Disturbed Lands Restoration: The Redwood Experience

Terry A. Spreiter
Redwood National Park, Orick, California 95555

James F. Franke
Twin Parks Company, Arcata, California 95521

David L. Steensen
Mining and Minerals Branch, U.S. National Park Service
Denver, Colorado 80225

Introduction

As urban populations increase and encroach on the remaining global wildlands, the value of those open spaces becomes increasingly important. Many wildlands have been disturbed by previous human activity, yet retain a significant potential for both human and ecosystem refugia. Restoration in these disturbed areas can greatly enhance the future human enjoyment of these lands and reestablish more naturally functioning ecosystems.

Lands disturbed by human activity often cause unwanted and long-lasting problems that affect natural resources removed from the immediate disturbance. Exotic plant invasion, unsightly scars, abandoned or unmaintained road networks, and mine sites, among many others, cause problems for park management in areas to be administered as wildlands. Abandoned roads for example, can seriously impact water quality and stream habitat by increasing erosion and sediment production. Increased sediment yield may lead to destabilized stream channels and dramatic geomorphic changes, ultimately altering habitats.

Restoring lands disturbed by human activity involves setting in motion the successional processes that will ultimately lead to a naturally functioning ecosystem. This does not necessarily mean precisely restoring all facets of the pre-disturbance conditions. It does, however, require establishing geologically and hydrologically stable landscapes capable of supporting the natural ecosystem mosaic. In some cases, natural processes left to themselves will accomplish more than human intervention. In other cases however, disturbed areas will not recover without assistance, even in centuries. Long-term natural recovery of the physical setting may result in undesirable changes to the more quickly responding biologic aspects of the ecosystem. Carefully designed physical restoration work will significantly accelerate recovery rates of all components of the landscape and ecosystem.

Redwood National Park, through a boundary expansion in 1978, inherited 48,000 acres of lands previously in timber production. The land had been intensively logged in the years preceding park expansion. A dense network of haul roads and timber skid roads serviced the area. Severe erosion, caused primarily by the road network, prompted the United States Congress to direct the National Park Service to implement an unprecedented program to restore the degraded watershed. Seventeen years later, about half of the haul roads in the park have been treated to varying degrees, primarily to control erosion. Recent work also targets physical restoration of conditions which favor re-establishment of natural vegetation, and minimize landscape and watershed disturbances. Interdisciplinary research, monitoring, and project evaluation is on-going, and has been consistently documented. Redwood National Park's Watershed Program provides the U.S. National Park Service with a restoration laboratory that has produced volumes of data and analyses on methods and techniques. All USNPS staff involved with restoration projects can learn from the experience gained from the Watershed Restoration Program at Redwood National Park.

Background

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

Erosion from the harvested private lands increased sediment delivery to streams and cumulatively resulted in aggradation of channels, increased scour of stream banks, and resultant loss of riparian and aquatic habitat. The Tall Trees Grove (the preeminent resource of the park) was subjected to increased recurrence of flooding, bank erosion, and an elevated water table.

The danger to the Tall Trees Grove provided a catalyst for a protracted environmental battle which, in 1978, resulted in the United States Congress enacting legislation expanding Redwood National Park by 48,000 acres (Public Law 95-250). The expansion included 36,000 acres that had been mostly logged within the ten years prior to 1978. Most of this acreage was directly upslope of the original park corridor along Redwood Creek. Associated with the logging were 300 miles of haul roads, 3,000 miles of timber skid roads, dozens of rock quarries and borrow pits, and thousands of acres of eroding hillslopes.

The legislation authorized the USNPS to initiate a program to rehabilitate areas within and upstream from the park, to reduce risk of damage to park resources. The primary threat was recognized as sediment generated from past logging disturbances and road conditions. Congress directed the USNPS to submit a comprehensive general management plan for Redwood National Park, specifically including the objectives, goals, and proposed actions designed to assure the preservation and perpetuation of a natural redwood forest ecosystem. $33 million was authorized for these restoration efforts.

The upper two-thirds of the Redwood Creek watershed remains in private ownership, and is still managed primarily for timber production. The expansion legislation established a Park Protection Zone, on private land in the middle third of the watershed, to provide a buffer for the park. The USNPS participates in the State of California's timber harvest plan process on these private lands, and is working with landowners to develop cooperative relationships, for the purpose of minimizing future erosion or other damage to park resources.

Setting

The rehabilitation effort is concentrated on USNPS lands in the lower one-third of the Redwood Creek basin. The Redwood Creek basin lies within the rugged Coast Range province and is underlain by folded and sheared sandstones, mudstones, and schists of the Franciscan assemblage (Harden *et al.* 1982). The region is subject to high erosion rates due to rapid tectonic uplift, the pervasively sheared and faulted condition of the underlying lithologies, and the imprint of complex and highly disruptive landuse activities (Janda *et al.* 1975). The climate is Mediterranean with an annual average precipitation of 80 inches (205 cm) occurring primarily as rain between October and May. Coastal fog is common in the summer months.

Watershed Processes and Conditions

In a natural setting, runoff flows from hillslopes via a complex network of surface and subsurface routes. Vegetation, soil, and forest duff stores runoff, to the point of saturation. This stored water is slowly released, moderating peak surface flows. Vegetation and other organisms (including soil micro-organisms) have adapted to these particular hydrologic patterns, including the natural erosion rates and processes.

In the Redwood Creek watershed, erosional processes were greatly accelerated during large-magnitude storm events in 1953, 1955, 1964, 1972, and 1975. Studies were initiated to determine primary sediment sources and causes of accelerated erosion. Study results clearly indicated that, in areas subjected to intensive timber harvest, road networks are the primary cause of accelerated fluvial erosion and mass wasting processes, and that surface erosion is a minor component of the total sediment yield.

Roads and logging disrupt the natural system in many ways, but with the common result that surface runoff increases. Road cuts intercept the shallow subsurface flow, compacted road surfaces reduce infiltration of rainfall, side-cast fills may compress and block subsurface flow routes. The end result is an increase in surface runoff. Ditch systems along roads collect this increased surface runoff, plus the dispersed overland flow. Flow is concentrated and diverted, and eventually discharged off the roadway. The receiving location may not be able to accept his increase in runoff, and downslope and downstream adjustments begin in the form of erosion and sedimentation.

Most management-related erosion in Redwood National Park can be traced to the intersection of roads and streams or flow courses, and failure or lack of adequate drainage structures. The most common drainage structures used in the park are metal culverts. Culverts are used at stream crossings and sometimes at intervals along the road to discharge accumulated runoff from inboard ditches. Culvert inlets may be overwhelmed by sediment, organic debris, and/or runoff. Additionally, culverts eventually wear through on the bottom, allowing the runoff to saturate the surrounding road fill. Numerous stream and flow course crossings do not have any drainage structure, and their runoff is directed down the road to an adjacent stream. Other stream crossing fills contain numerous logs, placed on the stream bed beneath the fill, allowing some runoff to pass under the road.

When drainage structures fail, the stream either flows across the road and returns to its natural course, or it flows down road, diverting from its natural course. The latter causes significantly more erosion, as the stream carves a new channel (gully), and/or saturates hillslopes or road fills not previously exposed to that quantity of runoff, causing landslides. The problems caused by stream diversions are compounded when the diverted flow and eroded sediment enters another stream channel.

Mass movements caused or exacerbated by roads also contribute significantly to the volume of erosion that has occurred in Redwood National Park. Pre-existing mass movement features may be aggravated by the discharge of runoff collected along a length of road, or they may be undercut or overloaded during road construction.

Roads constructed by cutting and filling or "side-casting", may develop stability problems within the side-cast fill as they age. Forest road fills commonly contain abundant woody debris. As the wood decays, structural integrity of the fill decreases, and collapse features, slumps and debris flows become common. Woody debris in the road fills of the park is now 20-50 years old. Where this woody debris is exposed or excavated, much of it is heavily decayed.

Saturation of road fills may occur as a result of water accumulating upstream of the road, leading to slumps or fill failures. Fills are generally deepest where roads cross stream channels and headwater swales, where surface and subsurface runoff naturally converge. These fills often contain large concentrations of decaying organic debris. Large volumes of sediment may be generated by failure of saturated fills. In steep headwater swales, the fills are prone to debris flows. These can rapidly travel long distances on steep slopes, scouring additional material as they go.

Buried, decaying woody debris and worn out culverts will provide new challenges in planning watershed rehabilitation work. Neither problem is immediately evident, and both are gradually worsening. These problems were not recognized as a threat when road removal priorities were initially established. A recent, comprehensive inventory of remaining park roads has documented numerous, serious problems developing as a result of aging culverts, worn through, or heavily corroded along the bottom. Many roads originally judged as stable and thus suitable for long term access, are now high priority for either removal or increased maintenance, including culvert replacement. The key will be to identify and treat these problems before they cause significant quantities of sediment to be released to the stream systems.

Development of the Watershed Rehabilitation Program

The watershed rehabilitation program at Redwood National Park began in 1977 with several small pilot projects intended to test techniques and evaluate overall program feasibility. By 1980, a wide variety of erosional problems had been treated through extensive experimental application of heavy-equipment and labor-intensive treatments. As erosion control is a primary goal and costly aspect of the rehabilitation program, an intensive monitoring program was established to evaluate effectiveness of the erosion control techniques and provide feedback to project supervisors about those techniques. Long-term monitoring was also established to document recovery of the biologic aspects of the ecosystem.

To reduce the impacts of roads on the natural hydrologic functions of the watershed, drainages must be returned to a more natural condition. This will reduce future erosion. At Redwood National Park, this is being accomplished by removing roads and their associated drainage structures.

The Watershed Rehabilitation Plan: Goals and Progress

A watershed rehabilitation plan for Redwood National Park was approved in 1981, setting specific goals for the restoration effort prescribed by Congress. The goals incorporated the intent of Congress (detailed in the legislation and the legislative history) and USNPS policies and philosophies. The goals specify minimizing erosion from past land uses, re-establishing native patterns of vegetation, and protecting aquatic and riparian resources within tributaries and along the main channel of Redwood Creek. The plan states that, ultimately, the rehabilitation efforts should speed the restoration of naturally functioning redwood and related ecosystems to a condition similar to what existed prior to disturbance by man.

The plan describes general methods used to implement rehabilitation work based on results of the experimental projects completed prior to 1981. The primary focus of the rehabilitation program is erosion control, specifically preventing or reducing erosion associated with roads. The plan details the removal of the majority of the inherited logging road network, and prioritized areas for treatment, based on potential sediment yield and risk of failure, as estimated in 1981. The underlying premise of the watershed rehabilitation plan is that until erosion is reduced to more natural levels, many of the biologic aspects of the ecosystem may not be able to recover to pre-disturbance conditions.

As of 1995, approximately half of the haul roads in the park have been treated to varying degrees. Work has begun on aquatic habitat restoration in one of the major tributaries, where most of the erosion control work is completed.

The watershed rehabilitation plan of 1981 is currently being updated to reflect work accomplished, successes and failures of various techniques in meeting program goals, and current erosion potential of remaining roads. Erosion control priorities will be melded with the needs and priorities of the other interdisciplinary aspects of the overall rehabilitation effort in determining the areas with highest treatment priority for the coming years. The erosion control priorities will rely in large part on a comprehensive inventory of current road conditions.

As part of the road inventory, the volume of sediment that may be mobilized and its downstream impacts have been estimated for each potential problem area, and the likelihood of this occurring has been rated. These estimates are subjective, but offer relative orders of magnitude of future resource damage. The road inventory clearly demonstrates that as roads age, they deteriorate. If road maintenance is not increased and/or removal efforts accelerated, there are many stream crossings and sections of road which will fail, releasing potentially damaging quantities of sediment to the stream system.

Erosion Control and Watershed Restoration Work

Erosion control measures at Redwood National Park have been divided into two categories: primary and secondary treatments. Primary treatments involve the initial earth-moving. Secondary treatments stabilize or protect the primary treatments. Re-establishment of vegetation is also essential for long term stability of the roaded and harvested lands. Both primary and secondary erosion control treatments assist in reestablishment of native vegetation by improving growing conditions, however, some are more effective than others. All are essential components of watershed restoration.

Primary Treatments

Primary treatments are generally accomplished by skilled operators using heavy equipment. Stream channel networks altered by haul road and skid road construction are returned to their natural flow paths, predominately by excavating road fill from stream channels (Figure 1). Stream channel excavations attempt to uncover the buried natural channel armor. Where this is possible, little erosion occurs. Hillslope drainage networks altered by road construction are restored by decompacting road surfaces, followed by replacing side-cast fill into the cut void, and approximately re-creating the original morphology (Figure 2). In some cases, unstable materials may be removed from landslide areas.

Cross-road drains (large waterbars) and ditches have been used on many miles of park roads to disperse road-captured runoff where future erosion problems were judged minimal. However, drain systems have been found to require periodic, though generally infrequent, maintenance. With time, sediment collects and clogs the generally low gradient drainage system. The problem is exacerbated by revegetation and collapse of cutbanks.

Currently, drains are used primarily to collect and divert runoff away from unstable areas. Future maintenance access and costs must be considered in planning drains and ditches, if eventual failure is unacceptable.

In recent years, larger heavy equipment has been employed, enabling more complete primary excavations and eliminating the need for the often costly secondary treatments. As the cost of moving fill is considerably less per cubic yard than the cost of trying to stabilize that fill by secondary structures (which are often temporary in nature), the overall costs decreased. Completed channel and flow course excavations are now left in a condition which closely mimics the original, natural configuration. Most experience little erosion. This also meets the program goal of restoring a naturally functioning ecosystem.

Secondary Treatments

Secondary treatments, stabilizing areas that were recently disturbed by a primary treatment, may be accomplished by either heavy equipment or labor crews. In stream channel excavations where original channel elements are not found, these treatments have included rock armor placement and check dam construction to inhibit downcutting or lateral scour. Surface erosion control has been achieved by a variety of mulches, seeding, erosion control blankets, and contour structures.

The effectiveness of secondary treatments designed to control short term post-rehabilitation channel scour in incompletely excavated stream channels was monitored until 1984. Many of these treatments required maintenance or modification, and were expensive to install. If not properly designed or constructed, secondary channel structures may cause as much erosion as they were designed to prevent. Wooden structures, such as check dams, gradually decay, and release their stored sediment or cause bank or channel erosion as they fail; they are no longer used. Rock armor, placed properly and in adequate quantities, works extremely well and is still used in unstable excavations, in spite of its expense.

A wide range of surface erosion control measures were applied and evaluated. Results of the effectiveness of secondary treatments, such as contour trenches, wooden terraces, and willow wattles show that they did not work well. In many documented cases, such secondary treatments actually caused more erosion than they prevented by concentrating water which caused rilling or gullying. These treatments were expensive because of the labor involved. Results from long-term vegetation survival-plots show that seeding grass inhibits the re-establishment of conifers, a phenomena seen in many other restoration projects. A variety of mulches and erosion control blankets were tried; most were quite effective at reducing surface erosion but were often expensive to purchase and install. As studies showed that surface erosion was a minor contributor to overall sediment yield compared to that generated by fluvial and mass wasting processes, surface erosion control is now limited to straw mulch on freshly excavated stream banks and areas with particularly harsh exposure.

The need for secondary treatments must be carefully assessed as to their effectiveness and cost-effectiveness in meeting the primary and long-term goals of the program. At Redwood National Park, most secondary treatments have now been eliminated, in favor of more thorough primary treatments.

Re-establishment of Vegetation

The return of natural vegetation is intimately connected with the goals of both erosion control and watershed restoration. Forest regeneration in the harvested areas is vigorous, though stand density and species composition has not yet evolved to resemble that of the old growth stands. Revegetation efforts currently focus on improving growing conditions along the road corridors to speed the recovery of the native vegetation. Primary treatments assist by decompacting road surfaces, restoring soil depth and natural runoff patterns, and retrieving side-cast and topsoil. Secondary treatments (now primarily mulch, organic debris, or duff) assist by protecting the seed bed. Natural dispersal provides the bulk of propagules for vegetation re-establishment. Pioneering native brush and tree species add to soil stability and provide the shade (and nutrients, if nitrogen fixing) necessary for forest succession to proceed. Redwood (*Sequoia sempervirens)* and Douglas fir (*Pseudotsuga menziesii*) seedlings are planted in areas where natural revegetation is not likely to occur quickly.

Costs and Cost-Effectiveness

The treatments and techniques employed and their associated costs are constantly being evaluated, primarily relative to their effectiveness in controlling erosion and fostering native patterns of vegetation. These cost-effectiveness analyses are the primary reason for the shift towards thorough primary treatment where a more natural morphology is restored to the road corridor. Technical changes in the erosion control and revegetation aspects of the restoration work at Redwood National Park have evolved in response to both quantitative and qualitative evaluations. The success in meeting other USNPS goals is judged primarily qualitatively, providing additional valuable input to the program.

Focusing on the erosion control aspect of the work, short term cost-effectiveness is evaluated by comparing treatment costs and the amount of sediment removed or prevented from entering active channels where it could be transported downstream. It also takes into account erosion occurring as a result of the work. Thus far, there is an order of magnitude variation in erosional cost-effectiveness (cost per cubic yard of sediment prevented from entering the stream system) of the various types of treatments used over the years. Complete channel excavations typically have the lowest cost per cubic yard; surface erosion control measures typically have the highest.

Over the years, there has been a wide range in erosion control treatment unit costs (cost per quantity, such as dollars per cubic yard moved) and production rates (quantity per time, such as cubic yards moved per hour), depending on site specific variables and equipment and approach used. Careful documentation and analysis of equipment used, costs, time and volume of material moved, eroded and potentially erodible are used to determine the best and most cost-effective techniques for achieving the erosion control goals of the program. Summary reports and cost analyses have been completed for each of the over 90 projects completed to date.

Specific primary treatment costs depend upon equipment operation rates, distance spoil material must be transported, depth of excavation, and site-conditions such as degree of saturation, amount of organic debris, etc. In general, unit costs decreased as larger equipment was used, and as equipment operators and supervisors became more skilled in road removal. The current cost per mile of road removed is highly variable, in large part because of the variation in volume of fill that needs to be moved per mile. At Redwood National Park, where the roads range from 20 feet to more than 40 feet in width, costs per mile of road removed (for near complete obliteration) have ranged from $10,000 to over $250,000 in areas of exceptionally unstable terrain.

The majority of project implementation costs are associated with the erosion control treatments of stream crossing excavations and retrieval of unstable side-cast. This work reduces erosion to near natural levels and benefits downstream aquatic resources. Recontouring the intervening stretches of road, not already treated for erosional reasons or used as a fill storage area, is generally a relatively minor portion of the overall project implementation cost, and has other benefits for re-establishment of vegetation and ecosystem restoration. The actual percentage varies depending on road width and size and frequency of stream crossings and other erosion-prevention excavations. For a typical erosion control project in Redwood National Park the cost increase may be between 5 and 10 percent (Steensen and Spreiter 1992).

Summary

Many of the earlier attempts at reducing erosion caused by the logging road network treated the symptoms of the problem rather than the underlying causes. As understanding of the geomorphic processes and common causes of road failure increased, treatments were designed that more effectively addressed the causes of erosion, and provided relatively permanent, maintenance free solutions. Increased understanding of equipment operations and development of techniques specific for road removal and watershed restoration decreased implementation costs.

Analysis of costs and effectiveness of stream channel excavations has guided restoration efforts toward complete stream channel excavations, using the largest heavy equipment appropriate for the majority of the project work. The expense and labor associated with secondary channel treatments has been essentially eliminated. The design of nature, carefully uncovered from beneath the road fill, has thus far proven to be the most stable channel configuration.

Observations of vegetation recovery over fifteen years indicate that the most cost-effective way to enhance re-establishment of vegetation is to retrieve side-cast fill and place it along the inboard, cut portion of the roadway, restoring soil depth and natural hillslope morphology. The retrieved side-cast fill contains the nutrient rich topsoil and organic material necessary for vigorous vegetation. This also reduces potential for woody debris laden fills to fail. The large heavy equipment used for cost-effective erosion control has also proven cost-effective in enhancing re-establishment of vegetation in non-critical erosion areas. This has minimized the need for planting, as natural colonization of successional plants occurs quickly.

Conclusions

In reviewing the various projects completed over the past 15 years, it is evident that the initial focus on erosion control through wooden structures and tree planting did not fully or cost-effectively achieve National Park Service goals of restoring a naturally functioning ecosystem. Years of monitoring the rehabilitation efforts and studying the natural processes have given park staff a much better understanding of the underlying causes of the problems hindering ecosystem recovery. This knowledge has guided the program toward the more complete, interdisciplinary treatments of recent years, which cost-effectively address the causes of ecosystem disturbance.

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

The greatest measure of permanent erosion control and revegetation potential is achieved by restoring the pre-disturbance morphology as closely as possible. Blending the disturbed area with the surrounding topography improves overall aesthetic appearance which complements the park's purpose and significance. Obliteration of roads through the excavation of road fill from stream crossings, the recontouring of roads, landings, and quarries to blend with the natural terrain, and the stabilization of management-induced mass movement features provide the greatest return in meeting the objectives of the program at Redwood National Park.

Occasionally, we hear the concern that conditions at Redwood are different than in other areas; thus, the approaches do not apply. In review of USNPS disturbed lands and restoration efforts servicewide, this concern does not bear out. For each area, in-depth knowledge of the site-specific interactions between geomorphic, biologic, and hydrologic processes is necessary to develop appropriate restoration treatments. But, while recovery *rates* and species differ between ecosystems, the generic *processes* are often very similar. Thus, the large field-scale laboratory at Redwood National Park offers insight to all those who wish to share in the wealth of information and expertise.

References

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

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

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

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

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

Popenoe, J.H. 1991. Watershed Rehabilitation and Revegetation in Redwood National Park. USDI-National Park Service, Reclamation and Vegetation Workshop.

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

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

Steensen, D.L., and Spreiter, T.A., 1992. Watershed Rehabilitation at Redwood National Park, *in* Proceedings of the 1992 National Meeting of the American Society of Surface Mining and Reclamation, June 14-18, 1992, Duluth, Minnesota, pp. 280-286.

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

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

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

Figure 1. A haul road stream crossing in Redwood National Park, before and one year after excavation.

Figure 2. A road in Redwood National Park, before and one year after re-contouring.

CITATION:

Spreiter, T.A., Franke, J.F., and Steensen, D.L., 1995. Disturbed Lands Restoration: The Redwood Experience. Eighth Biennial Conference on Research and Resource Management in Parks and Public Lands, April 17-21, 1995, Portland, Oregon; George Wright Society, Hancock, Michigan, p. 238.