

SOC

AN EVALUATION OF 1978 REHABILITATION SITES
AND EROSION CONTROL TECHNIQUES IN
REDWOOD NATIONAL PARK

NATIONAL PARK SERVICE
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CONTENTS

	Page
i. Abstract	1
ii. Acknowledgments	3
iii. Summary	4
I. Introduction	15
II. General Description of Area	18
III. 1978 Rehabilitation Projects	20
A. Introduction	20
B. Geomorphic Mapping and Planning of Rehabilitation Sites	23
C. Upper Miller Creek, Site 78-1	25
D. Emerald (Harry Weir) Creek, Site 78-2	45
E. Upper Bond Creek, Site 78-3	68
F. Lower Bond Creek, Site 78-4	93
G. C-Line Landing, Site 78-5	96
IV. Effectiveness of Erosion Control Structures	102
A. Waterbars	103
B. Planter Boxes	106
C. Check Dams	107
D. Water Ladders	118
E. Gully Plug	128
F. Energy Dissipators	131
G. Crossroad Drains	137
H. Willow Wattles	142
I. Mulches	143
V. Evaluation of 1978 Work Methods	147

TABLES

	Page
Table 1: Summary of 1978 Rehabilitation Projects.....	5
Table 2: Upper Miller Creek: Cost Per Equipment Task.....	30
Table 3: Upper Miller Creek: Labor Intensive Work.....	33
Table 4: Emerald Creek: Cost of Equipment Task.....	48
Table 5: Emerald Creek: Labor Intensive Work Contract.....	50
Table 6: Bond Creek: Cost Per Equipment Task.....	73
Table 7: Bond Creek: labor Intensive Work Contract.....	75

MAPS

Map 1: Upper Miller Creek - Rehabilitation Test Site.....	27
Map 2: Harry Weir (Emerald) Creek - Rehabilitation Test Site..	47
Map 3: Bond Creek Rehabilitation Test Site.....	71

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EVALUATION OF 1978 RHEABILITATION SITES
AND EROSION CONTROL TECHNIQUES

ABSTRACT

A long-term watershed rehabilitation program has been initiated in Redwood National Park to help restore lands damaged by logging activities prior to park expansion in March, 1978. Up to 30,000 acres of logged timberlands added to Redwood National Park by P.L. 95-250 will be treated under the rehabilitation program. Rehabilitation techniques and methods were tested during 1978 on five sites totalling approximately 230 acres. This report evaluates the effectiveness of those techniques after one year.

In general, heavy equipment work and erosion control structures used on rehabilitation sites were effective in reducing serious erosional problems during the first winter season. Heavy equipment was used for large earth-moving tasks. A dragline crane was effective in removing uncompacted, unstable or oversteepened road fills in road prisms, in stream crossings and in log landings, thus preventing mass slope failure in those areas. Backhoes were useful in excavating crossroad drains to direct water from seeping cutbanks across the road prism, and in redirecting diverted drainages into natural and more stable channels. Backhoes were also useful in clearing streams of organic and inorganic debris, and in removing culverts. Crawler tractors accomplished several tasks including disaggregating rocked road surfaces, outsloping excavated road fill material, pulling organic debris from unstable areas, and excavating cross road drains.

Labbr intensive work crews were contracted by the National Park Service to construct erosion control structures after the heavy equipment work was completed. Waterbars were built to divert runoff from skid trails. Checkdams were constructed to control downcutting in gullies and stream channels. The crews built water ladders and flumes to convey water across steep, erodible slopes. Willow wattles, a combination of a biological and physical barrier to rilling, were used extensively on disturbed slopes. Grass seeding, planter boxes, stem cuttings of sproutable species, and mulches were also used to inhibit soil erosion in specific areas. Winter maintenance of these structures appears essential to deal with unanticipated drainage problems on the sites and assure adequate protection of slopes and drainages through high rainfall periods.

TABLE I:

SUMMARY OF 1978 REHABILITATION PROJECTS

SITE	ACRES/ROAD MILES	HEAVY EQUIPMENT		LABOR INTENSIVE	
		Hours	Cost	Hours	Cost
1. Upper Miller Creek	80 acres/ 4000 feet	140	\$14,422.00	3800	\$43,000.00
2. Emerald Creek	90 acres/ 3170 feet	66	\$ 2,760.00	2900	\$53,557.00
3. Upper Bond Creek	51 acres/ Not applicable	157	\$ 6,025.00	4430	\$19,503.00
4. Lower Bond Creek	Not applicable/1500 feet	8	\$ 320.00	320	\$ 3,685.00
5. C-Line Landing	2 acres/ Not applicable	32	\$ 1,760.00	400	\$ 3,740.00

SUMMARY

Redwood National Park was expanded by 48,000 acres through Public Law 95-250 in March, 1978. About 33,000 acres of the expanded park had been logged during the past 10 to 20 years. As part of expansion, Congress mandated implementation of a watershed rehabilitation program to help restore parklands damaged by logging and to reduce erosion problems in the Redwood Creek watershed. Redwood National Park has initiated a watershed rehabilitation program to help correct erosion problems and to help return parklands to a mimic of their natural condition. The following pages summarize the reports conclusions and recommendations regarding 1978 rehabilitation projects and erosion control techniques. In determining areas for rehabilitation, a number of elements are weighed. Severity of damage to parkland varies with age and type of logging along with a host of natural factors. Problems are most significant on tractor logged clearcuts adjacent to perennial streams in highly erosive tributary basins. Other factors such as site location and accessibility play important roles in selecting an area. In addition, Redwood Park's ability to correct problems using known technology without causing new, serious damage also helps determine if a site will be restored immediately or delayed a few years.

Rehabilitation techniques were tested on five sites totalling about 230 acres during 1978. Each area contained typical problems found throughout parklands in the watershed. Table 1 summarizes results of 1978 work. Although specific rehabilitation prescriptions varied from site to site, a combination of heavy equipment and labor intensive crews were used to correct erosion problems. In general, heavy equipment was

used to reshape drainages, to remove oversteepened fills, to reshape roads, and to build erosion control structures. Labor intensive crews also built erosion control structures and added finishing details to other erosion structures started with heavy equipment. In addition, labor intensive crews spread grass seed, installed willow wattles, planted cuttings, and planted conifers to aid in revegetation of rehabilitation sites.

Heavy Equipment

Heavy equipment was effective in correcting erosional problems due to failure of uncompacted and oversteepened road fills, failure of road crossings in stream channels, slumping of road cut banks, and gullyng of logged slopes. In addition, diverted drainages that caused severe gullyng have been redirected into natural and more stable channels. Disaggregation of road surfaces has promoted more rapid infiltration of runoff and has probably accelerated the rate of revegetation on eliminated roads. Outsloping roads has directed surface runoff across the removed roads and has prevented runoff from concentrating and flowing along road alignments and ditches.

Based on one season's observation, heavy equipment was used too conservatively on 1978 rehabilitation projects. Some drainages should have been excavated deeper to prevent subsequent downcutting in the channels. More cross-road drains should have been constructed in some areas to better drain sites. All former logging haul roads accessible to caterpillar tractors should have been disaggregated by ripper teeth.

Contracts between Redwood Park and heavy equipment operators to rent machinery and operators (equipment rental agreements) seem to be advantageous to the Government in terms of cost, efficiency, job quality, and flexibility to changing project needs.

Erosion Control Structures

Structural erosion control devices are not a permanent solution to erosion problems. Surficial erosion problems will ultimately be corrected by re-establishing vigorous, dense vegetation on disturbed sites. However,

when placed properly, erosion control structures should endure 10- 30 years. This is ample time for vegetation to provide ground cover and increased root strength to soil, as well as adding an important organic component to the disturbed soils.

Waterbars

Waterbars divert surface water flow off of skid trails and roads. These small-scale diversions decrease the amount of rilling and gullyng on road surfaces and aid in re-establishing natural drainage patterns. Crucial factors in constructing an effective waterbar are: 1) locating waterbar at a point along road where runoff can successfully be diverted downhill to a less erodible slope, 2) spacing waterbars frequently to prevent road gullies between waterbars, 3) excavating waterbars into the ground surface so that runoff flows in a ditch, or gutter, rather than simply against a built-up berm that could wash out and 4) placing adequate energy dissipation at the waterbar's outlet to prevent downcutting. Ideally, waterbars should endure until the roads and the bar itself are revegetated and dense ground cover is re-established. Unfortunately, some skid trails were constructed through hillsides and formed deep, incised cuts. Rilling is a common problem on these throughcut roads, and waterbars are not effective on these sites.

Planter Boxes.

Planter boxes are barriers used to trap loose sediment on steep, ravelling slopes or in narrow chutes created by debris slides. In such harsh conditions, any physical barrier to the downslope movement of sediment (for example, logs, large pieces of bark, brush piles, etc.) can be

firmly anchored (or keyed) into the slope for this purpose. Split redwood boards were used in planter boxes; however, contract specifications can be broadened to include other materials. In some cases, it is useful to partially backfill planter boxes with fertile soil that otherwise would not collect there due to infertile upslope areas. Revegetation of the terraces upslope of the planter boxes will be critical in stabilizing these slopes.

Water Ladders.

Water ladders are wooden structures that convey water over a steep slope while preventing downcutting. For this purpose, water ladders are effective in relatively short, steep, unstable channel reaches. Extreme care must be taken in assuring that the ladders are watertight and that they are large enough in cross-sectional area to accommodate all water delivered to the channel. Proper design of the water ladder's entrance or inlet is critical. The entrance must direct all runoff onto the ladder, prevent any obstruction to the flow and prevent any leakage. Water flumes can be considered the equivalent of water ladders. Both designs require extensive energy dissipation devices at their outlets.

Gully Plugs

Gully plugs may be used to control the headcut retreat of a gully, and can locally be used in place of a water ladder or flume. The plug armors the headcut and prevents any further downcutting of the gully knickpoint, while conveying water across the break in slope. Gully plugs must be used in conjunction with intensive revegetation efforts to provide long term gully stabilization.

Check Dams

Check dams can be an effective means of controlling gully erosion and stabilizing gully banks and bottoms so that revegetation can become established. Check dams must be constructed to contract specifications. Strict adherence to these specifications for dimensions, orientation, spacing and installation of check dams is necessary because even a minor omission or alteration may lead to failure of the dam. The dams must be large enough and sturdy enough to accommodate large flow. It is also essential that vegetation be re-established on the channel banks and bed as soon as possible to assure some support and protection when the check dams eventually begin to deteriorate. Maintenance of the dams is critical, because a small problem can potentially cause the failure of a check-dammed reach of channel.

Crossroad drains

Crossroad drains are specialized ditches that drain cutbanks of roads, convey runoff water across a road prism and prevent water flow down the road alignment. They also prevent soaking (by groundwater seepage) and potential failure of road fill placed against cutbanks. Crossroad drains are constructed by heavy equipment during outslowing of roads. Final shaping may be done by shovel work. Drains are spaced fairly close together and are placed at the exact locations of major seepage areas and small drainages identified during the previous wet season. They were generally effective in draining surface runoff from a wet, unstable haul road, and in preventing gully problems and failure of the road prism. They did not effectively drain deep-seated slope instabilities and did not prevent further failure along pre-existing scarps.

Energy Dissipators

Energy dissipators protect bare earth from erosion by water diverted through erosion control structures. Water routed through checkdams, waterbars, water ladders, or crossroad drains has the potential energy to erode a channel if bare ground below the structures is not protected and the energy of flowing water dissipated. To prevent such erosion, waterbars and crossroad drains may be lined with rock. Rocking of drainage troughs only works if the rock is large enough to remain stationary during high runoff. Minimum rock size is dependent on stream discharge and channel slope.

Other energy dissipation devices tried on the 1978 rehabilitation sites included: 1) splashboards secured below check dams, 2) strategically placed and secured logging slash, 3) rocks lining the bed of a gully below a check dam spillway, 4) piles of rock anchored by stakes in a gully which slowly filter water through them, and 5) split boards anchored with stakes and rock on a steep slope in a herringbone pattern. When installed correctly, all of the above were effective.

Willow Wattles

Wattles are bundles of flexible twigs and branches. Wattling is the process of placing wattles in contour trenches on bare slopes, securing the wattles with stakes, and almost totally burying them with soil so wattles form small benches that contour the slope. The contour wattle benches retard surface erosion due to rainsplash impact and rilling, and if composed of sprouting species, twigs and branches in wattles can grow and effectively revegetate a slope. The critical factors in wattling are meticulous attention to proper procedures for cutting, handling and installing

sprouting plant wattles, and forming a distinct terrace at least 12 inches wide when covering wattle bundles.

In general, on 1978 rehabilitation sites, willow wattles were used too often and should be installed in more conservative quantities in the future. Wattles are most effective on steep, wet, and potentially unstable slopes, but are relatively expensive to install. Other physical barriers (such as terracing) may be equally effective in inhibiting surficial erosion processes, and will be investigated as alternatives to willow wattles.

Another limitation in using willow wattles is the lack of an ample supply of willows in the watershed. More experimentation with other sprouting species will be done and smaller amounts of sproutable material per wattle bundle could be used.

Sprig Planting (stem cuttings)

Stem cuttings help to rapidly establish vegetation on bare and disturbed rehabilitation sites. Initial results (June, 1979) show excellent sprouting success (ninety-nine percent) with willow stem cuttings, and less vigorous sprouting with baccharis cuttings. Root development in the willows in the first few months after planting was apparent, but not extensive. The method is relatively rapid and inexpensive, and more experimentation with several species will be conducted in the future. Stem cuttings were used with the intention of providing some protection and cohesion to the soil within a few years, rather than being an immediate solution to any instability problem. Consequently, an evaluation of sprig planting effectiveness must

be deferred until the young sprouts are firmly established (one to three years).

Mulches

Native, biodegradable materials used as mulches protect ground surface from rainsplash impact and rilling. Initial results of the few mulched sites are promising. Different types of mulches such as straw and wood chips will be tested, with an emphasis on those derived from native materials. In addition, the effect of mulches on soil chemistry, structure and texture, and on revegetation efforts, will be explored.

Other Techniques

Alternative erosion control and watershed rehabilitation techniques will be investigated further. Composting local waste materials and using the compost to protect and enrich the soil is one possibility. Hydromulching (the application of a slurry of fiber, seed, and fertilizer to provide rapid ground cover) may be tested for its suitability in treating erosion problems. Manually-constructed terraces and log cribbing may be used to stabilize and buttress unstable slopes. Use of explosives to remove debris jams in inaccessible channel reaches may also be explored.

Grass Seeding

Grass seeding was used as a temporary cover to protect disturbed ground on rehabilitation sites prior to establishment of native shrubs and trees on these sites. A rigorous test of the effectiveness of grass in inhibiting soil erosion did not occur in 1978 because grass cover was not dense enough to provide extensive ground protection, and the application rates of

grass seed were not strictly controlled. On sites where grass growth was dense and vigorous, the root mat did restrain surface particles from downslope movement, and grass trapped soil transported from upslope. Heavy rains transported much of the grass seed on steep slopes downhill and deposited it on wattle terraces. In the future, grass seeding should be done directly after heavy equipment work is completed, before ground settling occurs. A monitoring program to test effectiveness of grass seeding, fertilizing, and mulching disturbed slopes will be implemented in 1979.

Winter Maintenance

Erosion control structures are constructed in dry weather when the soil can be excavated without causing damage to slopes and stream channels. However, there is always an element of uncertainty as to how the structures will perform during winter flows. Thus, it is essential that the structures are observed and maintained periodically throughout the winter season to detect any problem at the initial stage before any serious erosional damage occurs.

I. INTRODUCTION

Redwood National Park was established by P.L. 90-545 in 1968 to preserve significant examples of the primeval coastal redwood forests and the streams and seashores with which they are associated. The Park's redwood forests include the world's tallest measured tree along with several others nearly as tall on alluvial flats adjacent to Redwood Creek. From the moment of Park creation, timber harvesting and road construction disturbances in the Redwood Creek watershed outside the park combined with natural processes to pose imminent threats to Park resources. Interactions between inherently unstable, highly erodible hillslopes, exceptionally severe storms and intensive land use practices have caused Redwood Creek and many of its major tributaries to transport for more sediment than natural.

Roughly 90% of the forests in the Redwood Creek basin have been logged since 1945. Logging practices have greatly accelerated erosional processes (Janda, 1975). Changes include increased runoff, a general modification of the natural hydrologic regime, increased sediment yield and accumulating sand and silt deposits in major stream channels. Other problems such as increased landsliding, filling and widening of stream beds, erosion of stream banks, damage to stream-side vegetation, and overall degradation of natural aquatic ecosystems have been documented (Nolan, 1976; Harden, 1978). The primary causes of these harmful changes include vegetation removal, pervasive alteration of hillside drainages, development of an extensive logging road network, and construction of thousands of miles of tractor log skidding trails.

Congress, in establishing Park boundaries in the 1968 Act, had not anticipated the magnitude of adverse impacts that occurred as a result of continued logging in the watershed upstream from Parklands. In 1978, Congress amended the Redwood National Park Act through P.L. 95-250 to enlarge the Park by 48,000 acres (75 mi²). It also mandated preparation and implementation of a watershed rehabilitation program aimed at accelerating erosional recovery of lands within the Redwood Creek basin, thereby eventually diminishing threats to Park resources.

In the summer of 1978, rehabilitation efforts were initiated on five sites within the Park. The sites represent a range of geologic, hydrologic, vegetative and soil conditions on logged-over lands, and were chosen for the purpose of experimentation of various rehabilitation techniques (Figure 1). The general approach on the sites included: 1) detailed geomorphic mapping to delineate erosional problem areas, 2) use of heavy equipment for major earthmoving tasks to rectify drainage diversions and clear stream channels of debris and 3) labor-intensive work to construct erosion control structures and to replant disturbed areas.

This report will evaluate initial results of the 1978 rehabilitation program after one winter season. The first winter is probably the critical season for erosion control structures in terms of withstanding high flows. A cost analysis of erosion control techniques used in 1978 rehabilitation programs is provided, as well as a critique of contracting methods used.

Initial results of revegetation efforts are cursorily examined; however, a full report on survival must necessarily wait until the stress of a hot, dry summer on the vegetation is evaluated.

II. GENERAL DESCRIPTION OF AREA

Redwood Creek drains a 280 square mile watershed in the mountainous coastal region of Northern California. The headwaters begin near elevations of 5000 feet and the creek flows north-northwest to the Pacific Ocean near Orick, California. Through most of the Parklands, Redwood Creek follows the trace of a major geologic structure, the Grogan Fault, which divides the land into two different terrains. The westside of the basin is underlain by well-foliated, mica-quartz-feldspar schist, and generally has steeper hillslopes, a more clay-rich soil and a higher drainage density. In contrast, the east side is primarily underlain by pervasively sheared sandstones and siltstones and it supports more gentle slopes, loamy soil, locally large earthflow prairie areas, and a lower drainage density. Specific descriptions of the physical characteristics of each rehabilitation site are given later.

Mean annual precipitation for Redwood Creek basin is 80 inches and mainly occurs in storms from November through March. The 1978-1979 precipitation, however, was 33% below average (Geological Society of America, 1979; Janda, 1975). From November, 1978, through August, 1979, five storm events occurred, and the largest 24-hour rainfall was 2.2 inches. In contrast, normal 24-hour rainfall (occurring once every two years) are 4.5 - 6 inches of rain (Janda, 1975). Even though total precipitation in the 1978-79 season was below normal, storms that did occur provided a test of the effectiveness of erosion control techniques.

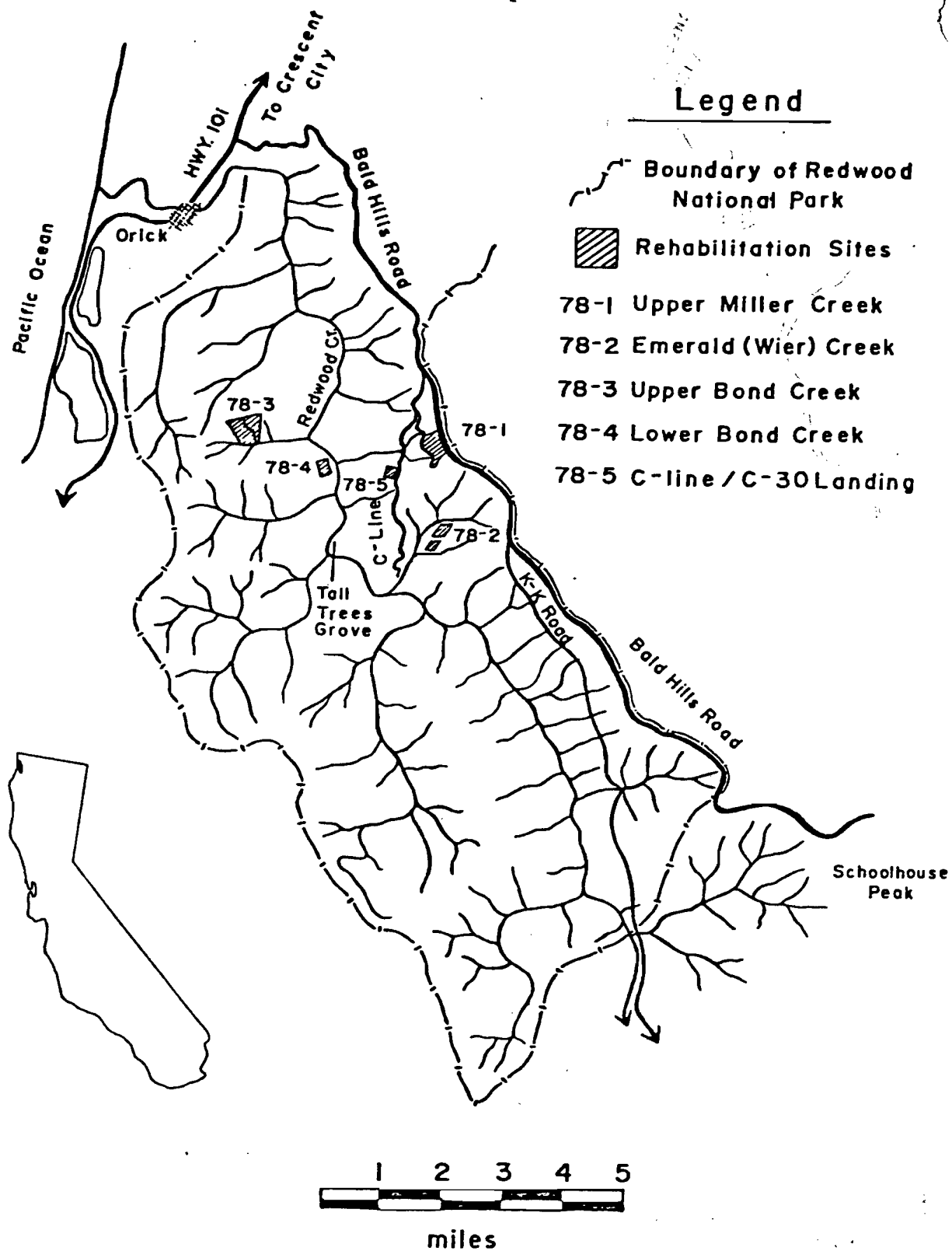


Figure 1: Location map of 1978 rehabilitation sites, Redwood National Park.

III. 1978 REHABILITATION PROJECTS

A. Introduction

Park lands modified by previous logging vary in severity of damage and erosional problems. The decision to rehabilitate a site and what type of methods to use depend on a number of factors including extent of damage, age of logging, and significance of erosion.

Some sites are so harsh little can presently be done to ameliorate the site environment. Examples of these problems are large, deep-seated mass failures along stream channels which periodically contribute large amounts of sediment to the fluvial system. Our present state of knowledge in treating most of these areas is inadequate. Revegetation is difficult, and is of doubtful value in treating the deep-seated source of the problem. In addition, accessibility to the sites frequently represents a monumental logistical problem. In addition, providing access for machines, materials and work crews may create even more erosional problems.

Another category includes those land use modifications which do not directly threaten Park resources. Here, the problems lie in revegetating compacted sites, such as stable roads and landings, or in treating minor erosional problems in advanced second growth forest stands. However, creating access through a vigorous stand of young trees may cause a more serious situation than the original problem, and these sites may be left alone. If revegetation of small areas

is not necessary for erosion control, these areas will receive a low priority for treatment, or may be left to reseed naturally without any treatment.

Finally, some sites pose serious threats yet are treatable within present technology. Sites, such as landings, unstable road fills, and stream crossings, potentially may fail and contribute large quantities to streams. Some have already failed, while others show evidence of instability and will fail in the near future. The problems may be large, but they are still within the capacity of cranes, backhoes and other heavy equipment to repair. Erosion control techniques have already been used to address these problems, and although experimentation will still play a large role in developing these techniques further, the basic technology now exists for treating these problems.

The rehabilitation program's present stage is focusing on this category of sediment problems in the Redwood Creek basin. A variety of treatments are possible on each site. For example, a road may be completely outsloped (Figure 2 and 3), or fill material may be completely removed and redeposited on more stable terrain, or the road surface may simply be decompacted and planted. Similarly, a landing may be outsloped completely, or it may be dewatered by the construction of drainage ditches, or perched organic and inorganic debris from its edge may be pulled back to a more stable location. The treatment used depends on severity of problems, site accessibility, and type of problems adjacent to the site in question. In some cases, a potentially unstable area will be purposely left alone to observe effects of non-treatment.

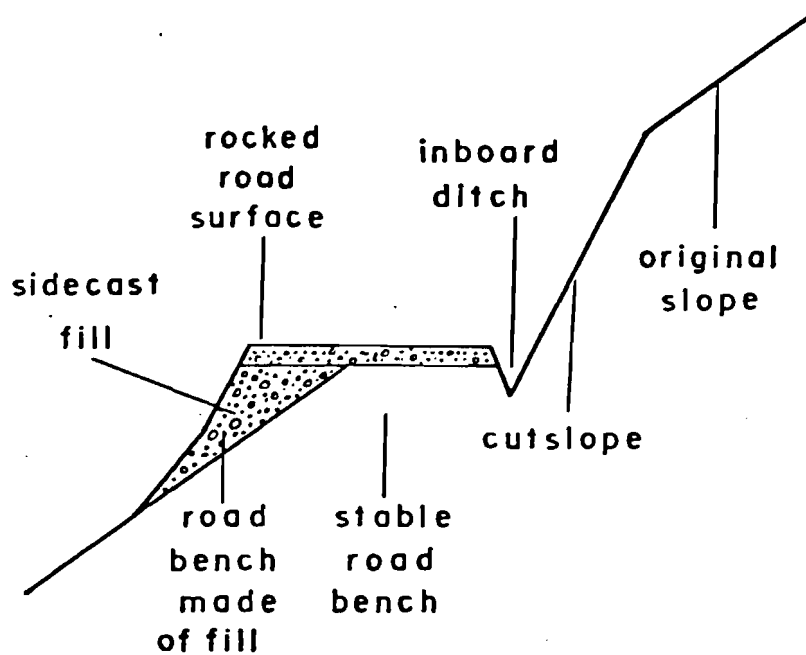


Figure 2: Typical logging road in cross-section.

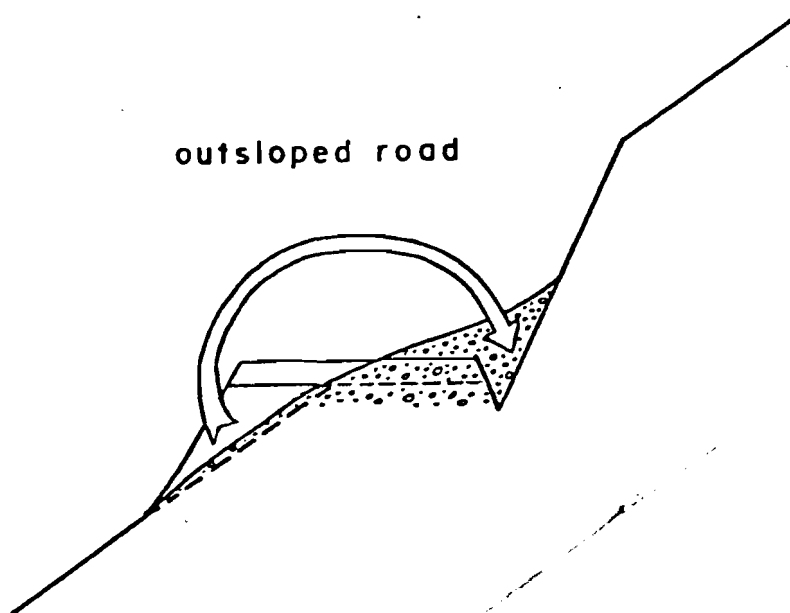


Figure 3: Slope configuration across logging road after heavy equipment transfers fill and grades on outslope.

B. Geomorphic Mapping and Planning of Rehabilitation Sites

Detailed geomorphic maps were prepared for all rehabilitation units prior to any earth-moving or revegetation work. In order to accomplish the mapping, a recent aerial photograph of each site was enlarged to a scale of approximately 1:1800. The photo was secured to a plane table board, and a sheet of mylar was attached as an overlay.

Surface drainage patterns including natural and modified features were mapped. In many cases, natural drainage networks had been disrupted by skid roads and haul roads, and runoff was concentrated, via inboard ditches and culverts, onto slopes which previously carried little or no runoff. Rapid channel erosion resulted, while at the same time some established channels carried reduced flows. Active and inactive channels were mapped, as well as rills and gullies.

Skid roads constructed across small drainages blocked stream channels. The streams continue to erode and gully fill material. In addition, when fills became saturated they could potentially collapse and cause destructive debris avalanches in the stream channels. Approximate volume of fill material, degree of revegetation of channel banks, relative stability of adjacent slopes, drainage area upstream of the fill crossing, and accessibility of the site were all noted on the map. The decision to use heavy equipment to remove a fill crossing was based on those factors as well as on an evaluation of the potential for debris failure.

Since skid road cutbanks frequently intercept ground water, locations



Figure 4: Most logging roads are surfaced with eight to twelve inches of rock and must be disaggregated to promote infiltration and revegetation. Here, a D-8 Cat decompacts the C-10 road with its ripper teeth.



Figure 5: Because of its long reach, a dragline crane is used to lift unstable side cast road material and organic debris to the road bench.



Figure 6: Excavated fill is piled along the inboard edge of the road and against the road cut bank. A tractor grades the fill to achieve a gentle outslope on the former road alignment.

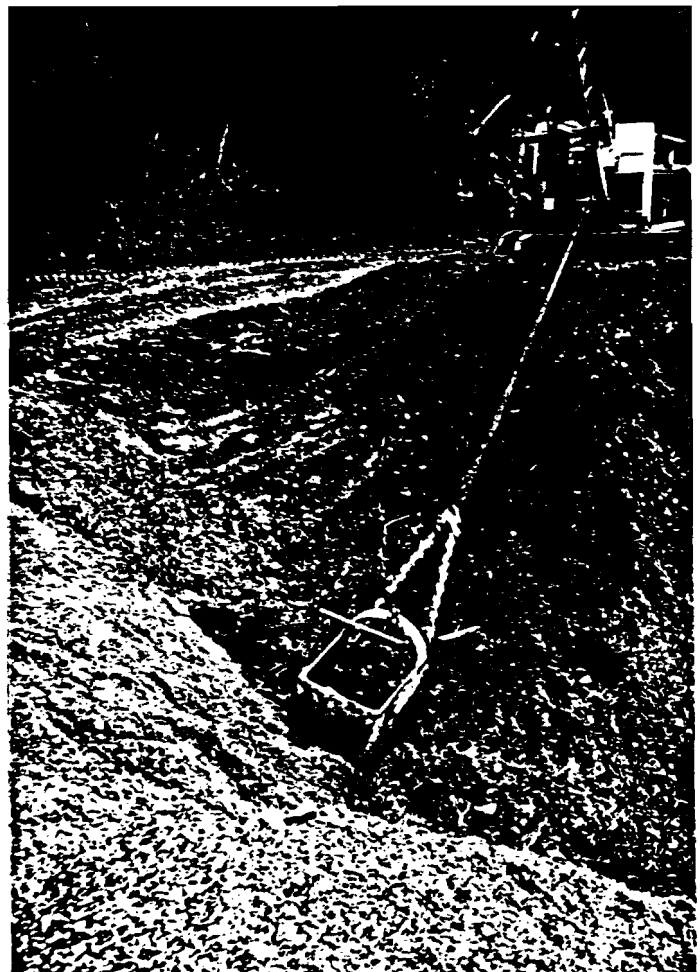


Figure 7: A dragline crane removes fill from a stream crossing and reshapes channel banks to a more stable configuration.

where ground water was emerging were indicated on the map and flagged in the field. These were considered potential sites for building diversion structures such as cross road drains. Specific criteria used in designing cross road drains are discussed later.

Skid roads frequently became gully courses following logging unless runoff had been diverted off the roads by waterbars. If waterbars existed, their success or failure was noted, and maintenance needs were compiled. In addition, if new waterbars were needed, the location was mapped.

Potential and active slope failures triggered by road construction, logging-related disturbances or stream erosion were also mapped. The possibilities of drainage diversions, gully stabilization, removal of unstable material to stable areas, and revegetation of the site were explored.

Once mapping was completed and severity of erosional problems was evaluated, an approach to site rehabilitation was outlined, taking into consideration both haul roads and adjoining upslope areas. Types of equipment to be used in large earth-moving tasks were chosen, and estimates of the time necessary to complete the heavy equipment work were made with the help of equipment operators.

Equipment with operators was rented by the National Park Service under equipment rental agreements. National Park Service staff supervised heavy equipment operation.

C. Upper Miller Creek Rehabilitation Test Site 78-1

Site Description

The upper Miller Creek rehabilitation test site includes 60 acres at the headwaters of the South Fork of Miller Creek. Arcata Redwood Company clearcut and tractor-yarded the entire portion of the drainage from 1970 through 1972. Geologically, the site is underlain by fractured and faulted lithic arenites (greywackes) with minor amounts of thin-bedded argillites and conglomerates. Hillslopes are dry and generally moderate (20-40%) on the upslope portions of the site and steepen (50-65%) on the downslope portions, especially below the C-10 road. The C-10 road is a rock-surfaced logging road that provides access to the Miller Creek rehabilitation site.

By 1978, the C-10 Road has been abandoned for six years and was the source of major erosional problems. The road disrupted natural drainage patterns in several ways. Water was concentrated in the inboard ditch with only a few culvert outlets leading from the ditch. Water from culvert outlets was discharged into channels that may have accommodated less flow prior to road construction. Cutbanks intercepted subsurface flow, and skid trails diverted runoff down trails and roads. Because revegetation was not occurring on the road alignment and infiltration was poor on the compacted surface, rainsplash erosion and gullyng were prevalent. As a result of the above disturbance, surface runoff probably increased over natural conditions. In addition, the road was contributing sediment into stream channels from fill slope failures, from failing stream crossings and from washouts.

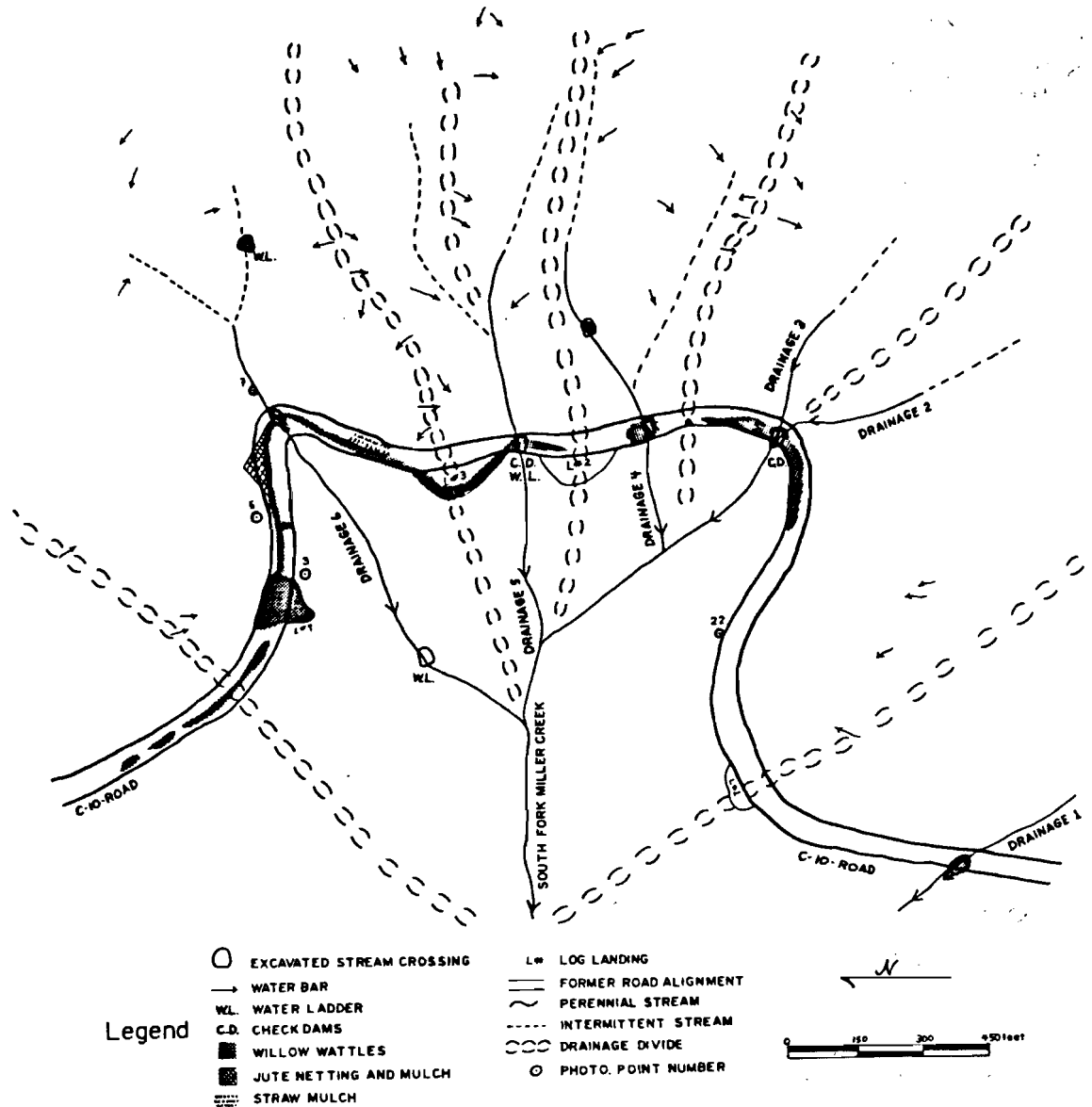
Approach

160 acres were mapped geomorphically on Miller Creek, in 10 days in June, 1978. Of that area, only 80 acres showed erosional problems that warranted treatment, and most of the rehabilitation work was done on a few acres along the C-10 road alignment. The site and work accomplished is shown on the following "Upper Miller Creek Rehabilitation Test Unit" Map.

The major task on this unit, "pulling" the C-10 road, was done in September, 1978, and took 13 days to complete. Figures 4 through 7 show the sequence of heavy equipment work. Initially, the road was decompacted (ripped) by a D-8 caterpillar tractor to increase infiltration. Then a dragline crane excavated sidecast fill material and deposited it along the inboard edge of the road adjacent to the cutbank. A crawler tractor outsloped this material to a gradient of 5 to 20% to prevent ponding or concentration of runoff. Stream crossings on the C-10 road were excavated by a dragline crane to approximately resemble pre-road channel gradient and streambank configuration. In addition, a few fill crossings on skid trails which disrupted drainage patterns above and below the C-10 road were removed and streambanks were recontoured.

Cost for heavy equipment work on the Miller Creek Unit was \$14,422.50 or 25% of the total cost of unit rehabilitation (labor and equipment combined.) A total volume of 10,000-12,000 cubic yards of material were excavated and reshaped, representing a cost of \$1.20 - \$1.44 per cubic yard of material. Details of cost and time involved for heavy equipment are listed in Table 2.

UPPER MILLER CREEK REHABILITATION TEST SITE



SITE MAP 1

UPPER MILLER CREEK

TABLE 2: COST PER EQUIPMENT TASK

TASK	EQUIPMENT	APPROXIMATE TIME (HRS)	TOTAL COST	COST PER MILE
Equipment work: preparation and supervision		150 person-hours		
Rip 4000 ft. of C-10 Road	D-8 Cat (\$75/hr)	4	\$ 300	\$ 400
Outslope 2000 ft. of pulled road	D-8 Cat D-6 Cat (\$50/hr) Dragline (\$60/hr)	4 14 43	\$ 300 \$ 700 \$2,580	 \$9,000
Remove C-10 road fill crossings from Drainage #:				
1	D-8 Cat	4	\$ 300	N/A
2 & 3	D-8 Cat & Dragline	4 ea	\$ 540	N/A
4	D-6 Cat & Dragline	3 ea	\$ 330	N/A
5	D-6 Cat & Dragline	3 ea	\$ 330	N/A
6	D-6 Cat & Dragline	11	\$1,210	N/A
Remove skid road fill crossings #1:				
1	D-5 Cat (\$40/hr)	3	\$ 120	N/A
2	D-5 Cat	4	\$ 160	N/A
3	D-5 Cat	5	\$ 200	N/A
Pull back log landing				
3	D-6 Cat & Dragline	13 ea	\$1,430	N/A
4	D-6 Cat & Dragline	24	\$2,640	N/A
Miscellaneous Road Work	All of the above		\$1,655	N/A
			<u>\$12,795*</u>	<u>\$17,000/mi</u>
Transportation costs:	Dragline	\$ 382.50		
	D-8 Cat	\$ 610.00		
	D-6 Cat	\$ 400.00		
	D-5 Cat	\$ 300.00		
		<u>\$1,692.50</u>		

Total Equipment Rental Cost: \$14,487.50

After heavy equipment work was completed, a contract was let to Aero-Marine Research, Inc. for labor-intensive erosion control work. Major tasks of this contract were to build checkdams and water ladders in potentially unstable drainages, construct willow wattles on steep, unprotected slopes, build waterbars on skid trails, and plant cuttings of sprouting species on unvegetated banks. A full description of erosion control techniques is given in section IV. Total labor costs for work on this site was \$43,000, and 3800 person-hours were utilized. A breakdown of cost and time is listed in Table 3. Costs and times were obtained from contractor's work sheets and may not reflect the true distribution of time or of costs for the rehabilitation site; however, they are a best working estimate of the true situation. In January, 1979, a Redwood National Park crew of four to six people planted 1020 redwood and 1080 Douglas fir containerized seedlings on areas disturbed by heavy equipment (about 4 acres). Seedlings cost 8¢ apiece. Total cost for materials for restocking the Miller Creek rehabilitation unit was \$170.00 and approximately 100 person-hours were needed for the task.

Documentation

A qualitative and quantitative monitoring program was developed to evaluate immediate changes on the site due to rehabilitation work and to monitor future changes on the recently modified slopes and channels. Several types of documentation were used. Twenty-five cross-sections perpendicular to the C-10 Road and to six stream crossings were surveyed by theodolite. In addition, two tag-line cross-sections were established on the largest tributary. Cross-section analysis yields an estimate of the volume material removed by heavy equipment. Survey reproducibility

ranges from good to excellent; error is approximately ± 0.5 feet. Longitudinal profiles for disturbed reaches of three streams were also surveyed. In addition, time-sequential photographs were taken from 32 permanently established photo points to visually document changes on the site. Several grids of erosion pins were installed on mulched and unmulched slopes to monitor soil loss differences between treatment areas.

The following photos illustrate use of heavy equipment in rehabilitating the Miller Creek Unit. Sequences of before and after treatment photos are also shown. If photos were taken from a permanently established photo point, the photo point number is noted as "PP#" below the photographs. Locations of photo points are given on contract maps for rehabilitation sites.

UPPER MILLER CREEK, 10/78 - 1/79

TABLE 3: LABOR INTENSIVE WORK

TASK	QUANTITY	CONTRACT UNIT PRICE/TASK	PERSON-HOURS/TASK
Field mapping of geomorphology	160 acres	N/A	80
Contract preparation		N/A	115
Contract supervision		N/A	200
Transportation: of people	3-4 man crew		546
of materials			145
Organization of Personnel			125
Discussion with Contracting Officer			33
Preparation of: split wood			185
cut willows			448
Wattles: cut and bundle	85,915 ft ²	\$370-\$380/1000 ft ²	17 hrs/1000
installation			
Check Dams	24 Dams	\$76.70/dam	16.5hrs./dam
Sprig Planting	20,550 ft ²	\$80/1000 ft ²	6.2 hrs/1000 ft ²
Waterbars: construction	31 bars	\$29-\$35/bar	3 hrs/dam
repair	68 items	\$14-\$30/repair item	1.5 hrs/item
Planter Boxes	14	\$20/box	
Water Ladder	1 (21 ft long)	\$15/1 ft. length	
Excavate Cross Road Ditch	1 (30 ft ³)	\$42/ditch	90 hrs.
Fertilize & Grass Seed	4 acres	\$75/acre	
Mulch and secure with jute netting and sprigs	3300 ft ²	\$185/1000 ft ²	unknown
Straw mulch and secure with sprigs	4000 ft ²	\$255/1000 ft ²	unknown
Planting conifer seedlings	1020 redwood	\$0.08/seedling	100
	1080 Doug fir		
TOTALS FOR CONTRACT		\$ 43,000	about 3800 person-hours



Figure 8: PP5a 8/22/78
 Before photograph of former culvert in Drainage 6. Culvert became plugged with debris and winter flows washed out about 800 cubic yards of road fill into the stream channel.

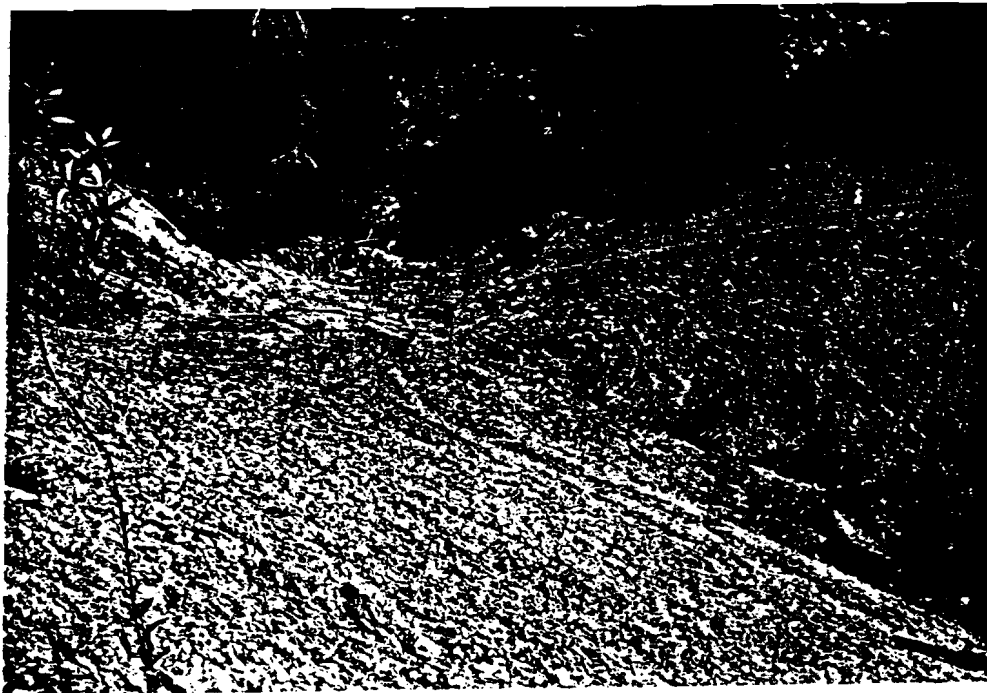


Figure 9: PP5a 10/9/78
 After photograph of Drainage 6. Dragline crane pulled back vertical banks to a more stable configuration, and a cat tractor outsloped the fill material removed by the crane.



Figure 10: PP7 8/22/78
 Before photograph of culvert washout in
 Drainage 6, close-up view looking downstream.
 Note person in channel for scale.

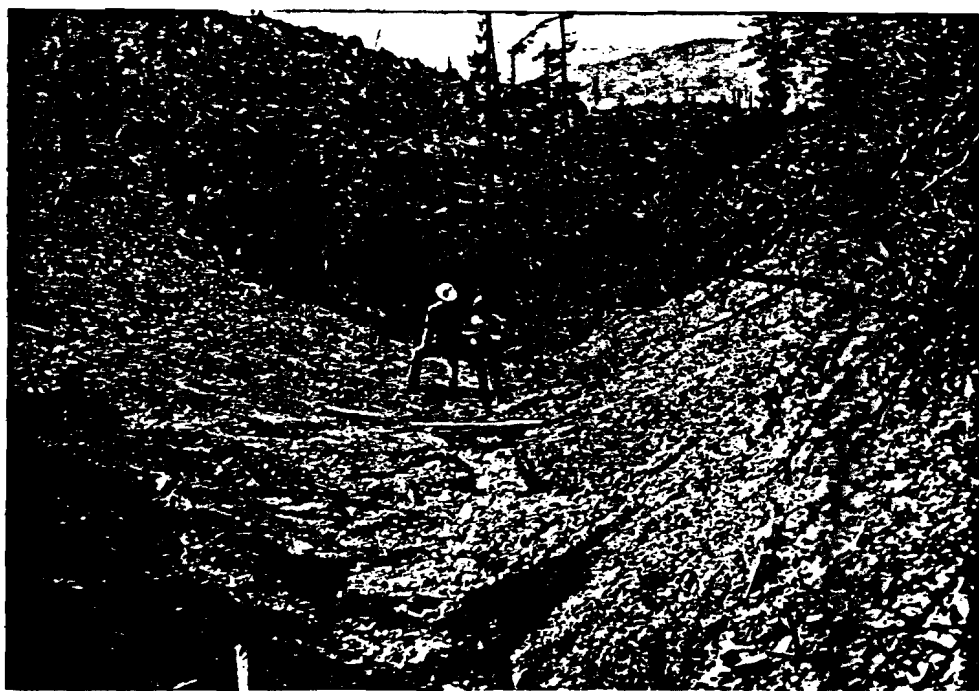


Figure 11: PP7 3/12/79
 After photograph of Drainage 6. Newly excavated
 channel exhibiting more gentle banks. Note rows
 of willow wattle installed on both banks.



Figure 12: PP3 8/22/78
Before photograph of oversteepened edge of log landing. Some fill material and organic debris have already failed downslope. In addition, water continued to pond on the landing, and tensional cracks suggested future failure of the hillslope.



Figure 13: PP3 3/12/79
After photograph of log landing. Edge of landing has been pulled back and fill material was outsloped. Drainage of runoff from the landing has been improved. Willow wattles were planted on the steep slopes below the former landing.

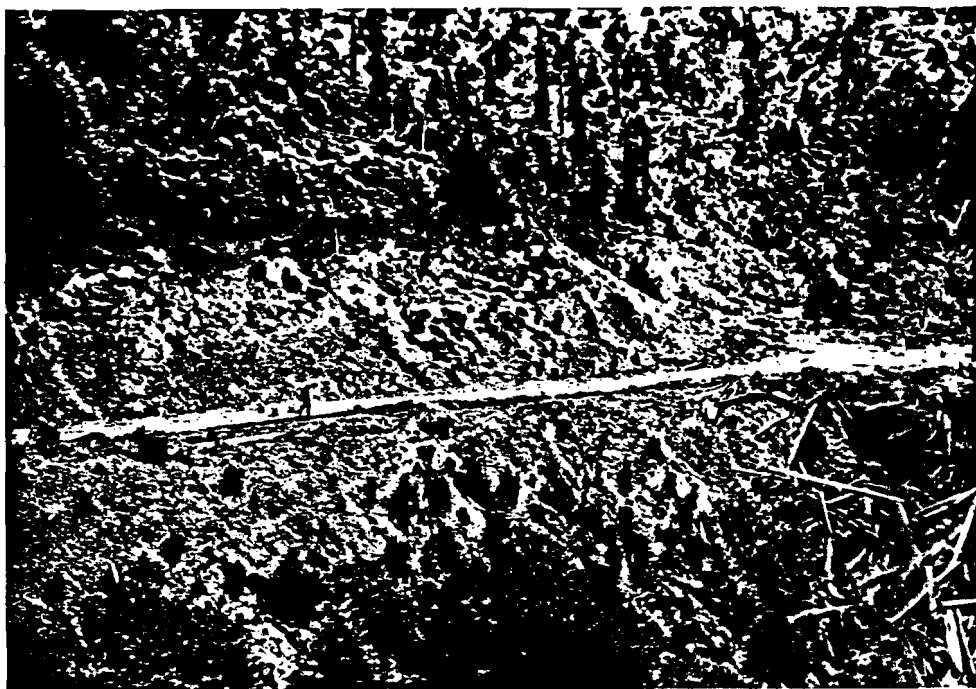


Figure 14: PP5c 8/22/78
Before photograph of abandoned haul road with unmaintained inboard ditch and steep fill slopes. Landing at right of photo shows perched debris beginning to fail downslope.

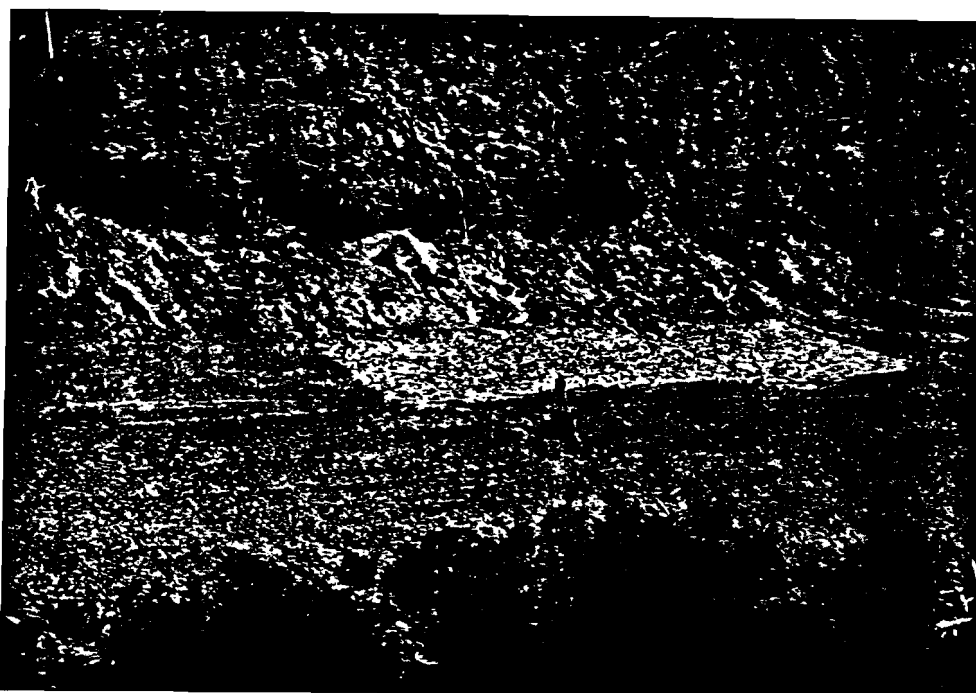


Figure 15: PP5c 10/9/78
After photograph. Inboard ditch has been eliminated. Steep road fill has been pulled back and outsloped. Perched debris on landing has been removed, and the landing itself has been outsloped to improve drainage. Slopes have been willow wattled and partly mulched with straw.

Effectiveness of Heavy Equipment on Miller Creek

Six stream channels were cleared of road fill where drainages crossed the C-10 Road. Nearly vertical banks were pulled back to a 25-30% slope, and no large bank failures occurred during the first winter. The largest channel, D6, had 1100 cubic yards removed from a road crossing. Under natural conditions, channels were almost straight; nevertheless, excavation generally decreased sinuosity slightly and, as a result, channel gradients increased slightly (from 0 to 3%).

Channels were excavated down to the estimated level of the original streambed. In three cases, the excavation was not deep enough and streams have since downcut 6 to 18 inches during the winter (Figure 18). As the stream downcut, a lag of rocks collected on the channel bed and began to armor the bed, inhibiting further downcutting. Channel bed stabilization is a high priority because channel downcutting can also lead to streambank failure as the toes of the slopes are undercut. Checkdams were needed to prevent vertical incision in some channels.

The C-10 road was outsloped with fill material placed along the inboard edge of the road. Cross-sectional gradient of the road changed from ^{nearly level} prior to rehabilitation to 20 to 25% after outsloping. The most extreme outsloping occurred where a large quantity of excavated material needed to be relocated and end-hauling of the material was not practical. Here the newly formed slope was 40-45%, which approaches the angle of repose of the material. However, the slope is dry, drains well, and the material has settled with no signs of slope instability.

Where fill material was potentially unstable (as indicated by tension cracks, incipient scarps, or buttresses of rotting organic debris), material was



Figure 16: PP22b 8/22/78
 Before and after sequence of a rocked haul road that was disaggregated (ripped) by a D-8 cat tractor to promote revegetation and infiltration of runoff. Note the paucity of vegetation on the compacted road surface even following 5 to 7 years of non-use.



Figure 17: PP22b 10/9/78

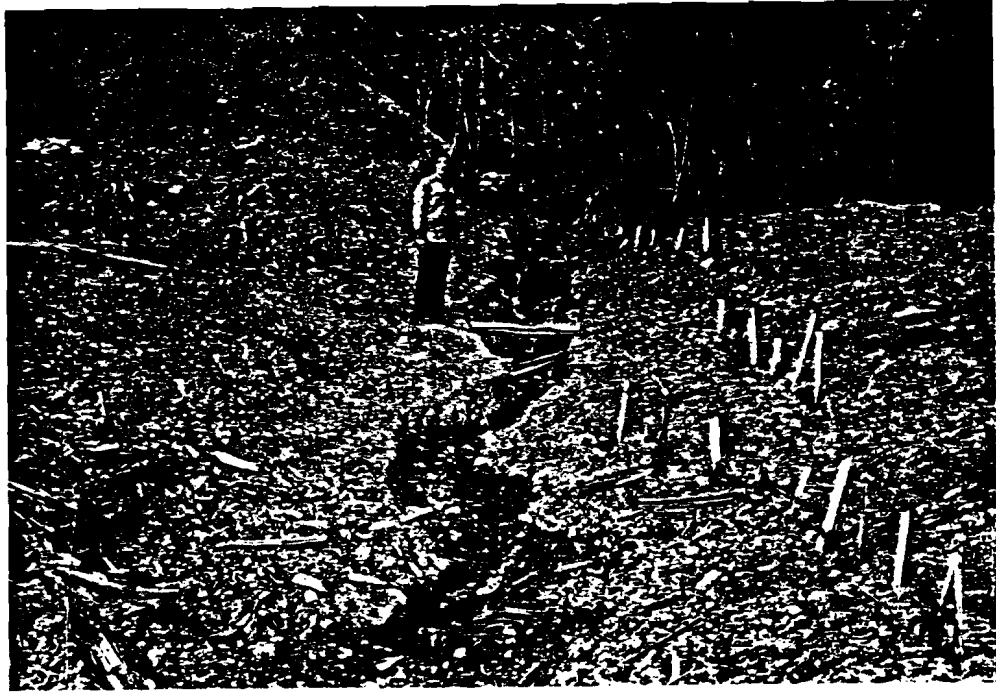


Figure 18: Drainage 5 in the Miller Creek Unit. Downcutting occurred in channel that was cleared of debris and road fill. The channel was not protected by an armor of rock prior to downcutting, although a lag of rocks is now beginning to form on the channel bed.

excavated and redeposited on stable ground. No tension cracks have reappeared, and no slope failures have occurred in excavated areas.

Outsloping has caused no major drainage problems on the road alignment. The most significant problem, ponding water, occurs where the road was not outsloped enough (that is, where the slope is less than 5%). This was especially a problem on large landings. In future work, cross ditches should be excavated on landings in order to drain these areas more efficiently.

Organic debris (slash) from unstable landings was incorporated into outsloping material placed on the road. Except for some minor settling, the slash has not adversely affected the results of the outsloping. However, as decomposition of the material occurs, drainage patterns on the outsloped road may be changed. If possible, burying organic debris in an outsloping operation should be avoided in the future.

Groundwater seepage from cutbanks has occurred in locations that were not recognized as problem areas in the summer months. Minor rilling and slumping have occurred in these areas. These problems could have been avoided, however, if the hydrology of the area had been mapped during the wet season.

Drainage patterns on cutover slopes above and below the C-10 road have been improved by equipment work. Road fill prone to mass failure was removed from stream channels. Water flow that had been diverted out of its natural drainage by tractor logging (skid trails, lay outs, etc.) was redirected into its original channel. Infiltration capacity of compacted soil was increased locally by "ripping" as evidenced by lack of standing water in treated areas that previously held a large amount of ponded water.

Decompaction by tractor rippers also promoted revegetation of the road align-

ment. On sample sites with similar conditions, an unripped section of road had only a trace of fescue (Festuca occidentalis) growing upon it. In contrast, an adjacent plot that had been ripped exhibited a 10% ground cover composed perennial rye (Lolium perenne)- 5% ground cover; bluegrass (Poa spp.); velvet grass (Holcus lanatus); hairgrass (Aira caryophylla and Deschampsia elongata); dogtail (Cynosorus echinatus); soft chess (Bromus mollis); nitgrass (Gastridium ventricosm) and others. Rye and velvet grass had been seeded by work crews; other species invaded the road alignment naturally.

Effectiveness of Vegetation on Erosion Control

Upper Miller Creek was broadcast seeded with a mix of 50% annual and 50% perennial rye grass at an application rate of approximately 40 pounds per acre in January, 1979. A small amount of other commercial seeds was included in the grass mix as well. Ammonium sulfate fertilizer (20-0-0) was applied at a rate of 100 pounds per acre. Grass germinated about a week after seeding, but cover was generally sparse and uneven, ranging from 0 to 30% ground cover. Rain on bare soil carried seed downslope, where it was caught on wattle terraces. Terraces now show the heaviest concentration of sprouting grass. Perhaps raking the soil after seeding would prevent, or at least inhibit, the downslope movement of seeds. It is now recognized that heavy grass seeding should be accomplished immediately following heavy equipment operations when the soils are loose and generally uncompacted. The first heavy fall rains tend to settle the soil structure and close the open pore spaces near the surface, thereby reducing the quality of the seed bed.

Tanoak (Lithocarpus densiflora) acorns, chinquapin (Castenopsis chrysophylla) seeds, sedge Carex sp., seeds alder (Alnus rubra) seeds, Juncus effusus seeds, Rumex crispus, seeds, maple (Acer sp.) seeds, and Baccharis pilularis

seeds were planted in mid-December. All species, with the exception of the alder and maple, showed some sprouting success in spring, 1979. Willow wattles were planted October through December, 1978. Stem cuttings of willow (Salix spp.), thimbleberry (Rubus parviflorus), coyote bush (Baccharis pilularis), Rhododendron macrophyllum, ceanothus spp., and elderberry (Sambucus callicarpa) were planted in the same period. Planting in the autumn (the dormant season) is best from a survival perspective, but this means that erosion control due to increased root strength and to leaf cover from brushy or grassy species is lacking for the first winter season.

Wattle terraces (when greater than 6 inches wide) were effective in trapping silts and fine sand carried downslope by sheetwash. A 3-foot vertical spacing of wattle rows seems to be working well. Rills seldom start between wattle rows. If they do begin, they are intercepted by the next wattle row downslope. In addition to dispersing water, the wattles probably increased the rate of infiltration on treated areas by providing a regularly-spaced porous medium on the slopes.

Locally, vigorous sprouting of grasses and Juncus formed a strong root mat and trapped fines from upslope. In general, however, slope material became armored by pea-sized gravel particles. Finer particles were mobilized by rainsplash impact and transported downslope by sheetwash. Sheetwash occurs on unvegetated, somewhat compact out-sloped road. Rainsplash pedestals up to one-half inch high are evident on sparsely vegetated slopes. Rainsplash impact compacts the previously "ripped" material, and fines loosened by rainsplash clog the "pore" spaces in the top layer of the soil. This

decreases the infiltration capacity of the soil, and may increase surface runoff from a site. Some immediate ground protection on disturbed soils is needed to prevent rainsplash, sheetwash and rill erosion from removing the fine fraction of the soil material, and to protect the porous structure of the decompacted material. Mulches are the best candidates for providing immediate ground protection.

D. Emerald Creek (Harry Weir Creek) Rehabilitation Site 78-2.

Site Description

The Emerald (Harry Weir) Creek rehabilitation unit is located at a wet, lower slope adjacent to Emerald Creek. The C-90 road, a 0.7 mile dead-end logging spur road, forms the unit's downslope border. Two tractor-yarded cut blocks, separated by a thin leave strip of old growth trees, total 60 acres of logged timberland above the C-90 road. Three landings were built along the road.

A major structural feature, the Grogan Fault, cuts through the unit. The fault trends north-northwest and separates unmetamorphosed Franciscan sandstone and siltstone on the ^ueast side of Redwood Creek from Franciscan schist on the east side of the basin. This fault cuts across the beginning of the C-90 road, creating extremely sheared bedrock. The combination of a lower slope, wet locality and the sheared bedrock results in severe slope stability problems at this site directly adjacent to Emerald Creek. Soil within the unit is derived from the highly foliated schistose rocks (the Masterson and Orick soil series) and sheared siltstones and sandstones (Hugo soil series). Regolith in the downslope portion of the unit is clay-rich and wet throughout much of the year. Massive slope instability problems occurred when large road cuts were made into the toe of these slopes.

Arcata Redwood Company constructed the C-90 road in 1975, and logged the two cutblocks by 1976. The C-90 road showed signs of massive instability soon after it was built. A number of mitigation measures were attempted to control slope instability. Sandbags were placed along the road's inboard ditch to buttress ditch banks against collapse and to keep ditch flow off the adjacent road surface (Figure 25). The North Coast Regional Water Quality Control Board also required construction of small check dams and

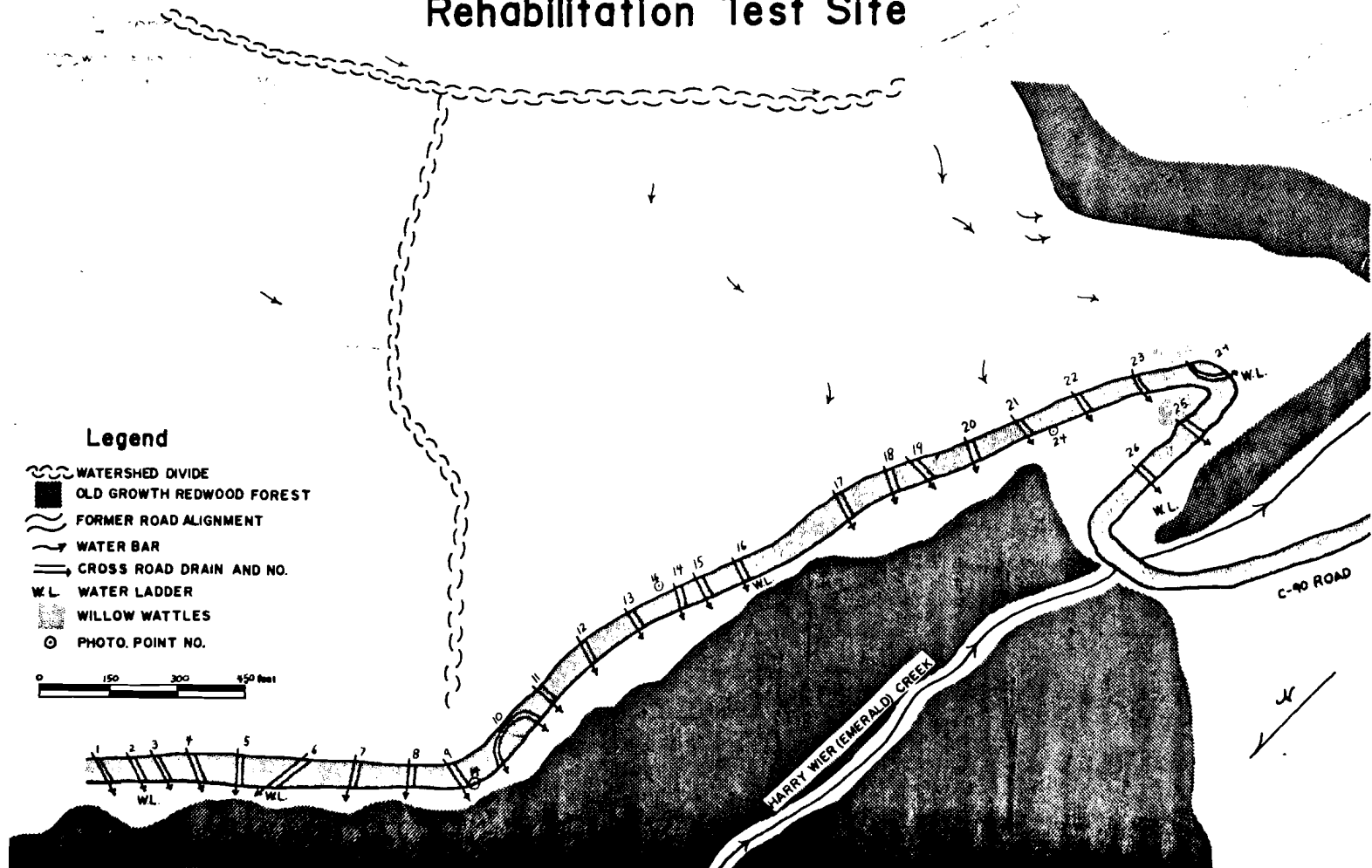
drainage structures to help abate erosion along the road. These measures were ineffective, having failed after only one winter.

Mass slope instability and severely altered drainage patterns caused by road construction and tractor-yarded logging were major concerns at this site. Failing cutbanks filled the inboard ditch and caused surface runoff to be diverted across the road, resulting in development of rills and gullies. Saturated areas along the road threatened stability of road fill. In addition, natural drainage patterns were disrupted by placement of five culverts leading from the inboard ditch and by some diversions caused by tractor disturbance on the hillslopes. A buffer strip of old growth redwood was left on the steep slopes bordering Emerald Creek; however, activation of major mass movement features along the road upslope may adversely affect forested slopes in the buffer strip.

Approach

Site mapping was accomplished in late spring, 1978. Heavy equipment was moved into the site in late summer. The C-90 road was pulled using a Case 580-C backhoe and a D-8 caterpillar tractor. The entire road was ripped by the D-8 tractor. Five culverts were removed and cross road drains were excavated and reshaped in former culvert locations (Figure 19). In addition to former culvert locations, in 21 areas where cutbanks intercepted ground water flow, drains were built across the road in order to drain these areas more efficiently (Figure 20). Where possible, the backhoe and cat tractor outsloped the road to improve drainage. Work accomplished is shown on the following Harry Weir (Emerald) Creek Rehabilitation Test Site Map. A discussion of the effectiveness on this approach is below.

Harry Wier (Emerald) Creek Rehabilitation Test Site



EMERALD CREEK

TABLE 4: COST OF EQUIPMENT TASK

TASK	EQUIPMENT	APPROXIMATE TIME (HRS)	TOTAL COST	COST PER MILE
Equipment work: preparation & supervision		105 person-hours		
Rip 3170 ft. of C-90 road	D-8 Cat (\$75/hr)	3	\$225	\$320
Construct 4 crossroad drains	D-8 Cat	13	975	
Remove 5 culverts	580-C Backhoe (\$30/hr.)	52	1560	
Construct 22 crossroad drains	580-C Backhoe			
			\$2760	\$3950

Equipment work took about seven days to complete and was finished by early October, 1978. Cost of work was \$2,760; details of equipment work are listed in Table 4. Heavy equipment work was confined to the road alignment. 470 cubic yards were excavated from crossroad drain sites and an additional 580 cubic yards were moved in the outsloping operation. This represents a total cost of \$2.63 per cubic yard of material excavated. 1.

After the road was outsloped and cross drains were excavated, a labor-intensive contract was let to line crossroad drains with rock, to construct water ladders or other energy dissipation devices downslope of crossroad drains, to plant willow wattles and cuttings on unprotected slopes, to construct waterbars on tractor yarded slopes and to do necessary shovel work to refine heavy equipment work. In addition, a trail was built to improve access to the site when the ground was wet and muddy. A horse was used to transport willows to different work projects on the site. Several local cooperatives did the work in a joint effort, or partnership. Total labor cost was \$53,560.00 and 2900 person-hours were utilized. A breakdown of cost and time is given in Table 5. A full description of the erosion control techniques used on this site is listed in Chapter IV.

In January, 1979, a five-person National Park crew planted 923 redwood and 125 Douglas fir containerized seedlings at a cost of 8¢/seedling, or \$150.00 for the rehabilitation site. Approximately 100 person-hours were used in replanting the former road alignment.

Documentation

Three types of documentation were established on the Emerald Creek site to evaluate changes through time. A longitudinal road profile covers 90% of the pulled portion of the C-90 road. It is a fairly accurate portrayal of

EMERALD CREEK, 10/78 - 12/78

TABLE 5: LABOR INTENSIVE WORK CONTRACT

TASK	QUANTITY	CONTRACT UNIT PRICE/TASK	PERSON-HOURS/ TASK
Geomorphic mapping of site			40
Contract preparation			100
Contract supervision			65
Transportation: of people	+16 man crew		237
of materials			47
of mill			13
Organization of Personnel			70
Discussion with Contracting Officer			45
Preparation of: split wood			400
milling wood			70
gathering brush & rock			74
Wattles: cut & bundle			155
installation	8375 ft.	\$2.95/ft.	0.05 hrs./ft.
Sprig Planting:			
Preparation of sprigs			
Planting of sprigs	232,200 ft. ²	\$42.99/1000 ft ²	2.12 hrs/1000 ft ²
Waterbars: construction	8	\$227 ea	3.6 hrs/bar
repair	5	\$179 ea	2.4 hrs/bar
Water ladder	4	\$730 ea	40.5 hrs/ladder
Trail consturction		\$1100	162
Rocking cross drains	20	\$373 ea	2.05 hrs/drain
Shovel work		\$1583	133
Dissipators	20	\$147 ea	3.9 hrs/dissipator
Grass seed	3 acres	\$54.50/acre	11
Tool Maintenance			21
Docu ~~ment~~ ation			57
Planting conifer seedlings	923 redwood 125 Douglas fir		

TOTALS FOR CONTRACT

\$53,557.06

2900 person hours

the road alignment ($\pm$ 0.5 feet). Twenty-six cross sections were surveyed across the C-90 road to monitor changes in slope topography before and after road outslipping by heavy equipment. Particular features (for example, swales) are well-defined by several cross-sections while more uniform sections of the road have fewer cross-sections. The profile survey was also used to construct a planimetric map of the rehabilitated portion of the road. The map was then used to compute the total material excavated from the C-90 road.

Twenty-seven permanent photo points were established on the Emerald Creek site. Photographs were taken of all work sites before heavy equipment work, after equipment work, and after labor-intensive work was completed.

The following photos illustrate the use of heavy equipment in rehabilitating the Emerald Creek site. Sequences of before- and after-treatment photos are also shown. If photos were taken from a permanently established photo point, the number of the photopoint is noted as "PP #" below the photographs. Locations of the photo points are given on the contract maps for the rehabilitation sites.



Figure 19: A backhoe excavated and removed culverts from the C-90 road, and smoothed out the resulting trough to form a cross road drain with gently sloping banks.



Figure 20: To prevent runoff from concentrating in the inboard ditch, cross road drains are excavated along the C-90 road by a backhoe.



Figure 21: PP16a 8/23/78
C-90 road prior to rehabilitation is showing signs of instability. Small cut bank failures are blocking the inboard ditch. Note the scarp of a road fill failure behind the person at the left of the photo.



Figure 22: PP16a 10/1/79
C-90 road after rehabilitation. The road has been decompacted, road fill has been pulled back, and the material has been outsloped. Note the rock cross drain behind the people, and the rows of willow wattles on the outsloped road.

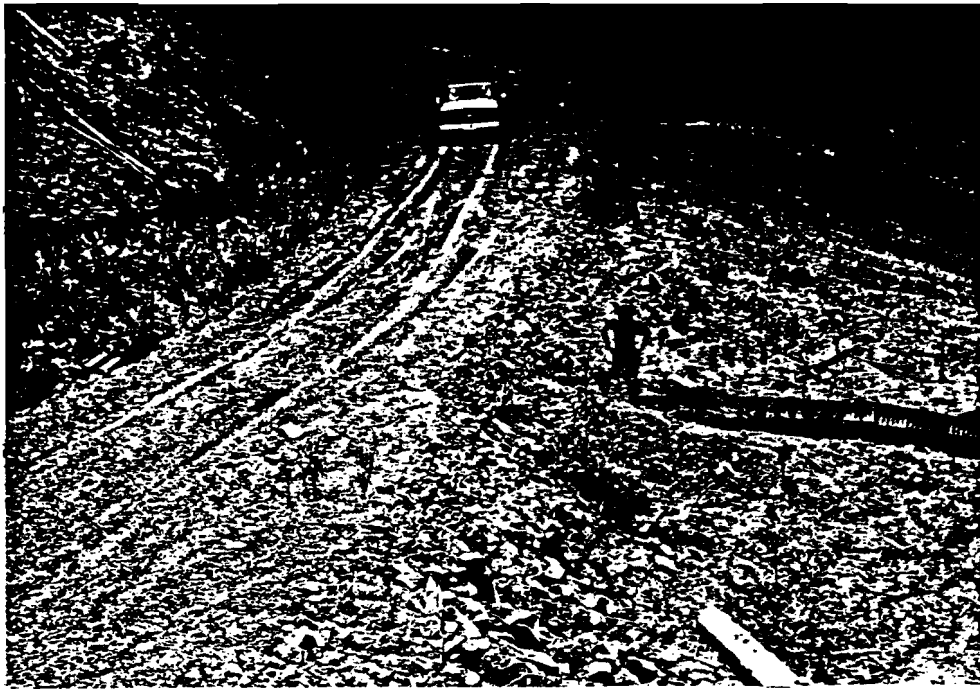


Figure 23: PP24 8/23/78
Before and after sequence of culvert removal
and road outslipping. A backhoe excavated a
cross road drain in the former culvert location.

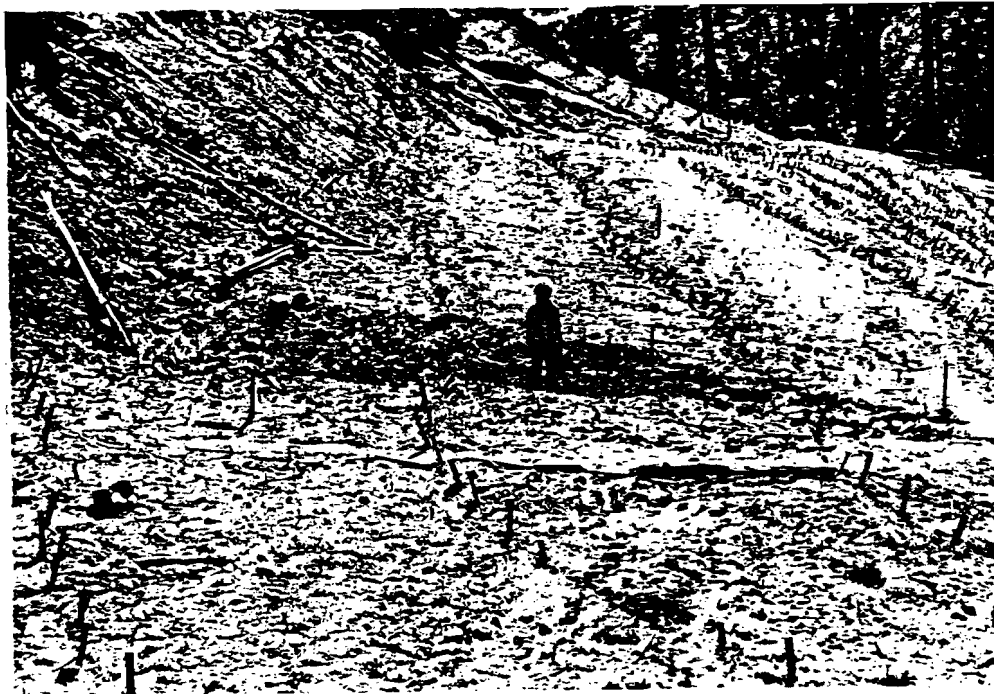


Figure 24: PP24 3/19/79



Figure 25: PP16c 8/23/78
C-90 road prior to rehabilitation. Sandbags line the unstable inboard ditch of the rocky haul road.



Figure 26: PP16c 3/19/79
After rehabilitation, C-90 road has been decompacted and outsloped, and the inboard ditch has been filled in. Surface runoff now crosses the removed road through cross road drains rather than concentrating and flowing along road alignment.



Figure 27: PP19b 8/23/78
Before and after sequence showing removal of
road and construction of cross road drains
on a portion of the C-90 road.



Figure 28: PP19b 3/19/79

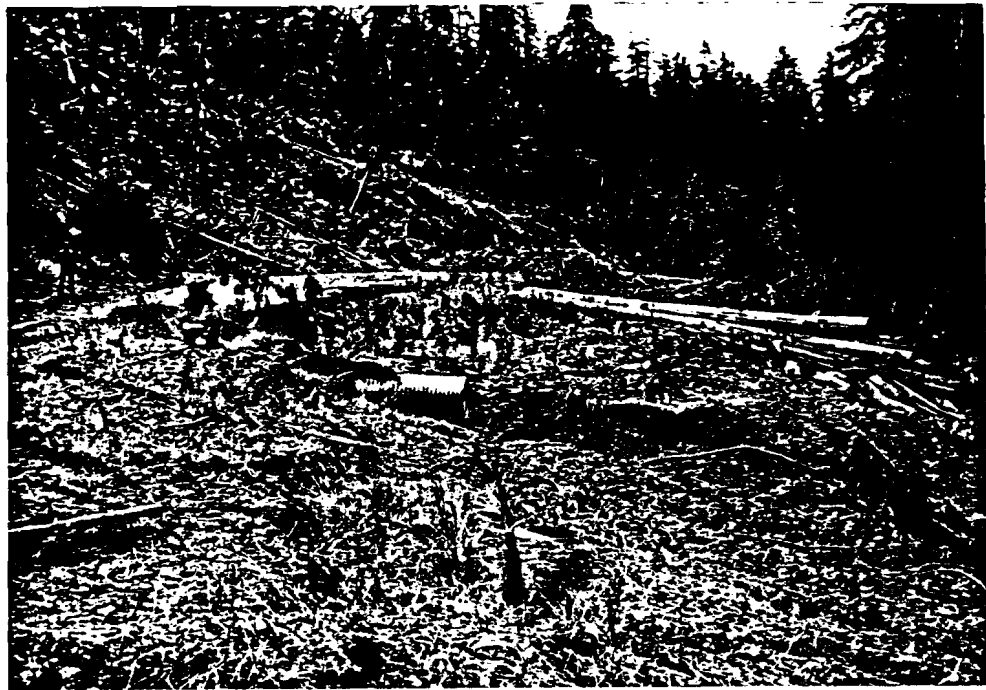


Figure 29: PP14d 8/23/78
Prior to rehabilitation, log landing is truncated by the scarp of a major failure. Culvert is no longer operational.



Figure 30: PP14d 3/19/79
After rehabilitation, culvert has been removed and cross road drains have been constructed to drain surface runoff from the site of the failure. In addition, a drainage ditch was dug at the toe of the cut banks to direct runoff into cross road drains. The deep-seated failure was not addressed except through upslope drainage diversions.

Effectiveness of the Heavy Equipment Work

Objectives at Emerald Creek were to eliminate the C-90 road as a barrier to surface runoff by outsloping the road and to construct crossroad drains (CRD's) to conduct water across the former road alignment. Both objectives were intended to prevent concentration of runoff downslope and to prevent saturation of the disturbed zone along the former road. Crossroad drains worked with varying degrees of success. Outsloping of the road has generally worked well and the slopes drain freely.

Of 26 crossroad drains constructed on this unit, 22 were excavated by backhoe. The uppermost four drains (CRD's #1-4) were built by a caterpillar tractor. All CRD's were later improved by hand labor under contract. The backhoe-constructed CRD's required less improvement by hand labor. Both types of drains were effective in directing water across the former road surface.

Nineteen of the 26 CRD's were rocked to prevent downcutting. Because the C-90 road had been rocked between CRD's #10 and #26, a good supply of coarse rock was available nearby. Rock sizes up to 15 inches maximum diameter were used and fist-size rocks defined the minimum size class. Rocking was definitely effective, especially where large rock (> 8" intermediate diameter) made up at least one-third of the rock blanket. Finer bed material became lodged in between the large rock and the blanket of trapped finer material and the coarse rock formed a protective channel-bed armor.

Geomorphology and hydrology of the unit was mapped in late spring when most seepage areas were no longer active. Most areas of seepage or flow were successfully identified. However, in a few cases where evidence of seepage problems was not apparent during mapping or heavy equipment work, groundwater

emerging the following winter was not channelized through cross road drains and caused rilling, gullying, and slope stability problems (see discussion of CRD's #10, 11, 12, and 13 below). At the mouth of CRD 23, seepage was purposely allowed to disperse across an outsloped section of the road. Because the amount of flow was small and the slope was wattled, rilling did not occur downslope of CRD 23.

In some cases, portions of the inboard ditch were kept open in order to intercept several rills and seep areas and to direct this flow into one cross road drain. This technique decreases the number of cross road drains necessary on a road, and it worked well as long as the catchment area of the cross road drain remained small and the portion of road was stable. However, cross road drains #10, 11, and 12 were apparently spaced too far apart (100 feet) because two slumps occurred at this site (Figure 31). Also the slope in the vicinity of these CRD's is unstable. Perhaps more drains in this area would have further dewatered the slope above the CRD's and prevented slumping. Slope wetness and the potential amount of emerging groundwater from cut banks must be considered along with surface runoff channels in planning spatial distribution of drains.

During the first two storms of the season, the road between CRD 12 and 13 received runoff that had not been anticipated from earlier mapping. After these early storms, ditches were manually dug to drain the slope. Along this section of road, noticeable tension cracks contour the slope, and a series of three step scarps indicate that a slump block has dropped 6 to 15 inches during the winter. The area was still wet in early June, and this incipient slump will probably continue to fail in the future. Perhaps

ditches could be dug deeper and steeper across the road to ameliorate the poor drainage in this area. However, much of the water entering the area is undoubtedly derived from subsurface flow, and surficial ditches will not treat that problem. For example, a contour ditch built to drain into CRD 11 did not prevent a small slump block from failing in that area.

Slope problems in the vicinity of CRD's 11-13 involve mass slope failure, and the techniques of road outsloping and construction of drains cannot be expected to solve such slope stability problems. It must be recognized that not all erosional problems can be treated by the rehabilitation methods employed on this unit, and the incipient road failure at CRD's 11, 12, and 13 is a good example of such an erosional problem.

Ditching at CRD's 12 and 13 after the first rain in response to unanticipated runoff from the cutbank and slope above definitely helped minimize surface erosion. This well-timed ditching is a good example of the great need for winter maintenance during the first major storms (as well as throughout the winter) to repair and modify troughs and structures so that they will function. On this unit, a day of ditch-digging during the first storm saved thousands of dollars worth of willow wattling and recontoured road surface, and prevented major washouts of some recently outsloped road sections.

Another area of instability along the C-90 road was the middle landing. This landing was constructed on an unstable slope. Prior to any rehabilitation work, tension cracks, pull-apart scarps, and rotational slumps on the slope above the landing indicated obvious slope instability. Attempting to stabilize this landing would have been a major heavy equipment effort. Removing

all perched fill would have necessitated rebuilding the C-90 road for drag-line crane access, using the crane to pull back debris, end-hauling the debris, and yarding out many large logs. In any case, these measures may not have stabilized the slope because of the deep-seated nature of the instability. Therefore, a decision was made not to stabilize the landing. Trenches were dug at the upslope end of the landing in an attempt to divert water from the landing surface, but because of the shallow gradient of the trenches across the landing, water could not drain freely. During the winter following rehabilitation work, the middle landing continued to fail and the slump block on the outer edge of the landing dropped six feet in early 1979 (Figure 32). The scarp from this rotational failure truncates the rock energy dissipator of CRD 10.



Figure 31: April, 1979.
A small slump occurred on a recently wattled slope in an area with few cross road drains.



Figure 32: April, 1979.
The outside edge of a landing failed where instability had previously been seen (see Figure 30 for comparison). The man's hand points to a cross road drain that has been truncated by the scarp of this failure.

The uppermost landing also had a large amount of perched debris at its edge, although the road was not as inherently unstable as the middle landing. Here the crossroad drains divert flow onto more stable areas, and no movement occurred during the winter.

Effectiveness of Vegetation on Erosion Control

Willow wattles were built on most pulled road surfaces and on outsloped fill materials. The wattle terraces trapped sediment ranging from silts and clays up to articles 12 millimeters in diameter (Figure 34). Few rills developed on wattled slopes, whereas they are more prevalent on similar slopes that are bare and unwattled.

A mixture of 50 percent annual rye grass seed and 50 percent Potomac orchard grass was broadcast seeded on the C-90 road alignment in late autumn, 1978. The application rate was approximately 40 pounds/acre.

The grass cover was not uniform over the unit (0 to 30% ground cover). Locally, thick stands of rye have trapped fine sediment from upslope. Where grass forms a thick mat along the sides of cross road drains, the amount of lateral erosion in the channel is a few inches less than along ungrassed reaches of the drain. Grass is not effective in inhibiting downcutting in channels, however.

Sprigs were planted on bare slopes to eventually provide ground cover and a strong root mass. As cuttings grow, their roots will increase shear strength of slope material and may eventually decrease mass movement activity. However, it will take several years before ground cover or a strong root mass is formed. Figure 36 shows a small slump that occurred on a cutbank which

was sprigged in order to prevent that very problem. Most other cutbanks showed little movement last winter. On these stabler slopes the sprigs may survive to increase the resistance to failure.

Stem cuttings of willow (Salix sp) showed 99 percent sprouting success in terms of new branches as of June, 1979. However, only 50 percent of Baccharis pilularis var consanguinea stem cuttings were sprouting.

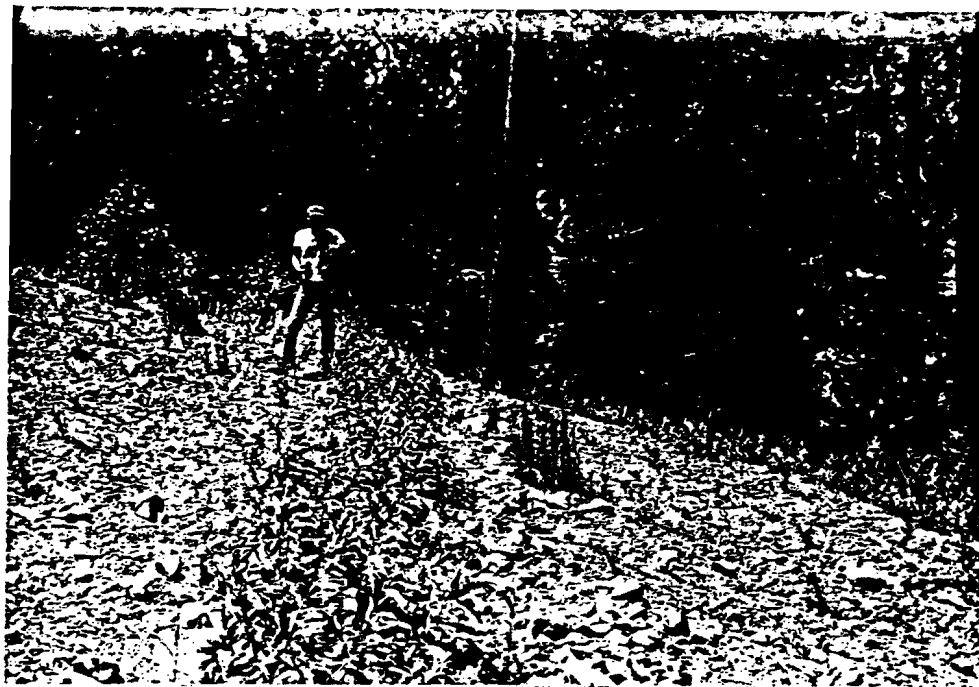


Figure 33: Willow wattles have sprouted vigorously on moist slopes on the Emerald Creek Rehabilitation Unit. Willows were planted 7 months before this photo was taken. Grass cover is sparse (1-2%).



Figure 34: Terraces upslope of willow wattles trap fine grained soil particles which are carried downslope by runoff. The wattles impede downslope soil movement and surface rilling by providing a physical barrier to runoff.



Figure 35: Although willow wattles can disperse small amounts of runoff and impede rilling, they are less effective when subjected to concentrated runoff. Here, a rill beginning upslope of a wattle row carries enough runoff to undercut the wattle and continue rilling downslope.



Figure 36: Slump in a cut bank that had been planted with willow stem cuttings a few months earlier. The young sprouts have not yet established an extensive enough root mass to prevent slumping. Note remaining stem cuttings to the left of the center of the photo.

. Upper Bond Creek Rehabilitation Test Site 78-3

Site Description

The Upper Bond Creek Rehabilitation Unit includes approximately 51 acres of cutover land near the headwaters of Bond Creek. The site is underlain by well foliated, highly deformed and fractured schists of the Franciscan formation. Locally, more competent "blocks" of schist protrude from the slope as resistant outcrops.

Schist bedrock weathers to form clay-rich loams of the Orick and Masterson soil series. Regolith derived from schists is generally deeper, redder, finer-grained and more cohesive than regolith derived from sandstone. Schist mechanically breaks down into finer, more weathered fragments than sandstone, and clay is common weathering product of schist minerals. Infiltration capacity and subsurface drainage are rated as good, and soils are moderately susceptible to surface erosion. (Iwatsubo, 1976).

Slopes within the unit average 40% and range from 15% within the central bench to over 85%. Steepest slopes are encountered along six well incised stream channels which traverse the site and are found immediately above the L-1-5 road which borders the base of the harvested area. Each drainage originates within several hundred feet of the L-1 road at the top of the unit. Four streams are fed by perennial springs within the rehabilitation area, and in total, nearly 5000 feet of incised stream channel are contained within the unit.

For the most part, slopes are relatively dry and stable. Emerging groundwater along steeper slopes at the base of the unit have locally caused

shallow soil failures to develop. Clay rich soils and deep road cuts along the L-1-5 road have aggravated this problem.

Incised, cobble-bed stream channels within the unit respond quickly to storm rainfall. The high clay content of local soils together with steepness of drainages (20%-50%) and their channel side slopes (40%-85%) contribute to rapid runoff. Elevation ranges from 750 feet along the L-1-5 road to over 1050 feet upslope along the L-1 road.

Louisiana-Pacific Corporation clear cut and tractor yarded the area over the two year period from 1975 to 1976. The original stand of vegetation was dominated by four to six foot diameter redwood with lesser amounts of Douglas-fir in the overstory. The sub-canopy consisted of scattered hemlock and tanoak while huckleberry, rhododendron, salal and ferns are common ground cover plants. In the fall of 1976, the remaining vegetation and slash was intensely burned to aid in site preparation and replanting.

None of the four perennial or two intermittent tributaries to Bond Creek which flow through the harvest area were afforded any protection from logging activities. Stream protection and equipment exclusion zones were not provided. As a consequence, each stream channel was heavily impacted during yarding operations and shade canopy was totally obliterated by broadcast burning following logging.

Approximately 70 - 80% of the area consists of relatively barren skid trails and other regions of exposed mineral soil. Where tractors crossed the incised stream channels, up to 15 feet of roadfill and logging slash were pushed directly into watercourses, disrupting natural drainage patterns and

Contributing large volumes of sediment to the stream system. Severe gullying of the 28 skid trail crossings had occurred in the two years since logging.

Virtually every intermittent and ephemeral stream channel had been used as a path for skidding logs to the L-1-5 road downslope. Thus, while fill crossings are generally absent on these watercourses, their entire lengths contain large areas of exposed soil. Diverted watercourses have also triggered several landslides and initiated gully systems elsewhere on the hill-slope.

Rehabilitation efforts were concentrated around the immediate vicinity of streams where bare soil in or adjacent to channels was continually subject to excessive rates of erosion. Restoring natural drainage network and removing inorganic and organic debris from watercourses were the main problems addressed on this unit. In addition, improperly placed waterbars, gully head cuts, small slope failures and numerous bare soil areas were treated. As work progressed, it was decided to leave three drainages alone for eventual comparison with the treated streams. As a result, the rehabilitation site was reduced to roughly 51 acres from the original 85 acres and incorporated 14 of the 28 stream crossing sites.

Approach

Detailed geomorphic mapping of the 85 acre plot was accomplished over a five day period in early July, 1978. Field mapping was accomplished on a mylar overlay of an enlarged aerial photograph of the area taken the preceeding year. Work accomplished is shown on the following "Bond Creek Rehabilitation Test Site" map.

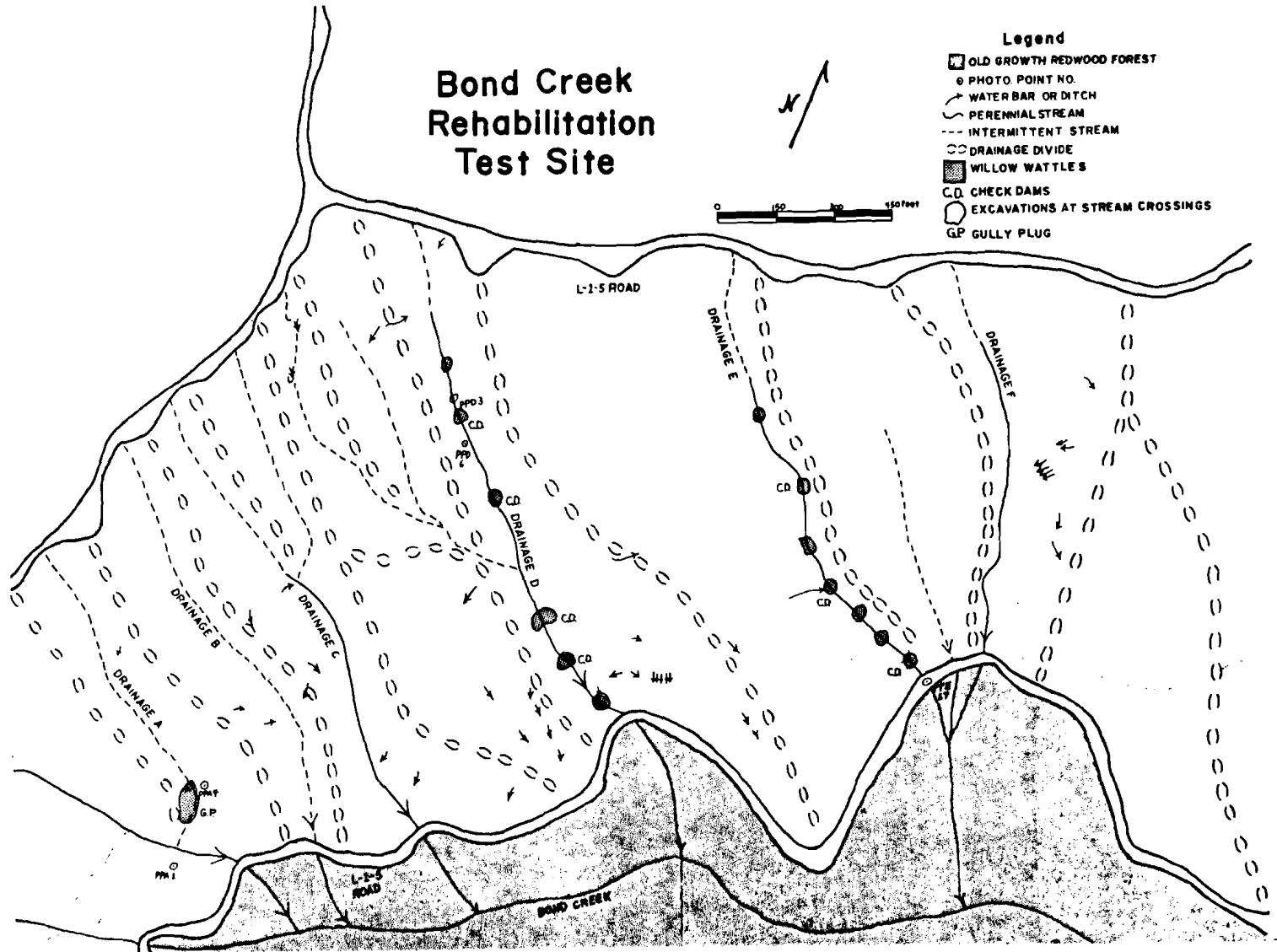
After work prescriptions were formulated, heavy equipment cleared drainages

Bond Creek Rehabilitation Test Site

Legend

- OLD GROWTH REDWOOD FOREST
- PHOTO POINT NO.
- WATER BAR OR DITCH
- PERENNIAL STREAM
- INTERMITTENT STREAM
- DRAINAGE DIVIDE
- WILLOW WATTLES
- C.D. CHECK DAMS
- EXCAVATIONS AT STREAM CROSSINGS
- G.P. GULLY PLUG

0 150 300 450 feet



of organic debris and roadfill sidecast material. A D-5 caterpillar tractor winched logs from the skid trail stream crossing sites and pushed as much material as possible to either side of the watercourse so it could not re-enter the channel. A Case 580-C Extend-a-hoe (rubber tired backhoe with extended reach) followed the tractor and excavated the bulk of the remaining soil from the fill prism. This excavated material was then back-bladed down the skid trail away from the stream and used to outslope the tractor trail approaches.

The equipment completed excavations in about nine days in early September. Of the tractor's work time, roughly 80% was spent winching debris while actual stream channel excavations (blade work) consumed less than 20% of the machine hours. A small portion of winching time was spent waiting while chokers were maneuvered around the logs or while the backhoe uncovered buried debris. In addition, a limited amount of time was allocated to the backhoe for waterbar construction to establish cost comparisons with manual installation. Final equipment expenses amounted to \$6025. Table 6 outlines the details of the equipment work and costs for the Upper Bond Creek Rehabilitation Site, 78-3.

Time constraints required development of the hand-labor erosion control contract before heavy equipment work was completed. This methodology, also followed on Upper Miller and Lower Weir contract sites, made it difficult to describe and define proposed work items. As a result, several change orders and changes in amount were required after the contract was awarded.

Three bids were received for the described work. They ranged from a low of \$23,660 to a high of \$57,929. Aero-Marine Research of Arcata, California was awarded the contract which involved waterbar repair and construction, ditch digging, wattling, sprig planting, checkdam construction, hand grass

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BOND CREEK

TABLE 6: COST PER EQUIPMENT TASK

TASK	EQUIPMENT	APPROXIMATE TIME (HRS)		TOTAL COST
Construct 15 waterbars	Extend-a-hoe (\$30/hr)	1		\$ 30
Remove fill and reshape crossing #	Extend-a-hoe (\$30/hr) & D-5 Cat (\$40/hr)	Hoe -- D-5 Cat		
7L	"	5	6	390
7K	"	5	6	390
7J	"	8	6	480
7I	"	4	3	240
7H	"	9	15	870
7G	"	2	3	180
7Q	"	2	2	140
7P	"	2	2	140
7O	"	2	2	140
7N	"	12	13 $\frac{1}{2}$	900
7M + $\frac{1}{2}$	"	3	2	170
7M	"	1	2	110
7M - $\frac{1}{2}$	"	6	10	580
7 A+C	"	7	14	770
Miscellaneous		2.5		75
Transportation Costs:	~~Warlick~~ extend-a-hoe	\$ 60		
	~~Duncan~~ backhoe	300		
	D-5 Cat	150		
		\$510		510
Total equipment rental cost				\$6025

seeding and fertilization, special planting and gully-plug construction. Work was accomplished between October, 1978, and January, 1979, for a total work time of approximately 4430 person-hours. Itemized person-hours and unit prices for each of the tasks are depicted in Table 7. Final cost, after all change orders, amounted to \$19,503. The specific erosion control techniques used by the contractor are evaluated in a later section.

Documentation

Cross sections were surveyed with a theodolite at seven cleared stream crossings and at one fill failure. The channels were surveyed before and after heavy equipment work. Planimetric maps of stream crossings were drafted as well, and the volume of material excavated from the crossings was computed. The reproducibility of the cross-section surveys was excellent; error was within ± 0.4 feet.

Permanent photo points were established at 58 locations in the rehabilitation unit to visually monitor changes in treated and untreated stream crossings. Photographs were taken before and after heavy equipment work, and after the labor intensive contract was completed.

Effectiveness of Heavy Equipment on Upper Bond Creek

The primary emphasis on this unit was to excavate the large volumes of debris previously deposited in the well-incised, steep stream channels at

BOND CREEK, 10/78 - 1/79

TABLE 7: LABOR INTENSIVE WORK CONTRACT

TASK	QUANTITY	CONTRACT UNIT PRICE/TASK	PERSON-HOURS/ TASK
Transportation: of people	2-15 person		802
of material to site	crew		82
of material on site			204
Organization of Personnel			346
Discussion with Contracting Officer			141
Preparation of: splitwood			292
willows			372
Wattles: installation	4341 ft.	\$1.00/ft	0.1 hr/ft
Sprig planting:			64
preparation			
planting	31,067 ft ²	\$80/1000ft ²	9.1 hr/1000 ft ²
Check Dams	128 dams	\$45/dam	5 hr/dam
Waterbar: construction	12 bars	\$30/bar	4.7 hr/bar
repair	10 items	\$15/rpr.item	1.6 hr/item
Excavating ditch	105 ft.	0.85/ft	0.6 hr/ft
Grass seed and fertilize:			
broadcast seeding	51 acres	\$43/acre	
test seeding	14 plots	\$20/plot	242
Gully Plug	1	\$768	84
Pack Animals	7 animals		60
Miscellaneous			88
Tool Maintenance			172
Conifer planting			
TOTALS FOR CONTRACT		\$19,503	4430 person-hrs.

14 tractor crossings. The high gradient nature of the channels, flashy response of the streams and unconsolidated condition of the fill material combined to yield excessive rates of erosion and stream channel sedimentation. While only a relatively small percentage of each fill had gullied in the two years since logging, large quantities of material remained to be removed. Excavating this sediment would thereby reduce potential long-term sediment yields.

Fourteen stream crossings were excavated at an average cost of \$393 (range = \$140 to \$870). Combined equipment time per crossing averaged just over 11 hours for a D-5 Caterpillar tractor and a Case 580C Extend-a-hoe working in concert. Where detailed surveys could be applied, volumes of material removed from fill crossings were computed at a unit cost of \$4.12 per yard (n=5). Sixty-two percent of that cost was expended on tractor work while the backhoe accounted for the remaining 38 percent.

Prior to excavation, streams were stair-stepped over each tractor crossing (no culverts or other drainage structures had been installed). Water surface gradients over the upper surface were less than 5% while flow spilled over outside fill surfaces generally over 50% in steepness. Following stream clearance, mean channel gradient through nine of the excavated areas averaged 31% (range = 25% to 37%). The length of stream channel impacted by rehabilitation efforts averaged 56 feet and varied from 20 feet at one small crossing to over 90 feet at a more heavily disturbed site.

At each of the tractor crossings, the channels were excavated down to the estimated original level of the stream bed. The presence of rounded cobbles, rotten organic debris and changes in soil characteristics were used as

indicators of the former stream bed and banks. In several instances, fills were not excavated to this level if it was judged that excessive side slope gradients, or other potential unstable conditions would exist following stream clearance. In addition, several stumps which had been pushed into the channels during logging were too large to remove with the D-5 winch. As will be discussed later, most of the excavated channels were protected from further erosion by the installation of split board check dams. However, even those which were not protected showed little scour (6 inches), over the first winter.

Slopes adjacent to the stream channels were originally quite steep (~80%). Excavation of each stream crossing necessitated reconstruction of these steep slopes with bare, relatively loose soil. The backhoe bucket was used to grade and tamp the newly placed soil but the slopes appeared to remain highly susceptible to erosion. Fortunately, winter rains helped compact and settle loose side-slope material and no failures or significant surface erosion has occurred.

In a number of instances, skid trail approaches to stream crossing sites were originally constructed (excavated) across slopes in excess of 70%. Soil material was simply sidecast along these approaches and frequently spilled into the adjacent stream channels. These oversteepened fill slopes were gullied, showed little sign of revegetating and often displayed fresh tensional cracks along the skid road surface; eventual failure in many cases was inevitable. Where these scarps were fed by seeps and springs emanating

from the skid trail cutbank, complete failure had either become imminent or had already occurred.

Each of the oversteepened, potentially unstable access skid trails were outsloped by the backhoe as it completed work in the stream channel and backed its way out of the crossing. Outsloping entailed excavating the fill material along the outside of the road surface and replacing and compacting it along the cutbank. Runoff generated on the former trail surface or in upslope areas then flowed directly across the recontoured slope rather than down the road as it had previously done. Areas of emerging groundwater were not covered over with loose fill material.

Since outsloping, no slope failures have occurred. Areas where tensional cracks and small scarps were previously located show no signs of renewed activity. No new failures have developed. Initial results suggest that excavation, even if only partially completed, unloads the slope sufficiently to stabilize fill slope instabilities. This appears to be an effective method to prevent the future introduction of soil material into adjacent stream channels. However, surficial soil erosion from these sites must be controlled to prevent gullyng of the steep, bare slopes.

Elsewhere on slopes within the rehabilitation unit, the backhoe was used to install a number of waterbars which, by tradition, are done by tractors. For comparative purposes a number of waterbars were also constructed by hand. The backhoe was able to excavate waterbars at a rapid rate and for a very low cost. Approximately 15 such structures were made in one hour's time at a cost of

roughly \$2.00 each. In the three bids received for the hand labor work on the Upper Bond Rehabilitation Site, unit prices for pick and shovel waterbar construction, ranged from \$30.00 to over \$300.00. Use of the heavy equipment is clearly less expensive. In other locations, limited access may prohibit the use of machinery.

An important factor in backhoe work on steep slopes and in stream channels was operator skill. Apparently only a few highly skilled operators work in the Northern California area. A number of backhoes have since been rented for similar jobs and their success in accomplishing the same tasks was highly dependent on their ability to maneuver across relatively steep slopes. As a result, the time and cost figures for each of the tasks as well as the success of the individual excavations elsewhere could vary substantially from the data presented in this report.

Effectiveness of Vegetation on Erosion Control

Approximately 4300 linear feet of wattling was installed. The vast majority was composed of 100% willow. Wattles were placed at roughly 3 foot vertical spacings on the steep, bare sideslopes which had been freshly disturbed by heavy equipment during rehabilitation. For the most part, wattle terraces have succeeded in storing sediment derived from the steep area between it and the next higher wattle. Although no deposition pins were installed, accumulations of silts and clays in depressions are obvious.

In a number of locations, wattle terraces have also acted to filter coarse material transported to the wattle bench by rills or by sheetwash while dis-

persing concentrated flow and acting to inhibit the formation of long, continuous rill systems. However, several rows of wattles not constructed on contour have actually contributed to the collection and concentration of slope runoff along paths which now show distinct channelized erosion. If rows are not level and on contour, each row will tend to collect runoff and discharge it in isolated locations onto the next wattle downslope. The cumulative effect can lead to significant rilling of the bare slope areas.

Roughly 10,040 square feet of disturbed area was planted with cuttings of willow. These areas were generally confined to less steep slopes where wattling was not warranted. In addition, cuttings were also planted along the stream channels below the last wattle row and within the abutments and catch basins of check dams. The gradual expansion of a root mass should aid the long term stabilization of the stream bed and banks but its initial benefits are limited to the immediate area surrounding each cutting.

Whipplea modesta, a creeping ground cover species, was transplanted in several locations. When established, it produces a solid mat of vines over the ground which, though untested, probably aids in controlling rilling and sheet erosion. Cuttings of individual stems had a relatively low success rate and appear to spread slowly. Transplantings of entire plants (about 1 square foot in surface area) were very successful and appear to be rapidly spreading from their central root mass. If planted in great enough density, ground cover from Whipplea modesta should aid in controlling surface erosion on harsh, dry sites where other species will not flourish.

A number of different grass species were sown over the Bond Creek rehabilita-

tion site in January, 1979. The purpose of the seeding was to provide temporary ground protection during shrub and tree establishment. Three mixes were used, State Highway Mix (1/3 common barley, 1/3 annual rye and 1/3 fawn tall fescue); Simpson Mix (1/3 crimson clover, 1/3 Wimmer rye and 1/3 Potomac orchard grass); and Dry Meadow Mix (1/3 perennial rye, 1/3 Potomac orchard grass and 1/3 velvet grass). The application rate specified in the contract was 40 pounds/acre, but some areas were seeded twice. Ammonium sulfate fertilizer (20-0-0) was applied at 100 pounds/acre on sites seeded with State Highway and Dry Meadow mixes while ammonium-phosphate-sulfate fertilizer (16-20-0) was applied at a rate of 200 pounds/acre to sites seeded with the Simpson Mix.

The success of the three grass mixes was difficult to evaluate because of differing site conditions on the seeded areas and uneven application. The most successful skid trails in terms of seed germination showed a 70% ground cover, 70% of which was composed of perennial rye (Lolium spp.). Cat's ear (Hypochaeris radicata), which invaded the roads naturally, provided 5% of the ground cover. Coyote bush (Baccharis pilularis var consanguinea) and bluebrush (Ceanothus thrysiflorus) seedlings were also apparent on skid trails and roads.

Dense grass cover on regarded skid trails appears to have alleviated widespread rilling found on these sites prior to rehabilitation activities. However, where concentrated runoff flows down a trail, grass cover was not successful in preventing continued erosion (Figures 53 and 54).

Steep areas between wattles were frequently washed clean of seed before the seed had germinated. Conversely, benches at each wattle trapped grass seed

and the wet conditions favored high initial success in these areas. This mat of grass helped filter coarse debris carried from upslope areas.

Red alder was broadcast seeded at approximately 10 pounds/acre on several stream crossings. Germination is evident and widespread on these stream crossings (Figure 52).

The following photos illustrate the use of heavy equipment in rehabilitating Upper Bond Creek site. Sequences of before- and after-treatment photos are also shown. If the photos were taken from a permanently established photopoint, the number of the photopoint is noted as "PP #. . . ." below the photographs. Locations of photopoints are given on contract maps for the rehabilitation sites.



Figure 37: Organic debris that was incorporated in road fill is winched out of stream crossings by a caterpillar tractor.



Figure 38: A small backhoe is used to excavate road fill and organic debris from stream crossings. Stream banks are recontoured to achieve stable slopes. The cat in the background of the picture is winching large debris from the channel before the backhoe does the 'finish-up' work in clearing the channel.

Figures 39-44: The following 3 pairs of photographs are before and after sequences that show perennial stream channels filled with organic debris and fill material from skid roads prior to treatment. The second photo of each pair shows the same channel reach after debris is cleared and excavated and the slopes are recontoured. A small backhoe was used to clear channels, and a tractor aided in winching debris from channels.



Figure 39: PPD6 9/7/78

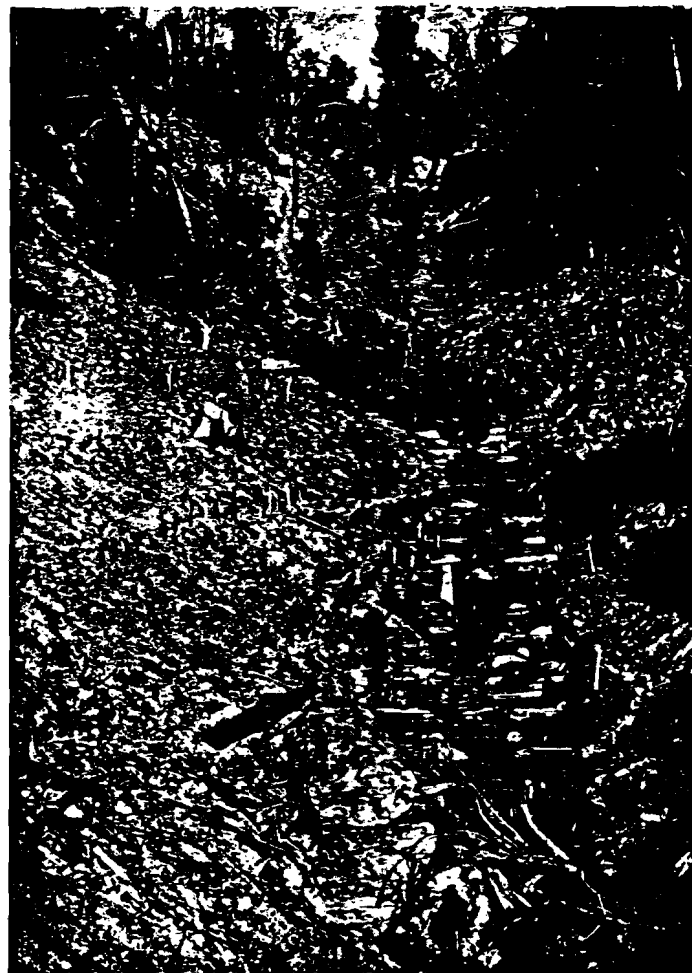


Figure 40: 1/4/79
Stream crossing 7-K. Note series of check dams in channel and willow wattles on slope. (Note: this photo will be reshot to get the same perspective as 39).



Figure 41: PPD3 10/3/78



Figure 42: 8/79



Figure 43: PPE17 9/7/78



Figure 44: 1/4/79
Note check dams in channel, willow wattles on slope, and staggered planter boxes staked into slope.



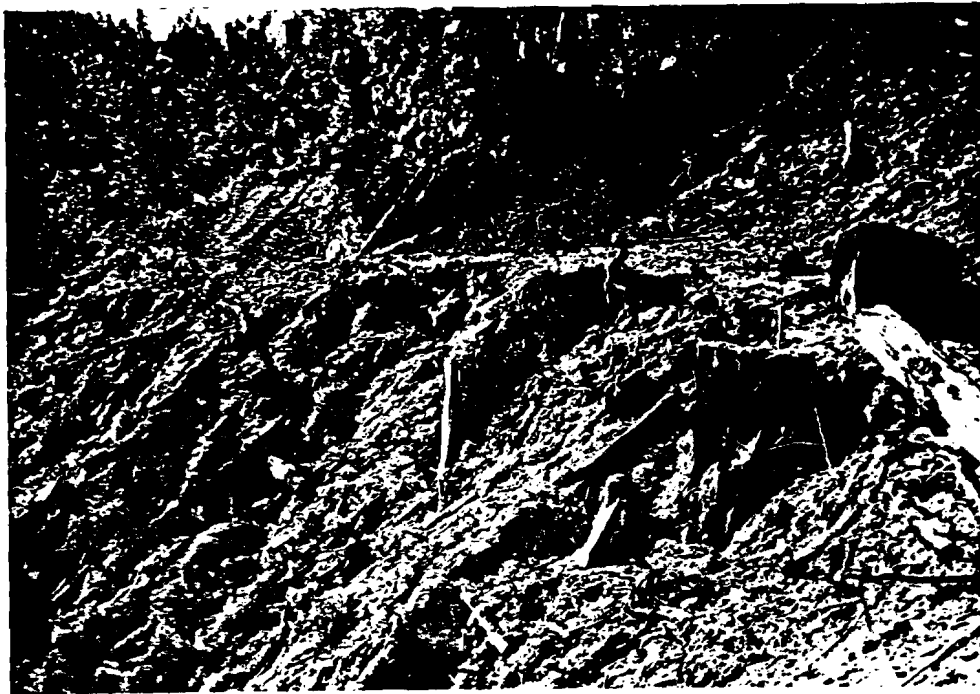


Figure 45: PPA4 9/7/78 Prior to rehabilitation, skid road has unstable, oversteepened fill at outboard edge of road.



Figure 46: PPA4 1/4/79
After rehabilitation, perched fill has been pulled back by a small backhoe, and road was outsloped. Contour rows of willow wattles were installed just prior to this photo.



Figure 47: PPA1 9/7/78
Before rehabilitation, this site shows two parallel skid roads, the unstable fill slopes, and a gully running down the length of the photo.



Figure 48: PPA1 1/4/79
After rehabilitation, unstable fill was removed, a small channel was cleared of debris, and slopes were willow wattled. A gully plug was installed at the headcut of a gully (lower center of photo) to prevent the headcut from migrating upstream. Details of the structure are given in Chapter IV.



Figure 49: June, 1979
Bare ground on Upper Bond Creek's recently disturbed slopes were sprig planted with willows in December, 1978 at a three foot spacing. The stem cuttings are beginning to sprout.



Figure 50: June, 1979
Close-up shot of a willow stem cutting that is sprouting vigorously. This site is damp year round.



Figure 51: Roosevelt elk and black-tailed deer browse on young willow sprouts. Nipped-off ends of sprouts are evident on this willow bundle, but generally little damage has occurred due to animal presence on the rehabilitation sites.



Figure 52: June, 1979. Young alder seedlings. Alder seed was broadcast seeded in January, 1979, on excavated stream channel banks on the Bond Creek Unit.



Figure 53: A rill has developed on a skid road which was seeded with grasses. Under high runoff conditions and where runoff is concentrated on roads, a grass cover does not prevent rilling. Ground cover is approximately 50%.

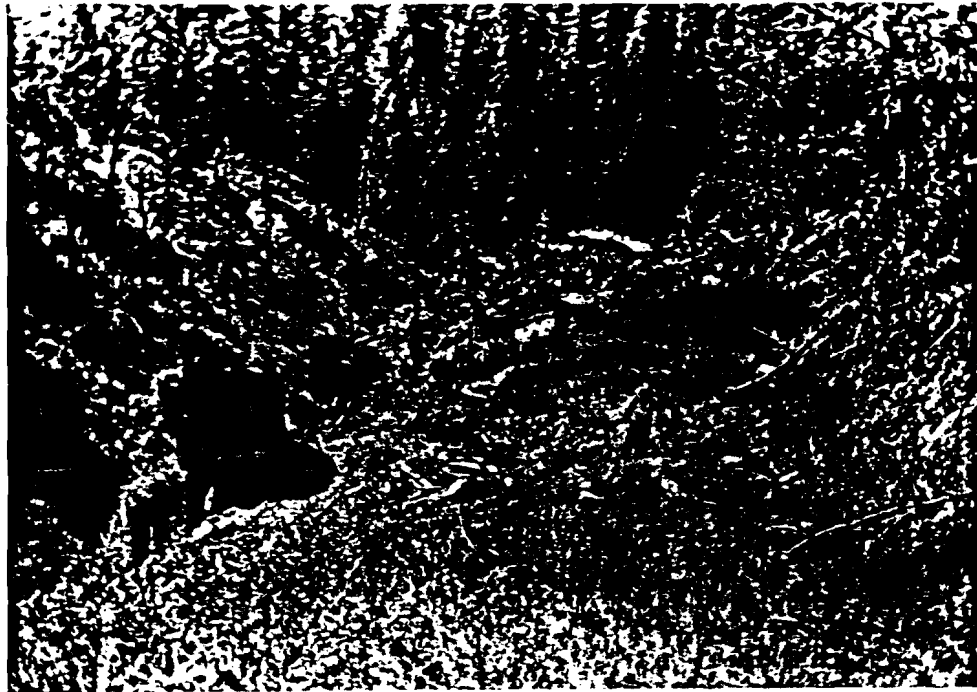


Figure 54: June, 1979

Skid road in Bond Creek Unit with thick stand of annual and perennial ryes and other grasses. The site was broadcast seeded in December, 1978. No rilling is present. Ground cover is about 70% of which 75% is perennial rye.



Figure 55: Grass seed and fertilizer were applied at equal rates on all areas of this skid road. The moist site on the left side of the photo has a fairly good grass cover developed; survival of grass is much poorer on the drier site on the right-hand side.

IV. EFFECTIVENESS OF EROSION CONTROL STRUCTURES

Several types and variations of erosion control structures were used after machinery work to stabilize slopes and gullies. The purpose of each structure and specifications for construction are described in NPS Technical Specifications (U.S.D.I., N.P.S., 1978). This section will evaluate effectiveness of structures after one winter season, and will discuss any problems that were encountered.

Erosion control structures were constructed from materials available on or near the rehabilitation sites. Redwood slats were used in all wooden structures. Because of Redwood's durability, properly placed wooden structures may last twenty years. In addition, correctly located rock structures are expected to endure at least that long, barring occurrence of extraordinarily large storm events.

Erosion control structures alone will not provide a permanent solution to erosion problems. Structures are a temporary answer to immediate erosion problems. Vegetation must be firmly re-established on these sites to provide a long term decrease in sediment yield to stream systems. Adjacent to erosion control structures, several types of vegetation were planted to accelerate revegetation. Grass and brush seeding and fertilizing promote rapid, but short-term, ground cover on disturbed sites. Alder seeding, willow wattles and stem cuttings were planted to provide a protective canopy and a cohesive root mass in a few years. In addition, redwood and Douglas fir seedlings were planted on the rehabilitation sites to promote the establishment of a well stocked conifer forest which mimics the original old-growth redwood forest.

A. Waterbars

Waterbars are used to divert water off skid trails and roads and to direct flow into its natural drainage. To be effective, a waterbar must intercept all water flowing down the road, divert the water onto a stable area, drain freely but must not downcut itself, and dissipate energy at its outlet.

In the Miller Creek Unit, waterbars were excavated at least six inches into the road surface and built up six to twelve inches above the road surface. The sandy, pebbly soil in the berm was loosened considerably after several freeze-thaw cycles, but the berms were massive enough to offset any weakening from decompaction. The gradient of troughs varies from 2 to 30%. Problems with downcutting in the trough occurred more as a function of discharge than gradient. For example, a 10%-grade bar carrying comparatively large discharges had downcut several inches, whereas a 20%-grade bar with less flow showed no signs of erosion. Where the gradient was less than 3%, water did not drain freely and some ponding and deposition occurred in the trough.

Energy dissipators for most waterbars were composed of rocks larger than 2½ inches in diameter (fist size). This size worked well to prevent erosion at waterbar outlets. In places, the rocks promoted deposition of fines upslope of the dissipator. If an unprotected break in slope exists near the outlet of a waterbar, energy dissipation should extend beyond the break, even if it requires more than three feet (contract specifications) of rock.

Few problems were encountered. Of 46 waterbars built or repaired on

the Miller Creek Unit, only three were rendered ineffective from winter flows. At one, the bar was breached where the berm was less than 12 inches high. At a second, ponding water in a 2% trough infiltrated through the bar, emerged downslope of the bar, and continued flowing in the gully. At a third waterbar, flow at an outlet cut back to the road where the berm was not extended far enough beyond the outside edge of the road.

On the Emerald Creek Site, five waterbars were repaired and eight more were hand-constructed according to the dimensions described above. Most of the waterbars received little flow, and only one problem was noted. A few inches of downcutting occurred on a steep waterbar where the ground was unprotected by rock or vegetation.

Waterbars on the Bond Creek Site were either excavated by backhoe or hand-excavated. Fifteen waterbars were dug by backhoe on a main skid trail, at a cost of approximately \$2 per waterbar. In contrast, 12 waterbars were hand-constructed at a cost of \$30 per bar. An example of a hand-constructed water bar on the Lower Bond Creek Unit is shown in Figure 61. Both types of waterbars were effective in diverting winter runoff flows from skid trails onto vegetated areas. Thus, the crucial factors in constructing an effective waterbar are: locating waterbar at a point along the road where runoff can be diverted off the road and onto a less erodible slope; spacing waterbars frequently enough to prevent road gullies between waterbars; excavating waterbars into the ground surface so that runoff flows in a ditch, rather than simply against a built-up berm that could wash out; and providing adequate energy dissipation at the outlet.



Figure 61: June, 1979
A hand-constructed waterbar on the Lower
Bond Creek Unit. Runoff from the skid
road is diverted into heavily vegetated
area behind the person in the photo.

B. Planter Boxes

Planter boxes are redwood slats staked at least three inches deep into a steep rocky slope to inhibit raveling on the slope and to protect downslope vegetation from rockfall. When keyed in adequately, these slats are effective in trapping loose soil and gravel before they roll into stream channels. Unfortunately, substrate caught upslope of the slats is usually gravelly and is not conducive to revegetation efforts. When constructed, a backfill of more fertile soil can be used, if available, to encourage vegetation upslope of the slats. Planter boxes may be staggered across a slope, but the entire width of the unstable slope should be protected at some point by the boxes. All planter boxes on the 1978 sites were made of redwood slats. Other physical barriers, such as logs and brush, may be staked into the slopes to achieve the same purpose at a lower cost.

On the Miller Creek Unit, all but one of the redwood slat planter boxes one foot high were filled to capacity on the 65% slope where they had been installed. Where jute netting was secured to the ground directly upslope of a box, sediment did not completely fill the area upslope of the slat. One slat was undercut by emerging groundwater and was rendered useless.

On the C-Line landing, all the planter boxes remained effective and sturdy through the winter. Stem cuttings of willow were planted upslope of the boxes, and were sprouting well in June, 1979.

C. Check Dams

Introduction

Check dams are small wood brush, or rock dams built in small perennial or ephemeral stream channels or gullies. Check dams help prevent further downcutting of eroding channels and help stabilize channel banks. Gullying and channel downcutting are substantial erosion problems on logged timberlands. Gullying on logged slopes occurs along logging skid roads, downstream from culvert outfalls, and on raw landslide surfaces. Downcutting can also occur in excavated stream channels where drainages have been cleared of road fill and organic debris by heavy equipment during rehabilitation. Once a gully is initiated, it will enlarge for many years because the infertile subsoil and oversteepened banks hamper natural revegetation.

Check dams are installed sequentially in a channel to prevent the failure of individual dams by downcutting at the base of a dam (Figures 62 and 64). The lowest check dam in a gully reach should be constructed on a non-erodible base, and all dams should be placed so that the sediment fill behind the downstream dam abuts the base of the next upstream dam. Therefore, check dams and their trapped sediment totally cover the channel reach, and running water moves over one check dam step, through the energy dissipator device, and onto the next lower level of ponded sediment.

The sediment deposited in the catch basins upstream of check dams also buttresses the toes of adjacent banks, and provides a substrate for vegetation. Revegetation of channel banks and channel beds will increase the long term stability of the channel.

On the Upper Miller Creek unit, twenty-four check dams were built according to contract specifications (U.S.D.I., N.P.S., 1978) in two

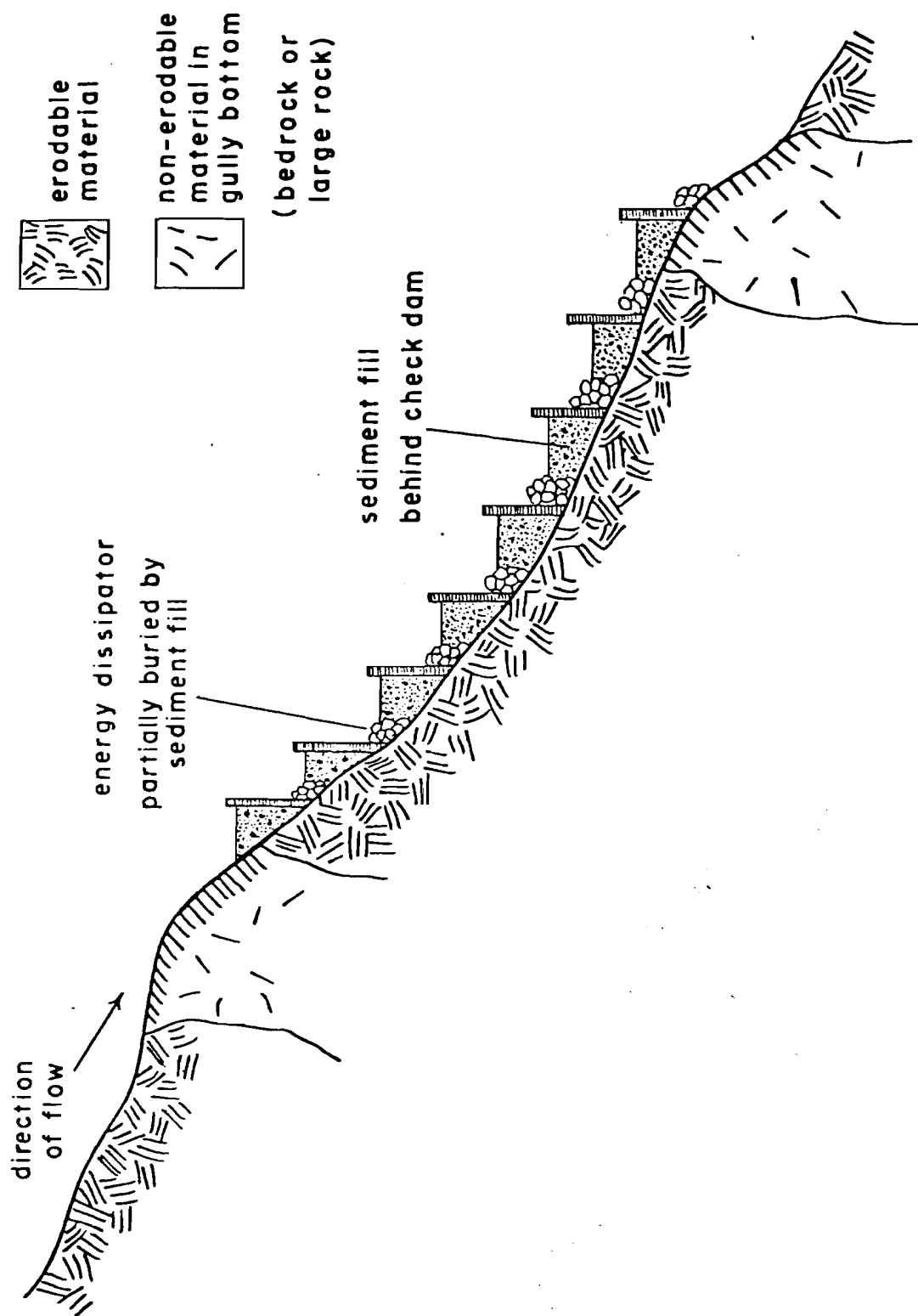


Figure 62: Profile along a gully bottom showing proper placement of a series of check dams with lowermost check dam built on a non-erodible base (called a base level).

drainages (Figure 63). In general, check dams prevented downcutting. Even where the dams were filled to capacity with sediment, they are secure and still well keyed into the adjacent banks. However, it was evident that several changes need to be made in the specifications to increase the efficiency of the dams.

A common problem in channels that were shallow, wide, and not well-defined is the inadequate length of an "average" check dam. It is often not feasible to mill a single slab long enough to extend the width of the high water channel, and in these cases wing walls were utilized. Wing walls are slats of wood staked in at an angle in the catch basin upstream of the dam to direct flow towards the spillway, and to prevent water from cutting laterally around the check dam. To be effective, wing walls must overlap the sides of check dams at least six inches. In addition, height of wing walls must be at least equal to the height of the check dam.

Another cause of lateral cutting is a too shallow spillway. Where the difference between effective dam height and total height (freeboard height) was less than five inches, lateral cutting occurred, even when channel width was not a problem. Revised contract specifications require a minimum of eight inches for the effective height of check dams.

Some dams are constructed with one board over another, (double slat dam), to provide adequate height to the dam. If the overlap between two slats is not watertight, care must be taken to caulk the seams with moss, clay, wood shims, etc., to prevent significant leaking between the slats.

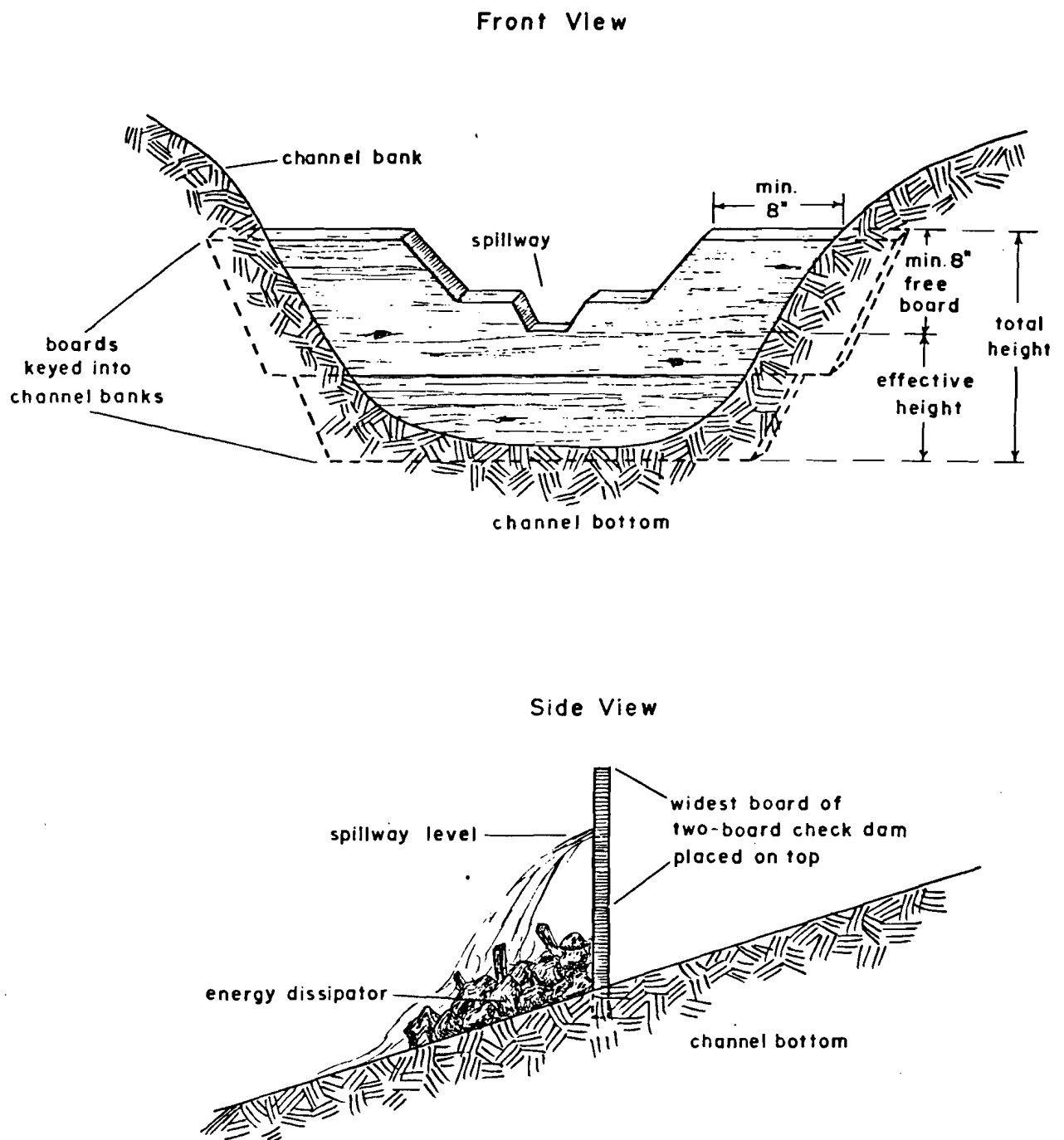


Figure 63: Schematic drawing of split redwood board check dam

Deposition of sediment occurred unevenly in several dams, especially those with wide catch basins where water did not drain freely from the sides of the basin to the center and over the spillway. To correct this problem, edges of the backwater basin could be sloped down towards the center when the dam is first constructed.

All dams on the Miller Unit had rock energy dissipators (Figure 63) that generally worked well. In a few cases, as water flowed over the spillway and hit the rocks below, it was diverted sideways to the edges of the backwater basin. Here water potentially could pond or cut laterally around the dam if preventive measures are not taken (for example, wing walls).

On the Bond Creek Unit, 128 check dams were installed in channels where road fill had been removed by a backhoe. Nearly all of the check dams are functioning as designed. At most of the former skid road crossings, the upper three to five check dams are filled to capacity with coarse sediment. Sediment in catch basins above the check dams becomes progressively finer downstream.

Both rock and splashboards were used as energy dissipators below check dam spillways at Bond Creek. The rock (fist-sized and larger) worked well, and scouring was a problem only where rock did not adequately protect the channel below the check dam spillway. Rocking the channel for the entire width of the spillway, and extending the dissipator at least fifteen inches downstream of the base of the check dam should

prevent the formation of a plunge pool below the check dam. The distance or width of energy dissipation below a check dam must be related to the height of the spillway and the potential stream discharge. That is, the greater the discharge and dam height, the farther the dissipation must extend down from the dam.

In cases at Bond Creek where a splashboard was used as an energy dissipator, the check dam was built on top of the splash board so that no undercutting would occur below the spillway. This design worked well in most cases; however, in a few instances leakage occurred between the splashboard and the base of the check dam (Figure 67). If fine material is used as backfill in the catch basin during construction of the dams, and if the material is packed well at the base of the dam, this problem could be prevented.

At the Bond Creek rehabilitation site, downcutting is a common problem upstream of the highest check dam, which may indicate one of several things: the crossing should have been excavated deeper, check dams should have been installed farther upstream, or the channel should have been armored with rocks to prevent downcutting.

Several maintenance needs for check dams became evident after high winter flows. A CETA-funded group did the necessary repair work on Miller Creek check dams in early June, 1979, as part of their training program. Wing walls were installed above five check dams where lateral cutting had occurred or where it threatened to occur. In backwater basins

where poor drainage presented a problem, fill was sloped towards the spillway to promote free-flowing drainage.

Seepage occurred at Miller Creek in a few dams where water flowed through the fill upstream of the dam and emerged underneath the dam. If seepage had continued, the dams would have become undermined. Seepage could have been prevented if clean, fine fill (i.e., no organic debris or large gravel and rocks) were used to pack the bottom and sides of the dams when they were first installed. The CETA crew removed the troublesome backfill and replaced it with fine-grained sediment to inhibit any further subsurface flow.

Banks along a check dammed reach are generally steep and somewhat unstable. Although willow wattles and stem cuttings were planted on the bank, more stem cuttings should be planted a year after check dam installation to take advantage of newly deposited sediment in catch basins. Cuttings should be especially dense along the edges of the channel at the toe of the banks. The new vegetation will contribute to the support of the banks and hinder later cutting in the channel. In the Bond Creek Unit, willow roots from cuttings planted along the channel have invaded the check dam basins and already add some binding to the fill material. Over a long period these roots will successfully stabilize the channel bed as wood check dams slowly decompose.

Most maintenance problems could have been avoided by careful adherence to contract specifications. Nevertheless, sufficient uncertainty exists at a site in the normal distribution and intensity of storms, the hydrologic mapping of a unit, and the effects of particular erosion control

structures in treating a problem that a winter maintenance crew is almost essential in preserving the effectiveness of erosion control efforts against unforeseen circumstances.

Brush check dams

At the Miller Creek Unit, small check dams made of Monterey pine boughs (an exotic species being eliminated from the park lands) were installed in rills on a through-cut skid road. The dams were six to eight inches tall and held in place by stakes cut from tree stems. In rills less than six inches deep, brush dams worked well, trapping fines and gravel from upslope. Brush dams were spaced four feet (slope distance) apart on a 55 percent slope, but they should have been spaced at half that distance. Gully downcutting may be reinitiated where brush check dams are spaced too far apart. Little experimentation has been done on park lands with brush check dams, but initial results indicate that further work with this medium is warranted.



Figure 64: June, 1979

A series of check dams protect a stream channel cleared of road fill and organic debris on the Bond Creek Unit. All dams are well keyed into channel banks and bed. Dams are located so that sediment deposited behind one dam abuts against the base of the next upper check dam. In this manner, the entire disturbed reach of channel is protected from downcutting.



Figure 65;

A close-up view of a series of check dams in the Bond Creek Unit. Summer flow is draining through low-flow spillways. Catch basins upstream of the check dams are filled with sediment deposited during winter high flows. Both rocks and splashboards are used as energy dissipators. Note willow stem cuttings are sprouting and locally, grass is well established.



Figure 66: January, 1979
Miller Creek Unit check dams convey winter flows through broad, high-flow spillways. Large rocks are used as energy dissipators below spillways. Note willow stem cuttings on both channel banks.



Figure 67: June, 1979
Leakage between splashboard energy dissipator and base of check dam. Ponding effect of the check dam is lost and consequently little sediment is deposited in the catch basin upstream of the dam.



Figure 68: September, 1979
Same series of check dams as figure 66 showing
revegetation after one season. Willow (salix, spp.)
have sprouted from stem cuttings while horsetail
(Equisetum, spp.) invaded naturally.

D. Water ladders

Water ladders are erosion control structures designed to convey water across a steep channel reach while protecting the channel from down-cutting. On the 1978 rehabilitation sites, they were used in conjunction with check dams or at the downstream end of cross road drains. Water ladders are useful where check dam installation is difficult because of unstable banks or because channel beds are difficult to excavate. If all flow can be directed over the ladder, they can also be used to protect a knickpoint or headcut in a gully from migrating upstream.

Water ladders must be designed to accomodate fairly large flow events (at least a 10-year storm). Since water discharge data is rarely available for sites where water ladders are required, other factors (original channel size, drainage area, soil, ground cover, and storm potential for the area) must be considered. Water ladder dimensions should generally be the same as the width and depth of the stream channel above or directly below the water ladder site.

Three designs of water ladders were used on the Miller Creek Unit (see sketches). Type 1 was built of hand-split and hand-sawed redwood slabs. Because the hand-split wood had an uneven surface, ladder treads were not flush with side pieces, and water seeped through these cracks to flow below the ladder. In addition, ladder treads were not level and water flowed towards the side of the ladder, accentuating leakage problems. Although the knickpoint under the top of the ladder was still protected, undercutting of the ladder would continue and eventually

Type I - Water Ladder

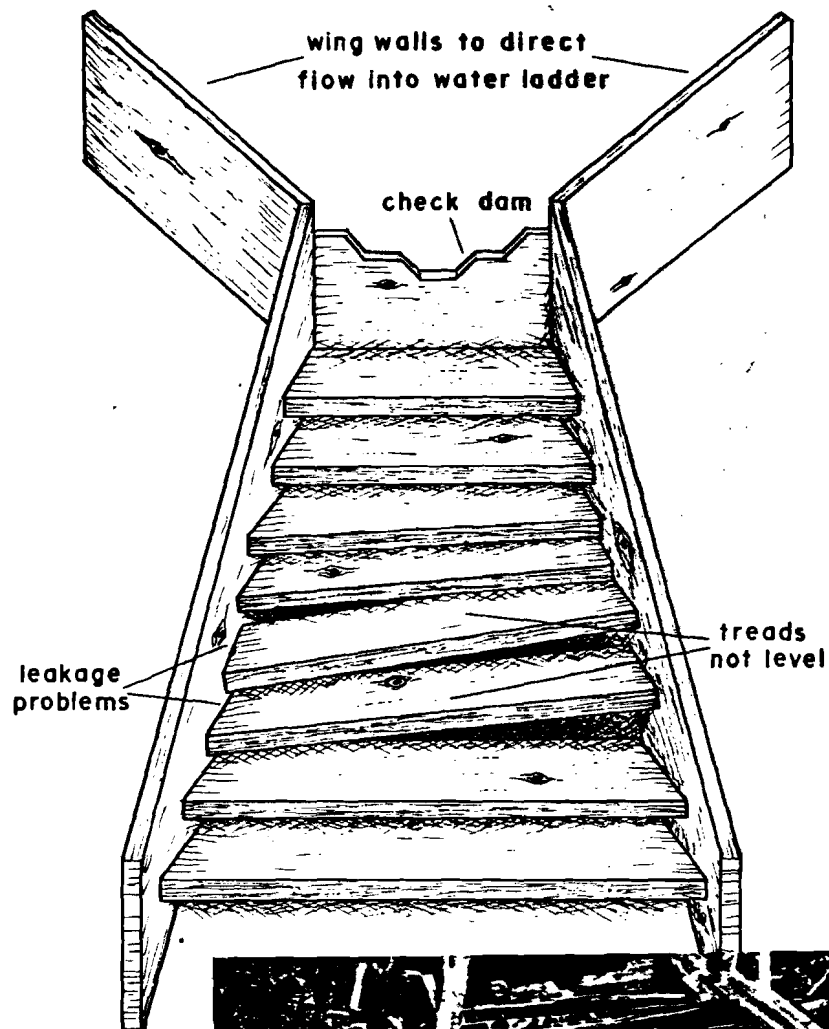


Figure 69:

Type 1 Water Ladder

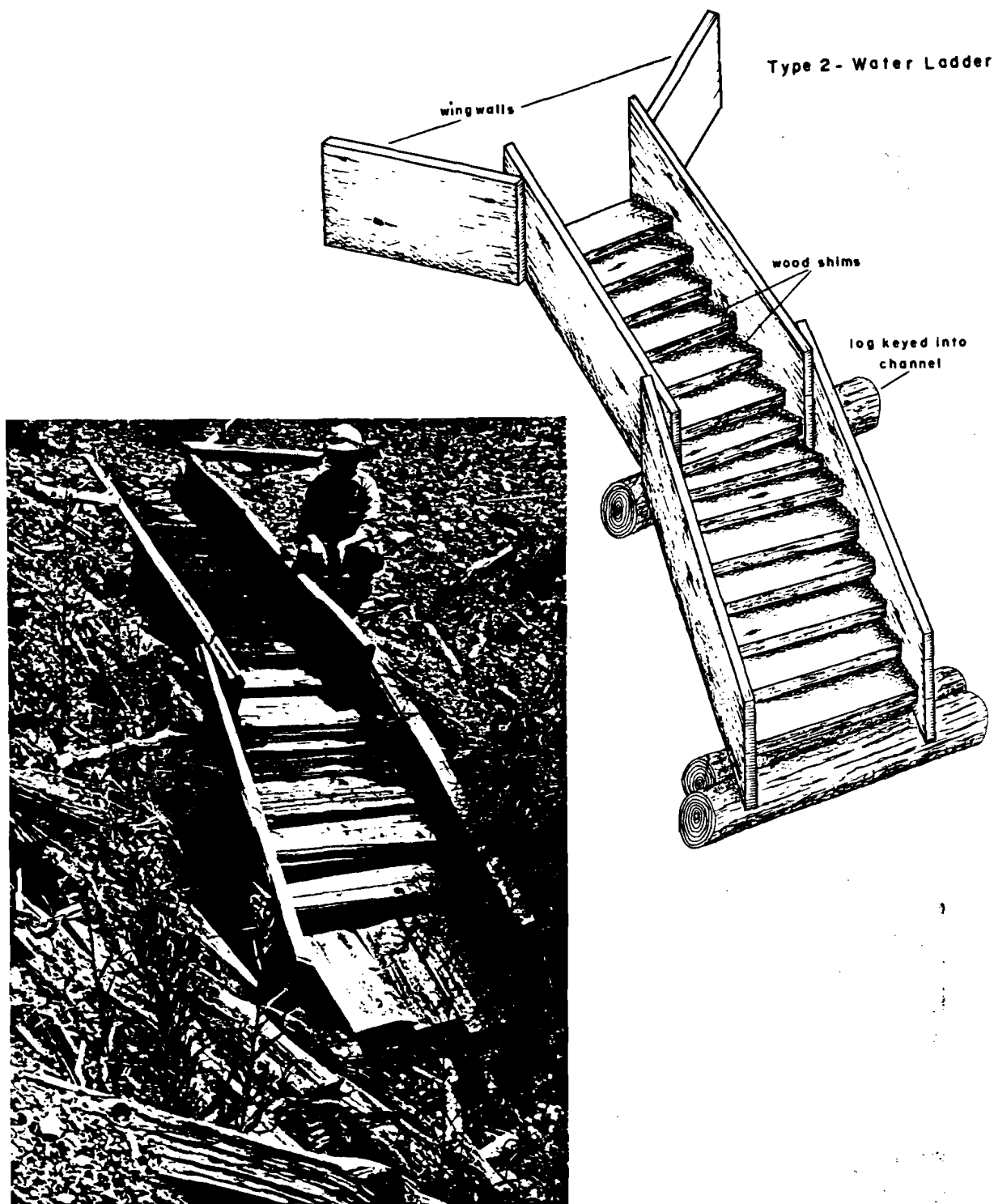


Figure 70: Type 2 Water Ladder

undermine the structure unless leakage problems were corrected. A solution to the leakage problem is to nail short slats of wood over and under the treads parallel and flush with the side pieces. Caulking leaks is another possibility. Also grooves can be cut on top of the treads to direct low flow towards the center of the ladder. In June, 1979, a CETA work crew repaired the water ladder to prevent further leakage. Figure 69 shows a Type 1 water ladder before repairs were made.

Type 2 water ladder (Figure 70) at Miller Creek is fully functional, and is also built from hand-split redwood. Wing walls above the ladder have been effective in directing flow over the ladder. The ladder is built in two overlapping sections, conforming to the channel configuration and in-channel debris. The top tread of the ladder is keyed into a partially buried log. Some scour (4 inches deep) occurred upstream of the log, but rocks were deposited in the scour hole. There is little danger of the entire log being undercut. The ladder was large enough for 1978-1979 winter flows; however, a large storm event would probably overtop the structure. Little leakage occurred between the ladder treads and the side pieces. Dry wood shims were hammered into all cracks. The shims swelled upon wetting and sealed the seams of the ladder. The energy dissipator at the foot of the ladder is composed of large logs in the channel (some of which were already keyed into the channel before the ladder was built). No downcutting occurred below the ladder.

Type 3 (Figure 71) was a water flume constructed from milled redwood slabs. A check dam built at the top of the water flume directed water through its spillway into the flume. A layer of large rocks was used

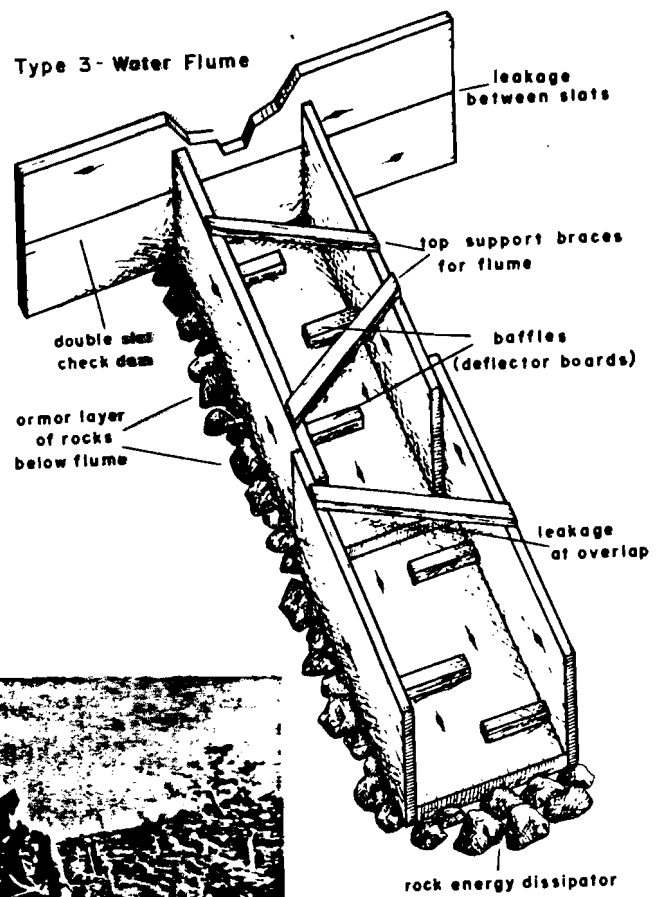


Figure 71: Type 3 Water Flume

to line the channel bed, and the flume (three 7-foot sections) was installed on top of the rocks. Braces built across the top of the flume add support to the structure.

Type 3 design at Miller Creek has several problems. Cracks between the two slats of the check dam allowed water to leak through and discharge into the channel outside of the flume. The area of the flume (18 x 18 inches) is too small to handle high flows. Some settling of the rocks under the flume occurred, and the flume has shifted slightly as a result. Overlap of the three sections is not adequate. Leakage occurs between sections, allowing water to flow through the rocks below, possibly causing the rocks to shift. Some of the baffles or deflection boards in the flume cause the water to jump over the sides at high flows. The water ladder outlet does not face downstream, but is slightly directed towards the left bank. An energy dissipator of large rocks placed in and around a trash rack was not sufficient to prevent bank erosion below the ladder.

To summarize, the most significant problem by far with Type 3 water ladders was the small cross-sectional area of the flume that will not accommodate runoff generated by even a 10-year storm event. The flume will probably wash out, creating severe erosion at the break-in-slope, leading to the development of a gully headcut.

At Emerald Creek, four of five water ladders were Type 4 design (Figure 72). The fifth was a one-section waterflume. All five were constructed at the downstream end of major cross-road drains. Wood for the

Type 4 - Water Ladder

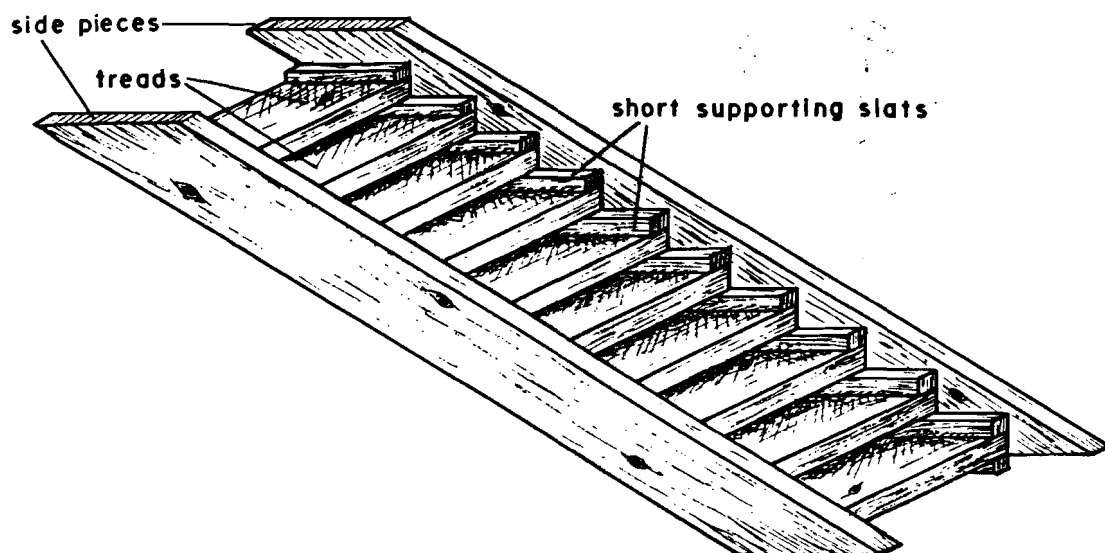


Figure 72: Type 4 Water Ladder

ladders and flume was milled with an Alaskan Mill.

Grooves (about $\frac{1}{2}$ inch deep) were cut into the top side of the Type 4 ladder treads to direct flow towards the center of the ladder. With Type 4 ladders at low flow and other three ladder types as well, drops of water tend to go over the edge of the tread, cling to the bottom of the tread while moving upstream slightly, and finally drip down (Figure 73 - top tread). If the overlap of the treads is not sufficient, the drops will fall on unprotected soil and flow under the ladder. Slats of wood nailed under the treads will prevent leakage from this source; cutting the downstream edge of the tread at an angle may also help (Figure 73).

Short slats nailed below treads parallel and adjacent to side pieces on Type 4 ladders seem to work well in preventing side leakage (Figure 74) except when the slats extend beyond the downstream edge of the tread. In those cases, water flowed over the treads onto the slats and leaked between the slats and the side piece of the ladder.

The entrance to the water ladder must be free of obstructions. Even a two inch high board at the top of one ladder has caused ponding and leakage problems. It is essential for the inlet of the water ladder to direct all runoff onto the ladder, allowing it to drain freely and preventing any leakage.

On the Emerald Creek Unit, ladder treads were level and dipped slightly downslope. Ladders were keyed in well to the channel, and conformed to channel (in this case, a crossroad drain) dimensions. No downcutting

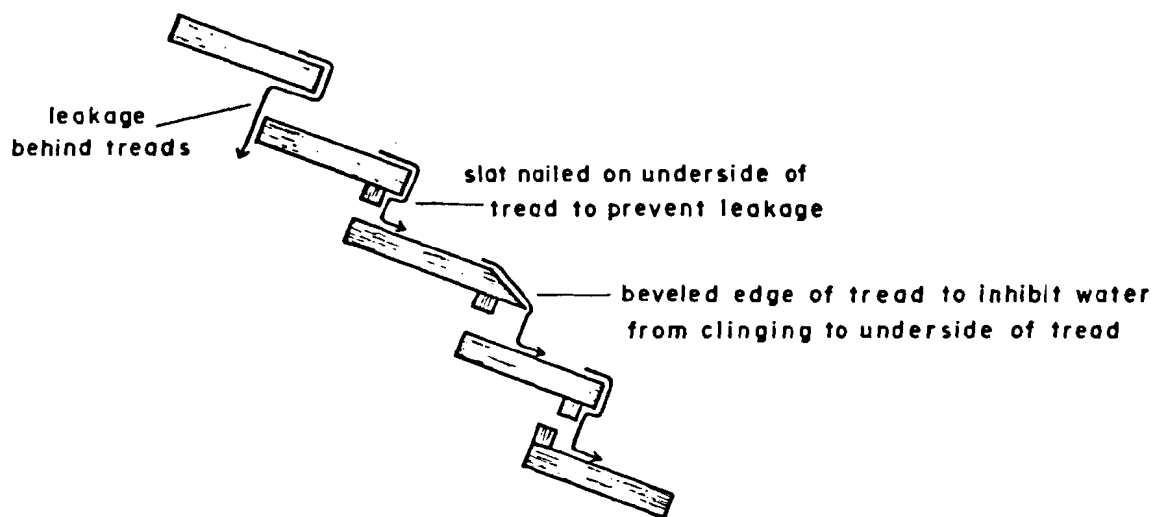


Figure 73: Side view of water ladder treads

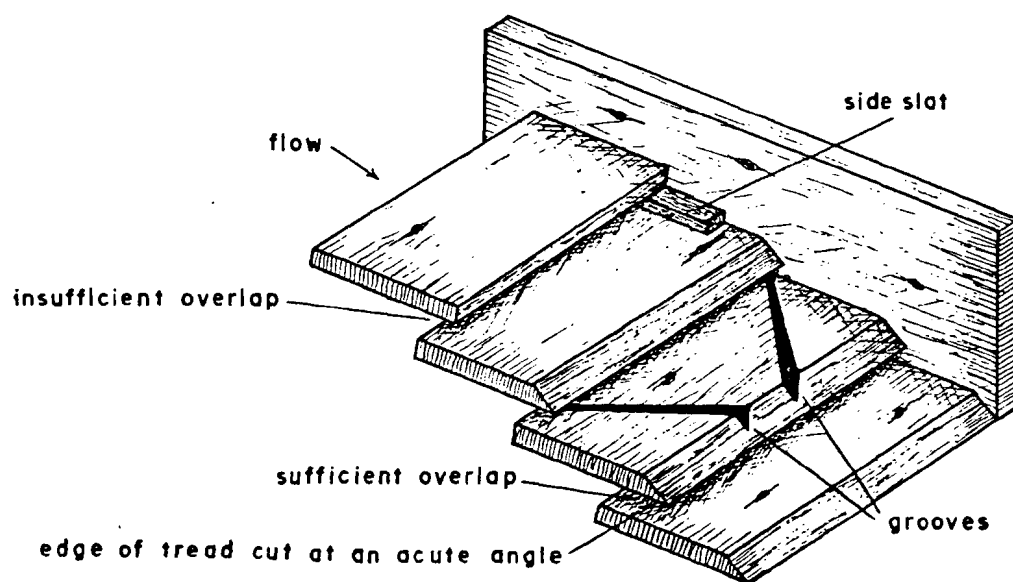


Figure 74: Oblique view of water ladder treads

has occurred where channels are protected by these water ladders.

Wing walls were effective in directing all flow into the water ladders. They are especially important in wide or poorly defined channels. Walls must be securely staked into the ground and must catch all flow (even at high discharges) that is conveyed through the channel.

A water flume was built at Emerald Creek in a design similar to Type 3 water ladder (described above). Baffles within the flume were raised slightly above the floor of the flume so that at low discharges water could flow unimpeded down the flume and no sediment would accumulate behind the baffles. At high flow, however, the baffles are effective in checking flow through the flume. This flume is watertight with no leakage problems and is set firmly into the channel bed (in contrast to the Miller Creek flume that was constructed on a layer of rock).

The flume enters a wide water ladder, which in turn discharges flow onto an energy dissipator. Wing walls were installed at the junction of the flume and the ladder to direct any flow that may have leaked out of the flume onto the ladder. The overlap between flume and ladder is adequate, and this structure has no apparent problems.

In general, where water ladders remained watertight throughout the winter, they did prevent the upstream migration of knickpoints in channels. Milled redwood (as obtained from an Alaska mill, for example) was more effective and much easier to work with than hand split wood. Because leakage can be a serious problem in water ladders,

it is recommended that milled wood be used in their construction to minimize the chance of failure.

Water ladders on the Emerald Creek site functioned better and are sturdier than those at the Miller Creek site. Use of milled boards in their construction is probably the major reason for their superior quality. Adequate energy dissipation below water ladders is also critical to the success of the ladders, as is correct engineering of the water ladder entrance point.

E. Gully plug

Stopping continued erosion of an upper end of a gully (headcut retreat) is a major goal in gully control because a headcut is a critical point of growth in an active gully. Gully plugs are devices that armor a headcut and prevent upslope migration of a gully. In addition, the gully reach below the plug must be stabilized by vegetation and/or check dams to prevent the gully plug from being undermined and failing.

By September, 1978, a long gully had developed on the Bond Creek Unit (Figure 48), and a six foot knickpoint in the gully was beginning to migrate upslope. A gully plug was installed at the knickpoint to protect the headcut from further migration and erosion while conveying water across the sensitive area (Figure 75). In this respect the gully plug was used as an alternative to a water ladder in treating this erosional problem.

The gully plug was constructed in the following manner: below the headcut, the gully was cleared of debris and re-bar was driven into the gully



Figure 75: January, 1979

The gully plug on the Bond Creek Unit has collected a considerable amount of gravel and fine-grained material while protecting the headcut of the gully from migrating upstream. Three check dams with submerged spillways are located directly upstream of the gully plug (by the person in the photo) to prevent downcutting above the gully plug.

bottom. A layer of hand-placed rock overlain by organic debris was wedged in and around the re-bar to cover the gully bottom. This armoring was capped by a double layer of chicken wire ($\frac{1}{2}$ inch mesh), and then secured into the hillslope with diagonally and vertically driven re-bar.

Three submerged spillways (that is, spillways flush with the channel bed) were installed in the gully directly above the headcut to prevent downcutting from occurring above the erosion control device. Below the lowest submerged spillway a horizontally placed, slightly outsloped splashboard was keyed into the head of the gully to direct the runoff away from the head scarp of the gully and onto the gully plug itself. The splashboard was supported and secured by rebar. A layer of rock and chicken wire was placed over the splashboard, extending from the base of the lowest submerged spillway to the rock and debris layers below the gully headcut.

The gully walls and the area around the submerged spillway were planted with stem cuttings of willow and with transplants of Whipplea modesta. Prior to this planting there was little vegetative cover on this site.

The gully carried heavy flows over the winter and a large amount of sediment was transported to the gully plug. Fine particles ranging up to small gravel filtered through the chicken wire and were deposited in the debris below. Cobbles and large gravel were deposited on the chicken wire or at the base of the gully, which represents only temporary storage of the sediment. The gully plug was not designed

to trap all the sediment derived from upslope, and some sediment will continue to be delivered to the stream channel below the gully plug.

The gully plug was effective in preventing the upward migration of the gully headcut. The channel directly above and below the headcut was adequately protected from erosion and no downcutting occurred around the erosion control structure. The structure remained keyed in securely after winter flows. Vegetation is beginning to be established adjacent to the gully and will eventually help stabilize the gully banks.

The gully plug cost \$770 to construct; the construction of an equivalent water ladder on this site would have cost approximately \$700.

The effectiveness of the two devices is similar. A gully plug seems to be the more advantageous of the structures at sites with ill-defined channels and an abundance of rocky debris on the site.

F. Energy dissipators

Wherever an erosion control structure discharges water, some device is needed to dissipate the energy of the flowing water to protect the slope or channel below. The dissipator may be made of rock, slash, or brush. The size and extent of the dissipator depends on the amount of flow an erosion control structure discharges. For example, a low-flow waterbar would not require an energy dissipator nearly as large or well-keyed in as a high-flow water ladder.

Several types of energy dissipators were used below water ladders, water flumes, and cross road drains (those used in conjunction with waterbars

and checkdams were discussed previously). Each energy dissipator design should break up the force of the flowing water, convey flow across a slope or channel reach while preventing erosion, and protect the upstream erosion control structure from undercutting.

On the Miller Creek unit, the energy dissipator for Type 1 water ladder was a pile of brush, logs and rocks six to twelve inches deep spread four feet down the channel. Because a natural "bench" (with a 20% grade) was at the foot of the water ladder and water flow was not very strong, the logs were not staked into the ground. Little movement occurred during the winter.

Type 2 water ladder was built to discharge onto a small log jam that was already well keyed into the channel bottom and banks. The large logs show no sign of movement and work well in dissipating the energy of the water. No problems with scour or undercutting are seen.

At the foot of the water flume (Type 3), a wood box was staked into the channel and filled with large rocks. At high flows, water overtopped the trash rack and eroded the left bank of the channel. For this steep (65%), perennial stream channel, more extensive energy dissipation is needed to protect the channel, banks, and water flume.

The Emerald Creek Unit has several types of energy dissipators below water ladders and at the outlet of cross road drains. At the foot of the water flume/ladder combination, slats of wood running from the edge of the water ladder to the channel bed were installed parallel to the stream channel. Under this type was a layer of large rocks.

Water from the ladder drips down the slats or trickles through to the rocks below. No signs of undercutting are visible (Figure 76).

Another form of energy dissipation is a herringbone pattern of slats of redwood staked into the ground and backfilled with rocks. Some slats were undercut by winter flows; others worked well. Success of the slats seems to depend on the pattern in which they are set (Figure 77). Alternating slats must overlap four to six inches and be fairly close together in order to effectively handle flows and minimize downcutting. Rocks upstream of the redwood slats are important in protecting the slats from the scouring action of unimpeded flow. Even with sufficient overlap of the herringbone energy dissipators, the dissipators do not prevent downcutting in the channel, and they should not be used in place of a water ladder or check dams to prevent erosion in an area where downcutting is expected.

Successive piles of rock held in place by redwood stakes in the channel is another type of energy dissipator (Figure 79). The drain in which this dissipator was installed did not receive much flow; therefore, the efficiency of these staked rocks was not rigorously tested. Nevertheless, the energy dissipator did handle the low-to-intermediate flows well, and no signs of undercutting are evident. More testing of all types of energy dissipators under high flow conditions is necessary.

By far the most effective energy dissipation is dense, compact concentrations of logging slash such as is left at the outer edge of landings

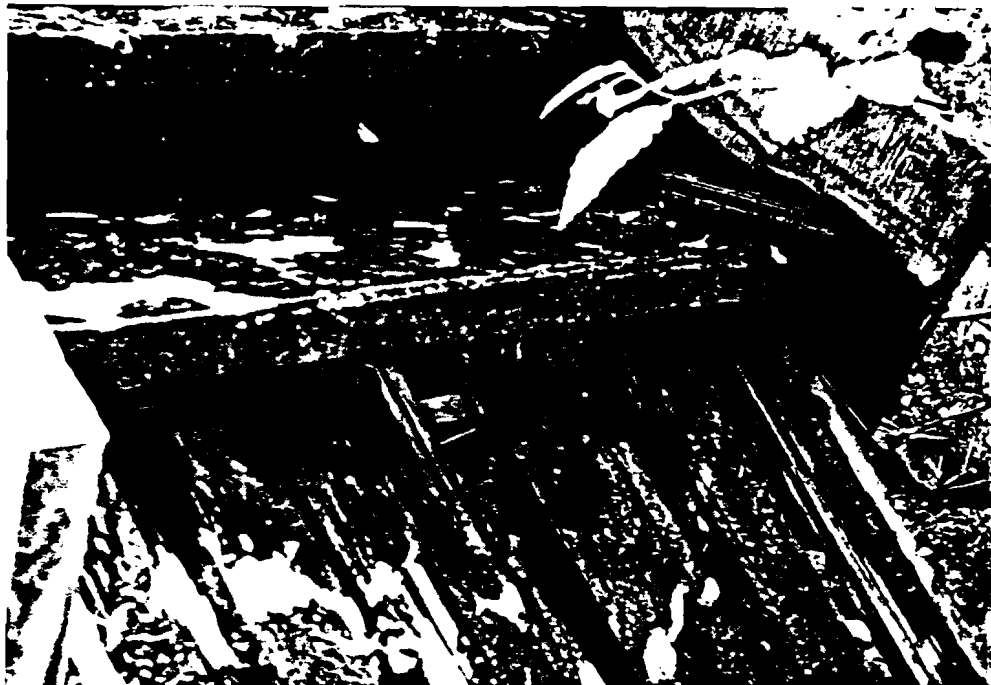


Figure 76: The 'grizzly' energy dissipator below a water ladder. Large rocks were placed under the slats of wood as well.

Figure 77: Design of herringbone energy dissipators.

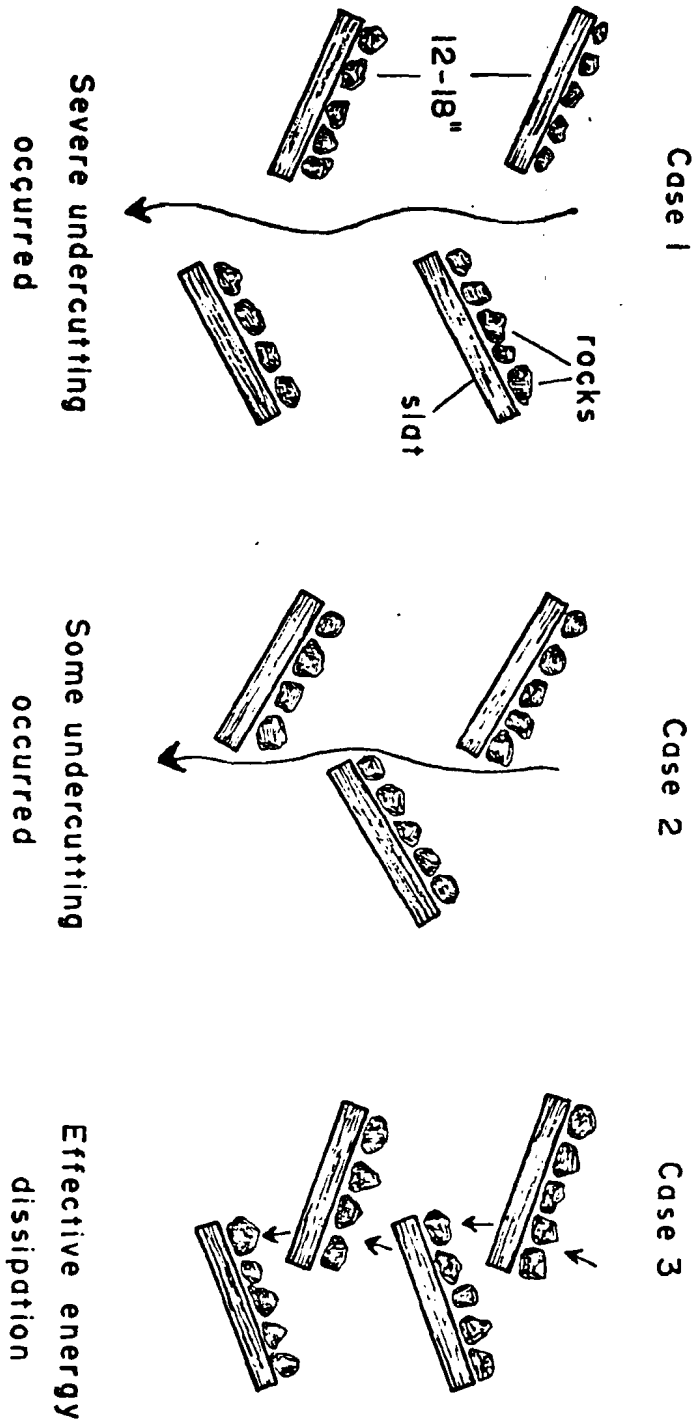


Figure 78: Emerald Creek
Herringbone energy dissipator
below cross road drain has
been undercut. In this case,
the distance between boards
was too large, and the
upstream sides of the slats
were not protected by rocks.



Figure 79: Emerald Creek CRD 15
Piles of rock anchored to the slope below a cross road
drain, filter runoff through them and dissipate erosive
energy.

during yarding operations. Unfortunately, it appears that hand placement of slash at the downslope end of cross road drains was not effective because runoff tends to flow under the slash rather than through and over it. On the Emerald Creek Unit, token placement of slash as a dissipating measure is a waste of time--if slash is to be employed effectively, it must be cut up to fit the dimensions of the channel, secured in place and be of sufficient concentrations to interrupt the flow of water.

The last type of energy dissipator tested was the installation of willow wattle bundles parallel to the stream channel below a cross road drain. The wattles that are still alive will probably not survive the summer because they have become too exposed by channel erosion. Perhaps the effectiveness could be increased by using wattles in conjunction with other channel stabilization structures.

G. Crossroad Drains

Crossroad drains are used to carry water across outsloped roads. In effect, they are short man-made stream channels. Crossroad drains were used primarily at the Emerald Creek Unit and most of the following discussion is based on results from that unit.

The proper location and frequency of crossroad drains is critical to insure a minimal amount of surface erosion and maximum possible slope stability for the recently outsloped roadbed. At the Emerald Creek site, crossroad drains were placed where culverts formerly carried runoff across the road alignment, at all places where surface runoff channels entered from upslope, in areas that showed evidence of being

excessively wet by the presence of Equisetum sp and Juncus sp, or persistent seepage during the dry season, and in areas where the cutbanks and/or slopes above the cutbank were unstable and actively failing through slumping or slump/earthflow. To ensure the best possible placement of cross road drains, areas of surface runoff, seepage, and slumps should be flagged along a road section during the winter season prior to road rehabilitation.

During construction of cross road drains, a catchment area should be excavated at the drain's upslope end to adequately collect runoff or emerging groundwater. The side slopes should not be excessively steep (see below), and where possible, the downslope end of the drain should feed into a pre-existing drainage course so that runoff will not erode a channel in the slope. In many cases, a cross road drain must discharge onto an uneroded slope. The placement of adequate energy dissipation in these instances is essential.

At the heads of a few cross road drains, slumping of the cutbanks occurred. Some cutbank failure was expected because of the inherent instability of the wet hillslope material. Thus, the cross road drains are wide enough (6-10 feet) to accomodate small failures and are still effective in draining water from the cutbanks. For the most part, dimensions of the cross road drains were adequate. Banks were pulled back to a gradient less than the angle of repose for the excavated material (less than 55%). For example, at Emerald Creek, cross road drain 16 was a former culvert location and a small failure occurred on the right bank because it was too steep. The channel gradient of

the cross road drain should be between 5 and 20 percent, depending on the slope of the adjacent hillside. Too gentle a slope leads to ponding water, whereas a steep drain promotes channel erosion and downcutting.

At the downslope end of most cross road drains, there was an abrupt break-in-slope where the remaining fill of the road bed dropped steeply to the natural slope below. In anticipation of downcutting problems at this break-in-slope, various energy dissipation devices (see above) were installed. Despite these preventive measures, downcutting at the downslope end of the cross road drains is occurring and this downcutting is starting to work its way headward along the troughs of the cross road drains, undermining the rock armor as it migrates up the trough. This downcutting has not progressed to any significant degree after one winter season, but it is clear that in winters to come, many cross road drains will be undermined to a greater or lesser extent by this process. In retrospect, check dams started on the natural slope and built progressively upslope to the level of the cross road drains may have prevented downcutting of those cross road drains where a drainage course already existed below the cross road drain. The problem is more difficult to treat where cross road drains discharge onto slopes without pre-existing drainage channels.

Since cross road drains are newly constructed channels carrying water for the first time, when excavated they are completely unprotected from high flows. When the catchment area of the drain is large, or when the gradient of the drain is steep, downcutting and channel enlargement may occur from winter flows if no protection is provided.

On Emerald Creek, lining the cross road drains by manually placing large

rocks (greater than four inches in diameter) in the channel worked well in protecting the drains from downcutting. Because the lower three-quarters of the former C-90 road had been rocked, there was a plentiful supply of suitable rocks available for the drains. Over the winter, fine sediment settled in between the rocks, tightly packing them together, and armoring the channel bed (Figures 80 and 81).

It is important to completely cover the channel bed with rocks, and the rocks must abut directly against the banks. Where the toe of the banks or the bed was exposed, lateral erosion and downcutting occurred during winter. Once a new channel starts eroding the toe of banks adjacent to the protective layer of rocks, the rocked channel bed is abandoned and rendered useless. In addition, adequate energy dissipation is needed at the outlet of the cross road drains because downcutting below the drain can migrate upstream and undermine the rocked channel lining. In a few cross road drains, an otherwise successfully rocked drain was starting to downcut at the downslope end because of inadequate slope protection below the break-in-slope. This is a serious problem that will probably be encountered at many different sites and may best be handled by check dams below the break-in-slope that protect the slope between the rocked drain and the naturally vegetated slope below.

Drains built on the unrocked portion of the C-90 road (at the upper end of the unit) were not rocked because of the lack of suitable material. These drains received little flow and have gentle gradients (less than 20%). No downcutting problems occurred. Grasses and cat-



Figure 80: Manually-placed coarse rock on the bed of a cross road drain prevents downcutting of the channel bed while allowing unhindered flow of runoff through the drain.



Figure 81: A thick stand of grass in a moist cross road drain adds support to the banks by its dense root mass. The grass and rocks trap fine soil particles that would otherwise be washed downstream.

tails are lush along the cross road drains, and their root masses help to stabilize the drains as well.

H. Willow wattles

Wattles are bundles of flexible twigs and branches of at least some sprouting, native species tied together. Wattling is the process of placing wattles in contour trenches on slopes, staking the wattles in place, and then covering the wattles almost completely with soil. Once in place, wattles retard surface erosion and revegetate bare slopes through the sprouting of branches in the bundles.

The effectiveness of wattles in inhibiting erosion on disturbed slopes seemed to vary with the individual rehabilitation sites, and the success of wattles was previously discussed in the evaluation of the respective sites. In addition, some general statements can be made that were applicable to all sites.

Wattles worked well on moist, steep sites in fine-grained material. This is fortunate because these slopes are most susceptible to surficial erosion and slumping, and they need the protection of vegetated terraces. The willows are sprouting vigorously where the ground is moist, and the texture of the soil was not rocky or gravelly. Wattle burial was an important factor in their success as well. The highest survival occurred in wattle bundles that were ninety to one hundred percent covered with soil and in which air spaces in the wattle bundles were partially filled with soil.

Wattles did not work well on dry, rocky slopes. On these sites, dry ravel is the major surficial erosion process, and physical barriers

should be used to restrain the downslope movement of material. From a time and cost perspective, wattles are not an efficient mode of erosion control on biologically harsh sites. Alternatives which depend less on revegetation for success should be utilized in the future. Nevertheless, on pulled stream crossings and similar sites, wattles are effective in stabilizing disturbed banks.

I. Mulches

Mulches may help keep soil in place on recently disturbed slopes. They form a permeable mat that can dissipate the impact of raindrops and impede rilling on the soil surface. Loose mulches (straw, wood chips, leaves, branches and bark) work well on flat, protected areas where mulching is desirable on steeper slopes (greater than 10%) or where wind exposure is a problem, an interwoven biodegradable fabric that can be staked in place can be used. Before mulch is applied, slopes should be seeded to establish vegetation on treated areas.

Three types of mulches were used on portions of the outsloped road in Upper Miller Creek (see Figures 82, 83, 84). The mulched slopes (7700 square feet in all) were composed of the same soil material and had similar gradients (20 to 30%). The mulches were spread by hand, and cuttings of willow and other species were planted through the mulch to secure it to the slope.

The effect of the mulches on soil properties (texture, pH, nutrient levels, etc.) is not yet known, but will be tested more extensively

in the future. Comparison data of seedling and stem cutting survival on straw-mulched versus control slopes are not yet available. Trace amounts of wild wheat (Avena sativa) were found on the straw-mulched sites, the seed of which may have been introduced with the straw.

In general, the mulch has shifted slightly downslope over the winter, but little movement of large soil particles has occurred. In June the ground under the mulches (especially the redwood chip mulch) was moist, while on the control sites the soil was dry. The mulches prevented some rockfall from upslope from continuing downslope onto wattled areas, and they intercepted and dispersed rills that originated upslope. This was especially evident on the straw mulch site.

Jute netting without an under-layer of mulch was used on a steeper, rockier slope. The planter box directly below the jute netting was the only one on that slope that did not fill with dry ravel and rockfall over the winter months. Thus, jute netting seems to inhibit the downslope movement of soil particles which would otherwise be susceptible to dry ravel.

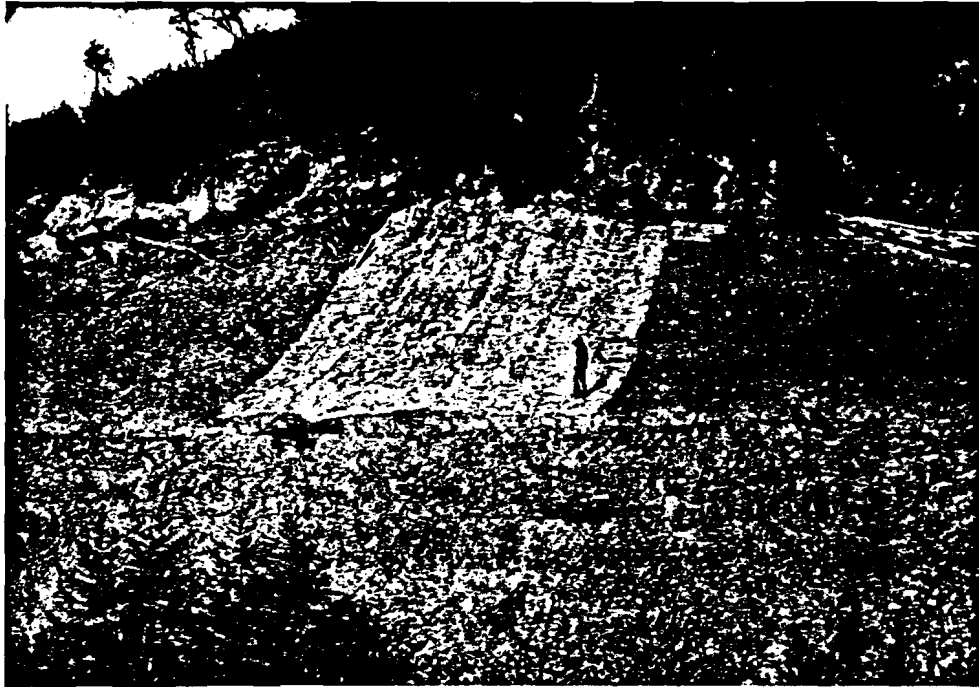


Figure 82: Redwood chip and brush mulch was spread on the outsloped road and Miller Creek, and was then covered with jute netting.



Figure 83: A close-up view at Miller Creek of the jute netting showing the stem cuttings which were used to secure the netting to the slope.



Figure 84: A close-up view of straw mulch and stem cuttings at Miller Creek Unit.

V. EVALUATION OF 1978 WORK METHODS

In order to rehabilitate the 1978 sites, equipment rental agreements were used to obtain heavy equipment for major earthmoving tasks. Fixed-price service contracts were written and let to manual labor work crews to build erosion control structures on the rehabilitation sites. The advantages and shortcomings of these methods are discussed below.

A. Heavy equipment rental agreements

In performing 1978 rehabilitation work, Redwood National Park entered into equipment rental agreements with local equipment operators to rent their equipment on an hourly basis. Because the amount of heavy equipment work was relatively small, this procedure offered several advantages over contracting to the Government. Problems treated by heavy equipment are unconventional, and site specific solutions must be formulated for them. Conditions in the field may change as excavation proceeds. A contract for heavy equipment use would require unusually detailed specifications, and yet would have to allow a great deal of flexibility to changing project needs. The administrative work involved in such a contract would be much greater than that involved with a purchase order for equipment rental. However, in future, larger, projects, an indefinite delivery contract (CFR #41, 1978) may be used.

In addition, some types of heavy equipment contracts require performance bonding to assure a quality job. Few bidders would want to risk bonding on these previously untested techniques, and the contract bids would increase in price accordingly. Through equipment rental, the Government accepts responsibility for the success of the project, and in turn, can

direct the equipment to exactly fulfill the needs of the project.

The disadvantage to the Government lies in the large amount of time spent by field personnel in supervising heavy equipment work (see Tables 3, 5 and 7). The heavy equipment must also be watched to assure that the operators do the job in the most efficient way possible. Nevertheless, the lower total price and high quality control seem to indicate that equipment rental agreements are advantageous to the Government.

B. Manual labor contracts

Rehabilitation of logged timberlands is a new field, and methods used in erosion control efforts are often unconventional or not well tested. It is to the Government's advantage to encourage innovation and creativity on the part of the contractor in supplying erosion control services. Flexibility in contracts is desirable. At the same time, high quality standards must be maintained and the objectives of the watershed rehabilitation program met. Many erosional problems must be treated on a site-specific basis, and do not lend themselves to description under broad, generic contract specifications. The design of a contract must reflect the needs of the specific rehabilitation project.

Several types of contracts exist (CFR #41, 1978), and there are advantages and disadvantages involved with each (Federal Procurement Regulations, #41, 1979). The contract chosen should promote the Government's best interests. Contracts vary in the degree of responsibility assumed by the contractor for the cost of performance. For example, under the formally advertised firm fixed price contract, the parties agree that the

contractor assumes full responsibility, in the form of profits or losses, for all costs under or over the firm fixed price. In contrast, under the cost-plus-a-fixed-fee contract, profit rather than price, is fixed and the contractor's cost responsibility is minimal.

Contracts for the three major 1978 rehabilitation units (78-1, 78-2, and 78-3) were formally advertised firm fixed price contracts. In this type of contract, the contractor assumes full responsibility for all costs under or over the fixed price, and he or she has a maximum profit incentive for effective cost control and contract performance. The advantage of this type of contract is that it imposes a minimum administrative burden on the contracting parties. A certain amount of flexibility can be written into these contracts. For example, a maintenance clause can be included to require the contractor to return to the unit during or after winter flows and perform any maintenance needed on the erosion control structures. A percentage of the total contract price would be withheld in this case until the maintenance was completed.

Flexibility is possible through another contract device, the bilateral modification. If a change in the contract is required after the contract is let due to some unforeseen circumstance, both parties may agree, in writing, to a change, and the purpose of the contract will still be achieved.

The 1978 contracts were considered service contracts, and performance bonds were not required of the contractors. In lieu of performance bonds, contract retention was used to assure a satisfactory and comple-

ted job. For each pay period, ten percent of the invoice was held back until the contract was successfully completed.

Several problems arose in using a firm fixed price contract, most of which could be avoided easily in the future. Because of time constraints, manual labor contracts were written before heavy equipment work was completed on the rehabilitation sites. Therefore, a contractor was bidding on a job that was only an estimate of what the true job would be.

Massive bilateral modifications had to be written and agreed upon after the equipment work was finished and after the contract was let to define the true job. In the future, labor contracts will be written after the heavy equipment work is completed.

In a firm fixed price contract, definite design and performance specifications are essential. In the 1978 contracts, several ambiguities in contract specifications surfaced during the term of the contract, and these will be corrected in future contracts. First, contractors were asked to bid on linear feet of willow wattles. Contractors were given the approximate area to be wattled (in square feet), but no formula was provided for computing the amount of linear feet of wattles required. Second, contractors were asked to bid on a price per check dam. Check dams may vary in height and width, and specific dimensions of gullies were lacking in the contracts. In addition, the number of check dams necessary to protect a channel reach depends on check dam height. A contractor may choose to build numerous short dams rather than a few taller dams. Thus, it may be better to ask a contractor to bid on check-

damming a gully of a specific length, width, and gradient instead of bidding on individual check dams. Third, the length of waterbars varied greatly from site to site; yet the contractor was asked to bid on an 'average' waterbar. Different tasks should be categorized and bid on as separate units.

Because the rehabilitation sites are erosionally sensitive, it is advantageous to have only one contract group working per site to minimize impact on the site. This is one reason why the 1978 contract bids were chosen on the basis of the total price bid, even though unit prices were required on the bid schedule. These contracts also specified a sequence of tasks to be done, assuring that priority erosion control structures were done first. The time of delivery was specified in these contracts; some tasks are weather-dependent and a clause for flexibility in timing should be included in future contracts.

Rehabilitation Sites 78-4 (Lower Bond) and 78-5 (C-Line landing) were done under the system of 'Requests for Quotations' rather than under actual contracts because the amount of work required was relatively minor. Specifications for erosion control structures were identical to the contract specifications. The advantage of the request for quotations is the minimum amount of time and of administrative processing necessary to initiate work on the site.

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F. Lower Bond Creek Rehabilitation Site 78-4

Site Description

The Lower Bond Creek Unit is located on the ridge between Forty-Four and Bond Creeks, 350 feet above the main channel of Redwood Creek. The unit is situated on a deeply-weathered clay loam underlain by Franciscan schistose rocks. Hillslopes are gentle (25 to 35%) and relatively dry.

Over a mile of rocked road crosses 50 acres of land that was logged about 20 years ago, and partially relogged in the early 1970's. In general, the road is stable; however, a culvert was unmaintained and had to be removed, the inboard ditch was downcutting in several sites, and locally runoff needed to be diverted off skid trails. For the most part, however, time had healed many early erosional problems and regrowth was well advanced.

Approach

One D-5 Caterpillar tractor with a winch worked for eight hours on this site (8 hours at \$40 per hour = \$320) to construct seven cross road drains, to remove a culvert and to reshape the channel banks of one small drainage. The actual length of treated road was 1500 feet. The tractor work was done in early September, 1978.

From September 25th through September 28th, a crew of about ten people constructed four waterbars, ten check dams, seeded and sprig-planted bare soil in cross road drains, and did some miscellaneous shovel work. The cost for

the labor contract was \$3685.50.

Documentation

No surveys were taken on this site, nor were any permanent photo points established. Miscellaneous photographs were taken before and during equipment work, during the manual labor phase, and after all work was completed.

Effectiveness of Rehabilitation Work

The cross road drains intercepted flow from the inboard ditch and diverted it across the road into heavily vegetated areas. No drain received much flow, the gradients of all the drains were gentle (less than 10 percent), and the subsoil was clay-rich and quite cohesive. Thus, no downcutting occurred in the drains.

At the site where the culvert was removed, the tractor was unable to completely excavate fill material from the stream channel. Consequently, some downcutting occurred at the lower end of the road crossing, and further downcutting may threaten upstream check dams. An inherent weakness of using tractors for this type of work is their inability to excavate or pull material upslope.

All check dams survived the winter flows well, and are still effective. The upstream-most dams filled with fine sediment. No bank failures occurred in the check-dammed reach of channel.

In late September the site was seeded with a 50-50 mix of annual and perennial ryes, at 40 pounds/acre, and ammonium sulphate fertilizer (20-0-0) was applied at 100 pounds/acre. Because the compacted road surface was not mechanically dis-

aggregated, grass seed did not take well . Raking and fertilizing plots did not have a noticeable effect on the survival of grass seed on this site. Much of the seed washed off the clay soils in the first few runoff events.

The site was inspected in mid-December, 1978. At that time, 236 out of 725 stem cuttings showed signs of sprouting, which represents an initial success rate of 33%. Both baccharis and willow stem cuttings were sprouting; bracken fern (Pteridium aquilinum var. pubescens) and redwood transplants also showed about 30% survival. In June, 1979, in addition to the above species, salal showed signs of sprouting. A thick carpet of young thistles invaded areas of the road surface which had been disturbed by tractor treads in the previous autumn. 57 redwood and 47 Douglas fir seedlings were planted on the road alignment in January, 1979.

Very little hillslope area in the unit was treated. Because of the advance age of the second growth and the relative stability of the area, few serious problems existed off the road alignment. A few small problems were so inaccessible due to revegetation that they were not treated. Revegetation on the road surface was poor because of the high degree of soil compaction, and in the future, treatment of similar roads should include the disaggregation of the road surface.

G. C-Line Landing, Rehabilitation Site 78-5

Site Description

Rehabilitation Site 78-5 is a two-acre former landing located in the Miller Creek drainage basin on the C-Line road. The Grogan Fault is exposed across the road from the site. The cut slopes expose the fault gouge in what appears to be rocks transitional in metamorphic grade between sandstone and schist. Soil material on the site is a sandy loam, and has a high organic content due to large amounts of slash, bark, etc. that have been incorporated into the soil.

The site was the location of a large log landing composed of loose soil, rock, logs, and smaller organic debris, all of which were compacted by heavy equipment. The outer edge of the log landing catastrophically failed about five years ago, sending tons of sediment and organic debris into the stream channel below. In 1978, the remainder of the landing was precariously perched above the stream, and failure of more debris into the stream was imminent.

Approach

In early October, 1978, a track-mounted dragline crane pulled back the perched debris on the landing and recontoured the slope below the landing to a more stable configuration. A D-6 Caterpillar tractor redistributed the removed fill onto adjacent stable skid trails. The machines worked sixteen hours each, resulting in a total machine cost of \$1760.

After the heavy equipment work, a manual labor crew (Northcoast Reinhabitation Group) under contract to the Park Service, performed the following

erosion control work between November 10th and 25th, 1978:

	<u>Cost*</u>
Installed 2500 feet of wattles, mixed species	\$1525.
Constructed 150 feet of planter boxes	110.
Sprig planted 8000 feet ² , mixed species, upslope of planter boxes and between wattle rows	<u>345.</u> \$1980.
Cost of seedlings for conifer planting (by park personnel)	<u>16.</u>
Total	\$2000.

*These costs, based on contract bid prices, do not represent the true cost of labor and materials to the contractor. The contractor purposely bid low in order to use this site as a testing/training ground.

Total cost of rehabilitation for this site was \$3740. Actual working time was about five days with crews of five to fifteen people. Park personnel seeded the entire landing with annual and perennial rye grass on December 1st and 5th, 1978, and the site was planted with conifer seedlings (70 redwood and 125 Douglas fir) in January, 1979.

Effectiveness of Rehabilitation Efforts

The crane and tractor were unable to remove all large organic debris at the toe of the slope of the landing. This debris is well keyed in, and buttresses the rest of the slope. At present it is stable; however, in time natural decomposition of the organics may weaken the support and lead to failure of some of the overlying material. Except for some minor settling in the

disturbed fill material, there are no indications at present of instability on or adjacent to the former landing. Eight photo points were established and will be used to document changes on the former landing in a qualitative manner (Figures 55-59).

The vegetation and erosion control structures have worked well on this site. The planter boxes (Figure 60) at the base of the recontoured slope are log and board barriers keyed into steep, infertile soil. They provide a protected, stable planting substrate in areas that would otherwise be difficult to revegetate. All the planter boxes remained secure and stable throughout the winter, and they trapped small particles of soil moving downslope.

The wattle bundles were buried in contour trenches, and the contour terraces formed by the wattling were purposely constructed wider than the dimensions specified in the contract. Most terraces were about eighteen inches wide. They were effective in providing a physical barrier to rilling and ravelling. An accumulation of fine sediment and grass seed is apparent on most terraces.

Species most successful in sprouting in these wattle bundles were: willow (Salix sp.), thimbleberry (Rubus parviflorus) and salmonberry (Rubus spectabilis); species showing limited sprouting were: coyote brush (Baccharis pilularis var. consanguinea), salal (Gaultheria shallon), and Rhododendron macrophyllum. Stem cuttings of willow, baccharis, thimbleberry, and salmonberry were also sprouting in June, 1979.



Figure 56: PP3 10/2/78
View towards C-Line landing prior to any rehabilitation work. Part of the landing failed, leaving much of the organic and inorganic debris perched precariously.



Figure 57: PP3 12/20/78
A dragline crane pulled back the unstable fill and debris, and a cat tractor moved it to stable skid roads. Wattle rows of willows and other species were planted on the slopes.



Figure 58: PP6 10/2/78

Before and after sequence showing the removal of the C-Line landing. The upper slopes have willow wattles; the steep lower slopes are protected by planter boxes.



Figure 59: PP6 12/20/78



Figure 60: 12/7/78

At the base of the C-Line landing (Site 78-5), below rows of wattles, planter boxes were secured to the slope. They were backfilled with soil and planted with willow stem cuttings to promote revegetation on an otherwise harsh site.



Unit: 78-1 Date: 8-22-1978, PP1, SOC



Unit: 78-1 Date: 10-9-1978, PP1, SOC



Unit: 78-1 Date: 9-7-1982, PP1, SOC



Unit: 78-1 Date: 8-22-1978, PP2A, SOC



Unit: 78-1 Date: 10-9-1978, PP2A, SOC



Unit: 78-1 Date: 9-7-1982, PP2A, SOC



Unit: 78-1 Date: 8-22-1978, PP3, SOC



Unit: 78-1 Date: 10-9-1978, PP3, SOC



Unit: 78-1 Date: 9-7-1982, PP3, SOC



Unit: 78-1 Date: 8-22-1978, PP4B, SOC



Unit: 78-1 Date: 3-12-1979, PP4B, SOC



Unit: 78-1 Date: 9-7-1982, PP4B, SOC



Unit: 78-1 Date: 8-22-1978, PP5A, SOC



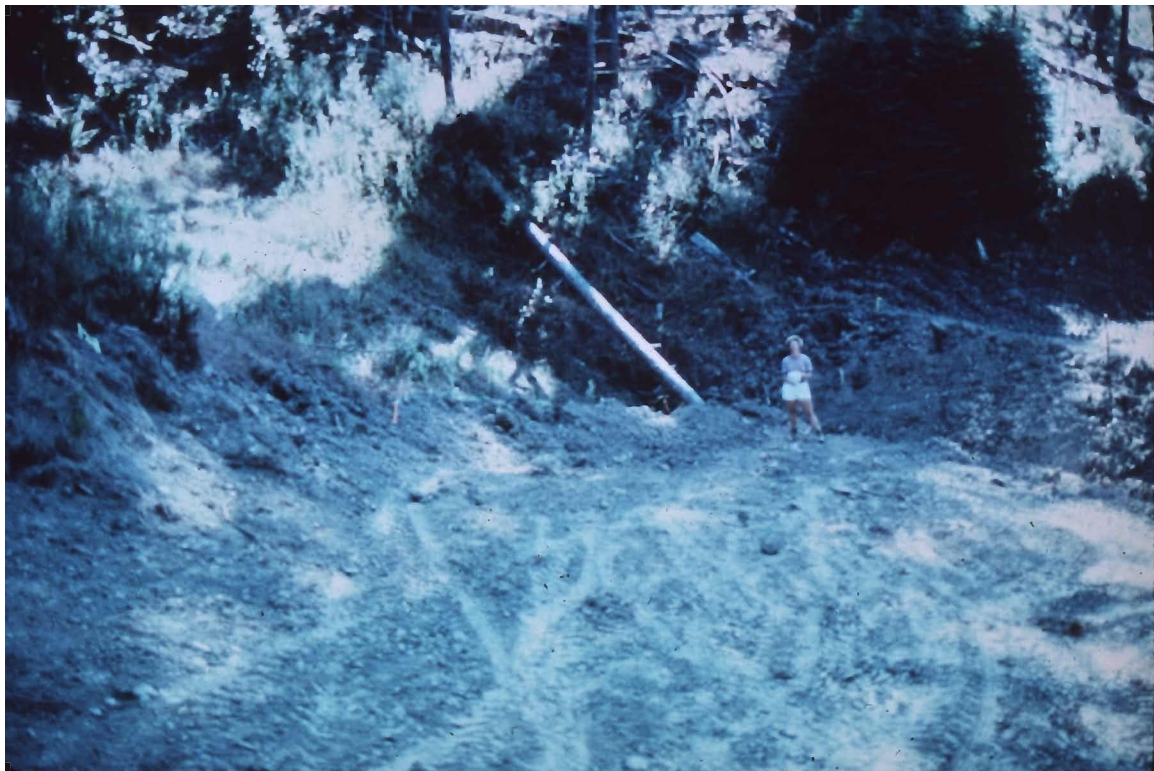
Unit: 78-1 Date: 10-9-1978, PP5A, SOC



Unit: 78-1 Date: 9-7-1982, PP5A, SOC



Unit: 78-2 Date: 8-23-1978, PP5C, SOC



Unit: 78-2 Date: 10-9-1978, PP5C, SOC



Unit: 78-2 Date: 10-1-1979, PP5C, SOC



Unit: 78-2 Date: 8-23-1978, PP10, SOC



Unit: 78-2 Date: 10-9-1978, PP10, SOC



Unit: 78-2 Date: 10-1-1978, PP10, SOC



Unit: 78-2 Date: 8-23-1978, PP17, SOC



Unit: 78-2 Date: 9-27-1978, PP17, SOC



Unit: 78-2 Date: 10-1-1979, PP17, SOC



Unit: 78-2 Date: 6-1981, PP17, SOC



Unit: 78-2 Date: 8-23-1978, PP19B, SOC



Unit: 78-2 Date: 9-27-1978, PP19B, SOC



Unit: 78-2 Date: 6-1981, PP19B, SOC



Unit: 78-3 Date: 9-14-1978, PPA3, SOC



Unit: 78-3 Date: 10-3-1978, PPA3, SOC



Unit: 78-3 Date: 9-14-1978, PPA4, SOC



Unit: 78-3 Date: 1-5-1979, PPA4, SOC



Unit: 78-3 Date: 9-14-1978, PPA6, SOC



Unit: 78-3 Date: 8-1-1979, PPA6, SOC



Unit: 78-3 Date: 8-4-1982, PPA6, SOC



Unit: 78-3 Date: 9-7-1978, PPD3, SOC



Unit: 78-3 Date: 10-3-1978, PPD3, SOC



Unit: 78-3 Date: 8-1-1979, PPD3, SOC



Unit: 78-3 Date: 9-7-1978, PPD10, SOC



Unit: 78-3 Date: 10-3-1978, PPD10, SOC



Unit: 78-3 Date: 8-1-1979, PPD10, SOC



Unit: 78-3 Date: 8-4-1982, PPD10, SOC



Unit: 78-5 Date: 10-2-1978, PP3, SOC



Unit: 78-5 Date: 12-20-1978, PP3, SOC