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Erosion control techniques used in Redwood National Park, Northern California, 1978-1979.

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Abstract. Redwood National Park has initiated a rehabilitation program to reduce erosion from lands impacted by timber harvest and road construction. Severity of damage to park lands varies with age and type of logging, underlying geology and hillslope gradient. For each rehabilitation site, detailed geomorphic maps delineated natural and disturbed drainages, slope instabilities, and other erosional problems. Next, heavy equipment disaggregated and outsloped logging roads, excavated road fill from stream channels, removed unstable road fill from road prisms, and restored altered drainages to their natural patterns. After heavy equipment work was completed, labor-intensive work crews constructed erosion control structures to stabilise gullies and stream channels, minimise rainsplash erosion and rilling, and promote revegetation of disturbed areas. Checkdams, water ladders and flumes, wattling, wooded terraces, mulches and vegetative techniques were used. Winter maintenance of these structures is essential to assure adequate protection of slopes and drainages through high rainfall periods. Costs and time involved for rehabilitation techniques are included.

Les techniques du contrôle de l'érosion utilisée dans Redwood National Park dans le nord du Californie, 1978-1979

Résumé. Redwood National Park a initié un programme de réhabilitation pour réduire l'érosion dans les terrains comblés par l'exploitation forestiére et la construction de routes. La sévérité du dommage causé aux terrains du parc varie selon l'âge et le type de l'exploitation, la géologie sousjacente, et l'inclinaison des pentes. Pour chaque site de réhabilitation, des cartes géomorphiques détaillées dépeignaient les drainages naturels et dérangés, les instabilités des pentes, et d'autres problémes d'érosion. Ensuite, de l'équipement lourd désagrégeait et déversait vers l'extérieur les chemins forestiers, excavait des comblements de chemin dans les lits fluviaux, enlevait des comblements instables aux prismes routiers, et remettait à l'état naturel les drainages dérangés. Apres l'achévement de ce travail, des équipes d'ouvriers intensives construisaient des structures pour contrôler l'érosion en stabilisant les rigoles et les lits fluviaux, en réduisant au minimum l'érosion pluviale et par sillons, et en encourageant la régénefation végétale des terrains dérangés. On utilisait des digues d'arrêt, des échelles à eau et des glissoires, des tressages, des terrassements boisés, du humus, et des techniques végétatives. L'entretien hivernal de ces structures est essentiel pour assurer la protection adéquate des pentes et des drainages pendant les périodes de précipitation intense. Le coût et le temps nécessaire pour ces techniques de réhabilitation sont inclus.

INTRODUCTION

Redwood National Park is located at the downstream end of Redwood Creek basin, an 88-km long structurally controlled drainage in north coastal California. The basin consists of intricately dissected terrain carved from the closely fractured and pervasively sheared sandstone, siltstone and schist of the Franciscan assemblage. Steep, highly erodible terrain, recent severe winter storms and intensive road construction and timber harvesting produce unusually high sediment yields in Redwood Creek (2800 t/km^2-yr). In 1978 the U.S. Congress set aside 19 400 ha of land in the lower basin to preserve a remnant of the once extensive coastal redwood ecosystem. Of this area, 13 400 ha has been severely disturbed by road building and logging, and is now the focus of a large-scale restoration program to reduce accelerated erosion rates and to speed the vegetational recovery of cutover lands.

The rehabilitation program, begun in 1978, is a multifaceted effort designed to meet the following objectives: (1) to minimize the amount of sediment delivered to stream channels from areas disturbed by logging, (2) to remove over 400 km of logging roads, (3) to protect or restore aquatic and riparian resources, (4) to accelerate the conversion of logged timberlands to a reasonable mimic of old growth coastal redwood forests, and (5) to encourage the prevention and control of accelerated erosion on private lands where timber is still being harvested upstream from the park. This paper will review the methodology and specific techniques Pedwood National Park is currently employing to control accelerated erosion on lands which have been impacted by past timber harvesting and road construction.

The primary erosional impacts of timber harvesting and related activities are: (1) massive soil disturbance on steep slopes logged by crawler tractors, (2) massive road cuts and fills which are prone

to mass failure, (3) widespread alteration of natural drainage networks, (4) cutbank interception of groundwater, and an increase in impermeable bare soil areas associated with logging roads, causing increased runoff during storms, (5) surface runoff disruption leading to extensive gully systems, especially on sensitive prairies, and (6) direct deposition of sediment and organic debris in stream channels. In addition, stream channels adjusting to the above impacts show an increase in streamside landsliding.

The rehabilitation program, begun in 1978, will continue for 15 years and will address each of the above problem areas. During the first five years, erosion control efforts will be concentrated on recently cutover terrain where severe erosional problems are adjacent to streams or threaten to deliver sediment directly to streams. Rehabilitation on such sites progressed in three stages: (1) geomorphic mapping and erosion inventory, (2) major earth moving using mechanized heavy equipment, and (3) installation of erosion control structures and revegetation by manual labor.

The first phase, detailed geomorphic mapping, delineated: (1) surface drainage patterns and gully systems, (2) areas of emerging groundwater, (3) slope failures, (4) culvert and waterbar locations and cut bank failures along roads, (5) tractor-constructed fill crossings of stream channels, (6) excessive organic or inorganic debris in streams, and (7) local sources of wood to be used in constructing erosion control devices. Erosion mapping was done during the wet winter months, at a rate of roughly 6 ha per person-day. The completed maps were used to plan the overall treatment of an area, as well as equipment access routes, and sources and storage areas for rock aggregate, check dam boards and mulches.

The second major stage of each rehabilitation project occurred in the dry summer months and used heavy equipment for major earth moving tasks. Dragline cranes and hydraulic excavators removed major road fill crossings from stream channels and reestablished the approximate pre-road channel configuration and gradient (Figs. 1 and 2). Crawler tractors and hydraulic backhoes worked in tandem to excavate debris and road fill from incised stream channels which were deteriorating by gully erosion or debris avalanches (Fig. 3). Where streams had been artificially diverted by logging activity, or where groundwater emerged from cutbanks, this same equipment relocated water to natural channels. Backhoes and excavators also placed large rock in the bottom of newly excavated channels to protect the streambed from downcutting during winter flows (Fig. 4).

Heavy earth moving equipment was used extensively to remove logging roads and stabilize log landings. Typically, the rock-surfaced road bench was first decompacted using chisel teeth mounted on a crawler tractor. Several passes of the tractor successfully disaggregated the upper 0.5 m of material and increased the infiltration rate of the previously impermeable surface. Then a drag-line or excavator, scooped loose, oversteepened fill material and organic debris from the outside edge of the road or landing and placed it on a stable bench. To "outslope" a road, a crawler tractor then graded this material against the cutbank at a $3^{o}$to 12^{o}gradient (Fig. 5), obliterating the inboard ditch and directing surface runoff across the former road alignment. Figure 6 shows the results of heavy equipment work on an unstable log landing.

Roads account for less than five per cent of the area of rehabilitation sites, but require 90 per cent of equipment time for correction

of erosional problems. For the seven sites analyzed for this report, total costs ranged from \$20-\$290/ha, depending on the severity of problems and the steepness of the terrain.

Tractor-constructed fill crossings excavated with backhoes and tractors cost \$120-\$1345, or an average of \$5.25/m^3 of fill removed. On large crossings where a dragline was used, costs were \$1.90/m^3 for excavations less than 750 m^3, and \$2.85/m^3 for larger fills. Costs for the removal of unstable portions of log landings ranged from \$2000 each (with little organic debris) to \$35 000 each (with large quantities of debris that had to be transported from the site). Decompacting rocked roads cost \$200-\$250/km; the cost for dirt roads would be somewhat less. Waterbars (small trenches to divert runoff off roads) cost \$10 each (tractor-constructed), or \$40 each (backhoe-constructed), as opposed to hand-construction costs of \$30-\$300 each.

The cost to outslope roads depended on hillslope gradient and type of equipment used. For roads built across steep, unstable terrain and removed with a dragline and tractor, costs were \$5900/km (at a rate of 0.15 km/10-h workday). Alternatively, tractor-backhoe teams outsloped roads with less sidecast material on more gentle slopes for \$3100/km (0.32 km/day).

Total costs to remove roads depended on hillslope gradient, number and size of fill crossings, and availability of storage space for excavated material. For low standard roads on gentle terrain costs ranged from \$620 to \$1235/km (0.5 km/day). A rock-surfaced road with 4-5 intermittent streams/km and mostly moderate-sized fill crossings (2-3 m deep) cost between \$9250 and \$18 500/km (0.15 km/day). Finally, permanent logging roads which cross steep (>25^{o}), unstable slopes, and frequent (2-3/km) major fill crossings of deeply incised streams (>3 m deep or >750 m^3), where endhauling of excavated material is necessary, cost from $18 500 to $55 500 (0.06 km/day); considerably more expensive and slower than for roads built across less steep and erodible land.

Following the geomorphic mapping and heavy equipment earthmoving phases of rehabilitation, labor crews refined the earthwork, constructed erosion control devices and replanted areas bared during earlier heavy equipment operations. Erosion control devices, installed prior to the first heavy fall rains, dissipate the erosive force of falling rain and flowing water in order to control rainsplash, and sheet, rill and gully erosion. These structures include waterbars, wooded terraces, contour trenches, check dams and submerged spillways, rock aggregate, gully plugs, water ladders and energy dissipators.

Waterbars are small (2-7 m), long troughs excavated 15-30 cm deep into road surfaces to divert surface runoff from bare soil areas onto more stable, vegetated ground, and thus decrease gullying. Unlike most erosion control devices, waterbars can be constructed by hand or with mechanized equipment. Due to higher costs for manual labor ($30-$300 each, 3-5 h), hand-constructed waterbars were built only where heavy equipment access would have been impractical or excessively damaging.

While waterbars divert concentrated surface runoff, wooded terraces and contour trenches prevent surface water from concentrating. Wooded terraces (soil benches constructed on a contour and supported on the downslope edge by woody material) disperse runoff, and through the terracing effect trap soil particles transported from bare upslope areas. Contour trenches are discontinuous ditches dug on contour into bare hillslopes, which act as small trap basins for surface runoff and

eroded sediment. Both structures promote infiltration of surface runoff into the soil, but are relatively expensive ($1.75 and $1.10 per linear meter, respectively). Preliminary data suggest that rainsplash, sheet and rill erosion play a minor role in total sediment delivery from rehabilitation sites, so these structures will only be used on critical areas.

Bank erosion and channel downcutting in gully systems and recently excavated stream channels are a substantial source of sediment in rehabilitated clearcut areas. Both check dams and rock armor were used to protect highly erodible channel banks and beds. In 1978-1979, check dams were confined to streams with less than 0.2 cms mean annual peak winter discharge. Most structures were constructed from redwood slabs which were split or milled at each work site. Installed in a sequence such that the sediment basin behind one dam abuts the base of the next upstream, check dams can effectively prevent further channel downcutting, help stabilize adjacent stream banks and provide a fertile substrate for vegetation (Fig. 7). Once erosion is retarded, vegetation becomes reestablished to provide root support and surface protection when the check dams begin to deteriorate after their minimum expected lifetime of 10 years (Fig. 8). Periodic maintenance inspections following winter storms prevents premature failure of check dams.

Check dams are typically 0.25-1.0 m high, and 0.5-2.0 m wide, depending on stream gradient and width. They require 5-15 person-hours to construct and install, and cost $45-80 each. Compared to other erosion control techniques, check dams are relatively expensive, but their high effectiveness in stabilizing rapidly eroding watercourses warrants their use in many cases. To achieve the same purpose, some check dams were imbedded into a channel until the spillway was flush with the streambed. This design is less likely to be undermined by channel downcutting than a conventional dam, although little sediment is trapped.

Rocking newly excavated stream channels also inhibited downcutting and lateral erosion. Like check dams and submerged spillways, rocking promoted immediate channel bank and bed stabilization while allowing time for vegetation to become established. Using heavy equipment to quarry, transport and place rock aggregate in channels cost about \$21/m^3 of rock (when rock was derived within 8 km of the site). Stream crossings required 12-110 m^3 of rock ranging from 20-100 cm in diameter. Average cost for treating 20 crossings was \$240 each. Manual rocking was used in channels inaccessible to dump trucks and in first- and second-order streams where large boulders were not essential. The costs varied from \$22-\$26/m^3 of rock. Rocks shift slightly in the first winter season until they are firmly bedded in the channel and minor erosion may occur during this adjustment period.

In channels that are too steep to use check dams or rocking, water ladders, flumes and gully plugs were used instead to arrest headcut erosion at stream knickpoints. Water ladders are stair-stepped wooden structures that convey concentrated runoff over short reaches of steep, unstable slopes, while dissipating the kinetic energy of the water. Water flumes are analogous structures which convey water in wooden or metal chutes with baffles instead of ladder treads. Both are effective erosion control tools in small watercourses, provided that all flow is diverted into the structures, they can accommodate high flows, and energy dissipators have been installed at the outlets. Gully plugs were installed at active headcuts to prevent upslope knickpoint

migration. They consist of woody slash and coarse rock secured by wire mesh and metal rods, and armor the headcut while conveying water across the break in slope. Because of their cost (\$300-\$800 per structure), ladders, flumes and gully plugs are only used where less expensive methods are infeasible.

To prevent erosion by flowing water at the outlets of structures, wood boards, coarse rock, and anchored logging slash were used to dissipate the energy of cascading water (Fig. 7). Energy dissipators are an integral part of the design and cost of structures (waterbars, checkdams, flumes, etc.).

Physical erosion control structures will eventually deteriorate, and vegetation must be reestablished on disturbed sites to assure a long-term reduction in sediment yield. Wattling combines physical and vegetative protection for disturbed slopes. Wattles are bundles of small branches and stems partially buried in contour trenches on hillslopes at a one meter vertical separation. The small terraces trap fine sediment derived from slope wash and disperse runoff before it begins to rill. If composed of sprouting species such as willow (Salix spp), wattles provide the added stability of a root structure as well as ground cover (Fig. 6b). Wattles are effective on moist, steep fine-grained soils, but are an expensive technique (\$3-\$8 per linear meter).

Mulches were applied to disturbed ground to provide immediate protection from sheet and rill erosion, as well as to preserve an open soil structure, high infiltration rates and moist soil conditions. Wood chips, logging debris (slash), straw, jute netting (loosely woven hemp) and a sawdust/cow manure mixture were used alone and in combination (i.e., straw overlain by jute). Tentative results of plot studies suggests all methods work well on slopes under 20^0, and that untreated plots have dramatically higher surface runoff rates. Mulching costs ranged from $750 to $2000/ha.

Broadcast grass seeding and fertilization were used to provide a temporary ground cover as protection from rainfall. Application rates varied from 45-100 kg/ha, and costs ranged from $100-$185/ha. Locally, vigorous grass growth bound loose surface soil and retarded ravelling and rill development; however, the general usefulness of grass as an erosion control tool has not yet been demonstrated.

Other revegetation efforts included dense plantings of stem cuttings of sprouting species, and transplanting and seeding ground cover, brush and tree species. The primary purpose of these efforts is to accelerate the development of a cohesive rooting system to stabilize stream banks and beds, and shallow slope instabilities. Stem cuttings cost $4300-$8600/ha when planted at a one meter spacing (215-950 person-hours/ha). Evaluation of the effectiveness of revegetation on erosion control must necessarily await several years of observation.

Labor intensive erosion control efforts are directed towards both short and long-term goals: to control potentially rapid rates of erosion immediately following heavy equipment operations and to provide protection to areas where deterioration of earlier erosion control work is inevitable.

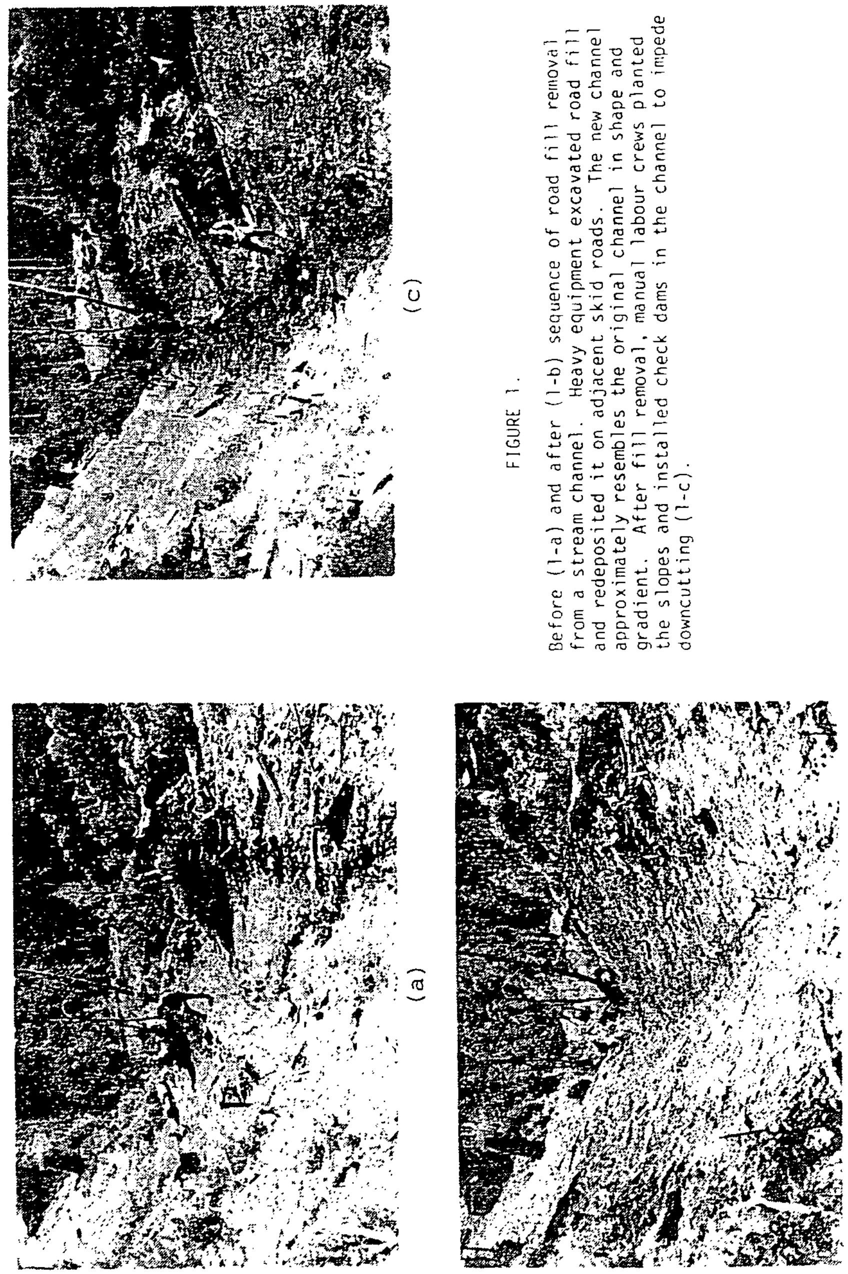

FIGURE 1.

Before (1-a) and after (1-b) sequence of road fill removal from a stream channel. Heavy equipment excavated road fill and redeposited it on adjacent skid roads. The new channel approximately resembles the original channel in shape and gradient. After fill removal, manual labour crews planted the slopes and installed check dams in the channel to impede downcutting (1-c).

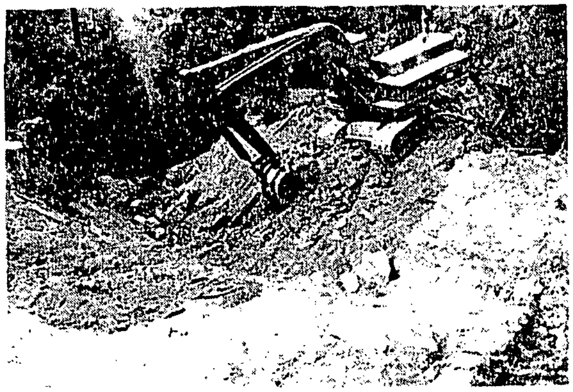

FIGURE 2

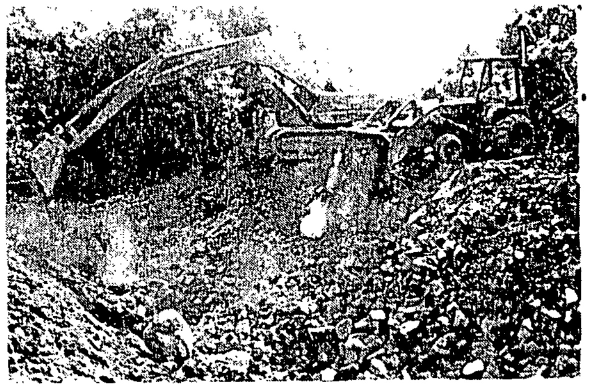

FIGURE 4

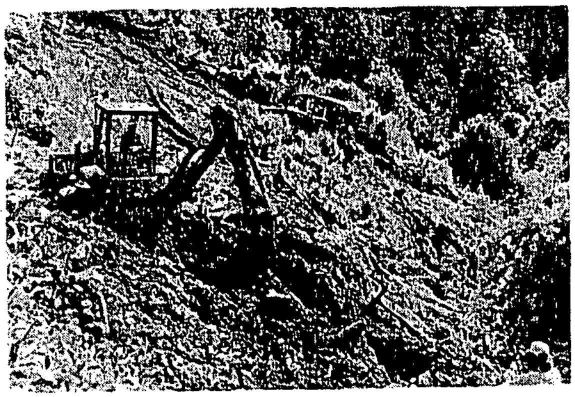

FIGURE 3

FIGURE 2. A hydraulic excavator removes road fill from a stream channel to the depth of the original channel bed, and grades the new channel banks to a stable slope.

FIGURE 3. A hydraulic backhoe and crawler tractor work together in clearing a stream channel. The tractor in the background winches out large organic debris. The backhoe (foreground) follows, excavating road fill and grading stream banks to a stable slope. Note person in channel for scale.

FIGURE 4. An excavator and backhoe line the bottom of a newly excavated stream channel with large rocks to prevent downcutting and lateral erosion during winter flows.

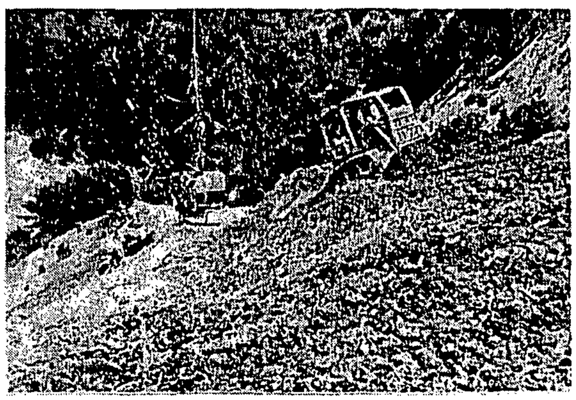

FIGURE 5

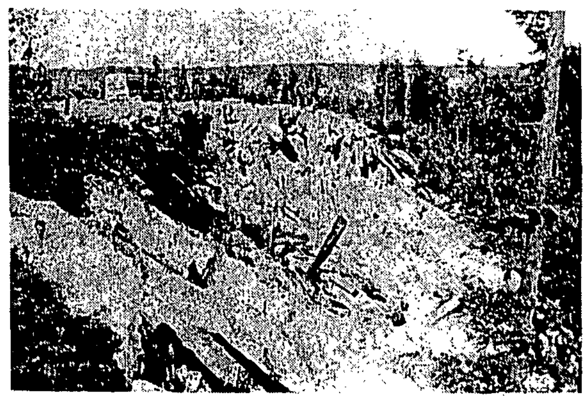

FIGURE 6a

FIGURE 5.

A dragline crane (background) excavates perched road fill from the outboard edge of the road and piles it against the road cutbank. A tractor (foreground) grades the fill to achieve a gentle outslope on the former road alignment.

FIGURE 6a and 6b. Before and after sequence showing the removal of an oversteepened fill slope from a log landing. Willow wattles, planted on hillslope contours after heavy equipment work, are beginning to sprout (6b).

FIGURE 6b

FIGURE 7. Redwood slat check dams were installed in a newly excavated stream channel to prevent downcutting of the stream bed and to help stabilise stream banks. They convey winter flows through broad, high-flow spillways.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. Stem cuttings of willow are planted on both banks to accelerate revegetation.

FIGURE 8. After one season the catch basins upstream of each check dam are filled with sediment. Sprouting willow stem cuttings and other plants are beginning to stabilise channel banks and bed.