AN EVALUATION OF EXPERIMENTAL REHABILITATION WORK, REDWOOD NATIONAL PARK

REDWOOD NATIONAL PARK

WATERSHED REHABILITATION

TECHNICAL REPORT

JULY 1987

19

WATERSHED REHABILITATION PROGRAM

In 1978, under the authorization of P.L. 95-250, the National Park Service implemented a program of watershed rehabilitation within the Redwood Creek basin. The goals of the program are to reduce sources of man-induced erosion and to restore naturally-functioning redwood and related ecosystems on logged lands within the park. Results are presented in technical reports, journal articles, and symposia proceedings.

NOTICE

This document contains information of a preliminary nature, and was prepared on an interim basis. This information may be revised or updated.

AN EVAULATION OF EXPERIMENTAL REHABILITATION WORK

REDWOOD NATIONAL PARK

Redwood National Park Watershed Rehabilitation

Technical Report Number 19

William E. Weaver

Mary M. Hektner

Danny K. Hagans

Lois J. Reed

Ronald A. Sonnevil

Gregory J. Bundros

National Park Service
Redwood National Park
Arcata, California
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PREFACE

In March 1978, Redwood National Park was expanded by 48,000 acres, including 36,000 acres of logged redwood forest land. Before these lands were added to the park, timber harvesting and related road construction had accelerated naturally high erosion rates and sediment deposition, and adversely affected water quality throughout the entire Redwood Creek basin (Janda and others, 1975). The congressional action which expanded the park to include these cutover areas (PL 95-250) authorized that a rehabilitation program be developed to minimize man induced erosion and to encourage the return of a natural vegetation pattern Sec.101(a)(b). This report describes and evaluates erosion control and revegetation work completed in 1979, the first fully funded year of the park's watershed rehabilitation program.

Since early work in 1977-78, the rehabilitation program quickly evolved into a multifaceted effort with three major objectives (USDI, 1981). First, most erosion control work was directly designed to minimize the amount of sediment delivered to stream channels from areas disturbed by past logging and road building activities. Secondly, to encourage a return of the natural pattern of vegetation of prairies and logged timberlands, a revegetation and vegetation management program was initiated. Finally, selected projects have been undertaken to restore and protect aquatic and riparian resources within tributaries and along the main channel of Redwood Creek.

Erosion control efforts have been directed at four main problem areas: tractor logged hillslopes and associated stream channels, logging roads, landslide areas and natural prairie grasslands that have been gullied. On hillslopes logged in the previous decade, tractors created a network of deeply cut trails to drag logs to nearby roads. Watercourses were often obliterated and streamflow was diverted across adjacent, bare hillslopes. On erodible soils, these diversions created complex, interconnected gully systems and locally generated tremendous quantities of eroded sediment (Weaver and others, 1982). On exposed, south facing sites, denuded hillsides were also slow to revegetate (Hektner and others, 1982; Reed, 1984).

Logging roads have caused the most severe erosion problems on cutover lands in Redwood National Park (Weaver and others, in press). Many older stream crossings on abandoned roads were not culverted. In other areas, undersized or unmaintained culverts were commonly overtopped by winter flood flows. These diverted waters washed out road fills, created large gully systems and caused landslides on the unprotected hillslopes. Elsewhere, road construction undercut unstable hillsides and initiated landsliding, while large volumes of sidecast material perched around yarder pads and landings eventually failed into nearby streams as fast moving debris slides.

The three rehabilitation units described in this report contained a wide variety of these erosion problems. For this reason, a large number of experimental treatments were employed and tested. Work experience, field observations and quantitative evaluations of this and earlier erosion control and revegetation work (Madej and others, 1980; Weaver experimental treatments were employed and tested. Work experience, field observations and quantitative evaluations of this and earlier erosion control and revegetation work (Madej and others, 1980; Weaver and Madej, 1981) shaped our current thinking regarding the most effective and cost-effective procedures for watershed rehabilitation on steepland cutover areas (Weaver and Sonnevil, 1984).

In earlier reports, erosion control efforts were evaluated after just one winter (Madej and others, 1980; Kelsey and Stroud, 1981), too short a period for the structures and excavations to adjust to dominant hydrologic conditions and too short to determine if plantings would meet with long-term success. Reed and Hektner (1981) reported on revegetation success on the 1978 experimental rehabilitation units, but again data were largely restricted to results obtained one year after treatment. In contrast, this report reflects four years of observations and includes a discussion and recommendations based on experience gained in more recent years. Both erosion control and revegetation worksites on the rehabilitation units have been sampled a number of times in the years following their implementation in late 1979 and early 1980. Although erosion control structure and excavated stream channels have been designed to withstand the 25-year flood runoffs, the 1979 worksites still have not experienced a large storm. Final evaluation of the erosion control work must await the occurrence of a severe runoff event.

Rehabilitation work performed in 1979 was still largely experimental. Many techniques were applied to test steepland erosion control and revegetation methods and to generate data necessary to evaluate their effectiveness and cost-effectiveness. More hand labor techniques for revegetation and controlling surface erosion were used during 1979 than in any subsequent year. While labor intensive treatments comprised a significant part of the work completed in 1979, evaluation of those treatments gradually led to their reduced use in subsequent years.

Much of the work completed more recently has seen dramatic change from the techniques used in 1979. For example, significant changes have been made in how heavy equipment is used for road removal and stream channel excavation work. From 1977 to 1980, heavy equipment work became an increasingly important component of rehabilitation activities. Less emphasis was placed on expensive hand labor practices designed to slow sheet and rill erosion from bare soil areas (for example, wattling, contour trenching and terracing).

Studies of soil erosion in the park, briefly described in this report and elsewhere (Kveton and others, 1983; Hagans and others, 1986; Klein, in press) support this course of action. Surface erosion from disturbed areas was found to play a secondary role in sediment production. Most soil loss at excavated stream crossings has been shown to originate from channel changes (widening and downcutting) and shallow slides caused by stream bank undercutting.

Since 1979, significant strides have been made in improving rehabilitation cost-effectiveness both by lowering costs and by improving the effectiveness of revegetation and erosion control practices (Weaver and Sonnevil, 1984). Based on data generated from the park's program, only the most cost-effective treatments are used.

Before rehabilitation commences, an erosion potential analysis and cost-effectiveness prediction helps determine which potential worksites should actually be treated and which others contain erosion features to large or too far advanced to cost-effectively address. Treatments such as diverting errant streamflow back into natural watercourses to dewater active gully systems have the highest possible levels of erosion control cost-effectiveness. These features are given high priority since large volumes of erosion may be prevented by committing relatively small expenditures.

By 1981, most of the techniques for treating potential and existing erosion sources on cutover land in the park were being routinely applied. For example, excavated stream channels were once routinely protected with a variety of structures, armoring layers and energy dissipating devices. These all needed to be installed or manipulated by heavy equipment or by hand and required long-term maintenance. Although these devices are no longer routinely prescribed, they will continue to be monitored to evaluate their long-term effectiveness.

Revegetation treatments have also been refined. Fewer species and techniques are used and site preparation by heavy equipment is now emphasized as a means of promoting natural revegetation (Hektner and others, 1982; Reed, 1984).

For all these reasons, the unit-cost data and effectiveness evaluations contained in this report should be of value to anyone interested in the rehabilitation of forested steepland areas. In addition, many of the planning and implementation procedures, erosion control and revegetation techniques and long-term monitoring methods can also be used in establishing and evaluating other programs for watershed improvement or repair.

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A number of support staff have provided invaluable assistance in the mechanics of preparing the final text. Lori Holden edited very early versions of the chapters and attempted to mesh the various author's styles. Lee Purkerson, Mary Ann Madej, Ed Wosika and Mike Sandecki reviewed the first fully assembled draft of the text. Their comments on the document markedly improved its content and organization.

Many of the maps and drawings were drafted by either Anne Kubert, Laura Parker or Sandi Potter. They did an admirable job of assembling the pertinent information considering the sometimes conflicting and always confusing array of information that was required on many of the maps.

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Finally, John Sacklin provided a critical editing job during the final stages of report preparation. He also directed the organization and preparation of the final copy for publication.

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I. INTRODUCTION

Four units were chosen for experimental watershed rehabilitation work in 1979 (Figure 1): 79-1, Bond Creek; 79-2, Bridge Creek; 79-3, Airstrip Creek and 79-4, Copper Creek.

They were selected primarily because of the variety of erosion and revegetation problems displayed, as well as the observed severity of ongoing and potential erosion. The Airstrip Creek unit has previously been described (Kelsey and Stroud, 1981). This report describes and evaluates work on the other three units.

Rehabilitation work on all three sites involved five steps: 1. mapping erosion sources; 2. prescribing treatments; 3. heavy equipment operations; 4. labor intensive erosion control and vegetation and 5. maintenance, documentation and evaluation.

Erosion features were mapped to identify the critical problem areas of each site. The time required depended on the size of the unit and the complexity of the erosion problems. Bond Creek and Bridge Creek required three weeks (less than 200 person hours) each. In contrast, the much larger, 600 acre Copper Creek site took 2 months or 1,100 person hours.

Following mapping, site-specific erosion control and revegetation prescriptions were developed to treat the identified problems. Work plans received interdisciplinary review from other park staff professionals.

The third step was the heavy equipment work. This included road ripping, road outsloping, construction of cross-road drains and ditches, excavation of logging road and skid trail stream crossings, removal of unstable fill material along roads and landings and placement of rock armor in newly excavated stream channels.

A variety of experimental labor intensive erosion control and revegetation measures followed the completion of heavy equipment operations. This was accomplished either by in-house labor crews (Bridge Creek), by fixed price contract (Bond Creek) or by a combination of the two methods (Copper Creek). Labor intensive measures applied on the 1979 rehabilitation sites included checkdams, hand-placed rock armor, flumes, water ladders, contour trenches, wooded terraces, ravel catchers, wattles, a variety of mulches, stem cuttings, seeding, transplanting and planting of various containerized species.

During succeeding years, minor adjustments and repairs to erosion control structures were performed as the need arose. Frequent field inspections were conducted on all the sites to document revegetation and erosion on treated areas. Several hundred photographs were taken annually from permanent photo points to document visible changes to worksites, and a number of established erosion monitoring stations were

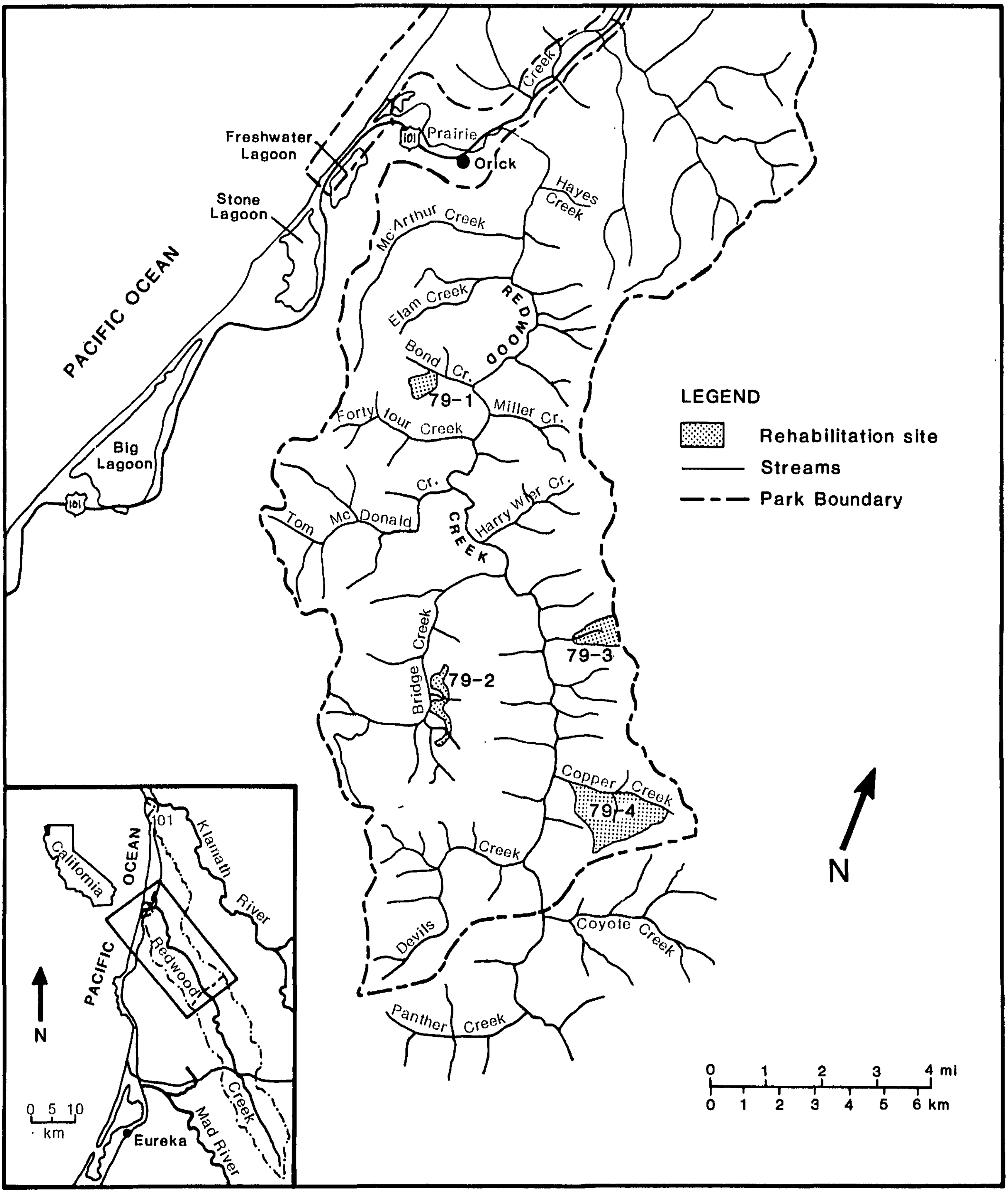


Fig. 1. Location map of rehabilitation units, Redwood National Park.

remeasured to quantitatively document post-rehabilitation erosion rates.

Table 1 summarizes elements of the three rehabilitation projects. The Bond Creek unit consisted of an unstable segment of logging road contributing sediment to adjacent perennial streams and a broad area of recently logged (1974) hillslope which had numerous tractor constructed stream crossings displaying various degrees of erosion. Erosion control efforts focused on removing unstable logging road fill slopes (by outsloping) and excavating logging road and skid trail stream crossings so they would not erode or cause stream diversions.

A wide variety of labor intensive erosion control techniques were employed at Bond Creek to test methods for controlling surface erosion from bare soil areas and scour in excavated stream channels. Similarly, revegetation experiments included a variety of species and techniques. Monitoring sites were established to determine the effectiveness of each erosion control practice and revegetation success was monitored throughout.

Work at the Bridge Creek rehabilitation unit focused on removing the M-7-5-1 logging road. The recently constructed (1977) forest road traversed steep, unstable hillslopes and crossed a number of perennial streams. Two cable yarded clear cuts (1978) displayed little post-harvest erosion by 1979. However several hillslopes and stream crossings failed during the two, low rainfall years since the road was constructed. Hence, much of the rehabilitation activity was aimed at preventing further erosion during subsequent years.

Extensive sidecast fill slopes and large volumes of fill in stream channels along the M-7-5-1 road dictated the use of heavy equipment in erosion control work. A dragline crane, backhoe and several tractors were used to remove unstable fill material on the site while dump trucks hauled excess material to more stable locations. Aside from mulching and revegetation efforts, checkdam construction in several of the excavated stream crossings was the primary labor intensive treatment used to control post-rehabilitation erosion. Channels which were not protected with checkdams were usually lined with coarse rock armor delivered and placed by the heavy equipment.

Finally, the Copper Creek rehabilitation unit was the largest and most complex site chosen for erosion control work since the inception of the rehabilitation program. Over 600 acres of tractor logged land and 6.7 miles of abandoned logging road were mapped and treated. The erosion problems on the unit included complex gully systems resulting from numerous stream diversions, washed out (eroded) logging road and skid trail stream crossings, logging road and log landing fill slope failures, multiple log jams in the main channel of Copper Creek and locally xeric sites which resisted rapid revegetation (Weaver and others, 1981).

TABLE 1

SUMMARY OF 1979 WATERSHED REHABILITATION PROJECTS

	BOND CREEK 79-1	BRIDGE CREEK 79-2	COPPER CREEK 79-3
Location	Headwaters of Bond Creek	M-7-5-1 Road in Bridge Creek	South Side of Copper Creek
Project Area	60 Acres	50 Acres	607 Acres
Road Length	0.5 Miles	1.3 Miles	6.7 Miles
Roads Removed or Worked on	L-1-5 M-11-1-1	M-7-5-1	1900, 1910 1920, 1930
Project Duration			
Heavy Equipment	July 5 - Aug 8, 1979	Aug 9 - Oct 17, 1979	July 5 - Oct 25, 1979
Labor Intensive	Nov 29 - Jan 26, 1980	Oct 29 - Nov 29, 1979	Nov - Dec, 1979
Method of Heavy Equipment Work	Equipment Rental, In-House Supervision	Equipment Rental, In-House Supervision	Equipment Rental, In-House Supervision
Heavy Equipment Costs	$51,595	$159,312	$205,613
Method(s) of Labor Intensive Work	Contract plus In-House Work	In-House Work Only	2 Contracts plus In-House Work
Labor Intensive Costs	$9,225	$7,546	$27,537
Total Cost	$60,850	$166,858	$233,150

Both heavy equipment and labor intensive erosion control techniques were employed at the Copper Creek rehabilitation unit. Diverted streams were re-routed into their natural channels and fill material was excavated and removed from stream crossings, unstable sections of logging roads and landings. A variety of labor intensive erosion control practices were also employed, including the construction of checkdams, ravel catchers, a water ladder and the placement of rock armor in excavated stream crossings. Following heavy equipment work, most bare soil areas were covered by mulches and seeded for surface erosion control. As on other sites, native shrubs, hardwoods and conifers were planted in the winter months to provide long-term revegetation, especially at stream crossing sites.

II. GENERAL DESCRIPTION OF AREA

Redwood Creek drains the 280 square mile Redwood Creek watershed in the mountainous, coastal region of northern California (Figure 1). The creek begins near 5,000 feet elevation and flows north-northwest for 55 miles emptying into the Pacific Ocean near Orick, California. The watershed is characterized by high relief, steep unstable slopes and narrow valley bottoms. Average hillslope gradients range from 31 to 45 percent.

Through most of the parklands in the lower one-third of the watershed, Redwood Creek flows along the trace of the Grogan fault, which divides the terrain into two distinct underlying rock types. The western side is underlain by well-foliated mica-quartz-feldspar schist. These northeast facing slopes are generally wetter, steeper and have a higher drainage density than the eastern slopes.

East of the fault, slopes are underlain by the pervasively sheared sandstone and siltstone of the Incoherent Unit of Coyote Creek and, in higher hillslope locations, the Coherent Unit of Lacks Creek (Harden and others, 1981). The Incoherent Unit of Coyote Creek supports gentler slopes whose soils are locally prone to extreme gully erosion and localized mass soil movement (earthflows). In contrast, the Coherent Unit of Lacks Creek contains relatively thick-bedded, resistant sandstones that form steep slopes with deeply incised stream channels. Abundant rock in the soils often retards the formation of gullies in areas underlain by this rock unit (Weaver and others, in press).

Mean annual precipitation for the Redwood Creek basin is approximately 80 inches and mainly occurs in storms from November through March. Major cyclonic winter storms and floods of note occurred most recently in 1955, 1964, 1972 and 1975. These events were responsible for triggering the majority of landuse-related fluvial and mass erosion in Redwood Creek since the advent of maodern logging in the 1940's. Peak discharges of Redwood Creek at Orick have not exceeded the seven year recurrence interval magnitude in the 12 years since 1975.

Redwood forests are concentrated near the coastal portion of the watershed, roughly coincident with the belt of summer fog that typically blankets the coast. Sitka spruce is a common associate near the coast while further inland Douglas-fir, western hemlock and tanoak become more important. Roughly 90 percent of the coniferous forests in the Redwood Creek basin have been logged since 1945. Within the park, approximately 65 percent of the forest lands have been cut or otherwise disturbed by construction of roads, tractor trails and log storage landings. Twenty-nine percent remains in old-growth and advanced second growth stands while the remaining six percent consists of prairie, oak woodlands and riparian areas (USDI, 1981).

III. BOND CREEK REHABILITATION UNIT 79-1

A. Unit Description

The Bond Creek rehabilitation unit 79-1, is located near the headwaters of Bond Creek, a tributary to Redwood Creek located three miles upstream from Orick, California (Figure 1). The unit is bordered to the north by the main stem of Bond Creek, extends south to the drainage divide with Fortyfour Creek and is bounded on the east and west by minor ridges (Figure 2).

Two logging roads traverse the unit, the M-11-1-1 road, located approximately midslope, and the L-1-5 road which traverses the lower slopes directly above Bond Creek. The M-11-1-1 was constructed in 1967 and the area above it clear-cut and tractor yarded in 1968 and 1969. The L-1-5 was built in 1973 and 1974 with the area between the two roads clear-cut and tractor yarded in 1974. Old-growth redwood forest below the L-1-5 road was not cut.

Elevation ranges from 600 feet MSL at the base of the unit to about 1,500 feet on the ridgetop. Slopes range from about 15 percent to more than 80 percent. The steepest slopes (55-80 percent), occur along the four intermittent streams and from the L-1-5 road down to Bond Creek (Figure 2). More moderate slopes (25-50 percent) occur near ridge systems between the four stream channels and the most gentle slopes (≤20 percent) are found above the M-11-1-1 road.

Bedrock of the Bond Creek area consists of well-foliated, highly deformed schists of the Franciscan assemblage. While most of these schists are fairly well sheared, large coherent outcrops are common.

Soils within the unit include Trailhead (Tentative new series, *correlated by SCS in 1984. See Popenoe, 1984) and Fortyfour on gentler* upper slopes, Coppercreek soils on steep, middle and lower sideslopes and Lackscreek soils on the steepest slopes near the more deeply incised channels. Very small areas of Devilscreek soils occur in some swales and in broader stream valleys. Together, the Trailhead and Fortyfour soils cover most of the Bond Creek tributary basin (Marron and Popenoe, 1986).

Trailhead and Fortyfour soils have clay loam or clay textures and red colors due to high iron content. These soils have undergone long periods of weathering and exhibit lower than average rates of fluvial erosion and mass movement. The high or moderately high clay and iron content and position on gentle slopes or locations near ridgetops account for their low susceptibility to fluvial erosion (Weaver and others, in press).

The old-growth forest below the L-1-5 road is dominated by redwood with scattered western red cedar, hemlock, Douglas-fir and grand fir. Typical understory shrubs are red and black huckleberry, rhododendron,

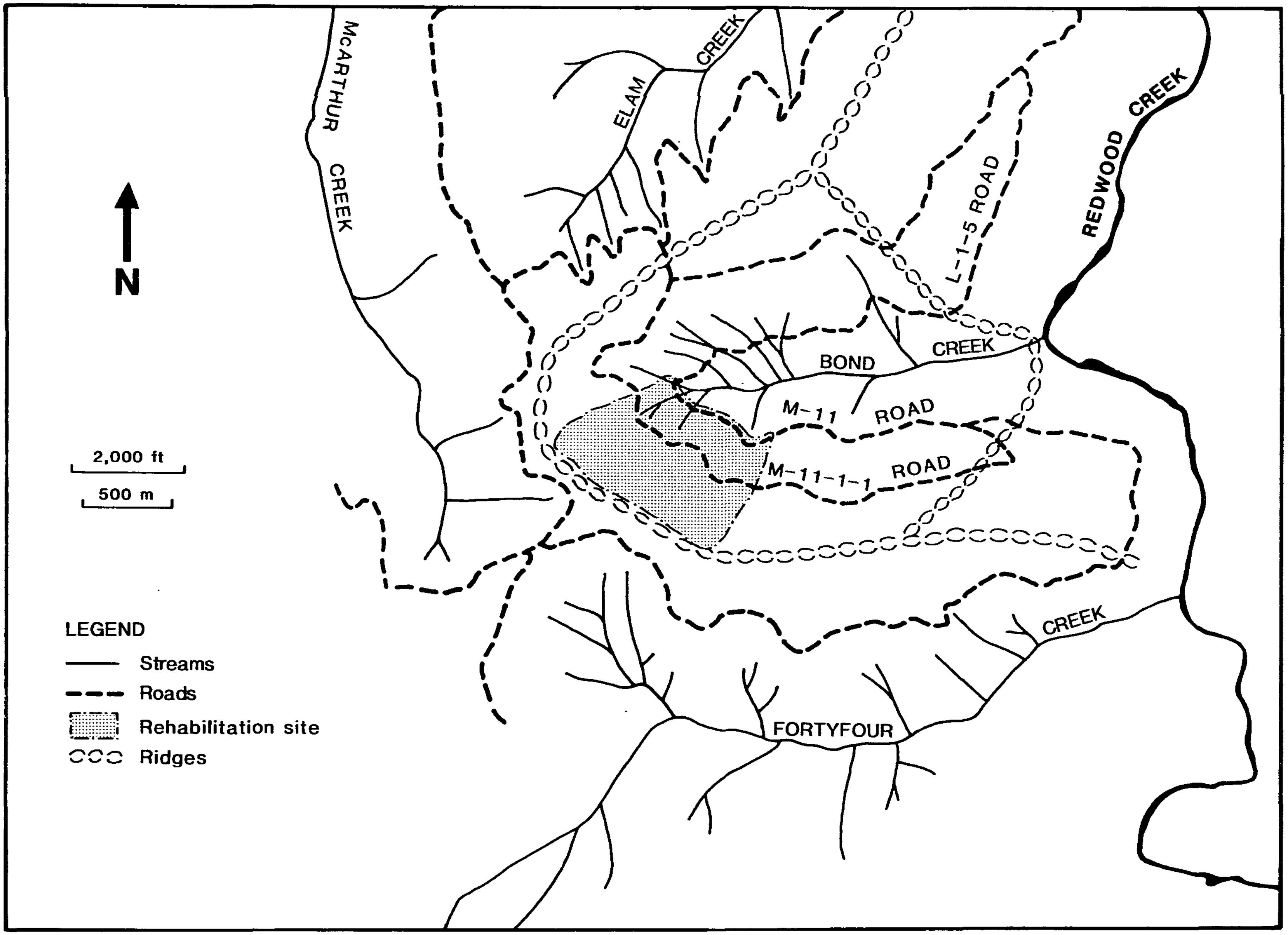


Fig. 2. Bond Creek rehabilitation unit 79-1.

salal and swordfern (see Appendix A for list of common and scientific plant names). Post-logging vegetation above the L-1-5 road includes large quantities of coyote brush and blueblossom with red alder becoming increasingly dominant in wetter areas.

Tractor yarding activities severely disrupted stream channels between the L-1-5 and M-11-1-1 roads. Large organic debris (logs, root wads and slash) and soil were pushed into the channels at 18 locations during the construction of skid trail stream crossings. Portions of these channels were also used as skid trails. Intersecting skid trail networks obliterated the former channels in the more gentle headwater regions. In contrast to the lower slope areas, erosion problems above the M-11-1-1 road were minimal. Slopes are gentle with deep, well-drained soils. Concentration of surface runoff along some skid trails had created minor gullying but had rarely delivered sediment to streams.

Bond Creek was chosen for rehabilitation for several reasons. First, sections of the L-1-5 logging road (both cutbanks and fillslopes) were unstable and likely to fail. Fillslopes along much of the L-1-5 showed numerous tension cracks and small scarps (Figure 3). These fills were located on steep slopes directly above stream channels. Second, a large cutbank landslide occurred during the 1978-79 winter as a result of

Fig. 3. Tension cracks in the fill slope, L-1-5 logging road.

runoff diverted from an upslope area. Several hundred cubic yards of earth and debris slid directly into a perennial tributary (north of location R4, Figure 4). Third, numerous skid trail stream crossings on steep slopes above the L-1-5 road showed signs of impending failure. Some fills were gullied. Others threatened to fail by debris torrent as supporting organic debris decomposed and fills became saturated during winter storms. At other locations, streamflow deflections were causing erosion of adjacent stream banks. Stream diversions were likely to occur at several locations.

Five years after logging, revegetation was minimal on roads and skid trails, despite the generally mild, northeastern aspect. Loss of protective vegetation resulted in harsh growing conditions, higher soil temperatures in summer and greater susceptibility to frost and surface erosion in the winter. The seed source for conifers was limited to the remaining old growth below the L-1-5 road. Sprouted redwood stumps were common, but few conifer seedlings had become established prior to rehabilitation. Loss of topsoil and soil compaction combined to limit the invasion of other species on the extensive skid trail network. Newly established vegetation on skid trail stream crossings was threatened by streambank failures. Below normal rainfall from 1976 to 1979 compounded the difficulties of revegetation.

B. Work Sequence

Detailed geomorphic mapping and erosion control treatment prescriptions were completed during three weeks of April 1979. Rehabilitation activities concentrated on removing 0.5 mile segment of the L-1-5 road and treating approximately 60 acres of cutover land between the L-1-5 and M-11-1-1 roads (aside from installing several new culverts, the M-11-1-1 was left intact to provide a cross basin travel route for future use and because it did not represent a significant erosional threat). Heavy equipment work began July 5 and finished August 8, 1979. Labor intensive work was completed between November 29, 1979 and January 26, 1980.

Heavy equipment operations started on the hillslope between the L-1-5 and M-11-1-1 roads. The backhoe and tractor excavated erodible fill and organic debris from skid trail stream crossings and repaired or constructed waterbars. Once hillslope work was completed, heavy equipment (crane, backhoe, loader, tractors and dump trucks) began L-1-5 road removal operations. This included stream crossing excavations, excavation and removal of unstable road fill material and road outsloping (including road ripping).

A wide variety of labor intensive measures were then prescribed and implemented to control erosion on the areas exposed during heavy equipment operations. Techniques included checkdams, flumes and rock armor in stream channels and wattles, wooded terraces, contour trenches, grass seeding and straw mulch on bare soil areas. Most of this work was done under a fixed-price service contract. Labor intensive revegetation work was completed last.

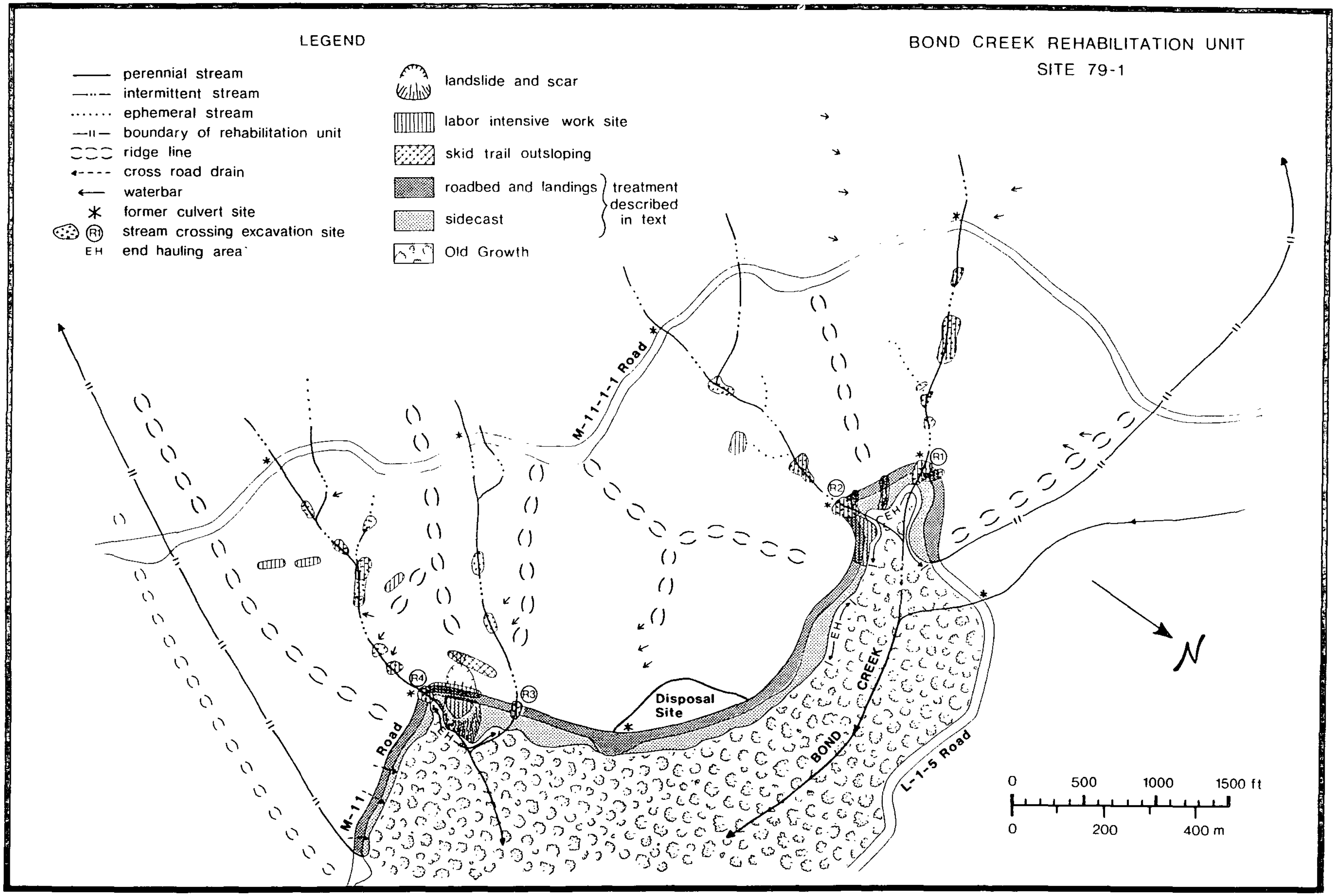


Fig. 4. Physical erosion control treatments, Bond Creek rehabilitation unit.

C. Monitoring and Documentation

Measures for monitoring post-rehabilitation erosion and revegetation included a variety of qualitative and quantitative techniques. Work areas were periodically photographed from established photo points. Erosion pin grids were established at four locations. Stream profiles and channel cross-sections were measured at two excavated stream crossings (R1, R4; Figure 4). Three plots with sediment collection troughs were installed to evaluate the relative effectiveness of treatments used to control surface erosion. Survival and growth of vegetation treatments were checked several times.

D. Heavy Equipment Work

Ten pieces of heavy equipment were used: two crawler tractors, a dragline crane, two tire-mounted backhoes, a loader, three dump trucks and a road grader (Table 2). Total heavy equipment cost was $51,600 (Table 3).

TABLE 2

Description and Hourly Rates Of Heavy Equipment, 79-1

Equipment Description	Cost/hour[1]
22B Series II Bucyrus Erie Crane, track mounted plus oiler/mechanic	$ 85.00
Caterpillar crawler tractor, D6	54.30
Caterpillar crawler tractor, D5	45.00
950 Caterpillar loader with log forks and 3 yd^3 bucket	47.80
Caterpillar road grader, Model 12	35.30
10 yd^3 dump truck	29.80
10 yd^3 dump truck	29.80
10 yd^3 dump truck	29.80
580 B Case extendahoe	32.50
580 B Case extendahoe	40.00

[1]All costs include operator.

TABLE 3

Summary Of Heavy Equipment And Labor Intensive Costs, 79-1

Heavy Equipment Treatments		Costs
Hillslope Worksites		
Excavation of ten skid trail stream crossings		$ 6,420
Outsloping crown of landslide		200
Waterbar construction		393
	subtotal	7,013
L-1-5 Road Removal		
Excavation of four stream crossings		$ 5,270
Road outsloping (includes endhauling and cross-road drains)		36,027
Log salvage and debris removal		2,252
	subtotal	43,549
Miscellaneous		
Transportation of equipment[1]		$ 1,298
Culvert placement on M-11-1-1 road		360
	subtotal	1,658
	TOTAL HEAVY EQUIPMENT COSTS	$ 52,220

Labor Intensive Treatments		Costs
Construction of ditches, waterbars and excavation of fill		$ 836
Stabilization of stream channels		2,810
Control of surface erosion		1,154
Combined treatments for surface erosion control and revegetation[2]		2,092
Revegetation[3]		1,178
Miscellaneous		429
	TOTAL LABOR INTENSIVE COSTS	$ 8,499
	TOTAL COST FOR REHABILITATION TREATMENTS	$60,719

[1] Includes transportation of equipment from Eureka/Arcata area and access to hillslope worksites from the L-1-5 road.
[2] Includes cost of grass seed, fertilizer and straw.
[3] Includes cost of conifer seedlings.

1. Hillslope Work

Hillslope work included the excavation of skid trail stream crossings, construction of waterbars to improve slope drainage and removal of unstable material from the crown-scarp region of a recent landslide. Estimated material excavated from each of the ten crossings (Table 4) ranged from 10 to 200 cubic yards, and averaging about 85 cubic yards.

Stable, large organic debris was left in the stream channels to minimize both site disturbance and equipment costs and to provide a fixed base level for the stream. Three skid trail crossings required only minor excavations (less than 50 cubic yards each).

Fill in skid trail crossings was excavated by backhoe and redistributed to stable locations by crawler tractor (Figure 5). The tractor was also used to perform preliminary excavations and to winch and remove organic debris. Total cost for the excavation of skid trail crossings was $6,400 or $7.70 per cubic yard (Table 4).

Removing perched material from the crown of a recent landslide above the L-1-5 road required five hours ($200) for a backhoe to complete. Surface drainage was dispersed across the slide to prevent failure of the remaining perched material. A small gully system which drained onto the landslide was diverted away from the unstable area.

Twenty waterbars were constructed on skid trails above the L-1-5 road by backhoe or tractor at a cost of $390. The seven backhoe-constructed waterbars cost an average of $40 each while thirteen tractor-made waterbars cost $9 each.

2. Road Removal

Removal of the L-1-5 road involved log salvage and debris removal, outsloping of the road and excavation of four logging road stream channel crossings (Figures 6 and 7). Salvageable logs were winched from the outer edge of the road prism by the two crawler tractors and transported by loader to storage areas outside the unit. Approximately 13,000 board feet of timber (60 percent redwood and 40 percent Douglas-fir) were salvaged at a cost of $2,300.

Several pieces of equipment were used to outslope the L-1-5 (Figure 6). Before outsloping, a blade-mounted chisel tooth on the tractor was used to decompact the western half of the road to a depth of about 12 inches. Fill material was then removed from the outside edge of the road with a drag-line crane and either loaded into dump trucks or deposited and graded uniformly up the cutbank. Because of insufficient stable storage area, dump trucks were used to end-haul much of the excavated fill to a disposal site (Figure 4). Approximately half of the total length of outsloped road required end-hauling.

In addition to the crawler tractors, equipment employed during road removal included a backhoe to dig cross-road drains and one French drain a front-end loader to move dirt, rocks and logs and a road grader to upgrade and maintain the road surface during end-hauling activities.

TABLE 4

Skid Trail Stream Crossing Excavation Costs, 79-1

Stream Crossing Worksite	Equipment: Backhoe Hours	Equipment: Backhoe Cost	Equipment: D-5 Crawler Tractor Hours	Equipment: D-5 Crawler Tractor Cost	Total Cost[1]	Excavated Volume (yd^3)	Unit Cost ($/$yd^3$)
S1	17	$ 680	11	$ 495	$ 1175	100	$ 11.80
S2	13	520	10	450	970	200	4.90
S3	2	80	---	---	80	10	8.00
S4	5	200	10	450	650	75	8.70
S5	3.5	140	2.5	113	253	75	3.40
S6	14.5	580	17	765	1345	150	9.00
S7	7.5	300	3	135	435	30	14.50
S8	5	200	10.5	473	673	100	6.70
S9	9	360	8	360	720	60	12.00
S10	3	120	---	---	120	30	4.00
TOTAL	79.5	$ 3180	72	$ 3241	$ 6421	830	$ 7.70

[1] Includes travel between worksites, removal of organic buried debris, excavation and placement of fill, and, tractor standby time.

Fig. 5. Tractor and backhoe excavating skid trail stream crossing.

Total cost to remove the L-1-5 road was $35,400, of which $12,700 was spent on heavy equipment standby costs (Table 5). The cost was approximately $71,000 per mile. Excluding standby time, the cost was lowered to about $47,000 per mile.

The four stream crossings on the L-1-5 were excavated by a drag-line crane, with finish work completed by a backhoe (Figure 7). Much of the excavated material had to be end-hauled due to insufficient stable storage area adjacent to the worksites. The amount of fill removed from the crossings ranged from 280 to 500 cubic yards. Costs varied from $1,200 to $1,500, averaging $1,320 per stream crossing ($3.80 per cubic yard of material removed) (Table 6). Total cost to excavate the four stream crossings was $5,300.

Miscellaneous heavy equipment costs on the Bond Creek unit (Table 3) included placement of two culverts on the M-11-1-1 road ($360), and transportation of equipment to the work area ($1,300).

E. Evaluation of Heavy Equipment Work

Heavy equipment effectively removed fill and debris from stream channels, excavated unstable fill from roads and landings and improved surface drainage by dispersing or redirecting it. In retrospect, cost-effectiveness could have been improved by using a hydraulic excavator at certain worksites and eliminating excessive standby time for road removal tasks. In addition, stream channel stabilization by labor intensive work could have been avoided at three of the four logging road stream crossing excavation sites had heavy equipment more completely removed fill material. Because channel excavations did not reach the original streambed, checkdams were installed to control anticipated downcutting.

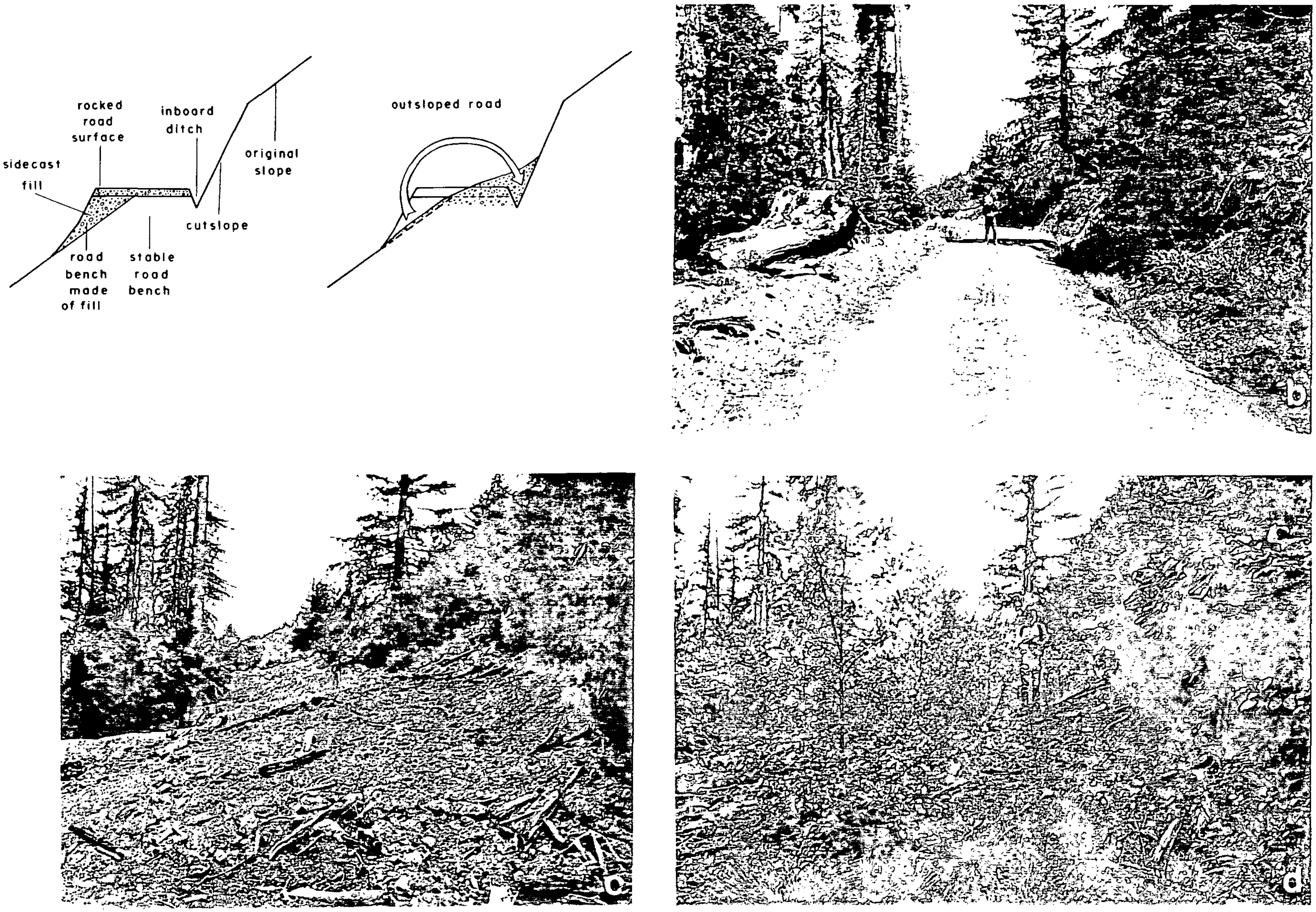


Fig. 6. Outsloping a segment of the L-1-5 road. A) diagrammatic sketch of road outsloping showing excavation of road fill and burial of inboard ditch and cutbank, B) before heavy equipment treatment (May 1979), C) immediately after outsloping and D) two year later (June 1983). All photos taken from the same viewpoint.

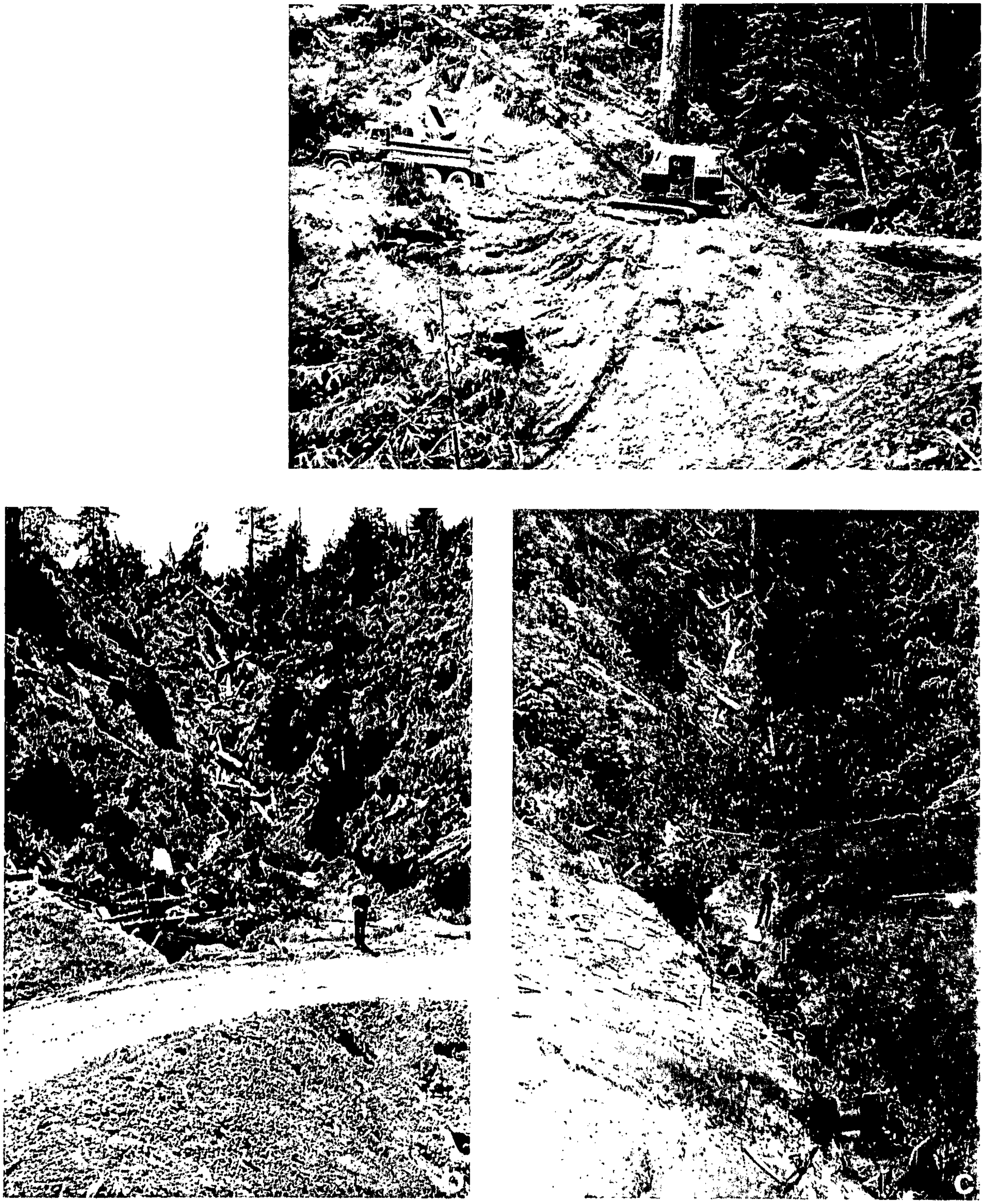


Fig. 7. Stream crossing excavation on the L-1-5 road. A) dragline crane excavates material from the crossing and places it in dump truck for endhauling to nearby storage area, B) before stream crossing excavation and C) after stream crossing excavation. Photos B and C were taken from the same viewpoint.

TABLE 5

L-1-5 Road Removal Costs[1]

Equipment	Hours Worked	Standby Hours	Total Hours	Standby Cost	Total Cost
Crane	120	0	120	$ 0	$10,200
Loader	20	125	145	5,975	6,931
Tractor (D6)	46	95	141	5,159	7,656
Tractor (D5)	24	14	38	630	1,710
Extendahoe	96	8	104	260	3,380
Dump Trucks	140	21	161	626	5,409
Grader	21	0	21	0	741
			TOTAL	$12,650	$36,027

1 Includes ripping road surface, end-hauling sidecast material to dump site, excavating road prism, removing organic debris exposed during excavation, outsloping road surface, constructing cross-road drains and one French drain, and standby costs. Excludes stream crossing excavation and log salvage costs (see Table 3).

Had skid trail stream crossings been excavated by hydraulic excavator instead of a backhoe, a savings of approximately $2,000 may have resulted. This estimate assumes a unit cost of $5 per cubic yard to excavate fill based on data from 1981 and 1982 rehabilitation units. In addition, cost differences for waterbar construction by backhoe ($40 each) and tractor ($9 each) demonstrated greater the cost-effectiveness of using tractors.

Excessive standby time accrued by the loader and a crawler tractor (Table 5) indicated that an "engine time only" contract would have been substantially cheaper. Those two pieces of equipment accounted for $11,135 or 88 percent of all standby costs. Total equipment standby costs amounted to 36 percent of road removal expenses.

Outsloping the L-1-5 road was necessary to avoid eventual failure of unstable road fill material into Bond Creek. However, a short segment of stable road between two ridges east of road crossing R4 could have been effectively treated by ripping and constructing cross-road drains. This would have resulted in a small savings in road removal cost.

Detailed surveys to quantify volumes excavated from outsloped road segments were not done, so unit costs ($/yd^3) are not available. Data from rehabilitation units completed since 1979 indicate that it is more

TABLE 6

Stream Crossing Excavation Costs for L-1-5 Road[1]

Stream Crossing Worksite	Equipment										Excavated volume (yd^3)	Total Cost	Unit Cost ($\$/yd^3$)
	Crane		D-6 Tractor		Loader		Backhoe		Dump Trucks				
	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost			
R1	7	$ 595	2	$ 109	3	$ 143	3	$ 98	9	$ 268	280	$1213	$ 4.30
R2	7	595	3	163	5	239	4	130	13	387	500	1514	3.00
R3	7	595	3	163	---	---	3	97	12	358	300	1213	4.00
R4	7	595	4	217	---	---	4	130	13	387	300	1329	4.40
Total	28	$2380	12	$ 652	8	$ 382	14	$ 455	47	$1400	1380	$5269	$3.80

[1]Includes removal of debris exposed during excavation, excavation of fill material and culverts from each stream crossing and final grading of stream channels and sideslopes.

cost-effective to outslope roads with a large crawler tractor than the crane/crawler tractor combination, as long as end-hauling is not required. There was no significant cost reduction in substituting other equipment for the crane on worksites requiring end-hauling (including stream crossing excavations).

F. Labor Intensive Work

Following heavy equipment work, a contract for labor intensive treatments was prepared. The Bond Creek labor contract called for the greatest variety of manual erosion control techniques used on a rehabilitation unit to date. For more discussion of these and other techniques, see Madej and others (1980), Weaver and Seltenrich (1981), Reed and Hektner (1981) and Hektner and others (1982). The technical specifications used in 1978 and 1979 contracts have undergone several refinements. Appendix B: Technical Specifications for Hand Labor Erosion Control Methods incorporates the refinements made during several years of use and evaluation.

The primary purposes of the labor contract work were to reduce surface and stream channel erosion and to reestablish vegetation at freshly disturbed heavy equipment worksites (Figure 4). The contract called for minor excavations at skid trail crossings which were inaccessible to heavy equipment, waterbar construction or repair of existing waterbars on skid trails and ditch construction. To have some tasks completed before winter rains began, some essential work was performed by National Park Service labor crews. All tree planting was done by Redwoods United Inc., a local handicapped worker organization. Table 3 summarizes the costs for all erosion control and revegetation treatments.

Four contractors submitted bids for the labor intensive work, with prices ranging from $9,900 to $30,930. Integrated Forest Management (IFM) of McKinleyville, California was awarded the contract. Subsequent to letting the contract on October 17, 1979, but prior to the award on November 11, 1979, Bond Creek received 14.5 inches of rain, with three separate runoff peaks. Runoff so altered some contract worksites that several prescribed items either required modification or were no longer necessary. Two change orders modified the amount and type of work performed, lowering the final cost of the contract to $7,215 (Table 7).

Contract labor crews began work on November 29, 1979 and finished on January 26, 1980, working a total of 25 days (1,326 person hours). This represented a cost to the National Park Service of $5.40 per hour, excluding costs for seed, fertilizer, straw and redwood boards which were furnished by the park. Work by the contract crews was regularly inspected by park staff.

1. Physical erosion control

Various erosion control techniques were utilized in stream channels and on bare soil areas (Table 7). Fifty-seven checkdams, the most common technique used to prevent stream channel erosion and bankcutting, were

TABLE 7
Labor Intensive Erosion Control and Revegetation Costs, 79-1

Description	Person Hours[1]	Quantity	Unit Cost[2]	Cost
TREATMENTS INSTALLED UNDER CONTRACT:				
Ditches	9.75	148 lin. ft	$ 0.38 lin./ft	$55.86
Waterbar - clean out	6.25	188 lin. ft	0.48 lin./ft	90.24
Waterbar - new construction	22.25	371.9 lin. ft	0.64 lin./ft	238.02
Manual excavation	45.0	1 job	452.20/job	452.20
Stream Channel Stabilization				
Rock and wire channel	97.25	270 sq. ft	2.22 sq. ft	600.45
Rock channel	14.75	383 sq. ft	0.48 sq. ft	183.84
Rock and stake channel	14.25	234 sq. ft	0.83 sq. ft	194.22
Checkdams	188.75	57	21.38 ea.	1,218.81
Submerged spillways	33.75	16	24.35 ea.	389.60
Log deflection points	15.0	3	25.10 ea.	75.30
Board deflection point	1.0	1	19.04 ea.	19.04
Notch log in channel	5.0	1	9.52 ea.	9.52
Log energy dissipater	8.5	1	47.60 ea.	47.60
Log retaining wall	9.5	1	38.08 ea.	38.08
Surface Erosion Control				
Wooded terraces	138.75	1616 lin. ft	0.53/lin. ft	856.49
Contour trenches	36.0	697 lin. ft	0.34/lin. ft	236.98
Ravel catchers	7.5	86 lin. ft	0.70/lin. ft	60.20
Surface Erosion and Revegetation				
Wattles	129.5	1669.6 lin ft	0.94/lin. ft	1567.02
Grass seed application		32.5 lbs	0.41/lb	13.33
Fertilizer application		224.5 lbs	0.52/lb	116.74
Straw mulch	2.0	4 bales	3.98/bale	15.92
Revegetation				
Transplants - all species (avg.)	34.5	516	0.33 ea.	172.49
Stem cuttings - all species (avg.)	6.0	588	0.23 ea.	133.59
Miscellaneous				
Stop work order costs (1)				400.44
Worksheets	12.25	1 job	28.56/job	28.56
		Total Contract Labor Cost =		$7,214.54
TREATMENTS INSTALLED BY NPS CREWS:				
Stream Channel Stabilization				
Flume	5.0	1	6.77/hr	33.85
Surface Erosion and Revegetation[3]				
Grass seed, fertilizer & straw mulch	56.0	56 lbs,550 lbs,42 bales	6.77/hr	379.12
		Total Labor Cost for NPS Crews =		$412.97
TREATMENTS INSTALLED BY REDWOODS UNITED, INC.				
Revegetation[3]				
Tree Planting	136.5	4,200	6.39/hr	872.39
	TOTAL LABOR COST FOR LABOR INTENSIVE TREATMENTS =			$8,499.90

[1] For contract work items this does not include 463 person-hours absorbed by the contractor, associated with transportation of people and materials to worksites, organization time, discussions with Contracting Officer, preparation of wooden stakes and tool maintenance.
[2] Unit Cost = Cost divided by Quantity or Person Hours, as appropriate.
[3] Does not include cost of materials.

placed in six excavated stream channel crossings (Figure 8). Submerged spillways were installed at three locations. Rock armor, secured with stakes or chicken wire, was used to protect portions of three stream crossings and four drainage ditches (Figure 9).

To reduce stream channel adjustment, wood was secured in or along channel banks. Log deflection points, board deflection points, notched logs, a log energy dissipater and a log retaining wall accounted for seven percent of the total contract cost. In addition to tasks completed by the contractor, park personnel constructed a flume at worksite S2 (Figure 10) to carry water over a steep reach of excavated channel. The flume took approximately five hours ($34.00) to build and install.

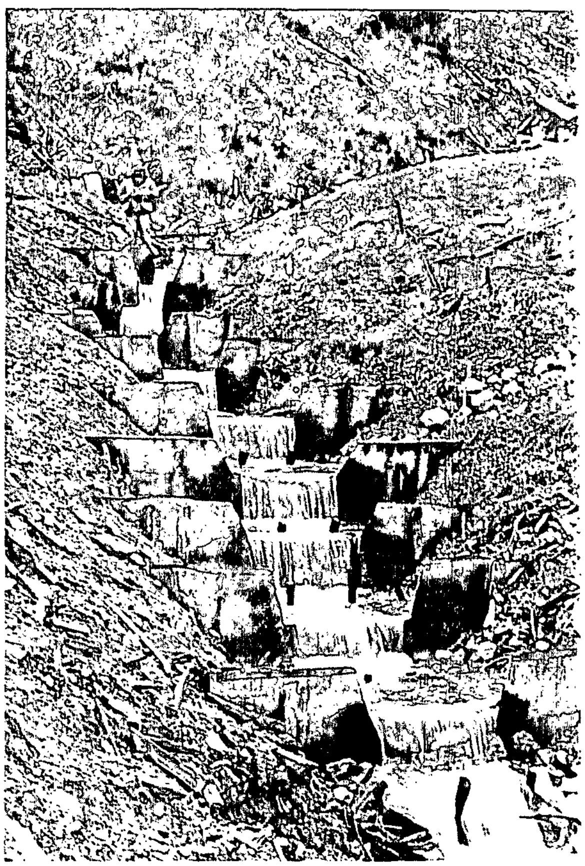


Fig. 8. Redwood board checkdams in an excavated stream crossing, L-1-5 road.

Physical erosion control techniques used on bare slopes to retard or prevent rainsplash, sheet and rill erosion included wooded terraces, contour trenches and ravel catchers (Figure 11). Contract labor costs for surficial erosion control work were 30 percent for wooded terraces, eight percent for contour trenches and two percent for ravel catchers. The remaining 60 percent was spent on treatments which combined

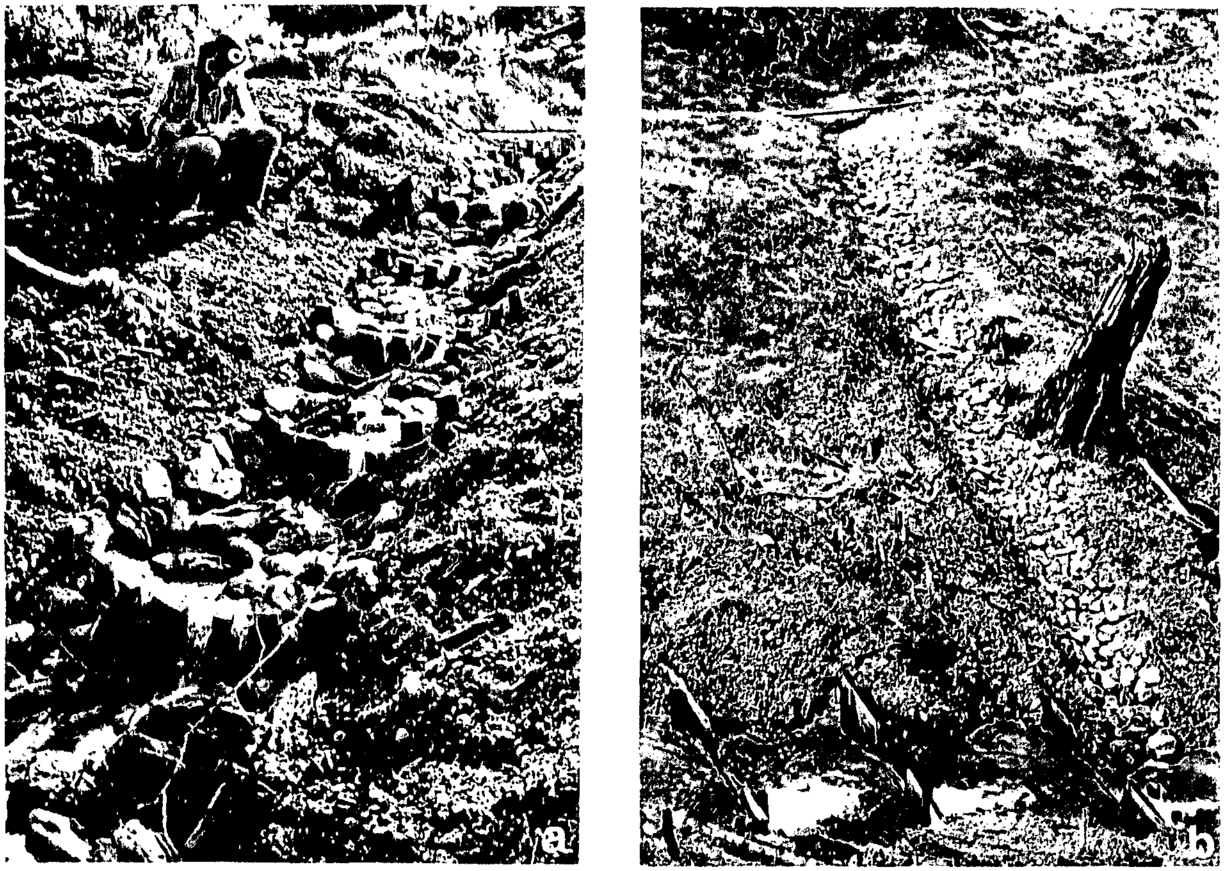


Fig. 9 (above). Hand-placed and secured rock armor in two small channels (A and B) excavated through the former L-1-5 logging road.

Fig. 10 (right). Water ladder, flume and rock energy dissipater constructed in incompletely excavated skid trail stream crossing.

revegetation with erosion control such as wattles (55 percent), grass and fertilizer (five percent) and straw (less than one percent).

2. Winter maintenance

Maintenance of erosion control devices during the winter immediately following rehabilitation consisted of repairing a washed-out checkdam (worksite S2) and clearing debris from checkdam spillways which were partially clogged (Figure 12). There was no need for maintenance during the winter of 1980-1981. Maintenance in 1981-1982 consisted of minor shovel work at worksite R3 and repair of one waterbar. Minor problems such as non-functional submerged spillways still exist on the site, but continued maintenance is not needed since they present minimal erosion problems.

3. Revegetation

Revegetation efforts addressed immediate, short and long term needs. Grass was seeded and willow and coyote brush wattles were installed to control surface erosion on the re-worked ground. Shrubs, alders and conifers were planted to speed forest reestablishment. Vegetation treatments were restricted to excavated stream crossings except for grass seeding and conifer planting (Figure 13). A variety of species were used experimentally as transplants and stem cuttings. Prescriptions emphasized species readily adapted to specific site requirements. Revegetation costs are listed in Table 8.

Wattles. Wattles are buried bundles of branches intended to sprout, thereby reducing surface erosion and revegetating bare slopes (see Appendix B). Willow wattles on 1978 rehabilitation sites showed limited sprouting or growth, but their value as a surface erosion control technique had not yet been evaluated. On unit 79-1, three types of wattles were installed by contact in January 1980: 100 percent alder, half willow/half alder, and 100 percent coyote brush. Wattles composed of willow or coyote brush were compared with alder wattles which were not expected to sprout. Alder also provided bulk in willow/alder wattle bundles, reducing the amount of willow needed from off-site sources. Wattles were installed on skid trails, excavated stream crossings and outsloped roads.

Transplants and stem cuttings. Eight native species were transplanted: alder, deerfern, swordfern, salal, rhododendron, coyote brush, and two rushes. Five species of stem cuttings were planted: willow, coyote brush, salmonberry, whipplea and wax-myrtle. These treatments were restricted to excavated areas which were relatively moist (stream crossings and cross-road drains).

Grass seeding and fertilization. Park personnel hand seeded and fertilized three outsloped road areas in early October following heavy equipment work (Figure 14b). The remaining areas were hand seeded and fertilized by contractors in late January. The grass seed mixture,

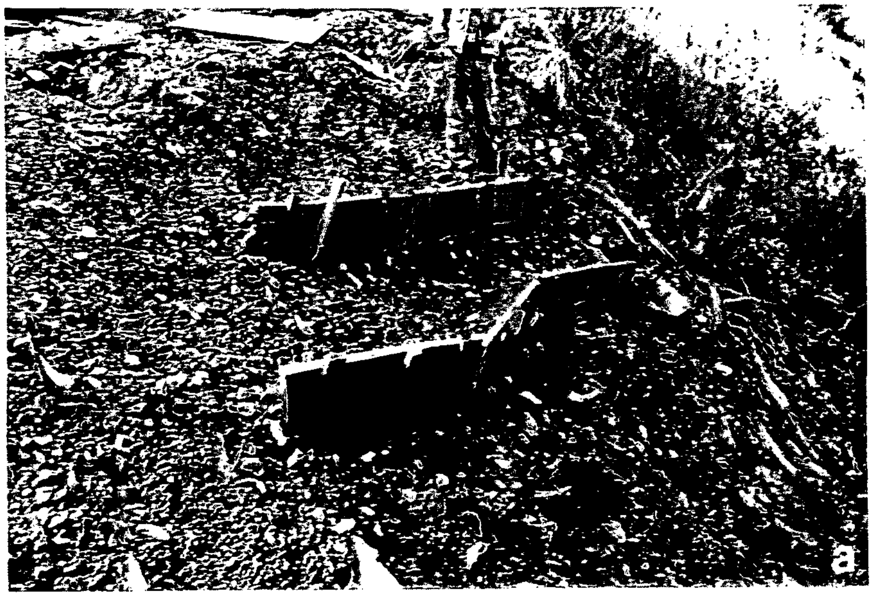


Fig. 11. Physical erosion control devices used to reduce surface erosion from bare soil areas. A) ravel catchers, B) contour trenches and C) wooded terraces.

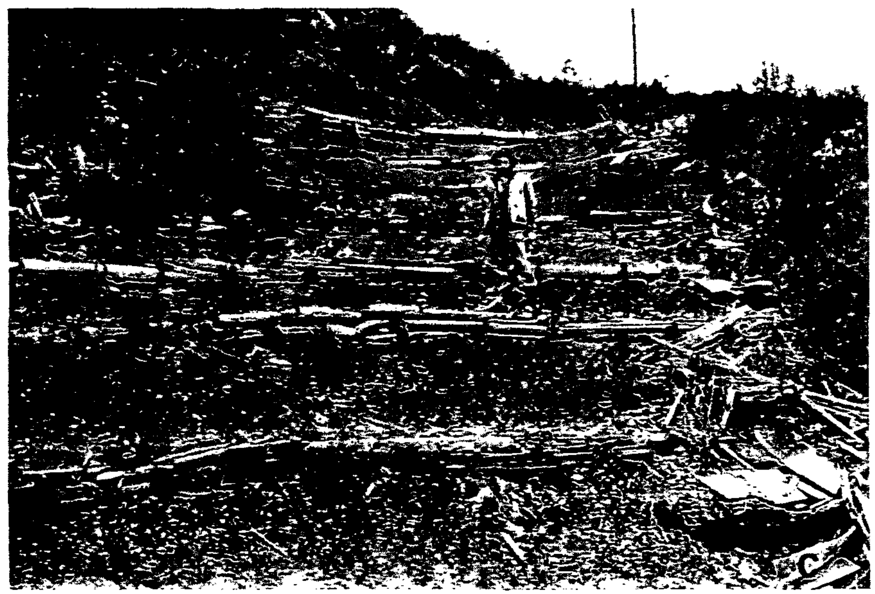


Fig. 12. Washed out checkdam. Organic debris plugged the spillway, diverted streamflow against the left bank and caused lateral scour around the structure.

applied at 50 pounds per acre, was composed of 33 percent 'Highland Colonial' bentgrass, 33 percent 'Akaroa' orchardgrass, 17 percent creeping red fescue and 17 percent 'Oregon' perennial ryegrass, by weight (hereafter referred to as the "RNP mix"). Fertilizer (16-20-0) was applied at a rate of 500 pounds per acre at the time of seeding.

Tree planting. One-year old containerized redwood and Douglas-fir seedlings were planted on rehabilitated road surfaces, skid trails and excavated stream crossings by Redwoods United, Incorporated. The trees were grown by the Simpson Timber Company and Louisiana-Pacific Corporation. Seed source was the California Department of Forestry seed zone 091, elevation <2000 feet. Two thousand redwood and 2,200 Douglas-fir seedlings were planted in 136.5 person-hours. Fertilizer tablets were used only in an experimental plot and no browse protection was used.

E. Evaluation of Labor Intensive Work

1. Physical erosion control

Most techniques used to control stream channel erosion worked well, preventing both downcutting and bank erosion. Checkdams were particularly effective, as demonstrated at worksite R2 (Figure 15). Runoff from early October storms downcut an average of two feet, eroding 22 cubic yards from the unprotected channel. Checkdams were then installed in the actively eroding channel. They succeeded in preventing further erosion and caused local aggradation of the streambed. Representative cross-sections (Figure 16) of worksite R2 demonstrated channel conditions which existed prior to the first winter storms, following the storm runoff and after installation of the checkdams.

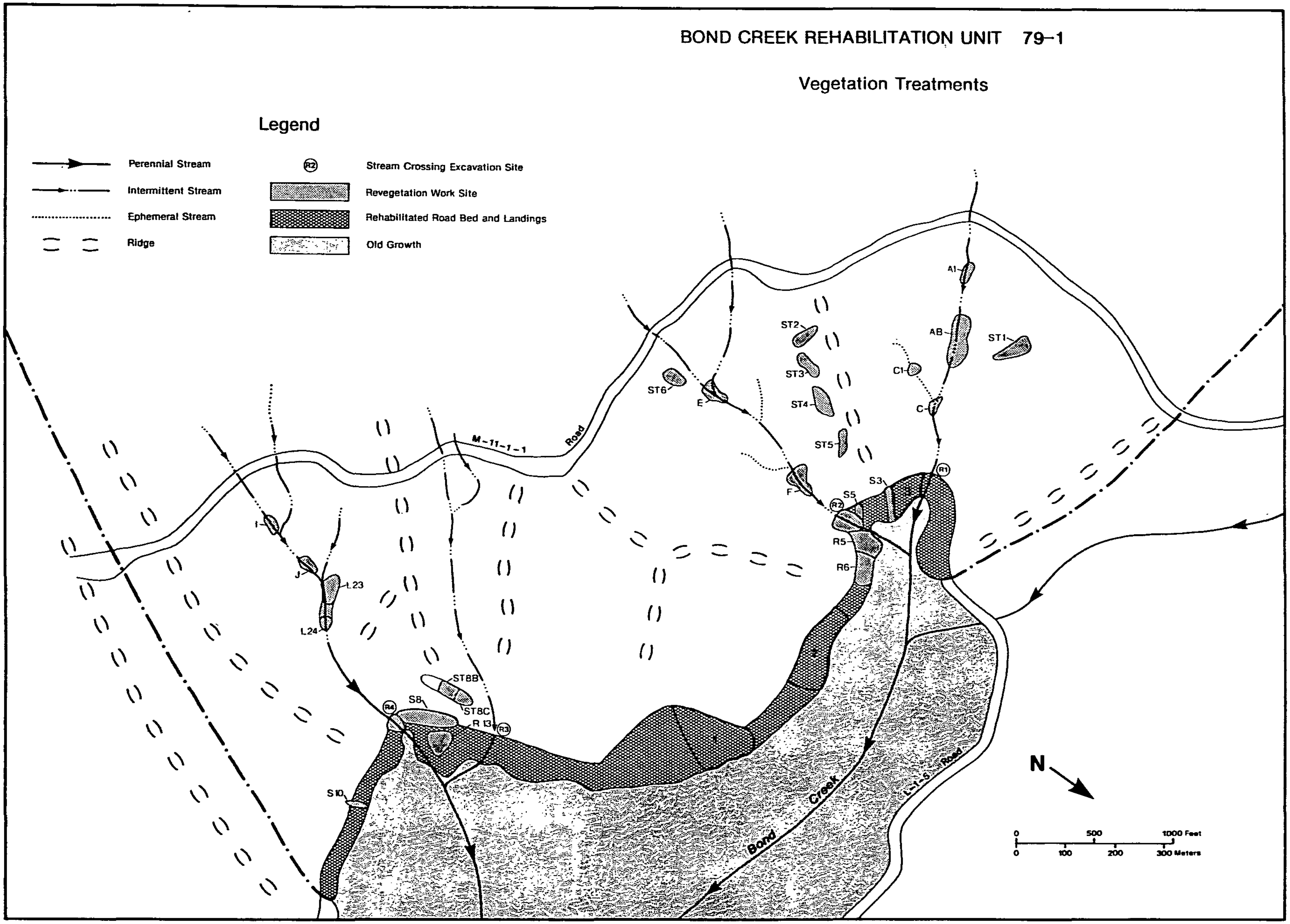


Fig. 13. Vegetation treatment work sites on the Bond Creek rehabilitation unit.

TABLE 8

Revegetation Costs

Treatment	Quantity	Labor Cost	Materials Cost		Total Cost	Total Unit Cost
WATTLES						
Alder	990.6 ft	$ 931.16	Native		$ 931.16	$0.94/ft
Willow/Alder	410.2 ft	402.10	Materials		402.00	0.98/ft
Coyote brush	268.8 ft	233.86	Used		233.86	0.87/ft
subtotal	1,669.6 ft	$1,567.02	(No Costs)		$1,567.02	
TRANSPLANTS (#)						
Alder	158	$ 55.30			$ 55.30	$0.35 ea.
Deerfern	35	11.20			11.20	0.32 ea.
Swordfern	76	31.92			31.92	0.42 ea.
Salal	78	24.96			24.96	0.32 ea.
Rhododendron	28	12.04			22.04	0.43 ea.
Coyote brush	59	21.24			21.24	0.36 ea.
Bolander's rush	4	1.64			1.64	0.41 ea.
Common rush	22	3.52			3.52	0.16 ea.
subtotal	460	$ 161.82			$171.82	
STEM CUTTINGS (#)						
Willow	508	$ 116.84			$116.84	$0.23 ea.
Coyote brush	40	9.60			9.60	0.24 ea.
Salmonberry	15	2.40			2.40	0.16 ea.
Whipplea	40	6.40			6.40	0.16 ea.
Wax-myrtle	25	4.75			4.74	0.19 ea.
subtotal	628	$ 139.99	0	0	$139.98	
ROAD SURFACES						
RNP Grass Mix	88.5 lbs	$ 36.29	$1.196/lb	$105.85	$142.14	$1.61/lb
Fertilizer	774.5 lbs	277.46	0.119/lb	92.17	369.63	0.48/lb
Straw	46 bales	211.36	3.10/bale	142.60	353.96	7.69/bale
Douglas-fir	2,200	456.94	0.10 ea.	220.00	676.94	0.31 ea.
Redwood	2,000	415.45	0.10 ea.	200.00	615.45	0.31 ea.
subtotal		$1,397.50		$760.60	$2,158.12	

TOTAL VEGETATION TREATMENT COST $4,036.95

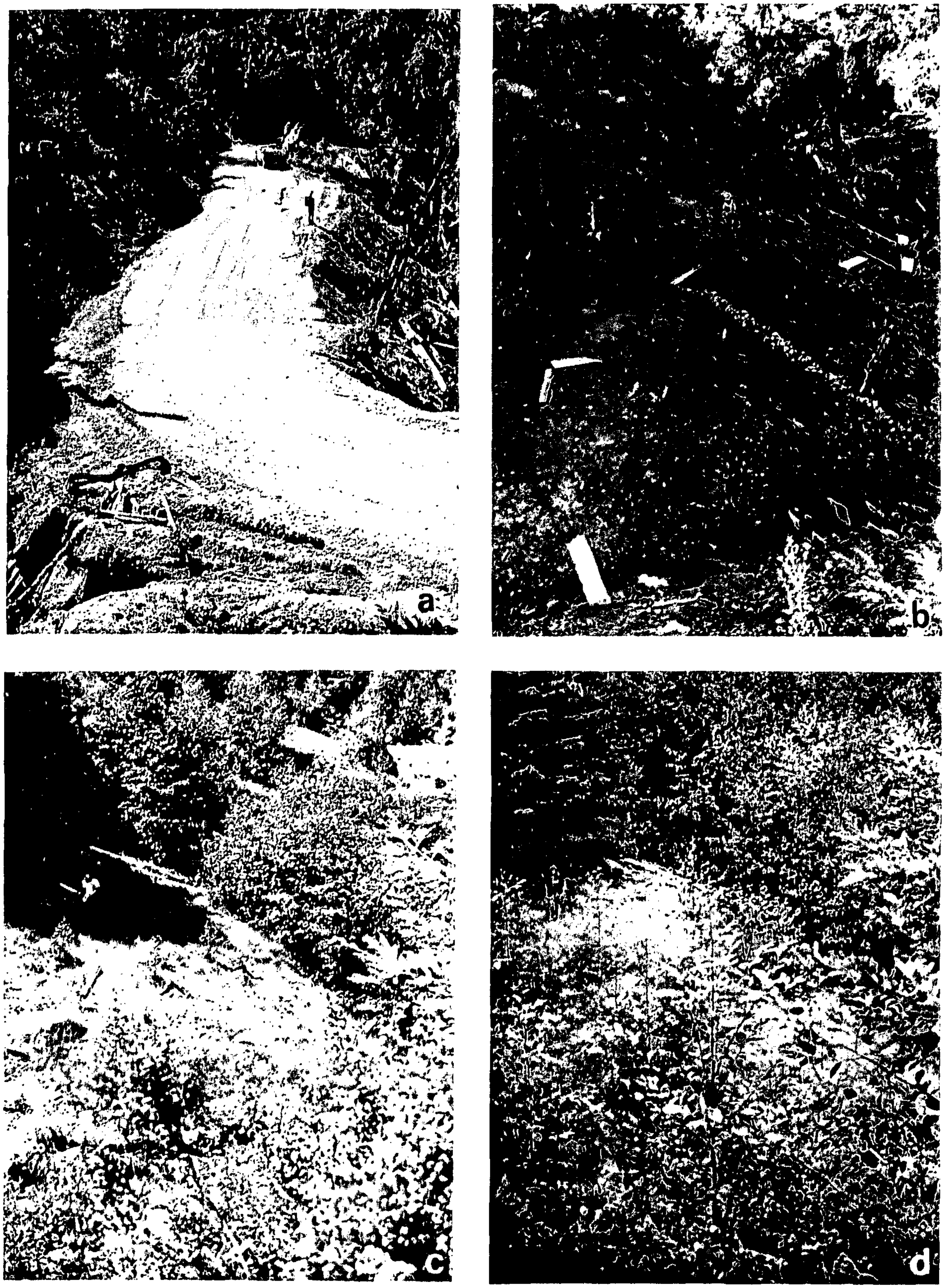


Fig. 14. Outsloping and revegetation of a portion of the L-1-5 road. A) logging road before treatment (May 1979); B) outsloped road (over half of the unstable fill and excavated material from the two stream crossings was endhauled to a nearby storage site); note the sediment trough erosion plots, grass seeded and straw mulched slopes, the hand-rocked cross road drain and the check dams in the foreground stream channel (February 1979); C) alder revegetation takes hold in the wetter areas (May 1981); D) same view in August 1982. All photos were taken from the same location.

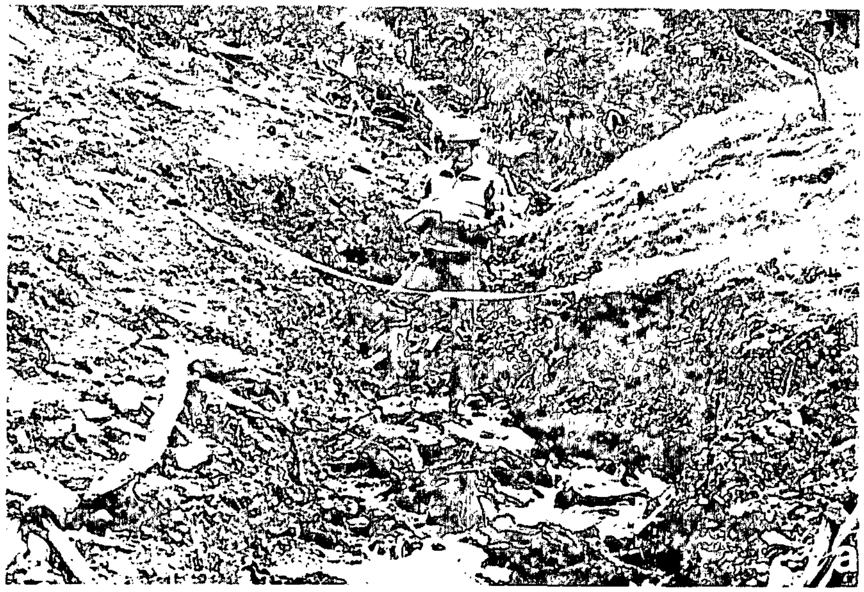
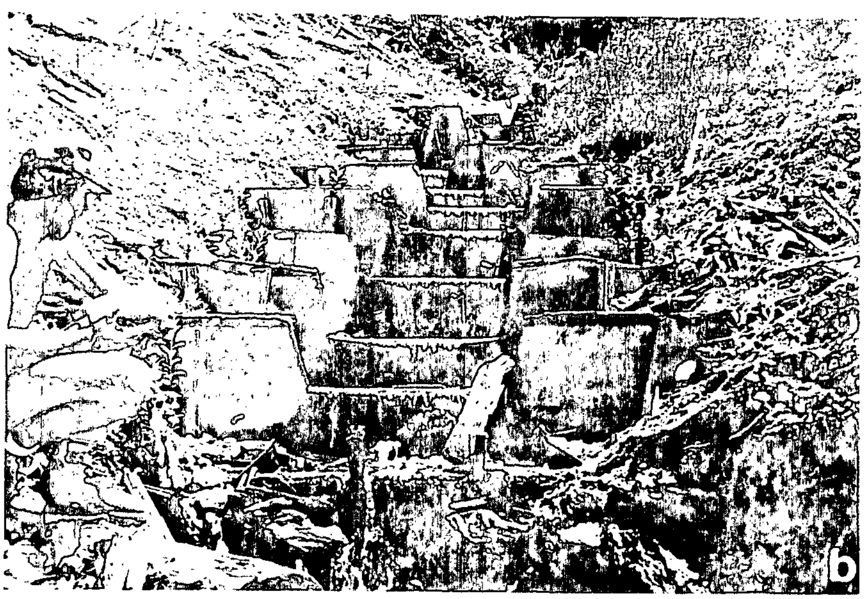


Fig. 15. The effect of checkdam construction on excavated stream crossing R2. Note down-cutting in the unprotected, excavated crossing following the first significant runoff of the 1979-80 winter (15A). A measuring tape is draped across the channel at the location of the former excavated ground surface. In 15B, the series of checkdams installed in the eroded channel caused aggradation and stabilizaton of the channel bed and banks.



Rock armoring was also effective in controlling channel erosion. At two locations, R3 and R4, chicken wire used to hold rocks in place had disintegrated by April 1982, but none of the rock moved. Likewise, small sized rock armor, secured to the bed by wooden stakes, has not changed appreciably since installation. Although rocking worked well, its application in four cross-road drains seemed excessive in retrospect because of the small amount of erosion expected to occur at these locations.

Within two years, submerged spillways no longer functioned at two of the three sites. Failure was caused by undercutting of the lower-most spillways which were not sufficiently excavated into stable substrate. However, the amount of erosion which resulted was minimal and did not warrant repair of the structures.

Techniques used to control stream channel erosion, such as a log retaining wall, energy dissipaters, a board deflection point and log deflection points were applied on a site-specific basis. All of these structures functioned as intended, except the log deflection points which were undercut by Spring 1980.

Four excavated skid trail crossings were left unprotected following heavy equipment work, but only five cubic yards eroded from three locations during the following three winters (1979, 1980, 1981). The amount of additional material which may be eroded during the next five to ten years was estimated to be less than 15 cubic yards. At similar excavated stream crossings which were protected with checkdams or rock armor (except worksite S2 which contained a large amount of earth fill), the amount of erosion prevented in the next five to ten years ranged from 10 to 30 cubic yards. The amount of erosion prevented at most of these worksites is small. Little impact would have occurred had they been left unprotected. Rocks and organic debris remaining in the channels and uncovered by subsequent downcutting appeared responsible for the post-excavation stability of the unprotected worksites (Klein, in press).

None of the four stream crossings along the L-1-5 road were excavated to the original channel bed. Consequently much fill remained within each crossing. One stream crossing excavation (R1) was also left unprotected and measurements show that ten cubic yards of material eroded between 1979 and 1982. Downcutting in R1 was controlled by abundant organic debris within the eroding fill material. Minimal channel adjustment occurred before the stable organics were uncovered (Figure 17). Crossing R2 lost 22 cubic yards during the first few storms after excavation and eventually could have yielded perhaps ten times that much had checkdams not been installed (Figure 15). Since there was less organic debris in the fill at R3 and R4, more channel adjustment would have occurred had checkdams or rock not been intalled. If each of the L-1-5 road crossings had been excavated to the original channel grade, the potential for subsequent erosion would have been considerably less and protection of the channels would not have been warranted.

Treatments to control surface erosion included installation of contour terracing structures to disperse concentrated runoff and promote sediment deposition and protective ground covers to prevent soil from eroding. Treatments to provide sediment deposition, in order of decreasing effectiveness, were ravel catchers, contour trenches, wooded terraces and wattles. The effectiveness of each technique depended on the width and slope of the terrace and the height of the berm or retaining structure on the downslope edge of each terrace.

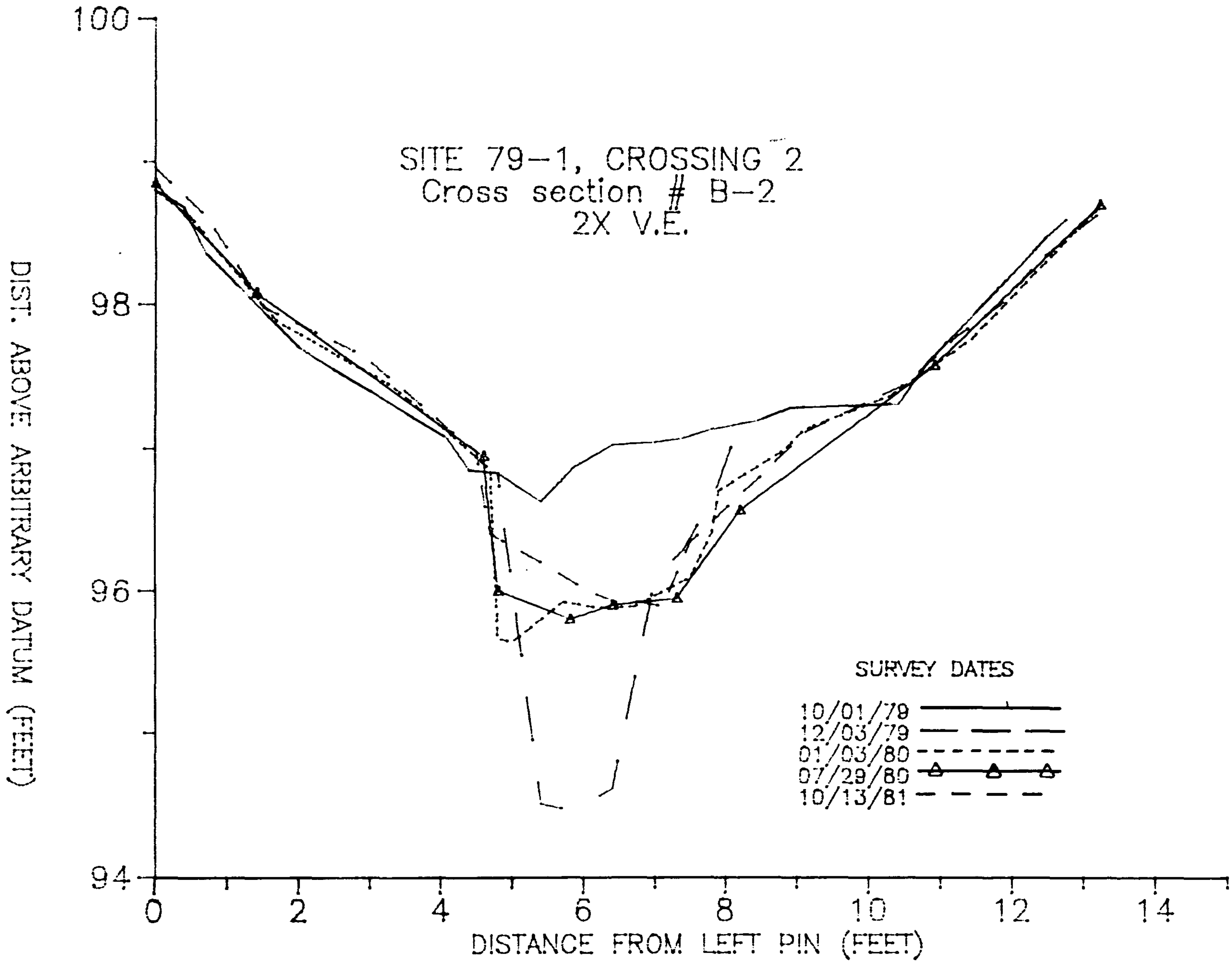


Fig. 16. Channel cross-sections of excavated stream crossing R2. Surveys were conducted immediately after crossing excavation (October 1979), after downcutting caused by the first major storm runoff of the 1979 winter (December 1979), following installation of a series of redwood board checkdams designed to stabilize the channel (January 1980) and during two subsequent remeasurements. Note the aggradation and subsequent stability of channel dimensions following construction of the checkdams.

Fig. 17. Serial photographs of channel changes at the excavated stream crossing R1. Even though the crossing had not been fully excavated, abundant concentrations of organic debris buried in the fill helped minimize subsequent channel erosion. Figure 17A: October 1979; Figure 17B: June 1980.

Wooded terraces, contour trenches and ravel catchers commonly caused concentration of surface runoff rather than dispersal. This resulted in minor rilling downslope of the structures. Wattles also tended to concentrate runoff, but to a lesser degree due to the relatively smaller sized terraces and lack of a sizeable berm or structure on the outside edges of the terraces. Wattles with vigorous growth were better able to capture sediment than non-sprouting wattles.

With the exception of coyote brush wattles, none of the terraced treatments prevented rainsplash or sheet erosion. After about two years coyote brush wattles began to control rainsplash and sheet erosion. This resulted from an accumulation of leaf litter acting as a protective ground cover and the bushes themselves intercepting rainfall. None of the other terraced treatments prevented rainsplash or sheet erosion. Construction of all terraced structures probably resulted in an increase of sheetwash erosion by creating small, over-steepened areas between terraces (Weaver and Seltenrich, 1981).

Grass seed and mulch were applied as surface treatments to prevent soil erosion. In areas where it was applied, straw mulch (2000 lbs/ac) controlled rainsplash and sheet erosion initially, but tended to become thin as the season progressed, reducing some of its protective value. Where straw was spread over an area that was initially seeded and fertilized, by the time the straw had deteriorated, the grass was established well enough to protect the ground surface (Figure 18).

Grass seeding, used as an erosion control treatment, did not prevent rainsplash or sheet erosion until late winter to early spring, due to the length of time between initial germination and the development of a fairly dense, uniform ground cover. During this time, much of the fine soil on the ground surface was eroded, leaving the seeded areas resembling the adjacent, unseeded areas. In some large drainage areas, such as through-cut skid trails, much of the seed was washed away before it could germinate, rendering the treatment ineffective for erosion control.

Where seed wash occurred on terraced structures, heaviest initial cover was found in the contour trenches or on flat areas above wattles and wooded terraces. Within one year, average grass cover for these localized areas increased to over 80 percent, with some areas exceeding 90 percent cover. It appeared that grass intercepted most of the concentrated sediment washing over and under wooded terraces. Sediment fans developed in the grassed areas without reaching the next terrace. Most of the rills in grass covered areas appear inactive and discontinuous and probably formed before the grass became established. Grass seeding may have inhibited the enlargement of these erosion features.

Surface erosion sediment-trough plots (10 feet x 25 feet; Figure 18) were installed to compare the effectiveness of three treatments to control surface erosion (Kveton and others, 1983). The treatments and results from the sediment trough plots are listed in Table 9. In the first season, plot 2 (50 pounds per acre grass seed) yielded 1.64 tons per acre of sediment with 61 inches of rain. Plot 1 (9,000 pounds per acre straw and 50 pounds per acre grass seed) yielded 90 percent less sediment than plot 2. Plot 3 (150 pounds per acre grass seed) yielded 75 percent less sediment than plot 2.

Fig. 18. Sediment trough plots installed on a segment of the outsloped L-1-5 road between crossings R1 and R2. The plots are numbered 1, 2 and 3, from foreground to background. Note the extensive grass cover which emerged by 1981 (Figure 18B).

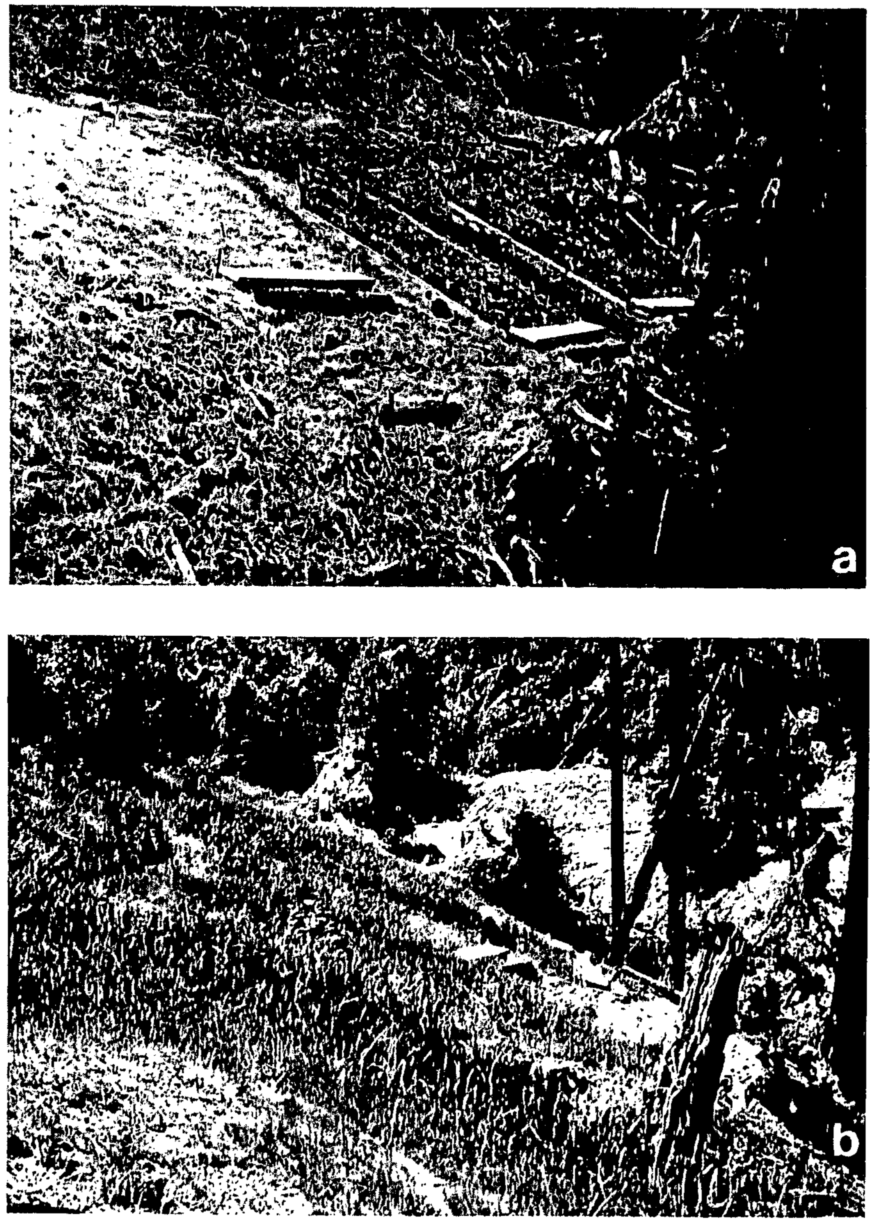


TABLE 9

Treatments and Data for Erosion Plots

Description	Plot 1	Plot 2	Plot 3
	---------------	Plot Data	--------------
Percent Slope	45	49	51
Treatment[1]	straw & grass seed	grass seed	grass seed
Application rate (lb/ac)	9000,50	50	150
1979-1980			
Number of samples	17[2]	19	19
Precipitation (in.)	60.9	60.9	60.9
Sediment yield (tons/ac)	0.17	1.64	0.40
1980-1981			
Number of samples	1	1	1
Precipitation (in.)	50.3	50.3	50.3
Sediment yield (tons/ac)	0.020	0.051	0.014
1981-1982			
Number of samples	1	1	1
Precipitation (in.)[3]	84	84	84
Sediment yield (tons/ac)	0.0104	0.0077	0.0007

[1]Fertilizer (500 lb/ac) was applied to all three plots.
[2]Due to the low yield of sediment, fewer samples were collected during the season.
[3]Due to missing precipitation data at the plot location the precipitation at a nearby station (Orick) is given. Actual precipitation at this unit was probably higher.

By the second winter, plots 2 and 3 supported a dense grass cover, averaging two feet tall. Where grass cover was not complete in plot 1, the ground surface was still protected by straw. During the second winter, sediment yields from all three plots dropped 85-95 percent from the previous year. Plot 2 still had the highest sediment yield, but differences between yields were insignificant.

Sediment yields from all three plots continued to drop the third winter. However, the physical size of the collected sediment samples was so small that sediment yield values were probably more influenced by sampling procedure and accumulated organic material in troughs than by actual differences in erosion rates.

Natural variation between yields from individual plots could not be ascertained without replicate plots. It was not possible to determine the absolute effectiveness of each treatment because no control or "straw only" plots were established at this location. However, data from the first winter indicated that straw mulch (9,000 pounds per acre) covering 50 pounds per acre grass seed was superior to 150 pounds per acre grass seed which was, in turn, superior to 50 pounds per acre grass seed. The effectiveness of a heavy straw mulch application to control surface erosion on several sites in the park has been discussed by Kveton and others (1983).

Three erosion pin grids, each consisting of nine equally spaced pins in a 2.7 square foot area, were established in the three sediment trough plots. The pins were initially measured in October 1979 and again in August 1980. The total change at each pin was averaged to obtain a net change for the entire grid. This value, in turn, was assumed to represent the average change for 1/3 of the sediment trough plot which contained the grid. Sediment yield, in grams, was then calculated for each plot assuming a sediment density of 1.5 grams per cubic centimeter. Table 10 compares the sediment yield calculated from the erosion pin grids with the amount of sediment measured in each trough during the sample period. There was no systematic correlation between the results obtained by these two methods. This probably resulted from an insufficient number of erosion pins or localized erosion and deposition.

Six additional erosion pin grids were established on the Bond Creek unit in October 1979 and remeasured in August 1980. Two grids were located on slopes treated with 2,000 pounds per acre straw mulch and 50 pounds per acre grass seed. The remaining grids were on bare, untreated slopes. Slope steepness was approximately 65 percent. Despite observations that surface erosion had occurred (indicated by the occurrence of soil pedestals) the net change measured at each grid showed overall deposition ranging from 0.8 to 3.2 millimeters, averaging 2.2 millimeters. Erosion pins used to measure surface erosion from bare soil areas did not appear to be a reliable or accurate monitoring technique.

TABLE 10

Comparison of Sediment Yields Determined by Erosion Pin Grids and Sediment Collection Troughs on Three Surface Erosion Plots, Winter 1979-80

	Calculated Sediment Yield from Erosion Pin Grids (grams)	Sediment Collected from Trough (grams)
Plot 1	135,570	755
Plot 2	4,452	7,416
Plot 3	71,832	1,833

2. Revegetation

Vegetation survival was monitored in December 1980, October 1981 (Table 11) and March 1982. There was little difference in measured survival.

Wattles. Sprouting of alder wattles was not evaluated during the first vegetation survey because alder was not considered a sprouting species and no sprouts were noted. The second year survey at R13, where 810 feet of alder wattles had been installed, revealed 20 sprouts, averaging 3-4 feet in height. To verify sprouting, several were dug up. Sprouting had occurred at the cut ends of branches, not from buds along the branches as with willow.

Few alder sprouts were observed on willow/alder wattles which had been installed at two sites. Willow/alder wattles at site AB (Figure 13) were located on a south facing slope, fairly high in the unit, but adjacent to an intermittent stream. Willow sprouting increased with proximity to the stream, with rates ranging from 70 to 100 percent. Willow growth during the first year varied in the same manner. Upper rows averaged 6-9 inches in height and were heavily browsed. Lower rows averaged 2-3 feet in height, but had only light browsing. Uniformly heavy browsing on all rows the second year reduced average sprout height to only 1-2 feet. The willow/alder wattles at site ST8B were located low in the unit on a northeast facing slope, but not adjacent to a stream. Though severely browsed, average sprout height remained consistently 0.5-1.5 feet, while sprout occurrence decreased from 76 percent to 58 percent the second year due to sprout die-back.

Sprouting of coyote brush wattles at three sites ranged from 70 to 90 percent. The bushy sprouts were 2-3 feet in height by the second year and bore little evidence of browse damage.

TABLE 11
Contract Vegetation Survival, October 1981

Treatment	Site	Quantity Planted		Quantity Living		Percent Survival
WATTLES						
Alder	R13	891 ft		20 sprouts		--
	J	100 ft		--[1]		--
Willow/Alder[2]	AB	228 ft		190 ft		83
	ST8B	183 ft		110 ft		60
Coyote brush	L23	60 ft		42 ft		70
	L24	46 ft		40 ft		87
	ST8C	163 ft		145 ft		89
TRANSPLANTS						
Alder	S3	20		19		95
	S5	20		20		100
	A1	66		54		82
	C1	18		14		78
	F	20		15		75
	J	9		8		89
	L	5		5		100
	subtotal	158	subtotal	135	average	88
Deerfern	A1	2		--[3]		--
	F	33		22		67
Salal	A1	13		--[3]		--
	F	55		31		56
	L	10		4		40
Rhododendron	F	28		9		32
Coyote brush	E	59		48		81
Bolander's rush	S10	4		4+		100
Common rush	S3	12		12		100
	J	10		10+		100
STEM CUTTINGS						
Willow	R2	45		43		96
	R4	169		106		63
	S8	54		40		74
	S10	4		4		100
	AB	115		38		33
	C1	15		11		73
	E	96		61		64
	F	10		2		20
	subtotal	508	subtotal	305	average	65
Coyote brush	R4	40		6		15
Salmonberry	R4	15		5		33
Whipplea	R4	40		12		30
Wax-myrtle	J	25		0		0

[1] Site J not sampled.
[2] Alder sprouts not included.
[3] Site A1 transplant area could not be relocated.

In summary the willow and coyote brush wattles sprouted fairly well at the Bond Creek unit. The wattles were well placed in suitably wet areas adjacent to an intermittent stream. Also, Bond is a relatively cool wet unit near old-growth. At other (1978), drier rehabilitation units however, sprouting and growth were much poorer (Reed and Hektner, 1981). Proper installation was time-consuming and essential to success (see Appendix B). Wattles were best restricted to readily sprouting species and wet areas such as stream banks. Alternative techniques such as direct seeding, transplanting and use of rooted and unrooted cuttings can be used to establish native species at far less cost. Since the same was true for wattles as an erosion control technique (i.e. mulches and ground covers were more cost-effective than wattles), the use of wattles as a rehabilitation technique was discontinued after 1979.

Transplants. The survival rate for most transplants was high (Table 11). The first year proved to be crucial, with little mortality occurring the second year. Alders had grown 2 - 12 feet by the second year after transplanting. Mortality was low except where the alders were completely browsed or severely trampled. Coyote brush transplant growth was not uniform. In the second survey, many coyote brush transplants were barely surviving while others had grown vigorously. The ferns appeared stressed the first year, but were becoming established by the second. Salal proved difficult to transplant. Although care was taken to retain a rootball, many were transplanted essentially "bare rhizome" and many fragile salal roots were damaged. Second years salal survival was 55 percent. Rhododendron had the lowest transplant survival, 30 percent. Some rhododendron transplants were still not well-established by the second year, but most were exhibiting new growth.

By the end of the first year, the individual rush transplants could not be distinguished in the continuous mass of rushes. It could not be determined whether transplants had grown to fill the area growing or if volunteers had invaded from nearby areas.

Transplanting is an excellent method for establishing native plants, especially when seed or plants are not commercially available. The maximum size found to be easily and properly transplanted by hand was 24 inches high.

Stem cuttings. The survival of stem cuttings showed greater variablity than either wattle sprouts or transplants. Average stem cutting survival varied from zero to 60 percent for the five species. No living wax-myrtle stem cuttings were found during post-rehabilitation surveys. Coyote brush survival was 15 percent. Browsing did not appear to have been a factor, but 40 percent of the coyote brush cuttings could not be located, either living or dead. No notations made during installation indicated any reason for low survival; however, the small number planted on only one worksite may not have been representative. Whipplea and salmonberry were planted at the same worksite as the coyote brush and showed 30 percent and 33 percent survival, respectively. Again, the small number of individuals on one site may not accurately reflect the potential for stem cutting survival. Willow cuttings had 60 percent survival. Browsing on willow was very heavy in most areas, but 1-2 feet of growth the second year was common for sprouts in streambank areas which were inaccessible to deer and elk.

Planting stem cuttings of sprouting species was successful and inexpensive where planting stock was locally abundant and the sites were sufficiently moist to prevent the cutting from drying out before rooting. Survival was further increased by rooting the cuttings prior to planting. Costs are higher, but rooted cuttings grown under contract could be produced at a reasonable price and the increased survival may outweigh the added cost.

Grass seeding and fertilization. Dense grass cover was obtained in most seeded areas by the spring following seeding, but patchy cover caused by seed wash was observed on some slopes. Ryegrass dominated the first year but was replaced by bentgrass the next year. Orchard grass and creeping red fescue constituted less than two percent of the cover by December 1987, even though they were 33 and 17 percent, respectively, by weight of the seed mix (Table 12). Orchard grass is a "slow starter" and does not become established until the second year (Markegard, personal communication). By the second year it was not able to compete with the aggressive bentgrass. Red fescue may not be a good competitor either, at least when used in a seed mix. It has since been seeded alone in coastal areas with good success. Both orchard grass and red fescue were deleted from seed mixes after 1979. Heavy browsing by deer and elk was common in grassed areas.

In certain areas, the contract specified that the seed be raked into the soil. However, raking was difficult because of locally frozen ground and no differences in grass cover were observed between raked and unraked areas.

Tree planting. Despite browsing, survival of both fertilized and unfertilized seedlings was 95 to 100 percent for two years in test plots set up on this unit. The surviving seedlings growing in good soil were bushy and healthy although browsing on seedlings in these plots was so heavy that height comparisons were inconclusive. Fertilized seedlings exhibited significant increase in girth, however. Use of fertilizer tablets with browse protection appears beneficial on rehabilitated roads where heavy ungulate use is anticipated.

Summary. There was dry, cold weather at the time of planting and the ground was frozen to a depth of several inches. Some treatments were apparently more susceptible to these conditions than others. Survival and growth of coyote brush wattles were much greater than for coyote brush stem cuttings. This was probably due to the added protection and greater numbers of branches in the buried wattle bundles. Coyote brush stem cutting survival (15 percent) was much lower than on the 1978 Lower Bond Creek rehabilitation unit (46 percent) located nearby (Reed and

TABLE 12

Grass Cover in Seeded Areas, December 1980

Site	Grass Cover (%)	---------Percent Cover by Species---------			
		Bentgrass	Ryegrass	Fescue	Orchardgrass
Outsloped Road, Area 3	95-100	98	2	<1	<1
Outsloped Road, Area 1	95-100	90-95	2-4	0	0
R5-R6, Contour Trenches	90-95	90	10	0	0
AB, Wooded Terraces	60[1]	90	10	0	0
A1, Wooded Terraces	90-100	99	1	0	0
C	90-95	95	5	0	0
I	95-100	90-95	5-10	0	0
ST1	70[2]	90	10	0	0
ST2	50[2]	90	10	0	0
ST3	75[3]	99	1	0	0
ST4	90	99	1	0	0
ST5	95-100	98	<1	1-2	0
ST6	90-100	99	<1	0	0

[1] Patchy grass distribution varying from 10-100 percent, mainly concentrated on terraces with less on slopes between terraces.
[2] Average; grass cover varied from 25 - 100 percent.
[3] Average; grass cover varied from 50 - 100 percent.

Hektner, 1981). The 1978 cuttings were installed during much wetter and milder weather conditions. Transplanting was also more difficult in frozen ground.

Little change was noted in vegetation survival three years after rehabilitation. The most striking changes were in the growth of transplanted alders and in the amount of natural revegetation (Figure 14). Many transplanted alders were over 15 feet tall, while naturally seeded alders averaged five feet. Fewer alders and other naturally colonizing trees and shrubs were found in heavily grassed areas. Hundreds of volunteer hemlock, Douglas-fir, western red cedar, salal and coyote brush seedlings were growing on the rehabilitated road where little natural vegetation existed before rehabilitation.

IV. BRIDGE CREEK REHABILITATION UNIT 79-2

A. Unit Description

The 50 acre Bridge Creek rehabilitation unit 79-2 consisted of a 1.3 mile segment of the M-7-5-1 road, an all-season logging road located on the east side of the Bridge Creek drainage (Figure 1). The unit was underlain by well-foliated sheared schists of the Franciscan Assemblage.

Slopes were steep, averaging over 50 percent. Stream channels were generally well incised, and stream sideslopes greater than 100 percent were common. The elevation of the treated road averaged 1,200 feet MSL while the elevation of Bridge Creek at the base of the unit ranged from 550 to 700 feet.

Much of the unit is mantled by deep colluvium. Soils formed in the colluvium are mostly in the Coppercreek (Tentative new series, correlated by SCS in 1984. See Popenoe 1984). and Devilscreek series. Surface textures are gravelly loams or light clay loams with 15 to 35 percent gravel and pH 5-6. The Coppercreek soils are well-drained, the Devilscreek soils moderately well to somewhat poorly drained. Both of these soils have a high gully erosion hazard when disturbed due to their lack of cohesion, moderate coarse fragment content and relatively small coarse fragment size. Numerous debris flows have occurred in the Devilscreek soils due to the incompetence of the underlying bedrock and frequent, elevated porewater pressures in wet swales where Devilscreek soils are found. The mass erosion hazard is much less in drier topographic positions where Coppercreek soils are found.

The M-7-5-1 road was being constructed by Louisiana-Pacific Corporation when the park was expanded in March 1978. Road crews had just completed construction of a large stream crossing when work was stopped in Fall 1977. Several old-growth redwoods had been felled in preparation for road construction and still remained on the slope beyond the last completed stream crossing at the time of park expansion. Two areas below the road had been logged and cable yarded, one in 1978 and the other during 1977 and 1978 (Figure 19).

All active erosion problems within this unit were associated with the M-7-5-1 road (Figure 20). No significant erosion was noted on the cable clearcuts. Problems included erosion of roadfill (Figure 21); accelerated movement of wet, naturally unstable hillslopes undercut by road construction; mass failure of road and landing fill material (Figure 22) and minor gullying resulting from concentrated inboard ditch flow culverted onto roadfill or bare soil areas on the slope below the road (Figure 23). All of these erosion problems would have been much more severe had the area experienced average or above average rainfall during the two years between road construction and rehabilitation.

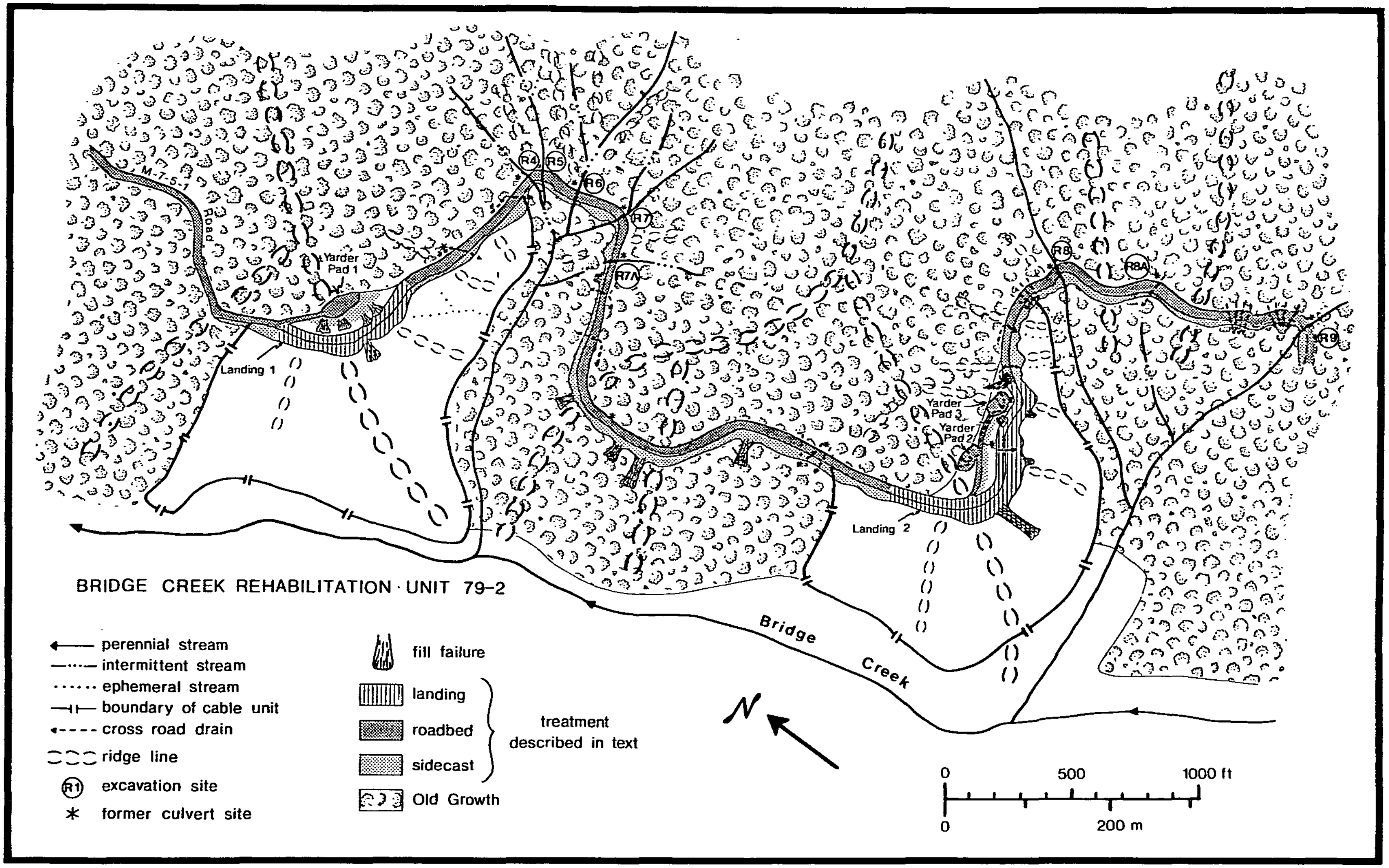
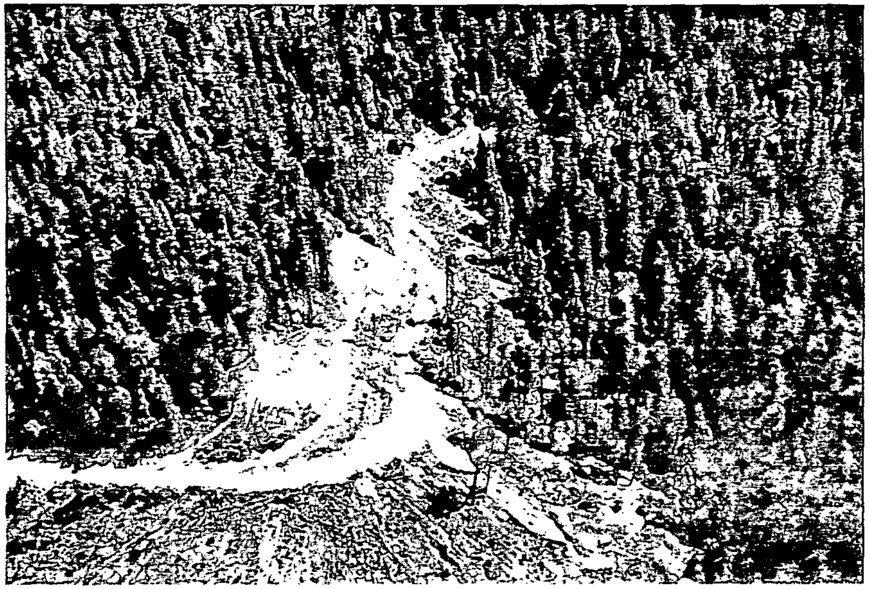
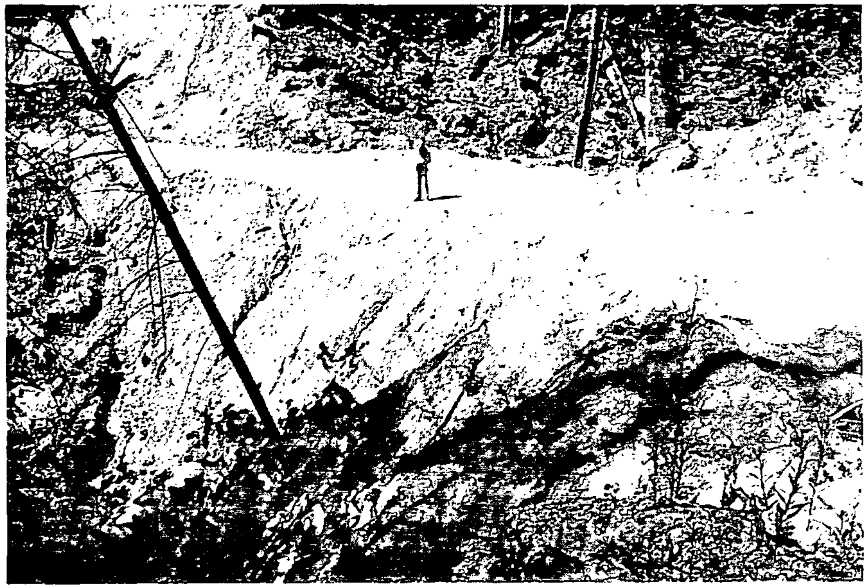


Fig. 19. Bridge Creek rehabilitation unit 79-2.





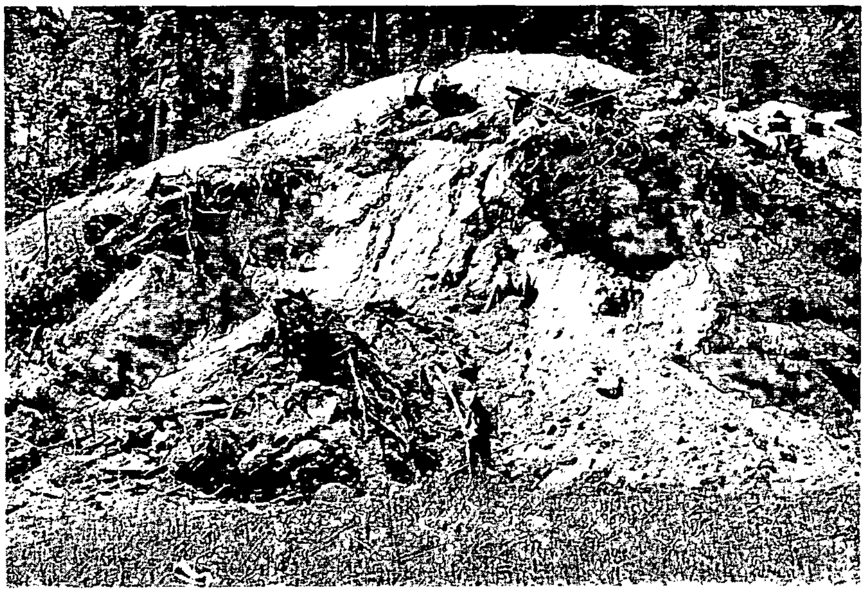


Fig. 20 (above left). Oblique aerial photograph of the M-7-5-1 road, landing 2 and the two yarder pads.

Fig. 21 (above). Gullied fill slope on a stream crossing site, M-7-5-1 road, prior to rehabilitation work.

Fig. 22 (left). Unstable, slumping cutbank on the M-7-5-1 road.

Fig. 23. Alluvial fan created by runoff from improperly drained yarder pad above the M-7-5-1 road.

Site conditions favored rapid revegetation. Redwood, Douglas-fir, tanoak and hemlock surround the road. Alder was present in the clearcuts and along Bridge Creek. Understory vegetation was intact in many areas and included rhododendron, huckleberry, wax-myrtle and ferns.

B. Work Sequence

Geomorphic mapping and prescriptions for heavy equipment work required about three weeks in May and June 1979. Heavy equipment work was performed between August 9 and October 17, 1979. Labor intensive erosion control was completed by park staff between October 29 and November 29, 1979. Park staff also completed most revegetation treatments in November 1979 and March 1980. Redwoods United, Inc. crews planted conifer seedings in late January 1980.

C. Monitoring and Documentation

Documentation and monitoring of physical changes included permanent photo points, repeated field visits for qualitative observations, installation of two sediment troughs (Figure 24), establishment of erosion pin grids and measurement of thalweg profiles and cross-sections on excavated stream crossings. Horizontal erosion pins were installed to measure changes in steep, excavated banks of stream crossing R6. Slope treatment plots were established at Landing 1 to examine the effectiveness of various treatments in controlling rilling on freshly disturbed surfaces.

Revegetation treatments were monitored and photographed in June 1981 and May 1983. Grass cover, invasion by naturally seeded vegetation, survival of trees and other planted vegetation was noted for road treatments.

Fig. 24. Sediment trough erosion plots installed on the steep right bank of excavated stream crossing R7. The 10' x 25' plots were established to monitor sediment yield from untreated side slopes at stream crossings. Sediment accumulated in the 1' x 1' x 10' sediment trough while runoff was funneled to 50 gallon drums, and later a large tipping bucket, for measurement.

D. Heavy Equipment Work

Following completion of heavy equipment work at Bond Creek, unit 79-1, most of the equipment was moved to Bridge Creek. Table 13 lists the equipment used to accomplish the following tasks: 1) salvage of commercial timber and tanoak from the road alignment, 2) removal of debris and complete outsloping of two landings, 3) excavation of fill material from seven stream crossings, 4) placement of rock armor at four stream channel excavations, 5) outsloping 1.2 miles of the M-7-5-1 road and 6) minor outsloping of three yarder pads.

Other heavy equipment costs incurred were for road maintenance and equipment transport costs, loading and transporting of culverts to a storage area and transport of supplies (boards, straw, seed and fertilizer) for labor intensive treatments (Table 14). Total cost for equipment work was $159,300.

TABLE 13

Description and Hourly Rates of Heavy Equipment, 79-2

Equipment Description	Cost/Hour[1]
22B Bucyrus Erie Crane with oiler	$85.00
Case 580B Extendahoe (backhoe)	32.50
D5 Caterpillar crawler tractor with winch	45.00
D6 Caterpillar crawler tractor with winch	54.30
D8 Caterpillar crawler tractor with winch	45.00
D8 Caterpillar crawler tractor with winch	80.00
950 Caterpillar loader	47.80
12 Caterpillar road grader	35.30
Six dump trucks, 10 yd^3	29.51
Water truck, 4,000 gallon	30.00
Short logging truck	29.51

[1]Includes operator

TABLE 14

Summary of Heavy Equipment and Labor Intensive Costs, 79-2

Heavy Equipment Treatments	Costs
M-7-5-1 Road Removal	
Timber Salvage	$ 26,411
Landing Removal (2)	
Debris Removal	54,594
Outsloping	16,392
Stream Crossing Excavations (7)	36,520
Rock Armoring of Stream Crossing Excavations (4)	5,139
M-7-5-1 Road Outsloping (1.2 miles)	10,939
Yarder Pad Outsloping (3)	3,363
subtotal	$ 153,358
Miscellaneous	
Road Maintenance during Rehabilitation	530
Transport of Culverts and Erosion Control Supplies	3,474
Equipment Transportation from Eureka/Arcata	1,924
subtotal	5,928
TOTAL HEAVY EQUIPMENT COSTS	$ 159,286

Labor Intensive Treatments	Costs
Stream Channel Protection	$ 1,212
Stabilizing Drains and Gullies	196
Treatments for Surface Erosion Control[1]	1,049
Combined Treatments for Surface Erosion Control and Revegetation[2]	2,049
Revegetation, Tree Planting	2,958
TOTAL LABOR INTENSIVE COSTS	$ 7,464
TOTAL COST FOR REHABILITATION TREATMENTS	$ 166,750

[1]Does not include cost of straw, jute netting or chips.
[2]Includes cost of grass seed, fertilizer and straw.

Approximately 140,000 board-feet (b.f.) of commercial timber (75 percent redwood and 25 percent Douglas-fir) and 30,000 b.f. of tanoak were salvaged at a cost of $16,200 and $10,200, respectively. About 65 percent of the commercial timber was salvaged from the hillslope directly beyond the last stream crossing. The remainder was salvaged from stream crossings and the M-7-5-1 roadside. A small amount of the redwood salvage was milled on-site for use in checkdams and ravel catchers. The rest was removed for use elsewhere in the park. Tanoak was salvaged from the yarder pads, landings and along the road. All four crawler tractors, a loader, grader, logging truck and four dump trucks were used during timber salvage.

Seventy-one thousand dollars was spent to remove potentially unstable sidecast fill and organic debris and outslope two landings. The fill material contained large amounts of logs and woody debris (slash and bark) mixed with soil, which would have rotted and failed. The unstable fill was excavated with a dragline crane equipped with a clamshell bucket, loaded into dump trucks and end-hauled 4.5 miles to a stable log deck. Debris removal costs were $54,600 or 77 percent of the total cost of landing treatment. Equipment standby costs totalled $4,500 or 8 percent of the debris removal costs. End-hauling costs (dump trucks, grader and water truck) were $28,000 or 51 percent of the debris removal costs.

Outsloping the two cleared landings was performed by dragline crane, loader and D-6 crawler tractor. Material excavated by the crane was locally placed and shaped into an outsloped surface by the D-6 crawler tractor and the remaining organic debris was handled by the loader (Figure 25). Total cost for outsloping was $16,400 (Table 15). Of this, standby costs of $4,500 (27 percent) were incurred because the loader and tractor could handle material faster than the crane.

Excavation cost for seven stream crossings (Figure 19) was $36,500 (Table 16). Fill removed from crossings ranged from 30 to 2,000 cubic yards and totalled approximately 5,900 cubic yards (Figure 26). As at Bond Creek, the crane excavated most of the fill material with finishing work done by backhoe. The smallest crossing (R5) was treated entirely by backhoe. Standby costs during stream crossing excavations ($8,000) accounted for 22 percent of the total excavation cost. Unit excavation costs averaged $6.20 per cubic yard ($4.90 without standby costs) but ranged from $3.23 to $7.23 per cubic yard. Fill from four crossings had to be end-hauled, inflating the average unit cost for excavation.

Four stream crossings (R4, R5, R6 and R8) were armored with large rock to protect against subsequent erosion (Figure 27). A total of 160 cubic yards of rock was placed by heavy equipment in the excavated stream channels at a unit cost of $32.10 per cubic yard (Table 17). This cost reflects rock gathering and loading by the loader, transport to the stream crossing by dump truck and placement by crane or backhoe. Most of the rock (145 cubic yards) was placed in the two larger excavations (R6 and R8).

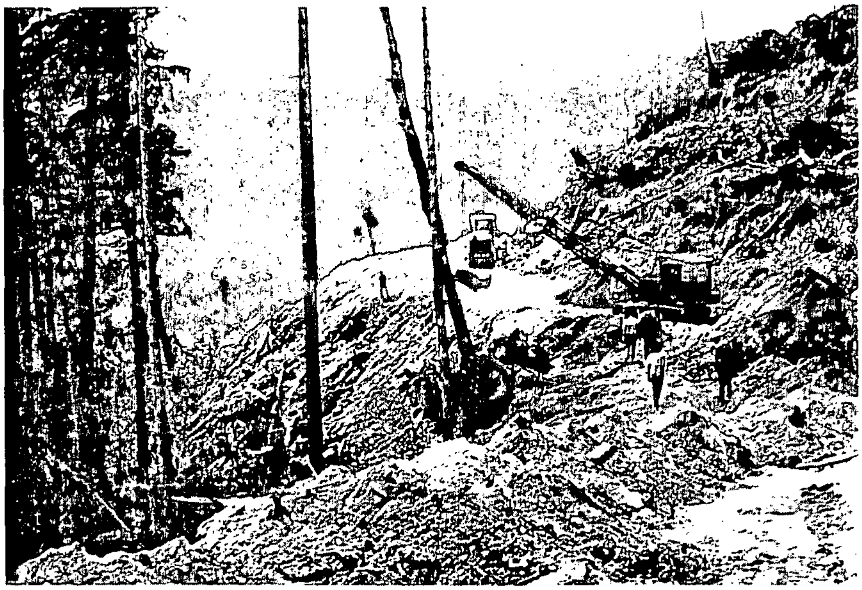


Fig. 25. Initial stages of outsloping on a segment of the M-7-5-1 road using a dragline crane and D-6 crawler tractor.

TABLE 15

M-7-5-1 Landing Removal Costs

Equipment	Hours		Costs
Debris Removal and End Hauling[1]			
Crane	167		$ 14,195
D6 Crawler Tractor	137		7,439
Loader	87		4,159
Grader	56		1,977
Dump Trucks	758		22,354
Water Truck	149		4,470
		subtotal	$ 54,594
Outsloping[2]			
Crane	100		8,458
D6 Crawler Tractor	85		4,588
Loader	70		3,346
		subtotal	$ 16,392
TOTAL LANDING REMOVAL COST			$ 70,986

[1]Includes removal of slash and debris from two landings, end-hauling and road maintenance.
[2]Includes outsloping two landings which had slash and debris removed.

TABLE 16

Stream Crossing Excavation Costs For M-7-5-1 Road

Equipment

Stream Crossing Work Site	Crane Hours	Crane Cost	D-6 Tractor Hours	D-6 Tractor Cost	Loader Hours	Loader Cost	Grader Hours	Grader Cost	Backhoe Hours	Backhoe Cost	Dump Trucks Hours	Dump Trucks Cost	Water Truck Hours	Water Truck Cost	Excavated Volume[1] (yd^3)	Total Cost	Unit Cost ($\$/yd^3$)
R9	43	$3,655	33	$1,792	43	$2,055	6	$212	10	$325	117	$3,438	4	$120	1,950	$11,597	5.95
R8	22	1,870	5	272	---	---	1	35	5	163	68	2,006	---	---	755	4,346	5.76
R7A	12	1,020	5	272	---	---	---	---	---	---	---	---	---	---	400	1,292	3.23
R7	33	2,805	20	1,086	50	2,390	8	282	4	130	67	1,977	---	---	1,200	8,670	7.23
R6	48	4,080	21	1,140	46	2,199	5	177	5	162	68	2,007	---	---	1,350	9,765	7.23
R5	---	---	---	---	---	---	---	---	6	195	---	---	---	---	30	195	6.50
R4	4	340	4	217	---	---	---	---	3	98	---	---	---	---	200	655	3.28
Total	162	$13,770	88	$4,779	139	$6,644	20	$706	33	$1,073	320	$9,428	4	$120	5,885	$36,520	6.21

[1]Volume determined by tape and clinometer measurement of excavated void.

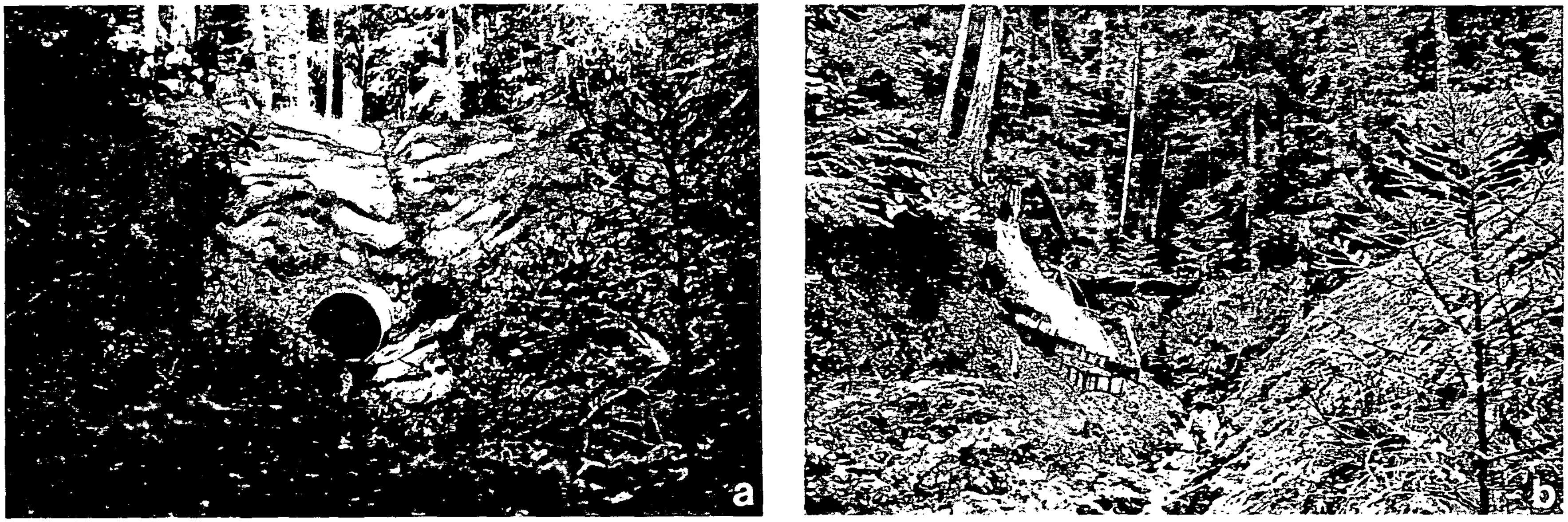


Fig. 26 (above). Excavation of stream crossing R9 at the end of the M-7-5-1 road. The fill material was primarily excavated by dragline crane. To complete the work, a backhoe was lowered to the channel bottom to finish detailed work on the stream bed. A) before treatment, (May 1979), and B) after excavation, (January 1980).

Fig. 27 (left). Heavy rock armor placed in the channel thalweg of excavated stream crossing R8. This treatment prevented subsequent erosion of the unexcavated material that still remained after heavy equipment work (July 1982).

TABLE 17

Armoring Excavated Stream Crossings, 79-2

Stream Crossing Worksite	Equipment								Rock Volume(yd^3)	Total Cost[1]	Unit Cost ($\$/yd^3$)
	Crane		Loader		Dump Truck		Backhoe				
	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost			
R8	9	$765	15	$717	20	$590	---	---	80	$2,072	25.90
R6	8	680	25	1,195	24	708	---	---	65	2,583	39.74
R5	---	---	---	---	---	---	5	163	5	163	32.60
R4	---	---	4	191	---	---	4	130	10	321	32.10
	17	$1,445	44	$2,103	44	$1,298	9	$293	160	$5,139	32.12

[1]Included quarrying, transportation and placement of rock.

Approximately 1.2 miles of the M-7-5-1 road were slightly outsloped (Figure 28) and cross-road drained by the D-6 crawler tractor and backhoe for $9,100 (Table 18), representing a unit cost of $7,600 per mile. A dragline crane outsloped another 0.02 miles or 105 feet for $1,800. Most of the road outsloping was accomplished by a crawler tractor. A backhoe was used for culvert removal, construction of cross-road drains and to pull back the outboard edge of the road at locations where it was awkward for the tractor to operate. The crane retrieved large concentrations of sidecast material to realign stream courses and remove culverts deeply placed in the road prism.

Three yarder pads were ripped, outsloped and drained by the crawler tractor and backhoe (Figure 29) for $3,400. A ditch system installed between pads 2 and 3 and outsloping of approximately 0.2 miles of access road is included in the cost.

E. Evaluation of Heavy Equipment Work

Heavy equipment removed the M-7-5-1 road and minimized potential sediment sources, but inflated costs due to excessive standby time, and landing removal and end-hauling reduced cost-effectiveness. Ninety-five percent of the $21,650 standby cost was attributed to the D-6 crawler tractor and loader (Table 19). This emphasizes the need to hire certain pieces of equipment on "engine time only" and to plan treatments which maximize equipment efficiency.

The most expensive and least cost-effective treatments were removal of fill and debris and outsloping landings (Figure 30). These totalled 45 percent of heavy equipment costs (Table 14). Without treatment, much of the landing fill would have failed, but only a portion of this material would probably have directly entered stream channels. Most of the failed material would have been deposited on hillslope benches below the landings (Figure 20). A more cost-effective treatment would have been to excavate fill material in the headwater regions of streams located below the landings and to provide a slightly outsloped surface to drain the remainder of each landing. Based on more recent rehabilitation work, a similar treatment, utilizing a crane or loader and large crawler tractor, would probably have cost about $5,000 for each landing.

Excluding standby costs, the treatments (excavation by crane and end-hauling by dump truck) for stream crossings R6, R7 and R9 were appropriate and cost-effective. Unit costs for these excavations do not significantly vary from similar sized excavations which were end-hauled during 1982. Modifications resulting in some savings could have been made for the treatment of stream crossings R4, R5, R7A and R8. End-hauling was not necessary at crossing R8 and much of this excavation could have been accomplished by a crawler tractor at a lower cost. Also, greater use of a crawler tractor in place of a crane or backhoe would have resulted in lower costs at R4, R5 and R7A.

Salvage of tanoak had minimal benefits for the cost incurred and could have been deleted.

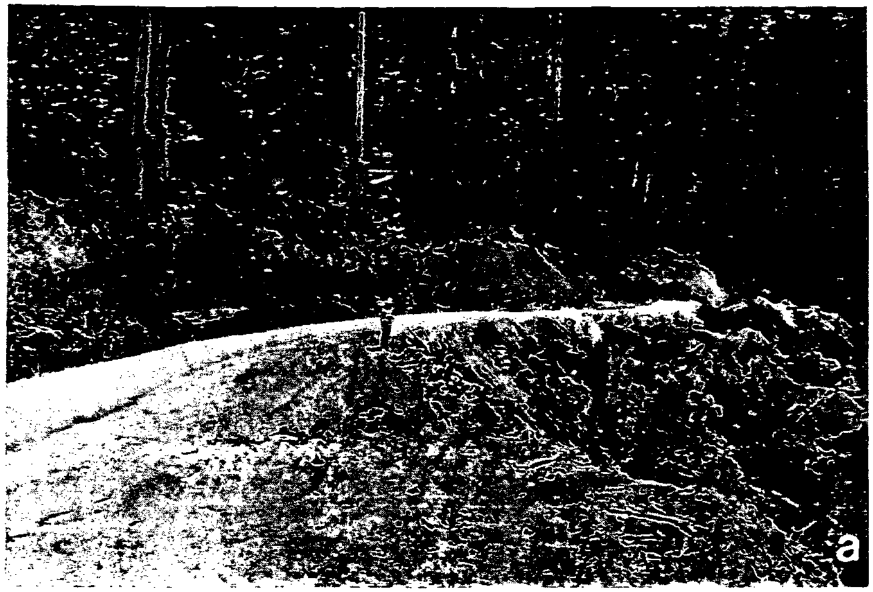


Fig. 28. Slight outsloping of a segment of the M-7-5-1 road. This was the most common type of treatment applied to logging roads on this unit. A) before outsloping (June 1979); B) after outsloping and application of straw mulch (January 1980); C) natural invasion of alder (June 1981).

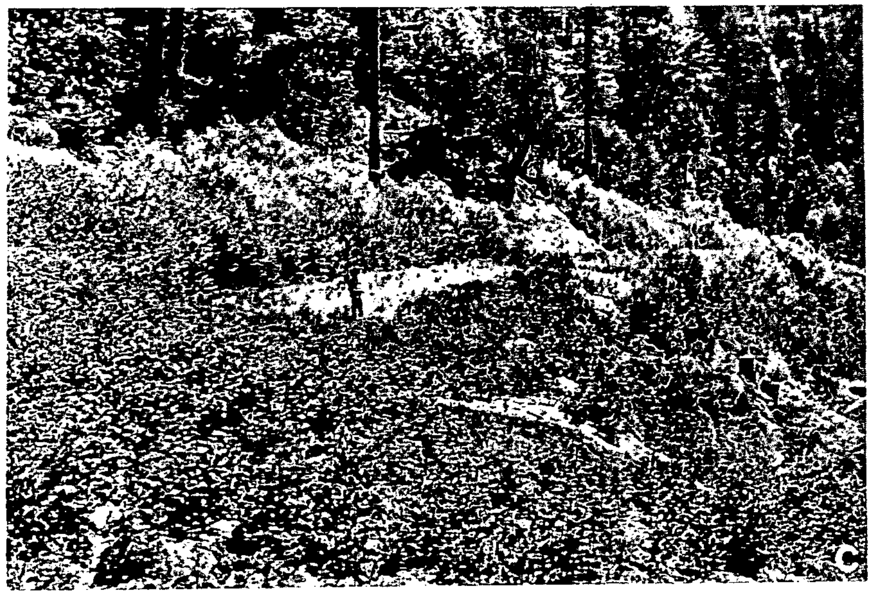


TABLE 18

Outsloping Costs for the M-7-5-1 Road and Yarder Pads

Equipment	Hours		Cost
M-7-5-1 Road Outsloping[1]			
Crane	21		$ 1,785
D6 Crawler Tractor	80		4,344
Extendahoe	148		4,810
		subtotal	10,939
Yarder Pad Outsloping[2]			
D6 Crawler Tractor	35		1,900
Extendahoe	45		1,463
		subtotal	3,363
		TOTAL OUTSLOPING COST	$ 14,302

[1]Includes outsloping approximately 1.2 miles of road surface and placement of cross-road drains.
[2]Includes outsloping Yarder Pads 1, 2, 3, and access roads to the pads and the placement of drains on Pads 2 and 3.

As learned in later years, most of the road outsloping and yarder pad treatment could have been accomplished with a large crawler tractor (D-8 size) in place of the crane and small tractor. This would have resulted in some savings. However, because the D-6 tractor was already on-site for other tasks, overall costs were not excessive.

Rock armoring stream crossing excavations by heavy equipment was experimental. Three of the armored stream crossings (R4, R5 and R8) have experienced little, if any, erosion (<5 cubic yards each). Approximately 116 cubic yards have eroded from R6 since rehabilitation (Figure 31). This erosion resulted from flows which were deflected around the rock armor and into the unconsolidated material of the stream sidebank (Figure 32). Streamflow proceeded to downcut, leaving the rock armor stranded above the waterline (Figure 32B). Portions of the undercut sidebank slumped into the stream (Figure 33).

Most erosion at R6 could have been avoided by using more rock along the channel banks or by systematically placing the largest four-foot diameter boulders against the banks. When located near the channel bottom, these deflected water against the sidebanks and caused erosion. While their "random" placement was an intentional experiment, the large boulders were also difficult or impossible to reposition by manual labor during later attempts at corrective winter maintenance.

Two excavated stream crossings were left unprotected and allowed to stablize naturally. These crossings, R7A and R9, have each yielded about 55 cubic yards of sediment.

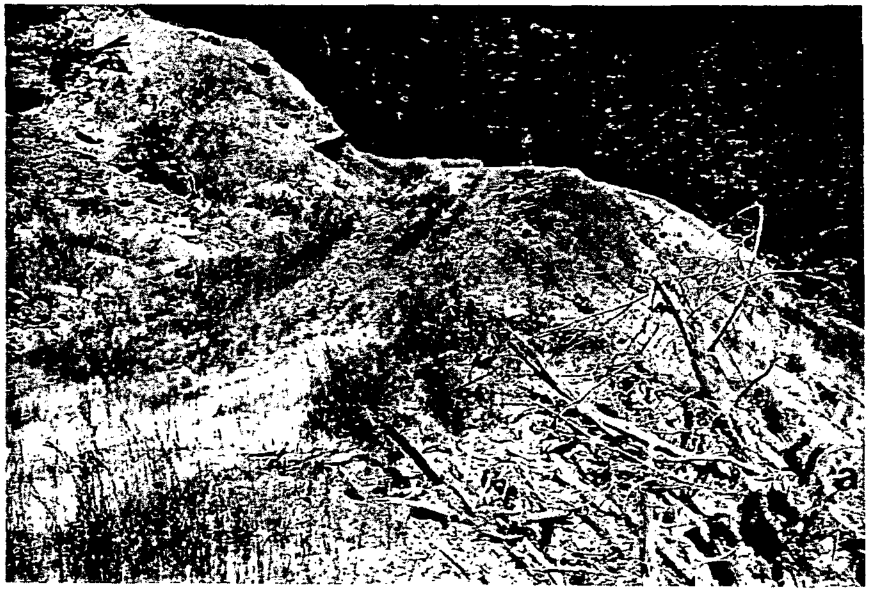


Fig. 29. Treated yarder pad above landing 2. A) before rehabilitation (note sparse revegetation) (June 1979); B) after outsloping and drainage improvements (January 1980); C) natural invasion of rushes and woody shrubs (August 1983).

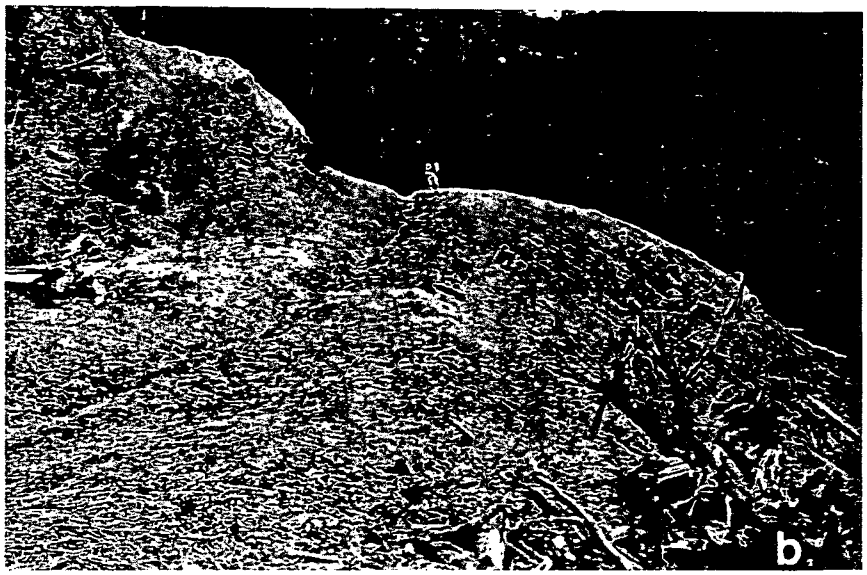


TABLE 19

Standby Costs For Heavy Equipment Treatments, 79-2

	Equipment								
	D6 Tractor		Loader		Backhoe		Dump Trucks		Total Standby
Treatment	Hours	Cost	Hours	Cost	Hours	Cost	Hours	Cost	Cost
Clearing Landings	53	$2,878	47	$2,247	---	---	---	---	$5,125
Outsloping Landings	40	2,172	56	2,677	---	---	---	---	4,849
Stream Crossing Excavations	33	1,792	122	5,832	---	---	12	$354	7,978
Rocking Channels	21	1,140	2	96	---	---	---	---	1,236
Yarder Pad Treatment	3	163	---	---	5	$162	---	---	325
Timber Salvage and Misc.	18	977	10	478	21	683	---	---	2,138
TOTALS	168	$9,122	237	$11,330	26	$845	12	$354	$21,651

Fig. 30. Serial photographs depicting the treatment and recovery of landing 2. Outsloping and debris removal along several portions of the M-7-5-1 road was expensive but resulted in reduced erosion and rapid revegetation. A) landing 2 before heavy equipment rehabilitation treatment (June 1979); B) after debris removal, outsloping and the natural invasion of alder seedlings approximately 3 years later (July 1982); C) roughly 4 years after treatment (August 1983).

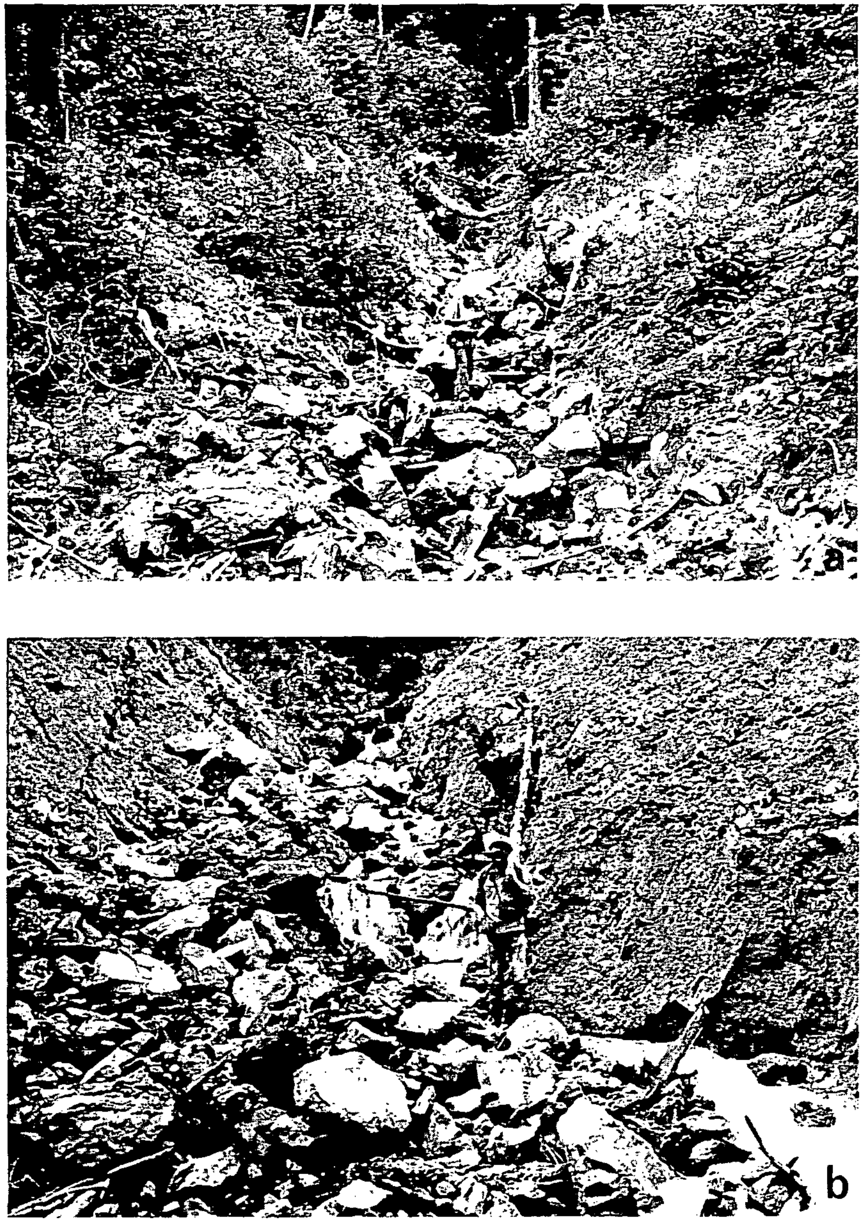


Fig. 31. Erosion of rock armored stream crossing R6. Sediment loss was caused by the presence of oversized rocks which diverted flow into and caused undercutting of the adjacent channel banks. Crossing R6 A) before heavy stream flows (October 1979) and B) after several winters (July 1982).

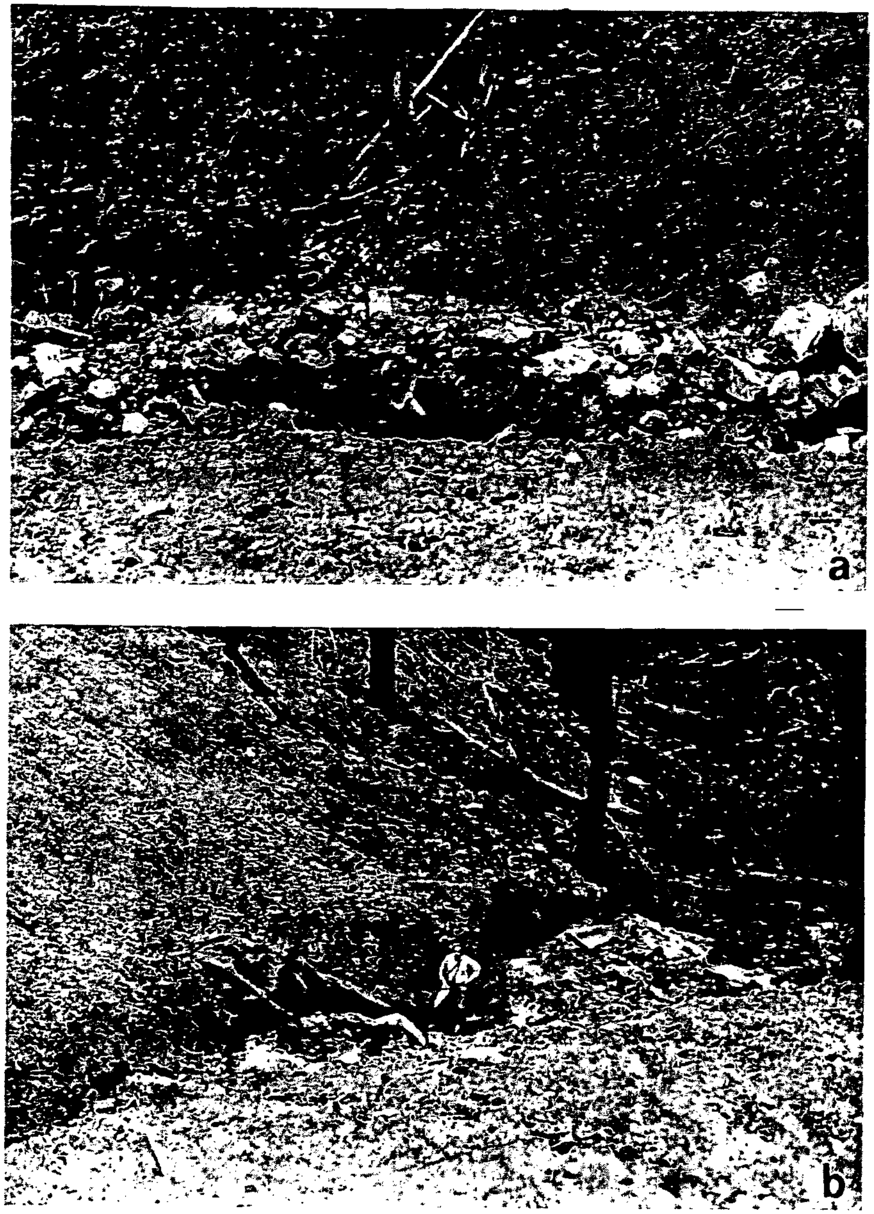


Fig. 32 (left). Excavated stream crossing R6. The two photos show views from A) top left edge of crossing, showing downcutting and terrace development along the right channel bank (rock armor is stranded above the new thalweg) and B) top right bank, showing consequent undercutting of the adjacent channel base. Photos taken October 1979.

Fig. 33 (below). Small landslide caused by deflection of streamflow around large rock armor, crossing R6 (October 1979).

F. Labor Intensive Work

The Bridge Creek area received nearly five inches of rain in 24 hours shortly after heavy equipment activities were completed. This resulted in numerous erosion problems. Heavy rilling occurred on several bare areas with moderately steep slopes (>45 percent). Two stream channels degraded and most of the spring and seep areas became active. The heavy rain intensified the need for immediate labor intensive erosion control work (Figure 34). Treatments were quickly performed to stablize eroding stream channels, arrest rilling and gullying and reestablish vegetation on freshly disturbed areas.

Fig. 34. Early winter rilling on the steep side slope of excavated stream crossing R7. Photo was taken prior to application of straw mulch and jute netting (October 1979).

1. Physical erosion control

Labor intensive treatments to control erosion in stream channels consisted primarily of checkdam construction at stream crossing R7 and the placement and adjustment of rock armor at stream crossings R6 and R8 and at one cross-road drain. At crossing R9, a ditch was dug to channelize flows from several high yield springs. Checkdams and a flume were constructed to protect this spring from gullying (Figure 35). Slash and rock checkdams were also constructed to stabilize small gullies draining yarder pads 2 and 3.

Fig. 35. Protection of a steep, rilled slope near crossing R9 using small checkdams and a flume with energy dissipater. In retrospect, this treatment was judged excessive for the comparatively small amount of runoff and erosion which would have occurred. As with this case, runoff volumes from treated areas and former springs are often difficult to predict.

Treatments for controlling erosion of bare soil surfaces included the application of straw mulch (2,000 pounds per acre) (Figure 36), straw (2,000 to 4,000 pounds per acre), covered with jute netting (Figure 37), grass seeding (50 pounds per acre), wood chip mulch (142 cubic yards per acre) and ravel catchers (Figure 38). Wood chips and ravel catchers were each used in only one location. Straw covered with jute, was applied only on slopes of crossings R7, R8 and R9 which already displayed severe rilling from early fall rains. The ground surface was raked smooth before applying the protective treatment to avoid enlargement of existing rills. Table 20 itemizes labor intensive physical treatments and costs.

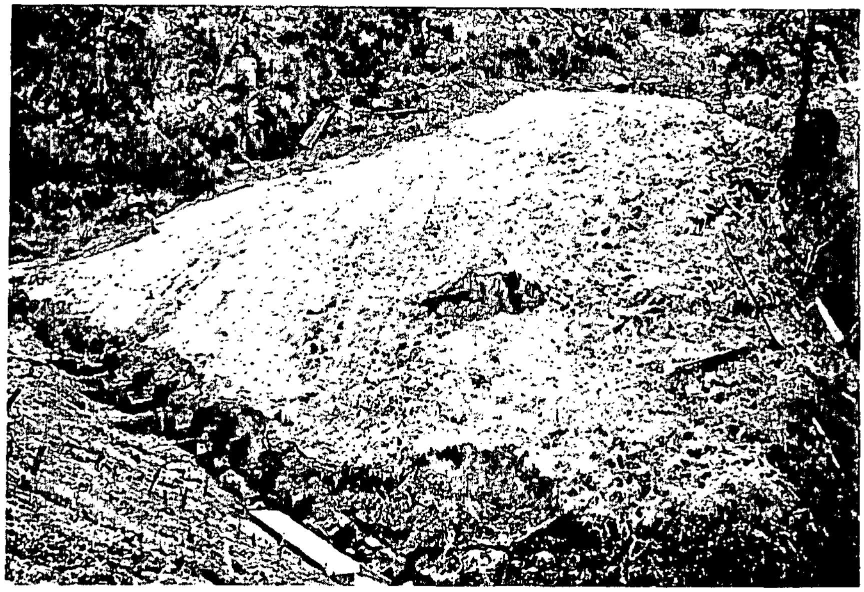


Fig. 36 (left). Surface erosion control on excavated stream crossing R7. The most cost-effective treatment for controlling surface erosion was the liberal application of straw mulch, secured by jute netting on slopes steeper than 70 percent. Photo shows same slope depicted in Figure 34.

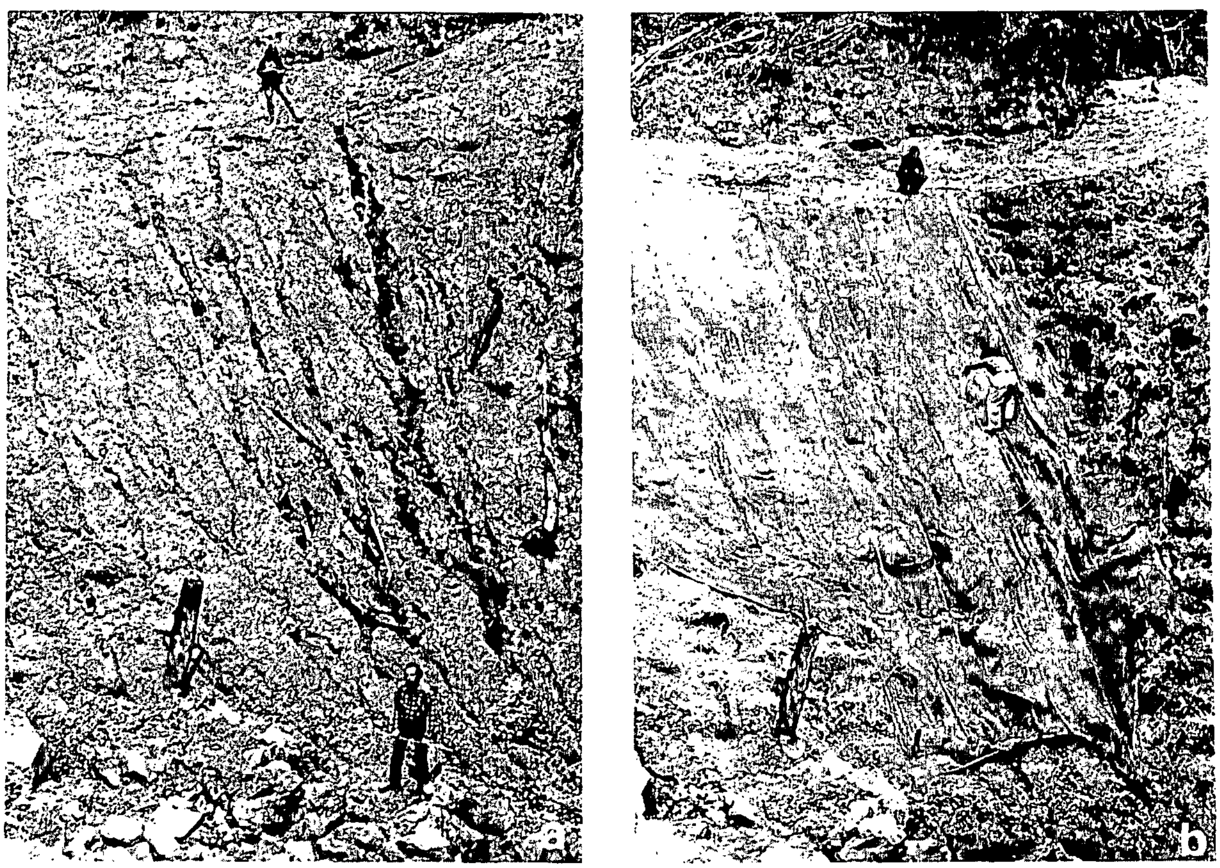


Fig. 37. Photos showing the left bank of excavated stream crossing 8A. A) after 5 inches of rainfall but prior to treatment for controlling surface erosion and B) during final stages of installation of jute netting over straw mulch. Once the original surface had rilled, it had to be manually raked (smoothed) before the jute and straw could be placed. No measureable erosion of the slope has since occurred.

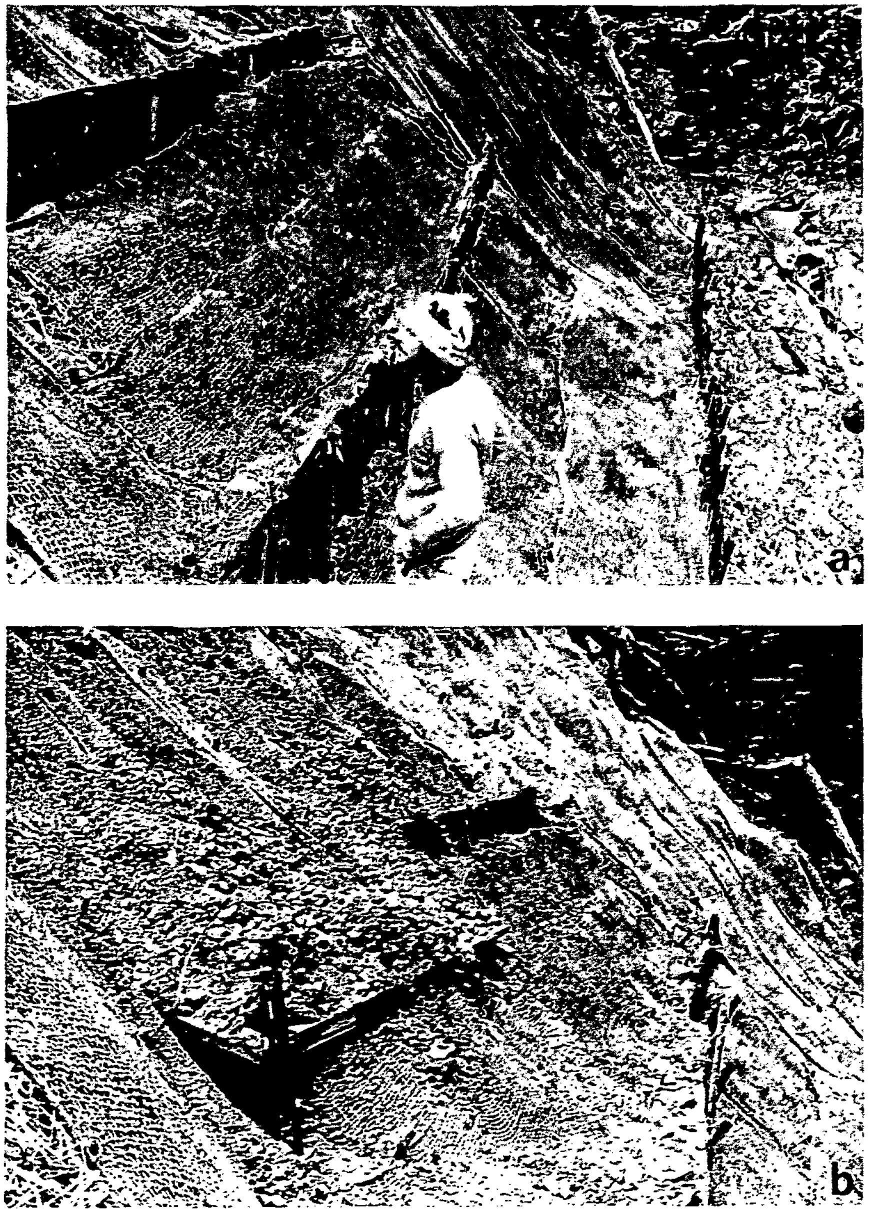


Fig. 38. Ravel catchers and jute-covered straw mulch on crossing R9. A) ravel catchers and jute-covered straw mulch were placed on the steep right bank of excavated stream crossing R9. B) following a small cutback failure on the former logging road at the top of the excavation, soil and rock passed over the jute (with no apparent damage) and either filled or toppled the ravel catchers.

TABLE 20

Labor Intensive Erosion Control Costs, 79-2

Description	Person-Hours	Quantity	Unit Cost ($)	Cost ($)
Transporting jute netting and straw[2]	32	n/a	n/a	$217[2]
Spreading straw[2]	80	4.88 ac 161 bales	$111/ac 3.37/bale	542[2]
Spreading straw and securing with jute netting[2]	80	0.16 ac	3,385/ac	542[2]
Spreading wood chips[2]	50	0.56 ac	604/ac	338[2]
Constructing ravel catchers (R9)[1,3]	25	132 ft	1.28 ft	169
Constructing checkdams: R7 (13 dams)[1,3]	48	13	25.00	325
R9 (35 dams)[1,3]	96	35	18.60	650
Constructing water flume (R9)[1,3]	8	1	54.16	54
Constructing slash checkdams in gullied drains (Yarder Pads 2 & 3)[3]	21	12	11.84	142
Rock placement and adjustment in stream channels[3]	35	n/a	n/a	237
Digging ditches[3]	6	2	20.31	41
Constructing trail[3]	20	n/a	n/a	134
TOTAL	501			$3,391

[1]Does not include price of materials.
[2]Does not include installation cost for slope treatment plots (Landing 1).
[3]Cost computed using average wage of workers (hydrologist, technician and laborer) at $6.77/hour.

2. Revegetation

Experimental treatments of grass seed, fertilizer and straw mulch were applied to most of the road surface in November 1979 (Figure 39 and Table 21). Grass seed and fertilizer were also applied at stream crossing excavations R7, R7A, R8 and R9. The RNP grass mixture was applied at 50 pounds per acre and 16-20-0 fertilizer was applied at 250 or 500 pounds per acre.

Over one-thousand willow stem cuttings were planted at 14 moist areas (Figure 40). Source for cuttings was near the Redwood Creek trailhead at Orick. On-site alder seedlings were transplanted at two sites. One-year old containerized alder seedlings grown by Simpson Timber Company were planted at R6 and R7. Twenty-six pounds of a grass/alder seed mixture were sown at stream crossings R4 and R7 in April 1980 (Figure 41). The grass/alder seed mixture was composed of 25 pounds "RNP mix" and one pound alder seed.

Redwoods United, Inc. labor crews planted 1,400 redwood and 2,600 Douglas-fir one-year old containerized seedlings on the road and landings. The seedlings were grown by Simpson Timber Company. Vegetation treatments and costs are given in Table 22.

G. Evaluation of Labor Intensive Work

1. Physical erosion control

The quality and cost of park-completed work compared favorably with contracted labor on other units. The main benefit of in-house labor was that all erosion control work was completed within a month after heavy equipment left the site, an impossible task had a contract been prepared for the site.

Checkdams initially stabilized watercourses. For example, during the October storms, stream crossing R7 downcut two to three feet (eroding 28 cubic yards) before encountering stable bed material. To avoid subsequent channel widening checkdams were installed in November 1979. Problems developed in 1981, however, when the spillway of one checkdam plugged with organic debris and the capacity of another was exceeded by high flows. Water scoured into the bank around these checkdams leaving one nonfunctional. Furthermore, high flows in December 1982, washed out the lowermost checkdam and caused the next dam above to become undermined and nonfunctional. Because this stream channel does not represent a large future sediment source, probably <50 cubic yards, the checkdams will not be repaired. Erosion at this worksite will continue to be monitored.

Checkdams installed on the drain at stream crossing R9 also became nonfunctional due to spillway plugging and scouring around the dams. Presently, water is flowing alongside most of the dams and does not constitute a serious erosion problem. In retrospect, the installation

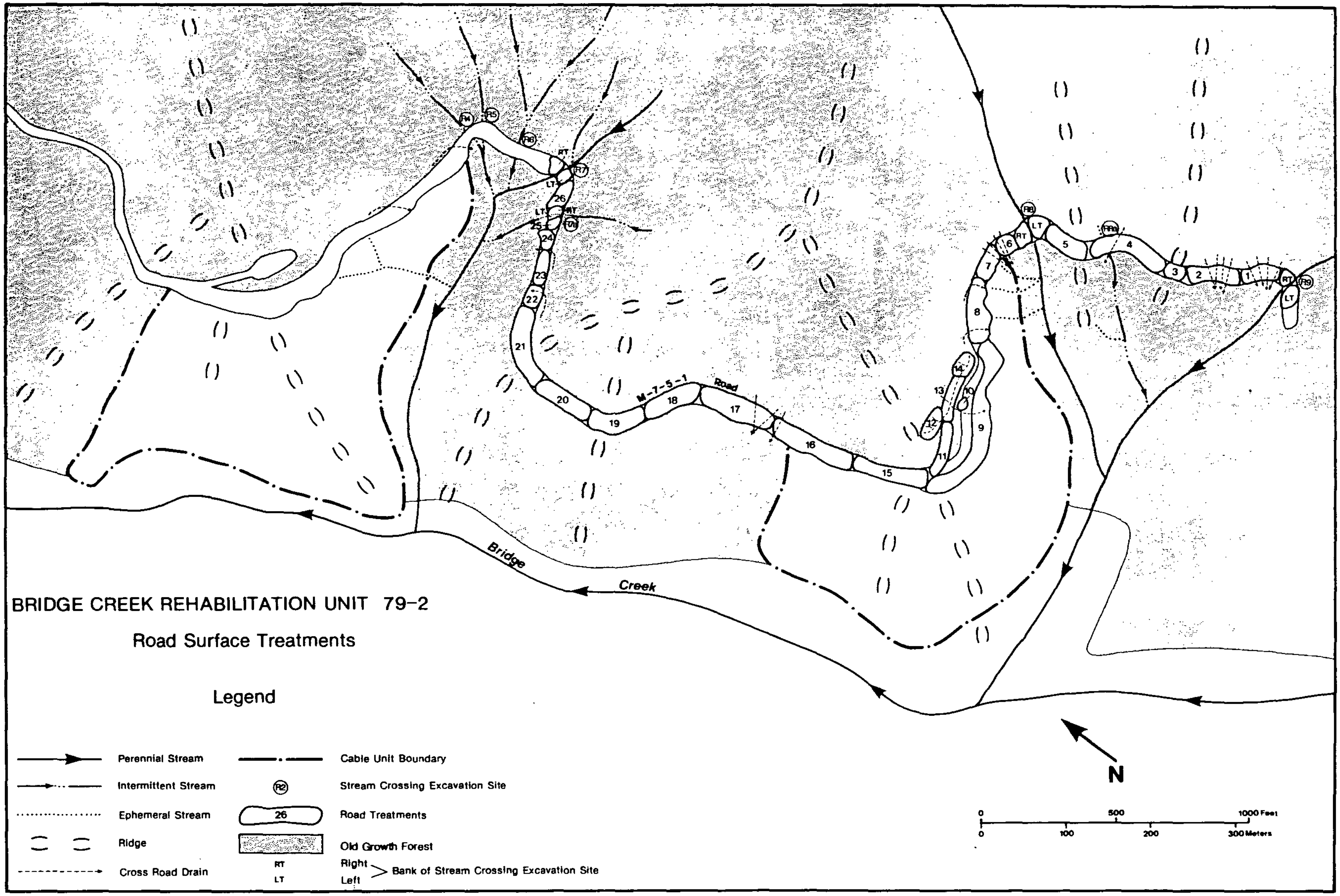


Fig. 39. Revegetation treatment plots established on the surface of the M-7-5-1 logging road following heavy equipment rehabilitation work. Surface treatments included grass, grass and fertilizer, straw mulch, wood chip mulch and untreated control plots (Table 21).

TABLE 21

Revegetation Treatments

Plot[1]	Treatment	Acres Treated	Grass Seed Rate (lb/ac)	Fertilizer Rate (lb/ac)	Mulch Rate (lb/ac)
1	grass & fertilizer	0.13	50	500	--
2	grass & fertilizer & straw	0.17	50	500	2,000
3	control	0.10	--	--	--
4	straw	0.48	--	--	2,000
5	control	0.29	--	-	--
6	straw	0.09	--	--	2,000
7	grass & fertilizer	0.13	50	500	--
8	grass & fertilizer & straw	0.20	50	500	2,000
9	straw	1.45	--	--	1,000
10	grass & fertilizer	0.03	50	500	--
11	straw	0.23	--	--	2,000
12	straw	0.22	--	--	2,000
13	straw	0.21	--	--	2,000
14	straw	0.26	--	--	2,000
15	chips	0.56	--	--	142yd^3/ac
16	control	0.40	--	--	--
17	grass & fertilizer & straw	0.58	50	250	2,000
18	straw	0.27	--	--	2,000
19	control	0.15	--	--	--
20	grass & fertilizer	0.28	50	500	--
21	straw	0.55	--	--	2,000
22	grass & fertilizer	0.28	50	500	--
23	control	0.21	--	--	--
24	grass	0.09	50	--	--
25	control	0.09	--	--	--
26	grass & straw	0.27	50	--	2,000

Crossing	Treatment	Acres Treated	Grass Seed Rate	Fertilizer Rate	Mulch Rate
R9 LB[2]	grass & fertilizer	0.11	50	500	4,000
R9 RB[3]	grass & fertilizer	0.06	50	500	4,000
R8 LB	grass & fertilizer	0.12	50	500	4,000
R8 RB	grass & fertilizer	0.05	50	500	4,000
R7A LB	grass & fertilizer	0.10	50	500	4,000
R7A RB	grass & fertilizer	0.02	50	500	4,000
R7 LB	grass & fertilizer	0.07	50	500	4,000
R7 RB	grass & fertilizer	0.07	50	500	4,000

[1] See Figure 39 for plot locations.
[2] LB = left stream bank.
[3] RB = right stream bank.

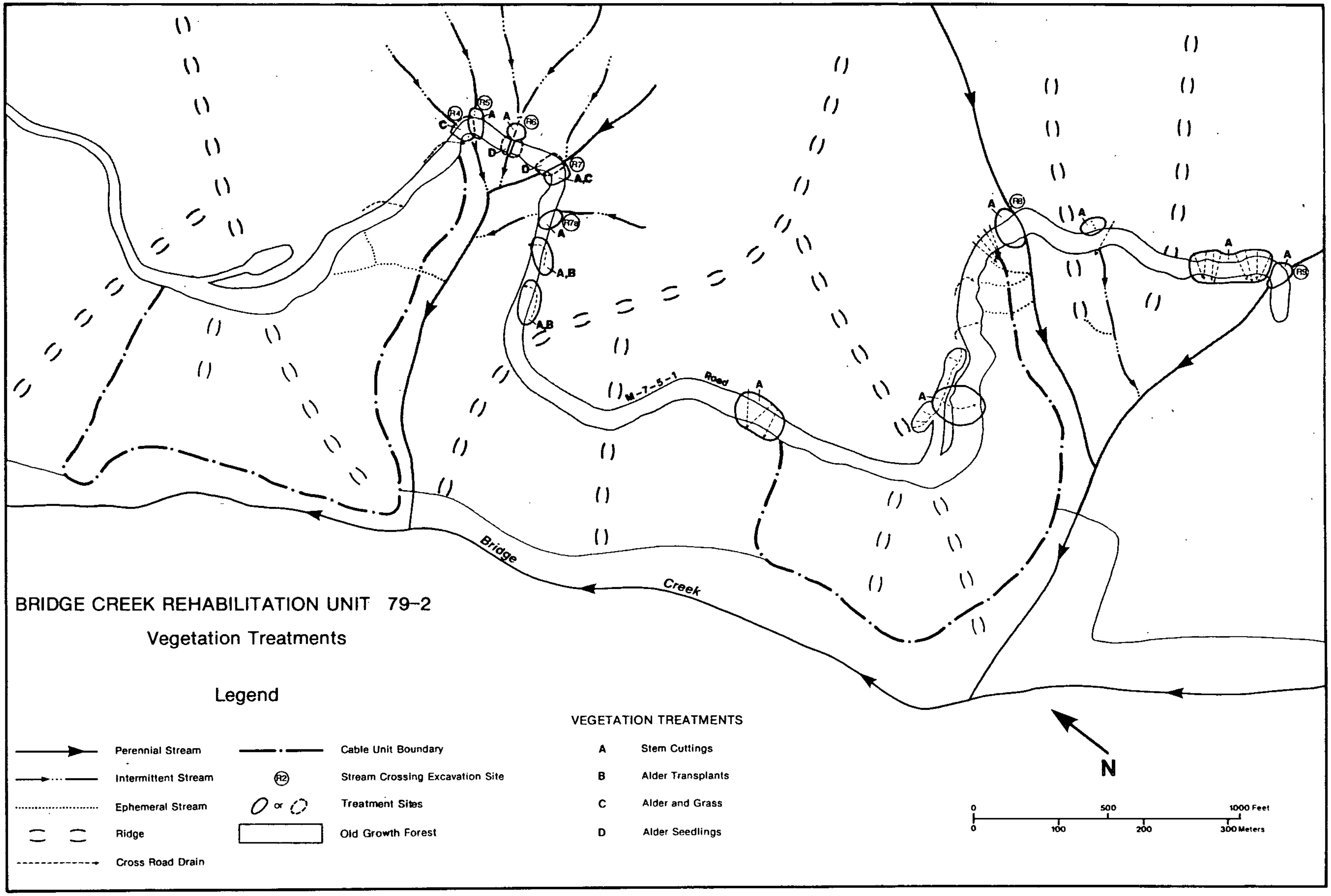


Fig. 40. Vegetation treatments, M-7-5-1 logging road.

Fig. 41. Alder and grass seed being hand spread at stream crossing R7.

of checkdams on this rehabilitation unit does not seem cost-effective, given the expense, the limited amount of erosion prevented and the short lifespan of these structures.

Treatments to control surface erosion included straw mulch, straw mulch covered by jute netting and wood chip mulch. Five (20 foot by 50 foot) side-by-side slope treatment plots were established to compare the effectiveness of these treatments to control rilling (Figure 42). In order of decreasing effectiveness the treatments were: straw mulch (8,000 pounds per acre) covered by jute netting; straw mulch (9,000 pounds per acre) punched into the ground surface with a shovel; straw mulch (9,000 pounds per acre); wood chips (305 cubic yards per acre) and no treatment.

The plots were established on an outsloped section of Landing 1 which had rilled severely during early rains in October and November 1979. After the plot boundaries were established, five equally spaced cross sections were surveyed across each plot and the volume of rill erosion was calculated. The plots were then raked smooth, erosion control treatments applied and each cross section resurveyed. Subsequent cross section surveys were made to measure post-treatment rill erosion following the winters of 1979-1980 and 1980-1981.

The control plot (#2) lost 134 cubic feet of soil to rill erosion before any control treatments were applied (Table 23). By Summer 1980, after the control plot had been raked smooth and remained unprotected for one

TABLE 22

Revegetation Costs

Treatment	Quantity	Labor Cost	Materials Unit price	Materials Cost	Total Cost	Total Unit Cost
ROAD SURFACES						
RNP Grass Mix	90.5 lb	$37.11[1]	$1.20/lb	$108.24	$145.35	1.61/lb
Fertilizer	580 lb	301.60[1]	0.12/lb	69.02	370.62	0.64/lb
Straw	161 bales	542.00[1]	3.10/bale	499.10	1,041.10	6.47/bale
Douglas-fir	2,600	938.19	0.10 ea.	260.00	1,198.19	0.46 ea.
Redwood	1,400	505.18	0.10 ea.	140.00	645.18	0.46 ea.
Subtotal		$2,324.08		$1,076.36	$3,400.44	
STREAM CROSSINGS						
RNP Grass Mix	30 lb	12.30[1]	1.20/lb	35.88	48.18	1.61/lb
Fertilizer	289 lb	150.28[1]	0.10/lb	34.39	184.67	0.64/lb
Straw	40 bales[2]	134.66[1]	3.10/bale	124.00	258.66	6.47/bale
Willow Stem Cuttings	1,000[3]	500.00[4]	--	--	500.00	0.50 ea.
Alder Transplants	24	12.00	--	--	12.00	0.50 ea.
Alder/Grass Seeding	52 lb	52.00	3.84/lb	199.78	251.78	4.84/lb
Alder Seedlings	405	300.00	0.13 ea.	50.63	350.63	0.87 ea.
Subtotal		$1,161.24		$444.68	$1,605.92	
TOTAL VEGETATION TREATMENT COSTS					$5,006.36	

[1]Cost estimates are based on Bond Creek labor costs. Detailed cost and person-hours by task were not kept for Bridge Creek.
[2]Cost computed using average wage of workers, $6.77/hr.
[3]Minimum estimated number.
[4]Estimated cost including collection, preparation and installation.

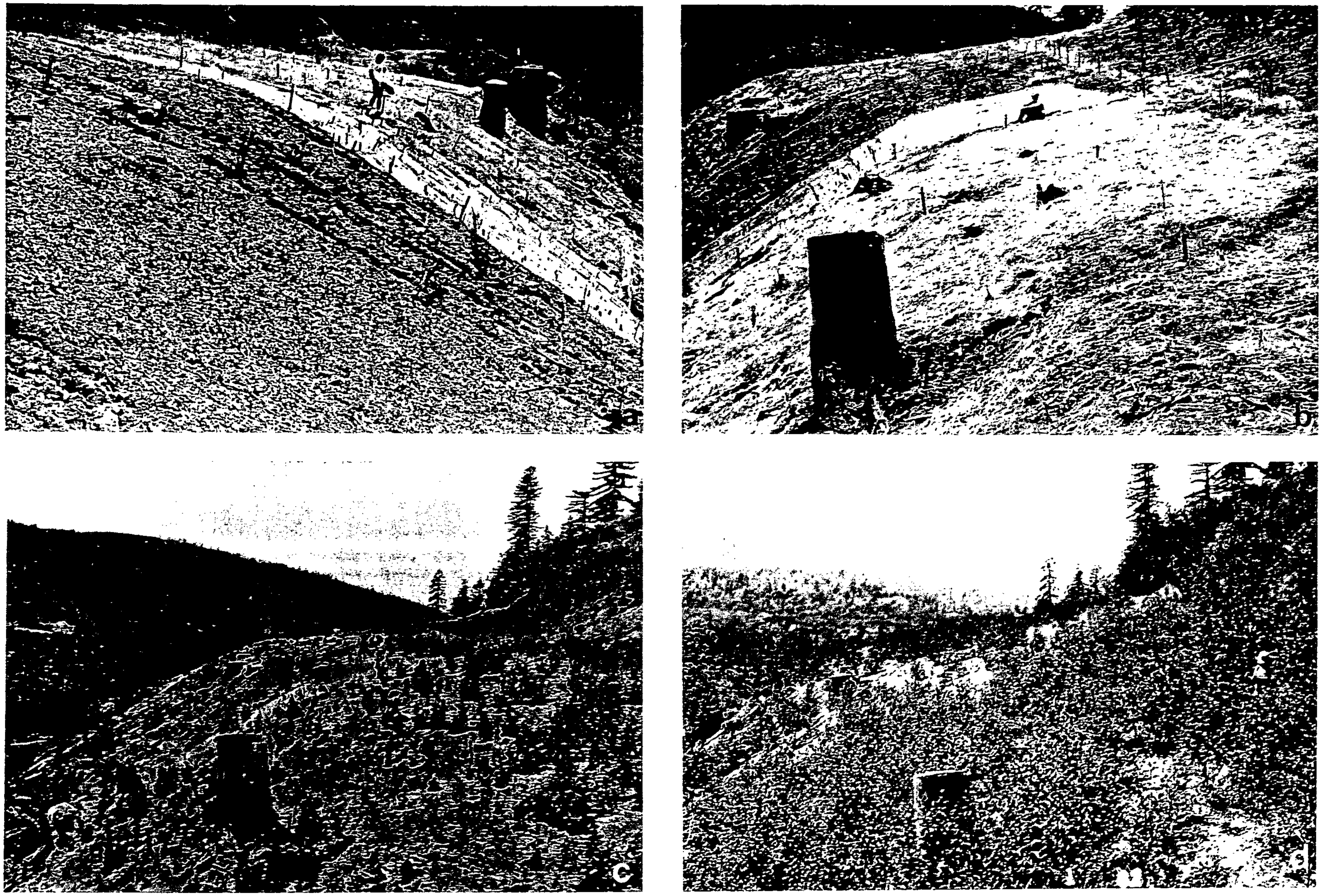


Fig. 42. Slope treatment plots established on the outsloped section of landing 1. A) plots, from foreground to background, included (1) wood chip mulch, (2) control (no treatment), (3) straw mulch covered by jute netting, (4) straw mulch, punched in by shovel, and (5) unsecured straw mulch. B) closer view of the straw mulch plots, #5 (foreground, beyond stump) to #3 (beyond person sitting on ground near break-in-slope). Photos A and B taken just after application of treatments (December 1979). C) natural invasion of alder two years following treatments (June 1981); note how chip mulch (background) has inhibited alder invasion. D) same view (July 1982).

TABLE 23

Measured Erosion from 1000 Sq. Foot Slope Treatment Plots

Plot	Treatment	Net Measured Erosion[1] (ft^3) Before Treatment (12/79)	After 1 year (8/80)
1	Wood chips (surface covered)	81.7	53.0
2	Control (no treatment)	134.2	94.7
3	Straw (8,000 lb/ac) covered and secured by jute netting	303.8	-26.8
4	Punched straw (9,000 lb/ac)	229.5	-5.0
5	Straw mulch (9,000 lb/ac)	162.1	18.6

[1]Calculated by measuring five cross-sections, computing net scour and averaging scour between cross sections. Net deposition indicated on plot #3 and #4.

winter period, 95 cubic feet of soil loss was measured. For our analysis purposes, it was assumed that all the other plots would have reacted in a similar, proportionate manner had they also not been protected with an erosion control treatment. The method used to measure surface erosion was not extremely accurate (Howell and Racin, 1978) and the lack of replicate plots precluded assigning definitive values of erosion control effectiveness. However, large differences in eroded volumes on the plots indicates a definite benefit in mulch coverings for erosion control.

Straw covered by jute was very successful in controlling rilling (Figure 37). However, the size and number of rills which developed on all treated sites were substantially reduced as compared to the same areas before treatment (immediately after the first fall rains). Following each winter, measurements showed that plots 3 and 4 (straw covered by jute and punched straw, respectively) actually trapped sediment which had been eroded from upslope areas. Plot 5 (straw mulch) reduced expected rilling by 85 percent and Plot 1 (wood chips) reduced predicted rilling by 13 percent (Table 23). There was less erosion with straw applied at 6,000 to 8,000 pounds per acre than with the 2,000 to 4,000 pound per acre rate. Wood chips prevented surface erosion on slopes less than 40 percent, but washed away and were ineffective on slopes steeper than 60 percent.

2. Winter Maintenance

Little winter maintenance was performed. Plugged checkdam spillways were cleaned out several times, but undercutting and failure of two dams at crossing R4 occurred during heavy rainfall. Because further erosion was expected to be minimal, those structures were not repaired. Some rock armor at R3 was moved after streamflow had been diverted against the channel bank, but most of the material was too heavy to manipulate. Ravel catchers at crossing R9, which had been flattened by a small debris flow from a cutbank failure, were not re-built (Figure 38).

3. Revegetation

By May 1983, plots with grass and fertilizer treatments had an average grass cover of 80 to 85 percent, regardless of straw mulch use (Table 24). There was little difference between the 250 and 500 pounds per acre fertilizer treatments, but grass always had less than 5 percent cover where no fertilizer was used. All grass treatments have persisted since June 1981 with gradual reduction in total cover. As at Bond Creek, unit 79-1, bentgrass was the dominant grass after the first year.

Little natural revegetation occurred on the grass seeded and fertilized areas, except on the very wet areas at the end of the road. There, mosses, liverworts, coltsfoot and horsetail were abundant. Alders began to invade bare spots within the grassed areas and on the edges of grass treatments. Alder, coyote brush, Douglas-fir and hemlock seedlings were more numerous in the wetter areas than on drier sites. Even less natural revegetation occurred on the wood chip plots, some alder, but few other species.

Natural revegetation was generally heavy on areas which were untreated, straw mulched or where grass without fetilizer was used (Figure 43). Many tree and shrub seedlings became established, as did hairy cat's ear, fireweed and whipplea.

Since grass seeding and wood chips inhibited natural revegetation and were less effective in controlling surface erosion, they have since been discontinued in favor of straw mulching which actually enhances natural revegetation (Popenoe, 1982; Reed and Hektner, 1983).

About 80 percent of the 1,000 willow stem cuttings relocated in June 1981 were living. Browsing was heavy, but the short, bushy plants were healthy and vigorous in wet, seepy areas. Willow stem cuttings were not as successful in areas with planted, seeded or invading alders. Several streambank areas with stem cuttings slumped into the stream channel, and some cuttings planted next to checkdams were swept away when checkdams failed.

Transplanted alder seedlings were taller and more robust than those which invaded the grass seeded areas. Transplants suffered little mortality. Initial height of transplants was 6 to 24 inches. After one year, the average height was 56 inches. Several years were gained by transplanting alders into grass seeded areas. Where transplants were available, this was a quick, effective technique for moist areas needing rapid revegetation.

TABLE 24

Natural Revegetation on Road Treatment Plots, May 1983

Treatment	Plot Number	Grass Cover(%)	Observed Natural Revegetation
Control	3	50	many Douglas-fir and hemlock seedlings
	5	5-15	some alder seedlings
	16	5-25	some alder seedlings
	19	5	some alder and Douglas-fir seedlings
	23	5	many alder, Douglas-fir and hemlock seedlings
	25	5	many alder seedlings
Straw	4	5-60	some Douglas-fir and hemlock seedlings
	6	20-60	many legume and coyote brush seedlings
	9	5	many alder seedlings in patches
	11	15	many species of seedlings
	12	5	some alder and Douglas-fir seedlings
	13	5	few alder seedlings
	14	5	few alder seedlings
	18	5	some alder and Douglas-fir seedlings
	21	5	many alder, some Douglas-fir seedlings
Grass	24	5	many alder seedlings
Grass & Fertilizer	1	90	many species of seedlings, but no alders; very wet conditions
	7	85	very few alder seedlings
	10	30-80	patchy grass with alder seedlings in bare areas
	20	90	very few alder seedlings
	22	85	a few very large alder seedlings
Grass & Straw	26	5	many alder seedlings
Grass & Fertilizer & Straw	2	90	many kinds of seedlings; very wet
	8	90	some alder seedlings on edges
	17	70-90	some alder seedlings on edges
Chips	15	5	many alders

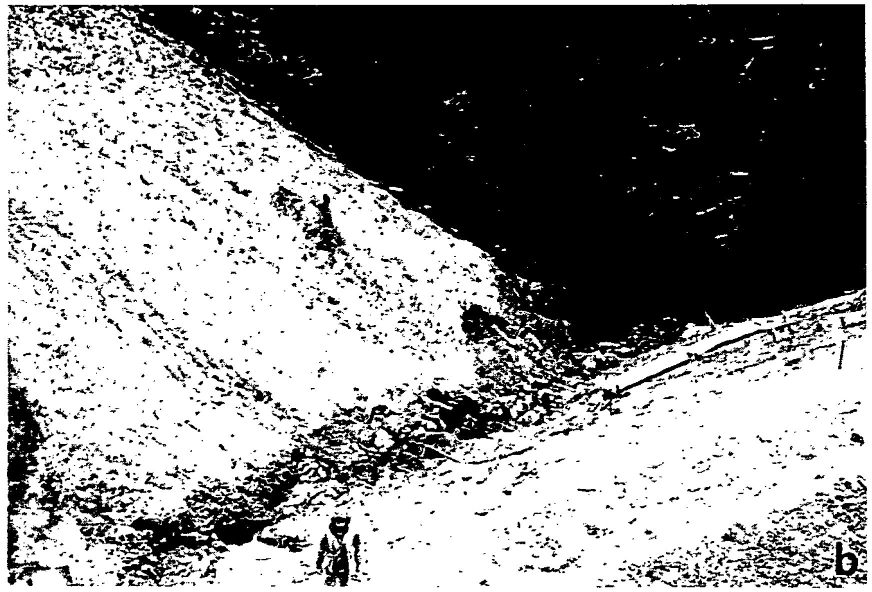


Fig. 43. View of the excavation and revegetation of stream crossing R7, M-7-5-1 logging road. A) M-7-5-1 logging road before rehabilitation and excavation of the stream crossing material (note drop inlet to culvert), May 1979; B) after channel excavation; note straw and jute netting on the left bank, sediment troughs on right bank, and checkdams in channel (January 1980); C) one year, eight months after rehabilitation, showing patchy alder growth from seeding (left bank) and growth of planted alder seedlings and grass (right bank) (May 1981); D) two years, nine months after rehabilitation, showing dramatic alder growth and essentially equal success (in both height and number) of seeded and planted alder at this locality (July 1982); E) three years, ten months after rehabilitation, showing complete closure of new canopy over excavated stream crossing (August 1983).


d


e

Outplanted containerized alder seedlings were less vigorous than the transplanted seedlings of comparable size. The field-grown seedlings were well-nodulated with nitrogen-fixing bacteria at the time of transplanting whereas the nursery grown seedlings were unnodulated. Survival of the transplanted seedlings was approximately 25 percent greater than the nursery seedlings. The transplants' height increased an average of 526 percent during the first year. Unnodulated seedlings' height increased an average of 93 percent (Sugihara and Cromack, 1982).

Greenhouse and field trials have since shown that alders grown from inoculated seed have even greater success (Sugihara, 1983). Seedlings from one nursery were nodulated while seedlings from the second were not. Further investigation revealed that the water source for the first nursery was stream water and the second, well water. Nitrogen-fixing bacteria from alders growing along the stream was apparently in the water used at the first nursery. The bacteria were not in the well water of the second. In order to have the second nursery's seedlings well-nodulated by planting time, alder root nodules were field-collected and ground up in a kitchen blender with water. A water/nodule mixture was then used to water the newly sown seed.

Grass/alder seed treatments resulted in heavy grass the first year, but alders were well-established the second (Figure 43). The grass did not persist because no fertilizer was used. Natural alder invasion in the unseeded area between stream crossings R5 and R6 resulted in similar alder cover as the seeded area between stream crossings R4 and R5. Grass sown without fertilizer in the spring-seeded areas did not exclude alders as did the fall-seeded grass sown with fertilizer in the road treatments.

Natural alder invasion resulted in dense, eight to ten feet tall stands after three years. In areas where alder was expected to seed naturally, hand seeding was not necessary or did not gain much advantage over natural colonization. Where seed source was unpredictable, seeding was desirable.

Few outplanted conifers survived in the grass or grass/alder seeded areas. Few redwood seedlings survived in any area, but numerous live Douglas-fir seedlings were relocated in unseeded areas. Where alders were established, redwoods were expected to eventually seed in and grow beneath the alder canopy. Douglas-fir and hemlock were invading many unseeded sites.

V. COPPER CREEK REHABILITATION UNIT 79-4

A. Unit Description

The Copper Creek rehabilitation unit (79-4) included 607 acres of cutover land and 6.7 miles of logging roads on the south side of the Copper Creek basin (Figure 1). Boundaries for the site included the main channel of Copper Creek to the north, oak woodlands and grasslands to the east and south, and the 1920-1900 road system to the west (Figure 44). The site was bisected by a prominent northwest trending ridge system. West of the ridge the topography was concave or bowl shaped, suggestive of ancient landslide or earthflow activity. East of the ridge, overall topography became more convex in profile. The unit generally faced north-northwest towards Copper Creek.

Elevation within the rehabilitation unit ranged from 1,500-2,400 feet. Slopes averaged between 30 and 50 percent, but locally exceed 80 percent near Copper Creek and Camp Creek. Three perennial streams (including Copper Creek) and eight intermittent streams were found within the unit. Only Camp Creek and Copper Creek were deeply incised, suggesting the role of mass-movement as a dominant landscape-shaping process on much of the unit. The area was underlain by the incoherent sedimentary rocks of the Coyote Creek Unit of the Franciscan assemblage and included fractured and sheared graywacke sandstone, mudstone and isolated outcrops of pebble conglomerate.

Much of the area was mantled by deep colluvium, with depth to bedrock usually exceeding six feet. Soils formed in the colluvium were well-drained and were dominated by the Coppercreek Series (tentative new series, correlated by SCS in 1984, see Popenoe, 1984) with lesser amounts of the Slidecreek Series. These soils were distinguished by their rock content: Coppercreek having 15 to 35 percent and Slidecreek having 35 to 75 percent. Surface textures were gravelly loams or gravelly clay loams with pH 5-6. The texture and pH of roadbed materials was similar. However, organic matter and nutrient elements in the roadbed were much lower, about equivalent to those in the upper B horizon of soils adjacent to the road (Popenoe, 1982). The soils had a high infiltration capacity, but were highly susceptible to surface erosion (Weaver and others, in press).

The Copper Creek basin experienced a complex logging history with three major periods of timber harvesting and tractor yarding (Figures 45 and 46). The majority of the area was selectively cut between 1958 and 1961. In 1963 and 1964, much of the area was selectively re-cut and, finally, in 1970-71 virtually all of the basin was clearcut (Figure 47). Each harvest involved re-use and expansion of existing roads and skid trails. Reforestation was attempted by planting and aerial seeding between 1970 and 1973.

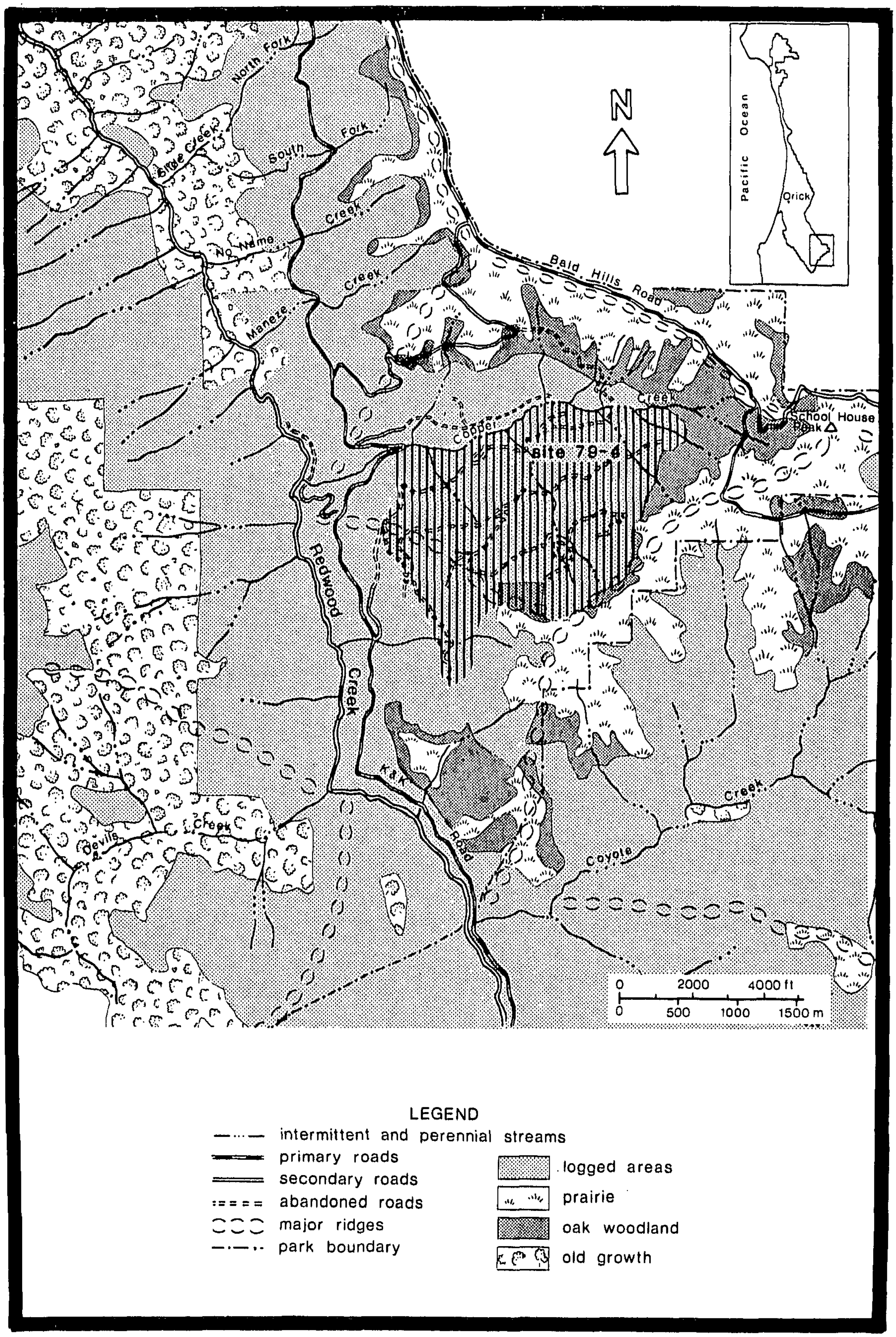


Fig. 44. Copper Creek rehabilitation unit 79-4.

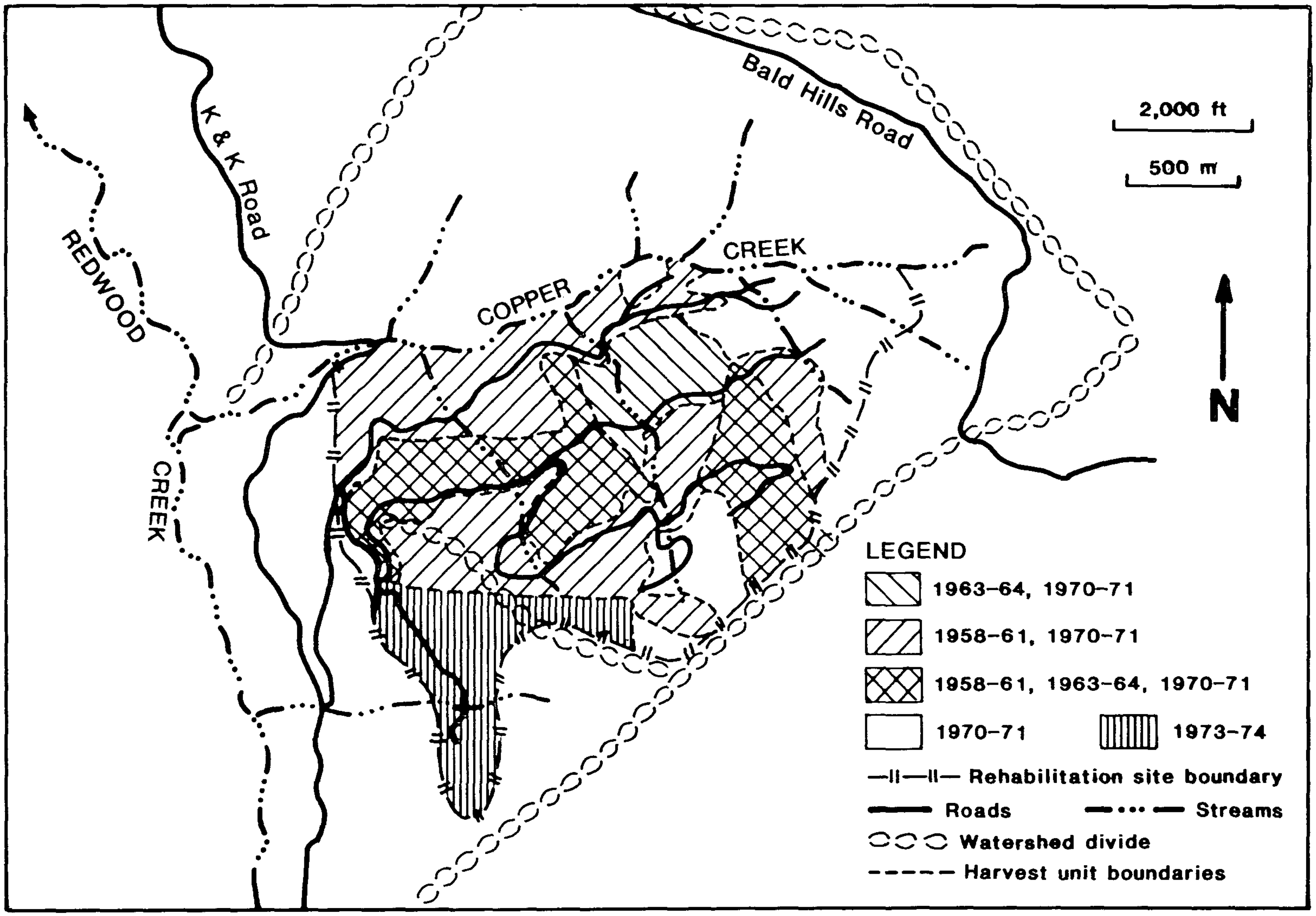


Fig. 45. History of timber harvest and road building on the Copper Creek rehabilitation unit. Note the multiple entry pattern which occurred over most of the area and the widespread clear cutting which was conducted in 1970-1971.

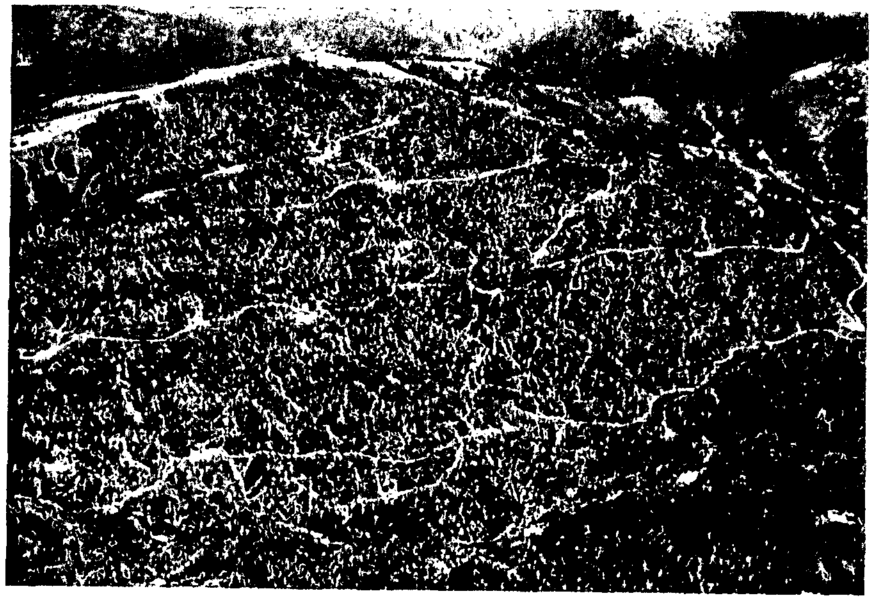


Fig. 46 (above). Oblique aerial photograph of the Copper Creek rehabilitation unit (August 1979). Most areas, except logging roads, major skid trails, landslides and large gullies have revegetated in the decade since the area was last logged.

Fig. 47 (right). Vertical aerial photograph of the south west portion of the Copper Creek site just following the 1972 storm and flood. Note the high degree of ground disturbance in the tractor logged areas. The remaining forest in the upper portion of the photo was clear-cut the following year.

Three major storms (one in 1964 and two in 1972) occurred immediately following major periods of logging in the Copper Creek basin. The area was also affected by another large storm in 1975. According to Coghlan (1984), all four were ten to fifty year return interval storms. A combination of large storms, disruptive landuse activities and poor road maintenance resulted in unusually high erosion rates (Weaver and others, 1982). Widespread tractor disturbance in and adjacent to poorly incised stream channels, combined with poor road drainage and numerous plugged culverts, caused streams to be diverted onto roads and skid trails. Water from these diverted streams either ran across the road prism and formed gully systems or entered adjacent stream channels and caused extensive bank erosion and channel enlargement (Figure 48).

Waterbars or cross-road drains were lacking on most roads and skid trails. Many of these bare areas became severely gullied by concentrated runoff (Figure 49). By 1979, many sections of unstable roads and landings had failed into adjacent stream channels (Figure 50). Approximately 163,000 cubic yards of sediment were eroded and lost from the area between 1964 and 1979 (Weaver and others, 1982).

Prior to logging, the principle overstory species were redwood, Douglas-fir, tanoak, big-leaf maple and madrone with an understory of huckleberry, rhododendron and salal. Following logging, the pioneer shrub coyote brush and the subshrub whipplea became prominent. Wild pea, star flower and iris invaded where topsoil was still present. On abandoned skid trails, roads, and landings without topsoil, the sparse vegetation was dominated by coyote brush and ruderal herbs such as plantain and hairy cat's ear. Sprouts and seedlings of forest species were gradually becoming established throughout the area on most bare soil areas (Popenoe, 1982).

Both heavy equipment and labor intensive rehabilitation treatments were employed to reduce on-going and future erosion and to encourage the return of natural vegetation. Diverted streams were re-routed into natural channels and fill was removed from logging road and skid trail stream crossings. Unstable landing fill was excavated where failure into nearby streams was probable. Mulches were spread and grass seeded for surficial erosion control. Shrubs, madrone and alders were planted for colonizing and intermediate stages of succession. Conifers were planted to speed forest re-establishment. Except for grass seeding and conifer planting, vegetation treatments were restricted to excavated stream crossings.

B. Work Sequence

Geomorphic mapping took place between February and April 1979 (1,100 person-hours) followed by prescription of heavy equipment and labor intensive treatments. Heavy equipment operations began July 5 and were completed October 25, 1979. Labor intensive contracts were prepared by November 1979 and the work was performed between December 1979 and February 1980. Follow-up maintenance took place in December 1980. Additional planting was done in April-May 1980 and February 1981.

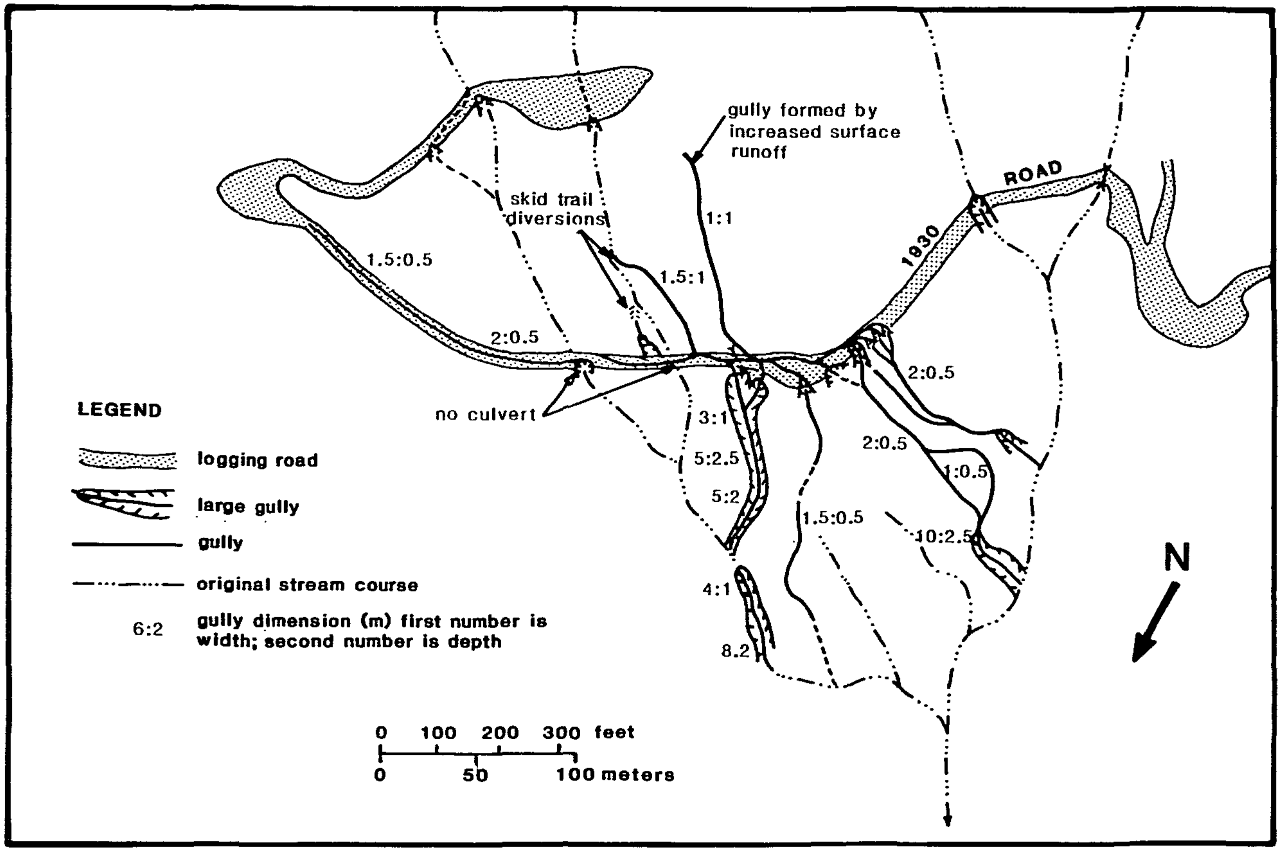


Fig. 48. Gully network mapped adjacent to the 1930 logging road. Gullies developed from increased surface runoff on skid trails and logging roads, stream diversions at skid trail watercourse crossings, stream diversions caused by plugged culverts on logging roads and stream diversions at road locations where culverts were never installed.

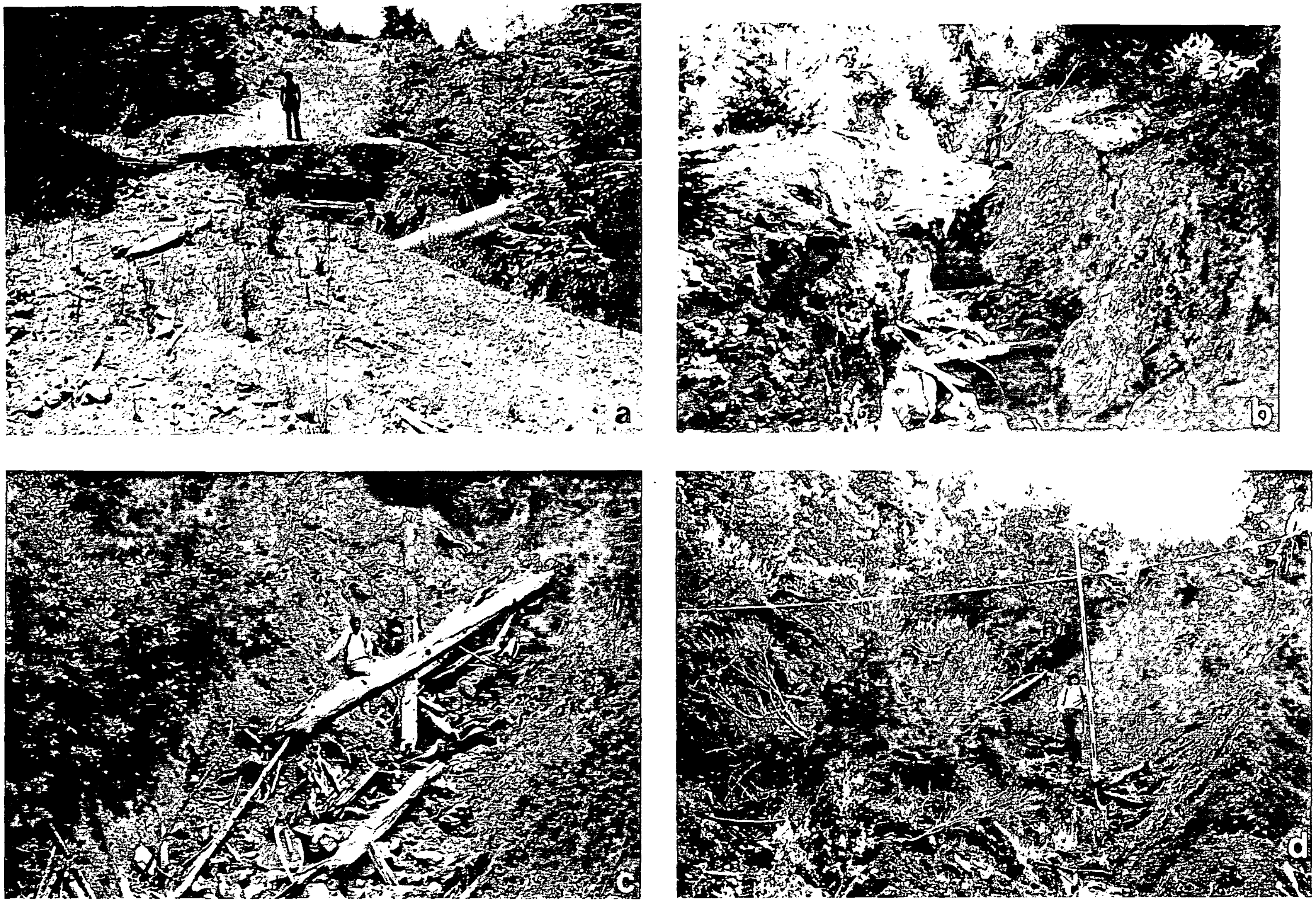
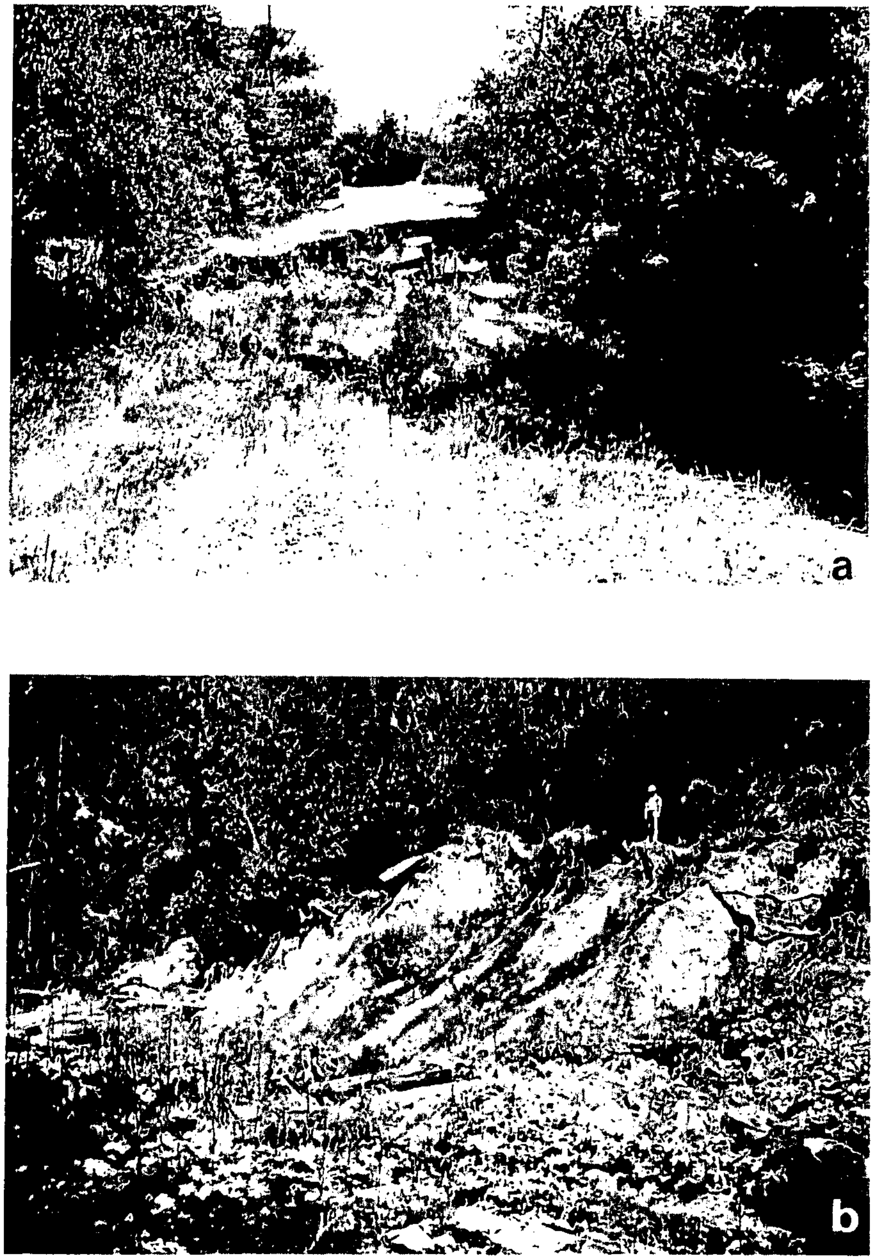


Fig 49. Examples of gully erosion on the Copper Creek rehabilitation unit. A) partially eroded stream crossing, B) severely gullied skid trail, C) gully headcut on hillslope and D) large gully formed by stream flow diverted out of its natural channel at an upslope logging road stream crossing.

Fig. 50. Examples of hillslope failures on the Copper Creek rehabilitation unit. A) slump, B) debris slide.



C. Monitoring and Documentation

Permanent photo points were established at most worksites to monitor changes. Photographs were taken before and after heavy equipment work as well as after labor intensive work. Selected photo points were rephotographed in subsequent years.

Detailed surveys were conducted at a log jam removal and bank stabilization site. Cross-sections and a channel profile were surveyed before and after heavy equipment work. A planimetric map was constructed and the volume of material excavated from the stream channel and adjacent side slopes computed. Subsequent surveys in the summer of 1980, 1981 and 1983 have documented sediment production and channel changes following rehabilitation.

Survival of planted trees and shrubs was checked in 1981 and 1983. Detailed documentation of natural colonization was done in 1980 and 1981 (Popenoe, 1982).

D. Heavy Equipment Work

Heavy equipment treatments included: 1) logging road and skid trail stream crossing excavations, 2) road and landing outsloping, 3) cross-road drain construction, 4) log jam removal, 5) road and landing ripping and 6) channel rocking (Figure 51). Eight pieces of heavy equipment were used (Table 25). Of $205,600 expended, 74 percent ($153,000) was spent on work addressing active erosion and sediment problems on roads and in stream channels (Table 26). Miscellaneous tasks, including log and culvert salvage, equipment transportation, standby and road winterization, accounted for the remainder.

1. Road reconstruction and equipment access

Many stream crossings had washed out prior to rehabilitation and some potential worksites were inaccessible. Stream channel crossings lower on the slope were more frequently and more completely washed out than crossings located higher on the slope due to their larger drainage areas and higher discharges. Crawler tractors temporarily reconstructed portions of roads and a flatcar bridge was installed on the 1910 road at R43 to avoid reconstructing the large, completely washed out crossing on Camp Creek.

2. Stream Crossing Excavations

Excavation of 49 logging road and 43 skid trail stream crossings totalled 35 percent of heavy equipment expenses (Table 26). Backhoes were generally used on small crossings requiring excavation of <150 cubic yards of material. Most crossings, however, were treated using a larger and more versatile hydraulic excavator (Figure 52). On the largest crossings (R9, 12, 34, 38, 41, 43 and 47), a dragline crane first removed material which was beyond the reach of an excavator or

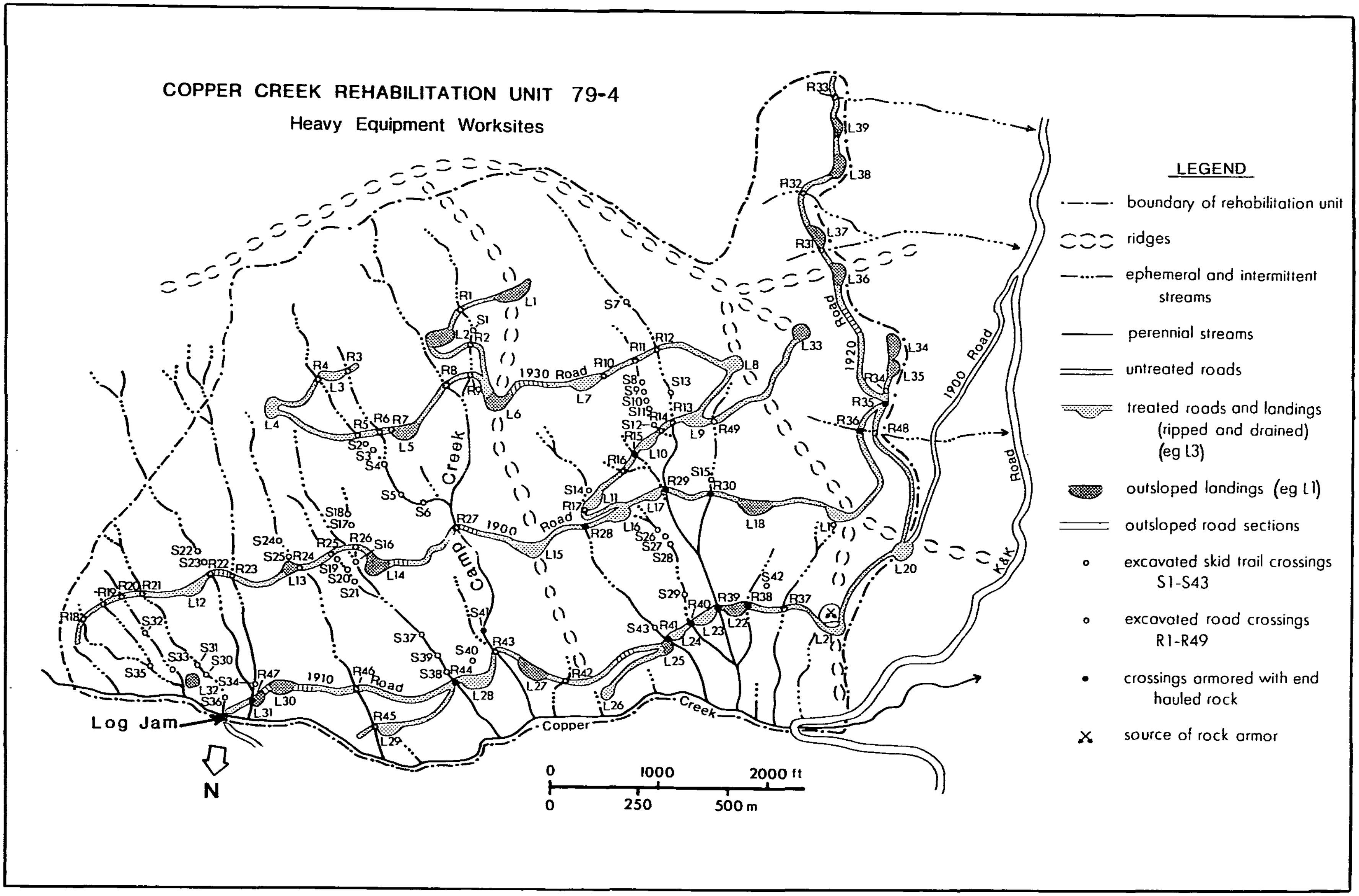


Fig. 51. Heavy equipment worksites, Copper Creek rehabilitation unit.

TABLE 25

Description and Hourly Rates of Heavy Equipment, 79-4

Equipment Description	Cost/hour[1]
22B Bucyrus Erie Crane with 40 ft. boom and 3/4 cubic yard bucket plus oiler/mechanic	$76.56
JD-690B John Deere Hydraulic Excavator with 25 ft. reach and 5/8 cubic yard bucket	67.40
TD-25 International crawler tractor with 2 ft. rippers	80.00
125B Michigan loader with 4 cubic yard bucket and log forks[2]	56.00
Peterbilt dump truck, 10-12 cubic yards[2]	30.00
580B Case Extendahoe with 24-in. (1/4 cubic yard) and 64-in. buckets	30.00
HD-16 Allis-Chalmers crawler tractor with winch	50.00

[1]Includes operator costs.
[2]Paid engine time only.

backhoe. Only three road crossings (R1, 2 and 32) were completely excavated by crane with crawler tractors performing the initial excavation work (Figure 53). A crawler tractor frequently assisted the excavating equipment by distributing material along adjacent roads or winching logs uncovered during excavation (Figure 54).

The cost to excavate 49 logging road crossings was $55,745. Average crossings contained 200 to 300 cubic yards of material, but ranged from 40 to 1,250 cubic yards. Costs for six typical crossings varied from $4.43 to $8.48 per cubic yard of fill removed (Table 27).

Thirty-five skid trail stream crossings were excavated by backhoe. The remaining eight skid trail crossings (S13, 25, 33, 36, 38, 40, 41 and 43) were treated with an excavator because they were near roads or were too large for the backhoe. The total cost to excavate 43 skid trail crossings was $16,164 or an average of $376 each (Table 26). Costs for four typical skid trail crossings (Table 27) varied from $4.76 to $8.13 per cubic yard. The estimated average fill removed from all skid trail crossings was 70 cubic yards.

TABLE 26

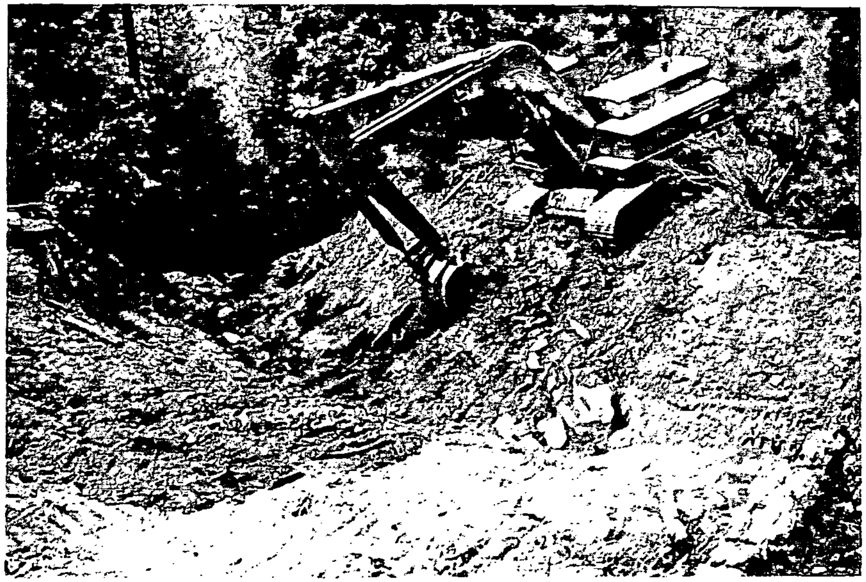
Summary of Heavy Equipment and Labor Intensive Costs, 79-4

Heavy Equipment Treatments		Costs
Road and Landing Worksites		
Road and Landing Ripping		$ 8,280
Road and Landing Outsloping		42,345
Cross-road Drain Construction		13,330
	subtotal	$63,955
Stream Channel Worksites		
Logging Road Stream Crossing Excavation		55,745
Skid Trail Stream Crossing Excavation		16,164
Log Jam Excavation and Slope Stabilization		10,247
Channel Rocking		6,874
	subtotal	$89,030
Miscellaneous Tasks		
Road Reconstruction		2,840
Flatcar Bridge Installation and Removal		3,273
Timber Salvage		16,574
Transit Time On-site		6,406
Standby Costs		9,580
Miscellaneous Costs		11,928
Park Road Winterization		2,027
	subtotal	$52,628
	TOTAL HEAVY EQUIPMENT COSTS[1]	$205,613

Labor Intensive Treatments		Costs
In-channel		$ 392
Hillslope/Stream Sideslopes		1,844
Rocking		12,961
Other In-Channel Work		780
Hillslope/Stream Sideslopes Treatment		1,742
Revegetation[2]		7,781
Administration Costs		$2,037
	TOTAL LABOR INTENSIVE COSTS	$27,537
	TOTAL COST FOR REHABILITATION TREATMENTS	$233,150

[1] Includes all costs incurred during heavy equipment work.

[2] Does not include in-house labor or supervision; cost for spreading seed and mulch or planting alders and willow stem cuttings.



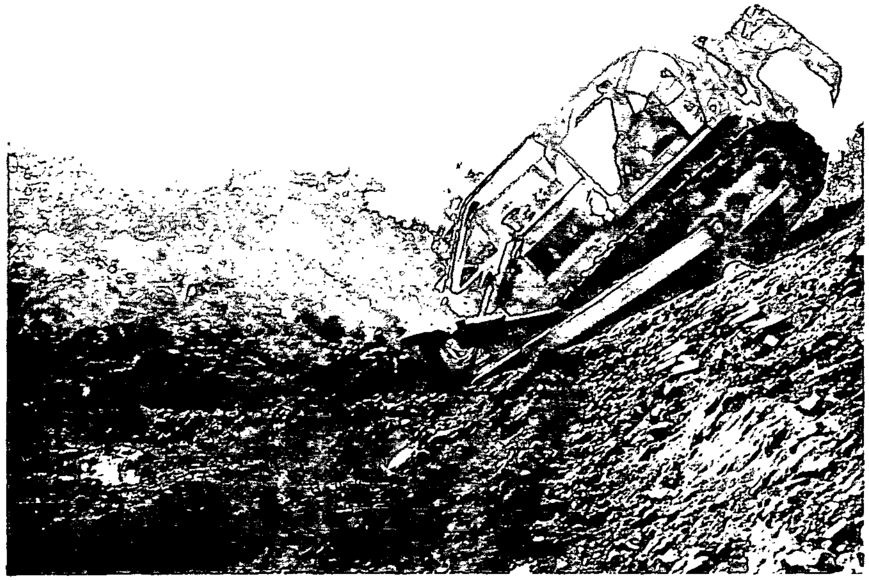


Fig. 52 (above left). Typical stream crossing being excavated by hydraulic excavator.

Fig. 53 (above). D-8 sized crawler tractor excavating debris from a stream crossing. As shown here, tractors were used to perform initial excavation work at a number of stream crossing sites. In recent years, many crossings have been entirely excuvated using only crawler tractors to both excavate and remove material.

Thirty-five percent of all skid trail crossings within the unit were excavated. An additional twenty percent warranted treatment but were left untreated due to their inaccessibility. The remaining crossings were totally washed out, or no longer represented significant current or future sources of erosion. They were not treated.

3. Road and landing outsloping

Thirty-nine landings were evaluated. One landing required no treatment since it was stable and revegetating adequately. Eighteen landings were ripped to increase infiltration and aid revegetation. The remaining twenty landings were both ripped and outsloped to provide unconcentrated drainage and to remove unstable material which could fail into nearby streams. A crane or excavator was used to remove perched material around landing edges (Figure 55) while crawler tractors shaped the material into gently sloping surfaces. Landing outsloping treatments totalled $39,240 or an average of $1,960 each.

Fig. 55. Dragline crane excavating soil and organic debris from the outside edge of a log landing.

Eight sections of road (total = 0.3 mile) were outsloped to improve drainage and stabilize oversteepened road fill (Figure 51). Outsloping was usually performed by retrieving sidecast material and placing it along the cutbank. Material was excavated by the backhoes or excavator and shaped by a crawler tractor. Road outsloping cost $3,100 ($9,020 per mile).

TABLE 27

Excavation and Armoring Costs for Selected Logging Road (R) and Skid Trail(s) Stream Crossings, 79-4

		Stream Crossing Excavations							Stream Channel Armoring				
Crossing Worksite	Equipment	Hours[1]	Standby Hours	Cost ($)	Total Exc. Cost ($)	Excavated Volume (yd^3)	Unit Cost ($/$yd^3$)	Unit Cost Minus Stby ($/$yd^3$)	Hours Rocking	Cost ($)	Total Rock.Cost ($)	Rock Volume (yd^3)	Unit Cost ($/$yd^3$)
R6	Backhoe	21.0		$630.00	$1,205.00	155	$7.77	$5.52					
	HD-16	11.5	7.0	575.00									
R12	Crane	21.0	3.0	1,607.76	5,531.56	1,250	4.43	3.61					
	Excavator	12.0		808.80									
	TD-25	11.5	3.0	920.00									
	HD-16	32.5	11.0	1,625.00									
	Backhoe	19.0		570.00									
R15	Excavator	20.0	2.5	1,348.00	2,388.00	300	7.96	5.67	8.5	$572.90	$1,088.90	70	$15.56
	TD-25	13.0	6.5	1,040.00									
	Dump Truck								6.0	180.00			
	Loader								6.0	336.00			
R20	Backhoe	9.0		270.00	270.00	42	6.43						
R22	Excavator	15.0		1,011.00	2,281.00	350	6.52	5.49					
	TD-25	13.3	4.5	1,060.00									
	Backhoe	7.0		210.00									
R29	Excavator	21.5		1,449.10	3,729.10	440	8.48	5.57	8.0	539.20	1,141.20	70	16.30
	TD-25	28.5	16.0	2,280.00									
	Dump Truck								7.0	210.00			
	Loader								7.0	392.00			
S3	Backhoe	6.5		195.00	295.00	62	4.76						
	HD-16	2.0		100.00									
S13	Backhoe	17.0		510.00	610.00	75	8.13						
	HD-16	2.0		100.00									
S41[2]	Excavator	11.5		775.10	1,225.10	185	6.62	4.73					
	HD-16	9.0	7.0	450.00									
S43	Backhoe	7.5		225.00	1,039.20	156	6.66						
	Excavator	8.0		539.20									
	HD-16	5.5		275.00									
Summary Totals		324.8	60.5	18,573.96	18,573.96	3,015	6.16		42.5		2,230.1	140	15.93

[1]Includes standby hours.
[2]Includes rocking channel and riprapping channel meander with rock present at crossing. No rock hauling costs.

4. Log jam removal

Five percent of the total heavy equipment costs were incurred in removing three log jams in Copper Creek. The log jams were composed of partially rotted saw logs (predominantly Douglas-fir) which were likely to fail and release the sediment stored behind them (Figure 56). Unstable sideslopes were also excavated and the toe of the unstable right bank between the upper and middle log jams was protected with riprap. Excavation and endhauling was done by crane, excavator, both crawler tractors, loader and dump truck (Figure 57). Figure 58 shows morphologic maps of the log jams prior to treatment and three years later.

Fig. 56. View up the Copper Creek stream channel above a three step log jam removed during rehabilitation. Most logs in the jam were cut on at least one end, attesting to their logging origin. The hydraulic excavator is shown working on top of the sediment stored above the log jam.

Fig. 57. Hydraulic excavator, dragline crane and crawler tractor excavating and disposing of material stored behind the log jam, Copper Creek.

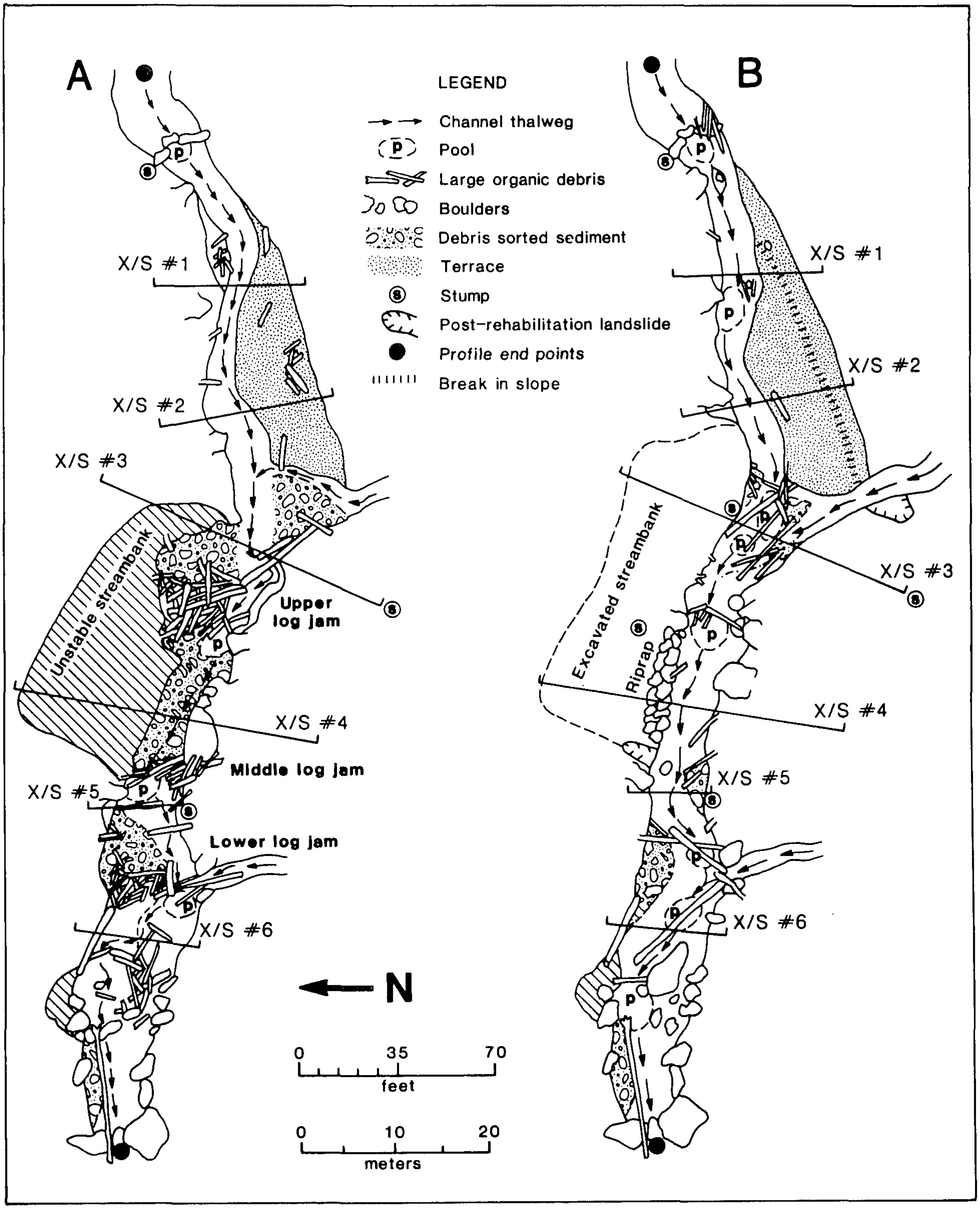


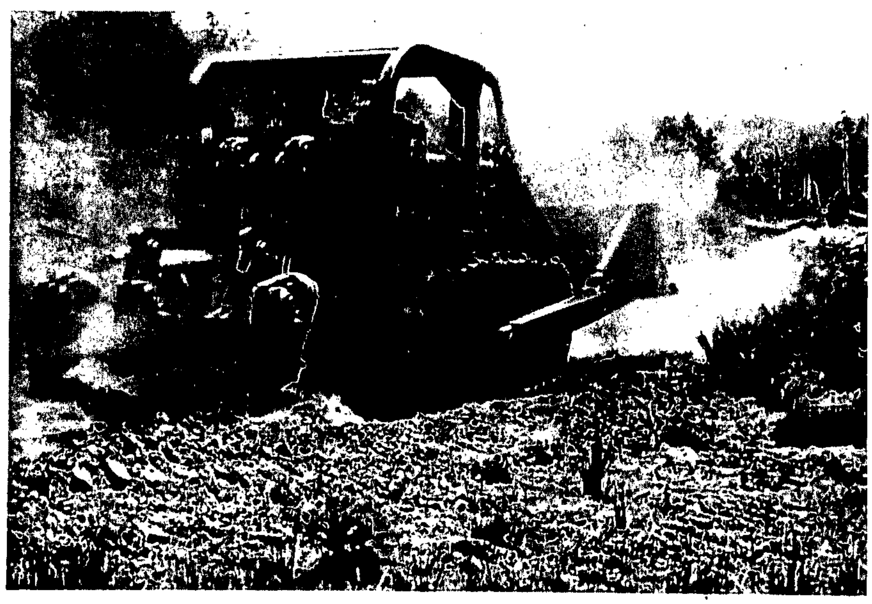
Fig. 58. Morphologic maps of Copper Creek in the vicinity of the log jam. A) before rehabilitation (Sepember 1979), showing the distribution of stored sediment, organic debris and locations of bank erosion, B) after rehabilitation (August 1982) showing the channel adjustments which had occurred in the subsequent winter.

Approximately 600 cubic yards of sediment was excavated during log jam removal at a cost of $7,760. The excavator and tractors removed an additional 850 cubic yards of unstable material along the channel sideslopes at a cost of $805. Riprapping the toe of the unstable right bank with boulders cost $1,680, including quarry and transportation costs. All material excavated from the log jams and side banks was placed in a stable location on the 1910 road between the log jams and R47 (Figure 51). The total heavy equipment cost associated with log jam excavations was $10,250.

5. Road and landing ripping

Approximately 6.7 miles of road and 38 landings, totalling 28.2 acres, were ripped (disaggregated) to a depth of 24 inches. Ripping was done by the TD-25 crawler tractor with a pair of hydraulically operated ripper or chisel teeth (Figure 59). Roads and landings were ripped to increase infiltration of water into the road surface and to promote revegetation of formerly compacted areas. Ripping was done throughout the heavy equipment phase of rehabilitation and, to avoid recompaction, shortly preceeding final road removal efforts. Total cost was $8,280 or an average of $700 per mile of road and $125 per acre of landing (Figure 60).

Fig. 59. A large crawler tractor with hydraulically operated three-pronged ripping attachment disaggregated compacted surfaces to a depth of approximately 18 inches. In a number of road reaches, ripping was the only rehabilitation treatment utilized.



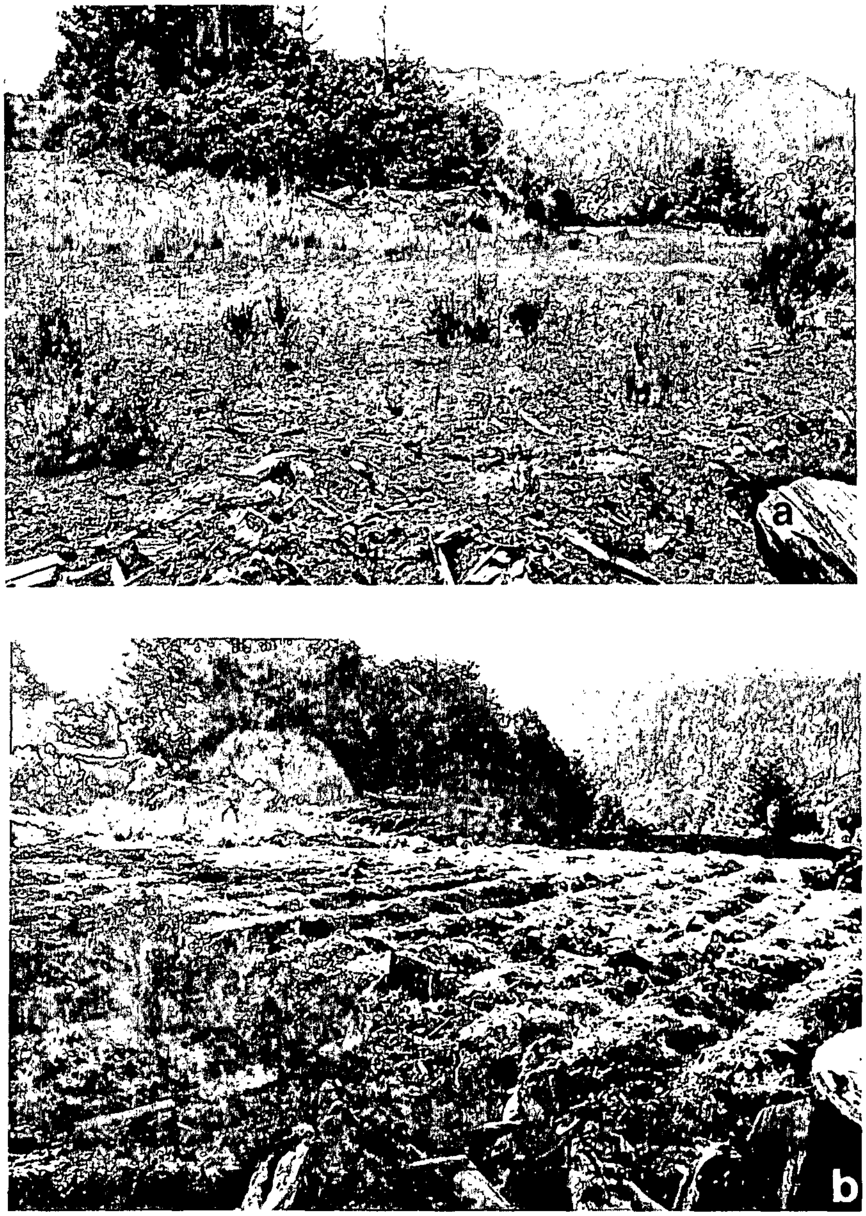


Fig. 60. Ripping a log landing on the Copper Creek rehabilitation unit. A) before disaggregation (May 1979) — note the sparse vegetation invasion of the compacted road surface in the ten years since the road had last been used; B) after ripping and the application of a straw mulch (December 1979).

6. Cross-road drain construction

Backhoes, crawler tractors and the excavator constructed 291 cross-road drains, drains across landings, and slope ditches at a cost of $13,330. Average costs per drain are misleading since drain dimensions varied greatly from 30 feet long to 200 feet long. Ditches and drains were constructed to route surface flow into less erodible areas and to disperse water which collected on the road surface (Figure 61). The

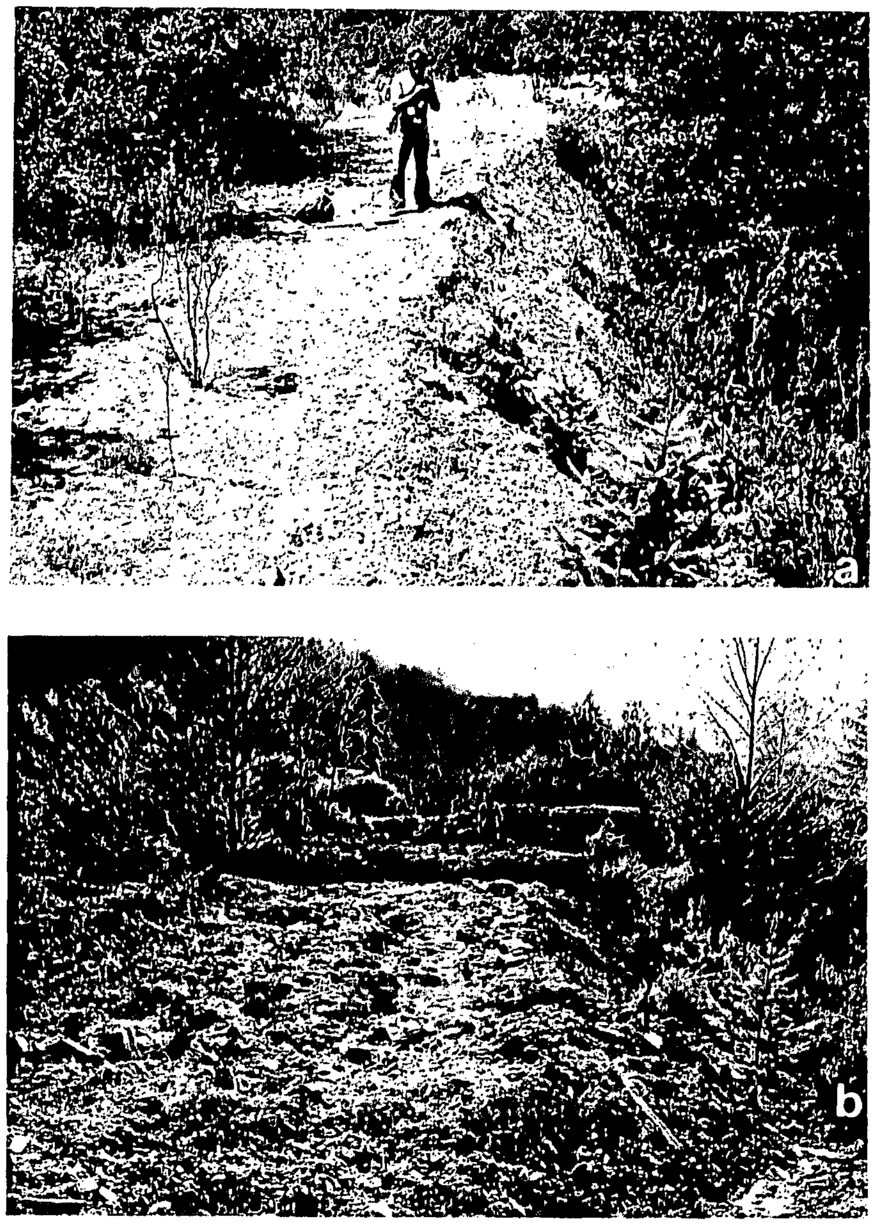


Fig. 61. Rehabilitation of a secondary logging road. A) after ten years of abandonment, but prior to rehabilitation treatments — note lack of revegetation on the road surface; B) immediately following road ripping and construction of cross road drains. Decompacted road has also been lightly mulched with straw.

size and spacing of drains was dependent upon local hydrology and road conditions. Roads lower on the hillslope frequently intercepted groundwater and spring flow, and thereby required more closely spaced drains. Table 28 lists the number of cross-road drains installed on each road. An additional twenty-four ditches were constructed near skid trail crossings to route surface flow into adjacent stream channels.

TABLE 28

Cross-Road Drain Frequency, 79-4

Road	Slope Position	Number of Drains	Drains/1000 Ft. of Road
1930	Upslope road	46	4.2
1900	Midslope road	65	7.2
1920	Midslope road	48	8.2
1910	Lowermost road	108	12.0
	Total	267[1]	

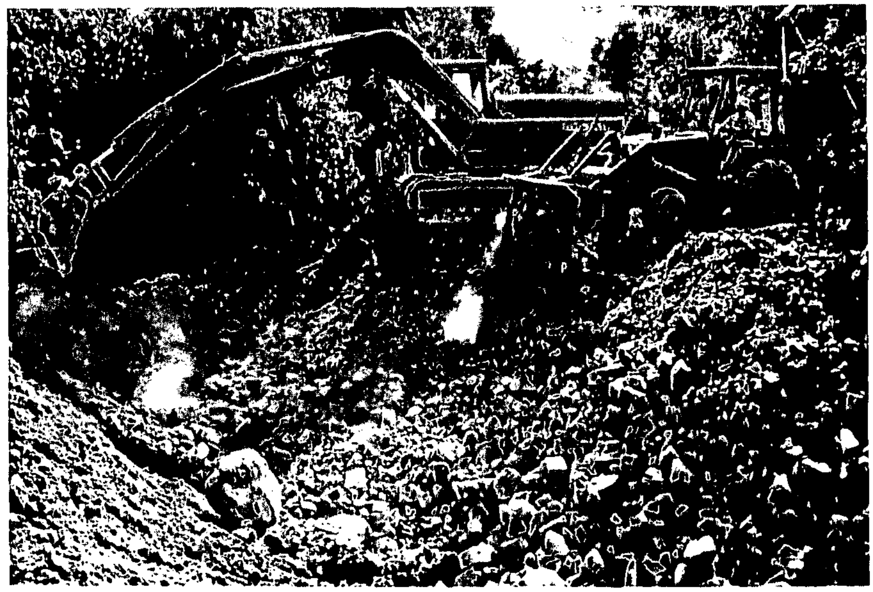
[1]Does not include 24 drains or ditches constructed on hillslope segments between roads.

7. Channel Rocking

Heavy equipment placed rock in twelve logging road stream crossings to minimize stream downcutting and sidecutting in the freshly excavated channels (Figure 51). This was done where there was dump truck access, high anticipated winter discharges in the channel and insufficient rock in the excavated channel to provide adequate protection. Skid trail stream crossings were not accessible to the dump truck, so no rocking by heavy equipment was done.

Rock was transported by dump truck to storage areas near the prescribed worksites. After crossing excavation, a backhoe or excavator placed rock in the channel (Figure 62). Total cost for channel armoring was $6,874, including quarrying, transportation and placement as well as the cost to reshape the Copper Creek rock pit (Figure 51) following use (Table 26). Approximately 410 cubic yards of rock were placed in channels at an average cost of $16.80 per cubic yard (Table 27 shows two examples: R15 and R29).

Fig. 62. Rock armor being placed in excavated stream crossing by excavator and loader. Rock used to protect newly excavated stream channels was derived locally for some crossings and from the Copper Creek rock pit for others (see Figure 51).



8. Salvage

Approximately 70,000 board-feet of timber (92 percent redwood and 8 percent Douglas-fir) culverts and cable were salvaged from landings and roadsides. Salvage costs were $16,600, with almost 25 percent spent on hauling culverts and discarded cable from the unit. Some of the salvaged logs were milled on-site by park crews. Boards were supplied to contractors for use in water ladder, ravel catcher and checkdam construction.

9. On-site transit between worksites

The transit costs of $6,400 included equipment moves which took longer than 15 minutes as well as some standby time for equipment idled when another piece of equipment broke down. Equipment movement time of less than 15 minutes between worksites were included in site treatment costs.

10. TD-25 standby costs

Standby costs of $9,580 were incurred because the TD-25 crawler tractor was contracted for at least 40 hours work per week. However, the sequencing of road ripping frequently resulted in the tractor working fewer hours. The guarantee for a minimum number of hours was necessary to keep the large tractor on-site for road ripping throughout heavy equipment work and for large earthmoving tasks. No equipment adequate for these tasks was available for lease on an engine-time only basis.

11. Miscellaneous costs

Miscellaneous costs totalled $11,928, including lowboy transportation of equipment to and from Eureka ($4,900), preparation of pads for mulch storage, use of a spiked roller to punch mulch into steep slopes (Figure 63), mulch spreading, changing between front end loader attachments (forks and bucket) and other tasks (Table 26).

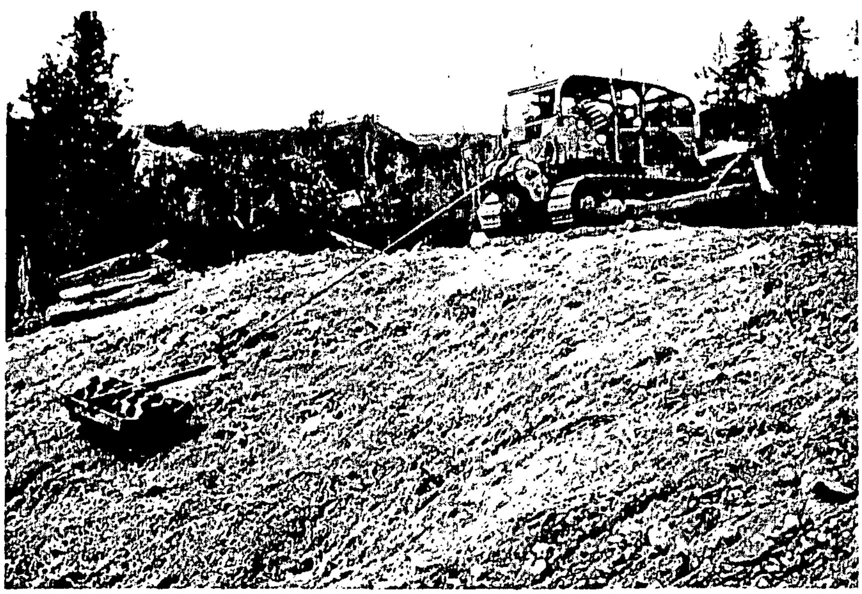


Fig. 63. Spiked roller used to punch straw into loose soil on steep, newly exposed slopes. An alternate treatment used on steep, inaccessible slopes elsewhere was the application of jute netting over the straw mulch (for example, see Bridge Creek Unit 79-2).

12. Road winterization

The cost of installing or renovating cross-road drains, road grading, breaching outboard road berms and cleaning culvert inlets on 7.0 miles of access road not removed were included in winterization costs of $2,030.

E. Evaluation of Heavy Equipment Work

Watershed rehabilitation of the Copper Creek unit treated nearly one square mile of hillslope, 6.7 miles of logging roads, over 50 miles of skid trails, 92 road or skid trail stream crossings and many unstable areas. Weaver and others (1982) found that heavy equipment operations corrected about 80 percent of the currently active sediment sources. However, many erosional problems were beyond the scope of cost-effective treatment. These sites were left untouched.

Stream crossing excavations resulted in the removal of 13,240 cubic yards of fill which probably would have entered the stream system. Estimated post-rehabilitation erosion from excavated stream crossings totaled 3,130 cubic yards; less than one-quarter of the volume which would have eroded from stream crossings had they been left untreated. Considerable erosion was also prevented by dewatering miles of active gullies and by re-establishing natural drainage patterns. Gullies were the greatest single source of sediment and redirecting water back into excavated stream crossings was responsible for the greatest estimated reduction in erosion rates.

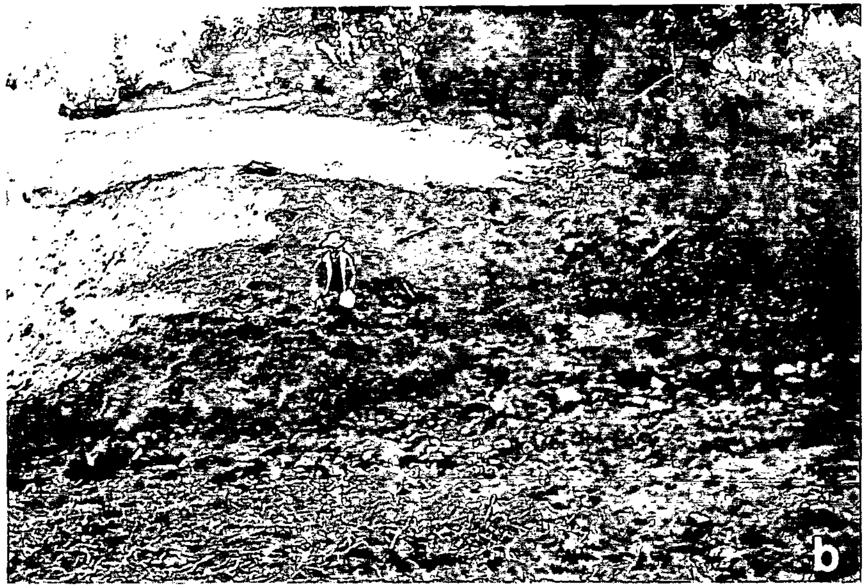
The effectiveness and total cost of rehabilitation was strongly influenced by the physical conditions encountered, by the appropriateness of the prescription, by the types of heavy equipment chosen and by the skill of the equipment operators (Weaver and Sonnevil, 1984). For example, excavations in unstable soils or at locations where the original channel could not be found often resulted in the greatest degree of post-rehabilitation channel adjustment and sediment loss. Original stream channel morphology (Figure 64) could only be reconstructed if subtle variations in soils and bedrock or buried stream channel indicators (root mats, boulder beds and concentrations of pre-logging organic debris) (Figure 65) were encountered and recognized.

Selecting the proper equipment for the specific work task, and effectively communicating the areal extent and depth of an excavation to the equipment operator prior to beginning work was also an important factor. Finally success was achieved by anticipating locations where all the fill could not be removed. When this was recognized, plans were made to utilize existing large organic debris as a stable local base level, or to have rock armor or other secondary treatments installed to prevent subsequent channel erosion.

1. Logging road stream crossing excavations

Stream channels were excavated by crane, backhoe or excavator. Use of these three machines on the Copper Creek unit permitted comparisons in their relative effectiveness. An excavator had an advantage over a crane by its greater mobility and ability to more easily reconstruct the natural configuration of the channel. Both the crane and the excavator had a 360 degree turning capability which allowed excavated material to be deposited well behind the machine and out of the stream channel (Figure 66). The excavator had only a 30-foot reach, but had sufficient hydraulic power for aggressive digging and manipulating most large organic debris. The excavator was thus more versatile than a crane where the longer reach was not required. Backhoes proved less efficient than the larger equipment due to small bucket size, short reach, low power, frequent break-downs and limited swing (90° to each side).

An excavator working with a crawler tractor was the most efficient equipment combination for removing fill and organic debris from stream channels on medium to large crossings (200 - 500 cubic yards). The tractor experienced only occasional slow periods. The tractor initially removed the upstream fill, worked material out along the adjacent road reaches, winched logs as needed and distributed fill removed by the



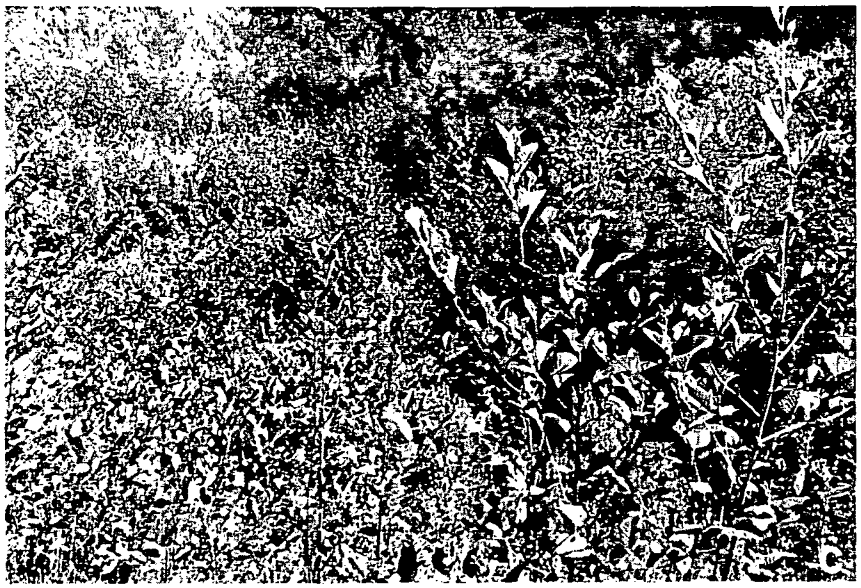


Fig. 64. Successful, minor stream crossing excavation. A) gullied stream crossing on abandoned logging road (August 1979); B) excavated crossing after several storms; note the low channel gradient, gentle side slopes and minimal widening (scour) of the channel bed (December 1979); C) same view after approximately four years, note the rapid, natural invasion of alder on the decompacted road surface (September 1983).

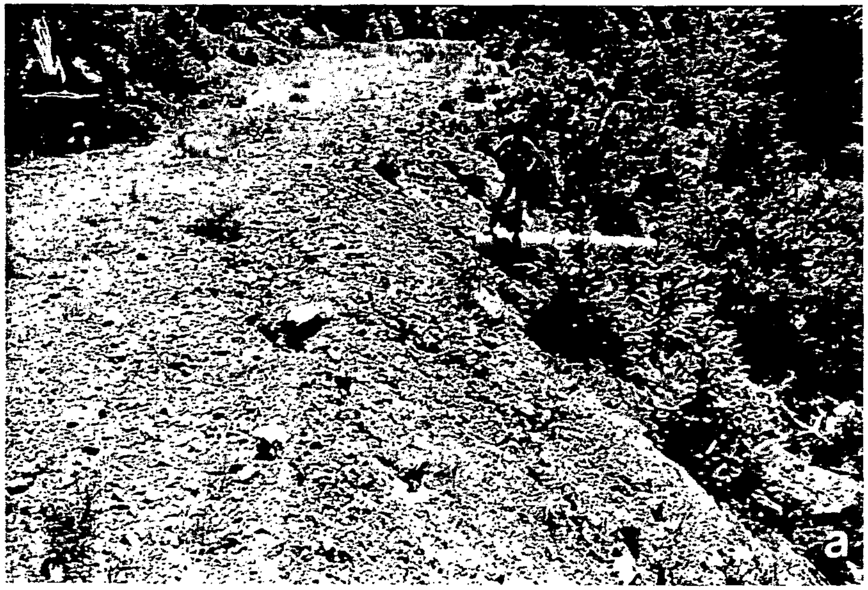


Fig. 65. Successful, major stream crossing excavation. A) intact crossing prior to rehabilitation work, note workers standing on the culvert inlet and outlet, and largely unvegetated road surface; B) same view of crossing taken immediately following excavation work; note the basal flair on the exposed redwood stump which indicates the original ground surface (stream channel bottom) was successfully exhumed; C) same crossing after three and one-half years; because the channel was excavated down to the original ground surface, there has been little erosion of the streambed following rehabilitation.

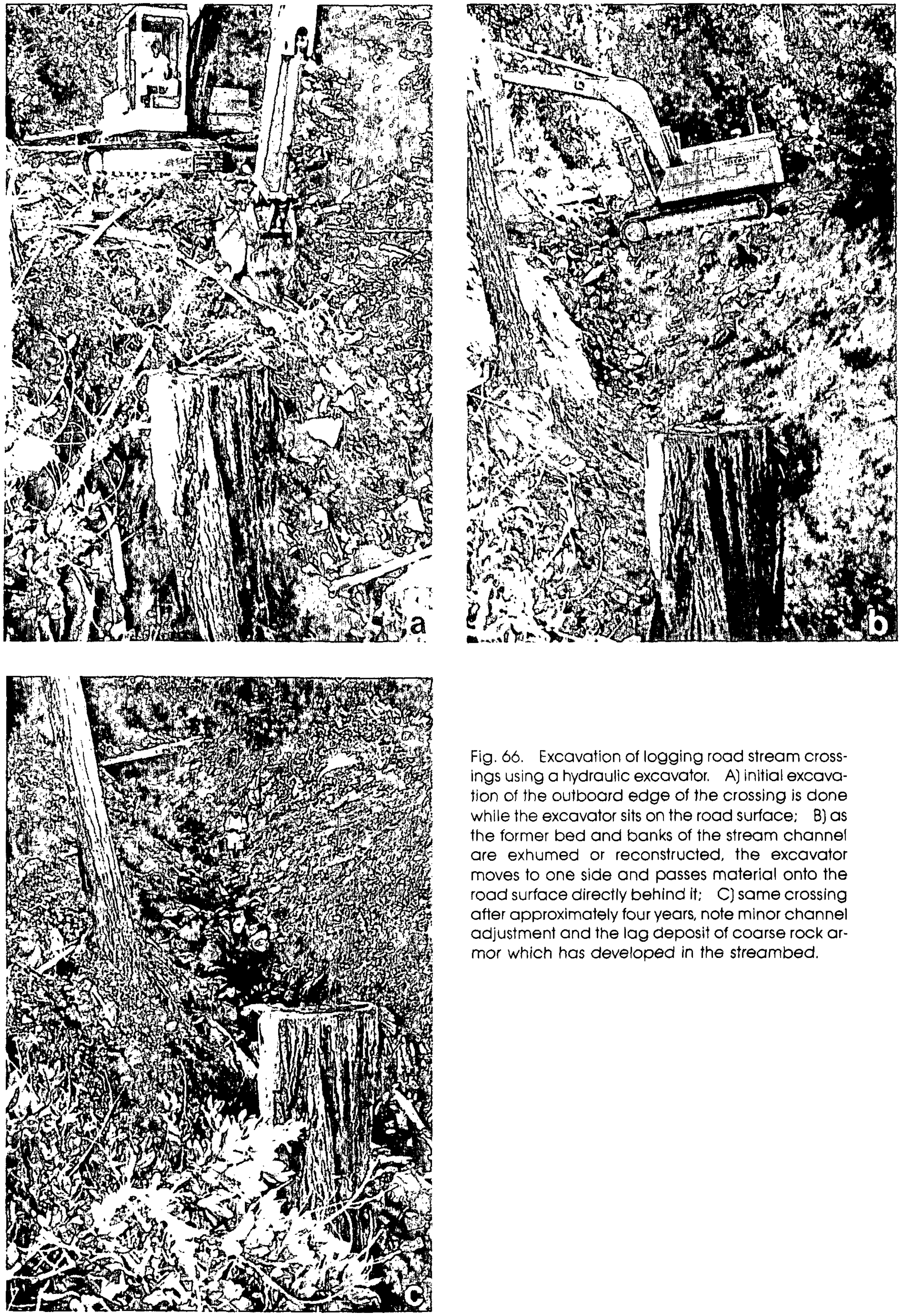


Fig. 66. Excavation of logging road stream crossings using a hydraulic excavator. A) initial excavation of the outboard edge of the crossing is done while the excavator sits on the road surface; B) as the former bed and banks of the stream channel are exhumed or reconstructed, the excavator moves to one side and passes material onto the road surface directly behind it; C) same crossing after approximately four years, note minor channel adjustment and the lag deposit of coarse rock armor which has developed in the streambed.

excavator. In excavating large fills (>1,000 cubic yards) in steep gradient streams (>35 percent), the use of an excavator and tractor often resulted in gentler than natural sideslopes. Tractors created the gentler slopes in order to efficiently push excavated material out of the crossing. Because of its large bucket, the crane was more cost-effective for excavating the largest stream crossings. However, with an experienced operator, even these treatments would have usually been less costly using the hydraulic excavator.

Crossings with large drainage areas and high discharges have greater potential for producing significant amounts of erosion. However, in Copper Creek, a qualitative survey of drainage areas above excavated crossings did not reliably predict post-rehabilitation erosion. Some post-rehabilitation erosion occurred on all drainages greater than ten acres where crossings were excavated to a "stable" base. Observations in subsequent years revealed that this was a one-time adjustment that will not result in continued high future sediment yields. Crossings not excavated to a stable substrate generated the largest volumes of eroded sediment.

2. Skid trail stream crossing excavation

Many of the skid trail stream crossings were left incompletely excavated because large logs and stumps could not be removed by the backhoes. Backhoes could not remove all fill on some crossings due to saturated soils, steep sideslopes or insufficient working space. Yet at these remote sites, complete excavation to reach the original channel grade and sideslope configuration was important since checkdams or rock armor could not always be installed. The track-mounted excavator, capable of climbing slopes as steep as 60 percent, was able to thoroughly excavate the fill material, restore the original channel configuration and distribute excavated fill without crawler tractor assistance on many small crossings.

3. Road and landing outsloping

Cranes were most useful for outsloping where large volumes of fill and debris were perched or failing on steep slopes (>70%) and where it was necessary to retrieve material from far down the hillslope. The 40 to 50 foot reach of the crane allowed excavation of material inaccessible to other equipment. In retrospect, some of the work done by the crane could have been accomplished more cost-effectively by an excavator or crawler tractor. When necessary to reach far downslope from roads and landing surfaces, lower benches could have been constructed to allow an excavator or tractor to retrieve most of the unstable sidecast or fill material.

Prior to rehabilitation work, 13 out of 20 landings outsloped exhibited tension cracks as well as other indications of pending failures. One-third of the landings had at least partially failed before the summer of 1979, and a few released several thousand cubic yards down the hillslope. Although it is difficult to assess the effectiveness of road and landing fillslope excavations, examination after three winters shows no failures have occurred on any treated landings. Treated landings which displayed signs of instability before rehabilitation have developed no new scarps, tension cracks or indications of impending failure. Several untreated landing fillslopes have failed.

4. Log jam removal

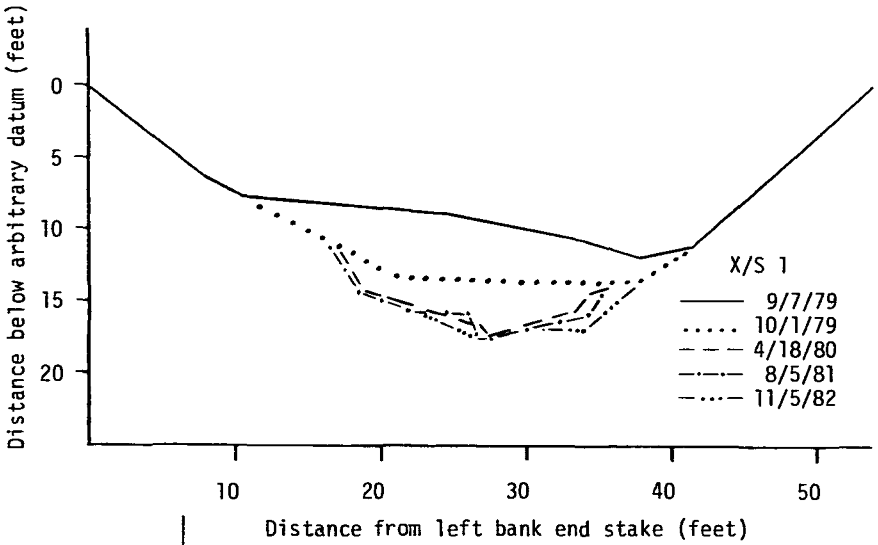
Organic debris and log jams commonly alter the hydraulics of a stream reach causing changes in channel morphology (Pitlick, 1981; Keller and Talley, 1979; Swanson and Lienkaemper, 1978). An abrupt step in the longitudinal profile may form at the log jam with an associated upstream decrease in gradient and increase in channel width. These effects were seen at the Copper Creek log jam worksite. The log jam also caused local hillslope failure by diverting flow into banks and undercutting the toe of an adjacent slope (Figure 58).

The two crawler tractors initially pushed material supplied by the excavator away from the unstable right bank of Copper Creek to a nearby storage area in a two-step procedure with each tractor pushing material approximately half the 300 foot distance. This resulted in the quickest and most efficient excavation on the unit ($1.05 per cubic yard).

Subsequently, the excavator and tractors began disassembling the upper log jam and removing stored sediment. Increasingly wet conditions encountered as excavation continued required changes in equipment. Due to saturated conditions, the narrow stream channel, steep sideslopes and large bedrock outcrops along streambanks, the excavator was the only equipment that could be used in the stream channel for removing the remaining two log jams. This frequently required the excavator to move the same material more than once before other equipment, such as the crane, could assist (Figure 57). Riprapping by excavator and loader was also slow because each rock had to be handled separately in order to key the rocks into position.

Frequently, some equipment was idle when all five machines were in the relatively small, confined area. Idle equipment, coupled with saturated conditions within the channel, caused the log jam sediment excavation cost to be the highest unit cost on the entire site ($12.90 per cubic yard). Unfortunately, work could not have been done more efficiently with other equipment.

Six channel cross-sections (Figure 67) and the stream longitudinal profile (Figure 68) at the log jam site were surveyed five times: prior to rehabilitation, immediately after heavy equipment work and after each of the next three winters. Maps of the area were made in 1979 (prior to rehabilitation) and following the third winter (Figure 58). These data were used to document post-rehabilitation channel changes and evaluate work effectiveness. Approximately 600 cubic yards of alluvium were excavated from the channel behind the log jams and 850 cubic yards from the oversteepened hillslope adjacent to the channel.


Distance below arbitrary datum (feet)
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Distance from left bank end stake (feet)
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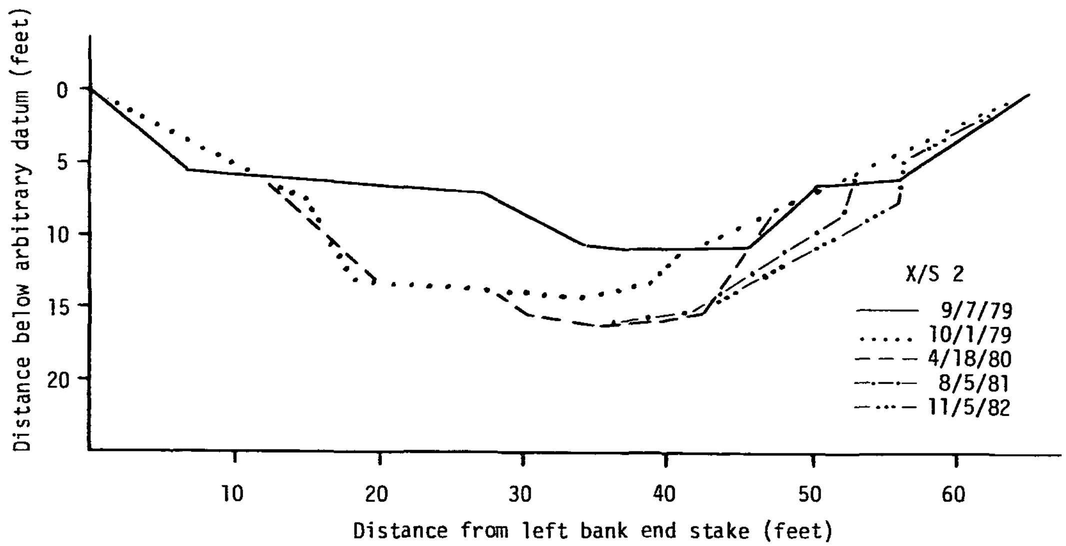
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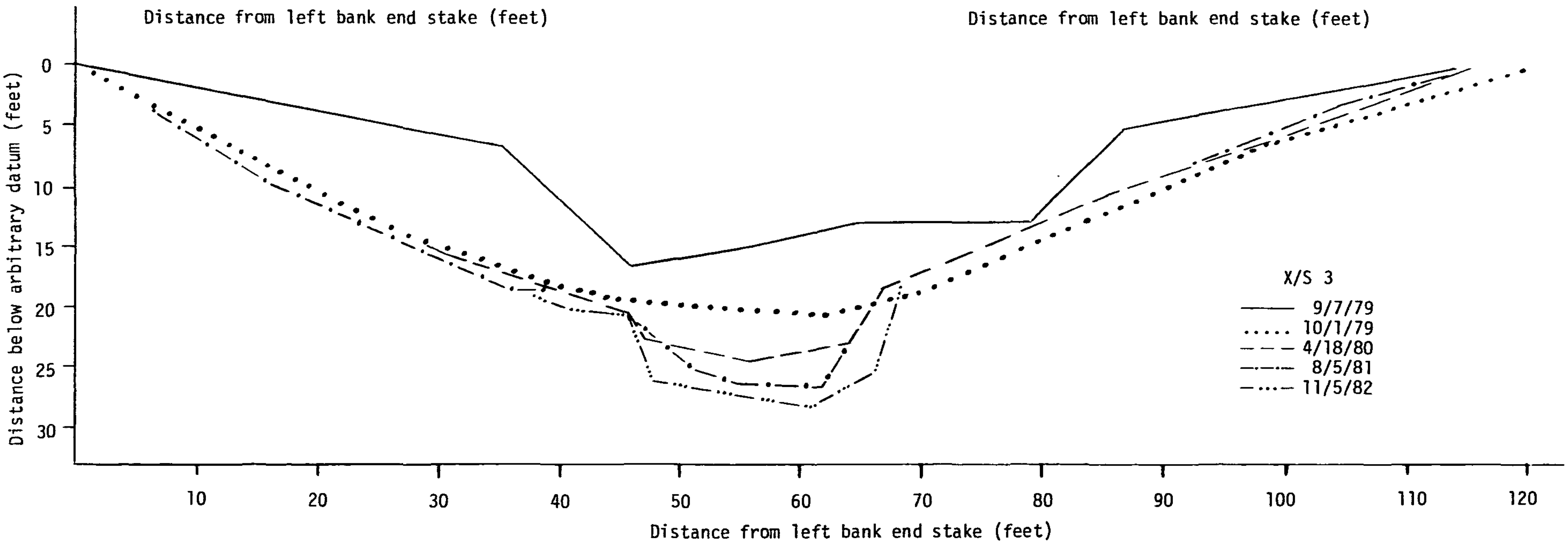
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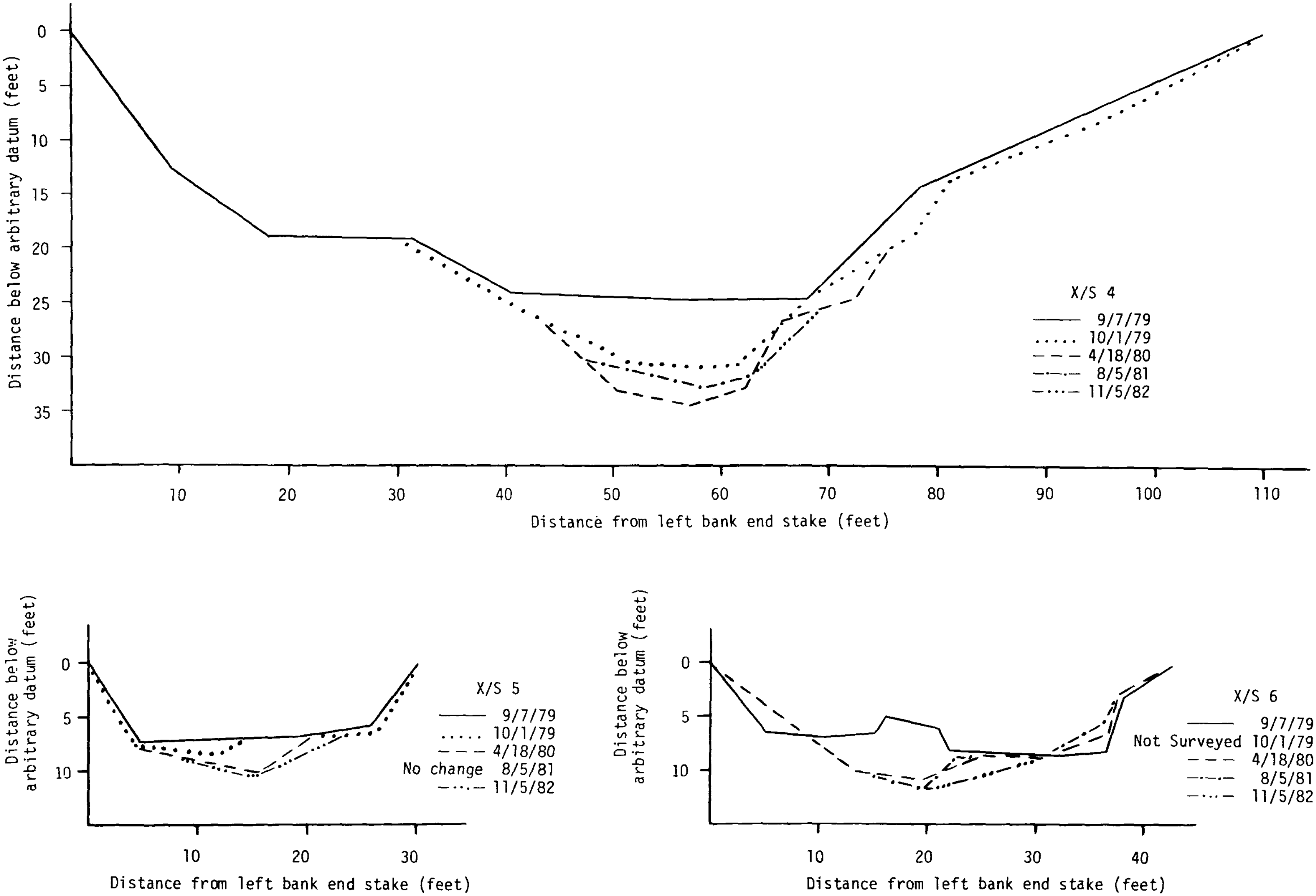

Fig. 67. Six channel cross-sections of Copper Creek at the site of the excavated log jam. Cross-sections were measured prior to log jam removal (September 1979), immediately following heavy equipment operations (October 1979) and once during each of the following three years (April 1980, August 1981, November 1982).

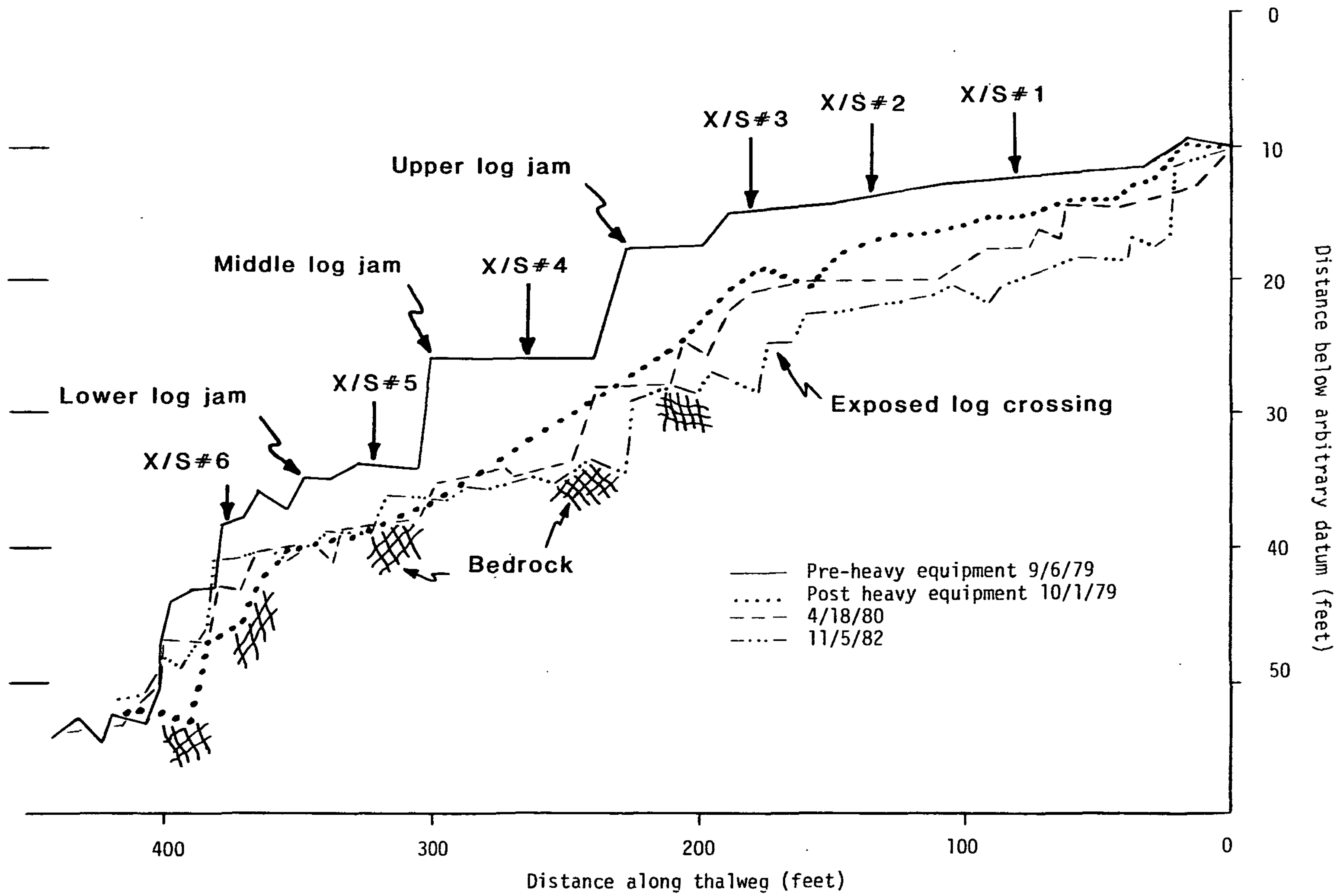

Fig. 68. Longitudinal profiles of Copper Creek at the log jam removal site. The four profiles show the trace of the channel thalweg before log jam removal, immediately following heavy equipment work and once during each of the following two years.

As a result of the 1980 winter storms, an additional 560 cubic yards were eroded from the site. Most of the bedload loss was associated with channel scour from increased flow velocities on the unprotected loose sediment within the excavated stream reach. During the following winter (1981) an additional 60 cubic yards were eroded (Figure 69). Most of this occurred near cross-sections 2 and 3 where an average of 2 - 4 feet of bank erosion was detected (Figure 67).

The change in erosional mechanisms from channel downcutting to channel widening was predictable. By 1982, in-place, stream-bed boulders were being exhumed throughout much of the log jam reach (Figure 70). The increase in particle size (roughness) coincided with the exposure of stumps whose basal flair indicated the stream channel was nearing its original grade. With the exception of the upstream migration of a few knick points in the channel profile (Figures 68 and 69), the dominant response to increased discharge was channel widening (Figure 67). The excavated, unstable hillslopes along the right bank (Figure 58) remained intact through November 1982. The primary objective of stabilizing the adjacent hillslopes through removal of the log jam was attained. Total cost for log jam removal including riprapping, was $10,250, averaging $6.00 per cubic yard of material excavated.

Pitlick (1981) suggests one approach for determining the feasibility of removing log jams for the purpose of reducing streambank instability. The approach centers around producing a quantitative statement of the erosion potential of the site. It is possible to define positive benefits or negative effects that will result from removing a log jam using only simple field measurements. In the event that the log jam is removed, measurements taken while work is in progress can help determine whether the excavation is adequate or beyond prescription.

5. Road ripping

In 1978, all roads were ripped prior to any road removal operations, such as outsloping. Because of the observed re-compaction of road surfaces during rehabilitation work and the resultant slow rate of revegetation seen on 1978 units, road ripping in Copper Creek was delayed until just before each road segment was to be removed. To keep the large TD-25 ripping tractor on site throughout the project, it had to be guaranteed 40 hours of work. Thus, many hours were paid for its intermittent use. The non-productive, standby hours greatly inflated the itemized costs for stream crossing excavations, outsloping landings and the ripping of roads and landings (Table 26). Approximately $25,000 (one-eighth of the total rehabilitation costs) were associated with standby or other non-productive hours of the TD-25 tractor.

Ripping roads as the last step during rehabilitation appeared to have enhanced natural seeding and revegetation efforts at Copper Creek (Figure 71). Ripping at this late stage appeared more effective than similar disaggregation practices done at the beginning of heavy equipment operations, when recompaction occurred. However, given the

Fig. 69. Channel view from the top of the middle log jam step, looking upstream at the upper log jam step. A) before treatment, large quantities of sediment stored in the channel behind the middle step (foreground) have partially buried the base of the upper log jam; B) same view following the first winter after treatment, note the rip rap placed against the right bank (left of photo) and the nickpoint forming where additional organic debris is being exhumed; C) three years following log jam removal (September 1983) note the persistent step in the channel profile created by the remaining organic debris (this step is graphically shown at station 250 feet on Figure 68).

Fig. 70. Exhumed cobbles and boulders in the treated reach between the middle and upper log jam steps, Copper Creek. Within the first two years following channel clearance, the stream had downcut and widened several feet and exposed stable boulders in the bed of the original channel.

high costs necessary to keep an expensive ripping tractor on-site for the project duration, this application of equipment was not cost-effective. In subsequent years, ripping cats have been extensively used for excavations and outsloping, warranting their continued use for ripping.

6. Cross-road drain construction

The combined use of a tractor and excavator was the most efficient for constructing cross-road drains (averaging 2-3 feet deep, 3 feet wide and approximately 35 feet long). The average costs for cross-road drain construction, including transit time between drains, are compared in Table 29. More recent rehabilitation work at Redwood National Park has shown that using tractors by themselves is the most cost-effective method for constructing cross-road drains.

TABLE 29

Comparison of Methods of Cross-Road Drain Construction, 79-4

Equipment	Number of Drains	Hours	Hours/Drain	Unit Cost
Backhoe	19	11.0	0.50	$20.26
Excavator	15	3.0	0.20	13.00
Tractor/Excavator	23	5.5	0.23	10.00

Fig. 71. Natural revegetation of a decompacted road surface. A) before rehabilitation. the former road surface showed little natural revegetation in the 10 years following its abandonment; B) same area immediately following decompaction and outsloping (November 1979); C) four years later (September 1983) the site has been covered with naturally invading coyote brush. Revegetation of this hot, dry southwest facing slope contrasts sharply with the cool moist areas in Bridge Creek (unit 79-2) which were invaded by rapidly growing alder.

F. Labor Intensive Work

Labor intensive work followed the completion of heavy equipment operations (Table 26 and Figure 72). Labor intensive erosion control work on areas not disturbed during heavy equipment work included waterbar construction, manual excavations, channel clearance, bank stabilization, gully diversions and gully headcut removal projects. The majority of treatments on sites disturbed by heavy equipment were rocking newly excavated stream channels, mulching and grass seeding. Other treatments included the construction of checkdams, water ladders and ravel catchers, knickpoint removal and some manual excavation. Revegetation treatments (transplants, stem cuttings, seedlings and seeding) were limited to areas disturbed during rehabilitation (Figure 73).

Copper Creek was divided into three labor intensive work areas (Figures 72 and 73). Park employees spread grass and fertilizer on the upper unit, planted Douglas-fir on the upper and middle units and spread mulch on all three (Figure 74). All other labor intensive work on the upper and middle work areas were completed under two Invitation-for-Bid (IFB) contracts. On the lower area, park labor crews did all physical erosion control work and some vegetative labor intensive work, while Redwoods United, Inc. crews planted redwood and shrub seedlings.

Portions of the unit were seeded with grass, fertilized and mulched by park personnel prior to October 15, 1979 in order to have treatments completed before the onset of winter rains. Barley and a mixture of perennial grasses (33 percent 'Highland' colonial bentgrass, 33 percent 'Akaroa' orchardgrass, 17 percent creeping red fescue, and 17 percent 'Oregon' perennial ryegrass, by weight) were applied at rates of 30 and 50 pounds per acre. 16-20-0 fertilizer was applied at 250 and 500 pounds per acre.

Straw and experimental mulches were also applied. Straw mulch was applied at a rate of 2000 pounds per acre. Experimental mulches included a manure-sawdust mixture, hardwood bark and Monterey pine, Douglas-fir and redwood chips. The redwood chips and hardwood bark were donated by local lumber mills with the only costs being for loading and transport. A park roadside thinning project provided Monterey pine and Douglas-fir chips. The "chips" were actually a mixture of partially shredded whole trees, branches and needles.

Combinations of grass seed, fertilizer and mulch (Figure 74) were applied to test areas to evaluate application rates, seed mixture survival and growth, and the effects of treatments on natural revegetation (Popenoe, 1982). Plot treatments are listed in Table 30.

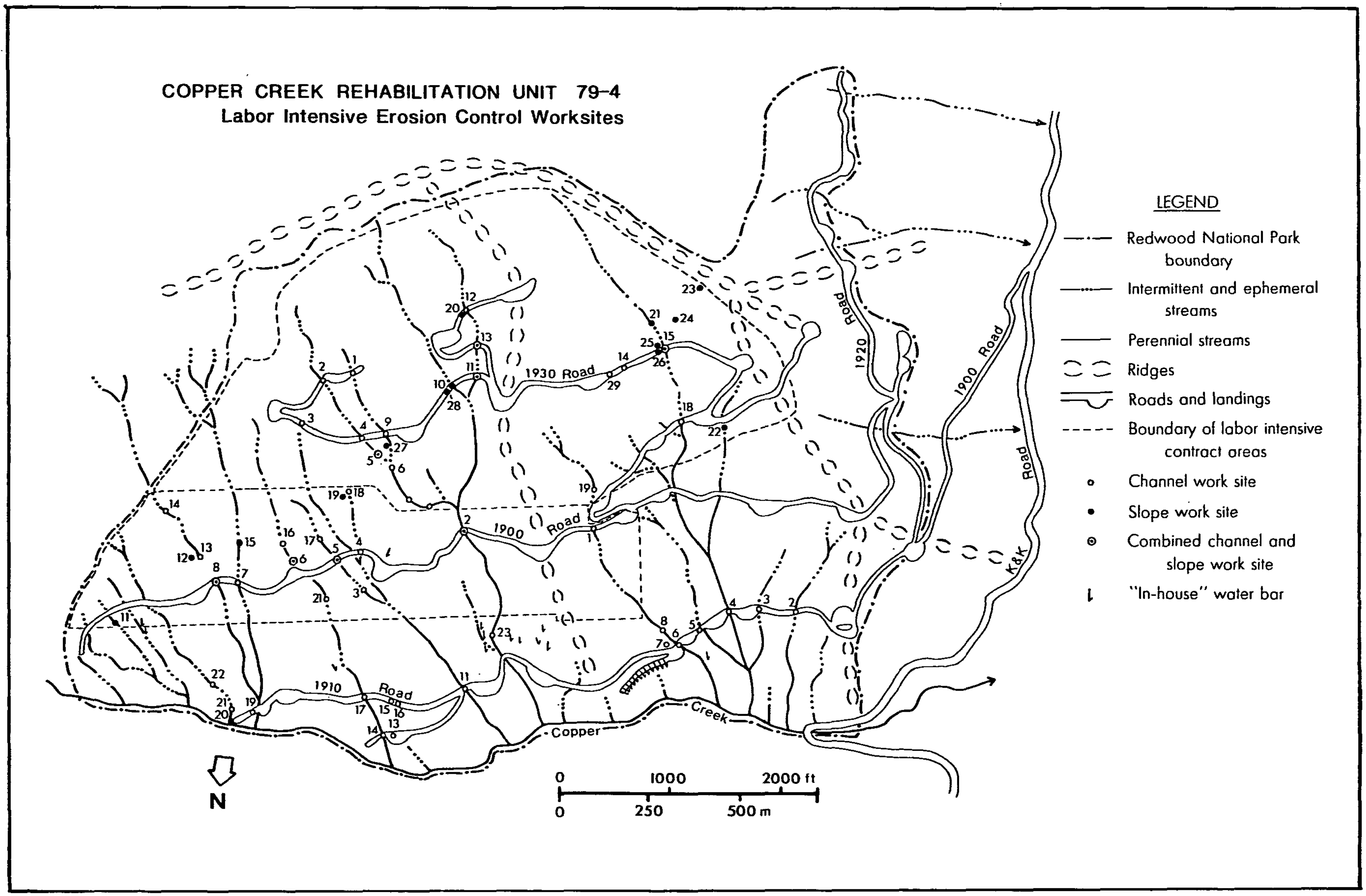

Fig. 72. Labor intensive erosion control work sites on the Copper Creek rehabilitation unit. Note the dashed lines which delineate the upper, middle and lower contract areas.

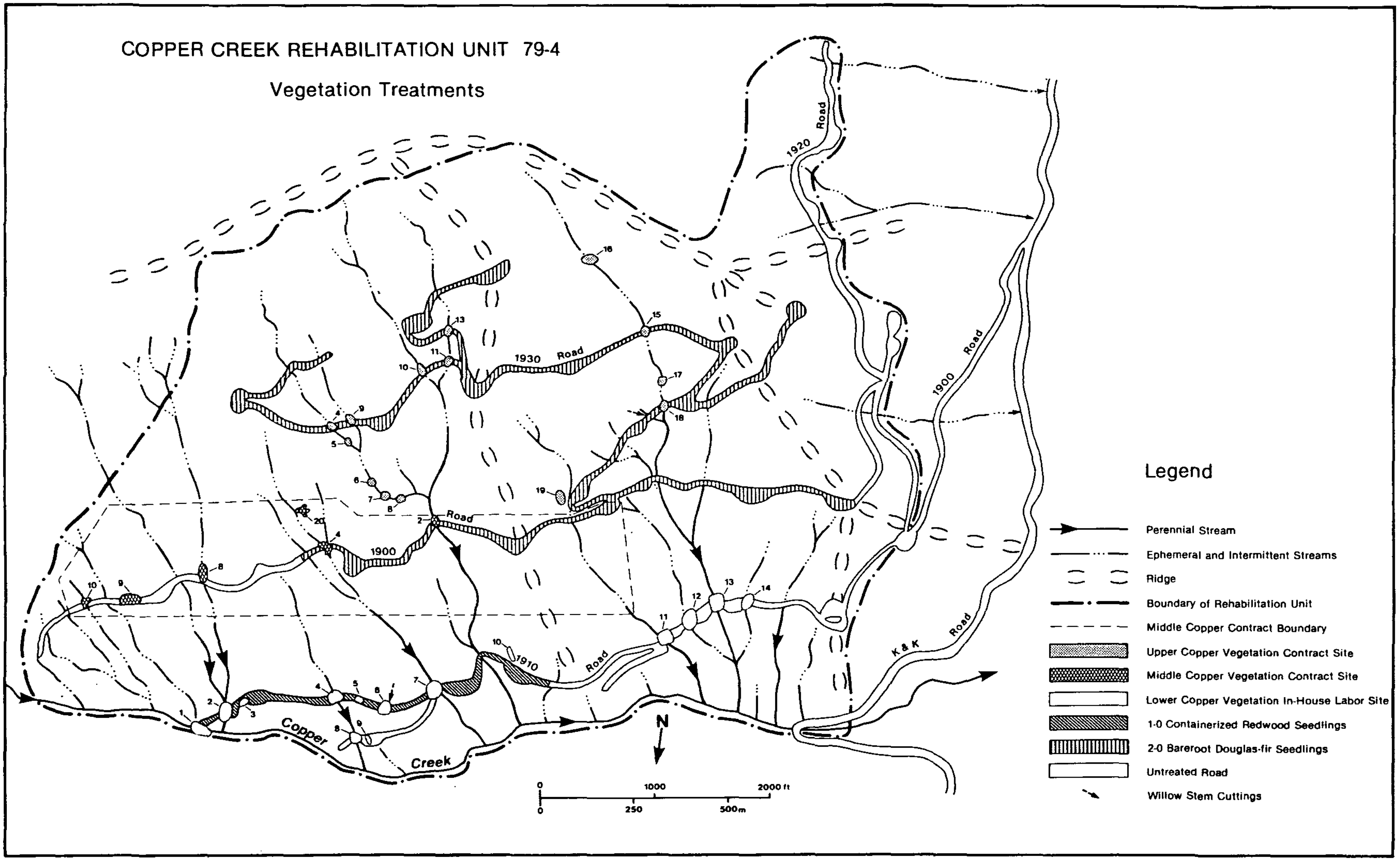

Fig. 73. Vegetation treatments on the Copper Creek rehabilitation unit.

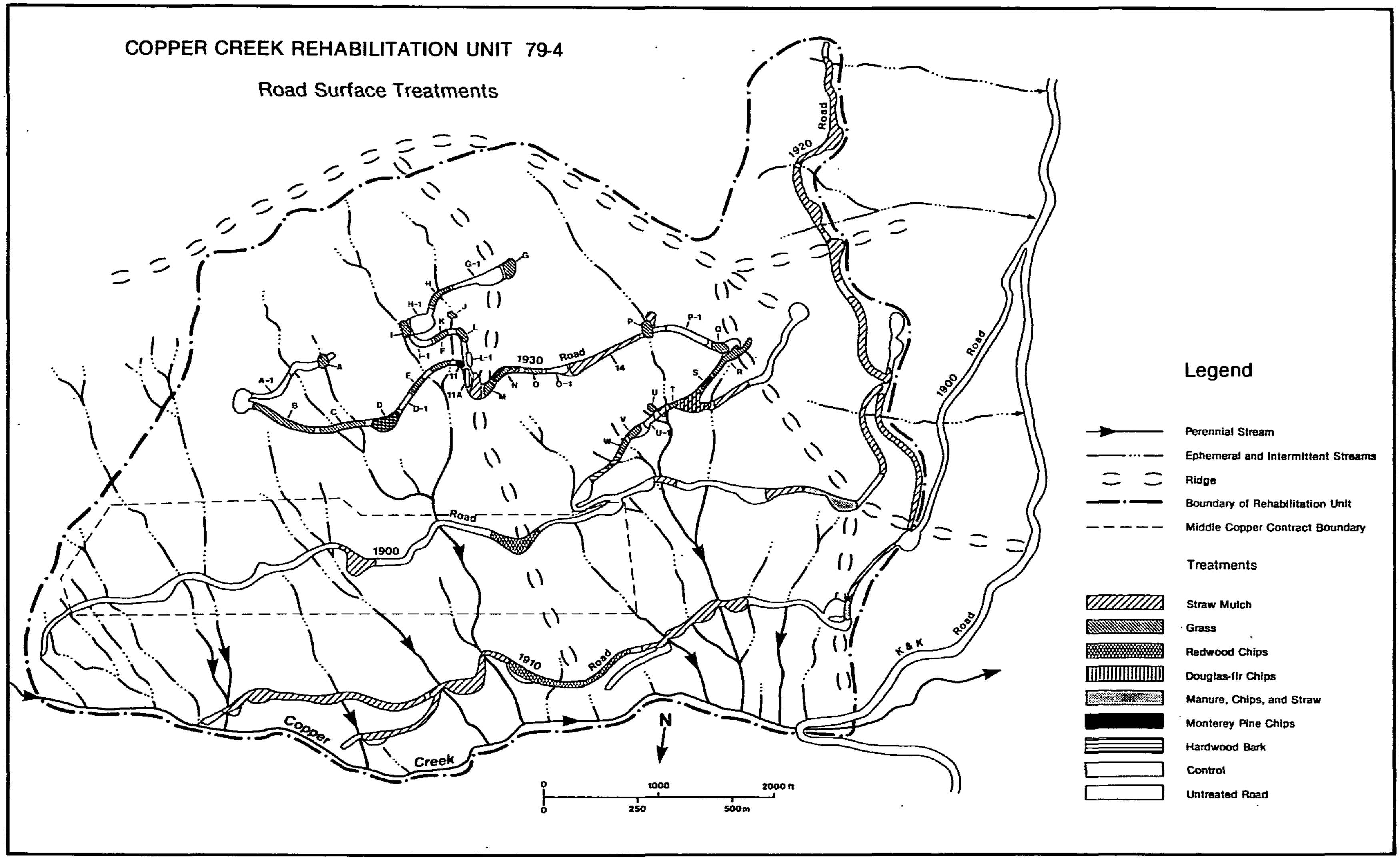

Fig. 74. Road surface treatments (mulching and grass seeding) on the Copper Creek rehabilitation unit.

TABLE 30

Upper Copper Creek Experimental Road Treatments

Plot[1]	Acres Treated	Grass Mix	Seed Rate (Lbs/Ac)	Fertilizer[2] Rate (Lbs/Ac)	Mulch
A[3]	0.30	RNP	50	250	None
B	0.28	Barley	50	500	None
C	0.26	RNP	50	500	None
D[3]	0.08	Barley	50	500	DF[4]
E	0.10	RNP	50	500	None
F	0.13	RNP	50	0	None
G[3]	0.33	Barley	50	250	None
H[3]	0.11	Barley	50	250	None
I[3]	0.15	RNP	50	250	None
J	0.07	Barley	50	250	None
K	0.06	RNP	50	250	None
L[3]	0.18	Barley	50	250	None
M	0.17	RNP	50	250	None
N	0.31	RNP	30	250	Straw[5]
O[3]	0.21	RNP	30	250	None
P[3]	0.17	RNP	50	250	None
Q	0.10	RNP	30	250	None
R	0.32	Barley	30	250	None
S	0.09	Barley	30	250	Straw[5]
T	0.05	RNP	50	250	None
U[3]	0.04	RNP	50	250	None
V	0.09	Barley	50	250	None
W	0.13	RNP	50	250	None

[1]See Figure 74 for plot locations.
[2]Ammonium phosphate (16-20-0).
[3]Control plot adjacent (see Figure 74).
[4]DF = Douglas-fir "chips".
[5]2,000 lbs/ac rate.

1. Upper Copper Creek contract

The upper Copper Creek labor intensive contract area incorporated approximately 220 acres of hillslope above and below the two mile segment of the 1930 road (Figure 72). A small amount of contract work was concentrated along the 1930 road within an approximately 20 acre area.

Treatments for the upper contract area were prescribed in September 1979. Contract specifications and the statement of work were written in October 1979. Park Service reviews and approvals were received by early November and the IFB contract was distributed to the public that month.

Six bids were received by December 3, 1979, ranging from $4,450 to $21,487. The lowest bid was retracted when it was determined that the bid was insufficient to complete the work necessary to fulfill specifications within the contract.

The next lowest bidder, Northcoast Reinhabitation Group, Inc. (NRG) of Blue Lake, California was awarded the contract for $10,156 on December 7, 1979. All work was completed between January 4 and January 28, 1980. Three change orders, totalling $1,156, were necessary to modify treatments to accomodate erosion following several early winter storms. The total upper Copper Creek labor intensive contract costs were $11,323 (Table 31). Hours worked were obtained from the contractor's daily worksheets and records kept by the project geologist.

a. Physical erosion control

In-channel treatments. Most of the physical labor-intensive work involved armoring excavated crossings. Fifteen of 28 stream crossing excavations were protected with hand-gathered four, six, or eight-inch mean diameter rock. Discharges were expected to be relatively low because the area was high on the slope and included stream crossing worksites with small drainage areas (4 to 26 acres). Streams with deeper incisions, larger drainage areas and higher estimated discharges received the largest rock.

Other in-channel treatments designed to minimize channel erosion included a rock and wood knickpoint plug, a channel clearance and bank stabilization task, notching of a log across a channel to act as a spillway and the manual excavation of fill material from a small channel. A waterladder was also constructed at worksite 9 (Figure 75) to prevent a cutbank headcut from developing and migrating upstream. The waterladder of Type 4 design (Madej and others, 1980) was made from milled redwood planks supplied by the park.

Hillslope treatments. Nine waterbars constructed on skid trails were the only labor intensive treatments designed to reduce minor hillslope gullying or stream sideslope surface erosion on areas not disturbed during heavy equipment operations. Hillslope work elsewhere included

TABLE 31

Upper Copper Creek Labor Intensive Contract Costs

Treatment	Person Hours	Number of Worksites	Quantity	Bid Unit Price	Total Cost ($)	Total Cost (%)	Actual Cost/Hr
IN-CHANNEL							
Rock Channel:4-inch	34	3	1,128 ft²	$0.96/ft²	$1,082.88		$31.85
Rock Channel:6-inch	111	10	3,269 ft²	0.73/ft²	2,386.37		21.50
Rock Channel:8-inch	42	2	918 ft²	0.84/ft²	771.12		18.36
Water Ladder	29	1	1	389.00	389.00		13.41
Rock/Wood Knickpoint Plug	4	1	1	111.00	111.00		27.75
Channel Clearance / Bank Stabilization	9	1	1	167.00	167.00		18.56
Log Across Channel	1	1	1	19.00	19.00		19.00
Channel Excavation	4	1	1	100.00	100.00		25.00
subtotal	234				$5,026.37	(44)	21.48
HILLSLOPE/STREAM SIDESLOPES							
Ravel Catchers	44	4	310 lin ft	$2.46/lin ft	$762.60		17.33
Contour Trenches	6	1	60 lin ft	1.11/lin ft	66.60		11.10
Wooded Terraces	4	1	46 lin ft	2.42/lin ft	111.32		27.83
Waterbars	15	9	217 lin ft	3.69/lin ft	800.73		53.38
Manual Excavations	4	1	5.0 hrs.	18.51/hr	92.55		23.14
Material Transport	3	1 job	1	50.00	50.00		16.67
subtotal	76				$1,883.80	(17)	24.79
REVEGETATION							
Transplants	123.5	12	1,498	$0.62-1.85ea	$2,552.59		20.67
Stem Cuttings	38.5	7	1,225	0.56-0.85ea	735.16		19.10
Grass Seeding/Fertilizing	1	1	6 lbs	2.49/lb	14.94		14.94
subtotal	163				$3,302.69	(29)	20.26
CONTRACTOR ADMINISTRATION COSTS							
Materials Preparation & Transportation	24						-
Personnel & Equipment Transportation	77						-
Organization Time	53						-
Discussion with C.O.R.	13						-
Tool Maintenance	15						-
Documentation of Person-Hours/Task	20						-
subtotal	202			$1,110.00		(10)	5.50
		TOTAL CONTRACT COST		$11,322.86		(100)	

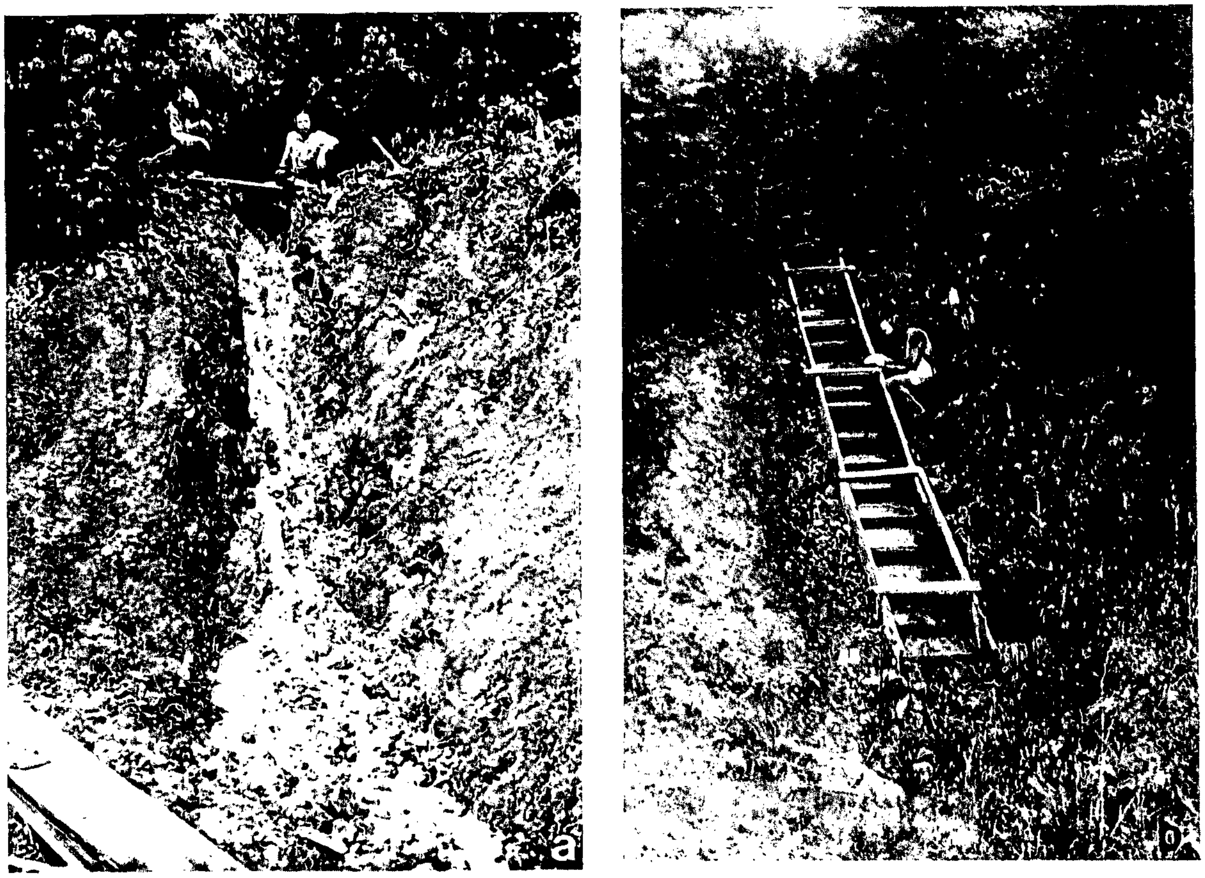

Fig. 75. Water ladder constructed at worksite 9, on the 1930 road, in the upper Copper Creek contract area (see Figure 72). A) before construction, runoff flowing down a former skid trail and over a steep cut bank was causing gully erosion and filling the inboard ditch of the abandoned logging road; B) since the water could not be diverted off the trail, a water ladder was constructed to carry the flow over the erodible bank.

construction of ravel catchers, wooded terraces, contour trenches and manual excavations (for descriptions see Madej and others, 1980, and Weaver and Madej 1981). Construction of ravel catchers along the sideslopes of excavated stream crossings accounted for much of the secondary hillslope treatment costs (Table 31).

b. Revegetation

Vegetation treatments were applied January 11, 25, 26, and 27, 1980 (Tables 31, 32). Seven native species were transplanted: 'Alta' fescue, cattail, coyote brush, madrone, rush, salal and whipplea. Five species of stem cuttings were planted: black huckleberry, coyote brush, salmonberry, sitka willow and whipplea. The transplants and stem cuttings were collected on-site.

The contractor spread a small amount of grass seed and fertilizer on one worksite following the installation of ravel catchers and contour trenches. The grass seed mixture was applied at 50 pounds per acre and ammonium phosphate fertilizer (16-20-0) was applied at 250 pounds per acre.

TABLE 32

Upper Copper Creek Contract Vegetation Treatments

Treatments	NUMBER PLANTED, BY SITE 4	5	6	7	8	9	10	11	13	15	16	17	18	19	TOTAL NUMBER	UNIT PRICE	TOTAL COST
Transplants																	
'Alta' Fescue											51				51	$2.31	$ 117.81
Cattail									20		12				32	0.73	23.36
Coyote Brush						65				156					221	1.54	340.34
Madrone	10				23										33	1.55	51.15
Rush									79			25			104	0.62	64.48
Salal	83	33				66			58	157			80		477	1.85	882.45
Whipplea	102		22		21	66		17	30	157			80	85	580	1.85	1,073.00
														subtotal	1,498	1.70	$2,552.59
Stem Cuttings																	
Coyote Brush		192		60				15	30			329			626	0.60	375.60
Huckleberry		33													33	0.57	18.81
Salmonberry								15							15	0.85	12.75
Whipplea		46	100	81											227	0.56	127.12
Willow							221	15	88						324	0.62	200.88
														subtotal	1,225	0.60	$735.16
Other Vegetation																	
Grass								1lb							1 lb	2.49	2.49
Fertilizer								5lbs							5 lbs	2.49	12.45
														subtotal	6 lbs	2.49	14.94
TOTAL COST OF CONTRACT VEGETATION TREATMENTS																	$3,302.69

construction of ravel catchers, wooded terraces, contour trenches and manual excavations (for descriptions see Madej and others, 1980, and Weaver and Madej 1981). Construction of ravel catchers along the sideslopes of excavated stream crossings accounted for much of the secondary hillslope treatment costs (Table 31).

b. Revegetation

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The contractor spread a small amount of grass seed and fertilizer on one worksite following the installation of ravel catchers and contour trenches. The grass seed mixture was applied at 50 pounds per acre and ammonium phosphate fertilizer (16-20-0) was applied at 250 pounds per acre.

c. Costs

Revegetation treatments totalled 29 percent ($3,300) and physical treatments were 61 percent ($6,910) of the total contract cost. Contractor administration costs were $1,110 (10 percent). Of the physical treatments, $5,030 (73 percent) was for in-channel work (mostly channel armoring) and $1,880 (27 percent) was for hillslope and stream sideslope work (Table 31).

2. Middle Copper Creek contract

The middle Copper Creek labor intensive contract area was located immediately downslope from the upper contract area. It consisted of approximately 90 acres of hillslope bisected by 0.8 mile of the 1900 road (Figure 72). Most erosion control and revegetation work locations were concentrated on approximately four acres along the road.

Both vegetal and physical erosion control treatments were prescribed over six person-days in September 1979. Contract preparation was completed in mid-November 1979. On December 20, 1980 the IFB contract was distributed to the public. Six bids were received, ranging from $4,888 to $76,122. On January 23, 1980, Forrest D. Lane of Orick, California was awarded the contract for $4,888. Work was completed between January 24 and February 22, 1980. One change order ($3,293) was issued to compensate for changes at worksites caused by early winter rains after the contract was prepared. The majority of the change order was for additional channel armoring at locations where up to 5 feet of downcutting had occurred. The total middle Copper Creek contract cost, including the change order, was $8,181 (Table 33). An analysis of actual cost-per-hour to perform work items was not possible due to inadequate documentation of hours expended to complete tasks.

TABLE 33

Middle Copper Creek Labor Intensive Contract Costs

TREATMENT	NUMBER OF WORKSITES	QUANTITY	UNIT PRICE	TOTAL COST ($)	(%)
IN-CHANNEL					
Rock Channel: 4-inch	2	392 ft²	$1.15/ft2	$ 450.80	
Rock Channel: 6-inch	3	1,066 ft²	0.65/ft²	692.90	
Rock Channel: 8-inch	4	6,155 ft²	0.60/ft²	3,693.00	
Rock Channel:12-inch	1	753 ft²	0.35/ft²	263.55	
Double Rock Channel: 8-in	1	438 ft²	1.20/ft²	525.60	
Rock Spreading	1	1	275.00	275.00	
Log Removal	1	1	35.00	35.00	
Log Across Channel	1	1	15.00	15.00	
Checkdams	1	5	21.50	107.50	
Channel Clearance	1	1	125.00	125.00	
Knickpoint Removal	1	1	75.00	75.00	
			subtotal	$6,258.35	(77)
HILLSLOPE/STREAM SIDESLOPES					
Ravel Catchers	4	486 lin ft	1.10/lin ft	534.60	
Waterbars	3	92 lin ft	2.30/lin ft	211.60	
Deep Waterbars	1	38 lin ft	2.50/lin ft	95.00	
Gully Diversion (Site 14)	1	1	200.00	200.00	
Gully Diversion (Site 18)	1	1	40.00	40.00	
Gully Diversion (Site 21)	1	1	100.00	100.00	
Ditch Extension	1	1	65.00	65.00	
Manual Excavation	1	1	12.00	12.00	
			subtotal	$1,258.20	(15)
REVEGETATION					
Transplants	1	70	1.75 ea.	122.50	
Stem Cuttings	5	533	0.50-0.75ea.	341.50	
			subtotal	$464.00	(6)
CONTRACTOR ADMINISTRATION COSTS				$200.00	(2)
			TOTAL CONTRACT COST	$8,180.55	(100)

a. Physical erosion control

In-Channel treatments. Hand placement of rock armor in excavated stream channels accounted for 94 percent ($5,900) of in-channel work on the middle Copper Copper contract area (Table 33). Nine out of eleven stream channel excavations were protected with four, six, eight or twelve inch mean diameter rock. Because the contract area was in the midslope region, drainage areas were generally larger (7 - 87 acres) and stream crossings had significantly higher discharges than in the upper area. Therefore, the average diameter of rock armor was eight-inches instead of the six-inches used in the upper contract area. Four work horses were used to transport rock aggregate from the ripped road and adjacent hillslopes to stream channel worksites (Figure 76). At worksite 1, about 25 cubic yards of rock were stockpiled by dump trucks during the heavy equipment operations. The contractor had only to distribute the rock, most of which averaged about 12 to 15 inches in diameter. This represents the upper size limit easily managed by hand.

Checkdams were installed by the contractor at worksite 8 to prevent headcut development and migration where a small stream crossed the steep sideslopes of a larger channel. Channel clearance of three to four cubic yards of fill and organic debris at worksite 3 was the only in-channel treatment performed where heavy equipment had not operated.

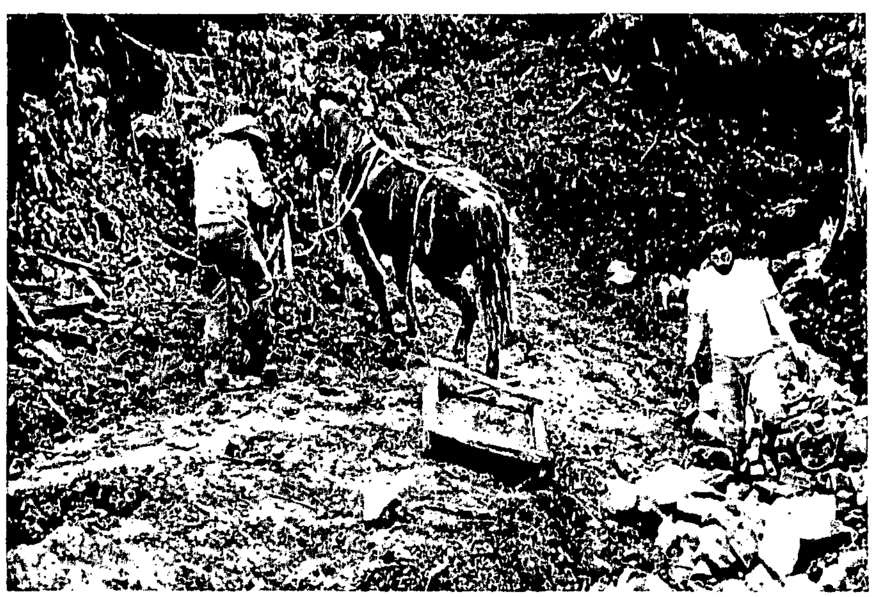


Fig. 76. Horses and sleds moving rock for stream crossing armoring in the middle Copper Creek contract area. The rocks were then placed in the channel by hand. In the smaller streams, hand-placed rock armor was generally successful in controlling post-rehabilitation erosion.

Hillslope treatments. Ravel catchers installed on the steep sideslopes of four excavated stream crossings were designed to control sheet and rill erosion on bare soil areas. To re-route concentrated runoff, waterbars, extra deep waterbars and ditch extensions were constructed at five locations, and minor gully diversion work was completed at three locations, (Table 33 and Appendix B).

b. Revegetation

The rehabilitated road was a narrow corridor through otherwise dense vegetation, requiring little treatment. Treatments were restricted to five excavated logging road stream crossings and one skid trail stream crossing. Whipplea and willow stem cuttings and whipplea transplants collected on-site were the only vegetation treatments used (Table 34).

TABLE 34

Middle Copper Creek Contract Vegetation Treatments

	--------Work Site--------						Total	Unit	Total
Treatment	2	4	8	9	10	20	Number	Cost	Cost
Whipplea Transplants	74						74[1]	$1.66	$122.50
Whipplea Stem Cuttings				66		167	233	0.50	116.50
Willow Stem Cuttings		34	80	115	183		412[2]	0.55	225.00
								TOTAL	$464.00

[1]Contract specified 70 and only 70 were paid for.
[2]Contract specified 300 and only 300 were paid for.

c. Costs

Labor intensive physical erosion control treatment costs totalled $7,520 or 92 percent of the total contract cost (Table 33). Of the total costs for physical treatment, 83 percent was spent on in-channel work and 17 percent for hillslope and stream sideslope treatments. Contractor administrative costs (primarily the preparation of daily worksheets) were $200 or 2 percent of the total contract. In contrast to the upper area contract, where vegetation treatments amounted to 29 percent of the total contract, vegetation treatments in the middle contract area represented 6 percent ($464) of the final cost. This reflects the abundant existing natural revegetation adjacent to rehabilitation-disturbed areas and generally more hospitable conditions for vegetation re-establishment.

3. Lower Copper Creek in-house work

Of the total 300 acres of hillslope within the lower Copper Creek area, most work was concentrated on a total of 20 acres along the 1.8 mile long 1910 road (Figure 72). Five NPS personnel spent two days in early December 1979 prescribing revegetation and erosion control treatments. Another day was spent drafting a work location map and outlining the treatment areas. Redwood National Park crews performed all labor intensive erosion control work and some revegetation work. The average labor crew consisted of eight persons. Crews from Redwoods United, Inc. planted redwood and shrub seedlings.

a. Physical erosion control

In-channel treatments. A total of 9,540 square feet of rock, averaging eight to twelve inches in diameter, was placed at 16 stream crossing excavations (Table 35). Where rock had been supplied by heavy equipment, laborers simply redistributed it. At the remaining half of the worksites, rock was hand-gathered from the adjacent road surface or hillslopes. Every stream channel which crossed the 1910 road was rocked.

Hillslope treatments. Waterbars and straw mulching constituted the other major work tasks. Twenty-five waterbars were constructed by hand at scattered locations above and below the 1910 road.

b. Revegetation

The lower Copper Creek area had abundant alder seed sources along narrow portions of the 1910 road, but large bare areas and slopes presented problems for rapid natural colonization. A small number of willow stem cuttings were placed in a single, wet section of road shortly after rehabilitation. The rest of the revegetation treatments were done on an experimental basis as plants became available from other projects. In March 1980, alder seedlings and alder/grass seed test plots were installed on moderate to harsh sites or those lacking an abundant seed source. Alder seedlings were planted at four sites on the 1910 road.

Five alder/grass seeding sites were sown to test the effectiveness of seeding alder in the spring. The grass was added to facilitate sowing the small alder seed. The seed mix was composed of 1:25 and 1:50 of alder seed and RNP grass mix, respectively.

Rooted cuttings of whipplea and coyote brush, and coyote brush seedlings from an experimental propagation contract, were planted by Redwoods United, Inc. crews between April 28 and May 8, 1980. One-year old containerized redwood seedlings and additional whipplea rooted cuttings were planted in February 1981 (Table 36).

TABLE 35

Lower Copper Creek In-House Labor Intensive Costs

Treatment	Person Hours	Number of Worksites	Quantity	Unit Price	Total Cost ($)	Total Cost (%)	Actual Unit Cost ($/hr)
IN-CHANNEL							
Rock Channel: 4-inch	11	2	171 ft^2	$0.43/$ft^2$	$73.00		$6.64
Rock Channel: 6-inch	10	2	274 ft^2	0.23/ft^2	63.00		6.30
Rock Channel: 8-12-inch[1]	365	12	9,095 ft^2	0.30/ft^2	2,684.00		7.35
Notch Logs Across Channel	4	2	2	14.00	28.00		7.00
				subtotal	$2,848.00	(35)	$7.30
HILLSLOPE/STREAM SIDESLOPES							
Waterbars	49	25	460 lin ft	0.75/lin ft	345.00		7.04
Manual Excavation	14	1	1	99.00	99.00		7.07
				subtotal	$444.00	(6)	7.05
REVEGETATION							
Grass/Alder Seeding	10	5	*[2]	*[2]	*[2]		*[3]
Alder Seedlings	*[3]	4	450	0.10 ea	45.00		*[3]
Shrub Planting	250	5	3,436	0.125-0.35ea	1,119.35		4.48
Redwood Seedlings	60		2,000	0.10 ea	200.00		*[3]
Willow Stem Cuttings	2	1	57	*[2]	*[2]		*[3]
Labor to Plant Seedlings and Shrubs					2,650.00		*[3]
				subtotal	$4,014.35	(50)	
MISCELLANEOUS COSTS							
Treatment Prescription	24				218.10		9.08
Labor Supervision	56				508.90		9.09
				subtotal	$727.00	(9)	$9.09
			TOTAL IN-HOUSE TREATMENT COST		$8,033.35	(100)	

[1]Half of rock was supplied and initially placed by heavy equipment.
[2]Documentation not available.
[3]Labor cost not available.

TABLE 36

Lower Copper Creek In-House Vegetation Treatments

Treatments	Date Completed	Work Site 1	2	3	4	5	6	7	8	9	10	11	12	13	14	1910 Road	Total Number	Unit Price	Total Cost
Willow Stem Cuttings	(10/79)						57										57	*[4]	*[4]
Alder/Grass Seeding	(3/80)	*[3]	*[3]	*[3]	*[3]	*[3]											*[3]	*[4]	*[4]
Alder Seedlings[1]	(3/80)											120	50	100	180		450	$0.10	$45.00
Coyote Brush, cuttings[2]	(4/80)	420	119				35	200	27								801	0.85	280.35
Coyote Brush, seedlings[2]	(4/80)	579	149				54		196								978	0.35	342.30
Whipplea, stem cuttings[2]	(4/80)	438	129				40	327	269	84							1,287	0.35	450.45
Whipplea, stem cuttings[1]	(2/81)										370						370	0.125	46.25
Redwood, 1-0 seedlings[1]	(2/81)	100	100				350	75			200					1,175	2,000	0.10	200.00
																TOTAL MATERIAL COST			$1,364.35
																LABOR COST			2,650.00
																TOTAL VEGETATION TREATMENT COST			$4,014.35

[1]Grown by Simpson Timber Co. Nursery, Korbel, CA.
[2]Grown by Nor-cal Nursery, Eureka, CA.
[3]Amount unknown, seeded by biological technicians.
[4]Labor and materials costs unknown.

c. Costs

Physical erosion control treatment costs totalled $3,290 or 41 percent of the total labor contract cost (Table 35). Of this, 87 percent was spent on in-channel treatments and 13 percent on hillslope and stream sideslope treatments. Vegetation treatments were 50 percent of the total labor intensive costs. Prescription development and labor supervision accounted for the remaining nine percent.

G. Evaluation of Labor Intensive Work

1. Physical erosion control

Rock Armoring. Forty-seven percent of the total labor intensive cost was for rocking newly excavated stream channels (Table 37 and Figure 76). A qualitative comparison of the effectiveness of rock armoring by heavy equipment and by hand is shown in Table 38. Evaluations were based on whether or not rock armor was necessary (if applied), needed (but not applied) and effective in preventing erosion.

TABLE 37

Labor Intensive Work Cost Summary for the Entire Copper Creek Unit

Treatment	---------Work Location-------- Upper Contract Costs	Middle Contract Costs	Lower In-house Costs	TOTAL COSTS ($)	(%)
IN-CHANNEL					
Primary[1]	$ 267	$ 125	0	$ 392	1
Secondary (Rock)	4,240	5,901	2,820	12,961	47
Other Secondary[2]	519	232	28	779	3
HILLSLOPE/STREAM SIDESLOPE					
Primary[3]	893	507	444	1,844	7
Secondary[4]	991	752	0	1,743	6
REVEGETATION[5]	3,303	464	4,014	7,781	28
ADMINISTRATION COSTS	1,110	200	727	2,037	8
TOTAL	$11,323	$8,181	$8,033	$27,537	100
PERCENTAGE OF TOTAL	41	30	29	100	

[1]Includes channel clearance and excavation, waterbars, some gully diversions and manual excavation at work sites where heavy equipment work did not occur.

[2]Includes checkdams, waterladders, knickpoint plugs, notching and removing logs in channels, remaining gully diversions and manual excavations.

[3]Includes waterbars, gully diversion work at site 14 (Middle Contract) and manual excavation.

[4]Includes ravel catchers, contour trenches, wooded terraces, gully diversions and manual excavations.

[5]Does not included in-house cost for spreading seed and mulch, or planting alders and willow stem cuttings.

Seventy-four of the 92 crossings showed little post-treatment erosion (Figure 77). These were either excavated down to the original channel or to a stable base level, or they were adequately protected with rock armor. The remaining 18 crossings showed substantial erosion (>5 percent of the excavated volume) which could have been prevented (Figure 78). Seven of these crossings had not received any secondary in-channel protection (Table 38).

Channel widening and downcutting were the dominant forms of erosion on the eleven rocked crossings experiencing scour (Figure 79). Problems included 1) rock too small to stay in place (8-12 inch mean diameter), 2) rock deflected flow into sideslopes causing bank erosion or flow channelization around rock armor and 3) stream channel gradients too steep to anchor or prevent transport of large rock (12-inch mean diameter). Rock armoring by hand was generally effective where streams drained less than 25 acres, but was not cost-effective on larger drainages. Larger rock supplied and placed by heavy equipment was found to be better for protecting channel beds. Most equipment-placed rock required some adjustment by hand after the first few major storms.

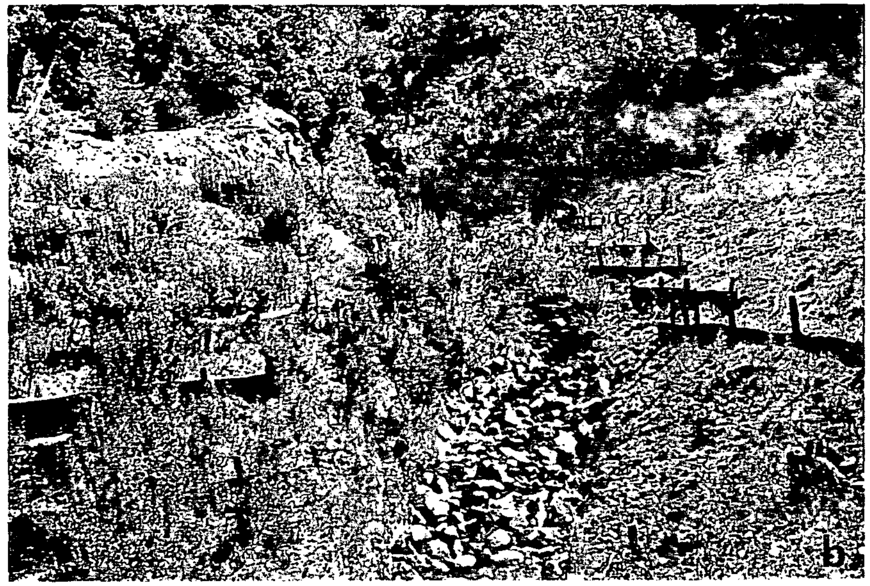
Other in-channel treatments. In-channel treatments other than rock armor totalled four percent of the labor intensive costs. Notched logs, knickpoint plugs and the waterladder were still functioning properly after four winters, but all will deteriorate and eventually fail. Checkdams and waterladders are comparatively cost-ineffective (Weaver and others, 1982) for correcting erosional problems but are used as temporary measures while vegetation is becoming established.

Hillslope treatments. All 38 hand-constructed waterbars were judged to be necessary treatments and were still working effectively to route concentrated hillslope flow toward nearby streams and away from mass movement features or slopes prone to gullying.

The majority of other labor intensive hillslope treatments were installed on sideslopes of freshly excavated stream crossings with sideslopes less than 60 percent. These included ravel catchers, wooded terraces, contour trenches and mulches.

With the exception of mulches, none of the treatments were judged to have been cost-effective or necessary. Many structures appeared to concentrate more runoff than they dispersed. Little sediment was impounded behind the structures, and rills usually developed where boards were joined or structures ended.

Weaver and Seltenrich (1981) and Weaver and others (1982) found that hillslope treatments such as ravel catchers, wooded terraces and contour trenches were most effective on slopes >60 percent. In most cases, straw mulches applied at 6,000 - 8,000 pounds per acre is more effective and cost-effective than hillslope structures for reducing surface erosion (Weaver and Seltenrich, 1981; Kveton and others, 1983) (Figure 80).



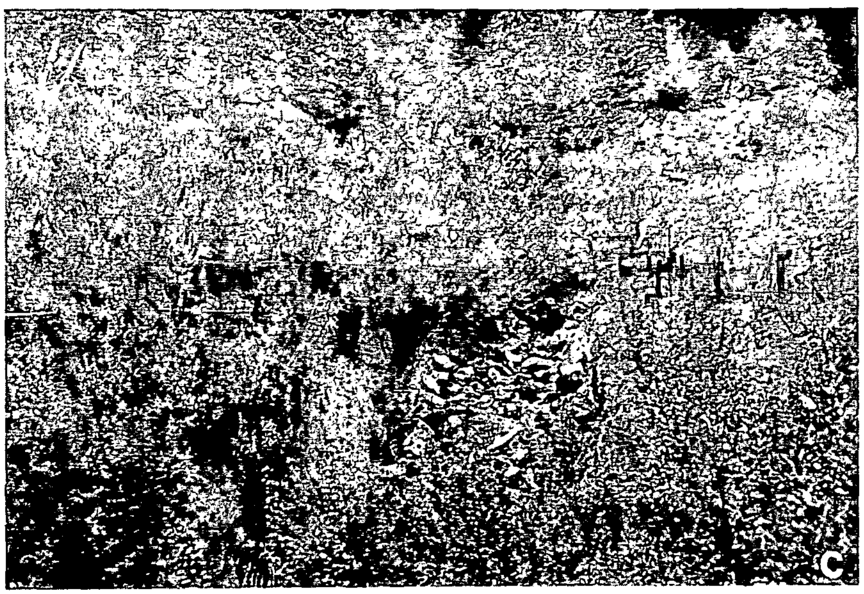


Fig. 77. Recovery of an excavated, rock armored stream crossing. A) the hand placed rock armor in this channel covered not only the channel bottom but also extended sufficiently far up the channel banks to protect the channel during higher flows; B) three years following treatment (September 1982), coyote brush has successfully invaded the site and little channel erosion has occurred; C) vegetation is now well established on the channel banks and within most of the channel bed (September 1983).

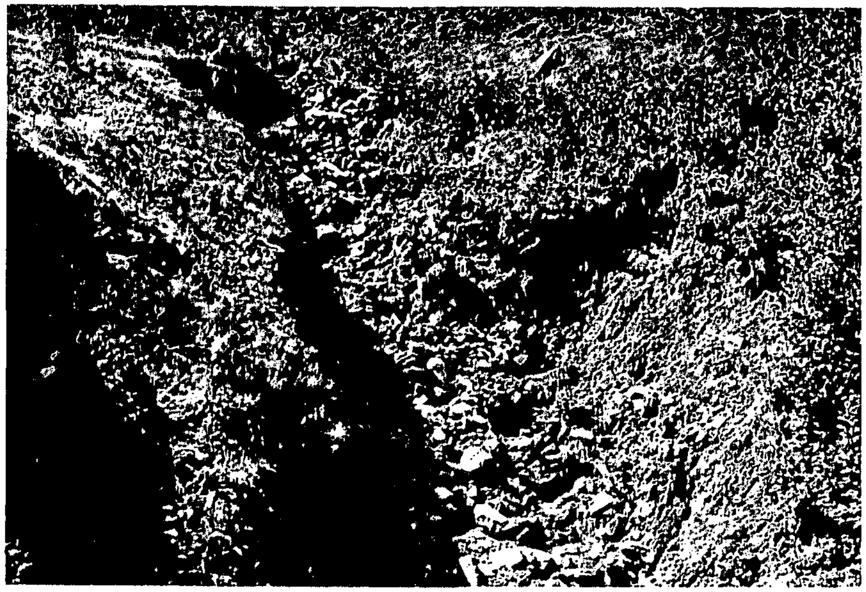


Fig. 78. Changes in an unprotected stream crossing following rehabilitation. The bed is now fairly well stabilized by the accumulation of a lag of cobbles and boulders, yet the oversteepened banks will still undergo continued adjustment as they collapse or are undercut (May 1982).

TABLE 38

Effectiveness of Rock Armor, 79-4

	Road Crossing		Skid Trail Crossing		
	Heavy Equipment	Labor Intensive	Heavy Equipment	Labor Intensive	TOTAL
ROCKED CHANNELS	NUMBER OF CROSSINGS IN EACH CATEGORY (ABOVE)				
Effective[1]	5	5	1	2	13
Effective, but unnecessary	1	8	0	3	12
Ineffective[2]	6	2	0	3	11
TOTAL	12	15	1	8	36
UNROCKED CHANNELS					
Effective	19		30		49
Ineffective, and needed rock	3		4		7
TOTAL	22		34		56

[1]Effective: <5 percent of excavated crossing fill eroded following rehabilitation.
[2]Ineffective: >5 percent of excavated crossing fill eroded following rehabilitation.

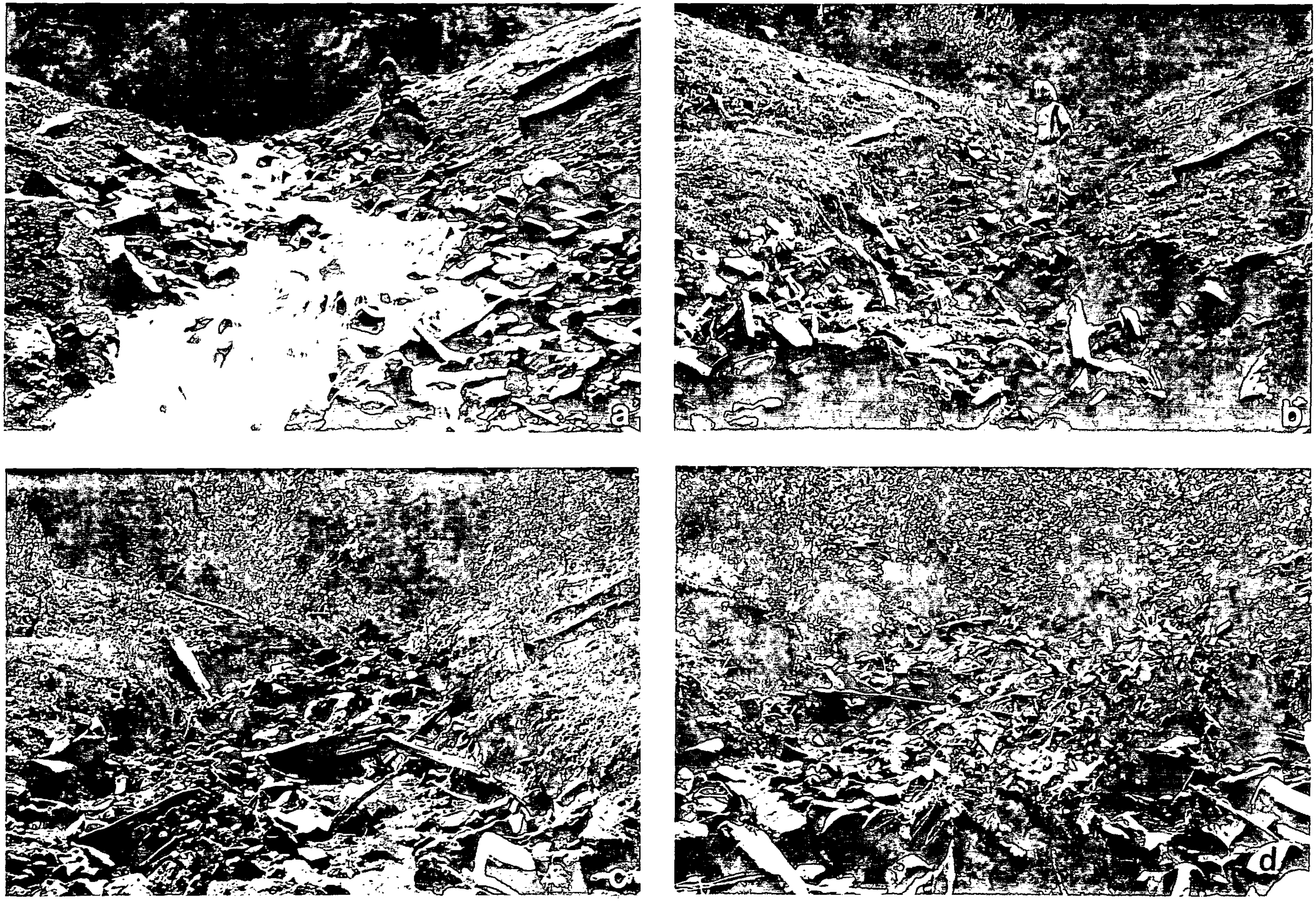


Fig. 79. Changes at an excavated stream crossing following rehabilitation. A) view upstream during the first winter flows; B) same view after first winter; note minor channel downcutting, considerable widening and the removal of under-sized rocks used in the channel armor; C) after the second year, the channel has downcut an additional foot and widened several more feet in response to sustained high flows during the winter (note the organic debris being exhumed); D) in 1983, 4 years after treatment, large boulders are now being exhumed as the stream finds its original, stable bed. Note also that widening continues to occur and young trees topple into the streambed.

Fig. 80. Straw mulch, applied at 6000 pounds per acre, was found to be the most cost-effective treatment to control surface erosion from bare soil areas on 1979 rehabilitation units.

Straw applied at 2,000 pounds per acre on all bare areas was marginally effective in controlling most surface erosion for the first year. Decomposition rapidly reduced coverage. Straw application along flat or gently sloping segments of cross-road drained roads and landings was not necessary to control the little erosion that occurred there. At these sites, straw mulch was used more as an aid in improving micro-climate and micro-site conditions for revegetation.

2. Revegetation

Vegetation treatments were designed to speed natural revegetation of freshly disturbed sites and to test the effectiveness of several untried techniques. The grass, fertilizer and mulch treatments on the 1930 road allowed documentation of grass species survival, revegetation success with various fertilization rates and observations of natural revegetation with different treatments.

Initially, the grass cover produced by the 50 pounds per acre rate of the RNP grass mix was higher than the 30 pound per acre rate; however, after three years the grass cover was similar for both application rates. Ryegrass was the early dominant species, but by the second year ryegrass cover had decreased while bentgrass increased. By the third year, bentgrass was dominant. Fescue and orchardgrass were present only as scattered individuals. Barley sprouted well with some shoots 2 - 8 inches tall by late September, but little remained by the second summer.

Little difference in response was noted between the 250 and 500 pounds per acre fertilization rates the first year, and no difference was observed by the third. Where the RNP grass mix was seeded and not fertilized, the total cover was low and remained lower than fertilized areas after three years. Ryegrass seemed to require fertilizer more than the bentgrass. This may be one reason why the ryegrass was strong the first year but less successful in succeeding years. The only straw mulch plot that was seeded with the RNP grass mix and fertilized had a lower average vegetative cover than comparable unmulched areas the first year. By the third year, the grass cover was equal to the unmulched areas.

Where the RNP mix was seeded and fertilized, grass persisted with sufficient cover (>60 percent) to exclude significant natural invasion (Figure 81). Coyote brush, the main woody colonizer, was relatively sparse on areas seeded with the RNP mix but abundant in unseeded areas and areas seeded with barley. The areas seeded with barley were nearly indistinguishable from untreated areas.

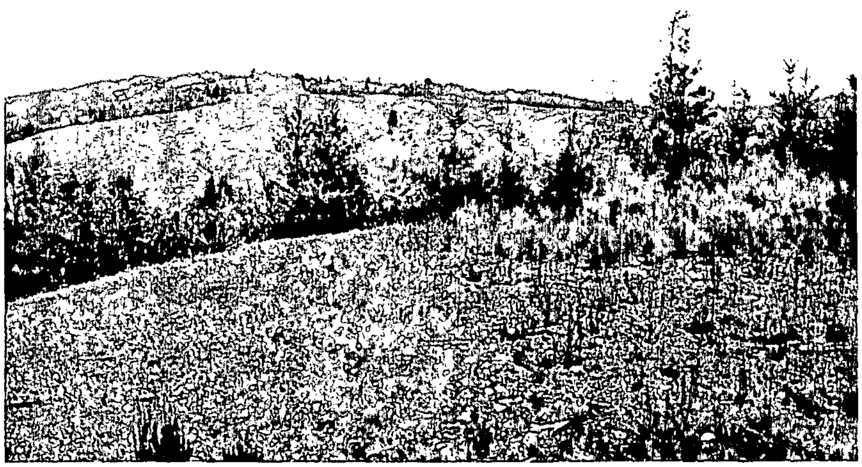


Fig. 81. Shrub invasion in unseeded (right) and grass seeded areas (left) on treated landing in Copper Creek. Competition with grass on the left half of the landing totally inhibited natural invasion of coyote brush and other shrubs.

The results of grass seeding and fertilization at Copper Creek were the same as the Bond and Bridge Creek units. Fertilization was necessary to establish dense grass stands. The difference between the 500 and 250 pounds per acre application rates was not significant enough to merit the heavier rate. A combination of ryegrass and 'Highland' colonial bentgrass rapidly produced a dense long lasting stand. However, grass seeding was not a good technique where rapid natural revegetation were desired.

The most widely used mulch was straw. Average straw cover the first year was 90 percent, but declined to <5 percent by the third year. Heavy natural invasion by coyote brush and herbaceous species was seen on many unseeded, strawed areas (Figure 82). Several areas mulched with

Fig. 82. Natural revegetation of excavated stream crossing with straw mulched side slopes, Copper Creek. A) Partially washed out stream crossing displays unstable banks and minimal natural revegetation eight years following road abandonment (July 1979); B) several months after excavation of fill (December 1979) showing straw mulch and rilling on side slope following first winter rains; C) four years after rehabilitation (September 1983), note abundant natural invasion of coyote brush on right bank.

manure, chips and straw developed a heavy cover of unseeded grass and weed species which excluded most naturally invading coyote brush and herbaceous species.

Natural revegetation varied with different mulches, but was greatest with straw mulch. Gentle, recently decompacted surfaces which were strawed throughout Copper Creek exhibited a denser cover of naturally seeded coyote brush and Douglas-fir seedlings compared to bare surfaces or where other types of mulches were used (Figure 82). The straw appeared to initially reduce the size of the coyote brush seedlings, but not the density. Rapid nitrogen uptake by micro-organisms decomposing the straw reduced plant-available nitrogen. According to Popenoe (1982), this early nitrogen reduction may actually encourage spring germinating species such as coyote brush. Many of the micro-organisms die after the straw has partially decomposed, making the nitrogen available to plants again. This occurs after the high nitrogen-requiring grasses have germinated in the fall and had difficulty becoming established in the low nitrogen conditions.

The Douglas-fir mulched areas had some natural Douglas-fir seedling invasion (some may have grown from seed in cones which were included in the "chips"), as well as coyote brush and other ruderals. Decomposing more slowly than straw, a large amount of the Douglas-fir mulch remained on the ground after three years. The areas mulched with Monterey pine chips had greater and more uniform coyote brush invasion. Most of the pine needles had disintegrated by the third year, mainly leaving stems. The redwood chip mulch was the most persistent of the mulches. The redwood chip mulch was highly inhibitory to coyote brush seedling establishment. Adjacent, identically prepared areas without chips were heavily revegetated with coyote brush after three years while the redwood mulched areas were still essentially unvegetated.

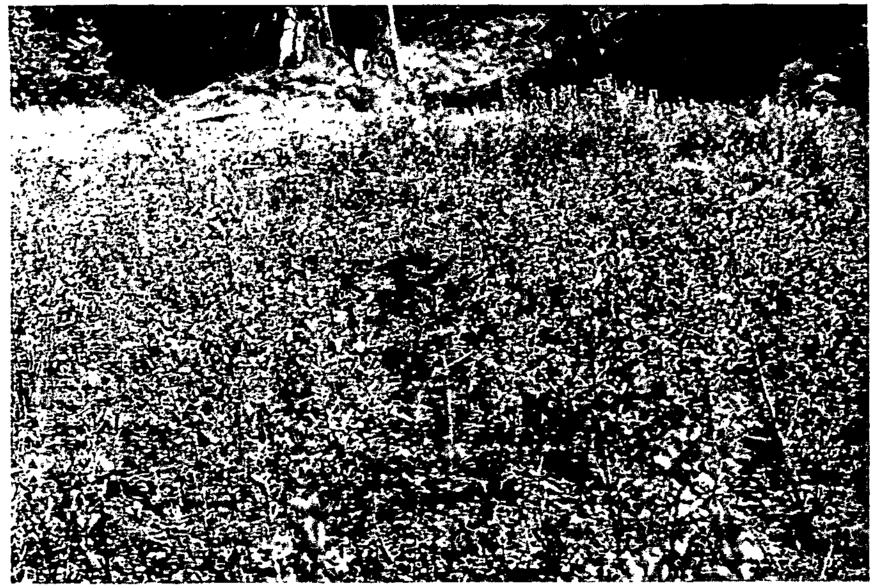
Observation of conifer seedling survival indicates species, initial size, and substrate affect the trees' health. By 1983, survival of redwood seedlings planted on the lower road was low (approximately 20 percent). Many of those surviving seedlings were stressed, but may become better established as alders shade more of the road. Observations of plantings in succeeding years indicated that two-year old bareroot stock (both redwood and Douglas-fir) have higher survival and growth rates than one-year old containerized stock. For this reason, and because the two-year stock are no more expensive than the one-year old containized seedlings, they are now preferred (Figure 83).

The two-year old, bareroot Douglas-fir seedlings planted on the upper and middle roads exhibited high survival. Growth of the seedlings was variable, however. In strawed areas, growth was good with most trees developing a healthy green color (Figure 84). Some trees were bushy from browsing by elk, deer and cattle, especially on the upper road. Survival was lower on rocky sections and trees tended to be chlorotic. Douglas-fir planted in seeded areas had lower survival (Figure 85). Greater survival and up to twice the stem diameter was

Fig. 83. Two-year old bareroot Douglas-fir and one-year containerized redwood seedlings were planted at Copper Creek.

Fig. 84. Slightly browsed, but healthy, Douglas-fir surrounded by coyote brush on mulched, unseeded road surface in Copper Creek. Approximately three years following planting.

Fig. 85. Competition from grass in heavily seeded areas lowered survival and reduced vigor of outplanted conifers. Concentrations of grass also attracted elk and deer which then browsed on the planted trees.



found for trees in areas with less than 50 percent grass cover than in more heavily seeded areas. The Douglas-fir survival and growth were high where barley was sown because there was little competition. Trees planted in the Douglas-fir mulch had the highest survival compared to other chip mulch areas. Trees planted in the pine mulch had slightly lower survival, with the lowest survival found in the redwood mulch areas.

Little natural conifer regeneration on the Copper Creek unit was observed, but stump sprouting redwoods and dense stands of aerially seeded Douglas-fir were found in some areas. The greatest number of naturally seeded conifers has occurred on the middle road. The lower road had few naturally seeded Douglas-fir. As the trees planted and aerially seeded by the timber companies mature, the seed source for unvegetated, disturbed areas will increase.

At the time of rehabilitation, much of the unit was bare with many skid trails in evidence. Natural and planted revegetation was slowly changing the appearance of the unit. Madrone and blueblossom seedlings were rapidly colonizing some of the rockier, drier stretches of road. Some tanoak and madrone were becoming established on skid trails, but the dominant colonizer was still coyote brush (Figure 86). In much of the unit, coyote brush and aerially seeded Douglas-fir were so dense that passage was difficult. Alder, established on the lower road, was altering the microhabitat to be more conducive to conifer establishment (Figure 87).

Fig. 86. Natural invasion of coyote brush. Unlike the Bond and Bridge Creek units, where alder was the principal early colonizer, the hot, dry, rocky skid trail and road surfaces of Copper Creek were quickly invaded by coyote brush.

Fig. 87. Natural revegetation of an excavated stream crossing on the 1910 road. Although soils are also rocky in many of the lower hillslope areas, moister conditions favor the invasion and establishment of red alder near water-courses. A) before stream crossing excavation (June 1979), B) following excavation (January 1980; note high rock content of soils) and C) four year following rehabilitation (September 1983).

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Upper Copper Creek contract. Transplants and stem cuttings were the main treatments in the Upper Copper Creek contract area. Transplants had greater survival than stem cuttings (Table 39). With 100 percent survival, rush and grass plant plugs were the most successful transplants.

TABLE 39

Upper Copper Creek Vegetation Treatment Survival

Treatment	Number Planted	--Percent Survival-- 6/81	4/83
TRANSPLANTS			
'Alta' Fescue	51	100	100
Cattail	32	56	44
Coyote Brush	221	64	*[1]
Madrone	33	48	39
Rush	104	100	100
Salal	477	16	11
Whipplea	580	43	46
TOTAL	1,498		
STEM CUTTINGS			
Coyote Brush	626	16	12
Huckleberry	33	12	0
Salmonberry	15	0	7
Whipplea	227	12	12
Willow	324	47	35
TOTAL	1,225		

[1]Transplants could not be distinguished from naturally seeded plants.

A leaf blight, common to Northcoast madrone, may have reduced survival of that species. However, surviving madrone are now well established. Salal, difficult to transplant due to its rhizomatous nature, was not entirely successful and showed low survival. High survival was found with well-trimmed, medium-sized whipplea transplants. Some of the whipplea transplants had been shaded with rocks and sticks. Coyote brush transplants were effective, but probably not necessary. Naturally seeded coyote brush covered many sites by the third year, making an inventory of transplanted coyote brush impossible.

Overlapping contract worksites with in-house grass seeding treatments created problems in assessing survival of transplants and stem cuttings. Survival of planted species and invasion by natural species was reduced where grass cover was high. The survival of salal, madrone, whipplea and coyote brush transplants and willow stem cuttings was probably lower than might have occurred due to grass competition. Browsing by elk, deer and cattle may have reduced survival. Greater second year survival of the whipplea was attributed to increasing size. In the first season, many small transplants were not found. The actual survival of willow stem cuttings may have been higher than recorded, but they were difficult to locate in the dense, streamside vegetation.

Based on survival per unit cost, the more expensive transplants were actually more cost-effective than the cheaper stem cuttings. However, stem cuttings may have been more successful under different weather conditions. Many stem cuttings were planted in favorable wet areas, but freezing weather occurred soon after. As the ground froze, frost heaving occurred, reducing survival. Willow stem cuttings grew well only near a water source. Coyote brush and whipplea stem cuttings were less successful than transplants of the same species. Neither huckleberry nor salmonberry stem cuttings were successful.

One site seeded by the contractor was an area around ravel catchers and contour trenches. By June 1983, grass cover behind ravel catchers was 80 percent but only 10 percent near contour trenches. Ravel catchers may have been more effective for trapping seed and providing a better seedbed. Orchardgrass was only found occasionally in areas which were seeded four months before the contract seeding. The time of seeding may have influenced the growth and survival of individual grass species.

Middle Copper Creek contract. Revegetation treatments on the narrow 1900 road were minimal. This area was planted a month later than the upper road. Although freezing was largely avoided, survival results were similar (Table 40). Whipplea transplants in this area were larger and unpruned. Survival was similar to that on the upper road, but the vigor noted in the initial survey was much lower. Heavy natural grass on several sites also made the treatments difficult to locate. Some of the whipplea stem cuttings appeared more like transplants since several rooted portions were often used. Resprouting of plants thought dead in the first survey increased the count of surviving whipplea stem cuttings during the second survey.

TABLE 40
Middle Copper Creek Vegetation Treatment Survival

Treatment	Number Planted	----Percent Survival---- 6/81	4/83
Whipplea Transplants	74	47	45
Whipplea Stem Cuttings	233	6	21
Willow Stem Cuttings	412	30	36

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Lower Copper Creek in-house work. Some of the willow stem cuttings for the lower area were lost when a road section eroded. Most of the remaining cuttings were successfully established by April 1983, attaining a browsed height of four feet.

The five sites sown with alder and grass had an average grass cover varying from 25 to 85 percent. Seed wash was a problem. The lower portion of slopes often had heavier grass than upper areas, and the grass was patchy across some slopes. Orchardgrass dominated, but bentgrass was also heavily represented. Little ryegrass or fescue was noted the third year, and none of these sites were fertilized. Alder success depended on grass cover. Where grass cover was high, few alders grew. Alder seeded alone in the spring would probably have been more successful than the alder/grass mix. The grass seed was used as a "bulking agent" in the "belly grinder" hand spreader to disperse the small alder seed. In retrospect an inert material such as vermiculite or fertilizer may have accomplished the same goal without adding the problem of competitive species such as grass. All sites where alder seedlings were planted had heavy alder cover by April 1983.

Planted coyote brush seedlings and rooted cuttings were difficult to distinguish from naturally invading coyote brush by Spring 1981; however, high survival of tagged plants indicated that overall survival was also good. Whipplea did not colonize as rapidly or aggressively as coyote brush, so survival was easier to evaluate. Survival varied from 0 to 93 percent, with an average of 33 percent. Highest survival was found on moist, shaded, north-facing slopes where grass competition was low. Whipplea did not do well on heavily grassed sites.

Whipplea and coyote brush survival was high considering they were planted in May. The plants had little time to become established before the onset of the dry summer. They had also been stressed by being left on-site in flats for several months before planting.

The results of the experimental propagation contract and succeeding contracts showed that certain natives can be inexpensively grown in large quantities. Coyote brush was grown from both cuttings and seed collected in the park. The nurseries found that coyote brush was most easily grown from seed. Whipplea seed was difficult to collect, so rooted cuttings was the method of choice. Because the seedlings had an established root mass when planted, survival was generally greater than survival of unrooted cuttings of the same species. The small number of transplanted whipplea could not be evaluated because heavy alder growth had obscured the site. Popenoe and others (1983) investigated methods for increasing survival and growth of whipplea and determined that survival of rooted cuttings and transplants is four to five times greater than for unrooted cuttings.

The plants for the first propagation contract were grown in 2 x 2 inch pots and delivered in flats. Carrying the plants to the worksite proved difficult. Succeeding contracts specified that the plants be in standard planting tubes or styroblocks, similar to that used for the conifer seedlings.

H. Post-Rehabilitation

1. Winter maintenance

Forty inches of rain, two-thirds of the annual precipitation, had fallen by the completion of rehabilitation work in mid-February 1980. High surface runoff and stream discharges immediately after the completion of the heavy equipment phase resulted in erosion and channel adjustment in some of the excavated stream crossings. Maintenance and erosion control work were often undertaken together during the first winter.

A total of 170 person-hours, at a cost of $1,124, were spent conducting winter maintenance work primarily at stream crossings on the lower 1910 road. Virtually all work was conducted in early December 1980. Most work consisted of gathering additional rock or redistributing existing rock in excavated stream crossings. Small headcuts that developed were filled with rock, and stream bank protection was provided at points where flow had scoured the sideslopes.

Other maintenance work included constructing six waterbars, breaking apart recently exposed organic debris which was deflecting stream flow into the right bank at the log jam worksite and manually excavating two deep trenches to channelize errant streamflow below excavated stream crossing R28 on the middle 1900 road. A total of 44.75 person-hours ($303) was spent digging 70 feet of trench (averaging 3 feet wide and 2 feet deep) to ensure that the streamflow reentered the natural channel below the worksite. The short-lived, rehabilitation-caused gully resulted in approximately 30 - 50 cubic yards of hillslope erosion of which approximately 20 - 35 cubic yards entered a stream channel.

2. Erosion caused by rehabilitation activities

Watershed rehabilitation work on the scale and complexity of the Copper Creek project resulted in some rehabilitation-generated erosion. A total of 1,360 cubic yards of soil was eroded from excavated logging road and skid trail stream crossings (870 and 490 cubic yards respectively) in the three years following rehabilitation. Of the 92 treated logging road and skid trail stream crossings, 41 were judged to have been excavated to or near the original channel gradient and sideslope configuration. Of these, 26 experienced subsequent channel adjustments and yielded volumes of sediment which totalled five percent, or less, of the originally excavated volume. That is, if 100 cubic yards was excavated during rehabilitation, 5 cubic yards or less had subsequently eroded at the treated site. Erosion on the remaining 15 crossings excavated to or near original grade was mainly caused by channel widening. This bank erosion usually resulted from underdesigned channel width.

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Watershed rehabilitation work on the scale and complexity of the Copper Creek project resulted in some rehabilitation-generated erosion. A total of 1,360 cubic yards of soil was eroded from excavated logging road and skid trail stream crossings (870 and 490 cubic yards respectively) in the three years following rehabilitation. Of the 92 treated logging road and skid trail stream crossings, 41 were judged to have been excavated to or near the original channel gradient and sideslope configuration. Of these, 26 experienced subsequent channel adjustments and yielded volumes of sediment which totalled five percent, or less, of the originally excavated volume. That is, if 100 cubic yards was excavated during rehabilitation, 5 cubic yards or less had subsequently eroded at the treated site. Erosion on the remaining 15 crossings excavated to or near original grade was mainly caused by channel widening. This bank erosion usually resulted from underdesigned channel width.

Of the 51 crossings judged not to have been fully excavated to the natural channel bottom, 17 logging road and seven skid trail crossings experienced erosion which totalled less than five percent of the original excavated volume. The stability of these "incomplete" excavations was influenced by how well workers had been able to "key" the channel bed into large, stable organic debris already in the channel near the downstream end of the excavated area. These stable base levels successfully limited channel erosion.

Five logging road stream crossings and seven skid trail crossings experienced subsequent erosion which exceeded 25 percent of the originally excavated volume. At these locations, either active, unstable slopes adjacent to the stream crossings failed, the equipment was physically unable to completely excavate all the fill material in the crossing, or it was mistakenly believed that the crossing had been excavated to a stable base level. The relatively high amount of erosion was caused by a combination of channel widening ranging from 3 to 10 feet, downcutting ranging from 2 to 4 feet and individual bank failures ranging up to 50 cubic yards. At S38 and R28, gullying related to bank failure and an unexcavated stream channel, respectively, resulted in an additional 60 and 350 cubic yards of post-rehabilitation erosion.

Annual follow-up reviews indicated most "under-excavated" crossings experienced the majority of the erosion the first winter following rehabilitation. However, when larger magnitude storms occur, additional channel erosion can be anticipated. It is estimated that one-half of the crossings which initially experienced higher rates of erosion would not have shown significant erosion had more appropriate and versatile types of heavy equipment been used, or had the excavations been completed to the original channel gradient instead of to "presumed" stable base levels. On the remaining half of the crossings, excavation to a stable, non-eroding configuration was not possible due to unstable sideslopes, stream gradients in excess of 40 percent (which limited equipment access) or the supervisor's hesitancy to destroy advanced second growth conifer vegetation on the channel banks. Channel armoring at these sites may have been beneficial.

3. Future sediment sources in Copper Creek

It is now possible to estimate the volume of future erosion expected from rehabilitation worksites on this unit. Table 41 lists those crossings where most future erosion is expected to occur. Only one of these crossings was excavated to near original gradient (R44) and only two were excavated to a stable base level (R13 and R39).

The expected mechanisms for future stream crossing erosion can be divided into four types: 1) large scale mass movements (>100 cubic yards); 2) shallow and relatively small failures along steep sideslopes; 3) headcut migration (channel deepening); and 4) bank erosion (channel widening). Any of these processes may initiate or influence the others.

TABLE 41

Future Erosion Sites, 79-4

Stream Crossing Excavation	Estimated Volume (Yd^3)	Principal Cause of Future, Expected Erosion
R5	50	Head cut migration.
R13	50	Head cut migration.
R28	175	Gullied channel enlargement and head cut migration.
R32	150	Head cut migration.
R36	500	Large scale mass movement and head cut migration.
R38	60	Channel adjustment and shallow sideslope bank failures.
R39	50	Channel adjustment and shallow sideslope bank failures.
R44	70	Channel adjustment and shallow sideslope bank failures.
S4	20	Head cut migration.
S30	30	Channel adjustment and shallow sideslope bank failures.
S36	40	Head cut migration and shallow sideslope bank failures.
S38	500	Large scale mass movement and channel adjustments.
S42	50	Head cut migration.
S43	25	Head cut migration.
TOTAL PREDICTED VOLUME	1,770 yd^3	

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TOTAL PREDICTED VOLUME	1,770 yd^3	

A total of 1,770 cubic yards of future erosion is expected from the stream crossings before they stabilize. Of this, 1,000 cubic yards are predicted to come from large scale mass movements near two stream crossings (R36 and S38). The volume of erodible material from shallow streamside failures and channel deepening is smaller than large mass movement features, but the frequency is greater. Five crossings are expected to experience shallow failures along stream banks, and virtually all the crossings listed in Table 40 will experience some channel downcutting through headcut migration.

The time when future erosion will occur is highly dependent on climatic and hydrologic events and hillslope characteristics. Erosion of incompletely excavated stream channels (crossings with large amounts of fill still present) is strongly influenced by the magnitide of peak discharges and the amount of exhumed organic debris which will act to arrest channel scour. In most cases, small amounts of material will be eroded episodically over many years. Most stream bank slides will occur as one event, triggered by saturated soils and high stream discharges during a storm. The modes of delivery on large scale mass movements are much more complex. Failures can occur either during a single episode or annually over many decades. With either mechanism, subsequent enlargement of the crown scarps, stream bank erosion of the landslide toe or gullying of the surface will result in long-term erosion.

Scarps indicative of slumping developed 100 feet upslope of crossing R36 during the winter of 1981-1982. The drainage area is small at the stream crossing and the slopes showed no evidence of instability prior to rehabilitation. While it is difficult to show that the developing landslide feature was affected by rehabilitation activities, it cannot be ruled out. Depending on the rate of continued slump development, the release of sediment is expected to be slow. Downstream effects will be influenced by the capability of the small ephemeral stream to remove introduced material.

The slope instability at S38 is much more active and was caused by stream downcutting below the original grade of the channel to expose unstable soils. An extensive system of scarps which had extended into upslope areas even before rehabilitation have enlarged since 1979.

The stream channel from below R44 to above S37 was severely modified by rootwads and sawlogs. Several thousand cubic yards of sediment and debris from a fill failure and debris torrent (Landing 14) were introduced and passed through the channel. This created a situation that could not be cost-effectively rehabilitated. Erosion rates will remain high (100 cubic yards per year) for many years until equilibrium is re-established.

Mass movement features are developing at two other locations. Both were identified as unstable before rehabilitation. Segments of roads crossing these unstable areas were outsloped or cross-road drained to improve surface drainage. At both locations, material involved in any future slope failure will be stored on the hillslope.

VI. SUMMARY OF FINDINGS

The work sequence on all three 1979 rehabilitation units consisted of 1) detailed geomorphic mapping to locate significant erosion problems, 2) erosion control and revegetation prescription development, 3) road removal and stream channel restoration by heavy equipment (designed to control erosion caused by past logging or road building activities), 4) labor intensive erosion control and revegetation work (designed to revegetate and minimize erosion on areas disturbed during treatment and 5) winter maintenance, monitoring and evaluation.

1979 was the first fully funded year of the rehabilitation program and the work was still largely experimental. Evaluation of 1979 and succeeding years' work has resulted in significant changes in techniques.

In 1978, heavy equipment work comprised from 5 to 25 percent of the total rehabilitation costs (Madej and others, 1980). In that year emphasis was placed on labor-intensive erosion control and revegetation treatments for bare soil areas and in freshly excavated stream channels. By 1979, heavy equipment costs rose to 85 to 95 percent of total expenditures.

This approximate ratio of expenditures continues today as stream crossing excavations and road removal procedures are more extensive and less emphasis is placed on controlling surface erosion. Studies in the park have confirmed that most post-rehabilitation erosion originates from stream channel adjustments and landsliding and not from rill and sheet erosion on the large expanses of exposed soil. For this reason, stream channel excavations are now performed more carefully and completely so that subsequent channel adjustments are minimal and rehabilitation cost-effectiveness is maximized (Weaver and Sonnevil, 1984).

Greater emphasis is now placed on treating only those potential and existing sources of erosion that could otherwise result in unacceptable damage to other park resources. For example, at Bridge Creek (79-2) a great deal of the costs of debris removal from the perimeter of the two landings and from along the M-7-5-1 road (Table 14) could have been avoided with little loss in the protection provided to local streams. Some of the material would have eventually failed and slid down the hillslope, but most of the debris would not have entered active stream channels. Landslide prevention work is now largely restricted to sites where there is a greater likelihood that failure would introduce material directly to perennial streams or damage undisturbed old-growth forest.

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On the Bond Creek unit, road outsloping and channel excavations were mostly done with a crawler tractor and dragline crane, and a large amount of soil had to be endhauled to a stable dump site. These two activities were responsible for the high unit costs for road treatment at that site (Table 3). Work in Bridge Creek and Copper Creek revealed that, where endhauling is not required, road outsloping can be done much more cost-effectively using a crawler tractor (bulldozer) in combination with an excavator.

For most situations the hydraulic excavator proved to be the most versatile and cost-effective machine for outsloping, constructing cross road drains and, in combination with a crawler tractor, for excavating stream crossings. Its 360 degree swing capability, relatively long reach, large bucket size and mobility on steep slopes made it an excellent choice for most road removal and hillslope rehabilitation work. Except in special situations, dragline cranes and backhoes were simply too limited in mobility, reach or bucket size when compared to excavators and tractors.

Equipment standby costs were high on all the units and this adversely affected rehabilitation cost-effectiveness. Unfortunately, these expenses were not altogether avoidable that year. In some instances, it was necessary to have certain pieces of heavy equipment on the site at all times, even though they were only needed on an intermittent basis. For example, road graders and water trucks were needed to occasionally maintain the surface of dirt roads when there was continuous endhauling using dumptrucks. Additionally, special ripping tractors were needed to disaggregate rocked and compacted road reaches as they were treated. It was judged necessary to keep decompacting equipment on-site during the entire project even if it was not used for other work. In later years, equipment used on a part time schedule was either contracted on an "engine time only" basis or prescriptions were modified to use and release the equipment in the shortest time possible.

On the 1979 rehabilitation units, a large variety of labor intensive erosion control techniques were tested and evaluated, especially those practices used to control erosion from bare soil areas and in excavated stream crossings. Two general categories of treatments were used to control surface erosion (Appendix B): 1) treatments consisting of contour terracing structures intended to disperse concentrated runoff and cause deposition of eroded sediment (wooded terraces, contour trenches, ravel catchers and wattles) and 2) treatments applied as a protective ground cover (mulches and seeding).

While waterbars diverted concentrated surface runoff, wooded terraces, wattles and contour trenches acted to disperse runoff or prevent surface water from concentrating. Wooded terraces (soil benches constructed on a contour and supported on the downslope edge by woody material) dispersed runoff, and through the terracing effect, trapped soil particles transported from bare areas upslope. Contour trenches, discontinuous ditches dug on contour into bare hillslopes, acted as small trap basins for surface runoff and eroded sediment. Both structures promoted infiltration of surface runoff into the soil, but were relatively expensive to install.

Wattles, bundles of small branches and stems partially buried in contour trenches on hillslopes, also trapped fine sediments derived from slope wash and dispersed runoff. When easy-to-root species such as willow were used, wattles also provided the stability of a rooted structure as well as ground cover. Vegetatively, wattles were only successful in areas of relatively high summer soil moisture such as seeps and stream channel banks. Wattles were expensive to install.

In several instances, contouring structures actually caused more erosion than they controlled. Plot studies, field observations and cost analyses showed these treatments less effective and more costly than area treatments such as mulching (Weaver and Sonnevil, 1984).

A number of mulches were applied to disturbed ground to provide immediate protection from sheet and rill erosion. Slope steepness, soil erodibility, and proximity to stream channels were the principal criteria which dictated the application rates for mulches. Wood chips, logging debris (slash), straw, and jute netting (loosely woven hemp) were used alone and in combination. Experimental plots were established on the Bridge Creek unit to test the effectiveness and cost-effectiveness of various mulches to control rilling. These revealed that jute netting applied over a thick layer of straw (8,000 pounds/acre) was the most effective technique. Straw alone (9,000 pounds/acre) was the most cost-effective treatment (Table 23). A minimum application rate of 4,000 pounds/acre straw mulch was found to be the most cost-effective treatment for controlling rainsplash and rill erosion (Weaver and Sonnevil, 1984).

Straw mulches also encourage natural revegetation by protecting the seedbed. By contrast, woody mulches (redwood chips and chipped Douglas-fir and Monterey pine) tested on the Bridge and Copper Creek units actually inhibited natural invasion.

Broadcast grass seeding and fertilization were also used in some areas to provide a temporary ground cover as protection from rainfall. Plot studies revealed little difference in grass cover between the 250 and 500 pounds/acre fertilizer treatments, but grass cover was always low where fertilizer was not used. The effectiveness of grass as a surface erosion control treatment was strongly correlated with cover density at the time significant winter rainfall began. Locally, vigorous grass growth bound loose surface soil and retarded ravelling and rill development. However, due to the seasonal occurrence of heavy rains, a complete ground cover was usually not established until late winter.

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In later years, hydroseeding was tested and found to be effective. The mulch provided immediate protection while the grass was becoming established. Its use was limited, however, since few park rehabilitation sites were easily accessible to hydroseeding equipment and dense grass discouraged growth of naturally invading or planted conifers.

Little natural revegetation occurred on the grass seeded and fertilized areas. Natural invasion was generally heavy on areas which were untreated, straw mulched or where grass was not fertilized. Seedlings planted in the fertilized, grass seeded areas had low survival. Survival and growth rates of planted species was further affected by browsing by elk and deer which appeared to be attracted to the sites with heavy grass cover.

In 1979 and later years, studies found that treatments to control stream channel erosion were generally more cost-effective than treatments to control surface erosion. This is primarily a reflection of the relative contribution of the two erosion processes to total sediment yield. Rainsplash, sheet and rill erosion generate far less material than erosion from partially or totally unexcavated stream channels (Kveton and others, 1983; Klein, in press).

Checkdams and rock armor were used to protect many of the excavated stream channels. Checkdams effectively arrested downcutting and stabilized several channels which had not been fully excavated during heavy equipment operations.

Armoring newly excavated stream channels with rocks also controlled downcutting and lateral erosion. Like checkdams, rocking promoted immediate channel bank and bed stabilization while allowing time for vegetation to become established. In general, hand placed rock armor was effective on streams with drainage areas less than 25 acres, or as long as flows were insufficient to remove the rocks. Larger streams, or those with steep gradients, required the use of heavy equipment to place larger rock.

Subsequent evaluations of erosion control effectiveness clearly demonstrate the usefulness of heavy rock armor in controlling channel erosion in newly excavated stream crossings (Weaver and Sonnevil, 1984; Unpublished data, Redwood National Park). It was found that proper rock size and placement were critical. For example, three of four armored crossings at the Bridge Creek unit displayed little post- rehabilitation erosion. However, at crossing R6, over 100 cubic yards were eroded, primarily because excessively large rock actually deflected stream flow into the banks and initiated channel scour that might not otherwise have happened. Rock armor needs to be properly graded for the expected discharges, and it needs to be placed up to and along the channel banks above the expected high water line.

A number of excavated stream channels were left unprotected at all three rehabilitation units. These exhibited varying amounts of erosion in the following years. The amount of scour was dependent on 1) the amount and size of woody debris and rock that was uncovered as downcutting occurred, 2) the stream power (a function of discharge and channel gradient) at the crossing site, and 3) the amount of unexcavated fill that was left in the unprotected crossing after heavy equipment work was completed. Streams with low stream power values, those that encountered abundant organics or rock fragments of all sizes during downcutting, or those crossings in which virtually all the original fill material was successfully excavated during rehabilitation showed the least propensity for erosion.

Based on results from 1979 and subsequent years' work, it is far more cost-effective to spend extra time with heavy equipment to fully excavate the fill material in a stream crossing (down to a stable grade, with stable sideslopes) than to only a partial excavation and use rock armor or some other secondary protection to control erosion (Weaver and Sonnevil, 1984). While this complete excavation is usually feasible, logistics, equipment limitations, or judgmental errors in identifying the original stream bed during excavation occasionally necessitate the use of in-channel protective measures. Areas where unstable soils were encountered, or where the original channel could not be relocated during excavation often created the greatest degree of post-rehabilitation erosion.

The success and total cost of watershed rehabilitation is strongly influenced by the appropriateness of the prescriptions, the types of heavy equipment used and the skill of the operator. Prescription development reflects the judgments and biases of the professional geologist or hydrologist and is based on field mapping and adherence to the established goals of the work. In the early stages of the program (1978-1980), fairly large variations in approach were taken by different professionals to solve similar problems. These differences were largely reduced through a regular program of peer review, both of proposed and completed work. More recently, prescription development has become much more systematic and routine, the effectiveness of the erosion control work has remained consistently high and the unit costs have dropped to a relatively low level.

1979 was also an experimental year for revegetation efforts. Three basic prescriptions were used: grass for surface erosion control, alders and colonizing shrub species for early succession and conifers for reestablishment of a redwood/Douglas-fir forest. Revegetation techniques tested over 20 species and employed methods such as wattling; planting of rooted and unrooted stem cuttings, conifer, shrub and hardwood seedlings; field transplanting and hand spreading grass and alder seed.

Wattles were vegetatively successful only when readily sprouting species were used and plantings were confined to wet areas. It was found that alternative techniques such as direct seeding, transplanting and planting rooted and unrooted cuttings can establish the same species for far less cost. Since wattles had low cost-effectiveness both as an erosion control technique and as a revegetation method, their use was discontinued after 1979.

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Checkdams and rock armor were used to protect many of the excavated stream channels. Checkdams effectively arrested downcutting and stabilized several channels which had not been fully excavated during heavy equipment operations.

Armoring newly excavated stream channels with rocks also controlled downcutting and lateral erosion. Like checkdams, rocking promoted immediate channel bank and bed stabilization while allowing time for vegetation to become established. In general, hand placed rock armor was effective on streams with drainage areas less than 25 acres, or as long as flows were insufficient to remove the rocks. Larger streams, or those with steep gradients, required the use of heavy equipment to place larger rock.

Subsequent evaluations of erosion control effectiveness clearly demonstrate the usefulness of heavy rock armor in controlling channel erosion in newly excavated stream crossings (Weaver and Sonnevil, 1984; Unpublished data, Redwood National Park). It was found that proper rock size and placement were critical. For example, three of four armored crossings at the Bridge Creek unit displayed little post- rehabilitation erosion. However, at crossing R6, over 100 cubic yards were eroded, primarily because excessively large rock actually deflected stream flow into the banks and initiated channel scour that might not otherwise have happened. Rock armor needs to be properly graded for the expected discharges, and it needs to be placed up to and along the channel banks above the expected high water line.

A number of excavated stream channels were left unprotected at all three rehabilitation units. These exhibited varying amounts of erosion in the following years. The amount of scour was dependent on 1) the amount and size of woody debris and rock that was uncovered as downcutting occurred, 2) the stream power (a function of discharge and channel gradient) at the crossing site, and 3) the amount of unexcavated fill that was left in the unprotected crossing after heavy equipment work was completed. Streams with low stream power values, those that encountered abundant organics or rock fragments of all sizes during downcutting, or those crossings in which virtually all the original fill material was successfully excavated during rehabilitation showed the least propensity for erosion.

Based on results from 1979 and subsequent years' work, it is far more cost-effective to spend extra time with heavy equipment to fully excavate the fill material in a stream crossing (down to a stable grade, with stable sideslopes) than to only a partial excavation and use rock armor or some other secondary protection to control erosion (Weaver and Sonnevil, 1984). While this complete excavation is usually feasible, logistics, equipment limitations, or judgmental errors in identifying the original stream bed during excavation occasionally necessitate the use of in-channel protective measures. Areas where unstable soils were encountered, or where the original channel could not be relocated during excavation often created the greatest degree of post-rehabilitation erosion.

The success and total cost of watershed rehabilitation is strongly influenced by the appropriateness of the prescriptions, the types of heavy equipment used and the skill of the operator. Prescription development reflects the judgments and biases of the professional geologist or hydrologist and is based on field mapping and adherence to the established goals of the work. In the early stages of the program (1978-1980), fairly large variations in approach were taken by different professionals to solve similar problems. These differences were largely reduced through a regular program of peer review, both of proposed and completed work. More recently, prescription development has become much more systematic and routine, the effectiveness of the erosion control work has remained consistently high and the unit costs have dropped to a relatively low level.

1979 was also an experimental year for revegetation efforts. Three basic prescriptions were used: grass for surface erosion control, alders and colonizing shrub species for early succession and conifers for reestablishment of a redwood/Douglas-fir forest. Revegetation techniques tested over 20 species and employed methods such as wattling; planting of rooted and unrooted stem cuttings, conifer, shrub and hardwood seedlings; field transplanting and hand spreading grass and alder seed.

Wattles were vegetatively successful only when readily sprouting species were used and plantings were confined to wet areas. It was found that alternative techniques such as direct seeding, transplanting and planting rooted and unrooted cuttings can establish the same species for far less cost. Since wattles had low cost-effectiveness both as an erosion control technique and as a revegetation method, their use was discontinued after 1979.

Like wattles, unrooted stem cuttings grew well if they were restricted to easy-to-root species placed in wet sites. Rooting the cuttings in a controlled nursery setting before planting increased survival.

Properly handled transplants were also successful, permitting the use of larger plants with well-developed root systems on sites where rapid establishment was desired.

Direct seeding of native species was limited in 1979. Attempts in later years met with mixed results due to the difficulty in obtaining, storing and handling seed, variable germination rates and harsh site conditions. If sufficient seed of readily germinating species is easily collected, however, direct seeding can be cost-effective, avoiding propagation costs and planting or transplanting shock. Direct seeding of natives in combination with grass was unsuccessful because the grass outcompeted the native species.

For large plantings, nursery grown seedlings are the most cost-effective. Inoculation of red alder nursery stock with nitrogen-fixing actinomycetes prior to outplanting improved initial survival and growth of seedlings upon outplanting.

Conifers were planted on all the 1979 rehabilitation units. Two-year old bare root seedlings displayed greater survival than one-year old container grown seedlings. The larger two-year old seedlings were also better able to withstand deer and elk browsing.

Many of the revegetation techniques and species used in 1979 were successful, yet are no longer used. Increased care in site preparation during the heavy equipment phase has resulted in substantial natural revegetation. Road surface decompaction, salvaging side cast and buried topsoil and straw mulching have been the keys to revegetation success. Today revegetation prescriptions almost exclusively use nursery-grown trees to speed the ultimate re-establishment of a redwood forest.

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VIII. APPENDICES

A. LIST OF COMMON AND SCIENTIFIC PLANT NAMES MENTIONED IN TEXT[1]

COMMON NAME	SCIENTIFIC NAME
'Akaroa' orchardgrass	Dactylis glomerata 'Akaroa'
'Alta'fescue	Festuca arundinacea 'Alta'
barley	Hordeum vulgare
big-leaf maple	Acer macrophullum
black huckleberry	Vaccinium ovatum
blueblossom	Ceanothus thrysiflorus
Bolander's rush	Juncus bolanderi
cattail	Typha latifolia
coltsfoot	Petasites palmatus
coyote brush	Baccharis pilularis var. consanguinea
creeping red fescue	Festuca rubra
deer fern	Blechnum spicatum
Douglas-fir	Pseudotsuga menziesii
fireweed	Epilobium spp., Erechtites ssp.
grand fir	Abies grandis
hairy cat's ear	Hypochoeris radicata
hemlock	Tsuga heterophylla
'Highland' colonial bentgrass	Agrostis tenuis 'Highland'
horsetail	Equisetum telmateia var. braunii
iris	Iris douglasii
legume	Lotus sp.
madrone	Arbutus menziesii
Monterey pine	Pinus radiata
"Oregon' perennial ryegrass	Lolium perenne "Oregon'
plantain	Plantago lanceolata
red alder	Alnus oregona
red huckleberry	Vaccinium parviflorum
redwood	Sequoia sempervirens
rhododendron	Rhododendron macrophyllum
rush	Juncus effusus
salal	Gaultheria shallon
salmonberry	Rubus spectabilis
sitka spruce	Picea sitchensis
sitka willow	Salix sitchensis
star flower	Trientalis latifolia
swordfern	Polystichum munitum
tanoak	Lithocarpus densiflorus
western red cedar	Thuja plicata
whipplea	Whipplea modesta
wild pea	Lathyrus torreyi
willow	Salix spp.
wax-myrtle	Myrica californica

[1]Nomenclature follows Munz and Keck (1973).

B. TECHNICAL SPECIFICATIONS FOR HAND-LABOR EROSION CONTROL METHODS

Introduction

Erosion control works can be constructed by hand labor methods, by heavy equipment, or by a combination of the two. For example, wattling is largely done by hand labor. Coarse rock armor, on the other hand, is necessarily placed by heavy earthmoving machinery. Many techniques can be accomplished entirely by hand or entirely by mechanized procedures (e.g. spreading straw mulch). Other practices, such as constructing rock checkdams, can most effectively be done by a combination of hand labor and mechanized procedures.

These technical specifications were developed for the application of a variety of erosion control measures in relatively remote steepland areas. As such, with the exception of hydroseeding, they consist entirely of labor intensive methods. All the procedures were initially used in Redwood National Park's watershed rehabilitation program from 1978 to 1980. Because of the national park setting, they emphasize the use of native, locally available raw materials which could be collected on-site.

More recent findings by National Park Service scientists indicate that certain of these practices may be much more cost-effective than others for controlling surface and channel erosion (the results of tests and evaluations of erosion control cost-effectiveness are available from the National Park Service; e.g. Weaver and Sonnevil, 1984). However, local conditions may warrant or dictate the use of one or more methods which have proven to be equally as effective in other environments.

If you plan to use the attached specifications for erosion control contracting, apply them loosely and use professional judgement and common sense to adapt them to your local conditions and requirements. If you have the opportunity, consult local experts and practitioners. Also, try to perform at least one trial application of each method, according to specifications, that you intend to employ later. This will tell you a lot about how the contract will work and where you must remain flexible in required methods or materials. In general, however, the attached specifications should provide a good basis for developing and implementing a broad variety of erosion control prescriptions.

Technical Specifications for Hand-Labor Erosion Control

SECTION A: SURFACE EROSION

SPECIFICATIONS FOR MULCHING

1. STRAW MULCH

A. Definition of job. Straw from bales is spread evenly over a predesignated area at an application rate set by contract specifications. The straw will protect the soil surface from rainfall impact and help to retain soil moisture on biologically harsh sites.

B. Specifications.

1. Straw shall be spread evenly within the flagged area. The amount to be spread will be given in number of bales (example: 3.5 bales) or in dry pounds-per-acre.
2. Bales are provided on site, but it will sometimes be necessary to transport them to the specific work area. Prospective contractors will be shown the location of the straw bales during the pre-bid "show-me" inspection of site.
3. Baling wire shall be removed from the site and properly disposed.
4. Mulching shall be the last task performed on the work area, following any contour terracing, wattling, wooded terraces, transplants or grass seed and fertilizer application.

C. Comments. For large areas, it's best to give a "lbs/acre" application rate. A rate of 6000 lbs/acre is good for erosion control; 8000 lbs/acre covers the ground surface completely. For small or irregular areas, it may be easier to compute the number of bales needed and then just specify exactly how much goes in each specific location. It is your option whether to provide the bales on-site or let the contractor figure it out and do the logistics. Specify whether hay, with all its seed, is a desirable or acceptable substitute for straw.

2. JUTE NETTING

A. Definition of job. Jute netting (a loosely woven hemp) is rolled over bare soil areas to hold soil in place and prevent rilling. Since jute is tacked or stapled onto the ground, it is very resistant to overland flow and disperses surface runoff. Rolls are usually 4-5 ft. wide.

B. Specifications.

1. Smooth ground surface where jute netting is to be used.
2. For ease of installation, roll jute down the fall-line of the hillslope.
3. Staple jute, or secure it with stakes, on 2 to 3 foot centers.
4. Staple all low points so jute is in continuous contact with ground.
5. Roll down second strip of jute netting, overlapping adjacent strip by at least 6 inches. Staple overlapping areas.
6. Staple second roll to ground.
7. Repeat until ground is covered.

C. Comments. Jute is usually reserved for slopes that are too steep, too wet or too windy for loose straw to adhere to. As such, it is usually used as a binding cover over other loose mulches (see "Jute Secured Straw" specification). Laying strips of jute on contour should usually be avoided because it may be difficult to keep overlapping areas together under the downslope stress of soil movement.

3. JUTE-SECURED STRAW

A. Definition of job. The bare soil is first covered with straw mulch (6000 lbs/acre) and then jute netting is secured on top. This procedure combines the effective surface protection afforded by straw mulch with the stability of the secured jute netting.

B. Specifications.

1. Apply straw mulch (as per "straw mulch" specification).
2. Secure jute netting on top of straw mulch (as per "jute netting" specification) being certain not to remove straw and expose bare soil.

C. Comments. This has been found to be the most effective treatment for preventing rainsplash, sheet and rill erosion from bare soil areas. Because it is much more labor intensive than straw mulching, and therefore more expensive, its use should be limited to steep (>70%) slopes or areas where wind or concentrated surface runoff would otherwise remove the straw mulch.

4. CURLEX MULCH

A. Definition of job. Curlex mulch, and other similar "bound mulches" are applied to prevent surface erosion (rain splash, sheet and rill erosion).

B. Specification.

1. Same procedures as for jute netting.

C. Comments. Curlex is composed of shredded aspen, bound between 2 layers of biodegradable plastic netting. It lasts and performs roughly equivalent to jute secured straw mulch. It is less expensive to purchase. Curlex should be reserved for erosion control on steep slopes.

5. WOOD CHIP MULCH

A. Definition of job. Wood chips are spread over a designated bare soil area to retard surface erosion. Application rates are set in the contract specifications.

B. Specifications.

1. At least 50% of the wood chips used for mulching shall have at least one dimension 2 inches in length. Smaller pieces are unacceptable.

2. Wood chips shall be evenly spread over the designated area covering at least 95 percent of the underlying soil surface.

C. Comments. Wood chips are much more difficult to move and spread by hand than straw mulch. Once on the ground, chips tend to slide downhill or to be blown across the surface during wind gusts. Some evidence suggests thick applications may retard natural revegetation. Variations of wood chips include logging slash, tree limbs and branches or chopped brush.

6. GRASS SEED AND FERTILIZER APPLICATION

A. Definition of job. Grass seed and fertilizer are hand spread with "belly grinders" within flagged areas. Application rates are predesignated and seed and fertilizer may be provided. Grass will serve as an immediate, temporary ground cover to decrease surface erosion.

B. Specifications.

1. When stored on-site, fertilizer is to be protected from dew and rain by plastic tarps. Grass seed must be stored under dry, cool conditions and protected from animals.
2. Application rates are listed as pounds of seed and pounds of fertilizer to be used in a specified area or, alternately, as pounds-per-acre of each.
3. Occasionally, no fertilizer is to be applied. This will be noted in the site-specific instructions.
4. Scales for weighing, buckets, "belly grinders" and rakes are to be provided by the contractor.
5. When a mixture of seeds with very different sizes and weights is to be applied care must be taken to ensure that seeds are evenly distributed in the mix, to obtain an even distribution on the ground. Since smaller seeds will settle to the bottom it may be necessary to periodically shake the belly grinder to redistribute the seeds.
6. Seed and fertilizer are to be applied as soon as possible after slope work (contour terraces, wattling, wooded terraces) is completed in order to take advantage of warm temperatures accompanying the first fall rains. Seed and fertilizer are to be applied before mulching.
7. Seed and fertilizer (applied separately) must be spread uniformly over entire area.
8. Unless otherwise specified, seed and fertilizer are to be raked into the soil immediately after application, covering them with 1/8 to 1/4 inch of soil.

C. Comments. Grass seeding can be an effective erosion control technique provided a thick, consistently uniform cover of grass is obtained prior to the advent of erosive rains. Its erosion control effectiveness is directly related to cover density. Unfortunately high cover density also effectively prevents the establishment of other planted or naturally seeded vegetation. Where site conditions are dry, sandy or otherwise harsh, grass may not be as successful or provide as immediate protection as mulching. The constituents of both the seed mix and fertilizer must be clearly specified. Heavy grass cover does inhibit natural colonization by other species and can persist for many years.

7. HYDROSEEDING

A. Definition of job. A slurry of wood fiber, grass seed, fertilizer and water is sprayed on bare soil areas. The mulch holds the seeds in place, provides a cool, moist environment for germination and protects the ground surface from erosion. Specifications can be complex.

B. Specifications. (excerpt from California Department of Transportation Standard Specifications; 1976)

1. The work shall consist of hydro-seeding erosion control material consisting of a mixture of fiber, seed, commercial fertilizer and water to embankment slopes and excavation slopes as shown on the plans.

2. Fiber shall be produced from non-recycled wood such as wood chips or similar wood materials and shall be of such character that the fiber will disperse into a uniform slurry when mixed with water. Fiber shall not be produced from sawdust or from paper, cardboard or other recycled materials. Fiber shall be colored to contrast with the area on which the fiber is to be applied, shall be nontoxic to plant and animal life, and shall not stain concrete or painted surfaces.

3. Seed shall consist of the following (names and amounts are for example only).

Botanical Name (Common Name)	Percentage (Minimum) Purity	Percentage (Minimum) Germination	Pounds per acre
Lolium multiflorum (Annual ryegrass)	99	85	51
Trifolium incarnatum (Crimson clover)	98	85	17
Festuca arundinacea 'Alta' (Alta fescue)	98	85	13
Eschscholzia californica (California poppy orange)	90	85	4

4. Before seeding, the Contractor shall furnish written evidence (seed label or letter) to the Engineer that seed not required to be labeled under the California Food and Agricultural Code conforms to the purity and germination requirements in these special provisions.

5. Seed designated without a purity or germination shall be labeled to include the name, date (month and year) collected, and the name and address of the seed supplier. Seed at the time of sowing shall be from the previous or current year's harvest.

6. Test methods specified in "Rules for Testing Seeds" from the Proceedings of the Association of Official Seed Analysts will be acceptable for determining the germination of seed.

7. All legumes shall be inoculated with a viable bacteria compatible for use with that species of seed. The application rate for seed shall be the weight exclusive of inoculated materials. All inoculated seed shall be labeled to show the weight of seed, the date of inoculation, and the weight and source of inoculant materials.

8. Inoculated seed shall be sown within 20 days of inoculation or shall be reinoculated.

9. The legume seed shall be inoculated as provided in Bulletin ACT-280, "Pellet Inoculation of Legume Seed," of the University of California, Agricultural Extension Service, except the inoculant shall be added at the rate of 5 times the amount recommended on the inoculant package.

10. Seed shall be mixed on the project site in the presence of the Engineer.

11. Commercial fertilizer shall have the following guaranteed chemical analysis:

Ingredient	Percentage (minimum)
Nitrogen	16
Phosphoric Acid	20
Water Soluble Potash	0

12. Water shall be of such quality that it will promote germination of seeds and growth of plants.

13. The erosion control (Type D) materials shall be mixed and applied in approximately the following proportions:

Material	Application Rate (lbs/acre)
Fiber	1,500
Seed	85
Commercial fertilizer	400
Water	As needed for application

14. The proportion of erosion control (Type D) materials may be changed by the Engineer to meet field conditions.

15. Mixing of erosion control (Type D) materials shall be performed in a tank with a built-in, continuous agitation system of sufficient operating capacity to produce a homogeneous slurry and a discharge system which will apply the slurry to the slopes at a continuous and uniform rate. The tank shall have a minimum capacity of 1,000 gallons. The Engineer may authorize use of equipment of small capacity if it is demonstrated that such equipment is capable of performing all the operations satisfactorily.

16. A dispersing agent may be added provided the Contractor furnishes evidence that the additive is not harmful to the mixture. Any material considered harmful, as determined by the Engineer, shall not be used.

17. The slurry shall be applied within 60 minutes after the seed has been added to the slurry.

18. The weight of fiber to be paid for will be determined by deducting from the weight of fiber, the weight of water in the fiber at the time of weighing in excess of 15 percent of the dry weight of the fiber. The

percentage of water in the fiber shall be determined by Test Method No. Calif. 226, in the same manner as provided for determining the percentage of water in straw. Commercially packaged fiber shall have the moisture content of the fiber marked on the package.

19. Before using fiber a Certificate of Compliance as provided in Section 6-1.07, "Certificates of Compliance," of the Standard Specification, shall be furnished to the Engineer.

C. Comments. For all the effort, hydroseeding is not a great deal more effective than broadcast seeding unless a very heavy application of wood fiber (2000-3000 lbs/acre) is used. This produces a true surface mulch. Still, application is considerably less effective for erosion control than straw mulch. For hydroseeding to reach its optimum value considerable knowledge or experience in suitable grasses, fertilizer requirements and mulching rates for local sites is desirable. Hydroseeding often results in quicker and more consistent germination and the establishment of a more uniform and continuous cover of grass than does broadcast seeding.

SECTION B: SURFACE EROSION

SPECIFICATIONS FOR DITCHES AND CONTOUR STRUCTURES

1. CONTOUR TRENCHES

A. Definition of job. A contour trench is a structural measure used to control surface runoff and retard erosion. Contour trenches are discontinuous ditch-like structures dug on contour into the hillslope. They act as small reservoirs which catch surface runoff (and sediment in transport) before it has a chance to concentrate and develop rills and gullies on a hillslope. Runoff generated during a storm is stored in the trench until the post-storm period. During this period, water seeps through the trench into the soil. It is imperative that trench dimensions (width, depth) account for soil infiltration rates and expected short duration, peak rainfall rates. Soils with slow infiltration rates will require larger trenches.

Unexcavated spaces between trenches on the same contour are an integral part of the trench. These spaces prevent excessive concentrations of water should a portion of a trench fail, and protects the remaining catch of a trench should only one segment fail. The storage capacity of a trench is eventually lost by slumping and sedimentation; however, it is anticipated that surface runoff will be sufficiently reduced, and that infiltration rates will be increased by the establishment of vegetation that the trench structure will no longer be needed.

B. Job specifications.

1. Work shall progress from the top of the slope to be treated downward to prevent excessive soil compaction and damage to the trenches.
2. The grade for contour trenches shall be absolutely level. The grade

shall be staked with Abney level, string level, or similar device, and shall follow the slope contour (i.e., trenches shall be horizontal).

3. Contour trenches shall be 10 feet long and spaced 5 feet apart on the contour (Figure B-1).

4. Spacing between rows of contour trenches shall be 6 feet (slope distance), or 3 feet vertically, whichever is less.

5. Trenches shall be excavated to a minimum depth of 8 inches and width of 14 inches across the top (Figure B-2).

6. Trenches and unexcavated spaces shall be arranged in a staggered pattern (see Figure B-1).

C. Comments. These specifications were developed for clay-loam soils; annual precipitation of 80 inches and peak 24-hour, 2-year rainfall of 5.5 inches. Designs should be modified to fit site conditions (slope, soil) and climate (peak rainfall rates).

2. DITCHES

A. Definition of job. Hand dug ditches are used to drain wet slopes and divert surface runoff to stable areas. They are generally shallow, compared to those dug by machines, and gently sloping.

B. Specifications.

1. Ditches shall be excavated at least 8 inches into mineral soil.
2. Top width of ditch shall be at least 12 inches.
3. The ditch shall slope gently towards direction of discharge (not so steeply as to erode its bed).
4. Ditches shall be free and clear of organic debris, soil or rocks which could block the flow of water.
5. Ditches shall discharge onto slash or rocks or similar energy dissipating materials.
6. Soil excavated during ditch construction shall be piled onto the downslope edge of the ditch as a continuous berm so as to contain excess flows within the ditch area.
7. In swampy areas to be drained, a number of small "feeder" channels shall be etched into the soil to drain standing water and saturated soils towards the beginning of the main drainage ditch.

C. Comments. Drainage ditches constructed by hand are relatively expensive and lack the capacity to carry significant discharges. However, in remote areas, ditches can be useful in diverting perennial spring flows away from sensitive hillslopes and unstable areas.

3. WATERBARS

A. Definition of job. Waterbars serve to divert surface runoff from bare soil areas (typically trails, skid trails and roads) onto vegetated areas or other areas where the flowing water is less apt to cause soil erosion. To satisfactorily accomplish this purpose, waterbars shall:

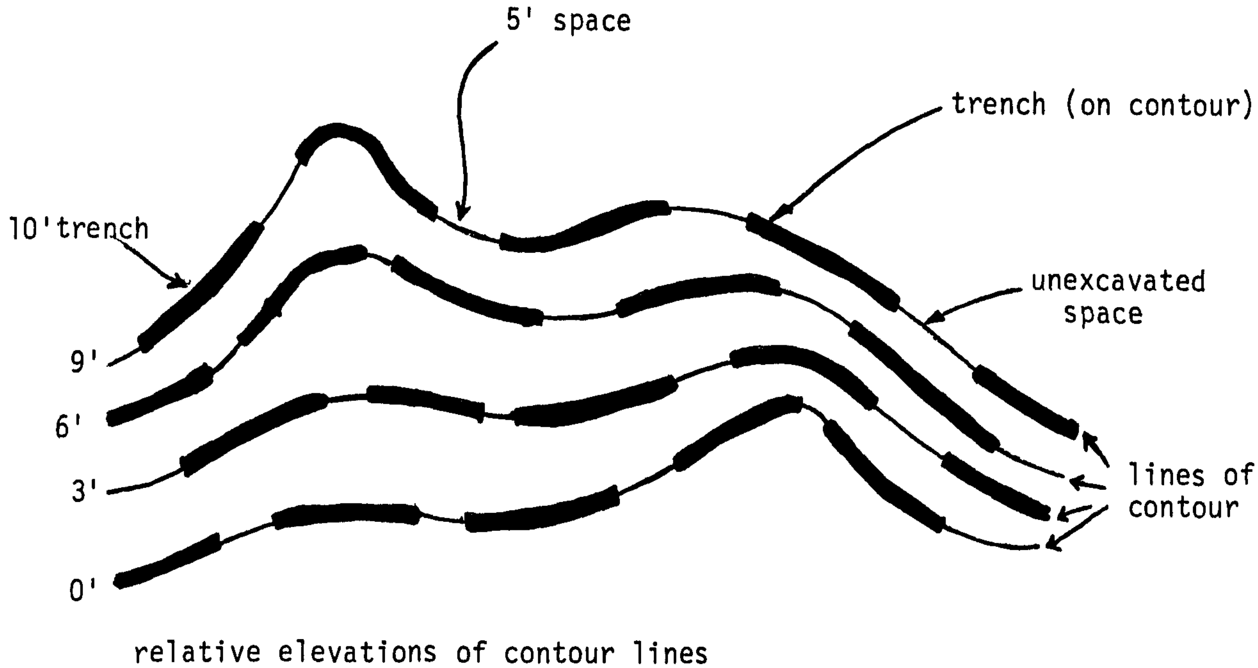


Figure B-1. Planimetric view of contour trenches (thick lines) dug on level contours (thin lines; note elevations).

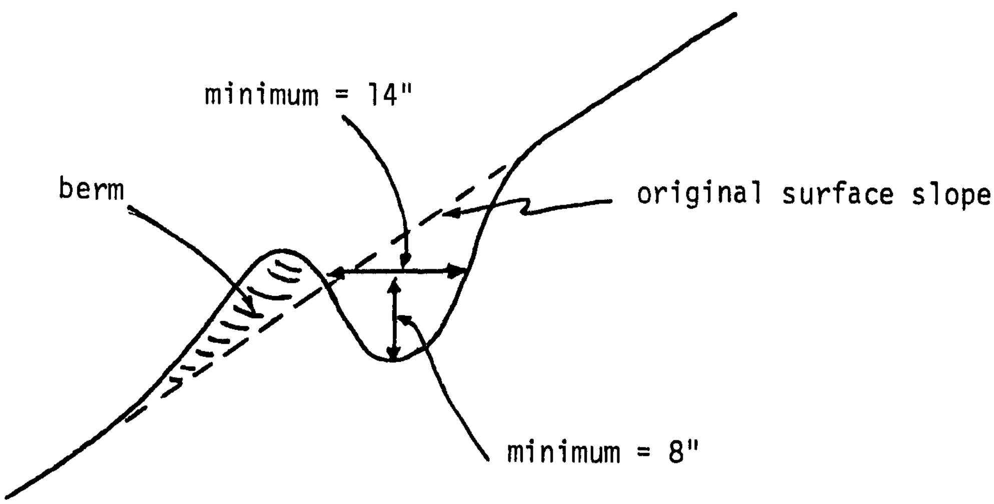


Figure B-2. Cross sectional view of a contour trench.

1. Be of sufficient dimensions to accommodate the surface runoff they divert without being overtopped or otherwise failing.

2. Be located properly to successfully divert all the water they are intended to intercept (i.e., when used on a skid trail, they shall extend from the inside edge of the trail to slightly beyond the outside edge of the bare soil area).

3. Be angled down the slope sufficiently to allow water to drain through the trough of the waterbar and freely discharge at the correct end of the structure. Thus, the slope of the waterbar shall be sufficient to drain the intercepted surface runoff without allowing ponding, yet not so steep as to cause erosion or gullying of the bottom of the trough.

4. Be constructed so the lower or discharging end of the waterbar is clear and free from debris and allows for the free discharge of runoff.

5. Be constructed so the point of discharge is onto slash (organic debris), rock, or some other form of energy dissipation. Runoff through the downslope end of the waterbar trough shall not be allowed to erode the soil in that location or within at least three feet immediately downslope. Sufficient energy dissipation shall be provided to prevent future erosion resulting from diversion of flow by the waterbar. Waterbars which discharge on steep bare slopes may cause erosional problems if not installed with energy dissipation at their discharge ends.

B. Specifications for New Construction.

1. Waterbar trough shall be excavated at least 8 inches into firm substrate (D=8"; Figure B-3).

2. Trough shall be at least 12 inches wide (W=12"), with a gentle uphill approach to the trough.

3. Trough shall be free and clear of debris or other obstructions so as to drain freely without ponding water.

4. Trough shall have a gentle slope toward the discharging end (there shall be a total drop of 6 inches to 18 inches along the run of a typical 10-foot long trough).

5. Trough shall abut inside bank of road or trail or otherwise be constructed to assure total diversion of runoff.

6. Berm shall be at least 8 inches high (H=8") and 12 inches wide (W=12").

7. Berm shall be composed of on-site inorganic sediment (rock and subsoil; preferably that material excavated from the trough) and shall be tamped with shovel, feet or otherwise hand-compacted.

8. Point of discharge shall be free and clear of debris so as to allow all water to drain freely from the trough.

9. Berm shall be constructed so as not to allow surface runoff to flow over or around it.

10. From point of discharge for a distance of 3 feet (slope distance) downslope, energy dissipation shall be placed in the path of the diverted surface runoff. This shall primarily consist of rocks 5 to 12 inches in diameter and secondarily (if sufficient numbers of rocks cannot be found within 100 feet of site) of slash or other woody debris no larger than 12 inches in diameter and 24 inches in length.

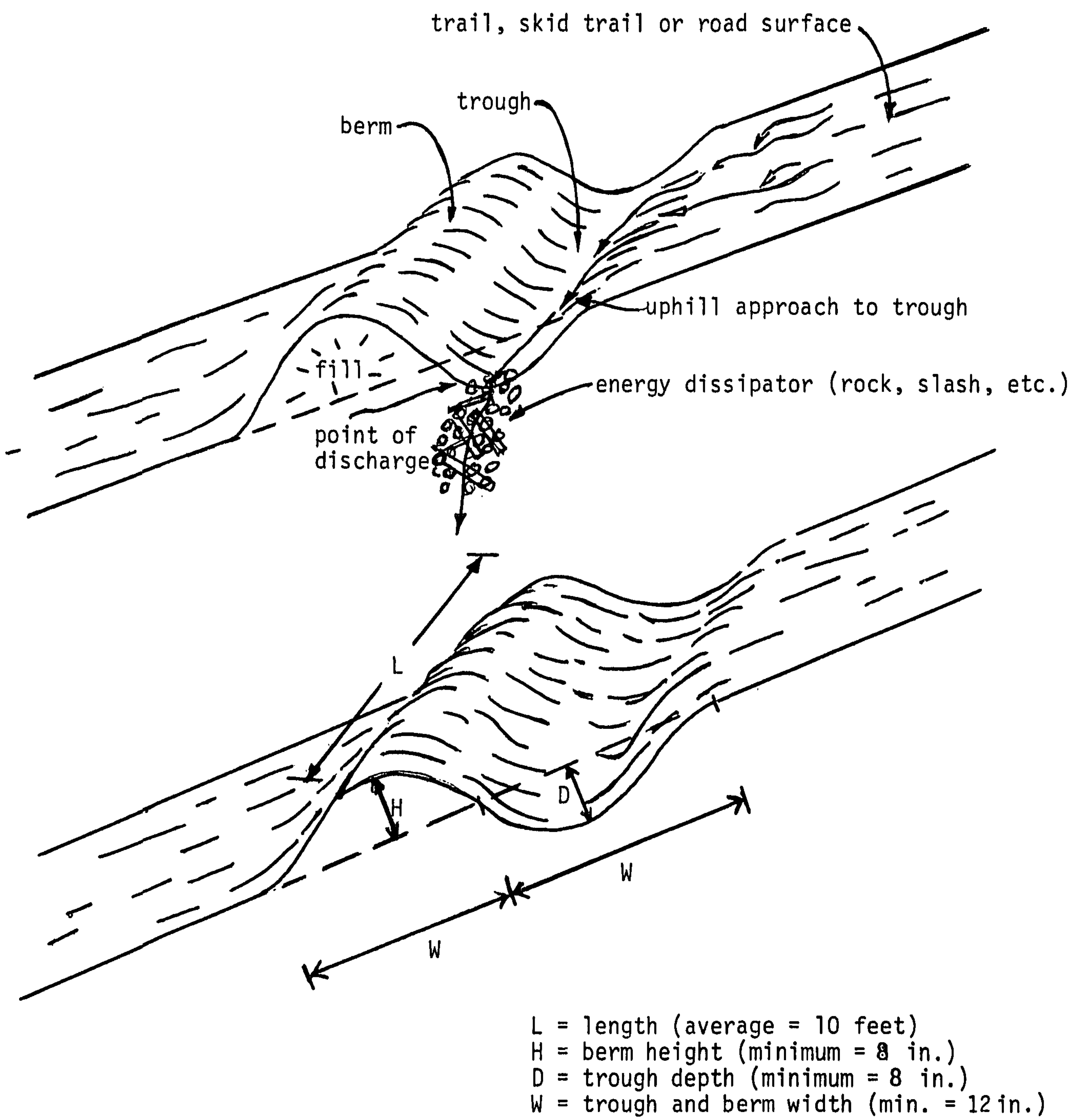


Figure B-3. Cross sectional view of a waterbar, showing main morphologic features and typical dimensions.

C. Specifications for repairing waterbars (Figure B-4).

1. Opening or unblocking point of discharge. (Open end of waterbar) The discharging end of the waterbar shall be cleared of organic debris, soil and rock which is preventing or hindering the free flow of water from the trough. Energy dissipator shall be placed below the point of discharge if there exists a gully over 8 inches deep and wide at that point which extends at least 3 feet downslope.

2. Clean out trough of waterbar.
The trough shall be cleaned of organic debris, soil and rocks so as to allow free drainage through the trough and across the point of discharge. If the bare slope below the point of discharge displays a gully greater than 8 inches in width and depth and 36 inches in length, energy dissipation shall be installed.

3. Extend end(s) of waterbar.
Additions to an existing waterbar shall be built at one or both ends of the waterbar so as to prevent water from flowing around the waterbar structure rather than being diverted by it. Typically, the lower end is not extended far enough downslope, so the surface runoff entering the trough flows around the downslope end of the waterbar rather than through the point of discharge (Figure B-4b). If not present, an energy dissipator shall be provided at the outlet.

4. Breach waterbars.
Some waterbars are doing more damage than good at their present location, and so shall be destroyed. To accomplish this, a 4-foot wide cut shall be made directly across the berm at the point opposite where most of the surface runoff is entering the trough from upslope (Figure B-4a). Excavated material shall be packed into the trough so as the assure all the water entering the pre-existing waterbar will now flow through the opened berm and not down the former trough (this point will likely be located just downslope in the trough below the new cut in the berm, thereby acting as a dam to surface flow). The berm shall be cut down and the floor of the remaining trough built up to the level of the former surface so the new profile is smooth. The cuts in the berm should be sloped toward each other with at least 2 feet of "flat" channel between.

D. Comments. Properly constructed and functioning waterbars are very effective in diverting and dispersing concentrated runoff from trails and other bare soil areas. They are commonly used on unsurfaced forest roads and in logging areas. Unfortunately, waterbars are both difficult and relatively expensive to construct by hand, especially on compacted surfaces. They also require occasional maintenance.

WATTLING

A. Definition of job. Wattles are bundles of flexible twigs and branches tied together. Wattling is the process of placing wattles in contour trenches on slopes, staking the wattles in place, and then partially covering the wattles with soil (Figure B-5). Once in place, wattles serve to retard surface erosion and revegetate bare slopes through sprouting of roots and branches from the bundles.

Contracted Repair

A. BREACH WATERBAR

B. EXTEND END(S) OF WATERBAR

C. REPAIR BREACHED WATERBAR

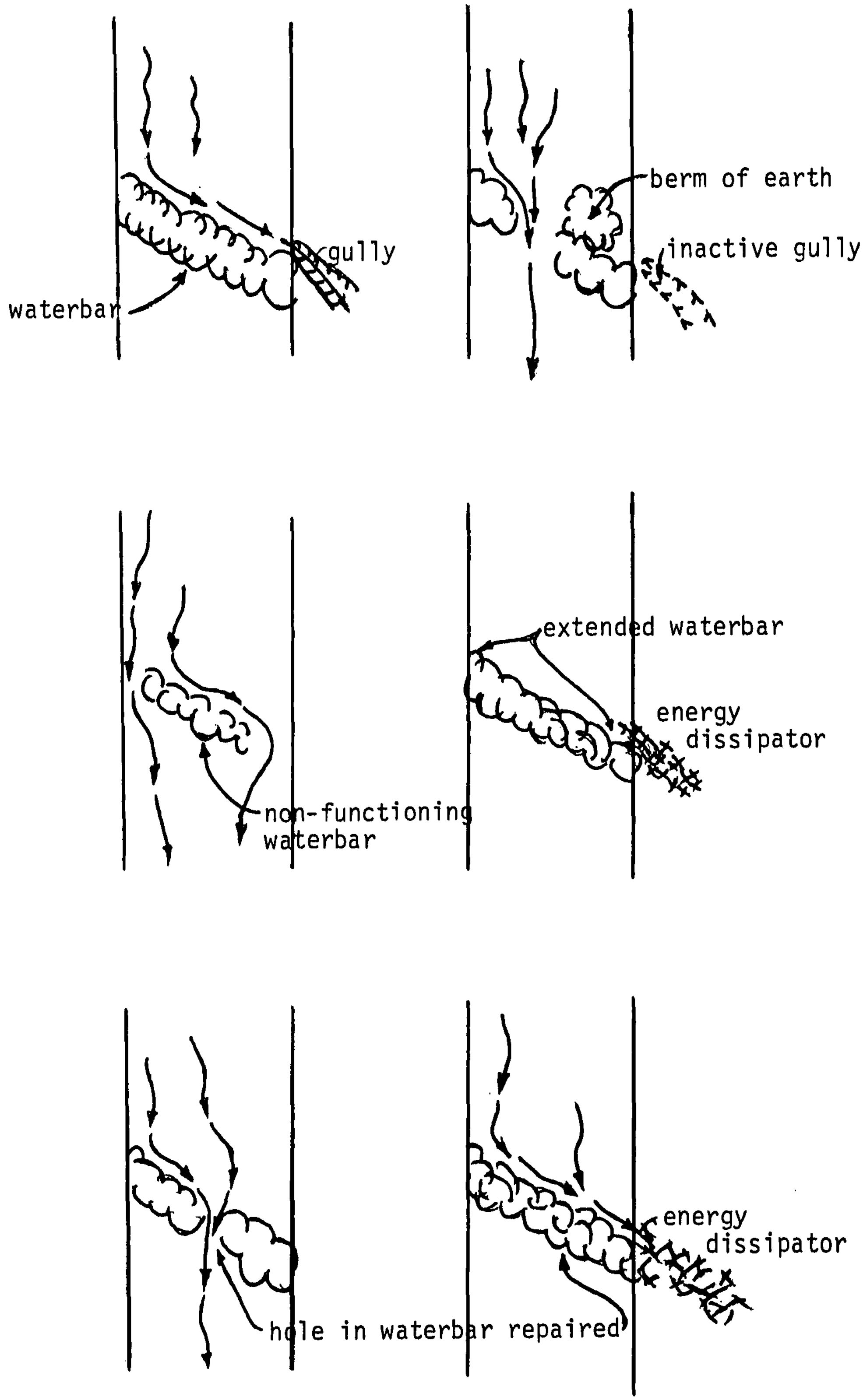


Figure B-4. Three typical repair procedures to waterbars.

B. Specifications.

1. Wattle bundles should be prepared from live material, native to the site. Willows (Salix spp.) is generally the preferred plant. Coyote brush (Baccharis) may be suitable for dry sites, and non-sprouting species such as alder (Alnus) may be used for wattles as a physical means of erosion control. Specific species for wattles will be designated in the S.O.W.

2. Wattling bundles may vary in length, but must taper at the ends, and the longest stems shall be 1 1/2 feet longer than the average length of the stems to achieve the taper. Butts of individual stems shall not be more than 1/2 inch diameter.

3. Stems should be placed alternately in each bundle so that approximately half the butt ends are at each end of the wattle.

4. Bundles shall be tied at not more than 15-inch spacings with 2 wraps of binding twine, or heavy tying material, with a non-slipping knot. When compressed firmly and tied, each bundle shall be approximately 8 inches in diameter (minimum, 6 inches; maximum, 12 inches).

5. Bundles shall be cut and tied not more than one day in advance of placement and the bundles shall be kept covered and wet between the time of cutting and installation. Cutting, tying and placing in trenches on the same day is desirable.

6. The grade for the wattling trenches should be staked out (see specifications 10 and 11 below) with an Abney level, string level, or similar device, and shall follow slope contours, (i.e., horizontal trenches).

7. Trenches shall be spaced three feet apart, vertically, unless otherwise specified in the S.O.W.

8. Bundles shall be laid in trenches dug to a depth equal to the diameter of the bundles, with ends of the bundles overlapping at least 12 inches. The overlap shall be as long as necessary to permit staking as specified below.

9. Bundles shall be staked firmly in place with vertical stakes on the downhill side of the wattle at no more than 36-inch spacing, or closer if stated in the S.O.W. At least one stake shall be driven through each bundle. A bottom stake shall be placed at the mid-point of the bundle overlap.

10. Stakes shall be greater than 1 1/4 inches in diameter and 24 inches long.

11. All stakes shall be driven to a firm hold and at least 15 inches deep. Where soils are soft and 24-inch stakes are not solid, longer stakes should be used. Where soils are rocky and/or compacted, steel bars should be used to open up stake holes for the stakes. Stake depths may be waived by the Contracting Officer or his/her representative on a site-specific basis at difficult sites where it is impossible to always meet minimum stake depths.

12. Work shall progress upward from the bottom of the slope to be wattled. The buried wattles shall have soil firmly tamped around them to minimize the possibility of drying out, however, the terracing effect created by the contour trenching shall be preserved.

C. Comments. The effectiveness of wattling is largely dependent on: 1) choice of proper plant materials, 2) proper installation techniques, and 3)

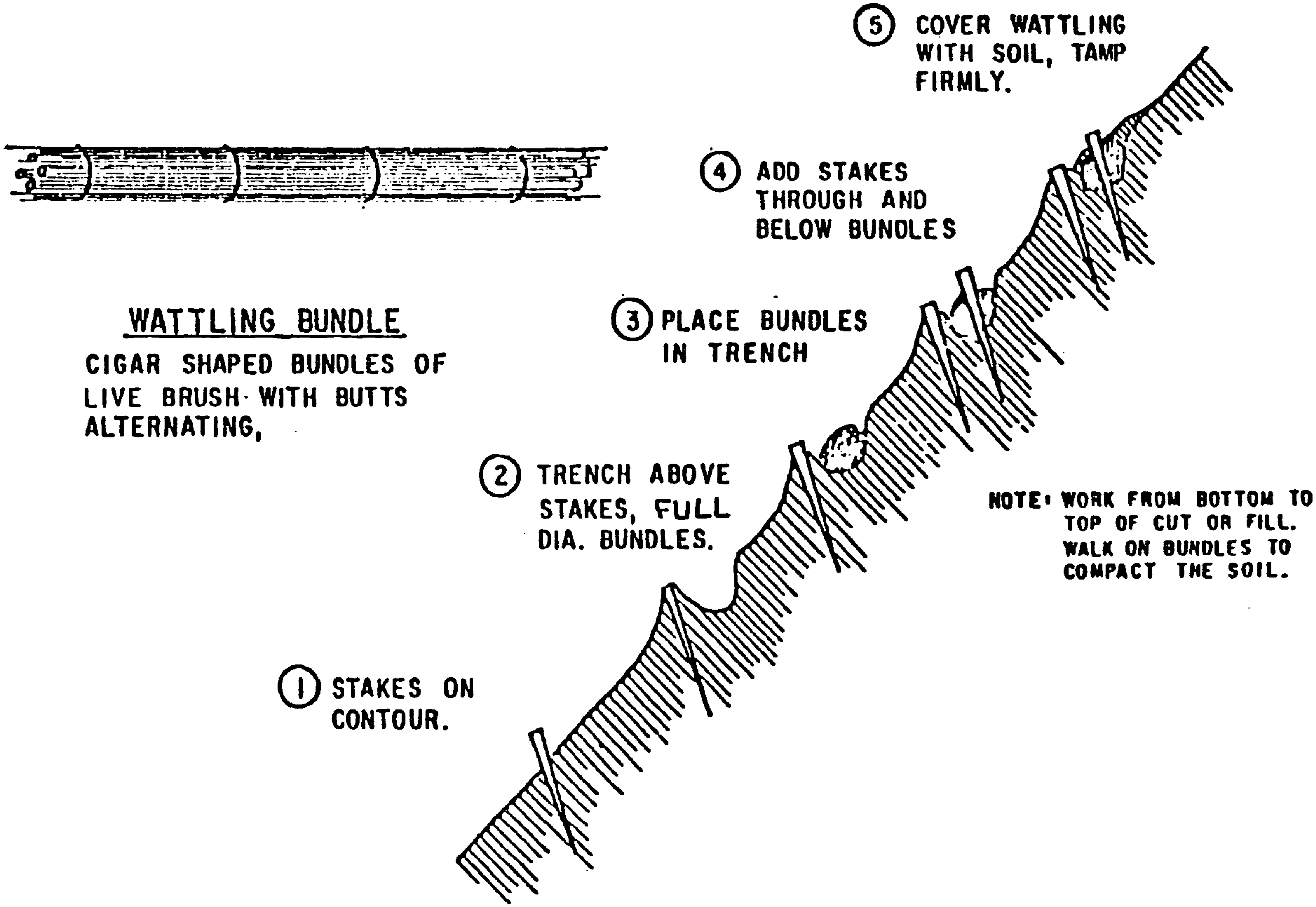


Figure B-5. Procedure for wattling a bare hillslope.(from A. Leiser).

favorable soil and environmental conditions. In many areas wattling has proven to be an effective erosion control practice. In other localities, less expensive procedures (e.g., straw mulch) can be more cost-effective.

5. WOODED TERRACES

A. Definition of job. A wooded terrace is a terrace constructed on a contour and supported by woody material. A wooded terrace is a structural measure which can retard surface erosion and hasten the establishment of vegetation.

B. Specifications.

1. Woody material is defined as limb, split product material or bark.
2. Statement of Work (S.O.W.) shall specify spacing (slope or vertical) of wooded terrace rows. If not specified a vertical spacing of 3 feet shall be used.
3. The grade for wooded terraces shall be level. Each terrace shall be staked with an Abney level, string level, or similar device to follow slope contours.
4. Cumulative diameter of woody material placed in a terrace shall be at least 8 inches. There is no maximum length for woody material; however, wood must contact the slope along its entire length.
5. Wood stakes, driven vertically into the hillslope, shall be used to anchor the wooded terraces. Stakes shall be greater than 1 1/4 inches in diameter and at least 24 inches long.
6. The maximum allowable spacing for stakes is 20 inches for woody material less than 40 inches in length; 30 inches for woody material greater than 40 inches in length. All ends of woody material must overlap stakes a minimum of 1 foot.
7. All stakes shall be driven to a firm hold and at least 15 inches deep. Where soils are soft and 24 inch stakes are not solid, deeper stakes shall be used. Stake depths may be waived by the Contracting Officer or his/her representative on a site-specific basis at difficult sites where it is impossible to always meet minimum stake depths.
8. Procedure for constructing multiple, level wooded terraces:
   a. begin at bottom of slope to be terraced and work upward.
   b. stake grade of the first terrace.
   c. lay a row of woody material and drive stakes against the downhill side along the entire row.
   d. back fill and cover the row of woody materials with clean soil found immediately upslope from the row until a flat terrace is formed. Tamp soil.
   e. repeat on next upslope level.

C. Comments. A vertical spacing of 3 feet seems to work well. Vertical spacing criteria ensure closer spacings on steep slopes and wide spacings on gentle slopes. Stakes made of cuttings of sprouting species (e.g. willow) can aid in revegetation. Because of their wide, level benches, wooded terraces are effective at trapping sediment eroded from upslope areas. However, if they are not constructed absolutely on the contour they may actually collect and concentrate hillslope runoff. In addition, they are relatively expensive to install.

6. RAVEL CATCHERS

A. Definition of job. Ravel catchers are boards, dug slightly into the hillside, and placed on contour (Figure B-6). They catch and store dry ravel during the summer and sheet and rill erosion products during wet periods. Ravel catchers can be placed on steep slopes where soil dry-ravels or can be easily washed downhill. When placed on cutbanks and/or other exposed subsoil, and then partially backfilled with fertile soil, ravel catchers can also act as protected planting sites for woody vegetation.

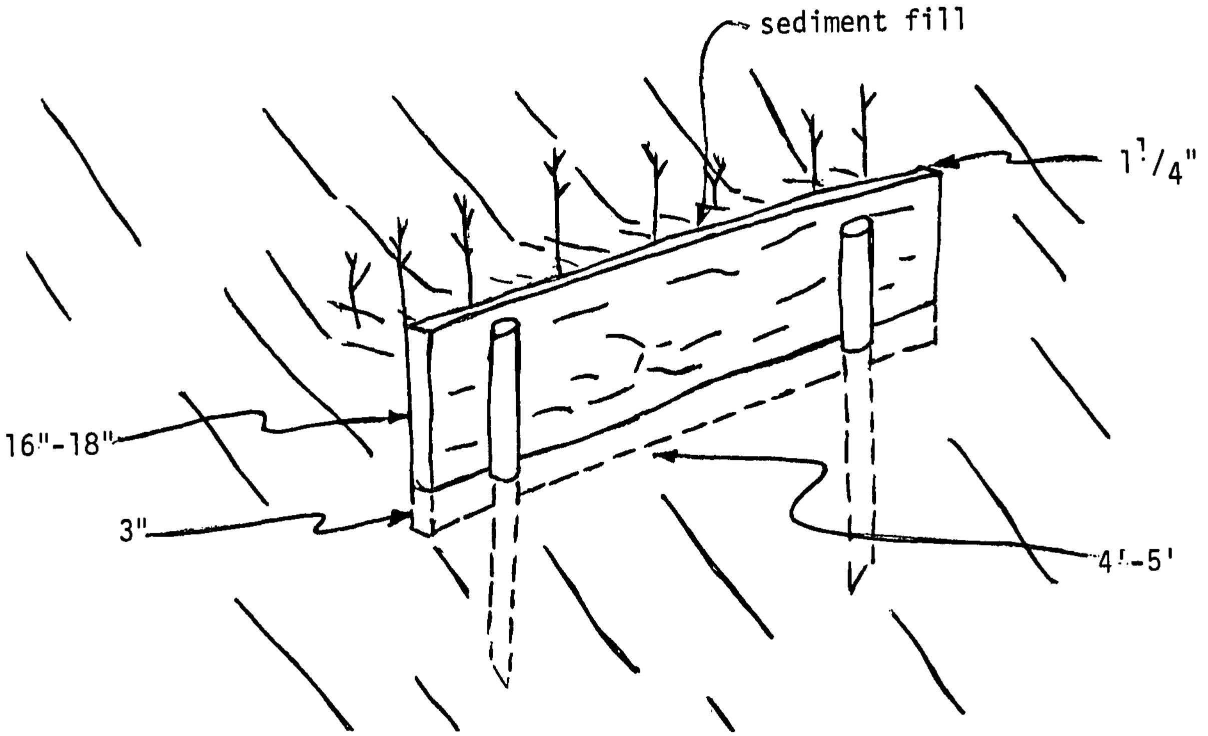


Figure B-6. Typical ravel catcher dimensions with sediment fill.

B. Specifications.

1. Ravel catchers shall be made of split or milled boards, or other suitable material specified in the S.O.W.

2. Boards shall be 16 inches - 18 inches wide, at least 1 1/4 inches thick and 4 feet to 5 feet long. In some cases, ravel catchers shall be continuous and the length of boards will be determined by hillslope micro-topographic characteristics.

3. A trench at least 3 inches deep shall be dug the length of the board. The board shall be placed vertically (on edge) and anchored by wood stakes.

4. Stakes greater than 24 inches deep shall be driven on the downslope side of the board. They shall be spaced no greater than 30 inches apart.
5. Once placed, the boards shall be partially backfilled with soil.

C. Comments. Ravel catchers should not be constructed long enough to collect and divert significant quantities of surface runoff. Ten feet is an upper limit, with 3 to 5 feet lengths preferable. Ravel catchers work best on steep slopes (>50%) which are prone to dry ravel.

SECTION C: REVEGETATION

1. STEM CUTTINGS

A. Definition of job. A stem cutting is a shoot, or cane, cut from a live tree or shrub. Cuttings from sprouting plant species will grow if planted in the ground under certain conditions.

B. Specifications.

1. Prepared cuttings shall have the following characteristics:

a. From healthy wood of a sprouting plant species native to the planting site.

b. Reasonable straightness.

c. Clean cuts with unsplit ends.

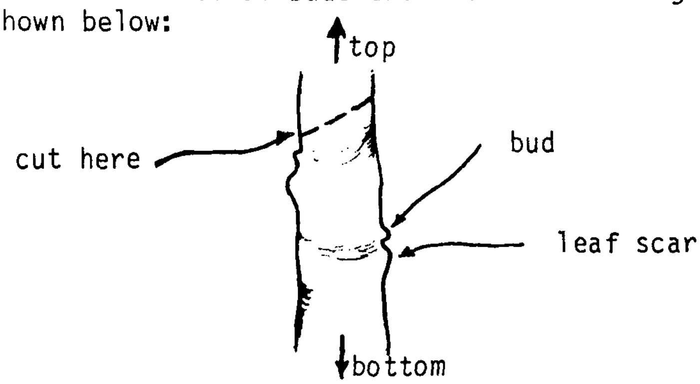
d. Length: 12-inch minimum length.

e. Diameter: 1/4 - inch minimum diameter; the thicker the cutting, the greater the reserves. Therefore, cuttings greater than 1 inch are desirable, though their numbers may be limited by the supply.

f. Stem cuttings shall *not* be from the tips of branches, but rather farther back on the stems. The top of each cutting shall be just above a leaf bud, the bottom cut just below one (see sketch below).

g. Trim branches from cuttings as close as possible.

h. At least 2 lateral buds shall be above the ground after planting, as shown below:



2. Leaves shall be stripped from cuttings which are to be used before normal leaf fall occurs. It is preferable to cut dormant stems.
3. Handling of cuttings between cutting and planting: Cuttings must not be allowed to dry out. Cuttings may be planted the same day, and at all

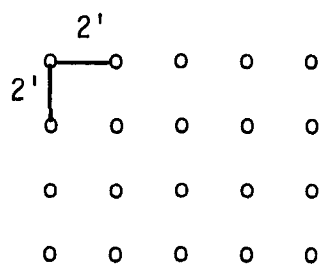
times must be kept covered and moist during transport and storage before planting. Under certain dry conditions of either the cutting site or the planting site, the Contracting Officer or his/her representative may require that cuttings be soaked at least 1 day prior to planting, though mandatory soaking will be uncommon. At no time shall a cutting be left exposed to the air to dry out prior to planting.

4. Planting of cuttings: Cuttings must be planted right-side-up. At least 50% of the cuttings length should be planted in the ground. It is preferable if 75% of the cutting length is in the ground, but at least two budding nodes shall be left exposed above ground. Deep planting minimizes loss of water due to transpiration and evaporation. Soil shall be firmly pressed around cutting to reduce moisture loss and improve soil contact.

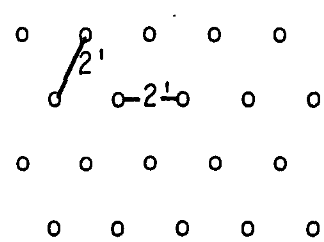
5. Time of planting: Basically, planting time is between September and April. The earliest possible planting time for wet sites is after first major storm in fall (greater than 1 inch rain). For dry sites, the earliest planting time is after the second major storm. The latest possible date is dependent on the particular year, but will be approximately March 1st. Additional soaking prior to planting may be required for late plantings. Optimum planting time is October through February, when ground is wet and plant material is dormant.

6. Cutting willow and other brushy species for planting: Cutting of plant material for use as wattles or cuttings will be done to minimize disturbance of vegetation and soil adjacent to the willow stands. Conifers must not be damaged. Ground cover must be preserved as much as possible. Willows should be used as efficiently as possible (i.e., when stakes for wattles are cut, excess branches should be used as cuttings or wattle bundle material). Willow shoots must be cut by either pruning shears, hand saw or chain saw. Branches from willow must be cut diagonally to expose more surface area to water and to provide a pointed end for stake driving and planting the cuttings. The basal ends of the shoots must be marked clearly in some manner so workers can determine which end to plant. Correct species identification is essential, particularly in the willows and alders which often look similar but have different habitat requirements which in turn may result in different survival success. Species identification should be confirmed by qualified personnel before collection.

7. Placement of stem cuttings and transplants: The required planting distance between transplants and/or stem cuttings will be stated in the S.O.W. as "2-foot spacing" or "3-foot spacing" etc. The rows must be staggered rather than be in columns, as depicted in the sketch below:

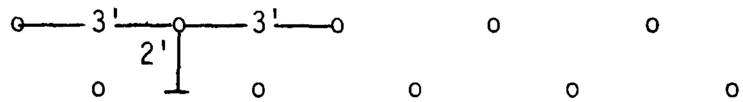


2-foot spacing
Wrong Way



2-foot spacing
Correct Way

Where the contract specifies planting in a zigzag pattern, x foot spacing, y foot offset, a double row is desired with x number of feet between each cutting or transplant in that row and the second row y number of feet to the side. For example, a zigzag pattern with 3-foot spacing and 2-foot offset would be planted as follows:



C. Comments. Planting stem cuttings of sprouting species can be an inexpensive, successful method for revegetating disturbed sites, especially if planting stock is composed of locally abundant native species. Proper identification of native species can be assured by consulting local experts in plant taxonomy or by using references such as Abrams Illustrated Flora of the Pacific States (Stanford Univ. Press).

It is imperative, for the success of any revegetation project utilizing stem cuttings, (for example direct planting or wattling), that you select only sprouting species which will survive in the project area's micro-environment. It is surprisingly easy to waste time and money by using species which have little or no sprouting potential, or by planting sprouting species where they will not survive. Common sense, professional advice and simple field or greenhouse experiments can virtually eliminate these problems.

Stem cuttings are often planted in the following types of locations:

1. Slopes: bare soil areas that show evidence of recent movement or active erosion of surface particles. Persistent wet areas, road-cut slopes with favorable soil conditions and bare soil areas on slumps are especially well suited for cuttings .

2. Gullies and channels: areas best suited for use of cuttings are the floors and banks of small incipient gullies, sediment fill behind checkdams, raw gully banks, stream channel banks, berms of waterbars and the area just below waterbar outlets, if suitable soil conditions exist.

3. In addition, any other location where cuttings may be deemed useful in establishing vegetation for minimizing erosion.

2. TRANSPLANTS

A. Definition of job. Transplanting is the intact removal of an individual plant from one place and replanting it in another.

B. Specifications.

1. Although determining the size of an adequate root ball is necessarily a judgmental decision best made on a plant-by-plant basis in the field, all plants must be dug with a ball of soil containing at least 60% of their

roots. If the soil is dry, the soil around the plant shall be soaked prior to digging so that the root ball will hold together. Plants must be transported to the site in such a way that the root ball does not shatter, exposing the roots (size of transplant and root ball varies with species; see species specific specification below).

2. All species shall be replanted within a maximum of 24 hours of being dug up. The root ball must be kept moist at all times to keep the roots from drying out.

3. The planting hole shall be large enough to accommodate the root ball easily, without cramping, bending or cutting roots. Adjust planting depth so that the old soil line (usually visible near the base of trunk or stem) is at the surface level of soil surrounding the planting hole.

4. The hole shall then be refilled about 3/4 full with soil, firmed around the roots and thoroughly watered. If settling occurs, the plant shall be readjusted and the remaining soil added, again firming the soil to eliminate any air pockets.

5. Transplants shall be obtained in such a way that at least one half of the original plants of the species remain scattered within the collection area. The source area must not be denuded of plants.

6. Holes created by removal of plants shall be filled with soil to the original soil surface.

7. Alder (*Alnus oregana*), coyote brush (*Baccharis pilularis* var. *consanguinea*) and rhododendron (*Rhododendron macrophyllum*) transplants: Minimum size plants shall be 6 inches high, maximum, 24 inches high. The larger the plant, the larger the root ball. At a minimum the surface circumference of the root ball shall equal the circle made at the drip line of the plant's canopy.

8. Deerfern (*Blechnum spicatum*) and swordfern (*Polystichum munitum*) transplants: Minimum basal diameter of fern clump shall be 4 inches, and the root ball shall include a minimum of 75% of the plant's roots.

9. Rush "plugs": Correct species identification is essential. Species identification shall be confirmed by qualified personnel before collection. *Juncus* "plugs," each with a 2-inch minimum basal diameter, may be obtained by dividing larger clumps.

10. Salal (*Gaultheria shallon*) and yerba de selva (*Whipplea modesta*) transplants: Both species root at the nodes, though salal does so less frequently. Transplants shall have root balls at least 8 inches in diameter and it is desirable to include at least 10 inches of the underground stems whenever encountered. Large plants may be divided, provided each division has an 8" root ball.

11. Placement of transplants: See 1.B.7. Placement of stem cuttings and transplants.

C. Comments. Transplants specifications used in #7, #8, and #9 above are examples for species in north coastal California. Similar specifications can be prepared for virtually any native species. Alternatives to field transplanting include direct seeding of native species or, for more rapid results, contracting at least one year in advance for a nursery to grow large numbers of containerized stock which can then be out-planted with excellent success.

3. SEEDLINGS

A. Definition of job. Seedlings are grown from seed rather than from vegetative parts. They can be grown in containers or in beds and lifted and replanted as bare root stock.

B. Specifications.

1. Seed source shall be from the area the seedlings are to be planted or upon the park's approval, from California seed zone 091 or 092, elevation 0-3000 feet.

2. One season old container grown seedlings shall be grown in styroblocks, leach tubes or book planters having a minimum 5 cubic inch volume. Roots must branch enough to hold the growing mix intact. A minimum 12 cm top height and 2.5 mm stem diameter is required.

3. Two season old bare root seedlings shall have a minimum 20 cm top height and 3.5 mm stem diameter.

4. Seedlings shall be dormant when lifted and packed. They must be kept cool, shaded and the roots moist, and they shall be planted within one week of delivery.

5. Planting holes must be at least as deep as the length of the root mass. No root pruning is allowed. Care must be taken to insure that the root "plug" of container seedlings is not shattered and the growing mix lost. No portion of the roots should be exposed or any of the needles or branches covered with soil. The roots must not be doubled up, twisted, spiraled or bunched. Adjust the plant's depth so the old soil line on the base of the stem is at the surface level of soil surrounding the planting hold. Soil must be filled in and firmed so that no air pockets remain.

6. All containers shall be returned, allowing 10% loss.

C. Comments. These are an abbreviated version of Redwood National Park's contract requirements. Greater detail is available upon request. For additional information, see:

Cleary, Brian D., R.D. Greaves, and R.K. Hermann. 1978. Regenerating Oregon's Forests, A Guide for the Regeneration Forester. Oregon State University, School of Forestry, Corvallis, Oregon. 287 p.

The U.S. Forest Service's Seeds of woody plants of the United States (U.S. Dep. of Agric. Hanb. 430. 1974. 883 p.) complies seed data on 188 genera of woody plants, including flowering and fruiting dates, seed processing methods, storage conditions, seed yields and weights, methods of breaking seed dormancy and germination tests.

In California, seed source for tree seedlings ordered from commercial nurseries can be specified by seed zone and elevation. The California Department of Forestry has divided and mapped the state by seed zones based on climatic and physiographic conditions. In other states, check with an equivalent agency. When having seed collected, require the following information: species, seed zone, elevation, date of collection, location (township, range and section) and for trees and shrubs, the number of plants from which the seed is collected.

SECTION D: CHANNEL EROSION

1. ROCK ARMOR (hand-placed)

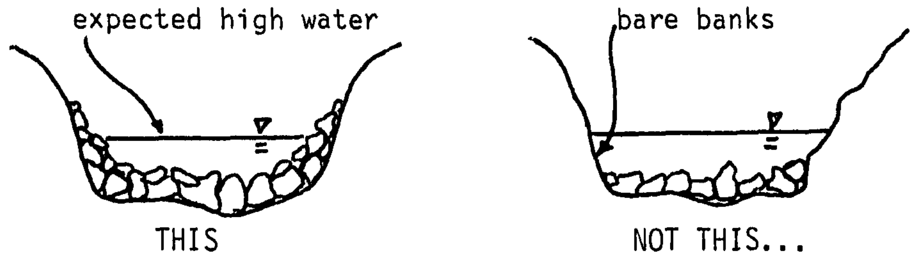
A. Definition of job. Rock armor is placed in small stream channels, gullies or other expected flow courses to increase turbulence and energy expenditures, slow velocities and eliminate scour of channel banks and beds.

B. Specifications.

1. Peak 20-year discharges for the channel reach shall be calculated using acceptable formulas (Rational method, SCS, etc.). Estimates must be substantiated by field evidence.

2. For newly constructed channels, the channel bottom shall be made wide enough to handle peak flows. Wide, shallow channels are preferable to deep, narrow cross sections.

3. When the S.O.W. calls for channel excavation and rocking channel bed, the channel will be excavated in such a way that the bed is slightly concave, and rocks will be placed far enough up the channel banks to contain anticipated heavy flow. This is an effort to prevent failures due to flat-bottomed, rocked channels, where bank cutting can occur during high water (see sketch below):

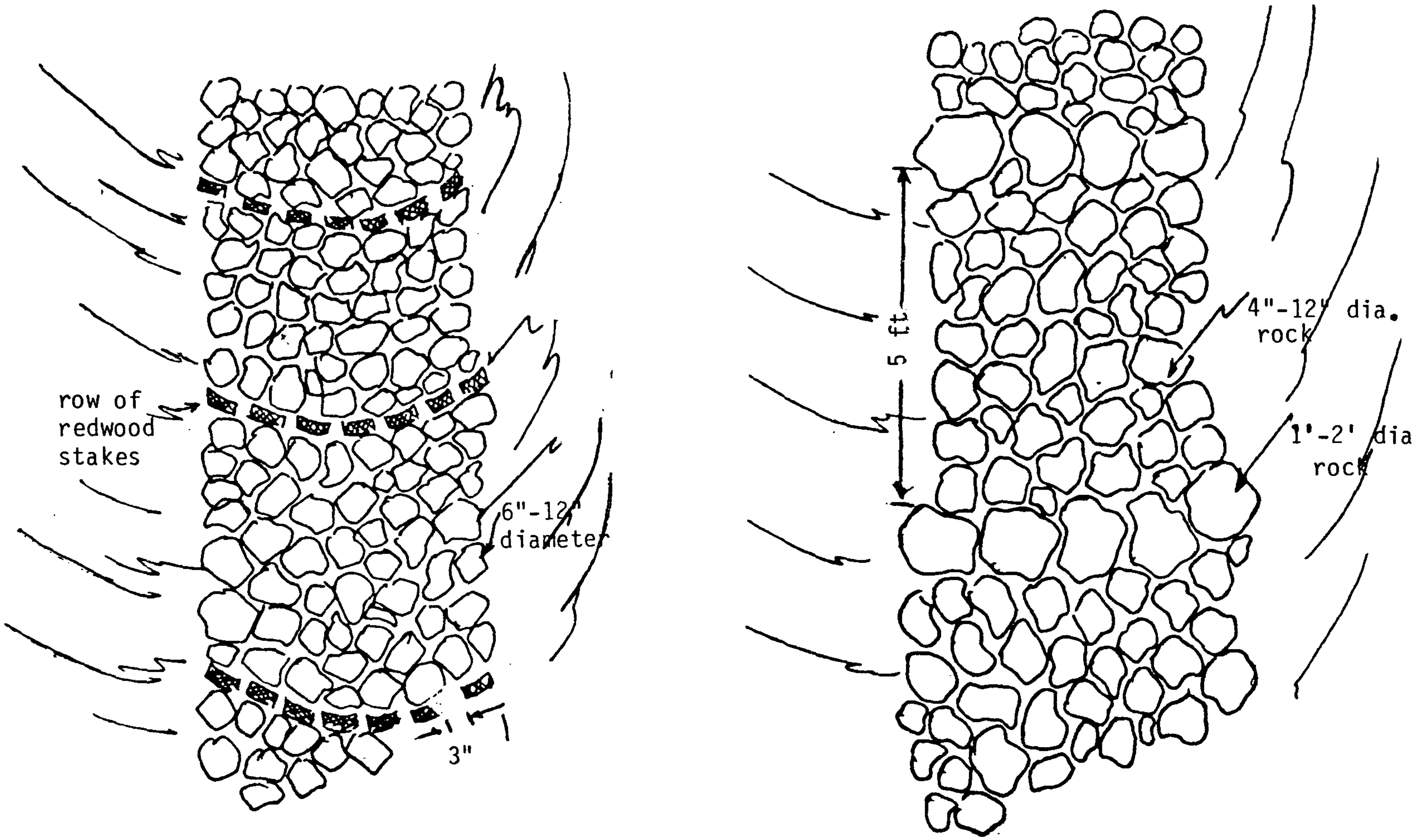


4. Sufficient quantities of rock shall be used to adequately protect and armor the bed of the channel.

5. Rock sizes and/or securing techniques shall be employed to assure that peak flows do not remove the protective material. A heterogeneous mixture of rock sizes shall be used which contains enough large rocks (rocks which cannot be moved during peak flows) to keep smaller rocks in place. Where only small rocks are available, securing techniques such as staking or wire reinforcing shall be used to anchor the armor material to the bed.

6. Rocks shall not be so large as to deflect streamflow into the banks.

C. Comments. Several potentially viable channel rocking methods are shown in Figures B-7 and B-8. The successful application of hand placed rock armor is limited by the maximum size of rock that can be moved in the channel. Rocks larger than 18 inches diameter are difficult to handle. In addition, in remote areas adequate sources of rock may not be locally available. Armoring with insufficient rock coverage or with rocks which will be transported by peak flows provides little channel protection. Finally, as with most erosion control devices, regular maintenance is needed for several seasons following installation.

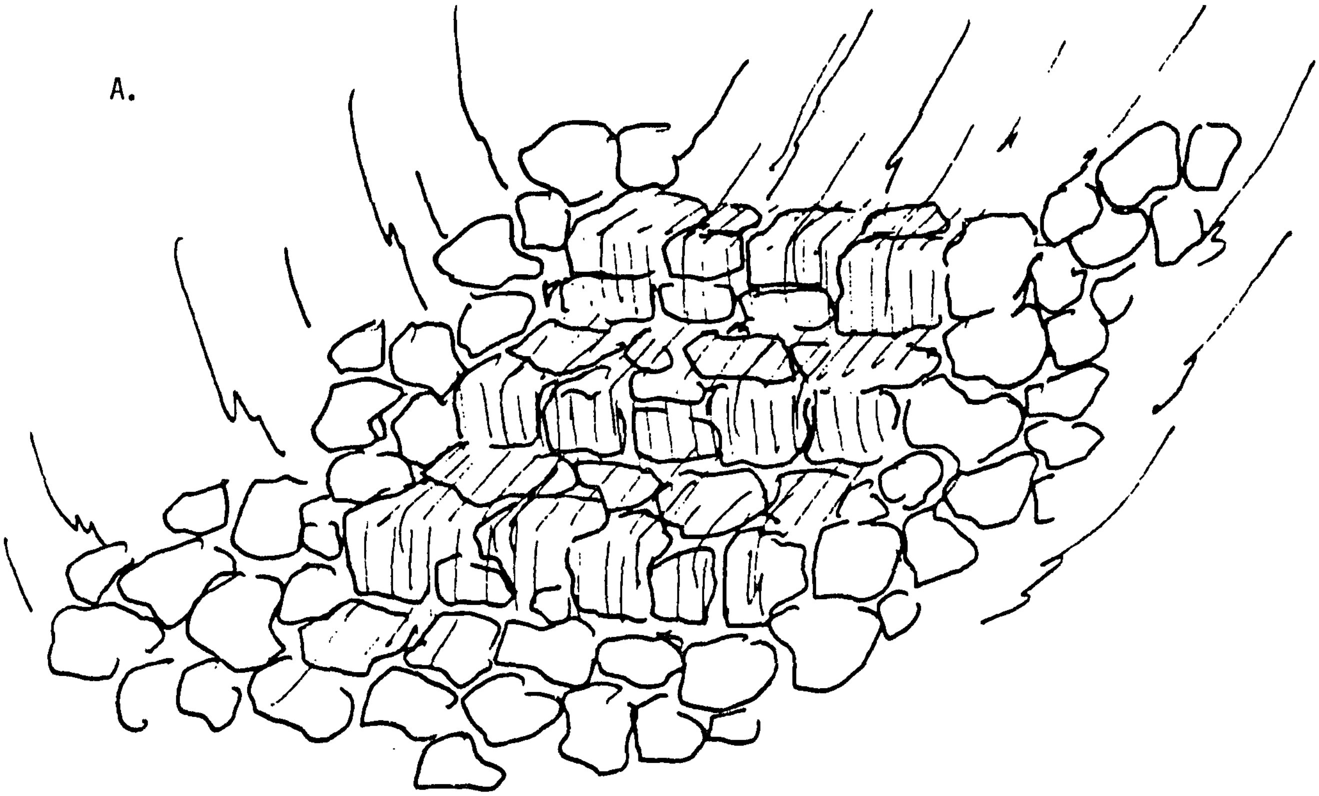


A. Plan view

B. Plan view

Figure B-7. Two methods of keeping small rock armor from being transported down stream are by the use of stakes (B-7a) or large boulders (B-7b) placed across the channel at regular intervals. Some typical dimensions are shown in the sketches.

A.



B.

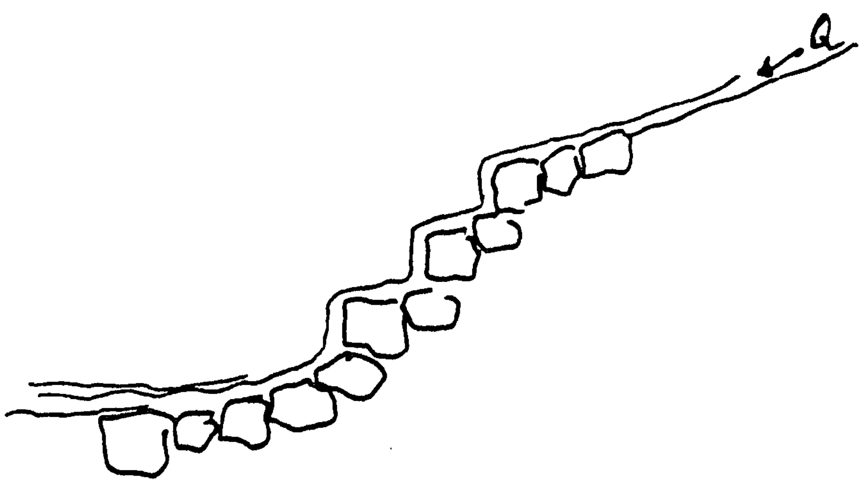


Figure B-8. Oblique view (A) and side view (B) of rock stepped stream channel. Boulders must extend up sides of channel and be large enough to resist plucking from the bed in high flows.

2. CHECKDAMS

A. Definition of job. Checkdams are constructed in gullies and stream channels to prevent scour of the bed and banks. By raising local base levels, the sediment fill behind dams can stabilize the adjacent channel bank by preventing gully downcutting and lateral cutting; provided runoff is directed through the spillway of the checkdam and the dam is not undermined by channel downcutting from below the dam. The sediment fill behind the checkdams and the bare soils on the adjacent channel banks (slopes) are planted heavily with cuttings or transplants after the checkdams have been installed.

B. Specifications.

1. Composition of checkdams. Checkdams can be constructed from on-site materials, such as split redwood or cedar boards from downed logs on the site or on nearby areas, purchased lumber, conifer boughs, rock, or other suitable material specified in the S.O.W. The choice of material will be determined by availability of the material at or near the site and the suitability of the material for the particular gully or stream.
Design criteria for checkdams may only be altered with written approval from the Contracting Officer, or his/her representative. In all other cases, the listed specifications shall be adhered to.

2. Proper placement of checkdams in a gully or stream channel. All checkdams shall be placed properly in a gully or stream channel, otherwise downcutting will continue and will undermine the dams. Checkdams shall be installed as integrated units, each of which acts to stabilize neighboring dams. Checkdams shall be aligned perpendicular to the channel. This will prevent concentrating flow at either bank.

Dam construction shall begin from the bottom of a gully or stream reach to be checkdammed, and must begin at a "stable" point. Ideally, the lowermost checkdam should be constructed on a non-erodible material such as bedrock, large boulders which the gully or stream cannot transport, or large logs partially buried in the gully or stream bottom (Figure B-9). All checkdams constructed upstream from the lowermost dam shall be placed so that the sediment fill behind the downstream dam (after it fills to the spillway level) abuts against the base of the next upstream checkdam. To assure this condition is met, use a line level to place upstream dams. Stretch a level line from the spillway level until it contacts the channel bottom upstream (Figure B-10). This point of contact denotes the location of the next upstream checkdam. Construct that checkdam and continue this process up the gully or stream reach to be checkdammed. Each checkdam's spillway shall be constructed before the next upstream checkdam is placed.

3. Split or milled board checkdams for small gullies and streams.

a. Thickness and length of checkdams. Checkdams shall be constructed of redwood or cedar boards long enough to span the entire width of the gully or stream channel and shall be keyed into the banks (see h. below). Boards shall be 1 inch thick. However, if dams are from 6 to 10 feet in length, allowable thickness shall be at least 1 1/4 inches-1 1/2 inches.

b. Free-board height. Checkdam free-board height is the vertical distance between the spillway level and the lowest point of the top of the checkdam (Figure B-11). Free-board prevents high flows from cutting

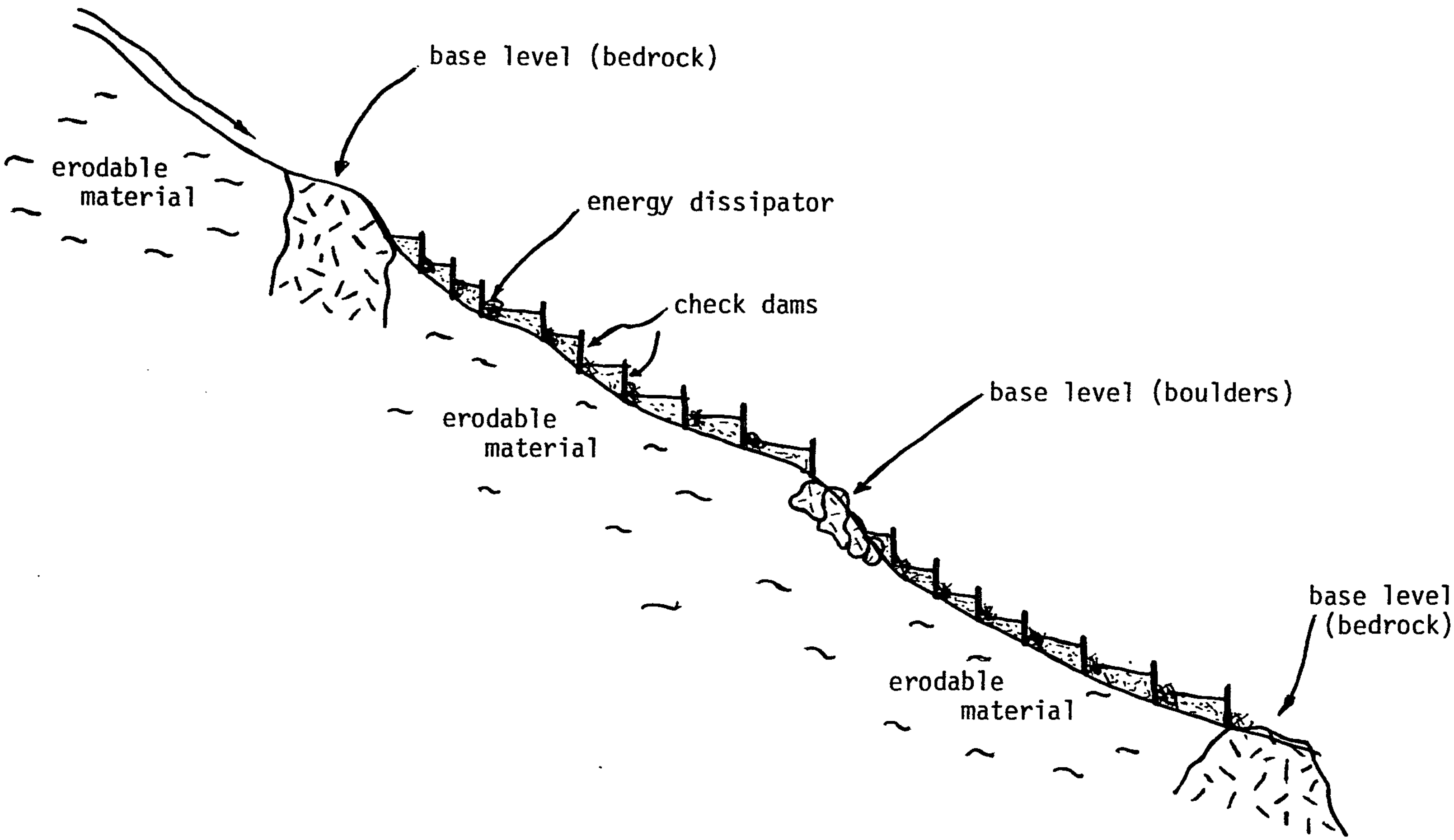


Figure B-9. Profile along a gully bottom showing proper placement of two sets of checkdams with lower-most checkdam constructed on a non-erodible base (called a base level).

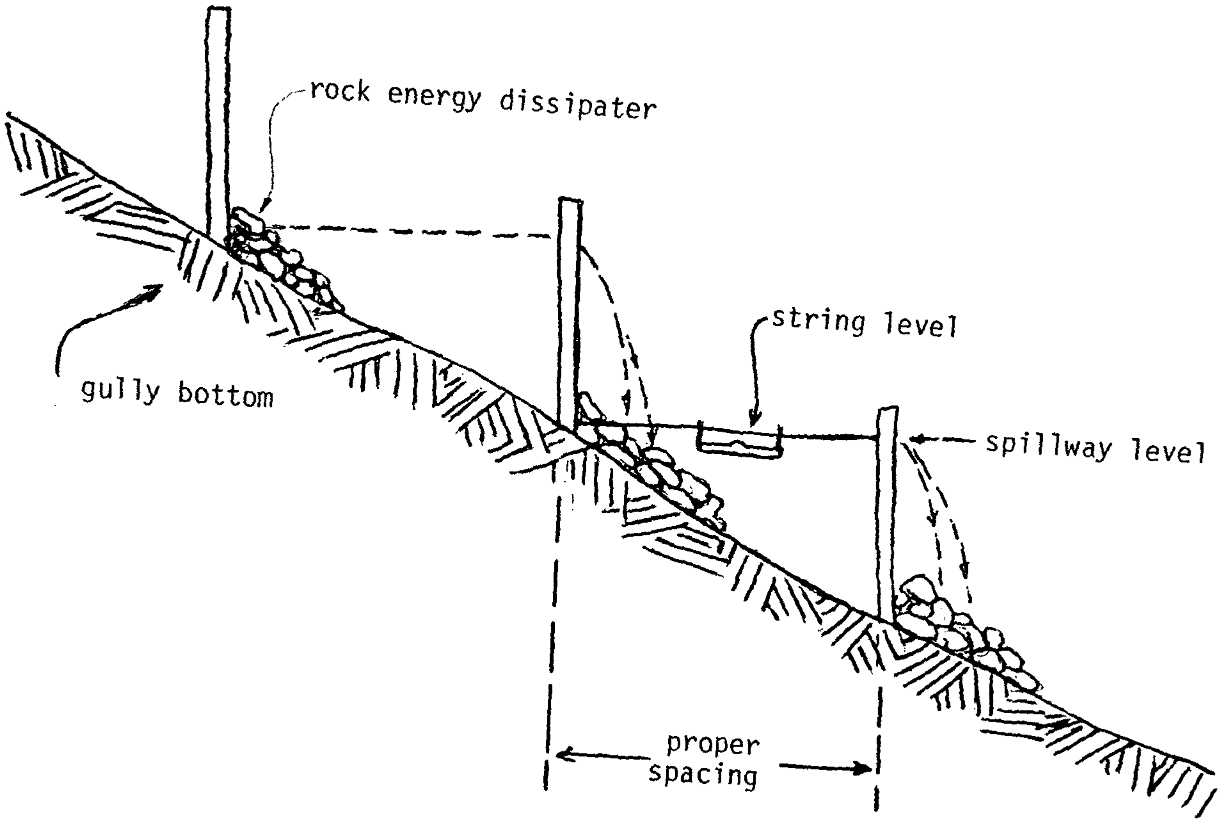
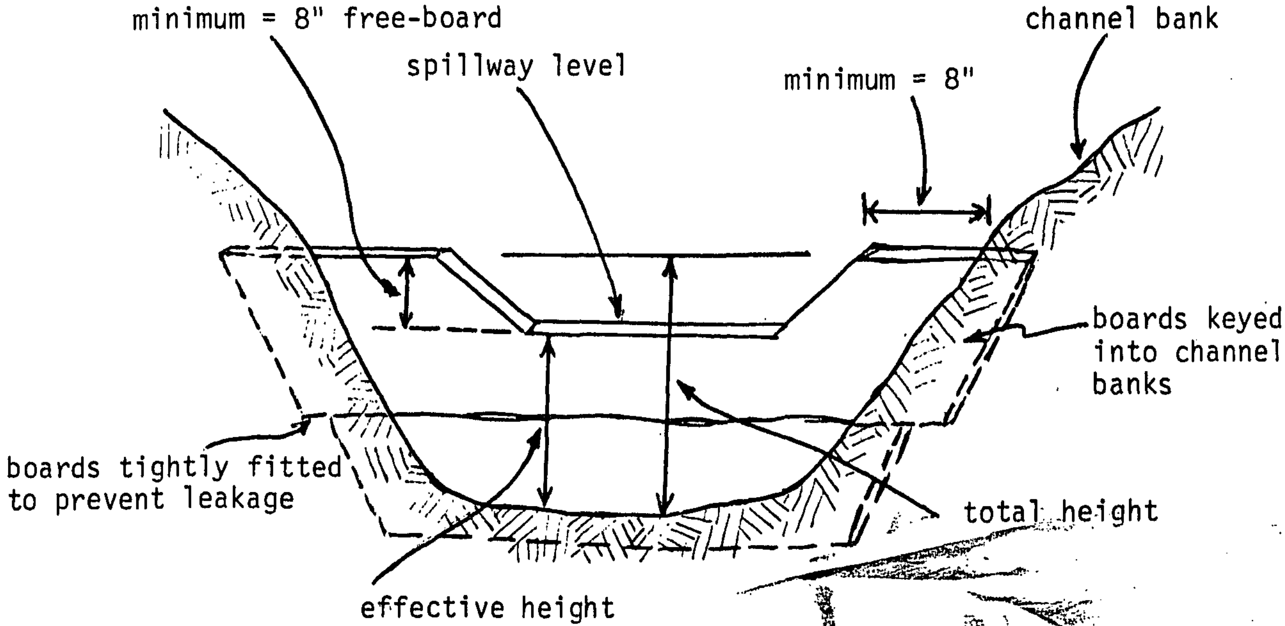


Figure B-10. Use of a line level to determine conservative distance between checkdams in a gully.

FRONT VIEW (cross section)



SIDE VIEW (profile)

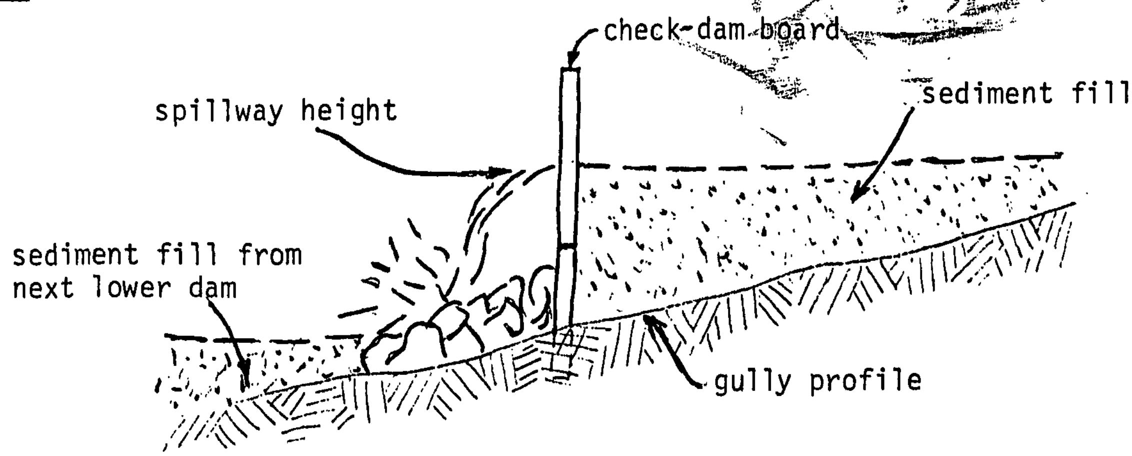


Figure B-11. Front and side views of checkdam showing major components, dimensions (typical) and final form in gully.

laterally into the channel banks and causing a checkdam to fail. Free-board height shall be at least 8 inches.

c. Effective height. The effective height is the height of a checkdam which actively traps and stores sediment (Figure B-11). It is the vertical distance between the channel bottom and the spillway. Effective height shall be at least 8 inches and maximized whenever possible.

d. Total height. Total checkdam height is the sum of effective height and free-board height, and is dependent upon channel bank height. Generally, the higher the banks, the higher total checkdam height can be. Maximum total checkdam height shall be 40 inches.

e. Multiple board checkdams. Two boards may be used in order to attain maximum total checkdam height. However,the widest board shall be placed on top and shall never be cut through entirely in order to construct a spillway.

f. Checkdam spillway. Board checkdams must have adequate capacity spillways to accommodate high flows in the gully or stream channel. The S.O.W. shall specify the spillway area for checkdams to be constructed in each channel reach. Checkdam spillways shall be constructed to contain the project design discharge (eg., the 20-year return period peak flood flow).

g. Optimizing spillway design. Optimizing spillway design is important to the efficient placement and spacing of checkdams in a channel. Spillway design shall proceed as follows (refer to Figure B-12).

1) Based on channel configuration determine the maximum total checkdam height.

2) Place checkdam perpendicular to channel and secure to channel.

3) Measure an 8 inch free-board line onto dam (line C).

4) Measure at least 8 inches from both banks where the checkdam board enters the channel bank (points "d").

5) Draw 45o to 75o side-walls from points "d" through line C.

6) Compute the spillway area.

7) If the spillway area is less than the specified area (needed to contain the design flood flow), increase the spillway side-wall angle to a maximum of 75o.

8) Compute the spillway area.

9) If spillway area is still not adequate, lower the spillway level (line C) and vary side-wall angle to attain desired spillway area.

An important point to remember about spillway design is that a spillway should never be wide enough to allow water cascading over the spillway to impact upon channel banks at the base of the checkdam.

h. Excavation into channel banks. Boards shall be keyed into (inset into) banks to provide strength and prevent lateral breaching of the dam. Banks shall be neatly excavated (notched) only enough to inset the boards to a minimum depth of 6 inches. Excavate channel bottom to a minimum depth of 3 inches. The only exception shall be if channel bank excavation threatens to collapse the bank, or if the bank is composed of rock, or wood. If bank collapse is a problem, a compromise between enough excavation to prevent lateral breaching and a minimum amount of excavation to preserve the integrity of the bank shall be reached by on-site decisions with the Contracting Officer or his/her representative. Once a dam has been placed and inset into bank, clean fill material (i.e., fill containing no large rocks and/or woody debris) shall be packed into the channel bank where the dam is inset and along the upstream bottom of the dam. Clean fill must be used to seal the dam.

i. Anchoring board checkdams. Checkdams shall be securely anchored to the channel by either wood or metal rebar stakes. Both shall be driven at least 2 feet into the channel bottom and/or banks, and still have

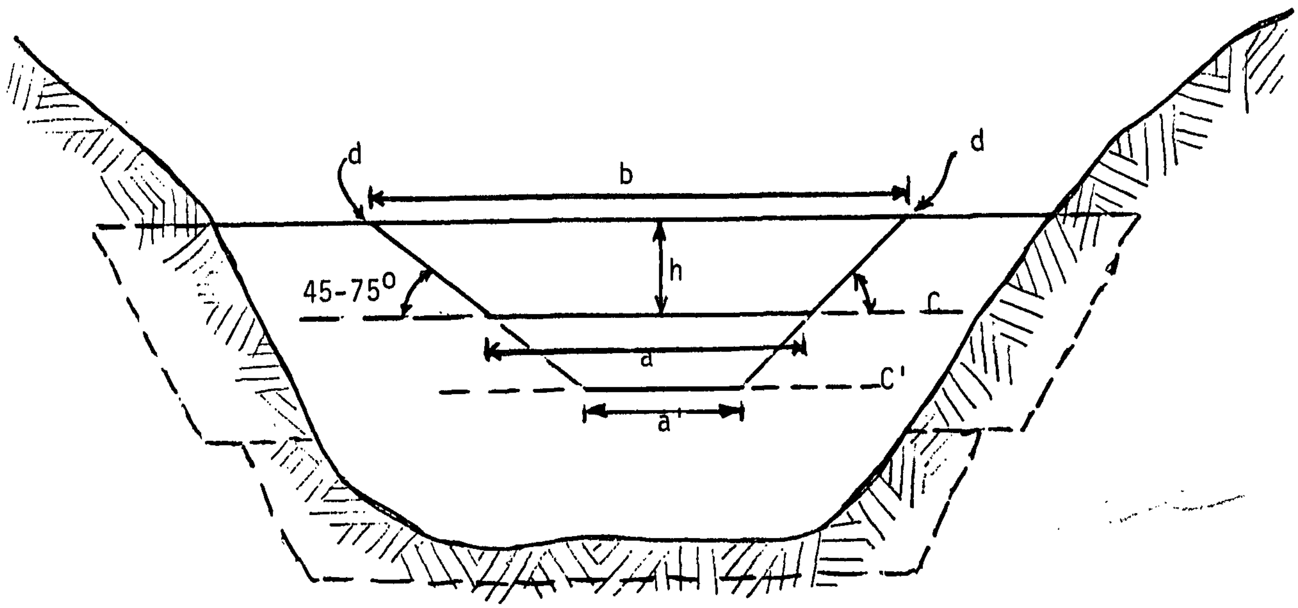


Figure B-12. Procedure for developing a spillway with adequate capacity for flood flows. See text for full explanation of symbols and derivation of procedure.

sufficient length to span at least 3/4 of the total checkdam height. A minimum of 4 stakes shall be driven; two on each bank, with one against the upstream and one against the downstream side of the dam. Stakes shall contact the surface of the checkdam and shall not interfere with flow through the spillway. When checkdams exceed 6 feet in length, two additional stakes shall be driven against the downstream side of the dam evenly spaced across its length.

j. Energy dissipation. All board dams must have adequate energy dissipation devices installed in the channel bottom immediately below the spillway. The energy dissipator can consist of rock, conifer or hardwood boughs, small woody slash, split or milled boards or a combination of the above. Dissipators shall be: 1) firmly secured to the channel bottom, 2) located immediately below the spillway, and 3) as wide as the widest portion of the spillway notch. There should be no gap between the checkdam boards and dissipators. Energy dissipators must extend continuously downstream at least 1 1/2 times the effective height of the checkdam.

4. Rock checkdams for small channels.

a. Size of rock. The largest rocks which can be transported manually and which are available from a nearby locality shall be used to build the dams. Smaller rocks shall also be used in the rock dam so that as many large holes as possible are filled in to reduce porosity.

b. Rock dam height. Rock dams shall be between 12 and 36 inches high.

c. Spillway. Rock dams shall be built with an adequate spillway notch at least 5 inches deep and 5 inches wide. Most importantly, the height of the rock dam shall increase from the spillway toward the gully bank so that all flow is channeled through the spillway region. It is recognized that spillway notches will be highly irregular and variable because of varying rock sizes.

d. Excavation into gully banks and gully bottom. Side banks shall be excavated at least 4 inches unless the ground is too rocky, or unless excavation threatens to collapse the bank. Gully bottoms shall be excavated at least 3 inches. These specifications may be altered by the Contracting Officer or his/her representative on a site-specific basis.

e. Energy dissipation. The slope of the rock dam on the downstream side generally provides adequate energy dissipation below the spillway. The downstream side of the rock dam shall not be so steep as to allow the free fall of water from the spillway notch onto the gully bottom (i.e., the rock dam shall also serve as an energy dissipator).

f. Anchoring rock checkdams in place with wire mesh. All rock checkdams shall be anchored securely in place using corrosion-resistant wire mesh. The wire mesh shall cover the rock dam, be fastened together with baling wire, and be secured to the gully bottom and side with wooden stakes or metal rebar. The entire rock dam, including the base, may also be enclosed in wire mesh, thereby forming an irregular shaped gabion. The wire mesh shall in all cases be securely anchored to the banks.

5. Bough dams for small channels.

a. Utilization of bough dams. Bough dams can be an effective type of checkdam in certain localities. No specifications for bough dams are given here. The use of bough dams in a gully or stream reach shall be discussed with, and approved by, the Contracting Officer in writing prior to any bough dam installation.

b. Anchoring bough dams to gully. Because bough dams totally lose their leaves in as quickly as 4 months, or sooner, after being cut and installed in gullies, it is important that the boughs be bound tightly together and staked firmly in the ground so that the bough dam does not become loose. Rocky gullies that do not allow adequate staking are generally unsuited for bough dams.

C. Comments. The above specifications are applicable to channel stabilization measures for small coastal streams (maximum drainage area of about 50 to 100 acres) in Northern California. A multitude of checkdam construction techniques have been developed for areas in the Western U.S., and elsewhere. The following references provide a good starting point for matching your particular situation with the proper type of channel protection measure.

1. Heede, Burchard H., 1965, Multipurpose Prefabricated Concrete Checkdam, U.S.D.A. Forest Service, Research Paper RM-12, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

2. Heede, Burchard H., 1966, Design, Construction and Cost of Rock Checkdams, U.S.D.A Forest Service, Research Paper RM-20, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

3. Heede, Burchard H., 1968, Conversion of Gullies to Vegetation Lined Waterways, U.S.D.A. Forest Service, Research Paper RM-40, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. (Dr. Heede is now located at the Forest Sciences Laboratory, Arizona State University, Tempe, AZ.)

4. U.S.D.A. Forest Service, 1974, Forest Service Handbook, FSH2509:12-Watershed Structural Measures Handbook, Amendments 1-3, July 1969, 103 pages.

5. High Sierra Resource Conservation and Development Council, 1981, Erosion and Sediment Control Guidelines for Developing Areas of the Sierras, California Water Resources Control Board - Central Valley Region, 170 pages.

3. SUBMERGED SPILLWAYS

A. Definition of job. A submerged spillway is nothing more than a submerged checkdam placed with the spillway at streambed level. Like checkdams, they can stabilize the adjacent channel bank by preventing downcutting and lateral cutting. They function properly if runoff is directed through the spillway, and the submerged spillway is not undermined by channel downcutting from below the structure. Submerged spillway construction is most applicable in broad channels with shallow, poorly defined channel banks and rock bottoms.

B. Specifications.

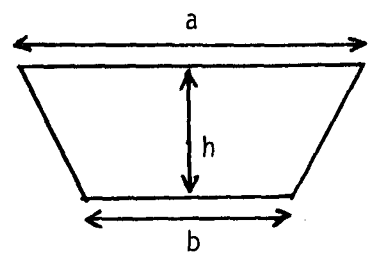
1. Thickness and length of submerged spillways. Submerged spillways are to be constructed from redwood or cedar boards and shall be keyed into adjacent banks (see B.6). Board thickness shall never be less than 1 inch and shall be at least 1 1/4 inches thick if submerged spillways are greater than 6 feet long.

2. Free-board height. Free-board height is the vertical distance between the spillway level and the lowest point of the top of the submerged spillway. Free-board height shall be at least 8 inches (Figure B-13).

3. Total height. The total height of a submerged spillway is the sum of the free-board height and that portion of the structure which is keyed (buried) into the channel bottom. Total height shall never be less than 14 inches (i.e., 6 inches of board surface keyed into the channel below the spillway level, plus 8 inches of free-board).

4. Spillway area. The S.O.W. shall specify the spillway area for submerged spillways to be constructed within a particular reach. A spillway can be cut into the board prior to installing the submerged spillway into the channel.

5. Spillway design. Construct the spillway in the form of a trapezoid. The formula to compute area of a trapezoid is $A=1/2(a+b)h$ (see sketch below):



6. Excavation into channel banks and bottom. Boards shall be keyed (inset) into the channel banks to provide strength and prevent lateral breaching of the submerged spillway. Banks shall be neatly excavated (notched) only enough to key the boards at least 8 inches into the channel banks. It will also be necessary to excavate the channel bottom 6 inches deep to receive the submerged spillway. Once a spillway has been placed into the channel, clean fill material (i.e., no large rocks or organics) shall be packed into the channel bank and bottom where the spillway is inset to create a seal.

7. Anchoring submerged spillways. Submerged spillways shall be securely anchored to the channel by either wooden stakes (1 1/2 inches diameter) or metal rebar. Stakes shall be driven at least 2 feet deep into the channel bank and/or bottom, and still have sufficient length to span the free-board height. A minimum of 4 stakes shall be driven: 2 on each bank with 1 against the upstream and 1 against the downstream side of the spillway. When submerged spillways exceed 6 feet in length, 2 additional stakes shall be driven against the downstream side of the spillway spaced evenly across its length. Stakes shall not extend into the spillway area.

8. Submerged spillway placement. Submerged spillways are always installed with the spillway at streambed level, and perpendicular to the channel. No energy dissipation is required downstream from the spillway. The S.O.W. shall specify the distance between each submerged spillway. Begin at the bottom of the channel to be treated. Excavate channel banks and bottom to receive the lowermost spillway, and stake into place. Measure channel distance to next submerged spillway as specified in S.O.W., and install the next structure. Channel areas between structures can be rock armored for added protection.

Comments. Submerged spillways described here have only been tested on very small streams (drainage area = 10-20 acres). They essentially act to control local base levels and keep streamflow near the center of the channel (away from the banks).

4. WATER LADDERS

A. Definition of job. Water ladders are wooden structures, similar in appearance to ladders, which serve to convey water across a steep slope while preventing channel downcutting. They serve the same purpose as half-

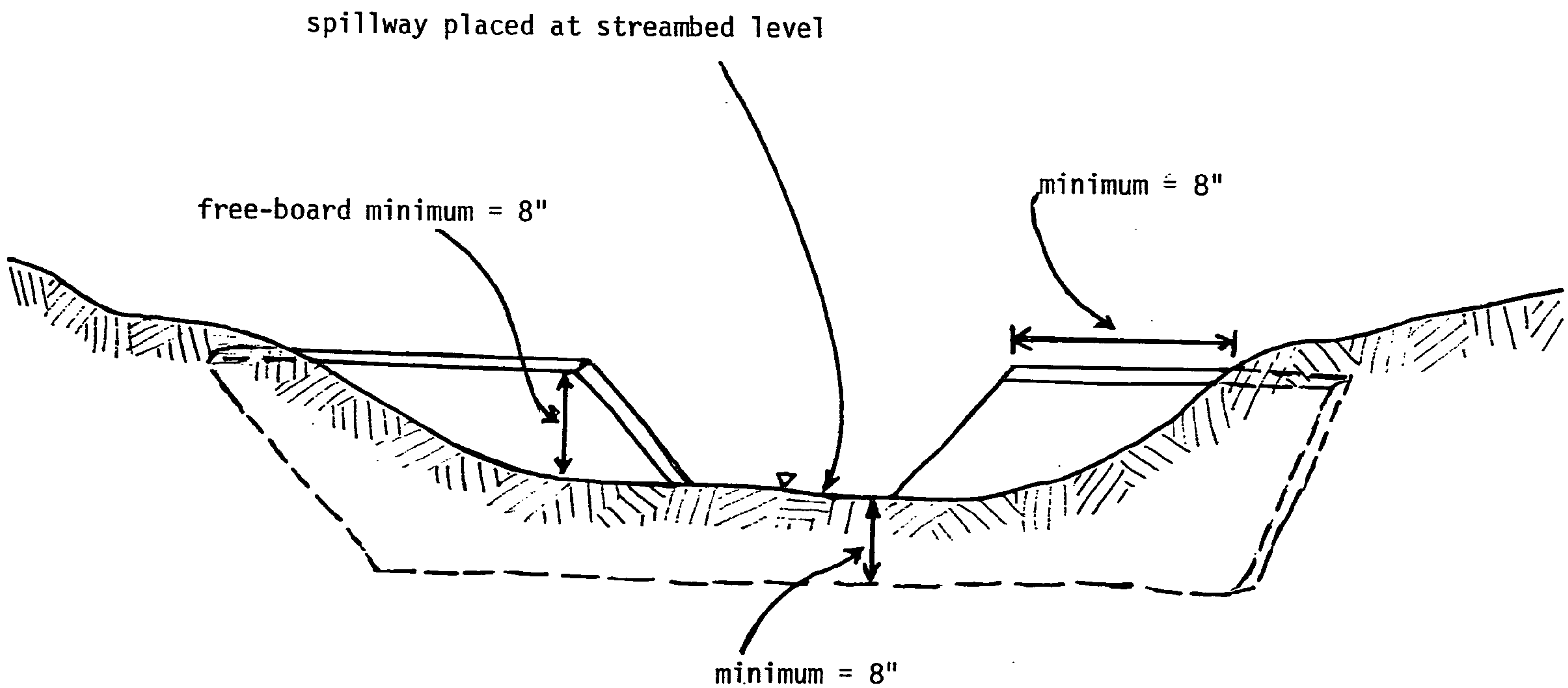


Figure B-13. Schematic drawing of a submerged spillway showing major components.

round culverts or concrete lined channels that conduct ditched or culverted water over steep road fills onto vegetated and/or slash-covered slopes. Essentially, water ladders are energy dissipation devices that can effectively carry concentrated runoff. They work well in conjunction with strategically placed slash and planting of stem cuttings.

Water ladders can be used in combination with checkdams or at the downstream end of cross-road drains. Alternatively, water ladders may be used in lieu of checkdams where dam installation is difficult because of unstable banks or channel beds which are too hard to excavate.

B. Specifications.

1. Construction of Ladder. Ladder construction will be left up to the discretion of the contractor, but the following criteria must be met in construction:

a. Each ladder must be large enough to carry design storm-flows. Each ladder must be at least 18 inches wide unless it is to be placed in a well-defined gully which is less than 18 inches in width. In all cases, the ladder must be as wide as the bottom of the ditch or drainage channel directly above the ladder.

b. Ladder treads must overlap and dip slightly downhill once the ladder is installed. Grooves (about one-half inch deep) may be cut into the top side of the treads to help direct flow towards the center. Bevelling of the leading edge of the treads and nailing of slats under the treads may also be used to help prevent backflow under the treads

c. Where necessary, wing walls should be installed at the top of a ladder to insure that all runoff is directed into the ladder. This may be especially important in wide or poorly defined channels.

d. Outlet areas below ladders should be defended with adequate energy dissipation (rocks, slash, etc.).

2. Placement of ladder. Ladders must be sufficiently inset into the slope so that runoff will course over the ladder treads and not run under or around the ladder. Adequate excavation and especially careful placement of the top of the ladder relative to the ditch or drain are crucial. Improperly placed ladders that do not successfully convey runoff over them (during the first winter season) must be re-installed on request of the Contracting Officer.

3. Type of ladder. Type and composition of water ladders will largely depend on availability of materials and equipment at the site. Boards of rot resistant wood, cut on-site with a portable mill or saw, are preferable. Hand split and hand sawed boards can be used but they may pose problems because of their uneven surfaces. Water leaking through cracks can cause undercutting of the structure. Dry wood shims should be hammered into all cracks and seams to seal them off. The following are examples of water ladders that can be constructed:

Type 1 - Split board water ladder (Figure B-14). This water ladder begins with a checkdam at the top to integrate with upstream channel stabilization structures. Note how uneven, non-level treads could cause flow concentration, leakage and eventual failure of the structure.

Type 2 - Fully functional, hand split wood ladder with log supports (Figure B-15). Ladder is built in two overlapping sections, conforming to

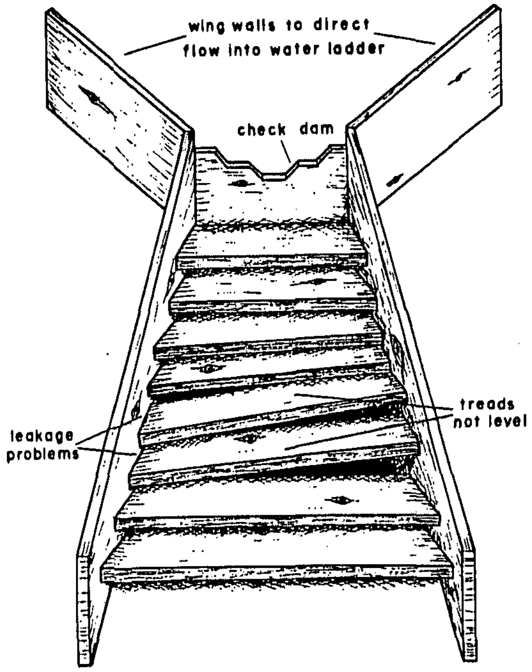


Figure B-14. Type 1 water ladder. Treads should be constructed level to prevent leakage.

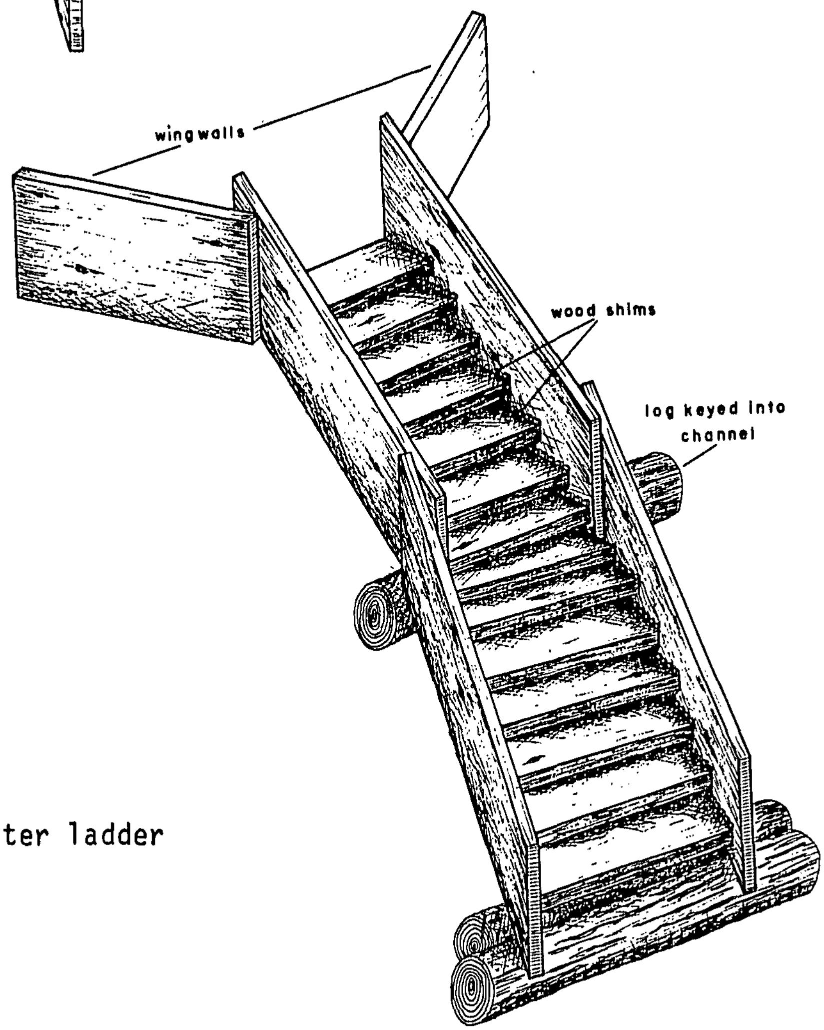


Figure B-15. Type 2 water ladder (right).

channel gradient. Ladder sides and treads may be keyed into partially buried logs for support. Wing walls at entrance ensure that all flow is captured.

Type 3 - Milled board flume (Figure B-16). Flume is constructed of plywood or wide boards. Instead of treads, baffle boards are nailed to the bottom to provide energy dissipation and reduce water velocity. The flume conducts water over a steep reach below the outlet of a checkdam.

Type 4 - Milled wood ladder (Figure B-17). Ladder is constructed from milled slabs and boards. Treads are supported on stair-stepped slats. Leakage was prevented by providing sufficient tread overlap and by utilizing slats, shims and groves to improve the fit between boards and to direct the flowing water (Figure B-18).

C. Comments. By nature, water ladders are relatively expensive to construct. The construction of structures that would be large enough to contain peak flows of streams with even a moderately high discharge (over 5 cfs) may also be physically and logistically impossible in many remote locations. If access for heavy equipment is available, it may be more cost-effective to excavate a channel which can then be protected with rock armor or checkdams. All-in-all, over the life span of the structure, water ladders can successfully prevent soil erosion. Their use is justified in remote, sensitive areas.

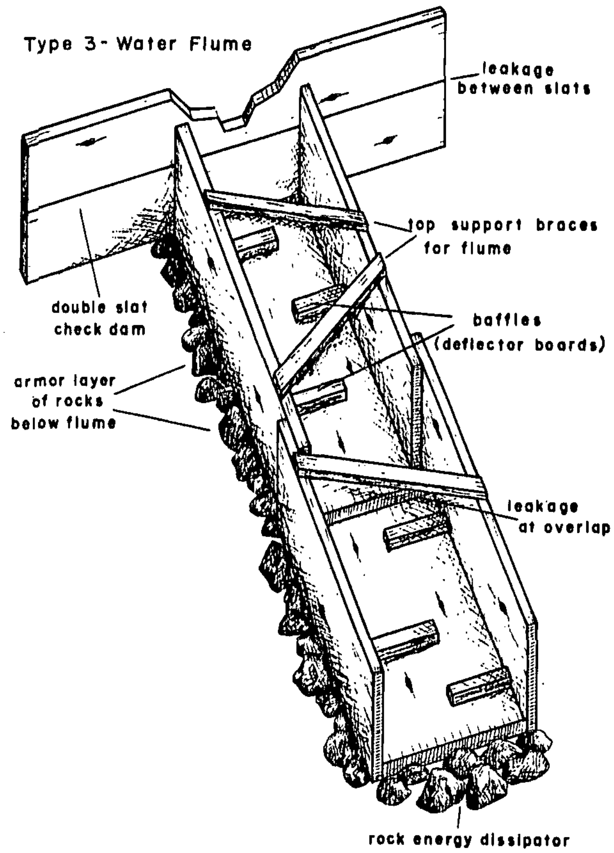
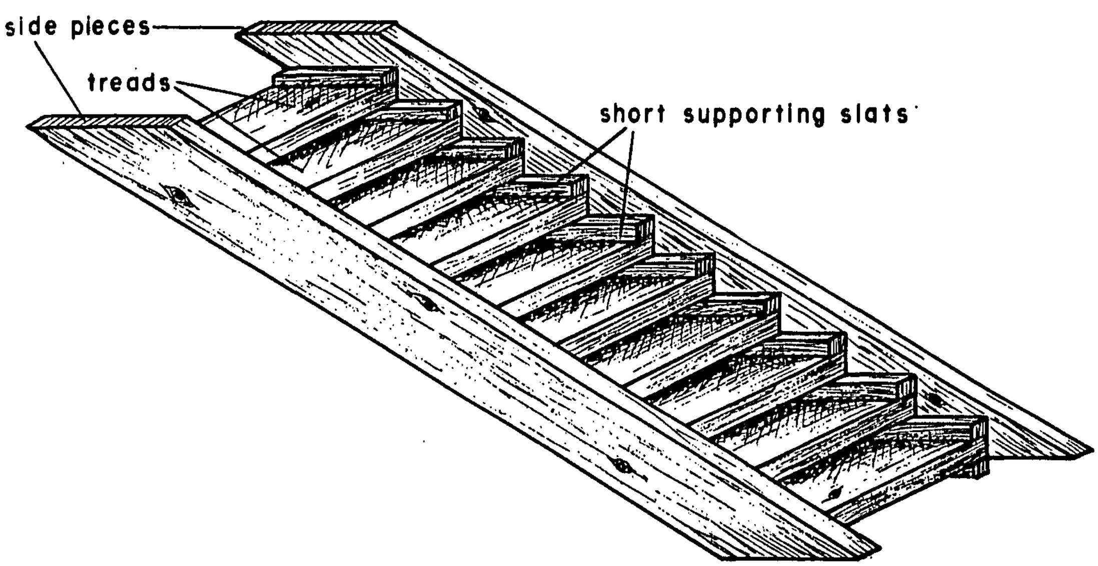
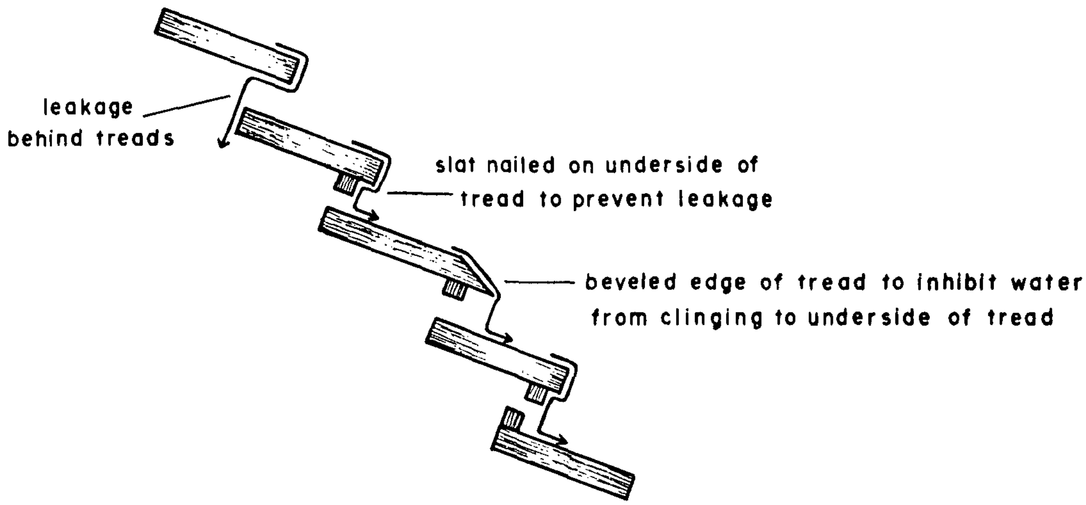


Figure B-16. Type 3 water flume (left).

Figure B-17. Type 4 water ladder (below).



A.



B.

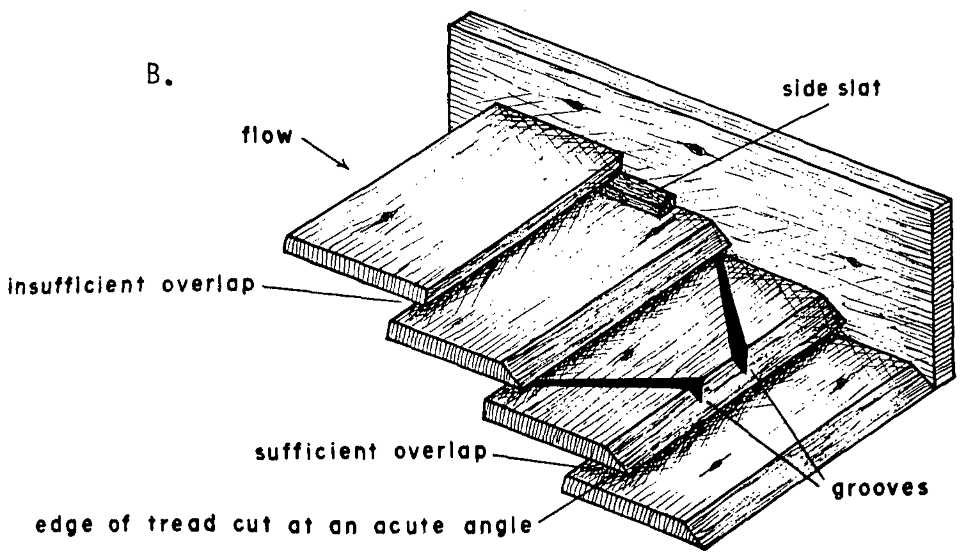


Figure B-18. Side view (A) and oblique view (B) of water ladder treads. Note causes of and solutions to common leakage problems.

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