REHABILITATION OF A 290 HECTARE SITE IN REDWOOD NATIONAL PARK

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Abstract. A 290 hectare (710 acre) site that had been tractor logged between 1969 and 1975 was mapped and treated for erosion control in 1980. Gullies up to 4.3 meters (14 feet) deep were the dominant erosion feature and were caused by the diversion of run-off by roads. A gully inventory in a 40 hectare (100 acre) sub-unit revealed management related erosion of 1.3 centimeters (one-half inch) in seven years although all mapped erosion occurred in gullies that occupied only a half a percent of the land area. The most cost-effective erosion control treatments were the de-watering of active gullies and the excavation of road fill from stream crossings.

INTRODUCTION

In this paper the logging related erosion processes and major erosion control treatments on a 290 hectare (710 acre) unit within the Bridge Creek drainage of Redwood National Park are described. This site was one of six sites which were mapped and rehabilitated in 1980 under the direct or indirect supervision of Redwood National Park geologists. The focus of this paper is on the major logging related sediment sources to the fluvial systems from this unit and on the treatments performed to reduce future sediment yields from those sources. The observations and conclusions are those of a single author and are based on experience within an area in which the surficial geology is not representative of the whole park.

This unit is located on the east valley side of Bridge Creek, a major left bank tributary to Redwood Creek. Total relief from the creek to the ridge top is 510 meters (1680 feet). Approximately 90 percent of the area mapped and treated has slopes of 35 to 45 percent but slopes of 100 percent or more are common next to channels draining 20 hectares (50 acres) or more.

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Figure 1 shows the location of the hillslope that was mapped in the spring of 1980 and treated beginning in the summer of 1980. Treatments of logging haul roads continued in 1981 but only 1980 treatments are discussed here.

About 90 percent of the old growth redwood and fir forest on the site was clearcut by tractor logging between 1969 and 1975. Skid trail density was measured from aerial photos to be 474 meters per hectare (635 feet per acre) and a total of 12.1 km. (7.25 miles) of haul roads had been constructed, all of which were still in place in 1980 except for where a stream had washed out the road fill of two crossings. The timing of logging with respect to the spring storms of 1972 and 1975 is shown in figure 2. Fifty percent of the unit was logged before the 1972 storm (1969 to 1971), forty-six percent was logged between the 1972 and 1975 storms (1972 to 1974), and four percent was logged after the 1975 storm (1975).

Soils and parent material are of critical importance to the potential erosion of a disturbed hillslope. In particular, the depth from the soil surface to competent bedrock or boulders determines the maximum possible depth of gullying by water that is diverted onto a hillslope. It also provides some insight to the stability of a channel after its bed and banks are disturbed by logging equipment, particularly if the channel substrate consists of strong tree roots overlying soils or weathered bedrock that are composed of small particles, easily entrained by flowing water.

Most soil in this unit was colluvial and had a brown, clay loam B-horizon of about 40 cm. (16 in.) thickness. A plus B-horizon thickness was 50 to 100 cm. (20 to 40 in.) (Jim Popenoe, Redwood National Park, oral communication, 1982). Schistose boulders were typically found in the cut banks of roads and in the bottoms of gullies at a depth of about 3 meters (10 feet). Boulders were also common in the beds of streams draining about 20 hectares (50 acres) or more. However, boulders or bedrock were seldom observed in the beds or banks of smaller streams, except where disturbance related erosion had enlarged a flowcourse. The roots of trees and understory vegetation were interwoven into a strong mat in the banks of all of the most stable channels, and appear to have been the major source of strength in the smaller channels prior to logging. The full extent of logging related disturbance in headwater tributaries was, however, not always obvious due to the high degree of disruption of channel beds and banks by logging equipment, disturbance of drainage networks by roads, and higher than normal sediment storage in channels during this period of post-logging slope readjustment.

GEOMORPHIC MAPPING AND INTERPRETATION OF EROSION PROCESSES

A total of about 50 person days were spent mapping the hydrologic and geomorphic features of this unit at a scale of 1:1800. The purposes of mapping were: 1) to provide the basic information necessary to plan and implement erosion control treatments; and 2) to document the erosion features associated with road construction, logging, and natural processes.

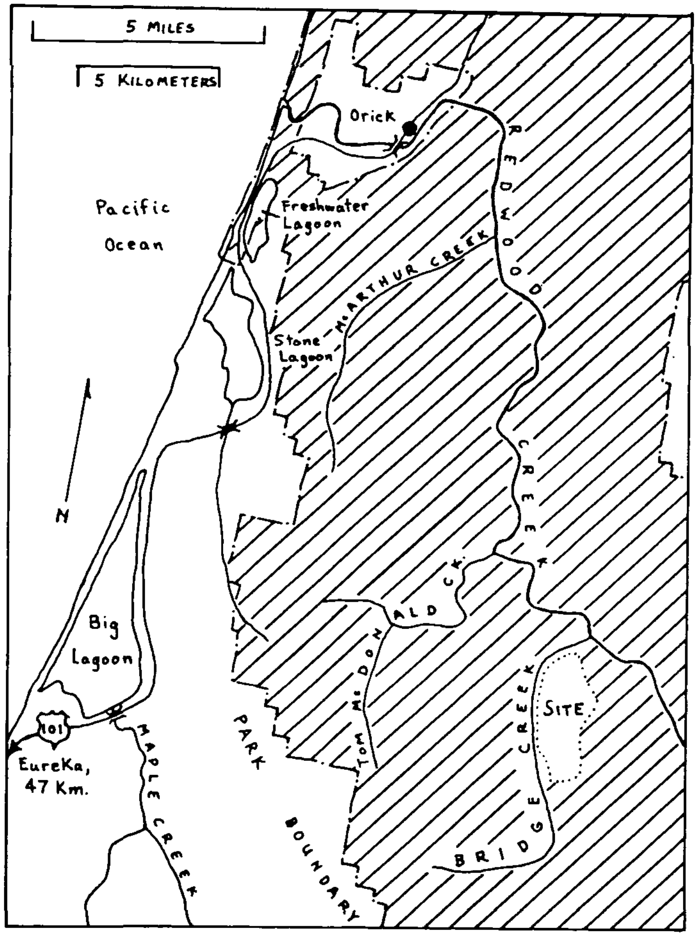

Figure 1. Location Map

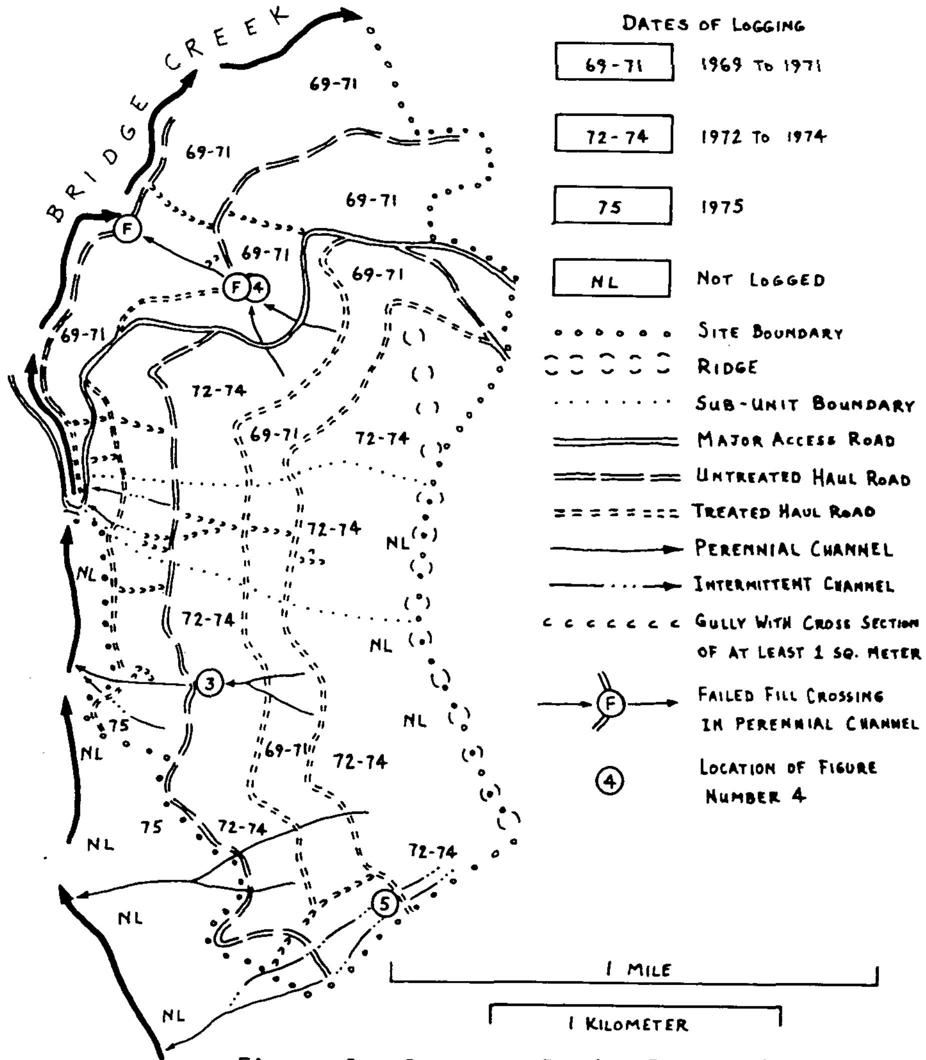

Figure 2. Streams, Roads, Dates of Logging, and Other Features on the Site

Field work revealed an assortment of gullies up to 23 square meters (250 square feet) in cross sectional area, up to 4.3 meters (14 feet) in depth, and ranging in activity from very inactive to very active. The most active gullies had vertical or overhanging banks, were deeper than they were wide, were totally unvegetated, and were observed to be contributing sediment at the time of mapping with water discharge during rainy periods in order of 10 liters per second (.36 cfs). The presence of all of these gullies can be explained by the diversion of water by skid trails, haul roads, and misplaced culverts. All of the most active gullies were found on slopes which had been logged since 1972. The most inactive gullies had beds and banks that were fully vegetated with alders. Their sideslopes had gradients of around 100 percent but were stable. In many cases their beds were composed of schistose boulders or bedrock. Some gullies had become inactive due to the water supply being shut off, for example by water from a culvert outfall finding a new course on a slope and cutting a new gully. Other gullies continued to convey the diverted runoff and eroded their beds and banks until a condition of relative stability was reached.

An important observation in terms of sediment yield was that the gully and stream channel network was very efficient at transporting fluvially eroded sediment. From observations of stored sediment it was estimated that 90 to 99 percent of the net gully volume eroded from this hillslope was delivered to Bridge Creek.

Figures 3, 4, and 5 show examples of three of the major sediment sources on this unit and also provide a sample of the geomorphic mapping. Figure 3 shows a skid trail crossing of a stream draining 28 hectares (68 acres). The crossing had been constructed by filling the channel with logs and earth fill to a depth of about 3 meters (10 feet). The major impact of this crossing as of the time of mapping was the diversion of flow out of the natural channel resulting in a gully from which 380 cubic meters (500 cubic yards) of soil had been removed in a distance of 46 meters (150 feet). The gully had become nearly inactive due to exposures of boulders in its bed and natural revegetation on its sideslopes, but the fill in the skid trail crossing constituted a future source of sediment.

Figure 4 shows a road failure at the intersection of a haul road and a stream draining 28 hectares (a different stream than the one mentioned in the preceding paragraph). At this location, about 23 cubic meters (30 cubic yards) had already been eroded and the potential for future erosion (without treatment) was estimated to be 100 cubic meters (130 cubic yards).

Figure 5 shows an example of one of the most important problems with haul roads on this unit, gullying due to a misplaced culvert. This problem was considered important for four reasons: 1) the volume of gullying was large; 2) such gullies on this site were still very active; 3) the problem was preventable at the time of road construction; and 4) the problem was easily treatable by rehabilitation techniques. In this example, a stream draining only 5.7 hectares (14 acres) was diverted out of its natural channel by the inboard ditch and through a culvert onto a slope about

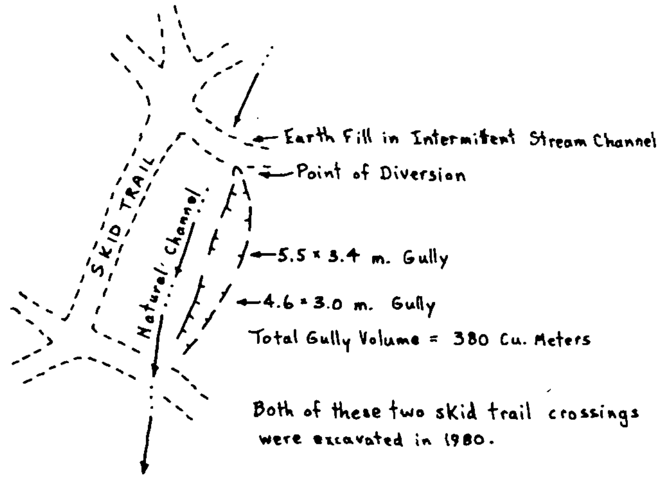

Figure 3. Gully Caused by Diversion of Stream at Skid Trail Crossing

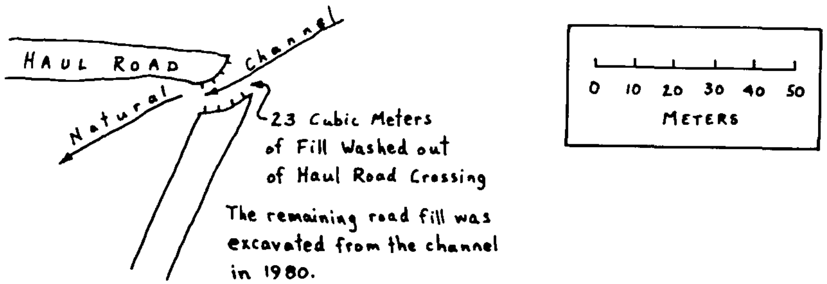

Figure 4. Failure of Earth Fill at Haul Road Crossing of Stream

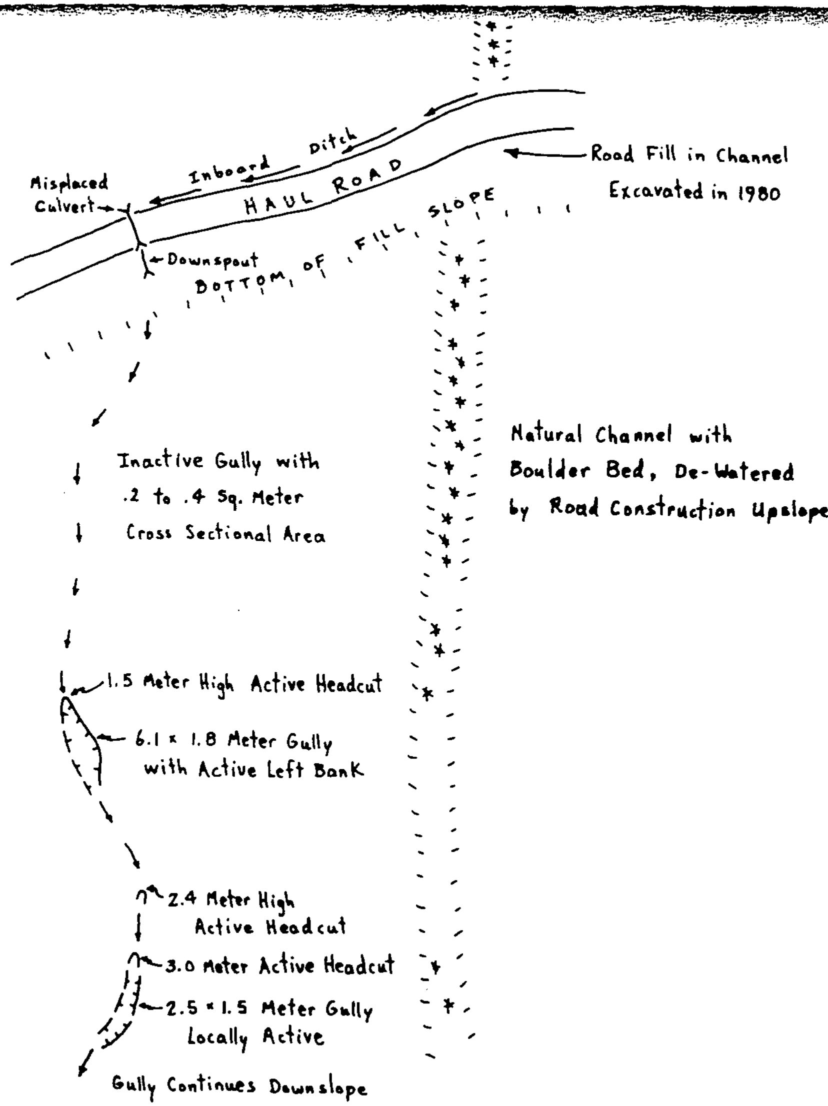

Figure 5. Gully Caused by Misplaced Culvert

Returning once again to the subject of erosion features on the whole 290 hectare site, the following generalizations and conclusions are made: 1) Gully erosion was relatively insignificant within an elevation of 100 meters (330 feet) of the ridge due to small drainage areas. 2) The most important sediment sources, in terms of volumetric yield of sediment to Bridge Creek, were gullies that resulted directly from skid trail and haul road construction procedures. 3) Some gullies had become virtually inactive as sediment sources by 1980 but other gullies clearly had the potential for continued sediment yield. 4) Failures of road fill at stream crossings were not as large a sediment source as gullies between the time of road construction and 1980. However, the relative importance of road fills at stream crossings would have been expected to increase with time as gully systems eventually stabilized and culverts at stream crossings occasionally became plugged or eventually disintegrated, thus exposing overlying road fill to erosion.

Only 2 haul road crossings, out of a total of 26 crossings of streams draining between 4 and 40 hectares (10 to 100 acres) on this site had washed out to the point of the road being impassable by truck, by 1980. However, there were 6 other crossings that were either partially washed out or which showed evidence of failure and repair prior to park acquisition of the land in 1978. Partially failed and intact crossings therefore represented a major potential sediment source because of their large volume (150 to 1150 cubic meters each) and their proximity to stream channels.

The relatively dry winters along the north coast between the time of park expansion and the winter of 1979-80 made it difficult to anticipate the full importance of a sediment source that has recently been observed to be a major one associated with roads in the park. This is the rapid mass movement of saturated haul road and skil trail fill into stream channels. Such failures occurred within this site and in other parts of the park in response to the storm of late December 1981 which brought 22 to 34 cm. (8.5 to 13.4 in.) of rain to the higher elevations in the park between 14 and 21 December. The record from the O'Kane recording rain gauge maintained by the National Weather Service near Highway 299 along Redwood Creek indicates that virtually all of this rainfall occurred in the three days of 18 to 20 December. Because these sediment sources were not anticipated, their treatment is not discussed in the next section.

TREATMENT METHODOLOGY

Erosion treatments were planned only after mapping of complete hydrologic units. This was considered important because of the extent to which natural drainage networks were disrupted by roads and trails. The main considerations in planning treatments were the potential for future erosion, cost of treatment, and the amount of ground disturbance that would result from treatment.

Future sediment sources (potential erosion) were categorized according to two main types: 1) hillslope gullying by diverted surface runoff; and 2) failure of road fill into stream channels. In simpler terms, these sediment sources are due to either water having been diverted where it

80 meters (260 feet) away. This diverted stream gullied its way downslope for a distance of 490 meters (1600 feet) and removed a volume of 1620 cubic meters (2120 cubic yards) before rejoining its natural channel.

The mapping of gullies on this site includes width and depth measurements in sufficient detail to quantify all gullies larger than .09 square meters (1 square foot) in cross sectional area. However, at this time only those gullies in a 40 hectare (100 acre) sub-unit shown in figure 2, have been tallied for this site. This sub-unit spans the full 510 meter (1680 feet) elevation range of the hillslope and is crossed by four logging haul roads. It is not necessarily quantitatively representative of erosion on the rest of the unit but the character of management related sediment sources and erosional processes is representative. Total mapped gully volume in this 40 hectares was 5200 cubic meters (6800 cubic yards), most of which was derived from gullies with cross sections of at least 5 square meters (54 square feet). The largest gully cross sections were 11.6 square meters (125 square feet) and the deepest gullies were 4.3 meters (14 feet) in depth. The pattern of gullies on this unit reveals discontinuities in plan view and in long profile that are a direct result of interception of water by skid trails; diversions by inboard ditches, culverts, and landings; and an increase in the volume of diverted runoff downslope. Tractor logging between the ridge and the highest haul road left a network of skid trails (almost completely without waterbars) which converged downslope. This network of skid trails intercepted storm runoff into the inboard ditch of the first (highest) haul road. This runoff, which under natural conditions would probabaly have been spatially dispersed and not even emergent as surface runoff, formed a gully with a cross sectional area averaging .91 square meters (9.7 square feet) between the first and second roads. At the second road the flow spilled out onto a landing which diverted the runoff in three different directions. The resulting gullies, each with a volume of at least a few hundred cubic meters, formed in response to different runoff events and probably in different years, as indicated by their different ages of natural revegetation. The flowcourses which caused these three gullies converged at the third road and below this point there was no more major gullying.

Erosion in the gully system described above could have been reduced by some simple procedures. Waterbars on the skid trail network between the ridge and the first road, along with more culverts on the two upper roads, would have kept runoff more dispersed on the hillslope. Also, some maintenance of the landing on the second road could have confined runoff into a single gully, the oldest of which was 2 to 3 meters (6.5 to 10 feet) deep and had begun to stabilize by the time the second gully formed.

Most of the erosion problems in the 40 hectare sub-unit originated on slopes which were logged between 1972 and 1974. Between the summer of 1972 and spring of 1980 there were seven rainy seasons. Erosion is therefore assumed to have occurred in seven years. Total volume of soil loss, which was mapped entirely as gullying by diverted surface runoff, was measured as 5200 cubic meters (6800 cubic yards). This is equal in volume to a loss of 13 mm. (.5 inch) averaged over the whole sub-unit although virtually all of the mapped erosion occurred on only about a half a percent of the area.

does not belong or dirt being placed where it does not belong. As trivial as it may sound, the preceding sentence leads directly to the main part of the treatment methodology: 1) put water back where it belongs on a slope (e.g. with waterbars and diversion trenches); and 2) remove earth fill from stream channels. These two types of treatments were the highest priority treatments and were accomplished almost entirely by heavy equipment (dragling crane, hydraulic excavator, tractors, and a backhoe). Decisions to treat or not to treat potential sediment sources were based on considerations of the volume of sediment that could be "saved", the degree of revegetation, the magnitude of storms to which the region had already been subjected, the amount of disturbance necessary for heavy equipment to reach the site, and site specific considerations of slope stability and possible erosion control techniques.

Figure 3 and 5 show examples of both types of sediment sources, as defined in the preceding paragraph. Both crossings in these two figures had sources associated with diversions (already eroded) and sources associated with fill in stream channels (potential erosion). Both crossings were excavated down to an approximate reconstruction of the corresponding channel long profiles and cross sections, thereby accomplishing both main types of treatments at the same time, that is, de-watering of active gullies and removal of fill from stream channels. Excavation of fill from the crossing in figure 4 and from most other crossings on this site falls under the second main category of treatment, or removal of earth fill from channels. The construction of waterbars and diversion trenches are examples which fall into the category of putting water back where it belongs on the slope, or the repair of micro-drainage networks.

The partially failed road crossing shown in figure 4 was also excavated down to a close reconstruction of the original long profile and cross section. Approximately 23 cubic meters (30 cubic yards) of this road fill had failed prior to excavation but it was estimated that additional 100 cubic meters (130 cubic yards) could be eroded in the future. This potential erosion was considered sufficient to justify heavy equipment access and complete removal of the road fill from the stream channel.

Sediment sources in the 40 hectare watershed discussed earlier were related to disturbances of types 1 and 2, therefore treatments consisted of both the reconstruction of drainage networks and the excavation of road fill from stream channels. Between the ridge and the highest road, 29 waterbars were constructed to disperse surface runoff. The highest haul road was cross-road drained (in addition to being ripped) in order to keep surface runoff from becoming concentrated in the inboard ditch. At the second haul road the flow was considered sufficiently channelized, and draining a sufficient area (5.2 hectares, 13 acres) to justify the full excavation of road fill from the channel. Between the second and third roads, a trench diverted the flow out of a very active gully and into an older, well-vegetated, gully. This part of the hillslope was so disturbed that no stable, natural channel was apparent. The third haul road was left intact in 1980 and at this point, the flow passed through a culvert and into well-defined, incised channel. At the fourth road the fill was fully excavated from the channel and at the fifth road, immediately above the right bank of Bridge Creek, the road was left intact and flow is accommodated by a properly placed culvert. Excavation of the untreated crossing was planned for a later date.

Task	Erosion Control Category	National Park Geologists	Heavy Equipment	Manual Labor
Geomorphic mapping and planning of treatments	C[1]	$5,690	--	--
Restoring small drainage networks (e.g. waterbars)	A		$28,207	$1,660
Removal of fill from close proximity to channels	A		36,447	833
Protection of excavated stream beds and banks by check dams, rocks, mulch and alder plantings	B		2,770	23,401
Seeding, fertilizing, mulching and planting roads	D		--	7,071
Salvage 60,000 board feet of timber	D		3,935	400
Miscellaneous costs	C	16,140[2]	1,351	2,967
	Sub-Totals	$21,830	$72,710	$36,332

Grand Total = $130,872

[1]A - decreasing fluvial shear stress on erosive materials.
B - increasing shear strength at points of high shear stress.
C - erosion control overhead costs.
D - non-erosion control costs.

[2]$14,000 of this was the cost of supervision.

Table 1. Cost Breakdown for Rehabilitation on this Site.

The next largest major category of work was the restoration of small drainage networks by heavy equipment. This included ripping and cross road draining 8.2 km. of the 12.1 km. of haul roads on the site (4.9 of the 7.3 miles), the construction of 48 waterbars on skid trails, the construction of 4 backhoe trenches, and the installation of 2 culverts on haul roads that were to remain on the site for one year or more. Thus 50 percent of the total cost, or $64,654 was spent on restoring small drainage networks and removing earth fill from stream channels with heavy equipment alone.

The third largest major expense from table 1 was the protection of the beds and banks (including sideslopes) of excavated stream channels in road fill crossings by manual labor, at $23,401 or 18 percent of the total cost. Most of this amount (68 percent) was spent on the seven largest crossings, the largest single cost being the construction of check dams. At the three most expensive installations, 32 check dams each with a capacity of .7 to 1 cubic meters per second (25 to 35 cfs) were installed at a cost of $7520. Compare this with the cost of excavating 1945 cubic meters (2548 cubic yards) of fill from the same three crossings at a cost of $11,780. There is a question concerning the cost effectiveness of check dams and the other treatments relative to each other in absolute terms. This is addressed in the next section.

COST EFFECTIVENESS

In this section, estimates are made of the costs per unit volume of erosion prevention by five different types of treatments. The costs of these treatments are known but the amount of erosion that would have occurred without treatments must be estimated. Although subjective, these estimates are based on many observations on this site of erosional features which are analogous to those that would probably have formed under non-treatment scenarios.

Two worksites provide examples of the de-watering of active gullies and were the most cost-effective treatments on this unit. One of the two sites consisted of excavating the road fill from the crossing shown in figure 5, thereby also de-watering the gully associated with the misplaced culvert. The other gully, not shown in a figure, was de-watered by the installation of an additional culvert and flow dissipation structures in a haul road that was to remain within the unit after 1980. The added culvert intercepted inboard ditch runoff and diverted it into a low gradient (25 percent), slope with very good vegetative ground cover and dense fir seedlings. The gully that was de-watered formed on a slope of 45 percent. Estimates of potential erosion without de-watering of these two gully systems are based on bank sloughing back to 100 percent side-slopes, upstream migration of headcuts for a distance of between 15 and 30 meters (50 to 100 feet), and gully bed width enlargement to 1.5 meters (5 feet).

De-watering the first gully by the excavation of a small (92 cubic meter) road fill cost $399 and it was estimated that the erosion of 1600 cubic meters (2100 cubic yards) was prevented, for a cost-effectiveness of 25 cents per cubic meter (19 cents per cubic yard). De-watering the second gully by installing the culvert and some additional flow control structures cost $1475 and prevented an estimated 3590 cubic meters (4700 cubic yards) of soil erosion for a cost-effectiveness of 41 cents per cubic meter (31 cents per cubic yard). The average cost-effectiveness of these two gully de-watering treatments was 36 cents per cubic meter (28 cents per cubic yard).

All earth fill in haul road crossings of stream channels was assumed to be a potential sediment source, even if there was a properly placed culvert in the fill, due to plugging or culvert intakes by debris, insufficient culvert capacity during a large storm, or culvert disintegration. The volume of fill that would have failed had the excavations not been done was estimated by assuming that streams would have eventually eroded the fill down to a straight long profile with a bed of 1 to 2 meters wide and with sideslopes of 70 to 100 percent. On the average, this represents about 70 percent of the volume that was actually excavated from the channels since sideslopes were excavated with gradients of about 55 percent. Therefore, about 70 percent of 4800 cubic meters or 3360 cubic meters (4400 cubic yards) of erosion was prevented at a cost of $36,447 (from table 1) for a cost-effectiveness of $10.85 per cubic meter ($8.28 per cubic yard). This does not include the added cost-effectiveness that would result if some road fills would have caused diversions and gullies had the excavations not been done.

The two preceding estimates of cost-effectiveness are for heavy equipment treatments directed at reducing fluvial shear stress on erosive materials. The first, de-watering of active gullies at 36 cents per cubic meter of erosion prevention, is probably very near the practical limit of maximum cost-effectiveness, and does not represent typical values for the repair of drainage networks in general. The cost per unit erosion prevention of the more common work in this category, such as the construction of waterbars and cross road drains, was probably lower although it would be difficult to quantify. This is because they do not serve to alleviate any easily identifiable point or linear sediment source as do stream crossing excavations and the de-watering of gullies. Thus, there is no overall estimate for the cost-effectiveness of restoring small drainage networks.

The next most cost-effective erosion control treatment was calculated to be the addition of quarried rock to the beds and banks of freshly excavated stream channels. A total of $3428 was spent in the quarrying, delivery, and application of 76 cubic meters (100 cubic yards) of rock for 7 channel reaches averaging 10 meters long and 2 meters wide (33 feet long and 6.6 feet wide). The costs of rock application ($1210 on heavy equipment and $778 for labor) also include the salvaging and placement of about 15 cubic meters (11 cubic yards) of rock encountered while excavating road fill. About half of the mass of rock applied to channels was composed of clasts larger than 35 cm. (1.1 feet).

Skid trail and haul road crossings were excavated down to a close mimic of the original stream long profile and channel bed widths. It was estimated that the difference in channel erosion with rocking and that without rocking would have averaged .75 square meters (8.1 square feet) in cross section. This yields a cost-effectiveness for channel rocking of $59 per cubic meter ($45 per cubic yard) of erosion prevention.

Subsequent to the construction of diversion trenches and excavation of fill from crossings, one or more follow-up treatments were prescribed at almost all work locations. The purpose of these treatments was to increase the resistance of stream beds, banks, and sideslopes to fluvial erosion. Freshly excavated sideslopes adjacent to stream channels were treated with straw mulch at a rate of 4.5 tonnes per hectare (2 tons per acre) and those sideslopes with a gradient of 55 percent or more were additionally treated with a layer of Curlex (a brand name for shredded aspen wood from American Excelsior Company). Nine of the sixteen excavated haul road and skid trail crossings were protected with quarried rock with a maximum dimension of 1 meter (3.3 feet) and/or check dams made of redwood boards. Factors considered for the prescription of these in-channel structures were channel gradient, expected peak flow, the probability of encountering buried channel boulders, logistics, and cost.

Most active gullies on the site were treated by parital or virtually complete de-watering, but not all gullies could be de-watered. One gully that could not be de-watered was instead stabilized by the installation of check dams, submerged spillways combined with energy dissipators or flumes at knick points, and flow deflector boards at undercut banks.

In the most fundamental context of erosional processes, the goal of keeping soil on the slope and out of the fluvial system must necessarily be achieved by a combination of: 1) reducing shear stress on materials of low shear strength; and 2) increasing shear strength at points of relatively high shear stress. De-watering active gullies, excavating earth fill away from close proximity to channels, and constructing waterbars served to reduce the actual and potential fluvial shear stress on easily eroded materials. Treatments that served to increase shear strength at critical points were the construction of check dams, submerged spillways, flumes, energy dissipators, and the application of rock in channels. Heavy equipment expenditures were strongly weighted in the direction of the former (25 to 1) while labor intensive expenditures were equally strongly weighted in the direction of the latter (also 25 to 1).

A total of $130,872 was spent on this 210 hectare site through the payment of wages, salaries, a labor contract, and for heavy equipment rental. Table 1 lists the major tasks that were accomplished and the costs per task. Two items are included that do not contribute directly to erosion control. These are seeding, fertilizing, mulching and planting roads; and salvaging downed timber that was either already sawn or was blocking access to work sites. The other costs were related to erosion control treatments and accounted for 91 percent of the total cost.

The largest single cost in table 1 was for the removal of 4800 cubic meters (6300 cubic yards) of fill from 18 skid trail and haul road crossings at a cost of $36,447 or 28 percent of the total cost. The ten largest excavations of road fill from stream channels had a volume of 4720 cubic meters (6180 cubic yards) and cost $30,800 to excavate.

The cost-effectiveness of check dams was estimated by assuming the me difference in erosion for treatment and non-treatment of an excavated ream crossing as for the application of rock. At a cost of $7520, 32 eck dams with 150 cm. by 30 cm. (5 ft. by 1 ft.) spillways were installed ong 37 meters (120 feet) of channel in 3 road crossing excavations. This elds a cost-effectiveness of $91 per cubic meter ($70 per cubic yard) of osion prevention for check dams. This does not include the cost of 80 eck dam boards consisting of about 2400 board feet of old growth redwood mber milled on site from salvaged logs.

A total of $5556 was spent for the control of surface erosion on 00 square meters (.91 acres) of freshly excavated sideslopes at 13 haul ad crossings. This included the spreading of straw mulch on all side-opes, the application of Curlex on slopes greater than 55 percent, and e planting of alder transplants on 30 to 61 cm. (1 to 2 ft.) centers. assuming a non-treatment effect of 1 cm. of additional soil loss, the st-effectiveness of mulching and planting excavated sideslopes is $150 r cubic meter ($115 per cubic yard) of erosion prevention.

The cost-effectiveness estimates described above span two and e-half orders of magnitude from $.25 to $150 per cubic meter ($.19 to 15 per cubic yard) of erosion prevention. Based on these estimates, e different categories of treatment can be arranged according to different sts per unit volume of erosion prevention. That is, in order of decreasing st-effectiveness: 1) de-watering of large active gully networks; 2) cavation of stream channel fills down to a close mimic of original channel ometry; 3) addition of rock to excavated channel beds and banks; 4) check n construction in excavated channels; and 5) application of mulch and nting of trees on freshly excavated sideslopes of channels.

In December 1981, there were two apparently rapid mass movement ilures of perched fill which traveled a distance of about 100 meters m slopes of 45 to 60 percent into stream channels on this site. If ey had been accurately anticipated, they could have been prevented with out the same cost-effectiveness as the excavation of road fill from stream ossings. However, it would have been much less cost-effective to "pull" entire road reach in order to prevent a single such failure. The careful ping of headscarps, breaks in slope, leaning trees, and anomalous soils l groundwater discharge zones can help identify potential failures of s type.

A point of agreement among geologists is the relatively greater cost-ectiveness of heavy equipment over manual labor for any job that is sible for equipment. For example, on this site the installation cost single board check dams with a backhoe assisting laborers was 70 percent that for installation by laborers alone ($47 versus $67 each). The iciency of equipment is also seen in waterbar construction costs which e 65 percent of the cost for manually constructed waterbars ($30 versus each). The most dramatic comparison is, however, the cost of excavation heavy equipment versus that by manual labor. Heavy equipment moved earth l an average of about 15 times further than that moved by labor contract at only one-fifth the cost per unit volume ($6.70 versus $32 per cubic meter). These comparisons do not take into consideration the additional benefits of heavy equipment relating to the speed with which it can accomplish a given task and improved safety through the reduction of total person hours at a work site.

The preceding paragraphs contain cost-effectiveness information that can be generalized in terms of conceptual and logistical approaches to reducing erosion on this site. The conceptual approach involved: 1) reducing fluvial shear stress on erosive soils by returning the micro-drainage network to a more normal state and by removing erosive materials from channels; and 2) increasing shear strength at points of high stress by armoring unnatural and disturbed flowcourses with rock, check dams, submerged spillways, flumes, and alder plantings. In simple terms, the logistical approach involved specific choices of using heavy equipment or labor in applying treatments that fall under 1) and 2) above. The estimates indicated that the most cost-effective techniques were in the category of 1) above and that heavy equipment use should be maximized in order to minimize the need for labor intensive work.

Comparisons of cost-effectiveness should not be taken as criteria for eliminating less cost-effective techniques. For example, mulching and planting channel sideslopes have purposes other than just erosion control, namely revegetation, aesthetics, and perhaps aquatic habitat improvement. Also, management policies in the national park are different than those on other lands. While the reduction of short term and long term sediment sources was the major goal of rehabilitation on this unit, the identification of goals and management criteria are organizational and personal decisions that differ with land ownership and with land managers.

CONCLUSION

Although some post-logging erosion features had apparently become inactive by the spring of 1980, there were many sites with obviously high potential for continued sediment yield. Active gullying associated with misplaced culverts was originally identified as the major sediment source for the next decade. However, debris flows from saturated haul road and skid trail fill during the winter of 1981-82 indicate that this source might have been at least as important as gullying would have been in the next decade. Failures of road fill from intact stream crossings would have been another major sediment source, as culverts intermittently failed at different stream crossings, probably over a period of decades.

The reduction of sediment sources on this sites was estimated to cost between less than a dollar and about ten dollars per cubic meter of sediment for the most cost-effective erosion control technqies. The least cost-effective treatments for which estimates were made, were mulching and planting excavated channel sideslopes, at a cost of around $100 per cubic meter of sediment reduction. The accuracy of cost-effectiveness estimates is expected to improve with time as the sample size of treated sites increases and as the sample becomes more representative with occasional large rain events. Improving these estimates is considered useful for application outside the park and for better identifying treatment priorities on future sites within the park.

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