WATERSHED REHABILITATION FOR EROSION CONTROL ON LOGGED LANDS IN REDWOOD NATIONAL PARK

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Goals and Focus of the Rehabilitation Program

Redwood National Park is currently starting a major watershed rehabilitation program that will address erosional problems on approximately 30,000 acres of recently logged timberlands in northern California. These logged lands comprise part of a 48,000 acre addition to Redwood Park, which was passed by Congress in March, 1977 (see below, article on history of Redwood National Park).

The rehabilitation program will be a multifaceted one designed to protect the resources of Redwood National Park and to restore altered terrestrial and aquatic ecosystems to more natural conditions. Broad objectives for the program include minimizing the amount of sediment delivered to perennial stream channels from areas disturbed by logging and accelerating the conversion of logged timberlands to a reasonable mimic of the original old growth redwood-Douglas-fir forest.

Rehabilitation work aimed at erosion control (as compared to rehabilitation work aimed at vegetation management through thinning and elimination of exotic plants) will concentrate on the approximately 30,000 acres of land logged in the past eight years. Erosion control efforts will be directed at four main problem areas: Caterpillar tractor-logged hillslopes, logging haul roads, active landslides, and natural prairies that are now gullied because of road construction.

Tractor-logged hillslopes account for approximately 90 percent of the acreage logged between 1970-1978. Because of the tremendous size of the trees in old growth redwood-Douglas-fir forests, tractors created deep cuts while making skid roads to drag out the logs. These deep tractor cuts on the hillslopes create major erosion problems and hamper revegetation: 1) skid roads frequently become gully courses unless properly placed waterbars direct runoff off the skid roads; 2) skid road cut-banks intercept ground water, which adds to the amount of surface runoff after rain storms; 3) the spider-web network of caterpillar skid roads severely disrupts the natural drainage network and frequently concentrates runoff, via skid roads, onto slopes which previously carried little or no runoff and must now respond by rapid channel erosion; at the same time, established channels may carry reduced streamflows; 4) skid roads that are constructed across small drainages block the stream channels; these fills may divert streams down skid roads and may cause saturation of soil fills, leading to destructive debris avalances and debris torrents moving down stream channels; and 5) where soil is totally removed on the cutbanks of skid roads, revegetation is difficult. Because of the problems created by Caterpillar tractor logging, a significant part of the rehabilitation work will be directed at tractor-logged hillslopes.

Logging haul roads and their effect on diverting surface runoff constitute one of the greatest erosion problems on the logged watersheds in Redwood National Park. The major road-related problems can be summarized as follows.

1. On steep slopes, large cuts and fills, required for road construction, are prone to mass slope failure. Fill slope failures are especially harmful since they often deliver sediment directly to perennial stream channels.

2. In most cases, fill slopes and cut slopes do not naturally revegetate because of slope steepness and a lack of soil cover. These unvegetated slopes are susceptible to erosion by both rilling and dry ravelling.

3. Major haul roads roughly parallel slope contours and intercept all surface runoff from upslope. Whereas major stream channels have culverts, most slope runoff is collected by inboard road ditches that drain across the road via culverts spaced at intervals of tens to hundreds of feet. Some inboard ditches carry a large volume of runoff during major storms and can become deeply gullied. In most cases, the ditch runoff is drained across the road into a small drainage course or onto a slope with no preexisting drainage channel and severe gullying results as the slope adjusts to accomodate the concentrated runoff.

4. Logging roads must be maintained, especially during and after major storms, or they become increasingly greater erosion hazards. Culverts and inboard ditches that become blocked will divert water onto the road surface causing new gullies and promoting saturation of road fills, leading to slope failures. Because major roads must either be maintained or eliminated from the hillslope as interceptors of drainage, the rehabilitation program will eliminate those roads that are no longer needed.

Stream side landslides in the upper reaches of the watershed, as well as slope failures triggered by road construction and logging-related disturbances, account for substantial quantities of sediment directly delivered to perennial streams. The deep-seated nature of many recently activated slope failures renders surficial rehabilitation techniques only partially effective. Revegetation, gully stabilization, drainage diversion to initial, pre-logging channels and site-specific structural control measures are expected to yield the greatest possible reduction in sediment production from these features. Those critical landslide areas most clearly associated with past landuse activities will receive priority treatment.

Redwood National Park has 3,000 acres of grass prairie, and practically all these prairies are traversed by ranch or logging roads. Many of the roads have altered the natural drainage established on these erosionally sensitive slopes by intercepting and diverting upslope runoff. Gullies several tens of feet deep and thousands of feet long, as well as newly activated slumps and earthflows, have formed as slopes adjust to altered hydrologic conditions. To help reverse these trends, prairie roads will be eliminated, natural drainages reestablished and existing gullies will be stabilized and perhaps filled in and seeded.

Timing and Coordination of Rehabilitation Activities

The rehabilitation program is expected to span 15 years (1978-1993), with the first five years being the most critical. Erosion problems, easily visible and accessible on logged lands during the first five years after harvest, become concealed by thick regrowth within roughly eight years. Natural revegetation will abate many erosional problems; but in numerous localities, serious erosion problems, such as deep gullies or stream channels blocked by tractor-constructed fill crossings, will remain even after revegetation has obscured their presence. Because most of the logging is now between two and eight years old, rehabilitation of these slopes must proceed as expeditiously as possible, before the problem areas are difficult to isolate and treat.

Rehabilitation work will be done on a subdrainage basis. All erosion control work will commence on the uppermost disturbed portion of a slope and will proceed downslope. Logging roads will be removed starting at their ends. Road removal and slope rehabilitation will be done in concert such that roads and slopes are treated together where they occur in the same watershed area. Rehabilitation work will be carried out in a variety of ways, from national park crews, to park-supervised equipment rental, to contract work, but all these labor forces will be coordinated in space and time such that each subdrainage unit is treated as an entity. In addition, rehabilitation work will be performed through a combination of heavy earth moving equipment and manual labor.

Rehabilitation Techniques for Major Roads

All logging roads in Redwood National Park that will not be used for park management or visitor access will be removed, or "pulled", with the aid of heavy equipment, so that they no longer intercept surface drainage or pose landslide hazards. A typical logging road in cross-section has a cutslope, an inboard ditch, a flat road bench underlain by either bedrock or fill or both and topped with surfacing rock, and a sidecast slope composed of fill (Figure 1). As a first step in removing a logging road, the rocked roadbed must be ripped with a tractor to disaggregate the hard, compacted road surface. After ripping the road, heavy equipment (backhoe or dragline) removes fill material from the outside of the road prism and redeposits it on the more stable inside of the road bench, burying the inboard ditch. The fill is then graded using a tractor blade or backhoe bucket to achieve an outslope, or downhill dip, so water will run across, not along, the road alignment (Figure 2). All culverts are removed and all small channels or swales are opened up across the road alignment so that surface drainage is no longer concentrated in selected locations by culverts. When removing channel fill, the equipment attempts to excavate down to the former channel bed to avoid future downcutting.

Following the heavy equipment phase of the road rehabilitation, manual labor crews with shovels further refine the earthwork on the road alignment and then plant the bare soils. The manual labor rehabilitation techniques for the roads are identical to the manual erosion control techniques for slopes, which are outlined below.

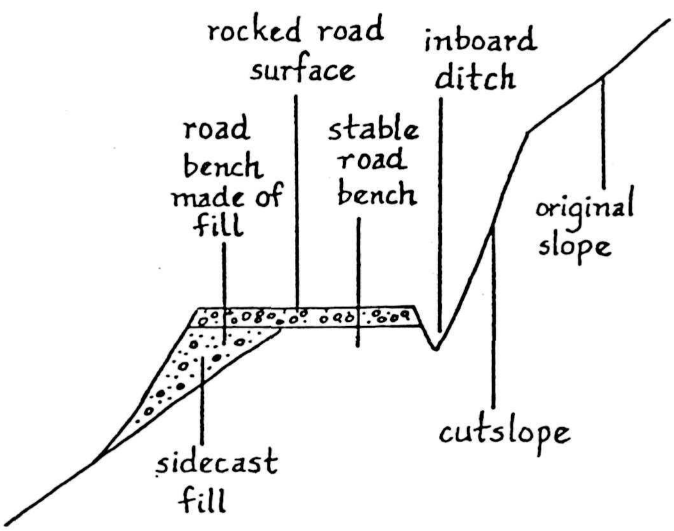


Figure 1: Typical logging road in cross-section.

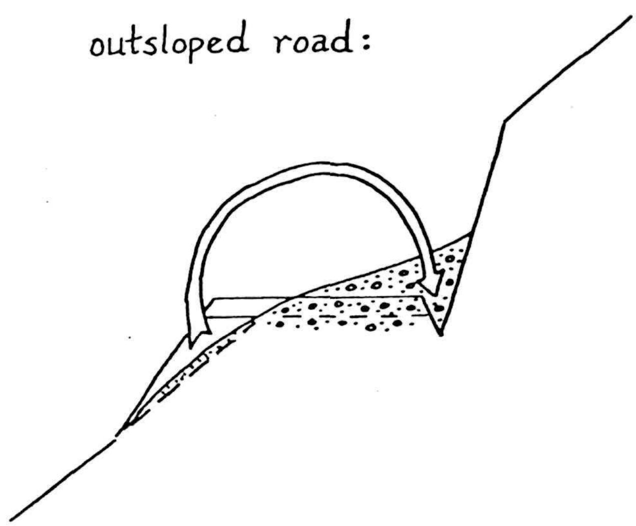


Figure 2: Slope configuration across logging road after heavy equipment transfers fill and grades an outslope.

Redwood National Park pulled the terminal portions of two logging roads during August and September, 1978. The objective of rehabilitation on both roads was to remove the oversteepened sidecast fill on the outside of the roads and landings and place this fill against the cutslope (Photos 1-2). The heavy equipment also opened up first and second-order tributary channels that were formerly the sites of culvert wash-outs along the road (Photos 3-4). Where the logging roads cut into especially wet slopes where groundwater seepage from the cutbanks was prevalent, a backhoe excavated wide troughs, or cross road drains, that intermittently drained the cutbanks, so the soil fill placed against the cutslope would not become saturated (Photos 5-6). Along the oversteepened outside edge of the log landings, which are wide portions along the road, tons of woody debris is incorporated into the soil fill, and this fill is especially prone to failure as the woody debris rots. A crane pulled back the outer edge of these unstable landings to remove the perched woody debris and grade the slope back to a more stable configuration (Photos 7-8).

Rehabilitation Techniques for Altered Drainages

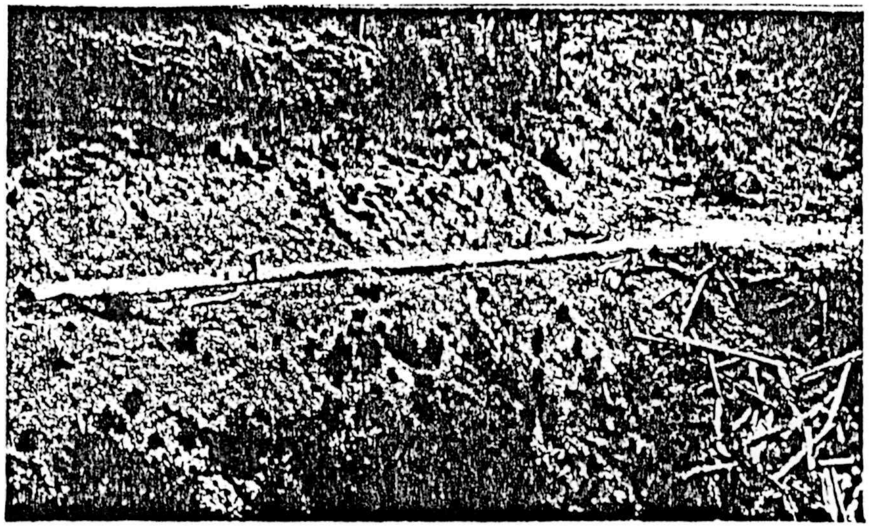
To redivert streams to natural channels and reduce in-channel erosion rates, tractor-constructed fill crossings of perennial, intermittent, and ephemeral stream crossings will be re-excavated using heavy equipment. Channel side slopes and longitudinal profiles will be returned to near pre-existing configurations and exposed sediment adjacent to the stream channels will be stabilized by manual labor erosion control measures. The relatively rapid revegetation of most cutover land within the park dictates the earliest possible attention to these fill crossings. Excessive disturbance of overgrown sites could conceivably result in greater erosion problems than no treatment at all.

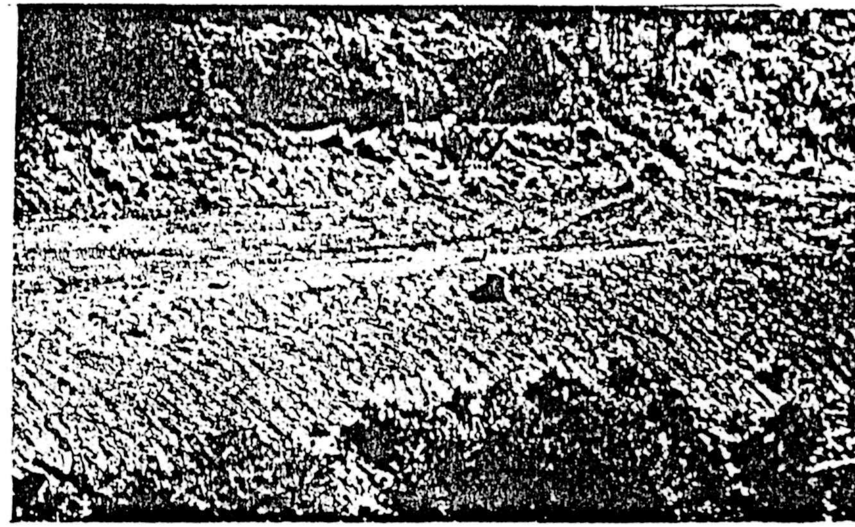
During September and October, 1978, a number of large fill crossings were excavated on two perennial stream channels in the park. The original, tractor-constructed approach trails were outsloped with material excavated from the prisms of fill deposited in the incised drainages (Photos 9-10). Gully and slope stabilization procedures (described below) were then utilized to revegetate and control erosion on the freshly exposed soils.

Rehabilitation Techniques for Disturbed Hillslopes

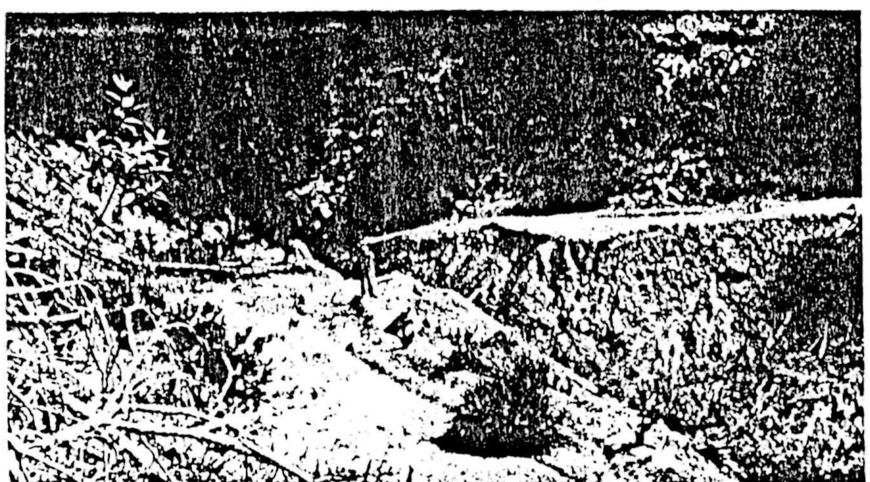
A wide variety of erosion control (watershed rehabilitation) techniques can be used on disturbed hillslopes to minimize rainsplash erosion and rilling, to stabilize gully banks and to arrest gully downcutting, and to promote revegetation. These are manual labor techniques (labor-intensive methods); some of these erosion control techniques first received wide use in the U. S. by the Civilian Conservation Corps in the 1930's (Kraebel and Pillsbury, 1934; Kraebel, 1936), though the general concepts probably stem from times when early agricultural practices first accelerated erosion of crop lands.

The aim of all the techniques is to disperse or direct surface drainage along the least erosive course and to promote revegetation for erosion control. Many of the techniques achieve both purposes. On each disturbed prairie or forested hillslope, and along each pulled road alignment, a combination of rehabilitation techniques will be prescribed by the Redwood Park scientific staff (or by a contractor if the contract calls for devising prescriptions), and a work program, or contract, will be formulated for implementation of the prescribed measures. During the past two summers, a total of ten contracts (including three major ones) were let out for rehabilitation work. Park



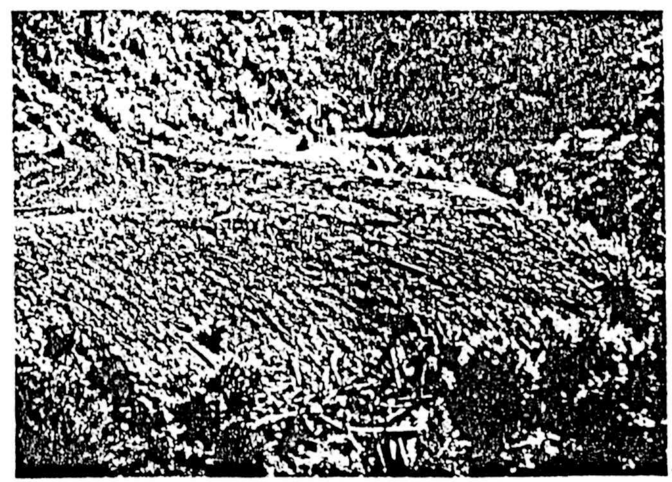


Photos 1 and 2 (August and October, 1978): Outsloping of a logging road in Redwood National Park, using heavy equipment--outside road fill removed and placed against the inside road cutbank. C-10 Road; Miller Creek drainage.



Photos 3 and 4 (August and October, 1978): Site of a culvert wash-out on a road crossing of a second order tributary--views showing before and after heavy equipment work. C-10 Road, Miller Creek drainage.


Photos 5 and 6 (August and October, 1978): Before and after views showing outsloping of road and installation of cross road troughs to drain the road cutbanks--note the elimination of the culvert and the inboard ditch in the October photo. C-90 Road, Harry Weir (Emerald) Creek.

Photos 7 and 8 (August and October, 1978): Rehabilitation of a log landing--note removal of woody debris and loose soil from the outer edge of the landing; this material was deposited on the inside stable bench of the landing. C-10 Road, Miller Creek drainage.

Photos 9-10 (August and October, 1978): To rehabilitate a reach of severly altered channel, a backhoe excavated a tractor-constructed fill crossing and redeposited the fill on adjacent skid roads. After removal of the fill crossing, manual labor crews will plant the slopes and install check dams in the channel to impede downcutting.

personnel chose the sites, and for six of the contracts, wrote the job items in the contracts based on detailed geomorphic field mapping. Following is a description of the types of labor intensive erosion control work that is being performed in Redwood National Park. As the state of the art of erosion control becomes more advanced, techniques will undoubtedly evolve and grow.

Waterbars and Ditches

Waterbars and ditches are both drainage troughs used to collect and direct runoff. Since waterbars divert water across a sloping surface, they must have a berm on the downslope side. Waterbars are the most effective means of preventing gullying along logging skid roads. When properly placed, they direct runoff on to a vegetated slope or into a slash pile where the runoff will be slowed down, dispersed, and perhaps soak back into the soil. Proper water bar placement immediately after logging could have prevented many of the deep, long gullies that now run along portions of many skid roads in the park. Along secondary roads presently in use, "rolling" water bars, which a vehicle can drive over, can effectively divert road runoff to adjacent vegetated slopes. The crucial factors in constructing an effective waterbar are 1) <u>location</u> at a point along the road where runoff can successfully be diverted downhill to a less erodible slope, 2) <u>sufficiently frequent spacing</u> of the waterbars to prevent road gullies between waterbars, and 3) <u>excavation</u> of the waterbar into the ground surface so that the runoff flows in a ditch, or gutter, rather than simply against a built-up berm that could wash out. A major part of the labor intensive work on tractor logged slopes involves directing surface runoff off skid roads and onto vegetated areas or into established stream channels through the construction of well-placed waterbars. Ditches are means of draining ponded, wet areas where persistently wet soils pose slope stability problems.

Cross Road Drains

Cross road drains are specialized ditches that drain the cutbanks of roads (Photos 5-6). These drains will in most instances be constructed by heavy equipment during outsloping, or pulling, of a road, though their final shaping may be done with shovels. The purpose of the drains is to prevent soaking, by groundwater seepage, of the fill placed against cutbanks, and to carry small drainages across the road prism. The drains should be placed, as best as possible, at the exact locations of major seepage areas and small drainages.

Energy Dissipation and Rocking of Troughs

When water is routed into the artificially constructed drains or troughs, erosion will likely occur in the excavated trough and directly downstream of the trough where concentrated runoff flows onto slopes of steeper gradient that do not already have stable channels. To try to prevent such erosion, waterbars, ditches, and cross road drains may be lined with rock (Photo 11). A device may then be installed on the slope directly below the rocked trough to dissipate the energy of the fast-flowing water. Rocking of drainage troughs only works if the rock is large enough to remain stationary during high runoff; in standard waterbars and cross road drains in the park (20'-30' long, 2%-6% grade), at least 25% of the rock should be ten inches or larger to assure a reasonable chance that the rock will remain in place and help armor the bed. Ideally, energy dissipation devices slow runoff and eventually become incorporated into the channel bed by trapping sediment and forming stable knickpoints in the channel profile. Energy dissipators take many forms--a sample list of techniques tried to date include: 1) strategically placed and secured logging slash (branches, small trees); 2) split "ricochet" boards, anchored with stakes and rock, and placed diagonally into the slope to divert water back and forth in pinball fashion down a steep slope; 3) piles of rock that lean against stakes in a gully and slowly filter water through them (Photo 12); and 4) bundled conifer boughs staked diagonally in a drainage course in a herringbone pattern.

Revegetation Techniques: Wattling

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 the wattles form small benches that contour the slope (Photo 13). The contour wattle benches can retard surface erosion due to rainsplash impact and rilling; and, if composed of sprouting species such as willow (Salix), the wattles can sprout and effectively revegetate a slope. Wattling as a revegetation and erosion abatement measure has been tried and proven by other workers (Kraebel, 1936; Leiser, 1974). The critical factor in wattling for revegetation is meticulous attention to the proper procedures for cutting, handling, and installation of sprouting-plant wattles. Branches are cut when dormant, kept cool and moist in the short interval between cutting, bundling and installation, installed at a time of the year when prolonged dry weather is unlikely, and buried sufficiently to prevent drying out. In the park, willow is the only species that so far has produced sprouting wattles, but experimentation with other sprouting species and wattling techniques is continuing. For instance, non-sprouting bundles that will serve as slope sediment traps may be anchored in place with sprouting stakes. Wattlings, in one of its many conceivable forms, will be a major revegetation-erosion control technique in the Park's rehabilitation program.

Revegetation Techniques: Stem Cuttings

Another method to rapidly establish vegetation on bare sites is to plant stem cuttings of sprouting species. Stem cuttings are short (approximately 12" to 24") sections of branches or twigs. In the California Coast Ranges, the cuttings are made in the fall after the plant becomes dormant and the ground is wet from the first rains. The cuttings are planted with at least half of their length below ground to minimize both dessication and root breakage from movement of the cutting in its hole. Willow (Salix) and Baccharis have both been successful when planted as cuttings; 80% of the willow stems planted in 1977 on one of the initial rehabilitation test sites were still alive in September 1978. Baccharis had a lower survival rate, possibly due to planting conditions. Much more experimentation with stem cuttings will be carried out, including the use of other plant species and possibly testing rooting compounds and applications of fertilizer. The rehabilitation program has done some dense planting of stem cuttings on unstable slopes prone to earthflow or slumping; if the cuttings become established and grow rapidly on these wet sites, they may help stabilize the slopes through dewatering and by increasing soil shear strength through the root mat. Stem cuttings probably will be used widely in the rehabilitation effort because the method is relatively rapid, inexpensive, and gives high promise of success if correct procedures are followed.

Revegetation Techniques: Log or Board Planting Terraces

Revegetation on steep, bare slopes is frequently hampered by the lack of a reasonably fertile soil mantle and by the constant dry ravel of particles down

Photo 11: Cross road drain lined with coarse rock to prevent downcutting. C-90 Road, Harry Weir (Emerald) Creek.

Photo 12: Piles of coarse rock held in place with wood stakes that serve as energy dissipation structures at the downslope end of a cross road drain. C-90 Road, Harry Weir (Emerald) Creek.

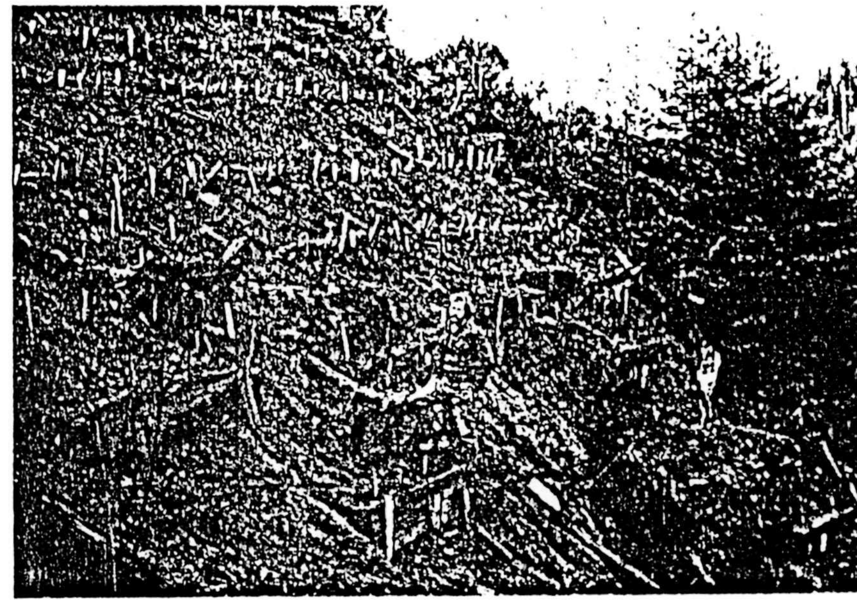


Photo 13: Willow wattles and redwood board planter boxes installed on a steep, bare slope that was reshaped by heavy equipment in September, 1978. C-Line landing, Miller Creek.

the slope in summer and the rilling of the slope during rainstorms in the winter. To create a stable pocket of soil on steep slopes and to protect this area from raveling or erosion, log or board barriers may be keyed into the slope along the contour; the barriers may have soil backfilled behind them and become planting boxes, or they may be left as catchment barriers above a planting box to protect the plantings from raveling or rilling (Photo 13). These log- or board-constructed planting terraces are most useful on slopes that are prohibitively steep for wattling, or on steep, straight slopes and narrow chutes created by debris sliding or debris avalanching.

Mulching and Grass Seeding for Ground Cover

Another expedient for keeping soil in place on recently disturbed slopes is to use mulches. Mulches form a permeable mat that, in some way, is intertwined and can dissipate the impact of rain drops and impede rilling on the soil surface. To date, straw, jute netting (loosely woven hemp) and a combination of leaves, small branches, and shredded bark have been used on pulled road alignments as mulch. Chipped wood from tree thinning projects can also serve as an abundant source of mulch. Loose mulches (straw, chips, leaves, branches, and bark) work well on flat, protected areas; where mulching is desirable on steeper slopes (greater than 8%) or where wind exposure is a problem, an interwoven biodegradable fabric that can be staked in place, such as jute netting, should be used solely or in conjunction with loose mulch. Regardless of the use of mulch, seeding slopes with grasses to establish a quick ground for the first year or two will be a standard technique on most slopes disturbed during rehabilitation.

Check Dams in Gullies

One of the major erosion problems on both logged timberlands and prairies within Redwood Park is gullying. The gullies range in size from a few inches deep to greater than ten feet deep and tens of feet wide with most averaging between 2-10 feet deep and 5-15 feet wide. On the prairies, practically all the artificially-created gullies are due to concentrated runoff coming off secondary roads with inadequate ditches, culverts, and energy dissipation devices. Gullying on tractor-logged slopes is a product of erosion along skid roads which were not properly waterbarred or where the installation of adequate waterbars was impossible, and in those areas where natural drainages were filled or diverted by logging debris.

Check dams can be an effective means of controlling gully erosion and stabilizing gully banks and bottoms so that vegetation can become established. During the past two summers, check dams were installed in four different locations in the park on first- and second-order perennial or intermittent drainages that were actively gullying. The three types of check dams, all constructed by hand and primarily using on-site or nearby materials, include split board dams (Photo 14), conifer bough dams, and rock dams reinforced with wire mesh. The check dams are typically 10-30 inches high and 2-6 feet wide, depending on gully width and gradient and type of construction.

Successful check dams are those which pond sediment in their basins while allowing free passage of water over the spillway. The ponded sediment prevents downcutting, stabilizes the adjacent gully banks by preventing lateral bank cutting, and provides a relatively permeable, fertile substrate for planting. The check dams must be well keyed into the bank, either by sufficient excavation or staking or both, so that water will not cut laterally around the end of the check dam. An adequately deep spillway that can accomodate high runoff further ensures that the dams will not be breached along the sides. Energy dissipation, in the form of branches, logs, boards, or large rock, must be placed in the channel below the spillway of each dam to deter plunge pool erosion and consequent undermining of the check dam. In actively downcutting gullies, a single check dam can easily be undermined from below as normal downcutting continues. Therefore, check dams are normally installed in a series so that undercutting cannot occur at the base of any one check dam. Ideally, the lowest check dam in a gully reach to be controlled should be constructed on a non-erodable base (bedrock, large boulders, etc.), and all check dams constructed upstream of this lowermost dam should be placed so that sediment fill behind the downstream dam (after the dam fills with sediment) abuts against the base of the next upstream check dam. Therefore, check dams and their trapped sediment totally cover the gully reach, and running water moves down the channel over the ponded sediment fill, over the check dam step, through the energy dissipation device, and onto the next lower level of ponded sediment.

In steep, rapidly eroding terrain such as the northern California Coast Ranges, check dams can be expected to fill with sediment after the first 1-4 major storms; and, in some cases, a series of dams can totally fill due to one large gully bank failure. Therefore, the trapped sediment behind the dams is only a tiny fraction of the annual sediment yield. The ponded sediment serves the primary purpose of stabilizing the adjacent bank and the gully bottom so that vegetation can become established. It is the revegetation which drastically reduces long term sediment yield.

Check dams can be extremely effective in abating erosion in gullies and providing a stable substrate for gully planting. However, they are a successful measure only if used in gully reaches where the discharge of the annual flood will most likely not wash out the dams and if the dams are well-placed, well-constructed, and maintained periodically. Periodic maintenance is most important in the first few years after installation before vegetation is well established; this maintenance entails repair of minor dam breaching and faulty energy dissipation structures. Under favorable conditions, redwood board check dams can be expected to function a decade or more, or until revegetation adequately stabilizes the channel from further erosion.

The testing and evaluation of a number of different check dam techniques in different types of gullies will be a major part of the watershed rehabilitation program in Redwood Park. Check dams are relatively expensive to build and require stringent construction standards, but they potentially provide great benefits in erosion control and revegetation on those areas with particularly high sediment yields.

Gully Plugs

Many gullies in Redwood National Park are discontinuous and start in distinct headcuts which migrate upslope during major runoff events. Gully plugs are devices that armor a headcut and prevent upslope migration of the gully. A simple plug may consist of a buried board check dam at the head of a gully; the buried dam forms a stationary knick point in the gully profile. Another type of plug consists of a thick layer of large rock placed on the exposed headcut; if the headcut is steep, the rock must be kept in place by vertical columns of rebar or solid wood stakes. Percolation of gully runoff through rock linings on headcuts will promote deposition of fine sediment that can then be seeded or planted. Stopping headcut retreat is a major goal in gully control because a headcut is a critical point of growth in an active gully. However, a plug will eventually become undermined and fail if the gully reach immediately below the plug is not stabilized by vegetation and/or check dams.

Photo 14 (December, 1978): Recently installed split-board check dams along an intermittent, second-order tributary in Redwood National Park. Each dam is ponding water, and sediment will settle out in the basin up to the height of the spillway. Note the close spacing of check dams, and the rock energy dissipation below the spillways; both measures protect the dams from gully downcutting. Note stem cuttings of willow (poles in gully bank) which are planted to accelerate revegation. Drainage just below C-10 Road, Miller Creek.

Photo 15 (December, 1978): Hand-constructed redwood board water ladder that is conveying stream runoff over a steep bank at the downstream end of a cross-road drain. The water ladder prevents gully cutting into the steep, bare bank and conducts the water downslope to less erodible, partially vegetated ground. Note rock energy dissipation at foot of water ladder. C-90 Road, Harry Weir (Emerald) Creek.

Water Ladders

Water ladders are wooden structures, similar in appearance to stairs, that convey water over a steep slope without downcutting (Photo 15). In Redwood National Park, water ladders have been employed in the following situations: 1) in steep gully reaches where check dams are impractical; 2) in the lower section of a cross road drain where the drain drops off the edge of the former road bench and there is no other method, such as channel rocking, that could prevent downcutting; and 3) in disturbed drainages where tractor-constructed dirt crossings fill the channel and a water ladder may prevent further downcutting into the fill. In many localities, water ladders can serve the same purpose as half-round culverts that conduct culverted water over steep road fills and onto vegetated or slash-covered slopes.

Water ladders are placed so that they become a part of the stable channel bed. They must be well embedded into the drainage so that runoff does not go around or under the ladder during high flows. Vegetation planted adjacent to the ladder and between the rungs will further stabilize the channel.

Summary

The first year of erosion control work in Redwood National Park ended October, 1978. During the next five years, the program will escalate in size. Most of the critical erosion problems in the park will be treated, many new techniques will be tested, and the established techniques will be refined. A rigorous evaluation program will proceed concurrently to assess the effectiveness of the rehabilitation. It must be recognized that active treatment of all problem areas may not always be the best approach. In some cases, the best treatment of disturbed landscapes may be no treatment. Regardless of the number of erosion problem areas treated, successful rehabilitation requires good planning, knowledgable supervision, adequate worker training, quality construction and planting, periodic follow-up maintenance, and an evaluation program which feeds back into continuing rehabilitation work.

Acknowledgments

The origins of the erosion control techniques described above come from a variety of sources, too numerous to list individually. The pioneering work of Charles Kraebel of the U. S. Forest Service is most noteworthy. A number of erosion control contractors who have worked in Redwood National Park have, through their own initiative, introduced innovative erosion control measures. Three groups worthy of mention are New Growth Forest Services of Ukiah, California, Northcoast Rehabilitation Group of Arcata, California, and Aero-Marine Research of Arcata, California. Finally, the conception, coordination, and supervision of the initial rehabilitation work has been carried out by the Resource Management Division of Redwood National Park; this rehabilitation team includes our colleagues, Steve Veirs, Mary Ann Madej, Greg Bundros, and Danny Hagans.

References

Kraebel, C. J., 1936, Erosion Control on Mountain Roads; U. S. Dept. of Agriculture, Circular No. 380, 44 pp.

Kraebel, C. J. and Pillsbury, A. F., 1934, Handbook of Erosion Control in Mountain Meadows; U. S. Forest Service Experiment Station, Berkeley, CA, 63 pp.

Leiser, A. T. et.al., 1974, Revegetation of Disturbed Soils in the Tahoe Basin; California Dept. of Transportation, Transportation Laboratory, Sacramento, California, report no. 7036-1-75-24, 74 pp.