Summary Report

2000 S.B. 271 Watershed Assessment and Erosion Prevention Planning Project for the Redwood Creek watershed, Marin County, California Contract # P9985121

prepared for

Muir Beach Community Services District,
California Department of Fish and Game,
Marin Municipal Water District
and
National Park Service

by

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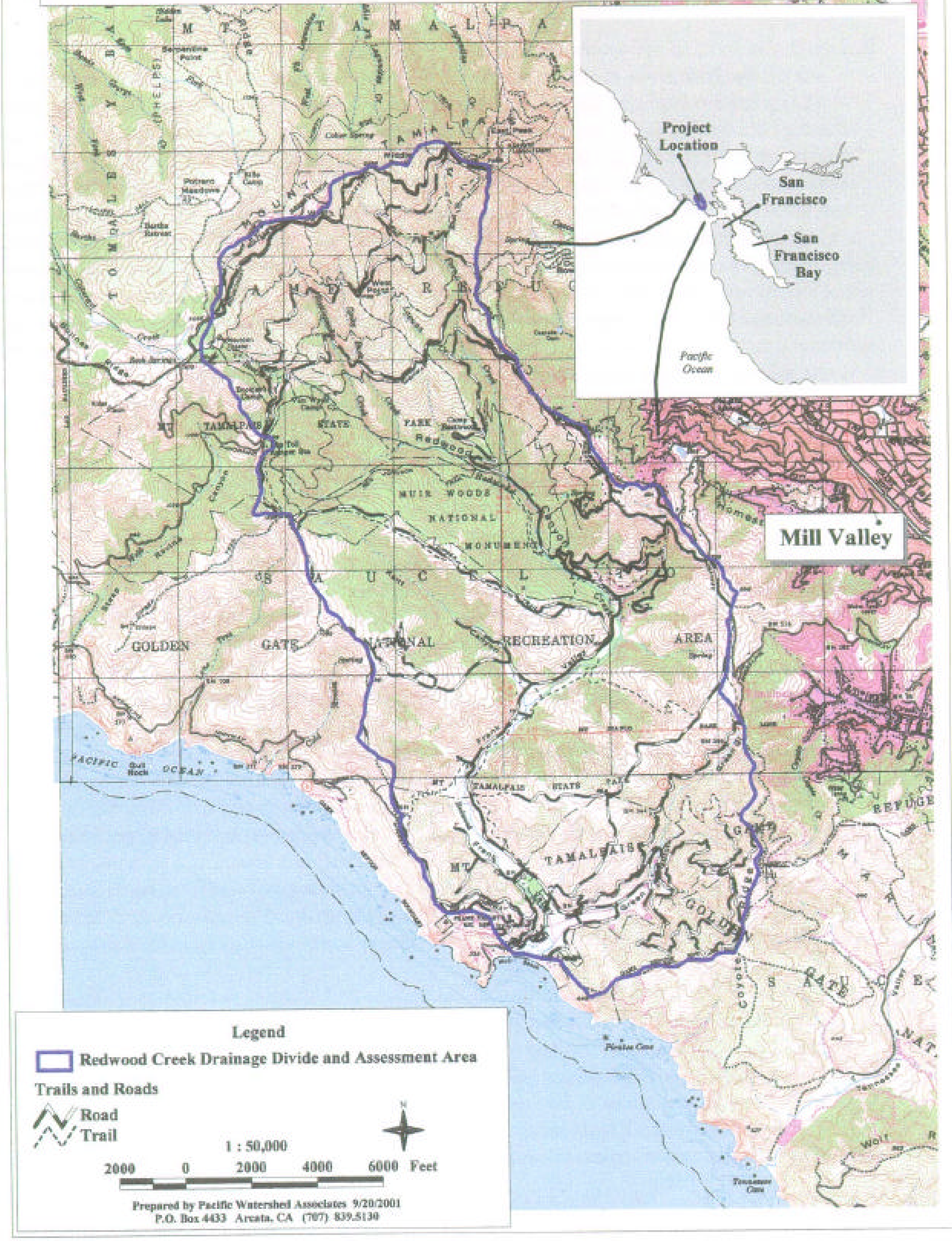
Introduction

Redwood Creek is one of the more productive and restorable anadromous fish streams within Marin County. Redwood Creek drains directly to the Pacific Ocean at Muir Beach approximately 6.5 miles northwest of San Francisco (Figure 1). This watershed is one of four major streams in the county that currently support native populations of Coho salmon and Steelhead trout. Approximately 7 miles of stream channel are utilized by anadromous salmonids in this 7.5 square mile watershed.

The Redwood Creek Watershed Group was organized to provide an informative, educational forum to discuss ecological concerns within the watershed. This group has representatives from all major land owners and land managers in the watershed. These include: Marin Municipal Water District, Mt. Tamalpais State Park, National Park Service, Green Gulch Farm and Muir Beach Community Services District. The group's concerns that road and trail maintenance, unsuccessful erosion control, and anthropogenic sedimentation were causing serious disturbance to aquatic habitats prompted the group to seek out the services of a consultant to provide an evaluation of sediment sources that are impacting fish habitat in the watershed.

Pacific Watershed Associates (PWA) was contracted by the Muir Beach Community Services District and the California Department of Fish & Game (CDFG) to complete a sediment source assessment and prepare a prioritized erosion prevention plan for 67 miles of roads and trails within the Redwood Creek Watershed. This project was funded through a CDFG S.B. 271 watershed restoration grant (Contract # P9985121) and was supplemented by funding through the National Park Service and Marin Municipal Water District. This project was specifically aimed at identifying future erosion sources that are impacting fish bearing streams and to develop prescriptions aimed at reducing sediment input to the watershed. This project was <u>not</u> concerned with those erosional features that are not delivering sediment to the stream network.

Figure 1. Project location map for Redwood Creek watershed, Point Bonita and San Rafael 7.5' USGS quadrangles, Marin County, CA



Redwood Creek watershed assessment

Perhaps the two most important elements needed for long term restoration of salmon habitat, and the eventual recovery of salmonid populations in the Redwood Creek watershed, are 1). the reduction of accelerated erosion and sediment delivery to the stream channel system and 2). improving estuarine rearing habitat. The latter is a very complex problem influenced by tectonic activity in the watershed, among other factors. In relation to reducing the effects of past and current land management practices on sediment production, this summary report describes the erosion assessment and inventory process that was employed in the Redwood Creek watershed. It also serves as a prioritized plan-of-action for cost-effective erosion control and erosion prevention treatments for 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 or potentially limiting factor to fisheries production, as is thought to be the case for Redwood Creek).

Road systems and trail systems (to a lesser extent) are perhaps the most significant and most easily controlled sources of sediment production and delivery to stream channels. Redwood Creek is underlain by erodible and potentially unstable geologic substrate, and both field observations and aerial photo analysis suggests that roads have been a significant source of accelerated sediment production in the watershed. In Redwood Creek, as in many other coastal watersheds, the disturbance caused by 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, trails 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 and trails have 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, 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 treatment immediacy in Redwood Creek have been identified as high priority for implementation so that fill failures, stream crossing erosion, washouts, ditch relief gully erosion and stream diversions do not degrade the stream system.

The completed assessment identified all recognizable current and future sediment sources from roads and trails within the watershed. The field inventory identified future sediment sources from approximately 27 total miles of highway, secondary and fire roads, as well as 40 miles of trail system in the watershed. The primary objective of the road and trail upgrading and decommissioning recommendations which have been prepared, is to implement cost-effective erosion control and erosion prevention work on sites that were identified as a part of this comprehensive watershed assessment and inventory. This assessment is also intended to be used as a tool for basin wide transportation planning in which the ecological impacts of specific roads and trails can be balanced against the needs for transportation, management, fire safety and public access.

Project Description

The watershed assessment process consisted of three distinct project elements. These included: 1) a historic air photo analysis of timber harvesting, landsliding, road construction and trail construction history for the watershed (beginning in 1943), 2) a complete field inventory of all future road and trail related sediment sources along 67 miles of roads and trails in the watershed, and 3) an inventory of sediment sources along approximately 7 miles of Class I streams in the watershed.

In the first phase of the Redwood Creek inventory project all roads and trails within the study area were identified and age dated from historic aerial photography (Map 1 and Table 1). Aerial photographs were analyzed to identify the location and approximate date of construction. A composite map of the road and trail system in the watershed was developed from GIS base maps provided by The National Park Service and Marin Municipal Water District. The composite map depicts the primary road and trail network in the watershed and was used as the base map for showing the location of sites with future erosion and sediment delivery to the stream system.

The only modern (post 1947) timber harvesting that occurred in the watershed was in Kent Canyon between 1953 and 1965. During this time period, approximately 1300 acres of old growth redwood forest was selectively logged using tractor yarding techniques. Based on the air photo analysis, the logging area had 20 - 30% of the canopy removed. Nearly 2 miles of roads and at least that many miles of skid trails were constructed for use during these logging activities. Since this period there have been no additional large scale commercial logging activities.

The second project element involved a complete field inventory of the road and trail systems in the watershed. 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 roads and trails, including both maintained and abandoned routes, were walked and inspected by trained personnel and all existing and potential sediment delivery sites were identified and described. Sites, as defined in this 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.

Inventoried sites generally consisted of stream crossings, potential and existing landslides related to the road or trail system, 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

1:8,000 scale aerial photograph. The database form (Figure 2) contained questions regarding the site location, the nature and magnitude of existing and potential erosion problems, the likelihood of erosion or slope failure and recommended treatments to eliminate the site as a future source of sediment delivery.

Table 1. Land management and landsliding for six photo periods, Redwood Creek watershed assessment area, Marin County, California.

Photo date	Road and trail[1] construction (mi)	Road and trail building rate (mi/yr)	Landslides (#)[2]	Landslide type
prior to 1947	58	NA	0	NA
1948 to 1952	0	0	1	1 debris landslide
1953 to 1965	5.0	0.4	2	2 debris landslides
1966to 1970	0	0	0	NA
1971 to 1982	4	0.3	9	8 debris landslides, 1 debris flow
1983 to 2000	0	0	5	3 debris landslides, 2 debris flows
Totals	67	1.3	17	17

[1] Some historic trail construction dates from Mt. Tamalpais History Project taken from *A Rambler's Guide To The Trails Of Mt. Tamalpais.* Several trails with no historical account and which are not visible in air photos have uncertain construction dates.
[2] It is likely that a number of small landslides were missed due to poor photo quality and/or incomplete coverages in the early photo year sets. Visibility difficulties in the intact old growth canopy of forested slopes also made landslide identification difficult.

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 easily exceed field predictions. All sites were assigned a treatment priority, based on their potential or likelihood to deliver sediment to stream channels in the watershed and 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

Figure 2. Road erosion inventory data form used in the Redwood 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** (3/98 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:							

quantification of future erosion volumes (assuming the stream crossing was to wash out during a future storm), decommissioning volumes (assuming the road was to be closed) and/or excavation volumes that would be required to complete a variety of road upgrading and erosion prevention treatments (culvert installation, culvert replacement, complete excavation, etc.).

In the final phase of the watershed assessment project, the main stem of Redwood Creek and a short segment (0.66 mi) of Fern Creek was inventoried for bank erosion sites and stream side landslides. Data was collected on the location and volume of sediment sources along approximately 7.5 miles of Class I stream channels. The channel survey procedures, results and recommendations are detailed in Appendix A. Data collected included the type of erosional process, the current activity level, the volume of sediment delivery, and applicable treatment prescriptions at sites where work has been recommended. In addition, erosion sites and general channel characteristics were mapped on mylar overlays over 1:8,000 scale aerial photos.

As will be shown by this assessment, the net benefit of treating the legacy of risk associated with road sediment delivery to streams exceeds, by orders of magnitude, the sediment impacts associated with trail or streambank erosional processes.

Inventory Results

Approximately 27 miles of roads and 40 miles of trails were inventoried for future sediment sources within the Redwood Creek watershed. Inventoried future erosion sites fell into one of two treatment categories: 1) upgrade sites - defined as sites on maintained roads or trails that are to be retained for access and management and 2) decommission sites - defined as sites exhibiting the potential for future sediment delivery that have been recommended for either temporary or permanent closure. Virtually all future road and trail related erosion and sediment delivery in the Redwood Creek watershed is expected to come from four sources: 1) the failure of road fills (landsliding), 2) erosion at or associated with stream crossings (from several possible causes), 3) road surface and ditch erosion, and 4) gully erosion below ditch relief culvert outlets.

Part 1: Road-related sites

Site types

A total of 282 sites were identified along 27 miles of road with the potential to deliver sediment to streams. Of these, 259 sites were recommended for erosion control and erosion prevention treatment. Approximately 48% (n=135) of the sites are classified as stream crossings, 37% (n=105) as ditch relief culverts, and 4% (n=11) as potential landslides. The remaining 11% (n=31) of the inventoried sites consist of Aother@ sites which include road reaches, springs, etc. (Table 2).

Stream crossings - One hundred thirty five (135) stream crossings were inventoried in the Redwood Creek assessment area including 118 culverted crossings, 14 unculverted fill crossings, and 3 bridges. An unculverted fill crossing refers to a stream crossing with no formal drainage structure to carry the flow through the road prism. Flow is either carried beneath or through the fill, or it flows over the road surface, or it is diverted down the road to the inboard ditch. Most unculverted fill crossings are located at small Class III streams that exhibit flow only in the larger runoff events. If the crossing has been made temporary or decommissioned by removing the majority of the fill, then these crossings are commonly known as Apulled@ or decommissioned crossings.

Approximately 38,250 yds^3 of future road-related sediment delivery in the Redwood Creek assessment area could originate from erosion at stream crossings, if the crossings were to wash out (Table 2). This amounts to nearly 53% of the total expected future sediment yield from the

Table 2. Site classification and sediment yield from all inventoried road sites with future sediment delivery in the Redwood Creek watershed, Marin 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)
Landslides	11	11	2,198	NA	NA	NA
Stream crossings	135	128	38,250	97	9	85
Ditch relief culverts	105	91	2,457	NA	NA	NA
Other	31	29	896	NA	NA	NA
Total (all sites)	282	259	43,801	97	9	85
Persistent surface erosion[1] (non-paved)	12.6	12.3	19,292	NA	NA	NA
Persistent surface erosion[2] (paved)	11.6	10.4	9,500	NA	NA	NA
Totals	**282**	**259**	**72,593**	**97**	**9**	**85**

[1] Assumes 20' wide road prism and cutbank contributing area, and 0.2' of road/cutbank surface lowering per decade over a two decade period.
[2] Assumes 20' high cutbank contributing area, and 0.2' of surface lowering per decade on Panoramic Dr. Assumes 15' high cutbank area, and 0.2' of surface lowering per decade on Highway 1 and Muir Woods road between Panoramic Dr. and Muir Woods National Monument. Assumes 5' high cutbank area, and 0.2' of surface lowering per decade on all remaining paved roads.

road system. Not all these crossings can be expected to wash out, but over long periods of time many will experience repeated episodes of partial erosion, stream diversion or complete failure. The rate of failure will be higher for crossings which are abandoned or for those which are not designed to current standards.

The most common problems which lead to erosion at stream crossings include: 1) crossings with undersized culverts, 2) crossings with culverts that are likely to plug, 3) stream crossings with a diversion potential and 4) crossings with 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 to the 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 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 Adiversion 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 135 stream crossings inventoried in the Redwood Creek watershed, 97 have the potential to divert in the future and 9 streams are currently diverted at stream crossing sites (Table 2).

Three road design conditions indicate a high potential for future erosion at stream crossings. These include 1) undersized culverts (the culvert is too small for the 100-year design storm flow), 2) culverts that are prone to plugging with sediment or organic debris and 3) stream crossings with a diversion potential. 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 in the Redwood Creek watershed assessment area.

Approximately 95% (n=128) of the stream crossings inventoried in the Redwood Creek assessment area will need to be upgraded for the roads to be considered Astorm-proofed.@ For example, 63% of the existing culverts have a Amoderate@ to Ahigh@ plugging potential and nearly 72% 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 constructing critical dips (rolling dips) at 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, and installing debris barriers and/or downspouts to prevent culvert plugging and outlet erosion, respectively.

Ditch relief culverts - Only those ditch relief culverts that currently deliver or will potentially deliver sediment to streams in the future were inventoried in this project. One hundred five (105) ditch relief culverts with potential sediment delivery were identified and these cumulatively account for approximately 4% of the inventoried sites in the Redwood Creek assessment area. 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 functional downspouts. Ditch relief culverts are expected to deliver approximately 2,457 yds^3 of sediment to Redwood Creek and its tributaries in the future. Correcting or reducing sediment delivery associated with ditch relief culverts generally involves dispersing excessive ditch flow by installing additional ditch relief culverts, installing rolling dips and outsloping roads. Reducing outlet erosion below these sites involves installing functional downspouts as well as replacing ditch relief culverts deeper in the fill.

Landslides - Only those landslide sites with a potential for sediment delivery to a stream channel were inventoried. Eleven (11) potential landslides were identified and these account for approximately 4% of the inventoried sites in the Redwood Creek assessment area (Table 2). Most of the potential landslide sites were found along roads where material had been sidecast during earlier construction and now shows signs of instability. Potential landslides are expected to deliver nearly 2,198 yds^3 of sediment to Redwood Creek and its tributaries in the future. Correcting or preventing potential landslides associated with the road is relatively straightforward, and involves the physical excavation of potentially unstable road fill and sidecast materials. Four (4) potential landslides will occur along public highway routes. Currently, road width is insufficient at these sites to allow unstable road fill to be excavated without compromising driver safety. Therefore, these sites will need to have an engineered fill constructed in order to prevent road slip outs and sediment delivery to the stream network while maintaining sufficient road width.

There are a number of potential landslide sites located in the Redwood Creek assessment area 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 overlays of the aerial photographs, but only those with the potential for future sediment delivery were inventoried using a data sheet (Figure 2).

AOther@sites - We estimate 896 yds^3 of sediment will be delivered to streams from the 31 Aother@ specific sites inventoried in Redwood Creek (Table 2 and Map 2). 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.

In the Redwood Creek assessment area, we measured approximately 24.2 miles of road surface and/or road ditch (representing 91% of the total inventoried road mileage) which currently drain directly to streams and deliver ditch and road runoff and sediment to stream channels. These roads are said to be Ahydrologically connected@ to the stream channel network. 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.

From the 24.2 miles of Aconnected@ road segments, we calculated over 28,792 yds^3 of sediment will be delivered to stream channels in the Redwood 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, rainfall, freeze-thaw processes, 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.

Relatively straight forward 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 and/or installation of 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 transportation planning, as well as identify and prioritize erosion prevention, erosion control and road decommissioning activities in the watershed. 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 potential or Alikelihood@ for future erosion (erosion potential - high, moderate, low),
3) the Aurgency@ of treating the site (treatment immediacy - high, moderate, low),
4) the ease and cost of accessing the site for treatments, and
5) recommended treatments, logistics and costs.

The ***erosion potential*** of a site is a professional evaluation of the likelihood that future 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 AHigh@, AModerate@ or ALow.@ 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 Atreatment 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 Aquickly@ perform erosion control or erosion prevention work. It is also defined as AHigh@, AModerate@ and ALow@ 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 AHigh@. *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.

One other factor influencing a site=s treatment priority is the difficulty (cost and environmental impact) of reaching the site with the necessary equipment to effectively treat the potential erosion. Many sites found on abandoned or unmaintained roads require brushing and tree removal to provide access to the site(s). Other roads require minor or major road rebuilding of washed out stream crossings and/or existing landslides in order to reach potential work sites farther out the alignment. Road reconstruction adds to the overall cost of erosion control work and reduces project cost-effectiveness. Potential work sites with lower cost-effectiveness, in turn may be of relatively lower priority. However, just because a road is abandoned and/or overgrown with vegetation is not sufficient reason to discount its need for assessment and potential treatment. Treatments on heavily overgrown, abandoned roads may still be both beneficial and cost-effective.

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 $2000 to develop access and treat an eroding stream crossing that would have delivered 500 yds^3 (had it been left to erode), the predicted cost-effectiveness would be \$4/yds^3 (\$2000/500yds^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 predicted cost-effectiveness value averaging in the general range of approximately \$5 to \$15/yds^3, or less. 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. During road decommissioning, groups of sites are usually considered together since there will only be one opportunity to treat potential sediment sources along the road. In this case, cost-effectiveness may be calculated for entire roads or road reaches that fall into logical treatment units.

Cost-effectiveness can be used as a tool to prioritize potential treatment sites throughout a sub-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 a predicted marginal cost-effectiveness value (>$\$15/yds^3$), 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 Aerosion-proofing@ program. However, these sites should be addressed during future road reconstruction (when access is reopened into areas for future management activities), 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 50- or 100-year storm. In contrast, properly decommissioned roads are closed and no longer require maintenance. Generic treatments for decommissioning roads and landings range from outsloping or simple cross-road drain construction, to full road decommissioning (closure), including the excavation of unstable and potentially unstable sidecast materials, road fills, and all stream crossing fills. The characteristics of storm-proofed roads, including those which are either upgraded or decommissioned, 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), removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of road surface runoff. Road drainage techniques include berm removal, road outsloping, rolling dip construction, and/or the installation of ditch relief culverts. The goal of all treatments is to make the road as Ahydrologically invisible@ as is possible.

Along some low strength road routes, re-rocking or repaving the road following stream crossing upgrading, installation of ditch relief culverts, rolling dip construction and road outsloping or insloping will often be necessary. These activities will incorporate pre-existing road rock into the new road shape design, thereby providing some road bed strength and stability. However, this often may not be enough material to provide safe passage in the winter months. Predicting the total amount of new road rock required can be difficult but, at a minimum, rock or pavement should be applied at all newly constructed rolling dips and culvert locations on roads which are currently rocked or paved and are proposed for upgrading and winter use.

FIGURE 3. CHARACTERISTICS OF STORM-PROOFED ROADS

The following abbreviated criteria identify common characteristics of Astorm-proofed@ roads. Roads are Astorm-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 Aguidelines@ can occur at specific sites within a forest or ranch road system.

STREAM CROSSINGS

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

ROAD AND LANDING FILLS

U unstable and potentially unstable road and landing fills are excavated (removed)
U excavated spoil is placed in locations where eroded material will not enter a stream
U excavated spoil is placed where it will not cause a slope failure or landslide

ROAD SURFACE DRAINAGE

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

General heavy equipment treatments for ***road decommissioning*** have been tested, described and evaluated (Moll, 1996; Harr and Nichols, 1993; Weaver and others, 1987; Weaver and Sonnevil, 1984; Weaver and Hagans, 1996 and 1999). Decommissioning essentially involves Areverse road construction,@ except that full topographic recontouring of the road bed is <u>not</u> normally required to accomplish erosion prevention and sediment reduction goals. While full recontouring of the original topography may not be necessary to obtain sediment delivery reduction, it is likely to be a desirable goal in a park setting. Additional costs can be added to supplement sediment delivery treatment costs to achieve these desired goals. Appendix B. has been included to help estimate the costs that would be involved for full recontouring of a given road segment. In order to protect the aquatic ecosystem, the goal is to Ahydrologically@ decommission the road; that is, to minimize the effect of the road on natural hillslope and watershed runoff. From least intensive to most intensive, decommissioning work will include at least some of the following tasks (Table 3 also lists a number of possible heavy equipment decommissioning treatments and their typical applications):

1. *Road ripping or decompaction*, in which the surface of the road is "decompacted" or disaggregated using mechanical rippers (usually ripping teeth mounted on the back of a bulldozer). This action reduces surface runoff and often dramatically increases revegetation rates.

2. *Waterbars and cross-road drains* are installed at 50, 75, 100 or 200-foot intervals, or as necessary at springs and seeps, to disperse road surface runoff, especially on roads that are to be decommissioned. Cross-road drains are large ditches or trenches excavated across a road surface to provide drainage and to prevent the collection of concentrated runoff on the former road bed. They are typically deeper than waterbars and do not allow for vehicle access.

3. *In-place stream crossing excavation* is a decommissioning treatment that is employed at locations where roads were built across stream channels. The fill (including the culvert) is completely excavated and the original stream bed and side slopes are exhumed (uncovered). Excavated spoil is stored at nearby stable locations where it will not erode, sometimes being pushed several hundred feet from the crossing by tractor(s). A stream crossing excavation typically involves more than simply removing the culvert, as the underlying and adjacent fill material must also be removed and stabilized.

4. *Exported stream crossing excavation (ERX)* is a decommissioning treatment where stream crossing fill material is excavated and spoil is hauled off-site for storage. Spoil is moved farther up- or down-road from the crossing, due to the limited amount of stable storage locations at the excavation site. This treatment frequently requires dump trucks to end-haul spoil material to the off-site location.

5. *In-place outsloping (IPOS)* ("pulling the sidecast") calls for excavation of unstable or potentially unstable sidecast material along the outside edge of a road prism or landing, and replacement of the spoil on the roadbed against the adjacent cutbank, or within several hundred feet of the excavation site. Placement of the spoil material against the cutbank usually blocks access to the road and is used in road decommissioning. In road upgrading, or where a decommissioned road is to be rebuilt in the future, the excavated material can be used to build up the road bed and convert an insloped, ditched road to an outsloped road. Otherwise, you=ll need to haul the spoil away to a disposal site (see below).

6. *Exported outsloping (EOS)* is comparable to in-place outsloping, except spoil material is moved off-site to a permanent, stable storage location. Where the road prism is very narrow, where there are springs along the road cutbank, or where continued use of the road is anticipated, spoil material is typically not placed against the cutbank and material is end-hauled to a spoil disposal site. This treatment frequently requires dump trucks to end-haul spoil material. This is typically a decommissioning treatment as part or all of the roadbed is removed.

Table 3. Sample heavy equipment techniques for decommissioning roads

Treatment	Typical equipment	Typical use or application
Ripping or decompaction of road bed	D-7 or D-8 size bulldozer with rear-mounted hydraulic ripper	improve infiltration; decrease runoff; assist revegetation
Construction of rolling dips and cross-road drains	D-6 or D-7 size bulldozer	drain springs; drain insloped roads; drain landings
Partial outsloping (local spoil site; fill against the cutbank)	Hydraulic excavator and bulldozer	remove minor unstable fills; disperse cutbank seeps and runoff
Complete outsloping (local spoil site; fill pushed up against the cutbank)	Hydraulic excavator and bulldozer	used for removing unstable fill material where nearby cutbank is dry and stable
Exported outsloping (fill hauled away and stored down-road at a stable site)	Hydraulic excavator and dump trucks; bulldozer at spoil site	used for removing unstable road fills where cut banks have springs and cannot be buried
Landing or turnout excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	used to remove unstable material around landing perimeter
Stream crossing excavations (usually with local spoil storage)	Hydraulic excavator and bulldozer	complete removal of stream crossing fills (not just culvert removal)
Truck end-hauling of spoil materials	Hydraulic excavator and bulldozer	hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream

Only in relatively few instances does road decommissioning have to include full recontouring of the original road bed. One exception would be park lands where full topographic recontouring is likely to be a desirable goal. Typically, potential problem areas along a road are isolated to a few locations (perhaps 10% to 20% of the road to be decommissioned) where stream crossings need to be excavated, unstable landing and road sidecast needs to be removed before it fails, or roads cross potentially unstable terrain and the entire prism needs to be removed. Most of the remaining road surface simply needs permanently improved surface drainage, using decompaction, road drains and/or partial outsloping. The road surface should receive revegetation treatments in locations where eroded sediment could be delivered to a stream (such as the side slopes to excavated stream crossings), but in the cool coastal setting much of the decommissioned alignment can be left to naturally revegetate from nearby seed sources. Labor intensive (hand labor) erosion control treatments are often needed on sites where heavy equipment has been used to perform road decommissioning. Hand labor is used to stabilize and revegetate soils exposed by heavy equipment operations. Only the most effective and cost-effective labor techniques have been prescribed. These include mulching, seeding and planting.

In general, heavy equipment will perform most of the significant erosion prevention and erosion control work in drainage basins and along road networks.

Successfully decommissioning roads in the Redwood Creek watershed can cost substantially less than complete or total topographic road obliteration, and can be significantly less expensive than road upgrading and continued long term maintenance. Costs are highly dependent on the frequency and nature of the potential erosion problems along the alignment, and on the frequency, type, condition and size (volume) of stream crossings.

Treatments

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of potential sources of road-related sediment delivery. Table 4 and Map 3 outline the treatment priorities for all 259 inventoried road-related sites with future sediment delivery that have been recommended for treatment in the Redwood Creek watershed assessment area. Appendix C. has been included as a supplement to table 4. This appendix enables determination of road name and property ownership associated with specific site numbers, sorted by treatment immediacy. Of the 259 sites with future sediment delivery, 47 sites were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 14,867 yds^3. One hundred fifty three (153) sites were listed with a moderate or moderate-low treatment immediacy and these account for nearly 26,779 yds^3 of future sediment delivery. Finally, 58 sites were listed as having a low treatment immediacy with approximately 2,155 yds^3 of future sediment delivery.

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 Ajump 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 5 outlines the proposed work according to treatment immediacy by road in the Redwood Creek watershed. Only the most Asite-rich@ roads have been listed. Those roads with the greatest total potential yield are listed first.

Table 6 summarizes the proposed treatments for sites inventoried on all roads in the Redwood Creek assessment area, including both the upper and lower watershed areas. These prescriptions include both upgrading and road closure measures. 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, tractor, dump truck, grader and/or backhoe.

Some hand labor is required at sites needing new culverts, downspouts, culvert repairs, trash racks and/or for applying seed, plants and mulch following ground disturbance activities. It is estimated that erosion prevention work will require the excavation of approximately 8,472 yds^3 at 54 sites. Approximately 78% of the volume excavated is associated with upgrading or properly decommissioning stream crossings and nearly 22% of the volume is proposed for excavating potentially unstable road fills (landslides). A total of 40 yds^3 of 0.5 to 1.5 foot diameter mixed and

Table 4. Treatment priorities for all inventoried road sediment sources recommended for treatment in the Redwood Creek watershed assessment area, Marin County, California

Treatment Priority	Upgrade sites (# and site #)	Decommission sites (# and site #)	Problem	Future sediment yield (yds^3)[1]
High	**7** (site #: 40, 41, 52, 139, 185, 203, 204)	**2** (site #: 194, 205)	8 stream crossings, 1 ditch relief culvert	1,925
Moderate High	**36** (site #: 50, 56, 57, 58, 59, 63, 66, 78, 79, 90, 94, 102, 104, 106, 107, 108, 118, 119, 127, 129, 137, 141, 143, 152, 154, 159, 180, 181, 182, 188, 215, 216, 231, 258, 265, 266)	**2** (site #: 245, 249)	23 stream crossings, 1 landslide, 11 ditch relief culverts, 3 other	12,942
Moderate	**70** (site #: 5, 6, 8.1, 10, 20.1, 28, 29, 30, 31, 33, 36, 37, 39, 42, 45, 46, 48, 49, 53, 55, 60, 62, 68, 68.1, 74, 80, 89, 91, 95, 100, 101, 109, 110, 115.4, 125, 132, 133, 138, 140, 144, 146, 149, 151, 153, 157, 163, 167, 174, 176.1, 176.3, 177, 189, 190, 202, 209, 212, 213, 226, 232, 236, 238, 242, 251, 253, 256, 257, 262, 263, 268, 272)	**8** (site #: 115.2, 193, 199, 200, 240, 246, 248, 267)	44 stream crossings, 6 landslides, 18 ditch relief culverts, 10 other	16,477
Moderate Low	**69** (site #: 4, 6.1, 7, 8, 10.1, 11, 12, 13, 21, 27, 32, 34, 43, 47, 61, 64, 65, 71, 75, 77, 81, 82, 83, 85, 87, 88, 111, 113, 115, 121, 122, 123, 124, 128, 130, 142, 145, 147, 148, 155, 156, 161, 164, 170, 172, 175, 176, 183, 186, 187, 192, 197, 201, 206, 208, 210, 211, 214, 218, 222, 225, 227, 237, 252, 259, 260, 261, 264, 274.1)	**6** (site #: 195, 250.1, 250.2, 250.3, 270, 273)	34 stream crossings, 4 landslides, 31 ditch relief culverts, 6 other	10,302
Low	**56** (site #: 1, 2, 9, 14, 20, 22, 23, 24, 25, 26, 35, 38, 44, 51, 54, 67, 69, 70, 72, 73, 76, 84, 86, 92, 96, 97, 98, 99, 103, 114, 115.3, 117, 120, 126, 131, 135, 136, 162, 166, 168, 171, 178, 184, 191, 196, 198, 207, 217, 223, 224, 239, 250, 269, 270.1, 274, 275)	**3** (site #: 116, 247, 271)	19 stream crossings, 30 ditch relief culverts, 10 other	2,155
Total	**238**	**21**	**128 stream crossings, 11 landslides, 91 ditch relief culverts, 29 other**	**43,801**

[1] Future sediment yield does not include persistent surface erosion.

clean rip-rap sized rock will be needed to construct 3 proposed armored wet crossings and to armor one (1) outboard fill face (Table 6). At 99 stream crossing sites, we have recommended replacing or installing new culverts designed for the 100 year storm. We have recommended 278 rolling dips be constructed at selected locations along the road network, at spacings dictated by the steepness of the road. A minimum of 123 new ditch relief culverts are recommended to be installed along the inventoried road routes to disconnect ditches from streams. Some proposed rolling dips can be replaced with additional ditch relief culverts at the discretion of the landowner, but there will be increased costs due to the need to purchase the culvert.

Treatment Conclusions

All the treatment recommendations listed in this report have the specific aim of reducing sediment delivery to the watershed=s stream network. These treatments will be effective at minimizing sediment delivery, and are generally the minimum, most cost effective prescriptions necessary to achieve this goal. Additional treatment activities might be considered at the time of implementation to meet broader park management goals. Broader park management goals may include, but are not limited to, full ecological restoration, restoration of native plant communities, successional processes, natural drainage patterns that provide diversity, wildlife habitat improvements, natural creek function and maintaining visually intact landscapes. Some additional treatment activities that are not necessary for sediment delivery reduction but may complement park goals to reduce impacts on natural resources are listed below.

$ Rerouting or abandoning problematic sections of roads or trails when the original alignment is so poor that it will never be sustainable.
$ The use of more extensive outsloping, with dips at small topographic drainage features, and elimination of as much inboard ditch as possible, rather than extensive use of rolling dips.
$ Removal of ditch relief culverts that are no longer functional after outsloping.
$ Addition of drain lenses and armored drains that may be used to drain springs and seeps which are bisected by a road or trail.
$ The use of culvert headwalls constructed of quick-crete sacks either independently or in addition to flaired inlets.
$ Complete topographic obliteration on decommission roads where no threat of sediment delivery exists.

These treatments listed above were considered as options if sediment delivery to a stream channel was a possibility, however our recommended treatments are the most effective and cost effective prescription. There are an infinite number of treatment possibilities that may appeal to park management goals. Specific treatments unrelated to sediment delivery reduction are up to park resource planners to incorporate at the time of implementation. Appendix B. lists a range of costs for some treatments that may appeal to park management goals. When the individual projects are actually in the proposal phase, we can assist managers with applying the additional costs in the appendix B to meet other park goals

Table 5. Treatment priorities for all inventoried sediment sources in the Redwood Creek watershed by road, Redwood Creek watershed assessment area, Marin County, California.

Road name	Treatment priority and future sediment yield								Total number of sites (#)	Future yield from sites (yds³)	Future yield from persistent surface erosion (yds³)	Total future yield (yds³)
	High and High moderate		Moderate		Moderate low		Low					
	Sites (#)	Future yield (yds³)	Sites (#)	Future yield (yds³)	Sites (#)	Future yield (yds³)	Sites (#)	Future yield (yds³)				
Panoramic	**10**	3,210	**10**	4,408	**10**	2,753	**6**	669	36	11,040	3,386	14,426
Alice Eastwood	**5**	5,485	**6**	4,414	**3**	109	**3**	61	17	10,069	474	10,543
Hwy 1	**1**	183	**6**	1,412	**11**	3,130	**6**	666	24	5,391	2,818	8,209
Muir Woods (upper)	**3**	189	**4**	1,650	**8**	1,635	**4**	268	19	3,742	1,546	5,288
West Point	**2**	2,224	**5**	466	**1**	118	**2**	49	10	2,857	1,394	4,251
Old Stage	**6**	454	**6**	256	**5**	158	**6**	48	23	916	2,612	3,528
Camino Del Canyon	**5**	443	**3**	508	**4**	290	**2**	30	14	1,271	1,598	2,869
Muir Woods (lower)	**3**	794	**4**	560	**5**	348	**8**	87	20	1,789	540	2,329
Deer Park	**1**	52	**4**	108	**6**	92	**2**	22	13	274	3,320	3,594
Green Gulch (roads)	**2**	247	**5**	453	**4**	45	**4**	45	15	790	1,612	2,402
Middle Green Gulch	**1**	78	**2**	58	**3**	373	**1**	23	7	532	1,770	2,302
Old RR Grade	**2**	606	**2**	235	**0**	0	**1**	4	5	845	1,124	1,969
Conlin	**3**	308	**3**	843	**1**	31	**0**	0	7	1,182	400	1,582
Kent Canyon	**2**	162	**2**	143	**3**	558	**2**	41	9	904	540	1,444
Ridgecrest	**0**	0	**7**	661	**4**	125	**7**	31	18	817	608	1,425

Table 5. Treatment priorities for all inventoried sediment sources in the Redwood Creek watershed by road, Redwood Creek watershed assessment area, Marin County, California.

Road name	Treatment priority and future sediment yield								Total number of sites (#)	Future yield from sites (yds^3)	Future yield from persistent surface erosion (yds^3)	Total future yield (yds^3)
	High and High moderate		Moderate		Moderate low		Low					
	Sites (#)	Future yield (yds^3)	Sites (#)	Future yield (yds^3)	Sites (#)	Future yield (yds^3)	Sites (#)	Future yield (yds^3)				
Coastal (north and south)	**0**	0	**2**	135	**2**	139	**0**	0	4	274	1,586	1,860
Diaz Ridge	**0**	0	**1**	24	**2**	123	**1**	13	4	160	1,380	1,540
Old Service	**1**	432	**0**	0	**1**	243	**1**	10	3	685	178	863
Banducci	**0**	0	**3**	53	**1**	8	**1**	4	5	65	466	531
Total	**47**	**14,867**	**75**	**16,387**	**74**	**10,278**	**57**	**2,071**	**253**	**43,603**	**27,352**	**70,955**

Table 6. Recommended treatments along all inventoried roads in the Redwood Creek watershed assessment area, Marin County, California.

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	39	To prevent stream diversions	Outslope road and retain ditch	6	Outslope and retain ditch along 490 feet of road to improve road surface drainage
Install CMP	4	Install a CMP at an unculverted fill	Install rolling dips	278	Install rolling dips to improve road drainage
Replace CMP	95	Upgrade an undersized CMP	Remove berm	9	Remove 2,080 feet of berm to improve road surface drainage
Excavate soil	54	Typically fillslope & crossing excavations; excavate a total of 8,472 yds^3	Install ditch relief CMP	123	Install ditch relief culverts to improve road surface drainage
Trash rack	8	Install trash rack to protect inlet from plugging	Inslope road	1	Inslope road along 240 feet of road to improve road surface drainage
Install bridge	0	Install bridge at stream crossing	Remove ditch	2	Remove 48 feet of ditch to improve road surface drainage
Flared inlet	11	Install flared inlet to increase culvert capacity	Install cross road drains	27	Install cross road drains to improve road drainage
Down spouts	31	Installed to protect the outlet fillslope from erosion	Clean/cut ditch	7	Clean/cut 280 feet of ditch
Wet crossing	3	Install 1 rocked ford and 2 armored fill crossings using 10 yds^3 rip-rap	Rock road surface	48	Rock road surface using 581 yds^3 road rock (includes 21 yds^3 at 5 road surface locations, 260 yds^3 at 13 stream crossing upgrades, 20 yds^3 at 2 ditch relief culverts and 280 yds^3 at 28 rolling dips.)
Clean CMP	16	Remove debris and/or sediment from CMP inlet	Armor fill face	1	Armor outboard fill face using 30yds^3 rip-rap
Reconstruct fill	4	Re-construct fill using engineered fix	Other	19	Miscellaneous treatments
Outslope road and remove ditch	51	Outslope and remove ditch along 25,215 feet of road to improve road surface drainage	No treatment recommended	23	

Special considerations regarding problematic roads

Several roads within the Redwood Creek watershed will be difficult to treat for sediment reduction and road maintenance. These difficulties arise from inherent problems associated with road location, poor construction techniques and/or hydrologic influence from adjacent county and state highways.

Both Deer Park Fire Road and Diaz Ridge Road were constructed on the ridge tops using through-cut construction techniques. This particular type of construction does not allow for proper drainage of the road surface and becomes more difficult to treat as annual grading practices and erosion continue to exacerbate the problem. Treatment prescriptions pertaining to these two roads will largely alleviate sediment delivery to stream channels but there will be continued chronic road maintenance problems that cannot be addressed with our basic treatment prescriptions. Park managers may consider, for maintenance purposes, road obliteration and realignment as an option. Obviously many issues (fire safety, road maintenance, sediment delivery, public access, rescue access, etc) would need to be weighed to consider this option.

Another road segment that becomes problematic to treat is Alice Eastwood Drive. The road segment between Panoramic Drive and Fern Creek crossing is receiving excessive road and ditch runoff from Panoramic Drive above. Ditch relief culverts from Panoramic Drive are piping excessive runoff down to Alice Eastwood Drive and this is causing significant fluvial erosion below ditch relief culvert outlets on Alice Eastwood Drive. Treatment prescriptions on Panoramic Drive will reduce runoff downslope but due to the excessively large drainage collection area created by the current drainage design on Panoramic Drive alignment, it becomes very difficult to disperse this runoff without major changes to the engineered road design. Treatment prescriptions on this Alice Eastwood road segment maintained the assumption that there would be continued runoff from above and continued fluvial erosion below ditch relief culvert outlets. Along the remaining segment of Alice Eastwood Drive the recommended treatments should largely eliminate sediment delivery.

Sites not recommended for erosion control treatment

As of 2001, seven stream crossings, fourteen ditch relief culverts and two Aother@ sites of the 282 sites of future sediment delivery identified in the Redwood Creek watershed assessment have not been recommended for treatment. These sites are correctly designed for the 100-year flood flow and / or have no other potential erosion problems that need to be repaired.

Equipment Needs and Costs

Treatments for the 259 sites identified with future sediment delivery in the Redwood Creek assessment area will require approximately 1,891 hours of excavator time and 1,840 hours of tractor time to complete all prescribed upgrading, road closure, erosion control and erosion prevention work (Table 7). 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. Approximately 336 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 1,074 hours of labor time is needed for a variety of tasks such as installation or replacement of culverts, installation of debris barriers and downspouts, and 120 hours are for seeding, mulching and planting activities. Roughly 56 hours of grader time is necessary to apply road surface treatments including outsloping.

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 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 $1,151,278 for an average cost-effectiveness value of approximately $15.86 per cubic yard of sediment prevented from entering Redwood Creek and its tributaries (Table 8). It should be noted that costs to re-rock or re-pave the entire upgraded road system following implementation of the proposed storm-proofing activities are not 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 Tables 7 and 8, 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 Asite,@ 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 to determine total equipment costs as shown in Table 8. Finally, the estimated equipment time needed to reconstruct or open roads which have been abandoned are listed as a separate line item in Table 8.

The costs in Table 8 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 and road decommissioning operations. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended treatments conform to guidelines described in AThe 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. It should also be noted that approximately 40% of the road length inventoried was on paved county roads and state highways where engineers may need to be involved in the design of upgrade work. Extra costs could include safety flagging, repaving, painting, guard rails, etc. This could add a significant cost to completing the proposed work.

Table 8 lists a total of 818 hours for Asupervision@ 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. It is expected that the project coordinator will be on-site full time at the beginning of the project and intermittently after equipment operations have begun.

Table 7. Estimated heavy equipment and labor requirements for treatment of all inventoried road sites with future sediment delivery, Redwood Creek assessment area, Marin County, California. [1]

Treatment Immediacy	Site (#)	Excavated Volume (yds^3)	Excavator (hrs)	Tractor (hrs)	Dump Trucks (hrs)	Grader (hrs)	Backhoe (hrs)	Labor (hrs)
High, High/Moderate	47	13,614	597	575	151	12	0	253
Moderate, Low/Moderate	153	21,980	1,103	1,143	185	39	20	639
Low	59	1,489	191	122	0	5	2	182
Total	**259**	**37,083**	**1,891**	**1,840**	**336**	**56**	**22**	**1,074**

[1] Equipment and labor times do not include hours necessary for road opening, travel between sites, and straw mulch activities.

Part 2: Trail-related sites

Site types

A total of 215 sites were identified along 40 miles of trail with the potential to deliver sediment to streams. Of these, 121 sites were recommended for erosion control and erosion prevention treatment. Approximately 87% (n=188) of the sites are classified as stream crossings, 2% (n=5) as ditch relief culverts, and 10 % (n=22) of the inventoried sites consist of Aother@ sites which include trail reaches, springs, etc. (Table 9).

Stream crossings - One hundred eighty-eight (188) stream crossings were inventoried in the Redwood Creek trail assessment area including 17 culverted crossings, 21 unculverted fill crossings, 80 bridges, 31 fords, and 39 armored fills. Many of the stream crossings identified in the trail portion of the assessment were armored fills, bridges and fords. These stream crossing types are generally the preferred design for trails.

Approximately 683 yds^3 of future trail-related sediment yield in the Redwood Creek assessment area could originate from erosion at stream crossings, if the crossings were not treated and they washed out (Table 9). This amounts to nearly 20% of the total expected future sediment yield from the trail system. Not all identified trail crossings can be expected to wash out, but over long periods of time many will experience repeated episodes of partial erosion and/or stream diversion, or complete failure.

The most common problems which lead to erosion at trail stream crossings include: 1) crossings with insufficient cross sectional area to allow peak flows to pass across armored fills or under bridges, 2) stream crossings with a diversion potential and 3) crossings with culverts which are likely to plug. The sediment delivery from stream crossing sites on trails, as with on roads, is always classified as 100%

Table 8. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work on all inventoried sites with future sediment delivery in the Redwood Creek watershed assessment area, Marin 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	20		20	2.400
	D-5 tractor	105	20	--	20	2.100
Road opening costs[7]	Excavator	165	19	--	19	3.135
Heavy Equipment requirements for site specific treatments	Excavator	165	1.522	457	1.979	326.535
	D-5 tractor	140	1.548	465	2.013	281.820
	Dump Truck	75	336	101	437	32.775
	Backhoe	85	22	7	29	2.465
Heavy Equipment requirements for road drainage treatments	Excavator	165	369	111	480	79.200
	D-5 tractor	140	292	88	380	53.200
	Grader	110	56	17	73	8.030
Laborers[8]		40	1.194	359	1.553	62.120
Rock Costs: (includes trucking for 561 yds³ of road rock and 40 yds³ of rip-rap sized rock)						18.630
Culvert materials costs (20' of 12", 5,280' of 18", 2,970' of 24", 1,200' of 30", 730' of 36", 610' of 42", 200' of 48", 510' of 54", 620' of 60", 270' of 84" and 60' of 96". Costs included for couplers and flared inlets)						226,725
Mulch, seed and planting materials for 7.5 acres of disturbed ground[9]						11.243
Layout, Coordination, Supervision, and Reporting[10]		50	--	--	818	40,900
Total Estimated Costs						**$ 1,151,278**
Potential sediment savings: 72,593 yds³						
Overall project cost-effectiveness: $ 15.86 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. Costs and dump truck time (if needed) for re-rocking the road surface at sites where upgraded roads are outsloped are not included and costs to re-pave upgrade sites are 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 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 five tractors and excavators, 4 hours round trip for five (5) crews to areas within the Redwood Creek watershed. Costs assume 2 hauls each for two pieces of equipment (one to move in and one to move out).

[7] Road opening costs are applied to roads that are currently abandoned and not driveable.

[8] An additional 119 hours of labor time is added for straw mulch and seeding activities.

[9] Seed costs equal $50/pound for native seed. Seed costs based on 25# of native 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. Does not include additional seed and mulch required on decommissioned road surfaces within the Water/Lake Protection Zones.

[10] 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 30% of the total excavator time plus 1 week prior and 1 week post project implementation

Table 9. Site classification and sediment yield from all inventoried trail sites with future sediment delivery in the Redwood Creek watershed, Marin 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	188	96	683	18	1	14
Other	22	21	421	NA	NA	NA
Ditch relief culverts	5	4	24	NA	NA	NA
Total (all sites)	215	121	1,128	18	1	14
Persistent surface erosion[1]	8.7	7.4	2,314	NA	NA	NA
Totals	**215**	**121**	**3,442**	**18**	**1**	**14**

[1] Assumes 4' wide trail surface and cutbank contributing area, and 0.2' of surface lowering per decade over a two decade period.

because any sediment eroded at the crossing site is then delivered to the channel. Even sediment which is delivered to small ephemeral streams will eventually be delivered to downstream fish-bearing stream channels.

Approximately 49% (n=93) of the trail stream crossings inventoried in the Redwood Creek assessment area will need to be upgraded for the trails to be considered Astorm-proofed.@ For example, 30% of existing fords, armored fills, and bridges have insufficient cross sectional area to allow peak flows to pass without erosion occurring at the crossing. Also, 82% of the existing culverts have a Amoderate@ to Ahigh@ plugging potential and approximately 10% of the stream crossings exhibit a diversion potential (Table 9). Because some of the trails were constructed years ago, stream crossings are typically under-designed for the 100-year storm flow. At stream crossings with insufficient cross sectional area, 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 excavating sufficient area and placing armor at armored fills, fords and bridges, constructing critical dips (rolling dips) at 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, and installing bridges at specified stream crossing locations.

Ditch relief culverts - Only those ditch relief culverts that currently deliver or will potentially deliver sediment in the future were inventoried in this project. Five (5) ditch relief culverts with potential sediment delivery were identified and account for approximately 2% of the inventoried trail sites in the Redwood Creek assessment area. Gully erosion can occur below ditch relief culvert outlets due to excessive trail 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 to high in the fill without functional downspouts. Ditch relief culverts are expected to deliver approximately 24 yds^3 of sediment to Redwood Creek and its tributaries in the future. Correcting or reducing sediment delivery associated with ditch relief culverts generally involves dispersing excessive ditch flow by installing additional ditch relief culverts, installing trail dips and outsloping trails. Reducing outlet erosion below these sites involves installing functional downspouts as well as replacing ditch relief culverts deeper in the fill.

AOther@sites - We estimate 421 yds^3 of sediment will be delivered to streams from the 22 Aother@ specific trail sites inventoried in Redwood Creek (Table 9). The main cause of existing or future erosion at these sites is surface runoff and uncontrolled flow from long sections of undrained trail surface. Uncontrolled flow along the trail may affect the trail bed integrity as well as cause gully erosion on the hillslopes below the outlet of ditch relief culverts. Concentrated trail runoff can also be a major source of fine sediment input to nearby stream channels. There are several trail segments in the assessment area where concentrated runoff and sediment persistently deliver to nearby channels. These segments will be difficult to disperse runoff and reduce surface erosion delivery due to the location of the existing trails. The only reasonable solution to reduce sediment delivery on these segments would be trail relocation. These trail segments are: Upper Bootjack between Mountain Theater and Old Stage Road, Middle Bootjack especially near Van Wyck meadow area, and Fern Creek trail segment adjacent to Fern Creek. Volumetrically these trails represent a very small percentage of the overall watershed sediment delivery therefore they are not considered high treatment immediacy.

In the Redwood Creek assessment area, we measured approximately 8.7 miles of trail surface (representing 22% of the total inventoried trail mileage) which currently drain directly to streams and deliver surface runoff and sediment to stream channels. These trails are said to be Ahydrologically connected@ to the stream channel network. When these trails are being actively maintained and used for access, they represent a potentially important source of chronic fine sediment delivery to the stream system.

From the 8.7 miles of Aconnected@ trail segments, we calculated approximately 2,314 yds^3 of sediment will be delivered to stream channels in the Redwood Creek watershed over the next 20 years if no efforts are made to change trail drainage patterns. This will occur through a combination of 1) mechanical pulverizing and wearing down of the trail surface by foot, bike, and horse traffic, and 2) erosion of the trail surface during wet weather periods.

Relatively straight-forward erosion prevention treatments can be applied to upgrade trail systems to prevent fine sediment from entering stream channels. These treatments generally involve dispersing trail runoff and disconnecting the trail surface from the natural stream channel network. Trail surface treatments include the installation of trail dips, outsloping and the occasional installation of ditch relief culverts. Treatment of trail drainage is very similar to road surface drainage treatment techniques. These trails are treated as if they are small roads.

Types of Prescribed Erosion Prevention Treatments

Trails can be storm-proofed by one of two methods: upgrading or decommissioning (closure).

Trail upgrading involves a variety of treatments used to make a trail more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially armored fills, fords or bridges to accommodate the 100-year storm flow and debris in transport, and to eliminate stream diversion potential), removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of trail surface runoff. Trail drainage techniques include berm removal, outsloping, trail dip construction, and/or the installation of ditch relief culverts. The goal of all treatments is to make the trail as Ahydrologically invisible@ as is possible.

Along some low strength routes, re-rocking the trail following rolling dip construction and outsloping or insloping efforts may be necessary. These activities will incorporate pre-existing rock into the new trail shape design, thereby providing some strength and stability. Predicting the total amount of new rock required can be difficult but, at a minimum, rock should be applied at all newly constructed rolling dips at locations that are currently rocked and are proposed for winter access.

For ***trail decommissioning*** heavy equipment techniques are generally limited to those trails that were initially constructed as roads and those trails that are currently accessible by heavy equipment. Decommissioning essentially involves Areverse road/trail construction,@ except that full topographic recontouring of the road/trail bed is <u>not</u> normally required to accomplish erosion prevention and sediment reduction goals. In order to protect the aquatic ecosystem, the goal is to Ahydrologically@ decommission the road/trail; that is, to minimize the effect of the road/trail on natural hillslope and watershed runoff.

Labor intensive (hand labor) erosion control treatments are often needed on sites where heavy equipment has been used to perform decommissioning. Hand labor is used to stabilize and revegetate soils exposed by heavy equipment operations. These include mulching, seeding and planting. Hand labor has been prescribed along trails where there is no access for heavy equipment. Hand labor treatments may include excavation of soils at stream crossings, hand digging of trail drainage structures such as trail dips, cross trail drains, outsloping and rock armoring at armored fills and fords. In general, heavy equipment will perform most of the significant erosion prevention and erosion control work along road networks and hand labor will perform most of the work along the trail networks.

Treatments

Basic treatment priorities and prescriptions were formulated concurrent with the identification, description and mapping of potential sources of trail-related sediment yield. Table 10 and Map 3 outline the treatment priorities for all 121 inventoried sites with future sediment delivery that have been recommended for treatment in the Redwood Creek watershed assessment area. Of the 121 sites with future sediment delivery, only 2 sites were identified as having a high or high-moderate treatment immediacy with a potential sediment delivery of approximately 140 yds^3. Fifty-eight (58) sites were listed with a moderate or moderate-low treatment immediacy and account for nearly 732 yds^3 of future sediment delivery. Finally, 60 sites were listed as having a low treatment immediacy with approximately 256 yds^3 of future sediment delivery.

Table 10. Treatment priorities for all inventoried trail sediment sources in the Redwood Creek watershed assessment area, Marin County, California

Treatment Priority	Upgrade sites (# and site #)	Decommission sites (# and site #)	Problem	Future sediment delivery (yds^3)[1]
High	**0**	**1** (site #: 366)	1 stream crossing	133
Moderate High	**1** (site #: 455)	**0**	1 stream crossing	7
Moderate	**25** (site #: 302, 311, 320, 323, 353, 359, 373, 383, 384, 386, 430, 437, 457, 460, 469, 472.1, 475, 487, 490, 502, 505, 508, 512, 517, 525)	**5** (site #: 309, 412, 414, 521.1, 522.1)	18 stream crossings, 2 ditch relief culverts, 10 other	542
Moderate Low	**28** (site #: 300, 306, 310, 317, 324, 339, 340, 344, 351, 356, 370, 371, 372, 385, 387, 407, 415, 428, 463, 471.1, 472, 482, 500, 509, 514, 520, 527, 529)	**0**	24 stream crossings, 4 other	190
Low	**60** (site #: 301, 303, 305, 307, 308, 312, 313, 314, 318, 325, 328, 329, 330, 331, 332, 334, 335, 337, 338, 343, 346, 348, 349, 360, 362, 368, 376, 390, 400, 404, 405, 409, 411, 413, 416, 417, 421, 424, 433, 451, 458, 459, 461, 462, 466, 470, 471, 486, 488, 503, 510, 511, 513, 518, 519, 521, 522, 523, 524, 530)	**1** (site #: 468)	52 stream crossings, 2 ditch relief culverts, 7 other	256
Total	**114**	**7**	**96 stream crossings, 4 ditch relief culverts, 21 other**	**1,128**

[1] Future sediment yield does not include persistent surface erosion.

Table 11 summarizes the proposed treatments for sites inventoried on all trails in the Redwood Creek assessment area. These prescriptions include both trail upgrading and closure measures. The database, as well as the field inventory sheets, provide details of the treatment prescriptions for each site. Some treatments require the use of heavy equipment, including an excavator, tractor, dump truck, bobcat and/or backhoe. Hand labor is required at sites needing ford, bridge,
and armored fill construction, new culverts, culvert repairs, and/or for applying seed, plants and mulch following ground disturbance activities.

Table 11. Recommended treatments along all inventoried trails in the Redwood Creek watershed assessment area, Marin County, California.

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	2	To prevent stream diversions	Install trail dips	538	Install trail dips to improve surface drainage on maintained trails
Install CMP	1	Install a CMP at an unculverted fill	Install ditch relief CMP	1	Install ditch relief culvert to improve trail surface drainage
Replace CMP	2	Upgrade an undersized CMP	Install cross trail drains	50	Install cross trail drains to improve drainage along recommended decommission trails
Excavate soil	39	Typically fillslope & crossing excavations; excavate a total of 697 yds^3	Rock trail surface	108	Rock trail surface using 6 yds^3 road rock (includes 6 yds^3 at 14 trail surface locations, 640 yds^3 at 93 stream crossing upgrades, and 10 yds^3 at 1 ditch relief culvert.
Install bridge	7	Install bridge at stream crossing	Other	10	Miscellaneous treatments
Wet crossing	23	Install 17 ford and 6 armored fill crossings using 6 yds^3 rip-rap	No treatment recommended	94	No erosional problems
Outslope trail and remove ditch	9	Outslope and remove ditch along 3,740 feet of trail to improve surface drainage			

It is estimated that erosion prevention work will require the excavation of approximately 697yds^3 at 39 sites. Approximately 96% of the volume excavated is associated with upgrading or properly decommissioning stream crossings and nearly 4% of the volume is proposed for excavating at Aother@ sites. A total of 6 yds^3 of 0.5 to 1 foot diameter mixed and clean rip-rap sized rock will be needed to construct 23 proposed armored wet crossings (Table 11). At many of these proposed stream crossing upgrades local rock is available to use for armoring. We have recommended 538 trail dips be constructed at selected locations along the trail, at spacings dictated by the steepness of the trail. One (1) new ditch relief culvert is recommended to be installed along the trail network.

Sites not recommended for erosion control treatment

As of 2001, ninety-four (94) of the 215 trail sites of future sediment delivery identified in the Redwood Creek watershed assessment have not been recommended for treatment. These sites are correctly designed for the 100-year flood flow and/or have no other potential erosion problems that can be repaired.

Equipment Needs, Labor Times and Costs

Treatments for the 121 trail sites identified with future sediment delivery in the assessment area will require approximately 31 hours of excavator time, 24 hours of tractor time, 15 hours of bobcat time and 1,794 hours of labor time to complete all prescribed upgrading, erosion control and erosion prevention work (Table 12). Excavator and tractor work is not needed at many of the sites that have been recommended for treatment. This is mainly due to the sites being inaccessible to equipment. Only 2 hours of dump truck time has been listed for trail work in the basin for end-hauling excavated spoil from stream crossings where local disposal sites are not available. Approximately 1,794 hours of labor time is needed for a variety of tasks such as installation or replacement of culverts, excavating soil at fords and armored fills, and 20 hours for seeding, mulching and planting activities. Roughly 15 hours of bobcat time is necessary to apply trail surface treatments including outsloping.

Table 12. Estimated heavy equipment and labor requirements for treatment of all inventoried trail sites with future sediment delivery, Redwood Creek assessment area, Marin County, California. [1]

Treatment Immediacy	Site (#)	Excavated Volume (yds^3)	Excavator (hrs)	Tractor (hrs)	Dump Trucks (hrs)	Bobcat (hrs)	Backhoe (hrs)	Labor (hrs)
High, High/Moderate	2	307	8	6	0	0	2	15
Moderate, Low/Moderate	58	339	20	12	2	15	15	994
Low	61	51	3	6	0	0	0	785
Total	**121**	**697**	**31**	**24**	**2**	**15**	**17**	**1,794**

[1] Equipment and labor times do not include hours necessary for trail opening and straw mulch activities.

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 trail surface erosion and associated sediment delivery to streams. The site-specific work is further divided into upgrading activities and closure (decommissioning) activities. The total costs for trail-related erosion control at sites with future sediment delivery is estimated at approximately $195,525 for an average cost-effectiveness value of approximately $85.57 per cubic yard of sediment prevented from entering Redwood Creek and its tributaries (Table 13). It should be noted that costs to re-rock the upgraded trail system following implementation of the proposed storm-proofing activities are not included in this table.

Overall site specific erosion prevention work: Equipment and labor needs for site specific erosion prevention work at sites with future sediment delivery are expressed in the database, and summarized in Table 12, as direct excavation and labor 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 Asite@ 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 to determine total equipment costs as shown in Table 13. Finally, the estimated equipment time needed to reconstruct or open trails which have been abandoned are listed as a separate line item in Table 13.

The costs in Table 13. 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 or laborers experienced in trail upgrading and decommissioning operations. The use of inexperienced operators would require additional technical oversight and supervision in the field. All recommended trail treatments are basic construction techniques currently utilized by various state and federal parks trail construction crews. Some treatment prescriptions conform to techniques described in the ATrails Handbook@ prepared by The California Department of Parks and Recreation. Other treatment prescriptions conform to techniques described in AThe Handbook for Forest and Ranch Roads@ prepared by PWA.

Table 13 lists a total of 552 hours for ALayout@ 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. It is expected that the project coordinator will be on-site full time at the beginning of the project and intermittently after equipment operations have begun. Labor crew supervision time of 707 hours has also been included in this cost estimate. This position is specifically for on-site supervision of labor crews during trail upgrading work and would likely consist of state or park service personnel in charge of trail maintenance and management of trail work crews. This position will coordinate with the project manager to facilitate proper upgrade and decommission trail construction.

Table 13. Estimated logistic requirements and costs for erosion control and erosion prevention work on all inventoried trail sites with future sediment delivery in the Redwood Creek watershed assessment area, Marin County, California.

Cost Category[1]		Cost Rate[2] ($/hr)	Estimated Project Times: Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	Total Estimated Costs[5] ($)
Move-in; move-out[6] (Low Boy expenses)	Excavator	[illegible]	8		8	[illegible]
	D-5 tractor	105	8	--	8	840
Road / trail opening costs[7]	Excavator	165	4	--	4	660
Heavy Equipment requirements for site specific treatments	Excavator	165	28	8	36	5,940
	D-5 tractor	140	24	7	31	4,340
	Dump Truck	75	2	1	3	225
	Backhoe	85	17	5	22	1,870
Heavy Equipment requirements for trail	Excavator	165	3	1	4	660
	Bobcat	110	15	5	20	2,200
Laborers[8]		40	1,814	544	2,358	94,320
Rock Costs: (includes trucking for 656 yds[3] of trail rock and 6 yds[3] of rip-rap sized rock).						19,650
Culvert materials costs (50' of 18", 10' of 24"and 40' of 72". Costs are included for couplers).						2,534
Mulch, seed and planting materials for 1.25 acres of disturbed ground[9]						1,911
Layout, Coordination, and Reporting[10]		50	--	--	552	27,600
Labor Crew Supervision[11]		45			707	31,815
Total Estimated Costs						$ 195,525

Potential sediment savings: 3,442 yds[3]

Overall project cost-effectiveness: $ 56.81 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. Costs and dump truck time (if needed) for re-rocking the trail surface at sites where upgraded trails are outsloped are 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 and abandoned roads/ trails, 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 two tractors and excavators, 4 hours round trip for two (2) crews to areas within the Redwood Creek watershed. Costs assume 2 hauls each for two pieces of equipment (one to move in and one to move out).

[7] Road/ trail opening costs are applied to roads / trails that are currently abandoned and not driveable.

[8] An additional 20 hours of labor time is added for straw mulch and seeding activities.

[9] Seed costs equal $50/pound for native seed. Seed costs based on 25# of native 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. Does not include additional seed and mulch required on decommissioned road surfaces within the Water/Lake Protection Zones.

[10] Layout time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, and post-project documentation and reporting). Layout times based on 20% of the total labor time plus 1 week prior and 1 week post project implementation.

[11]Labor crew supervisor time based on 30% total labor time. This position will provide technical assistance and supervision to labor crews during work as well as be in close contact with those designing the erosion prevention plan.

Conclusion

The expected benefit of completing the erosion control and prevention planning work lies in the reduction of long term sediment delivery to Redwood Creek, an important salmonid stream. A critical first-step in the overall risk-reduction process is the development of a watershed transportation analysis and plan. In developing this plan, all roads and trails in an ownership or sub-watershed are considered for either decommissioning or upgrading, which should first depend upon the risk of erosion and sediment delivery to streams, among other park concerns / values. Not all roads and trails 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 and trails in each sub-watershed, and within each ownership, based on their potential to impact downstream resources, as well as, their importance to the overall transportation system and to management needs.

Trail systems are treated and assessed in much the same manner as road systems. In the Redwood Creek watershed assessment area it has been shown that the trail networks have significantly less potential for erosional impacts on aquatic resources compared to road networks. Nearly 40 miles of trails could contribute approximately 2,285 yds^3 of sediment to the stream network, while 26.5 miles of roads could contribute nearly 58,124 yds^3 of sediment if left untreated. With this information provided, the focus of erosion prevention planning projects, for the benefit of anadromous fisheries, should be on road based treatment implementation.

Good land stewardship requires that roads and trails either be upgraded and maintained, or intentionally closed (Aput-to-bed@). The old practice of abandoning roads and trails, by either installing barriers to traffic (logs, Atank traps@ or gates) or simply letting them naturally revegetate, is no longer considered acceptable. These roads and trails typically continue to fail and erode for decades following abandonment. The proper word for proactive road and trail closure is Adecommissioning[1].@ Decommissioning may be either permanent or temporary, but the treatments are largely the same. Properly decommissioned roads and trails no longer require maintenance and are no longer sources of accelerated erosion and sediment delivery to a watershed=s streams. The impacts of reopening old, abandoned roads so that they can be correctly decommissioned has been evaluated on a case-by-case basis, but the benefits (large reductions in long term erosion) almost always far outweigh the negative effects (small, short-term increases in erosion from bare soil areas).

Currently unused, unmaintained and/or abandoned roads and trails in Redwood Creek were evaluated for either upgrading or permanent or temporary decommissioning. Decommissioning does not necessarily suggest permanent closure. Most decommissioned roads, if they are in stable locations, can be rebuilt and reopened at a future date, if they are needed, by simply reinstalling the stream crossings and regrading the former road bed. Some roads are to be permanently closed, and they will be ripped

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[2] Decommissioning has been defined as Aremoving those elements of a road that reroute hillslope drainage and present slope stability hazards. Another term for this is >hydrologic obliteration=@ (USDA, 1993). It involves such tasks as fully excavating stream crossing fills (not just Aculvert removal@), excavating unstable sidecast and road fill, decompacting road surfaces and installing road surface drainage (e.g., cross road drains or road outsloping). The decommissioning of unneeded, neglected, and high-impact roads may be one of the most urgent and significant restoration needs, based on the magnitude of ongoing and potential effects to aquatic ecosystems. Unstable, erodible and high risk (e.g., riparian) roads are prime candidates for decommissioning. Unneeded roads that pose little or no threat to aquatic resources should not be targeted for decommissioning on the basis of aquatic protection or watershed restoration.

(decompacted) and replanted. We have held discussions with land managers in the assessment area to discuss which roads represent good candidates for either permanent or temporary decommissioning but this needs further development by land managers and transportation planners before implementation can begin.

Road and trail upgrading consists of a variety of techniques employed to Aerosion-proof@ and to Astorm-proof@ a road or trail and prevent unnecessary future erosion and sediment delivery. Erosion-proofing and storm-proofing typically consists of stabilizing slopes and upgrading drainage structures so that the road or trail 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. Roads and trails in upper and lower Redwood Creek which have not been identified and prescribed for closure (decommissioning) have been prescribed for upgrading. The goal of upgrading is to strictly minimize the contributions of fine sediment from roads, trails 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.

It should be noted that recommendations made within this report are the minimum (most cost effective) necessary to achieve reduction of sediment or significant reduction of risk of sediment delivery to the watershed. It has been expressed by several land managers within the watershed that they may want to exceed recommendations made within this report to achieve more complete hillslope rehabilitation goals. Appendix B summarizes costs and methods that exceed recommendations made within this report that can achieve the same goals of sediment delivery reduction while also achieving aesthetic hillslope rehabilitation goals (full outsloping or recontouring of original topography). This sediment reduction plan does not in any way prevent land managers from taking steps that exceed recommendations made within this report. PWA can work with land managers to make recommendations that achieve both long term sediment delivery reduction as well as natural hillslope rehabilitation goals, but this work will go beyond the scope of this contract.

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Appendices

A. Redwood Creek channel survey
B. Cost estimates for supplementary treatments
C. Supplement to table 4.

Appendix A
Redwood Creek channel survey

Introduction

Approximately 7.5 miles of Class 1 stream channel was inventoried in the Redwood Creek watershed between August 20 and August 24, 2001. The goal of the channel assessment was to identify controllable sources of channel erosion and opportunities for cost-effective erosion prevention which exist along these stream channels. Mapping of past erosion locations associated with the stream channel was also conducted in this inventory.

Aerial photos (1:8,000) were used as base maps to record stream channel observations. A stream channel data form (figure A-1) was filled out for erosion sites that were identified as controllable and could be cost effectively treated. The channel survey started at the Muir Beach bridge that crosses the main stem of Redwood Creek near the Pelican Inn, and extended up the main stem approximately 7 miles to the limit of anadromy. The limit of anadromy on the main stem of Redwood Creek is approximately 1.8 miles upstream from the Fern Creek confluence and on the Fern Creek fork the limit of anadromy is approximately 0.6 miles upstream from this confluence.

Channel survey results

A total of 65 sites of significant past erosion were identified during these stream channel inventories. These were all bank erosion sites that have cumulatively yielded 1,759 yds^3 in the past and will continue to have some level of future activity. Because bank erosion is a natural process, even though it may be accelerated by landuse, erosion from these sites is considered to be difficult to control. Historic land development, including road building, has likely altered the natural flow regime which subsequently has caused morphological stream channel changes including accelerated bank erosion. Bank erosion locations alternate from stream bank to stream bank, causing oversteepend alluvial or colluvial banks to collapse into the channel. This collapse in many instances is depositing beneficial gravels into the channel.

Bank erosion is the dominant channel erosional process in the unconfined alluvial terrace reach of stream from Muir Woods National Monument downstream to near the Muir Beach Bridge. In order to prevent erosion at these locations it would be necessary to rip-rip both banks nearly continuously in the lower channel. This is not considered a viable option.

At one prominent location approximately 1,800' downstream from site #1 there is significant active bank erosion occurring. This feature is located at a sharp left bend in the stream channel and historic agricultural land on the right bank is actively eroding. There does not appear to be a viable cost effective erosion prevention solution without negatively impacting adjacent stream banks. This area may require a more detailed study to determine if any long term erosion control solution conforms with park management goals.

Upstream from Muir Woods National Monument, the alluvial valley narrows and the banks become more bedrock controlled. Beginning near Muir Woods National Monument parking lot, both the left and right stream banks have been intermittently rip-rapped. This rip-rap extends upstream for some undetermined distance beyond the Fern Creek confluence. As a result of the natural channel morphology and artificial revetment, bank erosion locations also become more sparse.

On the mainstem of Redwood Creek the limit of anadromy ends approximately 1.8 miles upstream from the Fern Creek confluence where the channel becomes constricted in a steep (12-15%), boulder and log choked chute just above a distinct left bend in the stream. On the Fern Creek tributary the limit of anadromy is approximately 0.6 miles upstream from its confluence with the mainstem. This is where old growth logs have fallen across the channel subsequently creating a pool. The channel steepens to 12% and begins a continuous boulder cascade upstream

Figure A-1. Stream channel inventory data form used in the Redwood Creek watershed assessment

PWA STREAM CHANNEL INVENTORY DATA FORM

General	Site #:	Date:	Mappers:	Air Photo:	Watershed:	Stream:
	Bank (L/R):	Treat?(Y)				
Problem	Debris slide	Slow, deep slide	Torrent channel	Bank erosion	Log jam:	Other:
	Past, future, both	Activity (A,W,IA):	Age (decade):	Hillslope (%):	Land use:	Undercut? (Y)
Erosion	Past width:	Past depth:	Past length:	Past vol:	Past del (%)	Past yld (yds):
E.P.:	Future width:	Future depth:	Future length:	Future vol:	Fut del (%)	Fut yld (yds):
Treatment	Immed: (H,M,L)	Complexity: (H,M,L)	Eqpt or labor (E, L, B):		Access: (Easy, Moderate, Hard)	
	Excavate soil	Rock armor/buttress	Log protection	Remove logs/debris	Plant	Other
hours:	Excavator:	Dozer:	Dump truck:	Backhoe:	Labor:	Other:
Problem:				Sketch:		
Treatment:						

of this location. Only one site has been identified as treatable along the 7.5 miles of inventoried channel. This site is a road fill/bank erosion site and is considered to have a moderate treatment immediacy due to the likelihood of potential failure, the delivery volume, treatment complexity and cost effectiveness of the proposed treatment (table A-1). This site is located directly adjacent to the Santos Meadow Trailhead on the Muir Woods Road. The treatment at this site would be relatively simple but the costs involved in treating the site are high due to road realignment needs and repaving costs.

Option 1. The proposed treatment includes excavating a keyway into the right side of the channel bed and removing oversteepend, failing road fill to a stable angle. This excavation will need to extend back into the existing road way. Next, approximately 65 yds^3 of coarse armor (2'-3' diameter) will need to be placed as bank protection. This treatment will involve shifting the existing road away from the stream channel. It would then be necessary to repave the road way.

Table A-1. Option 1. Treatment priority and costs for bank erosion site #1 along 7.5 miles of inventoried stream channel in Redwood Creek, Marin County, California.

Treatment Priority	Erosion Potential	Problem	Potential Future Yield (yds^3)	Heavy Equipment Costs ($) [1]
Moderate	Moderate-High	Bank erosion / Road fill failure	129	5,305

[1] Costs assume work will be completed with equipment already on site and do not include costs to realign and repave right-of-way. Equipment costs include 11 hrs excavator, 11 hrs dozer and costs to deliver 65 yds^3 of coarse rip-rap. Costs also do not include any supervisory expenses or engineering fees.

Option 2. Based on review comments received from the National Park Service, it has been determined that the above treatment is inappropriate for park management goals, although no specific alternatives were proposed. Therefore, option 2. was developed. The proposed treatment includes excavating and laying back the oversteepend, failing road fill/streambank to a stable angle (at least 2/1 or 50%). This excavation again would need to extend back into the existing road way. Next, a bioengineered structure such as a log crib wall or log revetment would be installed in combination with revegetation using native riparian plants and trees. A more detailed description of stream bank stabilization structures along with construction techniques can be found in the ACalifornia Salmonid Stream Habitat Restoration Manual@prepared by The California Department of Fish and Game. Next the road way would need to be shifted away from the stream channel and finally it would be necessary to repave the road way.

Conclusion

Although there are many locations in the channel where bank erosion is active, it would not be appropriate or cost effective to treat most sites. This is due to the alternating nature and spacial distribution of bank erosion locations. Generally, armoring one location will lead to increase flow velocity and deflection to the opposite bank. Therefore, reducing bank erosion in the channel will mainly be limited to road and trail treatment implementation that has been proposed in this plan for the upper watershed. These treatments may help to restore the natural flow regime by disconnecting roads and ditches from the drainage network and reducing the effect on runoff and peak flows.

Between Muir Woods National Monument and Banducci Farms, the channel morphology is relatively unaltered by direct human activity. In the reaches above Muir Woods National Monument, along Banducci Farms and below the bridge at Pelican Inn the natural channel has been altered through a number of historic engineering projects (e.g., channelization, rip-rap, etc). There are feasibility studies underway at several sites to determine whether or not channel and lagoon restoration projects in the lower watershed would be beneficial to the aquatic ecosystem. These projects should involve site-specific upland erosion control work as part of any larger scale channel restoration plan for these reaches.

Appendix B

Cost Estimates For Supplementary Treatments

Appendix B-1. Sample techniques and costs for decommissioning forest roads

Treatment	Typical application	General specification	Typical costs[1]
Ripping or decompaction	Improve infiltration; decrease runoff; assist revegetation	Rip roads, landings and compacted areas with multiple passes to average depth of 18".	\$500 - \$1500/mile
Construction of cross-road drains	Drain springs; drain insloped roads; drain landings	Drains deeper and wider than waterbars, extending from cutbank to outside edge of road (captures ditch flow).	\$1/ft (\$25-\$50 ea)
Partial outsloping (local spoil site; fill against the cutbank)	Remove minor unstable fills; disperse cutbank seeps and runoff	Road should be ripped before adding spoil for outsloping. Springs should not be covered. Ditches can be filled.	\$2500 - 12,500+ /mile
Complete outsloping (recontouring), local spoil site; fill against the cutbank	Used for removing unstable fill material where nearby cutbank is dry and stable	Road/ditch should be ripped and cutbank vegetation removed before adding spoil for outsloping. Springs should not be covered. Ditches can be filled.	\$10,000 - \$75,000+/mile
Exported outsloping (fill pushed or hauled away and stored down-road)	Used for removing unstable road fills where cut banks have springs and cannot be buried	Spoil site should be located in stable area where sediment will not be delivered to stream.	<\$1 - \$4/yd^3, depending on haul distance
Landing and fillslope excavations (with local spoil storage)	Used to remove unstable material around landing perimeter	Landing should be ripped and spoil placed on inside half of landing. Springs should not be covered.	\$1 - \$2/yd^3, high organics can increase costs
Stream crossing excavations (with local spoil storage)	Complete removal of stream crossing fills (not just culvert removal)	Excavate all fill from crossing, down to original channel bed with straight or concave profile; original or 2:1 side slope gradient; natural channel width	Averages \$2 - \$4/yd^3 but can vary considerably
Truck endhauling (dump truck)	Hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream		\$2 to \$4/yd^3 on top of basic excavation work

[1] These are direct treatment costs for equipment working at a site. They do not include transportation, moving from site-to-site, overhead, supervision, layout, or any other costs. Costs will vary from site to site and from watershed to watershed. Heavy equipment treatments performed using D-7 tractors and hydraulic excavators with average 2 yd^3 bucket size. Costs will vary with equipment types, rental rates and operator experience. Costs can vary considerably from these typical figures, depending on operator skill and experience, and local site conditions. Data from PWA and NPS (1992)

Appendix B-2. Typical logistics and costs for a variety of upgrading tasks for forest and ranch roads

Treatment	Equipment	Cost rate	Application rate and assumptions	Cost[1]
Outslope road and fill ditch	Grader with rippers	$110/hr	500 ft/hr for 20' wide road (road surface and ditch to be ripped prior to spoil placement)	$220/1000 ft
Rolling dip	dozer with rippers	$140/hr	1 hr each (20'-30')	$140 each
Remove berm or clean ditch	grader	$110/hr	1000'/hr (no trees on berm or in ditch)	$110/1000 ft
Rock road (1.5" - 2.0" crushed)	dump truck spread	$25/yd^3 delivered	4" deep x 20' wide = 250 yds3 / 1000 ft road	$6,250/1000 ft
Install ditch relief culvert (assumes 40' of 18" culvert)	back hoe or excavator + laborer	$85/hr $165/hr $40/hr	3 hours each + $7.75/ft + $16 coupler + $120 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
CMP downspout installation	hand labor (18 - 24") equipment (>24")	$40/hr $165/hr	20' x 24": 2 hours labor 40' x 36": 3 hours labor + 1 hour excavator	$80 + materials $285 + materials

[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., outsloping road and filling the ditch) may be performed for different rates using tractor instead of grader.

Appendix C

Appendix C. Treatment priorities, road names and property ownerships for all inventoried road related sites in the Redwood Creek watershed assessment area, Marin County, California

Treatment Immediacy	Site #	Road name	Ownership
H	40	Old RR Grade	mmwd
H	41	Old RR Grade	mmwd
H	52	West Point	mmwd
H	139	Panoramic Drive	mmwd
H	185	Camino del Canyon	mwnm
H	194	Old Service Rd	mwnm
H	203	Conlin ave	mwnm
H	204	Conlin Ave	mwnm
H	205	Conlin Ave	mwnm
HM	50	West Point	mmwd
HM	56	Old Stage Rd	mmwd
HM	57	Old Stage Rd	mmwd
HM	58	Old Stage Rd	mmwd
HM	59	Old Stage Rd	mmwd
HM	63	Old Stage Rd	mmwd
HM	66	Old Stage Rd	mmwd
HM	78	Muir Woods Rd	mtsp
HM	79	Muir Woods Rd	mtsp
HM	90	Muir Woods Rd	mtsp
HM	94	Muir Woods Rd	mwnm
HM	102	Alice Eastwood Rd	mtsp
HM	104	Alice Eastwood Rd	mtsp
HM	106	Alice Eastwood Rd	mtsp
HM	107	Alice Eastwood Rd	mtsp
HM	108	Alice Eastwood Rd	mtsp
HM	118	Panoramic Drive	mmwd
HM	119	Panoramic Drive	mmwd
HM	127	Panoramic Drive	mmwd
HM	129	Panoramic Drive	mmwd
HM	137	Panoramic Drive	mmwd
HM	141	Panoramic Drive	mmwd
HM	143	Panoramic Drive	mmwd
HM	152	Panoramic Drive	mtsp
HM	154	Panoramic Drive	mtsp
HM	159	Muir Woods Rd	mtsp
HM	180	Camino del Canyon	mtsp
HM	181	Camino del Canyon	mtsp
HM	182	Camino del Canyon	mtsp
HM	188	Camino del Canyon	mwnm
HM	215	Deer Park Rd	mtsp
HM	216	Muir Woods Rd	mtsp
HM	231	HWY 1	ggnra
HM	245	Kent Canyon Rd	mtsp
HM	249	Kent Canyon Rd	mtsp
HM	258	Middle Green Gulch Rd	ggnra
HM	265	Green Gulch Rd	ggnra
HM	266	Green Gulch Rd	ggnra
M	5	HWY 1	mtsp
M	6	HWY 1	mtsp
M	8.1	HWY 1	mtsp
M	10	HWY 1	ggnra
M	20.1	Ridgecrest	mmwd
M	28	Ridgecrest	mmwd
M	29	Ridgecrest	mmwd
M	30	Ridgecrest	mmwd
M	31	Ridgecrest	Mmwd

M	33	Ridgecrest	Mmwd
M	36	Ridgecrest	mmwd
M	37	Old RR Grade	mmwd
M	39	Old RR Grade	mmwd
M	42	Old Stage Rd	mmwd
M	45	Old Stage Rd	mmwd
M	46	West Point	mmwd
M	48	West Point	mmwd
M	49	West Point	mmwd
M	53	West Point	mmwd
M	55	West Point	mmwd
M	60	Old Stage Rd	mmwd
M	62	Old Stage Rd	mmwd
M	68	Old Stage Rd	mtsp
M	68.1	Old Stage Rd	mtsp
M	74	Muir Woods Rd	mtsp
M	80	Muir Woods Rd	mtsp
M	89	Muir Woods Rd	mtsp
M	91	Muir Woods Rd	mwnm
M	95	Muir Woods Rd	mwnm
M	100	Alice Eastwood Rd	mtsp
M	101	Alice Eastwood Rd	mtsp
M	109	Alice Eastwood Rd	mtsp
M	110	Alice Eastwood Rd	mtsp
M	115.2	Alice Eastwood Rd	mtsp
M	115.4	Alice Eastwood Rd	mtsp
M	125	Panoramic Drive	mmwd
M	132	Panoramic Drive	mmwd
M	133	Panoramic Drive	mmwd
M	138	Panoramic Drive	mmwd
M	140	Panoramic Drive	mmwd
M	144	Panoramic Drive	mmwd
M	146	Panoramic Drive	mmwd
M	149	Panoramic Drive	mtsp
M	151	Panoramic Drive	mtsp
M	153	Panoramic Drive	mtsp
M	157	Muir Woods Rd	mtsp
M	163	Muir Woods Rd	mtsp
M	167	Muir Woods Rd	mtsp
M	174	Diaz Ridge Rd	ggnra
M	176.1	Pan Toll Ranger Rd	mtsp
M	176.3	Pan Toll Ranger Rd	mtsp
M	177	Deer Park Rd	mwnm
M	189	Camino del Canyon	mwnm
M	190	Camino del Canyon	mwnm
M	193	Old Service Rd	mwnm
M	199	Conlin Ave	mwnm
M	200	Conlin ave	mwnm
M	202	Conlin Ave	mwnm
M	209	Deer Park Rd	mtsp
M	212	Deer Park Rd	mtsp
M	213	Deer Park Rd	mtsp
M	226	HWY 1	ggnra
M	232	HWY 1	ggnra
M	236	Banducci Rd	ggnra
M	238	Banducci Rd	ggnra
M	240	Banducci Rd	ggnra
M	242	Hogback Ridge Rd	mmwd
M	246	Kent Canyon Rd	mtsp
M	248	Kent Canyon Rd	mtsp
M	251	Coastal South Rd	ggnra
M	253	Coastal South Rd	ggnra
M	256	Middle Green Gulch Rd	ggnra
M	257	Middle Green Gulch Rd	Ggnra

M	262	Green Gulch Rd	Ggnra
M	263	Green Gulch Rd	ggnra
M	267	Green Gulch Parking Lot	ggf
M	268	Green Gulch Driveway	ggf
M	272	Green Gulch Abandoned #1	ggnra

ML	4	HWY 1	mtsp
ML	6.1	HWY 1	mtsp
ML	7	HWY 1	mtsp
ML	8	HWY 1	mtsp
ML	10.1	HWY 1	ggnra
ML	11	HWY 1	ggnra
ML	12	HWY 1	ggnra
ML	13	HWY 1	ggnra
ML	21	Ridgecrest	mmwd
ML	27	Ridgecrest	mmwd
ML	32	Ridgecrest	mmwd
ML	34	Ridgecrest	mmwd
ML	43	Old Stage Rd	mmwd
ML	47	West Point	mmwd
ML	61	Old Stage Rd	mmwd
ML	64	Old Stage Rd	mmwd
ML	65	Old Stage Rd	mmwd
ML	71	Old Stage Rd	mtsp
ML	75	Muir Woods Rd	mtsp
ML	77	Muir Woods Rd	mtsp
ML	81	Muir Woods Rd	mtsp
ML	82	Muir Woods Rd	mtsp
ML	83	Muir Woods Rd	mtsp
ML	85	Muir Woods Rd	mtsp
ML	87	Muir Woods Rd	mtsp
ML	88	Muir Woods Rd	mtsp
ML	111	Alice Eastwood Rd	mtsp
ML	113	Alice Eastwood Rd	mtsp
ML	115	Alice Eastwood Rd	mtsp
ML	121	Panoramic Drive	mmwd
ML	122	Panoramic Drive	mmwd
ML	123	Panoramic Drive	mmwd
ML	124	Panoramic Drive	mmwd
ML	128	Panoramic Drive	mmwd
ML	130	Panoramic Drive	mmwd
ML	142	Panoramic Drive	mmwd
ML	145	Panoramic Drive	mmwd
ML	147	Panoramic Drive	mtsp
ML	148	Panoramic Drive	mtsp
ML	155	Muir Woods Rd	mtsp
ML	156	Muir Woods Rd	mtsp
ML	161	Muir Woods Rd	mtsp
ML	164	Muir Woods Rd	mtsp
ML	170	Diaz Ridge Rd	mtsp
ML	172	Diaz Ridge Rd	mtsp
ML	175	Coastal Fire Rd	mtsp
ML	176	Deer Park Rd	mtsp
ML	183	Camino del Canyon	mtsp
ML	186	Camino del Canyon	mwnm
ML	187	Camino del Canyon	mwnm
ML	192	Camino del Canyon	mwnm
ML	195	Old Service Rd	mwnm
ML	197	Muir Woods Service Rd	mwnm
ML	201	Conlin Ave	mwnm
ML	206	Deer Park Rd	mtsp
ML	208	Deer Park Rd	Mtsp

ML	210	Deer Park Rd	Mtsp
ML	211	Deer Park Rd	mtsp
ML	214	Deer Park Rd	mtsp
ML	218	Muir Woods Rd	mtsp
ML	222	HWY 1	ggnra
ML	225	HWY 1	ggnra
ML	227	HWY 1	ggnra
ML	237	Banducci Rd	ggnra
ML	250.1	Kent Canyon Rd	mtsp
ML	250.2	Kent Canyon Rd	mtsp
ML	250.3	Kent Canyon Rd	mtsp
ML	252	Coastal South Rd	ggnra
ML	259	Middle Green Gulch Rd	ggnra
ML	260	Middle Green Gulch Rd	ggnra
ML	261	Middle Green Gulch Rd	ggnra
ML	264	Green Gulch Rd	ggnra
ML	270	Green Gulch Abandoned #1	ggnra
ML	273	Green Gulch Abandoned #2	ggf
ML	274.1	Green Gulch Spur Driveway #1	ggf
L	1	HWY 1	mtsp
L	2	HWY 1	mtsp
L	9	HWY 1	ggnra
L	14	HWY 1	ggnra
L	20	Ridgecrest	mmwd
L	22	Ridgecrest	mmwd
L	23	Ridgecrest	mmwd
L	24	Ridgecrest	mmwd
L	25	Ridgecrest	mmwd
L	26	Ridgecrest	mmwd
L	35	Ridgecrest	mmwd
L	38	Old RR Grade	mmwd
L	44	Old Stage Rd	mmwd
L	51	West Point	mmwd
L	54	West Point	mmwd
L	67	Old Stage Rd	mmwd
L	69	Old Stage Rd	mtsp
L	70	Old Stage Rd	mtsp
L	72	Old Stage Rd	mtsp
L	73	Old Stage Rd	mtsp
L	76	Muir Woods Rd	mtsp
L	84	Muir Woods Rd	mtsp
L	86	Muir Woods Rd	mtsp
L	92	Muir Woods Rd	mwnm
L	96	Muir Woods Rd	mwnm
L	97	Muir Woods Rd	mtsp
L	98	Muir Woods Rd	mtsp
L	99	Muir Woods Rd	mtsp
L	103	Alice Eastwood Rd	mtsp
L	114	Alice Eastwood Rd	mtsp
L	115..3	Alice Eastwood Rd	mwnm
L	116	Sierra Trail	mtsp
L	117	Panoramic Drive	mmwd
L	120	Panoramic Drive	mmwd
L	126	Panoramic Drive	mmwd
L	131	Panoramic Drive	mmwd
L	135	Panoramic Drive	mmwd
L	136	Panoramic Drive	mmwd
L	162	Muir Woods Rd	Mtsp

L	166	Muir Woods Rd	Mtsp
L	168	Muir Woods Rd	mtsp
L	171	Diaz Ridge Rd	mtsp
L	178	Deer Park Rd	mtsp
L	184	Camino del Canyon	mtsp
L	191	Camino del Canyon	mwnm
L	196	Old Service Rd	mwnm
L	198	Muir Woods Service Rd	mwnm
L	207	Deer Park Rd	mtsp
L	217	Muir Woods Rd	mtsp
L	223	HWY 1	ggnra
L	224	HWY 1	ggnra
L	239	Banducci Rd	ggnra
L	247	Kent Canyon Rd	mtsp
L	250	Kent Canyon Rd	mtsp
L	269	Green Gulch Driveway	ggf
L	270.1	Middle Green Gulch Rd	ggnra
L	271	Green Gulch Abandoned #1	ggnra
L	274	Green Gulch Driveway	ggf
L	275	Green Gulch Driveway #1	ggf