THE EVOLUTION OF APPROACHES AND TECHNIQUES TO CONTROL EROSION ON LOGGED LANDS IN REDWOOD NATIONAL PARK, 1977 - 1981

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Abstract. The erosion control program at Redwood National Park began in 1977 with several small pilot projects intended to test a limited number of techniques and to evaluate overall program feasibility. In 1978 and 1979, work focused on the treatment of a wide variety of erosional problems through extensive experimental application of heavy-equipment and labor-intensive treatments. By 1981, the best, previously tested techniques were being systematically implemented with the goal of maximizing the effectiveness, or cost-effectiveness, of erosion prevention and control. Over this five year period, rehabilitation has shifted from a methodology dominated by labor-intensive treatments to one which emphasizes the use of heavy, earth-moving equipment. The once subjective approach developing work prescriptions solely through professional judgement has largely been replaced by the application of more standardized objective criteria for decision-making. Future changes in the erosion control program are expected to be less substantial than those which have already occurred.

INTRODUCTION

Redwood National Park is located in the downstream portion of the Redwood Creek basin, an elongate, 55-mile long, structurally controlled drainage in north coastal California. According to Janda (1978), sediment yields in Redwood Creek are unmatched for comparably sized, nonglaciated drainage basins in North America. In 1978, the U.S. Congress expanded Redwood National Park to include an additional 48,000 acres of land in the lower end of the Redwood Creek basin to preserve and protect a remnant of the once extensive coastal redwood ecosystem. About 36,000 acres of this area, which had been previously modified by road building and timber harvest, is now the focus of a large-scale rehabilitation program to reduce accelerated erosion rates and to speed the vegetative recovery of cutover lands.

The rehabilitation program is a multifacted effort designed to meet the following objectives: 1) to minimize the amount of sediment delivered to stream channels from areas disturbed by logging, including removal of approximately 250 miles of logging roads; 2) to restore and protect aquatic and riparian resources within tributaries and along the main channel of Redwood Creek; 3) to encourage the return of a natural pattern of vegetation on prairies

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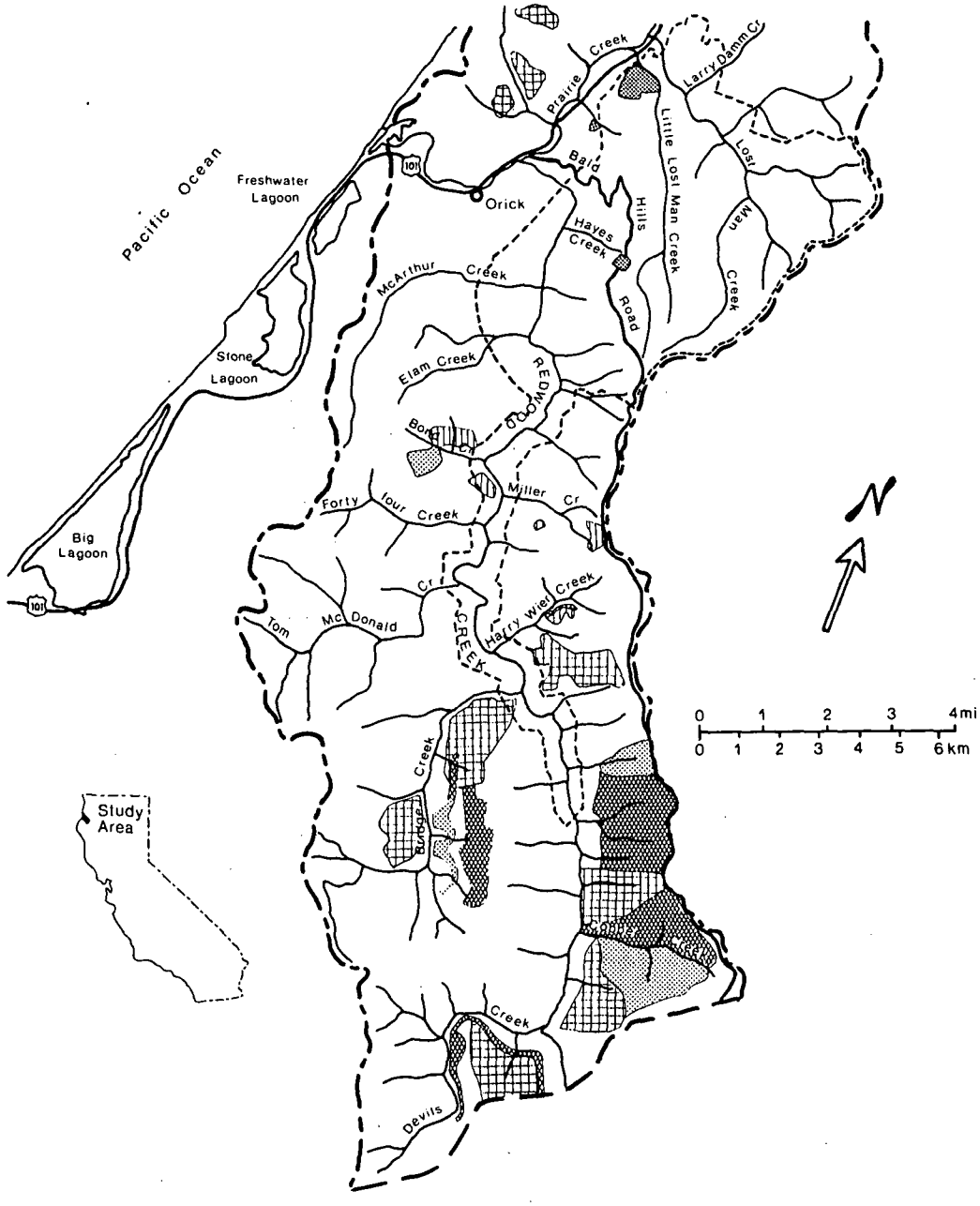

Figure 1. WATERSHED REHABILITATION PROJECTS IN REDWOOD NATIONAL PARK

- Pilot erosion control sites: 1977
- Areas treated in 1978
- Areas treated in 1979
- Areas treated in 1980
- Areas treated in 1981
- Park boundary
- Park boundary before expansion

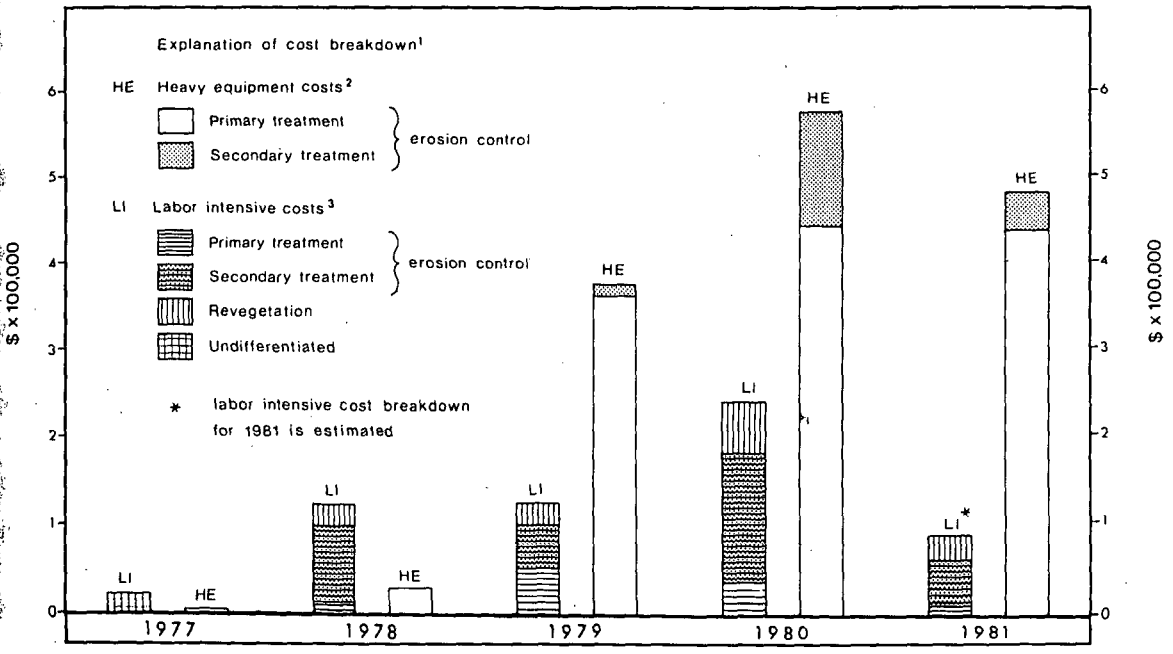

Figure 2. Comparison of erosion control costs at Redwood National Park: 1977-1981

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1 National Park Service salaries associated with planning, supervising and administrating rehabilitation activities are not shown.

2 Includes costs of heavy equipment rentals, with operators and fuel included.

3 Includes costs of labor contracts, salaries of in-house laborers used to perform miscellaneous rehabilitation work and materials used for erosion control and revegetation. Salvaged wood (no cost to government) and milling expenses for boards used to construct erosion control devices are not included. Costs for wattles included in erosion control, not in revegetation.

and logged timberlands and; 4) to encourage the prevention and control of management-related erosion on private lands where timber is harvested upstream from the park. Fulfilling the first objective has been the primary emphasis of rehabilitation on Redwood National Park lands from 1977 to 1981. This is being accomplished through the use of primary and secondary erosion control treatments[1] which incorporate heavy equipment and/or labor-intensive techniques. In addition to erosion control activities, a companion program addresses revegetation of bare soil areas, including those disturbed during erosion control work. Other programs which address the remaining objectives are also in progress. This paper will review changes in approaches and techniques for erosion control during the first five years of the watershed rehabilitation program at Redwood National Park. Other reports within this volume (Bundros, et. al., 1982; Teti, 1982) and elsewhere (Kelsey and Weaver, 1979; Madej, et. al., 1980; Weaver and Madej, 1981) discuss site-specific erosion control costs and methodologies. Revegetation techniques used at Redwood National Park are reviewed in this volume by Hektner, et. al. (1982).

ANNUAL OVERVIEW OF THE REHABILITATION PROGRAM AT REDWOOD NATIONAL PARK

1977

In anticipation of Redwood National Park expansion, three pilot projects were initiated in the summer of 1977 to study individual erosion control and revegetation techniques, and to investigate the feasibility of implementing a large-scale rehabilitation program (Figure 1). Prospective test sites were chosen by park staff. Local contractors were requested to submit proposals for erosion control. Under this Request for Proposal (RFP) procedure, bidding parties were responsible for proposing specific rehabilitation treatments to be used at the various sites. Following negotiations, contracts were awarded on the basis of prescribed treatments and bid prices.

The main emphasis of the 1977 program was to test labor-intensive techniques judged, at that time, critical to control accelerated erosion from logged lands. Most erosion control techniques consisted of labor-intensive primary treatments intended to control surface erosion on bare hillslopes and to minimize erosion along stream channels or in active gullies. A lesser emphasis was to examine the feasibility of using heavy equipment for logging road obliteration. Table 1 generalizes work performed during 1977 rehabilitation, while overall costs are shown in Figure 2.

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1. Primary erosion-control treatments are those designed to provide for the immediate reduction in the potential for, or rate of, management-related sediment production or yield. They generally consist of heavy equipment treatments such as outsloping, ripping, construction of cross-road drains and waterbars, removal of soil and debris from stream channels, landslide stabilization and stream channel rediversions. However, labor-intensive techniques, when applied under these conditions, also represent primary erosion-control treatments (e.g., debris clearance from stream channels, gully stabilization techniques, waterbar construction, etc.). Secondary erosion control treatments consist of labor-intensive or heavy equipment practices designed to minimize erosion from areas disturbed during primary treatment. Secondary treatments commonly include such procedures as check dam construction and channel armoring applied to excavated stream crossings. Mulching, wattling, planting and seeding bare soil areas created during road outsloping, landslide stabilization and stream channel excavations also represent secondary erosion-control techniques.

Table 1. Summary of erosion control activities and techniques[1] used in Redwood National Park 1977-1981.

	1977	1978	1979	1980	1981
Miles of road treated	0.6	1.6	10.4	16.2	19.1
Haul road stream crossings excavated	0	7	64	93	90
Skid trail stream crossings excavated	0	16	57	75	34
Excavated stream crossings protected with check dams	0	10	7	24	0
Excavated stream crossings protected with rock armor	0	3	48	104	30
Mass movement features treated	0	0	1	2	1
Heavy equipment used	BD	B,BD,C	B,BD,C,D, E,G,L	B,BD,C, D,E,L	B,BD,D, E,L
Heavy equipment techniques	CR,OS, RD,WB	CR,OS, RD,WB DC	CA,CR,FD, LJ,OS,RD, DC,WB	CA,CR,FD, OS,PR,RD, DC,WB	CA,CR,GS, OS,PR,RD, DC,WB
Misc. labor intensive techniques to control surface erosion	DC,S, W,WB	J,M,RC, W,WB	CT,J,M,RC MS,S,W,WB, WT	HM,EB,J, MS,RC,S, WB	EB,MS,S, WB
Misc. labor intensive techniques to control erosion in stream channels or gullies.	CA,CD, WL	CD,GP, WL,CA	CA,CD,DC, F,WL	CA,CD, F,DC	CA,CD

ABBREVIATIONS

Erosion Control Techniques:

CA channel armoring
CD check dam
CR cross road drains
CT contour trenches
DC debris clearance
EB excelsior blanket
F flume
FD french drain
GP gully plug
GS gully shaping
HM hydromulch
J jute netting
LJ log jam removal
M mulch
MS straw mulch
OS road outsloping
PR prairie restoration
RC ravel catchers
RD road decompaction (ripping)
S seeding (grass, etc.)
W wattles
WB waterbars
WL water ladder
WT wooded terrace

Heavy Equipment:

B backhoe
BD bulldozer
C crane
D dump truck
E hydraulic excavator
G grader
L loader

[1]For definitions see Madej et al., 1980; and Weaver and Seltenrich, 1981.

The scope and usefulness of rehabilitation work conducted in 1977 was limited by three principal factors. First, the National Park Service did not have access to cutover lands which were similar in harvest age, steepness of slopes, and erosional conditions to the proposed Redwood National Park expansion area (Figure 1). Second, funding for the experimental projects was not available until mid-summer 1977, allowing little time for planning and program design before the onset of winter rains. Thirdly, National Park Service personnel and local contractors were relatively inexperienced in erosion control techniques which could be successfully applied to steep, unstable lands found in the Redwood Creek basin. In a cooperative effort, the National Park Service drew heavily upon the experience and imagination of local contractors to design, test, and document various rehabilitation techniques.

Despite its limitations, the 1977 program was important because it revealed specific heavy equipment and labor-intensive techniques which would be useful and necessary for future rehabilitation work (Table 1). In addition, the 1977 program demonstrated some of the advantages of heavy equipment; revealed limitations of performing certain tasks with manual labor; educated park staff in certain contracting procedures; revealed the need for documentation of work accomplishments, unit costs, and task effectiveness; and pointed to the importance of the proper design, construction and maintenance of erosion control works.

1978

The expansion of Redwood National Park in March, 1978 (PL95-250) provided for the creation of a permanent staff to coordinate and direct rehabilitation activities in the newly acquired lands. During the following two years of experimental rehabilitation (1978 and 1979), emphasis was placed on the design, testing and refinement of various erosion control and revegetation techniques on areas displaying a wide variety of erosion problems. Incorporated into the program was a comparatively rigorous effort to document (by photographs and surveying) site conditions before, during, and after treatment together with detailed cost accounting of individual work items. Thus, a data base was established for a critical analysis of the cost and effectiveness of various rehabilitation treatments.

The five sites treated in 1978 (Figure 1) incorporated a wide variety of rehabilitation techniques (Table 1). Heavy equipment was used to "remove" roads (primarily by outsloping), reshape landings, and excavate fill material from road and skid-trail stream crossings constructed during previous logging operations. However, the majority of time, effort and money spent during 1978 involved the application of secondary labor-intensive treatments (Table 1, Figure 2) to protect areas from surface erosion, to prevent downcutting or widening of excavated stream crossings, and or promote revegetation on lands disturbed by heavy equipment during primary rehabilitation treatment. Labor-intensive contracts differed from the previous year in that individual work items were now defined by the Park Service and included as bid items. Under this Invitation for Bid (IFB) contracting procedure, contractors in 1978 were not responsible for prescribing the types of treatment to be performed on rehabilitation sites.

In 1978, National Park Service personnel were responsible for assessing and documenting erosion conditions on their sites, prescribing erosion control and

revegetation treatments, supervising heavy equipment operations (via equipment
ental agreements with local contractors), and preparing contracts and technical
pecifications for labor-intensive work. One major hindrance to effective
xperimental rehabilitation that year was an outcome of the late Spring, 1978,
egislative expansion of the park. National Park Service scientists were
nfamiliar with most of the newly added park lands and were rushed to locate
uitable sites to test rehabilitation techniques. The delayed schedule
everely restricted the time available for tasks such as erosion inventories,
ork-site prescription development, and contract preparation and advertising.
n addition, since a plant ecologist had not been hired for the 1978 season,
any revegetation techniques were modeled after 1977 methods. As a result,
ome of these techniques, especially the use of willow on dry sites, were
nappropriate for the locations where they were applied (Madej et. al., 1981,
eed and Hektner, 1981).

he fundamental goal of the rehabilitation program has always been erosion
ontrol and the reduction of elevated sediment yields. Yet, not until the end
f 1978 did it become apparent that extensive use of heavy equipment was
ecessary to fulfill this goal (Madej, et. al., 1980). Perhaps the most important
ontributions of the 1978 program were not those specifically associated with
ontrolling increased erosion. For example, major benefits which have proven
nvaluable in subsequent years include: the experience gained in labor
ontracting; the development of more accurate prescriptions for the use of
pecific heavy equipment and labor-intensive procedures; the formulation of
nit-costs for erosion control practices; and the development of a routine
ethodology for approaching watershed rehabilitation. In fact, this formulated
pproach (Department of Interior, 1981) continues to be applied to restoration
ork in Redwood National Park to the present time.

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contrast with previous years, work in 1979 included ample lead time for
anning and logistical arrangements. Early in 1979 critical sites had been
lentified, allowing park staff to inventory erosion features and finalize
ork prescriptions on three sites during the winter and spring months. This
sulted in much larger (Figure 1) and more complex rehabilitation sites. One
these incorporated an area of over 600 acres, contained in excess of 100
jor work locations, and required approximately $250,000 to treat. In
ldition, rehabilitation work on a fourth site was completed by means of a
quest for Proposal (RFP) contract (Kelsey and Stroud, 1981).

e most significant erosional problems addressed in 1979 had resulted from
ream diversions at poorly designed or unmaintained skid-trail and haul-road
ream crossings. Many of these diversions resulted in the development of
rge gully systems on adjacent hillslopes or caused bank failures in nearby
ream channels subjected to increased flows (Weaver, et. al., 1981a). Two sites
volved recently constructed roads and cutover areas located on steep slopes
jacent to Bond Creek and Bridge Creek (Figure 1). These areas contained
olated, active erosional features and other very large potential sources for
ture sediment production and delivery. Erosional problems similar to those
dressed in 1979 (particularly active or potential drainage diversions) have
ntinued to receive high priority consideration in subsequent years.

e most extensive experimentation with heavy equipment and labor-intensive
chniques in the five-year history of the rehabilitation program occurred in
79. A large variety of equipment was used (Table 1) including: machinery to
cavate and shape soil and debris removed from stream channels and road benches

(backhoes, bulldozers, cranes, and a hydraulic excavator), equipment to load and haul materials to and from work sites (dump trucks and loaders), and equipment to prepare and maintain smooth road systems for efficient end-hauling (grader and water truck). In addition to testing new techniques, different types of equipment were used for similar work tasks, and individual work tasks were performed to varying degrees. For example, landing treatments ranged from a minimum of decompaction and draining with ditches, through mild outsloping, to almost complete removal of the landing fill material.

In 1977 and 1978, heavy equipment use had been restricted to primary erosion control treatments. In 1979, secondary treatments accounted for three percent of the total heavy equipment expense. Extensive experimentation with heavy equipment in 1979 resulted in a comparatively high cost for total work accomplished. However, these tests also provided an invaluable data base which has been used for subsequent cost analyses of heavy equipment operations, and resulted in significant improvements in the cost-effectiveness of rehabilitation work during 1980 and 1981.

Labor-intensive treatments in 1979 involved a wide variety of techniques used to protect stream channels from downcutting and bank erosion, and to minimize surface erosion on bare slopes disturbed by heavy equipment (Table 1). Approximately 50 percent of 1979 labor-intensive expenditures were for primary erosion control treatments on the RFP contract site, especially the manual removal of organic debris from stream channels. Total costs for labor-intensive erosion control in 1979 were, therefore, somewhat "inflated" because 70 percent of this expense was for the one RFP contract site. The high project expenditure resulted primarily from the park's trial use of a previously untested contracting method (cost-reimbursable, fixed price contract) that, in this instance, proved highly inefficient for watershed erosion control work (Kelsey and Stroud, 1981).

While most of the labor-intensive work during 1979 was performed by contract labor (RFP contract on one site, IFB contract for parts of two other sites), a minor portion was accomplished by a newly established park labor force. Delays and time allowances required by formal government contracting made this labor group an appealing and potentially valuable addition to the rehabilitation effort. The use of in-house labor crews permits the rapid application of mulches and installation of erosion control devices immediately following heavy equipment operations, and well in advance of the onset of winter rains. This had not always been possible during previous years.

In addition to personnel who directed and coordinated rehabilitation activities, another group was formed in 1979 to monitor and evaluate erosion control efforts at Redwood National Park. Since 1977 this task had been performed by the core rehabilitation staff. However, as sites became larger, more numerous, and more complex, a separate staff was needed to install monitoring stations, to evaluate new techniques used in a variety of settings, and to conduct studies aimed at improving the cost-effectiveness of ongoing operations. Additionally, a plant ecologist assumed full-time responsibility for prescribing revegetation treatments on project sites supervised by park staff and evaluating all revegetation treatments applied within the park.

By Spring of 1980, preliminary results from monitoring studies indicated that erosion from bare soil areas on 1978 - 1979 work sites represented only a minor component of the total post-renabilitation soil loss occurring on these units.

Most of the erosion was found to be emanating from channel downcutting and widening. These findings supported the general trend of gradually reducing the relative emphasis placed on controlling surface erosion. Approximately 75 percent and 50 percent of the total cost for secondary erosion control treatments in 1978 and 1979, respectively, were designed to address this source of sediment. Significant reductions (to a low of 17 percent) continued in 1981. of the previously used labor-intensive techniques were also found to be excessively costly and/or ineffective, and some were discovered to create erosional problems greater than those they were designed to control (Weaver and Seltenrich, 1981). As a result, a number of techniques were discontinued or modified, and the thrust of future labor-intensive effort and experimentation was focused on stabilizing excavated stream channel reaches and promoting revegetation. Surface erosion was still to be treated on future rehabilitation sites, but in a more cost-effective manner.

1980

In 1980, twenty full-time personnel (geologists, hydrologists, plant ecologists, and technicians) were responsible for coordinating and supervising erosion control and revegetation activities on six rehabilitation sites (compared to six positions in 1979 and five positions in 1978). Five of these sites were supervised by park staff, the sixth site was treated by a contractor under a negotiated, firm, fixed-price RFP contract. A noncritical seventh site, located west of Prairie Creek (Figure 1), was treated as part of a training program conducted by a nonprofit, community service organization. This training site, discussed by Parsons and Rhode (1981), is not a source for data used in this report.

Heavy equipment treatments in 1980 continued to be partially experimental, but many techniques reflected standardized approaches developed over the previous three years (Table 1). Experimental use of heavy earth-moving equipment consisted of prairie restoration (gully and road obliteration), treatment of large scale mass movement features, the creation of new, artificial stream channel reaches, and extensive rock armoring of excavated stream channels. Secondary treatments (predominately rock armoring) accounted for 26 percent of the total heavy equipment cost in 1980 as opposed to only three percent of the year before.

Labor-intensive treatments in 1980 focused on the prevention of stream channel erosion in areas disturbed during the heavy equipment phase of rehabilitation. Most of the labor-intensive effort was spent on the construction of checkdams. Previously, in Redwood National Park, checkdams had only been constructed on stream channels draining between 10 and 40 acres. In 1980, checkdams were installed on larger stream channels draining up to 70 acres. This permitted cost and effectiveness comparisons of checkdams with machine-placed rock armor for similar sized streams. Labor-intensive techniques used to control surface erosion were simplified and involved only minor experimentation. The most expensive techniques (jute netting and excelsior blankets) were generally reserved for steep, freshly disturbed slopes judged capable of contributing significant quantities of sediment into adjacent stream channels. By far the most common treatment to control surface erosion on 1980 sites was the widespread application of straw mulch.

Most labor-intensive work on 1980 sites was accomplished by the recently enlarged park labor force. While two projects were completed by IFB and RFP contracts, a significant portion of the remaining labor-intensive work was provided by a nonprofit community organization for the handicapped (Redwoods United, Inc.), through a cooperative agreement with the National Park Service. The major advantage of having most of the labor-intensive work performed by park and Redwoods United labor forces was that nearly all erosion control treatments could be applied before the first, significant winter storms. In previous years, delays and legal time constraints associated with formal government contracting did not allow labor-intensive work to begin until well into the rainy season. However, in the absence of close supervision of in-house labor crews, some erosion control devices proved to be of lesser quality and/or more costly than similar devices constructed by contract labor.

Overall erosion control costs in 1980 were the highest to date for the rehabilitation program (Figure 2). This is primarily attributable to the amount spent for labor-intensive and heavy equipment secondary erosion control treatments. Weaver, et. al., (1982b) discuss the relative cost-effectiveness of primary and secondary treatments used at Redwood National Park and conclude that, in many cases, secondary treatments can be minimized or forfeited if a high-quality primary treatment is applied. This concept was used as a design criterion for much of the 1981 rehabilitation work and resulted in substantial savings with little noticeable decrease in the effectiveness of most rehabilitation work.

1981

In 1981, seventeen personnel were responsible for erosion control activities on six sites. Five sites were supervised by park staff and the sixth was treated under an IFB contract. Work in 1981 was designed to standardize, as much as possible, the approaches and techniques used for watershed rehabilitation. Prior to 1981, work prescriptions received varied amounts of review and were commonly based on subjective evaluations of the severity of existing or potential sediment sources to be treated. In some cases, this resulted in a very high unit cost for the amount of erosion prevented (i.e., dollars spent per cubic yard of soil "saved"). In 1981, prescriptions were determined by quantifying the potential for future erosion from each prospective work site and subjecting work plans to a detailed professional, peer reveiw. Decisions to perform individual work items were then based upon the size (volume) of the potential sediment source, the amount of damage which heavy equipment would do to the existing vegetation and the estimated unit cost for the amount of erosion prevented ($/yd^3). Additionally, individual treatments in stream channels were designed by quantifying the expected 20-year return-period discharge at each work site. As a result the decision to treat a work site within any one of the rehabilitation units became more defensible and less dependent on subjective judgment.

A primary emphasis of 1981 rehabilitation work was to minimize the application of costly and/or ineffective secondary erosion control treatments. At the same time, more emphasis was placed on thoroughly completing the more cost-effective primary treatments. This resulted in a measurable reduction (compared to the previous year) of heavy equipment expenditures (Figure 2). Additionally, the types of equipment used for rehabilitation tasks were standardized and much of the work was accomplished by the most efficient earth moving machinery: bulldozers and hydraulic excavators.

Unique to 1981, one rehabilitation project was totally devoted to the stabilization of a large, active landslide (near Emerald Creek at the site of a unit treated in 1978 (Figure 1)). Smaller and/or less active landslides in the park had been treated in previous years, but such work represented only single elements of larger rehabilitation units. The cost for the Emerald Creek landslide treatment represented approximately 18 percent of the total heavy equipment expenditure for primary erosion control treatments in 1981. However, this landslide had the potential for contributing at least as much sediment to Redwood Creek as the combined total of all other sediment sources identified and treated within Redwood National Park in 1981. While landslide stabilization is an extremely difficult and frequently unsuccessful undertaking, the potential benefits can be enormous.

Labor-intensive costs in 1981 were the lowest in four years and resulted from a concerted effort to minimize the application of less cost-effective secondary erosion-control treatments (especially checkdams) on rehabilitation sites. Most of the labor-intensive erosion control work was performed by the National Park Service and Redwoods United labor forces. One site had minimal treatment under an IFB contract. Revegetation work on two other sites was accomplished by IFB contract, and the remaining four sites were planted and seeded by park laborers.

SUMMARY AND CONCLUSION

Watershed rehabilitation at Redwood National Park has grown from small pilot projects all directed by one person, through an extensive experimental phase with five to six personnel responsible for four to five sites, to a multi-faceted organization of twenty to twenty-five people directing and evaluating erosion control and revegetation activities on six to seven sites. Expenditures expanded with an increase in personnel, experimentation, and size of rehabilitation sites but leveled off with refinement of the program. Evaluation of data from previous years directly influenced expenditures in 1980 and 1981 by emphasizing the most cost-effective treatments and minimizing less cost-effective work items.

Given the large number of changes in procedures and techniques which have occurred in the rehabilitation program, it is difficult to demonstrate improvements in the cost-effectiveness of work items and techniques with the generalized data in this report. The varied nature of complex physical conditions encountered on rehabilitation sites also makes it impossible to compare annual expenditures with the accomplishments listed in Table 1. However, the data presented does summarize annual trends in overall expenditures and demonstrates an evolution in the number and variety of erosion control practices used at the park.

The approach to erosion control shifted from an experimental phase, where judgements to treat an erosional problem were often subjectively formulated by individual project leaders, to a more systematic process implementing an objective approach, with considerable peer review, which attempts to quantify potential sediment sources and the benefits to be obtained by treatment. Additionally, various design criteria have been incorporated into the program to standardize and improve specific treatments.

Many significant erosional problems within the park are caused by debris in or near stream channels and result from the construction of roads or tractor skid trails during previous timber harvest activites. The methodology for treatment of these erosional problems has evolved from a program dominated by labor-intensive techniques to one emphasizing the use of more cost-effective heavy equipment treatments. In general, the most effective and efficient erosion-control practices have been those primary treatments which reduced existing and potential sediment sources through the use of heavy earth moving equipment.

Early in the program, secondary erosion control treatments were exclusively accomplished by manual labor. However, as the rehabilitation program evolved, the role of heavy equipment for secondary treatments in stream channels increased. This resulted because channel armoring with coarse rock fragments is more permanent and maintenance-free than wooden structures (i.e., checkdams, flumes, and water ladders). Additionally, the size and amount of rock needed for adequate channel protection commonly requires heavy equipment for cost-effective application. The amount of secondary, in-channel treatment has fluctuated considerably; a result of logistical access, cost-effectiveness analyses of previous years' treatments, and budgetary restrictions. For example, the percentage of excavated stream crossings which received secondary channel protection treatments (i.e. rock armor or checkdams) ranged from 57 percent in 1978, 46 percent in 1979, a high of 76 percent in 1980, to a distinct low of 21 percent in 1981. The treatment of surface erosion has remained labor intensive. Expensive treatments such as wattling, wooden terraces, and ravel catchers, however, have been replaced by a more cost-effective application of straw mulch.

The rate and degree of evolution of erosion control work at Redwood National Park has been substantial over the last five years. The majority of changes in the next few years will probably be variations of those practices which have already been tested. Two major factors which may affect the direction of future program changes include: 1) budget restrictions, which underscore the continuing need for increased cost-effectiveness, and 2) the continued evaluation of treatable sediment sources and causes of management-related erosion. Increased cost-effectiveness is likely to be accomplished through new procedures resulting from re-evaluation of in-house versus outside contracting methods to perform various labor-intensive work tasks, the examination of contracting methods for "routine" road removal projects, and by evaluation of the results of minimal in-channel secondary erosion control treatments emphasized on 1981 rehabilitation sites.

The continued evaluation of those sediment sources remaining in the park which are significant, accessible, and treatable will directly affect the level of future treatments applied and will also influence the role assigned to the prevention and stabilization of mass movement features. For example, much of the rehabilitation work completed between 1978 and 1981 has addressed recently cutover areas which contained skid trail stream crossings needing treatment. On many older cutover areas which have been subjected to major storms in the past two decades, skid trail crossings are commonly washed out and their treatment is no longer necessary. Extensive natural revegetation also makes reopening these areas less desirable. In the future, as the proportion of older cutover area to be treated increases, the number of skid trail crossings excavated each year will decrease. Consequently, assuming a

stable budget, the length of road annually treated and the size of individual rehabilitation sites is likely to increase. In addition, while the rehabilitation program emphasized the control and prevention of road and logging-related fluvial erosional problems, there has been a continual increase in the effort expended to control mass-movement features. Attempts to stabilize mass-movement features in the future will largely depend upon the potential for damage to downstream resources, the feasibility and cost of treatment, and the probability of success.

ACKNOWLEDGMENTS

The erosion control program at Redwood National Park has involved literally hundreds of people over its five year history. All of these individuals, through their ideas and their work, have influenced the content and evolution of this unique program. Legislation expanding Redwood National Park provided an initial direction to the restoration efforts. However, most of the change in succeeding years has come about through the efforts of labor and equipment contractors, through external scientific and professional peer reviews, and through an introspective analysis of the costs and effectiveness of procedural and technical elements of the program. The National Park Service is indebted to those individuals who have contributed to the evolution and success of the watershed rehabilitation program. We would like to thank Elizabeth Babcock, Danny Hagans, Mary Hektner, Lee Purkerson, Terry Spreiter, Pat Teti, and Ken Utley for their review of this manuscript.

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