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WATERSHED REHABILITATION IN REDWOOD NATIONAL PARK[1]

by

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Abstract. Redwood National Park was established in 1968 to protect significant examples of coast Redwood (*Sequoia sempervirens*) ecosystem. Timber harvesting outside Park boundaries threatened downstream park resources by causing unnatural and excessive erosion. Resultant sedimentation in Redwood Creek threatened the Tall Trees Grove located on an adjacent alluvial terrace. The Park was expanded in 1978 to include 36,000 acres of recently logged land. The Park was directed to design and implement a rehabilitation program with the goals of reducing management-related erosion and encouraging natural patterns of revegetation. Pilot projects were initiated to test a variety of erosion control techniques. Evaluation of these techniques has shown that many of the reclamation methods are effective. However, cost analysis shows that reclaiming original stream channels, restoring hillslope morphology, and recovering side-casted topsoil is the most cost-effective way to achieve the objectives. Procedures and techniques have evolved from dominantly small-scale hand labor work to primarily larger-scale heavy equipment operations.

Additional Key Words: erosion control, revegetation, slope stability, cost-effectiveness, reclamation techniques, stream impacts.

Introduction

Redwood National Park (RNP), located in northwestern California, was established in 1968 to preserve superlative examples of coastal redwood (*Sequoia sempervirens*) forest ecosystem (Figure 1). The 1968 park included several of the world's tallest trees growing on alluvial flats along the lower portion of Redwood Creek at a location known as the Tall Trees Grove. The original park lands along Redwood Creek consisted of a narrow 0.5 miles wide and 7.5 miles long corridor bracketing the stream. While the tallest trees were protected from being logged within the new park, timber harvesting and associated road construction continued upslope and upstream.

Erosional processes were greatly accelerated during large-magnitude storm events in 1953, 1955, 1964, 1972, and 1975. The principal causes of accelerated erosion were: 1) failure of (or lack of) road drainage structures, 2) diversion of stream flow out of natural channels onto unprotected hillslopes, and 3) failure of over-steepened cuts and/or fills (Hagans *et al.* 1986). These storm events also triggered release of natural sediment sources, such as debris torrents and earthflows. In combination with management-related erosion, large amounts of sediment were delivered to stream channels.

Increased sediment delivered to streams cumulatively resulted in aggradation of channels (infilling) and widening of cross-sectional profiles. This process resulted in increased scour of stream banks and loss of riparian habitat. The Tall Trees Grove (the preeminent resource of the park) was subjected to increased recurrence of flooding, bank erosion, and an elevated water table.

The danger to the Tall Trees Grove provided a catalyst for a protracted environmental battle which, in 1978, resulted in Congress enacting legislation expanding RNP by 48,000 acres (PL 95-250). The expansion included 36,000 acres that had been mostly logged within

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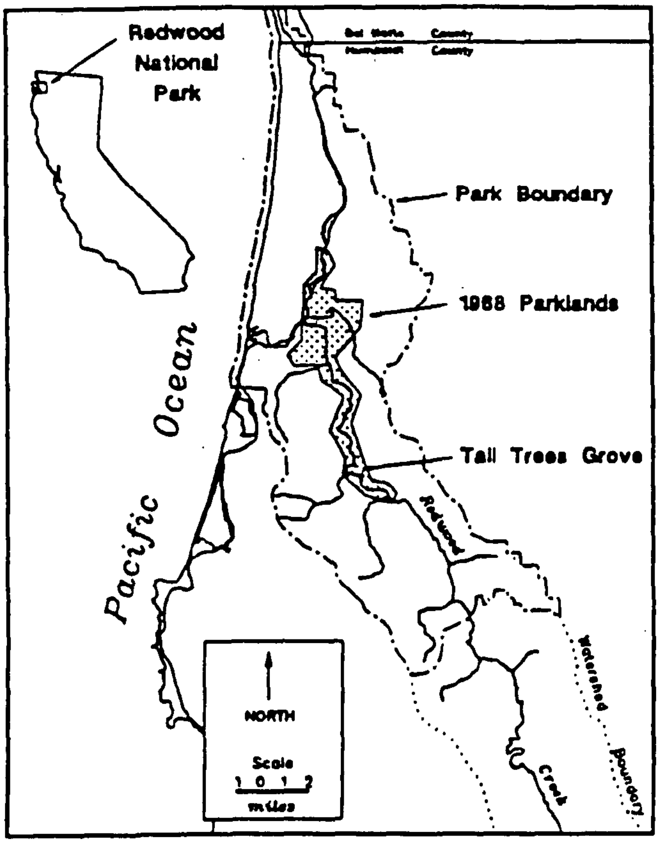
Figure 1. Location of Redwood National Park.



the ten years prior to 1978. Associated with the logging were 300 miles of haul roads, 3,000 miles of skid trails, dozens of rock quarries and borrow pits, and thousands of acres of eroding hillslopes.

Goals and Objectives

Congress authorized the park to design and implement a rehabilitation program designed to minimize management-induced erosion, re-establish native patterns of vegetation, and protect aquatic and riparian resources within tributaries and along the main channel of Redwood Creek. Ultimately, efforts should speed the restoration of naturally functioning redwood and related ecosystems to a condition similar to what existed before resource extraction. $33,000,000 was authorized for the program (USDI 1981).

Setting

The rehabilitation effort is concentrated in the lower one-third of the Redwood Creek basin (Figure 1). The climate is Mediterranean with an annual average precipitation of 80 inches (205 cm) occurring primarily as rain between October and May. Coastal fog is common in the summer months.

The Redwood Creek basin lies within the rugged Coast Range province and is underlain by folded and sheared sandstones, mudstones and schists of the Franciscan assemblage (Harden *et al.* 1982). The region is subject to high erosion rates due to rapid tectonic uplift, the pervasively sheared and faulted condition of the underlying lithologies, and the imprint of complex, highly disruptive landuse activities (Janda *et al.* 1975).

Approach

The watershed rehabilitation program at RNP began in 1977 with several small pilot projects intended to test a limited number of techniques and to evaluate overall program feasibility. In 1978, 1979, and 1980, work was expanded to treat a wide variety of erosional problems through extensive experimental application of heavy-equipment and labor-intensive treatments. An intensive monitoring program was established to evaluate the effectiveness of the erosion control techniques (Madej *et al.* 1980; Weaver *et al.* 1987) and to provide feedback to project supervisors about those techniques.

Erosion Control Work

Erosion control measures are oriented toward preventing or reducing gully, rill, and sheet erosion as well as small-scale mass movement features on logged hillslopes, roaded prairies, and damaged stream channels. Rehabilitation work entails five steps: 1) mapping erosion sources, 2) prescribing treatments, 3) implementing treatments utilizing heavy equipment, 4) implementing labor intensive erosion control and revegetation, and 5) maintaining, documenting, and evaluating the work. In determining which sites have the highest potential to continue to deliver sediment to stream channels, the potential erosional activity and the volume of sediment that may be mobilized is evaluated for each site. Downstream impacts of any increased sediment load are also estimated. Erosion control measures are divided into two categories: primary and secondary treatments. Both assist reestablishment of native vegetation by improving growing conditions.

Primary Treatments. Primary treatments entail earth-moving. Drainage networks altered by haul road and skid trail construction are redirected to their natural flow paths, and active and potential management-related sediment sources to streams are moved to stable locations.

Table 2. Cost-effectiveness of secondary erosion control treatments used to minimize short-term channel scour in Redwood National Park. (after Weaver *et al.* 1982)

TREATMENT[1]	COST-EFFECTIVENESS RANGE (\$/yd^3 "saved")[2]	COMMENTS
Water Ladders[3]	20-70	short reaches only
Brush check-dams[4]	10-30	short-lived, small gullies
Small board check-dams[5]	10-30	effective; need maintenance
Large board check-dams[6]	30-50	expensive; need maintenance
Hand-placed rock armor[4]	20-70	limited to small channels and minor storm flows
Equipment placed rock-armor[6]	7-50	effective; requires good access

1. These may, in certain circumstances, be also considered primary treatments. At RNP, they were employed at excavated skid-trail or haul-road stream crossings. The treatments are not interchangeable. Each technique is best suited to a particular situation. Therefore, the treatments are not directly comparable to each other.
2. Cost-effectiveness assumes that the treatment is 100% effective; most methods were only 60-90% effective in the first winter and experienced a reduced effectiveness with time (except equipment placed rock armor). These values are for first-year cost-effectiveness.
3. At RNP, these work best in channels that carry a 20-year peak discharge of 6 cfs, or less.
4. At RNP, these work best in channels with flows of 2 cfs, or less. Brush dams were only used in small gullies, not excavated channels.
5. Large board dams worked best in channels which carry a 20-year discharge of 20-30 cfs, or less.
6. Cost varies greatly due to required quarrying effort and hauling distance.

Evaluating the numerous techniques show that while most of the techniques are effective, there was a wide range in unit costs and there was an order of magnitude variation in cost-effectiveness.

For example, the cost-effectiveness of primary treatments employed from 1978 to 1980, and monitored until 1984, is shown in Table 1. Stream channel work is designed to withstand a 20-year flood event and as yet, the largest storm has been a 5-year event, in which most of the monitored sites experienced little erosion. Thus, the erosion control work has not yet been fully tested.

Table 3. Cost-effectiveness of secondary erosion control treatments used to minimize surface erosion in Redwood National Park. (after Weaver *et al.* 1982)

TREATMENT	COST-EFFECTIVENESS MEAN COST (\$/10,000ft^2)[1]	RANGE (\$/yd^3 "saved")[2]	RELATIVE EFFECTIVENESS[3]
Contour trenches[4]	430	40-80	6
Wooden terraces[4]	590	60-20	9
Wattles[4]	2500	250-500	10
Ravel catchers	668	70-140	7
Grass seed with fertilizer	99	10-20	8
Hydroseed	600	60-120	4
Straw mulch[5]	180	20-40	3
Jute-secured straw	2360	240-480	1 [6]
Excelsior blankets	1970	200-400	1 [6]
Wood chips	950	100-200	5

1. Based on 1978 and 1979 data.
2. Computations were based on treating a 10,000 ft^2 area (100 ft. long channel with 50 ft.long sideslopes at 50% gradient). Treatments were compared to erosion from a bare untreated area which was assumed to be 5 yd^3. The treatment was assumed to be 100% effective for cost-effectiveness computations, however, most were less than 80% effective.
3. Results from plot studies on rehabilitation sites, RNP data. Most effective has a value of 1, least effective 10.
4. Method not used after 1979.
5. The only surface erosion control method used since 1981.
6. Jute-secured straw and excelsior blankets are of essentially the same effectiveness.

The cost-effectiveness of secondary treatments designed to control short term post-rehabilitation channel scour is shown in Table 2. Many of these treatments have a high degree of effectiveness, yet are expensive to install. The cost-effectiveness of secondary treatments used to control surface erosion is shown in Table 3. Contour trenches, wooden terraces, and willow wattles did not work well, and in many documented cases, actually caused more erosion than they prevented by concentrating water which caused rilling or gullying. Cost-effectiveness was low due to the expenses involved with labor intensive work.

Current Techniques

An important result of the studies was that surface erosion contributes minor amounts of sediment to the stream system relative to that contributed by gullying and

These treatments include removal of road fill from stream crossings, removal of unstable materials from landslide areas, replacement of road fill back into the cut (outsloping), decompaction of road surfaces, and cross-road drain construction (large waterbars intended to disperse runoff onto hillslope areas).

Secondary Treatments. Secondary treatments stabilize areas that were recently disturbed by a primary treatment. In stream channels, these treatments include rock armor placement and check dam construction to inhibit downcutting or lateral scour. Surface erosion is controlled by a variety of mulches, seeding, erosion control blankets, and tree planting (long-term erosion control).

Revegetation

Revegetation efforts are intimately connected with the goals of erosion control. Primary treatments, through decompacting disturbed surfaces or restoring soil depth, and secondary treatments, by protecting the seed bed, both improve site growing conditions and assist efforts to reestablish native vegetation. Pioneering native brush and tree species add to soil stability which is necessary for forest succession to proceed. Redwood (*Sequoia sempervirens)* and Douglas fir (*Pseudotsuga menziesii*) seedlings are planted in areas where natural revegetation is not likely to occur quickly.

Results

The numerous techniques employed and their associated costs were evaluated relative to their effectiveness in controlling erosion and in fostering native patterns of revegetation. Technical changes in erosion control work at RNP evolved in response to quantitative evaluation. Methods which have been used to measure erosion and to evaluate the physical effectiveness of erosion control work in the park are straight-forward and numerous (Madej *et al.* 1980; Weaver *et al.* 1982, 1987).

Cost-effectiveness is evaluated by comparing treatment costs and the amount of sediment removed or prevented from entering active channels where it could be transported downstream. The measure of cost-effectiveness in the program at RNP is the unit cost-per-volume of potential sediment "saved" from sediment yield ($/yd^3) over a specified period of time (Weaver *et al.* 1982). This method has been used to determine the best techniques for achieving the goals of the program.

Table 1. Cost-effectiveness of primary erosion control treatments used to minimize sediment yield in Redwood National Park (modified from Weaver *et al.* 1982; Spreiter 1990).

TREATMENT	AVERAGE COST (IN RNP) ($)	COST-EFFECTIVENESS RANGE ($/yd^3 "saved")[1]
Correction of stream diversions	125-4000 ea.[2]	0.1-0.5[3]
Excavation of haul road stream crossings [4]		
under 750 yd^3	~2000 ea.	1-10
750-1500 yd^3	3000-3500 ea.	1-10
endhauling required	~4000 ea.	1-10
Excavation of skid-trail [4] stream crossings	125-1350 ea.	1-10
Road Outsloping	2500-9500/mi.	1-10 [5]
Removal of perched debris from perimeter of yarder pads	1000-5000 ea.	1-10
Large landslide excavations	20,000-30,000 ea.	1-10
Decompaction	350-450/mi.	unquantified [6]
Construction of cross-road drains [7]	1000-3000/mi.	unquantified [8]
Waterbar construction		
equipment constr.	5-50 ea.[9]	unquantified [8]
hand-labor constr.	30-300 ea.[10]	unquantified [8]

1. Goal is to minimize sediment production and yield (i.e., to "save" soil from entering the stream system). Complete loss of the excavated material is anticipated in a period of 10-100 years. Cost-effectiveness assumes total loss without reference to time.
2. Cost of diversion correction is associated with stream crossing excavations at the point of diversion.
3. Assumes diverted flow would continue to cause erosion and had not yet created a stable, non-eroding channel.
4. Excavations usually performed by bulldozer and hydraulic excavator combination.
5. Assumes erosion would have occurred had the work not been performed and it would have been translated into sediment yield in adjacent stream channels. Benefits from the prevention of diversions and associated gully erosion are not accounted for.
6. Treatment increases success of revegetation and decreases surface runoff. There is an unquantified decrease in road surface, ditch, gully, and downslope stream channel erosion.
7. Drains are constructed every 50-150 feet.
8. Treatment results in reduces concentration of surface runoff which produces an unquantified decrease in road surface, ditch, gully and downslope erosion.
9. Range in cost is related to accessibility of worksite.
10. Average cost is $60 ea.; range in cost is dependent on length and substrate hardness.

mass wasting due to stream diversion. Efforts to control rainsplash and minor rilling are not nearly as cost-effective compared to reestablishing streams in their natural channels. As a consequence, treatment for surface erosion is now employed in only select cases in RNP, such as protection of bare ground near stream channels.

Observations made over a ten-year period indicate that restoring soil depth along the inboard edge of the road prism (cut void) is the most effective way to enhance revegetation potential. Changes in techniques in the past few years have been made to include more outsloping in areas where revegetation potential would be enhanced by restoring soil depth (Hektner and Reed 1991) (see Figure 2). This more complete treatment adds between 5-10% in cost to a typical project in RNP. The actual percentage varies depending on disturbed area size, erosional problems, and location relative to streams.

By 1981, the best, previously tested techniques were being systematically implemented with the goal of maximizing the cost-effectiveness of erosion control. Consequently, rehabilitation efforts were shifted from dominately labor-intensive treatments to those dominated by the use of large earth-moving equipment (Sonnevil and Weaver 1982) which allow complete excavation and approximating the natural conditions (Figure 3). Improvements in heavy equipment sequencing and the use of larger, more expensive, but even more productive equipment has kept "cost per cubic yard saved" at an essentially even rate relative to an overall gradual increase in costs of labor, equipment, materials, and contracting in general. Revegetation work has shifted from temporary, short-term efforts at controlling surface erosion to those that foster long-term natural succession (Hektner *et al.* 1982).

Costs. Treatment costs depend upon equipment operation rates, distance spoil material must be transported, depth of excavation, and site-conditions such as degree of saturation, amount of organic debris, etc. The cost per mile of road removed is highly variable, depending on terrain, road width, drainage density and size, and other site specific variables (Spreiter 1990). At RNP the majority of the contract costs are in stream crossing excavations. This work reduces erosion to near natural levels and benefits downstream aquatic resources. Outsloping the intervening stretches of road is generally a relatively minor portion of the overall cost. Examples of current rehabilitation work costs are shown in Table 4.

Table 4. Summary of current rehabilitation costs in Redwood National Park (from Spreiter 1990).

GENERAL DESCRIPTION OF TREATMENTS[1]	RANGE IN TYPICAL COST/MILE (\$/mi.)
-small road, gentle terrain, few stream crossings	10,000-20,000[2]
-medium sized road, frequent small to medium sized stream crossings	20,000-40,000[2]
-major, mid-slope road, frequent large stream crossings	40,000-70,000[2]
-major road, low on slope, frequent large stream crossings, unstable terrain	100,000-250,000[2]
-rock quarries[3]	1,000-2,000/acre[2]
-straw application at 63 bales/acre	600-950/acre[4]
-tree planting, appx 400/acre	300-1200/acre[4]

1. A standard array of treatments is as follows:
   a) Outsloping (fill against cutbank) avgs. \$10,000/mi., or \$1.00/yd^3 along a road 30 ft. wide, 8 ft deep cut along the outboard edge, finished slopes of 3:1, that removes 1.7yd^3 per linear ft. of road.
   b) Exported Outsloping (fill moved some distance to a stable fill site) averages \$1.50 yd^3, but varies with distance to fill site.
   c) Decompaction (to a 2 ft depth) averages \$800/mi., or \$0.15/linear ft. for a 30 ft. wide area.
   d) Cross road drains (large waterbars) avg. \$1.00/linear ft. of drain.
   e) Skid trail stream crossings average \$2.00/yd^3 (includes 20% for gaining access to sites).
   f) Haul road stream crossings vary with size, amount of organic debris, amount of stream flow, fill saturation, etc. Relatively straight forward crossings average \$1.00 to \$2.00/yd^3.
   g) Truck endhauling, if required for exported outslopes or stream crossings, ranges from \$3.00 to \$5.00/yd^3 for hauling distances up to 2 miles.
2. Cost range is for heavy equipment cost only.
3. Includes mineral materials and common borrow.
4. Cost variation is related to density of application and how remote the site is.

Summary

Implementation of a wide variety of techniques has shown that an array of rehabilitation methods meet the goals of the program at RNP. However, cost-effectiveness analysis shows that using heavy equipment to reclaim original stream channels, restore hillslope morphology, and recover side-cast topsoil are the most cost-effective ways to achieve the stated objectives. These treatments are permanent, long-term, and maintenance free.

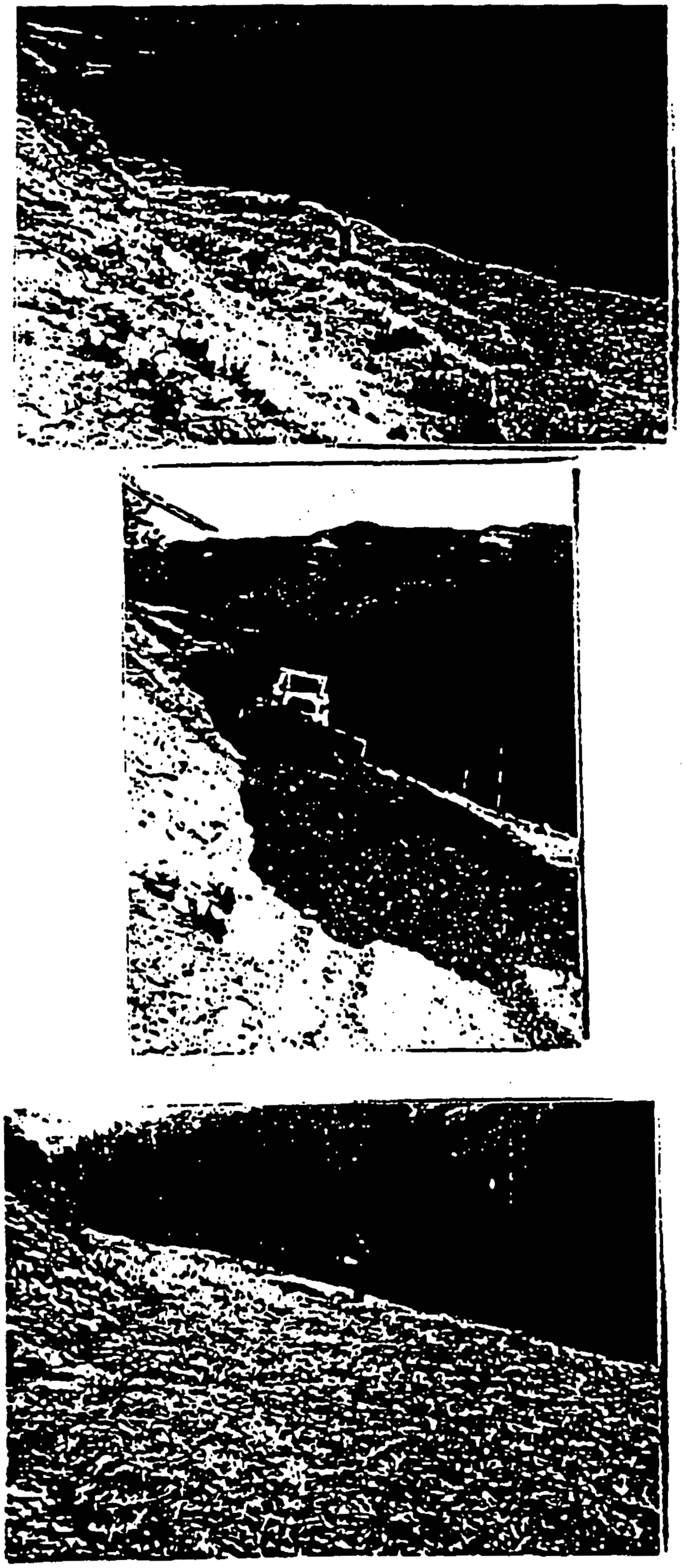


Figure 2. The sequence of three photographs below show the before, during, and after of an outsloped road section.

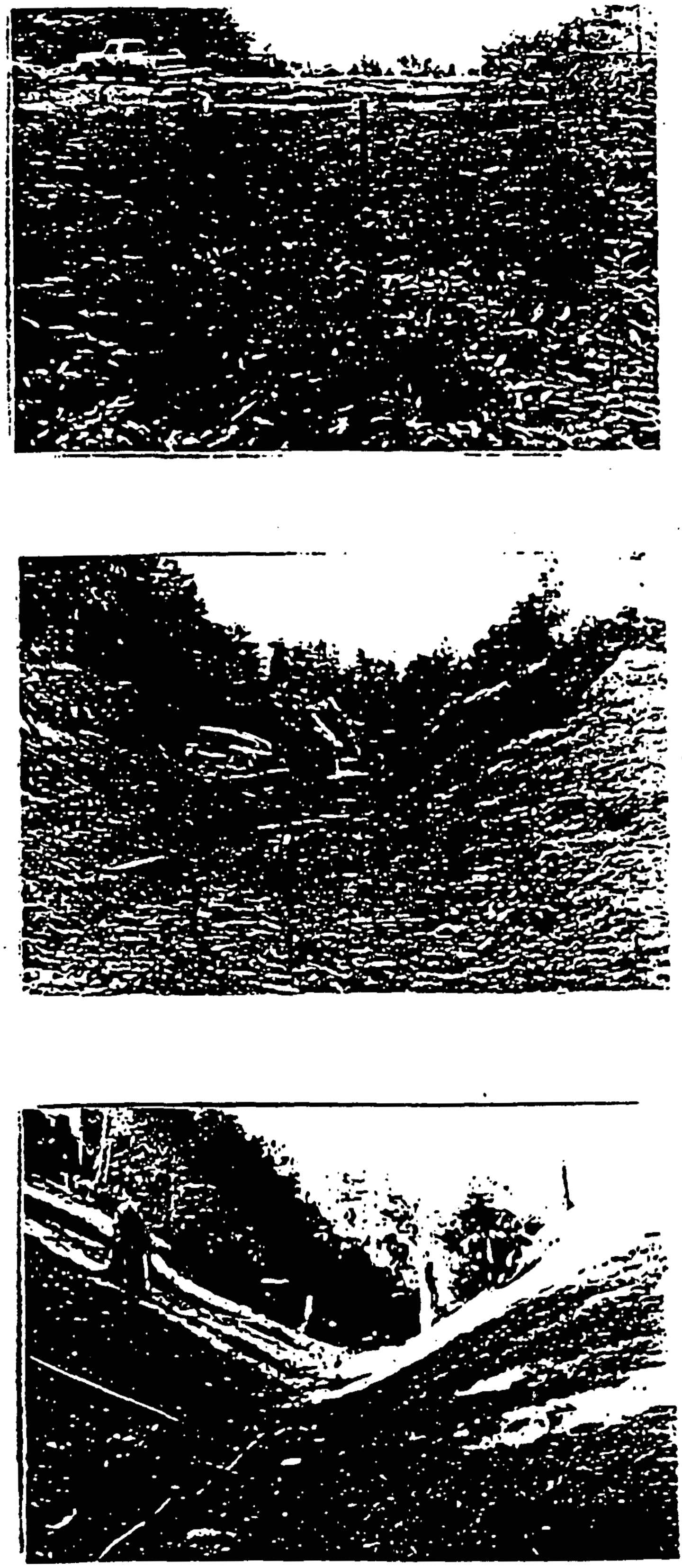


Figure 3. The sequence of three photographs below show the before, during, and after of a haul road stream crossing excavation.

Restoring the pre-disturbance morphology as closely as possible provides the greatest measure of erosion control and revegetation potential. Blending with the surrounding topography improves overall aesthetic appearance which complements the park's purpose and significance. Obliteration of roads through the excavation of road fill from stream crossings, the complete outsloping of roads, landings, and quarries, and the stabilization of management-induced mass movement features provide the greatest return in meeting the objectives of the program at RNP.

Literature Cited

Hagans, D.K., Weaver, W.E., and Madej, M.A., 1986. Long term on-site and off-site effects of logging and erosion in the Redwood Creek basin, northern California. p. 38-66. *in* G. Ice, ed., Papers Presented at the American Geophysical Union meeting on cumulative effects (San Francisco, Calif., Dec. 9-13, 1985). National Council of the Paper Industry Technical Bulletin 490, New York, New York.

Hektner, M.M., Reed, L.J., Popenoe, J.H., Mastroguiseppe, R.J., Vezie, D.J., Sugihara, N.G., and Veirs Jr., S.D. 1982. A review of the revegetation treatments used in Redwood National Park - 1977 to present. p. 70-77. *in* Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas: Proceedings of a Symposium (Arcata, Calif., August 24-28, 1981). Center for Natural Resource Studies, 360 p. Sacramento, Calif.

Hektner, M.M., and Reed L.J. 1991. Revegetation and Watershed Rehabilitation in Redwood National Park. 8 p. USDI-Redwood National Park in-service report. Redwood National Park, Orick, Calif.

Janda, R.J., Nolan, K.M., Harden, D.R., and Coleman, S.M. 1975. Watershed conditions in the drainage basin of Redwood Creek, Humboldt County, California, as of 1973. 266 p. USDI-Geological Survey Open-File Report 75-568. Washington, D.C.

Madej, M.A., Kelsey, H.M., and Weaver, W.E. 1980. An Evaluation of 1978 Rehabilitation Sites and Erosion Control Techniques in Redwood National Park. 152 p. USDI-National Park Service, Redwood National Park Technical Report 1, Redwood National Park, Arcata, Calif.

Sonnevil, R.A., and Weaver, W.E. 1982. The evolution of approaches and techniques to control erosion on logged lands in Redwood National Park, 1977-1981. p. 258-272. *in* Watershed Rehabilitation in Redwood National Park and Other Pacific Coastal Areas: Proceedings of a Symposium (Arcata, Calif., August 24-28, 1981). Center for Natural Resource Studies, 360 p. Sacramento, Calif.

Spreiter, T.A. 1990. Watershed Restoration in Redwood National Park. Field Seminar Manual. 38 p. (Orick, Calif., August, 1990). Humboldt State University and Redwood National Park Summer Field Series, Arcata, Calif.

U.S. Department of the Interior, 1981. Watershed Rehabilitation Plan. 92 p. USDI-National Park Service, Denver Service Center, Denver, Colo.

Weaver, W.E., Seltenrich, M.S., Son vil, R.A., and Babcock, E.M. 1982. The use of cost-effectiveness as a technique to evaluate and prove watershed rehabilitation for erosion control. Redwood National Park. p. 341-360. *in* Watershed Rehabilitation in Redwood National Park and Ot Pacific Coastal Areas: Proceedings of a Symposium (Arcata, Calif., August 24-28, 1981). Center for Natural Resource Studies, 360 p. Sacramento, Cal

Weaver, W.E, Hektner, M.M., Haga D.K., Reed, L.J., Sonnevil, R.A., and Bund G.J. 1987. An Evaluation of Experimental Rehabilitation Work, Redwood National Park. 205 p. USDI-National Park Service, Redwood National Park Technical Report 19, Redwood National Park, Arcata, Calif.