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

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Pacific Watershed Associates

P.O. Box 4433, Arcata, California

707-839-5130

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Executive Summary

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

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

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

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

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

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

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

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

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

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1.0 Introduction

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

1.1 Purpose

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

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

2.0 Organization of Report

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

3.0 Background

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

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

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

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

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

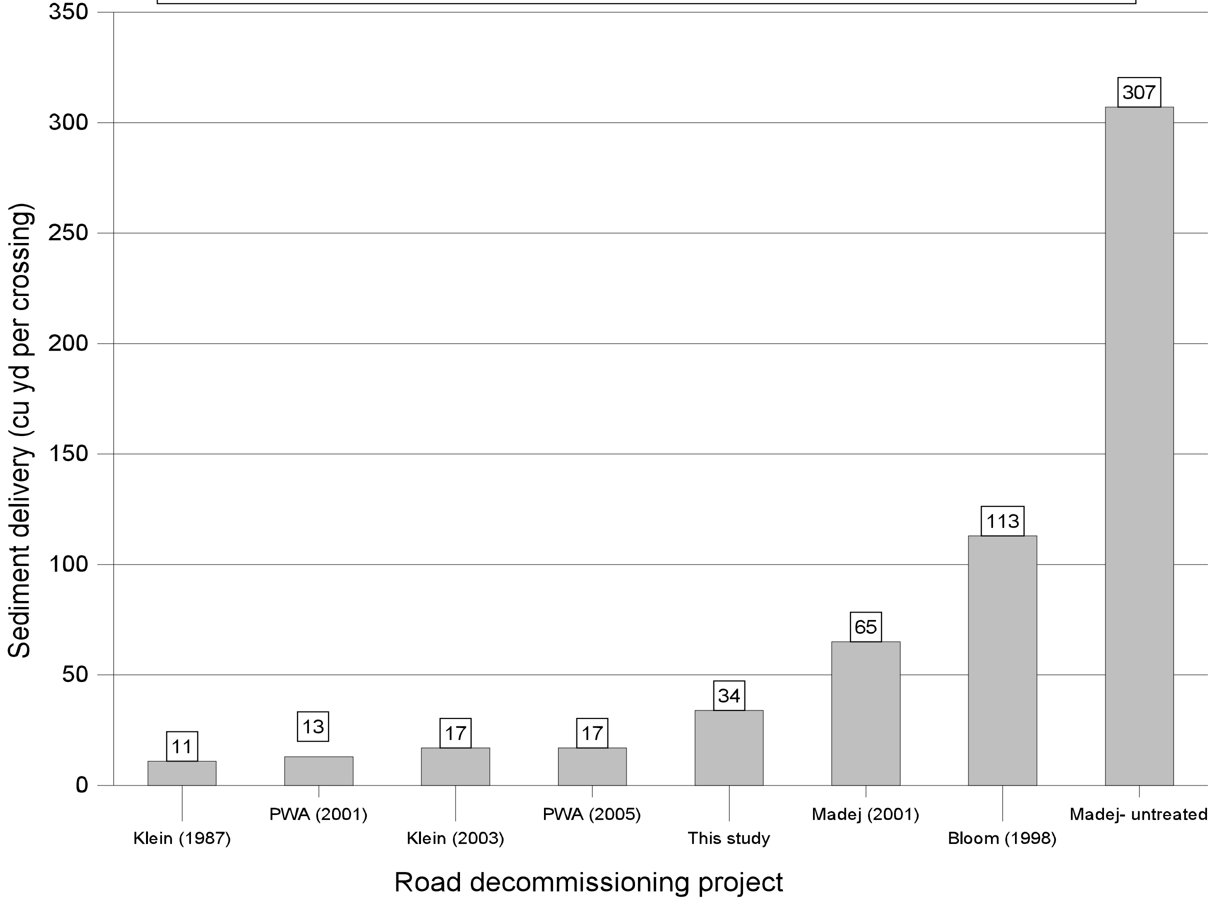
4.0 Previous Studies

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

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

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

Figure 1. Sediment delivery from decommissioned stream crossings



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

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

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

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

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

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

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

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

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

5.0 Geologic Setting

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

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

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

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

6.0 Methods

6.1 Study Approach

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

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

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

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

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

6.2 Sampling Strategy

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

6.2.1 Data acquisition

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

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

6.2.2 Geographic Segmentation

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

6.2.3 Sampling Strategy

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Step 4) Landowner contact and road access limitations.

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

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

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

6.3 Data forms

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.4 Assessment

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

6.5 Data Entry and GIS

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

6.6 Generally accepted standards for road decommissioning treatments

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

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

Stream crossings

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

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

Landslides

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

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

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

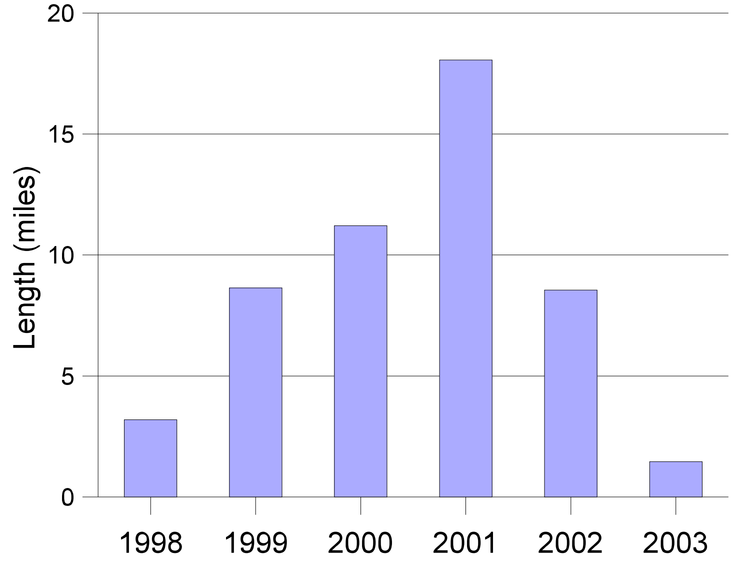
7.0 Results

7.1 Inventory Results

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

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

Figure 2. Inventoried decommissioned road, by age



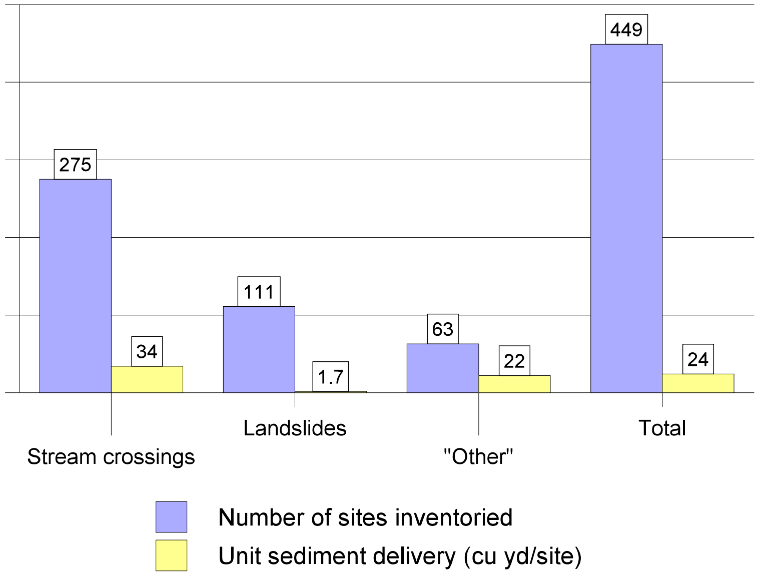
Ten different geologic bedrock types were encountered in this assessment. The predominant geology for each road was identified in the field and cross checked from one of three source maps: Ogle (1953), Jennings (1977), and McLauglin (2000). The geologic bedrock ranged from Paleozoic to Quaternary in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

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

7.2 Decommissioned Site Types

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

Figure 3. Unit sediment delivery from decommissioned sites



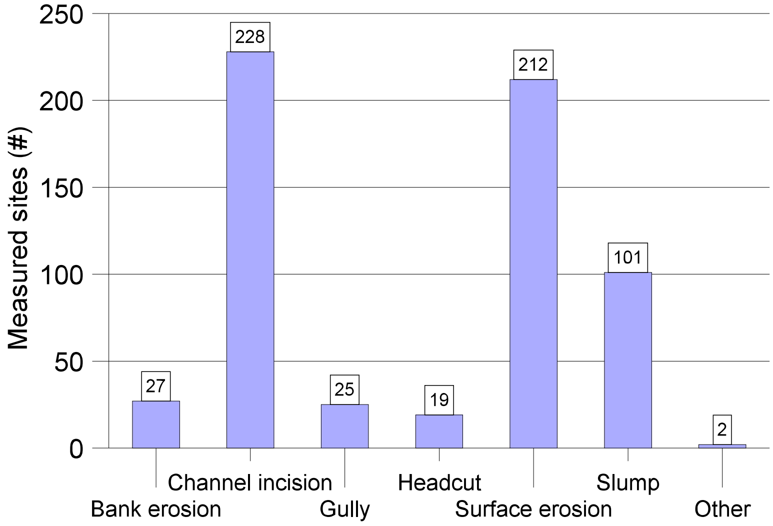
7.3 Erosion Features at Decommissioned Sites

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

Figure 4. Measured erosion features at all 449 sites

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

Figure 5. Measured erosion features at 275 stream crossings



Stream Crossings

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

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

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

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

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

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

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

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

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

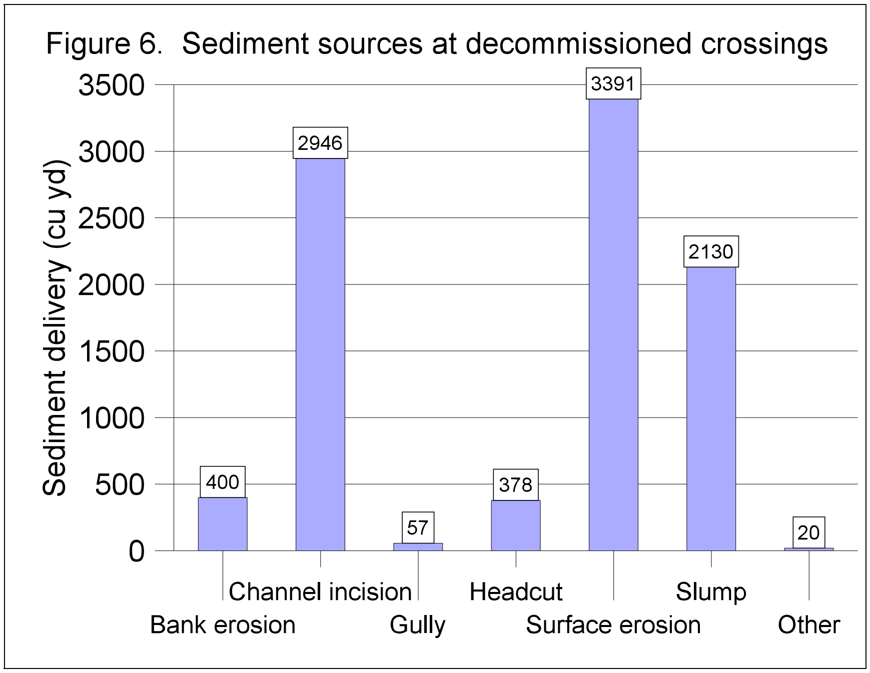


Table 4. Post-decommissioning sediment delivery from slope failures on the banks of excavated stream crossings, by slope class and slope shape, CDFG decommission monitoring study, North Coastal California.

Slope gradient of excavated banks (%)	Excavated slope shape	No. of failures on excavated channel sideslopes (#)	Post-decommissioning sediment delivery (yds^3)
<50% (gentle)	Concave	2	7
	Convex	2	12
	Straight	9	63
	Other	2	60
Subtotal		**15**	**142**
>50% (steep)	Concave	10	35
	Convex	18	618
	Straight	52	1,161
	Other	1	1
Subtotal		**81**	**1,815**
TOTAL		**96**	**1957**

Landslides *(exclusive of those at decommissioned stream crossings)*

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

“Other”

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

7.4 Causes of Erosion

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

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

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

7.4.1 Stream Crossings

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

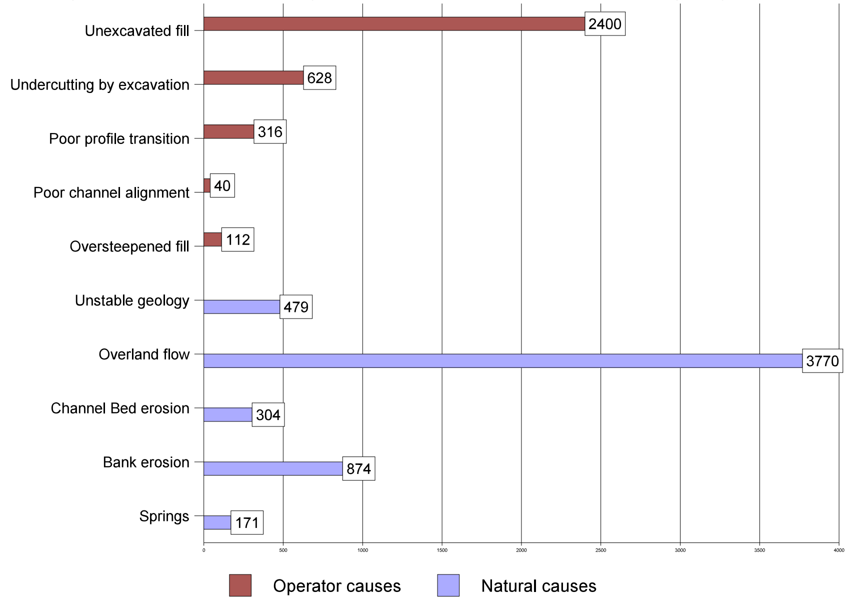
Table 5a. Stream crossing post-decommissioning erosion and sediment delivery, by cause, CDFG decommission monitoring study, North Coastal California

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

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

Of the 9,322 yds^3 of sediment delivery at stream crossings, 40% (3,770 yds^3) is associated with overland flow (surface runoff) and 26% (2,400 yds^3) is associated with unexcavated fill. In addition, approximately 13% (1,178 yds^3) of sediment delivery at decommissioned stream crossings is related to natural bank and channel adjustments (Table 5a; Figure 7). Approximately 3,496 yds^3 (38% of the total post-decommissioning sediment delivery) can be directly attributed to operator or supervisor error while nearly 5,600 yds^3 (60% of the total) can be attributed to “natural” or unavoidable causes. This assumes that most overland flow and associated surface erosion on the long sideslopes of large decommissioned stream crossings is largely unavoidable. The remaining 2 percent could be attributable to either operator error or unavoidable adjustments, or both (Table 5a).

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



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

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

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

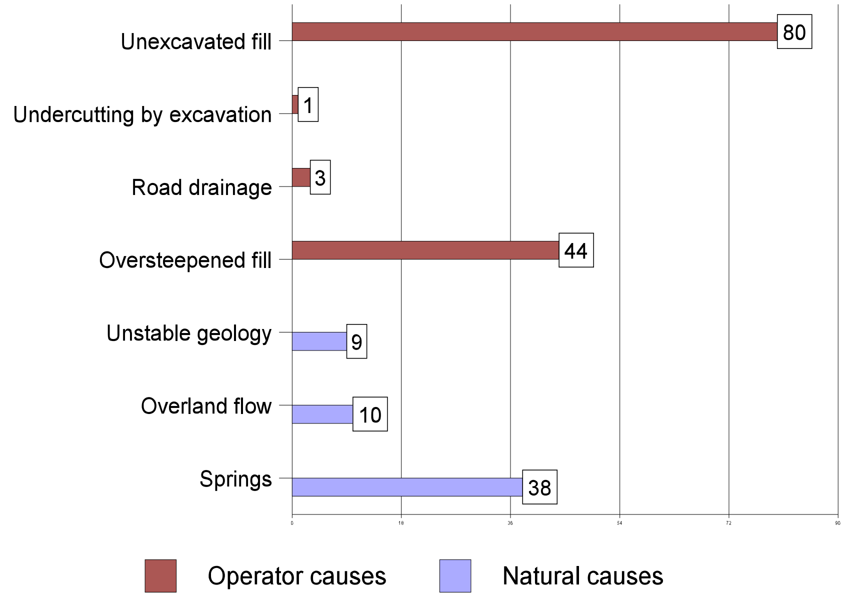
7.4.2 Landslides

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

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

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

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



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

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

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

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

7.4.3 "Other"

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

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

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

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

7.4.4 Erosion statistics

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

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

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

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

Table 6b. Landslide post-decommissioning erosion and sediment delivery statistics (n=111), CDFG decommission monitoring study, North Coastal California

Statistic	Post-decommissioning erosion (yds^3)	Post-decommissioning sediment delivery (yds^3)
Number of inventoried treated site types (#)[1]	24	16
Total delivery volume (yds^3)	624	185
Number of past erosion features associated with site type (#)	26	18
Mean volume (yds^3)	24	12
Median volume (yds^3)	9	3
Standard Deviation (yds^3)	47	19
Minimum volume (yds^3)	0.03	0.02
Maximum volume (yds^3)	237	71

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

Table 6c. "Other" sites post-decommissioning erosion and sediment delivery statistics (n=63), CDFG decommission monitoring study, North Coastal California

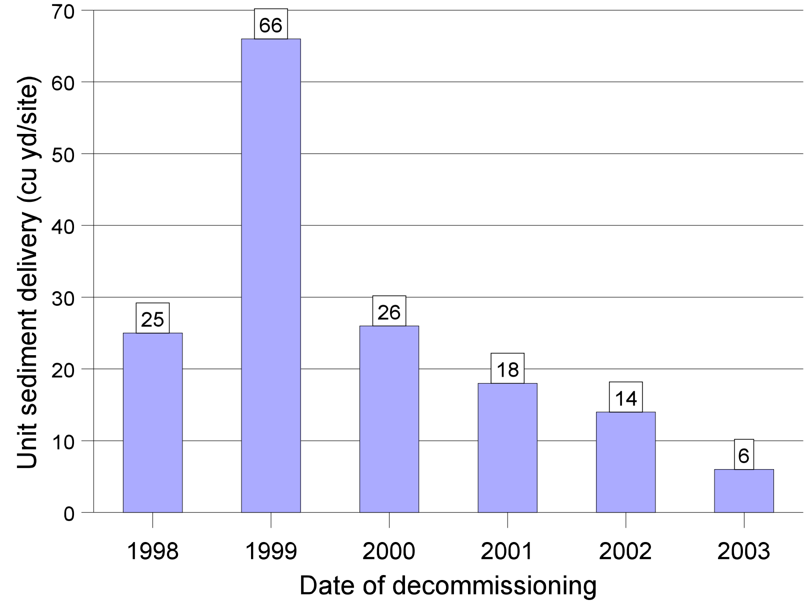
Statistic	Post-decommissioning erosion (yds^3)	Post-decommissioning sediment delivery (yds^3)
Number of inventoried treated site types (#)[1]	37	27
Total volume(yds^3)	3,542	1,405
Number of past erosion features associated with site type(#)	46	34
Mean volume (yds^3)	96	52
Median volume (yds^3)	2	4
Standard Deviation (yds^3)	374	178
Minimum volume (yds^3)	0.1	0.01
Maximum volume (yds^3)	2,235	911

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

7.5 Unit Sediment Delivery by Age

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

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



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

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

Table 7. Post-decommissioning erosion and sediment delivery, by date and site type, CDFG decommission monitoring study, North Coastal California

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

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

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

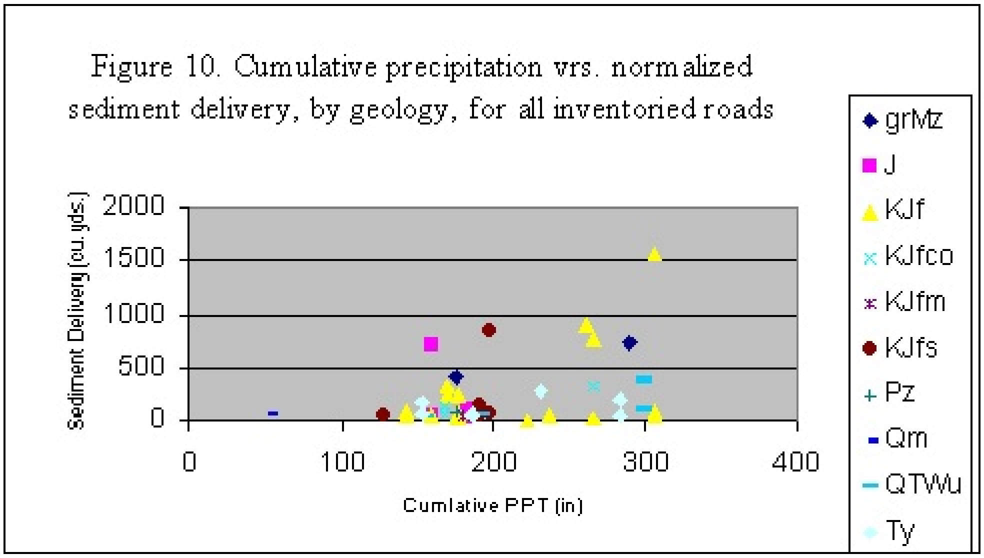


Figure 10. Cumulative precipitation vrs. normalized sediment delivery, by geology, for all inventoried roads

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

7.6 Unit Sediment Delivery by Geology

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

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

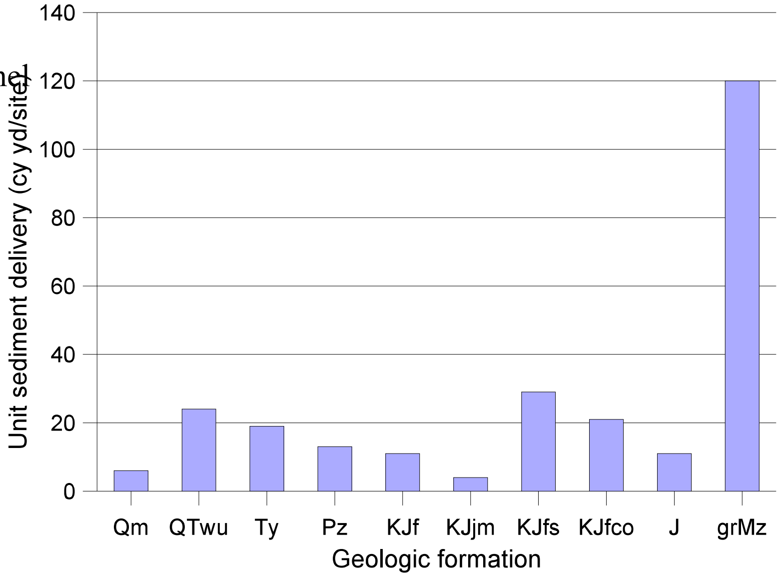
Geology	Site Type (#)				Post-decom erosion (yds^3)	Post-decom sediment delivery (yds^3)	Unit post-decom sediment delivery (yds^3/site)
	Stream crossing	Landslide	Other	Total			
Qm	1	2	0	3	92	17	6
QTwu	16	16	3	35	2,500	849	24
Ty	84	7	12	103	3,392	1,944	19
Pz	9	2	3	14	210	178	13
KJf	80	53	15	148	2,148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

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

7.7 Future Erosion

During the inventory of decommissioned roads and post-decommissioning erosion sites, we also made estimates of the location, nature and magnitude of future erosion that was likely to occur at each location. These estimates included the potential for future erosion, the volume of expected erosion and sediment delivery for each erosion feature. Not all the erosion features had the same potential for future erosion, and not all the features that are expected to erode will deliver sediment to the stream channel. Examples of future erosion identified in the field inventory included: continued channel incision through unexcavated fill, continued movement and delivery from active slumps, gully widening, and continued rilling of bare soil areas, among others.

Figure 11. Unit sediment delivery from decommissioned sites, by geology



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

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

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

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

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

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

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

Stream Crossings

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

Landslides

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

"Other"

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

Erosion potential

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

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

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

7.8 Treatment Effectiveness

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 12. Unit sediment delivery from treated sites

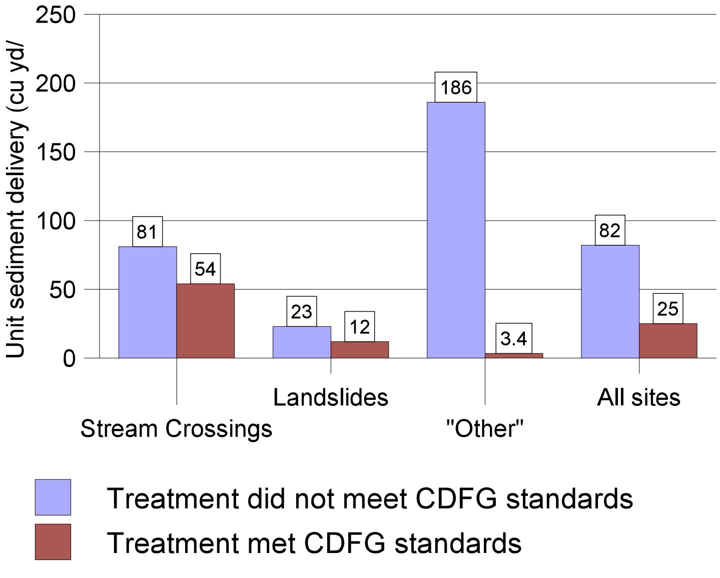


Table 13. CDFG protocol standards, by treated site type, CDFG decommission monitoring study, North Coastal California.

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

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

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

7.9 Spoils Disposal

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

7.10 Implementation Deficiencies

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

7.11 New Untreated Sites

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

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

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

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

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

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

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

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

7.12 Road Drainage

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

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

8.0 Discussion

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

8.1 Erosion Features and Causes of Erosion at Decommissioned Stream Crossings

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

Erosion Features

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

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

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

Causes of Erosion

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

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

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

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

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

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

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

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

8.2 Erosion Features and Causes of Erosion at Decommissioned Landslides

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

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

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

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

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

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

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

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

8.3 Erosion Features and Causes at "Other" Sites

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

Erosion Features

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

Erosion Causes

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

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

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

8.4 Geologic Influence on Erosion

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

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

8.5 Time Influence on Erosion

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

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

8.6 Rock Armoring

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

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

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

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

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

8.7 Spoils Disposal

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

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

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

8.8 Treatment Effectiveness

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

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

8.9 Road Drainage

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

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

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

9.0 Recommendations

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

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

9.1 Stream Crossings

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

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

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

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

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

9.2 Landslides

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

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

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

9.3 "Other" sites

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

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

9.4 New Untreated Sites

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

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

10.0 Conclusions

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

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

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

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

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

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

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

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

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

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

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

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

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

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Appendix A

Description of Geologic Units

from:

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

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

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

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

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

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

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

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

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

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

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

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

Appendix B

Maps 1 - 40
of
Decommissioned Roads

Appendix C

Decommission Monitoring Data Forms

Site Data Form

Road Data Form

New Untreated Site Data Form

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

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

STREAM CROSSING	Stream class (1, 2, 3)	Nat. upstream Ch grade (%):	Natural upstream Ch width (100 yr flood)(ft):				
Excavated Channel info	Design TOP to Exc. TOP length (ft):	Exc. TOP to IBR length (ft):	IBR to OBR length (ft):	OBR to Exc. BOT length (ft):	Exc. BOT to Design BOT length (ft):		
	Total exc. ch length (ft):	Average ch width (ft):	Excavated ch grade (%):				
	Excavated ch shape (concave, convex, straight, complex)	If complex, describe:					
	TOP transition (headcut, oversteepened, none):	Cause: (natural, construction, decommission)	BOT transition (headcut, oversteepened, none):	Cause: (natural, construction, decommission)			
	Channel bed materials (%)	Rip Rap:	Bedrock:	Boulders:	Coarse lag:	Erodible material:	Organic debris:
	Base level controls? (Y, N)	% vertical drop:	Location of armor (TOP, BOT, Channel,None)	Channel armor length (ft):			
	Proper armor placement (form): (Y , N)	Proper armor size (L, S, C):	Proper armor quantity? (L, S, C):				
Excavated side slope info	**Right side slope**	IBR slope %	IBR length (ft)	IBR slope shape (CC, CV, ST)	OBR slope %	OBR length (ft)	OBR slope shape (CC, CV, ST):
		If convex: 2nd IBR slope % :	IBR length (ft):	If convex: 2nd OBR slope % :	OBR length (ft):		
		Fillslope armor length (ft):	width (ft):	Proper armor placement (form): (Y, N)	Proper armor size (L, S, C):		
		Proper armor quantity?(L, S, C):	% bare erodible soil:	% Veg cover:	Seed/Mulch (Y, N , M)		
	Left side slope	IBR slope %	IBR length (ft)	IBR slope shape (CC , CV , ST)	OBR slope %	OBR length (ft)	OBR slope shape (CC , CV , ST):
		If convex: 2nd IBR slope % :	IBR length (ft):	If convex: 2nd OBR slope % :	OBR length (ft):		
		Fillslope armor length (ft):	width (ft):	Proper armor placement (form): (Y, N)	Proper armor size (L, S, C)		
		Proper armor quantity?(L, S, C):	% bare erodible soil:	% Veg cover:	Seed/Mulch (Y , N , M)		
Spoil info	Are spoils perched above or have access to a stream? (Y , N):						

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

OTHER SITES	Other feature type (Spring, Gully, Road surface, Ditch, Cutbank, Other)	Other (specify):
IMPLEMENTATION INFO	What was the treatment? (Stream crossing excavation, Landslide excavation, Rock/Log buttress, Retaining Structure, De-water landslide, Vegetation (planting), Dip at spring, Road decompaction, Ripping, Grade control (rock, check dams), Rock armor, Cross road drains, Surface drainage structure, Road shaping (IS, OS), Other)	

Was the treatment design appropriate for the site ? (Y , N , No data)	Explain:
Was the treatment implemented, as prescribed? (Y , N , No data)	Explain:
Did the treatment meet standard CDFG prescription protocol? (Y, N)	Explain:

COMMENT	

EROSION INFORMATION

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

TREATMENT EFFECTIVENESS INFORMATION

Should the site have been further treated (Y, N):

Should site have been treated (Y,N):

Possible treatments (circle): Deeper excavation | Wider channel | Sideslopes laid back further | Larger landslide excavation | Rock armor

Better surface drainage treatments | Better surface erosion treatments | Grade control | Better spoils management | Other (specify):

Comment on most common mistakes:

SKETCH

Photo point #	Location	View

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

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

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

Sketch

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

Sketch

Appendix D

Data Form Definitions and Explanation

Decommissioning Site Data Form
Definitions and Explanation

Front Side

GENERAL INFORMATION

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

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

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

Date: The date the evaluation is taking place.

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

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

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

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

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

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

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

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

Landowner: The current landowner of the road being evaluated.

Contractor: The heavy equipment operator that conducted the work.

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

Geology: The primary geology bedrock within the restoration site.

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

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

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

STREAM CROSSING INFORMATION

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

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

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

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

Excavated channel information

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

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

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

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

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

Total excavated channel length: The total excavated channel length of the stream crossing being evaluated.

Average channel width: The excavated channel width of the crossing being evaluated.

Excavated channel grade: The average excavated channel grade at the restoration site being evaluated.

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

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

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

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

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

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

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

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

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

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

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

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

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

- -Rip rap: purposely placed rock armoring usually over 1 foot in diameter.
- -Bedrock: The native rock within the evaluated crossing
- -Boulders: Natural rocks larger than .75 feet in diameter
- -Course lag: rock and gravel between the size range of .75 feet and sand size particles.
- -Erodible material: Fine grained material capable of being transported during the smallest stream flow
- -Organic debris: Organic matter incorporated into the channel bed materials.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Spoil Information

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

LANDSLIDE INFORMATION

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

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

Landslide excavation information

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

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

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

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

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

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

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

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

Spoil Information

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

"OTHER" SITES

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

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

Implementation Information

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

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

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

Decommissioning Site Data Form Definitions and Explanation

(continued)

Back Side

GENERAL INFORMATION

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

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

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

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

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

PAST EROSION INFORMATION

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

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

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

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

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

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

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

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

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

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

Stream crossing or landslide excavation related –

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

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

Stream crossing related –

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

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

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

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

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

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

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

Road surface drainage related –

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

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

Natural mechanism –

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

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

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

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

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

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

Other mechanism –

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

FUTURE EROSION INFORMATION

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

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

Treatment Effectiveness Information

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

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

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

Possible treatments

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

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

COMMENT ON MOST COMMON MISTAKES

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

SKETCH

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

PHOTO POINT TABLE

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

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

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

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

Appendix E

California Department of Fish and Game
Generally Accepted Road Decommissioning Standards

California Department of Fish and Game

Generally Accepted Road Decommissioning Standards

STREAM CROSSINGS

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

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

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

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

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

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

ROAD SURFACE

De-compacting and drainage technique

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

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

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

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

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

Re-contouring techniques

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

LANDSLIDES

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

GENERAL

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

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

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

Appendix F

Void Measurement Protocol

PWA Void Measurement Protocol

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

Where,

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

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

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

% delivery= The estimated percent of the surface erosion that has or is likely to reach a watercourse.

Field estimation of past surface erosion

Estimating the area: The area undergoing surface erosion is estimated in different ways, depending on the shape of the area being eroded. If the area is generally a square shape then the X and Y axis of the square is measured using either a tape, a laser range finder, or pacing depending on which is most appropriate and the two axis are multiplied together to get an area. If the area is triangular in shape then the X and Y axis of the triangle is measured using either a tape, a laser range finder, or pacing depending on which is most appropriate and the two axis are multiplied together and divided by two to get an area. If the area is shaped other than a square or triangle it is broken into different sections composed of both squares and triangles and the above methods are used to estimate the areas of the different areas and they are summed to get a final area of surface erosion. Finally, the overall percent of the area that is actually being eroded (as would be the case in a heavily rilled fillslope) is estimated to get a final surface area.

Estimating the average depth of surface erosion: The average depth of the surface erosion is measured in two different ways, depending on the consistency of the depth of erosion over the area being assessed. If two adjacent areas have different depths of erosion then they are analyzed as two separate erosion sites. If the area being eroded has a consistent depth of surface erosion, then the depth of the erosion is measured and the percent of the area that has been lowered is estimated and they are multiplied together to come up with an average depth estimate. If the area being eroded has a multitude of different surface erosion depths then multiple steps are taken to average the depth of erosion. First the different depths of the surface erosion are categorized and the estimated percent of the whole that each category encompasses is estimated. These depths are then proportioned by their percentage and multiplied by the percent of the area that is actually being eroded to come up with an average depth of erosion.

Estimation of delivery percent: Delivery percent is a professional estimation based on available field evidence at the erosion site. It is an estimation of percent of the eroded material that has been delivered to a watercourse.

Field estimation of future surface erosion

Future surface erosion is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future surface erosion. The area measurements are estimated using the same techniques mentioned above and the depth and percent area eroded are estimated. Estimations of depth and percent area eroded are based on geomorphic phenomena and professional judgment and are estimated for a 50 year time period.

CHANNEL INCISION AND MIGRATION: $V_{ci} = (W_{avg.} * D_{avg.} * L)/27$

Where,

V_{ci}= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the channel erosion taking place in the stream channel, in ft.

$D_{avg.}$= The average depth of the channel erosion taking place in the stream channel, in ft.

L= The measured length of the channel segment undergoing erosion.

Field estimation of past channel incision and migration

The averaged width, depth and the length of channel incision are directly measured at the site by using either a tape, a laser range finder, or pacing depending on which is most appropriate. The average depth and width of the incision or migration is measured in two different ways, depending on their consistency over the length being assessed. If the depth and width of the incision or migration is consistent throughout the length of channel being assessed, then the width, depth, and length of the erosion is measured and multiplied together in the equation above to come up with an estimated erosion volume. If the depth and width of the incision or migration is inconsistent throughout the length of channel being assessed then they are estimated using one of two techniques. If the erosion width and depth increase or decrease consistently throughout the channel segment being evaluated, then the end members are averaged to get a width and depth to multiply together in the above equation. If the channel incision or migration is inconsistent throughout the channel segment being evaluated then the channel was broken into segments consisting of segments of equal depth and width and the above technique was used.

Field estimation of future channel incision and migration

Future channel incision and migration is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests channel incision is ongoing or a headcut is continuing to migrate, then the evaluator uses the geometry of the crossing and the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in the equation above.

GULLIES AND RILLS: $V_g = (W_{avg.} * D_{avg.} * L)/27 * (\% \text{ delivery})$

Where,

V_g= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the gully erosion taking place in the area of interest, in ft.

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

L= The measured length of the gully being investigated.

% delivery= The estimated percent of the surface erosion that has or is likely to reach a watercourse.

Field estimation of past gully and rill erosion

The average width, depth and the length of gullies and rills are directly measured at the site by using either a tape, a laser range finder, or pacing depending on which is most appropriate. The average depth and width of the gully or rill is measured in two different ways, depending on their consistency over the area being assessed. If the depth and width of the gully or rill is consistent throughout the length of area being assessed, then the width, depth, and length of the erosion is measured and multiplied together in the equation above to come up with an estimated erosion volume. If the depth and width of the gully or rill is inconsistent throughout the length of channel being assessed then they are estimated using one of two techniques. If the erosion width and depth increase or decrease consistently throughout the channel segment being evaluated, then the end members are averaged to get a width and depth to multiply together in the above equation. If the channel incision or migration is inconsistent throughout the channel segment being evaluated then the channel was broken into segments and the above technique was used.

Field estimation of future gully erosion

Future gullying and rilling is based on continued erosion of areas that are currently undergoing erosion or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests gullying or rilling is ongoing or a headcut is continuing to migrate, then the evaluator uses the geometry of the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in the equation above. Future estimates of active gully or rill enlargement usually fall into one of two categories: 1) features that will continue to downcut and increase in depth, and 2) features that will no longer downcut but will experience layback of its side slopes. If the future gully or rill erosion falls into the first category, then a future depth estimate is made by evaluating the geometry of the erosional feature, and the on site geomorphic evidence. If the future gully or rill erosion falls into the second category, then the future erosion is considered to be "layback" of the gully or rill sideslopes to a stable angle. An assumption of a 45 degree angle of sideslope layback, on a gully that has vertical walls, results in a future erosion volume equal to the original gully volume.

SLUMP/SLIDE: $V_s= (W_{avg.}* D_{avg.}*L_{avg.})/27*(\% \text{ delivery})$

Where,

V_s= Volume of sediment delivered to a watercourse, in yd^3.

$W_{avg.}$= The average width of the slump/slide erosion taking place in the area of interest, in ft.

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

$L_{avg.}$= The average length of the slump/slide being investigated.

% delivery= The estimated percent of the slide volume that has or is likely to reach a watercourse.

Field estimation of past slump/slide erosion

Field estimation of past slump and landslide erosion is based on physical measurements of the boundaries of the feature being assessed. The length is measured from the crown scarp to the toe of the *surface rupture* (not to be confused with the toe of the landslide, defined here as the lower margin of the displaced material of a landslide, most distant from the main scarp). The width is measured between the scarps that define the lateral edges of the feature. The depth of the slide is measured perpendicular to the failure plane between the failure plane and the original ground surface. In all but a few cases the typical shape of a landslide does not lend itself to simple measurements of width, depth, and length to determine erosion volumes. In these cases one of two techniques can be employed (depending of the shape of the feature) to estimate the past erosion. If the slide is complex in shape then it is subdivided into different areas that have boundaries that lend themselves to reasonable estimates of average length, width, and depth. The volumes of the subdivided areas are then summed to come up with estimates of past erosion. If the feature in question is a slump or failed as a rotational feature then the volume can be calculated as a half of an ellipsoid with the equation ($V= 1/6 *\pi* L_{max}* W_{max}* D_{max}$). Once the volume of the failure is established an estimate of the percent of the eroded material that has been delivered to a watercourse is estimated and multiplied to calculate the eroded volume.

Field estimation of future slump/slide erosion

Future slump/slide erosion is based on continued erosion failure of areas that are currently undergoing instability or areas that are showing signs of susceptibility to future adjustments. For example, if on-site evidence suggests mass wasting is ongoing, then the evaluator uses the geometry of the erosional feature, and on-site geomorphic evidence, to estimate future width, depth, and length to use in one of the above equations depending of the shape of the feature.

Appendix G

Photos of common decommissioned roads and sites

LIST OF PHOTOS