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P.O. Box 944246
Sacramento, CA 94244-2460
Phone: 916-653-7209
Web: www.fire.ca.gov

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STATE FOREST ROAD 600: A RIPARIAN ROAD DECOMMISSIONING CASE STUDY IN JACKSON DEMONSTRATION STATE FOREST

Elizabeth T. Keppeler[1], Peter H. Cafferata[2], and William T. Baxter[3]

[1] Hydrologist, USDA Forest Service, Pacific Southwest Research Station, Fort Bragg.
[2] Forest Hydrologist, California Department of Forestry and Fire Protection, Sacramento.
[3] Fire Captain, California Department of Forestry and Fire Protection, Willits (formerly Forester II, Jackson Demonstration State Forest).

ABSTRACT

Road decommissioning work has been studied in the South Fork Caspar Creek experimental watershed since 1998, when a 4.6 km (2.8 mi) segment of Forest Road 600 was decommissioned. A total of 26 watercourse crossings and eight cross-drain relief culverts were removed, while an additional eight minor crossings remained untreated. A detailed time study documented costs associated with the different treatments implemented at these sites. Gully measurements were made after one and three over-wintering periods. Additional measurements consisted of a longitudinal profile with three to five cross-sections at nine benchmarked sites and a detailed topographic survey at a tenth crossing where the road crossed the main stem of the South Fork. Surveying work was completed at these sites after one and four winter periods. Mean erosion volumes measured at the treated crossing sites following one and three over-wintering periods were 24.6 m^3 (32 yd^3) and 27.4 m^3 (36 yd^3), respectively. Erosion volumes were mainly created after the first winter, with a 17% increase following three over-wintering periods. Only three decommissioned crossings continue to erode after eight winters. After three winters, gully erosion equated to four percent of the total volume of fill material removed at the stream sites. Approximately 50% of the total eroded volume measured was produced by only three of the decommissioned crossings, which is consistent with results from past studies, where most of the erosion volume is produced by a small percentage of the excavated crossings. Gullied stream crossings along the decommissioned roads accounted for nearly one third of the total inventoried erosion volume and 57% of the sediment load in the South Fork Caspar Experimental Watershed during the first post-treatment winter. The erosional costs associated with road decommissioning in this study were significantly greater than anticipated during project planning. Detailed pre-project survey work, operator skill, and diligent project inspection are critical to ensure proper excavation at treated crossing sites. In addition, boulder armoring of major crossings may help reduce post-treatment gullying.

INTRODUCTION AND LITERATURE REVIEW

While forest roads in general are known to be a major anthropomorphic cause of sedimentation in forest streams in the western United States (Megahan and Kidd 1972; Reid and Dunne 1984; Furniss and others 1991; Luce and Black 1999; MacDonald and others 2004), roads located within riparian zones are especially prone to sediment delivery to stream channels (WFPB 1997). Several studies in diverse geologic settings have concluded that roads located within 60 m (200 ft) of a stream channel deliver considerably more sediment than those located more than this distance. Rice and others (1979) described roads within 60 m of the stream channel as delivering sediment to stream channels in the South Fork Caspar Creek watershed, where the study described in this paper took place. Ketcheson and Megahan (1996) reported that sediment flow from most cross-drains extends less than 60 m in the Idaho batholith. More recently, Coe (2006) reported that sediment travel distance from forest roads was generally less than 40 m (130 ft) in the central Sierra Nevada.

Road decommissioning (abandonment)[4] near streams is a practice that has been used extensively in northwestern California to reduce long-term road sediment delivery, thereby lessening impacts to sensitive aquatic resources such as listed

[4] California Forest Practice Rules define “abandonment of roads” as procedures that permanently close a road in a manner that prevents erosion, maintains hillslope stability, and re-establishes natural drainage patterns (CAL FIRE 2007).

anadromous fish species (Harris and others 2006). Weaver and Hagans (1994) state that proactive road abandonment (i.e., closure or road decommissioning) is a method of closing a road so that regular maintenance is no longer needed and future erosion is largely prevented. Criteria that are commonly used to identify roads to proactively decommission include: (1) roads in close proximity to fish-bearing streams, (2) roads located in unstable inner gorge areas, and (3) roads with excessive amounts of perched fill (CDF 2002). Treatments include removing culverts and reestablishing channels to their original grade and channel configuration. Road prisms at watercourse crossings are pulled back to a stable slope configuration and the regraded channel may be armored to prevent downcutting or erosion of the old fill material.

An on-going program of road decommissioning and upgrade work throughout a forest ownership to remove existing and potential erosion sites and reduce long term sediment production is widely accepted as a valid approach to improve aquatic habitat conditions (Klein 2003, PWA 2005a, Luce and others 2001, Madej 2001, Switalski and others 2004). In addition to benefits from this type of road work, however, there are also short-term impacts due to channel adjustments following crossing removal, as documented in previous studies (Klein 1987, Bloom 1998, Madej 2001, Brown 2002, Klein 2003, PWA 2005a, PWA 2005b, Foltz and Yanosek 2005, Harris and others 2006). Results from three past studies are briefly described below.

Madej (2001) studied logging roads in the Redwood Creek watershed in Humboldt County. She reported that although road removal treatments do not completely eliminate erosion associated with forest roads, they substantially reduce sediment yields from closed logging roads. On average, treated roads contributed about one-fourth the sediment produced from untreated roads. Twenty percent of the excavated stream crossings accounted for 73% of the post-treatment erosion from crossings. For 207 crossings that had been decommissioned over a period of 17 years from 1980 to 1997, an average of 50 m^3 (65 yd^3) of sediment per crossing was reported. Almost 80% of the treated road reaches had no detectible erosion following a 12-year recurrence interval storm. Madej (2001) concluded that by eliminating the risk of stream diversions and culvert failures, road removal treatments significantly reduce long-term sediment production from retired logging roads.

In another study in Humboldt County, Klein (2003) conducted a monitoring project to determine volumes of erosion following road removal at excavated crossings and impacts to water quality in the upper Mattole River basin. The Sanctuary Forest, Inc. is implementing an erosion control and prevention program in this watershed to reduce long-term sediment yield, with the focus on decommissioning unneeded forest roads that pose sedimentation risks. Erosional void dimensions were measured at 18 excavated crossings. Both channel scour and bank slumps were documented for each crossing. Most of the erosion was found in the excavated channel areas, but erosion was also documented above crossings where culverts had been located. An average of

12 m^3 (15.5 yd^3) per crossing of post-excavation sediment was reported following one over-wintering period. Approximately 20% of the excavated crossings produced roughly half the total sediment volume. The average post-treatment sediment delivery measured in this study was about 14% of the estimated pre-treatment sediment delivery potential. Klein stated that if it is assumed that the longer term volume of sediment delivery at excavations is twice that of the first-year volume (similar to that reported by Madej 2001), then post-treatment sediment delivery may approach 28% of pre-treatment sediment delivery potential.

PWA (2005a) recently reported that erosion at excavated stream crossings was the principal source of post-decommissioning sediment delivery from treated roads in the Elk River watershed in Humboldt County. About 90% of post-decommissioning erosion and sediment delivery volumes originated at excavated stream crossings. Similar to the earlier studies, a few crossings produced the majority of sediment. As in the upper Mattole River watershed study, approximately 20 percent of crossings produced about 50 percent of the delivered sediment. The estimated average erosion at 52 decommissioned crossings was approximately 13 m^3 (17 yd^3) following two, four, and seven over-wintering periods. PWA (2005a) reported that post-decommissioning erosion from excavated crossings is minimized by excavating stable, low gradient sideslopes and by completely excavating erodible fill that was placed in the channel when the crossing was constructed.

In general, the results of past studies on road decommissioning work show that: (1) road treatments can reduce the long-term sediment production from abandoned and upgraded roads, (2) excavated crossings will be the major short-term source of sediment input to stream channels following road decommissioning work, (3) post-treatment sediment delivery will likely be approximately 20% or less than pre-treatment sediment delivery potential at excavated crossings, and (4) most of the sediment input at excavated crossings can be expected to occur during the first few winters following treatment.

SITE DESCRIPTION

The study site is a 4.6 km (2.8 mi) road network, including portions of Forest Road 600 and spur roads 602, 603, 604, and 606, located within the South Fork Caspar Creek experimental watershed on Jackson Demonstration State Forest (JDSF) (figure 1). Caspar Creek is a small coastal stream draining approximately 21.7 km^2 (5,360 acres) of predominately coast redwood and Douglas-fir forest that is approximately 140 years in age. The watershed is underlain by the Franciscan Complex, composed of well-consolidated sedimentary sandstone (Cafferata and Spittler 1998). Caspar Creek flows from an elevation of 320 m (1050 ft) to the Pacific Ocean, a distance of 13 km (8 mi), and supports anadromous fisheries of coho salmon and steelhead trout along most of this length (Nakamoto 1998).

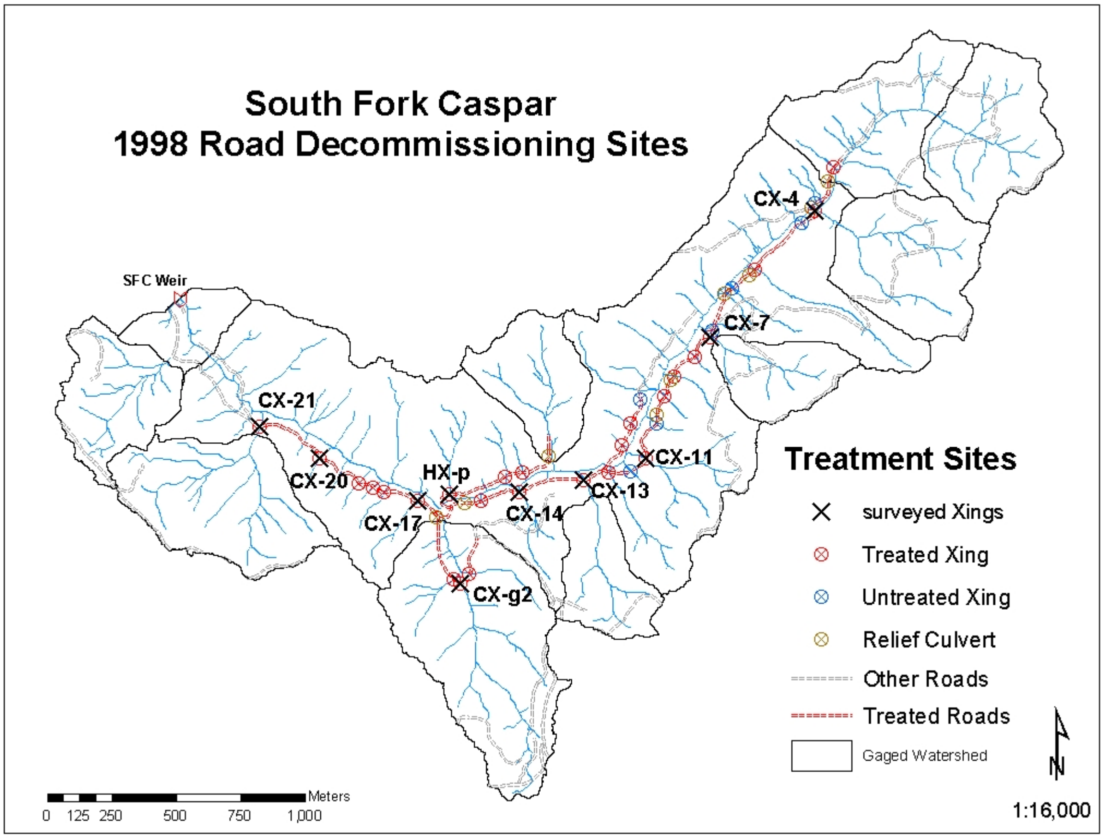

Figure 1. South Fork Caspar Creek Experimental Watershed, Mendocino County, CA.

The South Fork of Caspar Creek is a data rich environment. Streamflow at the South Fork weir has been gauged since 1962 (Henry 1998). Measurements of suspended sediment transport and bedload deposition have been ongoing since that date, as well. Since 1996, continuous measurements of instream turbidity have been recorded (Lewis and Eads 2001). Comprehensive summaries of sediment yields from both the South and North Forks of Caspar Creek have been completed (Lewis 1998, Lewis and others 2001, Keppeler and others 2003, Rice and others 2004). Changes in peak stream discharges associated with timber operations in the South Fork were documented by Ziemer (1981) and Wright and others (1990), and in the North Fork by Ziemer (1998).

The South Fork Caspar Creek road system was constructed during the summer of 1967 and expanded during the 1971-73 selection harvest of the watershed in order to facilitate tractor yarding (Krammes and Burns 1973, Rice and others 1979). Road construction and logging were designed according to the Caspar Creek Experimental Watershed study plan developed to quantify the impacts of these treatments on streamflow, sedimentation, and aquatic habitat. As such, the timber harvest and road system location, design, and construction were consistent with the management objectives and standards of the era (Krammes and Burns 1973). Road 600, the main haul road, was built within 61 m (200 ft) of the perennial stream. During construction, coarse woody debris, soil, and rock were deposited in the channel. Tractors operated in the streambed to build bridge crossings and landings, and to remove construction-related debris (Krammes and Burns 1973, Burns 1970).

Road 600 was used extensively for yarding and hauling activities between 1971 and 1973. Subsequently, the road was utilized year-round for post-harvest management, research access, and recreation until approximately 1994, when seasonal closures were implemented. During the 1980's and early 1990's, preventative maintenance was limited to annual grading, infrequent spot-rocking, and replacement of failed culverts. Spur roads 602-606 were largely ignored and unused since the mid-1970s.

By the mid-1990s, erosion incidents related to these roads were increasingly frequent. In 1994, a detailed landslide survey of the South Fork Caspar Creek watershed documented 10 significant features estimated to have occurred within the last five years. Nine were related to the road and skid trail system. In 1995, two additional failures occurred as a result of deteriorated steel culverts and displaced 434 m^3 (568 yd^3) of sediment, routing most of the material directly to the perennial stream channel. During the 1997-1998 El Niño storm season, five large road-related landslides occurred in the South Fork watershed, displacing 1,675 m^3 (2,190 yd^3) of sediment. Two additional landslides occurred, displacing 568 m^3 (743 yd^3) of material, but these were not related to the road system built in 1967 (Cafferata and Spittler 1998).

METHODS

Decommissioning Treatment, Timing, and Costs

Jackson Demonstration State Forest contracted for the decommissioning of 4.6 km (2.8 mi) of South Fork Caspar road segments in 1998 with an addendum to a timber sale agreement. Contract specifications required that stream crossings be excavated to the depth of the original channel, with side bank slopes not to exceed 50%. Jute netting was required to be installed for erosion control within 30 m (100 ft) of the well-defined channel area. Additionally, the contract specified that conifers were to be planted at a 3 m by 3 m (10 ft) spacing within the area covered by jute netting (figure 2).

Along the upper 2 km (1.2 mi) of Road 600, the contract required outsloping at a grade of 10% and berm obliteration to improve runoff dispersion. The contract further stated that the inboard ditch along this outsloped road segment was to be packed with soil to prevent flow concentration and conifers were to be planted along the road segment at 3.65 m (12 ft) spacing. Cross-road drains (i.e., waterbars) were required for all decommissioned road segments at an approximate spacing of 30 m (100 ft) and were to be installed with a grade of 5%,

Figure 2. Excavated crossing CX-21 with jute netting on side slopes, November 1998.

a width of 0.6 m (2 ft), an inlet depth of at least 0.15 m (6 in), and side bank slopes of less than 50%.

The project was implemented between August 6, 1998 and September 9, 1998, with a total cost of $32,495. There were 214 hours of excavator work, 75 hours of D-8 tractor work, 6 hours of D-6 tractor work, and 80 additional laborer hours. Stream crossing removal accounted for 47% of the total cost. A total of 17,900 m^3 (23,410 yd^3) of fill was removed from designated stream crossings, at a cost of \$0.85/m^3 (\$0.65/yd^3). Total outsloping costs were $4,465 or $2.15/m ($0.66/linear foot). Cross-drain construction ($1.68/m or $0.51/linear foot) and waterbarring ($0.45/m or $0.14/linear foot) accounted for the balance of the project expenses.

Erosion Measurements

To evaluate the erosional consequences of the road decommissioning treatment, measurements were made at a total of 42 road features: 26 excavated stream crossings, 8 excavated ditch relief culverts, and 8 untreated (minor missed) crossings where erosion or diversion problems were evident. Ten restored stream crossings were benchmarked prior to the arrival of the first winter rains. At nine of these sites, a longitudinal profile and several cross-sections were surveyed. A topographic survey was made at the tenth benchmarked feature, CX-4 (the mainstem crossing at the upper end of the treated segment of Road 600). Pre-winter photos were also taken at each of these ten sites. In spring of 1999, the longitudinal profiles, cross-sections, and the topographic survey were repeated. Longitudinal profiles and cross-sections were repeated at five of these sites in the summer of 2002. Change in cross-sectional area was calculated using the WinXSPRO computer software program (Hardy and others 2005). The topographic survey of site CX-4 was repeated in late 2001.

Additionally, after the first winter (1998-1999), gully erosion was documented at 32 of 34 sites by measuring the average width and depth of each gully at one meter increments along the length of the feature. The mean of these cross-sectional measurements was then multiplied by the length of the gully to determine the volume of each feature. These measurements were repeated in October 2001.[5] Photographs were taken a second time at established photo points during these remeasurements. A separate contract compliance survey was completed in November 2002. Finally, gully measurements were made a third time in 2006 at selected sites where fresh scour was visible.

RESULTS

After one winter, evidence of channel downcutting, gully erosion, and mass wasting was apparent (figure 3). Gully erosion measured at 32 sites totaled 651 m^3 (851 yd^3), with approximately half of this erosion occurring at just four sites--an eroded volume approximating four percent of the total fill removed (651 m^3/17,900 m^3). Erosion was negligible along the outsloped road surface and at most cross-drain locations.

Figure 3. Treated crossing CX-7 eroded severely and has yet to stabilize. In 2006, a debris flow deposit filled much of the void.

[5] This re-measurement included six additional sites not formally inventoried in 1999.

Mean erosion measured following the first winter at 25 decommissioned stream crossings was 24.6 m^3 (32 yd^3).[6] At 17 of the sites, gully erosion scoured 10 to 50 m^3 (13 to 65 yd^3) of sediment from the newly constructed channel crossings. New gullies of greater than 50 m^3 (65 yd^3) were created at three sites. At the main crossing (CX-4) at the top of treated Road 600, stream scour produced a 152 m^3 (199 yd^3) gully (figure 4). This excavated crossing on the mainstem of the South Fork is located within residual sediment aggradation from a historic splash dam built in the 1860's.[7] Thus, this site was prone to extreme post-treatment downcutting during the first winter. During the summer of 1999, stabilization was attempted with the placement of boulders to armor the headcut and large redwood logs and stumps within the gully to dissipate energy.

Erosion estimates from the surveyed cross-sections and topographic survey yielded similar eroded volume estimates as obtained with the gully survey work (table 1). Total erosion volumes for the gully survey and the cross-section survey for the same ten crossings after one over-wintering period were 451 m^3 (539 yd^3) and 421 m^3 (550 yd^3), respectively. Along the 10 surveyed longitudinal profiles, one channel incised as much as 2 m (7 ft), but most incised only 0.3 to 1 m (1 to 3 ft) (figure 5).

Following two additional over-wintering periods, most gullied crossings continued to downcut and widen at a decreased rate. However, gully size decreased at ten sites where channels aggraded due to revegetation and, in a few cases, the recruitment of new large wood. The total eroded volume from all the inventoried features increased from 651 m^3 to 759 m^3 (993 yd^3), an increase of 17%. Mean erosion following the three winter periods for the 26 decommissioned stream crossings increased to 27.4 m^3 (36 yd^3), an increase of about 11%. All but three of the crossing sites had less than 50 m^3 (65 yd^3) of erosion, the average reported by Madej (2001) in a comprehensive assessment of 207 crossings excavated between 1980 and 1997. The three crossings with the highest erosion rates accounted for 50% of the total erosion measured after three winters.

For the six crossings where the cross-sections were remeasured a second time (2002) and the topographic survey repeated (2001), the total eroded volume increased from 343 m^3 (449 yd^3) to 419 m^3 (548 yd^3), a change from June 1999 to summer 2002 (three additional over-wintering periods) of approximately 22%. The third topographic survey of site CX-4 indicates another 138 m^3 (181 yd^3) of volume loss within the crossing treatment zone, but this is largely due to re-entry impacts when heavy equipment was used in November 1999 to install the rock armoring and place logs and stumps in the gully. Additionally, an active seep has compromised the right bank.

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[6] Data is missing for one decommissioned stream crossing.
[7] Splash dam logging operations in the Caspar Creek watershed are described in Napolitano (1996) and Napolitano and others (1989).

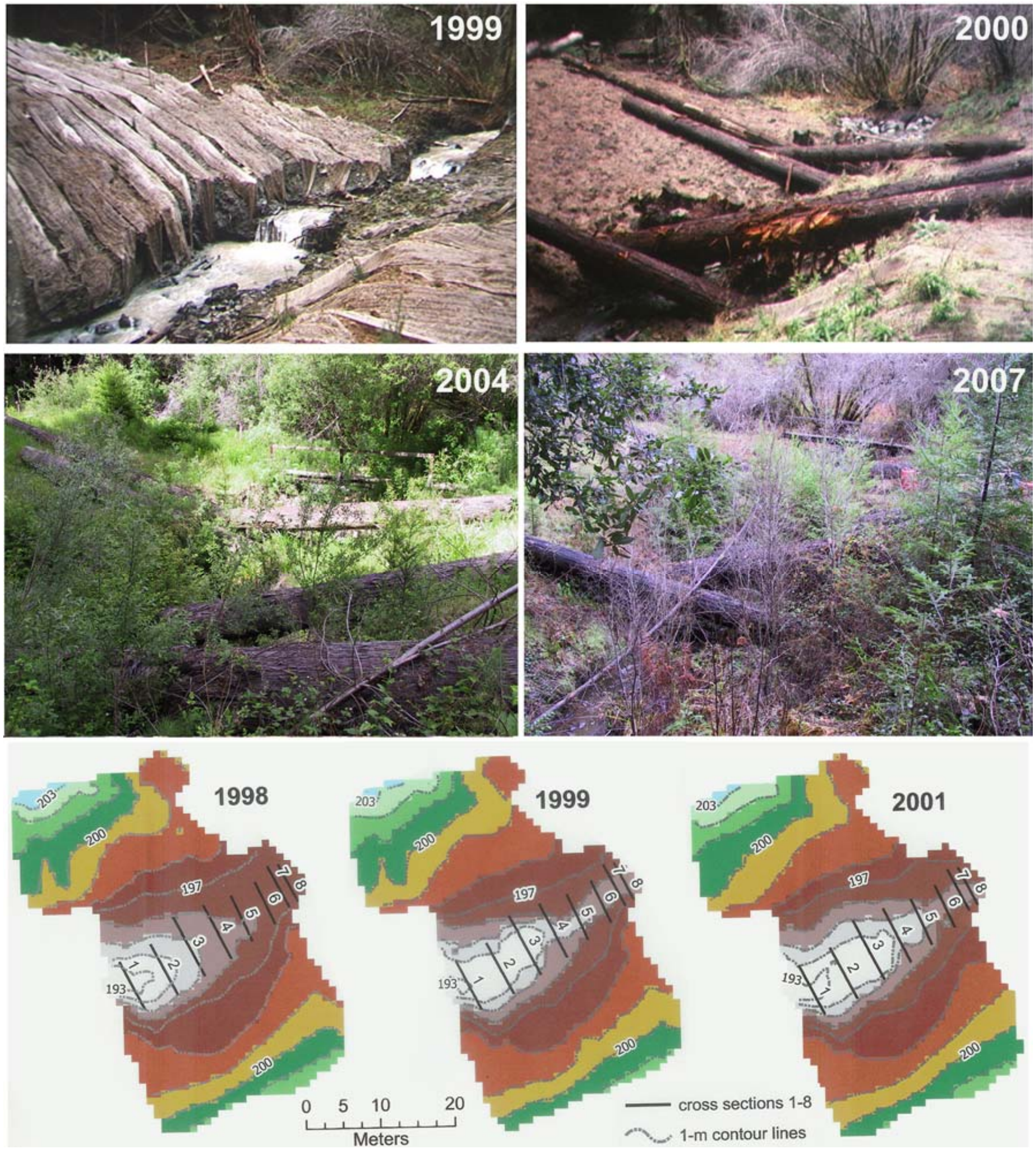

Figure 4. Photographs show channel adjustments and revegetation occurring between 1999 and 2007 at the large watercourse crossing (CX-4) on road 600. Surveyed grid elevations indicate almost 2 m (7 ft) of downcutting. Although further headcutting was halted by the boulder armoring done in 1999 and the placed redwood stumps have re-rooted, channel widening due to bank sloughing has continued.

Table 1. Erosion data for features evaluated along treated road segments (TX = treated crossings, UX = untreated crossings, R = excavated ditch relief culverts, and m = missing measurement).

Road	Feature		Volume		Length		Change	Surveyed X-Sections		
No.	ID	Type	Jun-99 (m^3)	Oct-01 (m^3)	Jun-99 (m)	Oct-01 (m)	1999-2001 (%)	Eroded Volume (m^3) 1998-99	1999-2002	Total
600	**CX-4**	TX	151.5	191.0	32	32	26%	93.9	37.6	131.5
600	**CX-7**	TX	86.2	99.2	41	42	15%	82.1	9.2	91.3
600	**CX-21**	TX	56.1	62.8	43	43	12%	69.9	2.8	72.7
600	**CX-11**	TX	32.9	34.9	33	32	6%	42.5	8.7	51.2
600	**CX-13**	TX	30.1	31.6	36	36	5%	31.6	-0.5	31.1
600	CX-5	TX	24.0	30.1	22	21	25%			
603	**CX-G2**	TX	29.9	28.6	23	23	-4%	35.5		
603	HX-un4	TX	18.7	23.7	33.5	33	27%			
600	CX-12	TX	19.9	23.4	33	35	18%			
600	**CX-14**	TX	20.1	22.0	37	37	9%	23.3	17.9	41.2
600	CX-18	TX	23.1	21.5	26	24	-7%			
603	X-un3	TX	17.9	18.6	22.5	22.5	4%			
600	**CX-20**	TX	15.6	17.5	27	27	12%	16.4		
602	**HX-p**	TX	17.8	17.2	32	32	-3%	12.1		
600	**CX-17**	TX	11.1	13.0	25	25	17%	13.3		
600	X-un6	UX	9.4	12.4	23.5	24	32%			
602	HX-602s	TX	7.3	12.1	28	28	65%			
600	X-un2	TX	12.3	11.4	31	31	-7%			
600	CX-9	TX	9.5	11.2	20	19	19%			
602	HX-606t	TX	9.0	8.9	18	18	-1%			
606	HX-606d	TX	11.1	8.7	15.5	15	-22%			
604	X-604y	TX	m	8.3	m	19				
600	X-z	UX	5.6	6.7	9	21	18%			
600	X-un1	UX	8.1	6.3	18	18	-23%			
600	X-ff	UX	m	5.1	m	17				
600	CX-10A	TX	1.8	5.1	5	17	191%			
606	CR-606d2	R	7.0	5.0	9.5	9	-29%			
600	CX-15	TX	2.7	3.8	14	14	38%			
604	X-604-e2	TX	2.6	3.7	17.5	17.5	42%			
600	CR-10	R	1.5	3.2	10	10	112%			
600	CX-19	TX	2.0	3.2	14	14	57%			
600	X-un8	UX	m	2.7	m	30				
600	X-un7	UX	m	2.0	m	16				
600	CR-un5	R	4.3	2.0	12	5	-55%			
600	CX-8	TX	1.3	1.1	25	21	-10%			
600	CR-6	R	0.9	0.9	7	7	0%			
603	CR-603-g1	R	m	0.7		10.7				
600	CR-16	R	0.0	0.0	15	15				
602	CR-602-f1	R	0.0	0.0	m	m				
606	CR-606c	R	0.0	0.0	m	m				
604	X-604-E1	UX	0.0	0.0	m	m				
606	X-606-a	UX	0.0	0.0	m	m				
	Totals	**42**	**651**	**759**	**758**	**861**	**17%**	**421**	**22%**	

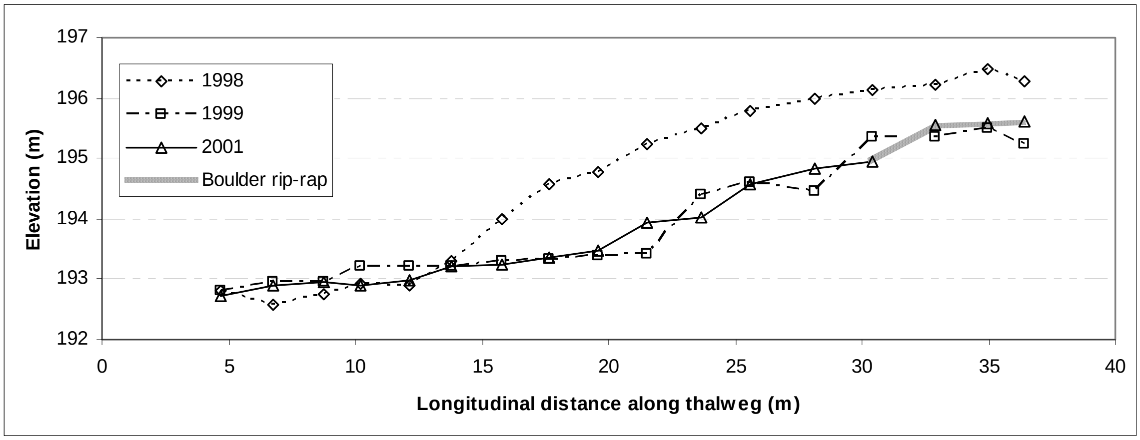

Figure 5. Surveyed longitudinal profile of the thalweg at crossing CX-4.

Subsequent observations from 2003 to 2006 indicate that the majority of crossing sites have stabilized with the exception of the two largest erosion sites—CX-4 (the main crossing at the top of Road 600) and site CX-7, and a mid-sized gully at site CX-G2. Each of these locations had special circumstances that interfered with successful and complete excavation. The latter crossing was the first significant excavation attempted in the project and was not fully excavated. As of 2006, these sites had continued to widen due to progressive bank failures. Site CX-4 enlarged by 17 m^3 (22 yd^3), or 9%. Crossing CX-7 experienced a net increase of 10 m^3 (13 yd^3), or 10%, as a result of enhanced erosion, even with partial in-filling from a large upslope debris flow. CX-G2 enlarged by 5 m^3 (6.5 yd^3), or 17%.

A November 2002 inspection evaluated project compliance with contract specifications for cross-drain placement, road surface outsloping, and stream crossing excavations. Incomplete excavation was noted at 12 crossing sites. Bank slopes exceeded the contract specification of 50% at three sites. At crossing CX-7, an exemption to the bank slope requirement had been negotiated in the field with the contractor due to the excessive excavation that would have been necessary to satisfy this specification. Other than these deviations, only minor variances were observed. The estimate of total fill volume removed for this project, 17,900 m^3 (23,400 yd^3), exceeded the pre-project estimate by 70% due to the inherent difficulties of making these estimates in heavily vegetated terrain and, in part, to the lack of training in this assessment skill. High levels of conifer mortality were noted for the planted seedlings in the retired roadbed, a result of poor soil conditions in the old roadbed and, to a lesser extent, red alder competition.

DISCUSSION

The first post-treatment winter (hydrologic year 1999) began in typical fashion. Rain events during December 1998 through February 1999 produced eight moderate storm peaks, with only one event having a return period of greater than one year. Rainfall totals for February and March were well above normal, resulting in annual precipitation 17% greater than the annual mean. The wet spring culminated in a major storm peak on March 24, 1999 with a discharge of 22.6 L/s/ha (338 cfs). This event had an estimated 44-year recurrence interval at the South Fork Caspar Creek weir, the highest flow in the 45-year record. A strong stressing storm of this magnitude is capable of testing the effectiveness of forest practices (Tuttle 1995), such as those implemented at the excavated crossing sites. Field observations suggest that the bulk of the treated crossing channel adjustments occurred during this extreme event. However, early season observations and photo records indicate that channel adjustments had initiated prior to this major spring storm. While a recent report prepared for the California Department of Fish and Game (CDFG) evaluating the erosional consequences of road decommissioning at 449 northern California sites treated between 1998-2003 did not detect a strong correlation between rainfall and post-treatment erosion (PWA 2005b), strong stressing storms occurring soon after treatment clearly contribute to severe down-cutting.

Long term comprehensive measurements of sediment production and erosion in the Caspar Creek experimental watersheds afford a unique insight into the consequences of road decommissioning on the sediment budget at a watershed scale. At the South Fork Caspar weir (SFC), continuous in-stream turbidity measurements are correlated with sediment concentrations from automated pumped water samples to determine event-based and annual suspended sediment yields (Lewis and Eads 2001). During the March 1999 storm event, recorded turbidity exceeded 2,000 NTU (the maximum value for the turbidity sensor). The SFC sediment load estimate for this storm event is 523 mT (123.4 mT/km^2) and 807 mT (190.3 mT/km^2) for the hydrologic year.[8] This annual load equates to an estimated volume of 602 m^3 (788 yd^3) using a bulk density of 1.34. Sediment accumulation at the South Fork weir debris basin measured an additional 547 m^3 (715 yd^3), the third largest annual accumulation in the 44-year record (1963-2006), exceeded only in 1998 and 2006. Thus, total South Fork Caspar sediment yield for 1999 was 1149 m^3 (1,503 yd^3), with erosion at the decommissioned crossings equivalent to 57% of this total. Sediment yields in 1998 and 1999 were similar to the peak yields measured in the mid-1970s when tractor logging occurred in the basin (figure 6).

Evidence of increased sediment production in the South Fork is documented in both sediment loads since 1997 and changes in mean bed elevation since 2000. From 1998 to 2003 sediment loads exceeded 1990 to 1997 loads by 36%. Suspended loads systematically exceeded the pre-1998 relationship during large storms (Keppeler and Lewis, in review). Channel cross-sections along the South Fork mainstem show a decrease in mean bed elevation from 2000-2006 of 0.04 m (0.13 ft) equating to roughly 522 m^3 (683 yd^3) of bed degradation over the

[8] The English units are: 807 mT = 890 t; 190.3 mT/km^2 = 544 t/mi^2. Long-term average annual sediment yield at SFC is approximately 137.5 mT/km^2 (393 t/mi^2).

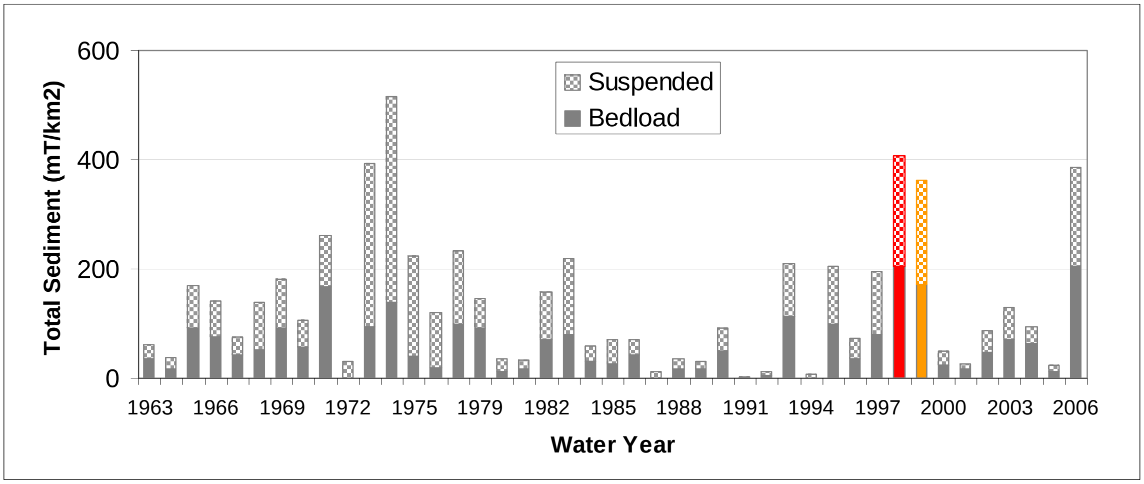

Figure 6. Total annual sediment yield for the South Fork Caspar Creek watershed 1963-2006. High yields from 1973-1975 reflect tractor logging impacts in the South Fork watershed (Rice and others 1979). High sediment yields in water year 1998 (shown in red) resulted from numerous landslides; high sediment yields in water year 1999 (shown in orange) resulted from road decommissioning work and landslide material which continued to be transported downstream. (2006 suspended load estimate is preliminary).

3160 m (2 mi) study reach. Although mainstem V* values, a measurement of fine sediments in pools, have been trending downward since data collection was initiated in 1992, a small increase occurred from 1999 and 2004 before declining again in 2005 and 2006 (S. Hilton, USFS-PSW, Arcata, unpublished data). These data suggest that much of the sediment from the decommissioned crossings, numerous landslides and other forms of mass wasting during 1998, and a large inner gorge debris slide in 1999, was effectively transported down the steep tributary channels and redeposited in the lower-gradient mainstem channel to await further mobilization during high flows. In 2006, sediment accumulation in the SFC debris basin totaled 649 m^3 (849 yd^3) and the preliminary sediment yield estimate was the highest since 1998, suggesting that the large storms in the winter of 2005/2006 mobilized substantial stored sediment.[9]

Depth-integrated samples collected above and below three treated crossings (CX-7, CX-13, and CX-21) during storm events in hydrologic years 2004-2006 suggest sediment concentrations below these crossings remain elevated. They averaged 165% of the concentrations measured at the stream gaging stations above these road crossing sites.

Decommissioned road crossings produced a substantial component of erosion measured in the SFC watershed during 1999. Field personnel document all erosion features displacing greater than 7.6 m^3 (10 yd^3) of material in an annual

[9] The December 28, 2005 storm produced an instantaneous peak discharge of 15.4 L/s/ha, which was estimated to have a return interval of eight years in the South Fork Caspar Creek watershed. The 2006 suspended load estimate is preliminary.

ground-based inventory of the Caspar watersheds (Keppeler and others 2003). Gully erosion (exceeding 7.6 m^3) along the decommissioned roads accounted for 28% (564 m^3 or 738 yd^3) of the annual erosion (2,026 m^3 or 2,650 yd^3) measured in the South Fork Caspar Creek 1999 inventory. About half of the remaining erosion volume resulted from a single re-activated inner-gorge debris slide. The rest of the erosion was the result of mass wasting along the untreated skid trail and road system developed in the early 1970s for the second-growth harvest. Inventoried erosion in 1999 was almost two times higher than the total annual sediment yield for that year, indicating that much of the hillslope material did not reach the SFC weir.

Longitudinal profiles show that most of the channel adjustments occurred on the downstream portions of the excavated crossings (figure 5). Treated roads were located at the break in slope above the inner gorge, making it difficult for the equipment operator and JDSF contract administrator to determine the appropriate target gradient. As in many road crossing excavations, excavation of fill was incomplete at many of the sites (PWA 2005b).

In general, crossings with larger contributing areas experienced the most erosion. Drainage area above a crossing explains 80% of the observed variation in erosion at the 10 sites where the more intensive survey methods were utilized. Crossings with longer affected lengths also experienced greater erosion, but excavated volume was not well-correlated with post-treatment erosion. Although Madej (2001) found that a surrogate for stream power (expressed as drainage area × channel gradient) and volume excavated were the best predictors of post-treatment crossing erosion, the Caspar study did not include channel gradient measurements.

Not all the stream crossings within the decommissioned road segments were treated. Eight crossing sites were either missed in the original project planning inventory or were overlooked by equipment operators. These sites were either small ephemeral channels or skid trails functioning as minor channels. Downcutting was evident at six of these locations, but averaged less than 6 m^3 (8 yd^3) per site. The other two sites experienced only minor rilling as a result of continued flow diversion onto the treated road segment where outsloping was not specified. Equipment access to these sites is no longer feasible, thus any additional rehabilitation efforts are limited to work that can be completed by hand crews. Fortunately, none of these sites appear to present a significant erosion hazard.

Both the outsloped and the cross-drained portions of the treated roads support ample herbaceous cover. The outsloped segments, where the road rock was disturbed, revegetated more readily. Little evidence of fill-slope sloughing has been observed post-treatment. The jute netting application does not appear to have provided significant benefit for erosion control. In some places, JDSF staff foresters observed that it has inhibited revegetation. The jute netting may have reduced sheet erosion, but given the amount of gully erosion that occurred at these sites, sheet erosion was likely insignificant in terms of total erosion.

One unforeseen consequence of the road decommissioning was the development of an entrenched foot trail by both recreational and research use. The trail has required additional erosion control measures to mitigate rilling.

CONCLUSIONS

- Mean erosion volumes measured at the treated crossing sites in this project following one and three over-wintering periods were 24.6 m^3 (32 yd^3) and 27.4 m^3 (36 yd^3), respectively. Average erosion at all 34 project crossings (including those untreated/missed) was 22 m^3 (30 yd^3). These values are within the range of those reported in the literature (11.5 m^3 [15 yd^3] to 50 m^3 [65 yd^3] per crossing).
- Gullied crossings along the decommissioned roads accounted for approximately one third of the total inventoried erosion volume and about half of the annual sediment load in the South Fork Caspar Experimental Watershed during the first post-treatment winter.
- Erosion voids were mainly created during the first winter, with only a 15-22% increase following three to four additional over-wintering periods. Three crossings continue to erode after eight winters.
- Only three of the decommissioned crossings produced about 50% of the total eroded volume measured. This is generally consistent with results from past studies, where a small percentage of decommissioned crossings account for most of the documented erosion volumes.
- After three winters, measured erosion at 34 excavated crossings and relief culvert sites totaled only four percent of the excavated volume of fill.
- The erosional costs associated with road decommissioning in this study were significantly greater than anticipated during project planning.

RECOMMENDATIONS

The main recommendations from this study for future crossing excavation work are:

- More careful determination of appropriate channel excavation depths should be made by experienced field personnel.
- Diligent inspection by contract administrators during field work is required to ensure that these excavation depths are reached at the treated crossing sites and that streambanks are sloped back from the channel to prevent slumping.
- Newly excavated channel bottoms at the larger crossings with significant contributing watershed areas should be armored with appropriately sized rip-rap, other types of large roughness elements, or grade control structures to prevent channel incision (Castro 2003).

- Beneficial practices along treated road segments include ripping and outsloping the road surface, and cross-drain installation to reduce the likelihood that missed crossings will become diversion problems. This treatment is especially important if the inside ditch in not obliterated. Also, ripping the road surface enhances revegetation and prevents new diversion problems associated with post-treatment recreational trail use.
- Cost savings may be achieved by: (1) permitting D8-sized crawler tractors to initiate fill removal until the top of the culvert is reached, rather than requiring this work to be completed by an excavator, and (2) allowing the tractor to push excavated fill material to the nearest stable location, rather than requiring end-hauling of all excavated material.
- Thorough evaluation of potential restoration needs in areas accessible only via a road system designated for decommissioning should be performed prior to finalizing treatment plans. A comprehensive watershed assessment is advised.

One approach to adequately accomplish pre-project work is to use the field survey procedures developed by Pacific Watershed Associates (PWA) in Chapter 10, Upslope Erosion Inventory and Sediment Control Guidance, California Salmonid Stream Habitat Restoration Manual (CDFG 2006). Their approaches were in part utilized for a similar road decommissioning project for JDSF Road 630, located in the Middle Fork Caspar Creek watershed, during the fall of 2005.[10] A detailed field study of channel adjustments following excavation work at four of the largest crossing sites is in progress, with field data collection scheduled to occur until 2007 or 2008. Preliminary observations after one winter show that on average the maximum channel incision is 0.6 to 1 m (2-3 ft) (J. Bawcom, CGS, Willits, personal communication). One crossing did show considerable incision, however, with a total eroded volume of 98 m^3 (128 yd^3).

It will likely be more than a decade before the effectiveness of these road treatments can be fully evaluated in terms of reduction of long-term erosion in the South Fork Caspar Creek watershed. Evidence from 2006 suggests that the treated roads are relatively small sources of new erosion, but the remaining skid trail and road system still poses risks in this watershed. Continuing research efforts in the Caspar Creek watersheds will investigate the implications of additional watershed restoration techniques, as well as the hydrologic consequences of additional timber harvest operations.

[10] The CDFG (2006) methodology was used as a guide. Excavation work was completed that was economically feasible with California Department of Fish and Game SB 271 grant funds available for decommissioning Road 630.

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Arnold Schwarzenegger

Governor

State of California

Mike Chrisman

Secretary for Resources

The Resources Agency

Ruben Grijalva

Director

California Department of Forestry and Fire Protection

California Department of Forestry & Fire Protection
P.O. Box 944246
Sacramento, CA 94244-2460