UNITED STATES GOVERNMENT

memorandum

N30

DATE: December 12, 1980

REPLY TO ATTN OF: Geologist

SUBJECT: Evaluation of Erosion Control Methods

TO: Associate Superintendent

Attached is our preliminary report entitled, "Summary Results Concerning the Effectiveness and Cost-Effectiveness of Labor Intensive Erosion Control Practices Used in Redwood National Park: 1978 - 1979."

The text describes the general conclusions which have been reached regarding the erosion control effectiveness of labor-intensive rehabilitation practices utilized within Redwood National Park during 1978 and 1979. Included is a brief summary of what was learned from the rigorous survey of rehabilitation sites, an analysis of the cost and cost effectiveness of each of the techniques used to control erosion on hillslopes and in stream channels (see Appendix A and B) and general recommendations on how and where to use certain techniques in the future. Techniques that were site specific or treatments that were one of a kind have not been included for just those reasons.

All 1978 and 1979 rehabilitation sites were extensively sampled, except Site 78-4 (lower Bond) and Site 79-3 (Airstrip Creek). Lower Bond Creek was not sampled because of the extremely small amount of erosion control work at that site. An evaluation of the Airstrip Creek Rehabilitation Site has been omitted from this report due to fundamental differences in the nature of contracting for labor-intensive work and the relative difficulty that would be involved in identifying unit costs for individual erosion control treatments.

Since much of this information, in an expanded format, is to be included in a final Evaluation Report of 1979 Rehabilitation Sites and Erosion Control Techniques, we would appreciate receiving constructive written comments and suggestions which can improve the quality and accuracy of our findings.

William Weaver

William Weaver

Summary Results
Concerning
the
Effectiveness and Cost-Effectiveness
of
Labor Intensive Erosion Control Practices
Used in
Redwood National Park

1978 - 1979

\- M E M O R A N D U M   R E P O R T -

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Issued - December, 1980

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I. INTRODUCTION

Most techniques which have been utilized to control erosion on logged land in Redwood National Park have focused on two principle sources of sediment: (1) sheet and rill erosion from bare hillslopes, and (2) stream channel erosion in natural water courses, at excavated stream crossings and within developing gully systems. The relative importance of each of these two types of erosion is not discussed in great detail within this report. However, most indications suggest that erosion on bare hillslopes is of lesser importance when compared to erosion which is occurring in excavated stream channels and gully systems.

Much of the surface erosion from bare hillslopes never enters active stream channel systems which would eventually transfer debris to Redwood Creek or its major tributaries. It therefore seems questionable, for the sake of erosion control, to provide blanket widespread treatments to control surface erosion on large expanses of bare soils which are not in close proximity to active stream channels. However, treatments used to control sheet and rill erosion on steep side slopes immediately adjacent to stream channels should assume comparatively high importance. While no direct comparison has been made between surface erosion treatments and channel erosion treatments, several of the relatively more expensive techniques which are utilized to control channel erosion could be viewed as more cost effective in the long run. Summary recommendations listed in Table 1 reflect this view.

TABLE 1

SUMMARY OF FINDINGS REGARDING LABOR-INTENSIVE EROSION CONTROL PRACTICES

TECHNIQUE (AS CURRENTLY UTILIZED)	RELATIVE EFFECTIVENESS	RELATIVE COST-EFFECTIVENESS	RECOMMENDATIONS
Check Dams	1	1	Continue use; extend experimental use to larger stream channels and modify design accordingly.
Channel Rocking	1	1	Continue use on small channels in which hand placed rocks can provide adequate protection; rock wetted perimeter of peak flow channel.
Jute With Straw	1	3	Use on steep slopes prone to extensive rilling near streams or gullies.
Straw	1	1	Use at 4,000 - 8,000 lbs/acre on areas where sheet and rill erosion may enter streams or gulies; e.g. excavated stream crossings.
Hydro-Seeding	1	2	Begin extensive test hydro-seeding on one or more 1980 rehabilitation sites.
Wood Chips	1	2	Experimentally apply on large test areas (moderate to steep slopes) where rilling is expected; in-plant with transplants.
Contour Trenches	2	2	Do not use extensively; limited use for dry ravel on steep slopes.
Ravel Catchers (Planter Boxes)	3	2	Limited use acceptable on steep slopes prone to dry ravel only; do not use long boards.
Grass Seed & Fertilizer	3	1	For erosion control purposes, use only if thick, uniform cover can be achieved prior to fall rains; watering may be necessary.
Wooded Terraces	3	2	Do not use as designed; new designs should be tested before widespread use.
Wattles	3	3	Discontinue use.

KEY: 1 = High 2 = Moderate 3 = Low

II. TREATMENTS USED TO CONTROL EROSION ON SLOPES

Most of the following treatments have been widely used in the park. Each of these techniques was compared in terms of their effectiveness in controlling erosion utilizing the following criteria:

(1) Ability to prevent or control rainsplash and sheet erosion.

(2) Ability to prevent or control rill erosion.

(3) Ability to trap sediment which has been eroded from upslope regions.

(4) Tendency to cause secondary problems (e.g. erosional, vegetative, aquatic, water quality, etc.).

Other aspects concerning each treatment that were also examined include:

(1) Percent slope on which the technique has been utilized.

(2) Aspect of hillslope on which the techniques were found.

(3) Quality of construction.

(4) Types of construction materials utilized.

(5) Construction methods.

Also, several mulches which have been quantitatively tested for controlling rill erosion at Site 79-2, and for preventing rainsplash and sheet erosion at Site 79-1 were also examined. While the complete results of these tests have yet to be analyzed, tentative observations have been incorporated within this report.

A. Contour Terracing Structures

Two methods have been used to treat slope erosion. The first involves installation, construction, or excavation of closely spaced rows of terracing structures which contour the hillslope. In general, these "terraces" are designed to disperse concentrated surface runoff and collect and store material which has been eroded from areas between rows, and to a lesser extent promote revegetation.

1. Contour Trenches

a. Advantages - Contour trenches are extremely efficient at trapping sediment derived from upslope rainsplash, sheet and rill erosion. At one location, contour trenches have controlled or stopped the downslope development of sizable rills. If they are not over-topped, the trenches intercept surface runoff and allow infiltration into the soil. This will reduce surface erosion but in some localities may adversely affect local slope stability (e.g. on steep slopes at excavated stream crossings).

b. Disadvantages - Contour trenches do not prevent or control rainsplash or sheet erosion and may actually aggravate these processes by creating small, over-steepened areas. Where infiltration rates are low, surface water collected by the contour trench has filled and overtopped the trench berm causing large rills to develop along its outside edge. In addition, the failure of a single contour trench near the top of the hillslope will result in the overtopping of each and every contour trench which lies in the path of surface runoff which emanates from the failed structure. Overall, this results in the development of large rills and substantial soil loss on slopes which may not have otherwise developed such features.

c. Recommendations - Our observations suggest contour trenches should not be used extensively at this time. They can frequently cause more erosion than they control. If a need does arise, they should only be used where infiltration rates are high. In the future, contour trenches may have limited use in areas with fairly steep (30% to 60%) slopes, good infiltration, and little excess runoff. In such circumstances they may act to inhibit dry ravel and minor surface erosion.

2. Wooded Terraces

a. Advantages - Wooded terraces are very effective at trapping sediment derived from upslope erosion. They provide large, level benches on which the products of upslope rainsplash and sheet erosion, as well as minor rill erosion, may be deposited without being transported further down the hillslope.

b. Disadvantages - Wooded terraces do not prevent rainsplash, sheet, or rill erosion. Construction of wooded terraces results in the creation of a sizable nick point and over-steepened area along their outside edge. Furthermore, they concentrate water and consistently cause rilling where this ponded water is discharged.

c. Recommendations - Wooded terraces have only been used at Site 79-1, although at this site they were used quite extensively. Several of these terraces are already failing after just a single winter's runoff. Judging from the condition of nearby hillslopes which were not treated, wooded terraces appear to cause more erosion through the collection and concentration of surface runoff than they control through the collection of sediment derived from upslope areas. As a result, we do not recommend the continued or widespread use of wooded terraces as a slope erosion control device unless the design is significantly improved. Any proposed design changes should be accompanied by at least one year of experimental application prior to wholesale utilization.

3. Wattling

a. Advantages - In general, it was found that wattles trap sediment on their terraces to a greater or lesser degree (mostly lesser) and occasionally control a rill that developed on upslope areas. Trapping efficiency depends largely on terrace width. Long-term slope stability may be enhanced if willow or other sprouting species are incorporated in the wattle bundles.

b. Disadvantages - More often, wattles do not prevent or control rilling, do not prevent rainsplash or sheet erosion, and trap insignificant quantities of eroded sediment. Like wooded terraces, construction of wattles creates oversteepened areas and small nick points across a slope. It was also not uncommon for a wattle to actually concentrate runoff and thereby cause a rill to develop that may not have been formed in the absence of the treatment.

c. Recommendations - It is recommended that the use of wattling as an erosion control technique be discontinued because of its expense and relative ineffectiveness. Other methods for re-establishing vegetation have met with better success and many less expensive and more effective techniques for surface erosion control have been developed and tested.

4. Ravel Catchers (Planter Boxes)

a. Advantages - Ravel catchers may be utilized on very steep slopes (60% or greater).

b. Disadvantages - Because planter boxes are virtually impenetrable barriers to surface runoff, they act to concentrate water and discharge it at discreet locations along the hillslope. As a result, approximately 50% of these areas where planter boxes have been used have shown significant rilling below this point of discharge. Additionally, planter boxes which store large amounts of material on steep hillslopes could potentially fail and deliver relatively significant quantities of sediment into nearby stream channels.

c. Recommendations - This technique has been used widely throughout the park in a variety of situations. Future use should be restricted to steeper slopes (greater than 50%) that are prone to dry ravel rather than slope failures or significant surface erosion. If use is continued, areas between planter boxes should be treated with some other technique such as a mulch to disperse concentrated surface runoff which may discharge near the "outlet" of each structure. In all cases the use of very long (greater than ten feet) multiple board planter boxes should be eliminated.

B. Surface Treatments

A second set of treatments which have been used to control surface erosion include those techniques which are applied as surface treatments over broad areas rather than as contour-distributive devices which tend to collect erosional products rather than prevent initial sediment movement. Surface treatments are designed to prevent erosion.

1. Grass Seeding with Fertilizer

a. Advantages - The degree of success for surface treatments such as grass seeding and mulch is directly related to the amount of cover which lies in direct contact with the ground surface. Therefore, where grass is thick (covering 90% or better - think of a lawn) rainsplash and sheet erosion is generally controlled (when viewing an area with 90% cover, 10% of the ground surface would be visible). In such conditions, runoff is somewhat dispersed and rill erosion is therefore fairly well prevented. Sediment that does move is frequently trapped by grass clumps and thatch or especially heavy concentrations of growth. Grass also generally looks good (cosmetic), improves soil structure, and is inexpensive to apply (see Appendix A). At Bond Creek (Site 79-1) and Upper Copper Creek (Site 79-4), grass has been locally effective in controlling frost heave, as well as rainsplash, sheet and rill erosion, but was not thick enough to be effective for at least the first half of the winter.

b. Disadvantages - For the most part, grass seeded at the 1978 rehabilitation sites has been ineffective as an erosion control technique. This has occurred because of late seeding, late germination, harsh site conditions, infertile subsoil, spotty and poor application procedures, plus other reasons which have together combined to produce generally poor surface coverage. On all 1978 rehabilitation sites, grass is doing well locally; but, on the average, covers less than 20% of any bare soil area. It appears that at least 80% or better coverage is needed for even minimal erosion control. Finally, reproduction of grasses at 1978 work sites has been very low. While 1979 sites appear to have developed more extensive stands of grasses in response to early seeding and fertilization, even moderate slopes (10% to 30%) show signs of sheet wash which occurred primarily during the first few rainstorms when the grass had not yet been established as an abundant (approaching 90%) ground cover. On slopes over 30%, rill erosion as well as rainsplash and sheet erosion is prevalent. While extensive and repeated fertilization may result in the development of healthy, vigorous stands of grass, such a program would result in local degradation of stream water quality. Fertilizing at the present rates may already be creating algae blooms in many of the streams down slope from treated areas. Other negative aspects which are associated with grass seeding as currently practiced on rehabilitation sites include:

(1) At the present degree of ground cover, grass only prevents minor rainsplash, sheet and rill erosion (literally none at Site 79-2).

(2) Grass does not trap significant quantities of sediment derived from upslope erosion.

(3) It attracts herbivores onto wet slopes.

(4) Grass appears to compete (fairly successfully) with native species.

(5) It performs very poorly on slopes with hot, dry aspects.

c. Recommendations - All sites which were sampled have been grass seeded and fertilized once, except Site 78-5 which was seeded twice. To this date, a consistently thick cover has not been obtained and may be unobtainable, although a much heavier and rigorous fertilizing program could do much to reach this end. Grass can be an effective erosion control technique provided a thick, consistently uniform cover of grass is obtained prior to the advent of fall and winter rains. However, to reach this end, a more rigorous management program is needed including a well planned fertilizing schedule and a head start on growth by providing irrigation or other watering prior to seasonal rains. If the present program is maintained, some erosional benefits will be achieved but the results will be more cosmetic than sustantive.

2. Hydro-Seeding

a. Advantages - Because a protective mulch layer is sprayed onto the ground surface together with grass seed and fertilizer, hydro-seeding avoids the problem of early rainsplash, sheet and rill erosion which now occurs on broadcast seeded areas. In addition, heavy applications of the bio-degradable wood fiber mulch material, along with grass seed and fertilizer, would result in protection which could approach that of straw mulch which has been spread by hand.

b. Disadvantages - Logistically, hydro-seeding excavated stream crossings and other steep, bare soil areas would require the close coordination and synchronization of rehabilitation activities during the heavy equipment phase of slope and road work. This could be difficult and not always feasible.

c. Recommendations - Although this technique has not been used in the park rehabilitation program as of 1979, it would be one way to provide immediate slope protection to those bare soil areas which would otherwise suffer accelerated surface erosion during the first few winter rains. In addition, the binding action of the mulch, water, seed, and fertilizer mixture is a viable method of producing the thick, consistent cover that is needed to achieve good surface erosion control. As a result, we recommend extensive test hydro-seeding be accomplished at one or more of the 1980 rehabilitation sites, where access is feasible.

3. Straw Mulch

a. Advantages - Mulching bare soil areas with straw has proven to be the most cost effective technique utilized to control surface erosion. It also reduces runoff (promotes infiltration), disperses runoff, retains soil moisture, and keeps the surface soil structure open. On environmentally harsh sites, these factors may combine to aid in a more rapid re-establishment of vegetation.

b. Disadvantages - At heavy application rates (4,000 - 8,000 lbs. per acre) negative effects of straw application may include:

(1) The prevention of seed sprouting and growth (observed reductions of about 25% at 4,000 lbs. per acre rate and about 80% or more at the 8,000 lbs. per acre application rate during the first growing season).

(2) The loss of straw during periods of heavy wind.

(3) The development of potentially unfavorable carbon/nitrogen relationships in the soil.

On steep slopes composed of loose fill material, a heavy application of straw has the potential to maintain high infiltration rates, possibly causing soil saturation and the development of local, shallow failures. Straw spread at a rate of 2,000 lbs. per acre is not considered as effective as the heavier rates and should be regarded as more of a vegetative technique than an erosion control measure. At this lower rate, rainsplash, sheet and rill erosion are neither adequately prevented nor controlled. However, grass and other vegetation easily grows through this light application of straw; thus, when grass seed and fertilizer is added, greater erosional benefits will be obtained once the grass has grown. Disadvantages of this technique are the same as for grass seed without straw.

c. Recommendations - Straw was spread at all 1979 sites, both by itself and in combination with other treatments. It was primarily spread at a rate of 2,000 lbs. per acre. Straw has been experimentally spread at a rate of 4,000 lbs. per acre (Site 79-1) and at 9,000 lbs. per acre (Site 79-2). Straw spread at rates from 4,000 to 8,000 lbs. per acre is generally effective in preventing and controlling rainsplash, sheet and rill erosion as well as being very effective at trapping sediment derived from upslope surface erosion. Straw's effectiveness in controlling rill erosion appears to be improved by punching the straw into the surface soil. This technique also helps to prevent wind blown straw from leaving the site. On areas of 25% or less slope gradient that do not receive abundant excess surface runoff, the 2,000 lbs. per acre rate is probably adequate. Slopes over 25% should have straw spread at the heavier application rate; the actual rate depends on the potential for excess surface runoff, the steepness of the slope and the inherent erosiveness of the soil material. On slopes over 70%, straw should be secured to the hillslope with jute netting or some other stabilizing agent (see below). In general, straw has proven to be one of the most effective and the most cost effective techniques for controlling surface erosion. Its use should be continued on a widespread basis in areas where erosion of exposed soil would likely contribute significant quantities of sediment to active stream channels or gully systems.

4. Jute-Secured Straw

a. Advantages - Jute over straw is the most effective slope treatment used in the rehabilitation program to control surface erosion.

b. Disadvantages - Revegetation is hindered to a greater extent when jute is used to secure straw to bare slopes. Also, since installation is relatively labor intensive, the relative cost effectiveness of jute-secure straw is lowered considerably by the comparatively higher cost associated with installation.

c. Recommendations - The expensive portion of the installation procedure involves placing and securing the jute over the straw. The actual erosion control device is the straw and surface soil could approach this technique in relative effectiveness (e.g. a heavy application of straw punched in by rollers or by hand could be equally as effective an erosion control measure). In general, most slopes that need to be protected need only the heavy application of straw. Those slopes which are prone to excessive rilling, have a large volume of surface runoff flowing over them during winter storm events, or are very steep, should be protected with jute over straw. It is recommended that this technique be utilized on steep side slopes at excavated stream crossings where soils are frequently wet and prone to surface erosion.

5. Woodchips

a. Advantages - In general, woodchips prevent rainsplash and sheet erosion, disperse runoff and prevent rilling fairly well, retain near surface soil moisture nearly as effectively as straw and trap sediment derived from upslope erosion.

b. Disadvantages - The most important negative aspect associated with utilizing woodchips (especially redwood chips) to control surface erosion is that they prevent or hamper the germination and/or growth of seeds. In several areas where chips have been spread on ripped road surfaces great expanses of native weeds and grasses have invaded the areas surrounding the chips but very little vegetation has grown within the treated region. Chips also exert demands on soil nitrogen unless they are composted, and are both much more expensive and logistically more difficult to use than straw.

c. Recommendations - Redwood chips have been spread at two locations in the park: Copper Creek (Site 79-3) and Bridge Creek (Site 79-2). A test plot also exists at Site 78-1 (Miller Creek) which consists of various conifer and shrub chips. The test plot at Bridge Creek is the only area where chips have been applied on several test areas on 1979 rehabilitation sites to control surface erosion on moderate and moderately steep side slopes (40% - 60%) of excavated stream crossings. Revegetation of these sites should be accomplished through transplanting rather than through direct seeding. Hardwood or composted chips will decompose more readily than redwood chips and may therefore yield to revegetation efforts more quickly. Fertilizer may need to be applied to achieve favorable carbon/nitrogen relationships in the soil.

III. TECHNIQUES USED IN STREAM CHANNELS

A variety of techniques have been used to control the erosive potential of concentrated surface runoff. These include energy dissipation devices, stream diversion techniques, channel armoring, and water conveyance structures. Only two of these, check dams and channel armoring (rocking) were compared for cost effectiveness (see Appendix B). Other techniques which have been used are briefly described but because of fundamental differences, they could not be adequately compared on a standardized basis.

1. Check Dams

a. Advantages - Excavated stream crossings that have been check dammed have undergone little or no channel adjustment. Check dams prevent channel downcutting, help stabilize channel banks, and provide a stable substrate for revegetation. Channel bank and channel bed revegetation increases long term channel stability through the development of root networks. In at least two sample locations check dams have protected near-vertical banks with no bank failure. Check dams at Bridge Creek (Site 79-2) and Bond Creek (Site 79-1 and Site 78-3) have stabilized stream channels that would have undergone significant channel adjustment and have prevented major bank failures at these locations. Where check dams have been installed after significant channel degradation (i.e. halfway through the first winter), they have halted further downcutting and bank-cutting in unstable stream reaches. Maintenance requirements of check dams appears to be less than originally forecast, with one yearly maintenance period during the winter being sufficient.

b. Disadvantages - No check dams sampled were failing although at one location headward erosion, now taking place below a check dam reach, may eventually cause the upstream structures to fail. Additionally, at one 1978 site and one 1979 site, organic debris had plugged the spillway notch and caused water to back up and scour around the edge of a single check dam. Over the long term, if stream banks and stream bed vegetation is insufficient or poorly established, channel downcutting will occur as check dams begin to deteriorate. This deterioration is expected to begin within ten to twenty years. The yearly maintenance period is also a disadvantage.

c. Recommendations - Bond Creek (Site 79-1 and Site 78-3), Miller Creek (Site 78-1), and Bridge Creek (Site 79-2) all had check dams installed to protect excavated stream channel reaches. At all sites, the check dams have performed excellently, although construction standards at Miller Creek were below that of the other sites. Milling of redwood boards in 1979 has reduced the contract price of check dams while increasing their overall quality (total cost, including mill workers' time and material has not been determined at this time). We recommend the continued use of check dams at excavated stream crossing sites because of their high success as a labor-intensive technique in stabilizing the channel and preventing both downcutting and bank erosion along potentially unstable reaches. Although relatively costly as compared to measures which control slope erosion, check dams act to inhibit or prevent major erosional problems from developing or enlarging in excavated stream channels and gully systems. Hence, their cost effectiveness must be viewed as extremely high in relationship to other labor intensive techniques which have been applied and in relation to the amount of erosion which has been successfully controlled.

2. <u>Channel Armoring (Rocking)</u>

a. Advantages - Hand rocking stream channels can effectively stabilize stream beds which would otherwise be scoured during winter events. It is also capable of offering some protection to a channel even if part of the rock within a channel is removed by high flows.

b. Disadvantages - Most of the channels rocked by labor-intensive methods have undergone some adjustment during the first winter. Side (bank) cutting is prevalent although many areas also show downcutting. In general, after one season's experience, this technique has not proven as successful as hoped, primarily because of the amount of channel adjustment which has occurred in response to a deficiency in the quantity of rock used to protect the bed and banks and the transport (removal) of smaller rocks which occurs during peak flow periods. Additionally, the use of rock large enough to prevent plucking is determined by the physical limitations of the workers. This disadvantage can be minimized by using horses to transport larger rocks than could be carried by hand. Many sites also lack nearby sources of adequately sized and graded rocks which can be used at stream crossing excavation sites. Finally, maintenance requirements for rocked stream channels is higher than was initially thought, with two or three maintenance periods the first year and perhaps one a season for the next several years being required.

c. Recommendations - Numerous variations of stream channel rocking have been performed within the park, among them double rocking, rocking and staking, and rock and wire reinforcing. Labor-intensive stream channel rocking is most successful if a fairly heterogeneous mixture of rock sizes is used which contain enough large rocks (rocks which will not be moved during peak flows) to keep smaller rocks in place. This mixture of rocks tends to protect the channel more fully than a homogeneous layer of large rock or a blanket of small particle sizes. Stakes and chicken wire with rebar have been used successfully instead of large rocks to prevent rock plucking, although these techniques have yet to be fully tested and evaluated. Other factors to consider when desiring to successfully rock a stream channel by labor-intensive methods include:

(1) The channel bottom of the excavation should be wide enough to handle peak flows.

(2) The rock should be placed high enough on the side bank to contain peak flows and prevent bank scour.

(3) Enough rock should be used to adequately protect and armor the bed of the channel.

(4) Rock sizes and/or securing techniques should be employed to assure that peak flows do not remove the protective material.

3. Water Ladders, Nick Point Plugs, and Their Variations

a. Advantages - Water ladders, nick point plugs and other related techniques (water flumes, etc.) are all used to convey concentrated runoff over steep sections of hill-slopes. These techniques prevent the headward migration of nick points and major gully headcuts. Although extremely site specific, all uses of these techniques have been successful in controlling continued erosion.

b. Disadvantages - The main disadvantage of these structures is that at some point in time they will deteriorate and fail. It is likely that the erosion being prevented at this point in time will be merely delayed to a later date. Furthermore, in the past, the placement of some structures has been questionable due to the relatively small discharge which they carry during the winter months. In these cases less costly techniques such as rock or secured slash could have been used with equal success. Additionally, the construction of structures that would be large enough to contain peak flows of streams with even a moderately high discharge may be physically or logistically impossible, as well as prohibitively expensive.

c. Recommendations - Ultimately, it appears to be more cost effective to perform minor excavations and develop at least partially excavated water courses at locations where nick point plugs or water ladders would otherwise have to be constructed. In areas inaccessible to heavy equipment these techniques should be relatively cost effective where peak flows would otherwise be sufficient to develop headcuts and form major gullies.

4. Log Deflection Points

Log deflection points have been utilized at only one site (Site 79-1) and although they functioned as intended during several storms (diverting stream flow away from unstable channel banks), the stream has now degraded below the level of the logs and has rendered three of the four deflection points useless (except perhaps at peak discharges). At isolated locations there may be some need for the continued use of these structures in the future. The same results may be accomplished by heavily aromoring the streambanks with rock provided the raw material can be derived locally.

5. Notched Log

This is a relatively minor rehabilitation operation which can be utilized to provide local base levels within a degrading reach of stream channel. Rather than remove large pieces of organic debris that are encountered during excavation or as stream channels adjust by downcutting, logs may be notched (with chain saws) to provide spillways similar to those utilized in check damming. These notched logs then act as local base levels, or check dams, below which stream channels are not likely to downcut.

IV. MISCELLANEOUS TECHNIQUES

1. Energy Dissipators

Most of the energy dissipators used on 1978 and 1979 rehabilitation sites are located at the base of other structures, such as check dams and water ladders. Numerous kinds of energy dissipators have been used and, generally, those made with rock have been the most effective; those using slash, etc., being somewhat less effective and those made from milled or split board being even less effective. An exception to this order has been the utilization of split boards as energy dissipators at the base of check dams in conjunction with wing walls in front of the next downstream check dam. Split boards set in herringbone fashion that were used at Site 78-2 to control minor rill erosion have been rendered totally useless after last season's storms. In the future, herringbone energy dissipators should not be utilized.

2. Manual Excavation, Ditches, Etc.

Manual excavations, general shovel work and other labor intensive activities of this type are considered to be cost effective because there is no alternative to them. The degree of effectiveness is highly dependent on the siting and prior approval of work to be completed, both of which are the responsibility of the Contracting Officer's Representative at the work site. Overuse of manual labor at rehabilitation sites can be extremely cost ineffective if not closely controlled to provide maximum erosion control effectiveness.

3. Waterbars

Waterbar construction, repair, and maintenance is an effective rehabilitation technique, although effectiveness is again dependent on the proper location and construction of these structures. Adequate site mapping and pre-planning for the placement of waterbars is necessary and can result in waterbars being one of the more cost effective techniques used to control surface erosion on rehabilitation sites.

V. CONCLUSIONS

Although many erosion control techniques have been used in the park, none have been one-hundred percent successful. This is due to a variety of reasons, of which the inherent capabilities of the technique is only one. Where the technique is used (generally) and where it is placed (specifically) are also very important factors, as is the quality of construction. It was apparent in some locations that more work should have been done to control erosion, while at other sites, techniques were utilized where no erosion control device was needed. The sophistication of where and when to use a particular technique will only come with experience. Guidelines set forth here should help.

As different labor-intensive techniques are used more extensively in the park, cost-effectiveness data can be refined further. Also, as techniques such as the check dams placed in the 1978 and 1979 sites grow older, more accurate predictions of their longevity can be made. In addition, through the continued use of these techniques, hybrids of methods to fit particular situations will also be made, adding to a technique's effectiveness.

In conclusion, probably the single most important factor in successfully prescribing labor-intensive erosion control techniques is proper site evaluation as to current and expected erosion processes and rates. For example, if the walls of a failed crossing are still vertical after many years, then the emphasis should not be so much to carefully outslope the excavation, but rather to make sure the channel bottom is wide enough to contain peak flows without climbing (or cutting) the banks. If site conditions are harsh with a hot, dry aspect, then the emphasis should be placed in controlling dry ravel and using a mulch to conserve precious moisture. Or, if a site is prone to high amounts of runoff (as evidenced by numerous rills, fans, etc.) then care should be taken to control future rills after the area is redisturbed. A mental noting of these types of signs can do much to aid in the selection of proper rehabilitation techniques.

APPENDIX A

Table 2 lists the slope erosion control treatments in descending order of their relative cost effectiveness. Also listed is their cost range, their average cost (weighted by how much of the technique has been used at a specific cost), the cost of treating a 1,000 square foot plot on a 50% slope (assume a 20 foot by 50 foot area, length going up and down slope), the cost range to treat such an area, the relative erosion control effectiveness of each technique, the cost effectiveness and finally, the cost-effectiveness range. The cost-effectiveness range was determined by the cost range and not by a range of effectiveness.

The effectiveness of each technique was determined in the following method: Upon completion of the field survey of the 1978 and 1979 sites, the results of how each technique fared in the following four categories were tallied and then totalled:

(1) Ability to prevent (control) rainsplash and sheet erosion.

(2) Ability to prevent (control) rill erosion.

(3) Ability to trap sediment which has been eroded from upslope areas.

(4) Tendency to cause secondary problems (e.g. erosional, vegetative, aquatic, water quality, etc.).

From these totals, a percentage of how often a particular technique prevented erosion, trapped sediment or caused problems, was obtained. For example, ravel catchers never prevented or controlled rainsplash or sheet erosion (0%), prevented some rill erosion (17% of the time), trapped sediment most of the time (82%), and caused problems (usually rills) 50% of the time (thus did not cause problems 50% of the time) for an effectiveness value of 149 (0 + 17 + 82 + 50). It should be noted that the numbers that were totalled to create the percentages were for "treatment areas" and not for individual parts of a technique. Using ravel catchers again; if there were six structures at one site and three were causing rills, and six at another site with none causing rills, then the number of ravel catcher sites causing problems would be 50% (causing rills at one site, not causing rills at another).

Cost effectiveness was determined by computing how much of a technique was needed to "cover" the hypothetical 1,000 square foot plot and multiplying this amount by the weighted average cost to obtain a total cost to treat the area. This cost was then divided by the effectivenss to obtain cost effectiveness (this figure was multiplied by 100 to put into a more understandable form).

It should be noted that the numbers in Table 2 are not absolute but are close to what the true relative value of the effectiveness of each technique is. The only effectivenss value that will probably change is the value for straw. As an erosion control technique, straw was generally applied (and hence sampled) at the 2,000 lb/acre rate. Thus, if it is used more at the 4,000 - 8,000 lb/acre rate, its increase in erosion control effectiveness could be more than offset by the increase in percentage of problems caused (primarily, vegetation exclusions). This change in value should not affect its position in the overall ranking scheme. As applications and structures begin to age, and more are installed, individual percentages for each category will probably change but overall values should remain fairly constant.

TABLE 2

COST EFFECTIVENESS TO TREAT A 1000 SQ FT, 50% SLOPE TREATMENT AREA

TECHNIQUE	COST RANGE	WEIGHTED AVERAGE COST PAID IN PARK($)	WEIGHTED AVERAGE COST FOR HYPOTHETICAL TREATMENT AREA ($)	COST RANGE FOR TREATMENT AREA ($)	EFFECTIVENESS 400 = TOTALLY EFFECTIVE	COST EFFECTIVENESS (x 100)	COST EFFECTIVENESS RANGE (x 100)
Straw @ 4000 lbs/acre	11.50-12.75 per 1000 sq ft	12/1000 sq ft	12.00	11.50-12.75	319	3.8	3.6-4.0
Grass Seed and Fertilizer	.93- 2.49 per lb	1.14 lb	9.89	9.45-33.74	141	7.0	6.7-23.9
Straw @ 8000 lbs/acre	23.00-25.00 per 1000 sq ft	24/1000 sq ft	24.00	23.00-25.00	319	7.5	7.2-7.8
Contour Trench	.34- 1.11 per ft	.36/ft	43.20	40.80-133.20	200	21.6	20.4-66.6
Hydro Seed (Theoretical)	40-80 (est) per 1000 sq ft	60/1000 sq ft	60.00	40.00-80.00	(est) 270	22.2	14.8-29.6
Wood Chips	80 - 110 per 1000 sq ft	95/1000 sq ft	95.00	80.00-110.00	250	38.0	32.0-44.0
Ravel Catchers	.70- 2.46 per ft	1.34/ft	66.76	35.00-123.00	149	44.8	23.5-82.5
Wooded Terrace	.53- 2.42 per ft	.59/ft	59.00	53.00-242.00	125	47.2	42.4-193.6
Jute w/straw @ 4000	181-281 per 1000 sq ft	230/1000 sq ft	230.00	181.00-281.00	327	70.6	55.3-95.9
Jute w/straw @ 8000	193-293 per 1000 sq ft	242/1000 sq ft	242.00	193.00-293.00	327	74.2	58.9-89.5
Wattles @ 6-foot spacing	.61- 2.95 per ft	1.46/ft	233.60	97.60-472.00	158	147.8	61.8-298.7
Wattles @ 4-foot spacing	.61- 2.95 per ft	1.46/ft	379.60	158.60-1262.00	158	240.2	100.0-485.4

APPENDIX B

Table 3 shows the relative cost effectiveness of check damming and hand rocking a 60-foot long channel with a gradient of 25%. For these comparisons, it was determined that nine check dams would be needed, each with an effective height of 1.5 feet, and that the rock should cover an area of 300 square feet (60 feet by 5 feet). This would insure adequate protection of side banks. The table contains the same categories as Table 2. Effectiveness was determined using the same method as before, except that only one criteria (the ability of the technique to prevent and/or control side cutting and downcutting) was used. All channels (including cross road drains) that were hand rocked or check dammed were included in the sample.

In conclusion, hand rocking of channels is both less effective and less cost effective than using check dams. Maintenance requirements of rocked channels is high the first few years, although the maintenance requirements of check dams may be higher overall. Total erosion over time for both techniques is probably about equal or perhaps more for check dams, since eventually they will fail and possible cause water to be diverted into channel banks.

Rocking with heavy equipment is probably more viable than hand rocking, although more than half of the heavy equipment rocked channels underwent fairly substantial channel adjustment. These channel adjustments may be avoided in the future through proper rocking techniques, such as excavating the channel bottom wide enough to contain peak flows and using a heterogenous mixture of rock.

It is difficult to say which technique is preferable at the present time and more studies should occur, mainly the trial check damming of large streams and the quantitative assessment of changes occurring in properly rocked channels.

TABLE 3

COST EFFECTIVENESS TO CONTROL CHANNEL EROSION IN A 60-FOOT LONG CHANNEL WITH A 25% GRADIENT

TECHNIQUE	COST RANGE (IN DOLLARS)	AVERAGE COST PAID IN PARK (IN DOLLARS)	WEIGHTED AVERAGE COST FOR TREATMENT (IN DOLLARS)	COST RANGE FOR CHANNEL TREATMENT (IN DOLLARS)	EFFECTIVENESS (100 = TOTALLY EFFECTIVE)	COST EFFECTIVENESS (x 10)	COST EFFECTIVENESS (x 10)
CHECK DAMS	20.40 - 45.00/ea	35.51/ea	319.59	183.78 - 409.00	88	36.3	20.9 - 46.5
ROCKING	.48 - 1.70/sq ft	1.23/sq ft	369.00	144.00 - 510.00	58	63.6	24.8 - 87.9