flow volume and 80 percent of the sediment flux.

Elevated Sediment Duration

In addition to the total suspended sediment load, the duration of elevated suspended sediment concentrations in a stream is important from a biological and a water quality perspective. Figure 28 shows the total (non-continuous) hours that thresholds of suspended sediment concentration were exceeded at each of the three Elk River sampling locations, based on the annual loess regressions (Figures 12, 13, 14).

Newcombe (1991), Newcombe and MacDonald (1994), and Newcombe and Jensen (1996) synthesized numerous studies on the physiological response of fish to increased suspended sediment concentration. They proposed a severity (SEV) of ill effects index that describes the response of fish to different doses [concentration (mg/L) × duration of exposure (hours)] of sediment. They created a SEV scale of 0-14 based on the regression of exposure duration and sediment concentration in the numerous studies that they examined. This allowed creation of multiple functions based on taxonomy, life stage, and life history. The SEV scale is provided in Table 6.

Figures 29, 30, and 31 show the continuous number of hours that particular suspended sediment concentration thresholds were met or exceeded at each of the three sediment sampling sites in Elk River based on the annual loess regressions (Figures 12,

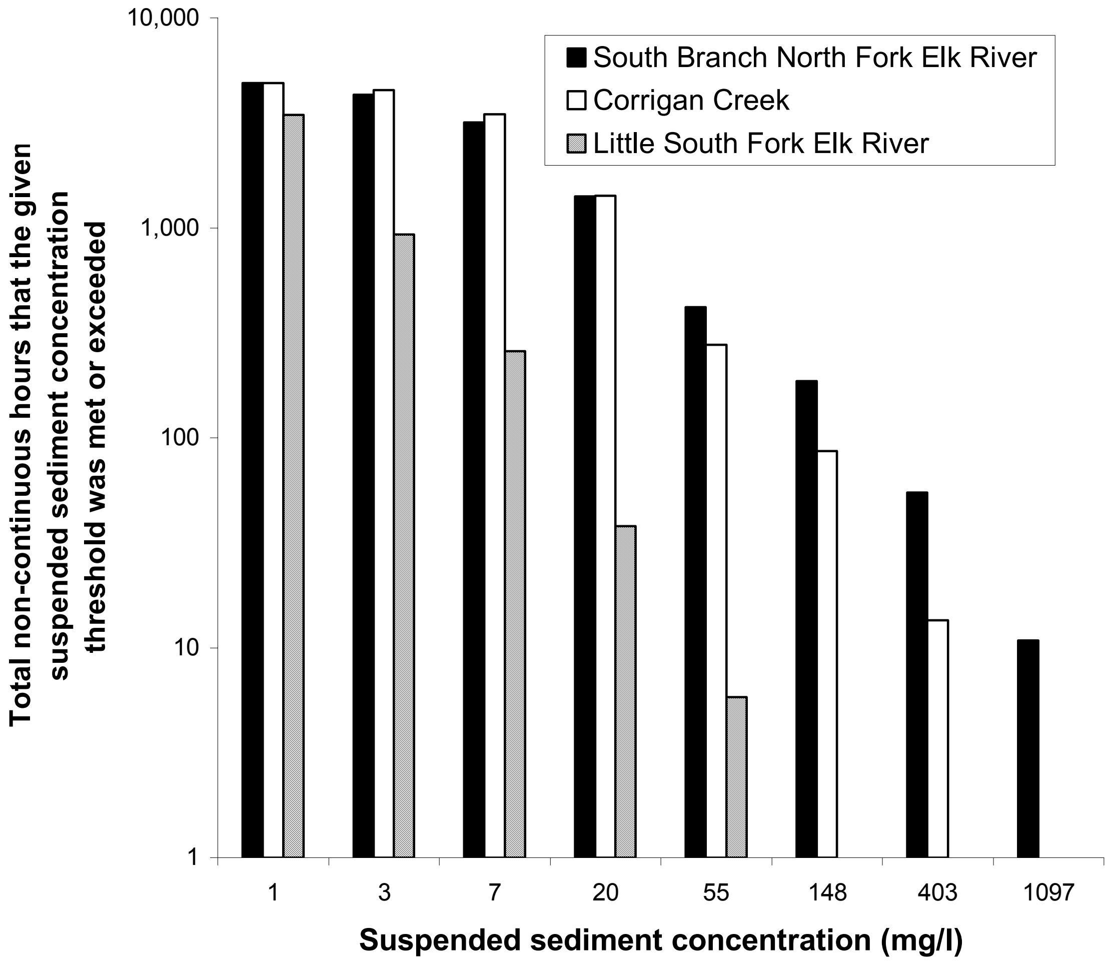

Figure 28. Total non-continuous hours that suspended sediment concentration thresholds were met or exceeded.

Table 6. Scale of the severity (SEV) of ill effects associated with excess suspended sediment. Reproduced from Newcombe and Jensen (1996).

SEV	Description of effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0-20% mortality; increased predation; moderate to severe habitat degradation
11	>20-40% mortality
12	>40-60% mortality
13	>60-80% mortality
14	>80-100% mortality

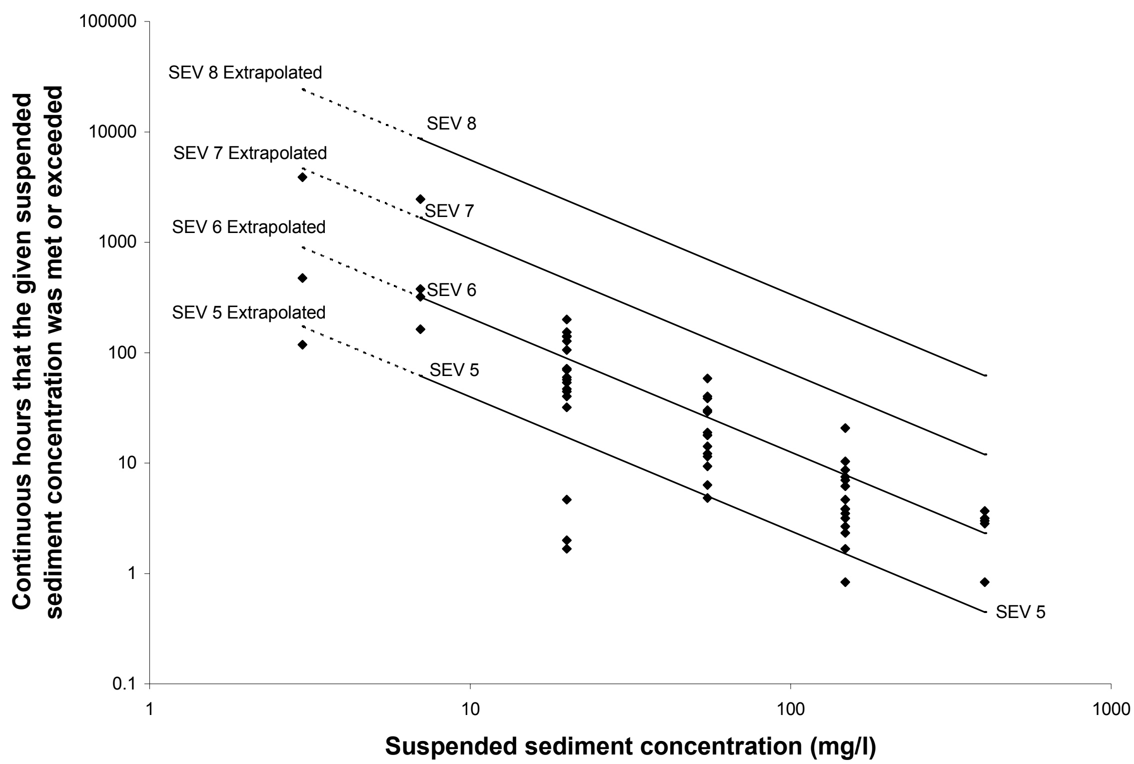

Figure 29. Continuous hours that a given suspended sediment concentration was met or exceeded at Corrigan Creek accompanied by Newcombe and Jensen model 1 severity of ill effects index (SEV) values for juvenile and adult salmonids.

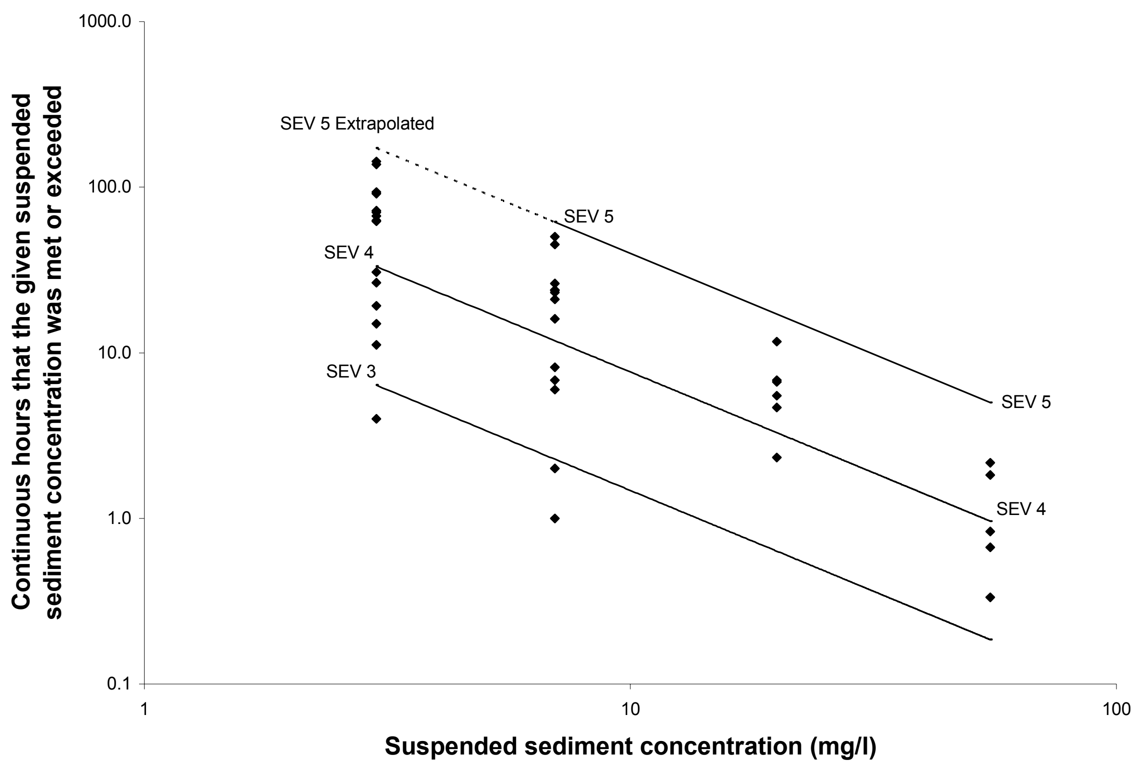

Figure 30. Continuous hours that a given suspended sediment concentration was met or exceeded at Little South Fork Elk River accompanied by Newcombe and Jensen model 1 severity of ill effects index (SEV) values for juvenile and adult salmonids.

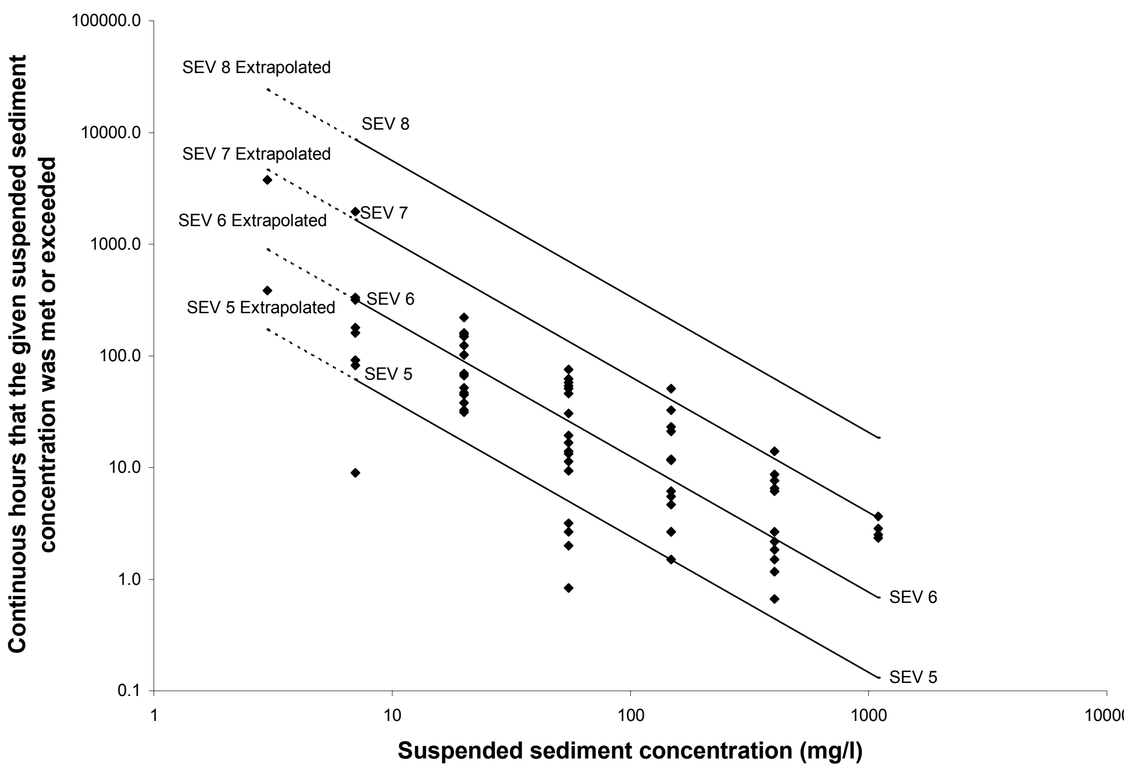

Figure 31. Continuous hours that a given suspended sediment concentration was met or exceeded at South Branch North Fork Elk River accompanied by Newcombe and Jensen model 1 severity of ill effects index (SEV) values for juvenile and adult salmonids.

13, 14). Each point on the plot shows the number of hours that a threshold was met or exceeded during a single occurrence (from when a concentration threshold was exceeded until the concentration fell below the threshold). The SEV values from Newcombe and Jensen (1996) model 1 are included on these figures. Model 1 describes the severity of ill effects experienced by juvenile and adult salmonids in 171 studies or experimental units that were summarized. The sediment thresholds on these plots are the same ones that were used by Newcombe and Jensen (1996). They were chosen because of biological significance and to facilitate logarithmic analysis.

Figures 32, 33, and 34 show the continuous number of hours that particular suspended sediment concentration thresholds were met or exceeded at each of the three sites in relation to the SEV values from Newcombe and Jensen (1996) model 4. Model 4 describes the severity of ill effects experienced by eggs and larvae of salmonids and non-salmonids in 43 studies or experimental units.

Newcombe and Jensen (1996) developed functions to describe SEV throughout a matrix of suspended sediment concentrations and time ranging from 1 mg/L to 162,755 mg/L and from 1 hour to 30 months. Some points in this matrix (especially at low sediment concentrations and extended durations) were not supported by actual physiological studies, but rather extrapolated from other points within the matrix that were supported by experimentation. Figures 29-34 contain dashed lines in areas where the functions have been extrapolated past the range of experimental data and solid lines

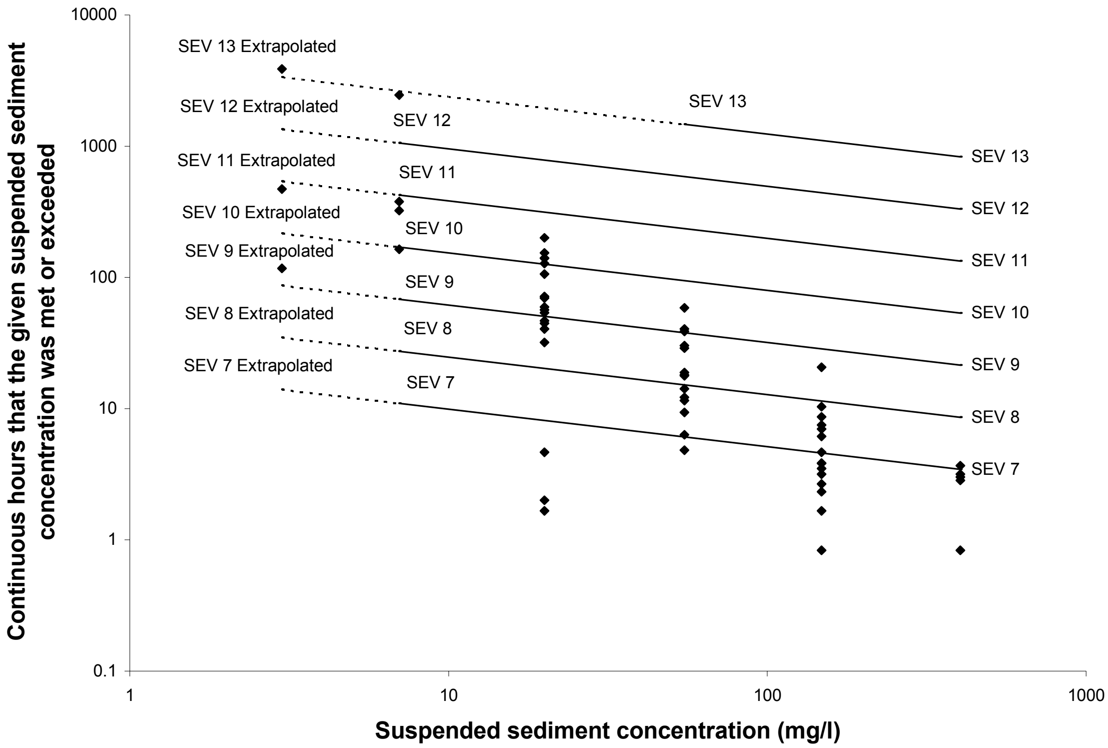

Figure 32. Continuous hours that a given suspended sediment concentration was met or exceeded at Corrigan Creek accompanied by Newcombe and Jensen model 4 severity of ill effects index (SEV) values for eggs and larvae of salmonids and non-salmonids.

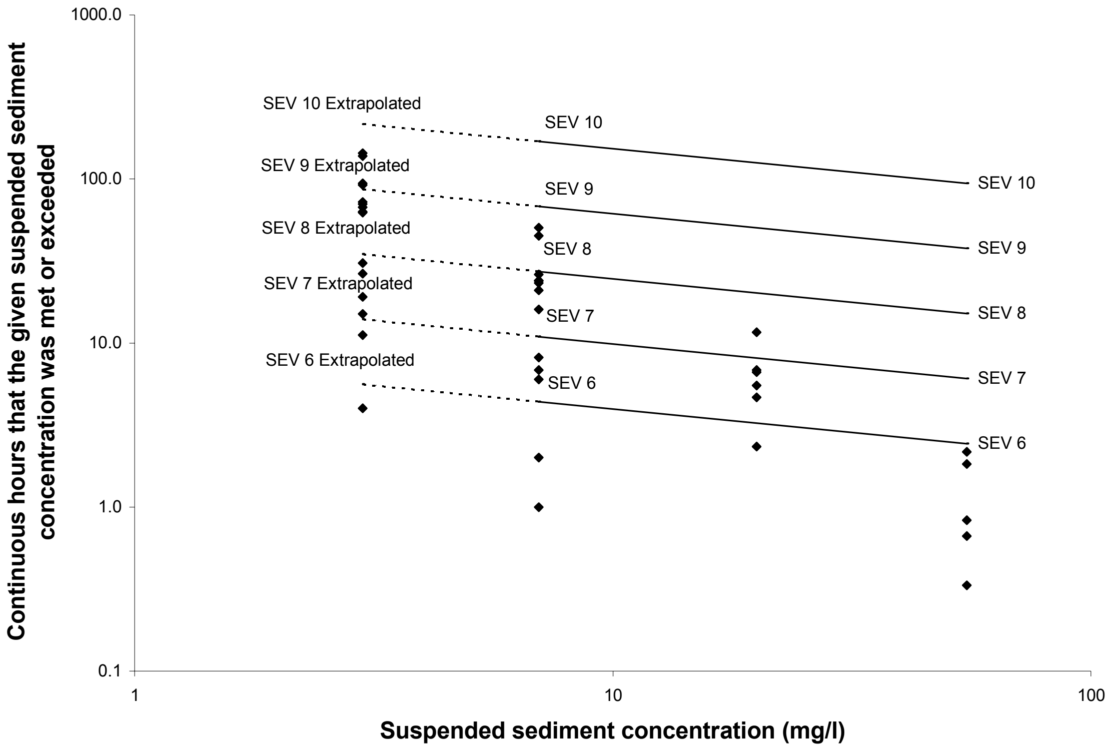

Figure 33. Continuous hours that a given suspended sediment concentration was met or exceeded at Little South Fork Elk River accompanied by Newcombe and Jensen model 4 severity of ill effects index (SEV) values for eggs and larvae of salmonids and non-salmonids.

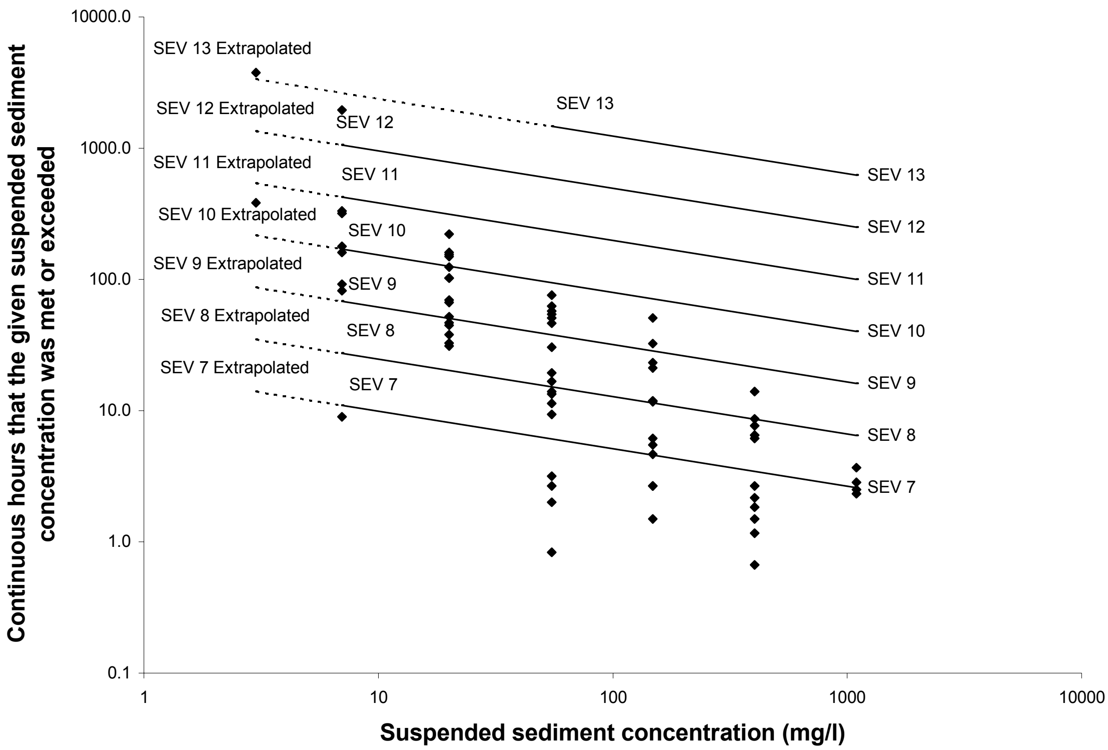

Figure 34. Continuous hours that a given suspended sediment concentration was met or exceeded at South Branch North Fork Elk River accompanied by Newcombe and Jensen model 4 severity of ill effects index (SEV) values for eggs and larvae of salmonids and non-salmonids.

where relationships are based on experimental data. Extrapolated data was not considered when evaluating SEV exceedance in this study.

The suspended sediment doses at South Branch North Fork Elk River and Corrigan Creek exceeded a severity of ill effects index of 6 (moderate physiological stress) and 7 (moderate habitat degradation and impaired homing) for juvenile and adult salmonids (model 1). SEV exceeded 4 (reduced feeding rate and success), but did not exceed 5 (minor physiological stress) at Little South Fork with respect to juvenile and adult salmonids. Egg and larval stages are more sensitive to prolonged exposure to sediment even at relatively low concentrations (Stober 1981). SEV exceeded 12 (>40-60% mortality) at both South Branch North Fork and Corrigan Creek while SEV 8 (indications of major physiological stress, long-term reduction in feeding rate and feeding success) was the highest level exceeded at Little South Fork with respect to egg and larval stages (model 4).

DISCUSSION

Annual versus Individual Storm Regression

When estimating sediment load, using a best fit relationship of the suspended sediment concentration to turbidity for the entire year can produce considerably different results than using one or several unique relationships for each individual storm event. The ability of suspended sediment - turbidity relationship to change for individual storm events (Peart and Walling 1982, Bogen 1992, Lewis 2002) gives strength to the argument that individual storm regression, especially of the largest storm events, is the most accurate way to estimate sediment load. Methods based on annual regression lack the precision inherent in creating unique relationships for individual storm events and even discrete portions of the hydrograph. Use of annual regression ignores the potential shifting of the relationship of suspended sediment concentration to turbidity, or to other continuously measured parameters such as stage, over the course of a season. This could ultimately lead to significant errors in sediment load estimates if such shifts occur.

Figure 19 is a plot of the suspended sediment concentration against turbidity at Little South Fork Elk River for water year 2004. This plot contains the entire annual data set as well as highlighting selected storm events. It is clear that the suspended sediment – turbidity relationship changed over the course of the year, though the progression was not a consistent one. Use of annual regression of this relationship for storm 7 (12/31/03-1/15/04) predicts a lower suspended sediment concentration for a given turbidity than storm-wise linear regression resulting in a 14 percent lower estimate of the storm load than storm-wise regression (Table 4). Annual regression of storm 13 (2/16 – 2/20/04) predicts a higher suspended sediment concentration for a given turbidity resulting in a 45 percent higher estimate of the storm load than storm-wise linear regression. A 45 percent difference in storm load estimates for this storm is important because storm 13 was the largest storm of the season and contributed one third of the total sediment load at Little South Fork Elk River (Figure 26). The sediment load estimated by annual regression for this event is outside the 95 percent confidence interval calculated by storm-wise linear regression (Table 4). This storm also exhibits considerable hysteresis: The suspended sediment – turbidity relationship shifts between the rising and falling limbs of the hydrograph (Knighton 1998). Use of annual regression for storm 17 (5/17-5/30/04) predicts a much lower suspended sediment concentration for a given turbidity than storm-wise regression, resulting in a 74 percent lower storm load estimate than storm-wise regression. This shows that the trend does not consistently increase or decrease at this station throughout the year.

The same plot of the same storms on Corrigan Creek (Figure 18) shows that the patterns observed at Little South Fork were not consistent at all of the sampling locations. One notable difference is that storm 7 (12/31/03 -1/15/04) showed no appreciable hysteresis at Little South Fork, but showed considerable hysteresis at Corrigan Creek. In addition, the suspended sediment concentration values for a given turbidity were lower on the rising limb of the hydrograph than on the falling limb of the hydrograph which is the opposite of the pattern observed during other storms exhibiting hysteresis in this study. Annual regression for storm 13 (2/16 – 2/20/04), the largest storm of the year at Corrigan Creek, estimated a sediment load that was 15 percent lower than that predicted by storm-wise regression. The sediment load estimated by annual regression for this event is outside the 95 percent confidence interval calculated by storm-wise linear regression (Table 4). Annual regression for storm 17 (5/17 – 5/30/04) predicted a higher storm load than the storm-wise regression. This is in direct contrast to the same storm at Little South Fork where storm-wise regression predicted a much higher load than annual regression for that event.

A similar plot at South Branch North Fork (Figure 20) shows no appreciable hysteresis or deviation from the annual regression for linear plots of the aforementioned storm events. There was no data available for storm 17 (5/17 – 5/30/04), so storm 14 (2/25 – 2/28/04) was plotted instead. At South Branch North Fork there was only one storm event (storm 2, 12/10 – 12/31/03) for which the storm load as predicted by annual regression was outside the 95 percent confidence interval calculated by storm-wise regression. Of the eight storms analyzed, there were three such storms at Corrigan Creek and four at Little South Fork (Table 4).

A potential explanation for the relative lack of agreement between individual storm load estimates based on annual regression and storm-wise regression at Corrigan Creek and Little South Fork Elk River is that the type and size of sediment being transported at these sites experiences greater change over time. The sediment sources that are activated by storms can vary with time and runoff intensity. Different sediment sources can vary greatly in the type of material that they contribute and the timing of delivery to the stream system (Knighton 1998). Plots of percent sand in sediment samples against discharge (Figures 21, 22, 23) have larger ranges and greater variability at Little South Fork Elk River and Corrigan Creek than at South Branch North Fork Elk River. Particle size variations can cause turbidity to vary by a factor of four for the same concentration of suspended solids with larger particles tending to have higher turbidity values for a given suspended sediment concentration (Gippel 1995).

The organic component of the suspended sediment load may also have influenced observed differences in the suspended sediment – turbidity relationship. The organic fraction of the sediment load tends to be higher at lower sediment concentrations (Madej 2005) and organic particles tend to have turbidity values two to three times higher than mineral particles for a given mass (Gippel 1995). Since suspended sediment concentrations were much higher at South Branch North Fork, the suspended sediment – turbidity relationship is less likely to be affected by potential variability associated with the presence of organic sediments. Madej (2005) also observed that the organic portion of the suspended sediment load may be larger in stream systems that have lesser degrees of management. This would help to explain the increasing variability in the suspended sediment – turbidity relationship with a decreasing degree of management that was observed in this study. The organic component of the suspended sediment load was not differentiated in this study. Measurement of the organic content of a subset of the sediment samples analyzed would provide valuable information that may explain observed trends, and is strongly recommended for future sampling protocols.

Individual storm regression helps capture the variability in load composition at the three sites and has the potential to generate more accurate sediment load estimates. The use of storm-wise regressions would also be expected to improve the reliability of the severity of ill effects model evaluations.

Sediment Load Composition

Every sediment sample was divided into two size classes; sands (>0.0635mm) and fines (0.0635mm – 0.001mm). This allowed for separate calculations of a sand load and of a fine load, each based on the same number of observations that were used to calculate the total suspended sediment load (Table 5). The percent of the total load contributed by fine material was similar for the two managed watersheds; 90 percent at South Branch North Fork and 87 percent at Corrigan Creek. Only 75 percent of the total load at Little South Fork was comprised of fine material. These results are consistent with other studies that found higher percent fines present in stream channels associated with an increased extent of logging and roads (Cederholm and Reid 1987, Adams and Beschta 1980) and with increased sediment inputs from timber management (Platts et al. 1989).

The percentage of sand in sediment samples was higher at lower stream discharges (a negative correlation) and showed greater variability at lower discharges at all three sampling locations (Figures 21, 22, 23). Little South Fork Elk River had the greatest variability and the highest sand fractions throughout the range of discharges. Rubin and Topping (2001) concluded that a negative correlation between percent sand and discharge is an indication that sediment transport is regulated mainly by the grain-size of the stream bed sediment; a supply limited system. A positive correlation between percent sand and discharge is associated with a flow regulated system. These findings suggest that Little South Fork Elk River is the most limited by sediment supply and that South Branch North Fork Elk River is the least limited by sediment supply of the three stream systems.

Despite having the lowest percentage of the total sediment load move as sand, South Branch North Fork had the highest total sand yield while Little South Fork had the lowest sand yield (Table 5). The total sand yield from a watershed is important because sands are the component of the suspended sediment load that is most likely to settle out of suspension and contribute to the bed material and to morphological response of the stream channel (Knighton 1998). It is useful to ascertain what component of the suspended sediment load does not settle out of suspension (the wash load) and, in the case of Elk River, is ultimately washed out to the ocean. These are typically very fine particles that have very low settling velocities (Knighton 1998). Surveys of the bed material composition of the low gradient reaches of Elk River would provide information about the size distribution of particles that settle out of suspension. This information could then be used to determine what particle size classes observed at the sampling stations have the greatest potential to affect stream morphology.

Sediment and Flow Regime

Most of the sediment load and flow volume at all three sites were transported during short periods of substantially elevated discharges and most of the time flows were low relative to maximum discharge (Figure 26). This is typical of the sediment and flow regimes of many small, forested watersheds (Rice et al. 1979). Total stream discharge per unit area was highest at South Branch North Fork Elk River and lowest at Little South Fork Elk River (Table 2). This is consistent with studies that have documented increased stream discharge following timber harvest (Bosch and Hewlett 1982, Harr 1980). These effects may be caused by decreases in evapotranspiration, infiltration, and interception leading to increased surface flow and water yield following timber harvest and road construction and tend to decrease as time after management increases (Brooks et al. 1987). The onset of storm events and the timing of peak discharges were nearly simultaneous for all three sites (Figure 24). This suggests that there is little spatial and temporal variability in rainfall in the vicinity of the sampled watersheds and that flow routing in the three watersheds has not been drastically altered by management activities.

Elevated Sediment Duration

Estimates of exceedance times at low suspended sediment concentrations (below 10 mg/l) are not as reliable as estimates at higher concentrations because field measurement errors due to minor fouling, nearby objects (e.g. water surface and channel bed), ambient sunlight, scratched optics, and calibration errors all become more important at low turbidities relative to sampling errors (Personal Communication, J. Lewis 2005.

Redwood Sciences Laboratory, 1700 Bayview Drive, Arcata, CA 95521). The SEV model is based on experimental physiological observations and does not provide direct evidence of adverse effects experienced by aquatic species in the three study streams. It is, however, a useful tool in examining how fish may be affected by varying sediment regimes in natural systems.

The SEV models suggest that adult and juvenile salmonids experienced similar degrees of ill effects due to prolonged exposure to relatively low concentrations of suspended sediment compared to shorter durations of exposure to elevated levels of suspended sediment at the Elk River sites during water year 2004 (Figures 29, 30, 31). Egg and larval stages, however, may have experienced higher degrees of ill effects as a result of prolonged exposure to relatively low suspended sediment concentrations in all three streams (Figures 32, 33, 34).

These trends are dependent on the timing, frequency, and magnitude of storm events and their interaction with available sediment sources. Additional data at these sites will provide more specific information about the dynamics of the sediment regime and the potential adverse effects to aquatic species. This, in turn, will allow resource managers to more effectively develop strategies for fisheries restoration and enhancement.

Sediment Yield

The locations of the sampling stations in this study were selected such that the watersheds above the sampling locations were of similar physiography (for details refer to “Study Site”). Despite their physical similarities, the three watersheds produced very different sediment yields. South Branch North Fork transported 20 times as much material per unit area as Little South Fork did and Corrigan Creek transported 10 times as much material as Little South Fork. Sediment production can increase 2 to 50 times after timber harvest and road building occur, but typically recovers to less than 5 times above background after 5 years and to less than twice background after 10 years (Reid 1993, Lewis 1998, Keppeler et al. 2003). If we interpret the sediment yield from the Little South Fork to represent an approximate background level for the given physiographic conditions, then continuation of the observed trends for several years would suggest that there is a delay in the recovery of the other two watersheds from their respective disturbances.

One possible explanation for a delay in recovery is that sediment sources activated by disturbance during management activities continue to contribute sediment to these systems. Sediment sources that have the potential to contribute sediment to these stream systems include mass wasting (landslides and debris flows), stream bank erosion, channel erosion, stream crossing failures, and surface erosion (mostly in the form of runoff from roads and areas compacted by management activities).

Roads have the potential to contribute large amounts of sediment to streams. Roads can contribute 50-80% of sediment that enters streams (Hagans et al. 1986) and the amount of sediment delivered to streams from forests with roads can be 300 times greater than the amount of sediment delivered from undisturbed forests (Morrison 1975).

A common technique used to appreciate the potential for sediment contribution from road systems is to measure the density of roads in a watershed within 200 feet of a stream. Roads in these locations have the greatest potential to contribute sediment to the stream system (Watershed Professionals Network 1999). Figure 35 shows mapped road and stream locations in the three watersheds (Hart - Crowser 2004). An analysis of the watersheds upstream of the sediment sampling sites shows that South Branch North Fork has the highest density of roads per unit area with 4.00 km/km^2. Corrigan Creek has 3.40 km/km^2 and Little South Fork has 0.75 km/km^2 of roads. Corrigan Creek, however, has the highest density of roads within 200 feet of a stream with 1.34 km/km^2. South Branch North Fork has a density of 0.99 km/km^2, and Little South Fork has 0.22 km/km^2 of roads within 200 feet of a stream.

Another useful tool in evaluating the potential for sediment contribution in a watershed is to look at the amount of area in a watershed with a high potential for landslides. SHALSTAB is a program that evaluates the risk for shallow, infinite-slope type landslides based on factors including slope angle, drainage area, and convergence of water (Dietrich et al. 1995). SHALSTAB modeling suggests that Corrigan Creek has the highest potential for these types of landslides; 32 percent of the area within the watershed of the sampling station is classified as unstable. In the South Branch North Fork and Little South Fork watersheds, 22 percent and 13 percent of the areas respectively, were classified as unstable.

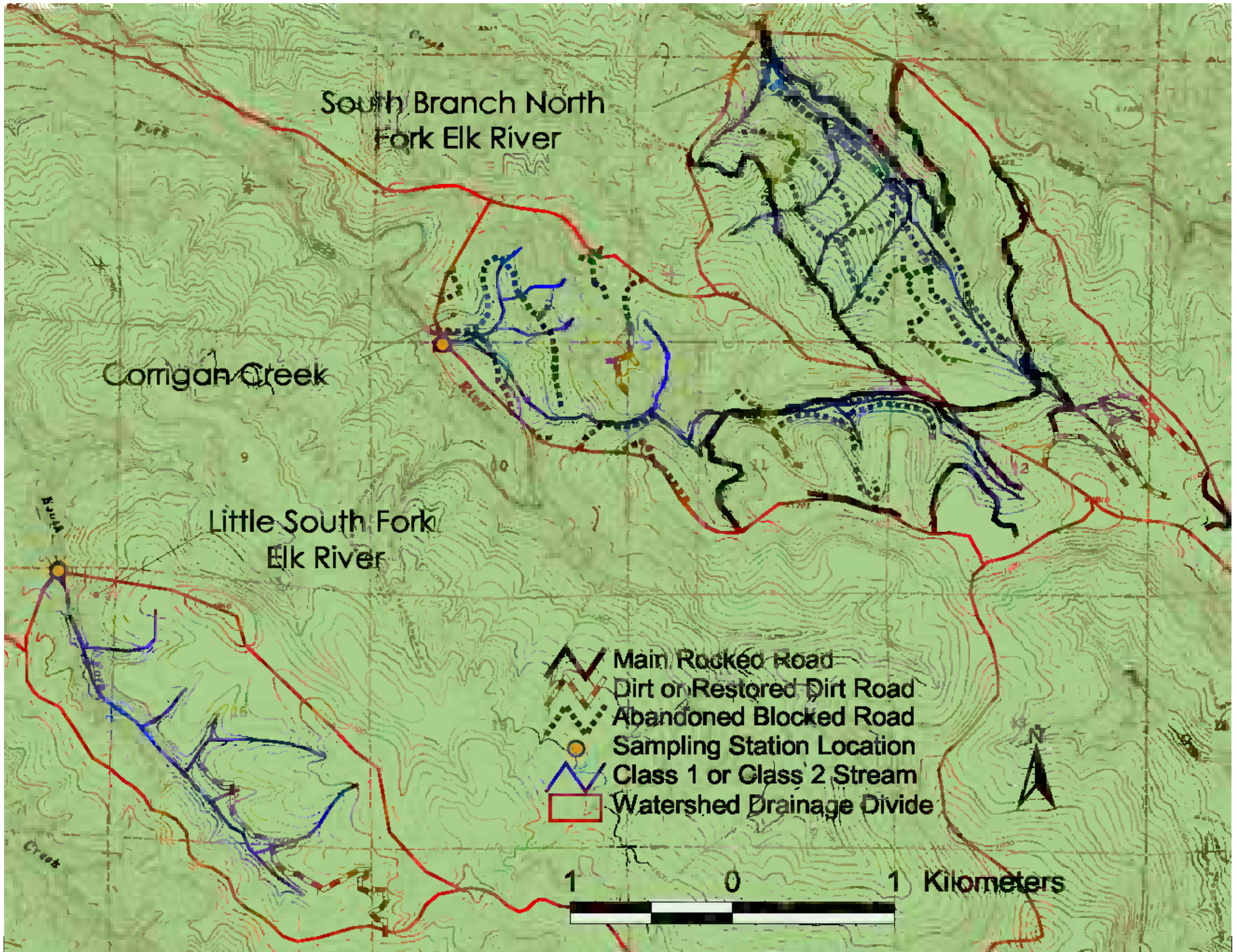

Figure 35. Mapped road locations in the Corrigan Creek, Little South Fork Elk River, and South Branch North Fork Elk River watersheds.

Trends in the SHALSTAB predictions rank the watersheds consistently with a mapping of actual shallow landslides conducted by Pacific Watershed Associates (Hart - Crowser 2004). Their landslide map shows 32 landslides in the Corrigan Creek watershed, of which 23 were classified as delivering sediment to the stream system. The South Branch North Fork watershed contains 12 mapped landslides with 7 delivering sediment to streams, and Little South Fork has 6 mapped landslides with 5 delivering sediment to streams.

The potential for shallow landslide activity, the actual number of shallow landslides contributing sediment to the stream system, and the amount of roads near streams all suggest that Corrigan Creek should have the highest sediment yield of the three sampled watersheds. The fact that the sediment yield at South Branch North Fork was double that at Corrigan Creek suggests that other sediment generating mechanisms are more important in determining sediment yield in these systems than roads near streams or shallow landslides.

Stream crossings can contain large amounts of stored material in locations that are directly connected stream channels. A single stream crossing can contain hundreds of cubic yards of sediment. Poorly designed, undersized, or unmaintained stream crossings are prone to failure during large runoff events potentially resulting in direct delivery of large volumes of sediment to streams (Weaver and Hagans 1994). Analysis of the available road maps (Hart – Crowser 2004) shows that the South Branch North Fork Elk River watershed has 16 stream crossings whereas the Corrigan Creek watershed has only

8 stream crossings. Little South Fork Elk River had 3 stream crossings, but these were decommissioned and all associated fill material was removed in 2003 eliminating the potential for large-scale, future sediment inputs from these areas.

Information about the size and condition of the shallow landslides, stream crossings, and roads near streams was unavailable and not examined. This information could provide insight into how these factors contribute to the observed sediment yields. Other sediment generating sources such as deep seated landslides, channel erosion, stream bank erosion, and surface runoff from compacted areas other than roads could also be contributing substantial amounts of sediment and should be evaluated. A field inventory of the size and contribution of actual sediment sources is the most effective way to gain an understanding of what sources are contributing large amounts of sediment to the stream system. With such information, one can more effectively create a strategy for mitigating sediment inputs and restoring watershed processes.

CONCLUSION

This study has shown that sediment yields from watersheds of similar size and physiography can vary widely. Management of these watersheds likely plays a large role in influencing these yields. Even after more than a decade since the most recent management activities, annual sediment yields varied by as much as a factor of 20.

Sediment yield data for the three streams from water year 2004 establishes points of reference against which recovery from management and response to future management activities can be evaluated. Though the sample period was average in terms of total rainfall, several years of additional data will be needed to observe how the sediment flux in these watersheds responds to annual climatic variations. Large annual variations in sediment yield for individual stream systems have been documented (Van Sickle 1981) and show the need for gathering multiple years of data in order to represent accurate long term averages.

Ultimately, it will be important to compare the sediment flux in these watersheds with other watersheds of varying size, physiography, and land-use history. Such an analysis would help to clarify how these factors interact to influence the dynamics of sediment storage and movement. This will provide land managers with an important understanding of watershed processes that is needed to make well informed policy and management decisions.

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DESIGNING FOREST ROADS TO MINIMIZE TURBID RUNOFF DURING WET WEATHER USE

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Abstract. Wet weather use on forest roads can be a significant source of turbidity and fine sediment in streams that in turn may be detrimental to aquatic organisms including salmonids. Regulations governing traffic use during wet weather in the Pacific Northwest have become increasingly restrictive with water quality in mind. Current methods of design for forest roads do not consider the environmental performance of roads and little research has been conducted on design methods to minimize sediment production from forest roads.

This research evaluates the environmental benefits of upgrading forest roads for use during wet weather. Alternative treatments for unbound aggregate pavement were developed with the goal of minimizing turbid runoff during wet weather use. Treatments were constructed on an active haul road in northern California. Sediment production from these pavement treatments with truck traffic and simulated rainfall was compared with a standard design of unbound aggregate pavement for forest roads.

Suspended sediment concentration was lower from pavement treatments that did not develop ruts in the wheel paths. These treatments were also more efficient in directing surface runoff off the road. Rut formation appeared to be a function of aggregate depth. After approximately 300 loaded truck passes, the aggregate pavement was still intact and pumping of the subgrade did not occur.

Knowledge of the environmental performance of these alternative designs for aggregate surfacing on forest roads gives road managers more flexibility to decide on a course of action to minimize the environmental effects of forest roads.

Keywords. Water quality, sediment, forest roads, road runoff, suspended sediment concentration

INTRODUCTION

Forest roads in the Pacific Northwest states are often constructed with a layer of unbound aggregate over a subgrade of native soil. Roads are hydrologically connected to streams through roadside ditches, gullies, and stream crossings (Wemple, 1994). Wet weather use on forest roads can be a significant source of turbidity and fine sediment in streams that in turn may be detrimental to aquatic organisms including salmonids. Regulations governing the traffic use of forest roads during wet weather have become increasingly restrictive to protect water quality. As a result, road managers are interested in ways to reduce the production of sediment from forest roads.

Researchers have shown that the characteristics of road segments and traffic can influence the volume of sediment generated by and available to runoff from unbound aggregate roads. Luce and Black (1999) found that sediment production from the surface of a forest road was a function of the length and slope of the road segment. Bilby *et al.* (1989) determined that the depth and type of the aggregate surfacing affected the sediment yield from a forest road where less sediment was produced from roads with a thicker aggregate layer. A study in the Pacific Northwest found that a road segment that was heavily used by haul trucks (more than four loaded trucks per day) contributed 130 times as much sediment as an abandoned road (Reid and Dunne, 1984). Burroughs et al. (1984) determined that a road with ruts in the wheel paths produced twice the sediment as a smooth road.

Forest roads may produce sediment from three different processes. Fine sediment is available in the surface aggregate at construction, especially for well-graded aggregate. Fine sediment is produced from the degradation of the surface aggregate during traffic. Finally, fine sediment is available in the subgrade and is described to "pump" through the aggregate layer with repeated loading during wet conditions (Koerner, 1998). No research has been conducted to determine the origin of fine sediments in road runoff, however it is commonly assumed that pumping of the subgrade material is a major source.

Current methods of design for unbound aggregate roads do not consider environmental performance but design for load support. Road managers who upgrade the standard road design for use in wet weather do not know the true environmental benefits of their efforts. The objective of this research was to evaluate the environmental benefits, in terms of sediment production, of upgrading forest roads for use during wet weather. Emphasis was placed on minimizing fines from the subgrade as a source of sediment.

METHODS

Two designs for unbound aggregate pavement for forest roads, including one developed by the authors based on theories from soil mechanics, were installed on a new road near Arcata, California. The goal of the road designs was to minimize turbid runoff during wet weather hauling. Sediment production from the different treatments caused by log truck traffic during simulated rainfall was compared to a standard design (control) of unbound aggregate pavement for forest roads.

The experimental road was located on Green Diamond Resource Company property in northern California. The average precipitation for this area is 150 cm (58 in) a year, occurring predominately as rainfall between October and April. A forest road was constructed in September 2005 for extracting timber during the coming winter. A 90 m (300 ft) section of the road that had a consistent gradient of 8 percent was used for this study. The road was constructed with an outsloped cross-section and an inboard ditch to allow hillslope runoff to bypass the section of experimental road.

The design of the aggregate pavement for the control segments consisted of 20 cm (8 in) of open-graded, aggregate as a base and a cap of 5 cm (2 in) of well-graded, crushed aggregate with a diameter up to 3.8 cm (1.5 in). Two alternative treatments were designed for the aggregate pavement to minimize the pumping of sediment from the subgrade. The design for the first treatment was the same as the design for the control but a geotextile was placed between the subgrade and aggregate for separation. The design of the second treatment was similar to the design of the control but with a greater depth of base aggregate. The depth of base aggregate was determined to minimize bearing capacity failures at the subgrade/aggregate interface. Thus, the depth of the base aggregate was determined based on local soil strength and traffic.

There were two sections of the control and the design with the geotextile and one section with the added depth of base aggregate. These treatments were randomly assigned to an 18 m (60 ft) road segment within the 90 m (300 ft) of the experimental section of road. The treatments were separated with a flexible water bar constructed from conveyor belting (Figure 1).

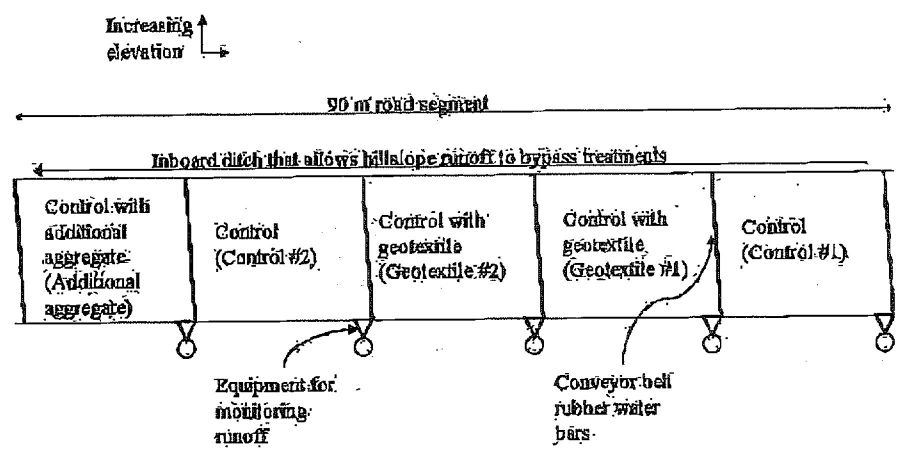

Figure 1. Schematic of the experimental road segment with five treatment plots.

A sprinkler system that was connected to a water truck was laid out along the hillslope side. A rainfall rate of 1.2 cm/hr (0.46 in/hr) was applied to the road surface. Runoff from the road collected at the water bars and samples were collected with ISCO automatic water samplers (Teledyne Technologies). Log trucks drove over the experimental section of road when they came to the harvest unit (unloaded) and then left the harvest unit (loaded). The number of trips of the loaded log trucks were counted until logging in the harvest unit was completed (Figure 2).

Sediment production from the different treatments was measured at the beginning of the logging when truck traffic commenced and again at the end of the logging when truck traffic was completed. Water samples were analyzed for turbidity and suspended sediment concentration (SSC). Suspended sediment concentration from the different treatments was compared to SSC from the control. At the end of hauling, the road surface was surveyed and a trench was dug through each of the treatments and into the subgrade to determine the depth and condition of the surface aggregate.

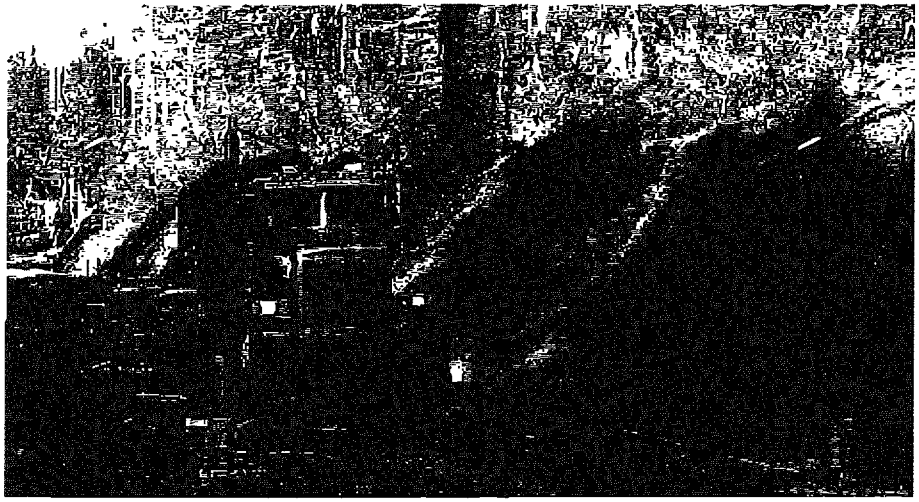

Figure 2. Loaded log truck traveling over the experimental road segment during simulated rainfall.

RESULTS AND DISCUSSION

The road was constructed with locally available aggregate. The base aggregate was open-graded with a diameter up to 8 cm (3 inch) and had very little fines. The cap material was crushed aggregate with 35 percent passing the 4.75 mm sieve. The geotextile used in the two geotextile treatments was woven with a weight of 136 g/m^2 (4 oz/yd^2). The depth of the base aggregate for the treatment with additional aggregate was 40 cm (16 in), exactly twice the depth of the aggregate in the control and geotextile treatments.

Suspended sediment in the runoff from the road surface was sampled after 145 trips by loaded log trucks in February of 2006 and again after 276 trips by loaded log trucks in April of 2006. The road surface was mapped and trenches were dug through each of the treatment segments in July of 2006 after 292 trips by loaded log trucks.

The precipitation delivered by the sprinkler system was sufficient to produce runoff. However, with the open-graded aggregate for the base layer, much of the precipitation infiltrated into and percolated through the aggregate and drained off the road at the surface of the subgrade. Surface runoff was produced mainly in the wheel tracks and it ran down the road to the water bars where it was sampled for 1.5 hours at four minute intervals during both of the sampling periods.

Seven passes of a loaded log truck occurred during the sampling periods and were included in the analysis. Truck passes were clearly identifiable in graphs of SSC over time. A peak value of SSC occurred immediately after a truck passed and then SSC returning to pre-pass values within 20 minutes. A graph of SSC versus time for the five treatments during two passes of a loaded truck is shown in Figure 3.

The peak values of SSC for each treatment during the seven passes of the loaded log truck were compared. The mean of the peak values of SSC from the treatments was significantly different after accounting for differences in truck passes ($p<0.001$ from an ANOVA test). The two geotextile treatments and the first control treatment had consistently higher values of SSC with truck passes than the second control and the treatment with additional base aggregate.

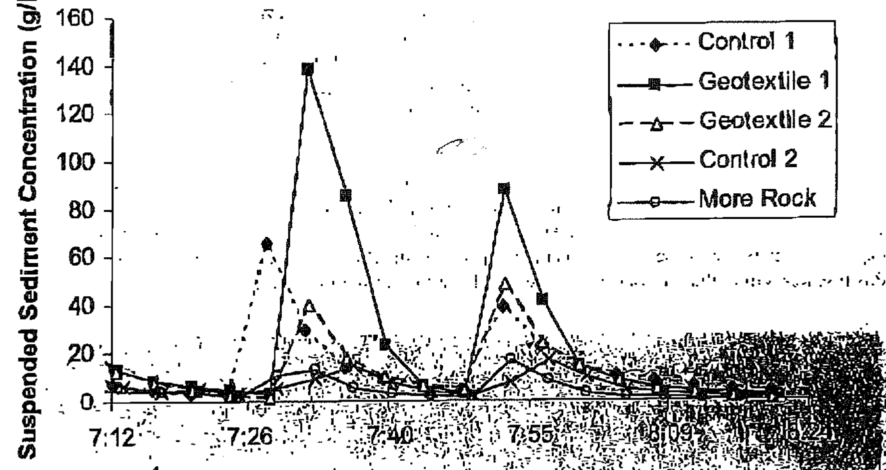

Figure 3. Suspended sediment concentration with time for the five treatment plots during the April of 2006 sampling period.

Ruts developed in the wheel paths with time and total traffic. Substantial ruts were observed in the geotextile treatments and in the first control treatment. These are the same treatments that produced the highest values of SSC with truck passes. When hauling ended on the road, ruts in the wheel paths of these treatments were as deep as 6.4 cm (2.5 in). Overall, the pavement treatments that held their shape produced lower values of SSC than the pavement treatments that developed ruts.

The geotextile treatments were particularly prone to rutting. This is possibly due to the failure with loading of the open graded rock on top of the geotextile. Because there was little fine material available in the base aggregate as placed, the aggregate in the pavement structure was not able to lock together into a stable structure well. Also, the geotextile prevented the aggregate from being pushed into the subgrade material and held in place.

As ruts developed, more runoff was directed down the road in the wheel paths. The pavement treatments that did not develop ruts efficiently directed surface runoff off the road and little runoff collected at the water bars. The total sediment production from the second control and the treatment with additional aggregate depth was not measured because these pavement treatments did not deliver surface runoff to a single location. This characteristic is ideal for a road surface to minimize sediment yield when surface runoff occurs.

Although the subgrade was outsloped, the surface aggregate developed a crowned cross-section with traffic. Upon further inspection at the end of hauling it was clear that the aggregate depth varied across each pavement treatment and the hillslope side of the road had increased aggregate depth. One of the geotextile treatments had an aggregate depth of 13 cm (5 in) on the hillslope side of the road and 27 cm (11 in) on the fillslope side (Figure 4). Final grading or construction of the aggregate pavement was not carried out for an outsloped cross-section and this created the differences in aggregate depth across the pavement treatments.

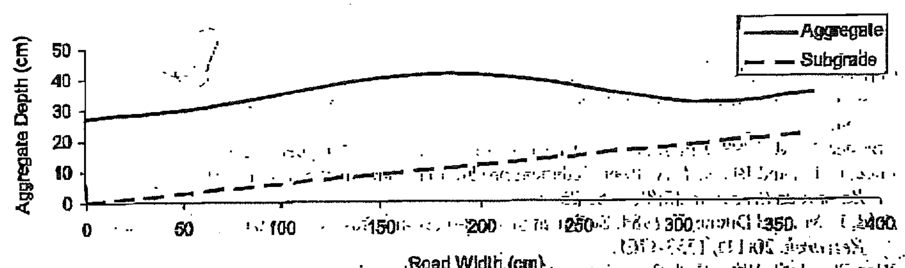

Figure 4. Sketch of a trench dug across the first geotextile treatment that shows the depth of aggregate above

The difference in aggregate depth across the treatments may have affected rutting, however, ruts developed in both wheel paths indicating that even the wheel paths on the fillslope side of the road did not have sufficient aggregate to prevent rutting. It is hypothesized that the second control treatment had more aggregate than called for to transition to the neighboring treatment that had twice the base aggregate. A trench dug across this treatment showed aggregate depths similar to the first control treatment, however, the trench was located closer to the geotextile treatment (upslope) than the additional aggregate treatment.

Trenches dug across the treatments revealed a clear boundary at all treatments between the aggregate and the subgrade (Figure 5). There was no evidence of pumping of the subgrade. Suspended sediment that was measured in the road runoff was thought to originate from fines that existed in the aggregate as placed. This suggests there is a fine line between too much and too little available fine material in the capping aggregate. Fines are needed for adequate compaction, stabilization, and for a smooth running surface but this research shows that this material is also available for transport from the road.

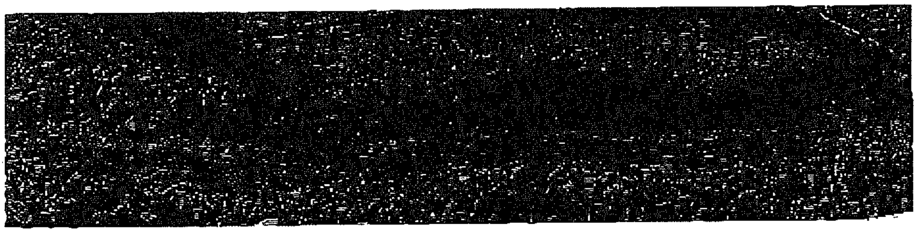

Figure 5. A trench across a geotextile treatment that shows a cross-section with significant rutting and differences in aggregate depth. The hillslope side of the road is on the left and fillslope side is on the right.

CONCLUSIONS

The pavement treatments that held their shape produced less sediment. Aggregate depth was an important factor in sediment production. The treatment with greater depth of aggregate did not develop significant ruts. Road managers that want to minimize the production and delivery of sediment from forest roads should design the aggregate surface to resist rutting.

Over a sampling period of one wet season and 292 passes with loaded log trucks, pumping of the subgrade material did not occur. This suggests that the gradation of the surface aggregate plays an important role in the production of fines from the road surface. Fines that were measured in the runoff originated from the surface aggregate.

Acknowledgements. This research could not have occurred without the support of John Plantin and the California Timberlands Division of Green Diamond Resource Company. John Davis and Joel Rink, also of Green Diamond, were instrumental in getting the field work completed and were always pleasant to work with. The authors wish to thank Amy Simmons, Dennis Feeney, Tim Royer, and Mary Pyles for help and guidance in the field and Joanna Warren, Liz Harper, and Chantal Goldberg for their patience with the tedious laboratory work.

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Watershed Management to Meet Water Quality Standards and TMDLS (Total Maximum Daily Load)

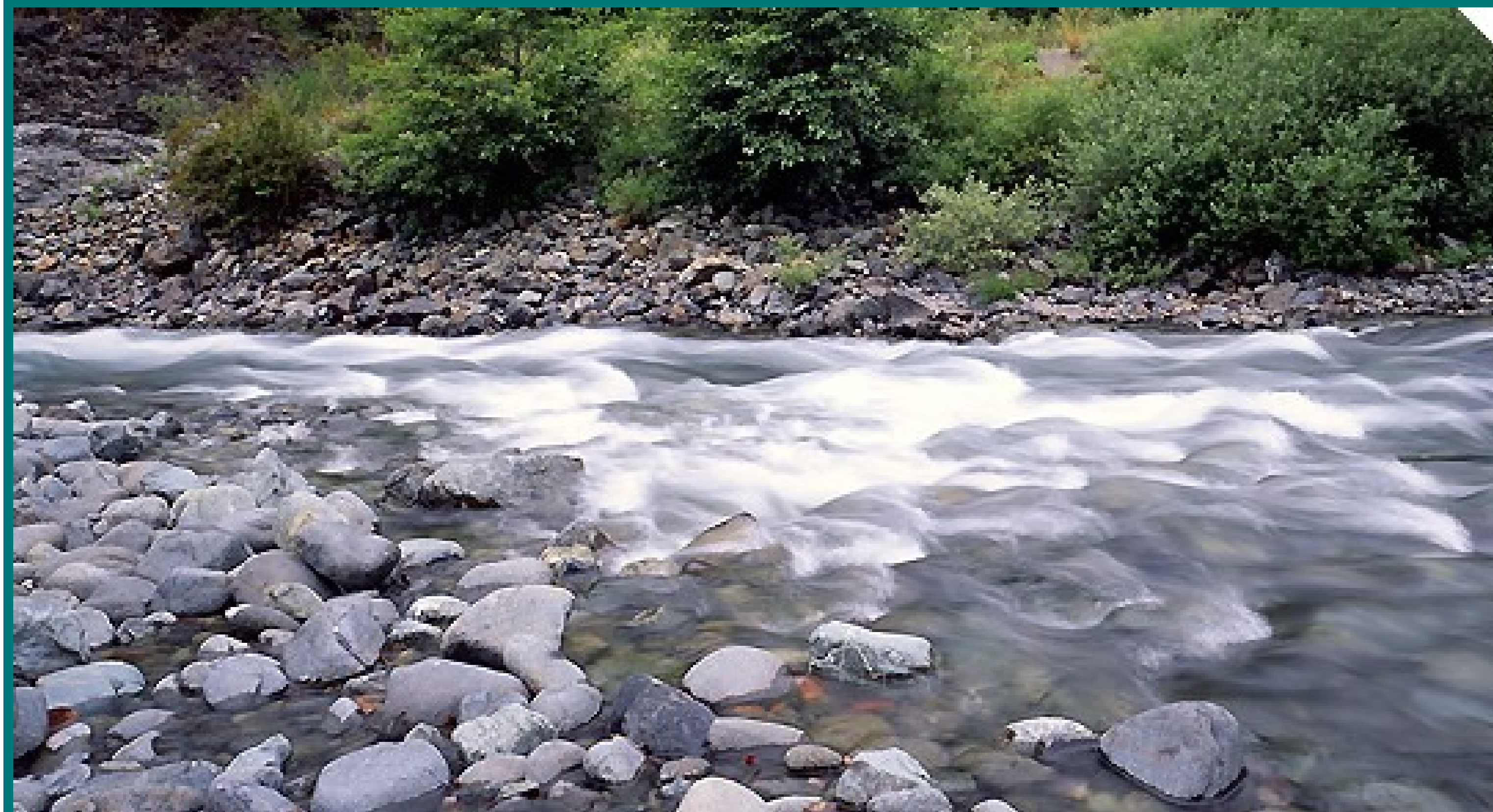
Proceedings of the
10 - 14 March 2007 Conference
Crowne Plaza Riverwalk
San Antonio, Texas

Cover photos are courtesy of USDA NRCS

Published by

American Society of Agricultural and
Biological Engineers
2950 Niles Road, St. Joseph, Michigan 49086-9659 USA

USDA Forest Service
Pacific Southwest Region



Best Management Practices Evaluation Program

1992-2002 Monitoring Results

November 2004

EXECUTIVE SUMMARY

The United States Forest Service (USFS), Pacific Southwest Region (Region 5) initiated its Best Management Practices Evaluation Program (BMPEP) in 1992. This program fulfills monitoring commitments to the State Water Resources Control Board (SWRCB) and facilitates adaptive management by assessing and documenting the efficacy of the USFS water quality management program. The BMPEP employs 29 different onsite (activity-level) monitoring procedures to evaluate the implementation and effectiveness of BMPs for a variety of activities in seven different program areas: timber, engineering, recreation, grazing, mining, prescribed fire, and vegetation management.

Since the BMPEP's inception, over 5,000 onsite evaluations have been conducted on the 18 national forests in California. Results from over 3,000 of these evaluations performed at randomly selected sites from 1992 through 2002 were analyzed to assess the performance of the USFS Region 5 water quality management program. Results indicate that while some improvements are necessary, the program performed reasonably well during that period of time. BMP implementation and effectiveness were relatively high for most activities and elevated effects on water quality and beneficial uses of water were relatively infrequent, particularly in recent years. In addition, both the BMPs and the BMPEP have been expanded and improved since monitoring results were last reported in 1998.

Key findings of the analysis include the following:

- From 1992 through 2002, an average of 357 random evaluations were conducted annually throughout the Region. This ranged from a high of 599 sites in 1996 to a low of 109 sites in 2000. Monitoring rebounded steadily to 301 and 425 sites in 2001 and 2002, respectively.
- A statistically significant relationship between BMP implementation and effectiveness was found for 16 of the 29 monitoring protocols ($p<0.10$). This demonstrates that for the activities evaluated by these 16 protocols, those with adequate BMP implementation are more likely to meet onsite water quality protection objectives than those without BMPs. The size or distribution of results was not adequate to demonstrate statistically significant relationships for the other 13 protocols. Ongoing database work will allow for eventual analysis of additional data, which will likely increase the number of evaluations with demonstrated associations.
- BMP Implementation
  - For all activities combined, BMPs were implemented at 85% of observation sites during the 1992-2002 monitoring period. Implementation rates from 1997 through 2002 were similar to those from 1992 through 1996.
  - From 1992 through 2002, BMP implementation rates were 87% for timber, 85% for engineering, 68% for recreation, 77% for prescribed fire, and 87% for vegetation management. Only qualitative results were available for grazing and mining.
  - Quantitative implementation rates were available for 24 of 29 protocols. Implementation rates for these varied between 50% and 100%. Rates were 90% or greater for nine of the 24 evaluations, 85% or greater for 14 of them, and 80% or greater for all but six evaluations. Only two evaluations had implementation rates less than 75%.
  - Between the first and second half of the 1992-2002 monitoring period, implementation rates increased by 5% or more for six of the 24 protocols for which quantitative data were available. Decreases of 5% or more occurred for five evaluations.
  - BMP implementation rates for individual forests ranged from 60% to 96%. Implementation was 80% or greater on 14 of 18 forests and 75% or greater on all but one Forest.

- BMP Effectiveness
  - From 1992 through 2002, BMPs for all activities combined were effective at 92% of the sites at which they were implemented. These rates were similar between the 1992-1996 and 1997-2002 monitoring periods.
  - BMPs were effective 94% of the time for timber, 89% for engineering, 89% for recreation, 98% for prescribed fire, and 89% for vegetation management. Only qualitative results were available for grazing and mining.
  - During the 11-year monitoring period, BMP effectiveness rates for individual evaluations ranged from 69% to 100%. These rates were 90% or greater for 15 of 24 evaluations with quantitative data and 85% or greater for all but three of them. Only one protocol had effectiveness rates less than 80%.
  - Effectiveness rates associated with two protocols increased by 5% or more between the first and second half of the 1992-2002 monitoring period. Decreases of more than 5% occurred for three evaluations.
  - BMP effectiveness rates on individual forests varied between 82% and 99%. Thirteen of 18 forests had rates of 90% or greater.

- When effectiveness problems were evident at project sites, field observers evaluated and commented on probable effects to beneficial uses of water. Observers' comments were used to classify likely effects with respect to their magnitude, extent, and duration and to establish an overall effects ranking. For all activities combined, water quality effects were classified as elevated at 78 (2%) of the sites monitored from 1992 through 2002. Most of these were related to engineering practices (46, <3% of engineering sites). Roads and in particular, stream crossings, were the most problematic. Twenty were associated with timber practices (<2%) and four (2%) occurred at recreation sites. Five (<4%) were related to grazing, one (<1%) resulted from a prescribed fire, one (<1%) was observed at a mining site, and one (<1%) was associated with vegetation management. The number of elevated effects observed between the first and second half of the 1992-2002 monitoring period was relatively similar for all practices, except those associated with road stream crossings. There were substantially more crossings with effects ranked as elevated during the second half of the 1992-2002 monitoring period than the first. This was primarily due an increased number of failures associated with the significant storms of 1997.

- Effects classified as elevated were typically caused by lack of or inadequate BMP implementation. Nonetheless, elevated effects occurred at some sites despite implementation of BMPs. These occurrences were infrequent and typically due to large storm events and/or especially sensitive site conditions.

- To facilitate adaptive management, monitoring results were used to identify and prioritize 25 issues and associated corrective actions. Nine of these relate to overall program management, including training, completion of revision to monitoring protocols, and consistent monitoring, analysis, and reporting. Three issues pertain to timber management, specifically streamside management zones, skid trails, and landings. Six issues were associated with engineering practices, including water source development, in-channel construction, snow removal, restoration of borrow pits and quarries, stream crossings, and road surfacing, drainage, and slope protection. The final seven issues involve recreation, grazing, mining, and prescribed fire, where an increased focus on BMP implementation is necessary.

- The USFS has implemented several other monitoring programs, including instream monitoring, to complement the BMPEP onsite evaluations. Together, these programs address a range of monitoring issues including project-level implementation and effectiveness of BMPs, validation of BMP effectiveness, compliance with regulatory standards, assessment of status and trends in water quality and aquatic resources, and evaluation of cumulative watershed effects (CWE).

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1. INTRODUCTION

This report summarizes the results of the United States Forest Service (USFS), Pacific Southwest Region (Region 5), Best Management Practices Evaluation Program (BMPEP) from 1992 through 2002. The objectives of the BMPEP are to: 1) fulfill USFS monitoring commitments to the State Water Resources Control Board (SWRCB), as described in the SWRCB/USFS Management Agency Agreement (SWRCB/USFS 1981) and *Water Quality Management for National Forest System Lands in California (USFS 2000)*; and 2) facilitate adaptive management by assessing and documenting the efficacy of the USFS water quality management program, specifically the implementation and effectiveness of Best Management Practices (BMPs).

Onsite Evaluations are the foundation of the BMPEP and are therefore the focus of this report. Results of these evaluations are described in Section 2. The USFS has also implemented several other monitoring programs, including stream monitoring, to compliment the Onsite Evaluations. These are described in Section 3. Together, these programs address a range of monitoring issues including project-level implementation and effectiveness of BMPs, validation of BMP effectiveness, compliance with regulatory standards, assessment of status and trends in water quality and aquatic resources, and development and validation of cumulative watershed effects (CWE) models.

2. ONSITE EVALUATIONS

2.1. Objectives and Methods

Onsite Evaluations are used to assess BMP *implementation* and *effectiveness*. Implementation evaluations determine the degree to which planned, prescribed, or required water quality protection measures were actually put in place on project sites. Effectiveness evaluations gauge the extent to which these practices met their onsite water quality protection objectives.

Twenty-nine Onsite Evaluation protocols are used to assess the implementation and effectiveness of individual BMPs or groups of closely related BMPs. Table 1 identifies each of these protocols and the corresponding BMPs they are designed to evaluate. Additional details regarding the BMPs and BMP evaluation protocols can be found in *Water Quality Management for National Forest System Lands in California (USFS 2000)* and *Investigating Water Quality in the Pacific Southwest Region, Best Management Practices Evaluation Program User's Guide (USFS 2002).*

Onsite Evaluation protocols are applied at both randomly and non-randomly selected project sites. The number of random evaluations to be completed each year are assigned to each National Forest by the Regional Office based on: 1) the relative importance of the BMP in protecting water quality in the Region; 2) those management activities most common on individual forests (e.g., grazing is emphasized on the Modoc National Forest, recreation is emphasized on the Angeles National Forest); and (3) identified problems with specific practices. Forests supplement these randomly

.TABLE 1: BMPEP Onsite Evaluation Protocols and associated BMPs

BMPEP Onsite Evaluation Protocol[1]	BMPs Evaluated[2]
T01: Streamside Management Zones (SMZs)	▪ SMZ Designation (1-8) ▪ Streamcourse and Aquatic Protection (1-19) ▪ Slash Treatment in Sensitive Areas (1-22)
T02: Skid Trails	▪ Tractor Skidding Design (1-10) ▪ 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) ▪ Log Landing Erosion Control (1-16)
T05: Timber Sale Administration	▪ Erosion Prevention & Control Measures During Timber Sale Operations (1-13) ▪ Erosion Control Structure Maintenance (1-20) ▪ Acceptance of Timber Sale Erosion Control Measures Before Sale Closure (1-21) ▪ Modification of Timber Sale Contract (1-25)
T06: Special Erosion Control & Revegetation	▪ Special Erosion Prevention Measures on Disturbed Land (1-14) ▪ Revegetation of Areas Disturbed by Harvest Activities (1-15)
T07: Meadow Protection	▪ Meadow Protection During Timber Harvesting (1-18) ▪ Slash Treatment in Sensitive Areas (1-22) ▪ Tractor Operation Limitation in Wetlands and Meadows (5-3)
E08: Road Surface, Drainage & Slope Protection	▪ Erosion Control Plan (2-2) ▪ Stabilization of Road Slope Surfaces and Spoil Disposal Areas (2-4) ▪ Road Slope Stabilization Construction Practices (2-5) ▪ Control of Drainage (2-7) ▪ Construction of Stable Embankments (2-10) ▪ Maintenance of Roads (2-22) ▪ Road Surface Treatments to Prevent Loss of Materials (2-23)
E09: Stream Crossings	▪ General Guidelines for Location and Design of Roads (2-1) ▪ Stabilization of Road Slope Surfaces and Spoil Disposal Areas (2-4) ▪ Road Slope Stabilization Construction Practices (2-5) ▪ Control of Road Drainage (2-7) ▪ Construction of Stable Embankments (fills) (2-10) ▪ 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) ▪ Diversion of Flows Around Construction Sites (2-15) ▪ Bridge and Culvert Installation (2-17)
E14: Temporary Roads	▪ Stream Crossings on Temporary Roads (2-16) ▪ 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) ▪ Constraints Related to Pioneer Road Construction (2-8) ▪ Timely Erosion Control Measures on Incomplete Road and Stream Crossing Projects (2-9)

[1] The R21 protocol (Designated Swimming Areas) no longer exists because the USFS no longer designates swimming areas.

[2] The BMP reference numbers as listed in USFS (2000) are provided in parentheses.

.TABLE 1: BMPEP Onsite Evaluation Protocols and associated BMPs

BMPEP Onsite Evaluation Protocol[1]	BMPs Evaluated[2]
	▪ Disposal of Right-of-way and Roadside Debris (2-19)
E19: Restoration of Borrow Pits & Quarries	▪ Regulation of Streamside Gravel Borrow Areas (2-18) ▪ Obliteration or Decommissioning of Roads (2-26) ▪ Restoration of Borrow Pits and Quarries (2-27)
E20: Protection of Roads During Wet Periods	▪ Traffic Control During Wet Periods (2-24) ▪ Management by Closure to Use (7-7)
R22: Developed Recreation sites	▪ Control of Sanitation Facilities (4-4) ▪ Control of Solid Waste Disposal (4-5) ▪ Assuring that Organizational Camps Have Proper Sanitation and Water Supply Facilities (4-6) ▪ Protection of Water Quality Within Developed and Dispersed Recreation Areas (4-9) ▪ 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) ▪ Protection of Water Quality from Prescribed Burning Effects (6-3)
M26: Mining Operations (Locatable Minerals)	▪ Water Resources Protection on Locatable Mineral Operations (3-1) ▪ 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) ▪ Regulation of Streamside Gravel Borrow Areas (2-18)
V28: Vegetation Manipulation	▪ Soil Disturbing Treatments on the Contour (5-1) ▪ Slope Limitations Mechanical Equipment Operation (5-2) ▪ Disposal of Organic Debris (5-5) ▪ 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) ▪ Control of Solid Waste Disposal (4-5) ▪ Assuring that Organizational Camps Have Proper Sanitation and Water Supply Facilities (4-6) ▪ Protection of Water Quality Within Developed and Dispersed Recreation Areas (4-9) ▪ Location of Pack and Riding Stock Facilities and Use in Wilderness, Primitive, and Wilderness Study Areas (4-10)

selected sites with additional ones based on local monitoring needs, such as those prescribed in environmental documents. Results associated with randomly selected sites are the focus of this report, since only those sites can be used to programmatically assess BMP implementation and effectiveness in an unbiased manner.

Monitoring procedures 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 projects were executed as planned and described in project documents. A numeric score is allocated to each question, depending on its relative importance and the degree to which the particular aspects of the BMP were met (e.g., whether the project exceeds, meets, departs insignificantly, or departs substantially from requirements). Scores for all implementation questions are then summed to create an overall implementation score. This score is subsequently compared to a decision threshold, selected *a priori*, to determine whether a given BMP or suite of BMPs is considered to have been implemented. BMP effectiveness is assessed independently based on indirect, site-level measures of water quality protection. These include observations (e.g., evidence of sediment delivery to channels) and quantitative measurements (e.g., amount of ground cover, percent of stream shade). A scoring system similar to that used for BMP implementation is used to assess BMP effectiveness. These scoring algorithms are applied automatically by the Regional BMPEP database, which stores all of the monitoring data.

This scoring approach results in a two-by-two matrix, where a given BMP or suite of BMPs are placed into one of four categories: implemented and effective (I-E); implemented, but not effective (I-NE); not implemented, but effectiveness objectives were met (NI-E); and not implemented and effectiveness objectives were not met (NI-NE). For sites with poor implementation or effectiveness scores, observers are asked to identify possible reasons and suggest corrective actions. Evaluators also use professional judgment to estimate the magnitude, duration, and extent of any likely or observed impacts to water quality.

Previously, results of these impact assessments were only recorded as comments. Recently, however, these assessments have been expanded to include a categorical ranking using the criteria described in Table 2 (see Section 2.2 for details). To provide consistency in this report, potential water quality impacts were assessed against the new criteria, whether they were evaluated before or after these criteria were adopted. This was achieved by comparing database comments, to the degree possible, against the new criteria. Subsequently, a weight-of-evidence approach was used to establish an overall effects ranking (minor, moderate, elevated) for each site. Only those sites with effects ranked as elevated are discussed in this report because they are the most important and the certainty associated with the classification of these sites is much higher than those for the other two categories. This is due to the fact that discriminating between sites with minor and moderate effects through *ex post facto* application of these criteria was much more difficult than identifying those with likely elevated effects. Because field evaluators have always been directed to describe potential water quality impacts when effectiveness problems were evident, it was assumed that an activity did not have elevated effects on water quality or beneficial uses if there were no such indications in the database comment fields.

TABLE 2: Newly Adopted Categories of Effects on Water Quality and Beneficial Uses of Water.

Effect Attribute	Category	Description
Magnitude	Minor	Pollutant was not likely (is not) observable and effects to beneficial uses were (are) unlikely.
	Moderate	Pollutant was likely (is) observable and effects to beneficial uses were (are) likely, but small.
	Elevated	Pollutant or effects to beneficial uses were likely (are) obvious and substantial.
Duration	Minor	The pollutant and/or its effects likely lasted (or will likely last) <5 days. Effects are typically associated with a single activity or precipitation event.
	Moderate	The pollutant and/or its effects likely lasted (or will likely last) > 5 days, but <1 season. Effects are typically expressed intermittently during high flow or precipitation events, dissipating to near background levels by the next season.
	Elevated	The pollutant and/or its effects likely lasted (or will likely last) >1 season. Effects are typically chronic.
Extent	Minor	Pollutant moved off-site, but did not reach the stream channel.
	Moderate	Pollutant moved off-site and reached the stream channel. Effects are evident at the stream reach scale (<20 channel widths downstream).
	Elevated	Pollutant moved off-site and reached the stream channel. Effects are evident at the drainage scale (>20 channel widths downstream) and typically extend downstream and are expressed in larger order channels.

2.2. Program Updates

Between 1999 and 2002, several changes were made to the Onsite Evaluations. First, two new protocols, one for road decommissioning (E10) and one for dispersed recreation (R30), were added to address these increasingly important activities on national forests in California. In addition, changes to several existing protocols were made based on a comprehensive, interdisciplinary review by specialists and program managers from the forests and the Regional Office. A detailed description of issues identified in the review and actions taken to resolve them are described in Table A-1 (appendix). This included the adoption of more objective, categorical, and quantifiable criteria for assessing the extent, duration, and magnitude of potential effects on water quality (Table 2). Besides protocol changes, significant database modifications were completed in 2002. This work corrected discrepancies between the database and field forms, incorporated the new and modified protocols, made reporting more user-friendly, and modernized the computer code. More database work was initiated in 2003 to address additional needs.

Due to the issues described in Table A-1, some monitoring data were not quantitatively analyzed (i.e., implementation and effectiveness rates were not determined) for this report (Table 3). No results are included for those data that can and eventually will be analyzed and reported quantitatively once the ongoing database work is completed. Because there were problems with some previous monitoring protocols, quantitative analysis of other data will not be possible even after the database is finalized. Consequently, these data were analyzed qualitatively (e.g., important implementation and effectiveness questions were evaluated) and the results of that analysis are included in this report.

TABLE 3: Data excluded from quantitative analysis in this report.

BMPEP Onsite Evaluation Protocol	Data excluded from quantitative analysis	# of evaluations excluded from quantitative analysis	# of evaluations analyzed qualitatively	# of evaluations to be recovered & quantitatively analyzed in the future	# of evaluations excluded from any analysis	Reason[3]
T03	1992-2002	95	0	95	0	Ongoing database modifications will allow for eventual quantitative analysis.
T06	1992-2001	57	0	57	0	See T03.
E13	1992-2001	108	108	0	0	Problems with previous protocols preclude quantitative analysis.
E18	1992-2001	25	0	25	0	See T03.
R22	1992-2001	142	142	0	0	See E13.
R23	1992-2002	46	0	46	0	See T03.
G24	1992-2002	152	130 (1992-2001 data)	0	22 (2002 data)	Problems with previous protocols preclude quantitative analysis of 1992-2001 data. The 22 sites collected in 2002 were used for pilot testing a draft version of a new protocol. This pilot testing identified other issues that need to be addressed before the protocol is finalized. Consequently, results of this monitoring are not reported here and will not be reported in the future. Implementation of the revised protocol is scheduled for 2005 or 2006.
M26	1992-2002	88	80 (1992-2001 data)	8 (2002)	0	Problems with previous protocols preclude quantitative analysis of 1992-2001 data. Ongoing database modifications will allow for eventual quantitative analysis and subsequent reporting of data collected after 2001.
M27	1992-2002	93	0	93	0	See T03.
TOTAL		806	460	324	22	

2.3. Interpretation and Reporting of Monitoring Results

This report describes implementation rates for each BMP and group of BMPs (e.g., engineering), the associated effectiveness rates, the percent of *all* monitored sites that met effectiveness objectives (i.e., did not exceed effectiveness thresholds), and the number and percentage of sites that had elevated effects on water quality and/or beneficial uses of water. Implementation rates are a direct measure of how well the USFS is executing its water quality management program. As described above, a BMP or suite of BMPs were considered "implemented" at a site if the overall implementation scores did not exceed the implementation thresholds. BMP effectiveness is a measure of how well BMPs, *when implemented*, meet effectiveness (i.e., onsite water quality protection) objectives. BMPs were reported

[3] See Table A-1 for details.

as "effective" at those sites where BMPs were implemented *and* the effectiveness objectives were met[4]. The percent of *all* monitored sites that met the effectiveness objectives, whether or not BMPs were implemented, is an indicator of the frequency that a given activity or group of activities posed little or no risk to water quality.[5] Finally, the number and percentage of sites classified as having elevated effects on water quality is an indicator of the frequency that effects, rather than *risks of effects*, were likely to have been expressed at monitoring sites. This is the most important measure of the program's performance.

As described earlier, Onsite Evaluations employ indirect, site-level measures to evaluate BMP effectiveness. Direct measurement of instream water quality parameters and comparison of those parameters to state water quality standards is not widely applied in these evaluations because this type of monitoring is extremely difficult and costly. This is primarily due to the fact that many pollutants of concern in forest and rangeland environments (e.g., sediment) are naturally occurring and differentiating between natural sources, current anthropogenic sources, and the effects of past activities poses significant challenges. In addition, the natural and human-caused sources of these pollutants are dispersed over large areas. Finally, because the concentrations of these constituents are highly variable at multiple spatial and temporal scales, detecting the effects of activities is not possible unless they are very large or the intensity of monitoring is very high and is conducted over long periods of time. Due to these limitations, this type of monitoring is being conducted in a few, intensely monitored sites such as the Kings River Experimental Watershed (Section 3).

Because these indirect measures are typically used, the BMPEP onsite monitoring does not provide absolute, definitive proof that water quality standards have been met at sites where BMPs have been ranked as effective. Nonetheless, because these indirect measures provide substantial evidence regarding whether pollutants were discharged to watercourses and if aquatic habitats have been altered significantly, it is very likely that water quality was protected at those sites where BMPs were ranked as effective. Poor effectiveness scores do not necessarily mean that a state water quality standard was violated or that beneficial uses were affected. Instead, they indicate that there were increased risks of impacts to water quality and beneficial uses at those sites. As described above, likely or actual impairment of water quality and/or beneficial uses of water are determined based on evidence at the site and application of professional judgment.

2.4.Results

The following sections describe the results of the BMPEP monitoring program from 1992 through 2002. First is a discussion of the relationship between BMP implementation and effectiveness. This is followed by BMP implementation and effectiveness results for all activities combined, individual program areas (e.g., timber), and individual evaluations (e.g., streamside management zones). To illustrate temporal trends in BMP implementation and effectiveness, this report describes results for the *composite monitoring period* (1992-2002) as well as the *first monitoring period* (1992-1996) and *second monitoring period* (1997-2002).

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[4] Mathematically, "implemented" is (I-E + I-NE)/(total # of all monitored sites) and "effective" is (I-E)/(I-E + I-NE), where I-E, for instance, means the number of sites that are implemented and effective.

[5] Mathematically, this is (I-E + NI-E)/(total # of all monitored sites).

2.4.1. Relationship Between BMP Implementation and Effectiveness

Chi-Square analysis was used to test differences in effectiveness scores between sites where BMPs were and were not implemented. The hypothesis tested was that effectiveness scores are not dependent on implementation scores. As summarized in Table 4, results of this analysis indicate that at the 90% confidence level, there is a statistically significant relationship between BMP implementation and effectiveness for 16 of the 29 evaluation protocols (see Table A-2 for details). This demonstrates that for the activities evaluated by these 16 protocols, those sites where BMPs are implemented are more likely to meet the effectiveness objectives than those where they are not. Since these objectives are indirect measures of water quality protection, it follows that sites where BMPs are implemented are more likely to protect water quality than those where they are not. A statistically significant relationship was not found for six of the monitoring protocols. For the remaining seven evaluations, insufficient samples in at least one of the four result categories precluded the use of a chi-square test. Upon completion of ongoing database modifications, inclusion of the additional data described in Table 3 will allow chi-square tests to be performed for more protocols. This is likely to increase the number of evaluations with a demonstrated statistical relationship between BMP implementation and effectiveness.

TABLE 4: Results of chi-square test of difference in effectiveness scores at sites where BMPs were and were not implemented.

Chi-Square Results	BMPEP Protocol
Statistically Significant ($p<0.10$)	T01, T02, T04, T07, E08, E09, E11, E12, E13, E14, E16, E17, E19, R22, F25, V28
Not Statistically Significant ($p<0.10$)	T05, E10, E15, E20, V29, R30
Test not Possible	T03, T06, E18, R23, G24, M26, M27

2.4.2. All Activities

A total of 5,007 BMP evaluations were conducted on the 18 National forests in California from 1992 through 2002 (Figure 1). These were performed at sites where timber, engineering, recreation, grazing, mining, prescribed fire, and vegetation management activities occurred. Of these evaluations, 3,932 were conducted at randomly selected sites. Quantitative results described in this report exclude data from 806 of these sites due to the protocol and database issues described earlier (Tables 3 and A-1). Consequently, the quantitative results are based on 3,126 random evaluations. Results of a qualitative analysis of 460 of the 806 sites are also included. An additional 324 sites will be quantitatively analyzed and reported once ongoing database modifications are complete. The remaining 22 sites were used to pilot test a draft revision to the grazing protocol.

On average, 357 random evaluations were conducted each year during the composite monitoring period. This fluctuated from a high of 599 sites in 1996 to a low of 109 sites in 2000. Monitoring rebounded steadily to 301 and 425 sites in 2001 and 2002, respectively. As shown in Figure 2, engineering BMPs

FIGURES 1 & 2

were the most commonly monitored practices from 1992 through 2002 (40% of all observations), followed by timber (35%), prescribed fire (6%), recreation (6%), vegetation management (5%), mining (5%), and grazing (4%). The total number of random evaluations completed by individual forests during the 1992-2002 monitoring period varied from 23 to 592 (Figure 3). All national forests except the San Bernardino and Los Padres evaluated more than 100 randomly selected sites. The Los Padres, however, has focused significant effort on evaluating non-randomly selected sites (144 since 1992).

For all evaluations combined, BMPs were implemented 85% of the time during the composite monitoring period (Figure 4). Implementation rates during the 1992-1996 and 1997-2002 monitoring periods were similar (Figure 5). By functional area, BMP implementation rates were 87% for timber, 85% for engineering, 68% for recreation, 77% for prescribed fire, and 87% for vegetation management. Only qualitative results for mining or grazing are reported for the reasons described previously (Tables 3 and A-1). BMP implementation rates for individual forests ranged from 60% to 96%. Implementation rates were 80% or greater for all but four forests (Angeles, Plumas, Shasta-Trinity, and Tahoe) and 75% or greater for all but one Forest (Angeles) (Figure 6).

During the composite monitoring period, BMPs for all activities were effective at 92% of the sites at which they were implemented (Figure 4). These rates were similar during the first and second monitoring periods (Figure 5). By functional area, BMPs were effective 94% of the time for timber, 89% for engineering, 89% for recreation, 98% for prescribed fire, and 89% for vegetation management. No quantitative data are available for grazing and mining practices. BMP effectiveness rates for individual forests varied from 82% to 99% during the 1992-2002 monitoring period (Figure 6). Thirteen forests had effectiveness rates of 90% or greater.

Considering all sites, including those where BMPs were and were not implemented, effectiveness objectives were met 87% of the time from 1992 through 2002 (Figure 7). Effectiveness objectives were met at 91% of timber, 84% of engineering, 74% of recreation, 96% of prescribed fire, and 87% of vegetation management activity sites. For all activities combined, water quality effects were classified as elevated at 78 (2%) of the sites monitored from 1992 through 2002 (Table 5). Most of these were related to engineering practices (46, <3% of engineering sites). Roads, especially stream crossings, were the most problematic. Twenty were related to timber practices (<2%) and four (2%) occurred at recreation sites. Five (<4%) were associated with grazing, one (<1%) resulted from a prescribed fire, one (1%) was observed at a mining site, and one (1%) was related to vegetation management. The number of elevated effects observed during the first and second monitoring periods was relatively similar for all practices, except those associated with road stream crossings. Substantially more elevated effects resulting from stream crossings occurred from 1997 through 2002 than from 1992 through 1996. Most of these were observed in 1997 or 1998 and many were caused by an increased number of failures triggered by the significant storms of 1997.

Details regarding different categories of BMPs, the causes of elevated effects, and actions necessary to address deficiencies are provided in the sections that follow.

FIGURES 3 & 4

FIGURES 5 & 6

FIGURE 7

TABLE 5: Summary of water quality effects classified as *elevated* due to their extent, duration, and/or magnitude.

		Composite Monitoring Period (1992-2002)		First Monitoring Period (1992-1996)	Second Monitoring Period (1997-2002)	1997 and 1998 only	Date elevated effects were last observed
Activity	**Total # Sites Evaluated**	**% of sites**	**# of sites**	**# of sites**	**# of sites**	**# of sites**	
T01	278	<3%	7	3	4	4	1998
T02	305	<2%	5	2	3	3	1998
T04	420	<2%	7	3	4	4	1998
T05	67	0%	0	0	0	0	N/A
T06	7	0%	0	0	0	0	N/A
T07	134	<1%	1	0	1	1	1997
All Timber	**1211**	**<2%**	**20**	**8**	**12**	**12**	
E08	284	<5%	13	5	8	8	1998
E09	362	6%	22	3	19	12	2003
E10	29	0%	0	0	0	0	N/A
E11	209	<1%	1	1	0	0	1995
E12	42	0%	0	0	0	0	N/A
E13	132	2%	3	2	1	0	1999
E14	133	2%	3	3	0	0	1995
E15	25	0%	0	0	0	0	N/A
E16	78	<3%	2	1	1	1	1998
E17	180	0%	0	0	0	0	N/A
E18	1	0%	0	0	0	0	N/A
E19	64	3%	2	2	0	0	1995
E20	66	0%	0	0	0	0	N/A
All Engr	**1605**	**<3%**	**46**	**17**	**29**	**21**	
R22	160	<3%	4	3	1	1	1997
R30	16	0%	0	0	0	0	N/A
All Rec	**176**	**2%**	**4**	**3**	**1**	**1**	
All Grazing (G24)	**130**	**<4%**	**5**	**2**	**3**	**2**	**2002**
All Fire (F25)	**254**	**<1%**	**1**	**0**	**1**	**1**	**1997**
M26	**80**	**1%**	**1**	**1**	**0**	**0**	**1995**
V28	99	0%	0	0	0	0	N/A
V29	89	1%	1	1	0	0	1994
All Veg Mngmt	**188**	**<1%**	**1**	**1**	**0**	**0**	
All BMPs	**3644**	**2%**	**78**	**32**	**46**	**37**	

2.4.3. Timber Management

From 1992 to 2002, BMP implementation and effectiveness were evaluated at 1,363 different components (e.g., skid trails, landings) of randomly selected timber projects throughout the Region. Because 95 evaluations for suspended yarding (T03) and 57 evaluations for special erosion control and revegetation (T06) have been excluded from this analysis, the following results are based on 1211 of those sites. From 1992 through 2002, timber BMPs were implemented at 87% of observation sites (Figure 8). Implementation rates were relatively similar, but slightly lower, during the second monitoring period than the first (85% vs. 89%). For individual evaluations, average implementation rates during the composite monitoring period varied between 83% for streamside management zones (SMZs, T01) and 94% for timber sale administration (T05)[6]. Implementation rates were 89% or greater for all timber BMPs except those pertaining to streamside management zones (T01) and skid trails (T02).

Implementation rates for meadow protection (T07) increased moderately between the first (1992-1996) and second (1997-2002) monitoring periods (89% to 97%), but rates declined moderately for some other practices. These include SMZ protection (T01, 86% to 80%), skid trails (T02, 86% to 81%), and timber sale administration (T05, 97% to 90%). For all timber activities combined, problems associated with BMP implementation most frequently occurred during the layout and administrative phases of the projects (Table 6).

TABLE 6: Phases during which problems occurred when BMPs were not implemented, Timber Management (1992-2002)[7].

Project Phase	TO1	TO2	TO4	TO5	TO6	TO7	All Timber
Site Evaluation	9	10	11	*	0	0	30
Plan Prescription	8	6	8	*	0	1	23
Environmental Analysis	11	6	4	*	0	1	22
Contract	6	8	8	6	0	3	31
Contact Modifications	*	*	*	0	*	*	0
Layout	29	18	15	11	0	4	77
Administration	33	36	30	*	1	5	105
Administration of Standard Operating Procedures	*	*	*	29	*	*	29
Post Sale	7	*	*	*	*	1	8

* = Not applicable

[6] Special erosion control and revegetation (T06) is exluded from this discussion due to small sample size. Implementation rates and effectiveness rates were 100% for T06 based on seven samples.

[7] * = not applicable to this protocol

FIGURES 8 & 9

FIGURE 10

When implemented, timber BMPs were effective 94% of the time (Figure 9). Effectiveness rates during the first and second monitoring periods were approximately equal. Average effectiveness rates for individual evaluations ranged from 85% for SMZ protection (T01) to 98% for landings (T04), timber sale administration (T05), and meadow protection (T07) (Figure 9). All timber BMPs, except SMZ protection, had effectiveness rates above 95%. Between the two monitoring periods, effectiveness rates for skid trails (T02) increased moderately from 91% to 98%, but rates for SMZs (T01) decreased from 89% to 82%. No other substantial changes occurred. Considering all timber sites, including those where BMPs were and were not implemented, BMP effectiveness objectives were met 91% of the time from 1992 through 2002 (Figure 10). This ranged from 79% for SMZs (T01) to 99% for timber sale administration (T05). Based on their likely extent, duration, and/or magnitude, effects were classified as elevated at 20 (<2%) sites. These effects were typically associated with poor BMP implementation. No elevated effects have been observed since 1998. Details regarding individual timber BMPs are provided in the sections that follow.

2.4.3.1. Streamside Management Zones (T01)

BMPs for SMZ protection were implemented 83% of the time from 1992 through 2002 (Figure 8). Implementation rates during the 1997-2002 monitoring period (80%) were somewhat lower than those from the 1992-1996 monitoring period (86%). At the 48 sites where these BMPs were not implemented, minor departures most commonly resulted from failures to follow SMZ width criteria (26)[8], adhere to SMZ prescriptions (26), and exclude mechanized equipment (22) (Table A-3). Major departures were most frequently caused by failures to treat the SMZ as prescribed (14) and to exclude mechanized equipment (13). Problems with implementation of SMZ BMPs occurred most often during the layout and administrative phases of projects (Table 6).

During the composite monitoring period, these BMPs were effective at 85% of the 230 sites at which they were implemented (Figure 9). These rates decreased from 89% to 82% between the first and second monitoring periods. Of all 278 sites evaluated, effectiveness objectives were met 79% of the time (Figure 10). At the 59 sites where these objectives were not met, minor departures were most common for streambank disturbance (24) and ground cover (19) criteria (Table A-4). Sediment discharge to the SMZ or stream channel was the criterion for which major departures were most frequent (38). Based on their likely extent, duration, and magnitude, effects were classified as elevated at seven (<3%) sites (Table 5). Four of these occurred during the most recent monitoring period, but none have been observed since 1998. Elevated effects at all seven sites were caused by inadequate BMP implementation. This included failure to properly identify and exclude equipment from watercourses and SMZs. Poor placement and construction of roads, stream crossings, and skid trails were also problematic.

[8] values in parenthesis are the number of occurrences

2.4.3.2. Skid Trails (T02)

From 1992 through 2002, BMPs for skid trails were implemented at 84% of monitored sites (Figure 8). BMP implementation was moderately lower during the second monitoring period (81%) than the first (86%). At the 50 sites where these BMPs were not implemented, minor departures were most often due to poor location (19) and drainage and erosion control failures (24) (Table A-3). Major departures were also most frequently associated with these criteria (10 and 9 sites, respectively). Specifically, common causes of poor BMP implementation were the inadequate use of waterbars (number, location, construction), logging during wet periods, and placement of skid trails too close together or on steep slopes. Most implementation problems occurred during the layout and administrative phases of projects (Table 6).

When implemented, these BMPs were effective 95% of the time during the composite monitoring period (Figure 9). Effectiveness rates were moderately higher during the second monitoring period than the first (98% vs. 91%). Considering all 305 sites that were evaluated, effectiveness objectives for skid trail BMPs were met 92% of the time (Figure 10). At the 26 sites where these objectives were not met, erosion on skid trails (8) and below waterbars (8) comprised the greatest number of minor departures (Table A-4). The most frequent major departures were for skid trail surface erosion (12), sediment below waterbars (14), and sediment delivery to the SMZs or stream channels (12). Effects were classified as elevated at 5 (<2%) sites. Three of these were observed during the most recent monitoring period, but none have occurred since 1998. Elevated effects at four of the sites were caused by inadequate BMP implementation, including insufficient planning and environmental analysis and poor location (e.g., on steep slopes, near ephemeral channels) and construction (e.g., too few waterbars) of skid trails. Effects at one site, however, were ranked as elevated even though BMPs were implemented. This was due to high site sensitivity after a fire and public pressure that precluded SMZ treatments intended to increase ground cover.

2.4.3.3. Suspended Yarding (T03)

BMP implementation and effectiveness was evaluated at 95 different suspended yarding sites from 1992 through 2002. No quantitative results are available for these activities due to the issues described in Tables 3 and A-1. Results from all of these evaluations will be analyzed and documented in future reports once ongoing database work is complete.

2.4.3.4. Landings (T04)

BMPs for landings were implemented at 89% of the 420 sites monitored from 1992 through 2002 (Figure 8). Implementation rates were similar during the first and second monitoring periods. Minor departures at the 47 sites where these BMPs were not implemented most commonly resulted from inadequate drainage (32) (Table A-3). Major departures were most frequently related to landing location (6), drainage (4), and stabilization (4). Specifically, implementation problems were typically caused by locating new landings too close to watercourses or on unstable areas or using existing landings with similar problems. Inadequate use of waterbars, failure to till landings after use, and poor groundcover also caused implementation failures. Most of these problems occurred during layout and administration (Table 6).

From 1992 through 2002, these BMPs were effective at 98% of the 373 sites at which they were implemented (Figure 9). These rates were not substantially different during the 1992-1996 and 1997-2002 monitoring periods. For all 420 sites, effectiveness objectives were met 95% of the time (Figure 10). At the 22 sites where these objectives were not met, minor departures were most frequently due to rilling or gullying below drainage structures (8) and rilling on fillslopes (6) (Table A-4). The most common major departures were sediment delivery to SMZs or stream channels (19) and rilling on the landing surface (12). Based on their likely magnitude, duration, and/or extent, effects were classified as elevated at seven (<2%) sites. Four of these occurred during the 1997-2002 monitoring period, but none have occurred since 1998. Effects at these seven sites were caused by poor placement of waterbars, insufficient rehabilitation (e.g., tillage, mulch), and placement of landings too close to watercourses.

2.4.3.5. Timber Sale Administration (T05)

BMPs for timber sale administration (TSA) were implemented at 94% of the 67 sites monitored from 1992 through 2002 (Figure 8). Rates of implementation were moderately lower from 1997 through 2002 (90%) than from 1992 through 1996 (97%). Of the four instances where BMPs were not implemented, minor departures from erosion control requirements were found at two sites (Table A-3). Failure to implement erosion control requirements, maintain erosion control devices, and obtain approval for changes to decisions made during environmental analysis were the causes of major departures at two sites. Problems with implementation of TSA BMPs were most frequently associated with administration of Standard Operating Procedures (Table 6).

When implemented, these BMPs were effective 98% of the time from 1992 through 2002 and these rates did not change significantly between the 1992-1996 and 1997-2002 monitoring periods (Figure 9). Considering all 67 monitored sites, effectiveness objectives for these BMPs were met 99% of the time (Figure 10). A minor departure for wet weather operations and a major departure associated with sediment discharge to a SMZ or stream channel was found at the one site where these objectives were not met (Table A-4). No sites had effects classified as elevated (Table 5).

2.4.3.6. Special Erosion Control and Revegetation (T06)

BMPs for special erosion control and revegetation were implemented and effective at all seven sites monitored in 2002 (Figures 8 and 9). Fifty-seven sites monitored between 1992 and 2001 were excluded from this report due to the issues described in Tables 3 and A-1. Upon completion of ongoing database modifications, analysis of these additional sites will provide more substantive results.

2.4.3.7. Meadow Protection (T07)

BMPs for meadow protection were implemented at 93% of the 134 sites monitored from 1992 through 2002 (Figure 8). Implementation rates increased between the first (89%) and second (97%) monitoring periods. At the nine sites where these BMPs were not implemented, minor departures were most commonly associated with failure to exclude mechanical equipment (7) (Table A-3). Major departures were most frequently caused by failures to identify meadows on sale area maps (2). Implementation problems occurred primarily during the administrative phase of projects (Table 6).

From 1992 through 2002, these BMPs were effective at 98% of the sites at which they were implemented (Figure 9). Effectiveness rates did not change substantially between the first and second monitoring periods. Considering all 134 monitored sites, effectiveness objectives for meadow protection BMPs were met 96% of the time (Figure 10). Major departures from disturbance criteria were found at all six sites where these objectives were not met (Table A-4). Effects were classified as elevated at one (<1%) site evaluated in 1997 (Table 5). They were caused by a combination of poor BMP implementation associated with road construction, extreme site sensitivity, and a major storm event.

2.4.4. Engineering

From 1992 through 2002, implementation and effectiveness was evaluated at 1572 different randomly selected sites where engineering BMPs were to be applied. Because 108 in-channel construction practice (E13) evaluations and 25 pioneer road construction (E18) evaluations were excluded from this report for the reasons described earlier (Tables 3 and A-1), results described below are based on 1,439 of those sites.

On average, engineering BMPs were implemented 85% of the time during the composite monitoring period (Figure 11). Average implementation rates were similar during the 1992-1996 and 1997-2002 monitoring periods. For individual evaluations, average implementation rates during the composite monitoring period ranged from 71% for in-channel construction practices (E13) to 95% for servicing and refueling (E12) (Figure 11).[9] All BMPs, except those pertaining to control of sidecast material (E11), in-channel construction practices (E13), water source development (E16), and restoration of borrow pits and quarries (E19) had implementation rates greater than or equal to 85%. During the second monitoring period, implementation rates increased moderately to substantially for control of sidecast (E11, 75% to 84%), servicing and refueling (E12, 94% to 100%), rip rap composition (E15, 87% to 100%), water source development (E16, 74% to 86%), and protection of roads during wet periods (E20, 90% to 96%). Temporary road (E14) and snow removal (E17) BMPs had lower implementation rates during the second monitoring period, decreasing 6% and 17%, respectively. For all engineering activities combined, problems associated with BMP implementation most frequently occurred during the maintenance and administrative phases of the projects (Table 7).

[9] Pioneer road construction is omitted from discussion due to a sample size of one.

During the composite monitoring period, engineering BMPs were effective at 89% of the sites at which they were implemented (Figure 12). Effectiveness rates were similar during the first and second monitoring periods. Average effectiveness rates for individual evaluations varied from 69% for water source development (E16) to 100% for servicing and refueling (E12). All engineering BMPs were effective 88% of the time or more except those pertaining to water source development. Effectiveness rates increased for restoration of borrow pits and quarries (E19, 88% to 100%), but decreased for rip rap composition (E15, 92% to 83%) and water source development (E16, 78% to 58%). Effectiveness rates for the remaining practices were relatively unchanged between the two monitoring periods. Considering all 1,439 monitored sites, effectiveness objectives were met 84% of the time (Figure 13). Based on their likely magnitude, duration, and/or extent, effects were classified as elevated at 46 (<3%) sites. The number of engineering sites where elevated effects occurred was similar between the 1992-1996 and 1997-2002 monitoring periods for all engineering practices, except those associated with stream crossings. A substantially larger number of effects at these sites were ranked as elevated during the most recent monitoring period. Most of these were observed in 1997 or 1998 and were the result of increased failures associated with the large storms of 1997. Elevated effects were typically associated with poor BMP implementation. Details regarding individual engineering BMPs are provided in the sections that follow.

TABLE 7: Phases during which problems occurred when BMPs were not implemented, Engineering BMPs (1992-2002).

Project Phase	E08	E09	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	All Engineering
Site Evaluation	*	*	0	1	0	0	1	0	4	3	0	1	0	10
Location	8	5	*	*	*	*	*	*	*	*	*	*	*	13
Design	14	14	*	*	*	*	*	*	*	*	*	*	*	28
Plan Prescription	*	*	0	9	1	0	1	1	9	1	0	6	1	29
Environmental Analysis	7	7	0	6	1	1	0	0	7	3	1	2	0	35
Contract	5	6	1	10	1	1	6	0	3	2	0	3	1	39
Layout	*	*	*	2	0	0	2	1	3	2	0	0	0	10
Construction	14	17	*	*	*	*	*	*	*	*	*	*	*	31
Maintenance	25	23	*	*	*	*	*	*	*	*	*	*	*	48
Administration	*	*	3	19	2	4	10	2	8	19	0	11	3	82
Follow-up Treatment	*	*	0	*	*	*	*	*	*	*	*	*	*	0

FIGURES 11 & 12

FIGURES 13

2.4.4.1. Road Surface, Drainage, and Slope Protection (E08)

From 1992 through 2002, BMPs for road surface, drainage, and slope protection were implemented at 85% of the 284 sites evaluated (Figure 11). Implementation rates during the first and second monitoring periods were similar. At the 40 sites where these BMPs were not implemented, consistency of drainage structure repair with road management objectives was the criterion for which both minor (18) and major departures (8) were most common (Table A-5). Problems with implementation of these BMPs most frequently occurred during project design, construction, and maintenance (Table 7).

During the composite monitoring period, these BMPs were effective 90% of the time that they were implemented (Figure 12). These rates were not substantially different between the first and second monitoring periods. Considering all monitored sites, effectiveness objectives for road surface, drainage, and slope protection BMPs were met 83% of the time (Figure 13). At the 47 sites where effectiveness objectives were not met, minor departures were most frequently associated with rilling on road surfaces (15) and fillslopes (21) (Table A-6). Sediment discharges to SMZs or stream channels were the most common type of major departures (42). Effects were classified as elevated at 13 (<5%) sites, eight of which occurred during the most recent monitoring period. All eight of these were observed in 1997 or 1998 and were associated with the major storm events of 1997. Inadequate BMP implementation caused the elevated effects at all but one of these sites. Specifically, these effects were initiated by placement of sidecast into or near stream channels and failure to properly install culverts, ditches, or cross-drains. Lack of suitable road surfacing (i.e., rocking) and waterbars, blocked waterbar outlets, and poor road location were also problematic. Effects were considered elevated at one site even though BMPs were implemented. This was caused by the presence of highly erosive soils and the 1997 storm events.

2.4.4.2. Stream Crossings (E09)

Stream crossing BMPs were implemented 85% of the time during the composite monitoring period (Figure 11). These rates did not change substantially between the first and second monitoring periods. At the 39 sites where these BMPs were not implemented, minor departures from drainage structure maintenance specifications were the most common (21) (Table A-5). Major departures were most frequently associated with failure to identify design objectives (5) and meet contract specifications for slope stabilization (5) and drainage (6). Problems with implementation of these BMPs occurred most often during the design, construction, and maintenance phases of the projects (Table 7).

From 1992 through 2002, these BMPs were effective at 88% of the sites at which they were implemented (Figure 12). Effectiveness rates were similar during the 1992-1996 and 1997-2002 monitoring periods. Considering all 304 sites, effectiveness objectives for stream crossing BMPs were met 80% of the time (Figure 13). At the 60 sites where these objectives were not met, minor departures were most frequently caused by a failure to meet vegetative cover requirements on fillslopes (23), puddling on road surfaces (15), erosion near drainage ditches (20), and plugging of culverts (15) (Table A-6). Major departures were most commonly caused by diversion potential (27), rilling of road surfaces (30), and rilling (26) and failure of fillslopes (25). Based on their likely extent, duration, and magnitude, effects were classified as elevated at 22 (6%) sites. Nineteen of these occurred during the most recent monitoring period. Most of those were observed in 1997 or 1998. Effects were classified as elevated at only three sites monitored since 1998. Inadequate BMP implementation was the cause of elevated effects most of the 22 sites. Specifically, improper location of a culvert in a sensitive area, inadequate drainage, culvert installation below grade and out of alignment with the channel, poor road alignment, improper fill material, and lack of revegetation and slope stabilization were problematic. Large storm events and site sensitivity were cited as the cause at several sites where elevated effects occurred despite implementation of BMPs.

2.4.4.3. Road Decommissioning (E10)

BMPs for road decommissioning were implemented at 87% of the 29 sites monitored since 2001, when this protocol was first applied (Figure 11). Of the four sites where BMPs were not implemented, minor departures from side slope configuration requirements were found at three sites (Table A-5). Major departures occurred once for fill excavation, channel configuration, and disposal area criteria. Specific causes of poor implementation included inadequate site excavation, poor road closures, unclear contract language, and failure to include an earth scientist in project review, design, and implementation. Problems most frequently occurred during the administrative phase of projects (Table 7).

During the composite monitoring period, these BMPs were effective at 93% of the sites at which they were implemented (Figure 12). Considering all 29 sites, effectiveness objectives for these BMPs were met 89% of the time (Figure 13). At the three sites where these objectives were not met, minor departures from road surface rilling and channel reconfiguration were each found once (Table A-6). Major departures were found one time for traffic control, channel adjustment, slope failure, and side slope rilling criteria. No sites had effects classified as elevated.

2.4.4.4. Control of Sidecast Material (E11)

BMPs for control of sidecast material were implemented 79% of the time during the composite monitoring period (Figure 11). Implementation rates increased between the first and second monitoring periods, from 75% to 84%. Minor departures from requirements to limit sidecasting in plans and to designate disposal areas were found at 32 of the 45 sites where these BMPs were not implemented (Table A-5). Minor departures from requirements to limit sidecast were found at all of these sites. No major departures from any implementation criteria were found. Problems most frequently occurred during the contract and administrative phases of projects (Table 7). Specifically, incorporating sidecast requirements from environmental documents into contracts was found to be problematic.

From 1992 through 2002, these BMPs were effective 95% of the time that they were implemented (Figure 12). These rates did not change between the first and second monitoring periods. Effectiveness objectives for BMPs related to control of sidecast material were met at 88% of all 209 sites observed during the composite monitoring period (Figure 13). At the 25 sites where these objectives were not met, most minor departures were associated with placement of sidecast in an SMZ (14) or near a stream channel (10) (Table A-6). Deposition of sidecast on stream crossing fills (16) or near stream channels (15) or ditches (13) were the most common types of major departures.

Effects were classified as elevated at one site (<1%) evaluated during the first monitoring period. This was caused by poor BMP implementation, specifically the placement of large amounts of sidecast less than 10 feet from a stream.

2.4.4.5. Servicing and Refueling (E12)

From 1992 through 2002, BMPs for servicing and refueling were implemented 95% of the time (Figure 11). Implementation rates increased from 94% during the first monitoring period to 100% during the second. At the two sites where BMPs were not implemented, minor departures from requirements to develop a spill prevention plan and to properly locate a storage area were found once each (Table A-5). A major departure was found once for failure to meet storage area requirements and to construct spill containment devices. Due to a small sample size, problems were not evident in any particular phase of projects.

From 1992 through 2002, these BMPs were effective at 100% of the sites at which they were implemented (Figure 12). Effectiveness objectives for servicing and refueling BMPs were met at 98% of all 42 monitored sites (Figure 13). A major departure occurred at one site, where there was evidence of discharge within 50 feet of a waterway (Table A-6). No effects on beneficial uses were observed (Table 5).

2.4.4.6. In-channel Construction Practices (E13)

Due to the issues described in Tables 3 and A-1, only 2002 data for E13 could be analyzed quantitatively. The 1992-2001 data was analyzed qualitatively to assess performance during that time period. This assessment was based on responses to individual implementation and effectiveness questions at all monitored sites.

<u>2002 Data</u>

BMPs for in-channel construction were implemented at 71% of the 24 sites monitored in 2002 (Figure 11). Minor departures at the seven sites where BMPs were not implementation were most often the result of improper management of excavated materials (5) and failure to restore the channel (3) (Table A-5). A major departure related to implementation of requirements for diverting flow around construction sites was noted at one site. Most problems occurred during the administrative phase of projects (Table 7).

When implemented, these BMPs were effective at 88% of the sites monitored in 2002. Considering all 24 sites, effectiveness objectives for these BMPs were met 79% of the time (Figure 13). At the five sites where these objectives were not met, a minor departure occurred once due to fill on the floodplain (Table A-6). Major departures were associated with changes in channel riffle substrate (2) and turbidity plumes below crossing sites (2).

1992-2001 Data

From 1992 through 2001, most of the 108 sites either met or exceeded the implementation and effectiveness criteria, or these criteria did not apply (Tables A-7 and A-8). Consequently, no major problems appear evident during those years.

Effects were classified for all sites monitored from 1992 through 2002. Effects were elevated at three (2%) of the 132 sites. All of these were caused by poor implementation of BMPs, including failure to revegetate exposed soils, dewater sites, and consult an earth scientist.

2.4.4.7. Temporary Roads (E14)

BMPs for temporary roads were implemented 91% of the time during the composite monitoring period (Figure 11). Implementation rates were lower during the second monitoring period (88%) than the first (94%). At the 12 sites where BMPs were not implemented, minor departures were most commonly associated with drainage (5) and road closure requirements (5) (Table A-5). Major departures were most often related to road closure requirements (6). The majority of problems occurred during the administrative phase of projects (Table 7).

Between 1992 and 2002, these BMPs were effective at 90% of the sites where they were implemented (Figure 12). These rates did not change considerably between the two monitoring periods. Effectiveness objectives for temporary road BMPs were met at 87% of all 133 monitored sites (Figure 13). At the 17 sites these objectives were not met, minor departures were most commonly associated with road surface rilling (4) (Table A-6). Major departures were related to sediment delivery to or near a stream channel (4). Two sites had effects classified as elevated due to their extent, duration, and/or magnitude. Both of these occurred during the first monitoring period. Effects at both sites were caused by insufficient BMP implementation, specifically the failure to obliterate roads as specified in the contract and lack of stabilization and drainage for a stream crossing.

2.4.4.8. Rip Rap Composition (E15)

Rip rap BMPs were implemented at 92% of the 25 sites evaluated from 1992 through 2002 (Figure 11). Only two sites had poor BMP implementation. Implementation rates increased from 87% from 1992 through 1996 to 100% from 1997 through 2002. Minor departures from requirements that rip rap be free from organic and other non-structural materials occurred at both sites (Table A-5). Major departures occurred once for failure to use specified rip rap material and once for failure to place it as prescribed. Most problems occurred during the administrative phase of projects (Table 7).

When implemented, these BMPs were effective 89% of the time during the composite monitoring period (Figure 12). Effectiveness rates decreased from 92% during the first monitoring period to 83% during the second. Considering all 25 monitored sites, effectiveness objectives for rip rap BMPs were met at 84% of the time (Figure 13). No minor departures from individual effectiveness criteria occurred at the four sites where effectiveness objectives were not met (Table A-6). Major departures from scour criteria occurred at each of these four sites. No elevated effects on water quality were observed (Table 5).

2.4.4.9. Water Source Development (E16)

BMPs for water source development were implemented 79% of the time from 1992 through 2002 (Figure 11). Implementation rates increased from 74% to 86% between the 1992-1996 and 1997-2002 monitoring periods. At the 16 sites where these BMPs were not implemented, minor and major departures were most frequently associated with failure to include water quality protection measures in project plans (eight and four occurrences, respectively). Problems most frequently occurred during plan prescription, environmental analysis, and administrative phases of projects (Table 7).

These BMPs were effective 69% of the time that they were implemented during the composite monitoring period (Figure 12). Effectiveness rates decreased from 78% to 58% between the first and second monitoring periods. Considering all 78 sites observed from 1992 through 2002, effectiveness objectives for water source development were met 64% of the time (Figure 13). At the 28 sites where these objectives were not met, there were no minor departures from any individual effectiveness criteria (Table A-6). Major departures were most often associated with evidence of rilling into streams (22). Based on comments from field evaluators, adjacent roads and stream crossings appear to be the cause of poor effectiveness in many cases. Effects were classified as elevated at two sites (<3%) sites, one during each of the two monitoring periods. Effects at one of these sites were caused by a lack of BMP implementation, specifically failure to provide adequate soil cover. Heavy cattle use caused elevated effects at the site where BMPs were implemented.

2.4.4.10. Snow Removal (E17)

BMPs for snow removal were implemented 86% of the time from 1992 through 2002 (Figure 11). Implementation rates were considerably different between the 1992-1996 and 1997-2002 monitoring periods, decreasing from 94% to 77%. Of the 26 sites where BMPs were not implemented, minor and major departures occurred most often when snow removal standards in a contract or forest policy were not met (20 and six occurrences, respectively) (Table A-5). Specific problems included removal of the road surface during plowing, poor drainage due to lack of breaks in snow banks, plowing when the ground was too wet, and lack of an established prescription. Administrative phases of these activities were most problematic (Table 7).

During the composite monitoring period, these BMPs were effective 88% of the time that they were implemented (Figure 12). Effectiveness rates were relatively similar during the first and second monitoring periods. Considering all 180 sites monitored, effectiveness objectives for snow removal BMPs were met at 86% of the time (Figure 13). At the 25 sites where these objectives were not met, road surface rutting caused the most minor departures (17) (Table A-6). Major departures were related to sediment delivery to an SMZ or stream channel (24). No sites had effects categorized as elevated.

2.4.4.11. Pioneer Road Construction (E18)

BMPs for pioneer road construction were implemented and effective at the one site monitored in 2002 (Figures 11 and 12). No effects on beneficial uses were observed. This activity is relatively uncommon in the Region, so it is not possible to obtain large sample sizes. Twenty-five sites monitored between 1992 and 2001 were excluded from this analysis due to the issues described in Tables 3 and A-1. Upon completion of planned database work, analysis of these additional sites will provide more substantive results.

2.4.4.12. Restoration of Borrow Pits and Quarries (E19)

BMPs for restoration of borrow pits and quarries were implemented 77% of the time during the composite monitoring period (Figure 11). Results were not significantly different during the first and second monitoring periods. At the 15 sites where these BMPs were not implemented, minor and major departures resulted most often from a failure to treat the land surface as specified (six and nine occurrences, respectively) (Table A-5). Problems occurred most frequently during the administrative phase of projects (Table 7). Based on database comments, the lack of restoration plans for these areas was also problematic.

From 1992 through 2002, these BMPs were effective at 90% of the sites at which they were implemented (Figure 12). Effectiveness rates increased from 88% during the first monitoring period to 100% during the second. Considering all 64 monitored sites, effectiveness objectives were met 80% of the time (Figure 13). At the 13 sites where these objectives were not met, minor departures were most often associated with sediment delivery from work areas to SMZs or stream channels (3) (Table A-6). Major departures were most commonly the result of failure to meet road cover requirements (12), erosion below excavations (11), and sediment delivery to SMZs or stream channels (11). Effects were classified as elevated at two (3%) sites, both of which occurred during the first monitoring period. These effects were caused by poor BMP implementation, specifically the failure to stockpile soil and rip, seed, or mulch a site.

2.4.4.13. Management of Roads During Wet Periods (E20)

During the composite monitoring period, BMPs for managing roads during wet periods were implemented 92% of the time (Figure 11). These rates were slightly higher during the most recent monitoring period (96% vs. 90%). Failure to install closures as specified was the most common cause of minor departures (4) at the five sites where these BMPs were not implemented (Table A-5). Major departures occurred once for failure to close roads as specified and implement wet weather operations policies. Administrative phases of this activity were most problematic (Table 7).

When implemented, these BMPs were effective 89% of the time during the composite monitoring period (Figure 12). Effectiveness rates did not change between the two monitoring periods. Considering all 66 sites, effectiveness objectives were met 86% of time. At the nine sites where these objectives were not met, minor departures were most commonly associated with road surface rutting (3) (Table A-6). Rilling (4) and sediment delivery (8) to channels were the most frequent causes of major departures. No sites had effects ranked as elevated due to their extent, duration, and/or magnitude.

2.4.5. Recreation

BMP implementation and effectiveness was evaluated at 222 randomly selected recreation sites from 1992 through 2002. Results described below are based 176 of those sites because 46 evaluations for location of stock facilities in the wilderness (R23) were excluded for the reasons discussed previously (Tables 3 and A-1). Thirty-four of the 176 sites were analyzed quantitatively and the remaining 142 sites were qualitatively evaluated. Once ongoing database work is complete, inclusion of the additional R23 evaluations will provide more substantive results.

Recreation BMPs were implemented at 68% of the 34 sites analyzed quantitatively (Figure 14). Problems associated with BMP implementation at these sites occurred most frequently during the layout and administrative phases of the projects (Table 8). BMPs were effective at 89% of the sites at which they were implemented (Figure 15). Considering all 34 sites, effectiveness objectives were met 74% of the time (Figure 16).

Effects were classified for all 176 sites, whether they were analyzed quantitatively or qualitatively, based on their likely extent, duration, and/or magnitude. Elevated effects occurred at four (2%) of these sites.

TABLE 8: Phases during which problems occurred when BMPs were not implemented, Recreation.

Project Phase	R22	R30	All Recreation
Site Evaluation	1	0	1
Plan Prescription	0	0	0
Environmental Analysis	0	0	0
Permit/Operating Plan	*	*	0
Contract	0	0	0
Layout	0	6	6
Administration	1	4	5

2.4.5.1. Developed Recreation Sites (R22)

Only 2002 data for R22 could be analyzed quantitatively because of the issues described in Tables 3 and A-1. Consequently, the 1992-2001 data were analyzed qualitatively to evaluate performance during that time period. This evaluation was based on responses to individual implementation and effectiveness questions.

<u>2002 data</u>

BMPs for developed recreation sites were implemented 83% of the time in 2002 (Figure 14). At the three sites where BMPs were not implemented, minor departures were found once for washing within 100 feet of water and failure to meet SMZ protection, runoff control, and ground cover requirements (Table A-9). Only one major departure occurred. This was caused by a failure to provide adequate runoff control from impervious surfaces. No project phases were more problematic than others (Table 8).

FIGURES 14 & 15

FIGURE 16

These BMPs were effective at 80% of the sites at which they were implemented (Figure 15). Considering all 18 observation sites, effectiveness objectives were met 67% of the time (Figure 16). At the six sites where these objectives were not met, minor departures were most common for sediment delivery to stream channels (4) and ground cover criteria (3). Major departures occurred only once for failure to control runoff (Table A-10).

1992-2001 data

Tables A-11 and A-12 display the frequencies of responses to individual implementation and effectiveness questions at the 142 sites monitored between 1992 and 2001. At the majority of sites, most of the implementation criteria were met or did not apply. However, minor and major departures from requirements to keep substances that could degrade water quality greater than 100 feet away from watercourse occurred at 69% and 20% of sites, respectively. There also appear to be some effectiveness problems, since major departures associated with cleaning or washing at hydrants and faucets and sediment delivery to stream channels were found at 18% and 21% of sites, respectively. Many developed recreation sites were sited and developed prior to formal adoption of BMPs. This may be a cause of some of the problems noted above.

Effects were classified for all 160 sites, whether they were analyzed quantitatively or qualitatively. Elevated effects were observed at four (<3%) sites, three of which occurred during the 1992-1996 monitoring period. Elevated effects were caused by poorly maintained roads at three sites and heavy foot traffic at one site.

2.4.5.2. Location of Stock Facilities in the Wilderness (R23)

Data from this evaluation have been excluded from this report for the reasons described in Tables 3 and A-1. This data will be quantitatively analyzed and reported once ongoing database work is completed.

2.4.5.3. Dispersed Recreation Sites (R30)

BMPs for dispersed recreation sites were implemented 50% of the time since this protocol was first applied in 1999 (Figure 14). At the eight sites where BMPs were not implemented, minor departures most commonly resulted from failures to meet refuse disposal (5) and ground cover criteria (6) and provide SMZ protection (5)(Table A-9). Major departures occurred once for sanitation facilities and groundcover criteria and once for failure to visit the site to evaluate water quality impacts. Problems with implementation of these BMPs occurred most frequently during the layout and administrative phases of projects (Table 8).

These BMPs were effective at 100% of the sites at which they were implemented (Figure 15). Considering all 16 monitored sites, effectiveness objectives for these BMPs were met 81% of time (Figure 16). At the three sites where these objectives were not met, major departures were found for water quality degradation from human waste, animal waste, or sediment (Table A-10). No sites had effects that were classified as elevated due to their extent, duration, and/or magnitude (Table 5).

2.4.6. Grazing

From 1992 through 2002, BMP implementation and effectiveness was evaluated at 152 different grazing sites. Due to the issues described in Tables 3 and A-1, no quantitative results are currently available for this activity. The monitoring protocol was revised in 2001 to address these issues and pilot testing of the draft revisions began in 2002. This pilot testing identified other concerns that need to be resolved before the protocol is finalized. Resolution of these issues and completion and implementation of the revised protocol is scheduled for 2005 or 2006.

Despite these problems, qualitative analysis of results from the 1992-2001 monitoring was possible. Based on responses to individual implementation and effectiveness questions (Table A-13), there were modest problems with implementation of these BMPs. No sites had major departures for any of the individual implementation criteria, but a large percentage of sites had minor departures from requirements to conduct site-specific range analyses (70%) and stock counts (50%). Attaining effectiveness criteria was less successful (Table A-14). Major departures from streambank disturbance criteria, for example, occurred at 18% of sites and minor departures occurred at 48% of sites. While these data indicate that streambank disturbance associated with grazing warrants continued attention, they should be viewed with caution because the methods used to obtain the data have since been determined to provide inconsistent results. Achieving riparian ground cover objectives was also problematic, with major and minor departures present at 11% and 25% of sites, respectively. However, caution is also warranted in applying these results, because they are inconsistent with those of Weixelman (2003).

Effects were classified as elevated at five (<4%) sites, three of which occurred during the second monitoring period. Based on comments from field observers, these effects appear to have been caused by a lack of adequate BMP implementation. Specifically, they resulted from exceeding the number of allowable cattle on an allotment, salting too close to water, inadequate monitoring of cattle, and excessive streambank trampling from grazing a site too long.

2.4.7. Prescribed Fire

BMPs for prescribed fire (F25) were implemented 77% of the 250 sites evaluated during the composite monitoring period (Figure 17). Implementation rates fell from 79% to 74% between the first and second monitoring periods. Problems with implementation of these BMPs occurred most frequently during development of the burn prescription and the burn itself (Table 9). At the 59 sites where BMPs were not implemented, minor and major departures from requirements to consider water quality protection measures in the burn plan prescription and to implement those measures occurred with similar frequencies (Table A-15).

FIGURES 17 & 18

FIGURE 19

TABLE 9: Phases during which problems occurred when BMPs were not implemented, Prescribed Fire.

Project Phase	F25
Site Evaluation	0
Burn Prescription	27
Burn	23
Mop up	1
Patrol	0

From 1992 through 2002, these BMPs were effective at 98% of the sites at which they were implemented (Figure 18). Effectiveness rates were relatively similar during the 1992-1996 and 1997-2002 monitoring periods. Considering all 254 observation sites, effectiveness objectives for prescribed fire BMPs were met 96% of the time (Figure 19). At the 10 sites where these objectives were not met, minor departures were most common for hydrophobic soils (4) and upslope rilling (3) criteria (Table A-16). Sediment discharge to the channel (6), upslope rilling (6) and upslope ground cover (7) were the criteria for which major departures were most frequent. Based on their extent, duration, and/or magnitude, effects were classified as elevated at one (<1%) site. These effects were caused by inadequate BMP implementation, specifically the failure to provide adequate ground cover on a project in 1997.

2.4.8. Mining

BMP implementation and effectiveness was evaluated at 181 different mining sites from 1992 through 2002. No quantitative results are available for these activities due to the issues described in Tables 3 and A-1. However, quantitative results from eight M26 evaluations conducted in 2002 and all 93 M27 evaluations will be reported once ongoing database work is complete. Results from a qualitative analysis of the M26 data collected from 1992 through 2001 is provided below.

2.4.8.1. Mining Operations, Locatable Minerals (M26)

Individual implementation criteria were met or exceeded at most sites monitored from 1992 through 2001, or these criteria did not apply (Table A-17). Major departures were found at 5% to 8% of sites, depending on the criterion. Implementing required erosion control work and completing this work prior to the wet season were most problematic. Major or minor departures from individual effectiveness criteria were found at a relatively high percentage of sites (Table A-18). Major departures associated with erosion and sediment delivery to streams from dumps, excavations, and fillslopes were most problematic, occurring at 15%-19% of monitored sites. Effects were considered elevated at one (1%) site (Table 5) that was observed during the first monitoring period. These effects were caused by inadequate BMP implementation, specifically the lack of environmental analysis and operating plans.

2.4.8.2. Common Variety Minerals (M27)

Once ongoing database work is complete, all results for M27 will be quantitatively analyzed and presented in subsequent reports.

2.4.9. Vegetation Management

BMP implementation and effectiveness evaluations were conducted at 188 randomly selected sites where vegetation management activities had occurred from 1992 through 2002. On average, these BMPs were implemented 87% of the time (Figure 20). Implementation rates increased from 84% to 91% between the first and second monitoring periods. For all vegetation management activities combined, problems associated with BMP implementation most frequently occurred during the administrative phases of projects (Table 10).

During the composite monitoring period, these BMPs were effective 89% of the time that they were implemented (Figure 21). Effectiveness rates were relatively similar between the first and second monitoring periods. Considering all 188 sites, effectiveness objectives were met 87% of the time (Figure 22). Due to their extent, duration, and/or magnitude, effects were classified as elevated at one (<1%) site. Details regarding individual vegetation management BMPs are provided in the sections that follow.

TABLE 10: Phases during which problems occurred when BMPs were not implemented, Vegetation Management.

Project Phase	V28	V29	All Vegetation Management
Site Evaluation	0	2	2
Plan Prescription	1	1	2
Environmental Analysis	5	1	6
Contract	4	2	2
Layout	1	2	3
Administration	4	10	14

2.4.9.1. Vegetation Manipulation (V28)

From 1992 through 2002, BMPs for vegetation manipulation were implemented 90% of the time (Figure 20). Implementation rates were similar between the 1992-1996 and 1997-2002 monitoring periods. At the 10 sites where BMPs were not implemented, minor departures most commonly resulted from failures to include in the project plan or contract the soil and water quality protection measures identified in environmental documents (3) and failure to implement these provisions as prescribed (3) (Table A-19). Major departures were most often related to failures to identify soil and water quality protection measures in environmental documents (5), failure to include these in project plans or contracts (4), and failure to apply treatments to prescribed areas (4). Problems with implementation of these BMPs most commonly occurred during the environmental analysis, contract, and administrative phases of projects (Table 10).

FIGURES 20 & 21

FIGURE 22

When implemented, these BMPs were effective 98% of the time during the composite monitoring period (Figure 21). Effectiveness rates were similar during the first and second monitoring periods. Considering all 99 sites, effectiveness objectives were met 96% of the time (Figure 22). At the four sites where these objectives were not met, minor departures were most common for rilling criteria (2) (Table A-20). Major departures were most often related to sediment discharge to a stream channel (3) and failure to meet ground cover objectives (3). No effects were classified as elevated due to their magnitude, extent, and/or duration (Table 5).

2.4.9.2. Revegetation of Surface Disturbed Areas (V29)

BMPs for revegetation of surface disturbed areas were implemented 84% of the time from 1992 through 2002 (Figure 20). Between the first and second monitoring periods, these rates increased from 80% to 93%. Minor and major departures at the 15 sites where BMPs were not implemented were most often caused by failures to implement the revegetation requirements specified in environmental documents (nine and three occurrences, respectively) (Table A-19). Administrative phases of projects were most problematic (Table 10).

When implemented, these BMPs were effective 80% of the time during the 1992-2002 monitoring period (Figure 21). These rates were relatively similar during the 1992-1996 and 1997-2002 monitoring periods. Considering all 89 sites, effectiveness objectives were met 78% of the time (Figure 22). At the 20 sites where these objectives were not met, minor departures were most common for soil surface cover criteria (7) and sediment delivery to stream channels (6) (Table A-20). Major departures were most common for the same criteria (10 and 14, respectively). Effects were considered elevated at one (1%) site, which was observed during the 1992-1996 monitoring period. These effects were caused by pre-existing erosion problems that the project was unable to address.

2.5. Discussion, Issues, and Corrective Actions

2.5.1. Program Management

While some improvements are necessary, overall, the USFS Region 5 water quality management program performed reasonably well during the 1992-2002 monitoring period and improvements have been made in recent years. BMP implementation and effectiveness were fairly high for most activities and elevated effects on water quality and beneficial uses of water were relatively infrequent. In addition, both the BMPs and the BMPEP have been expanded and improved since monitoring results were last reported in 1998. Specifically, the Region's BMPs were updated in 2000 based on an interdisciplinary review comprised of staff from the USFS Regional Office and forests, the SWRCB, and various Regional Water Quality Control Boards (RWQCBs). There have also been considerable improvements to the BMPEP, including the addition of protocols for road decommissioning and dispersed recreation, enhancements to existing protocols, and database upgrades.

While monitoring declined throughout the Region in 2000, it rebounded in 2001 and 2002 due to increased emphasis on this program from the Regional Forester, the Regional Leadership Team (Regional Forester, Deputy Regional Foresters, Regional Staff Directors, and Forest Supervisors), Forest Resource Staff Officers, and Forest Hydrologists. Monitoring results indicate that there is a statistically significant relationship between BMP implementation and effectiveness for 16 of the 29 monitoring protocols. An increase in the number of protocols with a demonstrated statistical relationship is expected once ongoing database modifications are complete.

For all activities combined, BMPs were implemented 85% of the time from 1992 through 2002 and were effective at 92% of the sites at which they were implemented. There were no major differences in implementation and effectiveness rates between the first and second monitoring periods. BMP implementation rates were 85% or higher for all functional areas except recreation and prescribed fire, which were 68% and 77%, respectively. They were 80% or higher for all but four forests and 75% or greater for all but one Forest. BMP effectiveness rates were 89% or greater for all functional areas. All forests had effectiveness rates of 82% or higher and 13 forests had rates of 90% or greater.

From 1992 through 2002, there were relatively few sites (78, 2%) where effects on water quality were classified as elevated due to their magnitude, extent, and/or duration. Most of these were associated with engineering practices (46, <3% of engineering sites). Consistent with published research (e.g., Gucinski 2001) and other related monitoring programs (e.g., CDF 2002), roads were the most problematic. This was particularly true for those activities near or connected to watercourses (e.g., stream crossings). Twenty of the elevated effects were associated with timber (<2% of timber sites), four were observed at recreation sites (<3%), and one was caused by a prescribed fire (<1%). One was observed at a mine (1%), one occurred at a vegetation management site (<1%), and five were related to grazing (<4%).

Actions needed to maintain and improve this level of performance are described in Tables 11-17.

TABLE 11: Issues and Corrective Actions, Program Management

P-1	
Issue	With the recent recovery since 2000, the amount of BMP monitoring being conducted meets expectations at a Regional scale. Ongoing emphasis on the program is needed to ensure these improvements are maintained. Analysis and reporting of monitoring results from the Regional Office and some forests has not met expectations described in the Management Agency Agreement (MAA) between the Forest Service and the SWRCB. This is necessary to ensure timely identification and correction of water quality problems.
Corrective Action	The Regional Office and forests will monitor, analyze, and report results consistent with the MAA. The Regional Office will provide this direction to forests via the FY 2005 budget direction and additional memoranda, as needed.
Status	FY 2005 budget direction will be provided when Congress approves the 2005 budget appropriation.

Priority	1
P-2	
Issue	The BMPEP was developed by interdisciplinary teams from the Forest Service with extensive input from regulatory agencies, industry, environmental groups, and other interested parties. However, the program has never been externally peer-reviewed. A peer review is desirable because: 1) RWQCB staffs have requested it to determine whether there are any program deficiencies; and 2) the Forest Service plans to begin implementing this monitoring program nationally and it would be beneficial to identify needed improvements before this occurs.
Corrective Action	The Regional Office will conduct an external peer-review of the BMPEP and incorporate changes as appropriate.
Status	In September 2004, the Regional Office signed a contract with Dr. Lee MacDonald from Colorado State University to peer review the BMPEP. A final report is expected in January 2006. The BMPEP will be modified thereafter, as needed.
Priority	1
P-3	
Issue	Periodic training for all staff areas is needed to ensure BMPs are implemented and effective.
Corrective Action	Forests will develop and implement routine BMP training. The Angeles, Plumas, Shasta-Trinity, and Tahoe national forests will place particular emphasis on this training since BMP implementation rates on these forests were lower than 80% during the 1992-2002 monitoring period.
Status	BMP training will occur on each Forest by the end of 2006.
Priority	1
P-4	
Issue	There is a potential for inconsistent implementation of the BMP monitoring program due to staff turnover and protocol changes.
Corrective Action	The Regional Office and forests will develop and implement an interdisciplinary training and Quality Assurance (QA)/Quality Control (QC) program for BMP monitoring, including application of the protocols and field forms and use of the BMPEP database.
Status	Three training sessions on use of the new BMPEP database were held between May and July 2003. The Region will develop a training and QA/QC program in 2005 and begin its implementation in 2006.
Priority	1

P-5	
Issue	Despite significant improvements to the BMPEP database, additional work is needed. This work will allow for eventual quantitative analysis of some of the data excluded from this report (Tables 3 and A-1).
Corrective Action	The Regional Office will implement needed database work and subsequently report results associated with the data excluded from this report.
Status	Additional database work was initiated in 2003 and will be completed in early 2005. Results associated with these data will be included in future reports.
Priority	1
P-6	
Issue	Without a standard method for evaluating the implementation and effectiveness of off-highway vehicles (OHV) BMPs, it is not possible to evaluate the performance of OHV program at a Regional scale.
Corrective Action	The Regional Office and forests will develop and implement a standard OHV monitoring protocol.
Status	A draft protocol was developed and initial field tests were conducted in summer 2004. The protocol is currently being modified based on results from those tests and final field tests will be conducted in 2005. Regional implementation of the final protocol will begin in 2006. Database modifications to accommodate the new protocol will be made in 2005 or 2006.
Priority	1
P-7	
Issue	The protocol for grazing was significantly modified in 2001 to address previously identified shortcomings. Nonetheless, additional concerns were identified during pilot testing and discussions with other resource specialists. Consequently, the new protocol not been finalized and implemented.
Corrective Action	The Regional Office will complete the revision of this protocol based on the pilot testing. Once the revision is complete, forests will implement the new protocol.
Status	The revised protocol will be finalized in 2005. Implementation will begin in 2005 or 2006.
Priority	1
P-8	
Issue	The SWRCB and RWQCBs have expressed a desire for monitoring programs beyond the existing Onsite Evaluations ("hillslope monitoring").
Corrective Action	The Regional Office and forests will implement monitoring programs to compliment the BMPEP Onsite Evaluations as issues arise and funding permits.
Status	As described in Section 3 of this report, several other monitoring projects and programs, including stream monitoring, have been implemented throughout the Region to compliment the BMPEP Onsite Evaluations. Together, these additional

	programs address a range of monitoring issues including validation of BMP effectiveness, compliance with regulatory standards, assessment of conditions and trends in water quality and aquatic resources, and development and validation cumulative watershed effects (CWE) models.
Priority	2
P-9	
Issue	Inability to complete crossing reconstruction work within the normal operating season and failure to account for wet-weather (fall-spring) erosion control measures during project planning on the Shasta-Trinity National Forest resulted in issuance of a Clean Up and Abatement Order (No. 99-77) in Fall 1999. Although limited impairment to beneficial uses of water were observed during subsequent monitoring, notable problems associated with meeting the SWRCB/USFS Management Agency Agreement surfaced as a direct result of this project. They included: (1) communication barriers between the USFS and the North Coast Regional Water Quality Control Board (Regional Board); (2) lack of full inclusion of BMPs into project design and contracts; and (3) insufficient interdisciplinary awareness of the USFS's responsibilities as a Water Quality Management Agency.
Corrective Action	a) National forests in the North Coast Region (Mendocino, Shasta-Trinity, Klamath, Six Rivers, and Modoc) and the North Coast RWQCB developed and are implementing an Interagency Action Plan to address these issues. b) The Shasta-Trinity National Forest complied with the Clean Up and Abatement Order (No. 99-77) and Time Schedule Order No. R1-2000-21.
Status	a) The Action Plan continues to be implemented with positive results, including improved relationships between the North Coast RWQCB and USFS and strengthened water quality programs on the national forests in the North Coast Region. b) The Shasta-Trinity National Forest complied with the Clean Up and Abatement Order (No. 99-77) and Time Schedule Order No. R1-2000-21.
Priority	1

2.5.2. Timber Management

Overall, the timber program performed well during the 1992-2002 monitoring period. Implementation and effectiveness rates were relatively high (87% and 94%, respectively). Relatively few timber sites (20, <2%) had water quality effects rated as elevated and none of these effects were observed after 1998. Nonetheless, improvement is needed in some areas. Specifically, overall implementation rates fell from 89% during the first monitoring period to 85% during the second. These decreases were primarily caused by decreases in implementation rates for SMZs (T01) and skid trails (T02). While implementation rates for timber sale administration (T05) also decreased, these are not of significant concern because they were based on a relatively small sample size and implementation rates for these BMPs remain high. Additional details are provided in Table 12.

TABLE 12: Issues and Corrective Actions, Timber Management

T-1	
Issue	While BMP implementation rates for SMZs (83%) were not particularly problematic during the composite monitoring period, they decreased from 86% to 80% between the first and second monitoring periods. In addition, effectiveness rates decreased from 89% to 82%. This raises some concerns, since proper management of SMZs is one of the most important aspects of water quality protection.
Corrective Action	a) Through a variety of means (e.g., formal direction, program reviews, site visits, annual meetings), the Regional Office will direct Timber Sale Administrators to emphasize these BMPs, particularly during layout and administration. Earth Scientists will focus on these BMPs during the timber sale planning and contract development process and use the results presented in this report to improve performance. To enhance BMP implementation, forests will concentrate on following SMZ width criteria, adhering to SMZ prescriptions, and excluding mechanical equipment. Forests will focus on limiting streambank disturbance and meeting ground cover objectives to enhance BMP effectiveness. b) Forests will emphasize these practices during their BMP training sessions. c) More monitoring will be focused on this activity. d) Forests will continue to comply with the recently adopted RWQCB timber harvest waivers. This is expected to improve BMP implementation for this activity, since the waivers require interdisciplinary review of projects.
Status	a) Timber program reviews were conducted on six national forests in 2004. Five or six additional forests will be reviewed in 2005. Also in 2005, Sale Administrator certification exams, Sale Inspector certification exams, and Sale Administrator maintenance inspections will occur on several forests. The Regional Office staff director responsible for Timber Management has identified BMP implementation, particularly pertaining to SMZ protection, skid trails, and landings, as emphasis items for Sale Administrators during these reviews and inspections. Preliminary BMPEP monitoring results and associated corrective actions were presented at the Regional Forest Management Conference on April 28, 2004.

	b) BMP training will occur on each Forest by the end of 2006. c) Monitoring targets for this activity were increased in 2004. d) Forests continue to implement the RWQCB waivers and have been reminded of their requirements in a variety of formal and informal ways.
Priority	1
T-2	
Issue 2	While implementation rates for skid trails (T02) from 1992 through 2002 were acceptable (84%), they declined from 86% to 81% between the 1992-1996 and 1997-2002 monitoring periods. Relatively few timber activities had elevated effects on water quality, but skid trails represented a substantial percentage of those sites.
Corrective Action	a) See T-1. b) BMP implementation and effectiveness will be improved by emphasizing proper skid trail location and drainage and erosion control. Particular focus will be placed on the layout and administration phases of projects.
Status	See T-1.
Priority	1
T-3	
Issue 3	Implementation and effectiveness rates of landing BMPs (T04) were not particularly problematic. In addition, relatively few timber activities had elevated effects on water quality. Nonetheless, landings represent a substantial percentage of those sites.
Corrective Action	a) See T-1. b) To improve BMP implementation, forests will emphasize proper landing location, drainage (e.g., placement of waterbars), and stabilization, especially during layout and administration. Interdisciplinary teams (IDT) will be encouraged to consider using contract clauses that provide for special erosion control and prevention [C(T)6.602] near watercourses and on unstable terrains. IDTs will also be directed to exercise caution when reusing existing landings that may not have been optimally located, designed, or constructed.
Status	a) See T-1. b) Monitoring targets for this activity will be increased in 2005.
Priority	1

2.5.3. Engineering

In general, the performance of the engineering program from 1992 through 2002 was satisfactory. BMPs were implemented at 85% of monitored sites and were effective 89% of the time. Effects classified as elevated were relatively infrequent (46, <3% of sites), but occurred more often than in most other program areas. Road-related BMPs, especially road surface drainage and slope protection and stream crossings were the most problematic and accounted for most of these effects. Specific issues and corrective actions associated with engineering practices are described in Table 13.

TABLE 13: Issues and Corrective Actions, Engineering

E-1	
Issue	Implementation and effectiveness rates of road surface drainage and slope protection BMPs (E08) were not particularly problematic. However, these activities represented a disproportionately large percentage of the sites with elevated effects on water quality.
Corrective Action	a) Watershed and roads analysis will continue to be used to identify opportunities to reduce the amount of inadequately maintained roads, where problems are more likely to occur. b) The Regional Office will continue to emphasize road maintenance and as appropriate, decommissioning, by placing a high priority on these projects through the Ten Percent Roads and Trails (TRTR) and deferred maintenance funding processes. Forests will continue to focus attention and resources on these BMPs. Specifically, forests will continue internal pooling of engineering, fisheries, and watershed funding with external grants to implement road restoration projects (e.g., over the past several years, forests have used matching USFS funds to obtain several million dollars per year in road restoration grants from various outside sources). c) Through technology transfer (e.g., USFS Water/Roads Interaction products), site visits, functional assistance trips, and program reviews, the Regional Office will continue to disseminate information and specific examples of good and poor road construction and maintenance practices to the forests. d) These practices will be emphasized in BMP training. e) More monitoring will be focused on this activity.
Status	a) Watershed and roads analysis continue to be implemented throughout the Region. All Forests have completed a forest-level roads analysis. Forests have conducted watershed analysis on 71 watersheds comprising 7.4 million acres in CA. Analyses for an additional 28 watersheds covering 3 million acres are planned or underway. b) Project proposal requests for 2007 TRTR and deferred maintenance funding will be sent to the forests in 2005. These will continue to emphasize watershed improvement and correction of passage problems for aquatic organisms. Congressional earmarks were also used to address anadromous fish passage issues in FY 2003 and 2004. This focus will continue if these earmarks remain in 2005. c) Informal Regional Office reviews and Functional Assistance Trips for road system

	operation and maintenance occurred on the Sequoia, Stanislaus, Eldorado, Plumas, Klamath, San Bernardino, and Mendocino national forests in FY 2004. Informal reviews will be conducted on at least five national forests in FY 2005 along with any Regional Office Directors' reviews that may be scheduled. As opportunities and issues arise, the Regional Office continues to disseminate information and specific examples of good and poor road construction and maintenance practices to the forests. d) BMP training will occur on each Forest by the end of 2006. e) Monitoring targets for this activity were increased in 2004. A combined hillslope/instream BMP validation study (see Section 3.2) that addresses this activity was initiated in 2004.
Priority	1
E-2	
Issue	Implementation and effectiveness rates for stream crossings (E09) were fairly high from 1992 through 2002 (85% and 88%, respectively). However, activities related to road crossings represented a disproportionately large percentage of the sites with elevated effects on water quality and many of these occurred during the most recent monitoring period (1997-2002).
Corrective Action	See E-1.
Status	See E-1.
Priority	1
E-3	
Issue	While implementation rates for water source development (E16) increased from 74% to 86% between the first and second monitoring periods, effectiveness rates remain low and declined between the first and second monitoring periods. Roads appear to be the cause of poor effectiveness in many cases.
Corrective Action	a) See E-1 (a) through (e).
Status	a) See E-1 (a) through (d). b) Monitoring targets for this activity were increased in 2004.
Priority	2
E-4	
Issue	Implementation rates for in-channel construction (E13) were inadequate (71%). While these quantitative rates are based on a small sample size (n=24), the inherent risk associated with these activities warrants additional attention.
Corrective Action	a) See P-5.

	b) See E-1 items (c), (d), (e).
Status	a) See P-5. b) See E-1 items (c), (d), (e).
Priority	2
E-5	
Issue	During the 1992-2002 monitoring period, implementation rates for snow removal (E17) were acceptable (86%). However, these rates declined substantially between the first and second monitoring periods (94% to 77%).
Corrective Action	a) Forests will review all existing snow removal contracts to ensure that applicable water quality requirements have been included. Contract modifications will be made as necessary. Water quality provisions will be emphasized to contractors through formal and informal correspondence. Contracting Officers will be reminded that all new contracts must contain needed water quality provisions. b) More monitoring will be focused on this activity.
Status	a) Forests will review snow removal contracts in 2005 and make any required changes in 2006. Water quality provisions pertaining to snow removal will be emphasized to contractors prior to winter of 2004-2005. b) Monitoring targets for this activity were increased in 2004.
Priority	2
E-6	
Issue	Implementation of BMPs for restoration of borrow pits and quarries (E19) needs improvement.
Corrective Action	These practices will be emphasized during engineering and mining program reviews and in BMP training. In particular, the need to develop and implement restoration plans will be stressed.
Status	BMP training will occur on each Forest by the end of 2006.
Priority	2

2.5.4. Recreation

Overall, BMP implementation rates for recreation were fairly low (68%) during the composite monitoring period. However, it is not clear whether these results are representative of the program. Many evaluations were excluded from this report due to the issues described in Tables A-1 and 3. The low rates for recreation practices as a whole were driven by poor implementation of dispersed recreation BMPs. Results also show that these BMPs were generally effective when they were implemented. Effects were classified as elevated at four (2%) recreation sites, which were caused by roads at all but one site. It is suspected that many of the problems associated with these sites were due to the fact that they were developed prior to today's standards (e.g., buffer widths). Specific issues and actions needed to improve execution of the water quality components of recreation activities are provided in Table 14.

TABLE 14: Issues and Corrective Actions, Recreation

R-1	
Issue	See E-1.
Corrective Action	See E-1.
Status	See E-1.
Priority	1
R-2	
Issue	a) At developed recreation sites, major departures from requirements to exclude substances that could affect water quality from within 100 feet of watercourses were found 20% of the time. Minor departures occurred at 69% of sites. Washing of food and animals wastes at hydrants and faucets was found at 18% of sites and sediment delivery to stream channels occurred 21% of the time.
Corrective Action	a) Concessionaires will be formally informed of requirements to exclude possible contaminants from with 100 feet of water and to avoid washing of food and animal wastes near hydrants and faucets. Concessionaires will be encouraged to notify the public, through a variety of means (e.g., signage), to adhere to these requirements. Developed sites will be assessed for possible sediment sources and site-specific remedies during reauthorization of special use permits. The Capital Improvement Program (CIP) or other means will be used to address sites where major investments are necessary to meet all BMP requirements. b) Forests will emphasize these BMPs during their training sessions.
Status	a) Concessionaires will be notified via letter in 2005. Developed sites will be assessed for possible sediment sources and site-specific remedies during reauthorization of special use permits, which varies by site. CIP project proposals will be submitted as needed.

	b) BMP training will occur on each Forest by the end of 2006.
Priority	2
R-3	
Issue	Implementation rates for dispersed recreation BMPs (R30) were low (50%). The sample size for this activity is small because the protocol was just recently developed and implemented. It is therefore unclear whether these results represent isolated cases or if implementation problems are more extensive.
Corrective Action	a) Forests will emphasize these BMPs in their training sessions. b) More monitoring will be focused on this activity so that additional data are available to determine if BMP implementation problems for this activity are widespread.
Status	a) BMP training will occur on each Forest by the end of 2006. b) Monitoring targets for this activity will be increased in 2005.
Priority	2

2.5.5. Grazing

As previously described, quantitative analysis of grazing BMPs was not possible. However, based on a qualitative analysis, there appear to be modest problems associated with implementation of these BMPs. Attaining some of the effectiveness criteria, including streambank disturbance and riparian ground cover, may also be problematic. However, as described elsewhere (Table A-1), streambank disturbance and riparian cover data should be viewed with caution because the methods used have been determined to provide inconsistent results. Few (5, <4%) sites had potentially significant water quality effects. More specifics regarding these issues are described in Table 15.