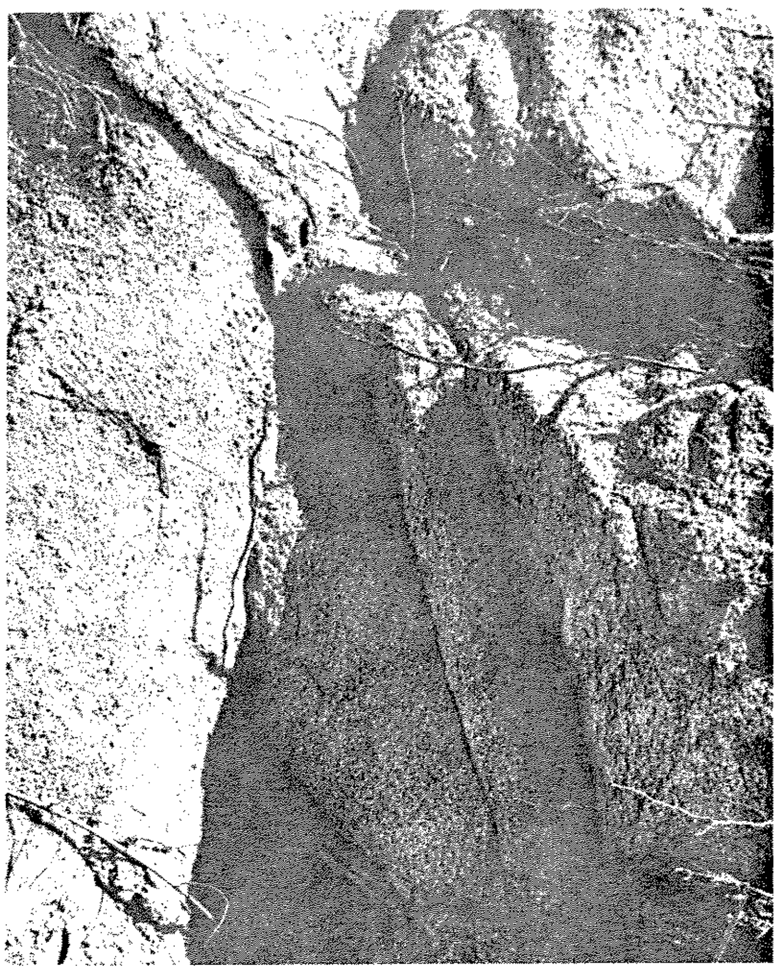
Proceedings of the Conference on

DECOMPOSED GRANITIC SOILS: PROBLEMS AND SOLUTIONS

October 21-23, 1992, Redding, California



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Sari Sommarstrom, Ph.D.
Conference Coordinator &
Proceedings Editor

UNIVERSITY EXTENSION
University of California, Davis 95616-8727

PREFACE TO THE PROCEEDINGS

A proceedings is essentially the only permanent record of the presentations made at a conference. I felt strongly that we needed such a record because this conference was the first time that experts and practitioners on the subject of decomposed granitic (DG) soils have assembled together to pool their knowledge. In addition to syntheses of past research, new findings were also shared. All of this information needs to be brought into the literature for wider dissemination (we won't have to keep citing "personal communication" for our references).

All of the authors deserve your appreciation for their hard work. Many presenters developed their presentations and papers on top of their regular job duties, and they generously succumbed to my arm twisting to participate. You will notice some changes from their original presentations. A few titles were altered, text was expanded to substitute for slides used in the presentation (a picture is worth close to a 1000 words?), and additional material was added, all to help with clarification.

In addition to the conference papers and poster abstracts, an "invited paper" is included by Janine Castro, a geologist with the USDA Soil Conservation Service, who presented such a clear explanation to me on the field trip of the unique properties of the Shasta Batholith that I thought other non-geologists could also benefit from her clarity.

Another supplement to these Proceedings is the complete publication list by Walter F. Megahan, who is sometimes referred to as "Dr. DG", on the subject of geomorphic processes on granitic materials. His "mega-research" contributions over the past 20 years on the Idaho Batholith have done more than those of any other single individual to increase our understanding of the behavior and control of DG soils. While his paper in the Proceedings synthesizes much of that research, we now may be able to locate the title of that elusive "I-know-it's-a-Megahan" reference in this comprehensive collection.

Post-Conference Evaluation

Conference participants provided us with an 80% return rate (100 out of 125) of the Evaluation forms! This remarkable response indicated that 94% agreed or strongly agreed that overall, the Conference was valuable, 82% felt the length was just right (13% said too short), and 86% thought the level was just right. People seemed generally pleased with the expertise and quality of the speakers, the diversity of topics and disciplines, the practical applications discussed, the descriptions of failures as well as successes, and the food.

Suggestions for improvement included more time for audience questions, workshops with direct participation and hands-on solutions, less repetition or redundancy by speakers, more hand-out materials, and more elbow room. Only 25 responded to the question about whether a conference on this subject should be repeated. Most (23) replied that it should, suggesting about every 2-3 years. Anyone interested in taking the next one on?

Special Thanks

I was given more credit than I deserved in the success of this Conference. Many, many thanks must also go to the following University Extension staff, whose professional efforts made this Conference a reality and a success: Dennis Pendleton for supporting the original concept and shepherding it through all the hoops, Bruce Winner for his unflappable assistance with the publicity, brochure and Conference, Debbie Roberts for tracking all the details and for patience and grace under pressure, Mary Erba for smoothly handling the daily details during the Conference, and the many others at Davis who also helped. Appreciation for logistical assistance with the field trip is also given to Bill Brock of the U.S. Fish and Wildlife Service, Weaverville and John McCullah of the Trinity County Resource Conservation District.

Sari Sommarstrom, Editor and Coordinator
Etna, California
May, 1993

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OPENING REMARKS

SARI SOMMARSTROM
Conference Coordinator

Welcome! I'm so glad to see all of your gathered here today. When the idea of this conference first popped into my head several years ago, I was not sure what the response might be. It has become my "Field of Dreams": create it, and they will come. Well, we created it and you did come! As of this morning, at least 125 are registered participants, plus our 23 speakers.

Some of you may be "fanatics" on this subject who have spent a lifetime studying granitic soils, while others may have only recently learned that DG stands for something besides the Data General. Preventing or controlling erosion on decomposed granitic (DG) soils is commonly viewed as a very intractable problem. These sugar-like, non-cohesive soils have been described as behaving like wet oatmeal or concrete when saturated. Another analogy I've heard is that DG soils are like a hemophiliac: they appear normal on the surface (and even grow good trees), but once the surface is cut, they will bleed and bleed. Exceptional efforts are then required to stop this "bleeding".

PURPOSE OF CONFERENCE

The purpose of this conference is to pool our knowledge about the behavior and control of disturbed decomposed granitic soils and, as a result, come away more knowledgeable about preventing and correcting DG erosion problems. As a corollary, the intent is also to build a network of resource managers, researchers, and erosion control specialists who can assist one another with their DG problems. Some of this networking is already happening, based on recent phone calls, because of the urgent needs for erosion control on newly burned granitic sites such as the El Dorado National Forest and the Salmon River, Idaho.

To help succeed in this endeavor, the conference has 5 components:

Speakers

Over the next two days, 23 speakers will share their knowledge with you. These speakers come from a variety of disciplines: geology, soil science, watershed management, forestry, geotechnical engineering, fishery biology, horticulture, and landscape architecture. They also are employed by different sectors: government (local, state, and federal), private industry, and universities. Some are professional researchers summarizing years of studies, while others are field people reporting their observations from personal experience. All of these perspectives are important in understanding the problems and solutions of DG soils.

In addition, a broad range of geographical experience is represented: from the Idaho Batholith to the southern Sierra Nevada, from Lake Tahoe to the Klamath Mountains. Descriptions of these widespread granitic areas will help us better understand their similarities and differences. For example, how transferable are the research conclusions developed on granitic soils in the Idaho Batholith to specific DG areas in California?

Poster Session

Not all of the interesting findings could be reported by speakers, so a concurrent Poster Session in an adjacent room is also available. Summaries of these 13 displays are included in the Conference Syllabus. I encourage you to view the posters and talk to their presenters in the Poster Room during the breaks, at lunch, and this evening.

Field Trip

One of the reasons this Conference is being held in Redding is that we are close to one of the most severe cases of accelerated erosion in California's granitic terrain: the Grass Valley Creek watershed in eastern Trinity County. About 72% of this 23,500 acre watershed is underlain by decomposed granite parent materials (of the Shasta Bally Batholith). The optional field trip on Friday will explore some of the erosion problems and control efforts with the help of 12 different speakers. Examples will include sediment storage ponds and dam, cut and fill slopes, timber harvested sites, sediment monitoring methods, and log check dams.

If time is available, a stop will also be made in the Middle Creek watershed just west of Redding, which represents an older and less erosive granitic pluton (Mule Mountain Stock).

Proceedings

Each speaker's presentation will be written up for a Proceedings, which will be published by University Extension in early 1993. This will be the only permanent record of the Conference and will provide a new reference for the various findings not previously published. Each participant will receive a copy and extra copies will be available for distribution to sustaining sponsors, libraries and, at cost, to those requesting one.

Participants

After looking over the registration list, I couldn't help noticing that you, the participants, also share the diversity of disciplines, employment, and geography that our speakers represent. Please share your knowledge on DG soils with each other and the speakers so we can all learn from one another. Time for socializing is provided by having lunch together each day in the adjoining room and leaving unscheduled time in the evenings. Networking can continue with the help of the list of participants and speakers, which U.C. Extension will have available to you before the Conference is over.

ACKNOWLEDGEMENTS

I'd like to offer special thanks to our sustaining sponsors for their financial contributions which allowed this Conference to be so affordable. Initial seed money was provided by the Trinity River Basin Fish and Wildlife Task Force and the Klamath River Basin Fisheries Task Force because of the very pressing problems these two watersheds are experiencing from excessive granitic sediment impacting salmon and steelhead habitat. In addition, the California Dept. of Forestry and Fire Protection and the U.S. Forest Service - Pacific Southwest Region have contributed to the Conference because of their management concerns with decomposed granitic soils.

We also appreciate the 12 co-sponsors, who have endorsed the purpose of the Conference and distributed the Conference announcement to their members or mailing lists.

DECOMPOSED GRANITE IN CALIFORNIA

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ABSTRACT

Granitic rocks are composed of tightly interlocked grains of feldspar, quartz and dark minerals. They are tough and resistant before weathering but decompose into a granular material called grus, or decomposed granite (DG). This weathering takes place in three stages. Biotite weathering creates minor fractures, causing the rock to become permeable, lose strength and eventually disintegrate. Decomposed granite is extremely erodible and produces problems for road builders, foresters and engineers.

Photo 1. Decomposition and erosion have sculptured granitic rock on Twin Peaks near South Lake Tahoe. *Photo by J. Hildinger*

INTRODUCTION

Granitic rocks are exposed throughout California, particularly in the mountainous regions of the State (Figure 1). Granitic rocks are tough and resistant before weathering, but decompose to form a soft granular material that is easily eroded. Distinctive, peculiar landforms develop on decomposed granitic rock as it erodes (Photo 1). The granular weathering product of granitic rocks is called grus. The process of grus formation is called grussification. Foresters, road builders, and others who must contend with erosion problems in granitic terrain refer to grus as decomposed granite or simply "DG".

GRANITIC ROCKS

Granitic rocks are composed of tightly interlocked grains of feldspar, quartz, and dark minerals including biotite, hornblende, and pyroxene. Granitic rocks are classified and given names such as granite, granodiorite, or quartz diorite, based on the

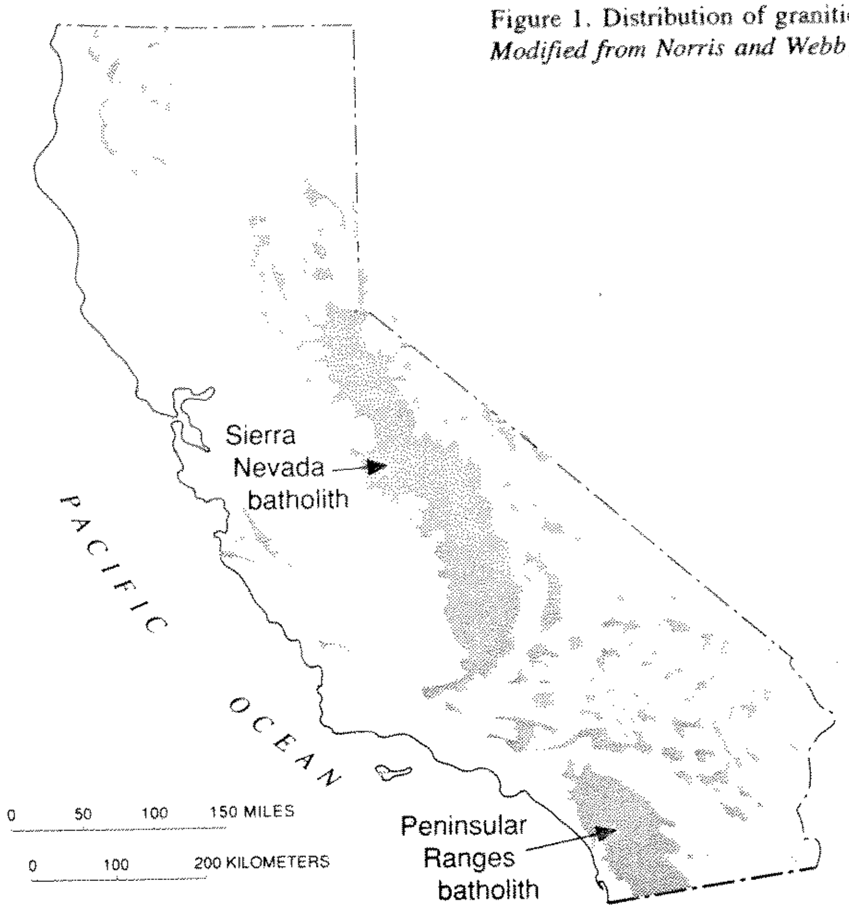

Figure 1. Distribution of granitic rocks in California. *Modified from Norris and Webb, 1976.*

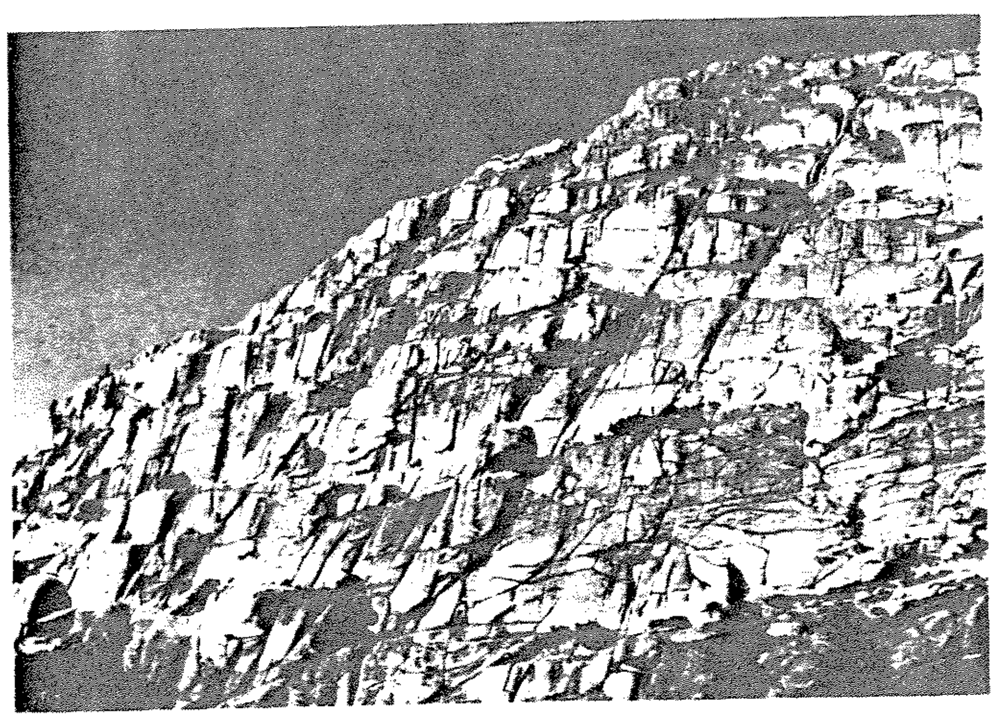

Photo 2. Jointed granitic rock in northern Yosemite National Park. *Photo by D.L. Wagner.*

proportions of potassium feldspar, plagioclase feldspar and quartz in each rock. The term granite is often loosely applied to all granitic rocks although true granite is not abundant in California.

Granitic rocks are formed when molten rock, or magma, invades preexisting rocks deep within the crust of the Earth. The magma cools slowly, allowing the feldspar, quartz, and dark minerals to crystallize into interlocking grains that are large enough to identify with the naked eye. Eventually the magma solidifies into bodies of granitic rock called plutons. Numerous plutons emplaced over large spans of geologic time form granitic masses, called batholiths, which contain astounding volumes of rocks. The Sierra Nevada batholith, for example, crops out over an area about 400 miles (650 km) long and up to 50 miles (80 km) across in California alone. As uplift and erosion proceed, the surface rock is stripped away to expose the granitic rock to weathering.

Weathering of Granitic Rocks

Unweathered granitic rock gives a resounding ring when struck with a hammer. In contrast, weathered granitic rock gives a dull thud when struck with a hammer. Fresh rock is usually greenish to bluish gray; weathered granitic rock is usually chalky white with orange iron stains. The end product of granitic rock weathering is a sandy, clay-rich soil. The process takes place in stages as shown in Figures 2a and 2b.

In the first stage, fresh rock begins to weather along fractures (Photo 2). Decay of the granitic rock occurs along a front that progresses inward, parallel to fracture surfaces. In this stage the rock is still hard but it takes on a white color. Microscopically, the rock appears unchanged (Wahrhaftig, 1965). At this stage the rock is still essentially fresh.

During stage two the granitic rock begins to disintegrate to yield grus and core-stones. Grus is fragmental material consisting of granules of feldspar, quartz, hornblende, and biotite. Core-stones are rounded boulders of intact rock that may be fresh or decomposed. Photo 3 shows a core-stone surrounded by grus.

Feldspar weathers by altering to sericite (a mica mineral) and biotite alters to clay minerals such as vermiculite. These alteration reactions involve a volume increase that causes microscopic fractures to develop (Wahrhaftig, 1965). As a result, there is an increase in permeability and a decrease in the tenacity of the rock. The rock's increased permeability allows the introduction of more water to further weather the minerals. Moreover, the clay minerals expand when wet, thereby enlarging the fractures. Wahrhaftig (1965) observed that the fractures radiate from biotite grains and cut across the feldspar, quartz, and hornblende grains. This observation was later confirmed by Isherwood and Street (1976). As the rock weakens, concentric surfaces parallel to the weathering front develop, imparting a noticeable exfoliation pattern to the rock (Photo 4). Differential erosion strips away weakened rock to leave the core stones, sometimes referred to as tors (Photo 5).

Intact decomposed granitic rock is similar to fresh granitic rock in texture and mineral composition but there are significant physical differences. Unweathered biotite is shiny and black. Weathered biotite is shiny yellow (Photo 6). Fresh unfractured granitic rock is impermeable. The expansion of the biotite during weathering increases the permeability and porosity while decreasing the bulk density by about 25 percent (Isherwood and Street, 1976). These physical changes are important factors in the slope stability and the erodibility of decomposed granitic rock.

Stage three of the decomposition process is the actual grussification of the remaining core-stones. Continued fracturing and mineral alteration causes the rock to disintegrate, leaving the granular material, grus.

The fourth and final stage is the weathering of grus to clay-rich sandy soil. The clay is usually kaolinite and the sand grains are dominantly quartz. Feldspar and the dark minerals have been completely weathered.

EROSION AND SLOPE STABILITY PROBLEMS OF DECOMPOSED GRANITIC ROCK

Decomposed granitic rock and grus are extremely erodible and have a high debris-flow susceptibility. Serious erosion problems can occur after timber harvesting or in the aftermath of forest fires. Landslides are not common on slopes underlain by fresh granitic rock, due to its impermeability and strength. In contrast, weathered granitic rock is permeable and, during intense rainfall, can become

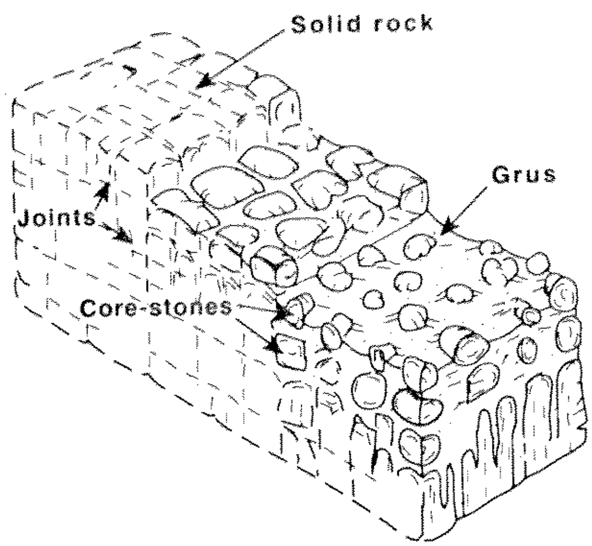

Figure 2a. Block diagram illustrating the development of corestones and grus. *Modified from Huber, 1987.*

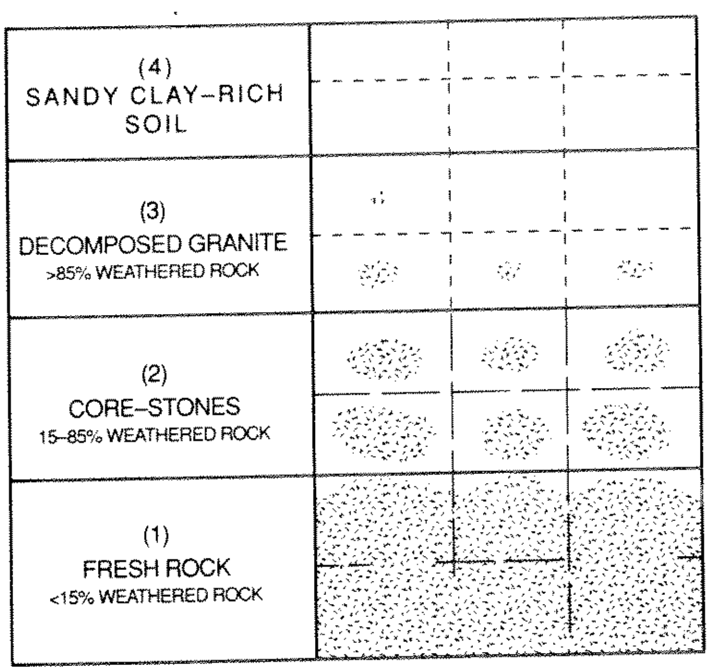

Figure 2b. Stages of weathering of granitic rock. During stage one, the rock begins to weather by taking on a white color but the rock is still essentially fresh. During stage two the granitic rock begins to break down to form grus and corestones. During stage three, the rock has disintegrated to form grus with only remnant core-stones present. During stage four, the grus has weathered to a clay-rich sandy soil. *Modified from Durgin, 1977.*

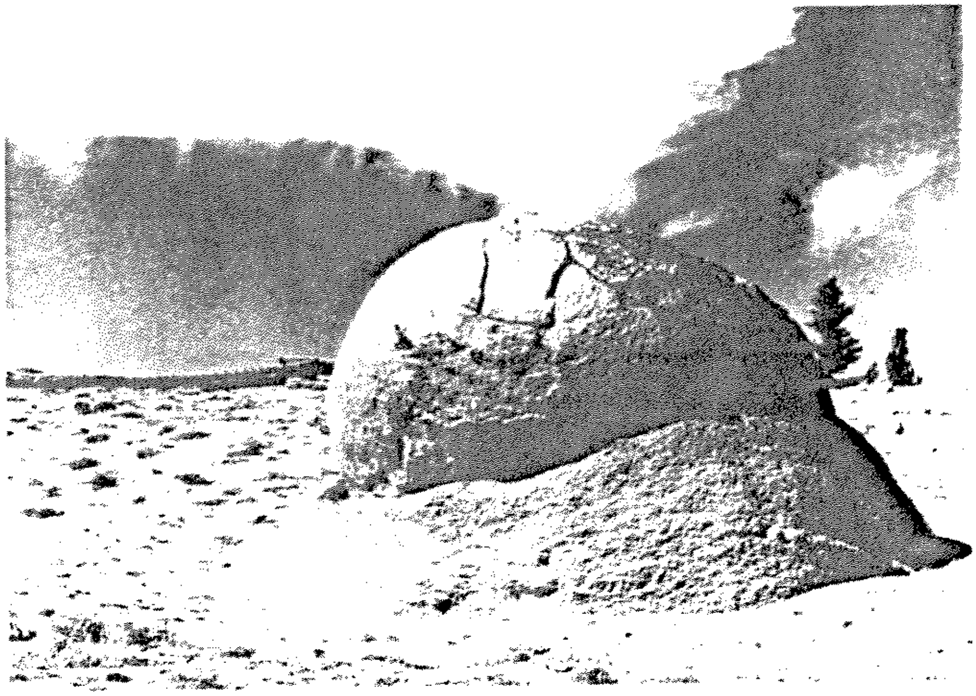

Photo 3. A deeply weathered granitic core-stone perched on decomposed granitic rock near Ebbets Pass. White granular material in foreground and background is grus. The core-stone shows typical spheroidal weathering. *Photo by J. Hildinger.*

Photo 4. Exfoliation developed in decomposed granitic rock. This exfoliation causes the spheroidal weathering typical of core-stones. *Photo by J. Hildinger.*

Photo 5. Boulder core-stones formed by differential weathering of decomposed granitic rock. *Photo by J. Hildinger.*

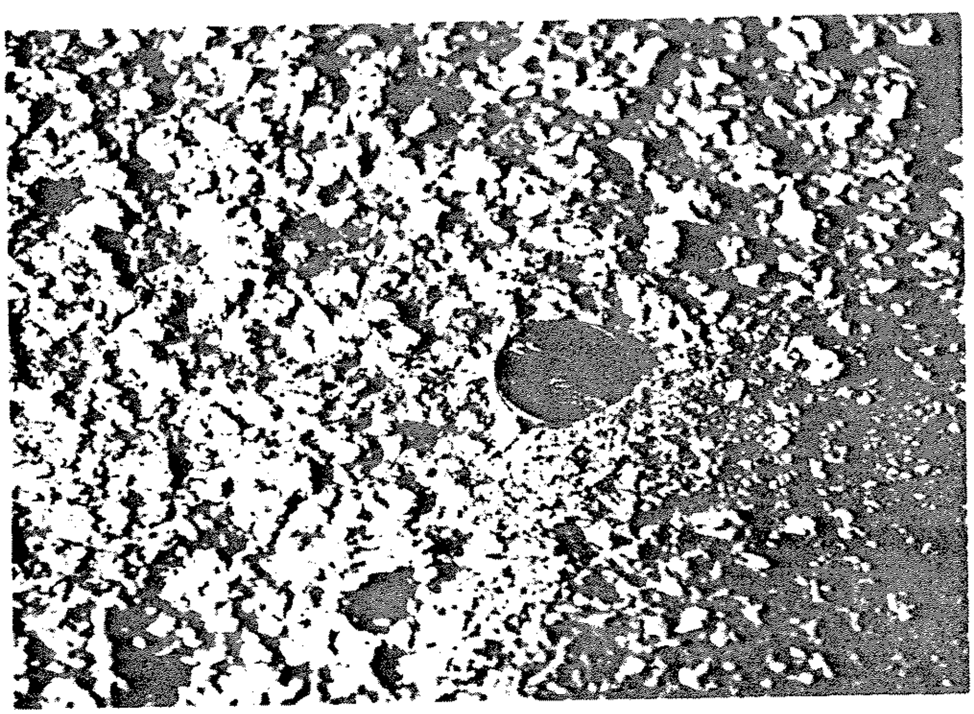

Photo 6. Close-up view of decomposed granite. The dark grains are weathered biotite and the white grains ae weathered feldspar. The fine golden material is also weathered biotite. The penny gives the photograph scale. *Photo by D.L. Wagner.*

saturated with water. When the pore pressure exerted by the water exceeds the strength of the rock, the weathered mass instantaneously becomes fluid and a debris flow occurs.

During floods of January 1982 the San Francisco Bay region had very destructive debris flows, termed debris torrents (Reneau, 1988), that demolished many homes in the granitic terrain at Inverness, western Marin County. The slopes in the Inverness area are steep and were, prior to the 1982 storm, remarkably free of landslides. However, during 10- to 15-minute pulses of intense rainfall (Reneau, 1988), the decomposed granitic rock became saturated and failed, resulting in debris torrents that moved along drainages as fast as 32 feet/second (Reneau, 1988).

Photo 7 shows the track of a debris torrent that flowed down a drainage during the 1982 storm. The debris torrent stripped away the vegetation and scoured the decomposed granite down to fresh bedrock along the drainage. The debris, slurries of water and decomposed granite, swept tree trunks and foliage downslope. Large amounts of decomposed granite were deposited in flat canyon bottoms. Photo 8 shows the top of a pickup truck that was buried by decomposed granite from debris torrents during the 1982 storm.

Photo 7. Track of a debris torrent in granitic terrain of Inverness, Marin Co. January 1982.

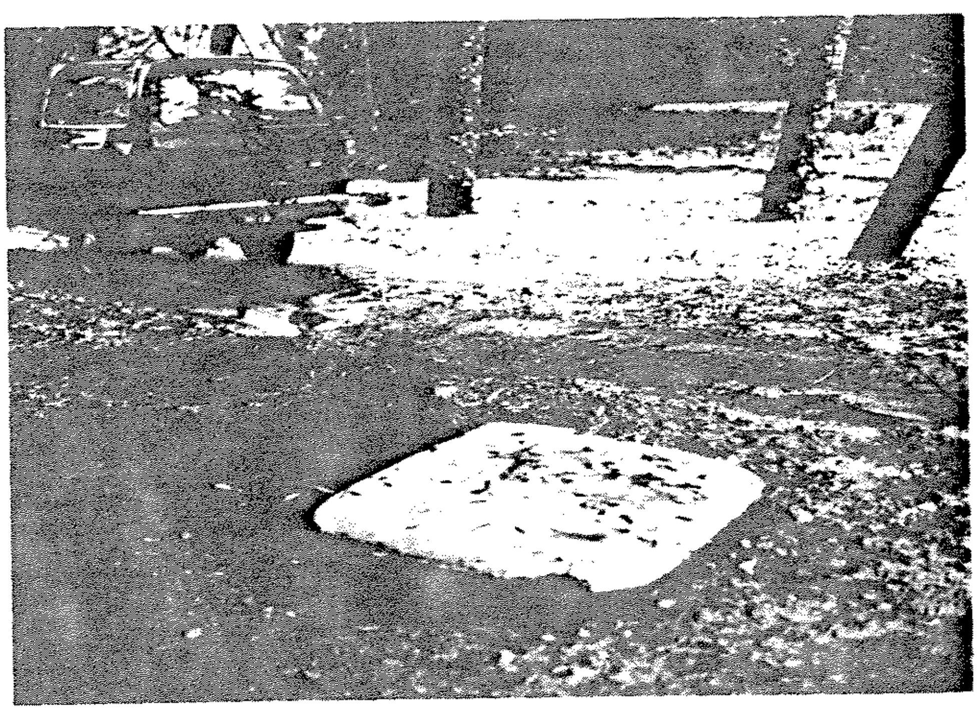

Photo 8. Pickup truck buried by grus deposited in a flat canyon by a debris torrent in Inverness, Jan. 1982. *Photos by D. Wagner.*

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Ed. Note: This article was published in a similar form by the author in California Geology (November 1991), v. 44 (11), pp. 243-249.

AN OVERVIEW OF EROSION AND SEDIMENTATION PROCESSES ON GRANITIC SOILS

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ABSTRACT

Surface and mass erosion processes in relation to major types of forest disturbances, including fire, timber harvest and road construction, are discussed, based on research primarily conducted in the Idaho Batholith. Since accelerated erosion is a given whenever granitic soils are disturbed, numerous erosion control methods to reduce the amount of both surface and mass erosion are summarized and compared. In addition, information is presented describing how granitic sediments move over slopes and become delivered, stored and transported in steep, headwater channels.

INTRODUCTION

Granitic soils associated with batholiths in the western U.S. are noted for high erodibility because of their relatively coarse texture and lack of cohesion. For example, Andre' and Anderson (1961) used surface aggregation ratio as an index of erodibility for soils collected at 168 different sites in California. Soils derived from granitic rocks were the most erodible of the eight geologic parent materials sampled.

Figure 1 depicts the extent of major batholiths in the western states. There are three major batholiths in California, portions of which extend into southern Oregon, western Nevada, and northern Mexico. Additional batholiths are found in northeastern Oregon, three in northern Washington that also extend into Canada, one in northeastern Washington and northern Idaho, one in central Idaho and eastern Montana, and one in the southwestern portion of Montana. I have been fortunate to have visited portions of all of these different batholiths and have been surprised at the uniformity of erosion and sedimentation processes in spite of large variations in climate and vegetation conditions.

The purpose of my paper is to provide an overview of erosion and sedimentation processes on granitic soils. Much of the pertinent research has been conducted in the Idaho Batholith and provides the bulk of the available information reported here. Excellent research has been conducted on granitic soils in other locations; some of that work will be cited as appropriate. I discuss both surface and mass erosion processes in relation to major types of forest disturbances including fire, timber harvest and road construction. Additional information is presented to describe how granitic sediments move over slopes and on the storage and movement of granitic sediments in steep, headwater channels.

EFFECTS OF FIRE ON EROSION

Some of the most dramatic examples of erosion from wildfire have occurred on granitic soils. Photographs have illustrated the severity of erosion that can result on areas subjected to high intensity wildfire on the San Dimas study watersheds in southern California, on the mountains above Boise, Idaho and on the Dog Valley study watersheds in western Nevada.

Surface Erosion

Surface erosion on granitic soils is accelerated by forest fire because of increased raindrop impact, overland flow and dry ravel. Connaughton (1935) reported large increases in erosion with increased burn intensity and slope gradient on both cut and uncut forest stands following a wildfire on granitic soils in southern Idaho (Figure 2). For example, less

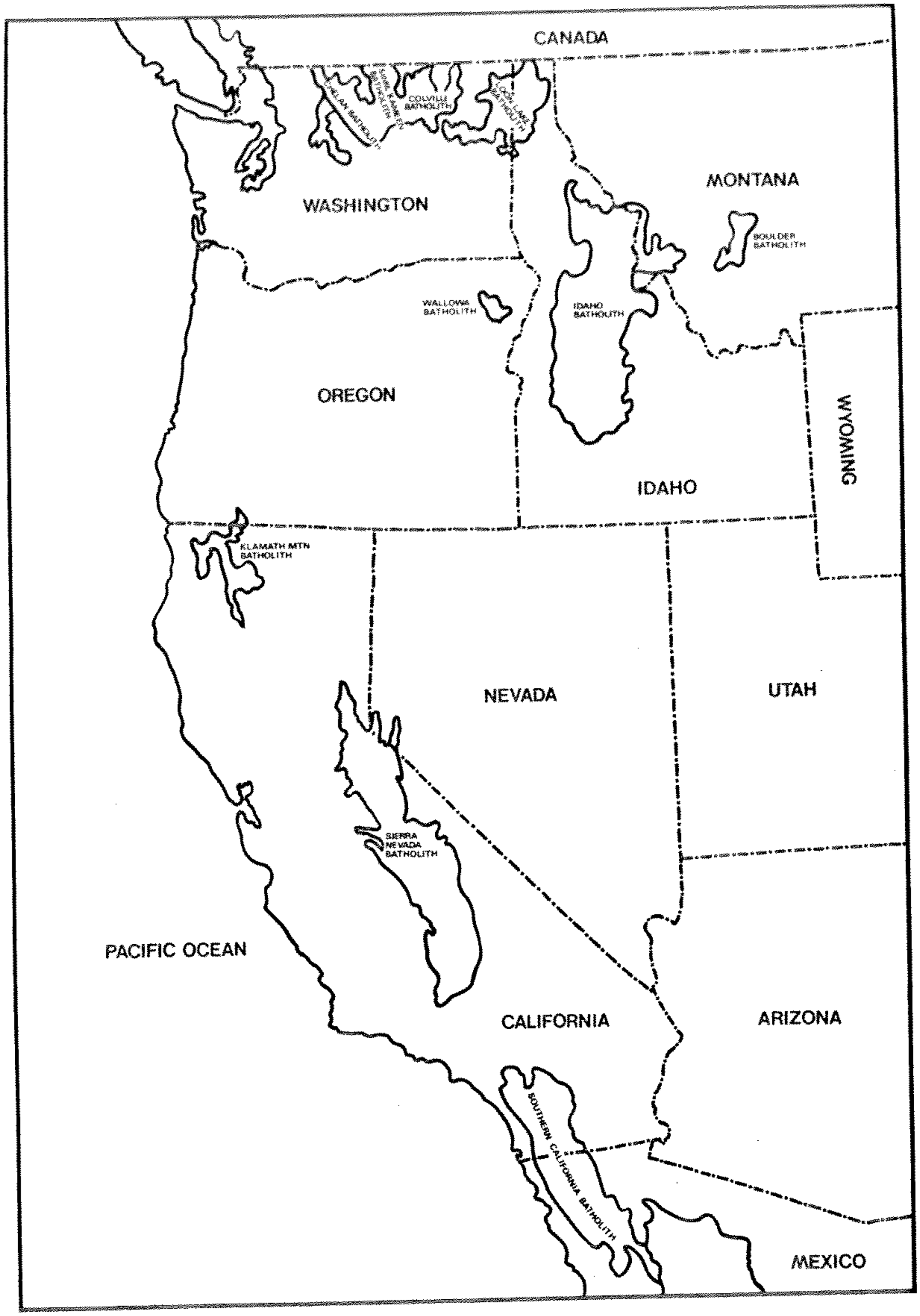

Fig. 1. Location of major batholiths in the western United States.

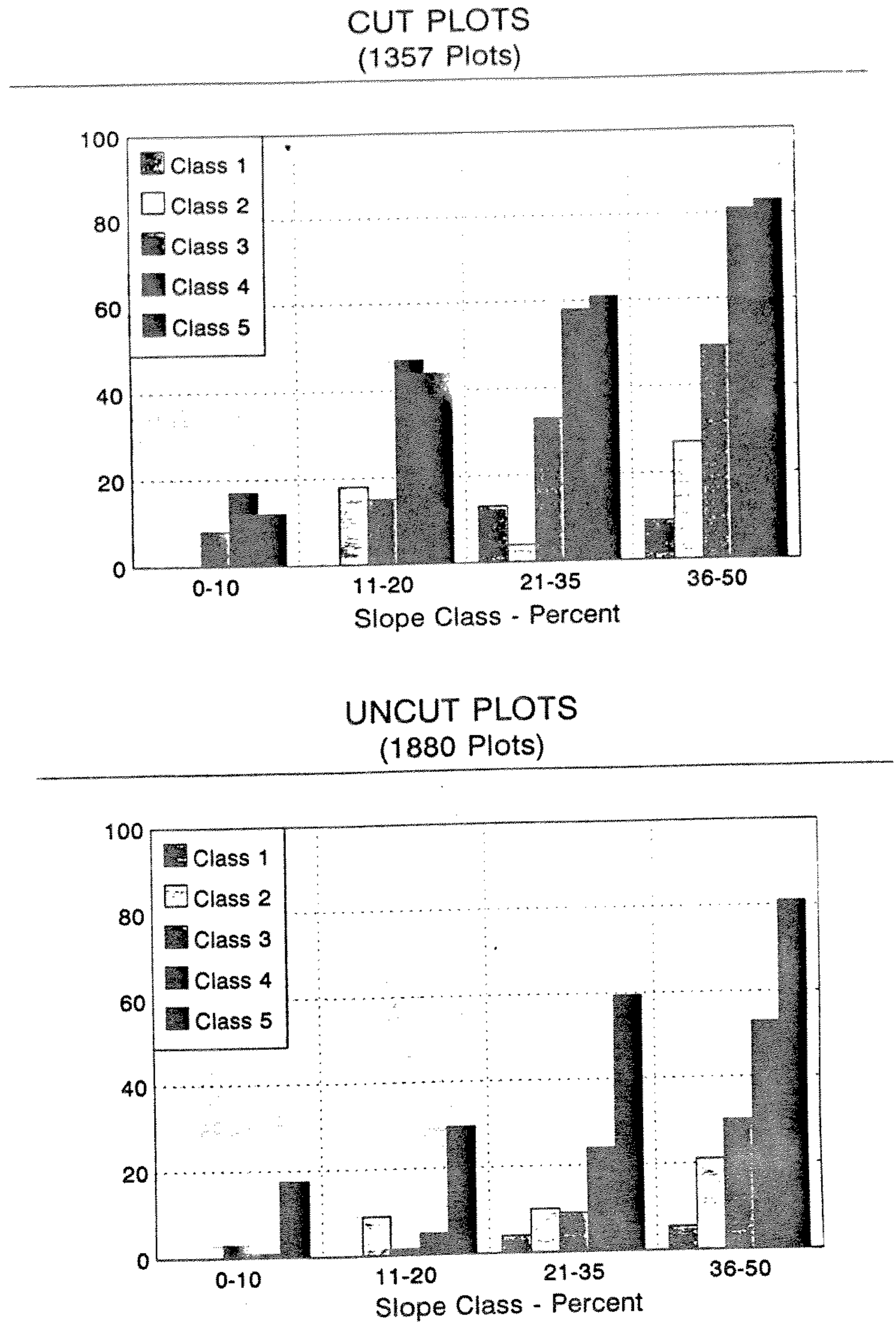

Fig. 2. Effects of slope gradient, burn intensity, and logging on surface erosion following wildfire.

than 10 percent of his sample plots were eroded on cutover forest where slopes ranged from 0 to 10 percent as compared to 50 percent eroded when slopes ranged from 36 to 50 percent. Likewise, a light ground fire caused erosion on 5 percent of the plots on cutover land whereas a crown fire caused erosion on about 50 percent of the plots. For given burn intensities and slope gradients, however, average erosion following wildfire was about 60 percent greater on cut lands as compared to uncut lands. This increase was attributed to greater fuel loading caused by logging slash and by the fact that needles from tree crowns not consumed by the fire fell to the ground soon after the fire on uncut areas causing a protective surface mulch.

A later study confirmed the results of Connaughton's earlier work (Megahan and Molitor, 1975). A series of erosion pins was used to document soil movement following wildfire on a clearcut watershed and on a nearby uncut watershed. Figure 3 shows considerably more soil loss on the clearcut watershed compared to the uncut watershed. Based on estimates of fire reaction intensities, the fire intensity was about 3 times greater on the clearcut watershed. The more intense fire exposed more bare soil on the cutover watershed creating the opportunity for greater surface erosion. The greater burn intensity also increased the opportunity for fire-induced soil water repellency.

DeBano (1981) describes the formation of water repellent layers as a result of wildfire. Repellency is increased with burn intensity and is more serious on coarse-textured soils such as those found on granitic bedrock. Megahan and Molitor (1975) conducted a series of drop tests to confirm the presence of water repellency on the Idaho study watersheds. Water repellent layers tended to be thicker on the intensely burned watershed and were accompanied by greater soil losses (Figure 4). The researchers confirmed one additional factor contributing to reduced erosion on uncut areas earlier noted by Connaughton (1931). Needle drop from trees killed by the fire on the uncut watershed provided additional ground cover that also helped to reduce erosion.

In the study reported by Megahan and Molitor (1975), the net soil loss amounted to about 7 tons per acre during the first year after burning on the clearcut watershed. Within three years, no soil losses occurred because of rapid vegetation regrowth on the north facing watersheds. Such rapid erosion recovery does not occur on south facing slopes based on sediment yield data from a 400 acre study watershed in the same general vicinity of the study reported by Megahan and Molitor (1975). Active erosion was still occurring on clearcut/prescribed burned areas within the study watershed ten years after cutting and causing continued increased annual sediment yields amounting to about 100 percent at the mouth of the basin, as seen in Figure 5 (Megahan, 1989). Vegetative cover data also showed that bare soil averaged 50% on the burned portions of cutting units in 1978 and 30% in 1986 (Figure 6). The length of bare soil openings on the burned areas followed a similar trend amounting to 6.0 m in 1978 and 3.8 m in 1986. In contrast, unburned portions of the cutting units had bare soil openings amounting to 3% in 1977 and 19% in 1986 and respective bare soil openings of 1.6m and 2.3 m. Slow vegetation recovery in these south-facing burned areas was attributed to a combination of shallow, coarse-textured granitic soils with low moisture holding capacity and hot, dry summers. Increases in the percentage bare soil and bare soil opening size in the unburned areas were attributed to decay of logging slash.

Mass Erosion

Mass erosion on granitic soils can also be accelerated by forest fire when slope gradients are steep, usually in excess of 60 percent. Erosion is in the form of debris slides, avalanches, flows and torrents. Mass erosion on a 1,000 acre burn on steep slopes adjacent to the South Fork of the Salmon River in Idaho produced 45,000 cubic yards of sediment directly into the river as a result of one rain-on-snow storm event (Jensen and Cole, 1965). Post-fire contour trenching designed to prevent gully erosion from high intensity summer storms aggravated the mass erosion problem during the rain-on-snow event. Apparently the terraces were not designed to withstand the saturated soil conditions occurring during rain-on-snow events.

EROSIONAL EFFECTS OF TIMBER HARVEST AND ROAD CONSTRUCTION

Surface Erosion

Surface Erosion on Logged Areas. Soil disturbance associated with tree cutting and log skidding exposes mineral soil to raindrop splash erosion and, in areas where soils are compacted, to erosion from rilling. Bethlahmy (1967) used a sprinkling infiltrometer to measure surface erosion on both logged and unlogged north and south slopes on

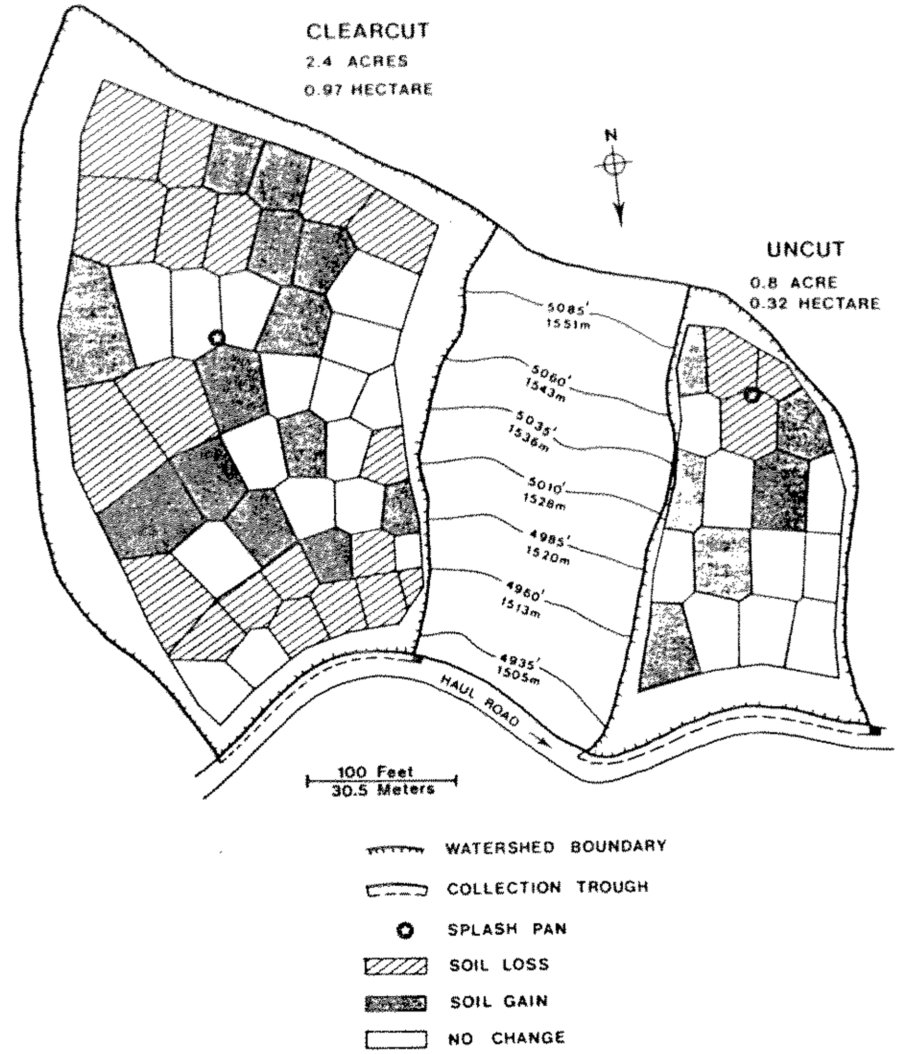

Fig. 3. Soil erosion on logged and unlogged watersheds following wildfire.

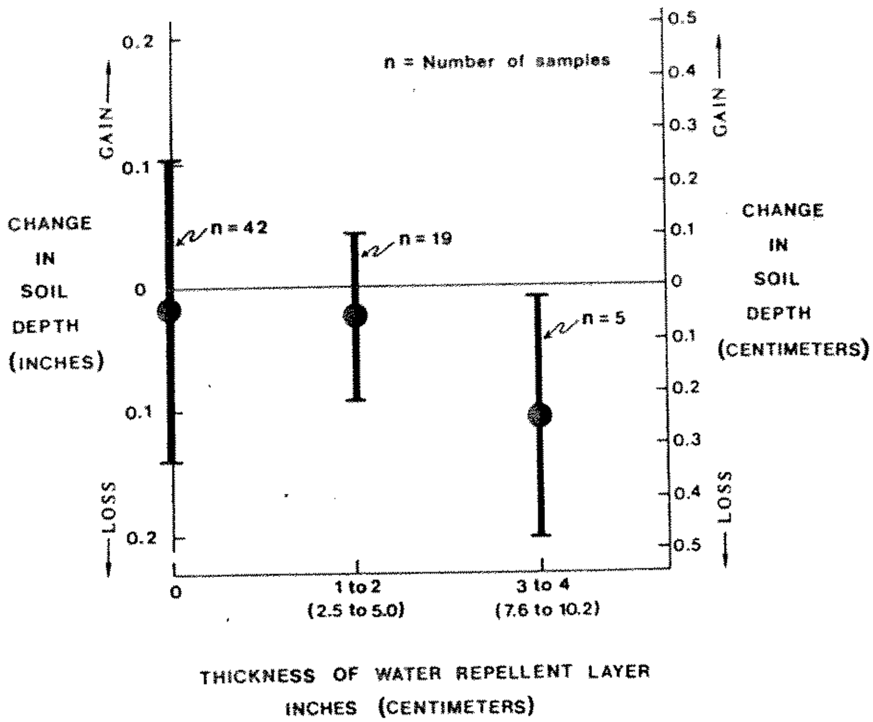

Fig. 4. Soil loss in relation to thickness of the water repellent layer following wildfire.

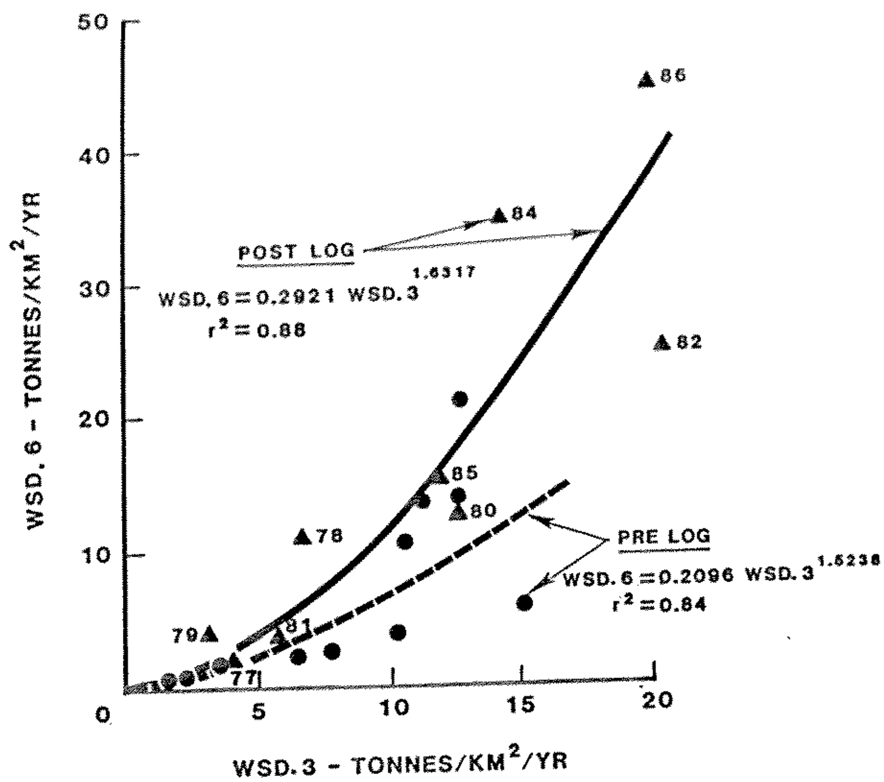

Fig. 5. Long-term sediment yield responses before and after logging and prescribed burning on study watersheds.

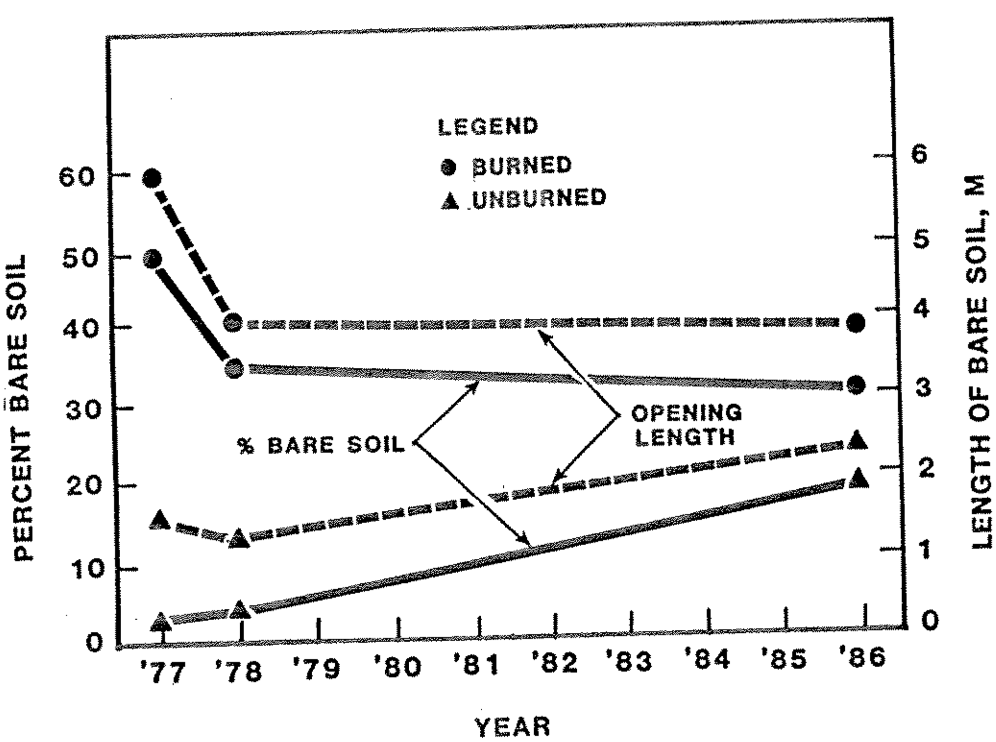

Fig. 6. Time trends in percentage of bare ground and length of bare soil openings on logged areas with and without prescribed burning.

granitic soils in southern Idaho. Erosion rates were greater on undisturbed south slopes as compared to north slopes because of naturally lower ground cover density on the south slopes. Skyline logging caused statistically significant increases in erosion on the south slopes but not on the north slopes. Subsequent work by Megahan and Kidd (1972a) in the same area evaluated sediment yields from areas logged by downhill skyline yarding systems. Over a 6 year study period, sediment yields for undisturbed study watersheds averaged about 25 tons/mi^2/year. Sediment yields from logged areas (including both north and south slopes) averaged about 40 tons/mi^2/year for the same study period, representing an increase in erosion rates of about 60 percent.

Aside from accelerated erosion caused by poor slash burning practices, surface erosion from logged areas is confined to skid trails. Kidd (1963) studied erosion on 70 skid trails constructed in granitic soils to evaluate effects of variable slope gradients (20 to 90 percent), cross ditch spacings (10 to 75 feet), type of erosion control structure (cross drains and sediment filters), and skid trail location (side hills and ravines). As expected, erosion rates increased with slope gradients and with the spacing of erosion control measures. Erosion rates tended to be higher on skid trails located on south slopes because of more limited vegetation growth and on trails located in ravines. Cross ditches were more effective than sediment filters. Kidd (1963) developed a spacing guide for skid trail erosion control structures based on slope gradient and trail location (sidehills vs. ravines). Haupt and Kidd (1965) reported limited sediment production from tractor logged areas where careful layout, close supervision of logging, and prompt installation of erosion control measures minimized the delivery of sediment to streams.

Surface Erosion on Roads. Soil disturbance caused by road construction is much more severe than that occurring from tree cutting and skidding. All surface organic layers are destroyed, exposing a polydispersed mixture of mineral particles in fill areas and raw saprolite in cuts. In addition, road treads are intentionally compacted to maintain trafficability, and cut and fill slopes are necessarily steeper than the undisturbed slope in order to provide a driving surface.

Interception of subsurface flow further aggravates erosion on roads constructed on granitic slopes. Figure 7a depicts a granitic slope in the undisturbed state. The perched water table is quite common in areas of water concentration because of differences in hydraulic conductivity between granitic bedrock and granitic soil. Water supplied by large volume rainstorms or snowmelt events percolates down through the very permeable sandy soil and reaches the restricted zone at the top of the bedrock where it accumulates and runs downhill as subsurface flow. After a road is built on a granitic slope (Figure 7b), all the subsurface flow is now intercepted by the road cut. Megahan (1983) studied the amount of subsurface flow interception by roads constructed on granitic slopes. Total volume of subsurface flow interception was 7 times greater than runoff from precipitation falling directly on the road surface. Clearcutting and subsequent burning of the slope above the road increased the volume of subsurface flow interception to 18 times that from precipitation alone and was accompanied by large increases in peak subsurface flow rates as well.

Given the combination of reduced interception loss, greatly reduced infiltration within much of the road prism, and greater runoff from intercepted subsurface flow, one would expect greater unit area rates of surface erosion on roads as compared to slopes subjected to only cutting and skidding. In addition to measuring erosion on areas affected by cutting and skidding, Megahan and Kidd (1972a) also measured surface erosion on logging roads. Unit area sediment yields from the access roads averaged about 5,500 tons/mi^2/yr for the same 6 year study period. This amounts to an increase of 220 times compared to erosion rates for undisturbed slopes. Considering that tree cutting and skidding only increased erosion rates by 0.6 times, this study clearly shows that forest roads are the primary cause of increased sedimentation from timber harvest activities on steep, granitic soils.

The value of 5,500 tons/mi^2/yr for surface erosion on roads reported by Megahan and Kidd (1972a) represents the average for a 6 year study period. In a subsequent paper, Megahan and Kidd (1972b) described the 6 year time trend in road erosion rates (Figure 8). Surface erosion decreases rapidly during the first and second years after disturbance. This occurs because of seasoning of the erosion surfaces and the accumulation of vegetation and litter. By the end of the second year after disturbance, erosion rates remain fairly constant primarily because of long-term sediment yields from road cut slopes. Erosion rates at this time were still accelerated, averaging about 50

Figure 7a. Granitic slope in undisturbed state with perched water table.

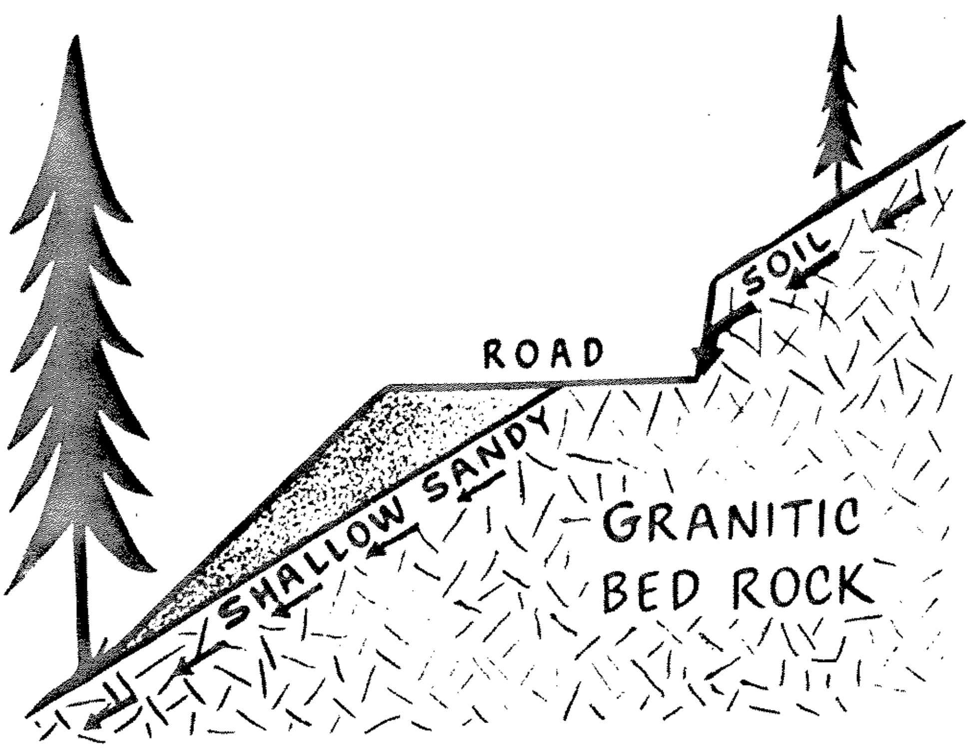

Figure 7b. Road built through granitic slope and now intercepting the subsurface flow.

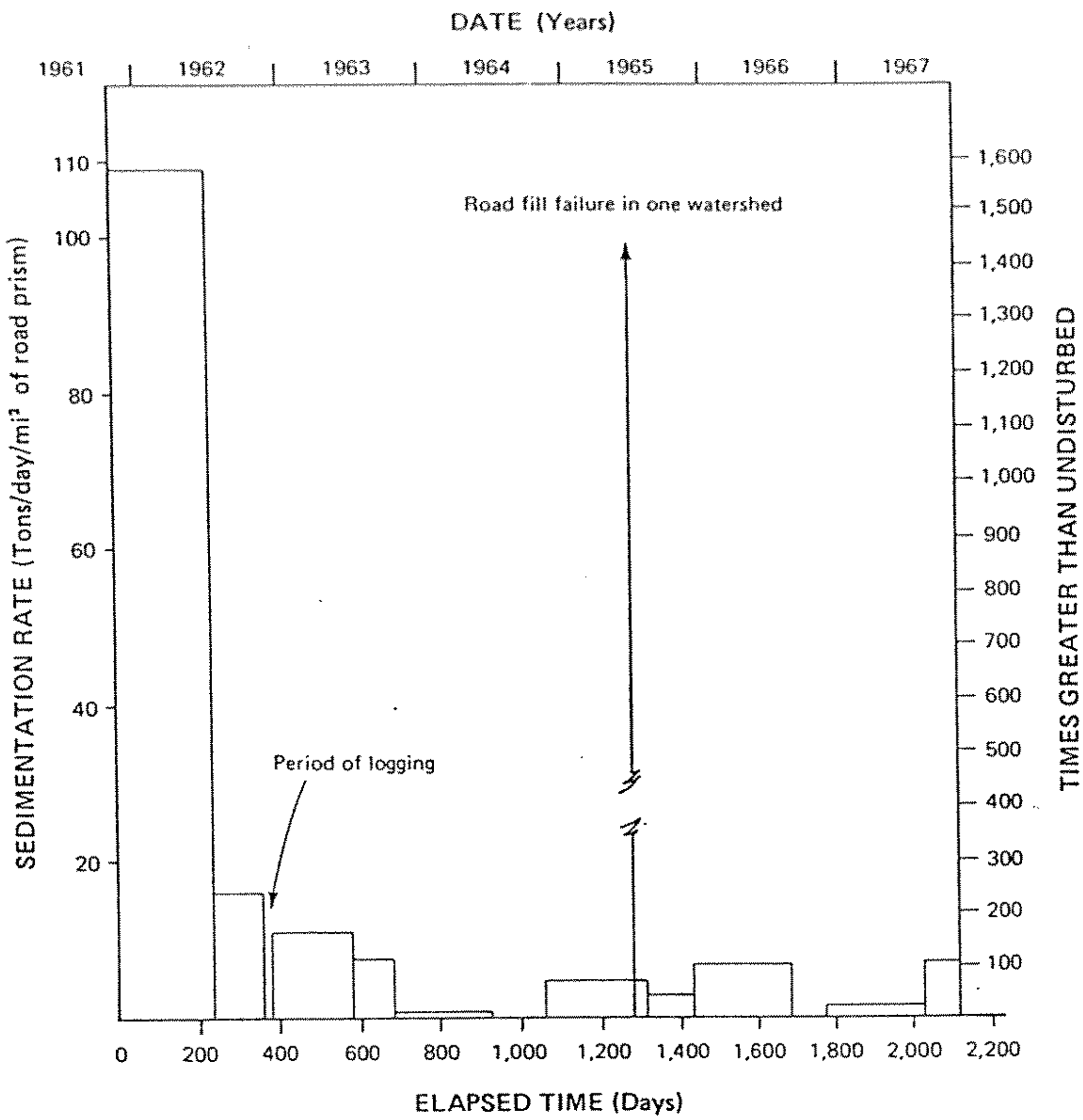

Fig. 8. Time trends in surface erosion and landslide occurrence on logging roads.

times greater than undisturbed.

Erosion Processes on Road Fills. Megahan (1978) used bordered plots to study erosion processes on granitic roadfills. Three erosion control treatments were compared: planted trees without mulch, planted trees with mulch, and untreated controls. Data were collected in the spring after snowmelt and in the fall. Additional data collection was done weekly on all unmulched plots. Winter erosion rates corrected for the time of snow cover were considerably less than erosion rates during the summer. Greater summertime erosion rates were attributed to greater rainfall kinetic energy associated with high intensity summer convective storms. During all three years of the study, planted trees were relatively more effective in controlling erosion during summer periods as compared to winter (Figure 9). Apparently the young trees were most beneficial in reducing splash erosion during the high intensity summer storms. The summertime erosion data were collected at weekly intervals which made it possible to define erosion rates for both rain and no-rain periods.

Erosion rates resulting from dry creep on the steep road fills during non-rain periods ranged from 15 to about 50 percent of the total summertime erosion. The young trees reduced erosion during non-rain periods an average of 45 percent, presumably by reducing wind shear at the soil surface (Figure 10). An analysis of rainfall erosivity for individual storms included in each rainfall sample period made it possible to develop a relationship between erosion and rainfall erosivity (Figure 11). Although the fitted regression coefficients were statistically significant, the relationships exhibited large variance, part of which was attributed to strong winds during some of the high intensity storm events.

Given the high variance associated with using storm erosivity (EI) values to predict erosion reported by Megahan (1978), a subsequent study was designed to evaluate the utility of EI values summed over summer and winter snow-free periods for predicting erosion. Megahan et al. (1991) used a series of 29 bordered plots to measure sediment yields on granitic roadfills located in the Silver Creek study area of southwest Idaho. Sediment yield data were collected for the snowfree season for a duration of 3 years following road construction. Data collected during the first over-winter period following construction showed that localized, shallow mass failures played a dominant role in generating sediment yields causing sediment yields to be about 5 times greater than would be expected from surface erosion alone. Accordingly, the data were not included in the regression analysis to develop a surface erosion prediction model. Various site factors were tested by regression analysis for their effects on sediment yield, but only ground cover density and erosivity index were statistically significant. The prediction equation had an r^2 value of 0.55 and an error mean square of 0.146 log units and is shown as follows:

$$\log_{10}E = 0.7531*\log_{10}EI - 0.6166*\log_{10}GC - 0.35495 + e$$

where: E = Measurement period cumulative erosion in metric tons per ha per year.
GC = Ground cover density in percent.
EI = Snowfree period erosivity index in megajoule millimeters per hectare hour.
e = An error term with a mean of zero and variance of 0.146 log units.

Analysis of 22 years of snowfree period rainfall erosivity data showed that erosivity was log-normally distributed and established the parameters for the probability density function. These data, coupled with the prediction equation from the regression model, were then used in a Monte Carlo simulation model to define the probability of occurrence of sediment yields from granitic road fills given various levels of ground cover density (Figure 12). Equations were also derived to extend erosion predictions to varying fill slope gradients and lengths. Results of this study make it possible for managers to assess the risk of sediment yields from road fills in relation to various types of road design and erosion control practices that alter fill slope gradient, fill slope length and ground cover density on granitic road fill surfaces.

Erosion Processes on Road Cuts. Early work (Megahan et al., 1983) utilized exposed roots to estimate long-term cumulative erosion on granitic road cuts. The original road cut surface was defined by projecting a straight line from the toe of the cut past the end of the exposed root to the intersection of a straight line projected along the surface of the hillslope. A cross-sectioning technique was then used to determine erosion to the present road cut surface (Figure 13). A total of 41 exposed root sites were used to estimate erosion on a 1350 meter long section

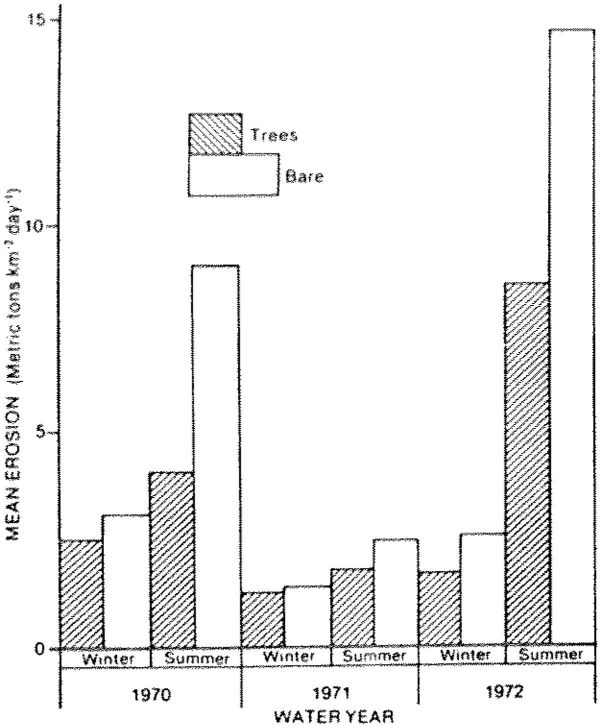

Fig. 9. Effectiveness of tree planting on surface erosion control during winter and summer seasons over a 3 year study period.

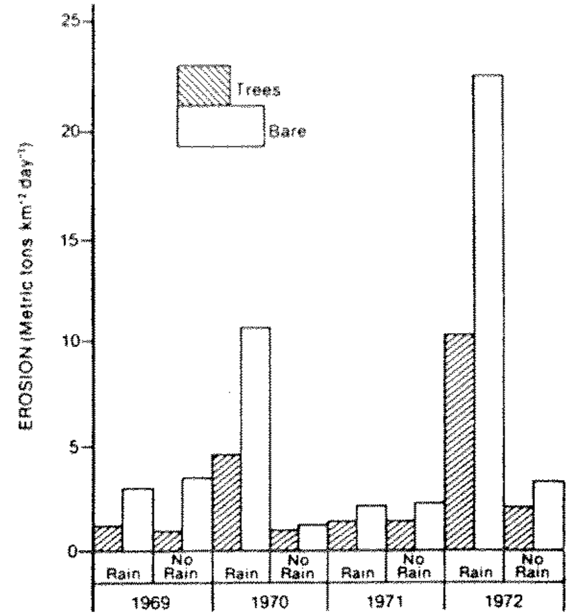

Fig. 10. Effectiveness of tree planting on surface erosion control during rain and no-rain periods for 4 summer seasons.

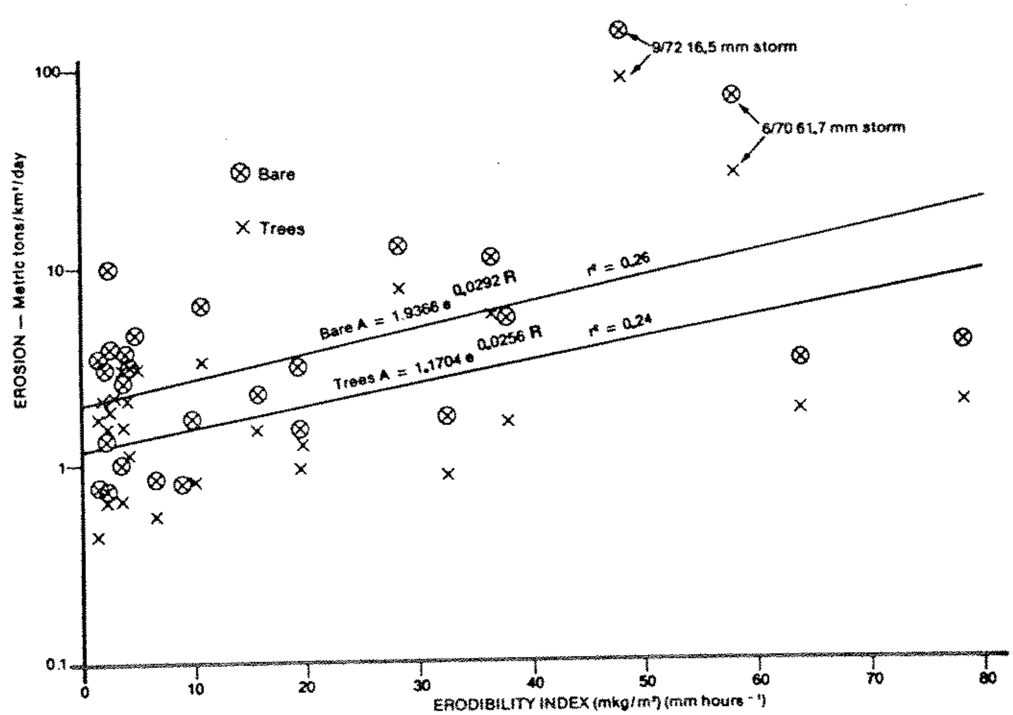

Fig. 11. Roadfill erosion as a function of the USLE erodibility index for individual summer rainstorms for plots with and without planted trees.

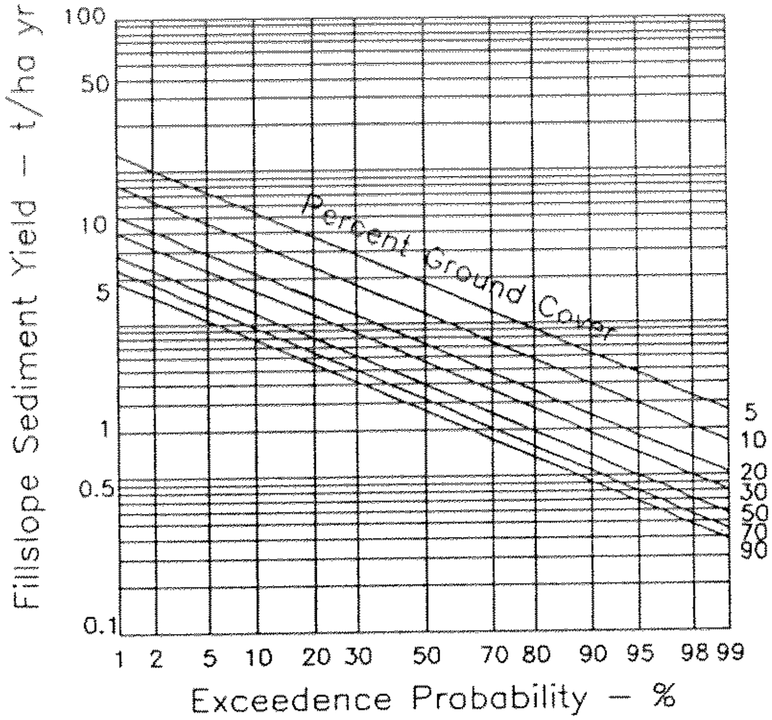

Fig. 12. Probability of erosion from granitic fillslopes as a function of ground cover density in percent.

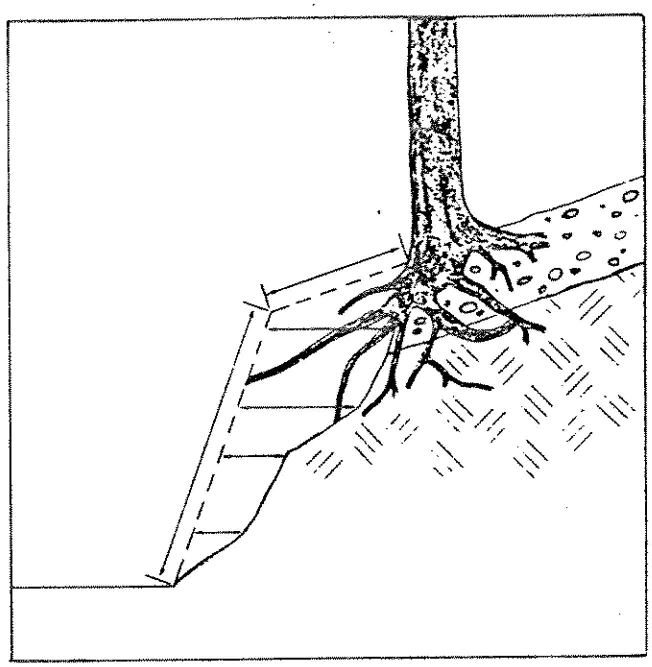

Fig. 13. Evaluation of long-term erosion on granitic roadcuts was based on exposed tree roots.

of road. Average erosion was 1.0 and 1.1 cm/yr for soil and bedrock respectively. Buttressing by tree roots caused lower erosion rates for soil as compared to bedrock. Both bedrock and soil erosion data showed statistically significant correlations with the gradients of the original cut slope (Figure 14). The bedrock erosion data provide an estimate of the disintegration rate of the exposed granitic bedrock in the area.

A recent study was designed to provide more insight into erosion processes on granitic road cuts utilizing annual sediment production data (Megahan et al., 1993). (The following information is presented to illustrate factors influencing erosion processes on granitic roadcuts; it should not be used for predicting erosion without reference to this report.) Data were collected in 75 cut slope erosion collection troughs over a period of 4 years. Similar to road fills, the first over-winter sediment yields from road cuts were excessive because of localized, small-scale mass failure of surface materials disturbed by construction. Accordingly, data from the first over-winter period were not used to derive prediction equations.

Regression analysis was used to develop sediment yield prediction equations from site factors. Site factors shown to have a statistically significant influence on cut slope erosion included slope gradient, erosivity index, slope aspect, ground cover density, cut slope age and rock weathering characteristics. The cut slope age and rock weathering variables are difficult to assess in the field and contributed little to the overall prediction equation. Accordingly, they were dropped from the prediction equation leaving a relationship with an r^2 of 0.58 and a error mean square of 0.361 log units of the form:

$$\log_{10}E = 1.3434*\log_{10}A - 0.2904*\log_{10}GC + 0.9266*\log_{10}EI + 5.7343*\log_{10}S - 14.5516 + e$$

where:
- E = total sediment yield for the measurement period (Mg/ha yr)
- C = ground cover density (%)
- A = aspect (°)
- EI = total erosivity index for the measurement period for snowfree periods (Mj mm/ha hr)
- S = slope gradient (%)
- e = an error term with a mean of zero and variance of 0.361 log units

A sensitivity analysis of the cut slope erosion prediction equation was developed to show the relative influence of the different variables on cut slope erosion. Erosion values were calculated using a range of plus or minus 100 percent from the mean of each independent variable while holding the value of all other independent variables at their respective means (Figure 15). The analysis showed that cut slope erosion was extremely sensitive to increasing slope gradient and moderately sensitive to increases in aspect toward the south and to increases in rainfall erosivity index. Increases in ground cover density reduced erosion rates with most sensitivity at lower ground cover levels.

While some road builders advocate constructing vertical cuts in granitic terrain, the data reveals that if you build them steeper, they are going to erode faster. Granitic road cuts will eventually end up at the natural angle of repose; it depends whether you want it now or later. In certain kinds of rock weathering classes (see Clayton, this Proceedings), all of the erosion will occur later - all at once.

Erosion Processes on Road Treads. Information regarding erosion on road surfaces constructed in granitic materials is limited. Packer (1967) developed prediction equations for road cross drain spacing based on the length of road required to obtain a rill of one inch depth on the road surface. Packer used a regional scale regression analysis based on a stratified random sampling technique to conduct his study. Six different types of parent materials were included in the analysis including granitics scattered throughout north Idaho and Montana. Important variables influencing road tread erosion were: the proportion of water-stable soil aggregates > 2mm on the road surface, road grade, topographic position, aspect, and slope steepness above the road. Total r^2 for the relationship was 0.43 with surface aggregate stability and road grade accounting for most of the variance.

Packer's study provides some guidelines for controlling erosion on granitic road treads but does not provide much insight into erosion processes on road treads. Vincent (1985) made detailed measurements of runoff and erosion on granitic road surfaces located on the Silver Creek study area in the south, central Idaho. Data were collected on three 30.5 meter long study plots located on an unsurfaced logging road built six months prior to the start of the study. Data were collected over a period of 1.5 years and included two summers and one winter. Gradients

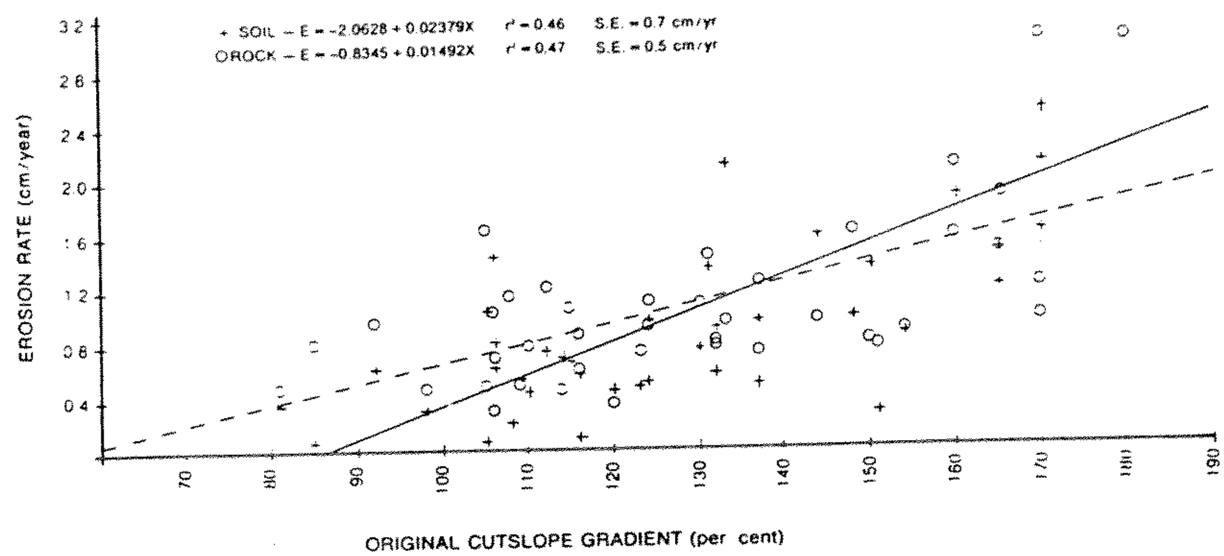

Fig. 14. Long-term average annual erosion for soil and bedrock on granitic roadcuts as a function of original cut slope gradient.

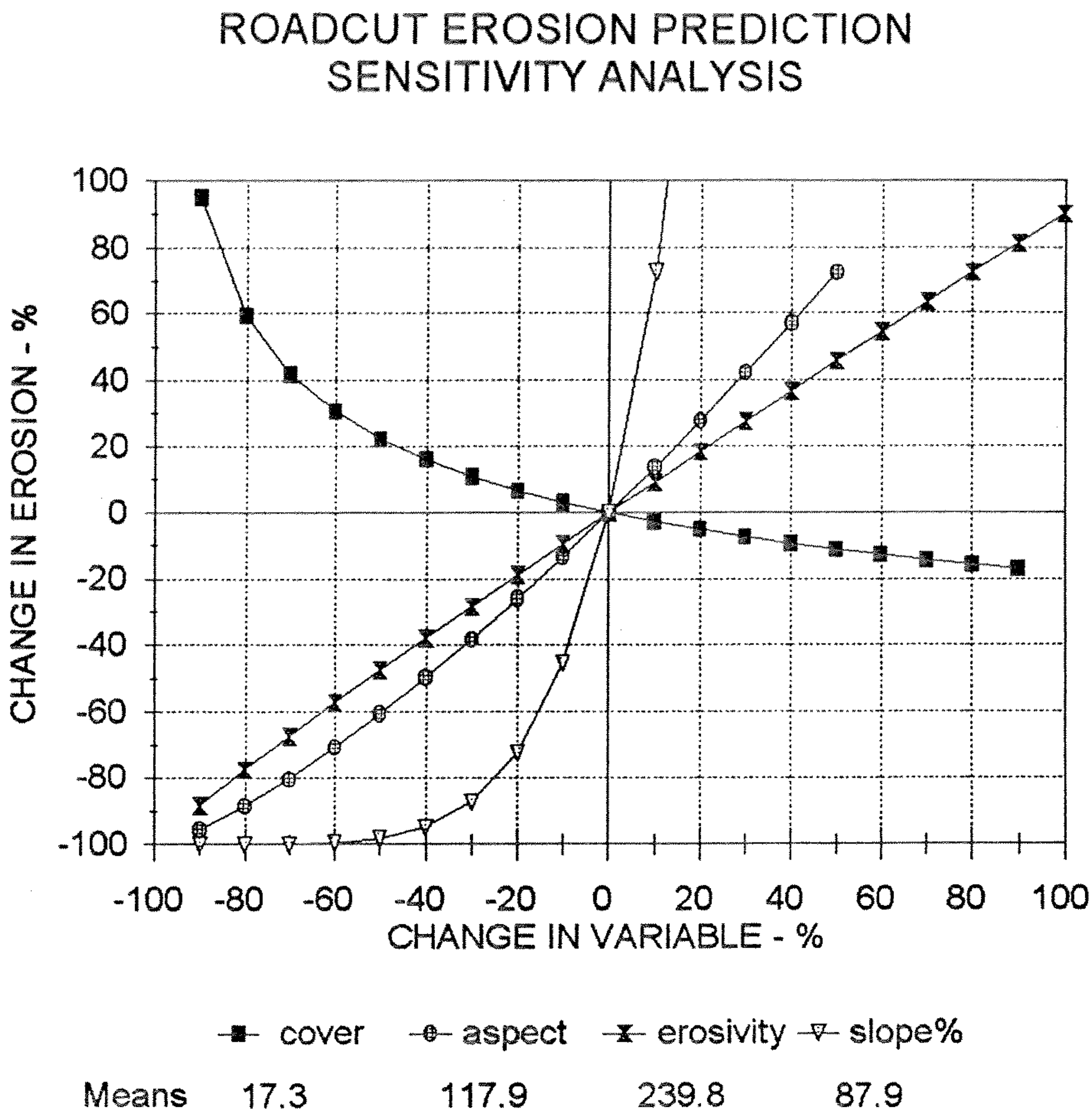

Fig. 15. Sensitivity analysis for statistically significant variables affecting road cut erosion.

of the sample plots ranged from 6.3 to 13.4 percent. Erosivity index data were calculated for all rainstorm events causing erosion. A regression analysis of erosion showed that daily sediment yield was closely correlated with rainfall erosivity and road grade. The prediction equation had a r^2 value of 0.97 for a sample size of 12 and had the form:

$$E = 0.0028 * EI^{1.7} * G^{1.6}$$

where:
- E = daily sediment yield (gm/m^2)
- EI = daily rainfall erosivity (ft tons/acre hour)
- G = road gradient (%)

Applying EI data from throughout the year to the equation provides an estimate of annual sediment yield from granitic road treads of 21, 37, and 71 t/ha for respective road grades of 6.3, 9.0 and 13.4 percent. Only about 10 percent of the annual sediment yield occurred from spring snowmelt runoff; the rest was caused by rainfall events. There was evidence that road tread erosion rates decreased over time following construction. However, effects of traffic were not evaluated in the study.

Mass Erosion

Surface erosion is ubiquitous on granitic soils following soil disturbance. However, mass erosion can also be a concern on steep slopes. In their 1972 study, Megahan and Kidd (1972a) found that average erosion rates on steep, granitic slopes were increased by a factor of about 0.6 times by surface erosion from log skidding, and 220 times by surface erosion on roads for a 6 year study period. A landslide also occurred on one of the roads in the study area. The slide occurred about 3.5 years after construction and was completely unrelated to the time trend for surface erosion (Figure 9). Rather, it was the result of a large rain-on-snow storm in the area.

Megahan et al. (1979) inventoried over 700 landslides in the Middle Fork of the Payette River drainage in the south central part of the Idaho batholith. About 90 percent of the landslides were of the debris avalanche type; the rest were slumps. Only 3 percent of the slides occurred on undisturbed sites; the rest were associated with forest disturbances including wildfire, timber cutting and mostly roads. Landslide activity was concentrated during years with extreme storm events. Jensen and Cole (1965) underscore the importance of roads. They reported that 90 percent of all landslides in the vicinity of the Zena creek drainage in the Idaho batholith were associated with road construction; the remaining 10 percent occurred in logged areas. Gonsior and Gardner (1971) conducted detailed slope stability analyses of many of the landslides in the same Zena Creek location. They concluded that gradients of road fill slopes should not exceed 35 degrees without utilizing special provisions to assure stability. They also recommended compaction of fill material during construction to reduce landslide hazards.

Gray and Megahan (1981) conducted slope stability studies to evaluate the effectiveness of forest vegetation in controlling mass erosion on a study site in the Pine Creek drainage in south central Idaho. Slope gradients on the study area averaged about 70 percent. Results of the field studies indicate that vegetation often provides a critical margin of safety to forested slopes for debris avalanche types of landslides. Slope stability equations were developed for the granitic soils to illustrate how woody vegetation contributes to stability by root reinforcement and by providing soil arching restraint between tree stems. Vegetation also contributes to stability by regulating groundwater levels by transpiration and interception and by regulating snow accumulation and melt rates. Additional work by Megahan (1983, 1985) in the same study site quantifies the effects of clear cutting and wildfire on slope hydrologic function and on the volume and rate of water intercepted by roadcuts.

Subsequent work by Megahan and Bohn (1989) shows that sapping types of mass failures may also be accelerated by vegetation removal on coarse-textured granitic soils. Such failures can occur on much gentler slopes as the result of seepage forces exerted by soil water movement and tend to be progressive over a period of years. Slope gradients at sapping failure sites averaged 25 percent, considerably lower than slope gradients at debris avalanche sites. Failures were all located in swale areas and were all associated with increased ground water levels resulting from timber removal by logging. Two of the slides occurred in cutting units without any influence from road construction; the third initiated in a road cut slope and progressed upward into a previously logged basin. Sediment yields from the failures appeared to be correlated to ground water levels, with greater activity occurring during years with higher runoff.

EROSION CONTROL

Accelerated erosion is a given whenever granitic soils are disturbed. However, there are numerous methods to reduce the amount of both surface and mass erosion that occurs.

Surface Erosion

Figure 8 suggests important timing guidelines for surface erosion control on granitic materials. Measures to control surface erosion must be installed as soon after disturbance as possible and must include practices that provide immediate surface protection in addition to providing long-term vegetative or other type of stabilization.

Logged Areas. Bethlahmy (1967) shows that logging on granitic soils is more likely to cause accelerated erosion on south slopes than on north slopes. Megahan (1989) found increased erosion rates 10 years after logging on south slopes subjected to post-logging prescribed burning. Both these studies point out the need to protect ground cover in areas of granitic soils subjected to hot, dry summers. Kidd (1963) studied skid trail erosion on granite and basalt soils in west, central Idaho. Erosion was greater and rate of healing was slower on the granitic soils. Guides for cross drain spacing were developed for both parent materials based on slope gradient and skid trail location.

Road Fills. Early studies documented the effectiveness of various kinds of erosion control measures on granitic road fills (Table 1). Tree planting alone reduced erosion by an average of 50 percent. Addition of mulches including wood chips, straw and jute netting provided additional erosion control effectiveness ranging from 61 to 93 percent. Combinations of straw mulch held in place by netting or asphalt tackifier reduced erosion rates by 97 to 99 percent. Later work quantifies the erosional risk of alternative levels of ground cover, slope gradient and slope length for controlling erosion on road fill surfaces (Megahan et al., 1991).

Additional studies (Megahan et al., 1992) compared the cost-effectiveness of many alternative fill erosion control treatments . A total of 16 different treatments were compared to untreated control plots; of these, 9 showed statistically significant reductions in erosion, one showed a statistically significant increase, and 6 showed no effect (Tables 2 and 3). At a value of 71 percent reduction in erosion, hydromulch with seed and fertilizer was one of the least effective treatments in terms of total erosion reduction but was almost 100 percent more cost-effective than all other treatments because of reduced unit costs of application.

In addition to testing the cost-effectiveness of alternative erosion control practices applied to road fill surfaces after construction, Megahan et al. (1992) also tested the effectiveness of alternative fill slope construction methods including side cast, layer placement and controlled compaction, all with and without surface rolling. There were no statistical differences in erosion rates for the 3 construction methods but surface rolling increased erosion rates by 314 percent. Apparently the rolling reduced infiltration rates leading to surface saturation that resulted in micro-scale liquefaction as well as erosion by overland flow.

Road Cuts. In spite of the fact that road cuts exhibit the highest erosion rates of any of the components of road prisms constructed in granitic materials, there has been very little research conducted to evaluate methods for controlling erosion. Megahan et al.(1993) developed prediction equations that make it possible to assess the erosion control effectiveness of alternative road design features linked to slope gradient, slope aspect and ground cover density. In addition, they tested the effectiveness of several erosion control treatments including hydroseeding, dry seeding, and benching over a 4 year period. All treatments caused statistically significant reductions in erosion ($P < 0.10$) amounting to 39 percent for benching, 50 percent for dry seeding sites with soil and underlying saprolite, 57 percent for hydroseeding and 89 percent for dry seeding in locations with deep soils and favorable growing conditions. Only one treatment, that of dry seeding in sites with deep soils and favorable growing conditions, was better than other treatments ($P < 0.05$).

Road Treads. Studies by Packer (1967) and Vincent (1981) provide a means to alter road gradients and install cross drains to reduce road tread erosion on unsurfaced granitic road treads. Additional erosion control benefits occur when road treads are surfaced. Burroughs et al. (1984) used a rainfall simulator to measure the effects of dust oil and bituminous surfacing on erosion from road surfaces constructed on granitic materials in the Silver Creek basin in Idaho. Respective reductions in

Table 1. Effectiveness of surface erosion control on granitic road fills in Idaho.

Measure Used	Change in Erosion (percent)	Reference
Tree planting	- 50	Megahan, 1974
Wood chip mulch	- 61	Bethlahmy & Kidd, 1966
Straw mulch	- 72	Ohlander, 1964
Jute netting	- 93	Ohlander, 1964
Straw mulch + asphalt	- 97	Ohlander, 1964
Straw mulch + netting + planted trees	- 98	Megahan, 1974
Straw mulch + netting	- 99	Bethlahmy & Kidd, 1966

Table 2. Erosion reduction and cost effectiveness of post construction roadfill erosion control treatments

treatment	arithmetic mean erosion rate	change in erosion[1/] rate	change in erosion[1/] percent	cost per acre[2/]	cost effectiveness[3/]	type treatment[4/]
	t/ac/y	t/ac/y	pct	$/ac	t/$1000	
1. Straw, crimp, seed, fertilizer, transplant	0·4*	−9.0	−95	17 980	0.50	3
2. Straw, net, seed, fertilizer, transplant	1·6*	−7.8	−83	31 250	0.25	3
3. Straw, crimp, net	0·7*	−8.7	−93	18 720	0.46	2
4. Straw, polymer, seed, fertilizer, transplant	1·3	−8.1	−86	16 520	0.49	3
5. Steep slope seeder	4·5*	−4.9	−52	23 270	0.21	1
6. Steep slope seeder, transplant	1·8*	−7.6	−81	31 320	0.24	1
7. Hydromulch, seed, fertilizer, transplant	2·9*	−6.5	−69	15 440	0.42	3
8. Straw, net	2·0*	−7.4	−79	16 800	0.44	2
9. Hydromulch, seed, fertilizer	2·7*	−6.7	−71	7 410	0.91	3
10. Sprig, transplant	2·2	—[5/]	—	81 930	—	1
11. Polymer, seed, fertilizer, transplant	6·1	—	—	13 040	—	3
12. Sprigging	4·3	—	—	73 880	—	1
13. Straw, crimp	13·7	—	—	3 530	—	2
14. Hydromulch	4·9	—	—	6 920	—	2
15. Untreated control	9·4	—	—			
16. Straw, polymer	8·3	—	—	4 920	—	2
17. Polymer	19·5*	+10.1	+107	3 980	−2.53	2

[1/] Compared to average of control plots.
[2/] Costs are based solely on application of erosion control measure on study plots.
[3/] Tonnes of soil loss prevented each year for each acre of treated roadfill.
[4/] 1 = revegetation alone, 2 = surface amendment alone, 3 = combination of 1 and 2.
[5/] No data are shown for treatments that were not statistically significant.
*Indicates statistically significant difference from untreated control (P = 0.05).
ac = acre (2·471 acres = 1.0 ha).
$ US$ 1982.
t tonne (1 tonne = 0.984 ton).

Table 3. Description of soil stabilization measures.

measure	description	
hydromulch	mixture of cellulose fiber and water sprayed on the slope	2 240 kg ha^{-1}
straw	straw hand-placed evenly on the slope	4 500 kg ha^{-1}
crimp	rolling of placed straw with a sheepsfoot roller	—
seed	a combination of nine locally adapted grasses plus alfalfa and clover applied to the slope by hand spreader or added to the water-fiber mixture used for hydromulching	125 kg ha^{-1}
fertilizer	application of N-P-K by hand spreader or added to the water-fiber mixture for hydromulching	N-70 kg ha^{-1} P-35 kg ha^{-1} K-35 kg ha^{-1}
transplant	a combination of nine locally adapted shrubs plus Ponderosa pine (*Pinus ponderosa* Laws)	1·2 m spacing
net	jute erosion control netting hand-placed on the slope and pinned in place	100 per cent coverage
steep-slope seeder	a mechanical device designed to rake mini-terraces on the slope, drop seed and fertilizer in the furrow and incorporate the seed into the soil by rolling with small-meshed drums. A hydraulic, telescoping boom crane is used to position the device on the slope (Spink, 1978)	—
sprigging	hand transplanting of rhizomes of Louisiana sagebrush (*Artemisia ludoviciana* Nutt.)	0·3 m spacing
polymer	spray application of an emulsion of water plus a liquid erosion control product designed to adhere to the soil surface and control erosion	1 890 l ha^{-1}
control	no treatment was used. Control plots were kept free of volunteer vegetation by occasional spraying with herbicide	—

erosion by dust oil and bituminous surfaces were 85 and 97 percent.

No data were found for effectiveness of gravelling on granitic soils. However, Burroughs et al. (1985) used a rainfall simulator to test erosion reduction by a 4 inch lift of 1.5 inch minus crushed rock on Idaho batholith border zone rocks (gneiss and schist) in central Idaho. Erosion was reduced 79 percent by the treatment, a value very similar to erosion reduction documented at other study locations by addition of 6 to 8 inches of crushed gravel to native road surfaces on a variety of other geologic materials. It is important to note that rock used for road surfacing must be hard in order to withstand traffic loading. This precludes most granitic rocks except for rock weathering class 1 and perhaps 2 based on the system described by Clayton et al. (1979). Granitic rocks considered for surfacing purposes should be tested for hardness.

Mass Erosion

Prediction models such as those developed by Gray and Megahan (1981) specifically for granitic materials or by Hammond et al.(1992) for a variety of parent materials provide a means to estimate the effects of timber removal on debris types of landslides occurring in natural slopes. Proper geotechnical design, road location, and careful road construction and maintenance practices are needed to avoid mass erosion on roads constructed in granitic materials. In addition, work by Durgin (1977) and Clayton et al. (1975) suggest that road construction in areas of highly weathered bedrock (class 7 rock according to the classification of Clayton et al.,1979) should be avoided. Gonsior and Gardner (1971) provided some specific recommendations to reduce mass erosion on roads constructed in granitic materials based on their studies of landslides in the Zena Creek drainage of Idaho. Recommendations from Gonsior and Gardner (1971) relating to mass erosion on roads are as follows:

1. Fill slopes should be specified by the design engineer and based upon suitable stability analyses. In no cases should unretained fill slopes exceed 70 percent.

2. In general, alignment should be sacrificed whenever possible to avoid deep fills and/or cuts.

3. All fill slopes should be compacted to a degree consistent with design standards and material properties.

4. Drainage facilities should be provided to prevent damaging concentrations of surface runoff and to avoid high pore pressures in cuts and fills.

5. Specifications requiring log and debris removal from fill slope sections must be rigidly enforced.

SEDIMENT DELIVERY TO CHANNELS

Aside from site productivity and issues of aesthetics, erosion of granitic soils is only a concern if eroded sediments reach channels. Early work by Haupt (1959) in the Little Owl drainage in Idaho provided a means to estimate the travel distance of granitic sediments below roads based on road cross drain interval, a slope obstruction index, road fill length, and road gradient. Suggested uses for the procedure were made, such as the addition of logging slash on the slope below the road to reduce travel distance. Later work by Packer (1967) developed a regression equation to predict sediment travel distance below roads based on data collected from 6 different parent materials, one of which was granite. Significant variables in the equation included cross drain spacing, initial distance and type of obstruction on the slope, fill slope cover density, road age, and percent of soil particles and water-stable aggregates larger than 2 mm diameter on slopes adjacent to roads. Recommendations for use of the equation to prevent or reduce sediment delivery to streams is presented in the article. By including other types of parent material in the data set used to derive the prediction equation, Packer's equation (1967) may be less reliable for granitic sediments than that derived by Haupt (1959).

Both Haupt (1959) and Packer (1967) included variables to index the amount of onsite road erosion as well as variables to index downslope sediment travel distance in their prediction equations. Such an approach makes it impossible to evaluate sediment travel distance for any road situations other than those described by the variables in the regression equations. Ketcheson and Megahan (1989) took a different approach to predicting sediment travel distance. They assumed estimates of total road erosion would be available from other sources, for example, from the equations described above for predicting erosion on road cuts (Megahan et al., 1993), fills (Megahan et al., 1991), and treads (Vincent, 1985). They then developed equations to predict sediment travel distance below cross drain culverts, rock drains, and fill slopes in recognition of the different sediment transport potentials associated with different types of drainage devices.

Sediment travel distance below cross drains was a function of volume of eroded sediment, runoff source area above the culvert inlet, an index of obstructions on the slope surface below the culvert, and the gradient of the slope below the culvert. For rock drains and fill slopes, travel distance was a function of volume of eroded sediment and the obstruction index. This approach makes it possible to estimate travel distance of sediments for all types of road design features and erosion control measures. Additional data were provided by Ketcheson and Megahan (1989) to describe the probability distribution of sediment travel distance below cross drain culverts, rock drains and fill slopes. Such data provide a means to develop quick estimates of the risk of downslope sediment travel. Given unacceptable risk, more detailed estimates of travel distance can be made with the sediment travel prediction equations.

Sediment travel distance is usually not the primary question in sedimentation studies. Rather, the key issue is how much sediment reaches streams. To deal with this issue, Ketcheson and Megahan (1989) also measured annual volume of sediment deposition on slopes below roads by 15 foot increments from the toe of the road cut to the end of the sediment deposit. Data were collected at 10 different sediment deposits over a 4 year period. Expressed as a dimensionless curve relating percent of volume to percent of length, the data can be used to estimate what percentage of sediment volume is delivered to given distances along a sediment flow length. Combining this relationship with the sediment travel studies discussed above, estimates can be made of the probability of sediment delivery volumes to channels.

SEDIMENTATION IN HEADWATER CHANNELS

Sediment Size

Most granitic rocks are moderately low to highly weathered in fluvial landscapes. However, less weathered rocks are found in: 1) glaciated regions; 2) locations with rapid (on a geologic time scale) erosion such as on slopes adjacent to rivers that are rapidly downcutting (known locally as inner gorge or breakland areas); and 3) some localized areas of mineral alteration such as in dike zones. Weathered granites are structurally weak and are easily broken down. However, except for localized areas such as shear zones, weathering has not progressed to the point of clay formation. The result is coarse-textured, easily eroded soils and a predominance of weak bedrock that is easily broken down into sands with very little silts and clays. Sediments produced from such materials are unique for most mountainous lands because of the predominance of poorly graded sand size particles. Such sediments move predominately as bed load in streams. Suspended loads are relatively low consisting of very fine sands and some silts. Turbidity is characteristically low in granitic regions because of a dearth of clays.

Data collected in a second order stream from an undisturbed study watershed in Idaho illustrates characteristic sediment sizes (Figure 16). Data were collected in Helley - Smith bed load samplers, in sediment detention basins at the watershed mouths, and on the streambed surface at intervals along the entire length of the channel. Values on the three curves indicate the average percentage of particle sizes less than or equal to the value. For example, 50 percent of the particles collected in bed load samplers averaged less than or equal to about 1.1 mm size. Respective median particle sizes (D50) in sediment samplers, sediment basins and on the streambed were about 1.1 mm, 1.4 mm and 5.8 mm. Median particle size values indicate the predominate sediment sizes for a stream and tend to be low in granitic areas for sediment in transport as well as that on the streambed. Similar low values are found for the D84 and D16 size classes for both sediment in transport and in storage on the steambed.

Sediment Yields in Undisturbed Tributaries

Annual sediment yield data are available for a number of undisturbed, forested watersheds in the Idaho Batholith (Megahan, 1975). Data were collected in sediment detention basins at the mouths of study watersheds. A log Pearson type III frequency analysis was used to develop sediment yield frequency curves for undisturbed basins with 7 or more years of available data (Figure 17). Data used for the analysis were not corrected for trap efficiency.

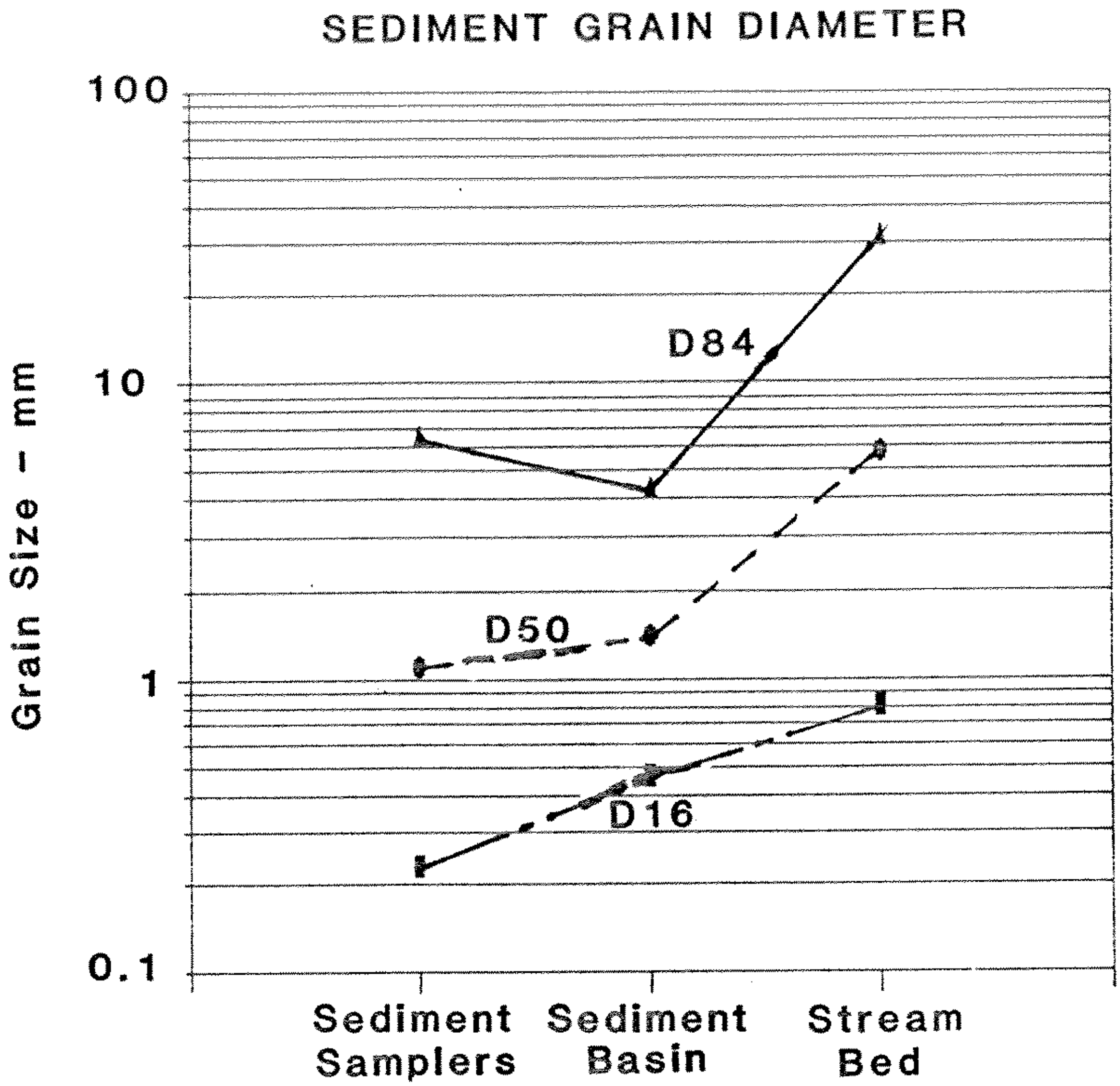

Fig. 16. Probability of sediment particle sizes for sediment samples collected in bedload samplers, detention basins, and on the stream bed.

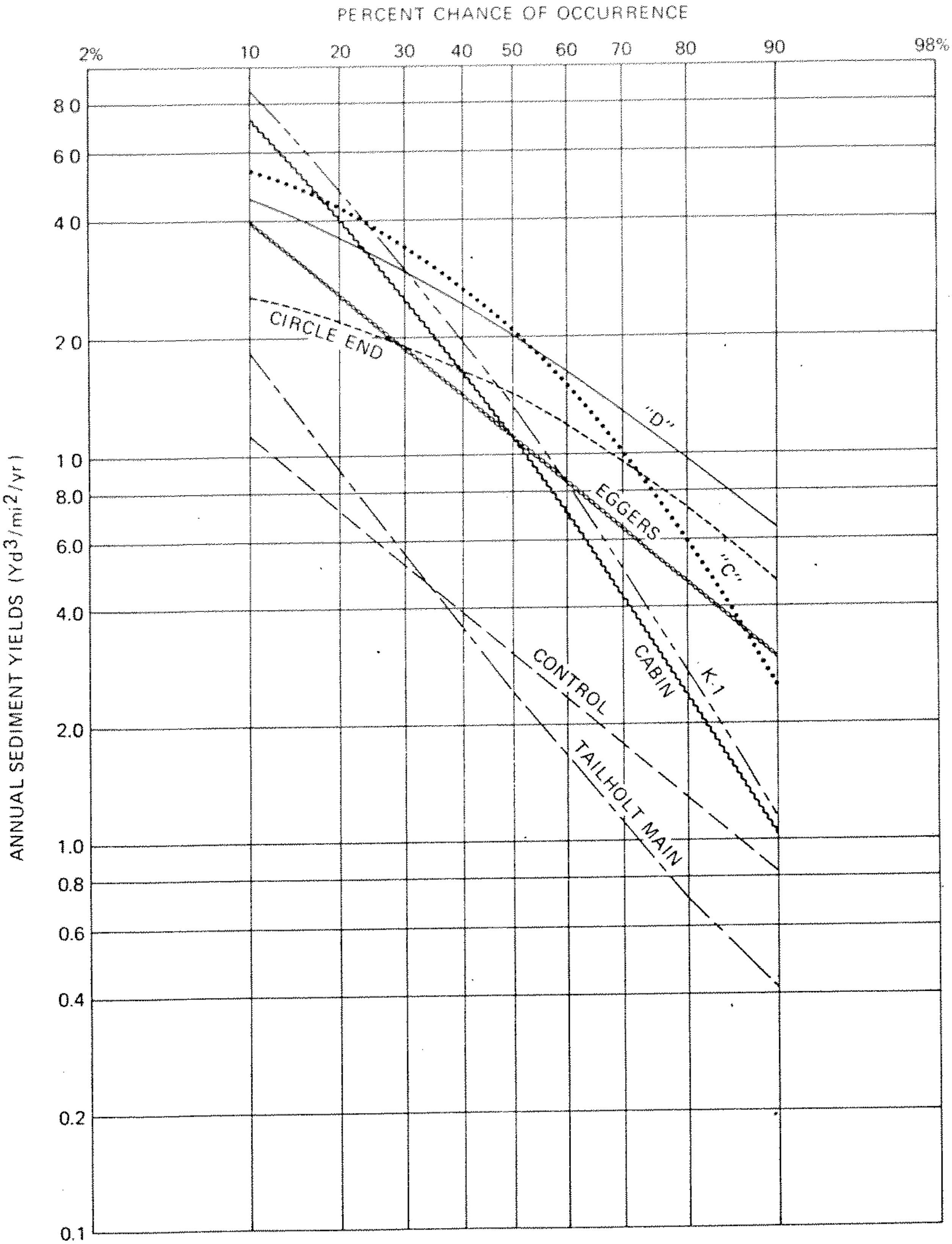

Fig. 17. Probability of annual yield of granitic sediments for undisturbed, forested watersheds in Idaho.

However, limited data on sediment basin trap efficiency suggest that the values shown on Figure 16 represent about 80 percent of the total annual sediment yield. Variation is the primary message from Figure 17, both between watersheds and within an individual watershed over time. There is an order of magnitude difference between watersheds for the P50 values and individual watersheds typically exhibit a range of two orders of magnitude between P10 and P90. These data represent a relatively short period of record, longer data sets would exhibit even greater extremes for individual watersheds. Much of the range in sediment yields is explained by variations in annual streamflow. Figure 18 shows the relation between annual sediment yield and annual streamflow for the Egger's Creek basin with an r^2 value of 0.82 and has a curvilinear relation similar to that often found in sediment rating curves.

Sediment Transport

Steep mountain channels in forested areas normally exhibit a step-pool profile. Figure 19 shows the channel profile for Egger's Creek located on the Silver Creek study area in west, central Idaho. Steps usually result from organic debris in the channels, including logs as well as smaller branches and other debris. Steps can reduce the effective channel gradient considerably. For example, the overall channel gradient in the figure is 7.2 percent. If the gradient is corrected for all the vertical drops within the channel caused by organic debris, the effective channel gradient is reduced to only 2.1 percent. Excess shear stress on the streambed surface exerts a strong influence on bedload transport. In turn, shear stress is strongly dependent on slope of the streambed. Therefore, by influencing effective channel gradient, organic debris has a strong influence on bedload sediment transport. Johnejack and Megahan (1991) tested the effects of organic steps on sediment transport using different transport equations compared to measured sediment discharge data. Predicted sediment transport exceeded measured by three orders of magnitude using overall channel gradient but were within one order of magnitude using effective channel gradient.

Channel Sediment Storage

Organic steps in headwater channels serve another function. Granitic sediments are trapped behind the miniature detention basins created by the organic materials. Sediment storage in this manner can be very large. Megahan (1982) measured this type of sediment storage in 7 Silver Creek streams over a 6 year period. On average, there was 2.9 m^3 of sediment in storage per 30 m of channel length. Considering total channel length for each stream, there was an average of 171 m^3 of sediment storage per stream. Sediment yield data are available for the study streams. A comparison of sediment yield to sediment storage shows that an average of 15 times more sediment is in storage behind obstructions in these tributary channels than is delivered to the mouth of the watersheds each year. The magnitude of the sediment storage effect of organic debris has some important management implications: 1) disturbance to channels should be kept to a minimum in order to maintain existing storage capacity; 2) timber cutting adjacent to channels should be planned to maintain a long-term source of organic material for channel sediment storage; 3) channel sediment storage must be considered in any monitoring program designed to relate changes in on-site erosion to downstream sediment yields.

Figure 18 shows that annual sediment yield is strongly influenced by annual flow rates. A comparison of the change in sediment storage between years in an undisturbed study watershed suggests that much of the increased sediment yield during high flow years is produced from sediment stored behind obstructions in the channel (Figure 20). Figure 20 illustrates an inverse relationship between annual peak flow and sediment stored behind channel obstructions. The fitted curve is a hyperbola showing a rapid decline with increasing flow at low flows and approaching a constant at high flows. The shape of the curve suggests that sediment yields are strongly influenced by changes in channel sediment storage at lower flow levels but are influenced more by watershed sources of sediment at higher flows.

EDITOR'S NOTE: A complete listing of all of Dr. Megahan's publications dealing with geomorphic processes on granitic materials is provided at the end of this Proceedings.

References cited in this article follow immediately after Figure 20.

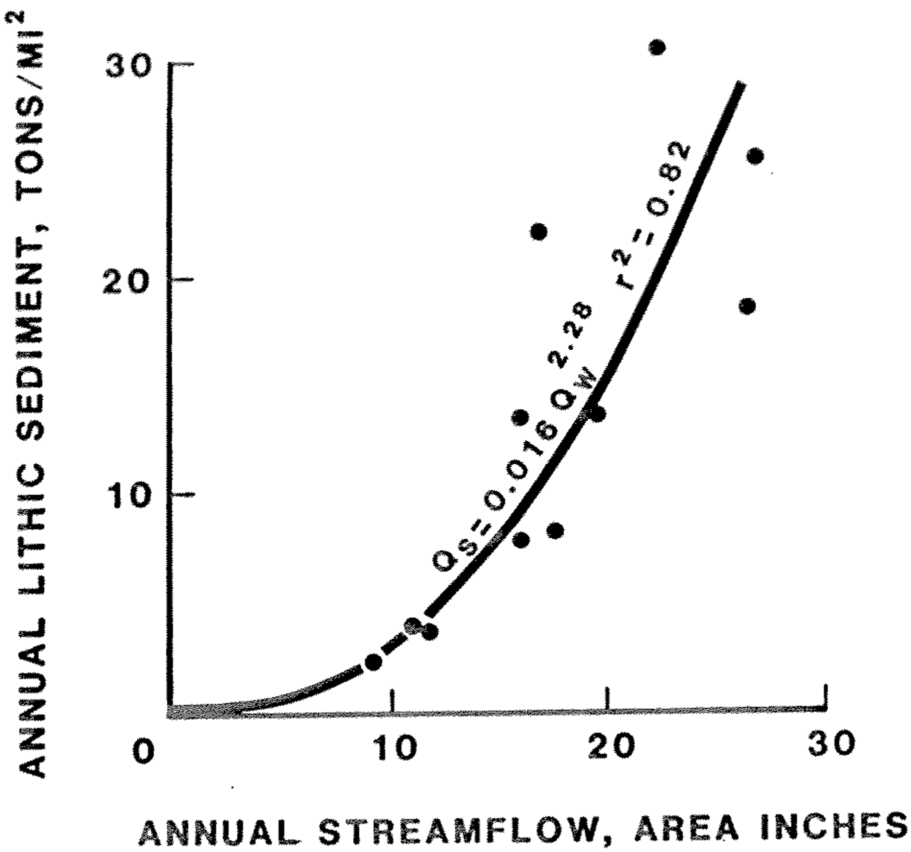

Fig. 18. Annual sediment yield as a function of annual water yield for Egger's Creek, an undisturbed, forest watershed in Idaho.

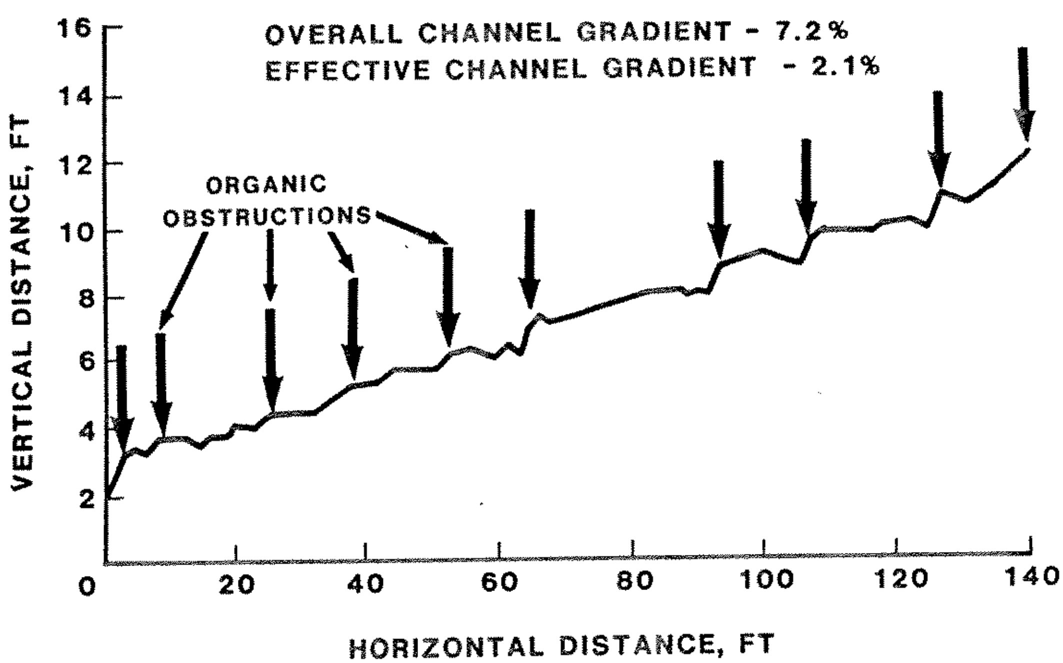

Fig. 19. Detailed profile for the Egger's Creek channel showing the effects of organic debris on channel gradient.

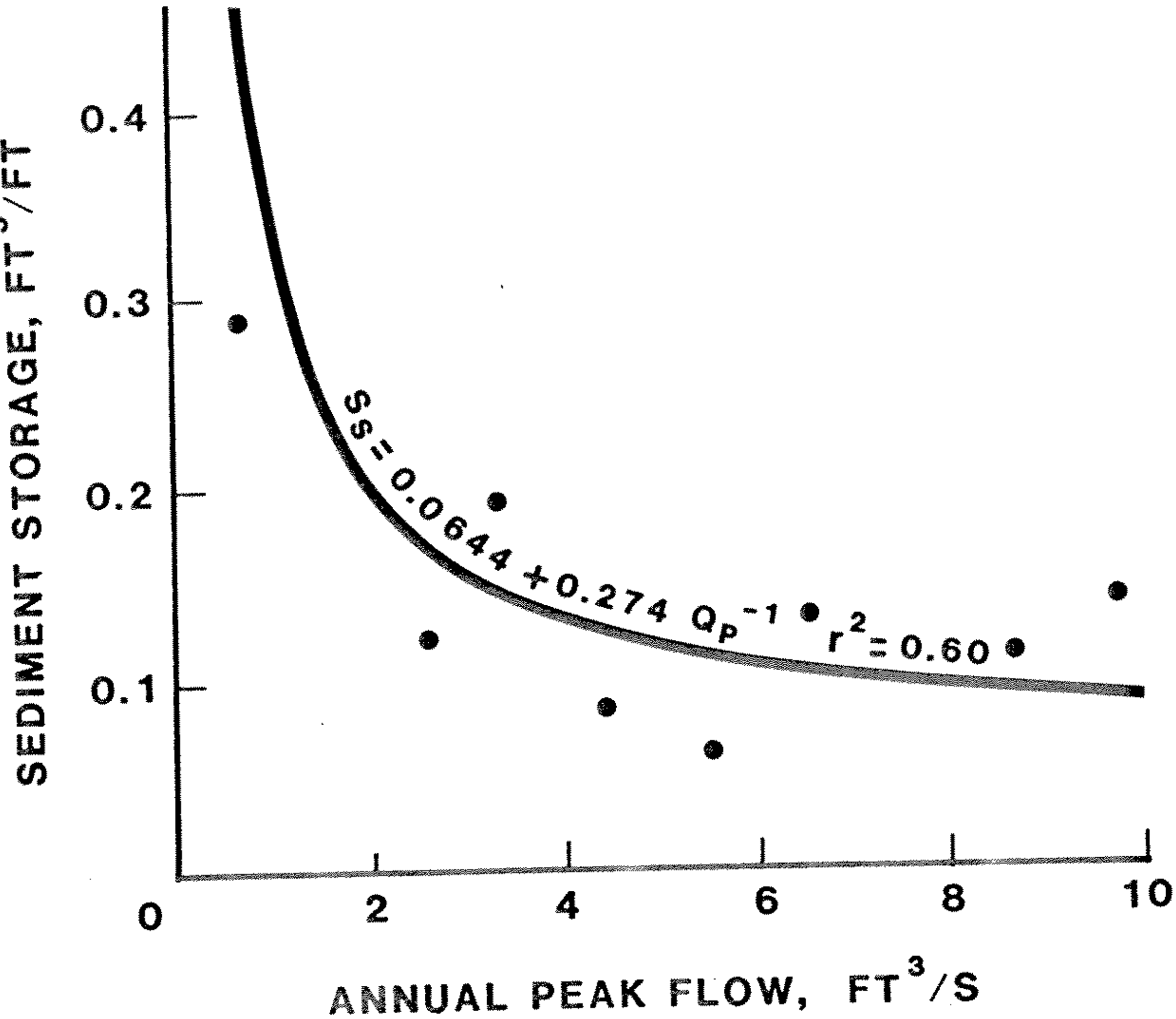

Fig. 20. Sediment storage behind channel obstructions in relation to annual peak flow in Egger's Creek.

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MECHANICAL AND HYDROLOGICAL PROPERTIES OF GRANITIC ROCK ASSOCIATED WITH WEATHERING AND FRACTURING IN THE IDAHO BATHOLITH

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ABSTRACT

A classification system designed to differentiate weathering and fracture density characteristics of granitic rock in the Idaho batholith has proven to be useful to land managers for interpretations of slope stability and various physical site descriptors such as effective soil depth. Under laboratory conditions, the weathering classification is a reliable predictor of rock strength and other physical properties (porosity, velocity of sound wave transmission, bulk density, etc.). A review of studies that have evaluated field applications suggests that the rock classification system is useful for predicting porosity, water holding capacity, and saturated hydraulic conductivity, but may be limited in applications of slope stability because of site variability and interactions with other driving variables such as slope steepness.

INTRODUCTION

The Idaho batholith (IB) is a large expanse (> 41,000 km^2) of plutonic rock, widely exposed in central Idaho (Fig. 1). The Late Cretaceous IB is a member of a chain of batholiths located in the Western Cordillera of North America, and includes the Sierra Nevada and Southern California batholiths. The IB is divided into a northern (Bitterroot) and southern (Atlanta) lobe, separated by Precambrian metamorphic rocks of the Salmon River arch. Both lobes are similar chemically and mineralogically. There are several plutonic phases ranging from oldest to youngest: tonalite, biotite granodiorite, muscovite-biotite granite, and fine-grained leucocratic granite (Lewis et al., 1987).

Plutons in the IB lack the zoning and distinct contacts that characterize Sierra Nevada plutons, and IB rocks are also lower in mafic minerals and higher in silica. The IB intrudes Paleozoic metasediments along its eastern border, much of which is now covered by Eocene volcanic rocks of the Challis formation. The western edge of the batholith contacts metavolcanic and metasedimentary rocks, overlain by higher grade metavolcaniclastics and believed to be accreted oceanic crust material (Jones et al., 1977; Brooks and Vallier, 1978).

Land Use Effects

As with other western batholiths, the IB is largely forested, mountainous terrain, and contains a variety of high resource values including recreation, water, mining, timber, forage, wildlife, and fish. Conflicting demands for use of these resources is exacerbated by the fragile nature of soils in granitic batholiths. The granitic rock of the IB produces shallow, coarse-textured, cohesionless soils that exhibit high erosion rates, especially when disturbed.

Prior to 1950, logging activity in the IB was confined to gentler landscapes with relatively low erosion hazards (Megahan, 1975). Most of these areas had been logged by the mid-1950s. As logging and road construction activities moved into steeper lands, erosion and sediment production greatly increased. Megahan and Kidd (1972) reported sediment production over a 6 year period following jammer logging in central Idaho at 770 times natural rates, and 84% of the surface erosion occurring during the first year after disturbance. The combined effects of

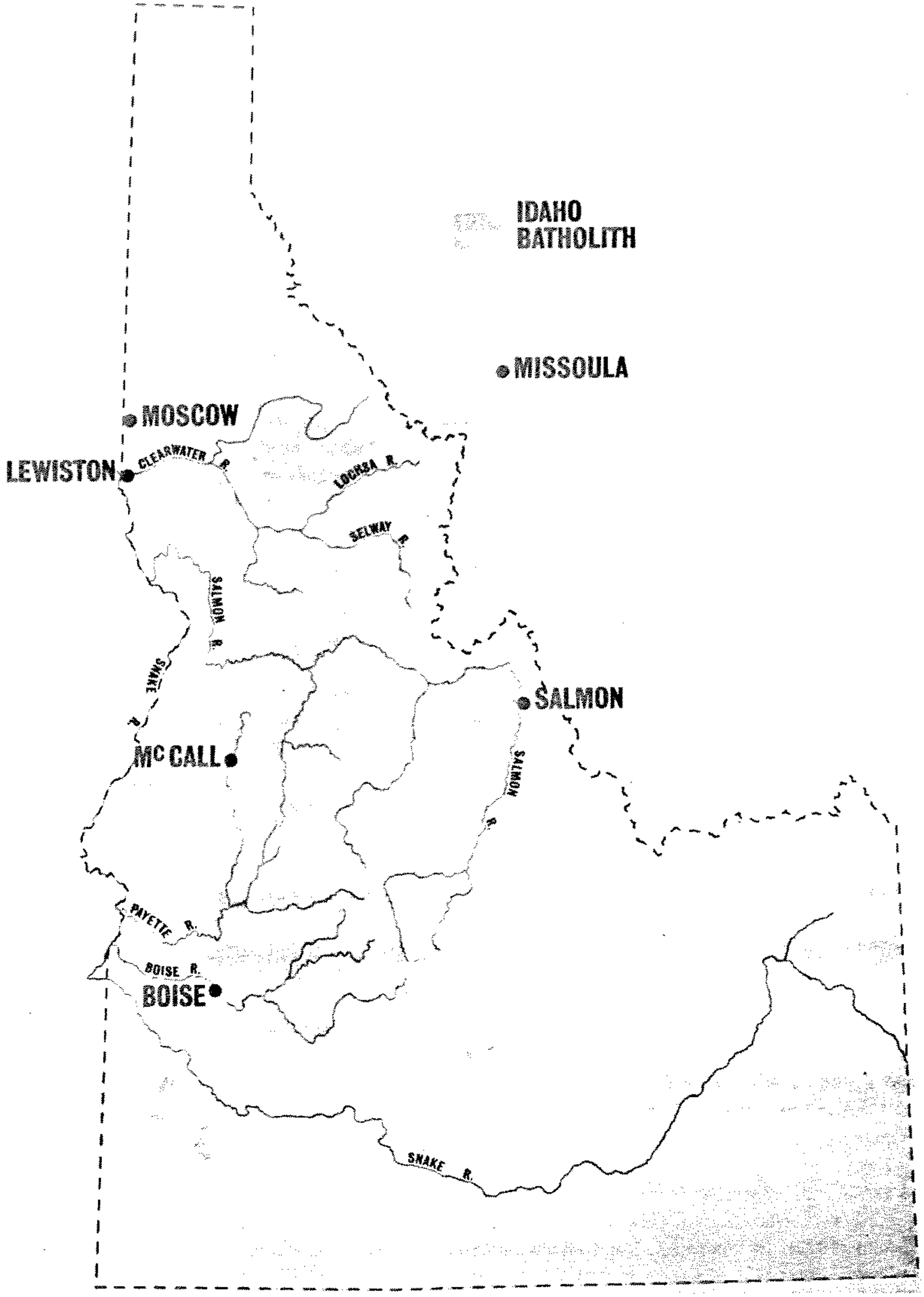

Figure 1. Location map of the Idaho batholith.

logging activity and natural disturbances from fire and high intensity storms in the South Fork of the Salmon River (SFSR) basin resulted in massive amounts of sediment, estimated at 73,000 Mg (metric tons) annually delivered to the stream (Megahan et al., 1992).

Most of the logging activity took place in the upper 1,000 km^2 of the watershed and, by 1968, resulted in widespread channel aggradation estimated at 2 million Mg (Arnold and Lundeen, 1968). The SFSR is considered crucial spawning and rearing habitat for anadromous fish in the Columbia River basin. Concern about increased sediment production by the U.S. Forest Service (USFS) resulted in a logging and road construction moratorium on national forest lands, which was instituted in 1965 and remained in effect through 1978.

Research History

Largely in response to problems like the SFSR, in the late 1960s the Watershed Research Work Unit of the USFS Intermountain Research Station accelerated its program to study erosion and sediment production in the IB. The relationship between rock properties and slope stability was recognized early in the program as an important, but largely neglected, aspect of watershed research (Megahan, 1973). We saw distinct, but then unquantified, relationships between the degree of weathering of rock in road cuts and the accumulated sand in road ditches resulting from surface erosion or dry ravel. Similarly, we began to see associations between mass erosion in the IB and highly weathered or altered granitic rock that contained clay seams.

In 1970, the Intermountain Research Station entered into a joint venture with Howard University's Dept. of Civil Engineering to conduct research on the engineering and hydrologic properties of granitic rock and soil in the IB. One of the original objectives was to relate rock properties to the recently developed granitic rock classification scheme of Clayton and Arnold (1972). In this paper, I will review general findings relating engineering and hydrologic properties to rock weathering and fracturing characteristics, and review results of subsequent studies relating rock classification to a variety of topics including slope stability and water transmission and storage.

WEATHERING AND FRACTURE DENSITY KEY

Field Classification

The field classification system of rock properties published by Clayton and Arnold (1972) was intended to allow easy classification of grain size, fracture density, and weathering characteristics of granitic rock based on field observation of rock outcrops, or rock exposed in roadcuts. There are 5 classes of fracture density, ranging from very high (< 15 cm spacing) to very low (> 180 cm spacing). There are 3 classes of grain size: fine (< 2 mm), medium (2-5 mm), and coarse (> 5 mm). The weathering classification has 7 classes ranging from class 1 (unweathered), to class 7 (very well weathered). Several observable field criteria are used to classify weathering: color, ease with which rock can be broken by hand, distinctiveness of joints and fractures, root penetration, the sound of a striking hammer blow, degree of spalling, and whether or not rock exhibits plastic properties when wet. These weathering criteria are related to changes in microfractures associated with unloading and weathering, and formation of secondary weathering products.

Weathering Processes

When batholith rocks are uplifted to near the earth's surface by faulting and overburden removal, the unloading expands joints and other planes of weakness in the unweathered rock. This eventually creates pathways for water entry and mineral weathering. Biotite weathering has often been implicated as important in the transformation of hard granitic rock to grus. Initial weathering of biotite involves proton exchange for non-framework K, followed by hydrolysis of Fe and Mg and oxidation of released Fe. Visual evidence of this weathering process includes expansion of biotite sheets, fringed edges of grains, iron oxide staining and a change in color from black, through brown, to golden (Walker, 1949; Helley, 1966; Clayton et al., 1979).

However, biotite alteration is apparently not essential for grussification of all granitic rock. Marchand (1974) found little evidence of biotite weathering during grus formation in the White Mountains, CA. He suggested that the harsh physical weathering environment at his study site may have accounted for grus formation while biotite grains showed little evidence of chemical weathering.

Visual evidence of feldspar alteration by chemical weathering is not as distinct as changes in biotite appearance. Typically, feldspar grains will progress from clear and translucent to opaque, and then appear powdery as weathering progresses (Clayton et al., 1979). Thin section and x-ray diffraction studies suggest this progression is due to increasing microfractures within mineral grains and accumulation of secondary weathering products. Scanning electron microscopy studies of weathered plagioclase grains from the IB suggest the development of etch pits contributes to the changes in the macroscopic appearance of feldspar grains (Inskeep et al., 1993).

Physical and Mechanical Properties by Weathering Class

Physical and chemical weathering processes result in dissolved loss of matter, formation of secondary weathering products, and changes in intergrain geometry. These changes increase rock porosity and decrease rock strength. Hampton et al. (1974) and Clayton et al. (1979) evaluated several physical and mechanical properties of granitic rocks sampled from 29 locations in the IB. Rocks were sampled to provide a full range of weathering classes for laboratory testing.

Rock bulk density for weathering class 1 ranged from 2.6 to 2.75 Mg m^{-3}, approximately the weighted mean solid phase density of the constituent minerals (Clayton et al., 1979). Bulk density decreased rapidly in an approximately linear fashion to a mean value of 2.3 Mg m^{-3} as weathering increased through class 3, then decreased less rapidly to a mean value of 2.1 Mg m^{-3} as weathering increased to class 6 (Fig. 2a). Weathering class 7 rock contained sufficient clays to exhibit plastic, cohesive properties, and bulk density averaged 1.8 Mg m^{-3} for class 7 rock samples. Porosity of individual rock samples (not including fractures) was approximately zero for class 1, then increased rapidly to a mean value of 0.14 for weathering class 3 (Megahan and Clayton, 1986). Porosity increased to 0.20 for class 6 rock, then increased to approximately 0.30 for class 7 rock.

Unconfined compressive strength (UCS) of rock core samples was tested for all weathering classes except class 6, which lacks sufficient strength to form cores (Clayton et al., 1979). Class 1 rock cores had a UCS ranging from 80 to 130 MPa (megapascals), with a mean of 110 MPa (Fig. 2b). There was a dramatic loss of strength on weathering from class 1 to class 2, to a mean value of 38 Mpa. This loss in strength was associated with formation of microfractures between mineral grains. Class 2 rock UCS values ranged from 20 to 70 MPa for 16 different core samples. There was a gentle decline in strength through weathering class 5, to approximately 12 Mpa. Two core samples of class 7 rock had UCS values of 7 and 11 MPa.

Sonic wave velocities at peak axial loading (4 MPa) were measured on the same rock cores and showed trends similar to the UCS trends (Clayton et al., 1979). Sonic velocities of Class 1 rock averaged approximately 5,000 m sec^{-1}, declined to about 3,000 m sec^{-1} for class 2, then declined slowly reaching a mean velocity of 2,100 m sec^{-1} for class 7 (Fig. 2c). The results of the UCS and sonic velocity tests suggest that rock samples lose considerable strength during initial weathering processes when evidence of mineralogical changes are minimal.

Hampton et al. (1978) reported results relating rock hardness as measured with a scleroscope to weathering classes, bulk density, UCS, sonic velocity, and secant modulus at peak stress. The authors concluded that hardness tests are a simple, inexpensive means for characterizing rock properties. Hardness was inversely proportional to weathering classes, and directly proportional to bulk density, sonic velocity and strength. Fitted regressions of rock properties on hardness exhibited r^2 values ranging from 0.74 to 0.89.

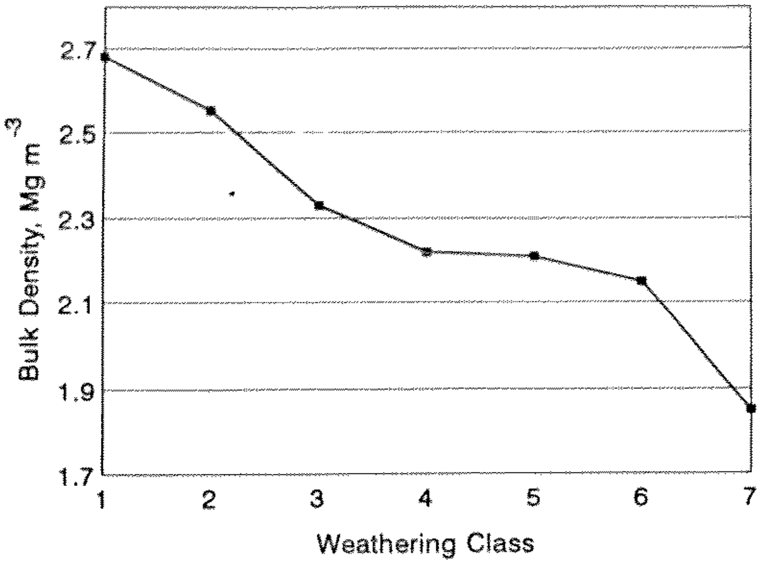

Figure 2a. Bulk density of granitic rock plotted by weathering class.

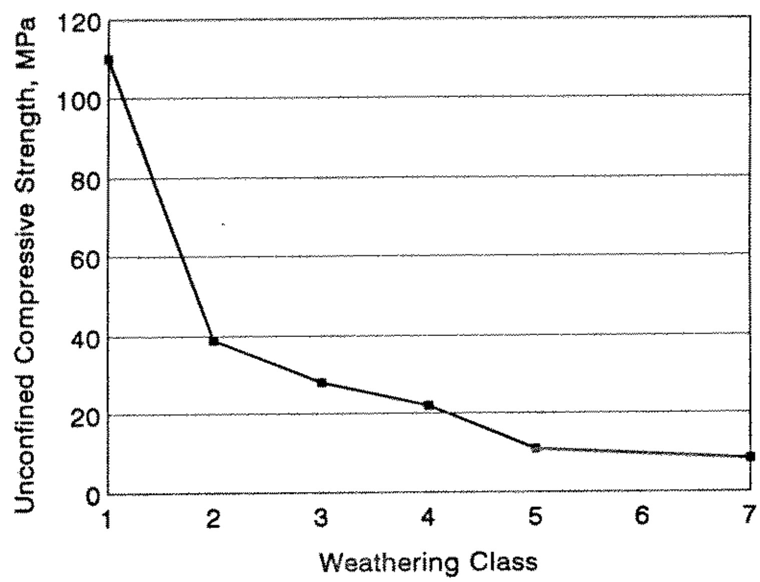

Figure 2b. Unconfined compressive strength of granitic rock plotted by weathering class.

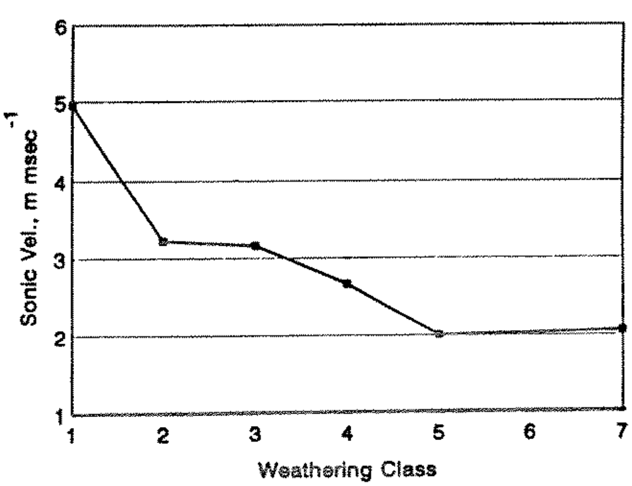

Figure 2c. Sonic wave velocity at peak axial loading plotted by weathering class.

FIELD STUDIES OF ROCK PROPERTIES

Megahan et al. (1978) evaluated relationships between rock properties and landslide occurrence in the Clearwater National Forest (NF) in northern Idaho and along the Middle Fork Payette River in the south central IB. About 50% of the area inventoried in the Clearwater NF is in the IB. A total of 877 landslides located in the IB were described. The authors presented data on landslide frequency by both rock weathering class and fracture density. There was an increasing trend in landslide occurrence with increasing weathering class through class 3, and no consistent trend in classes 4-7 (Fig. 3a).

There was a more consistent relationship between landslide occurrence and fracture density, with landslides more frequent as the distance between fractures decreased (Fig. 3b). The authors explained this on the basis of greater exposed surface area and increased hydrostatic pressure associated with the higher fracture density. The relationships between weathering and landslide occurrence did not account for the frequency distribution of weathering classes, which would have likely resulted in a stronger correlation. For example, weathering class 7 rock was associated with 10% of landslides, yet it is a very uncommon weathering class on an areal basis (Clayton and Arnold, 1972).

In 1980 the Forest Service constructed a road in the Silver Creek Experimental Watersheds, Boise National Forest. This area has been the center of much of the watershed research in the southwestern IB. The road is a collector road, designed to accommodate regular forest traffic as well as logging. Prior to construction, geophysical surveys of seismic velocity and electrical resistivity were conducted along the proposed road location. Data from these surveys were incorporated into a model to predict the degree of weathering and rock alteration (Fausset et al., 1978), based on principles of rock and fluid mechanics. Using criteria of low resistivity (<2,000 ohm-ft) and low seismic velocity (<3,500 ft sec^{-1}), the authors predicted that the road would intercept 21 zones of weathering class 6 or 7 rock.

Following construction, Clayton (1983) classified the weathering characteristics of exposed road cuts, and evaluated the geophysical survey predictions in light of the post-construction survey. The pre-construction surveys were very efficient at identifying highly weathered rock; 11 of 12 zones identified as highly weathered following construction met one or both of the pre-construction criteria. However, using the same criteria, 10 other zones were incorrectly predicted to contain highly weathered rock. Although this is a high percentage of false-positive findings, it greatly delimited the number of zones that might require further geophysical exploration or extra care with drainage. Several drainage features were redesigned based on results of the geophysical surveys.

A subsequent study along this same road measured cutslope erosion collected in 75 troughs (Department of Geology and Geophysics, 1984). Preliminary results suggest annual cutslope erosion rates on weathering class 5 rock are approximately double erosion rates on class 4 rock, and weathering class 6 rates are approximately triple the erosion rates on class 4 (W.F. Megahan, pers. com.) (Fig. 4). Erosion rates in class 7 rock are less than class 6, which may result from the greater cohesion due to the presence of clay minerals in class 7 rock. There were no samples in weathering classes 1 through 3. In spite of the logical trends, weathering class explained little of the variability in erosion rates in this data set, and cutslope angle was a stronger predictor of erosion.

Megahan and Clayton (1986) investigated *in situ* hydrologic properties of granitic rock in the IB using borehole permeability tests. Fifty eight permeability tests were obtained from 10 different locations along a north-south transect in the IB. Saturated hydraulic conductivities (K_{sat}) were calculated based on hydrostatic pressure, volume of water delivered, borehole length, and time. Four tests were obtained in weathering class 1 rock. Previous studies (Clayton et al., 1979) indicated that intergranular porosity of class 1 rock was zero, so all permeability would be confined to fractures. Three of the tests resulted in zero K_{sat} values, however the fourth test gave a value of 0.17 cm day^{-1}. Class 2 rock had the highest K_{sat} values, ranging from 15 to 70 cm day^{-1}. Weathering classes 2 through 7 showed a statistically significant

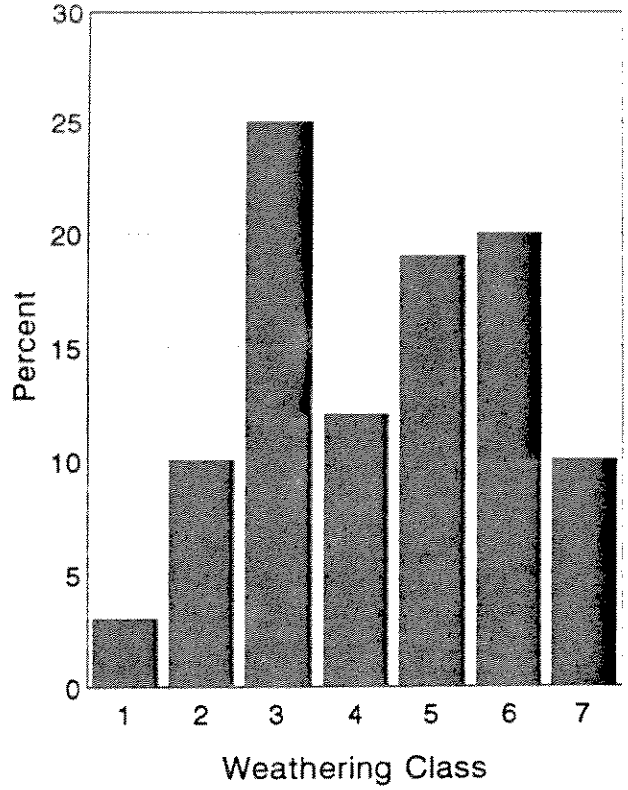

Figure 3a. Frequency of occurrence of landslides by rock weathering class for batholith locations in the Clearwater and Boise National Forests.

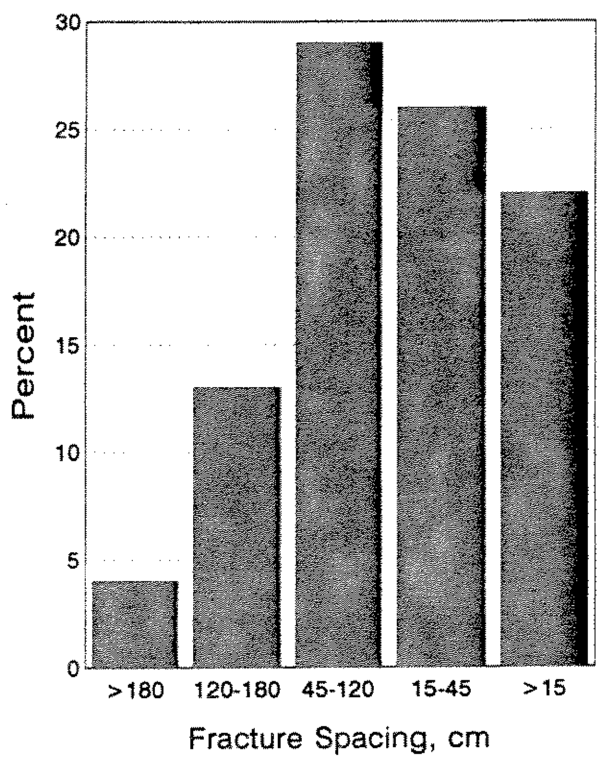

Figure 3b. Frequency of occurrence of landslides by fracture spacing.

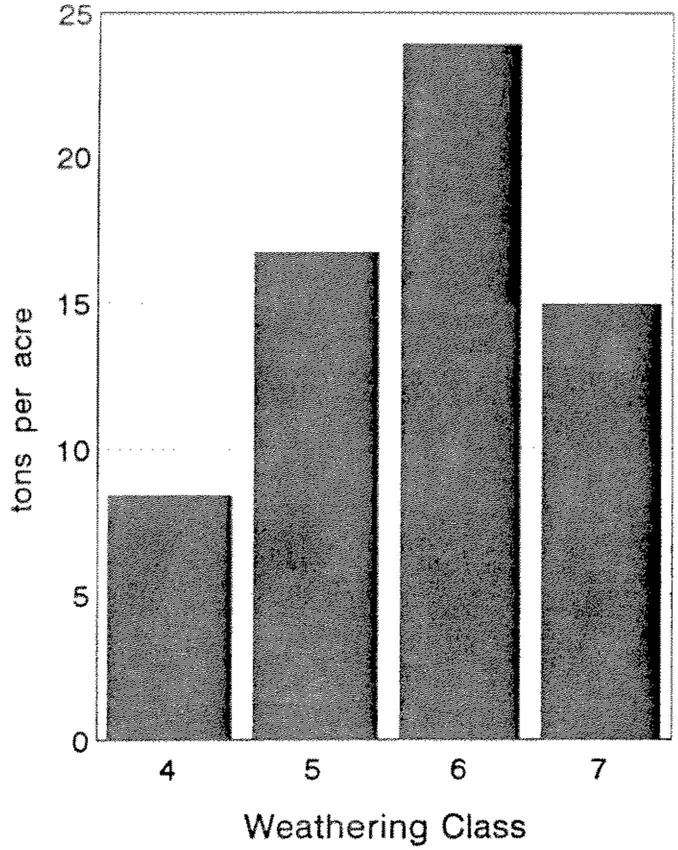

Figure 4. Average annual cutslope erosion rates (tons per acre) over a three year period following road construction, southern Idaho batholith.

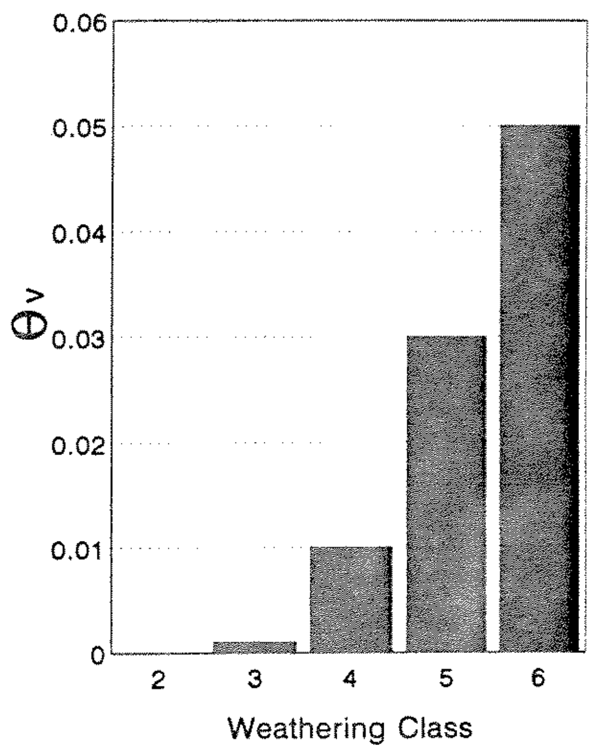

Figure 5. Volumetric water content, θv, for weathered granitic rock from the southern California batholith.

decline in K_{sat} with increased weathering, with means in the range 20 to 1 cm day^{-1}. Since there are only slight increases in intergranular porosity between class 1 and 2, Megahan and Clayton (1986) suggested that most water transfer must be taking place along fractures. The decreases in conductivity with increasing weathering were attributed to progressive increases in clay formation and mineral expansion with weathering.

Jones et al. (1990) studied the volumetric water content, θv, of weathered granitic rock in the Southern California batholith as part of study of water use by chaparral vegetation. The exploitation of weathered rock by plant roots is an important survival mechanism for many plants in coarse textured granitic soils. The authors classified the rock weathering characteristics using weathering classes of Clayton and Arnold (1972). Rock less weathered than class 4 held essentially no water against gravity. Class 4 rock had an average θv=0.01 and ranged up to 0.05 for weathering class 6 rock (Fig. 5). The authors did not encounter class 7 rock. A volumetric water content of 0.05 for class 6 rock is only 25% of the mean porosity value for that class (Megahan and Clayton, 1986). It is possible that some rock matrix pores were not readily accessible to water entry, and also the presence of larger cracks that would freely drain made up some of the pore space.

DISCUSSION

The degree of granitic rock weathering can be classified in the field using a few easily described properties. Both weathering and fracture density show strong relationships to mechanical and physical properties of rock. As weathering progresses, bulk density, strength, and hardness all decrease, and intergranular porosity increases. Increasing fracture size and density accompany unloading and weathering, however, increased weathering causes accumulations of weathering products that coat and fill fractures.

Studies of water transfer through rock and water holding capacity of weathered rock near the surface suggest that fractures play a dominant role. Much of the intergranular porosity resulting from mineral grain weathering may be occluded, or of sufficiently small diameter that liquid water movement is very slow. Saturated hydraulic conductivity of granitic rock is lowest for weathering class 1, peaks with weathering class 2, and then slowly declines. This decline is attributed to increasing fracture plugging as rock weathers.

Losses in strength and increasing clay content as weathering progresses are related to slope stability, although a variety of field studies in the IB have found mixed success with such correlations. Poor correlations may be a result of assigning a single weathering or fracture density class to a study site with inherent high variability in these properties. When selecting sites for studies relating weathering to rock properties, we purposely sought locations with uniform rock properties. However, high spatial variability is the rule rather than the exception in the IB. Because of this variability, attempts to assign weathering classes to rock at the level of soil resource inventory mapping units (typically tens to hundreds of hectares) is probably of no value.

However, there are some general regional relationships that have planning value. Higher elevation landscapes that have been glaciated tend to have a much higher proportion of relatively hard (class 1 and 2) rock than other areas in the IB. Glaciers may have scoured away more highly weathered overburden, in essence rejuvenating the weathering surface. On a broad regional scale, Clayton et al. (1975) reported on the relationship between remotely-sensed linear features and the occurrence of class 7 rock in the southern IB. The Middle Fork of the Payette River valley and its major tributaries appear to be structurally controlled by a well defined fault system. The presence of faults provides a deep plumbing system for the circulation of fluids that contributes to a higher than normal surface expression of class 7 rock, and a high frequency of landslide problems. In addition, numerous hot springs are present along the extent of the linear features.

Weathering and fracture density play important roles in controlling strength and subsurface hydrologic properties of granitic rock. The classification system developed by Clayton and Arnold (1972) has been widely used in the IB as a planning tool for road construction and evaluation of revegetation potential. Rock classification should be done on a project basis because site variability is too high to rely on general resource inventories of rock properties. Pre-construction geophysical surveys should be considered in hazardous terrain where previous problems with mass erosion were experienced.

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LANDSLIDE AND SURFACE EROSION RATES IN THE ENGLISH PEAK BATHOLITH AND ASHLAND PLUTON, CENTRAL KLAMATH MOUNTAINS, CALIFORNIA AND OREGON

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ABSTRACT

Landslide episodes in the English Peak Batholith (Little North Fork Watershed) and in the Ashland Pluton (Ashland Creek Watershed) have occurred in close association with severe floods in 1964, 1971, 1972, and 1974. Road construction and timber harvest began in 1955 at Ashland Creek, and in 1965 at Little North Fork, raising landslide rates above undisturbed levels in both watersheds. From 1965-1975, the Little North Fork produced landslides at a rate of 1.08 yds^3/acre/year. The rate for undisturbed land was 0.30 yds^3/acre/year, harvested land 8.71 yds^3/acre/year, and roaded land 85.09 yds^3/acre/year. In comparison, the rate for this time period at Ashland Creek was 0.33 yds^3/acre/year, with undisturbed land producing 0.04 yds^3/acre/year, harvested land 0.02 yds^3/acre/year, and roaded land 22.48 yds^3/acre/year. The distribution of landslides across the landscape at Little North Fork was found to be related to elevation zones and to geomorphic terranes. In 1964, landslides were concentrated at 4,000 feet in elevation, whereas from 1965-1975, they were concentrated at 2,500-3,500 feet. This clustering is probably related to the occurrence of rain on a heavy snow pack at those elevations. The inner gorge geomorphic terrane accounted for 84% of the total landslide volume (1965-1975). At Ashland Creek, landslides were concentrated at an elevation of 3,500-4,000 feet (1965-1975).

Sediment produced by surface and channel erosion at Little North Fork and Ashland Creek was not limited to flood years as was the case for landslides. Rather, these processes generated sediment even during dry years, and the rate was strongly influenced by the level of watershed disturbance. From 1965-1975, a wet period, surface and channel erosion at Ashland Creek produced sediment at a rate of 0.71 yds^3/acre/year. About 10% of the watershed was occupied by roads or harvest at that time. From 1976-1986, a dry period, the rate was 0.02 yds^3/acre/year, with the same disturbance level. In contrast, at the English Peak Batholith, Olsen Creek produced sediment from surface and channel erosion at a rate of 3.8 yds^3/acre/year from 1987-1992, a relatively dry period. About 75% of this watershed was burned by wildfire in 1987.

INTRODUCTION

The English Peak Batholith and the Ashland Pluton are Mesozoic granitic bodies within the Klamath Mountains physiographic province [Figure 1]. The terrain they occupy is rugged and mountainous and supports a forest cover. Soils are highly erodible, and landslides are common in some parts of the landscape. Shallow debris avalanches and flows involving soil and colluvium are the most common type of landslide. Debris torrents occur during high stream flow conditions and are usually initiated by landslides, but some are caused by intense summer showers which mobilize channel sediment without triggering landslides.

Large floods have been documented in this area in 1861, 1890, 1955, 1964, 1971, 1972, and 1974 (Coghlan, 1984). Corresponding landslide episodes have been identified in 1964, 1971, and 1972, at the English Peak Batholith, (de la Fuente and Haessig, 1992; USFS, in preparation), and in 1964 and 1974 at the Ashland Pluton (Wilson and Hicks, 1975; Smith and Hicks, 1982).

The purpose of this article is to: (1) present findings on erosion and sedimentation rates for two granitic areas in the Klamath Mountains, the English Peak

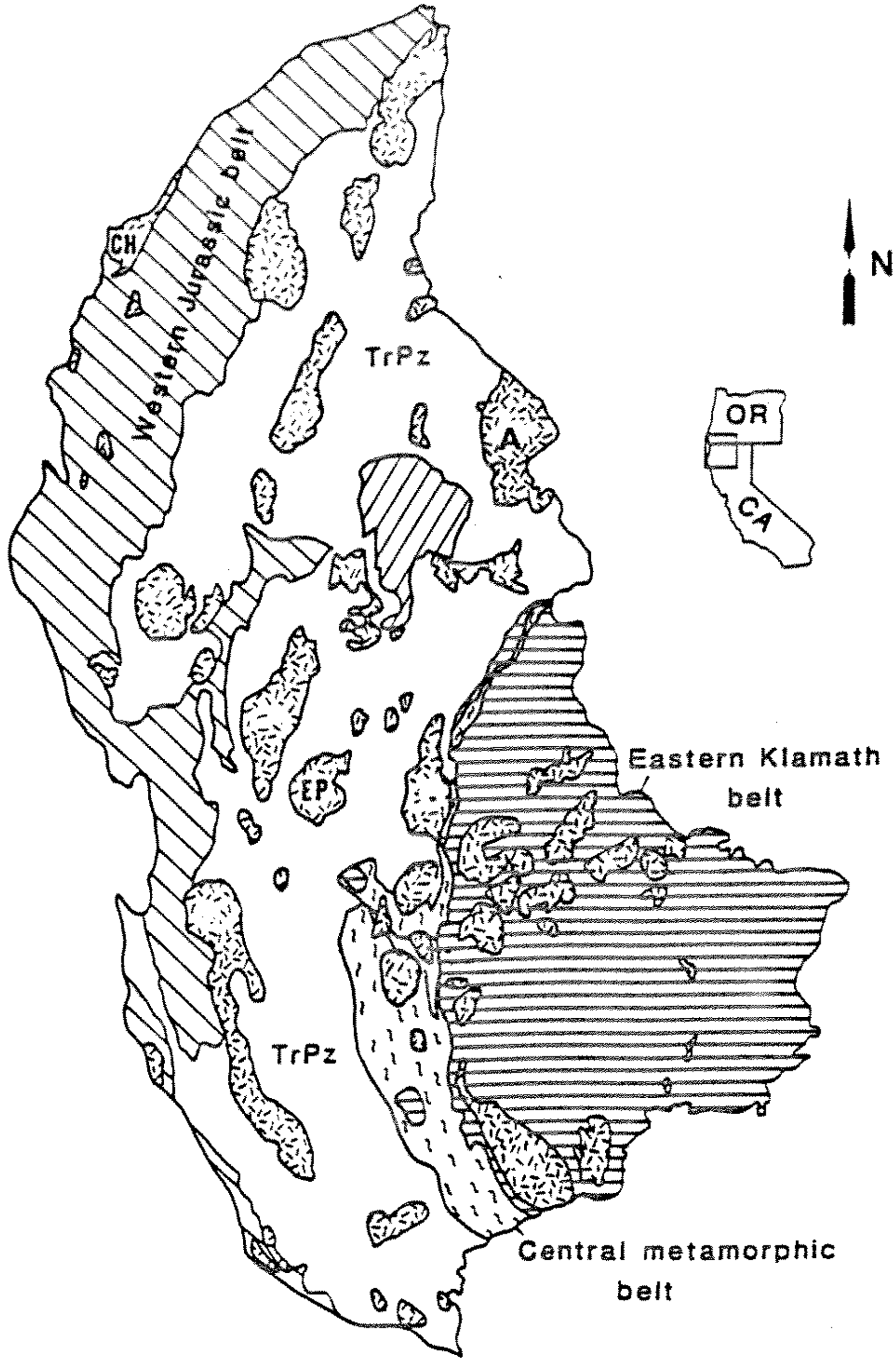

Figure 1. Simplified geologic map of the Klamath Mountain province in California and Oregon, showing the four lithotectonic belts, and granitoid plutons. **TrPz** is the Western Paleozoic and Triassic belt; for simplicity, subterranes of this belt are not shown. **EP** is the English Peak Batholith; **A** is the Ashland Pluton. Figure modified after Irwin, 1985.

Batholith and the Ashland Pluton; (2) describe the influence of geomorphic and climatic factors on sedimentation rates; (3) describe the effects of watershed disturbances (roads, timber harvest, fire) on sedimentation rates; (4) discuss the relative importance of landslides, surface erosion, and channel erosion in granitic watersheds.

PHYSICAL ENVIRONMENT

English Peak Batholith

The English Peak Batholith [Figure 1] lies in the center of the Klamath Mountains, a few miles northwest of Sawyers Bar, California, and is entirely within the Salmon River watershed, a triburary to the Klamath River. This batholith is late Jurassic in age, 159-161 million years old, (Irwin, 1985), and varies compositionally from granodiorite to tonalite, diorite, and gabbro (Seyfert, 1964). A remnant erosional surface is evident at approximately 3,000 feet in elevation along the SE margin of the batholith. This surface is gentler than slopes at higher elevation [Figure 2], and its distribution along the margins of the modern valley suggest that it is associated with an ancient valley floor. Bedrock is deeply weathered below the surface, and it is dissected by streams. Similar surfaces have been described along the Klamath River, near Happy Camp, California (Baldwin and de la Fuente, 1989).

The Little North Fork is a 20,801 acre watershed along the east margin of the English Peak Batholith. It is comprised of 10,765 acres of granitic rock and 9,036 acres of metamorphic rock. Elevations range from 2,000-7,322 feet, and annual precipitation varies from 30 inches near the mouth to about 90 inches in the headwaters. Snow predominates at elevations above 4,000 feet. Broad, U-shaped valleys in the headwaters of several of the tributaries provide evidence of extensive Pleistocene glaciation. Glacial deposits (moraines and outwash) occupy 8% of the watershed (USFS, in prep.).

Prior to 1964, the watershed was in an undisturbed state with the exception of a minor amount (less than 10 acres) of timber removal and jeep trails near the mouth. Timber harvest and road construction was initiated around 1965, and by 1975, there were 794 acres of harvested land and 82 acres of road in the watershed. Of this, 501 acres of harvested land and 50 acres of road were on granitic land, comprising 4.7% and 0.5% respectively, of the total granitic land area. Wildfire burned about 50 acres of the granitic part of the watershed at low intensity in 1987. The Little North Fork is seasonally inhabited by chinook and coho salmon as well as steelhead, and the entire Salmon River is recognized as an important habitat for these anadromous fish.

Olsen Creek is an 865 acre watershed along the south margin of the English Peak Batholith, and it is underlain entirely by granitic rock. It ranges in elevation from 1,750 to 6,700 feet and is steeper in channel gradient as well as average slope gradient than the Little North Fork. Slopes are more deeply weathered and dissected below 3,000 feet in elevation. Above 5,600 feet, the watershed is gentle and appears to have been shaped by glacial erosion. Below 5,600 feet, it is fan-shaped and steep (70-80%), with most tributaries coalescing above 2,800 feet in elevation. Much of the area burned in 1977, and again in 1987. Helicopter salvage logging of scattered patches of fire killed timber was conducted from 1977-1982. During the 1987 fires, 74% of the Olsen Creek watershed was burned at high and moderate intensity. These burned areas were observed to erode severely, with several inches of soil removed in the heads of steep (80% or greater) swales (USFS, 1990). Immediately following the fires of 1987, a debris catchment basin was built near the mouth of the creek. In 1988, a road segment 2,700 feet in length was built across the headwaters in gentle terrain.

Ashland Pluton

The Ashland Pluton straddles the California-Oregon border, immediately southwest of the city of Ashland, Oregon, and is within the Klamath and Rogue River watersheds. This late Jurassic pluton is 147-164 million years old (Irwin, 1985), and varies compositionally from diorite and granodiorite to tonalite and quartz monzonite. Erosion rates were measured in the Ashland Creek watershed, a 12,406 acre north-facing drainage which is underlain entirely by granitic rock. Elevations range from 2,800-7,533 feet, and precipitation as well as topography and dissection is similar to that of the Little North Fork. Glacial cirques and moraines are present in the headwaters, but they constitute a much smaller proportion of the watershed than do those in the Little North Fork. Reeder Reservoir, an 850 acre- feet impoundment on Ashland Creek, is the main water supply for the City of Ashland. Landslide rates (Wilson and Hicks, 1975; Smith and Hicks, 1982)

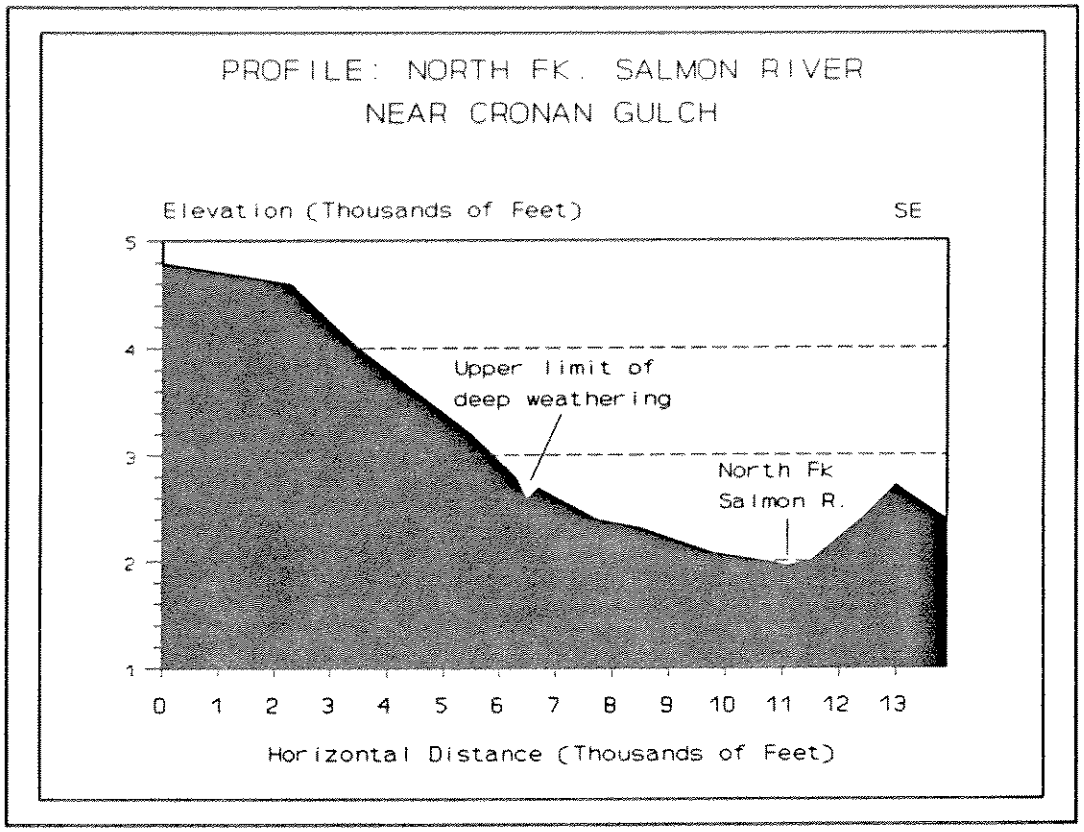

Figure 2. Profile of North Fork Salmon River near Cronan Gulch.

and reservoir sedimentation (Rolle et al., 1987) were measured for the portion of the watershed above the reservoir. Timber harvest and road construction occurred in the watershed from 1955-1969, and a ski area was built in around 1964. Roads occupy 1% of the watershed, harvested land 7%, the ski area 1%, and undisturbed land 91%, (U.S. Forest Service, 1977).

METHODS

The focus of this paper is on: a) sediment volumes determined by direct field and air photo measurements of landslide volumes on the hillside, and b) sediment volumes in a reservoir and a debris basin. Though modeled estimates of surface erosion have been developed for batholiths in this area (Montgomery, 1977; Sommarstrom et al., 1990; USFS, in prep.), they are not addressed here. Landslide production for Little North Fork during the time period 1965-1975 is compared to that of the Ashland watershed since this is the only period for which similar data exist for both watersheds. Sedimentation associated with surface and channel erosion at Olsen Creek from 1987-1992 is compared to that of Ashland Creek from 1965-1975, and 1976-1986.

English Peak Batholith

Little North Fork of the Salmon River. Analysis was limited to the granitic portion of the watershed. Landslide production from 1944-1988 was determined by a combination of field and air photo techniques, which measured the volume of landslide debris delivered to the stream system (Hicks, 1973; Pillsbury, 1976; USFS, in prep.). A total of 373 landslides were inventoried. Ages of landslides were determined by use of a chronological sequence of air photos.

The granitic portion of the watershed was stratified into geomorphic terranes, that is, lands with similar geomorphic histories, slope processes, and landslide production rates. Timber harvest and road construction occurred on only three of these terranes, which included: (a) granitic inner gorge (the steep landform which develops adjacent to rapidly downcutting streams); (b) steep granitic mountain slopes; and (c) gentle to moderately steep granitic mountain slopes. Landslide rates for undisturbed, harvested, and roaded conditions were computed for all granitic land in the watershed for the time period 1965-1975. In addition, individual rates were computed for three geomorphic terrranes during the same period.

Olsen Creek. Sedimentation rates from 1987-1992 were determined by counting the number of truckloads of material removed from the debris catchment basin at the mouth. The volume presented here should be considered a minimum value because the basin overflowed for a period of time (an estimate of overflow volume is included in the total), and through-flow of suspended sediment was not measured.

Ashland Pluton

Ashland Creek Watershed. Since Ashland Creek is underlain entirely by granitic rock, all of the watershed above the reservoir was analyzed. Landslide production from 1965-1975 was determined by field measurement of all identified landslide scars and estimating the volume of debris which left the site and entered the stream system (Wilson and Hicks, 1975). The vast majority of this volume was associated with the flood of 1974. The total sediment volume delivered to the reservoir was determined by topographic surveys run before and after the flood. The difference between the landslide volume measured on the hillslope and the total sediment volume measured in the reservoir was assumed to have originated as channel erosion and surface erosion.

Density differences between reservoir sediment and landslide sites were not accounted for due to lack of data. Reservoir sediment varies in specific weight from about 52 pounds per cubic foot for silts to 109 pounds per cubic foot for sands (Vanoni, 1977). The average specific weight of sediment at Reeder Reservoir is probably on the order of 90 pounds per cubic foot (no data are available), and the in-situ specific weight of landslide material in granitic terrane is about 105 pounds per cubic foot. Based on these two assumptions, one cubic yard of landslide debris (measured in-situ on the hillside) would occupy approximately 1.17 yds^3 when deposited in the reservoir.

Sediment delivered to Reeder Reservoir from 1976-1986, a relatively dry period, was determined by comparing topographic surveys taken before and after the cleanout of 1986. An estimate of silt accumulation on the reservoir walls, above the area which was cleaned out, was obtained by a field study (Rolle et al., 1987). Additional volume is known to be stored in the channels above the reservoir (Dan Sitton, personal communication, 1992), but it is not accounted for here.

RESULTS

English Peak Batholith

Little North Fork. Our data revealed that during the 1964 flood, the Little North Fork of the Salmon River produced 332,590 yd^3 of landslide-derived sediment. At that time, the watershed was essentially undisturbed. About 73% (242,478 yd^3) came from the granitic portion of the watershed which occupies 52% of the watershed. Thus, landslide sediment from the watershed was produced at a rate of 22.52 yds /acre of granitic land. There was a pronounced concentration of landslides at an elevation of 4,000 feet [Figure 3]. The 1964 flood produced a peak flow of 100,000 cfs in the Salmon River, and was associated with 11 inches of rain (recorded at Sawyers Bar), from December 20-24, 1964, on a heavy snowpack.

From 1965-1975, landslides delivered 130,907 yd^3 of sediment to the stream system, of which 116,462 yds^3 originated in granitic lands. This amounts to 10.82 yds /acre of granitic land, or 1.08 yds^3/acre/year if averaged over the 10 year period. Of the total, 37% was road-associated, 37% harvest-associated, and 26% came from undisturbed land. Roaded lands produced landslides at a rate of 85.09 yds^3/acre/year, harvested lands at 8.71 yds^3/acre/year, and undisturbed land at 0.30 yds^3/acre/year [Table 1]. The granitic inner gorge terrane produced landslides at a rate of 7.88 yds^3/acre/year (all disturbance classes) while the steep granitic mountain slope terrane produced landslides at 0.54 yds^3/acre/year, and the moderate to gentle granitic mountain slope terrane at 0.03 yds^3/acre/year [Table 2].

Landslides were concentrated at elevations from 2,500 - 3,500 feet, with the largest number at 3,500 feet [Figure 3]. The bulk of the volume occurred in association with two storms in 1972, one on January 21-23, and the other on March 2-3. More than 3 inches of rain per day fell during those storms.

The effect of these landslide episodes was severe. The 1964 event scoured many tributary channels, caused aggradation over several miles of the floodplain on the Little North Fork, and also created massive debris dams. The 1965-1975 events scoured some of the same streams as well as some different ones, mostly at lower elevations, and further disturbed the main floodplain.

Olsen Creek. From November 1, 1987 to October 31, 1992, Olsen Creek yielded about 15,900 yds^3 of sediment to the debris basin, mostly sand, silt and organic material. This equates to an average rate of 3.67 yds^3/acre/year. During the 13 month period from November 1, 1987 to December 1, 1988, it yielded 12,000 yds^3 (12.81 yds^3/acre/year). Peak one-day precipitation in excess of 3 inches occurred on December 2, and 7, 1987, and 2 inches fell on December 10, 1987 (Sawyers Bar recording station). Storms in November of 1988 also produced a large amount of sediment. A summer thunder shower in September of 1990 produced the last significant influx to the debris basin (about 1,800 yds^3) and generated a small debris torrent. The intensity of this storm is unknown, but field observations (USFS, 1990) revealed that burned areas exhibited sheet wash, rills, and gullies, whereas forested areas did not. No landslides were documented in the watershed from 1987 to 1992, so that all the volume measured can be attributed to surface and channel erosion.

Ashland Pluton

During the flood of 1964, Ashland Creek delivered a large volume of landslide-derived sediment to Reeder Reservoir. Much of this was related to timber harvest and roads. Actual volumes were not measured, but one study (Montgomery, 1977) estimated the total at about 60,000 yds^3.

The flood of 1974 produced more landslide volume than the 1964 flood (Wilson and Hicks, 1975), delivering a total of 130,000 yds^3 of sediment to Reeder Reservoir. Of this, 41,400 yds^3 (32%) was attributed to landslides, and 88,600 yds^3 (68%) was attributed to surface and channel erosion, primarily through mobilization of stored channel sediment. Thus, landslides delivered sediment to the reservoir at a rate of 3.31 yds^3 /acre of land [Table 1], and the rate for surface and channel erosion was 7.14 yds^3 /acre. Averaged over the 10 year period from 1965-1975, landslides produced sediment at a rate of 0.33 yds^3/acre/year, and surface and channel erosion at a rate of 0.71 yds^3/acre/year.

The landslide-derived volume was 88% from roaded

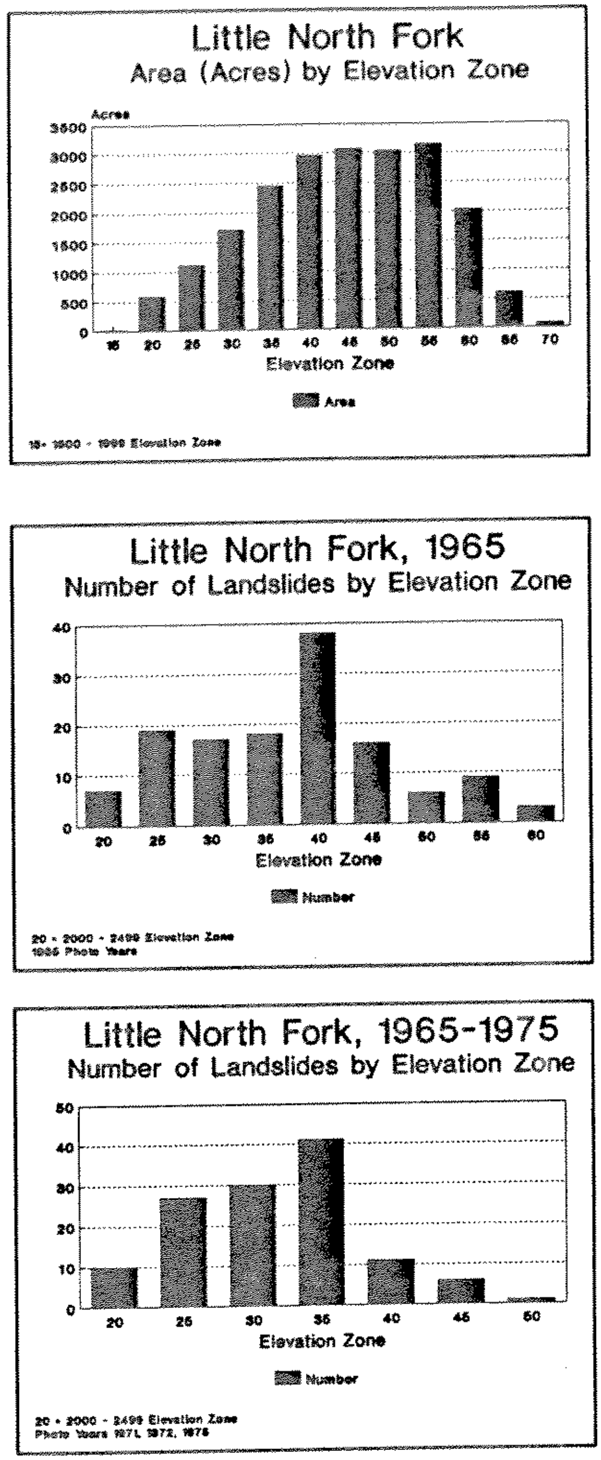

Figure 3. Landslides and elevation zones, Little North Fork watershed. Values for 1965 address the flood of 1964.

Table 1. Sediment production from landslides. **A.** Landslide rates by disturbance class for the 1965-1975 period in Little North Fork watershed. **B.** Landslide rates by disturbance class for 1974 in Ashland Creek watershed.

A. LITTLE NORTH FORK 1965-1975 (ENGLISH PEAK BATHOLITH)				
	Undisturbed	**Harvest**	**Roads**	**All Disturbance Classes**
Area, Acres	10,214*	501*	50*	10,765*
Volume Delivered yds.^{3}	30,286	43,620	42,546	116,452
Volume/ Area, yds.^{3}/Acre	2.97	87.07	850.92	10.82
Increase Over Undisturbed		X 33	X 319	X 4.6

B. ASHLAND CREEK 1974 (ASHLAND PLUTON)				
	Undisturbed	**Harvest**	**Roads**	**All Disturbance Classes**
Area, Acres	11,215	1,029	162	12,406
Volume Delivered, yds^3	4700	200	36,500	41,400
Volume/ Area, yds^3/Acre	0.42	0.19	224.75	3.34
Increase Over Undisturbed		X 0.45	X 535	X 8

* Granitic lands only.

Table 2. Sediment production from landslides in three geomorphic terranes; Little North Fork, 1965-1975.

LITTLE NORTH FORK 1965-1975 (ENGLISH PEAK BATHOLITH)					
Geomorphic Terrane Type		**Undisturbed**	**Harvest**	**Roads**	**All Disturbance Classes**
Steep Granitic Mtn. Slope	Area (acres) Volume Del. Volume/Area	2,837 8,200 2.89	88 1,314 14.93	14 6,309 450.64	2,939 15,823 5.38
	Increase Over Undisturbed		X 5.14	X 1.55	X 1.86
Mod. Granitic Mtn. Slope	Area Volume Del. Volume/Area	4,362 152 0.03	261 -0- -0-	26 1,415 54.42	4,649 1,567 0.34
	Increase Over Undisturbed			X 1,814	X 11.33
Granitic Inner Gorge	Area Volume Del. Volume/Area	990 13,532 13.67	152 42,306 278.32	10 34,882 3,482	1152 90,660 78.70
	Increase Over Undisturbed		X 20.3	X 254	X 5.76

Area, Acres; Volume Delivered, yds^3; Volume/Area, yds^3 /Acre land, 1% from harvested land, and 11% from undisturbed land. The production rate from roaded lands was 22.48 yds^3/acre/year, 0.02 yds^3/acre/year for harvested lands, and 0.04 yds^3/acre/year for undisturbed lands. Landslides were concentrated at elevations from 3,500 to 4,000 feet in elevation (Dan Sitton, personal communication, 1992).

A sediment cleanout operation in 1986 removed a total of 17,000 yds^3 of material from the floor of Reeder Reservoir which was associated with surface and channel erosion. However, sampling prior to cleanout determined that only 10,000 yds^3 was new sediment (sand and silt), and the other 7,000 yds^3 was material which was already in the reservoir in 1976 (Rolle et al., 1987). In addition to the 10,000 yds^3 of new sediment cleaned from the reservoir floor, 11,000 yds^3 of silt was deposited on the reservoir walls above the cleaned out area. Thus from 1976-1986, a total of 21,000 yds^3 of sediment was delivered to Reeder Reservoir, or about 0.16 yds^3/acre/year.

An independent estimate of sediment production by surface and channel erosion processes was conducted from 1978-1982 by the Rogue River National Forest. Small debris basins maintained below the ski area produced sediment at a rate of 0.22 yds^3/acre/year (Dan Sitton, pers. comm., 1992).

DISCUSSION AND CONCLUSIONS

Landslide, Surface, and Channel Erosion Rates

For the period 1965-1975, it was found that landslide production at Little North Fork was considerably higher than at Ashland Creek (6 times higher for undisturbed land, 450 times higher for harvested land, and 4 times higher for roaded lands). These findings do not necessarily mean that the Little North Fork is more unstable than Ashland Creek, since little is known about the actual intensities of the storms which caused the landsliding. Rather, the volumes presented here allow a preliminary characterization of the range of sedimentation rates which are possible in granitic lands of the Klamath Mountains.

Lack of data prevented direct comparison of surface and channel erosion rates for the same time period at the Ashland Pluton and English Peak Batholith. From 1965-1975, a wet period, the Ashland Pluton (Ashland Creek) produced sediment from surface and channel erosion at a rate of 0.71 yds^3/acre/year. At that time, about 10% of the watershed was occupied by roads or harvest. During the period 1976-1986, with the same 10% disturbance level, surface and channel erosion delivered sediment to the reservoir at a rate of 0.16 yds^3/acre/year. This period was much drier than the 1965-1975 period. Comparing sedimentation rates from 1965-1975 to those of 1976-1986 is further complicated by the fact that many landslide-generated debris torrents occurred from 1965-1975, but not in 1976-1986. These torrents assisted in the transport of channel sediment to the reservoir. Thus, some of the sediment generated from 1976-1986 is still stored in channels above the reservoir.

Data from Olsen Creek immediately after the fire of 1987 revealed that surface and channel erosion delivered sediment to a debris basin at a rate of 3.67 yds^3/acre/year from 1987-1992. No landslides occurred during this time. In summary, the rate of sedimentation associated with surface and channel erosion varied from 0.16 -.71 yds^3/acre/year in the Ashland Pluton, to 3.67 yds^3/acre/year in the English Peak Batholith.

Climatic and Geomorphic Influences on Erosion Rates

In the English Peak Batholith, the 1964 flood occurred in a wet climatic cycle which lasted from about 1950 to 1975 and triggered landslides at an unprecedented rate, despite the fact that the watershed was unroaded. This flood produced peak flows in the Salmon River of 100,000 cfs. Storms from 1965-1975 produced several landslide episodes, and all coincided with peak flows in the Salmon River in excess of 40,000 cfs. Since 1912, only two peak flows (1953, 1956) have exceeded 40,000 cfs without initiating landslide episodes at Little North Fork [Figure 4].

Landslide production rates at Little North Fork are strongly influenced by the geomorphic history of the watershed. The erosional surface identified at an elevation of about 3,000 feet is dissected by streams, and steep inner gorges have formed adjacent to the streams. The deeply weathered granitic rock which is exposed on the inner gorge slopes is prone to shallow landsliding. In contrast, other geomorphic terranes such as gentle granitic mountain slopes and glacial moraines experience low landslide rates, due in large part to low slope gradients. The clustering of landslides which was observed in certain elevation zones [Figure 3] was probably the result of rain on snow patterns and associated infiltration of snowmelt,

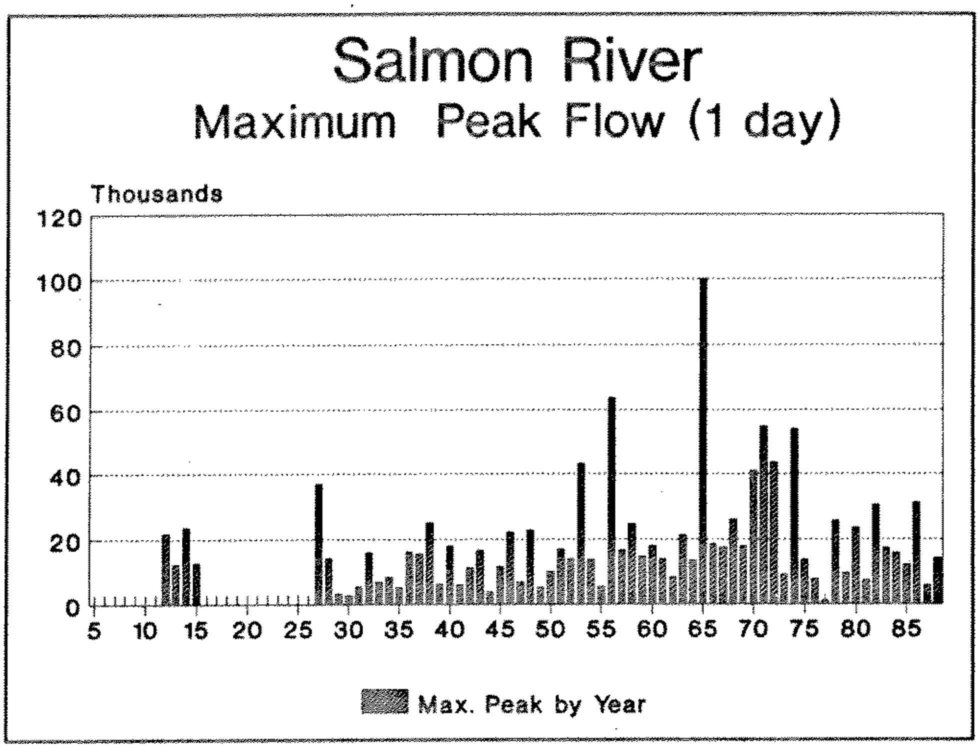

Figure 4. Maximum 1-day peak discharge of the Salmon River at Somes Bar station #11522500, for the period 1904-1988. Discharge is cfs.

but also could have been affected by soil properties which vary with elevation.

Effects of Roads, Timber Harvest, and Fire on Erosion Rates

Roaded lands produced landslides at a rate 319 times higher than undisturbed lands at Little North Fork, and 535 times higher than undisturbed land at Ashland Creek. However, the rate for undisturbed land at Little North Fork is 7 times higher than at Ashland Creek. Increased landslide potential associated with roads is extremely sensitive to road location and construction practices, but no data are available to differentiate between the watersheds examined here.

The concentration of landsliding in harvest units in the Little North Fork (1972) and in Ashland Creek (1964, and to a lesser degree 1974) is unusual relative to other granitic bodies in this part of the Klamath Mountains. Reasons for this could be related to local soil/colluvium characteristics, or to the fortuitous timing of intense storms occurring within a few years of timber harvest. The low landslide production from harvested land (0.19 yds^3 /acre) in Ashland Creek from 1965-1975 may be associated with age of timber harvest, since all of the harvest occurred more than 10 years prior to the storm of 1974 (Wilson and Hicks, 1975). Alternatively, the 1964 storm may have triggered the sites most prone to landsliding prior to the 1974 event, such that the only new sliding in harvest units consisted of minor enlargements of 1964 landslides. Other watersheds in the granitic land adjacent to Ashland Creek experienced landsliding in harvest units during the 1974 storm but no quantitative data are available on these landslides (Dan Sitton, pers. comm., 1992). The lack of landslides in the severely burned Olsen Creek watershed from 1987-1992 is likely due to drought conditions which existed during those years.

Fire greatly accelerated surface and channel erosion in the English Peak Batholith (Olsen Creek). Post-fire surface and channel erosion in Olsen Creek delivered 3.67 yds^3/acre/year averaged over the period from 1987-1992. In contrast, from 1976-1986, the relatively undisturbed Ashland Creek watershed produced sediment at a rate of 0.16 yds^3 /acre per year. Precipitation was low during both time intervals.

Comparing Landslide Rates to Surface and Channel Erosion Rates

The highest landslide-generated sediment production rate identified by this study was 22.52 yds^3/acre/year at Little North Fork for the winter of 1964-1965. In contrast, landslides were produced at a rate of 0.30 yds^3/acre/year at Ashland Creek, and 1.08 yds^3/acre/year at Little North Fork during 1965-1975. Surface and channel erosion for this same interval was produced at a rate of 0.71 yds^3/acre/year in Ashland Creek (the only data available). This surface and channel rate was 2.4 times higher than the corresponding landslide rate at Ashland Creek, but only 2/3 as large as the landslide rate at Little North Fork. From 1976-1986, Ashland Creek yielded surface and channel erosion sediment at a rate of 0.16 yds^3/acre/year, whereas from 1987-1992, Olsen Creek yielded 3.67 yds^3/acre/year, or 23 times higher.

The landslide rate on harvested land at Little North Fork (1965-1975) was 2.4 times larger than the surface and channel erosion rate on land denuded by fire at Olson Creek (1987-1992). Selection of the time interval for calculating average annual rates greatly affects the results. Average annual landslide production rates at Little North Fork are taken for the period 1965-1975. If they were computed for the years of the primary storms, 1971 and 1972, results would be 5 times larger.

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PREDICTING SEDIMENTATION FROM DECOMPOSED GRANITIC SLOPES OF THE SCOTT RIVER WATERSHED, CALIFORNIA

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ABSTRACT

A study was undertaken to investigate sedimentation and delivery from granitic soils upslope from the Scott River, an important anadromous fish stream in northern California. The objective was to characterize upslope processes and quantify the relative importance of sources. Timber harvest history, elevation, slope, aspect, vegetation type and canopy coverage, watershed boundaries and hydrology, roads, skid trails, soils, geology, sites of streambank scour and debris slides, rainfall isobars and private versus public lands all became part of a working geographic information system (GIS) database at a resolution of 1.6 acres. Universal Soil Loss Equation (USLE) calculations were facilitated with the GIS.

Average annual erosion for the entire road prism was 737 tons per mile (63% of total loss), while losses from skid trails averaged 239 tons per acre per year (13% of total). Granitic terrane streambanks averaged 382 tons per mile per year (23% of total). Losses from rill erosion on harvest sites was about double the geologic rate of erosion. Total erosion was estimated to be about 340,450 tons per year. A sediment delivery ratio of 0.21 was used, resulting in an estimated average annual yield to the Scott River from the sub-basins of 71,500 tons. The values suggest that about 60 percent of the sediment yield is accelerated, or due to the activities of man.

INTRODUCTION

The decomposed granitic (DG) soils upslope from the Scott River have long been suspected of degrading salmon and steelhead spawning habitat. The Scott is a principal tributary of the Klamath River in Siskiyou County and supports an important anadromous fishery. Of a 215,000-acre study area in the southwestern portion of the basin, about 26% (57,000 acres) is derived from DG parent material (mainly the Russian Peak Pluton, plus several smaller plutons).

The study objectives were to characterize sedimentation and delivery from granitic soils of the watershed and quantify the relative importance of sources. This was part of a larger study which included an evaluation of DG sediment effects on spawning habitat in the Scott River system (Sommarstrom et al, 1990). These objectives and a limited budget would not justify intensive field sampling for statistical robustness, so procedures were sought that supported defensible, reasonable estimates.

In a northern California study, Anderson (1976) concluded that decomposed granitic soils deliver three and one-half times more sediment to reservoirs than those from other parent materials. The granular soils are non-cohesive and well-recognized to be some of the world's most erosive. In many areas of the Scott Basin, the DG parent material is so soft it can be crushed by hand.

METHODS

A Preliminary Reconnaissance

The first step in the assessment procedure was to conduct reconnaissance-level field and aerial photo work. The goal was to identify the important erosion, storage and delivery sources and processes on the slopes.

Important processes active in decomposed granite in the study area include debris slides, debris torrents, dry ravel, and rill and gully erosion. Debris sliding tends to be shallow and typically occurs on road cuts or other steep areas. Some sliding is initiated by the interception of subsurface flows of water by road cuts, a process described by Megahan (1972). Debris sliding is not as common in the Scott watershed as has been reported in neighboring basins (de la Fuente, pers. comm., 1989), apparently because of gentler slopes and lower rainfall. Evidence of debris torrents can be seen in upper watershed stream channels which have been scoured, usually (but not always) dating back to a major rain-on-snow flood in 1964. These debris torrents appear to be completely natural as there usually are no areas of timber harvest and little road building above the scoured sites.

Raveling is the dominant process on road cuts and fills. Particles are dislodged by any disturbance including raindrop impact, then tumble down the oversteepened slopes. Rills and gullies may be difficult to find except immediately after storms, as they tend to collapse in on themselves. They are, however, important on almost all bare DG surfaces, and are especially noticeable on road beds.

Many short-term and long-term storage sites of eroded DG material can be found in the study area. Some material stays on slopes behind obstructions such as logs, herbaceous vegetation and skid trail water bars, at least for the short term. Low-order swales receive annual deposits of colluvial debris. These may or may not be vacated yearly; the deposits are often irregular in shape with little young vegetation, suggesting a recent event. However, studies in other areas have shown material in such swales to be a whole range of ages (de la Fuente, pers. comm., 1989; Dietrich & Dorn, 1984). Channel margins and floodplains also serve as storage sites. The study area contains some low-gradient stream reaches populated with willows and alders downstream from sites of extensive streambank scour, evidently areas of long-term storage of the scoured material. Most in-channel material is stored as bedload because of the large DG particle sizes.

Compiling Geographically-Referenced Data

The goal for this portion of the project was to characterize the Scott River Basin in as much detail as possible for our own use and to explain similarities and differences between our results and those from other study areas. Managing the data collection from maps, aerial photos and land use records was facilitated with a geographic information system (GIS).

A timber harvest history was developed from records of the U.S. Forest Service (USFS) and California Dept. of Forestry and Fire Protection (CDF), which found between one-third and one-half the granitic portions of the sub-basins to have had historic timber harvest. Some data were purchased or were otherwise available: vegetation cover maps were provided by the USFS and digital elevation models by the Defense Mapping Agency. Additional coverages were digitized from existing maps or aerial photos by using stereo pairs and correcting for photographic distortion as images were transferred onto USGS 1:24,000 topographic quads.

All skid trails with less than 100% cover were mapped from aerial photos. Timber harvest history and road maps were updated from the photos, and erosion scars were mapped and dated using historic photo sets. We ended with coverages of: hydrology by stream order, roads, skid trails, soils, geology, vegetation, sites of debris sliding or streambank scour, harvest history, private and public lands, rainfall isobars, and elevation, slope and aspect to a resolution of 1.6 acres.

From the GIS, descriptive tables were then produced of areas, lengths and sums to allow comparisons of our area with others by numerous measures that could explain differences in watershed behavior. For instance, only one small sub-basin, Crystal Creek, was found to approach the road density of the "notorious" Grass Valley Creek in Trinity County, thought to be the biggest DG sediment producer in the west (Dybdal et al, 1990). Table 1 is a sample of the descriptive data produced from the GIS.

Stratifying the Landscape

Stratification is a procedure for breaking up the landscape into similarly responding units in order to improve the precision of estimates developed from sampling. Important differences were found in the study area based on elevation. Precipitation ranged from 20 to 50 inches, and 30-50% of it was snow above 4,000 ft. Erosion appeared to be maximized at mid-elevations. Higher elevations had snowpack that was protective except during rain-on-snow events such as the 1964 flood, when it amplified effects. The weather is also colder at higher elevations, so physical weathering usually predominates over chemical processes. In most sub-basins there was heavy armoring of streams and slopes by boulders at the upper elevations. At lower levels, less erosion is

Table 1. Road mileage, area, and density by watershed and by granitic portion of each watershed.

Watershed	Road miles	Road miles on granitics	Road acres	Road acres on granitics	Road density (ft/acre)	Density on granitics (ft/acre)	Density on granitics (mi/sq.mi.)
Shakleford/Mill	153	10	764	48	25	31	3.7
Kidder/Patterson	155	13	773	67	21	13	1.6
Crystal	20	17	101	84	46	55	6.7
Johnson	31	11	155	56	38	45	5.6
Mill/Etna	75	29	372	142	23	26	3.2
Clark	20	5	100	23	33	29	3.6
French	119	74	594	367	31	29	3.5
Sugar	41	18	202	92	26	20	2.4
Wildcat	38	4	188	21	39	71	5.3
South Fk. Scott	93	20	465	99	33	27	3.3
Fox	23	15	117	73	27	21	2.5
Boulder	50	42	251	209	33	38	4.7
Little/Big Mill	22	7	107	33	19	17	2.0
East Fk. Scott	175	14	102	69	20	39	4.8
"Callahan"	19	9	96	45	43	40	4.9
TOTALS	**1034**	**288**	**4387**	**1428**	**25**	**27**	**3.2**

obvious because of gentler slopes and lower rainfall.

Based on reconnaissance observations, the study area slopes were stratified by elevation, timber harvest history, and glacial till versus soils formed in place. Roads were broken up by elevation and surface type (paved, rocked, or bare), and streams by order.

Field Work

Field sampling was targeted proportionally to the stratified areas, with emphasis on roads. Some streambank erosion estimates were available from a 1983 Forest Service stream survey in which upper bank mass wasting and lower bank cutting were rated. The ratings were converted to volume estimates. Some limited sampling of harvested and unharvested hillslopes were done to collect components of the ground cover value necessary to run the Universal Soil Loss Equation (USLE), modified for forest conditions (Curtis, 1977), to estimate sheet and rill erosion. Field values were verified against literature values and local measurements made using troughs by the USFS.

Roads and skid trails were by far the biggest physical scars on the landscape, and these were the focus of sampling activity. The Direct Volume Procedure for channel erosion (Steffen, 1983) was used to estimate volume of losses on cuts, fills, and road or skid trail surfaces. A section of road that looks subjectively uniform is paced off, the height of the scar is estimated, and a Lateral Recession Rate (LRR) assigned. The LRR is a means of annualizing erosion based on root exposure and other physical evidence of soil movement (Table 2). Since tree roots do not grow naturally towards air, one can assume that all the exposed root area and then some was caused by road construction and subsequent erosion.

Putting all erosion estimates on an average annual basis provided a means of comparing and ranking sources. Estimates were adjusted based on any knowledge that could be collected of when roads were constructed and annual maintenance procedures. Estimates were most difficult on road surfaces because maintenance practices often obscured the physical evidence of erosion. The volumes arrived at by the sampling procedure were multiplied by an estimate of the material density to get tons (100 pcf).

Data Extrapolation and Modeling

Channel erosion field data were extrapolated to similar areas throughout the watershed based on the same categories by which the area was stratified. Sheet and rill erosion for harvested and unharvested hillslopes as well as skid trails was calculated using the GIS. We combined field ground cover values with the midpoints of canopy cover ranges from the vegetation maps, used a constant slope length of 25 feet, derived slope from the digital elevation model, adjusted rainfall intensity measurements from low and high elevations using the isobar maps of average annual precipitation, and modified all results based on aspect, elevation and timber harvest history. Timber harvest areas were divided into high-impact and low-impact categories, and were adjusted linearly over 35 years to their pre-harvest condition.

RESULTS

Erosion Estimates

Figure 1 depicts the proportion of upslope erosion coming from various sources in the granitic areas of the Scott Basin. Average annual erosion for the entire road prism was 737 tons/mile, or 149 tons/acre. These values are within the range but slightly higher than the average reported by others on sandy loam soils (Dendy and Champion, 1978; Megahan et al, 1983). Sixty-four percent of road erosion was from the cut bank, which was the highest category of soil loss from all sources at 40 percent of the total. Losses from skid trails averaged about 239 tons per acre per year. About 12.6 tons/acre of this loss was due to sheet and rill erosion.

Granitic terrane streambanks averaged 382 tons/mile annually, or 23 percent of the total. Streambank scour from the 1964 flood occurred in two drainages, tripling the average rate for all streams in those areas. Losses from sheet and rill erosion on harvest sites are about double the geologic rate of erosion. These and losses from debris slides are minor compared to other sources.

Total erosion from granitic sources is estimated to be about 340,500 tons/year. Individual sub-basins contribute amounts closely related to the proportion they represent of all granitics in the Study Area, with some minor variance above or below the average.

Erosion rates higher than tolerance values, which

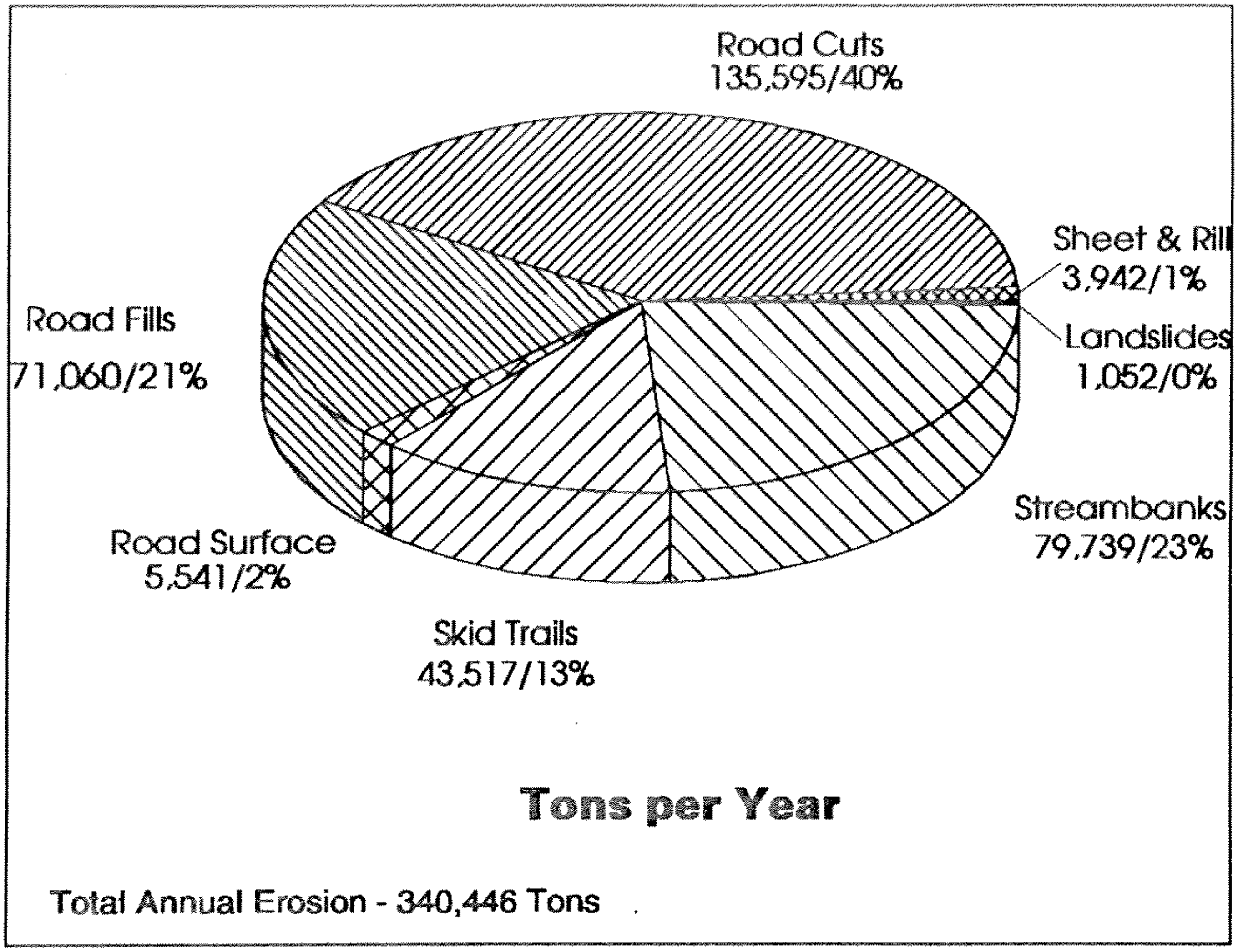

Figure 1. Partitioning of upslope erosion sources by total tons and percent, from granitic parent material only.

Table 2. Road cut and fill lateral recession rate categories and descriptions *(after Steffen, 1983)*.

Lateral Recession Rate (ft/yr)	Category	Description
0.01-0.05	Slight	Some bare roadbanks but active erosion is not readily apparent. Some rills but no vegetative overhang. Ditch bottom is grass or noneroding.
0.06-0.15	Moderate	Roadbank is bare with obvious rills and some vegetative overhang. Minor erosion or sedimentation in ditch bottom.
0.16-0.30	Severe	Roadbank is bare with rills approaching one foot in depth. Some gullies and overhanging vegetation. Active erosion and sedimentation in ditch bottom. Some fenceposts, tree roots or culverts eroding out.
0.30+	Very Severe	Roadbank is bare with gullies, washouts and slips. Severe vegetative overhang. Fenceposts, powerlines, trees and culverts eroded out. Active erosion and sedimentation in ditch bottom.

range from one to two tons per acre depending on soil type, mean the soil is being eroded faster than it can be replaced by soil formation processes.

Sediment Yield Estimates

In most years, eroded material is stored in the upper watershed. Primary storage sites include hillslope swales, hillslopes outside of swales, upper streambanks, channel margins and fans, and channel bedload. These areas become sources of small annual amounts and large, episodic pulses of sediment. Channel bedload appears to be a source of annual sediment rather than a site for long-term storage. In areas of streambank scour, there is a downstream alluvial section populated with willows and alders where at least some of the resulting sediment has been stored for the last 25 years.

For evaluating the effects of erosion on fish habitat, it is important to know how much material is actually delivered to channels. There is no direct means of measuring sediment yield except for reservoir surveys, but a variety of estimation procedures are available. If a standard sediment delivery ratio (Roehl, 1962) is applied for the size of our study area, the average annual sediment delivered to the Scott River from upslope sources would be about 10 percent of all losses, or about 34,000 tons/year. If a sediment delivery ratio is used based on another northern California reservoir with similar proportion in granitics, similar climatic regime, similar methods used to estimate upslope erosion, and where a bathymetric survey was undertaken (Antelope Reservoir in Plumas County), the result is 21 percent, or 71,500 tons annually.

A method known as PSIAC (developed by the Pacific Southwest Interagency Committee, 1974) which was modified for forested conditions in nearby Trinity County (Dybdahl et al., 1990) is a means of estimating yield without a delivery ratio. It is based on evaluation of a set of watershed, climate, soil and land use characteristics and results in a figure of 63,000 tons/year. A sediment delivery ratio of 55 percent was used for Grass Valley Creek in Trinity County, based on the "slope-continuity" method where the proportion of a basin in steep versus gentle slopes (areas of deposition versus areas of delivery) is calculated.

The reservoir survey method is preferred, given similar watershed conditions. The Antelope Reservoir survey resulted in an average of 570 tons per square mile per year delivered (CDWR, 1990). An average was estimated of about 800 tons per square mile delivered annually in the Scott River sub-basins, the higher amount due to evidence of higher erosion rates in our Study Area. Sub-basins of the Scott River deliver more or less than this amount depending on land use intensity and differences in proportions of gentle versus steep slopes.

In the Idaho batholith, there has been some work showing sediment yield to be less than 10 percent of on-site erosion in a watershed less than 300 acres in size (Megahan & Clayton, 1983). Since larger basins should show lower delivery rates because of more opportunities for deposition, one would expect sediment yield values much higher than our estimates to require corroborating evidence. Documented reservoir surveys for basins of similar size (Dendy and Champion, 1978) show our estimate to be on the high side but within the range of these reports. Parent material is not reported for these other basins.

Different erosion sources have different delivery rates to channels. Presuming our erosion and overall sediment yield estimates to be reasonable, we apportioned the sediment delivery ratio among the various sources as depicted in Figure 2. The upper set of arrows shows the portion of eroded material coming from each source, while the lower set of arrows shows the proportion contributed to channels from each source.

The sediment yield values presented suggest that about 60 percent is accelerated, or due to the management activities of man.

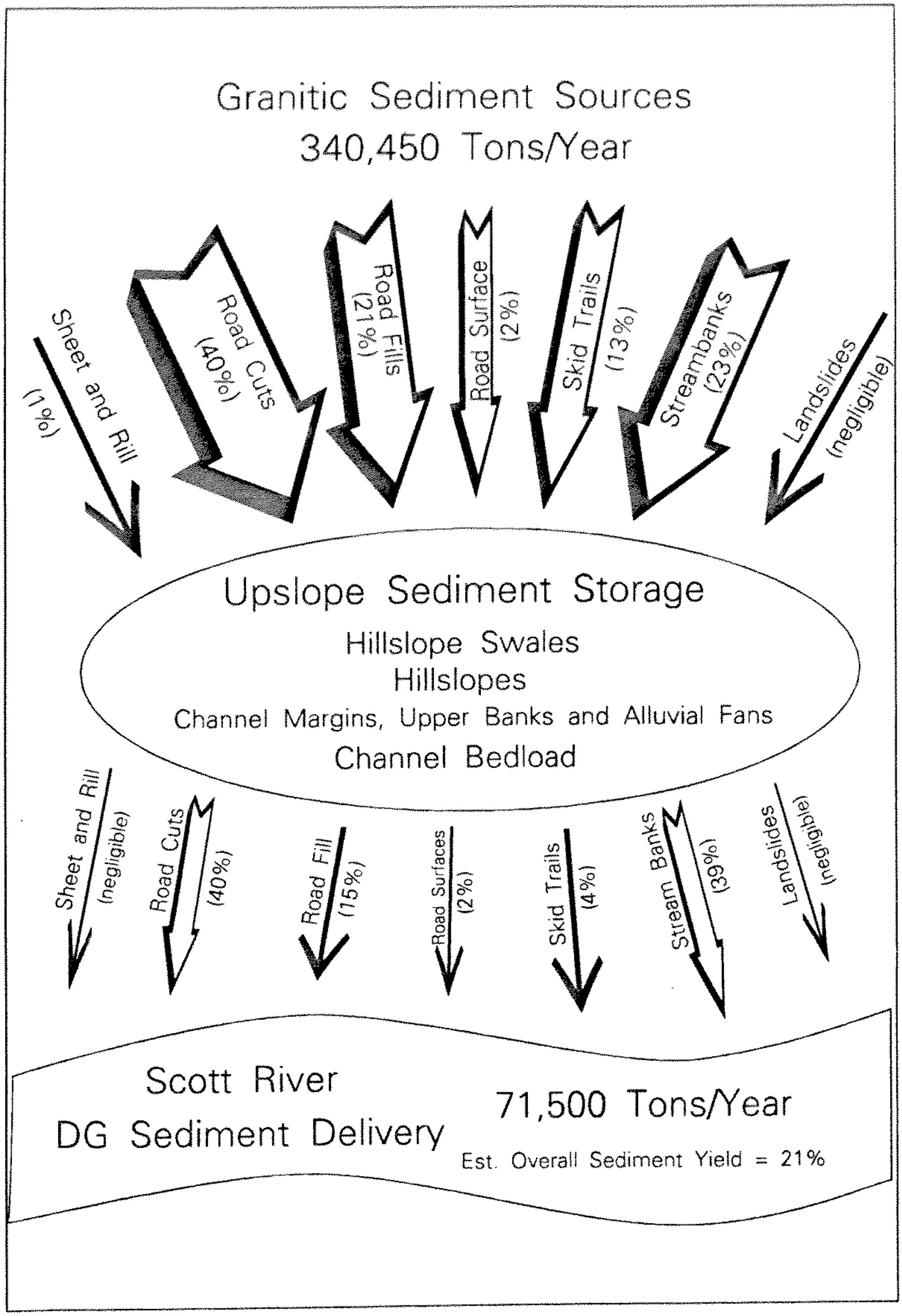

Figure 2. Partitioning of erosion, storage and delivery by source.

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Management Problems and Solutions

MANAGING SOIL AND WATER WHILE HARVESTING TIMBER IN DECOMPOSED GRANITIC TERRAIN

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ABSTRACT

Successful management of soil and water in areas of decomposed granitic soil can occur only if everyone involved exercises proper thought and care. Applying techniques that may be usable elsewhere without considering the physics of the soil may cause extreme environmental damage. Successful management of soil and water in areas of decomposed granitic soil must include: 1) identification of the engineering properties of the soil and weathered bedrock; 2) analysis of the environmental condition of a stream; and 3) assessment of the potential for eroding soil or landslides to damage the beneficial uses of water or to reduce soil productivity. Frequently, the least damaging activities mimic natural site conditions.

Just as it is important that land managers base their practices on the specific concerns of an area, government regulators must also apply creative thought to assessing potential impacts. Because no two areas are exactly alike, preconceived prescriptions based on general conditions may not be appropriate for a specific problem. If land is to be managed without significant environmental impacts, management activities must be designed and reviewed with an understanding of site conditions and the physical processes that will affect or be affected by actions taken. If all people involved with managing timberlands work together to conserve resources, timber can be harvested while soil and water are protected.

INTRODUCTION

Increases in erosion and related sedimentation following land use activities in areas of decomposed granitic soil have been observed world wide (Duijsings, 1987; Howart, 1985; Isherwood and Street, 1976; Kohno et al., 1978; Krank and Watters, 1983; Lumb, 1962, 1983; Megahan and Clayton, 1983; Mosley, 1980; Sommarstrom et al., 1990). These increases can result in damage to fish habitat (Phillips et al., 1975; Cordone and Kelly, 1965), degradation of water quality (Adams and Stack, 1989), and loss of soil productivity (Brown et al., 1973). In some areas, the degradation has affected the environment for far longer than the lives of those who triggered it. For example, deforestation of the cedars of Lebanon by the Phoenicians rapidly depleted the formerly fertile soil of the area (Loudermilk, 1943). In ancient Syria, evidence of the depth of soil erosion is found in doorsills of stone houses now 3 to 6 feet above bare rock (Loudermilk, 1943). In Rome, the erosion rate increased 700 to 2000 percent during the second century B.C. due to deforestation and grazing (Judson, 1968). These deforested and over-grazed areas still suffer from reduced soil fertility thousands of years later.

The demands of our modern society dictate a constant supply of timber, some of which is growing in areas of decomposed granitic soil. Because of the potential sensitivity of land use actions in these areas, special care must be taken for the timber resource to be managed while conserving soil and water. The following discussion outlines potential sources of variation in stability and erodibility of decomposed granitic soil, and geomorphic features that may behave differently to land management activities. Based on experience with private and state timberlands in California, possible approaches to common problems in areas of decomposed granitic soil are also briefly discussed.

GRANITIC BEDROCK -- DECOMPOSED GRANITIC SOIL

Soil derived from the decomposition of granitic bedrock is properly referred to as grus, but is generally referred to as DG. Land use practices (including timber harvest-related road construction and yarding of logs) which create little or minor erosion in other soil types can result in major environmental problems in DG areas. The reason is the physical nature of decomposed granitic rock.

Not all granitic rock is the same (Wagner, these Proceedings). Little of the granitic bedrock in California is true granite. Granitics form from partial melting of mantle or lower crystal material. As the molten masses are emplaced they may be contaminated by the rocks through which they pass. In addition, as the granitic magma cools and crystallizes, the chemistry of the remaining material changes, resulting in a complex and highly variable mixture of minerals. Differences in the ratios of potassium, sodium, and calcium determine which feldspar minerals (the dominant light colored crystals) are formed. Similarly, differences in ratios and overall amounts of iron, magnesium, silicon, aluminum, and other elements will determine quartz content and, important in the evolution of DG soil, the type of fero-magnesium minerals (dark colored crystals) formed.

The granitic rock masses, called plutons, crystallize and cool slowly within the crust of the earth. Forces responsible for both the formation of the granitic masses and the avenues through which the molten fluid can rise are related to mountain building. This explains why granitic plutons form the cores of the Sierra Nevada, Klamath, and Trinity Mountains. The complex mountain building processes determine the cooling and stress histories acting on the plutons that are emplaced at depth. The rate of cooling and types of stresses that occur during the formation of a granitic pluton determine the grain sizes and textures of the final rock.

If the granitic bedrock is coarsely crystalline and composed of sodic and potassic feldspars, quartz, and biotite, it will weather rapidly into classic grus (DG). If, on the other hand, the bedrock is a fine-grained hornblende quartz diorite with calcic feldspars, and little or no biotite, the weathering product will contain more clay and iron oxides and be far less susceptible to erosion than classic grus.

The purpose of this discussion is to point out the high degree of variability in granitic bedrock and the resulting high variability of DG soil. Therefore, it is not sufficient to simply identify the parent material of an area as granitic. When evaluating the potential for soil erosion or mass wasting of a specific site, the engineering properties of the soil must be properly determined.

AREAS OF CONCERN

To evaluate the potential impact from land uses, managers and reviewers should have a basic understanding of the physical processes acting on individual portions of watersheds. Local areas within any watershed have evolved under conditions specific to that location. Fortunately, watersheds can be subdivided into process-determined geomorphic features that respond differently from one another to physical forces. Therefore, management actions and limits can and must be based on the location in the watershed where work is proposed and the downstream beneficial uses that could be impacted. For water quality and fisheries habitat, the principal concern is the quantity and timing of stream sedimentation, not the volume of material that erodes or slides on the hillslope.

The three major subdivisions of a watershed that must be evaluated include: stream channels, stream sides, and hillslopes. The order of these is deliberate. In general, the sediment delivery ratio (the ratio between the quantity of sediment eroded from an area to that which enters a stream) is far higher for erosion or landsliding in and adjacent to a channel than it is from areas on hillsides. Clearly, activities directly within stream channels will impact the stream. The stream channel is also the part of a watershed most sensitive to change where protection is most needed. Stream sides are slopes in close proximity to a stream channel. These riparian or stream protection zones are secondary areas of sensitivity. Ground disturbed in these locations may result in direct impacts due to immediate access of disturbed soil to channels. Hillslopes are defined as the areas above the limits of stream side zones. Although they are removed from channels and eroded sediment may not have direct access to streams, hillslopes comprise the largest area of a watershed.

Stream Channels

Stream channels can be separated into reaches, or segments that behave in a relatively uniform manner. Sediment actively erodes in head water areas of streams, a natural and unpreventable dynamic. Elsewhere along a stream channel, changes in the local base level, such as uplifts or mechanical removal of in-stream structures, can result in down-cutting. These areas, called eroding reaches, are inherently sensitive to modifications, both within the channel and along the slopes.

In other locations, the channel may be relatively stable and not eroding; material that enters it is immediately carried away. Although these transport reaches are less prone to damage than eroding ones, sediment that enters them can damage downstream reaches.

Pools, lakes, reservoirs, deltas, fans, flood plains, and ultimately the ocean, are all areas where sediment is deposited. Depositional reaches within the watercourse system, including pools, lakes, and reservoirs, are the most susceptible to sedimentation. These low gradient areas, also known as storage or depositional reaches, must be evaluated to determine the health of a watershed. Adverse conditions are indicated by aggradation or raising of the stream bed, by pool filling, by embedded stream gravels, or by unstable channel banks. Although any or all of these conditions may naturally occur, their presence indicates that additional care is needed in any land use activities.

Stream Sides

Stream sides can be subdivided into active inner gorges, relatively stable slopes, and depositional areas such as flood plains and alluvial fans. Activities that do not threaten stable slopes could result in extreme damage if practiced in an active inner gorge. Fortunately, the stability of stream sides is closely related to the slope, which allows managers to recognize and respond to the risks present.

Hillslopes

Although discussed last in this paper, hillslopes must be addressed in any watershed analysis. Hillslopes are where most of the trees grow and ultimately the source of sediment that enters stream channels. Understanding slope materials and erosion/mass movement processes determines the success of water protection measures utilized during timber management activities. A Timber Harvesting Plan (THP) that is designed to accommodate landscape conditions will be far more successful at minimizing impacts than one that is imposed upon it.

To limit sediment delivery to streams in a highly erosive or unstable area (such as one with DG soil), timber harvest activities must be designed for site conditions and not be based on generic textbook thinking. Problem areas that are identified can then be avoided where possible and mitigated where not avoidable.

To illustrate the need to fit land-use activities to site specific conditions, consider building a road across a draw. The least damaging method of crossing a draw with a V-shaped cross section, particularly one with a stream channel, is to angle the road down toward the axis of the draw. The low point should be above the stream crossing to reduce the possibility of diverting stream flow from its channel. For these conditions, a bridge would provide the greatest protection. As discussed below, if the draw has a broad U-shaped cross section with no defined channel, constructing the low point of the road at the axis of the draw would substantially reduce slope stability.

Hillslopes can be divided into hollows, noses, and side slopes (Hack and Goodlett, 1960; Hack, 1965 as referenced in Reneau and Dietrich, 1987a). A hollow is any area on the slope that is concave outward away from the ridge. These are inclined U-shaped topographic depressions, frequently called swales, that typically form over V-shaped bedrock hollows by accumulating soil and weathered bedrock. Over time, gravity, in concert with rain, falling trees, burrowing animals, and soil-forming processes, results in loose material accumulating in these inclined depressions. The loose material is inherently less stable than the parent bedrock. The configuration of the colluvium-filled hollows also concentrates soil water, which further reduces slope stability. The resultant stored colluvium is subjected to irregular fluctuation of weather patterns.

When the depressions are on slopes inclined between 50 and 100 percent and the forces resisting failure (i.e., the internal strength of the colluvium) are exceeded by gravity and elevated pore-water pressures during high-intensity rainstorms, the accumulated colluvium fails as debris flows and debris avalanches (Campbell, 1975; Ellen and Fleming, 1987; Reneau and Dietrich, 1987b). Reneau et al. (1986) have shown that colluvium in individual hollows which failed in the San Francisco Bay Area's 1982 storms was frequently thousands to tens of thousands of years old. Road construction can profoundly affect the factors related to the stability of colluvium-filled depressions.

A road that dips downward toward the axis of a U-shaped depression increases the risk of debris flow landsliding in two ways. Material excavated during road construction is often used as fill across the low point in the swale. This effectively adds mass to the colluvium, mechanically imitating hundreds to thousands of years of natural slope processes. Secondly, a road that dips toward the axis of the depression intercepts, collects, and transports surface runoff to the area of greatest colluvium (and fill) accumulation, amplifying the effect of individual storms.

An alternative to sloping a road down toward the axis of a U-shaped draw is illustrated in Figure 1. By arching the road across a broad depression, excavated material is not concentrated in the axis of the draw. Arching with an outslope also distributes accumulated runoff on the slope away from the center of the draw.

Although always changing and never absolutely stable, natural landscapes have evolved through the interaction of climate and vegetation on the hillslope materials. As with any system, changes to any part of a watershed will likely affect other parts. The amount of change to a watershed is dependent on the type, location, and magnitude of the causal land use activities.

Watershed systems evolve through mass wasting. Too much or too little sediment can change the geo-hydrology of a watercourse and influence channel conditions. Therefore, managers and reviewers should not attempt to stop all natural erosion or landsliding. The best means of reducing the impacts to a watershed are to minimize changes from natural conditions in the dynamics of sediment and hydrology.

MINIMIZING IMPACTS

Nothing should be considered absolute in natural systems, but some situations will be either positively or negatively impacted from modifications of land-use practices or implementation of special, protective techniques. Some of these will be stated as truisms, followed by a more complete description.

1. There is no such thing as a permanent culvert.

Culverts are sized for certain frequency storms, typically a 50-year return period storm event. In an area the size of California, one or more local sub-watersheds will probably experience a storm with a longer return period each year. Entire regions may receive storm totals in excess of a 100, 500, or even-1000 year event. Unless drastically oversized, culverts in these watersheds will fail. Even during smaller storms, plugging of culvert openings is an all too common problem.

Culverts are only appropriate on permanent roads that will be adequately maintained during the winter period. Because of the high risk (and environmental cost) of culvert plugging, a backup structure is needed. A broad rolling dip capable of transporting flood flow should always be included in a culvert crossing design to keep streams from diverting from their channels. Temporary crossings should be used on seasonal roads where possible or where the interval between operations is long.

Rocked Crossings

For low-order streams and draws, particularly ones that only flow in response to rainfall, the least potentially damaging type of crossing is usually a rock-lined dry ford. This crossing type is especially applicable where channel gradients and slopes are moderate. The design should provide for the entire flow within the limits of the rock lining. The overflow face should be protected by placing boulders large enough to dissipate the flow's energy along the downstream face of the crossing. Geotextile fabric separating the boulders from the fill will prevent subsurface flushing and piping of fine-grained material that may reduce the stability of the natural and applied armoring.

Log Crossings

Where the watercourse banks are steep and well-defined, temporary log crossings can be installed and removed with only minor impacts to stream channels (Figure 2). In areas of flowing water, a culvert capable of carrying the flow expected during the period of operation should be placed at the base of the log fill. Installation of these temporary Humboldt crossings (often called "Spittler" crossings in Timber Harvesting Plans submitted in the Sierra Nevada) should include the pruning of vegetation along the alignment (as opposed to blading-off with a tractor) and installing fill logs. The logs are held together with choker cables in groups that can be easily

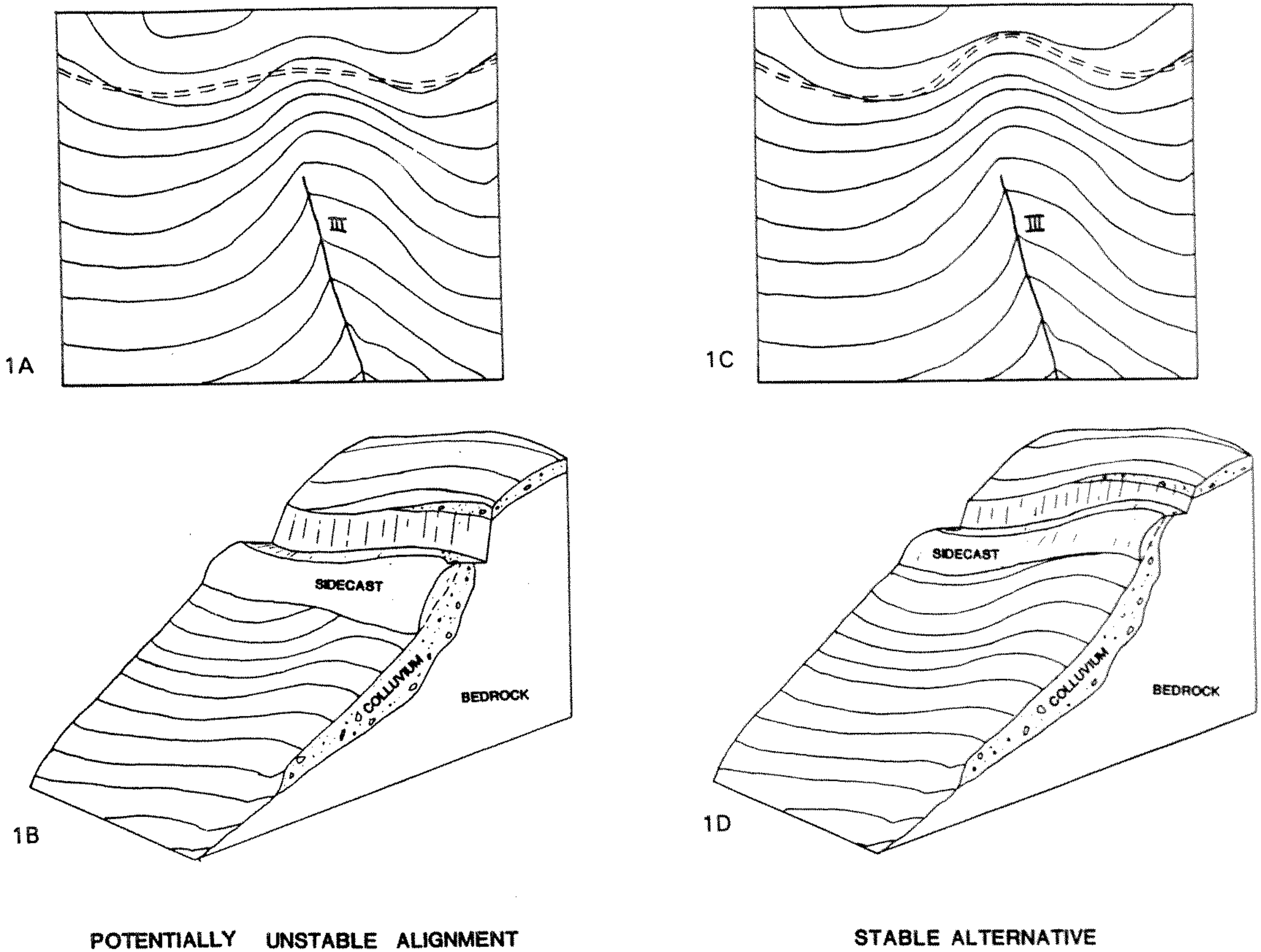

Figure 1. Dipping a road toward the axis of a a U-shaped swale (1A and 1B), results in the accumulation of fill upon existing colluvium and soil. The road configuration also concentrates surface runoff to the point of greatest colluvium and fill thickness. A less potentially damaging alternative is to arch roads across U-shaped swales (1C and 1D). Not only is less fill placed in potentially unstable locations, but surface water is distributed away from the axis area.

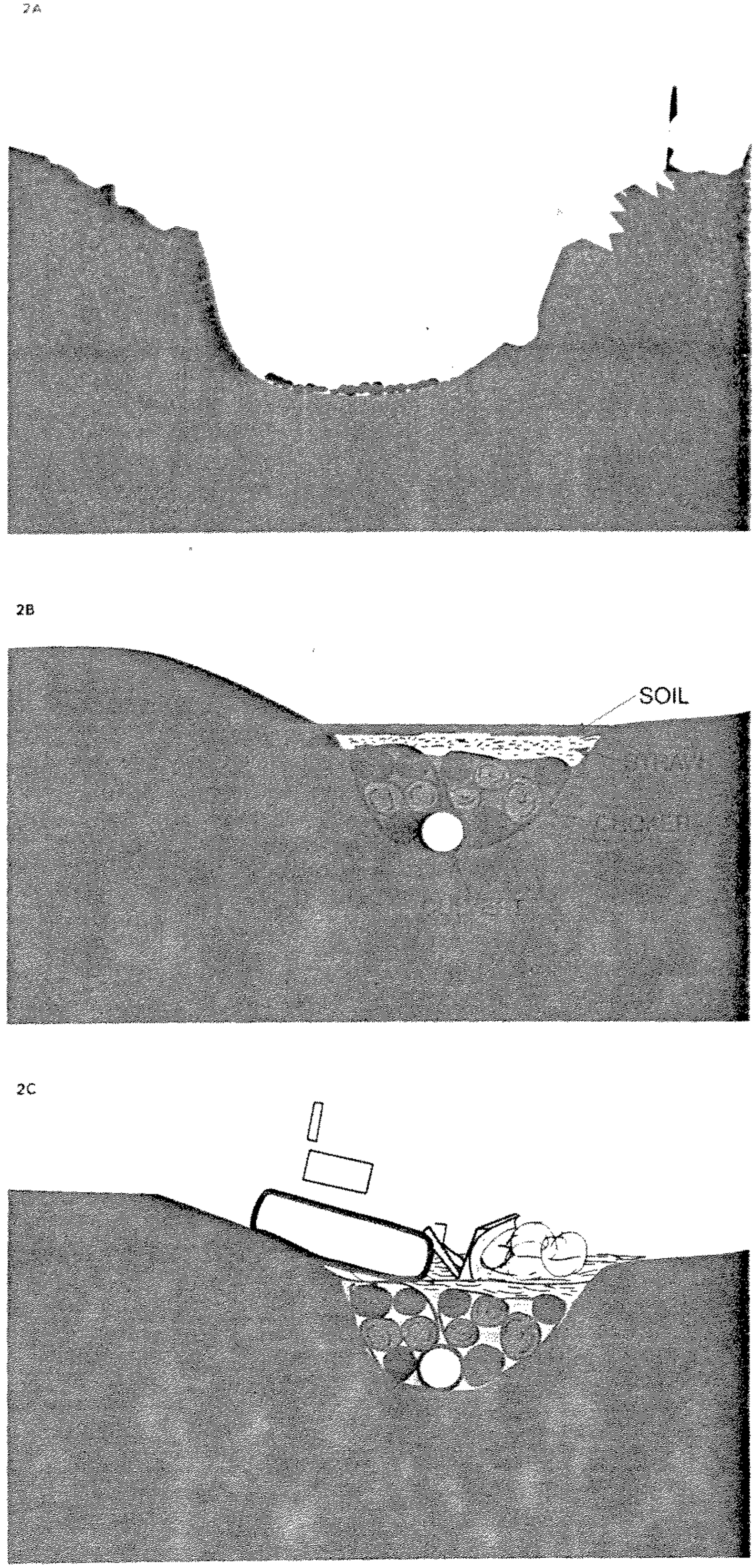

Figure 2. For areas where stream channels and banks are well defined (2A), an alternative to installing a culvert and soil fill at temporary crossings is a temporary log fill (2B). Sound logs take up most of the volume of the fill. The logs must be cabled together in bundles that can be pulled with equipment that is on-site. Where surface flow is expected, a culvert should be also be used. A 6 inch or greater thickness of straw is needed to separate the fill logs from the soil running surface. Upon completion of use, before the start of the winter period, the soil can be easily removed with a tractor (2C), and the logs and culvert pulled.

removed with a loader. Straw placed below the logs can protect sensitive stream banks or channels. When the log fill is about 18 inches below the temporary crossing grade, large spaces between the upper logs should be filled with smaller material. Covering the entire log fill with at least 6 inches of straw prevents the overlying road surface soil from infiltrating between the logs. Local soil is generally adequate for the running surface, and the straw layer enables easy removal of the capping soil fill. A major benefit of this type of crossing is that beds and banks of streams only need minor preparation work.

As with every aspect of road construction and drainage control, temporary log-filled crossings are not always appropriate. The choice of crossing must be based on site-specific conditions. Materials and techniques necessary to effectively employ a temporary log-filled crossing include: 1) use of sound culls or merchantable logs. Poor quality logs may not be strong enough to be removed; 2) chokers or some other means of removal must be available and provided at the time of crossing installation; and 3) the straw layer must be thick enough (>6 inches) to separate the soil running surface from the logs.

Early versions of the temporary log-filled crossing used sheet plastic or geotextile filter fabrics to minimize soil migration between logs. Although these materials effectively separated the soil from the logs, they proved to be less successful than straw in keeping soil out of streams during removal. In addition, torn pieces of plastic or fabric could not be removed. These materials may pose a hazard to wildlife and are visually offensive.

2. Through-cuts and inside ditches are functionally watercourses (Figure 3).

Long through-cuts cannot be drained. The drainage area of a through-cut is its watershed. Precipitation that falls within that local watershed will supply the runoff for the new watercourse. Similarly, an inside ditch often acts as a stream. For example, an inside ditch has a bed and bank. Where the flow of an inside ditch is drained into a natural stream channel (a common occurrence), sediment is also transported to the stream channel.

The State Forest Practice Rules (CDF, 1991) do not prescribe the distance between inside ditch relief drains. They do state that adequate drainage must be provided. Indicators of inadequate relief drains include: 1) gullying of the inside ditch; 2) gullying or sliding of the slope below the outflow of a cross drain; 3) direct transport of sediment along an inside ditch to a watercourse; or 4) loss of capacity of culvert cross drains due to filling with sediment.

By comparison, a road that is outsloped and drained by rolling dips (Figure 4), involves less movement of spoils and greater cutbank stability. A 14-foot wide road with a three-foot wide inside ditch requires the excavation of almost 60 percent more material than would be required for an outsloped road. Not only must the greater volume of material be moved, it must be transported to stable areas for disposal. In addition, the 20 percent increase in cut bank height required for an inside ditch reduces cut slope stability by nearly 50 percent.

3. Controlling sediment transport and deposition is more expensive than controlling erosion.

The installation and maintenance of in-stream sediment catchment structures is very expensive and the corrective measures may not work. The cheapest and most effective means of dealing with erosion and sedimentation is to avoid it in the first place. Avoidance can be achieved most easily by mimicking the natural landscape and keeping water and soil where they naturally occur.

CONCLUSION

To manage soil and water while harvesting timber in areas with DG soil, land managers and regulators must be aware of the physical properties and site conditions that affect slope stability or erosion potential. The best model is not found in a text book or engineering design, but in the natural landscape. Water should be kept where it belongs. Earth movements should be minimized, and the role of vegetation on the stability of a site should be assessed. While these guidelines apply to most land use activities in mountainous terrain, their importance increases dramatically on DG soils. Remember, the laws of physics govern what happens on the ground. How a proposed harvest is planned and executed must be based upon the physical conditions of the area, not on wishes, hopes, or snake oil (Figure 5).

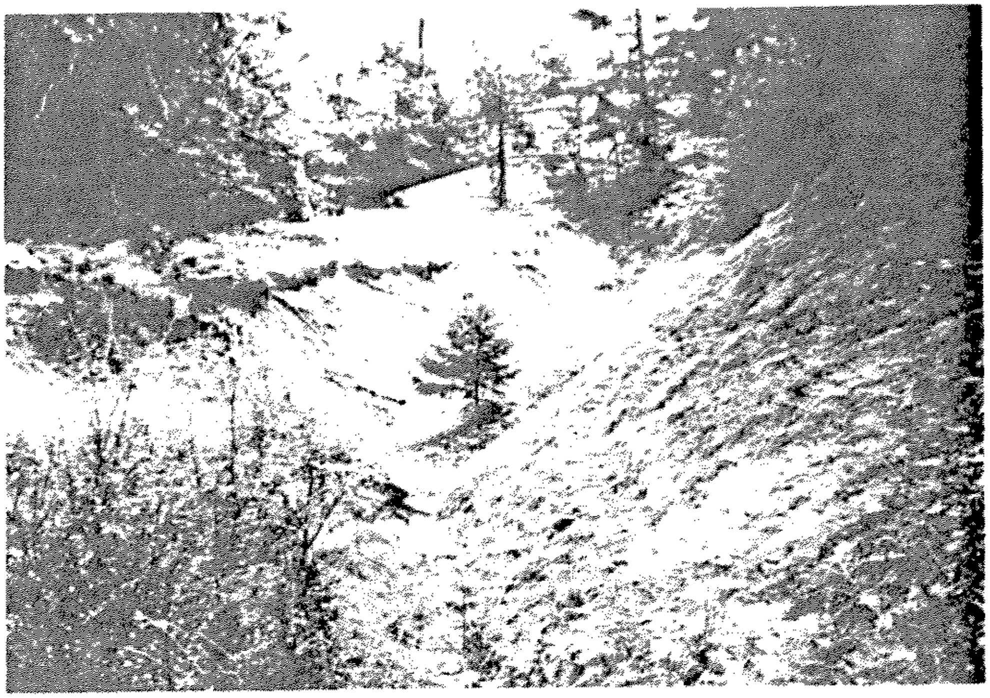

Figure 3. Where inside ditches collect and concentrate runoff, gullies can form along roads and below culvert out-falls.

Figure 4. An out-sloped road drained by broad rolling dips reduces the chance of water concentration.

Figure 5. To succeed, timber harvesting activities in areas with DG soils must be based on the actual site conditions and an understanding of physical processes, not on preconceived prescriptions, engineering designs, or snake oil remedies.

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ZERO NET INCREASE: A NEW GOAL IN TIMBERLAND MANAGEMENT ON GRANITIC SOILS

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ABSTRACT

The Grass Valley Creek Watershed, located in Trinity County, California, contains 23,525 acres, of which 70 percent is underlain by decomposed granite. The combination of a sensitive geology with management practices incompatible with this geology has caused sustained, high yields of sediment to be discharged into the Trinity River. In 1990, private landowners and several agencies agreed that a "zero net increase" in sediment should be the standard applied to future timber harvesting. Guided by this principle, the USDA Soil Conservation Service developed an approach called the "Zero Net Increase" (ZNI) sediment budget method. ZNI is grounded in this equation: Excess Erosion = Accelerated Erosion - Baseline Erosion. Once a sediment estimate is completed, Best Management Practices are applied to reduce the estimate back to a zero net loss from the plan area. Since 1991, ZNI has been voluntarily applied to five timber harvest plans covering 3,000 acres. The value of this methodology lies not in its quantification of sediment produced, but rather in its educating landowners of the impacts their management activities may have, and how to reduce these impacts. In the future, ZNI may evolve into a tool used to evaluate the relative impacts of various land management scenarios in other sensitive watersheds.

INTRODUCTION

A sediment budget approach that balances the impacts of timber harvest on the soil and water resource with Best Management Practices designed to offset these impacts is a new tool being used in the management of the Grass Valley Creek Watershed (GVCW), Trinity County, California. The method, called the Zero Net Increase (ZNI) potential sediment budget method, is now applied to all timber operations on decomposed granite soils within the Grass Valley Creek area. This paper describes the evolution of land management leading to the method, summarizes the methodology, and explains how the method has worked so far and how it might best be applied elsewhere. An example of the Zero Net Increase method is also provided.

Background and History

The 23,525 acre Grass Valley Creek Watershed is situated in east central Trinity County. State Highway 299 West, after crossing the Shasta County - Trinity County line, traverses a portion of it. Grass Valley Creek is a tributary to the Trinity River. GVCW ranges in elevation from 5,950 feet at the headwaters to about 1,900 feet at the Trinity River. Approximately 70% of the watershed area is occupied by soils derived from decomposed granite, part of the Shasta Bally Batholith.

Beginning in the 1940's, land management activities, primarily industrial timber harvest and related operations, significantly altered the complexion of the Grass Valley Creek Watershed. By the mid-1950's, nearly all of the watershed had been entered to remove selected forest products (Dan Fisher, Champion International, pers. comm.). These historical management activities included road building, tractor yarding, and skidding on the decomposed granite soils of the watershed. In many cases, timber operations and silvicultural prescriptions proceeded without due regard for the sensitive and highly erosive nature of these granitic soils. Roads and skid trails frequently followed intermittent and ephemeral drainages, landings were constructed in channels, and stream crossings were left at risk for failures or diversions. Silvicultural prescriptions often left little or no residual canopy to provide litter recruitment, resulting in the baring of steep hillsides, erosion of soil "A" horizons, and conversion to brushfields.

The combination of a sensitive geology with past land management practices incompatible with this geology have caused sustained, high yields of sediment to be discharged from the GVCW into the Trinity River. In 1986, the USDA Soil Conservation Service (SCS) estimated that the Grass Valley Creek Watershed produced an average of 143,000 tons of sediment annually (USDA SCS, 1986), most of this being decomposed granite supplied as bedload material to the Trinity River. This bedload was cited as a significant contributor to the decline in anadromous fisheries populations following construction of the Trinity and Lewiston dams in 1963 (see Brock, this Proceedings).

Increased Scrutiny Leads to "Zero Net Increase" Policy

Since 1985, activities in the Grass Valley Creek Watershed and the rest of the Shasta Bally Batholith have been under ever-increasing scrutiny from both the public and the resource agencies attempting to meet water quality goals in the Trinity River Basin. While the original adoption of Forest Practices Rules by the California State Board of Forestry in 1974 halted many of the damaging activities in the watershed, significant problems still remained. Despite subsequent amendments to the rules (CDF, 1991a), they were not preventing the continued degradation of the watershed.

In 1986, special mitigation measures were first developed by the California Dept. of Forestry and Fire Protection (CDF) for the purposes of limiting the types and timing of disturbance on decomposed granite soils, with emphasis on GVCW. The effectiveness of these "Grass Valley Creek Mitigation Measures", as they have become called, were later qualitatively evaluated by a multi-agency committee and revised (CDF, 1991b). Land management within the watershed has continued to evolve, with more rigorous oversight of ground-disturbing activities by a number of entities (see Dunlap, this Proceedings.)

In 1990, the North Coast Regional Water Quality Control Board (NCRWQCB) recommended that any future sediment production from timber harvest and related activities in the Grass Valley Creek Watershed be balanced by sediment savings through mitigating activities, either on- or off-site. The NCRWQCB's stated goal was a "zero net increase" in sediment produced from future activities. The development of a budget quantifying potential sediment produced which would then be "saved" by mitigations was the necessary first step.

The landowner affected by the NCRWQCB decision requested SCS assistance in producing this budget. In July, 1991, SCS released a sediment budget, which is more commonly referred to as the Zero Net Increase Methodology (USDA SCS, 1991).

THE METHODOLOGY

The sediment budget relies on baseline erosion information published in the SCS's 1986 GVCW sediment study. Additional sources of technical guidance used in developing this method included Leaf (1974), Megahan and Kidd (1972), and Megahan (1974). Professional judgement was also a necessary component to keep the budget practical and site-specific. The greatest challenge in developing and applying this method lies not so much in the technical details, but rather in retaining its simplicity so expectations of accuracy are not raised too high.

The method is grounded in the following equation:

EXCESS EROSION = ACCELERATED EROSION − BASELINE EROSION

Here, "baseline" is defined as an average annual erosion rate for various sources of erosion in the Grass Valley Creek Watershed; "accelerated" erosion is the increase in erosion following disturbance of an area; and "excess" erosion is the remainder following subtraction of baseline erosion. This method is appropriate for estimating surface erosion processes but not for mass failures.

Three sources of erosion are most affected by timber operations in the Shasta Bally Batholith: 1) erosion from roads, skids and landings; 2) stream erosion; and 3) sheet and rill erosion. An erosion estimate is derived for each source using erosion acceleration factors specific to each.

The acceleration factors are based on a compilation of research on time trends in sediment production from roads in decomposed granite of the Idaho batholith, modified to meet local conditions using Universal Soil Loss Equation (USLE) transects and other SCS technical guide criteria. Megahan and Kidd (1972) exhibited a histogram of sedimentation rates over time, concluding that roughly 84% of the total sediment production occurred the first year, and 9%

the second year following road construction. Megahan (1974) further details results of time trend studies suggesting an asymptotic decline in sediment yield over the six year study period of the Deep Creek watershed in Idaho.

Using information derived from USLE transects of disturbed and undisturbed areas as adjusted by climatic data specific to the GVCW, the relative acceleration rates due to disturbing activities affecting roads and stream channels was assigned at 45 times the baseline erosion rate for the first year following disturbance, and 5 times the baseline level the second year after disturbance (Figure 1). The third year it was assumed that sediment production rates approached baseline levels, although intuitively it is understood that the baseline level (17 tons per acre per year) is now fractionally larger than before new operations commenced.

Acceleration factors for sheet and rill erosion were based on information presented by Clayton (1981), who examined the acceleration of erosion rates on granitic soils following timber harvesting and broadcast burning in Idaho. For the most critically disturbed areas, Clayton found accelerated rates of 10 times over undisturbed conditions the first year following disturbance. Despite dissimilarities in site conditions of Clayton's study, this value was assigned as the sheet and rill acceleration factor for both the first and second year following disturbance (Figure 2). No asymptotic decline from year one to year two was assigned to this erosion source. The observations of a number of resource professionals who have worked in GVCW consistently suggest that sheet and rill erosion tends to accelerate for a period of time greater than two years following timber operations due to the loss of canopy cover and the recruitment of forest litter.

Armed with baseline erosion levels and acceleration factors for each erosion source, the method allows development of a potential, unmitigated "excess erosion" estimate. A sediment estimate is then derived by multiplying "excess erosion" by the estimated ratio of erosion that reaches a stream channel, or by what is termed a "sediment delivery ratio."

Once an estimate of potential sediment production from a plan area is established, the next step is the application of Best Management Practices (BMPs) and other mitigations that will reduce sediment production potential from each erosion source. These BMPs are spelled out in the Forest Practices Act (CDF, 1991a), the literature, and in special Grass Valley Creek mitigations (CDF, 1991b). By applying a percent reduction factor to each BMP used on the plan area, a balance nearing zero between potential sediment produced and sediment mitigated is hopefully achieved. Any volume of sediment remaining would be subject to additional mitigations, either on-site or in other parts of the landowner's property.

CALCULATING ZNI: AN EXAMPLE

A hypothetical Timber Harvest Plan (THP) in the Grass Valley Creek watershed, the "Roberts THP" (Figure 3), will be used for the basis of illustrating the procedures used in calculating ZNI. An estimate of potential erosion and sediment yield from only the "critical areas" (i.e., roads, skid trails, and landings) will be derived in this example. For the complete procedure, estimates are also calculated for potential sediment yield from hillslope sheet and rill erosion and stream erosion.

Part 1. Unmitigated Erosion Yield

Step 1. Calculate Acreage Disturbed. Measure length of existing roads to be reused within Plan boundaries. Multiply length by 26 foot standard width to calculate acres of existing road to be redistributed. Determine the length of new road construction (proposed) and multiply by 26 feet to establish acreage. Complete same procedure for existing and new skid trails, except multiply by standard 20 foot width to determine acreage.

Existing roads = (6600 ft x 26 ft) ÷ 43,560 ft^2/ac = 3.9 acres
New roads = (13,200 ft x 26 ft) ÷ 43,560 ft^2/ac = 7.8 acres
Existing skids = (15,840 ft x 20 ft) ÷ 43,560 ft^2/ac = 7.2 acres

Proposed skids = (7,920 ft x 20 ft) ÷ 43,560 ft^2/ac = 3.6 acres

Next determine the area of existing and newly constructed landings. A total of 8 landings are detailed on the Plan map, all existing:

Existing helicopter service = 1 @ 1.25 ac/ea = 1.25 acres.

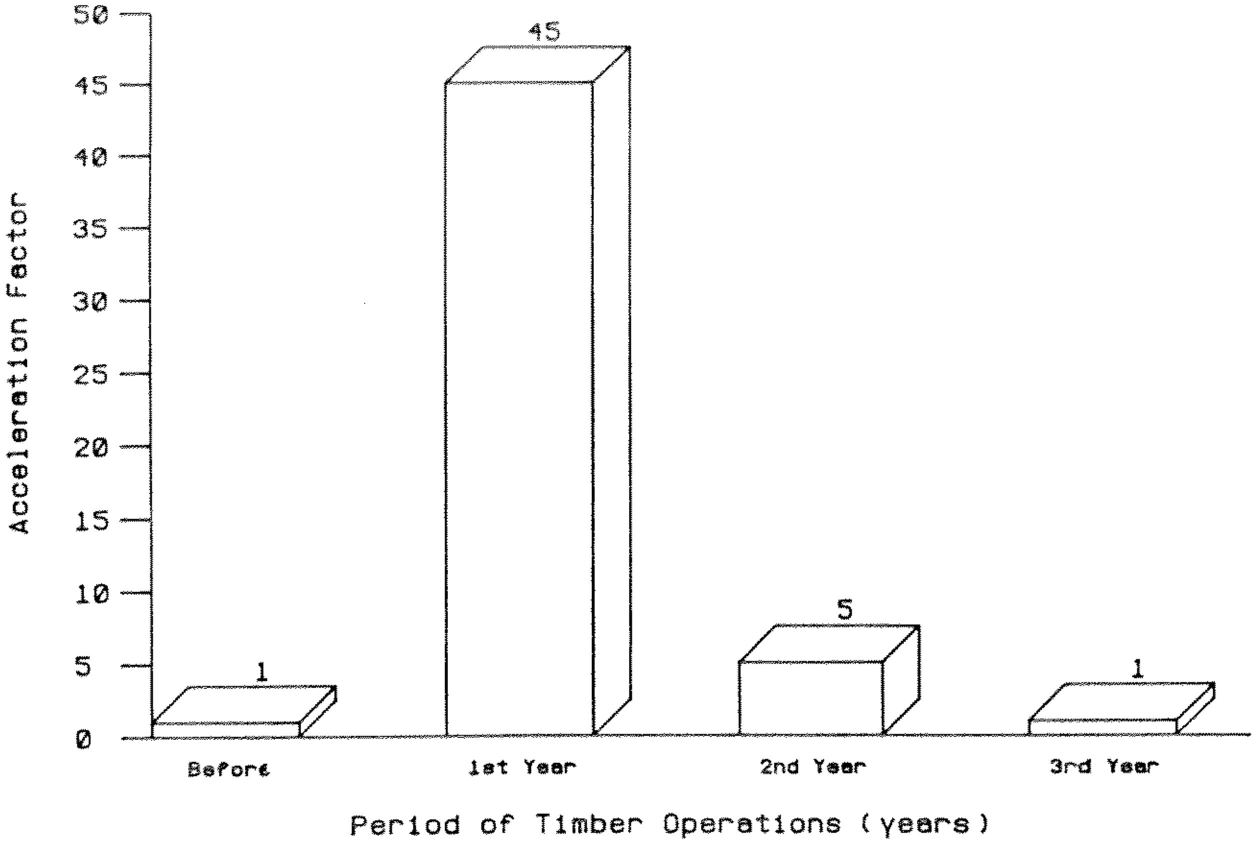


Figure 1. Road and stream erosion acceleration factors used in completing the Zero Net Increase Method for the year prior to and three years following timber operations in DG soils, Grass Valley Creek Watershed.

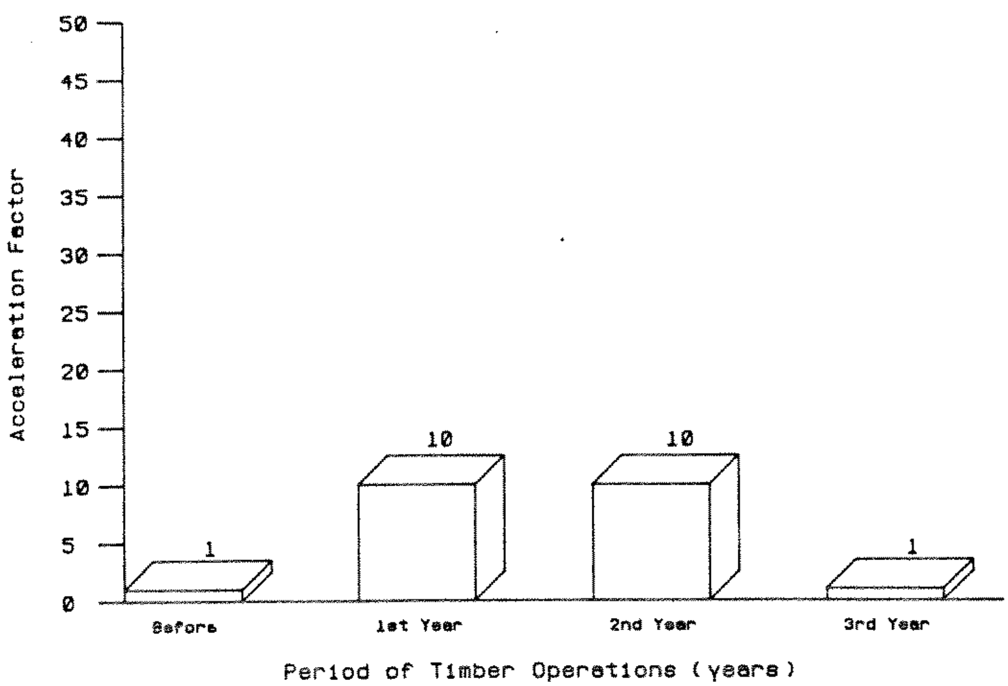
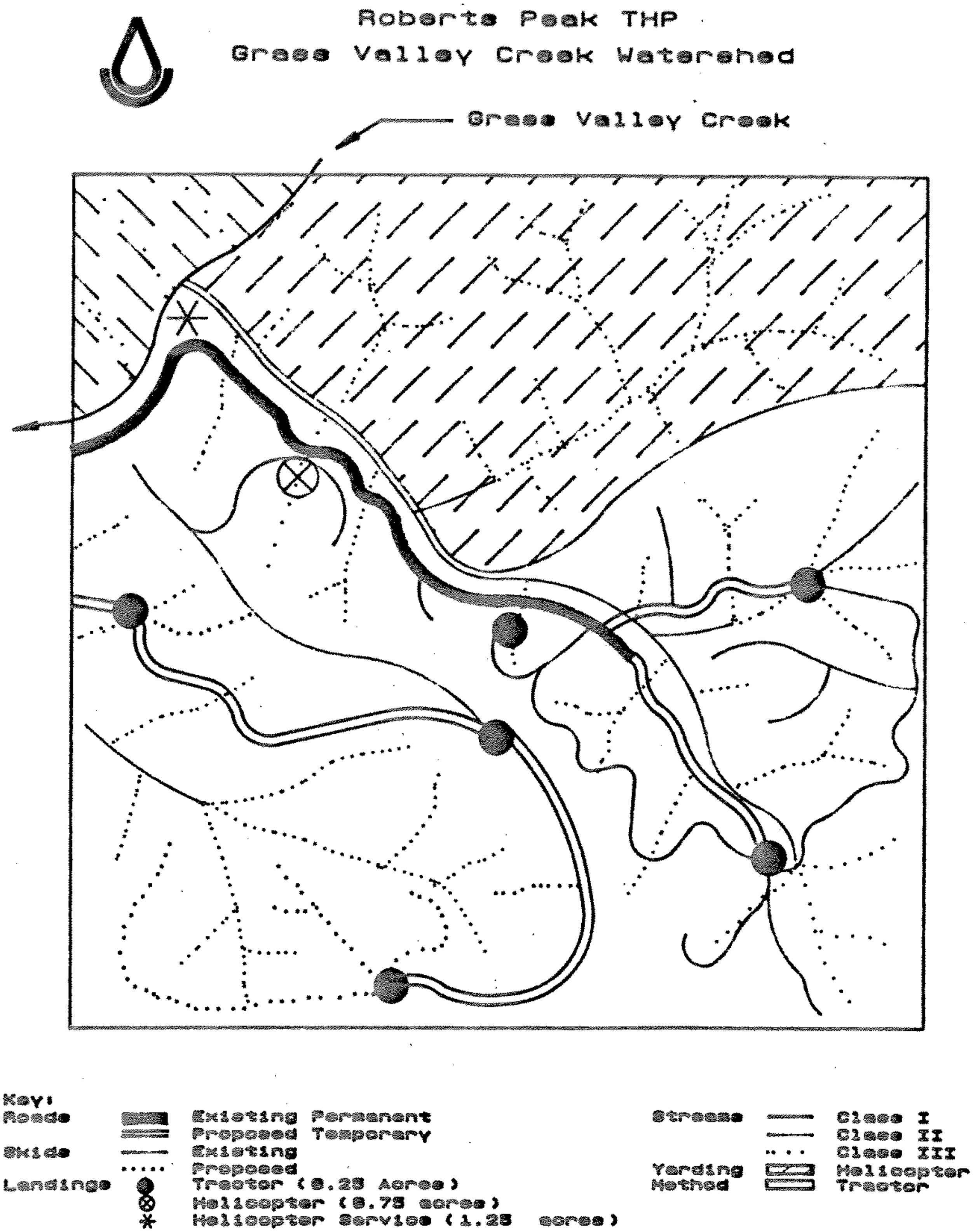


Figure 2. Sheet and Rill erosion acceleration factors used in completing the Zero Net Increase Method for the year prior to and three years following timber operations in DG soils. Grass Valley Creek Watershed.

Figure 3. Hypothetical Timber Harvest Plan map used in completing Zero Net Increase Method. Grass Valley Creek Watershed, Trinity County, California.



Existing helicopter landing = 1 @ 0.75 ac/ea = 0.75 acres.

Existing tractor landings = 6 x 0.25 acres/ldg = 1.50 acres. Total landings = 3.5 acres.

	Existing	Proposed
Roads	3.9	7.8
Skids	7.2	3.6
Landings	3.5	0
Total	14.6 acres	11.4 acres

Step 2. Determine Baseline Erosion. Calculate the baseline tons of erosion from the existing disturbed areas. Based on critical area erosion rates derived from the GVCW study (USDA SCS, 1986), steep, granitic terrain produces 17 tons/ac/yr.

For existing redisturbed critical areas:
14.6 acres x 17 tons/ac/yr x 2 years = 496 tons.

Note: New roads are not included in baseline calculations.

Step 3. Determine Accelerated Erosion following Timber Operations. Calculate the accelerated erosion from the disturbed critical areas due to timber operation:

Existing = 14.6 acres
Proposed = 11.4 acres
26.0 acres

Based on assigned acceleration rates (Fig. 1), the amount of accelerated erosion is:

1st year: 26 ac x 17 tons/ac/yr x 45 = 19,890 tons
2nd year: 26 ac x 17 tons/ac/yr x 5 = 2,210 tons

Total Accelerated Erosion = 22,100 tons

Step 4. Calculate Excess Erosion from Critical Areas following Timber Operations.

Baseline erosion yield = 496 tons
Accelerated erosion yield = 22,100 tons

EXCESS = 22,100 − 496 = 21,604 tons

Note: This excess erosion estimate is prior to mitigations.

Part 2. Reductions in Potential Erosion Yield Through Application of Mitigations.

Step 5. Reduction of Erosion from Critical Areas. Critical areas can be mitigated by a number of erosion and sediment control practices. SCS (1986) showed that the distribution of erosion yield from road prisms in GVCW is approximately the following: road cuts - 59%; road fills - 23%; road surface - 18%. Applying these percentages to the 21,604 tons estimated in Step 4 produces unmitigated erosion amounts by source: road cuts - 12,746 tons; road fills - 4,969 tons; road surface - 3,889 tons.

Mitigation treatments can be applied to each portion of the road prism to reduce erosion or sediment delivery potential in the following amounts:

Source	Treatment	Reduction	Tons
Cut	Outsloping	60%	7,648
Cut	Haybales	15%	223
Fill	Energy dissipation	20%	994
Fill	Seed & mulch	60%	2,385
Surf.	Rocking road	80%	3,112
Surf.	Rolling dips	30%	223

Total Mitigated Erosion = 14,694

The treatment reduction percentages applied here are based on the literature or professional judgement. If all of the above mitigations are applied to the THP, the potential erosion yield will be reduced by 68% (14,694 tons ÷ 21,604 tons).

Step 6. Achievement of ZNI in Potential Sediment. Assuming a sediment delivery ratio of 55% (based on the 1986 SCS study), 11,882 tons of potential sediment could enter the Grass Valley Creek stream system from these critical area sites (21,604 tons x 0.55). However, 68% of this potential sediment will be controlled due to the above mitigations, leaving 3,800 tons remaining to enter the system (11,882 tons x (1-0.68)).

This final number suggests that, for the landowner to achieve a Zero Net Increase in sediment production on this THP, changes in the harvest plan or additional on-site or off-site (i.e., contiguous to THP, if possible, but within the watershed) mitigations will be needed.

CONCLUSIONS

Status Report

Zero Net Increase has had a positive impact on land management decisions made in the Grass Valley Creek Watershed. The method has been voluntarily applied to 5 timber harvest plans totaling over 3,000 acres since 1991. This approach has represented, better than any qualitative or subjective process ever could, the relative consequences various operational scenarios can have on water quality impacts in this sensitive watershed. The value of this methodology lies not in its quantification of "tons of sediment" produced or saved, but rather in its educating land managers of the potential impacts their management activities may have, and what steps may be taken to reduce potential sediment production. Once land managers are provided alternatives that balance economics with resource protection through the use of BMPs identified as being most appropriate for decomposed granite terrain, they are much more likely to buy in to sediment-reducing activities.

Application To Other Watersheds

In order to apply this method to other sensitive watersheds, a clear understanding of the watershed's problems and their causes must first be accomplished, followed by defining the goals and objectives that address these causes. Once a consensus is built on these important starting points, Zero Net Increase can then be evaluated to determine whether this method is the most appropriate vehicle for achieving the stated goals.

This method requires a solid foundation of baseline information on: basin-wide or stratified erosion rates; on acceptable, documented acceleration factors; sediment delivery ratios for a watershed; and agreed-on sediment reduction percentages for each of the common BMPs applied in the watershed, obtained from reliable literature sources and local expertise.

The Zero Net Increase Methodology is a rigorous method grounded in sound science. The method, however, has yet to be validated for accuracy through an intensive monitoring program. Honest disagreement on the subjective details necessary to complete this method can be a roadblock to successful application. Procedural requirements, such as development and review of plans prior to application of the ZNI sediment budget, are important issues to be addressed by professionals planning on implementing this approach.

Future Value

In the future, the long-term value of the Zero Net Increase Methodology will be as an educational tool, rather than as a regulatory instrument. The method was developed and should only be viewed as an interim step towards achieving a long-term goal of sediment reduction in the Grass Valley Creek Watershed, as it only suggests a zero net increase in potential sediment production, rather than a net improvement in watershed conditions. Zero Net Increase will likely evolve into a mechanism for evaluating the relative impacts of alternative land management practices in sensitive, heavily impacted watersheds of Northern California and elsewhere.

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EROSION MONITORING AND ITS IMPLICATIONS FOR MANAGEMENT

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ABSTRACT

In 1985, the Shasta-Trinity National Forests initiated a study of surface erosion. The objectives of the study were to establish and correlate erosion rates for major soil families with varying slope and ground cover conditions, evaluate the need to modify management practices to prevent significant surface erosion, and to evaluate the effectiveness of filter fabric dams as a soil erosion monitoring tool. Fabric dams were placed in gentle swales of upper watershed areas with no defined channel. Data analysis of the soil volumes lost from the sites yielded only a weak correlation between ground cover percent and erosion rates due to site selection. Parent material was the only variable having a strong correlation to soil loss.

We concluded that ground cover is an important factor contributing to erosion rates in granitic soils and that retaining an intact forest floor is necessary to reduce soil erosion. Charred duff and litter are commonly lost from broadcast burned sites during the first year, so provide no benefit. Reduced ground cover on hydrophobic soils leads to significant surface erosion. Fabric dams were found to be excellent surface erosion monitoring and demonstration tools and were cost-effective. The following recommendations are made for managing granitic soils: 1) Maintain maximum ground cover following timber harvesting and site preparation; 2) Control logging system disturbance and minimize skid trail erosion problems; 3) Minimize disturbance in ephemeral stream channels and swales; 4) Control road drainage adjacent to harvest units and keep erosion control measures current; 5) Use Best Management Practices.

INTRODUCTION

It is well documented in the literature that soil formed from granitic parent material is highly erodible. Observations on the Shasta-Trinity National Forests in Northern California indicated that surface erosion was significant in granitic soils, but evidence generally disappeared rapidly. Rills which formed after summer and fall rains collapsed and filled as the soil dried, due to the non-cohesive nature of granitic soils. Therefore, soil loss estimates were difficult to perform and the problem was generally overlooked by land managers.

The Forest Service Handbook directs land managers to plan and conduct monitoring to determine if soil management goals, objectives and standards, as outlined in Forest Plans, are being achieved. In 1985, due to our suspicion that surface erosion was more significant than previously believed, we initiated a study of surface erosion.

The objectives of the soil erosion study were to:

1. Establish and correlate erosion rates for major soil families, including soils formed from granitic parent material, with varying slope and ground

cover conditions.

2. Evaluate the need to modify management practices to prevent significant impairment of long-term soil productivity and degradation of water quality due to surface erosion.

3. Evaluate the effectiveness of filter fabric dams as a soil erosion monitoring tool on western landscapes.

The purpose of this paper is to describe how this monitoring project was performed, the conclusions which were made and the management recommendations which resulted from the study.

METHODS

Fabric dams (also called sediment or silt fences) were chosen as the means to measure surface erosion because they are relatively inexpensive and easy to construct, they avoid micro-topography bias that erosion pins and troughs can present, and if properly placed, can yield an accurate value for the amount of sediment leaving the site. Approximately 50 fabric dams were placed in gentle swale areas within upper watershed areas (zero order watersheds) where there was no defined channel. We felt that if soil was moving through this uppermost portion of the fluvial system, it would eventually move off-site and would result in loss of soil productivity and reduced water quality. This study was not designed to measure statistical differences in erosion rates, but was meant to establish relative differences in erosion rates between various soil types having different slope gradients and ground cover percentages.

The dams were constructed similar to those used by Dissmeyer (1982), in the southeastern United States. Due to the steeper slopes, snow loads and potentially greater sediment loads in the study area, his design was modified (Chase, 1992). The dams are constructed using steel fence posts driven in several feet, which are generally spaced 2 to 4 feet apart. A trench is dug in front of the posts, then chicken wire and UV-resistent filter fabric is attached to the posts, with the lower portion buried in the trench. Guy wires are attached to key posts and anchored upslope. The dams are approximately 3 feet in height, and generally 20 to 75 feet in length.

The volume of soil lost from the site and trapped by the dam is measured using a stake grid pattern. Stakes are installed with a known area around each stake. Cubic volume is determined by multiplying the area times the depth of the soil deposited around each stake. Adding together the cubic volume around each stake gives the total volume behind each dam. By determining the contributing area above the dam, cubic volume is determined on a per acre basis.

The study was designed to analyze surface erosion for five dominant soil families. To evaluate ground cover and slope factors, we attempted to find multiple sites for each of the five soil types which had different slope gradient classes and different ground cover conditions. The study was also designed to monitor the effects of various land treatments on surface erosion, therefore sites were chosen in areas that had different harvest and site preparation practices.

RESULTS

In analyzing the data, it became apparent that a great amount of variability in erosion rates was unaccounted for in the study design. Factors other than erodibility, ground cover and slope greatly influenced surface erosion. Storm intensity, site disturbance, soil hydrophobicity and the quality and size of the ground cover were determined to be significant factors in surface erosion. Data analysis yielded only a weak correlation between ground cover percent and erosion rates. We believe that this is due to the lack of detailed data collection on the quality of ground cover and because we had no sites with more that 30% effective ground cover.

Parent material was the only variable having a strong correlation to soil loss. A significant difference in erosion rates was seen for soils formed from granitic parent material (Figure 1). Granitic soils had a range of 2.1 to 330 cubic feet per acre of soil loss, with a mean of 75.6 cubic feet per acre. The soils derived from ultramafic, volcanic and metasedimentary rocks have a range of 1 to 10.3 cubic feet per acre of soil loss, with a mean of 2.4 cubic feet per acre.

The data indicate that if prudent land management practices are applied to areas having non-granitic soils, surface erosion is not significant. Results also indicated that soils derived from granitic parent rock require special management considerations in order to protect against significant soil loss.

The study also verified the effectiveness and cost of fabric dams for soil erosion monitoring on steep

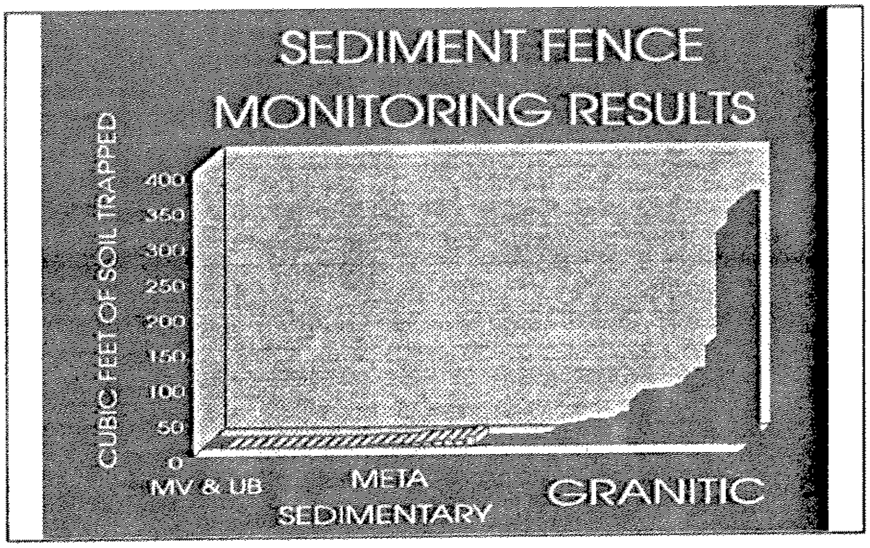

Figure 1. Comparison of erosion rates according to parent material.

slopes. Less than 10 percent of the dams failed during the study period. The cost of materials for each dam ranged from $75 to $150, and each could be constructed by two people in less than a day.

Future studies need to better focus on the specific aspects of ground cover and erosion prevention. The continuity and condition of the duff and litter layer, the distribution of ground cover size classes, and the extent of disturbance are all important factors which were not addressed by this study.

OBSERVATIONS AND CONCLUSIONS

Soil Loss and Management

Based on the data collected during this study and observations which were made, the following conclusions were drawn regarding management of granitic soils:

1. Ground cover is an important factor contributing to erosion rates.

   This study has shown that soil erosion is a complex process and that many factors can influence the rate of surface erosion. The amount of ground cover is the one factor that can be controlled through management practices. For highly erodible soils, a minimum of 70 percent effective ground cover is needed to prevent significant surface erosion. To be most effective in preventing surface erosion, ground cover should approach 100 percent.

2. Retaining an intact forest floor, including duff, litter, and small and large woody material, is necessary to reduce soil erosion.

   It is apparent that the duff layer is the most important component of ground cover, as it serves as a "sponge" to hold moisture and is actually the binding agent just below the forest floor. Retention of the forest floor, especially the duff layer, is difficult during broadcast burning. Even when ground cover is retained through "cool" burns, the critical duff component is often charred or destroyed. Soil loss generally comes from areas having inadequate ground cover.

   Field observations indicate that large woody debris alone is often ineffective in reducing soil erosion. Although debris can provide local sediment traps, rill patterns deflect around large woody material in areas lacking sufficient soil cover. The key to reducing soil loss is to retain an intact forest floor, including duff, litter and woody material. One component alone does not provide adequate protection from soil loss.

3. Charred duff and litter is commonly lost from broadcast burned sites.

   Following broadcast burning, charred duff and litter is often lost through rapid oxidation, surface runoff, or wind erosion, thereby, reducing the level of effective ground cover. Soil loss begins once the protective forest floor layer is lost.

4. Reduced ground cover on hydrophobic soils exacerbates surface erosion.

   Ground disturbance and the reduction in effective ground cover becomes extremely important when the soils are hydrophobic. Rainfall is repelled and not readily infiltrated into the soil profile which results in concentrated runoff and soil erosion. The forest floor, especially the duff layer, acts as a "sponge" by holding moisture and allowing water to infiltrate slowly. Loss of the duff layer reduces moisture retention capabilities and increases soil loss potential.

The majority of granitic soils in the Klamath Mountains generally occur at elevations greater than 4500 feet, in the frigid soil temperature regime where decomposition of organic material is relatively slow. As Debano(1969) documents, soils which are rich in organic material and are coarse textured, such as granitic soils, tend to be hydrophobic.

From our observations, much of the soil deposited behind silt fences came from the first 1 or 2 storms of the year. Little additional soil was measured in the following spring suggesting that summer and fall rain on dry hydrophobic granitic soils is one of the main reasons for high erosion rates. Once the hydrophobic soils wet-up, they are far less water repellent.

Fabric Dam Effectiveness

Just as significant as the conclusions drawn on the importance of ground cover on granitic soils, we learned the benefits of using fabric dams as a monitoring tool. The study provided information on the effectiveness of the fabric dams for determining soil loss attributed to timber management activities.

1. Fabric dams are excellent surface erosion monitoring and demonstration tools.

   Fabric dams are a good visual tool to demonstrate surface erosion to land managers. They provide the means to see the total soil loss from collective rills, which otherwise might seem somewhat insignificant. Land managers can use the visual evidence to qualitatively compare soil loss associated with different management practices.

2. Visual results eliminate confusing or abstract measurement terms that are unfamiliar to most land managers and the general public.
   Rather than trying to comprehend 15 cubic feet of soil loss per acre for a particular site, the sight of that amount of sediment trapped behind a fabric dam makes a greater impression. Conclusions and comparisons can be drawn by land managers without exact measurements.

3. Fabric dams are effective to measure erosion and are cost effective.

   Fabric dams are effective in capturing eroding soil within a harvest unit. The fabric dam structures are inexpensive and easy to install. They serve as an excellent method to measure soil movement and can be used as a comparative tool in assessing soil loss under varied conditions. The structures can be used over a 3-5 year period, depending on their size and the contributing area. We have found the fabric dams to be a valuable management tool which have a great potential for monitoring soil erosion and the effectiveness of Best Management Practices.

MANAGEMENT RECOMMENDATIONS

As previously mentioned, one of the objectives of the study was to evaluate the need to modify management practices to prevent significant impairment of long-term soil productivity and degradation of water quality due to surface erosion. Based on what was learned during this study, the following recommendations are made for management activities on granitic soils:

1. Maintain maximum ground cover following timber harvesting and site preparation through the use of special practices.

   a. Minimize site preparation and plant within slash, where possible.

   b. Avoid broadcast burning. It is extremely difficult, if not impossible, to broadcast burn and maintain the fragile duff layer that is critical to maintaining soil stability in highly erodible soils.

   c. Yard unmerchantable material (YUM) to reduce fuel loads and to provide planting sites.

   d. "Lop and scatter" material to get slash in contact with the ground, which provides additional ground cover and promotes more rapid decomposition of the slash.

   e. Avoid scalping around seedlings because it drastically reduces effective ground cover. If scalping is performed, drag back slash into scalped area.

2. Control logging systems.

   a. Pre-designate skid trail locations to limit disturbance to less than 15 percent of the site.

   b. Use extended end-lining in conjunction with designated skid trails to lower site disturbance.

   c. Restrict tractor logging to slopes less than 35 percent in order to minimize site disturbance and skid trail drainage challenges.

   d. Consider the use of low ground disturbance harvest systems such as cable skyline and helicopter logging systems to minimize ground disturbance.

3. Minimize skid trail erosion problems.

   a. Use minimum water bar spacing. On steep grades, space water bars no more than 20 feet apart to prevent water concentration.

   b. Spread slash or mulch skid trails at the completion of timber harvest activities in order to restore ground cover and minimize soil movement.

   c. Consider tilling skid trails to reduce compaction and surface runoff.

4. Control practices in ephemeral stream channels and swales.

a. Maintain 100% ground cover in ephemeral stream channels and swales where surface water concentrates.

b. Control timber felling away from these areas in order to minimize ground disturbance during subsequent yarding operations.

c. Designate all ephemeral draws and swales within granitic terrain as "sensitive" on sale area maps, and exclude equipment entry in order to minimize ground disturbance and potential impacts.

5. Control road drainage adjacent to harvest units.

a. Control drainage from roads and landings to avoid concentrating it in non-drainage areas within harvest units. Concentrated runoff can lead to severe gullying in highly erodible soils.

6. Keep erosion control measures current.

a. Erosion control measures need to be kept current throughout the operating season. Summer thunderstorms are often one of the principal erosion causing events during the year.

7. Use Best Management Practices.

a. Strictly adhere to applicable Best Management Practices in highly erodible soils. They represent a collection of the most effective erosion control measures. Always be looking for ways to improve the practices.

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ENGINEERING DESIGN CONSIDERATIONS IN GRANITIC TERRAIN

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ABSTRACT

Decomposed granitic soils are notoriously erosive and problematic to land managers, yet roads and other engineering projects are routinely constructed in granitic soils. Granitic soils have high natural erosion rates and typically, construction activities greatly accelerate erosion. Through experience, much information has been gained about design and construction in granitic soils, and many design and roadway drainage measures have been developed to minimize erosion. Engineering design, construction and maintenance practices effectively used in granitics and those used to control water and reduce erosion are presented. However, despite the application of erosion control measures, erosion will typically continue to be a problem in granitic soils because the soils are unforgiving and construction practices inexact.

Measures to minimize erosion are reasonably well known, including cut and fill slope stabilization, control of surface and subsurface drainage, compaction, maintenance practices, etc. These known measures must be applied in construction and erosion control practices. Managers must be willing to spend the money needed to implement these measures, pay attention to the details of surface drainage, and do needed maintenance. Finally, the application of known effective biotechnical and vegetal erosion control techniques are outlined and encouraged.

INTRODUCTION

Decomposed granitic soils are notoriously erosive and problematic to land managers, yet roads and other engineering projects are routinely constructed in granitic soils. The objectives of this paper are: 1) to offer a perspective on the impacts of construction in granitic soils; 2) to discuss engineering properties of typical granitic soils in the northwestern United States; and 3) to review many of the engineering design and construction measures and considerations which can reduce the amount of erosion and associated problems working in granitics.

This information is not intended to be an in-depth study of engineering design practices, nor is the information new, but it does represent a collection of information gained from projects in granitic soils over many years by the author and others. Many of the measures described herein should be considered common construction practices when working in granitics, particularly on low standard roads. Mistakes have been made and erosion will continue to be a problem, but much has been learned in engineering design, construction, and maintenance practice to minimize problems associated with granitics.

IMPACTS OF CONSTRUCTION IN GRANITIC SOILS

Concern for management activities, including road building, and need for careful engineering practices and mitigation to minimize erosion is clear. Recent Coordinated Resource Management (CRM) studies (USDA-SCS, 1989) on the relatively flat, eastern portion of the Plumas National Forest in northeastern California have shown that watersheds in granitic terrain have the highest erosion rates forestwide, with an average erosion rate of 1100 tons/square mile/year. The source of about half of the sediment is the road prism, including the cut slope, fill slope and road surface. Numerous other studies support the fact that road construction can greatly accelerate erosion on forest lands. Studies in steep granitic terrain in the Idaho Batholith (Megahan and Kidd, 1972) have shown that road construction can accelerate the sediment production rate of an area by as much as 770 percent. Cut slopes, ditches, and fill slopes, particularly when untreated, contribute the majority of the sediment, with the traveled way contributing a minor portion (Burroughs et al., 1984). Thus, road-related erosion needs to be minimized whenever possible, and can be reduced with the application of the following four basic principles (Megahan, 1977):

1. Minimize the amount of disturbance caused by road construction by reducing road length and road surface area;
2. Avoid construction in high erosion hazard areas;
3. Minimize erosion by construction of the variety of practices designed to reduce erosion, and;
4. Minimize off-site impacts by avoiding waterways and keeping sediment on-site.

Observations on construction-related erosion in western granitic soils support the following general conclusions:

1. To minimize erosion, disturbance should be minimized, or totally avoided if an area is critical and high erosion rates are unacceptable.
2. To minimize erosion, considerable extra erosion protection, design practices and drainage measures are needed, as well as much attention to on-the-ground detail to control water and continued long-term maintenance on projects.
3. Granitic soils are very unforgiving, engineering practices inexact, and construction control is variable and often minimal, so occasional "disasters" <u>will</u> occur, and higher than "natural" sediment rates can be expected in a project area.
4. Fortunately many design and construction measures can be used to lessen or minimize erosion in granitic soils. However, the extra costs and needed extra effort <u>must</u> be expended to reduce erosion. Too often the extra effort is not taken, the "steep and cheap" road is built, and erosion-related problems persist. Also, many past mistakes need correction.

Road location is an important factor to avoid problem areas initially. Ideally, steep or dissected slope areas, unstable features and wet areas should be avoided or minimized. Roads should be located high in the watershed, as far away from water courses as possible. Routine erosion control measures are needed when working in granitic soils, and conflicting factors must be evaluated. Unstable material on steep slopes may move a long distance and eventually be transported to stream channels, but good location can greatly minimize the needed measures and volume of sediment movement.

TYPICAL GRANITIC SOIL CHARACTERISTICS

Granitic soils are typically highly erosive because they have low to no cohesion and they have a relatively fine grained, silty-sand texture. However, granitic soils, particularly typically coarse grained soils, have generally good engineering properties, including high frictional strength (phi > 30 degrees, minimal cohesion), high bearing capacity, and good resistance to rutting.

Soils formed from granitic rock range from a slightly weathered rock to a moderately weathered saprolite to a totally decomposed residual soil, and are all broadly characterized as "decomposed granite". Soils which have formed in-place often exhibit a high degree of variability in decomposition due to the differential weathering characteristics of granite. Weathering proceeds inward along joint surfaces in the rock, followed by general mineral disintegration and decomposition (Wagner, 1991). It is also common to find more highly decomposed material beneath less decomposed boulders, and pockets of soft material at depth.

<u>Weathering Variability</u>

Various rock weathering classification schemes have been developed to describe degree of weathering (Clayton and Arnold, 1972) and rock condition for engineering purposes (Williamson, 1984). A recent decomposed granite classification scheme (Lee and de Freitas, 1989) uses six weathering grades, ranging from fresh rock to a residual soil. Grade IV Highly Weathered rock/soil and Grade V Completely Weathered soil correspond to the coarse disintegrated and decomposed granitic soils which can be excavated with a pick or shovel. Grade VI Residual Soil corresponds to the most weathered, usually finer grained granitic soils which can be excavated by hand.

Weathering of granitics is dominantly a function of parent rock mineralogy, texture and joint structure, and environment. "Granitic" rocks vary somewhat in their mineral composition of quartz, biotite, hornblende, and the two types of feldspars (Travis, 1955). The Sierra Nevada and western foothills vary from a quartz monzonite to a granodiorite, the Shasta Bally and Klamath Mountains plutons range from a quartz diorite to a granodiorite, and the Idaho Batholith is dominantly quartz monzonite. Each mineral has a varying resistance to weathering, which accounts for some variation in decomposition, yet soils produced from each of these rock types are surprisingly similar, with common materials characteristics. In Sierra Nevada granodiorites, the expansion of biotite in contact with water is a major weathering process which causes rock disintegration (Krank and Watters, 1983) and produces coarse silty sands and the coarse sandy talus material commonly known as grus.

Elevation and climate have a major affect on weathering, where warm wet climates, typical of elevations below 3500-4000 feet west of the central Sierra Nevada, produce the most weathered, residual granitic soils. Drier, colder areas above 4000 feet in the central Sierra Nevada and east produce the more typical coarse-grained granitic soils (saprolites). Generally, finer textured rock and more closely spaced joints lead to an increased degree of weathering. Saturation and areas of accumulated moisture also accelerate weathering.

Depth of weathering varies greatly in granitic rock. Very weathered soils (saprolites and residual soils) are common to tens of feet deep and saprolites and weathered rock are found over a hundred feet deep in the western Sierra Nevada and Klamath Mountains. Depths of weathering in the higher elevations of the Sierras, particularly with a glacial history, and the Idaho Batholith are generally more shallow, with a thin zone of 0 to 10 feet of decomposed and disintegrated granite over relatively competent weathered rock to depths of tens of feet. Again, pockets of weathered material may be found at depth.

By far the most common form of granitic soil in the western United States, particularly at higher elevations, is disintegrated or only slightly decomposed, whitish ("salt and pepper") granite (saprolite) (Weathering Classification Grade IV & V). This material is typically classified as a non-plastic, silty sand to sand (SM to SW)(Unified Soil Classification). Though relatively coarse-grained and having good engineering properties, the lack of cohesion allows for high detachability of the particles and makes the material very to extremely erosive.

Less common and found in local areas, particularly at lower elevations, are highly decomposed, residual granitic soils. They are often reddish-yellow to a chalky white color, relatively fine grained clayey sands to sandy silts (SC, ML, or CL Soil Classification). They may be slightly plastic, and often have generally poor engineering properties. Because they are fine grained but have little plasticity, they are very moisture sensitive, where a small amount of moisture changes their character from a solid to a liquid state. They can be very frost susceptible. Again, they are highly erosive because of their very fine grain texture, with low to no cohesion.

Engineering Properties

Table 1 presents a comparison of typical properties and commonly used engineering data for granitic soil samples from a variety of Forest Service locations and projects in the western United States. In most cases, the dominant coarse soil type is shown, along with some available data on finer grain soil also found in that geographic area. Because of the local variability which can exist in granitic soils, specific engineering design parameters for large, costly, or sensitive projects should be determined by site specific project testing. However, granitic soils broadly fall into two engineering soils types, and most soils are dominantly coarse with relatively good engineering properties. Thus, many small projects and low standard road construction work, typical of most Forest Service projects, can appropriately be designed and constructed using generalized data as presented herein, based upon soil classification and visual description of the soil.

Other engineering data on western granitic soils, including compressive strength, California Bearing Ratio (CBR), bulk modulus, porosity, permeability, etc., are available from reports by Krank and Watters (1983), Gonsior and Gardner (1971), Hampton et al. (1974), and Remboldt (1990). Yapa et al. (1992) have reviewed data on granitics worldwide and discuss behavior of granitic soils under high loading conditions, including effects of particle breakage and settlement. Granitic soils formed under tropical or humid conditions, such as in Colombia, Hong Kong or southern Japan are generally finer and have higher plasticity than those soils considered in this paper.

Finally, in-situ residual and saprolite soils have considerably better strength and erosional resistance properties than do the same soils once excavated and remolded. In-situ soil typically has some original rock

TABLE 1. Typical Decomposed Granitic Soils Properties

Site (Location)	# of Data	USC Class.	% Minus 200 Sieve	Dry Density Range T-99 pcf	PI AASHTO T-90	LL AASHTO T-89	SE AASHTO T-176	c'[1] psi	Phi'[1] deg.
Sly Ck. Plumas NF-W	3	SM	25-44	81-93	NP	-	22-58	0-3	32-38
Notson TS Plumas NF-E	2	SM	12-13	118-119	NP	-	45-55	1-3	35-41
Elephant Plumas NF-E	5	SM	13-28	112-121	NP	-	18-58	-	-
Hartman Plumas NF-W	1	SM	26	106	NP	-	32	2-7	36-40
Grizzly	21	SM	10-35	81-110	NP	-	-	0	40
Hydro PNF-M	11	SM	4-30	115-125	NP	-	-	0	44
French Ck Plumas NF-W	5	SM	28-41	107-117	NP	-	13-32	2-8	28-36
Buckhorn- 299- STNF	2	SM	17-20	115-119	NP	-	28-33	2-5	34-35
Buckhorn-	4	SM	13-20	-	NP	-	27-36	3-7	33-34
299- CALT	1	ML-CL	60	-	12	35	-	-	-
L.N. Fork	2	SM	7-11	116-124	NP	-	-	-	-
Klamath NF	1	SM-SC	24	-	8	29	-	-	-
Crapo Land Klamath NF	3	SM	19-28	-	NP	-	-	-	-
Bullards B Tahoe NF-W	3	SM	26-28	-	0-5	34-43	26-33	1	36-38
Bass Lake Sierra NF-W	3	SM	27-39	104-115	NP-9	26-43	17-24	-	-
Shaver Sierra NF-M	8	SM	11-27	111-122+	NP	28-35	26-57	-	-
Auberry Sierra NF-W	10	SM-SC	12-37	122-133+	NP-8	28-32	16-40	-	-
Batholith Idaho*	50+	SM?	6-12 Mean	106-124	-	-	-	0-6	26-44
S.Fk.Salmon Idaho	27	SM	10-33	119-136 NP-3	- -	-	-		
S.Fk.Salmon 11 Idaho	SC-CL	32-52	115-129	1-15	-	-	-	-	
Bass Lake Sierra NF-W	2	ML-MH	52-63	90	9	64	9	-	-
Musick Sierra NF-W	3	ML-CL	55-68	105-113+	10-19	39-56	6-12	-	-
French Ck	2	SM-ML	49-51	104-105	9	37-42	10-12	6	27
Plumas NF-W	5	SM-ML	31-53	-	5-9	35-39	7-17	-	-
	1	SC	43	113	14	35	11	-	-

PNF = Plumas Nat. Forest, Quincy, CA. STNF = Shasta-Trinity NF, Redding, CA.
SNF = Sierra Nat. Forest, Fresno, CA. W, M, E = West, Mid, or East Sierras
1/ Typically Consolidated-Undrained Tests; + = T-180 Max. Dry Density
* Data originally from Hampton, Megahan & Clayton (1974)

structure which gives the soil a higher effective cohesion and unconfined compressive strength. In-place material decomposition also generally decreases with depth so, in relatively shallow soils, competent non-erosive soil/rock is reached within a few feet to tens of feet. Most soil classification test data is based upon remolded samples, so some of the characteristics of the original soil are lost. Some of the most dramatic and severe erosion problems have occurred in fill areas where granitic soil had been imported and partially compacted. The depth of erosion is typically the bottom of the fill.

NATURAL MASS INSTABILITY

Though surface erosion and typical road construction activities are the main focus of this paper, mass instability in granitic soils periodically exists and may require engineering solutions or land management decisions. Mass instability or landslides in granitics is generally not a pervasive problem, except for some known problem areas, and should be evaluated on an area-by-area or case-by-case basis. Instability "problems" appear to be a combination of factors, often including fine-grained (SC or ML) soils, deep colluvial deposits, geomorphic history, disturbed sites and roads, steep slopes, high intensity rainfall or rapid snowmelt events, and "socially" sensitive watersheds.

Because of the frictional nature of the soil, the most common type of instability is the shallow debris slide. They are common in steep topography where shallow colluvial soil deposits exist over bedrock swales which can become saturated. Debris slides are often associated with areas of fires, logging, road construction or other disturbance and high intensity rainfall. The "infamy" of slide problems in areas such as the Mt. Ashland watershed in Oregon or the Lake Tahoe Basin in California/Nevada does not appear to be as a result of uncommonly poor granitic soils, but rather typical granitic soil behavior combined with sensitive local watershed and high water quality values.

Deep-seated rotational or rotational-translational features are uncommon in western granitics, but have been observed in the deeply incised canyons such as along the American River in the Sierra Nevada foothills. Small localized rotational slide features are also occasionally seen in deeply weathered residual soils. The depth of sliding is often more shallow than initial observation may suggest, where the depth of sliding is controlled by a shallow residual soil layer over less weathered, stable saprolite.

Debris slide problems are often best managed by potential slide recognition and avoidance of slide prone areas. Where necessary debris slide catchment basins can be constructed, slide diversion or deflection dikes or structures can be placed, etc. For rotational slides, conventional stabilization or management techniques, such as drainage, buttresses, slide removal or relocation, may be necessary. A good general treatment of slope stability problems, analysis, and management in granitic soils is presented by Gray and Megahan (1981).

ENGINEERING PRACTICES AND GUIDELINES

The following general considerations, guidelines, or observations appear appropriate for engineering design and construction in decomposed granitic soils, particularly for low standard roads.

Cut Slopes

Cut slopes, designed to be stable and to minimize surface erosion, require several considerations and attention to the specific degree of weathering of the local soil (Figure 1). Well-vegetated flat slopes of any height offer the best short- and long-term slope protection. However, high flat slopes, especially in steep terrain, are impractical or impossible. Low cut slopes, to roughly 8-10 feet high, should be cut to a 1 1/4:1 slope (near angle of repose, about 37 degrees), or preferably flatter (1 1/2-2:1 slope) to facilitate vegetal stabilization. With time, many granitic slopes will ravel to the angle of repose slope regardless of the cut slope angle.

Mid-height cuts in coarse granitic soils (saprolite) can be near vertical (1/4:1) in the western Sierra Nevada, since most slopes will stand near vertical (excluding discontinuities and seepage) to roughly 10-20 feet given their in-place effective cohesion (Photo 1). The steep slope minimizes the area of exposure to surface erosion, as well as minimizing the cut height in steep terrain. Experiences reported by researchers like Megahan (in this Proceedings) and Prellwitz (USFS Forestry Sciences Lab., Missoula MT, pers. com.) in the Idaho Batholith with vertical cut slopes have been poor, perhaps because of the influence of that area's moisture and frost conditions.

High cut slope designs should be based upon stability

Figure 1. Ideal cut slopes in decomposed granite.

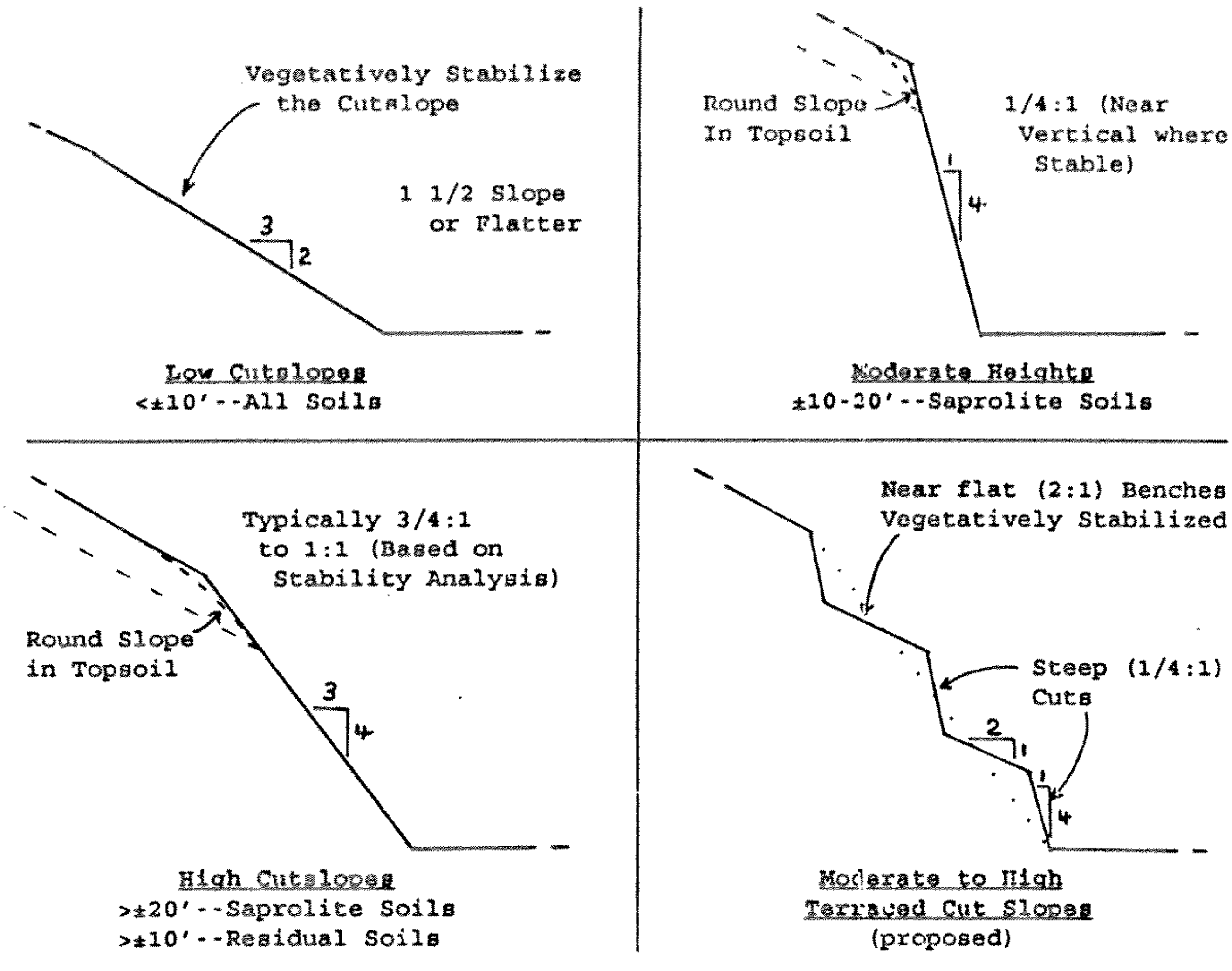
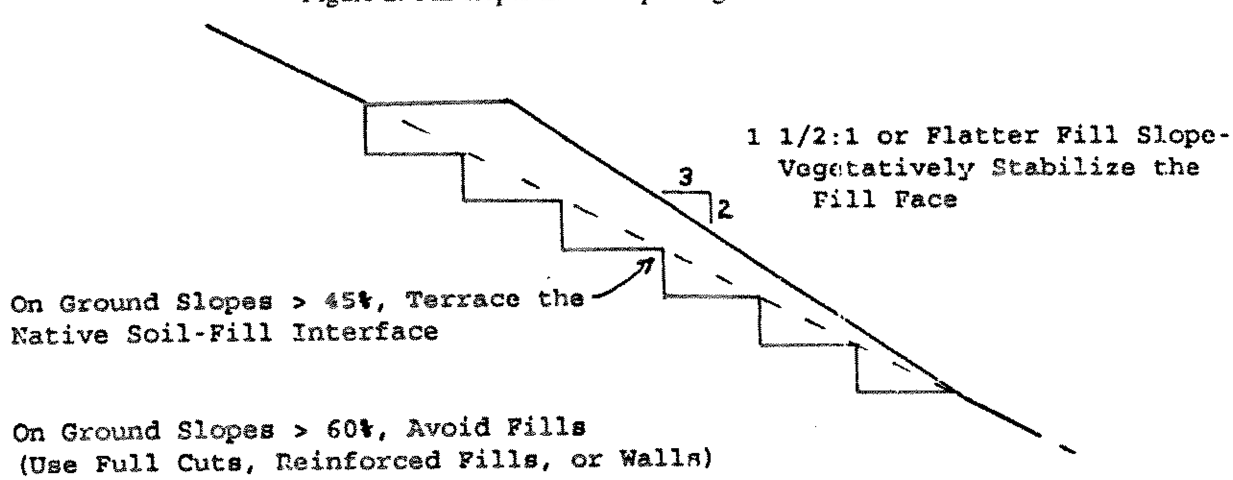


Figure 2. Fill slopes in decomposed granite.



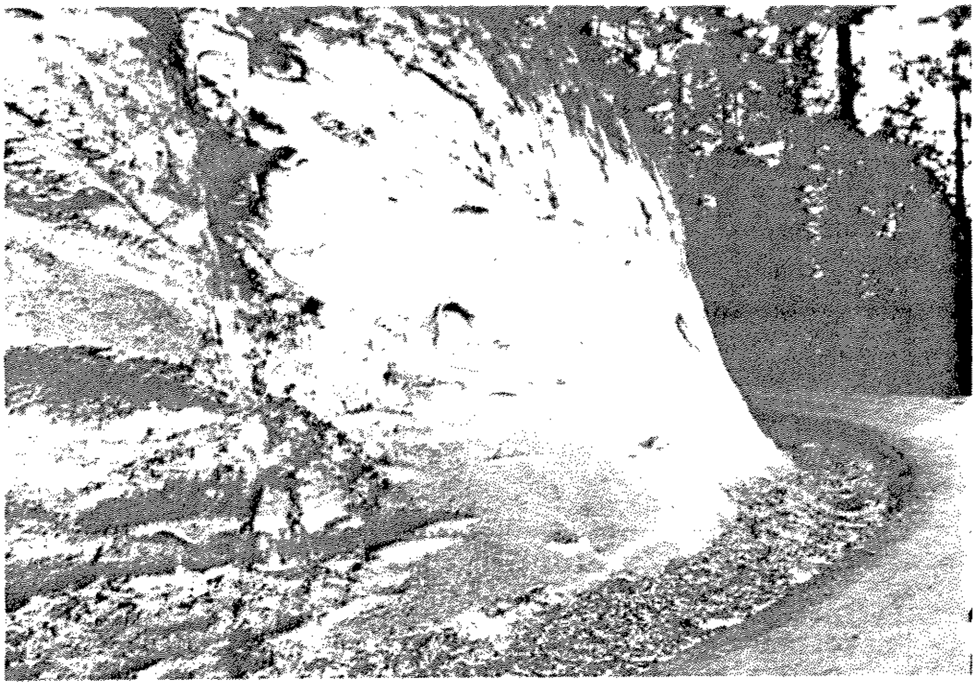


Photo 1. Near vertical cut in decomposed granite.

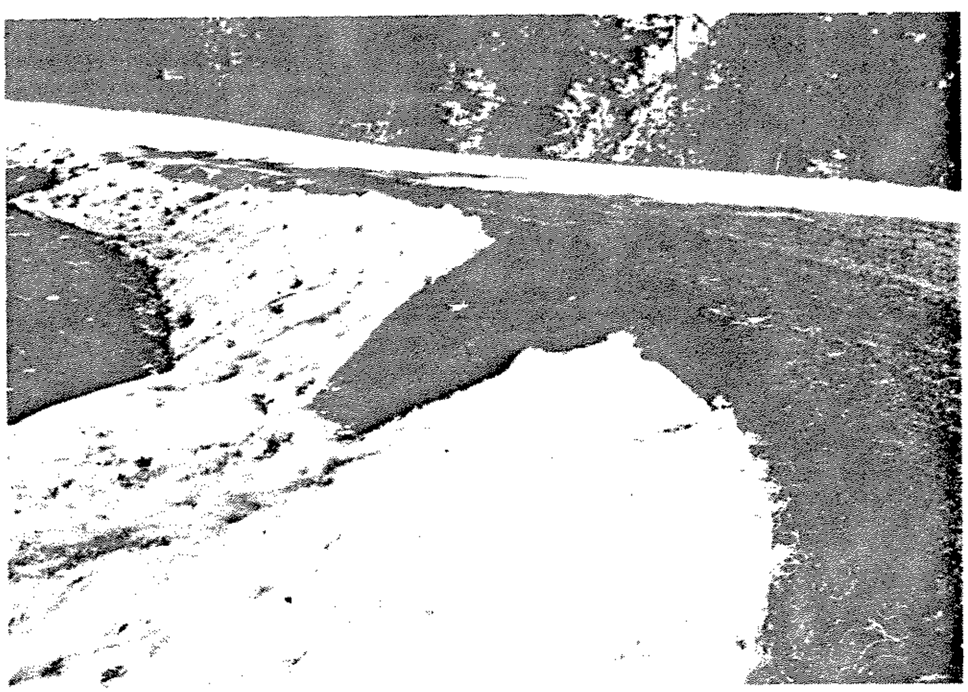


Photo 2. Fill slope with erosion netting (and local failure area).

analysis. In high cuts and mid-to-high cuts in very weathered, residual granitic soil, a 3/4-1:1 slope is most commonly used, but will be subject to moderate erosion and ravel. Table 2 presents stable cut slope height information based upon classic slope stability analysis and typical coarse granitic soil (saprolite) strength parameters. All natural cut slope heights and slope angles should be chosen based upon a combination of analysis, site conditions, and local experience. Duncan and Buchignani (1975) offer a useful method of preparing slope stability charts using local field data from stable and unstable slopes.

Other options to maximize slope stability and minimize erosion include compound slopes where the lower portion of the slope in less weathered soil is steep and the top of the cut in more weathered soil is relatively flat and vegetatively stabilized. Also terraced cuts with an overall 3/4-1:1 slope, using several foot wide, gently sloped and vegetated benches with several foot high vertical steps appear promising. Serrated cuts with small 1-2 foot wide benches appear to ravel significantly and thus preclude stabilization.

Fill Slopes

Embankment fills constructed with remolded material must be placed on a slope flatter than the angle of repose of the material, and commonly are built with a 1 1/2:1 face slope. Controlled compaction helps insure overall stability. However, the typically foot thick zone of loose fill slope face material dictates a 1 1/2:1 or flatter slope and need for surface erosion control measures. Side cast material achieves an angle of repose slope with a Factor of Safety of 1.0, leaving no margin of stability for effects of water or vibration. Thus sidecast slopes should not be used on large fills or on fills adjacent to sensitive areas. On steep slopes, over about 45 percent, the natural ground slope should be terraced at the contact of the fill to prevent a "sliver fill" failure (Figure 2). On slopes steeper than 60 percent, fills should be avoided because of the long, thin fill slope distance or inability to ever "catch" the natural slope.

Fill faces are highly erosive. As a result, concentrated water must be kept off them or conveyed over them in stabilized channels or conduits. Grass seed and mulch, applied at a rate of at least 4000 pounds per acre of straw with netting or crimping, have been generally effective for erosion control. Netting or erosion control matting must be well-anchored and have an intimate contact to the slope (Photo 2) to prevent erosion under the matting. Large fill slopes should incorporate other erosion control measures in addition to seeding and mulching. The fill slope should be broken up with use of vegetated benches or terraces/layers of brush, slash or other vegetation at roughly a 15 to 20 foot vertical spacing on the fill slope face.

Rock armoring of low fills, using 4-6 inch minus graded rock or small riprap, from the outside edge of the roadway to the toe of fill has been very effective to prevent fill erosion. Placement of construction slash on the fill face and in windrows at the toe of fill slopes has also proven very effective to trap sediment moving off the fill slope (Hartsog and Gonsior, 1973).

In steep terrain, use of reinforced fills with a stabilized 1 1/4:1 or 1:1 face slope is an alternative to conventional fills. Cost effective retaining structures may also be built as needed, using earth reinforcement concepts, subsurface drainage as needed, and native decomposed granitic soil for backfill material (Keller, 1990). Confinement of the granitic soils with products such an GEOWEB® or other cellular confinement grids can produce desirable composite structures, such as retaining walls or a surface for low water crossings.

Earthwork Shrink/Swell

Shrink/swell factors for earthwork in granitic soils vary depending on the depth of earthwork and particularly the degree of decomposition of the soil. Weathered rock and soil with "bulk" specific gravities over 2.35 (Grade IV weathering) (Krank and Watters, 1983) will likely have very little shrinkage or a net swell of 5 - 15 percent (fresh quarry rock may have a swell of up to 25 percent). Typically coarse granitic soil (Grade V saprolite) will likely have a net shrink in the range of 5 - 15 percent. Very weathered residual soils (Grade VI) with "bulk" specific gravities less than 2.0 will likely have a net shrink of 15 - 30 percent, particularly if they are topsoils which contain some percentage of organic matter. Additional losses may occur during materials moving and clearing of vegetation.

A higher degree of compaction specified for the earthwork will cause more shrinkage. Also shrink/swell factors are very sensitive to in-place densities, (a function of degree of weathering),

Table 2. Cut slope recommendations. (Appropriate for most in-place coarse granitic (saprolite) soils, assuming no seepage or discontinuities.)

These recommendations are based on the following drained soil parameters:

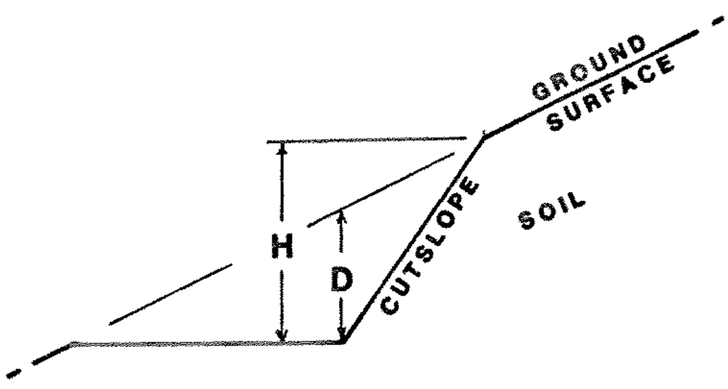
Phi = 40° c = 125 pcf. Moist Density = 125 pcf.

A ground water table significantly below the ground surface is assumed, a sliding wedge method of analysis is used, and the recommended cutslope heights reflect a Factor of Safety of 1.2.

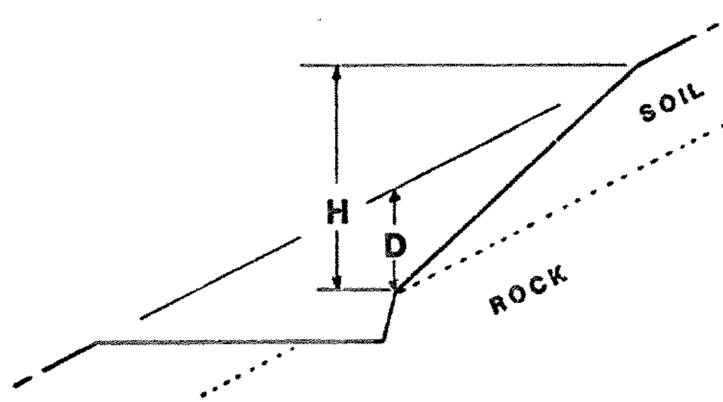
Groundslope %	Cutslope Ratio	Depth (D)[1] (ft)	Height (H)[2] (ft)
70%	.50:1	6'	10'[3]
70%	.75:1	12'	26'
70%	1:1	14'	47'
70%	1.25:1	20'	150'
60%	.50:1	7'	10'
60%	.75:1	15'	27'
60%	1:1	21'	52'
50%	.50:1	7'	9'
50%	.75:1	17'	27'
50%	1:1	29'	58'

Example: On a 60% (31°) groundslope, a .75:1 (53°) cutslope should be used where the soil depth overlying bedrock is found to be between 7 and 15 feet. Deeper cuts in soil should be placed on a slope of 1:1 or less.

1. Depth (D) is the vertical depth below the ground surface. This depth pertains only to material whose properties are described above. In many cases the maximum depth considered will be the depth to bedrock (see figures below).
2. Height (H) is the vertical height from the corresponding depth to the elevation where the cut daylights on the natural slope.
3. Cutslopes steeper and higher than indicated may be possible in local areas of in-place coarse soils.



FULL CUT IN SOIL



CUT INTO SOIL AND ROCK

particularly for materials in the transition condition between "weathered rock" and "soil". During the weathering process expansion or solution loss can amount to as much as 40 percent. Careful characterization of the material is needed and on large earthwork projects a comparison of in-place densities and specified compaction (T-99 or T-180) densities should be made, or an earthwork test section may be desirable. Most low standard road construction projects in "decomposed granite" soils use an earthwork factor in the range of 15 to 25 percent shrink.

Road Surface Drainage

Control of surface water is critical! Every effort needs to be made to disperse water as often as possible, to avoid concentration of water, and to reduce the quantity and velocity of water.

- Minimize road grades to less than 15 percent. Steeper grades are very difficult to drain properly. In the tradeoff of longer roads versus steeper roads, the longer road in granitics appears generally desirable since needed drainage can more likely be accomplished.

- Roll grades and use frequently spaced cross-drains, particularly rolling dips, typically on a 50-150 foot spacing, depending on grade. On grades over 10 percent rolling dips are difficult to use and so water bars are preferred. Megahan (1977) has presented useful criteria for cross drain spacing as a function of slope, soil type and topography.

- Outsloped roads are generally preferred to disperse water and minimize cost in non-critical areas. However, adjacent fills or natural slopes must be naturally stable or well- stabilized to endure the sheeting water from the road surface. Where interim berms (until stabilization is achieved) or local berms are needed across fills, use stabilized ditches or downdrains to carry the water to stable ground.

- Inslope roads in areas of high and unstable fills. Also, insloping offers the best ultimate water control if done in conjunction with other relatively costly measures including stabilized inside ditches, frequent cross-drains (culverts or dips), and energy dissipators. Insloping is safest on steep road grades with winter use. Haupt, Rickard, and Finn (1963) have documented the tradeoffs of insloping versus outsloping during intense storm events.

- Armor road surfaces with aggregate, particularly on grades over 5 percent (Photo 3). For erosion protection, a 4-inch minimum thickness of surface course aggregate is commonly effective. Aggregate surfacing of roadway approaches to stream or drainage crossings is particularly useful to prevent the direct movement of road surface material into the watercourse.

- Armor ditches with slopes over 5 percent with rock, and use riprap, energy dissipators, or catch basins at ditch/pipe outlets (Photo 4), as well as choosing naturally stable locations, to minimize local erosion. Use of drop inlets for culvert cross-drains helps control the ditchline elevation and minimizes downcutting (Photo 5).

Various publications outline road drainage and other measures effective in reducing erosion impacts from roads, including an excellent discussion by Megahan (1977) and others, including Packer and Christensen (1964), Hartsog and Gonsior (1973), and Keller et al. (1981).

Subsurface Drainage

Underdrains, french drains, filter blankets and other subsurface drainage measures should be used as necessary to control subsurface moisture and minimize frost damage. Since most granitic soils are well graded, even when fine-grained, filter design criteria is relatively easy to satisfy, using either graded sand and gravel or geotextiles (preferably woven or needlepunch non-woven geotextiles). Geocomposite drains wrapped in geotextiles have proven to be a cost-effective alternative to conventional graded aggregate underdrains (Stuart, Inouye, and McKean, 1991).

Satisfying filter criteria is very important in erosive granitic soils, particularly fine grained silty soils, to insure the function of the structure and prevent erosion loss. A filter, either graded aggregate or geotextile, must prevent the migration of soil particles between materials of different grain size due to water movement, while at the same time prevent pore

Photo 3. Aggregate surfaced road with rolling dip (background).

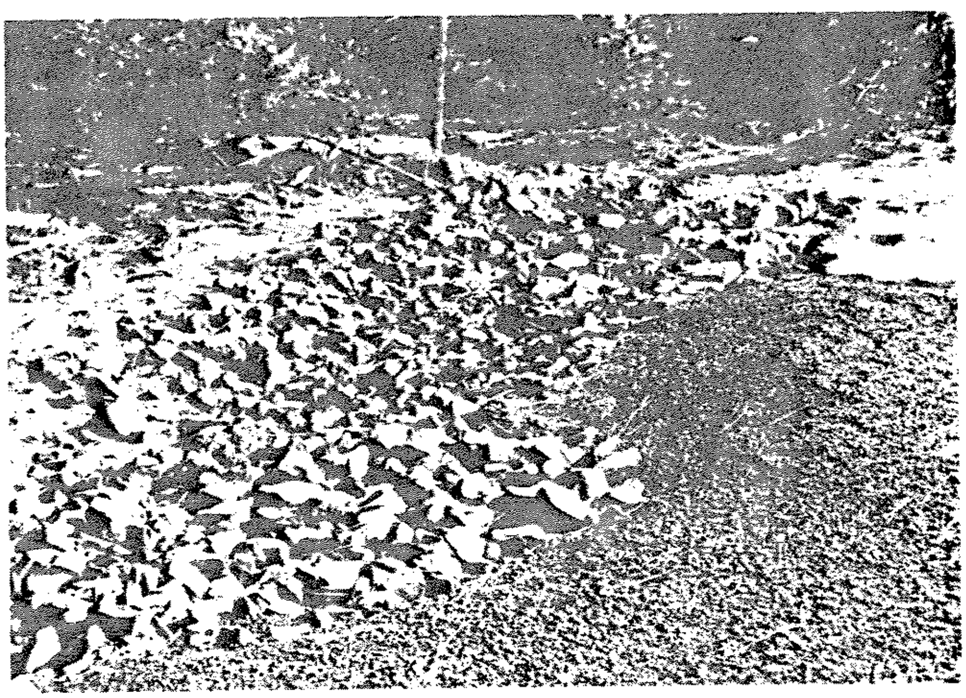


Photo 4. Pit run riprap used for ditch protection and energy dissipation.

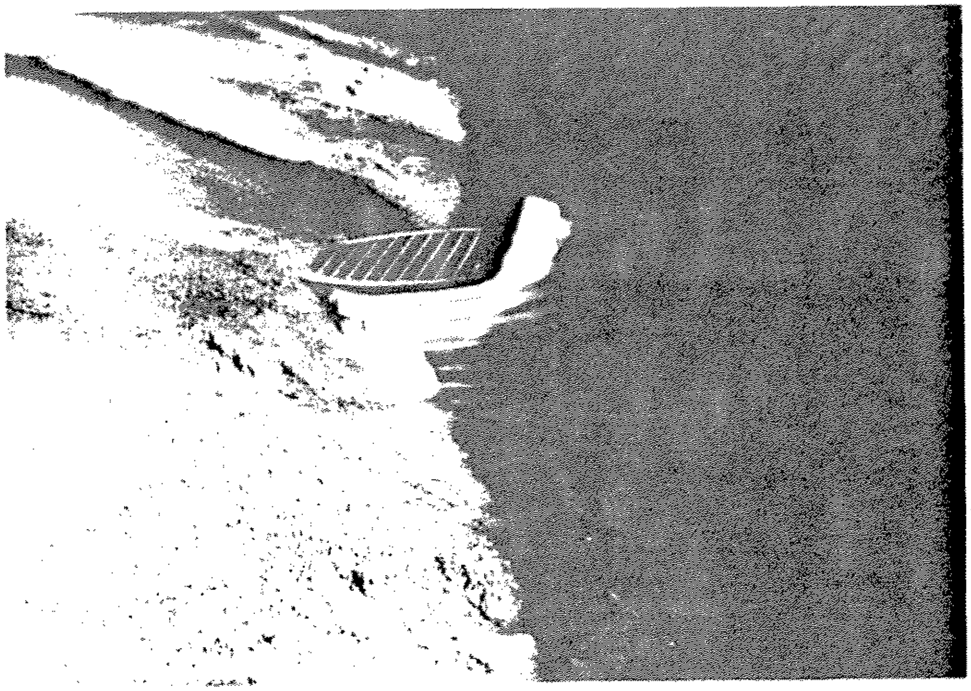


Photo 5. Culvert drop inlet to control grade of ditchline.

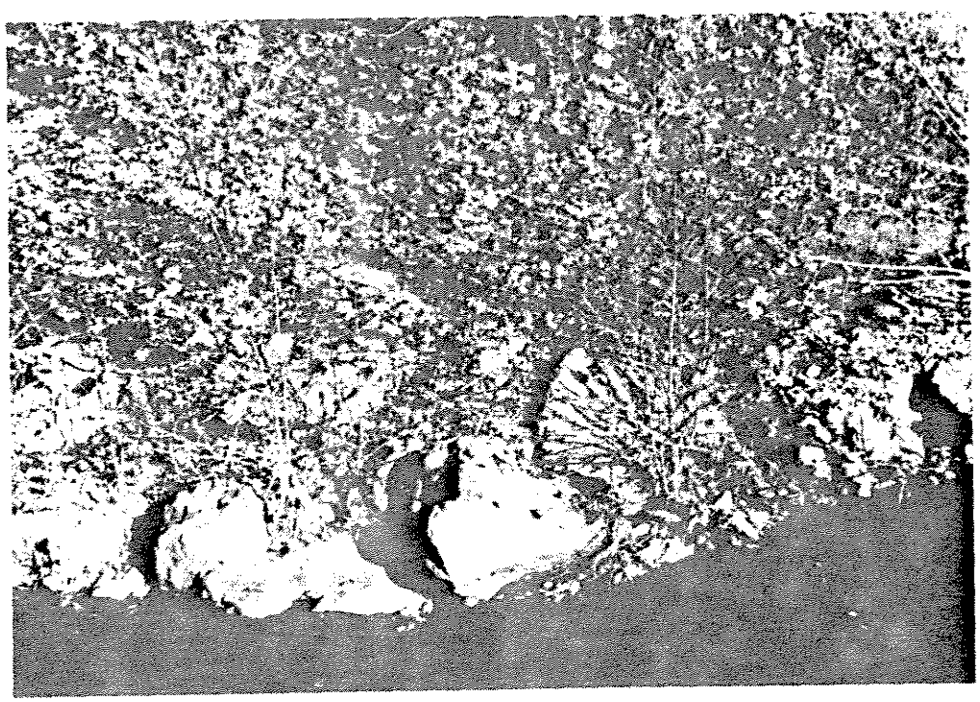


Photo. 6. Biotechnical measures - riprap interplanted with willows.

pressure buildup and allow free drainage of the soil.

Filter criteria is commonly applied to the design of subsurface drainage but should also be considered behind riprap and rock armoring to insure that the native soil does not move when subject to the movement of water. Classic graded material filter design criteria are available in soil mechanics texts such as Terzaghi and Peck (1968), while filtration design with geotextiles is presented by Koerner (1986). Figure 3 presents filter design information developed for a range of typical granitic soils.

In-situ permeabilities in granitic soils vary considerably, particularly as a function of degree of weathering, but data obtained from projects in granitic soils suggests a typical range of values. Highest permeabilities are seen in saprolites (Grade IV & V) with values ranging from $1x10^{-3}$ to $1x10^{-5}$ centimeters per second. Lower permeabilities are typical in more weathered residual soils (Grade VI), with values lower than $1x10^{-5}$ cm/sec. The most frequent granitic soil permeability observed has been around 10^{-4} cm/sec.

Culverts

Culvert installations in granitic soils can be problematic and have had a high incidence of failure, especially for +24-inch pipes, due to erosion and piping. Flat pipes can plug easily with sediment, while pipes installed on gradients over 15 percent are very susceptible to piping. Culverts in natural drainages should be placed at the natural stream gradient, with the inlet and outlet areas protected with headwalls, riprap, etc. Imported clayey soil or gravelly material are both preferable to granitic soil as a bedding material. Alternatively, use of seepage collars or cutoff walls, along with careful compaction, will reduce the risk of piping failure. Rubber gaskets should be used at all joints to prevent leakage. Compaction should normally be specified and achieved at 90-95 percent of the AASHTO (American Assoc. of State Highway and Transportation Officials) standard T-99 maximum density.

Cross drain pipes should be sized for appropriate short duration, high-intensity rainfall events (5 to 10 minute duration, 20 year events). Natural drainages are typically designed for their appropriate time of concentration, at least a 20 year recurrence interval, and corresponding rainfall intensity or other appropriate storm event data. All culverts should also be sized considering channel debris and sediment load.

Culverts installed in flat granitic terrain often contribute to headcutting because of excavation of a pipe inlet basin below natural ground or stream channel level and subsequent headward migration and erosion. Either pipes should be carefully placed at natural grade or inlet/outlet basins should be protected (i.e. with riprap) to prevent headcutting and scour.

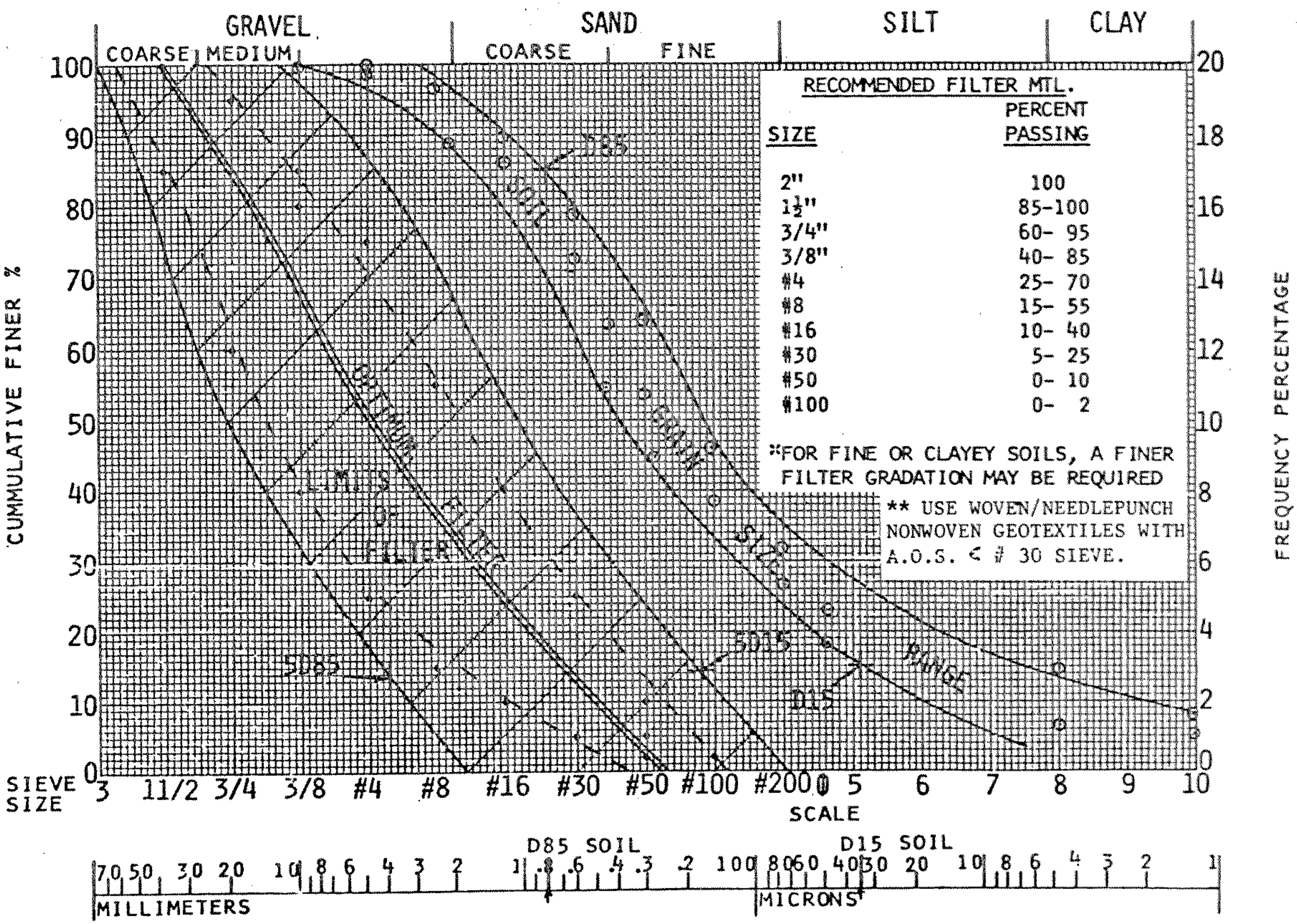
Culverts require maintenance to keep them functional. Ideally use of culverts in granitics on low standard roads should be minimized. Use of armored rolling dips, waterbars, outsloping, and armored fords or low-water crossings can eliminate the need for culverts and reduce costs. Armored fords in lieu of culverts are particularly useful for crossing debris slide or debris torrent prone drainages in steep terrain to pass debris without plugging the pipe.

Compaction

Compaction on granitic soils is important to achieve maximum strength, lower moisture contents, reduce frost susceptibility, and to maximize resistance to erosion. Compaction standards for various projects typically vary from 90 percent of the maximum AASHTO T-99 density to 95 percent of AASHTO T-180. Compaction is generally not difficult at a T-99 standard but can be problematic at the T-180 standard because of the increased compactive effort needed. In addition, many low standard road contractors are not familiar with achieving the increased compaction. Granitic soils' compaction curves are typically not tight, but compaction does require moisture control and appropriate compactive effort, especially in finer silty soils.

Whackers and a variety of rubber tire, steel wheel and sheepsfoot compactors have been used successfully to achieve all levels of specified compaction. High native soil moisture contents and moisture sensitive (tendency to liquify) fine granitic soils can make compaction difficult. As a result, static compactors, without vibration, and low-of-optimum moisture content often produce the best results.

Figure 3. Particle size analysis - Filter Design - typical weathered granitic soils* (U.S. Forest Service, Materials Investigation Section.)



Paving

Asphalt concrete pavements are routinely placed on granitic soils. Typical coarse granitic soils (SM) are structurally sound, with California R-Values over 60 (CBR > 15). Thus, typical structural sections for moderate to high traffic volume forest roads use 2 to 3 inches of asphalt concrete over 4 to 6 inches of a base course aggregate. Full depth pavement over native granitic soils has been used successfully for moderate traffic volume roads, and it can be the most cost effective design. However, local soil variability necessitates careful sampling and testing for a pavement design without base aggregate.

Full-depth Open Graded Pavement on granitic soils can be structurally adequate, but can lead to shoulder erosion from piping through the open graded aggregate. Either a protective mat is needed over the native soil or enough shoulder width is needed, with coarse backfill, to prevent piping.

Dust Palliatives

Dust oils and lignin sulfonate have generally been the most successful and cost effective dust palliative treatments on granitic soils. Water and magnesium chloride are also used successfully, but are cost-effective only for very low haul volumes (less than a couple million board feet (MMBF) of log haul volume) because of the frequent applications of water required. For moderate haul volumes, road mixing of oils and lignins into granitic soils and aggregate has been used successfully (Padgett, 1981). Effective application rates of 0.5 to 1.0 gallon per square yard of lignin per 10 MMBF of timber hauled have been achieved once an initial residual quantity of lignin sulfonate had built up (Keller and Ganske, 1984). Oils offers the best long term dust palliation because they are not water soluble and will continue to build up with multiple applications.

Aggregate/Borrow Material

Decomposed granitic soil deposits have often been used for select borrow material because of their good materials engineering properties, extensive size of deposits, and relative ease of excavation. Deposits often contain a small percentage of large granite boulders (corestones), but these can be rejected or used as large riprap. As discussed herein, the borrow material will be highly erosive and will require protection if not confined.

Hard, fresh granitic rock has periodically been used to produce riprap or crushed aggregate, particularly where other suitable quarry rock is unavailable or excessively expensive. Successful quarries exist in the Sierras and the Idaho Batholith, but they typically produce a marginal quality aggregate (see Table 3). Fresh granitic rock and tunnelmuck have at best marginal L.A Rattler Abrasion Test losses of 35-50 percent, so degradation of aggregate on the road surface is common, and it is undesirable as a concrete aggregate. Local intrusive material (i.e. dikes or sills) in granitic rock have produced a desirable aggregate where quantities were sufficient.

Granite rock quarries have also been developed to produce large riprap in the northern Sierra Nevada. These quarries have produced a high percentage of reject fines due to variable weathering common in granitic rock. Careful examination of rock quality, jointing and weathering patterns, combined with subsurface investigation, is recommended for potential quarries in granitics. Also the coarse orthogonal jointing, combined with surface exfoliation joints, can lead to production of "oversize" rock blocks during blasting.

Maintenance Practices

Road maintenance practices are very important to the function of road drainage to minimize erosion. Poor practices can also accelerate erosion. Culvert pipe inlets must be kept free of debris to prevent clogging. The slope of insloped/outsloped roads must be graded periodically to function as designed. Rolling dips or waterbars need periodic reshaping after traffic. Maintenance offers the opportunity to correct design mistakes, add needed drainage detail, and stop erosion problems while they are small (the "ounce of prevention"). Maintenance inspections during rainstorms are very desirable to observe the performance of drainage measures and to visually appreciate the erosive forces of water.

Poor maintenance activities include the common practice of leaving an outside berm on a road designed to outslope, thus concentrating water in unspecified locations. Cut bank sluff or material cleaned out of ditches and culvert inlets is often sidecast at the closest available fillslope. This material retards slope stabilization and may move off-site. Material should be moved to a location distant from water courses where it can be vegetatively stabilized. Excessive brushing or

Table 3. Test Data--Granitic Rock Used for Aggregate

Site (Location)	LA Abrasion Loss(%) AASHTO T-96*	Durability Index AASHTO T-210	Specific Gravity AASHTO T-85
Powerhouse 8 Tunnelmuck, SNF	38 (Grad B)	-	2.69
Blue Canyon Quarry, SNF	48.6 (Grad B)	85 (Coarse)	2.74
Providence Quarry Surface, SNF	69 (Grad A)	80 (Coarse)	-
Kerckhoff 2 Tunnelmuck, SNF	50.7 (Grad A)	79 (Fine)	2.74
Strawberry Tunnelmuck, SNF	51 (Grad C)	-	-
Ross Crossing Quarry, SNF	42,40 (Grad A)	-	2.70
Tobin Tunnelmuck, PNF	36 (Grad B)	-	2.81
FOREST SERVICE SPECIFICATIONS	**40 MAX**	**35 MIN**	

* = 500 revolutions. SNF = Sierra Nat. Forest, Fresno, CA. PNF = Plumas Nat. Forest, Quincy, CA.

thinning beyond the ditchline may not improve site distance and is usually counterproductive to slope stabilization. Undercutting of the cut slope should also be avoided.

Road closure, or obliteration for permanent closure, is desirable to minimize recurrent road maintenance costs by reducing the number of miles of roads needing maintenance. Vegetal stabilization measures on the road surface, as well as on the cuts and fills, can be implemented and allowed to grow. If culverts are not removed from the road system, they may still require maintenance, whether the road is open or closed.

Vegetal Erosion Control Measures

Many erosion control measures using a variety of vegetative techniques and mulches have proven to work effectively in granitic soils (Kay, 1974, 1978). Erosion control measures should be applied soon after disturbance since erosion rates in disturbed areas are greatest just after construction. Interim winter measures may be needed in multiple year projects. At a minimum, seeding and mulching with at least 2 tons per acre of straw, or using thick erosion control netting, is recommended. Conventional hydromulching has been generally inadequate for granitic soils.

In addition to grasses, woody plants (i.e., brush and trees, such as ponderosa pine) should be incorporated into erosion control prescriptions. They will provide long-term protection after the grasses die, as well as deep-rooted stabilization (Megahan, 1974). Biotechnical measures combine the use of traditional "hard" structures for initial protection (riprap, gabions, buttresses, etc.) with vegetation for added root strength and long-term protection. This combination is perhaps "the best of both worlds" (Photo 6). Gray and Leiser (1982) present an excellent reference on biotechnical slope protection and erosion control measures.

CONCLUSIONS

In conclusion, much information has been gained about design and construction in granitic soils. Many design and roadway drainage measures have been developed to control surface water and minimize erosion in granitic soils. Their use can be very effective to reduce erosion. Despite knowledge of these measures, however, erosion will typically continue to be a problem in granitic soils because the soils are unforgiving and construction practices inexact.

Measures to minimize erosion are well-documented. Most important is to use these known measures in construction and erosion control practices, be willing to spend the money needed to implement these measures, pay attention to the details of surface drainage, program for frequent maintenance, and review projects under storm conditions to assess effectiveness of the measures and needed changes. Finally, apply the many known effective biotechnical and erosion control techniques, particularly combining the use of "hard" measures with vegetal stabilization.

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EVOLUTION OF GRANITIC POLICY ON THE UMPQUA NATIONAL FOREST

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ABSTRACT

Although there are only 25,000 acres of granitic terrain on the Umpqua Nationa Forest, this terrain is recognized as the most sensitive area on the forest in terms of erosional processes. Concern for managing granitic landscapes has evolved as a result of several major storm events that resulted in significant watershed damage. The first management activities (i.e., road building, timber harvest) occurred 5-10 years prior to an intense storm in 1964 and were consistent with existing practices of the times. As a result of this storm, noticeable watershed damage led to an investigation of the Callahan Timber Sale. This investigation identified several hundred erosional features created by the event which were associated with management. As a follow-up, the forest developed a number of recommendations that were designed to minimize future impacts. A number of additional management activities occurred on granitic terrain which incorporated the new recommendations, where possible. A 60-year event in 1974 resulted in 2 additional granitic watersheds impacted by storms. Studies in 1974 and 1978 led to the recognition that the majority of erosional problems on the the granitics were on slopes in excess of 60%. Establishment of a management policy for granitics was adopted in 1979 and has resulted in the Standard for the present Forest Plan. This standard states that granitic lands on slopes in excess of 60% will be classified as unsuitable.

INTRODUCTION

The Umpqua National Forest, located in southwestern Oregon, is responsible for managing about a million acres. It has approximately 25,000 acres of ground mapped as granitics, all on the Tiller Ranger District. Geologically, the area is considered a part of the Klamath Mountain physiographic province. About 15,000 acres were mapped as granitic terrain exceeding 60% slopes in an Order 3 soil survey. All the granitic terrain drains into the South Umpqua River Basin. The South Umpqua River is recognized for its suitability as Wild and Scenic River Status and for its diversity of anadromous fish species.

Early records associated with the first entry by the U.S. Forest Service in 1958 in the granitic terrain show that "the Forest Service sought to minimize damage to private land owners resultant from granitic lands management."

Before the Forest Service entry, private harvest had occurred in the area for 15-20 years. During the original planning process, concerns were identified that suggested the need for more restrictive timber sale contracts, focusing on the need for intensified sale administration. Damage to watershed resources had been noticed by the agency and local residents for some time and records show that correspondence between the Forest and the Washington office had occurred before any Forest Service entry to the area.

HISTORIC STUDIES

The 1964 Storm Evaluation

The December 1964 storm event delivered 16.5" of rain in the area, causing intensive damage in a newly harvested portion of Callahan Creek and Hatchet Creek, tributaries to the South Umpqua River. The Forest initiated a study on the Callahan Timber Sale to assess the damages from this event. The sale harvested 960 acres with a clearcut prescription in a 4000 acre area. A number of fuel practices, logging systems and road construction techniques were evaluated to determine the effects on the watershed.

This study identified three processes that contributed to the loss of soil resources and the resultant sedimentation downstream:

A. "Sheet Erosion" (i.e., debris slides/ avalanches) was mapped on 330 sites, with an estimated loss of material at 15,400 cu.yd. The report also stated that only 5 of these slides were not in or adjacent to a clearcut and noted that 95% of the slides were on slopes over 60%.

B. "Stream Scour" (i.e., debris torrents). A number of the the debris slides initiated in ephemeral draws/swales/headwalls and snowballed into debris torrents as they migrated downslope. These washed a number of newly constructed roads and left an estimated 1.7mmbf in debris jams associated with the channels. The survey estimated that 26,000 cu.yd. were scoured from channels within the units and an additional 22,000 cu.yd. along the way. Approximately 36,400 lineal feet of stream were scoured to bedrock.

C. Gullying. Four principle causes of gullying were identified:
   1. Tractor skid trails - no waterbars
   2. Cable swing trails - no mitigation for erosion
   3. Fire trails - only looked good where canopy remained
   4. Roads - gullying confined to native surface; rocked road held up

The team, composed of foresters and a soil scientist, developed a number of recommendations as a result of the findings. These recommendations focused on three areas:

1. Highlead Logging

- Consider downhill logging to reduce need for roads
- Limit unit to less than 40 acres
- Careful landing location and more landings (no sidecast)
- Layout unit to save residual stand and reproduction
- Minimize use of temporary spurs
- Use skyline where cable swing is necessary
- Avoid contour logging

2. Tractor Logging

- Use in partial cuts and retain 45% crown closure
- Limit tractors to slopes less than 30%
- Use Pre-work Conference to agree to pre-approved skid trails
- Consider one end suspension of log with use of arch/boom

3. Road Construction

- Rock all temporary spurs
- Install functional waterbars
- Reduce runoff of water on large fills
- Do not use inslope without ditch

1974 Storm Evaluation

A January storm in 1974, identified as a 60-year event at the nearest recording station, resulted in significant damage to several tributaries to Callahan Creek by multiple debris slides and debris torrents. Damage included fill failure of a road at the confluence of these tributaries. Although the integrity of the road was lost, the remaining fill section trapped thousands of yards of material and prevented additional scouring of the lower reaches of the channel. In addition, a number of other road-related failures were identified, particularly in association with road drainage features.

The main intent of this 1974 study was to trace the debris torrents back to their source, which turned out to be harvest units clearcut following the original 1965 recommendations. An aerial photo review of adjacent Granite Creek was initiated after finding the relationship to management, and 15 debris slides were identified that post-dated the 1964 review. Of these, 12 were in clearcut headwall areas.

This evaluation was the first direct evidence that clearcuts on granitic headwalls have a high probability of failure. At this point, a correlation was developed between Soil Resource Inventory (SRI) soil types and hazard rating.

After recognizing the additional failures in the 1974 aerial review, it was determined that additional analysis was needed. Multiple debris slides/torrents had scoured out over 2 miles of Granite Creek (a Class 1 stream). The resulting sediment was delivered as far as 5 miles to the South Umpqua River.

It is worth noting that the sale chosen for evaluation employed the 1965 recommendations, including smaller clearcuts (the largest was 22 acres), a reduction in fuels treatment, minimal sidecast construction, and special road design measures.

This study was the first time clear objectives were set that would:

a. Determine sedimentation from 1974 storm
b. Evaluate amount of land where long-term productivity had been impacted
c. Compare erosion and sedimentation rates
d. Identify landscape types and look for patterns of occurrence
e. Identify apparent cause of landslips
f. Develop future management plans for granitic soils

The conclusion reached in this study was that granitic slopes associated with headwalls were the source areas for 90% of the debris slides. This landtype correlates with Soil Resource Inventory (SRI) unit 61 and is highly dissected with headwalls less than 200 feet apart. Units located on slopes less than 60% did not show evidence of failure.

As a result, it was recommended that no timber harvest be allowed on granitic headwalls over 60%, mapped as SRI 61 (note there are mapping problems with Order 3 work). The basis used to support this recommendation was to maintain small root strength.

CURRENT SITUATION

In 1979, new management direction was developed for granitic lands on the Umpqua National Forest. It stated there would be no harvest of granitic lands on slopes in excess of 60%, as identified by the existing SRI or updated field verification. Since then, there have been several efforts to try different techniques in these areas, including updated road construction techniques, silvicultural prescriptions, and alternative logging systems. Unfortunately, little base line information was collected prior to these trials to allow full evaluation of these techniques. In addition, the area has not been subjected to intense storm events in the last decade.

In 1989, the Umpqua National Forest adopted the current Land and Resource Management Plan, which contains specific language relative to the granitics on the forest. Soil Productivity Standards and Guidelines # 8 states:

> "All lands classified as unsuitable due to irreversible soil damage, including all steep (greater than 60% gradient) granitic soils found in SRI mapping units 61, 612, 617, 623, 624, 631, 673 will not have tree cutting or any other ground disturbing activities that likely will increase the risk of mass movements."

Currently, there are indications that additional investigation of the granitic terrain by teams of geotechnical engineers and geologists could be of value in assessing risk and consequences of activities and processes. This new study could result in reclassification of granitic terrain using additional criteria besides slope gradient.

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SEDIMENT TRANSPORT

AND

BIOLOGICAL EFFECTS

FISH RESPONSE TO FINE SEDIMENT DEPOSITION IN THE IDAHO BATHOLITH

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ABSTRACT

The interaction between sediment and fish populations is an area of national research emphasis. Human activities and natural events in watersheds can amplify the transport and deposition of sediment. The published literature illustrates the detrimental effects of increased sediment on fish populations. In this paper we: 1) discuss the unique properties of granitic soils that contribute to their importance to fish; 2) describe existing knowledge of fish response to increased sediment deposition by examining four life-stages (spawning and incubation, summer rearing, overwintering, and adult staging); and 3) illustrate fish response by examining a long-term data set from the South Fork Salmon River, Idaho.

INTRODUCTION

The interaction between sediment and fish populations is an area of national research emphasis. A recent survey of biologists and managers (Marcus et al., 1991) reported that the highest priorities for fisheries research were to improve our understanding of how land use affects sediment delivery to streams and the consequences of that sediment delivery to salmonid survival .

Human-induced activities in watersheds, such as livestock grazing (Chaney et al., 1991), mining (Nelson et al., 1991), realignment of stream channels (Bottom et al., 1985), residential development, and logging and road construction (Megahan et al., 1980), in addition to natural events such as fire (Minshall et al., 1989), can amplify the transport and deposition of fine sediment in streams.

The published literature includes many studies illustrating that increased deposition of fine sediment in streams reduces fish populations. Sedimentation decreases pool depth, alters substrate composition, reduces interstitial space, and causes channel braiding (Beschta and Platts, 1986; Everest et al., 1987; Clifton, 1989; Lisle, 1982; Megahan et al., 1980; Sullivan et al., 1987). However, relationships between sediment and various life-stages of fish are not well understood. Consequently, reliable and quantitative predictors of fish response to increased sediment are not currently available (Everest et al., 1987; Chapman and McLeod, 1987).

In response to this need, the Fisheries and Watershed Research Units at the USDA Forest Service Intermountain Research Station are cooperating with the National Forests and other agencies to create a better understanding of sediment transport and delivery and to evaluate the response of fish populations to sediment. Our goal is to develop tools for quantitative assessment of fish-sediment relationships. We believe this information has application in protecting critical habitats, monitoring management activities, evaluating restoration efforts, and expanding knowledge of the basic biology of species.

We describe existing knowledge of fish response to increased sediment deposition. Where feasible, we confine our remarks to watersheds draining granitic soils. Within Idaho, granitic soils are found within the Idaho batholith, a 41,400 km^2 area of granitic rock. Our objectives are to: 1) describe the unique properties of granitic sand that may contribute to its importance to fish; 2) describe fish response to increased granitic sediment; and 3) examine a long-term data set from the South Fork Salmon River (SFSR) to illustrate fish response.

UNIQUE PROPERTIES OF GRANITICS

Granitic soils are unique and important to fish for several reasons. First, soils in granitic watersheds are typically shallow and highly erodible (Megahan et al., 1980). Second, granitic soils tend to be coarse-textured. Compared to sediment in streams draining other parent materials, for example, batholith sediment has a much larger proportion of fines (less than 4 mm) in the 0.25-2 mm size fraction (Figure 1). Finally, because of its coarse texture, a large percentage moves as bedload (Megahan et al., 1980). Because it moves as bedload, granitic sediment tends to affect the structure of the stream channel. Consequently, sediment deposition can reduce habitat quality for stream dwelling fish populations.

FISH RESPONSE TO GRANITICS

Evaluating fish response to increases in sediment becomes an extremely complex question. Watersheds within the Idaho batholith support a diversity of game and non-game fish species exhibiting a variety of life history patterns. The SFSR, for example, supports the following indigenous anadromous salmonids: steelhead (*Oncorhynchus mykiss*), chinook salmon (*O. tschawytscha*), and sockeye salmon (*O. nerka*). Resident salmonids include westslope cutthroat (*O. clarki*), bull (*Salvelinus confluentas*) and rainbow trout (*O. mykiss*); and mountain whitefish (*Prosopium williamsoni*) (Thurow, 1987).

Each species has several life-history patterns and within each species, different life-stages use different habitats in the stream environment. Steelhead for example, select spawning sites with specific gravel sizes, depths, and velocities. Eggs and alevins incubate in these gravels from spring to summer. After emergence from the gravel, fry rear in shallow waters along the main channel and in side channels. As fry attain a larger size, they begin to select deeper water areas characterized by large substrate and faster water velocities. Juvenile steelhead may rear in tributaries for one to three years. During this freshwater rearing stage, juvenile steelhead typically seek winter cover in interstitial areas beneath large substrates consisting of cobbles and boulders. After rearing in tributaries, they migrate downstream into larger rivers and ultimately to the ocean. Steelhead remain in the salt water environment for one to three years before returning to their natal streams to spawn. Returning adults depend on large pools in fresh waters for staging areas enroute to spawning grounds.

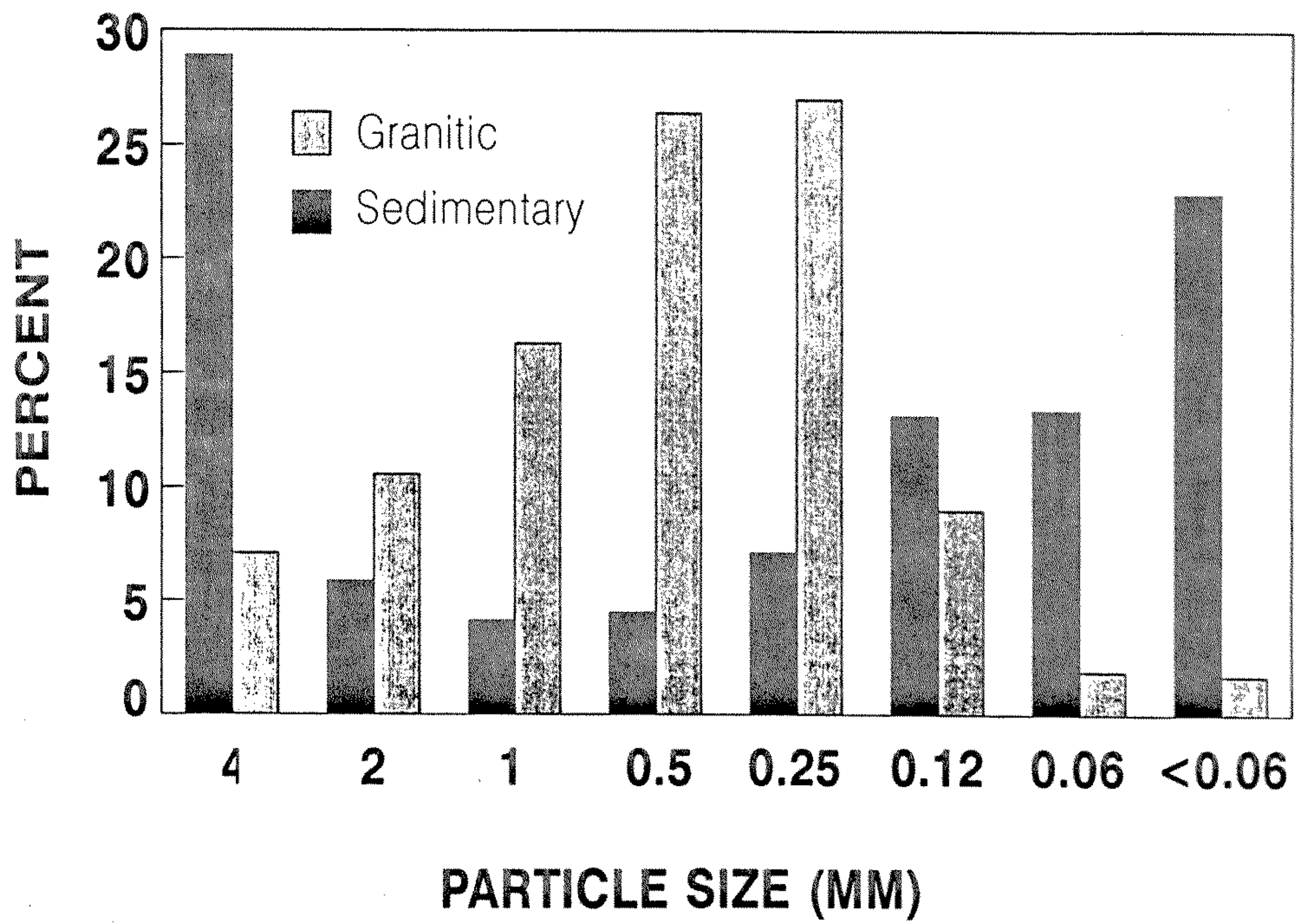
Because the rate of fine sediment transport and deposition varies across instream habitats, each life stage of each species may respond differently to increases in fine sediment. Relatively subtle changes in habitat quality may favor one species over another (Everest et al., 1987). To illustrate fish responses to granitic sediment, we will discuss four different life stages common to all resident and anadromous salmonids: spawning and incubation, juvenile rearing, adult staging, and overwintering.

Spawning and Incubation

High concentrations of fine granitic sediment can reduce reproductive success of spawning salmonids. As fines increase in spawning gravels, egg-to-fry survival rates tend to decline rapidly, especially as concentrations of fines less than 6.4 mm exceed 20% (Stowell et al., 1983). The primary mechanisms of mortality are the reduction of flow through the redd and entrapment of fry in the substrate. As flow is reduced, eggs may be smothered as insufficient aeration occurs and metabolic wastes are no longer removed. Fry that are unable to emerge from gravels will perish as the yolk sac is absorbed.

Certain species appear to be more tolerant of fine sediment than others. Westslope cutthroat exhibited the highest mortality and chinook salmon the lowest in laboratory incubation tests (Irving and Bjornn, 1984). Individual populations may be locally adapted to fines in watersheds with naturally high sediment levels. Van Den Berge and Gross (1989) suggest that populations with smaller eggs are better adapted to spawning in systems with smaller substrate. The influence of sediment on reproductive success will be dependent on local adaptations and on the timing and location of spawning and incubation. Different species and stocks within a species will use a large variety of gravels in a locale (Kondolf, 1988). In most batholith streams, salmonids are spawning and incubating in gravels year-round (Figure 2). Spring-spawning species (steelhead, cutthroat trout, rainbow trout) experience different patterns of sediment transport and deposition than species spawning in late summer

Figure 1. Comparison of the particle size distribution of sediments less than 6.4 mm in streams draining granitic and sedimentary rock. The values on the x axis reflect particles greater than or equal to the centered value and less the value to the left. For example, 0.5 represents particles larger than or equal to 0.5 and less than 1.



(chinook and sockeye salmon) or fall (bull trout, mountain whitefish).

Spawning location is determined by fish size and by behavioral preferences of individual species. Steelhead and chinook salmon of similar size may spawn in identical areas at different times. Large fluvial bull trout, however, may bypass spawning areas in lower reaches of watersheds and spawn in colder, higher elevation reaches. Species such as mountain whitefish and chinook salmon may spawn in groups over relatively large homogeneous areas while westslope cutthroat and bull trout may construct individual redds wherever a small pocket of suitable size gravel has been sorted. At the location fish select to spawn and incubate, hydrological factors will determine the rate of sediment deposition.

Salmonids are not passive spawners (Everest et al., 1987) and they may mitigate some effects of fines by loosening the gravel and displacing fines during redd construction. The location of egg deposition or the "egg pocket" may contain fewer fines than other locations within the redd (Figure 3). The redd environment is unique morphologically and movement of water through it aerates the eggs and removes metabolic wastes (Coble, 1961).

Although salmonid spawning results in dispersal of fines during redd construction (Thurow and King, 1991), it is not known if there is a threshold concentration of sediment beyond which fish are no longer able to remove fines in the egg pocket. In cases where sediment completely fills interstitial areas or creates a layer of sediment blanketing gravels, fish may not mitigate the effects of fines. Secondly, although fines may be reduced during spawning, it is not known if the egg pocket accumulates fines during incubation. Measurements of intrusion rates of fines suggest that, where sediment sources exist, fine sediments rapidly accumulate in free interstitial areas (Thurow and King, 1991). Thurow and King (unpublished) observed accumulation of fines in "clean" gravel even during base flow periods. These observations suggest that fines may accumulate rapidly unless the morphology of the redd prevents fine accumulation.

Summer Rearing

Granitic sediment poses a problem for rearing salmonids because it may simplify habitat complexity, reduce rearing space, and reduce aquatic insect production. Although existing data do not permit reliable quantitative predictions, as fines increase in rearing areas, densities of juvenile salmonids tend to decline (Chapman and McLeod, 1987). A few studies report a strong negative relationship between measures of fine sediment and rearing densities of juvenile salmonids (Bjornn et al., 1977; Kelly and Dettman, 1980; Shepard et al., 1984; Thurow and Burns, unpublished).

As habitats are sedimented, they tend to become less complex and more uniform. As a result, the range of microhabitat depths, facing velocities, and substrates will be reduced, thereby reducing locations preferred by certain species and life stages. Where large amounts of sediment deposition occurs, a reduction in habitat volume may reduce living space and fish density (Bjornn et al., 1977). As complexity and living space are reduced, fish may be displaced from sedimented habitats and experience increased mortality as they seek other habitat. In cases where aquatic insect production is reduced, fish may experience reduced growth and increased susceptibility to predation and disease. Similar aged fish of smaller size may also experience higher winter mortality than larger fish (Hunt, 1969).

Different species and life stages use a variety of different habitats for rearing. Sediment transport and deposition varies across the different habitats. Within most batholith streams, habitat partitioning occurs both between life stages of the same species and between species of the same life stage. For example, age 0 steelhead rear in shallow water habitats with low velocities typically found in stream margins or side channels. Age 1 and older steelhead select deeper, faster water habitats with large substrate and velocity shears (Everest and Chapman, 1972). In contrast, age 1 and older cutthroat trout tend to be most abundant in pools with low gradients and slow velocities.

Adult Staging

Most salmonids exhibit seasonal movements. During migrations, adult salmonids tend to gather and stage in large pools while enroute to and from spawning grounds. Sediments affect adult salmonid staging habitats when pool volumes are reduced.

An examination of changes in the abundance of large pools illustrates the potential influence of sediment on

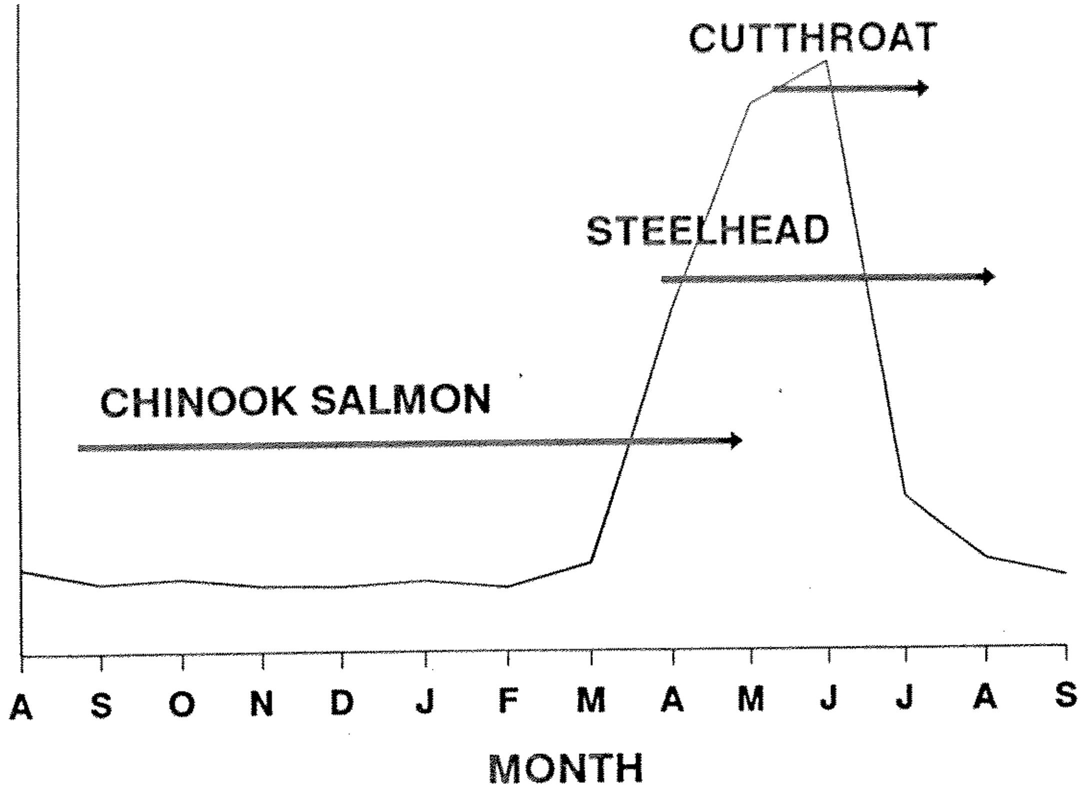


Figure 2. Spawning and incubation timing for three salmonids in Idaho.

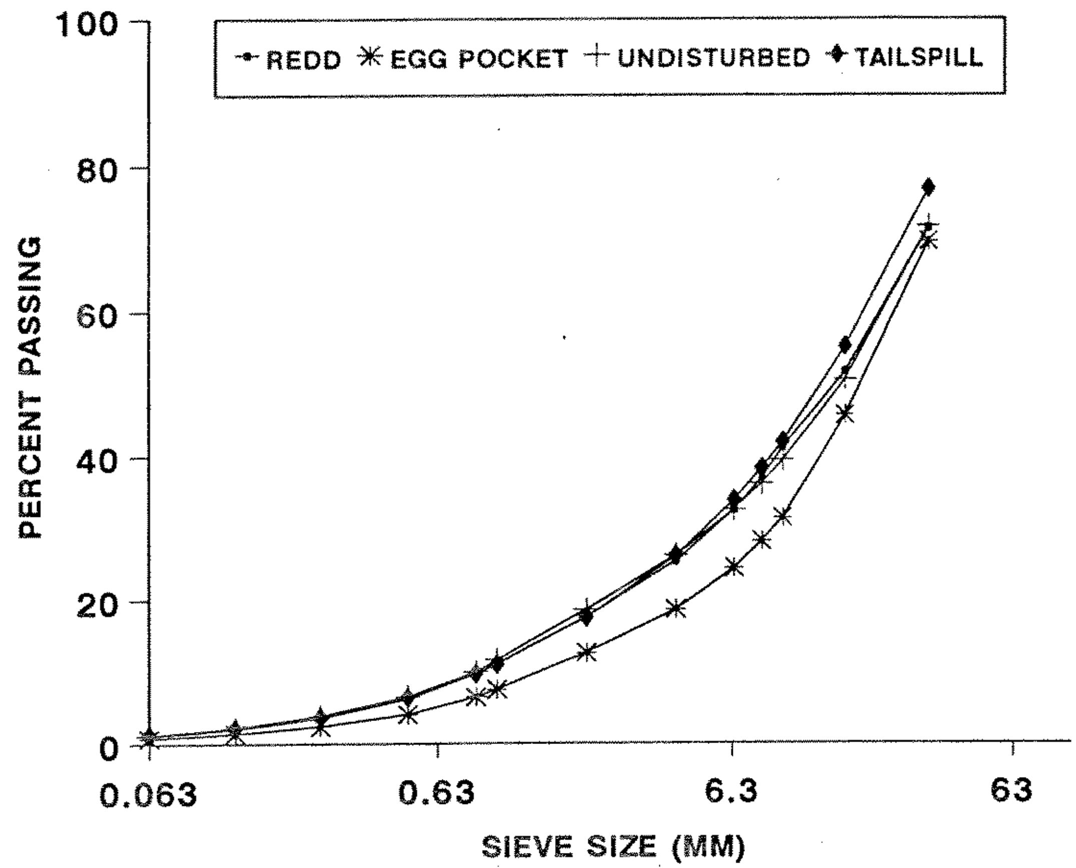


Figure 3. Particle size distributions in locations within and outside cutthroat trout redds.

adult staging habitats. From 1935-1942, the Bureau of Commercial Fisheries surveyed nearly 5000 miles of anadromous fish habitat in the Columbia River Basin (Sedell and Everest, 1990). In 1990-1991, scientists from the Intermountain and Pacific Northwest research stations re-surveyed reaches of 6 wilderness watersheds and 5 non-wilderness watersheds. Preliminary data analysis suggests that within wilderness watersheds, the abundance of large (>1 m deep) pools has remained similar during the past 50 years. In non-wilderness watersheds, the abundance of large pools declined by approximately 50%. The decline in pools is a result of several factors, including channelization, water withdrawal, and sedimentation from land use activities. Encroachment into watersheds tends to reduce the abundance of large pool habitats. Because large pools function as rearing areas as well as adult staging areas, loss of pool volume or pools will reduce the suitability of a stream for adult salmonids (Chapman and McLeod, 1987).

Overwintering

Overwinter ecology is the least understood aspect of salmonid life history. However, it may be the period that is most limiting to fish production. Most stream dwelling salmonids in the intermountain West exhibit two overwintering strategies: 1) migration from summer habitat into deep water in downstream areas (Mallet, 1963), or 2) movement into interstitial areas of the substrate (Chapman and Bjornn, 1969). In most batholith streams, salmonids begin winter migrations or enter the substrate after water temperatures decline below 10° C (50° F). High concentrations of fine granitic sediment pose a risk to fish using either overwinter strategy because fines reduce living space in downstream reaches and fill interstitial areas (Chapman and McLeod, 1987).

The influence of sediment on overwinter survival depends on local environmental conditions, winter behavior, and locations where fish overwinter. Not all salmonids behave similarly in winter and fish of the same species may behave differently in different habitats (Chapman and Bjornn, 1969). Apparent differences in winter behavior may be associated with fish size, severity of winter conditions, and availability of refugia from freshets (Chapman and McLeod, 1987). Salmonids may also exhibit diel behavioral shifts in winter. Fish that remain concealed in the substrate during daylight may move out of cover and into the water column at night (Campbell and Neuner, 1985; Contor, 1989). Consequently, fish may use a broad range of habitat during the winter.

Although addition of fines reduces winter carrying capacity and causes fish to leave embedded habitats, the importance of this is not well understood and warrants additional study. Where suitable winter habitat is not available, fish appear to move downstream until they locate such habitat. Do fish that are forced from once suitable habitat suffer higher mortality? Juvenile salmonids appear to seek winter habitat in the most upstream locations near summer rearing areas. As Chapman and McLeod (1987) suggested, upstream areas may be more suitable because: 1) upstream reaches may be better insulated from wide temperature fluctuations; 2) predators would have less access to fish in small, snow-bridged reaches; and 3) longer migrations to winter habitat would increase risk of predation. Fish might also expend less energy to reach nearby winter habitat. In addition, if suitable winter habitat is less abundant in downstream areas, displaced fish may need to compete for a limited resource.

Summary

Fish response to granitic sediment is a complex ecological process. Quantitative relationships are not fully described and additional research is warranted. Fish response is dependent on biological aspects such as species and life stage, and on local hydrological and geomorphic processes. Increases in fine granitic sediment can cause declines in fish populations and result in a net loss in productivity. Some life stages may be more sensitive and certain habitats may be more more limiting to the population than others. To illustrate the potential influence of granitic sediment on fish populations, we examined the following case history.

CASE HISTORY

Historically, the South Fork Salmon River was the single most important summer chinook salmon spawning stream in the Columbia River basin (Mallet, 1974). Since the 1940s, human-induced activities (primarily logging and road construction) have caused erosion of unstable granitic soils and damage to aquatic habitat (Megahan et al., 1980). Severe damage occurred in 1964-65 as pools were completely filled with sediment and spawning areas buried under sand (Corley, 1976). In 1966, 16,000 yd^2 of sand were dredged from the Krassel Hole, a large adult staging and juvenile rearing pool. Within one year, the pool had re-filled with sediment (Platts and Martin, 1980).

Resident and anadromous fish populations declined in the SFSR as a consequence of the severe habitat degradation and the simultaneous effects of hydoelectric development on the Snake and Columbia Rivers. Figure 4 illustrates a time trend in chinook salmon redd counts in the drainage. Angling for chinook salmon and steelhead was closed in 1965 and 1968, respectively, and has not reopened.

A moratorium on timber harvest and land disturbing activities was initiated in 1965 and rehabilitation efforts began. As fines moved through the system, conditions improved and the quantity of surface sediments declined (Megahan et al., 1980). Recovery continued until the mid 1970s, when an apparent equilibrium was reached. By the early 1980s, a large quantity of interstitial fine sediment remained and most of the cleansing of interstitial areas had yet to occur (Burns, 1984). Additional recovery may be contingent upon additional watershed rehabilitation efforts and adequate flushing flows (Platts et al., 1989).

An examination of stock-recruitment relationships (returning adults or recruits produced by a given group of parents) illustrates the importance of maintaining good quality habitat. A Beverton-Holt curve (Ricker, 1975) for Snake River chinook salmon, after 50% of the historic habitat was made inaccessible by dam construction, shows the effect of altered habitat (Figure 5). The upper (corrected) curve reflects 70% mortality of smolts migrating to the ocean (Raymond, 1979). The diagonal line represents the replacement line with 20% mortality (via harvest and passage impediments) on returning adults (recruits). If 20% of the remaining habitat productivity is lost, recruits decline from more than 6,000 to less than 3,000 (curve intercepts and the area bounded by vertical arrows). If 50% of the remaining habitat productivity is lost, the population falls below the replacement line and will no longer replace itself. This examination illustrates that, although mortality of smolts is the primary source of reduced productivity, degradation of remaining habitat is an additive source of mortality. Habitat degradation tends to hold stocks at a low level where their viability is threatened. To ensure persistence of the stock, returning fish must have access to the best available habitat. Further, as downriver passage problems are alleviated, the salmon population would be more resilient to recovery if adults and juveniles had access to quality habitats that have the potential to respond to the productive potential of the stocks.

CONCLUSIONS

As illustrated by the SFSR case history, activities that increase the transport and deposition of granitic sediments in streams can reduce the productive potential and threaten the viability of fish populations. Other species and all freshwater life stages should be considered in order to more fully appreciate the effects of fine sediment on aquatic ecosystems. To date, most research has focused on spawning and incubation of anadromous stocks. The spawning and incubation phase may not be the most important factor regulating fish abundance. As Everest et al. (1987) observed, the question that needs to be addressed is not whether sediment is detrimental, but how sediment effects the diversity and integrity of the aquatic community?

Fish-sediment research and management is most meaningful when applied in a context of risk management. It is misleading to attempt to define the specific affect (# fish lost or gained) of removing or adding a specific number of truckloads of sediment. The preferred approach is to provide managers with the tools to assess risk of decisions to aquatic resources. Following that logic, management decisions should be based on what we don't know. The less we know, we should assume, the larger the risk of adverse effects to fisheries.

In view of the threatened status (under the federal Endangered Species Act) of several fish stocks in batholith watersheds and the limited information available, a careful assessment of risk needs to be applied to management decisions. Land-disturbing activities can influence a myriad of factors, including water temperature, streamflow, and channel morphology. It may be difficult to isolate sediment effects from other changes. Land managers need to maintain the overall health and integrity of the aquatic ecosystems and the watersheds on which they depend (Everest et al., 1987), rather than focus on limited variables such as sediment and chinook salmon. Individual variables should only be used as a limited index of ecosystem health.

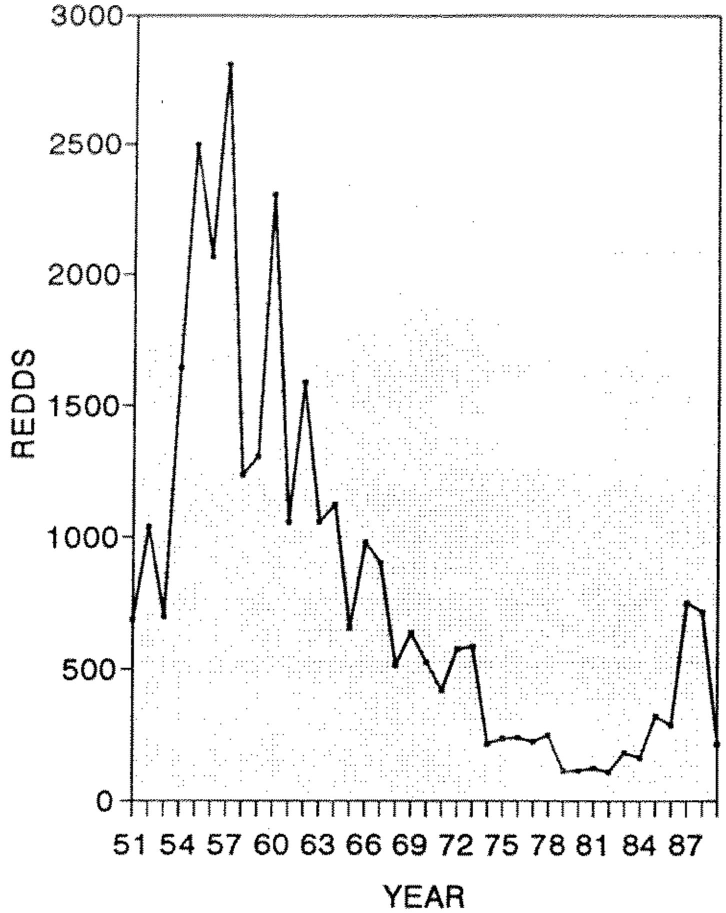


Figure 4. Chinook salmon redd counts in the South Fork Salmon River, 1951-1989. Counts after 1980 are influenced by hatchery reared fish.

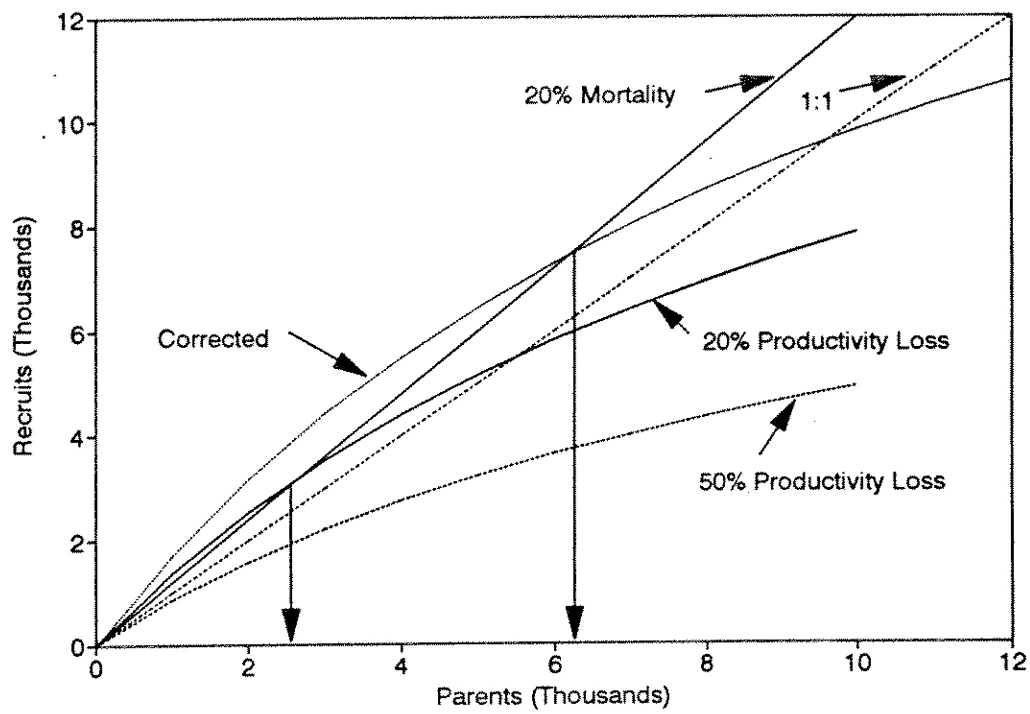


Figure 5. Reproductive relationships for Snake River spring chinook salmon. The 1:1 replacement line is for no recruit mortality and the diagonal is the line with 20% recruit mortality. The corrected curve assumes 70% smolt mortality. The other two curves reflect 20% and 50% losses in habitat productivity.

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DETERMINATION OF FLUSHING FLOW REQUIREMENTS IN THE TRINITY RIVER BELOW LEWISTON DAM: A PROGRESS REPORT

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ABSTRACT

The purpose of this three-year study is to specify a flushing flow for the Trinity River below Lewiston Dam that will maximize transport and removal of fine sediment (predominantly coarse granitic sand delivered from Grass Valley Creek) from spawning reaches and minimize the transport of gravel (whose upstream supply has been eliminated by the reservoir). Progress on two years of data collection is reported, based on controlled release periods of 3,000 and 6,000 cfs. While the higher release was useful, it was probably not optimal for flushing fine sediment from spawning gravels. Given the economic value of water released for flushing flows and the large quantity of sand currently in the river, the most prudent and cost-effective strategy for removing fine sediment from spawning gravels in the Trinity River appears to be a combination of continued dredging of sand from pools to remove sand from the system, accompanied by flushing flows to maintain a loose gravel texture and to remove fine sediment from the gravels.

INTRODUCTION

Since closure of Trinity Dam in 1960, 90 percent of the flow of the upper Trinity River has been exported from the Trinity to the Sacramento River basin. High flows were virtually eliminated in the reach below the reservoir: the mean annual flood decreased from 525 m^3s^{-1} (18,500 ft^3s^{-1}) pre-dam (1911-1960) to 73 m^3s^{-1} (2,600 ft^3s^{-1}) post-dam (1964-1990). The two-year flow decreased by a factor of 18 over the same period. Timber harvest in the tributary watershed of Grass Valley Creek, underlain by highly erodible decomposed granitic soils, resulted in accelerated erosion and delivery of coarse sand to the mainstem Trinity River, especially during an exceptionally large storm in December 1964. (See related papers on the Grass Valley Creek watershed in these Proceedings.)

The reduced flow regime has been inadequate to transport these tributary-derived sediments, which have filled pools, buried cobble substrate, and infiltrated spawning gravels (Frederiksen, Kamine, and Assoc., 1980). These effects have impacted aquatic habitat for anadromous salmonids, which were formerly abundant in this reach (Smith, 1976). To restore fish habitat, sand is periodically dredged from several pools. Long-term management will probably involve continued dredging as well as flushing flow releases, which are controlled releases designed to mimic the effects of natural floods in removing accumulated fine sediments from the river bed (Reiser et al., 1988; Milhous, 1990).

The objective of our study is to specify a flushing flow that will maximize transport and removal of fine sediment from spawning reaches and minimize the transport of gravel (whose upstream supply has been eliminated by the reservoir). Such differential transport rates are observed in the field, where sediment load composed predominantly of sand may be entrained from a sandy gravel bed at some discharges (e.g., Jackson and Beschta, 1982; Leopold, 1992). Although gravel transport during a flushing flow should be minimized, some entrainment of gravel is desirable to permit winnowing of fine sediment from beneath the bed surface to loosen the gravel structure. That such a condition is possible is suggested by laboratory observations of differential transport from a sandy gravel bed, for which a range of flows produced local movement of most or all of the gravel clasts on the bed surface in the presence of sand transport at rates of one or two orders of magnitude larger than that of the gravel (Wilcock and McArdell, In press).

This paper presents a progress report on the first two years of a three-year study of flows required to flush these fine sediments from spawning gravels in the Trinity River.

METHODS

We have made detailed observations of flow and bed sediment before, during, and after controlled releases made for our study and for related investigations. In May 1991, 85 m^3s^{-1} (3,000 ft^3s^{-1}) was released for four days. In June 1992, 170 m^3s^{-1} (6,000 ft^3s^{-1}) was released for six days. We made current meter measurements from rafts maneuvered across the channel by a network of climbing ropes and pulleys anchored on the bank. Observations of bed sediment included before and after observations of the grain-size distribution of the bed and the emplacement of tracer gravels (distinctively marked gravel particles whose movement can be followed to provide an indication of overall gravel movement) in the bed.

Our efforts are concentrated at two study reaches containing characteristic and, historically, heavily-used spawning gravels. The study reaches, located between Lewiston and Weaverville, California, are Poker Bar (15 km downstream of Lewiston Dam) and Steelbridge (20 km downstream of the dam, near the site of an abandoned bridge)(Figure 1). At each reach, we observed stage (water surface elevation) at ten cross-sections and measured water depth and velocity across the upstream section and along three downstream cross-sections centered over the spawning gravels (Figure 2). Price AA current meters were used for all velocity measurements (Rantz et al., 1982), with observations at different heights above the bed at each station. To obtain the most accurate possible measurements of depth and vertical position of the meters, we made our velocity measurements with wading rods whenever possible, using 2.5-m and 4.5-m long wading rods. When the current was too strong to use these rods, we made our velocity measurements using a cable-suspended current meter.

We have surveyed the cross-sections, sampled surface particle size using the pebble count method (Wolman, 1954), and collected bulk samples of the river-bed sediments (Lisle, 1989) before and after each release to document changes in channel configuration and bed material size. We have also emplaced tracer gravels in the downstream cross-sections to document bed mobility. Our 1991 field observations piqued our interest in measurement of bedload transport rates, so in 1992 we designed a floating platform and boom from which we could deploy a Helley-Smith sampler as well as the current meter and its lead weight (Figure 3). The 75 kg sampler is lowered to the bed, where it sits and collects sand and gravel moving as bedload along the river bed (Emmett, 1980).

In addition to our work at the detailed study reaches, we have also monitored changes in sand storage in pools between the study reaches. At selected pools, we have surveyed cross-section networks adequate to provide detailed topography of the bed before and after the release to document net scour or fill of sand.

RESULTS TO DATE

Thus far, our results indicate that the controlled release of 85 m^3s^{-1} (3,000 ft^3s^{-1}) in 1991 produced only partial movement of the bed, with up to 30 percent of the surface tracer gravels mobilized, and no movement of surface gravels at many sites. Bulk gravel samples and surface pebble counts displayed virtually no change during the flow. The bed surface was covered by distinctive stripes of sand on the days immediately following the flow (Figure 4), but these stripes had disappeared by the time we repeated pebble counts. Cross-sections over the study reaches showed little change in bed elevation, with minor

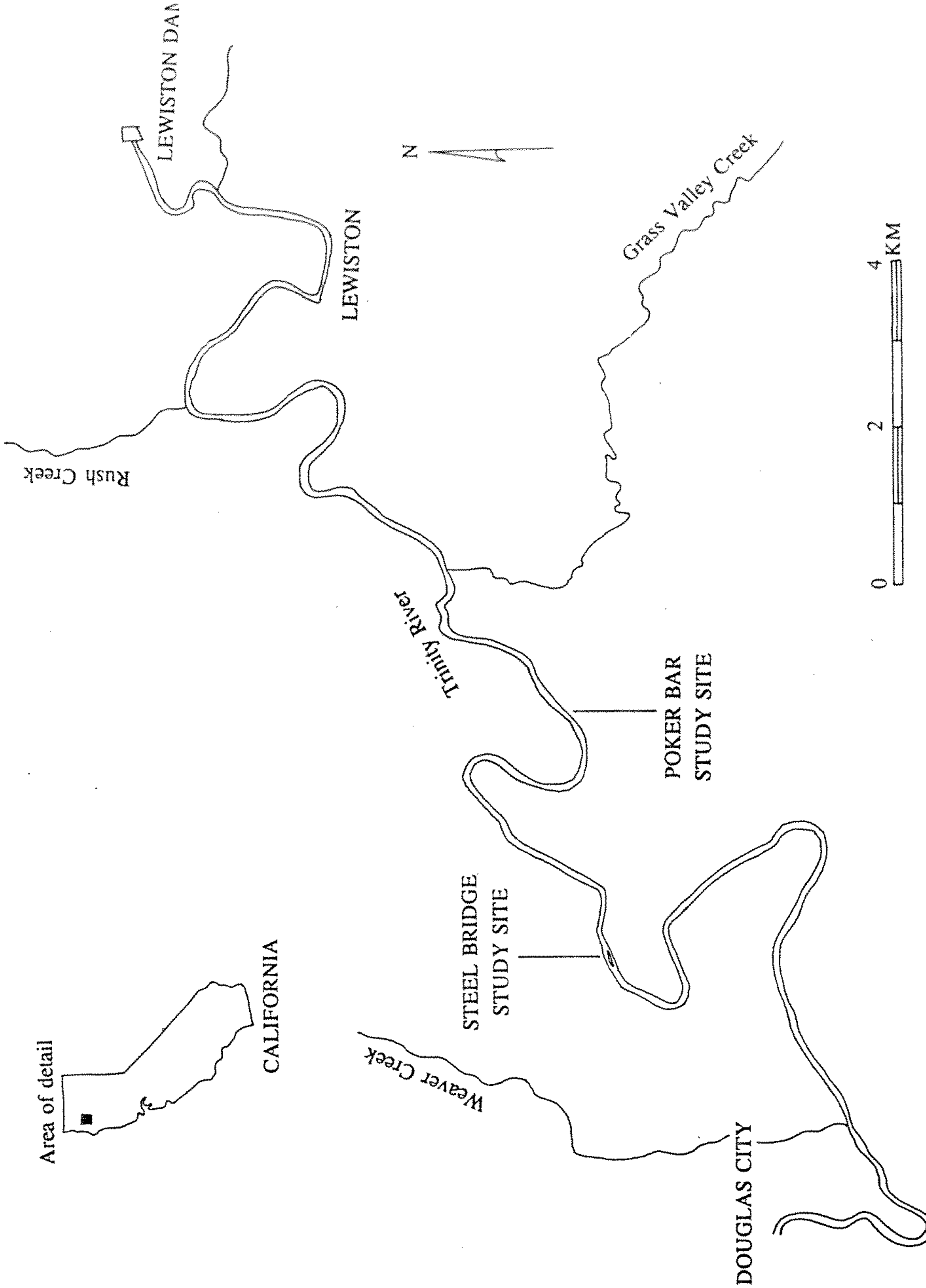

Figure 1. Location map showing Trinity River below Lewiston Dam, with locations of study reaches indicated.

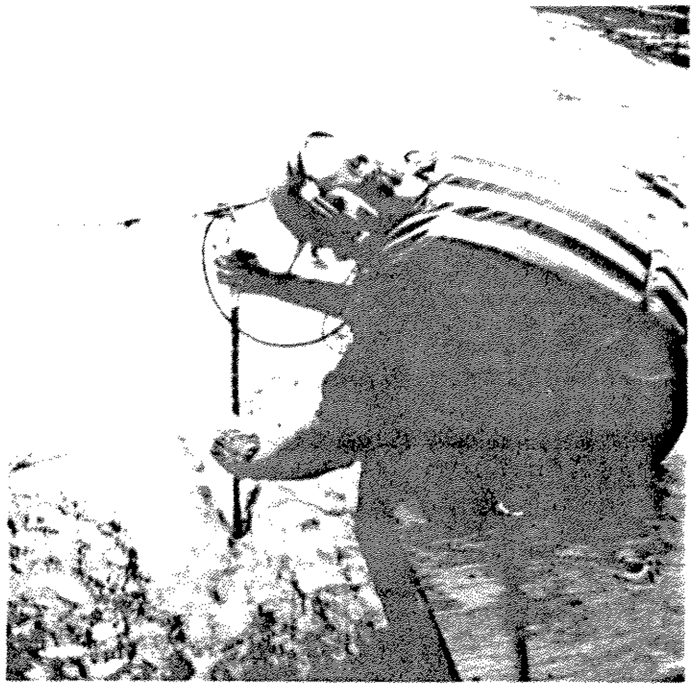

Figure 2. Photograph showing measurement of velocity using 4.5-m wading rod from sampling platform, June 1992. *Photo by Wilcock.*

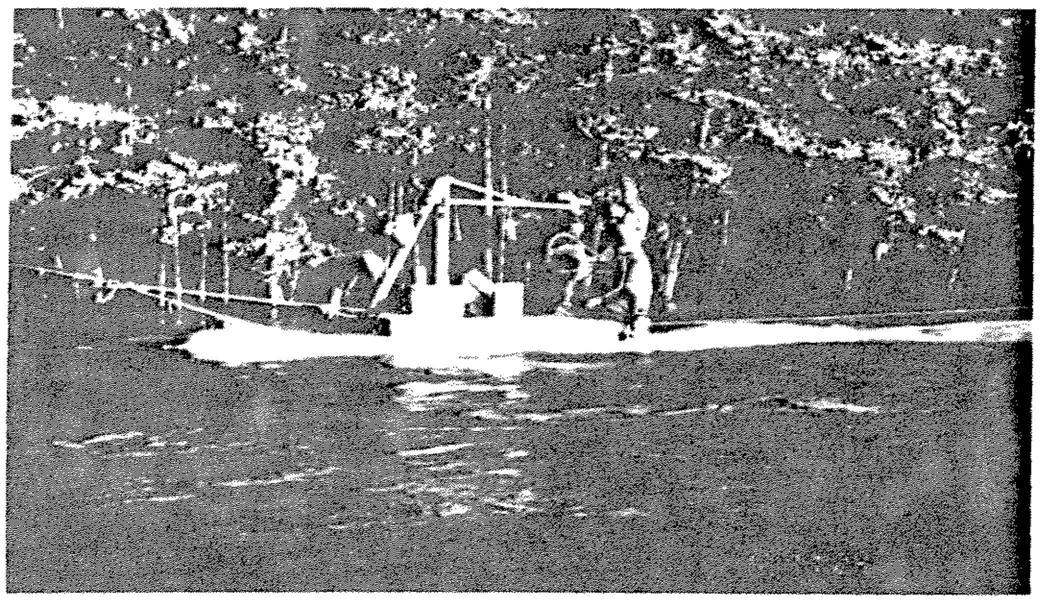

Figure 3. Photograph showing sampling platform, with Helley-Smith bedload sampler being deployed from crane, Poker Bar study site, June 1992. *Photo by Barta.*

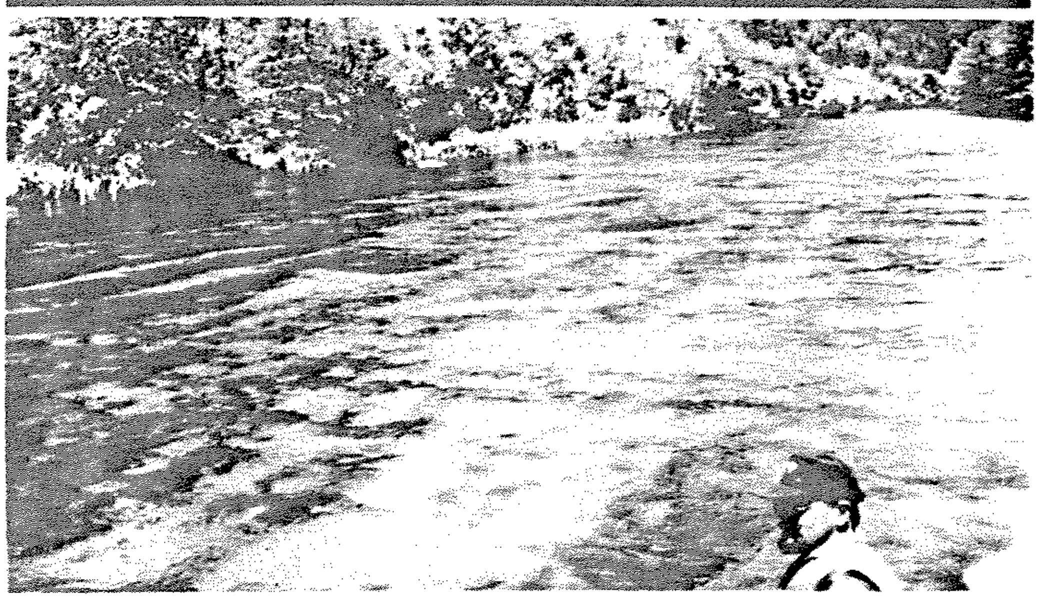

Figure 4. Photograph showing sand stripes on bed at Steelbridge site immediately following controlled release, 1991. *Photo by Kondolf.*

scour and fill roughly balanced. Pools showed net scour, suggesting that sand moved from pools onto the riffles.

The controlled release of 170 m^3s^{-1} (6,000 ft^3s^{-1}) in June 1992 resulted in movement of 50-100 percent of the surface layer at our study sites. Results were variable, with general movement at most Poker Bar observation sites, but no movement at one Steelbridge observation site. Bulk gravel samples displayed virtually no change, but the bed at Poker Bar experienced a net reduction in surficial fine sediment, as measured in pebble counts (Figure 5), while the bed surface at Steelbridge was essentially unchanged. Cross-sections over the study reaches showed little net change in bed elevation (Figure 6). As in 1991, pools showed net scour during the 1992 flow.

DISCUSSION

Our results suggest that the controlled release of 170 m^3s^{-1} (6,000 ft^3s^{-1}) was useful, but probably not optimal, for flushing fine sediment from spawning gravels. A higher flow, resulting in more general bed movement, could permit flushing from beneath surface gravels without serious loss of the gravels themselves. It is unlikely that a flow greater than 240 m^3s^{-1} (8,500 ft^3s^{-1}) would be feasible because of potential for flooding human settlements, which have encroached onto the formerly active channel bars, largely in response to perceived flood protection. The channel has narrowed in response to flow regulation by the dams, and this effectively confines the flow, so shear stresses adequate to entrain the bed can be achieved with lower flows than would have been the case in the wider pre-dam channel.

Our observations have been concentrated at two study sites containing characteristic and historically-used spawning gravels, and our observations have been fairly consistent between sites. However, spawning gravels elsewhere in the river may occur in different channel configurations and thus might have different flushing flow requirements.

Given the value of water released for flushing flows and the large quantity of sand currently in the river, the most prudent and cost-effective strategy for removing fine sediment from spawning gravels in the Trinity River appears to be a combination of continued dredging of sand from pools to remove sand from the system, accompanied by flushing flows to maintain a loose gravel texture and to remove fine sediment from the gravels. Spawning gravels need not be perfectly clean for fish to use, and the fish themselves reduce the fine sediment content in gravel as they construct their redds (Kondolf et al., In press). If flushing flows alone were employed to remove fine sediment from the gravels, the durations required would be prohibitively expensive. If dredging alone were prescribed, the net storage of sand-sized sediment in the channel would be reduced, but fine sediment within spawning gravels would remain. Dredging is effective within pools, but is not feasible on shallow gravel riffles.

ACKNOWLEDGEMENTS

This study has been funded by the U.S. Fish and Wildlife Service (USFWS) Trinity River Flow Study, with additional support from Southern California Edison. We benefitted enormously from the invaluable advice and support from Andy Hamilton, Paul Zedonis, and Mark Hampton of the USFWS in Lewiston. Dedicated and competent field support from Tom Benjamin, Stuart Cook, Danielle DeClercqe, Brendan DeTemple, Gary Fleener, Jennifer Gilson, Ashley Goldhor-Wilcock, Paul Harper, Bette Kim, Don Parrish, Mark van Steeter, Becky Thomas, Barbara Walker, and Jack Wallace is gratefully acknowledged.

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Trinity River at Poker Bar Cross Section 2 Pebble Counts

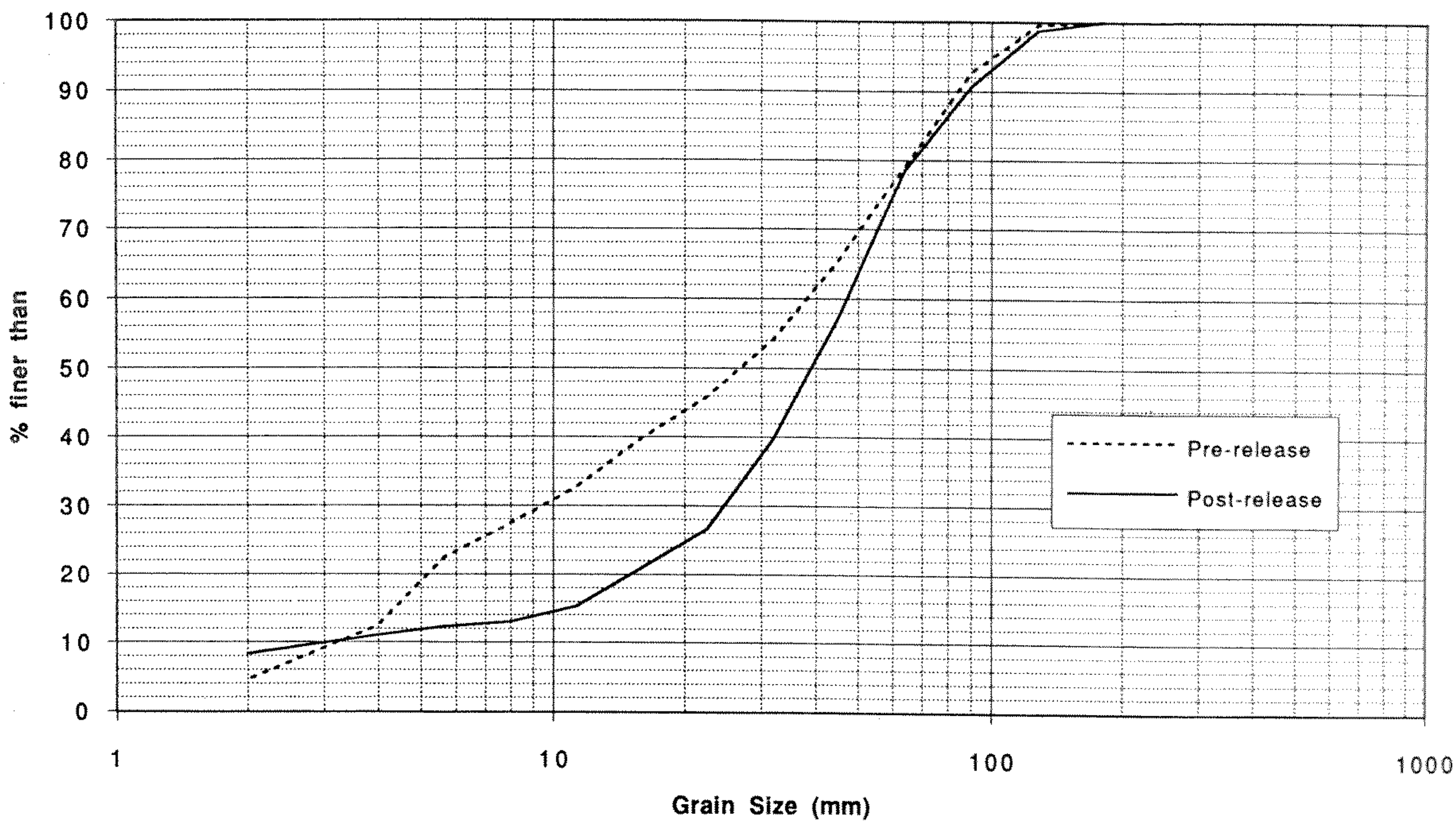

Figure 5. Size distributions of bed material from pebble counts before and after 1992 release, Cross Section 2 at Poker Bar site.

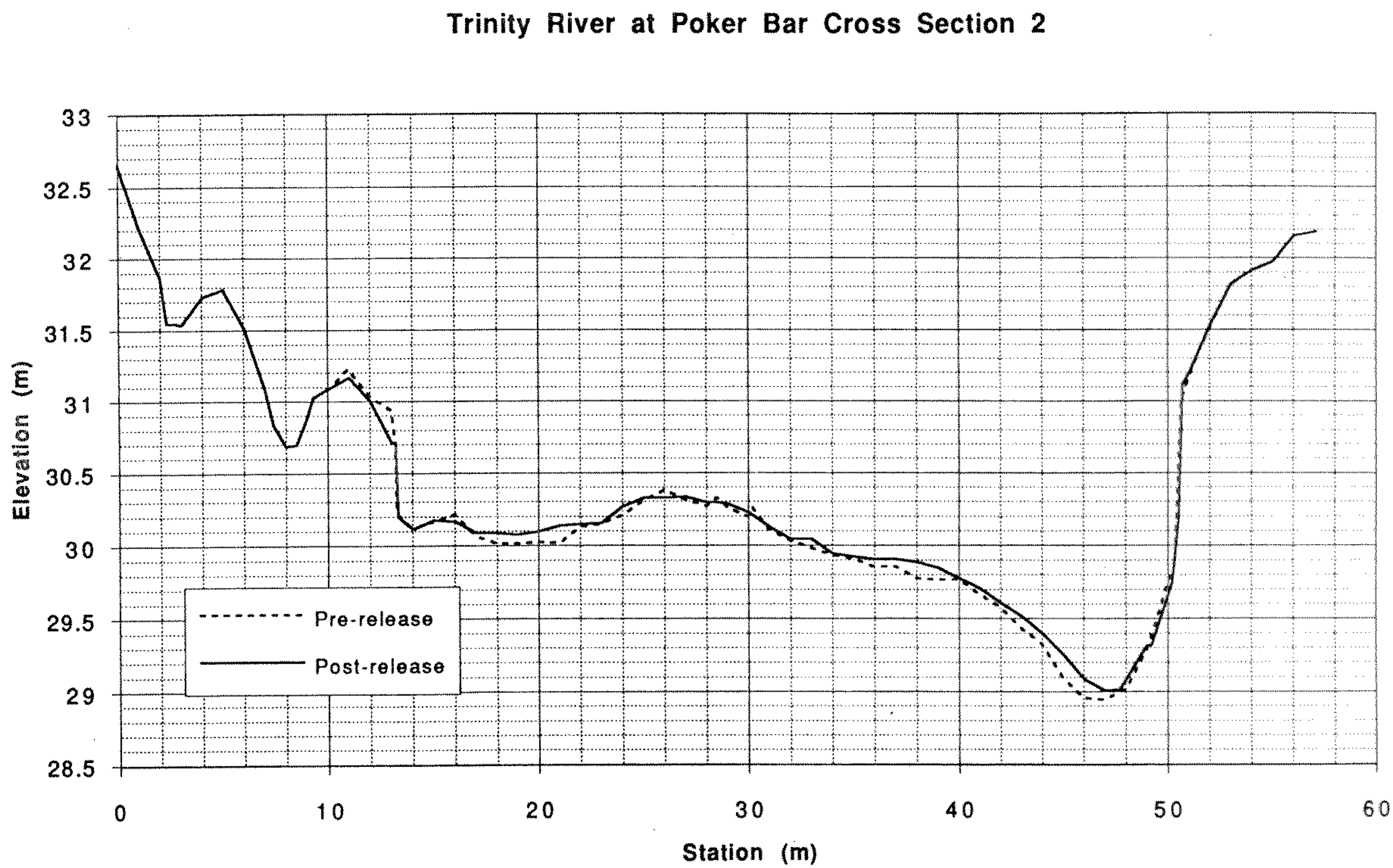

Figure 6. Elevation profiles at Cross Section 2, Poker Bar study site, before and after 1992 release.

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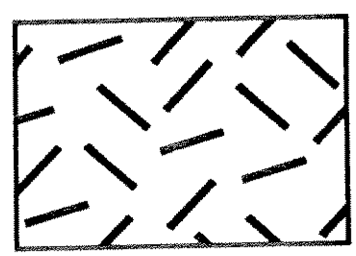
EROSION CONTROL



REVEGETATION OF DECOMPOSED GRANITIC SOILS WITH WOODY PLANTS

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ABSTRACT

Research was conducted on various plant materials and revegetation treatments on decomposed granitic soils in the Lake Tahoe region. Willow wattling was usually successful in stabilizing badly eroded cut and fill slopes by reducing a long slope into a series of short slopes, thereby dissipating the energy of detritus and water movement downslope. Native woody species were planted between the wattling rows. It is essential that willow cuttings for wattling be treated as live material and not be exposed to wind or sun before planting. Spring planting was generally superior in this area to fall planting because of frost heaving and erosion during the winter. Rock breast walls, constructed at the toe of a road cut, also helped stabilize cut slopes, which could then be planted. Grasses were useful for interim stabilization, while woody plants provided long-term erosion control.

Editor's Note: Below is a representative sampling of the author's publications on related subjects for further reference.

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RESPONSE OF REVEGETATION ON A SEVERELY DISTURBED DECOMPOSED GRANITIC SITE

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ABSTRACT

This paper examines recovery of vegetation eliminated in Lost Canyon of the Helms Pumped Storage Project due to a pipe failure in September, 1982. After 10 years, results are reviewed from the perspective of goals established at the beginning of the project and how well the re-established vegetation has progressed. The 10 years included many phases of restoration, such as site analysis and study, mitigation agreements with regulatory agencies, planning and specification preparation, implementation/contracting of plantings, documentation and reporting, and remedial follow-up work. In addition to the harsh environmental conditions resulting from the scouring of the canyon and poor access, drought in the last six years added to the difficulty of restoration. This paper includes difficult site conditions encountered, strategies to recover the primary vegetation types, techniques used to re-establish plant species, and characteristics and response of plant materials.

BACKGROUND

On September 29, 1982, during the testing phase of Pacific Gas and Electric (PG&E) Company's Helms Pumped Storage Facility, a 22-foot diameter pipe failed and released an average flow of water of 40,000 cfs into Lost Canyon (PG&E, 1983a). This area is located on the Sierra National Forest, about 70 miles east of Fresno, in the southern Sierra Nevada Batholith.

The flow scoured the canyon and removed 1.75 million cubic yards of soil and rock. The following is a description of the impact taken from an excerpt of the "Helms Project Environmental Recovery Plan" (PG&E, 1983b):

> "The upper one mile of Lost Canyon was relatively unaffected by the pipeline failure, although some minor undercutting of the canyon sides occurred in the narrower areas of the canyon. Some of these slopes may slough over the winter or during the spring snow melt. This region of the canyon had been used to dispose of the granite spoil from tunnel construction and was essentially clear of any vegetation.
>
> The stretch of Lost Canyon and Short Hair Creek from the end of the spoil disposal area to Lake Wishon was affected significantly. Prior to the pipe failure, the area of Lost Canyon below the spoil disposal area supported a riparian plant community, with red fir and lodgepole pine predominantly along the canyon bottom. The vegetation along the bottom of the canyon has been removed or damaged for a distance of 2.5 miles and from 100 to 150 feet on either side of the original creek bed. The extent of this damage will be assessed in the comprehensive study that is being prepared. Approximately 1.5 million board feet of timber was affected. This figure includes trees still standing along the edge of the affected area whose roots have been exposed and those located on hillsides which were undercut by the water.
>
> Between the former Switchyard Road Crossing and the spoil disposal area, it is estimated that the canyon floor has been lowered 5 to 10 feet in places, severely undercutting the canyon sides in several locations. Below Switchyard Road, and to about one-half mile above Lake Wishon, the canyon has been lowered an average of 15 to 20 feet below the original creek bed, creating 15-20 foot vertical drop-offs in many areas. Of particular concern is a 60-foot exposed sandy bank near the confluence of Lost Canyon and Short Hair Creeks. The new canyon floor is primarily granite rock, gravel and sand.
>
> The creek bed of the half mile of Short Hair between Lost Canyon and Lake Wishon is now

granite bedrock. A narrow, 30-foot deep canyon has been created at the top of the hill above the lake and increases to a width of 500 feet at the foot of the hillside. No soil, rocks, or gravel remain in this area. Most of the soil and rock removed from the canyon has been deposited in a newly-formed delta at the end of Short Hair Creek. The delta extends about 200 feet into Lake Wishon and is approximately 600 feet wide.

A multi-discipline task force was developed to restore the affected environment. This paper deals with the revegetation portion of the mitigation. The goal of the revegetation was to re-establish the native vegetation in proportions of vegetation types that existed prior to the pipe failure and to prevent erosion and sedimentation."

REVEGETATION STRATEGY

The revegetation strategy was based on responding quickly to an emergency situation, testing and understanding difficult site conditions, and implementing specific treatments to site conditions, including specific techniques and placement of species. Three major vegetation types that had to be re-established were identified in the mitigation plans. These were:

- riparian/wetland
- montane chaparral
- conifers

In addition, grasses and legumes had limited occurrence prior to the pipe failure but were important for the rehabilitation of the canyon. The purpose of establishing herbaceous cover included preventing erosion and sedimentation, providing wildlife habitat, and developing biomass in the canyon to accelerate soil development.

To restore the vegetation in Lost Canyon and to prevent erosion and further degradation, the 4 major objectives were emphasized:

1. Initiate mechanical and vegetative measures to prevent erosion and sedimentation.

   Initial measures included aerial seeding, fertilizing (avoiding placing fertilizers in the streams), planting willow cuttings, and installing mechanical measures such as building sedimentation checks, diversion channels, sand bags, hay bale checks and filtration devices.

2. Determine the most effective planting techniques and promising species.

   Planting methods ranging from the simplest reforestation type of planting to the most intensive method using a planting collar, fertilizer, protective screen, and watering were compared. Special attention was given in selecting representative site conditions ranging from fairly favorable to extremely difficult (see "Revegetation Trials" section below). Data collected one year after planting provided invaluable information which was consistent during the restoration period. Thirteen primary woody species were tested in the planting trials, although eventually twenty-three species were used in the operational planting (see Plant List, Table 1).

3. Implement operational planting based on the trial plantings and experience gained working on-site.

   Acquisition of plant materials began during the mitigation phase to expedite restoration. Acquisition included obtaining a U.S. Forest Service collecting permit, collecting native site-specific plant materials, and contracting with a specialty native plant nursery. In addition, with concurrence of the U.S. Forest Service, non-local sources of native plants were acquired in order to complete the mitigation within the required time period. Based on the results of the planting trial, specifications for the operational revegetation plantings were prepared and bid to begin the restoration plantings at the earliest possible date.

   To implement the most promising treatments, the canyon was divided into 200 foot segments with numbered placards beginning with the lowest number at the highest elevation and progressing downstream. Qualified personnel identified species composition, planting patterns and most favorable planting spots in each segment by placing coded color flags at each planting spot. This work was performed prior to the planting crew's arrival.

4. Perform remedial plantings as needed.

   At the end of each growing season, qualified personnel surveyed the planting in the Canyon

Table 1. Woody Plant List: Lost Canyon, Helms Pumped Storage Project, 1983 - 1988.

Botanical Name	Common Name
Chaparral species	
*Arctostaphylos patula**	Greenleaf manzanita*
Ceanothus cordulatus	Snowbush ceanothus
Prunus emarginata	Bitter cherry
Quercus chrysolepis nana	Dwarf canyon live oak
Quercus vaccinifolia	Huckleberry oak
*Sambucus caerulea**	Blue Elderberry*
Sambucus racemosa	Red Elderberry
Sorbus scopulina	Mountain-ash
Castanopsis sempervirens	Chinquapin
Conifer species	
Abies concolor	White fir
Abies magnifica	Red fir
*Pinus jeffreyi**	Jeffrey pine*
Pinus monticola	Western white pine
*Pinus murrayana**	Lodgepole pine*
Riparian species	
Alnus tenuifolia	Mountain alder
Cornus stolonifera	Redstem dogwood
*Populus tremuloides**	Aspen*
Populus trichocarpa	Black cottonwood
Salix scouleriana	Scouler's willow
Salix species HC	Helms Creek willow
Salix species LPM	Lily Pad Meadow willow
Salix rigida	Yellow willow

* Overall, most promising species in planting trials.

and identified deficiencies in survival and species composition. Plant acquisition was initiated in order to perform remedial planting the following season. In addition, annual "walk-throughs" with the regulatory agencies were conducted to review and discuss the progress of the restoration.

Revegetation Trials

In order to determine the efficacy of various planting methods and species and to estimate the magnitude of the planting, planting trials were established in the Fall of 1983 (Chan, 1984; Chan and Wong, 1988). Although data collected one year after planting would produce limited information, experience has shown that trends of first year data are extremely valuable. In addition, continued observations of the test plots in the second and third years were still useful because they reflected what could be anticipated for the operational plantings which were one and two years younger.

Planting methods tested ranged from planting a liner size plant with slow-release fertilizer similar to reforestation planting to an intensive planting method (Figure 1). The intensive method consisted of planting a liner size plant into a tapered cylinder called a "collar" which is positioned in the planting hole. Slow-released fertilizer is placed below the plant and a protective screen is secured to the collar. The above-ground part of the collar provides a trough for watering. Watering was applied at the time of planting for all plants but during the following growing season only the intensive treatment received minimal irrigation. Minimal irrigation consisted of approximately 2 inches of water in the collar every 2 to 3 weeks. Results of the planting methods trial are presented in Figure 2.

Overall, the most promising species in the planting trials were Aspen, Lodgepole pine, Greenleaf manzanita, Blue elderberry and Jeffrey pine. Depending on individual sites, these species were consistently established within a range of 50 to 90%.

Mechanical Measures

Mechanical erosion control measures implemented in Lost Canyon included:

Gabion sedimentation checks
Diversion channels
Sand bags and hay bale checks
Water energy dissipaters and filtration devices
Toe logs
Water bars
Mulching
Riprapping

These measures are considered fairly standard practices. Other measures not commonly utilized were developed based on observations in Lost Canyon and the Helms Project. These are applicable to steep erodible granitic slopes and included:

Creating rough surfaces with heavy-equipment. Rough surfaces can be created by using heavy equipment such as a caterpillar tractor, excavator or crane with a bucket. The objective is to mix rocks and soil fines along with organic matter such as bark and herbaceous material when constructing a slope. The more erodible the slope, the higher percentage of rock is needed. Placing slash over the surface will provide additional protection. The feasibility of this treatment depends on the availability of materials and equipment. This treatment lends itself to providing immediate erosion protection and favorable niches for the establishment of a range of herbaceous and woody plany species.

The other two biotechnical measures are similar in concept and application. In their applications, they differ in regards to the severity of the erosion that is occurring on the slope, whether rilling or gully formation. These are very specific treatments to prevent erosion and also provide favorable niches for plant establishment. They are based on the following principles:

- Controlling runoff velocity by breaking up slope length and diverting flow
- Trapping sediment
- Creating a favorable medium for pioneer species
- Inoculation of the medium with soil micro-organisms as well as pioneer species
- Establishing woody plant species, not only by cuttings on moist sites, but also establishing upland species by direct seeding on dry sites

Installing artificial wattling on slopes with rilling. Artificial wattling (Figure 3) consists of mechanically producing a wattle that is more economical to produce and install compared to conventional wattling. The wattle bundles should be approximately 10 feet in length and 10 inches in diameter for ease of handling, storing and shipping. The wattles may be

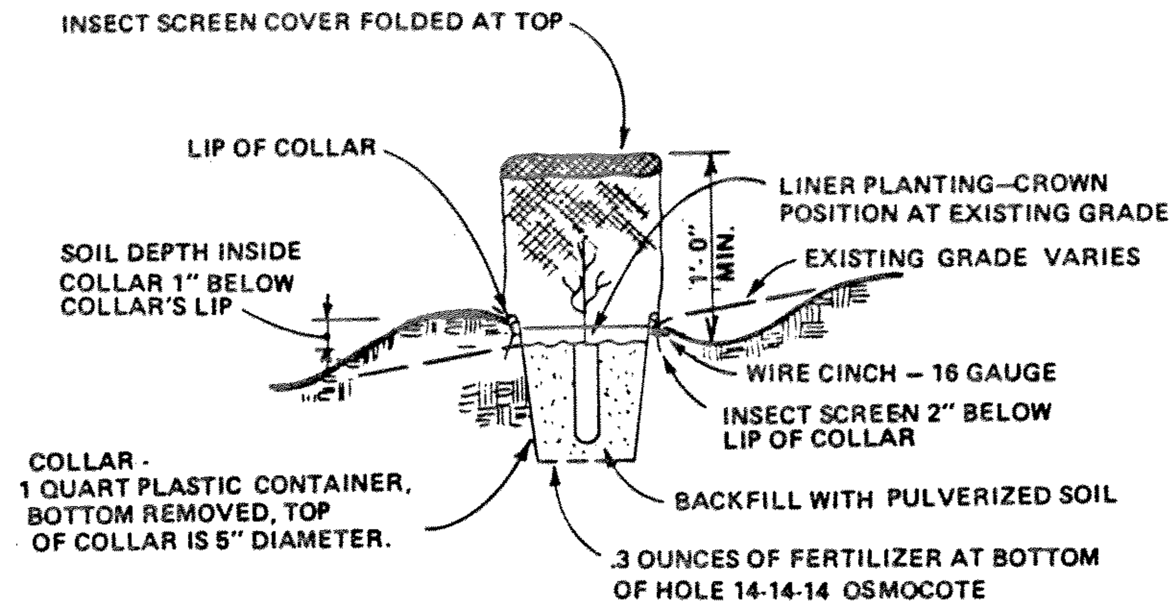

Figure 1. Liner Planting with collar and protective screen.

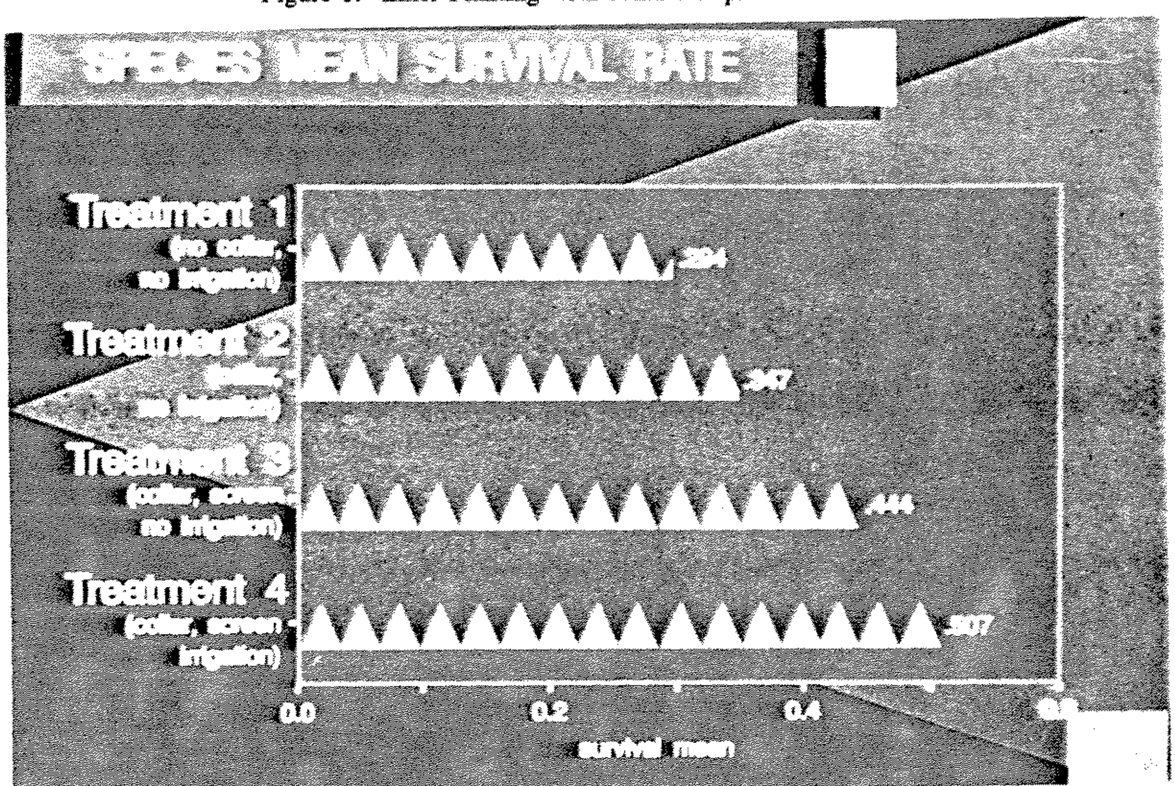

Figure 2. Efficacy of four planting methods tested in a range of site conditions at Lost Canyon. Overall, the most intensive method was the most effective.

produced by harvesting and bundling native hay whenever feasible; or field grown hay such as native perennial grasses currently under production in California; or by harvesting rice straw which can then be inoculated using topsoil and native straw seeding (see text).

Wattle row intervals are important depending upon steepness of slope, erodiblity of soil type, length of slope, and required time for recovery to minimize erosion risks. Cost is also a determining factor. In the worst case, wattle row intervals may be 5 to 6 feet apart. The further apart the wattle rows, the more intensive the revegetation seeding and planting between rows should be. Another guideline is to space wattle rows the same distance as conventional wattling (i.e., 3 to 4 feet difference in elevation).

Installing hay bale wattling on slopes with moderate gullies to approximately 2 feet deep. Hay bale wattling (Figure 4) is essentially the same in concept as artificial wattling except it would be used on slopes with more severe erosion and where its effectiveness would warrant the greater cost. To stabilize moderate gully areas, a structure similar to a short underground silt fence is anchored securely to the substrate. Hay bales or half-sized hay bales are placed uphill and against the silt fence. The hay bales are placed so only 4 to 6 inches are above the final grade. Visually, only rows of the upper portion of the hay bales are seen. Inoculation, seeding, and treatment in between rows are similar to artificial wattling.

Operational Planting

Operational planting will be described in terms of typical planting situations encountered in Lost Canyon. Specific examples of the variable planting conditions and specific treatments used are provided. Most of the planting methods used were those of the planting trials (see text). Methods used were based on the severity of the site conditions and plant establishment characteristics of the plant species. The more severe the conditions, the more intensive the planting method used.

Steep and Dangerous Slopes. Some large slopes were steep and too dangerous for crews to work on. Undercutting of the top of the slope was common. To exacerbate the situation, large trees were hanging on to these edges, precluding their removal by cutting. Very little was practical to apply on these slopes except aerial seeding. A seed mix of upland and riparian species as well as Lodgepole pine seed was applied (Chan, 1984). Fine-seeded species had a better chance of retention on the slope. Lodgepole pine seed germinated in a range of soil and rocky conditions including cracks and crevices of decomposing granite.

Dry Slopes. Many of the slopes were very dry. Selecting adapted species was important. The predominant species included conifers, particularly Jeffrey pine and Lodgepole pine, and the montane chaparral species notably Snowbush ceanothus, Greenleaf manzanita, Bittercherry, Red elderberry and Blue elderberry. At the base of dry slopes, sufficient moisture was often available to establish Aspen, Scouler's willow and Redstem dogwood.

The most effective method for this planting situation was the collar, fertilizer, screen and minimal irrigation (Figure 1). The planting collar was effective because it allowed efficient watering which otherwise would not have been feasible. The water was confined to the root zone by the collar. Without the collar, water would run off the slope or spread out, only allowing shallow penetration. By localizing the water in the collar, only 2 inches of water applied in the collar wetted the soil 10 to 12 inches deep. This conservative amount of water was effective and very important in poorly accessible sites. Hand watering utilizing local sources of water was often the only feasible means of irrigation. Depending on weather conditions, the standard watering schedule was to apply water every 2 to 3 weeks during the first growing season. Many species were established with this schedule but, because of prolonged drought, spot watering after the first year was only applied as needed.

The protective screen was effective against animal depredation. It was designed to provide the first year's protection but in some cases screens were left on for protection for 3 years. This was done because of slow growth and high probability of browsing from marmots and other animals. At the beginning of each growing season, the screens had to be straightened out and opened if the plants were sufficiently large. Thus, partial protection was afforded. The planting collar was not used in fine-textured soil where frost-heaving was a common problem.

Another effective technique on dry slopes which have a rough surface for seed retention was broadcast

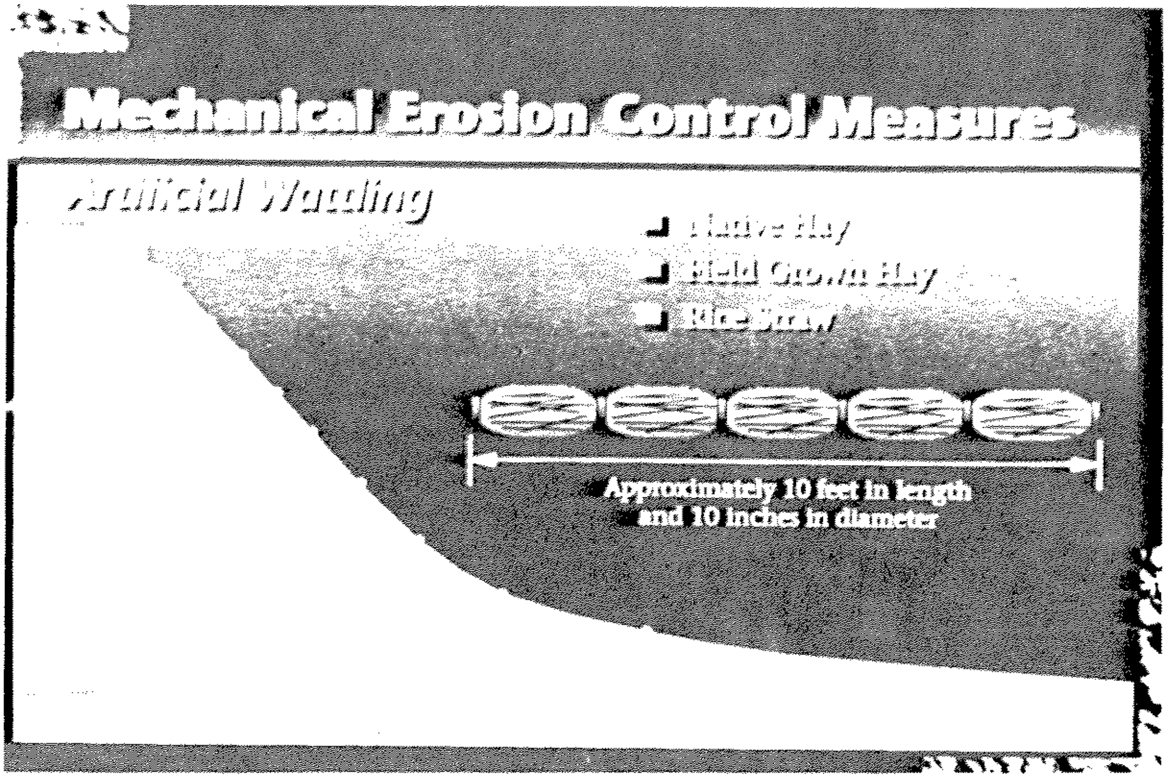

Figure 3. Artificial wattling for steep granitic slopes with surface rilling. The rows of wattles not only provide mechanical erosion control protection by slowing the velocity of run off but provides favorable niches for herbaceous species to develop and further invade bare areas in-between rows.

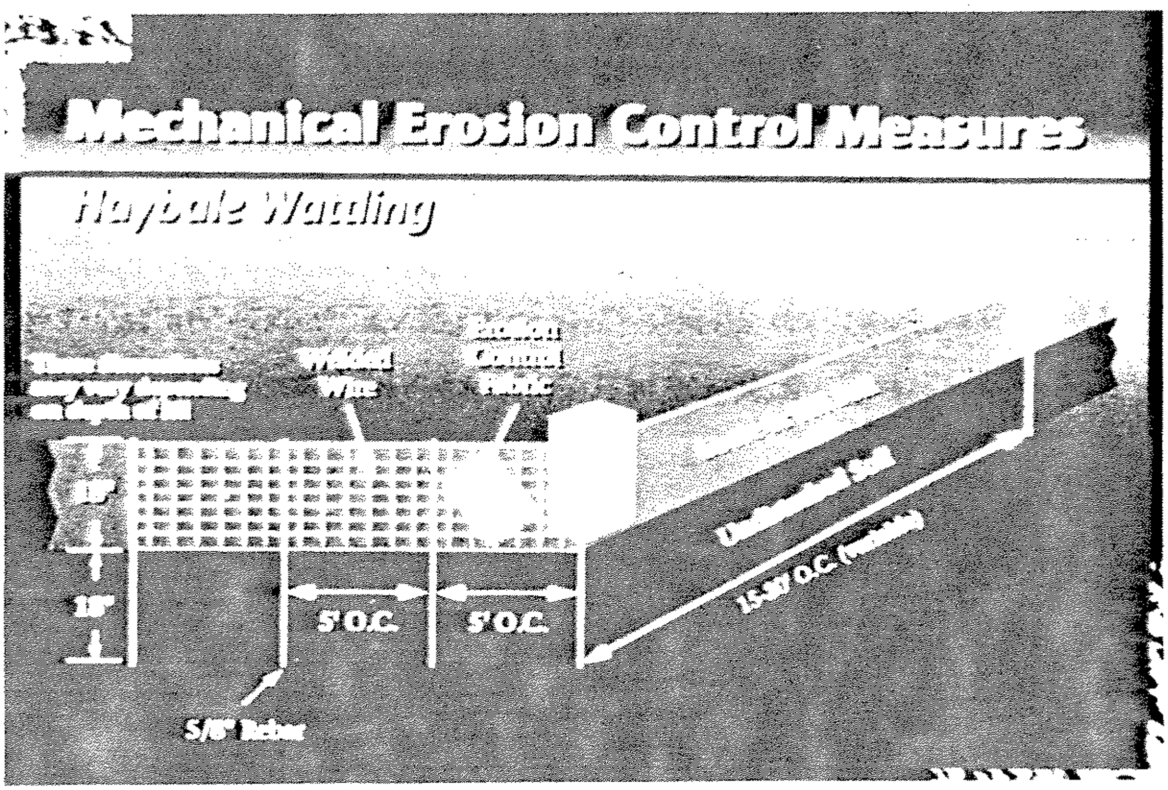

Figure 4. Hay bale wattling for steep granitic slopes with gullies. Short underground silt fencing provides stability to rows of half-sized hay bales positioned slightly above final grade. The hay bales are inoculated with topsoil and adapted native herbaceous species.

seeding of pretreated Ceanothus seed (Chan, 1974). Pretreated seed can also be direct seeded in spots but the method is more labor intensive. In cases where seed quantity is limited, it may be advisable to direct seed in spots. The pretreatment of Ceanothus seed consists of subjecting the seed to boiling hot water (212°F). Snowbush ceanothus (*Ceanothus cordulatus*) seed is placed in a volume of boiling hot water approximately 4 to 5 times the volume of seed. The seed remains in the tumbling water for 20 to 25 seconds and then is immediately cooled down by adding tap water. The seeds are removed from the water and stored in the refrigerator in plastic bags until seeding is implemented. Usually pretreatment is performed just before seeding is done in the fall. The reason for this timing is to allow seeds to imbibe water from natural rainfall and to allow natural stratification to occur. The boiling hot water overcomes seed coat dormancy and stratification overcomes embryo dormancy of the seed.

Gravels with Soil Fines. These sites often occur in level areas with a limited intermittent water flow. They are well-drained and usually the intermittent flow is insufficient to preclude using a planting collar. Unless depredation is imminent, the protective screen is not used. Fast-establishing species watered with minimal irrigation was effective. Aspen, Scouler's willow, Blue elderberry, Lodgepole pine and Snowbush ceanothus were especially successful (Figure 5).

Spoil Areas. Spoil areas are similar to areas with gravel with soil fines except they are artificially constructed. Because of this, it is advisable, whenever feasible, to mix angular rock with the fines during construction. Mixing creates a gradation of particle sizes that allow proper drainage and resist erosion. At the upper spoil area of Lost Canyon, a 3/4 to 2 inch layer of topsoil was spread over part of the spoil area. This amount of topsoil was the only available material in the area. Results were striking with this limited amount of topsoil. Rather than a growing medium, it appeared that the topsoil acted as an inoculant. The grasses as well as the pine seedlings were especially vigorous and two to three times larger than the non-treated area. The interesting observation was that the trees were growing well in spite of the grass competition (Figure 6).

Bedrock or Hard Rock Areas. Limited woody plant establishment is possible in hard rock areas. However, significant establishment was observed with planting willow in seams of hard rock and aerial seeding of Lodgepole pine over rocky areas. Liner-size willows were inserted bareroot into seams of hard rock areas using a piece of rebar to create an opening in the seam. Rain water seeping into the seams appeared sufficient to establish the willows. No evidence of water seeping out of the rocks was observed. Similar observations were made in areas that had bedrock with shallow soil overlaying the bedrock. Various species of pine including Jeffrey and Lodgepole pines were established. Even if plants grown in hard rock have limited growth, they still provide benefits. Thorough stocking in bare areas in Lost Canyon was important to allow the maximum cover to develop. By selecting adapted species, surprising results have materialized in Lost Canyon.

Sand Dune Areas. In certain areas, thick deposits of sand created a dune-like planting situation. These were difficult to revegetate primarily because the upper layer of sand dries out rapidly in the early part of the growing season. However, by using the planting collar technique with minimal irrigation, good results were achieved. Selecting native species of willow that are known to grow in dry dune areas, such as Scouler's willow, is important.

Riparian/Wetland Area. Wherever moist riparian areas were encountered, re-establishing riparian vegetation was easily achieved (Chan and Wong, 1988). In perennial moist areas, cuttings were effectively established. In drier riparian areas, planting liner stock was more effective than cuttings. Growth of liner plants appear to be more vigorous than cuttings in drier areas. Most riparian species exhibited tolerance to a considerable range of soil moisture conditions, even quite dry conditions. Species included Aspen, Black cottonwood, Redstem dogwood, Scouler's willow and Spiraea. Other species of willow and Mountain alder did not exhibit such tolerance to dry conditions. An effective technique of establishing willow was to collect cuttings from prolific seed-producing individuals. The plants propagated from these individuals were planted along the stream channel and had a very high tendency to produce seeds which created rapid regeneration.

Native straw seeding was a very effective technique in re-establishing native herbaceous riparian vegetation. Mature seed heads are harvested by a high-wheel mower with a catch bag or a weed-eater type equipment with a catch bag. The harvested

Figure 5. Diversity of vegetation is important in Lost Canyon. Dynamic changes in species composition is anticipated with time. Revegetation accelerates the restoration process.

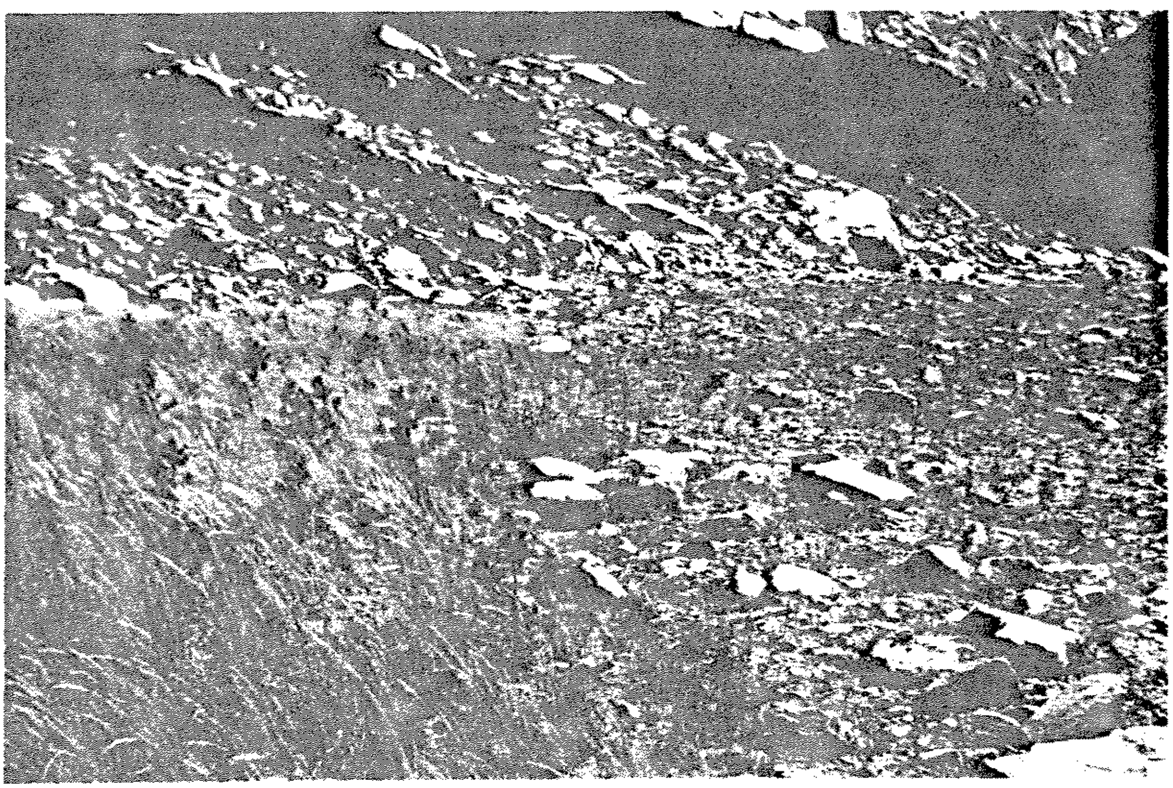

Figure 6. Three-quarters to two inches of topsoil was sufficient to enhance grass and tree establishment in a granitic spoil area. Trees are growing well with the grass competition. Note the non-treated area on the right.

material was uniformly spread over a prepared seed bed and lightly raked. This technique was also effectively used in dry upland areas using species such as Newberry penstemon, Azur penstemon, Lupine, Pearly-everlasting, Sulfur buckwheat, and native grasses. Native straw seeding implemented at the pond area near the pipe crossing in 1983 established a natural source of riparian/wetland species that spread downstream 3 miles within 5 years.

RESULTS OF MITIGATION REQUIREMENTS

For the revegetation mitigation requirements (Anonymous, 1985; Chan et al., 1986-1991; Degraff and Chan, 1988), the U.S. Forest Service required 400-500 woody plants per acre to be established. These plants were to consist of three vegetation types in proportion to the original vegetation in the Canyon area: conifers, montane chaparral, and riparian/wetland (Figure 7).

Results were successfully achieved as documented by a plant establishment survey conducted in 1988 which involved statistical sampling and analysis (Wong, 1988). The analysis indicated that an average of 621 woody plants per acre were established. The 3 vegetation types were established in the following numbers: 23,156 conifers; 2,475 montane chaparral species; 16,065 riparian species.

More recent review has revealed that plant numbers in Lost Canyon appear to be higher than the 1988 Survey in spite of six years of drought. Natural regeneration as well as regeneration of planted species have increased the total numbers of plants. Very few plant losses have occurred within the last four years.

CONCLUSION

Revegetation results have been achieved at more favorable levels than expected. Mitigation requirements were achieved and the established vegetation is improving and showing signs of continual perpetuation. Plants have responded surprisingly well in quite sterile and limited soil conditions. Even small plants that are over 5 years old show signs of adequate growth development in the future based upon their healthy color and appearance which is commonly seen in other plants growing in nature.

Lost Canyon should be considered a living laboratory for native plant studies. It offers opportunities to study plant growth and ecological development. Questions such as "how quickly can soil develop?", "how are soil micro-organisms re-established?" and "what are interactions and interrelationships of organisms in the development of an ecosystem?" are exciting to explore.

Ten years of results in restoring an ecosystem such as that in Lost Canyon is like a blink of an eye compared to the centuries that is required to reach maturity. However, for the 10-year period, dramatic changes have occurred. Initial establishment and species inoculation have been successfully achieved. We have begun the restoration process that nature will further develop and fine tune.

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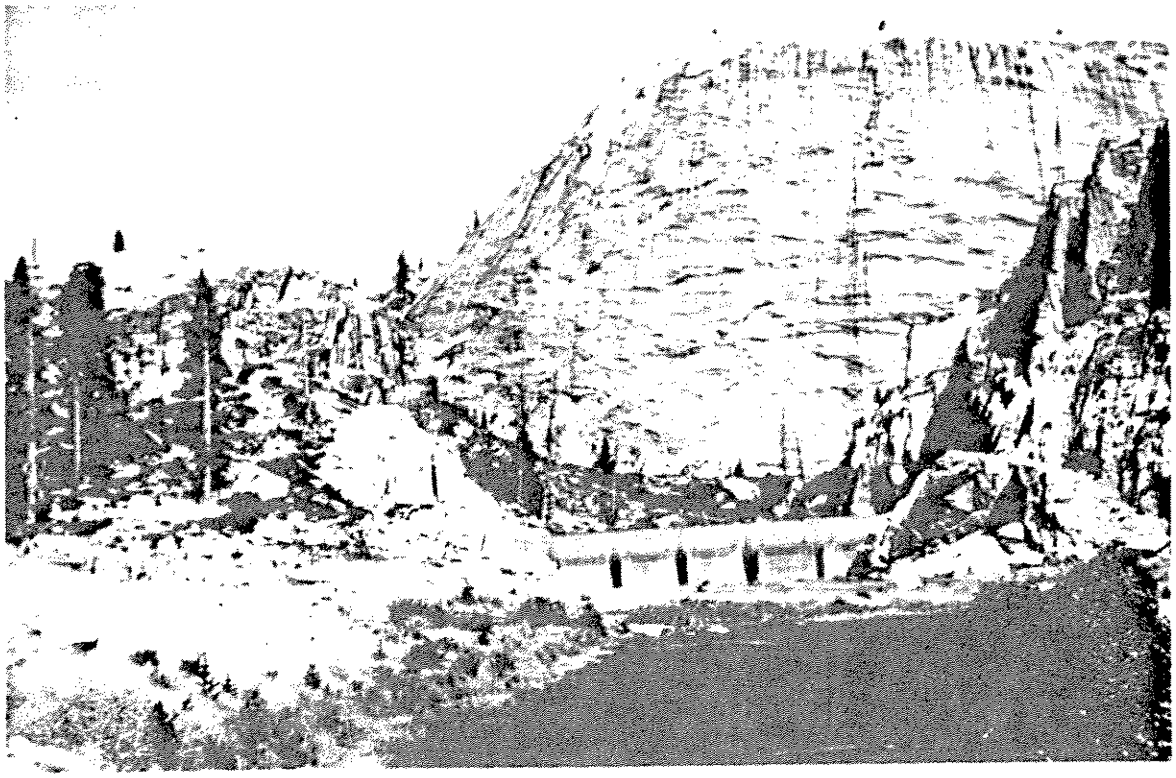

Figure 7. Pipe crossing at Lost Canyon. Photo was taken October, 1992, 10 years after pipe failure. Vegetation includes riparian/wetland, upland grasses, montane chaparral and conifers.

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ACHIEVING EFFECTIVE EROSION CONTROL AT LAKE TAHOE

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ABSTRACT

Revegetation is the most important aspect of erosion control. The three basic requirements for successful revegetation are: (1) a thorough, well-written set of plans and specifications, (2) quality installation, with full-time supervision by a revegetation specialist, and (3) quality follow-up work (inspection, watering, and replanting). Having a plant survival requirement helps to achieve a quality job.

INTRODUCTION

Lake Tahoe is famous for the clarity and purity of its water. It is one of the clearest lakes in the world. Yet, over the past 20 years, the transparency of its waters has been declining at the rate of 1-1/2 feet per year. In other words, a visitor to the lake today can see about 30 feet less far down into the water than he or she could 20 years ago. During this same period, the measured growth rate of algae in the lake has more than doubled.

Much of this decline in water quality is due to the effects of land development. When land is disturbed for road building or construction, the erosion rate increases from two to 2,000 times the natural rate. It has been estimated that the amount of sediment now entering Lake Tahoe each year is 20 times above the natural background rate. The eroded soil contains a mixture of nitrogen, phosphorus, iron, and other nutrients that stimulate algae growth, which is directly responsible for the diminished clarity of the lake.

The California Tahoe Conservancy is a state agency which purchases and restores environmentally sensitive lands on the California side of the Lake Tahoe Basin. The Conservancy also implements or gives grants for erosion control, stream restoration, wildlife enhancement, and public access projects. To date the Conservancy has funded 60 erosion control projects totaling over $25 million.

Except for the north end of the lake, which is volcanic in origin, most of the Tahoe Basin is granitic. Thus, most of the Conservancy's erosion control work involves stabilizing decomposed granite soils. Nevertheless, when we are doing erosion control and revegetation, we typically evaluate various site factors such as aspect (the direction a slope faces with respect to the sun), shading, slope steepness and length, soil moisture and fertility, and adjacent, undisturbed plant communities. These factors are discussed in detail later in this paper. While the origin of the soil is important, we usually do not specifically identify the soil type when doing a project, since the soils are usually quite similar (loamy sands, sandy loams, and sands).

The majority of the Conservancy's site improvement funds have been spent on grants to local agencies to implement erosion control projects in their jurisdictions. Revegetation is and has been the number one priority of the Conservancy's erosion control grant program. I believe it is the most important and cost-effective thing we can do to protect the lake. Revegetation typically costs 5-10% of the total cost of a project. While structural measures like curb and gutter and retaining walls typically cost $15-$30 per foot, revegetation costs about $0.10 to $0.50 per square foot ($0.10 for seeding and mulching only, higher for planting, blanketing, irrigating, etc.).

THREE RULES FOR REVEGETATION PROJECTS

After seven years of observing erosion control projects in the Tahoe Basin, I am convinced that the three basic requirements for a successful revegetation project are:

1. A thorough, well-written set of plans and specifications.

The plans and specifications become part of a contract -- a legal document that governs the performance of a job. By themselves, they don't ensure the success of project, but without them it is difficult to have success. For example, one recent project called for planting willow on a steep, bare slope. The specifications neglected to call for native species of willow to be obtained locally or from a similar elevation and climate. The contractor who won the job cut willows on his own property near Auburn, California (elevation 1,000 feet) and brought them to the project site at elevation 6,230 feet. The willows did not survive.

2. A quality installation, with full-time supervision by a revegetation specialist.

A first-rate set of plans and specifications is meaningless unless they are scrupulously followed during installation. Planting crews typically have minimal training and experience in proper revegetation practices. A revegetation specialist, not an engineer, should be on the job site throughout the project: first to train both the laborers and their supervisors how to do the work correctly, then to follow behind them to make sure they are doing it right.

For example, our specifications typically call for root balls to be loosened before planting and circling roots removed. On unsupervised plantings, we have found plants planted with their containers still on and rootbound plants loosely sitting in uncompacted planting holes. Such plants have a poor chance of surviving.

Since we have found that licensed landscape contractors tend to do a better job with revegetation than prime contractors (who are usually grading and excavating contractors on our projects), on recent jobs we have added the requirement that the revegetation portion of a project must be performed by a licensed landscape contractor.

3. Quality follow-up work.

Follow-up work after planting is often necessary to ensure successful revegetation. Maintenance watering during the first year after planting is particularly critical during prolonged droughts, like the one that has occurred in California over the past six years. The Conservancy usually requires one year of watering after planting and a performance standard for plant survival. After one year, planted areas are inspected. If the survival standard is not met, the contractor must replant back to the original planting density. The presence of these requirements in the project specifications does not, however, guarantee that they will be adhered to. The agency in charge of the project must make it absolutely clear that the contractor will be held accountable to them.

On the willow example site discussed above, a slide occurred shortly after the project was completed. The slope had to be repaired, and the county decided to cover it with riprap. Since the original specifications called for plants three feet apart, I insisted that plants be installed through the riprap and that they be watered until established. This planting was done, and now, three years later, woods rose, rabbitbrush, and other native species are thriving on the site. These plants, some of which are more than three feet high, have softened the appearance of the site, and will eventually provide the long-term stability that is desired.

Plant survival and irrigation standards are discussed in more detail later in this paper and in Table 1.

CRITICAL FACTORS FOR SUCCESSFUL REVEGETATION

The following factors are critical to achieving successful revegetation on difficult sites, such as decomposed granite slopes in the Tahoe Basin. Attention must be paid to these factors in the plans and specifications, during installation, and in follow-up work.

1. Evaluate the site conditions.

As discussed above, most of the sites we are working with in the Tahoe Basin contain decomposed granite soils. However, when evaluating a site to determine the plant selection, we also pay attention to:

Aspect. Aspect is the direction a site faces with respect to the sun. South- and west-facing slopes are the hottest and driest. North-facing slopes are the coolest. East-facing slopes are in-between.

Table 1

SAMPLE PLANT SURVIVAL AND WATERING STANDARDS

PLANT SURVIVAL

Minimum Survival Time

The survival of revegetation shall be guaranteed for at least two years after planting. Plants shall be maintained in a healthy condition.

Inspection

All revegetation sites shall be inspected by the contractor and the revegetation specialist one year and two years following planting. The contractor shall determine the percentage of plants which did not survive and submit for approval by the revegetation specialist a replanting plan for each site. The replanting plans shall provide for the replanting of all areas that do not meet the survival standard. Such areas shall be replanted with the species mixes and planting densities called for in the original specifications. Compensation for such replanting shall be included in the unit prices for revegetation bid items.

Herbaceous Plant Survival

A substantial ground cover of live grasses and forbs shall be maintained throughout all seeded areas such that there is no evidence of rills, gullies, or other erosion.

Shrub and Tree Survival

At least 80% of planted shrubs and trees shall be alive and healthy.

Willow Wattling

On the average there shall be at least one live shoot per foot of willow wattling.

Willow Cuttings

At least 50% of willow cuttings shall have live top growth.

WATERING

1. Plants shall be watered as often as necessary to ensure their survival.

2. As a general rule, plants shall be watered when the top two inches of soil become dry.

3. When watering, the soil shall be saturated to a depth of at least two inches below the roots of the planted vegetation. After each watering, the contractor shall check the soil with a moisture meter or by digging small test holes to verify that water has penetrated to the proper depth.

Exposure. Exposure is the amount of shading throughout the day. A steep north-facing slope will receive little direct sun. A south-facing slope could receive continuous sun, but if it is adjacent to tall trees, it could be as shaded as a north-facing slope. Sites that are shaded in the afternoon should be moister than sites shaded in the morning, because the afternoon sun coincides with the highest air and ground temperatures.

Slope Angle and Length. Steep slopes are the hardest to revegetate. Erosion can occur on a steep slope due to gravity alone (i.e., without rain or runoff). Slopes that are very steep or long probably require benching or terracing. Installing a rock breast wall or a wood or block retaining wall at the toe of a slope allows the slope above the wall to be at a gentler angle. It also may allow for a flat area behind the wall where vegetation can grow easily. Mid-slope benches can be created by installing willow wattling or simply by shaping a flat spot on contour with a shovel or hoe. The flat spot is an easy place for plants to become established. It is also a good place for workers to stand when planting a slope. Plants that get a toehold on slope benches can become the seed source for spreading the vegetation to the rest of the slope.

Soil Moisture. While decomposed granite soils are typically well-drained and dry, they can be quite moist if there are seeps or if a cut bank intercepts a subsurface flow. Looking at the existing plant community and spacing gives clues about the moisture condition. If there are willows present, there is probably a seep. If the ground is relatively flat and the plants are widely spaced, the site is probably quite dry.

Soil Fertility. Most decomposed granite soils are low in key nutrients, particularly nitrogen, phosphorus, and sulfur. They are also low in micro-organisms which convert organic or atmospheric nitrogen into a form plants can use. In addition, they are low in nutrient-holding capacity because they are coarse-textured soils, which are lacking in clay and silt-size particles. Many of our revegetation sites are roadcuts, where topsoil has been removed and infertile subsoils are exposed.

Since the Conservancy wants to avoid adding nutrients to Lake Tahoe, we normally specify a slow-release fertilizer. Slow-release fertilizers are highly compressed or coated, and thus release their nutrients over a period of months rather than days or weeks. Though not as effective as fast-release fertilizer for establishing a quick grass cover, they seem to be effective for establishing a long-term cover.

Recently we have been using soil amendments such as Biosol®, which is a by-product of penicillin manufacturing and contains beneficial micro-organisms. The micro-organisms in the soil amendments are for the purpose of enhancing soil development. Biosol® has been used successfully on several projects in the Tahoe Basin.

2. Select the right plants for the site.

The plants used for revegetation should be adapted to the site conditions found by evaluating the above factors. The native plants growing on adjacent undisturbed areas are a good indicator of the types of plants that can eventually become established on a disturbed site. Though we usually want to re-establish the native plant community, the poor subsoils exposed at the surface may not initially support the native climax vegetation. Thus, we often specify plantings of native, colonizing species such as sagebrush or bitterbrush, which are better adapted to harsh sites, with poor soils and poor growing conditions (exposed to sun and wind, etc.).

Ideally, plants used for revegetation should be grown from locally collected seeds or from a plant source in a similar climate. The Nevada Division of Forestry nursery in the Carson Valley grows the majority of plants used for the Conservancy's revegetation projects.

3. Plant at the right time.

Most revegetation in the Tahoe Basin is done in the fall after construction of structural improvements (retaining walls, pipes, etc.) are completed. When planting container or bare-root plants in the fall, the ground should either be moist from fall rains or the plants should be watered at the time of planting. If watering is done, it should be continued until permanent snow cover occurs or until temperature and sun conditions (sun angle and day length) are such that the ground will no longer dry out completely between waterings. It is preferable to plant by October so that plants have some time to begin rooting before winter.

Grass seeding in the fall generally should be done as late as possible but before permanent snow cover occurs. The risk of seeding earlier is that the seeds will germinate and the young seedlings will be subjected to freeze-thaw conditions and frost kill. Our recent experience has shown that this risk may not be as great as previously thought. Alternatively, grass can be seeded early in the fall and irrigated until established, so that it is large enough to withstand freezing conditions before winter hits. The grass will also be able to withstand erosion from heavy rains, which are much more likely to occur after the middle of October.

The advantages of spring plantings are that the soil is normally moist from snowmelt and winter rains, temperatures are cool, but days are long. The disadvantages of spring plantings are: (1) the risk of frost kills from spring cold snaps (which is greater at higher elevations, such as at Lake Tahoe), (2) difficulty of site access due to partial snow cover or muddy ground, and (3) the necessity to irrigate over the entire summer if plants are not well-established before it stops raining and hot weather arrives. The need to irrigate is greater for spring plantings than for fall plantings.

4. Prepare the ground for planting.

Seed beds should be rough and loose, so seeds can fall into crevices in the soil and be covered with soil. If the soil is reasonably soft, hand raking with a dirt rake should be sufficient to roughen the seed bed. If the soil is hard or compacted, it should be loosened by ripping or disking. Ripping is done by pulling a bar behind a tractor which contains a row of large steel tines. The tines are usually six to twelve inches long.

5. Seed and install plants properly.

To germinate, a seed needs to absorb water. A seed surrounded by soil can absorb water much better than a seed on the surface. Hand seeding is better than hydraulic seeding, because hand-sown seeds tend to have good seed/soil contact. Some of the seeds fall into small crevices in the soil, while others are easily covered by light raking. In contrast, hydraulically-applied seed tends to get pasted on the surface, particularly when it is applied with wood fiber mulch. After seeding, the ground should be raked lightly to cover seeds with 1/4 inch to 1/2 inch of soil.

Planting holes should be dug by hand. (One contractor devised a method of punching plant holes with a metal probe welded onto a backhoe bucket. The side walls of these holes felt like the inside of a terra cotta pot.) The hole should be dug slightly deeper than the length of the roots (Figure 1). We normally place a little slow-release fertilizer in the bottom of the hole, then put the plant in and backfill with the native soil. We prefer to use the native soil rather than imported topsoil, because roots do not like to go from one soil medium to a poorer one. They also do not like to go from a loose soil to a compacted soil, which is why hole punching is undesirable.

Finally, we require that a small well or depression be dug around each plant. The wells trap rain, irrigation water, and snowmelt, which helps the plant to survive. On slopes without wells, it is very difficult to get water into the root zone of the plants, because most of the water runs off the surface, which is often hard or crusty. Where a well is present, a person using a hose with a soaker attachment (a nozzle with lots of large holes, which discharges a large volume of water at low velocity) can apply a half gallon of water in a few seconds, and most of that water will percolate to the roots of the plant.

An alternative to wells is a cylindrical collar, made of four-inch plastic pipe (Figure 1) or cottage cheese containers without bottoms. The collars not only facilitate watering, but also make it easier to find the plants.

Though our project specifications typically require plant wells, they are rarely constructed properly, if at all, unless a trained inspector is present. The inspector needs to demonstrate how to construct a well, explain why it is important, then observe the workers as they plant. The wells should be constructed by excavating a circular depression around the plant rather than mounding soil, because mounds tend to break down quickly during storms or during watering, which fills in or eliminates the pocket.

Similarly, details like digging the planting hole to the proper depth, loosening the roots, and breaking off circling or J roots often get overlooked unless a revegetation specialist is on the job site. It is common for a planting crew to start a job properly, but get progressively sloppier as the day or week wears on. This is human nature. Holes are dug shallower and shallower, root balls are left compacted, and some plants are even planted in their containers.

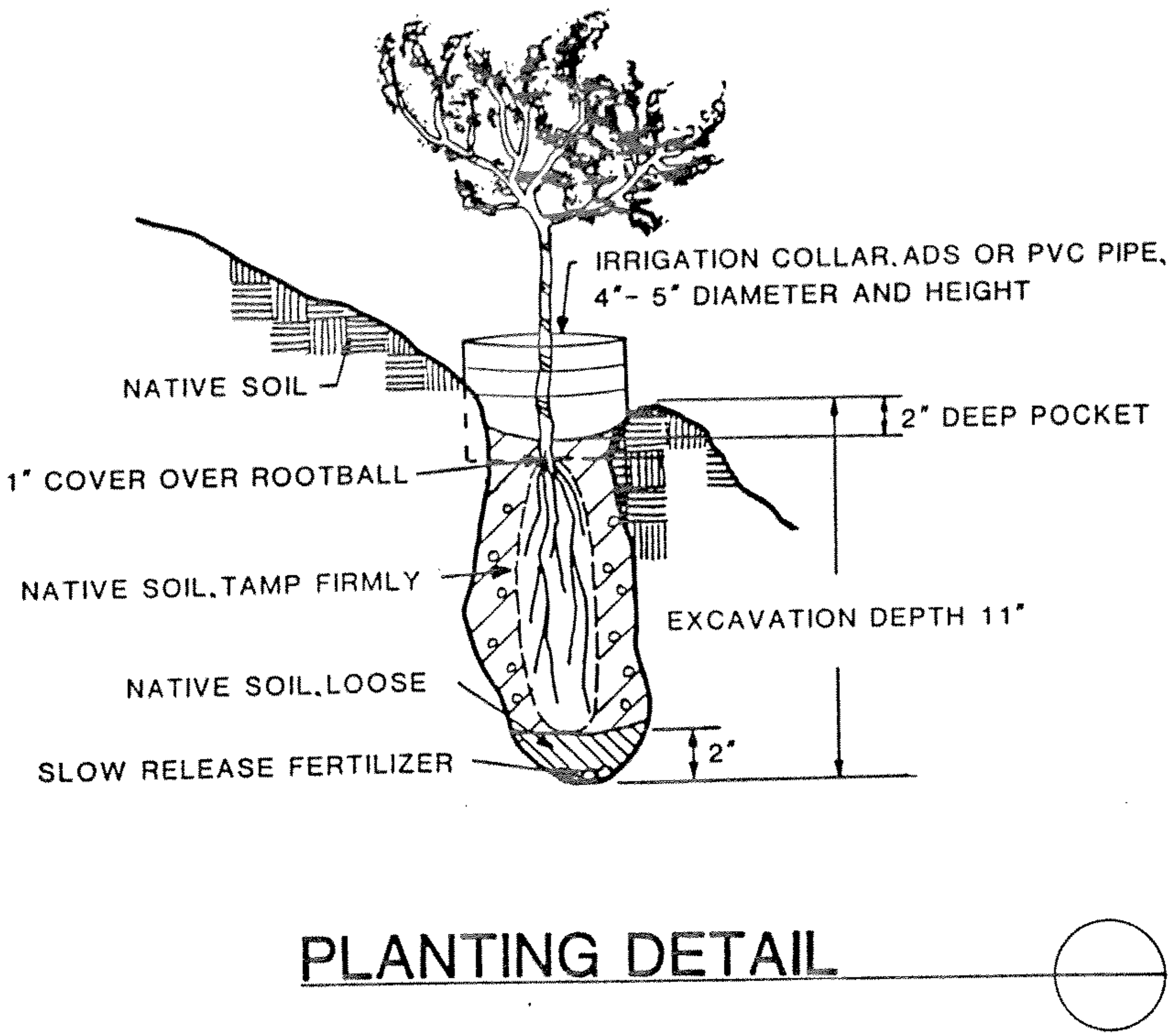

Figure 1. Sample planting detail

Planting properly can mean the difference between survival or death for a plant, or between success or failure of a job. That little bit of water trapped in a plant well may give a plant that little extra help it needs to survive. The inspector can ensure work is done properly if he or she is on the site.

6. Apply mulch properly.

Straw mulch and mulch blankets made of straw or excelsior have proven to be much more effective than wood fiber mulch in preventing erosion and establishing vegetative cover. To be effective, however, mulch must be applied properly.

Straw must be applied at the correct rate (at least 3,000 pounds/acre) and must be well anchored. If a tackifier (i.e., a glue) is used, it must be applied at the correct rate. Watered-down tackifiers do not hold effectively. If straw is anchored by punching or crimping, the punch holes should be no more than about six inches apart.

I have observed numerous job sites where the first strong wind blew away more than half of the straw. While rain can help hold straw in place by making it heavy, storms are often preceded by high winds which blow away the straw before the rain can mat it down.

Mulch blankets provide a longer lasting mulch cover than tacked straw. Straw blankets typically last two to three years, compared to a year or less for tacked straw. Again, to be effective, the blankets must be installed correctly. Outer edges must be keyed into the ground. Staples must be long enough to achieve a firm hold. A six-inch staple in loose, sandy soil probably will not work. That is why we now specify "Staples must be long enough to achieve a firm hold," rather than calling for staples of a specific length. Many times, a contractor has had to order longer staples to complete a job after finding that the initial staple size was not long enough.

7. Check soil moisture and water when needed.

Soil moisture must be checked regularly. During mild or cloudy weather, one check every two weeks may be sufficient. However, during hot, dry periods, more than one inspection per week may be necessary. Our standard specification calls for watering when the top two inches of soil become dry (see Table 1).

Soil moisture can be checked with a moisture meter or a finger, or by digging small holes with a shovel or trowel. A moisture meter is a simple device that can be purchased at a hardware store or garden shop for $10-$15. It consists of a soil probe connected to a meter. Several readings at different locations and depths are desirable to obtain an accurate picture of soil moisture conditions. While a finger can suffice as a moisture meter, a shovel or metal rod may be necessary to break through a hard surface crust to reach the subsoil in the root zone.

Water infrequently but deeply. Our specification calls for wetting the soil to a depth at least two inches below the bottom of the roots, to make the roots grow down for water. If the top layer of soil is kept continuously wet, roots remain near the surface. Then, when watering is stopped, the top layer dries out and the plants die. To survive, a plant's roots must reach a depth where it can find water throughout the dry season.

El Dorado County has achieved plant survival rates exceeding 90% on sites which were watered during the first year following planting (Figures 2 and 3). During the summer, a county worker travels around the county checking soil moisture on the various revegetation sites. If he finds low readings on a site, he calls in the county water truck. Normally, watering can be discontinued after the first year.

In contrast, on other sites within the Tahoe Basin where watering was not done, survival rates have been as low as a few percent.

8. Inspect plants for survival and replant if necessary.

A survival standard is critical to achieving quality control during planting and watering. If the contractor knows that he or she will have to replace dead plants, he or she will be more likely to do a careful job. If plant survival does not meet the standards in the project specifications, the contractor or grantee agency must replant to the original planting density.

The Conservancy generally requires that plant survival be guaranteed for at least one year after planting. While two years is preferable, both the contractor and the administering agency are usually anxious to close out the project and release the bonds as soon as possible.

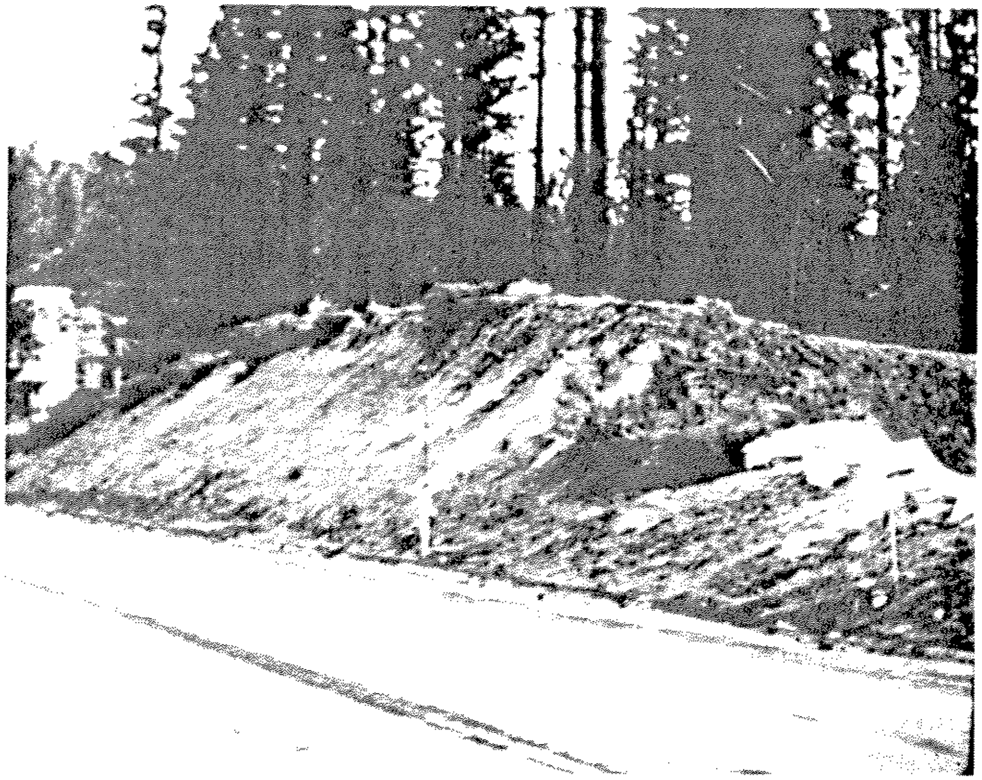

Figure 2. Bare roadcut on Pioneer Trail, El Dorado County, 1989, before revegetation. This roadcut had remained devoid of vegetation for nearly 30 years, despite an earlier attempt to revegetate it in the early 1980's.

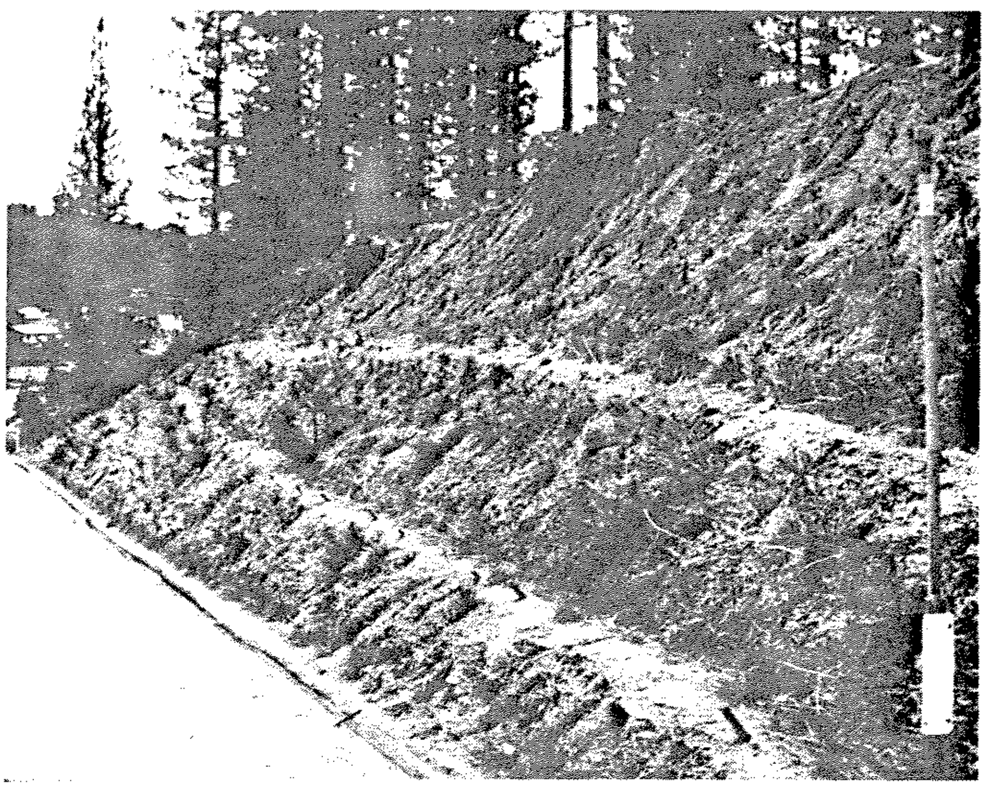

Figure 3. Pioneer Trail roadcut, April 1992, 2-1/2 years after revegetation, using willow wattling, straw blankets, grasses, shrubs, and trees. It was watered during the first year after planting.

The Conservancy's standard specifications (Table 1) for plant survival are:

1. 80% for container plantings of shrubs and trees.
2. A substantial cover of grasses and forbs, such that there is no evidence of rills, gullies, or other erosion.
3. One live shoot per foot of willow wattling.
4. 50% of willow cuttings have live top growth.

An inspection is done one year after planting, normally in the fall. The inspection is attended by representatives of the local agency and the contractor, and preferably by the revegetation specialist who supervised the planting. It is important that all parties be present so that a consensus can be reached on how much replanting is necessary. If the contractor is not present and does not personally see the dead plants and eroding areas, disagreements often arise.

The decision whether replanting is necessary is often a judgement call. If the precise survival standard was not achieved, but the site looks stable, then the contractor may be released from his or her replanting responsibility.

CONCLUSION

Successful revegetation of decomposed granite or any disturbed soils takes effort and attention to detail. As previously stated, the prerequisites are good specifications, quality installation, and quality follow-up work (inspection, watering, and replanting). Failure in any one of these areas can result in failure of the job. However, if the person or agency responsible for the project cares enough and is willing to persevere through all the little details and stand up to those who try to cut corners, success will be achieved.

A NURSERYMAN'S VIEWS ON REVEGETATING DECOMPOSED GRANITIC SOILS: LESSONS LEARNED FROM REFORESTATION

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ABSTRACT

Revegetation of decomposed granitic soils with long-needled pine species, where appropriate, and using stock types and methods developed by the forest products industry for reforestation of harvest areas offers a great potential for success, at relatively low cost. Reforestation methods used to maximize the probability of success are relatively simple in concept, but often difficult to execute. Success requires: 1) selection of appropriate species; 2) acquisition of good seed or other propagation material; 3) selection of competent growers; 4) understanding production cycles and providing the grower with sufficient lead time; 5) proper stock handling prior to planting; 6) selecting competent and experienced planters; and 7) planting at the optimum time.

DEFINING "SUCCESS"

This paper proposes that revegetation of decomposed granitic soils with long-needled pine species, where appropriate, using stock types and methods developed by the forest products industry for reforestation of harvest areas, offers a great potential for "success", at relatively low cost. Other woody species offer similiar benefits on appropriate sites.

"Success" means establishment of vegetation which re-establishes the natural condition of a deeply penetrating root system and a stable, uninterrupted surface mulch layer. This condition often exists even on formerly disrupted sites, where a sufficient density of long-needled pines has become established.

Benefits of Long-needled Pines

There are three reasons long-needled pine species, especially ponderosa and jeffrey pine, are potentially the best choice for many sites. First, they occur naturally on decomposed granitic soils. Second, the long needles form an effective mulch which resists wind and downslope movement even on quite steep and exposed road cuts. Third, pine seedlings have been produced in large quantities for the forest industry and therefore, the horticulture requirements (from seed collection and storage, to nursery culture, packing, storing, and planting) are well known. This means that the chance of success is much greater with these species than with the host of obscure native plant species which tend to find their way onto the revegetation "wish" list (White and Franks, 1978).

LESSONS FROM REFORESTATION

Seedlings and methods used by the forest industry tend to be the lowest cost way of getting the most successful possible reforestation of a site, because of the economic restraints placed on company management. For example, foresters for Fruit Growers Supply Company out of Hilt, California decided to revegetate bare decomposed granitic cut and fill slopes along access roads near Etna, California (Figures 1 and 2). Using their regular containerized ponderosa pine planting stock and a commercial planting crew, they planted approximately 20,000 ponderosa pine on 4-6 foot spacing. At a cost of $0.13 per seedling, and $0.17 for planting (including adminstrative costs), this works out to about $0.30 per planted seedling or about $522.00 per acre. The second year survival on this particular planting is around 90%.

The short-term benefits of this planting are limited to a small amount of mechanical stabilization of the slope by the stems of the trees. However, potential long-term benefits are a deeply penetrating root system and a permanent needle mulch cover which will effectively eliminate erosion (Megahan, 1974). This result is in contrast to many grass seed and erosion blanket applications where the short-term benefits are great, but the long-term benefits are

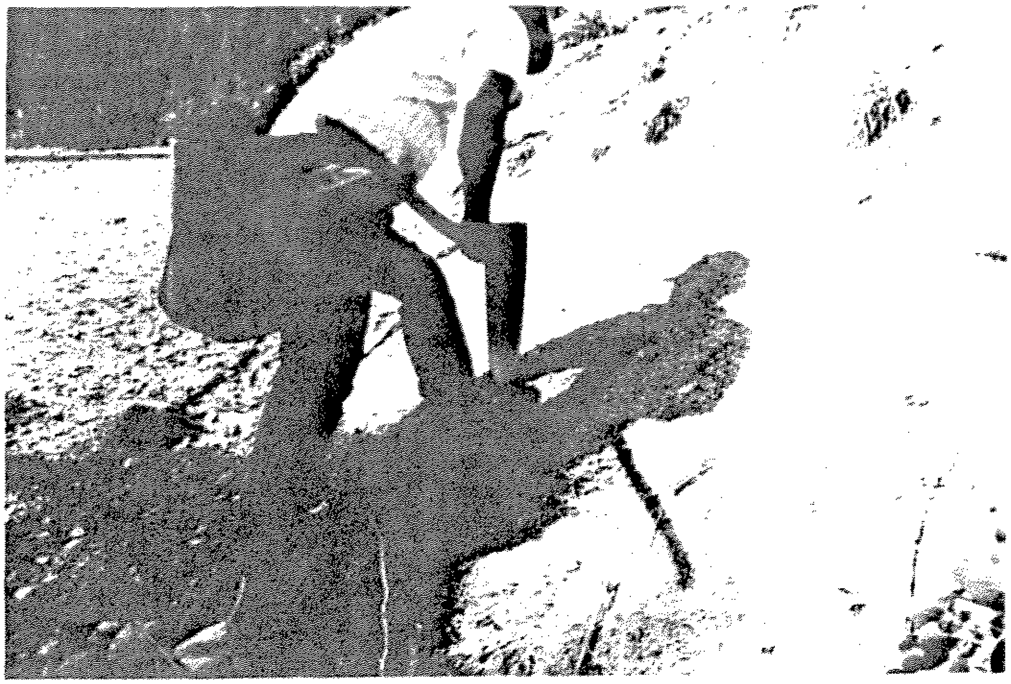

Figure 1. Commercial planting crew member using hoe-dad to plant pine seedling in granitic road cut.

Figure 2. Example of spacing for ponderosa pine seedlings on granitic road cut. After one year, these seedlings have had a 90% survival rate.

essentially nil.

Keys to Success

Reforestation methods used to maximize the probability of success are relatively simple in concept, but often difficult to execute. Success requires:

- selection of appropriate species
- acquisition of good seed or other propagation material
- selection of competent growers
- understanding production cycles and providing the grower with sufficient lead time
- proper stock handling prior to planting
- selecting competent and experienced planters
- planting at the optimum time

Selection of Species

Selection of species which will have the highest probability of success can be achieved as follows (Gray and Jopson, 1979). First, choose species which are capable of growing on the actual site. The best way to avoid mistakes is to limit the choices to species which already occur on the site or on very similiar sites. Second, choose species which have been grown and planted successfully in meaningful quantities under the conditions found on the site. Third, choose species for which reproductive material (seed or cuttings) is readily available, or can be made available, in suitable quantities. Fourth, choose species which, if they survive and grow, can demonstrably contribute to the long-term stability of the site (Megahan, 1974). What will they look like in ten years?

There are very few species available which can meet all of the criteria. This paper focuses on the conifers, and the long-needled pine species in particular, just because they come closer than any other to meeting all of the criteria. However, there are many sites for which they are not appropriate and suitable alternatives are difficult to find. Species which fail to meet all of these criteria should be considered experimental. The probability of success will be low until more experience with them has been acquired.

Seed Collection

Acquisition of seed for woody plants from appropriate sources may require substantial lead times (often years) and in-depth knowledge of seed collection requirements. The standard in the forest industry is plus or minus 500 feet from the site elevation and from the same climatic or seed zone (U.S. Forest Service, 1974). The difficulty is that conifers, and many other woody species, do not produce collectable seeds every year. The average years between good seed crops for ponderosa pine is about 7 years. Thus, advance planning is a must. When seed is collected, it must be collected at the proper time, and handled in the proper way to insure maximum viability. Trying to grow seed which has been collected too early or badly handled is a nurseryman's nightmare. Many agencies, such as the U.S. Forest Service and state forestry departments, and private seed companies have expertise in these areas and should be at least consulted before seed collection is attempted.

Seedling Production

Seedling production also requires advance planning. The highest probability of obtaining quality seedlings will be achieved by selecting a nursery which has experience in the production of seedlings for wildland plantings. Most likely this will be a reforestation nursery. Too many revegetation plantings fail because the stock is obtained as cast-offs from other projects, grown as a 'class project' by the local high school or ROP program, or from other socially meaningful but often horticulturally distastrous sources.

The lead time for a typical containerized seedling includes approximately three to four months prior to the March or April sow for contract finalization, seed shipment, and seed stratification. The seedling would then be available for planting if the Fall of the same year or the Winter or Spring of the following year. Giving the nurseryman sufficient lead time will allow production of the best possible seedling.

Packing and Storage

If seedlings are to be planted in Winter or Spring, they will have to be packed and stored. Appropriate packaging (i.e., vapor barriers in boxes or bags) and storage conditions (either freezer -1 °C or refrigerator +1 °C) allow seedlings to be stored for up to four months with little loss of vigor, assuming they were in a dormant condition when packed.

Planting

Proper planting is a crucial step which requires attention to two factors: timing and method. The "right" time to plant a seedling is when the soil is warm enough to allow good root growth (5-10 °C), and the moisture content is at field capacity. Of course it is also nice if a warm rain falls every day for the next two weeks and the wind doesn't blow at all. Cold soil means that the seedling will sit in the planting hole and do nothing at all. It may as well still be in storage where it is not subject to desiccating winds and being eaten by animals. Planting outside of the ideal conditions means the probability of success diminishes.

Good planting method is dictated by three factors: good people, good people, and good people. Good means caring about the result of the planting, experienced in planting seedlings, and willing to be flexible to achieve the goal of planting each seedling at the right time and in the right place. Good also means supervision by people who understand the importance of timing, know what constitutes a good planting job, and who are willing to do whatever inspections and enforcement are necessary to insure the best possible job.

In inland areas, away from the coast, these criteria are most likely to be met in the spring of the year, after the soil have warmed up a little. In coastal areas, the soil temperature criteria may be met almost all year, leaving the moisture criteria as the most important. In areas of reliable summer rainfall, the criteria may be met in the summer.

The quantity of plants on a typical revegetation project tends to be small, so that most of the planting can be accomplished at the right time. This fact, if used to best advantage, will enhance the chance of success of the project.

CONCLUSIONS

The lessons learned from many years of wildland reforestation offer significant hope to those who are attempting the more difficult task of revegetating disturbed decomposed granitic sites. Those lessons provide a basis for evaluating the probability of success of a wide range of potential practices and point to specific practices which have a high probability of success if adopted for use by revegetation specialists. The technology is not glamorous, but it does have the advantage of a proven record of success when properly executed.

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HEADCUT AND GULLY CONTROL ON DECOMPOSED GRANITIC SOILS OF THE SIERRA NATIONAL FOREST

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ABSTRACT

Watershed rehabilitation efforts using innovative bowl structures have been very successful in stabilizing headcuts on the Sierra National Forest. This unique method uses geotextiles (filter fabric) to relieve subsurface seepage pressures and help prevent soil piping. Gullies within channels have also been successfully treated using various types of structures in conjunction with the use of filter fabric.

PURPOSE

Repairing gullies and headcuts by building in-channel structures that stay in place and accomplish their intended purpose is a difficult task. Many methods have been used in the past with varying success. Even with repeated maintenance, these methods typically fail due to inadequate spillway size and/or soil piping. This paper will give some suggestions and describe successful methods of gully and headcut control used on the Sierra National Forest.

PROBLEMS

Constructing in-channel dams is the standard method to trap sediment and allow headcuts and gullies to stabilize. Building materials include logs, bags of soil, soil cement, single and double rock fences, loose rock dams and poured concrete. Dam construction requires annual inspection and maintenance to detect any signs of failure and repair them before the entire structure is rendered unusable.

Most causes of structure failure are inadequate spillway design and soil piping. The dams are usually built with little or no bank armoring. Bare soils are not protected from high flows and are easily eroded around one end of the dam. Soil piping is another major cause of structure failure. Saturated soil flows through holes in the dam or around and under the structure, resulting in it being washed out.

Another problem unique to headcut repair is the upstream migration of the headcut above the structure, which can leave the structure behind without stopping the headcut. Failure is caused by continual soil movement through the structural material,
allowing the headcut to continue its upstream migration.

GEOTEXTILES

This material comes either as a woven or felt-like fabric. It is used to relieve the subsurface pore pressure by allowing water, but not soil, to pass freely through it. As the water flows from the soil through the fabric, it carries fine particles with it. Larger soil particles stay behind and form a thin layer adjacent to the fabric. This layer acts as a filter for smaller particles. As this particle migration process continues, it forms a graded filter system that helps to prevent the clogging of the cloth (Figure 1) (University of California, 1985). Geotextile material comes in different pore sizes and should be sized for the specific soil at the site of use. Sizing is important because it prevents clogging of pores too small and piping with pores too large. Check with a geotechnical engineer for this sizing procedure.

Either woven or felt cloth can be used. Felt will stretch and conform to uneven contours better than woven and, if rock is applied by a machine, it is tougher and will not tear as easily. Always completely cover the cloth to protect it from ultra-violet (UV) light. Even if it is UV resistant, covering

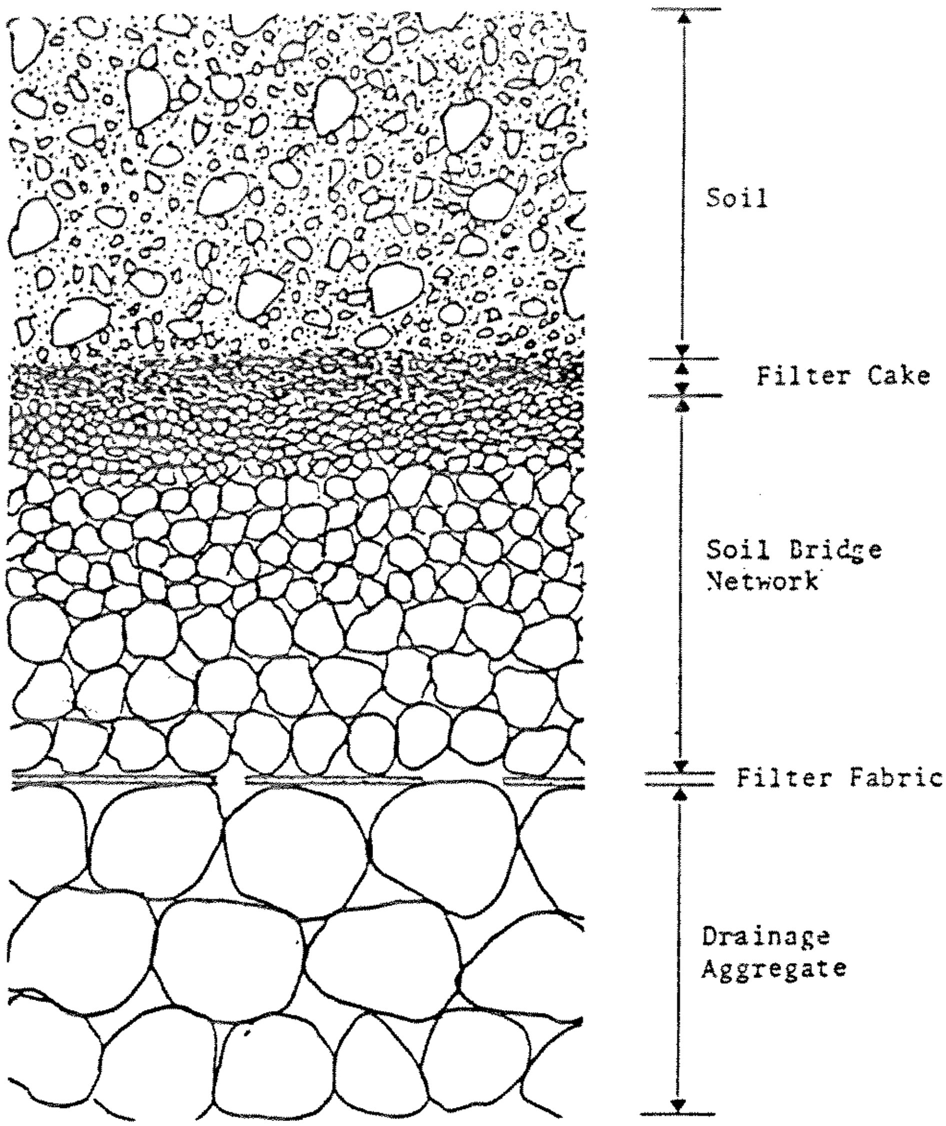

Figure 1. Filter formation (not to scale).

will protect it from animals and people.

SPILLWAY TECHNIQUES

Spillways should, at a minimum, be sized to contain the 2 year bank-full discharge. A quick measurement of the channel above the problem will reveal the necessary size. Armoring of the spillway ends and providing an armored rout for higher flows will help insure the structure will not wash out the first year. This practice is no guarantee, however. Water will find its own path, and not always the one expected.

Another method is to divert the high flow out of the channel and spread it onto the meadow. Care must be taken to locate the exact spot the water will re-enter the channel, and armor that spot. Failure to do this will usually result in a new headcut.

DAM CONSTRUCTION TECHNIQUES

The use of filter fabric on all structures is the biggest secret to success. Line the upstream side of the structure with cloth as if you were trying to seal and make the dam hold water. This practice will help prevent piping. Nothing will "guarantee" piping will not occur, but this method is the best one found so far.

All structures need to be keyed into the channel bottom and sides. Extend the ends of structures into the banks at least 18-24 inches, and into the channel bottoms 12-18 inches. If a rock bottom is found, extend the filter cloth upstream over the bare rock and cover it with compacted soil and 6 inches of rock. Insure cloth is wrapped around the ends of the structure keys and secured. This will help hold the fabric in place while the structure is being built.

BOWL STRUCTURES FOR HEADCUT CONTROL

Filter cloth is ideal and absolutely necessary for repairing headcuts. Oftentimes these cuts are not aggravated by overland flow, but from ground water seepage. The weight of the saturated soil is more than can be supported at the vertical angle and mass movement occurs. The cloth will allow the water to flow out, reducing the weight and preventing continued failure.

The headcut must be sloped back to a 1 1/2 to 2:1 ratio. The filled material must be covered with the appropriate pore-sized filter fabric (Figure 2). The top of the headcut should be notched and the fabric tucked into this notch. All of the cloth should be covered with 6 to 12 inches of 6 inch plus angular rock. Place larger rock at the bottom and work up slope, fill all voids with smaller rock. Insure cloth is not exposed to light. Wedge rock into the notch at the top to hold the fabric in place. If the structure is in a channel and carries water, extend the cloth up the channel a few feet, bury its end into the substrate and cover it with rock. This extra effort will insure water will flow over the cloth and not under it. Be careful not to block the channel with the angular rock. Extend the rock below the structure for a distance equal to the height of the headcut (Figure 3) (DeGraff, 1990).

Round river rock can be used, but it must be covered with a wire mesh to prevent it from being washed away under heavy flows. The mesh is unsightly, may cause injury to people and animals, and will eventually need to be replaced. Angular rock is best, as it will stay in place during most flows without assistance. Soil can be placed in the rock to speed up the revegetation process. Seeding with local native species is also recommended.

MAINTENANCE

All structures must be inspected after the first year. If they fail, it will usually occur the first year. Maintenance costs are usually low for bowl structures compared to dams. Leave some extra rock at each site to use the next year. Soil sometimes settles and additional rocking may be needed. Rock may also be washed away in high flows and must be replaced. Dams are notorious for needing continual maintenance. Inspect annually, especially if heavy storms occurred.

CONCLUSION

Hopefully, this paper has stimulated some ideas. No two situations are alike and techniques will not always work the same. Since conditions vary, do not be afraid to experiment with a new idea. Experiment on a small scale so, if it does not work as well as expected, all is not lost. Use filter fabric to prevent piping and plan for high flows over the dams. These techniques have been used on the Sierra National Forest for the past 5 years with good results.

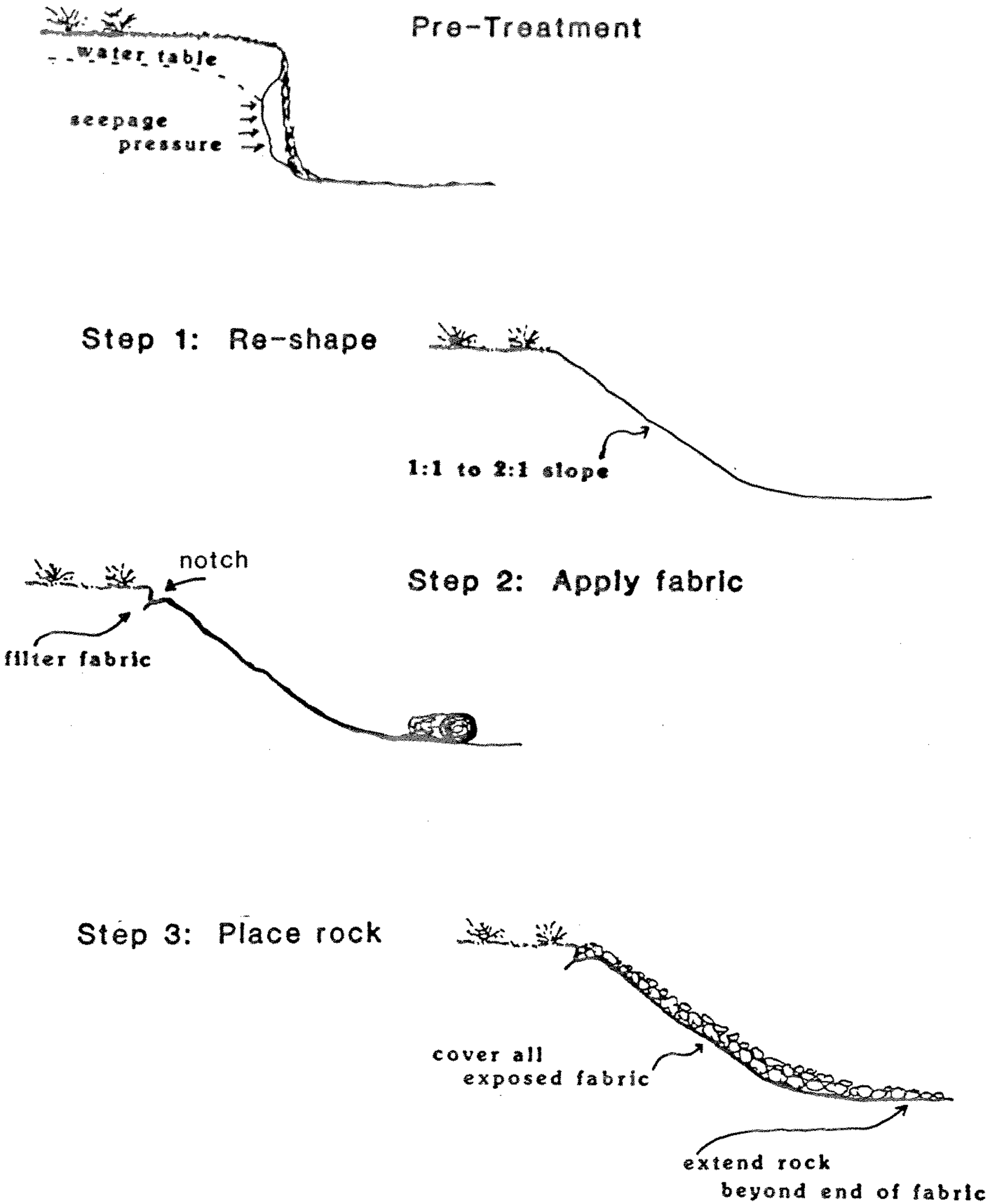

Figure 2. Diagram showing basic steps in meadow headcut stabilization *(DeGraff, 1990).*

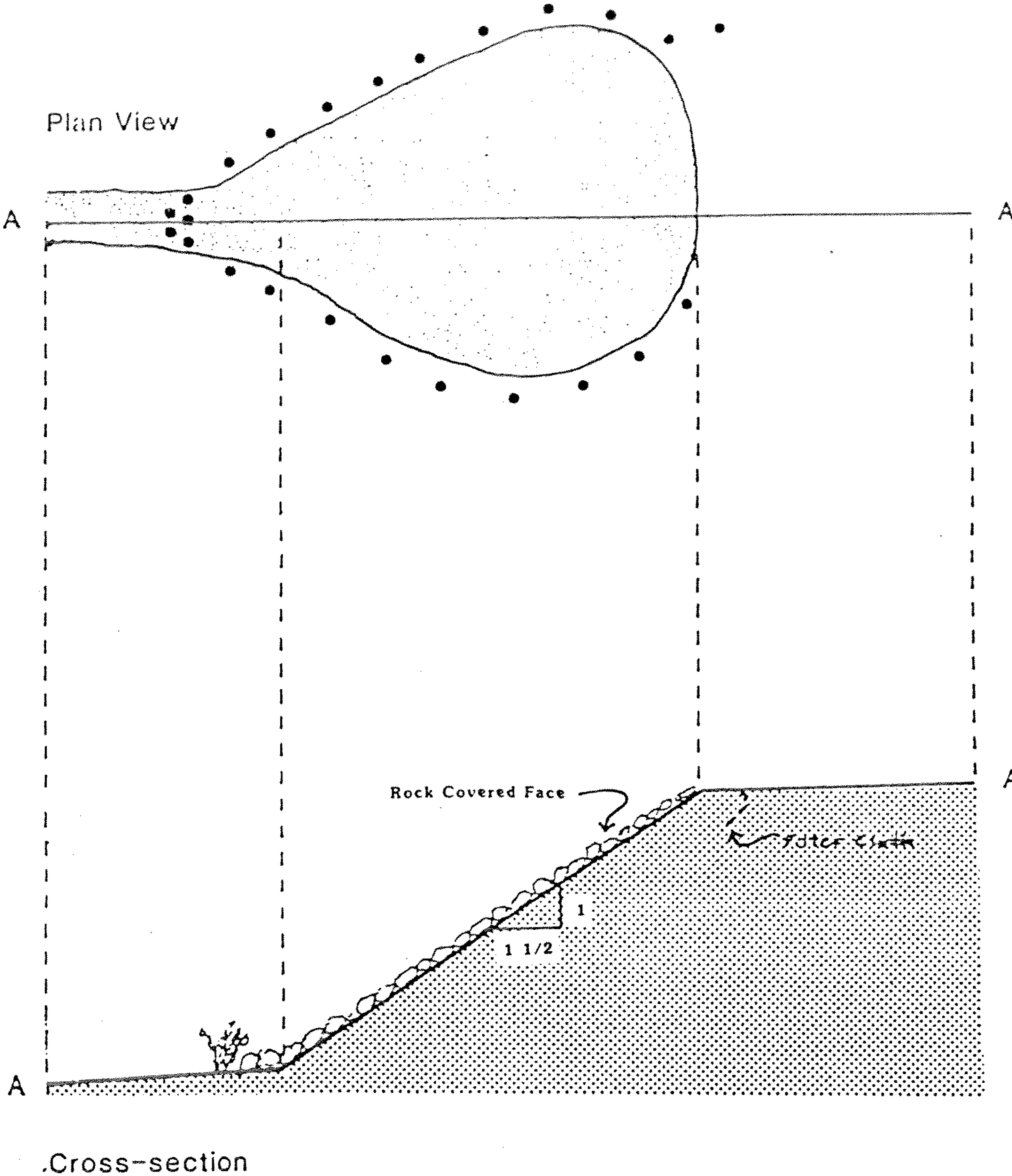

Figure 3. Typical headcut treatment *(DeGraff, 1990)*.

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LOWER SOUTH FORK TIMBER HARVEST PLAN: A DECOMPOSED GRANITE RESTORATION CASE STUDY

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ABSTRACT

Following the 1990 logging of a timber harvest plan in the Mokelumne River watershed, field review revealed that the implemented mitigation practices were insufficient to stabilize many of the granitic slopes. Restoration efforts on the sites in 1991 and 1992 have included various erosion control practices: lining all insloped road ditches with rock and other materials; rocking all cross drains and waterbar discharges; seeding and mulching cut and fill surfaces; and recontouring and stabilizing slopes. The cost of materials and installation are described. We have learned we must identify decomposed granitic soils early in the timber harvest planning process and treat them with great care during harvesting operations to avoid severe problems.

INTRODUCTION

In 1991 and 1992, the Georgia-Pacific Corporation (located at Martell, California) carried out a series of tests on synthetic and natural erosion control materials. These studies were performed in a mid-elevation (3,600 - 4,600 ft.) area of the South Fork Mokelumne River drainage, which is located in the Sierra Nevada Batholith and consists primarily of decomposed granitic (DG) soils. These tests were part of an extensive follow-up mitigation project carried out by the company on one of its recently harvested sites and reviewed by the California Dept. of Forestry and Fire Protection and the California Dept. of Fish and Game.

My pictorial review of this project at the Conference covered several before-and-after sequences of restoration work in progress and highlighted the cost of materials and installation at each site. Evaluations of equipment and operators were also reported on. In addition, several native plants particularly adapted to colonizing bare DG soils were noted. The principal message of this presentation is the increased awareness we now have toward identifying DG soils early in the timber harvest planning process and revolving all other operations around the fact that these soils must be treated with great care.

RESTORATION EFFORT

The Lower South Fork Timber Harvest Plan was logged in the summer of 1990 and, while completion reports were filed, further review in the summer of 1991 showed the mitigation practices insufficient to stabilize many of the slopes. The major issue in planning the further restoration of the area was whether the roads should be insloped or outsloped. After much consideration, it was decided to continue insloping the roads using erosion control materials in the inside ditches and piping the water under the road surface through culverts and riprapped drains. Several miles of new road had been constructed in conjunction with this sale and large areas of fresh fill were exposed without protection.

Erosion Control Materials: Lessons Learned

Phase I of the mitigation project included lining these inside ditches with various erosion control materials and rocking all cross drains and waterbar discharges. It also included the seeding and mulching of all cut-and-fill surfaces which had not completely recovered after the logging. We learned a number of things about the erosion control materials, such as:

- Wider is better. Two-foot and four-foot wide erosion control materials tend to divert water to their edge where it rills and begins gullying if not treated immediately. The six and a half-foot wide rolls of Curlex and Palm Matting were found to be the most economical and most effective materials for ditch liners which would not sustain traffic.

- Trench and tuck. Any synthetic erosion control material used which is in a roll form needs to be dug in-to the ground in order to prevent rilling or gullying under the material. These trenches are approximately 4 inches wide and 6 inches deep, cut perpendicular to the flow. The erosion control material is simply tucked into the trench and packed with dirt.

- Expensive exotics do not equate to more control. Materials costing 60 to 80 cents per square foot were not found to be any more effective in controlling rilling on road surfaces than those materials costing 12 cents per square foot.

- Rock is expensive, but hard to beat for durable, effective installations. When installing rock at cross drains or culvert discharges, it is critical that a channel, at least 8 inches deep, be dug for the water to flow in and back fill with rock. The surface of the rock should form a slight depression for a channel, and should be at grade with the outslope of the crossing or drain. My preference for rock is 6-inch minus limestone. It does not float in water with high velocity, it is small enough to provide many voids for the passage of water, and its rounded edges do not damage truck tires during hauling.

Road and Landing Berms

Before-and-after pictures of a number of road fill and landing projects are shown where an excavator has been used to pull back the unstable edge or berm of the road or landing. In the cases of landings, this extra material was used to recontour the cutslope and to fill any through cuts which have been created for skid trails. Road and landing berms were covered with a 4-foot wide Curlex Excelsior material, which cost approximately 12 cents per square foot installed. While the material was effective in preventing the erosion of the berm, its thickness or a reaction of the excelsior with young grass seedlings prevented or prohibited grass germination and growth. This problem was not observed with the thin, 6-1/2-foot wide Palm Matting, and to a lesser extent with the 6-foot wide North American Green plastic material.

Revegetation

Four grass seed mixes were tried on different locations on the project. These sites will continue to be observed over the next two years to see which of the perennial plant groups has the greatest success in establishment. One mix was primarily Berber Orchard grass and Zorro fescue, an annual. A second mix was recommended by the University of California at Davis Agronomy Department for high mountain elevations, but these were all species introduced from other Mediterranean climates. A third mix consists of all California native grasses; and a fourth is simply barley and wheat mixed with mulching straws.

The Sickle-keeled Lupine (*Lupinus latifolius*?) and the Wagonwheel Trefoil (*Lotus corniculatus*) were two plants found native on the DG soils, and both produced extremely long tap roots and a considerable amount of protective foliage which helps to absorb the energy of raindrops. Commercial sources for these two plants are currently being sought.

Slope Stabilization

Application of erosion control materials on a recontoured fill slope included complete covering with Curlex Excelsior, straw mulch with netting, and hydroseeding. The complete Curlex blanket was least effective in stimulating grass germination, but did minimize surface rilling on the fill slope. In the few cases where hydroseeding was attempted (on near vertical saprolite faces), it was very effective on that surface. The grass mix was nearly 100 percent Zorro fescue which matured and produced seed. The most effective technique and material we tried was simply using straw and a tackifier sprayed on to reduce the movement of straw in the wind.

Slope length remains the most critical factor in the acceleration of erosion on fill slopes. Through participation in this DG Conference and observation of restoration techniques for the Cleveland Fire site, we now have new ideas for stabilizing steep fill slopes. Micro-terracing, straw wattling, and side hill falling and digging-in of pole-size trees all have application for shortening slope length and slowing water movement.

In the 1992 mitigation work, a freak sequence of events produced some very interesting results for tackifying straw and compacting a fill slope. Cattle, which had not been removed from the range on time, moved through a recently-seeded and mulched area just after it had received approximately 4 inches of rain. The trampling by the cows on the wet ground compacted the surface soil, which had been dry, and produced thousands of small cups, slowing runoff and producing an abundance of grass growth. The half-inch mesh plastic netting, which is sold as a substitute for a chemical tackifier to hold straw in place, was found to be ineffective and particularly dangerous to wildlife and livestock. This netting, used on two separate locations, was removed after the first season.

Recontouring Slopes

We have found that removal of roads and landings by recontouring the slopes is possible and not unreasonably expensive when there are few alternatives. Equipment used on both seasons of mitigation work varied from a Cat-225 excavator working in conjunction with a Cat-960 front-end loader, to a high-track Cat-D5 with a 6-way blade and grapples. These three pieces of equipment had the greatest versatility and highest efficiency of the equipment used. The high-track Cat with grapples manuevers easily, rarely gets stuck, and, with its grapples, can pick up rocks, logs, and other energy dissipation or stream deflection materials and locate them exactly where the project supervisor desires. As with any type of equipment, knowledgeable and experienced operators can save each project considerable time and money.

Silt Fencing

A large amount of synthetic silt fencing was used during Phase I of the restoration project. Overall, the effectiveness of the material is excellent, but these fences, which do collect silt, must be cleaned throughout the season in order to prevent overflow of soil and loss downstream. When the location of the silt fences is carefully planned, they also act as silt basins where sediment can be measured and used to determine delivery ratios for soil movement from small watershed areas or from road surfaces which are tributary to the silt fence. We did not observe ultraviolet (UV) deterioration of the silt fence material itself. However, the polypropylene rope used to guy and secure the silt fence was readily affected by UV light. This problem was also apparent in a number of the other plastic materials used. Enkamat, which is a 3.8-foot wide by 3/4-inch thick, black, woven plastic material, did not show any sign of UV deterioration. Enkamat acts like riprap and allows light to readily penetrate, producing excellent grass germination results. The drawback with Enkamat is its high initial cost and the fact it does not come in widths greater than 3.8 feet.

CONCLUSION

This presentation ends with a series of slides which illustrate the clues available to the timber sale planner and operator which should heighten their awareness of the severe problems associated with logging operations on decomposed granitic soils.

The Lower South Fork Restoration Project will continue at least one more year with the installation of gully-stabilizing materials such as tire baffles, straw check dams, and log dam silt basins. Tables 1 and 2 give details on the Lower South Fork Timber Harvest Plan, the operators who did the restoration work, the various kinds of materials used, and the cost per square foot installed.

Table 1.

GEORGIA PACIFIC CORPORATION EROSION CONTROL CASE STUDY

Lower South Fork THP #4-90-105

Description of Study Area

South Fork Mokelumne River Watershed area: 30,000 acres

River length: 27 miles

Elevation change: 1050' to 6950'

2/3 of the watershed lies above 4000'

Average annual precipitation:

Water yield data (1934 to 1991): Lowest peak flow (1977) - 69 cfs; Highest peak flow (1986) - 7300 cfs

THP plan area: 813 acres

Previously logged: 1959

Plan elevation change: 3600' - 4600'

Aspect: South-facing

Geology: all Granitic

Soil Types: Chawanakee (7129), Holland (716), Tish Tang (7125) (from Calif. Soil-Veg Maps)

New road construction or reconstruction: 3.78 miles

Total miles of road used on the Plan: 21.21 miles

Highest downstream beneficial use: domestic water

Restoration Plan

Restoration plan design: Michael Skenfield, RPF, Murphys CA

Plan Contractors: Simmons Landscape, Jackson CA; Wolin & Sons, Inc., Sutter Creek CA; Emerson Assoc., Martell CA

TOTAL COSTS TO DATE: $135,000+

Table 2.

MATERIALS LIST AND COSTS

EROSION CONTROL BLANKETS

TRADE NAME	MANUFACTURER	ROLL SIZE	COST/SQ.FT. INSTALLED *
Regular Curlex	Am. Excelsior	180' x 4'	.12
High Velocity Curlex	Am. Excelsior	100' x 4'	.20
North Am. Green	North Am. Green	83.5' x 6.5'	.59
Enkamat	AKZO Ind.	328' x 3.21'	.78
Palm Matting	?	150' x 6'	.17
Jute Netting	Sacramento Bag	4' x 225'	.03-.05

* Labor Rate: $25/hour/man, includes benefits, insurance, Workers Comp

GRASS SEEDING

		COST/ACRE	COST/SQ.FT.
G-P Erosion Control Mix	35/lbs/acre	$ 43.05	.001
G-P Calif Native Mix	35/lbs/acre	142.80	.003
Fertilizer 16-20-0	250/lbs/acre	33.25	.001
Straw Mulch	2" thick blown	227.00	.005
Labor: seed, fertilize & mulch		360.00	.008
Erosion Control		$ 663.30	.015
Cal Native		$ 763.05	.018
Hydroseeding		$1000	.023

DRAIN ROCK 6 INCH-MINUS LIMESTONE

Rock: 120 lbs/cu.ft., 16.7 cu.ft./ton; cost delivered to waterbar $22.60/ton

Waterbar rock backhoe installed 2' x 18' x 1' @ $8.89/lin.ft.

Ditchliner excavator installed 4' x 150' x 1' @ $8.61/lin.ft.

SILT FENCES

Amoco Fabric, approx. $5.80/lin.ft., installed each section approx. 25'

STRAW BALE DIKES INSTALLED

Straw @ $2.65/bale; 2 wood stakes/bale @ $.75/stake

10 minute installation @ $25/hour = $4.17; $8.27/bale or $2.07/lin.ft.

Grass Valley Creek, Trinity River Basin: A DG Watershed Case Study

GRASS VALLEY CREEK WATERSHED AND THE RESTORATION OF SALMON AND STEELHEAD IN THE TRINITY RIVER

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ABSTRACT

Numerous factors have contributed over the years to the serious decline of salmon and steelhead populations in the Trinity River system: mining, timber harvesting, dam construction and water export. Although only a "medium" sized (36 sq. mi.) subbasin, the Grass Valley Creek watershed has played a greater role in the decline of the Trinity River fish resource than any other area. This predominantly granitic watershed was intensively roaded and logged without proper erosion controls for many decades. Subsequent storms have delivered excessive amounts of sand-sized sediment to one of the, historically, best spawning reaches of the Trinity River. Efforts are currently underway to eliminate commercial timber harvesting and perform extensive watershed rehabilitation.

INTRODUCTION

The precipitous decline of anadromous salmonid populations supported by the Trinity River system has several contributors. Degradation of tributary watersheds is one of the leading causes. Among degraded watersheds of the Trinity River Basin, the Grass Valley Creek (GVC) watershed is clearly most responsible (Figure 1). Its role in the decline and consequent rehabilitation of the salmonid fishery is described below.

Several sources indicate that one-half million adult chinook salmon historically migrated from the ocean up through the Klamath River estuary on an annual basis prior to the initiation of large-scale, land-based disturbances. Adult steelhead runs may have been twice as numerous. Nearly half of the individuals of all salmonid species migrating up the Klamath would turn right (south) at the Trinity River confluence (River Mile 40) and disperse throughout the Trinity River system to spawn.

Native peoples have for centuries harvested these adult fish. These human populations have always been so small, however, that decreases in run sizes resulting directly from their harvests were inconsequential. Developmental pressure on the Trinity River Basin's natural resources did not proliferate until settlers of European origin immigrated into the Basin around 1850.

CHRONOLOGICAL REVIEW OF TRINITY RIVER FISHERY DECLINE

Mining

A century of intensive gold mining activities began in 1850, but a core period from 1860 to 1920 marked the most intensive effort. This was the timeframe when pressurized hydraulic system nozzles, associated with hard rock or quartz-vein mining, "blasted away" at mountainsides. The erosional materials were then sorted after delivery to lower lying areas. Numerous large piles of cobble can be found throughout Trinity County as a result. Those found along smaller tributaries were handplaced, often by Chinese labor. Larger piles along the Trinity River and in lower floodplains of major tributaries were produced by floating dredging machines.

Anadromous salmonids were affected in several ways from these activities. Spawning areas were obliterated or covered with fine sediment. Juvenile rearing habitat was buried with silt and debris. Historically productive tributaries were diverted, inadvertantly preventing fish migration access. Roads were built with no regard for fish passage,

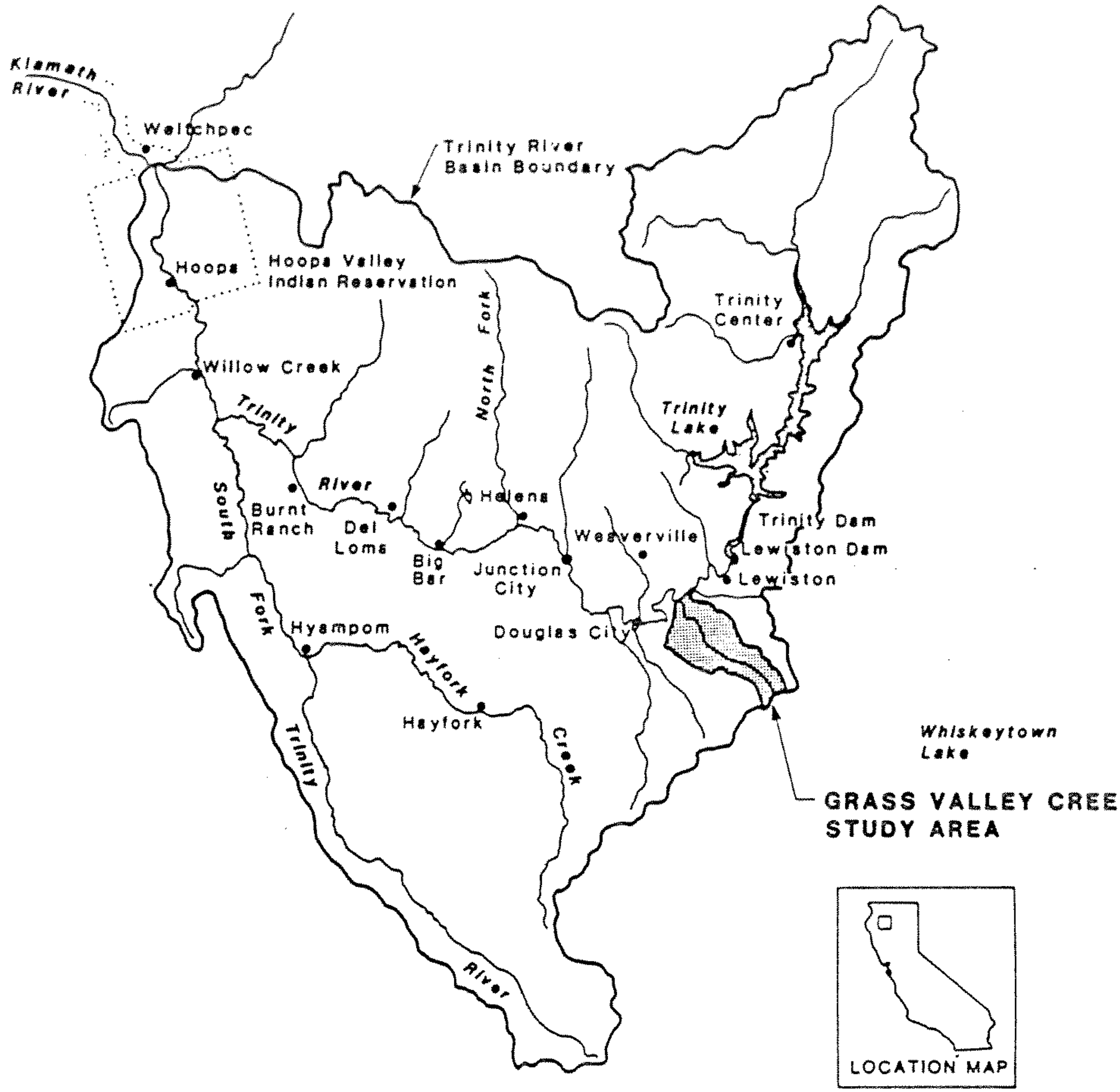

Figure 1. Trinity River Basin and Grass Valley Creek Drainage.

frequently blocking migration. Some preliminary timber harvesting was also required to build bridges and water-diverting flumes required for hydraulic operations.

An indication of the impacts resulting from these gold mining activities is described by former Trinity County Supervisor and life-long local resident, Jim Smith, who was instrumental in the development of the Trinity River Basin Fish and Wildlife Restoration Program. An avid fisherman, Jim states that the first time in his life that he saw the Trinity River flowing in a non-turbid condition clear enough to see large fish was when he was on leave from World War II at the age of 19. A Federal War Order had forced mining operations to cease during the War (Jim Smith, personal communication).

Anadromous fish populations of the Trinity River may have been reduced by one-third during the century of cumulative mining activity impacts, as suggested by one researcher (O.R. Smith, 1939, as cited in KRBFTF, 1991).

Commercial Timber Harvest

Large-scale mining efforts dwindled when "diminishing returns" were reached around 1950. But with 1.1 million acres of commercially available private and public timberlands in the Trinity River Basin, the local area was positioned to maximize productivity when the post-World War II housing boom began. For example, the number of lumber sawmills expanded from one to over fifty while the annual lumber volume increased from one million to more than 600 million board feet during the period between 1940 and 1956 (CDWR, 1962). The timber industry continues today as the primary source of revenue within the Basin. But the number of operating mills and concurrent employment have plummeted because of increasing mill efficiency and decreasing volume of timber available.

Virtually thousands of miles of logging-related roads were constructed locally during the initial boom years of the timber industry. Both road construction and timber harvest practices were conducted with no legal language to be found concerning erosion prevention practices during these early years. As a result, the two floods to affect the Trinity Basin in 1955 and 1964 combined with the enormous levels of land disturbances to devastate many tributaries within the Trinity Basin. For example, the 1964 flood is hydrographically described as a 100 year return interval flood event. However, aerial photography analysis of the Trinity Basin just prior to and after the event clearly indicates dramatic changes to many tributaries and the entire lower South Fork on a scale that may have required a "millenia" of time to create in an undisturbed condition.

Many streams have largely recovered from the devastating flood of 28 years ago but others, including the lower reaches of the South Fork Trinity, have improved little. Numerous streams in this category clearly have suffered irreversible damage and will never provide the habitat conditions of previous quality. Perhaps the adverse effects of these two storms and continuous timber harvest operations up to the present time may be responsible for a decline of an additional 30% in the anadromous salmonid fishery of the Trinity Basin during the past 50 years.

Trinity River Division of the Central Valley Project

The feasibility of damming the Trinity River near the town of Lewiston was explored as early as the 1930s. In 1955, authorizing legislation was successfully put forward for construction, with language indicating that the existing anadromous fishery would be not only protected but enhanced.

The pair of dams and reservoirs (Trinity and Lewiston), completed in 1963, impound water from 750 square miles of the upper mainstem Trinity River watershed. While the affected area comprised one-third of the natural mainstem drainage area, it represented up to one-half of the historic anadromous fish habitat. Sixty stream miles of chinook salmon habitat and over 100 miles of steelhead trout habitat were blocked by the two dams. A fish hatchery constructed at the base of the lower dam for the purpose of project mitigation has had a spotty record of success. Generally, fall chinook and steelhead production, as well as adult escapement returns to the hatchery, have failed to compensate for the historic numbers that once migrated past this reach of river upwards toward former spawning areas.

Dramatic changes have occurred in the mainstem of the Trinity River to the first forty river miles immediately downstream of the dams during the three decades since project completion. These changes may not have been anticipated at the general time period of project construction. From the confluence of the North Fork Trinity upstream to Lewiston, the natural river gradient decreases significantly compared to the fifty mile reach below the North Fork. The lower section is typified by a steep walled bedrock canyon gorge, causing a plunging cascade river bed.

The forty mile section upstream of the North Fork has always been a reach of the river conducive to mainstem spawning and rearing of thousands of salmonids. When upstream access was blocked by the dams, the reach below became inundated with adult fish, half trying to get further upstream and half content to stop below the dam site. This condition of severe overcrowding was detrimental to all of the salmon and steelhead.

In less than ten years after diversion began, significant channel changes were evident below the dam. The constant discharge of 150 cfs allowed for extensive recruitment and survival of riparian vegetation seedlings which rapidly encroached on the "dwarfed" flowing river bed. After several years, the encroaching vegetation created a natural revetment-like corridor immune to removal upon future greater flows or large storms.

The acreage of riparian habitat has increased several hundred percent since dam completion. The narrowing, faster flowing channel has greatly reduced the acreage of original suitable spawning and rearing habitat while occasional large pulses of tributary sediment, especially from Grass Valley Creek, have buried other remaining habitat. Today, the acreage of former salmon and steelhead habitat that once existed from Lewiston downstream forty miles to the North Fork is clearly less than half the historic area once available. Blockage of the river upstream combined with shrinkage of habitat downstream are primarily responsible for causing current salmonid returns to be less than one-tenth the average they were in the decades prior to dam construction.

<u>Other Impacts</u>

An increase in adult salmonid harvest since the mid-1800s has also played a part in reducing annual returns of adult escapement. These impacts have varied widely during the past 100 years. Effects resulting from annual harvests have ranged from true harvestable surpluses being taken all the way to the catch impinging seriously upon a given years' potential escapement. Since the late 1800s, it has not been uncommon to have between 100,000 to 250,000 adult Klamath River Basin salmon and steelhead harvested annually in the cumulative fisheries of ocean commercial, ocean recreational, river recreational and Indian net harvest.

GRASS VALLEY CREEK AND THE TRINITY RIVER FISHERY

Grass Valley Creek (GVC) is but a "medium" sized (36 square miles) tributary to the Trinity River yet has played a greater role in the decline of the Trinity River fish resource than any other tributary. Two-thirds of the watershed is underlain by the youngest (127 million years old) and most erosive batholith of decomposing granitic rock found within the entire Klamath River Basin.

The granitic portion of GVC has likely been the most erosive terrain in the Trinity River Basin ever since the rising pluton became exposed at the surface. However, not until the Trinity Division was completed did the coarse sand originating from its sideslopes seriously impact the Trinity River fish resources.

Nearly all of the granitic portion of GVC has been privately owned for decades and three-fourths of it grows a vigorous coniferous forest. Most of this forest has been zoned for commercial timber harvesting and in the late 1940s, intensive logging began here as it did throughout the Trinity River Basin.

The privately owned forests in GVC were initially cut using a "heavy selection" type of harvest method. Logging was done with tractors but small trees were apparently left standing. One to two hundred miles of logging access roads were haphazardly constructed during this "frenzied" period. Neither the road construction nor timber harvest practices were conducted with any regard for (or legal requirement of) erosion prevention practices.

A large storm in 1955 provided up to a 70,000 cubic feet per second (cfs) flow in the Trinity River at Lewiston. The enormous contribution of recently-disturbed coarse sand sediment pouring forth from GVC, however, apparently did little damage to the fishery for the remaining 35 miles of prime fish habitat down to the North Fork confluence. No evidence of reported impacts to fish habitat can be found in the literature following this storm despite fish surveys conducted regularly after the event.

A completely different outcome resulted after the December, 1964 flood event. Timber harvesting continued during the intervening decade between the two storms but the pace of cutting had actually slowed. The 1964 flood created a measured discharge into the newly created reservoir of 110,000 cfs. Uncontrolled spills never occurred below the dam, however; the reservoir was nearly empty before the storm event and could contain the equivalent of more than two normal winters of run-off. Hence, only 150 cfs was released at the base of the dam when over 100,000 cfs would have been passing the site just two years earlier.

The tributaries throughout the Trinity Basin were of course flowing at unimpeded levels and the contrast was conspicuous just below the dam. Grass Valley Creek, entering the "placid" river just seven miles downstream from the dam, likely pumped over one million cubic yards of coarse granitic sand bedload into the slowly moving river. Nearly all of it settled out shortly after reaching the larger river course. GVC has plagued this historically productive reach of river with sand deposits ever since as numerous large but more frequent storms have replenished sediment supplies initiated by the 1964 flood event.

The conspicuously white sand river bed downstream of GVC was noted after 1964 during salmon spawning surveys. Surveyors also noted during the late 1960s that spawning salmon shifted their emphasis to the area within two miles of the base of the dam and began to avoid the reach of river downstream of GVC.

Public furor increased during this period and, with legislative assistance, a primordial inter-agency Trinity River Task Force was formed and funded to develop the groundwork for a river restoration program (Calif. Resources Agency, 1970). Grass Valley Creek was ultimately denoted as a distinct restoration "Action Item" among eleven created by the Task Force. Meanwhile, several hundred acres were cut annually on private timberland in GVC (continuing today) with several miles of new access road built in conjunction (see Dunlap, these Proceedings). The Task Force grew to include 14 member agencies and received $57 million in funding in 1984 as part of the Trinity River Restoration Act (Public Law 98-541).

Plans were initially developed that appeared to address the symptoms of problems in GVC in lieu of the problems themselves (CDWR, 1978). A sediment entrapment dam and reservoir was designed and funded through a separate Act of Congress that passed in 1980 and was then modified in 1984. The ensuing Environmental Impact Statement (EIS) preferred the alternative to construct the debris dam at the "Buckhorn" site and excavate several sediment entrapment ponds at the lower end of GVC (USBR, 1986). Such is the situation today.

The Trinity River Basin Fish and Wildlife Task Force ultimately became convinced that commercial timber harvesting, conducted under stringent special rules beyond those routinely applicable under the State Forest Practices Act, was incompatible with the goals of the Restoration Program. A process was begun several years ago to explore the feasibility of purchasing the majority of the private timberland overlying the decomposed granite (DG) in Grass Valley Creek, which was completed during the fall of 1992. Funds were appropriated from a combination of sources, including the original Restoration Program budget, the Bureau of Reclamation budget, and FY93 Interior appropriation money. The Bureau of Land Management (BLM) will eventually inherit the 16,000 acres and manage the land for purposes other than harvesting timber.

The most important aspect of this management change in the GVC Basin may be the funding of several million dollars dedicated toward watershed rehabilitation. Rescuing the DG portion of GVC from commercial timber harvesting is beneficial, of course, but because the granitic areas are weathered down to depths of sixty feet, many erosional areas less than ten years old will be yielding sediment for many years into the future if not treated aggressively.

The Soil Conservation Service was assigned, by the Trinity River Task Force, to conduct thorough erosion inventories of the entire DG portion of

GVC, which was done in 1991 (see Spear, these Proceedings). Watershed rehabilitation began in mid-summer 1992 and is continuing today (see McCullah, these Proceedings). Although structural restoration will play an integral role in rehabilitation, revegetation will ultimately be most responsible in reducing sediment yield. Beginning in a few years, plantings along with natural revegetation will be responsible for permanent sediment yield reduction long after Restoration Program funds have been exhausted.

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INVENTORY OF SEDIMENT SOURCES IN GRASS VALLEY CREEK WATERSHED AND ITS IMPLICATIONS FOR RESTORATION AND MANAGEMENT

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ABSTRACT

The restoration of the Grass Valley Creek Watershed, the single largest contributor of sediment to the upper Trinity River, is a top priority of the Trinity River Restoration Program in attempting to restore the Trinity River fishery. Despite many watershed projects, accelerated erosion is still occurring and must be addressed through a combination of land treatment and land use changes. To help facilitate the implementation of a land treatment plan in the watershed, a comprehensive inventory of sediment sources was conducted by the USDA Soil Conservation Service in 1991 and completed in February 1992. The results are now being used to direct an aggressive, basin-wide land treatment program in the watershed. However, a fundamental change in forest land management philosophy must accompany the rehabilitation efforts on the decomposed granitic portions of the watershed.

INTRODUCTION

As described in Bill Brock's presentation, the Grass Valley Creek Watershed is a notorious source of sand-sized sediment to the upper Trinity River (Brock, these Proceedings). Of its 23,525 acres, about 17,000 acres, or 72%, is underlain by decomposed granite (DG) parent materials. Historic logging, recreation, and access activities have caused significant disturbances in this sensitive watershed.

Many erosion control efforts have been attempted in recent years: Buckhorn Sediment Dam in the middle of the watershed, Hamilton Sediment Ponds at the creek's mouth, restrictive timber harvesting mitigation measures (see Dunlap, these Proceedings), purchase of commercial timberlands, state highway road drainage and erosion control measures, off-road vehicle (ORV) ordinance, power line right-of-way erosion control plan, and several small rehabilitation projects.

Despite all of this work, substantial accelerated erosion is still occurring. This erosion can only be addressed through a combined effort of land treatment and land use changes. To help facilitate the implementation of a land treatment plan in the watershed, a comprehensive inventory of sediment sources was conducted by the USDA Soil Conservation Service (SCS), Weaverville Field Office, in 1991 and completed in February 1992.

OBJECTIVES OF INVENTORY

The objectives of this inventory were to: 1) Identify and locate site-specific problem areas; 2) Quantify erosion potential; 3) Recommend best management practices (BMPs) to treat each of these critical sediment-producing areas, including associated costs and operation and maintenance considerations; 4) Provide an economic picture on the cost of alternative treatments and their effectiveness in protecting the watershed; 5) Recommend areas that would be more suitable to other land uses and that would not be able to meet the goals of "Zero Net Increase" if left in timber production (see Komar, these Proceedings); 6) Develop a framework for a monitoring program that would monitor the effectiveness of restoration efforts throughout the watershed.

METHODOLOGY

Previous studies had described the physical features, evaluated potential erosion and sediment control measures (USSCS, 1981), and developed a sediment budget for the watershed (USSCS, 1986). The next step required an intensive survey of the entire watershed, conducted during 9 months in 1991.

Decisions were made relative to site-selection and mapping intensity of erosion problem areas as follows:

1) A high mapping intensity would be devoted to the DG areas and a minimal intensity to the non-DG areas, focusing primarily on the road network (landslide erosion not inventoried since it occurs primarily on non-DG areas);

2) Only site-specific sediment sources would be inventoried, excluding more indefinable sources such as sheet and rill erosion on upland slopes;

3) Eroding areas had to show significant sediment delivery potential, i.e., a high probability that eroding material would end up in a stream course in the immediate future;

4) Individual problem areas had to be significant sediment sources: a) a future potential sediment yield of 10 yards or more within 25 years, and b) a moderate rate of erosion or greater (as defined in USSCS, 1986);

5) Emphasis was placed on man-induced problems, but natural problems were also inventoried if significant and treatable.

Data were recorded for erosion problems associated with roads, skid trails, landings, stream channels, stream crossings, gullies, ORV areas, landslides and debris slides. Gross erosion estimates, both past and future, were made using the direct volume method and ocular estimates of voided areas, as time did not allow more precise measurements of each site. Since not all of the eroded material ends up as sediment delivered to a stream course, we applied a sediment delivery ratio (SDR) of 65% to convert gross erosion into sediment yield (USSCS, 1986).

Treatment Design

Treatment site locations were recorded on field maps, with problem areas grouped by proximity or relationship (e.g., road cuts, fills, and surface). For each problem area inventoried, up to 3 alternative treatments were identified. Alternative 1 addressed the cause of the problem, while Alternatives 2 and 3 focused mainly on treating the symptom of the problem in case the first alternative could not be implemented, for whatever reason (e.g., unwilling landowner).

The treatment philosophy in this inventory was to reduce the concentration of water. In the case of roads, this is best achieved by an outsloped road design (sloping towards the fillslope) which effectively spreads the water and significantly reduces the sediment delivery potential. For upland areas, reducing runoff and overland flow can be achieved by increasing the quality and quantity of the vegetative cover and surface organic litter.

The cost and percent effectiveness (in controlling erosion) of each land treatment was also determined. To estimate the total sediment savings of applying the prescribed measures, the percent effectiveness was multiplied by the gross sediment yield (gross erosion times SDR). The cost divided by the sediment savings represented the cost-effectiveness (i.e., cost per cubic yards saved) for each treatment.

RESULTS AND DISCUSSION

Rehabilitation

A total of 1,164 problem areas were identified, which were grouped into 966 treatment sites. The rehabilitation strategy emphasized prioritization of work to be done based upon 33 sub-watersheds and 3 stream corridors rather than individual treatment sites (Figure 1). By grouping, better coordination of rehabilitaion equipment and labor crews should be achieved with concentrating them in small areas for long periods of time. Furthermore, a much greater overall benefit to the watershed as a whole can be achieved by treating all significant sediment sources within a defined sub-watershed instead of just treating widely-distributed high priority sites.

A fundamental principal in watershed management is to begin restoration efforts at the top of the watershed and work down. The net result of this approach is the cumulative benefit realized. After upper watershed problems are corrected, the costs and extent of land treatment required for lower watershed problems are significantly reduced or negated altogether. Conversely, problems left untreated above may have an adverse impact on problems treated below.

Only problem areas exceeding 15 cu. yards gross sediment yield were included in priority rankings, since smaller problems were determined to not be cost-effective. Based on cost-effectiveness, expressed as cost per cubic yard of material saved, and location on DG soils, sub-basins were assigned a priority ranking from 1 to 36. Table 1 shows this ranking for Alternative 1.

The implementation of Alt. 1 would involve repairing

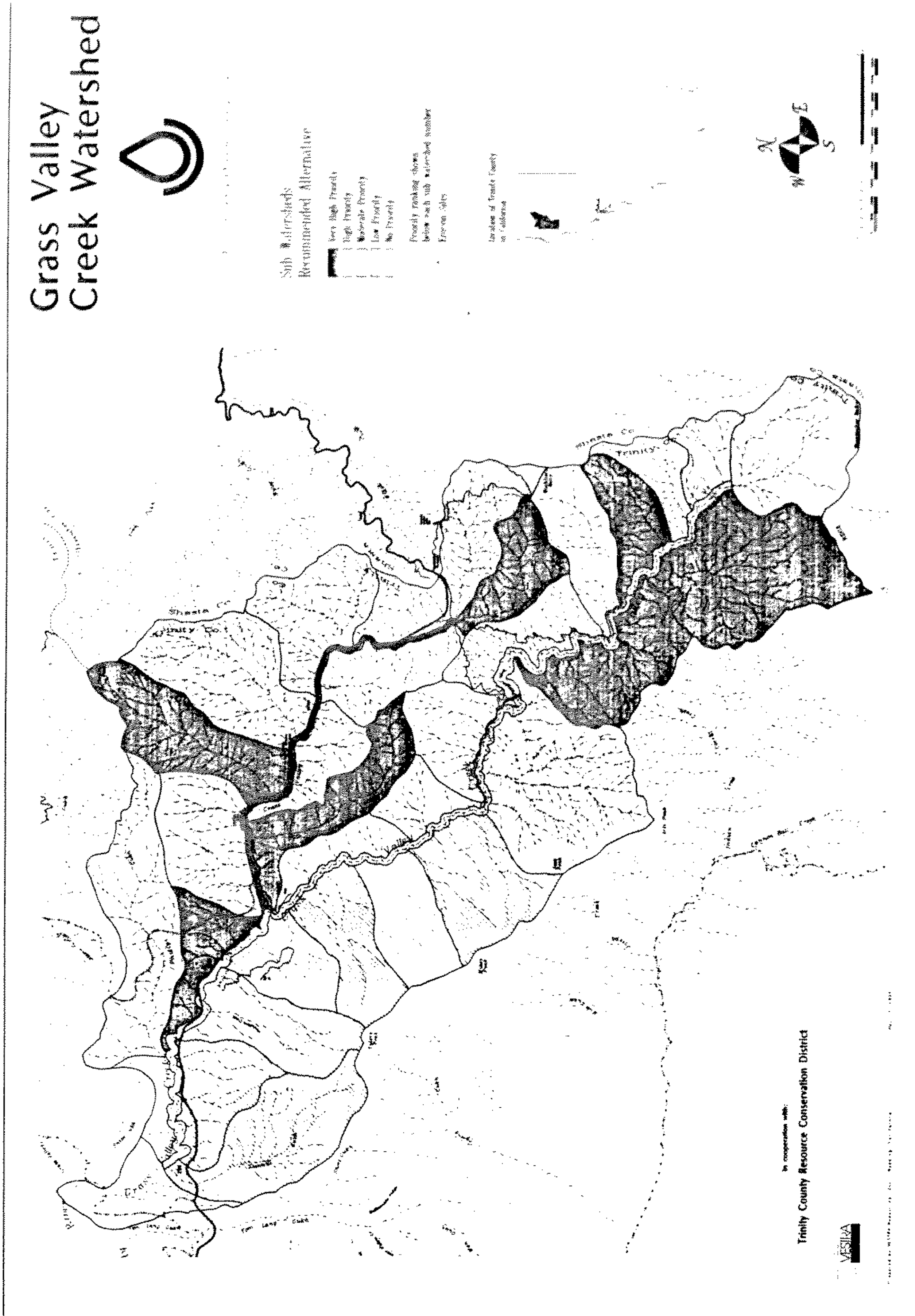

Figure 1. Site location map representing rehabilitation priority for recommended alternative

Table 1. Rehabilitation priority - Alternative 1, based on cost per cubic yard saved.
(Recommended Alternative)

Sub-Watershed	Priority Ranking	Priority Category	Soil Type	Cost	Yards Saved	Cost/ Yards Sa
29	1	VH	dg	$106,574	39887	$2.6
15	2	VH	dg	39,524	9908	3.9
11	3	VH	dg	114,242	22308	5.1
21	4	VH	dg	83,516	15519	5.3
24	5	VH	dg	59,540	10745	5.5
31	6	VH	dg	22,018	3894	5.6
36	7	VH	dg	15,022	2640	5.6
10	8	VH	dg	236,291	40147	5.8
19	9	H	dg	37,665	6300	5.9
26	10	H	dg	34,443	5743	6.0
18	11	H	dg	133,269	20863	6.3
23	12	H	dg	67,653	9960	6.7
16	13	H	dg	30,005	3381	8.8
14	14	H	dg	29,666	3239	9.1
20	15	H	dg	32,666	3519	9.2
17	16	H	dg	190,796	20310	9.4
27	17	M	dg	102,220	10129	10.0
28	18	M	dg	41,162	4041	10.1
30	19	M	dg	69,957	16410	10.5
32	20	M	dg	85,832	8038	10.6
13	21	M	dg	108,229	8996	12.1
22	22	M	dg	31,311	2544	12.3
9	23	M	dg	206,617	15949	12.9
35	24	M	dg	106,907	7670	13.9
12	25	M	dg	69,975	4910	14.2
25	26	M	dg	149,755	10458	14.3
6	27	L	non-dg	3,000	794	3.7
3	28	L	non-dg	12,488	2945	4.2
8	29	L	non-dg	2,502	543	4.6
4	30	L	non-dg	7,674	837	9.1
2	31	L	non-dg	13,432	1448	9.2
5	32	L	non-dg	14,944	1407	10.6
1	33	N	non-dg	0	0	0.0
7	34	N	non-dg	0	0	0.0
33	35	N	non-dg	0	0	0.0
34	36	N	non-dg	0	0	0.0
Totals:				**$2,360,000****	**316,000**	**$7.5**

Key: Priority Category (Very High, High, Moderate, Low, None)

** Does not include administrative charges.

over 95% of the problems inventoried at an estimated cost of $2,360,000, resulting in a potential sediment savings of 316,000 cu.yds.(or 84% of total sediment yield). These figures translate to an average cost-effectiveness of $7.50 per cubic yard saved. Included in the costs are equipment, materials, labor, project planning and design, landowner coordination and education, but not administration. Operation and maintenance (O&M) costs are estimated at $18,200 annually for 25 years following installation of practices. Costs may change following the specific project design phase.

Alternatives 2 and 3 would cost $1,361,000 and $578,000 and save 229,000 and 123,000 cu.yds., respectively. Alt. 1 was selected as the recommended land treatment plan due to its overall effectiveness and much greater benefit to the watershed as a whole.

Interpretations

A wide variety of interpretations and trends in estimated gross sediment production can be derived from the field data, as summarized in Table 2.

Roads. All road-related problems, including problems associated with roads, skid trails, landings and stream crossings, accounted for 59% or 214,000 cu.yds., but the actual sediment production historically may have been significantly higher. Most of the old temporary roads were constructed next to or in ephemeral drainages and generated most of their sediment within 5 to 10 years following timber operations. The permanent road network has altered the natural drainage patterns, resulting in downslope effects. Gullies below inventoried roads will probably produce 13,000 cu.yds. in the next 25 years. In addition, the inboard ditch of insloped roads deliver a lot of sediment from the road cutbanks. As seen in Table 2, road cutbanks have the greatest potential for sediment yield of the five road components evaluated.

Stream Crossings. Temporary and permanent roads and skid trails intersecting stream channels were identified as stream crossings. Three problems most common to crossings were inventoried: crossing diversions, where water is diverted down a road or skid trail (17,000 cu.yds. sediment produced); crossing failures, where the crossing is eroded away by concentrated water (19,000 cu.yds.); and Humboldt crossings, or log structures covered with soil typically used as temporary means to cross stream channels. A high density of stream crossings per road mile was expected and found in this extremely-dissected granitic watershed.

Landings. Most problem landings were situated in ephemeral stream channels, commonly at the confluence of two or more drainages and where DG deposition had accumulated. Gullies associated with landings accounted for the greatest percentage of estimated sediment yield.

Skid Trails. The most prevalent problem was gully erosion or from the skid encroaching upon drainages. The old practices of skidding logs up and down ephemeral stream channels has resulted in significant damage to the natural hydrologic function of these sub-basins by altering water flow paths and bringing water to the surface due to ground disturbances within the channel. Headcutting and enlarged stream channels are the result. Skid trails adjacent to channels behaved similarly to roads. Ridgetop skid trails have discharged concentrated runoff onto sparsely vegetated, south-facing, steep sideslopes. Water bars have failed from poor construction or large storm events.

Streams. Within the DG portion of the watershed, erosion and sediment production from stream-related sources contributed 25% of the estimated gross sediment yield identified in this inventory. Streambank and headcut erosion accounted for nearly 52,000 and 36,000 cu.yds., respectively. The causes center around disturbances within and adjacent to stream channels (see above) and with the impacts associated with changes in hydrologic conditions of the sub-basins resulting from timber harvesting.

Few sites were identified for sheet and rill erosion and landslides/debris slides in DG areas, due to the criteria described above.

MANAGEMENT CONSIDERATIONS

Our inventory report suggests that a fundamental change in management philosophy accompany any efforts to rehabilitate the watershed. Past management has created the poor conditions we see today. The only long-term solution to the significant sediment problems is to adjust timber-related management in combination with rehabilitation efforts. While Alternative 1 will very likely save an estimated 316,000 cubic yards of sediment, this inventory did not capture the erosion and sediment production

Table 2. Sediment estimated to be produced from sites located in the decomposed granite (DG) soil type, sorted by source of problem and nature of problem.

Source	Nature	Sediment (cu.yds.)
skid	gully	38,788
	cut	294
	fill	11,307
	surface	4,838
road	gully	16,747
	cut	46,557
	fill	8,528
	surface	5,487
	ditch	2,268
landing	gully	20,738
	cut	190
	fill	12,529
	surface	172
crossing	diversions	22,583
	failures	20,603
	humboldts	2,567
stream	streambank	51,831
	headcut	35,818
	log-jam	3,182
sheet & rill	surface/ORV	54,895
gully	gully	1,133
slides	debris slides	108
	landslides	2,928
	Total estimated DG sediment:	364,091*

* Note: estimated gross sediment production from Grass Valley Creek watershed is 377,000 cubic yards. Estimated gross sediment production from the non-DG portion of the watershed is 12,516 cubic yards.

associated with widespread sheet and rill erosion. The steep slopes, shallow soils and non-cohesive nature of granitic parent material leaves this watershed inherently susceptible to soil erosion. Although natural storm sequences may have produced significant sediment yields from Grass Valley Creek, soil erosion and sediment have been exacerbated by a significant reduction in the quantity and quality of vegetative cover and from the alteration of hydrologic processes in the watershed over the past five decades.

Our results reveal that sparsely-vegetated south- and west-facing DG slopes produce disproportionately high sediment yields: 65% of total sediment production was derived from south-facing sites, 44% from southwest-facing sites. These areas tend to be brittle environments because of extremely droughty conditions, shallow and coarse-textured soils, and physical weathering of the soil (frost-heaving). Even when cover is established, the capacity of these sites to support this vegetative cover is a fragile balance that is easily disturbed.

Wide-scale disturbance of this brittle environment results in significant changes to the site, and beyond. Removal of significant portions of the basal area from steep, south- and west-facing slopes results in a change in the ability of the site to absorb the effects of physical and water-based erosion forces. Excessive removal of the overstory results in three significant problems on-site: 1) loss of the protective canopy cover that provides shade for understory regeneration; 2) loss of the recruitment of the litter material that acts as a sponge to absorb the impact of rainfall and slow runoff through the subwatershed; and 3) loss of live root material that can take up and transpire water.

The removal of significant basal area through frequent timber harvest essentially forces a change in the hydrologic process of the subwatershed area as the area must now adjust to a new set of site conditions. This readjustment to a new equilibrium results in accelerated sheet and rill erosion on-site and the down-cutting of stream channels to adjust to the increased runoff off-site. While site recovery following disturbance has been seen to occur in some areas the year following disturbance, it often takes the more severe sites far longer to recover; some sites are so impacted by removal of the overstory that the area has converted to brushland.

Another contributing factor is the extensive road network, which tends to intercept subsurface water and bring it to the surface. The concentrated water is then discharged into stream channels unaccustomed to accommodating the increased volumes of water. Combined with the removal of vegetative cover, these effects of the road system have led us to the situation we are faced with today in the Grass Valley Creek watershed.

Possible Solutions

The silvicultural systems used in the harvesting of timber from these decomposed granite areas must be revisited. Silvicultural systems that ensure sufficient regeneration exists beneath the overstory prior to overstory removal will lessen harvesting impacts on sediment production. Vegetation management programs that promote and enhance regeneration should be investigated further. Perhaps an adjustment in wood products expected to be produced from the watershed that increases the value of timber, allowing longer rotations or more prudent harvesting of select trees, will help maintain watershed equilibrium. Harvesting methods must be selected that minimize the severe impacts associated with road building and tractor yarding. Finally, a concerted effort to minimize the concentration of water through prudent road design will reduce the impacts so clearly evidenced by the findings presented in this report.

Simple answers elude us, but the general direction is clear: forest land management in the decomposed granite portion of the Grass Valley Creek watershed must be management that places value on the retention and enhancement of a sufficient quantity and quality of ground cover on the brittle exposures so as to not overly disturb the fragile nature of the geologic and hydrologic characteristics of this watershed.

CONCLUSION

In conclusion, land treatment alone will not get the job done. Only a combination of land treatment and a change in the overall management philosophy within the decomposed granite portion of the Grass Valley Creek watershed will result in a sustained, significant reduction in sediment production. Doing so will provide immediate and sustainable economic returns through improved forest soil productivity, constant timber volume yields, enhanced water quality and increased anadromous fish production.

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TIMBER HARVESTING WITHIN THE GRASS VALLEY CREEK WATERSHED: HISTORIC AND CURRENT PRACTICES ON DECOMPOSED GRANITIC SOILS

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ABSTRACT

Grass Valley Creek, a small northern California stream, is located in a watershed comprised primarily of easily eroded decomposed granitic (DG) soils. The watershed has experienced extensive timber harvesting resulting in large increases in soil disturbance, accelerated erosion, and stream sedimentation. Deposited sediment is transported downstream into the Trinity River; increased sediment deposition has been shown to be a significant factor in the decline of the anadromous fisheries historically present in the river. The California Department of Forestry and Fire Protection, the state agency responsible for regulating private timber harvesting, has developed special mitigation measures for timber operations in DG soils that will help reduce the risk of accelerated erosion.

INTRODUCTION

Timber harvesting on decomposed granite (DG) soils is a major environmental concern throughout the western United States. Such harvesting has often resulted in dramatic increases in accelerated erosion and subsequent stream sedimentation. In Grass Valley Creek (GVC), accelerated erosion and stream sedimentation followed extensive timber harvesting within the watershed. It is estimated that 175,000 or more cubic yards of decomposed granite sediment were deposited each year from GVC into the upper Trinity River (USSCS, 1981). After the completion of Trinity Dam in 1963, lower river flows have allowed decomposed granite to accumulate in the spawning gravels used by salmon and steelhead (see Brock, this Proceedings). Anadromous fish populations have declined by up to 90% from historic levels (CDWR, 1978; USFWS, 1980).

Controlling sources of DG sediment is a critical part of the effort to restore anadromous fish stocks within the Trinity River Basin. Toward this goal, the California Department of Forestry and Fire Protection (CDF), in cooperation with other resource agencies, has developed mitigation measures to reduce the risk of accelerated erosion on private timber harvesting operations on decomposed granitic soils.

BACKGROUND

Grass Valley Creek is a major tributary of the Trinity River located in eastern Trinity County. It lies midway between the communities of Redding and Weaverville, and borders State Highway 299. The watershed is 36 square miles in area, approximately 23,000 acres; three-quarters of the watershed is underlain by soils derived from the decomposed granitic parent material of the Shasta Bally Batholith (Figure 1). Annual rainfall varies from 30 to 60 inches year. Stands of conifer timber cover 97% of the watershed (USBLM, 1986). Slopes within the drainage are moderate along the major streams, but increase sharply in the upper drainages, typically ranging from 50% to 75%.

Ownership

Historically, the state and federal governments owned approximately 20% of the watershed, with small private and large industrial ownerships holding the balance (CDWR, 1978). This pattern will substantially change following the 1992-93 purchase of Champion International Corporation's land holdings within the watershed by the federal government, to be managed by the U.S. Bureau of Land Management. As a result, government ownership will increase to 90%.

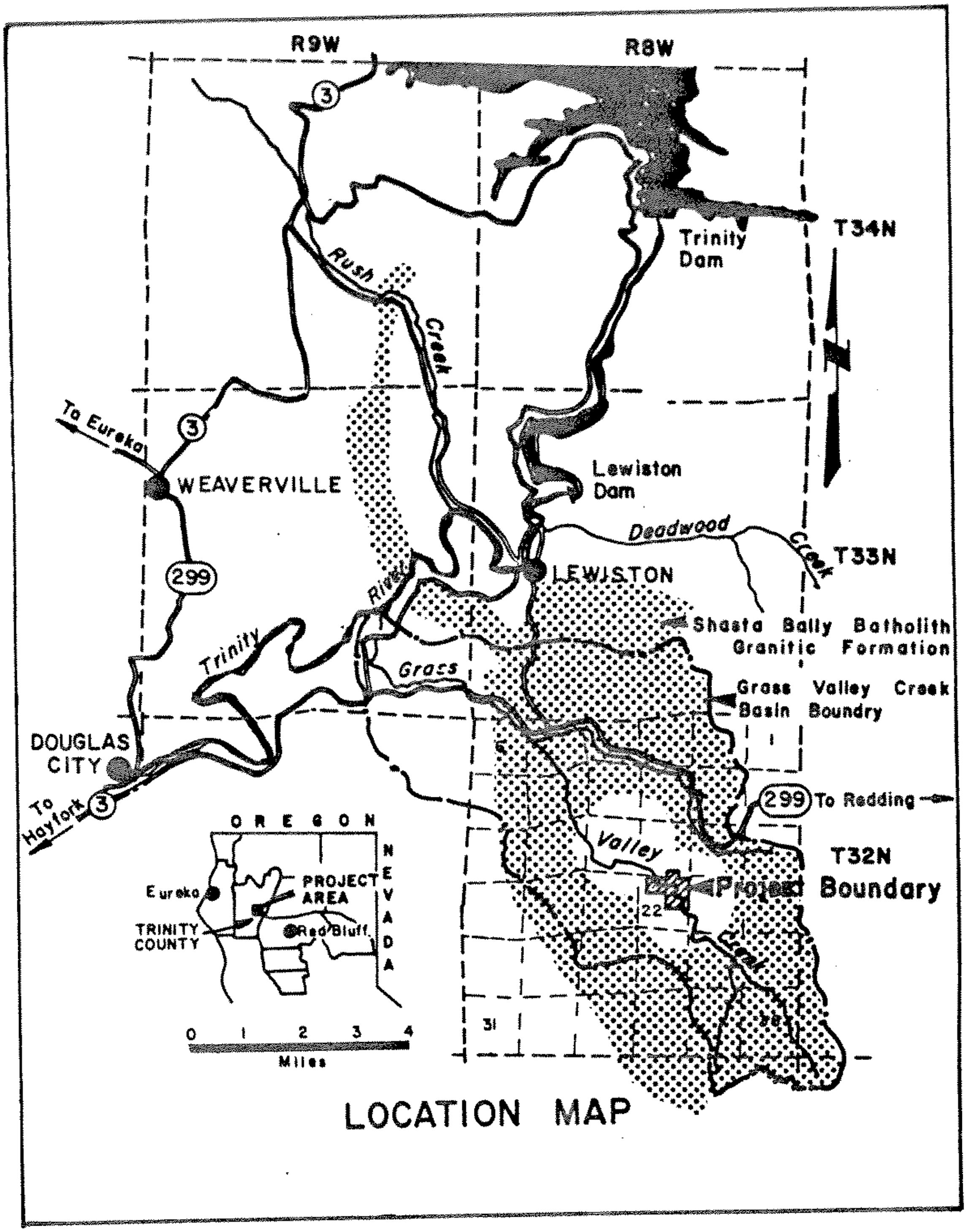

Figure 1. Location of Shasta Bally Batholith and Grass Valley Creek Watershed (CDWR, 1978).

TIMBER HARVESTING

Timber harvesting efforts within GVC began in earnest following the end of World War II. A small logging company, Shasta Box, was one of the early harvesters within the watershed. U.S. Plywood Corporation continued harvests into the 1960s, followed by Champion's purchase of its holdings (Dan Fisher, pers. com., 1992).

Operating Practices

Early logging operations removed large volumes of old-growth timber using tractor skidding equipment. Trees were felled down hill and removed via the stream channels. Roads and landings were constructed on the alluvial flats adjacent to the watercourses. Often, intermittent streams were filled in to provide room for landing logs. High storm flows occurring after logging operations would cause severe gully and rill erosion and stream diversions (see Spear, these Proceedings).

Following the passage of the California Forest Practice Act in 1973, stronger resource protection measures were required on private timber harvesting operations; in addition, CDF implemented regular inspection and record keeping procedures. Since 1974, 44 Timber Harvest Plans have been submitted to CDF for harvesting operations within the GVC watershed. These harvests covered 15,055 acres; of this total, 12,824 acres were harvested by industrial owners and 2,230 acres by non-industrial forest landowners. Average harvesting per year totaled approximately 500 acres, with a high of 5300 acres harvested in 1988 (Figure 2).

Yarding Methods

Tractor skidding has been the primary yarding method used to harvest timber within Grass Valley Creek. It is generally the most cost-effective (short-term) method available, and existing road systems are conducive to its use. In contrast, cable yarding requires the use of ridge top road systems that allow the cable yarder to be positioned above the timber to be logged. The topography is very broken in the Shasta Bally Batholith, making road construction on the upper slopes difficult, so cable logging is little used. The alternative to tractor skidding, more commonly used during the past four years, is helicopter yarding. Costs associated with helicopter yarding are 250-300% higher than tractor logging (Dan Fisher, pers. com., 1992). Figure 3 illustrates the acreage harvested by yarding system. Harvesting operations using helicopter yarding typically involve significantly less ground disturbance than tractor logging. Timber may be flown several miles to centralized landings, often greatly reducing the number of road miles and landings that would normally be constructed for other yarding systems.

Silvicultural Systems

Selection and Shelterwood Removal are the primary silvilcultural systems used to harvest timber within the GVC basin. Both systems involve removing some or all of the larger overstory timber. On north- and east-facing slopes, post-harvest timber stands still contain fairly dense canopies that provide good protection from erosion by supplying organic litter to armor the soil surface. Stands on south- and west-facing slopes often contain significantly fewer trees per acre, and a heavy harvest of conifer timber may significantly reduce the future supply of soil-protecting organic litter. Attempts at revegetating disturbed areas on south- and west-facing slopes have proven to be less successful than on other aspects (see Spear, these Proceedings). Figure 4 shows the acres harvested by silvicultural method.

CDF'S SPECIAL MITIGATION MEASURES

Development

CDF'S "Special Mitigation Measures for Operations on Decomposed Granite Soils in Grass Valley Creek and Nearby Drainages", were first developed in 1986 by a multi-agency committee in response to increased public concern regarding impacts of logging-related sediment upon the anadromous fisheries in the Trinity River. Committee members represented the following agencies and companies: Trinity County Board of Supervisors, North Coast Regional Water Quality Control Board, USDA Soil Conservation Service (SCS), California Dept. of Fish and Game, Sante Fe Timber Company, Champion International Corp., California Div. of Mines and Geology, Fruit Growers Supply Company, Central Valley Regional Water Quality Control Board, California Forest Protection Association, and the California Board of Forestry/CDF. The committee reviewed past timber harvesting activities in the field during the spring of 1986 and again in 1991. Several additional mitigation measures were developed and suggested for inclusion into future projects. The results of the committee's

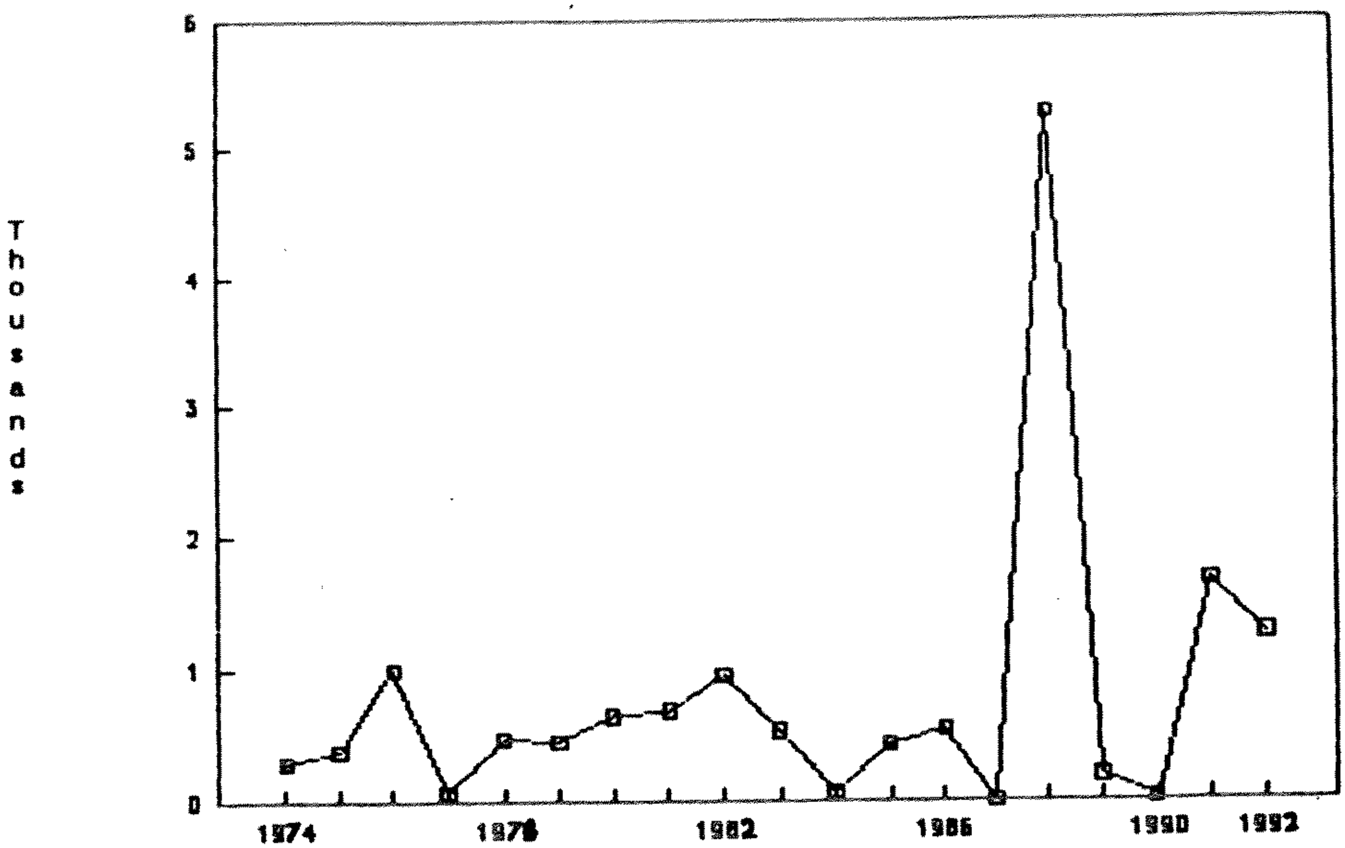

Figure 2. Timber harvest acreage, 1974-1992, Grass Valley Creek Watershed (CDF data).

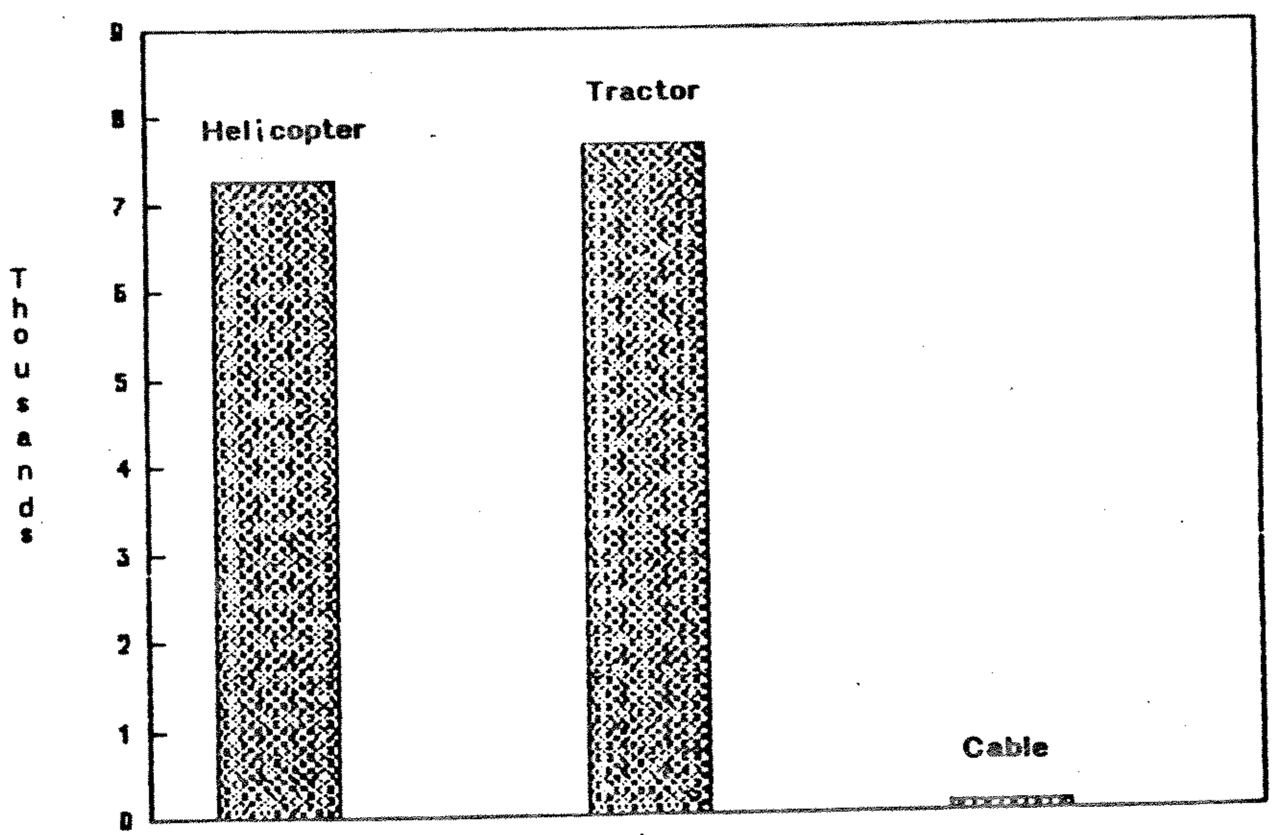

Figure 3. Acreage by harvesting methods, Grass Valley Creek Watershed, 1974-1992 (CDF data).

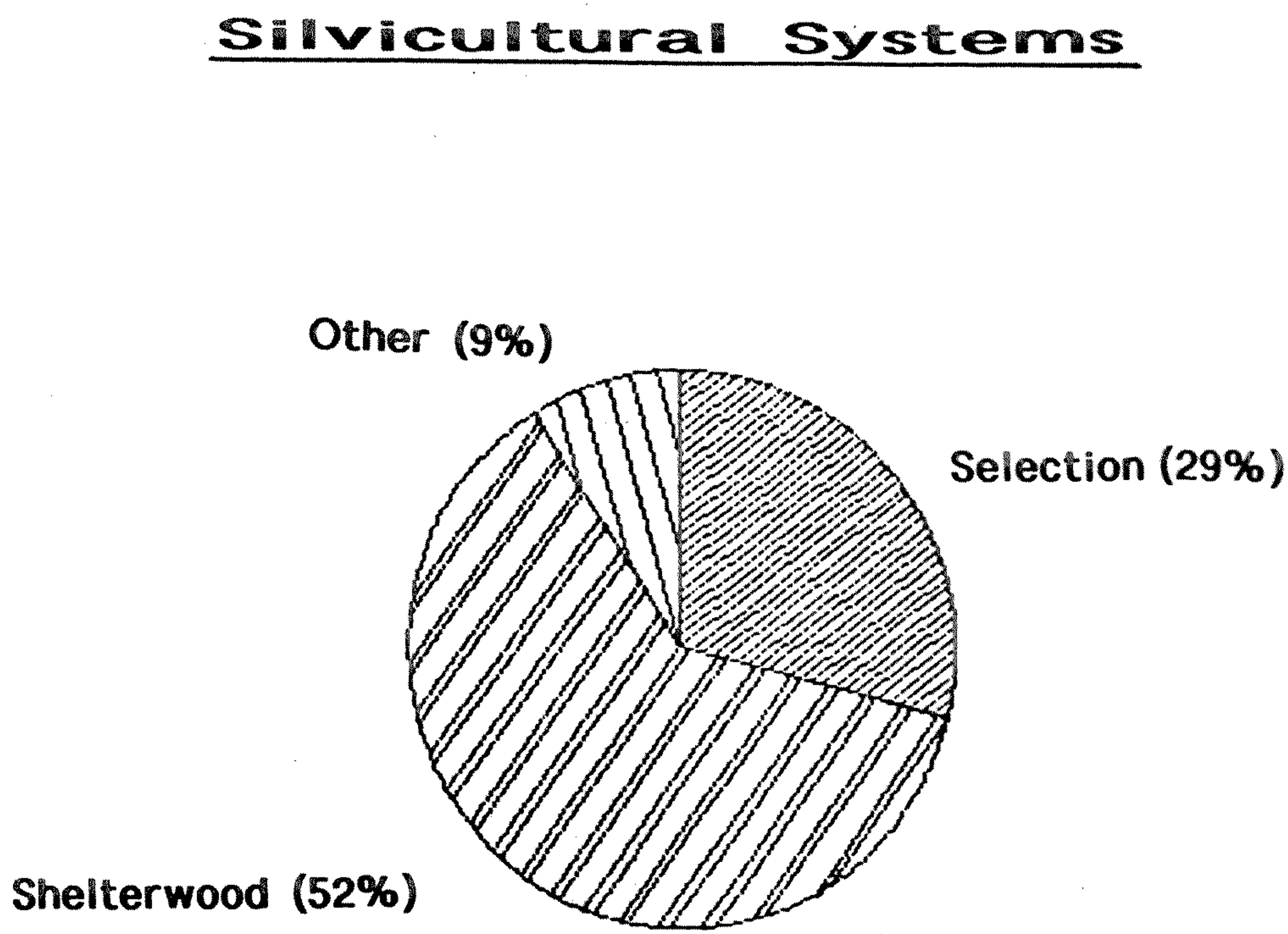

Figure 4. Silvicultural systems used in Grass Valley Creek watershed, 1974-1992 (CDF data).

latest recommendations are contained within the 1991 revision of the mitigation measures (see attached).

Content

Results of the committee's field review indicated the following:

1) Reducing soil disturbance would result in less erosion.
2) Stream diversions were the cause of the largest erosion events.
3) Controlling run-off and preventing its concentration on easily eroded areas was critical.
4) The most successful erosion control strategy was to retain natural vegetation in areas of high erosion risk and to revegetate areas of disturbed soil as soon as possible.

The 1986 GVC sediment study by SCS found that 70% of the sediment produced by the watershed was caused by accelerated erosion occurring as a result of land management activities, primarily timber harvesting. Of this total, the single largest contributor was logging roads and landings. Reducing this source of sediment is a primary goal of CDF's mitigation measures. To accomplish this, several practices are recommended:

1) Road systems should be located as far from watercourses as possible.
2) Permanent road surfaces should be armored with course, angular rock.
3) Permanent fills should incorporate non-DG fill material, and be rock-armored. Culvert diameters should be increased by a factor of up to 150%.
4) Temporary crossings should be used whenever possible.
5) Temporary roads and fills should be stabilized with treatments of straw mulch and grass seed immediately following operations.

Tractor skid trails were also observed to be a significant source of sediment. To alleviate this, it was recommended that tractor operations be limited to slopes less than 50%, and that tractors would be limited to ridgetop trails and lateral contour trails. Waterbreaks would be constructed at 50 foot intervals to reduce the velocity of run-off and therefore reduce erosion.

To protect water quality, watercourses containing fish, domestic water supplies, or aquatic habitat were to have watercourse and lake protection zones (WLPZs) a minimum of 100 feet in width on each side of the stream. Tractors would be prohibited from entering this zone, and any areas of disturbed soil within the zone would be treated with straw mulch and grass seed.

Evaluation

The success of the mitigation measures has been evaluated over the past 6 years. Harvesting operations which have implemented them have experienced less erosion than historical logging projects. However, recent logging operations have not been tested by flood-causing storm events, so the long-term effectiveness of the measures has not been established.

Recent Developments

Continued concern over the ongoing deposit of sediment into the Trinity River raised the issue of whether just reducing logging-related sediment was sufficient. To address this concern, the "Zero-Net Increase" formula was jointly developed by the North Coast Regional Water Quality Control Board, SCS, the Calif. Division of Mines and Geology, and the CDF (see Komar, these Proceedings). The method attempts to estimate the amount of sediment that will be produced by the proposed project and to offset this increase by rehabilitating existing erosion sites within the GVC watershed, reducing erosion by a like amount. Additionally, project proponents are required to develop a monitoring program to evaluate the success or failure of their project and mitigations used. This approach has been used on several THPs within GVC since 1990; project evaluation is ongoing.

CONCLUSION

Land management activities have resulted in very large increases above the natural erosion rate in the GVC watershed. Timber harvesting has been identified as the management activity responsible for most of this increase. Logging roads and landings are the primary point sources for sediment production, with stream diversions causing the largest erosion events. CDF, in conjunction with other resource management agencies, has developed mitigation measures that have reduced the risk of accelerated, logging-related erosion. Continued monitoring of recent harvesting projects will be necessary to determine if the measures are sufficient to reduce accelerated erosion to acceptable levels.

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RECOMMENDED MITIGATION MEASURES

FOR

TIMBER OPERATIONS

IN

DECOMPOSED GRANITE SOILS

WITH PARTICULAR REFERENCE TO

GRASS VALLEY CREEK AND NEARBY

DRAINAGES

Prepared by

CALIFORNIA DEPARTMENT OF FORESTRY

AND FIRE PROTECTION

Revised March 1991

PREAMBLE

In highly erodible decomposed granite soils alternative yarding systems and road locations should be investigated in preparing the Timber Harvesting Plan by the Registered Professional Forester on behalf of the applicant. In selecting these alternative yarding systems and road locations, the RPF will be guided by the terms of Section 898 (Feasible Alternatives) and Section 943 (Logging Roads and Landings) from the Board of Forestry's regulations.

Mitigations described herein will be selected to fit site specific locations on individual timber harvesting plans. They will be described in sufficient detail that the timber operator knows exactly what is expected and where. These mitigations are intended to be used in addition to applicable forest practice rules and are not intended to supplant those rules unless they provide greater resource protection than the rules.

Definitions: Temporary road - one year use; put to bed before October 15.

Permanent Road - More than one season of use; road surface will be rocked.

I. ROAD CONSTRUCTION

A. New road construction within the WLPZ is prohibited. Exceptions may be approved where these locations will result in less impact to the watercourse. Exceptions must be explained and justified.

B. Utilize favorable topography and minimize excavation.

C. Minimize fill sections where side slopes exceed 50% by utilizing:

1. Full-bench roads.

2. End haul, slot doze and place brow logs, where necessary, to prevent sidecasting.

D. Leave native vegetation in place in the lower 1/3 of the road prism. Leave or place cut vegetation and slash at toe of fill.

E. Cut Slopes.

1. Cut slopes should be as steep as possible, but not to exceed 1/4:1.

2. Minimize through cuts.

F. Roads widths should not exceed 12 feet to minimize cut height. Exceptions must be explained and justified in the THP.

G. Fill Slopes

1. Construct berms, only where necessary, to protect fill sections on permanent roads.

2. Armour fill slopes that contact stream flow with competent angular rock or alternative material that will provide equal or better protection; this shall include the approaches to removed temporary crossings.

3. All through fills must be crowned.

H. Culverts

1. Culverts shall be installed only on permanent roads that will receive continuous maintenance.

2. Culverts will be sized to a 50-year storm and over-sized when streambed conditions warrant. Woody slash and debris must be cleared out for a minimum of 30 feet above inlet to culvert.

3. Culverts shall be a minimum of 18 inches in diameter.

4. Use a backhoe or excavator for culvert installations and removals except where other methods are justified.

5. Decomposed granite soils must be compacted in a moist condition when used as fill material around culverts. Importing clay soil for fill material is recommended where feasible.

I. Roadbeds shall be outsloped at 2%, except for short inslopes immediately above culverts and/or where out-sloping will result in diverting runoff onto fill slopes longer than 10 feet or non-vegetated soils.

II. ROAD CONSTRUCTION

A. Evaluate impact of reconstruction versus new construction and be prepared to explain reasons for choice selected to the review team.

B. Identify previous failures on THP map and redesign using appropriate mitigation measures described herein.

III. EROSION CONTROL

The EHR of road and skid trail areas shall be rated as extreme.

Reduce volume and velocity of water by directing it off the road, skid trail or landing surface as soon as possible at controlled locations.

A. Permanent Roads

1. Control discharge of all drainage structures or facilities by utilizing;

   a. Natural vegetation.

   b. Hand-placed energy dissipaters, such as straw bales, slash, logs, rock overside drains or a combination of the above.

2. The road-running surface must be rocked. Rock will consist of current Cal Trans standard specifications for Class II aggregate base (or equal) 1 1/2" or 3/4". Pit run shale may be substituted. The rock will have a compacted depth of 6 inches over the entire width of the road including turnouts and landings.

3. Fill Slopes

   a. Seed, straw mulch and fertilize (see stabilization section) all sidecast over 10 feet in length.

   b. Place logging slash from road right-of-way along toe of fill.

4. Cut Slopes

   a. Where necessary, treat exposed cut slopes; i.e., hydromulch, or seed, straw and fertilize.

B. Temporary Roads

1. Control discharge of all drainage structures or facilities by utilizing:

   a. Natural vegetation.

   b. Hand-placed energy dissipaters such as straw bales, slash, logs, rock overside drains, or a combination of the above.

2. Fill Slopes

   a. Seed, straw mulch and fertilize (see stabilization section) all sidecast over 10 feet in length.

   b. Place logging slash from road right-of-way along toe of fill.

3. Remove temporary crossings on all Class I, II and III watercourses. Bring channels to natural grade and width, and armor with competent angular rock to stabilize reconstructed channel.

4. Waterbreak Construction

   a. Waterbreak spacing shall not exceed 50 feet.

   b. Straw bales, slash or natural vegetation must be used to control waterbreak discharge.

   c. Waterbreaks ~~constructed by hand~~ shall be a minimum of 18 inches in height (bottom of trench to top of berm).

5. Scarify, seed, mulch and fertilize road running surface after use.

C. LANDINGS

1. Locate away from watercourses and outside WLPZ unless otherwise explained and justified and approved by the Director.

2. Keep to a minimum size and number. Use favorable topography.

3. Minimize cuts and fills. Seed, straw mulch and fertilize sidecast over 10 feet in length.

4. Use brow logs, where necessary, to minimize sidecasting during construction and landing cleaning.

5. Restore drainages to original gradient and width. Stabilize and armour the drainages crossing landings.

6. Scarify, seed, mulch and fertilize landing surfaces and fill slopes prior to October 15.

D. SKID TRAILS

1. End line logs, wherever possible, to minimize skid trail construction. Logs within 100 feet of a skid road will always be endlined on slopes exceeding 30%.

2. Flag primary skid trails prior to preharvest inspection and show locations on THP map.

3. Confine skid trails to:

   a. Ridge tops.

   b. Contoured laterals.

   c. The construction of skid trails on slopes over 50% shall be prohibited. This prohibition shall include contoured laterals and skid trails on steep ridges. Exceptions should only be allowed where adequate control of sidecast material and protection from erosion are assured.

4. Waterbreak Construction

   a. Install waterbreaks at 25-foot intervals for the first 100 feet, or as agreed upon, on skid trails which exit onto haul roads and landings.

   b. Waterbreaks shall be installed at no more than 50-foot intervals in all other areas.

   c. Waterbreaks ~~constructed by hand~~ should be a minimum of 18 inches in height (bottom of trench to top of berm).

   d. Use straw mulch, slash or natural vegetation to control waterbreak discharge.

   e. Waterbreaks shall be located to discharge into natural vegetation. Where this is not possible, slash or straw bales shall be placed at the discharge point to effectively dissipate water, or waterbreak spacing shall be reduced to 25 feet.

   f. Where feasible, waterbreaks shall be discharged on the slope with the heaviest vegetation or on the gentlest slope, if adequate vegetation is present.

5. Seed, straw mulch and fertilize for a distance of 100 feet, all skid trails which exit onto landings or roads.

IV. WATERCOURSE PROTECTION

Watercourse and lake protection zones shall be flagged prior to the Pre-Harvest inspection. Exceptions shall be explained and justified in the THP. The location of Class I, II, and III watercourse crossings shall be shown on the THP map.

A. 1. WLPZ width shall be a minimum of 100 feet on Class I and II watercourses.

2. Equipment exclusion zones, 50 feet in width minimum, shall be designated on Class III watercourses.

B. Increase WLPZ and EEZ widths (by at least 50%), as necessary, to prevent erosion when the following conditions are present:

1. Adjacent slopes exceed 50 percent.

2. Areas of instability are present.

3. Sparse vegetation exists either prior to or projected after the operation.

4. Excessive natural or man-caused erosion is present.

5. The watercourse or nearby downstream channels support fisheries.

C. Scarcify, seed (see stabilization section), straw mulch and fertilize all of the following areas of exposed soil within the watercourse protection zone:

1. Road (unless rocked), landing and skid trail running surfaces including sidecast.

2. Temporary crossing approaches.

D. Use brow logs, where needed, to minimize sidecast within the WLPZ's.

V. WATERCOURSE CROSSINGS

Watercourse crossings shall be designed such that watercourse flows cannot divert onto the road running surace. Class I, II and III crossing locations and skid trail approaches shall be flagged prior to PHI.

A. Permanent Crossings

1. Minimize excavation by using a backhoe or excavator, when necessary.

2. Rip-rap inlets and/or install flared inlets.

3. Insofar as practical, cross watercourses at right angles.

4. Install culverts at natural channel grade.

5. Control direction of the discharge by the culvert to grade and center of stream channel.

6. <u>Culverts shall be sized for 50 year return interval storm.</u>

B. Temporary Crossings

1. Evaluate use of metal pipe vs. Humboldt crossing <u>vs. Rocked Dip</u> in THP, and explain reason(s) for choice.

2. Cross drainages at right angles.

3. <u>Minimize excavation and remove by October 15.</u>

4. Culverted crossings:

a. Use a backhoe <u>or excavator,</u> where practical, for installation and removal.

b. Minimum culvert size 18 inches.

c. Use washed rock as fill material, if available.

5. Humboldt Crossings

a. Use sound logs just long enough to facilitate skidding or transporting logs. Maximize number of logs to minimize amount of fill.

b. If possible, install and remove logs with a front-end loader.

c. If access restricts front-end loader, pre-attach chokers prior to installation or provide for choker attachment upon removal.

d. Minimize ground disturbance during installation and removal.

e. Keep fill depth to a minimum.

f. Use brow logs on skid crossings, where necessary, <u>to minimize sidecast.</u>

VI. STABILIZATION

A. Seed Requirements

1. The following seeding specifications have all proven effective:

a. Recommendation #1 (to be used on wetter sites, and northfacing slopes)

Species	Lbs/Acre
Topar or Luna Pubescent Wheat Grass	50
Akaroa or Burber Orchard Grass	20
Legume (Red Clover)	30

b. Recommendation #2 (to be used on harsh, dry sites)

Species	Lbs/Acre
Topar or Luna Pubescent Wheat Grass	12
Tegmar Dwarf Wheat Grass	12
Zorro Annual Fescue	10

c. Recommendation #3 (to be used on moderately wet sites)

Species	Lbs/Acre
Topar or Luna Pubescent Wheat Grass	30
Akoroa Orchard Grass	15

d. Recommendation #4 (to be used on dry sites where existing grass stands are found)

Species	Lbs/Acre
Topar or Luna Pubescent Wheat Grass	30

e. Other species mix as recommended by local SCS.

B. Fertilizers

1. Chemical analysis should be 16 percent nitrogen, 20 percent phosphous, and 0 percent potassium (16-20-0).

2. The application rate should average 250 pounds per acre.

3. The fertilizer should not be applied more than 15 days prior to seeding.

C. Straw mulch

1. The application rate should average 3,000 pounds per acre or 3 to 4 inches thick.

2. If straw is blown on, it should not be reduced to less than 6 inches in length.

3. On the steeper slopes, over 60 percent, the straw mulch should be tucked into the soil.

VII. TIME SCHEDULES

The following time frames should be strictly followed. Our experience indicates that fall rains can cause serious erosion problems when the schedule is not met.

A. Winter operations are prohibited.

B. All log skidding and waterbreak construction shall be completed by October 15.

C. All stabilization work shall be completed by October 15, or sooner.

D. No more than three active landings per side shall be without waterbars.

VIII. SILVICULTURE

A. All trees to be cut will be marked prior to the preharvest inspection.

B. The RPF and the review team will evaluate the adequacy of protective vegetative cover that will remain following harvesting to protect the site from unacceptable erosion.

IX. MAINTENANCE PERIOD

Maintenance will be conducted for a period of 3 years following conclusion of timber harvesting operations. Maintenance will include repairs of dysfunctional drainage structures and erosion control measures.

EROSION CONTROL PROJECTS IN GRASS VALLEY CREEK WATERSHED

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ABSTRACT

The Trinity County Resource Conservation District is dedicated to reducing erosion and sedimentation in the Trinity River Basin. It currently uses education, cooperative agreements, and project implementation to achieve this goal. The District is in charge of restoration and erosion control work within the Grass Valley Creek watershed, which contains mostly decomposed granitic soils and has over 1,000 sites identified as significant sediment producers. To implement the project work in the most feasible and cost-effective manner, the District has been using USDA Soil Conservation Service designs and labor by state inmates, California Conservation Corps, and local contractors.

INTRODUCTION

The Trinity County Resource Conservation District (RCD) began working on the implementation of Trinity River Basin restoration projects in 1989. The close relationship between the USDA Soil Conservation Service (SCS) and the RCD has resulted in the District implementing various erosion control efforts on private land, predominantly decomposed granite (DG) areas, within the Trinity River Basin. These projects were designed by the SCS and are intended to reduce erosion within the basin and reduce sedimentation of the Trinity River.

The District is currently in charge of coordinating and implementing the restoration efforts in the 23,000 acre Grass Valley Creek (GVC) watershed. With funding and direction from the Trinity River Basin Fish and Wildlife Task Force, the goal is to treat the priority erosion sites and reduce sedimentation into Grass Valley Creek and the Trinity River by an estimated 300,000 cubic yards. Over 1000 erosion sites were identified in the SCS inventory of the GVC watershed (see Spear, these Proceedings).

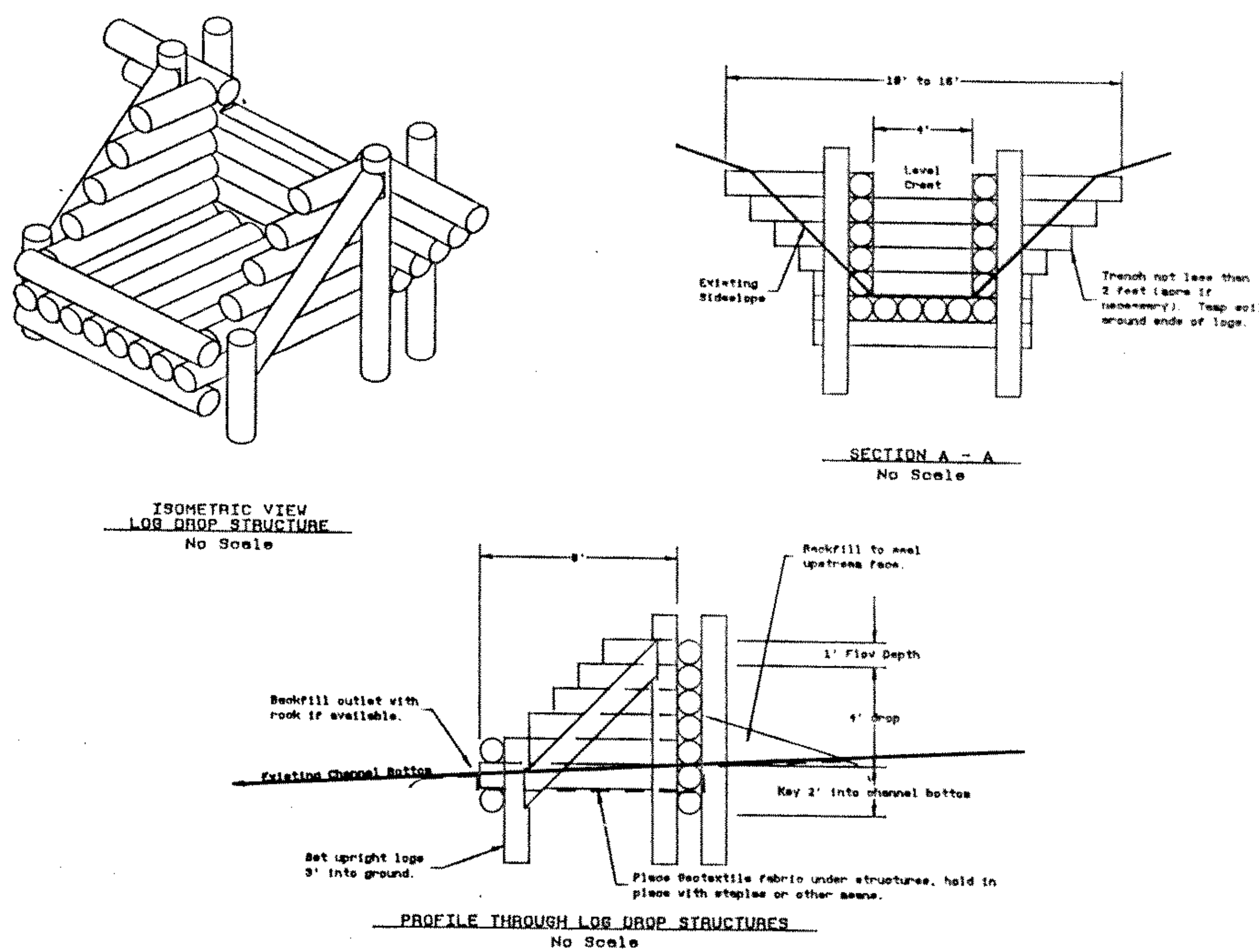
EROSION CONTROL PROGRAM

Our watershed program started in March 1992 and will proceed through 1995. Developing treatment strategies and appropriate cost-effective designs, and managing the labor needed to complete this work in three years, presents many challenges. Peer group tours and meetings will continue to be held so the RCD can learn, be more innovative, and put the most effort "on the ground" while maximizing benefits.

In the first year of the program, several projects were completed. Reconstruction of the County Line Road South involved outsloping and rocking over 2 miles of the road surface. SCS designed the project and contracted labor and equipment were used to complete the work. Outsloping is a very effective treatment for roads constructed on DG soils because the inboard ditch is removed, allowing the toe of the cutslope to become stabilized while reducing sediment transport and concentrated flows. Crews from the California Conservation Corps (CCC) were used to enhance the work by selectively clearing trees before construction, placing slash on the fill slopes, installing overside drains and energy dissipation where necessary, and then applying seed, fertilizer and mulch to the road shoulders and other disturbed areas.

The District has also used CCC and Trinity River Conservation Camp inmate crews to construct nearly 100 log check dams. These grade stabilization structures were designed by SCS for the 25-year storm and are generally 3 to 4 feet high, constructed primarily of local salvaged pine, and lined with filter fabric to prevent failures around or under the structures (Figure 1). They are mainly intended to reduce gully erosion - headcutting, downcutting, and widening - and secondarily intended to trap and store sediment. Since the structures are temporary (an expected life of 5 to 10 years), our revegetation efforts are very important to provide long-term stability of these sites. Biotechnical treatments, such

Figure 1. Various views of log drop structure, USDA-SCS design, Grass Valley Creek Watershed.



as willow stakes, willow wattles, softwood cuttings, and indigenous vegetation, will be used to enhance the effectiveness and longevity of these structures. Critical area treatments (i.e., applying seed, fertilizer, and straw mulch) are also applied to all disturbed sites. The RCD intends to incorporate more native grass seeds into the blends developed for site treatment.

The SCS and RCD are developing strategies for revegetating with trees and shrubs. These plants are being contract grown and will be planted by local labor and CCC and inmate crews. Over 80,000 trees and shrubs will be planted in the winter and spring of 1992 and 1993. We hope the woody vegetation will provide the necessary long-term solutions to many of the problems associated with historic land use practices. Many south-facing slopes harvested for timber over 40 years ago have remained unvegetated and continue to affect the hydrology by increasing runoff. Drainages used as skid roads are also a major problem. Intensive revegetation is intended to mitigate these problems and reduce the watershed's sensitivity to storm events.

Other project work will emphasize using heavy equipment to excavate stream diversions and road crossings. Over 200 miles of roads currently exist, including haul, skid and permanent roads. Since a majority of the erosion is road-related, our efforts will focus on removing road diversions and treating the resulting gullies. This approach is also intended to reduce the likelihood of extreme sediment production and delivery when severe storms occur.

The District has also played a lead role in educating landowners on resource issues and facilitating cooperative efforts that serve the needs of the landowners while reducing sedimentation. Caltrans is now working cooperatively with the RCD to control erosion in the state highway corridor within the GVC watershed (see Haynes, these Proceedings). Pacific Gas & Electric Company (PG&E) and Champion International Corporation have contributed to efforts to reduce the offroad vehicle (ORV) abuse within the decomposed granite areas. PG&E has also requested that the RCD develop an erosion control plan for the Humboldt-Cottonwood 115kV powerline that runs through the GVC watershed. This powerline, and its associated access, has historically contributed sediment and provides a very attractive access for motorcycles. The RCD believes that providing education and alternative management strategies to landusers will allow for long-term and significant reduction in erosion and sedimentation.

EROSION CONTROL RESEARCH FOR HIGHWAY PROJECTS IN DECOMPOSED GRANITE

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ABSTRACT

The proposal by CalTrans to realign a portion of state highway within the Grass Valley Creek Watershed triggered a series of research efforts on erosion control in decomposed granite. Experiments were done on field test sites adjacent to the watershed as well as in the lab at the University of California, Davis. Erosion rates on various cut and fill slope designs, with and without treatments, were measured. Storm damage to the test sites in November 1992 has caused the research effort to be reevaluated even before some of the proposed erosion control plans were completed. Stabilizing the large cut slope site with a bioengineering approach is the present priority.

INTRODUCTION

The Redding (District 2) office of the California Dept. of Transportation (Caltrans) has undertaken preliminary studies to realign a portion of State Route 299W over Buckhorn Summit, about 25 miles west of Redding, to straighten or realign the switchback curves. The realignment would provide for a safer route, decrease the travel time and provide for more environmentally sensitive roadside treatment. One of the earliest concerns for this realignment was the potential for erosion in the decomposed granite materials. Because of the efforts of many other agencies to control erosion and sedimentation to the Grass Valley Creek watershed and the Trinity River, it was recognized that we would not be allowed to build if we could not control the erosion.

EROSION CONTROL RESEARCH PROJECTS

Cut Slope Research

To investigate the erosion potential of decomposed granites, Caltrans initiated a research project with L. Kavvas and R. Govindaraju from the University of California at Davis. A cut slope was constructed by Caltrans maintenance (regretfully on Champion International property instead of our right-of-way) on which several experiments were conducted. It was found in this work that sheet flow quickly led to rills, and they were observed to transport most of the surface water. The erosion occurring within them is more than an order of magnitude larger than that occurring over adjacent overland flow sections. Predictions based on design storms showed that a slope gradient of 1.5:1 produces close to the maximum erosion. Sediment loss can be reduced by increasing the steepness of the slope, but that raises questions of overall slope stability, viability of establishing vegetation, and long-term sediment production.

A number of commercial erosion control blankets were installed to determine their effectiveness on decomposed granite. There was far less surface runoff and erosion from the blanket-covered portion than from the bare hill slope. Since runoff was reduced and slowed, there was practically no erosion. Seed was applied prior to installation of the blankets, but vegetation establishment was sparse. The denser blankets retarded or prevented emergence, especially of broadleafs.

Under a separate contract with District 2 to monitor erosion rates off the experimental slope during the winter of 1991-92, John McCullah and Neil Youngblood of Trinity County Resource Conservation District discovered that there was significantly more erosion from dry creep caused by freeze-thaw cycles than from rain-induced erosion.

Fill Slope Research

A second portion of the University of California research was to model erosion rates on a fill slope. Rather than design a slope for research purposes only, it was decided to repair some existing problem areas and use those slopes for our research. A previously identified eroding slope (aka "Old Faithful") provided an additional cut slope, and the material removed from there was used for a curve correction project, which provided fill slopes (Figure 1).

New construction sites gave the opportunity to explore new design options for newly constructed decomposed granite slopes. Numerous multi-disciplinary team meetings were held to determine slope configurations, erosion control treatments and revegetation practices. Slope configurations for the cut slopes (Figure 2) included a typical 1 1/2: 1 (h/v) plainer slope, stepped or benched slopes with various bench sizes on slopes of 3/4:1, 1:1 and 1 1/2:1, and a "Japanese" terrace (borrowed from a project in Japan) with 16 1/2 foot wide 2.4:1 terraces and seven-foot vertical faces. A sixteen-foot wide bench was constructed about one-third the way up the slope to capture surface and subsurface flows and to provide access to the research sites. Wooden staircases were also provided for access to the higher portions of the site.

The two fill slopes were constructed at a 1 1/2: 1 slope design. The smaller fill slope was constructed with brush layering at 6, 8 and 12 foot intervals (Figure 3). (In contrast to the plans, the brush (willow cuttings) was placed six stems per foot, crissed-crossed, instead of the six-inch mat shown in the detail.) The brush layering was installed in lifts as the slope was brought up to grade. The larger fill slope was provided a bench sixty feet below the roadway to collect surface and subsurface flows.

Detailed and complex erosion control plans were designed by Vickie Bacon, District 2 Landscape Architect (Figures 4a and 4b). The erosion control was designed to evaluate various amendments such as imported topsoil, native duff, manure, fertilizers, grass and legume seed mixtures and surface treatments including commercial erosion control blankets, straw treatments and straw wattles. Some of the erosion control measures and revegetation planting was to be done by researchers instead of the general contractor.

Erosion Rates and Revegetation Research

Two contract research projects were funded to study erosion rates, effectiveness of materials and revegetation on the study sites. "Evaluation of Erosion Potential of Bare and Vegetated Cut/Fill Slopes of Decomposed Granite at Buckhorn Summit" is being performed by Kavvas, et al., U.C. Davis. The objective of this research is to develop a method for assessing surface erosion loss under the presence of vegetation and under each alternative of slope configuration and treatment. A rainfall simulator would be used to perform experiments under various rainfall intensities. The slopes would be instrumented with ring infiltrometers to characterize the infiltration. A computer model would be developed to predict soil loss from cut and fill slopes in terms of slope gradient, surface roughness, soil erosiveness, with particular emphasis placed on the influence of vegetation on erosion loss through interception and infiltration capacity of the soil. This project would also instrument the slopes for solar radiation and temperature fluctuations to develop a model for predicting soil loss through frost action.

The second research project, "Soil Conditions and Mycorrhizal Infection Associated with Revegetation of Decomposed Slopes" is being performed by Victor Claassen and Robert Zasoski, also of U.C. Davis. The objective of this study is to identify soil chemical and microbiological conditions associated with the establishment of long-term plant growth in disturbed slopes of decomposed granite. The goal of this project is to determine the nutrients or amendments necessary to maintain a vegetative cover, to determine how to maintain a cycling of those nutrients, and to allow a natural re-invasion of the native forest. Work already completed indicates the following soil nutrient status of freshly exposed DG: Potassium levels get better as the soil ages, Phosphorus is initially plentiful but may quickly become unavailable, Nitrogen is always deficient, Sulfur is low but easily added, micronutrients aren't limiting but increased growth occurs in the lab with their addition.

Erosion Control Research

There was to be a third research project: "Erosion Control Treatments and Vegetation Reestablishment on Newly Constructed Cut and Fill Slopes on Decomposed Granite Slopes", performed by John McCullah and assisted by Neil Youngblood with the Western Shasta Resource Conservation District. This project was amended to Vic Claassen's project due to funding constraints because of the state budget impasse. The objective is to identify the erosion

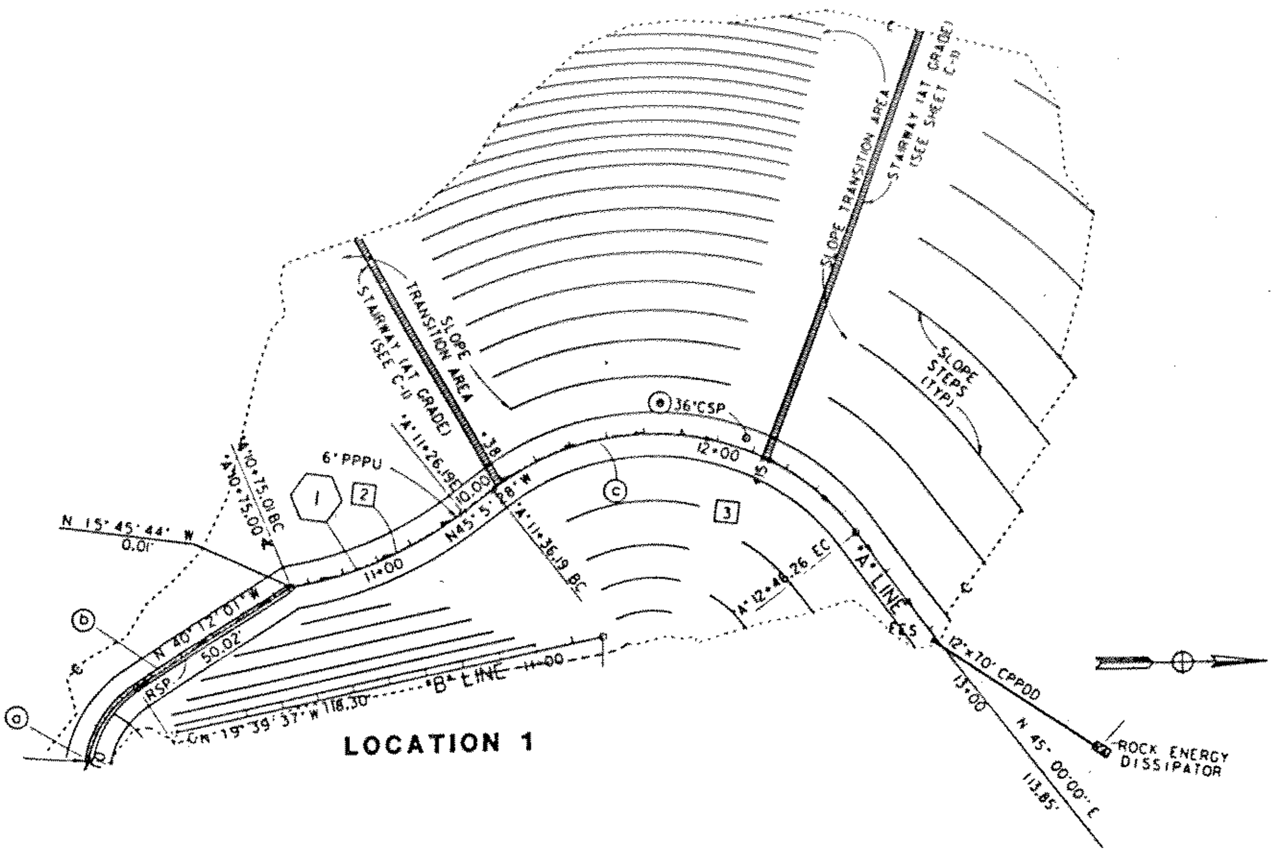
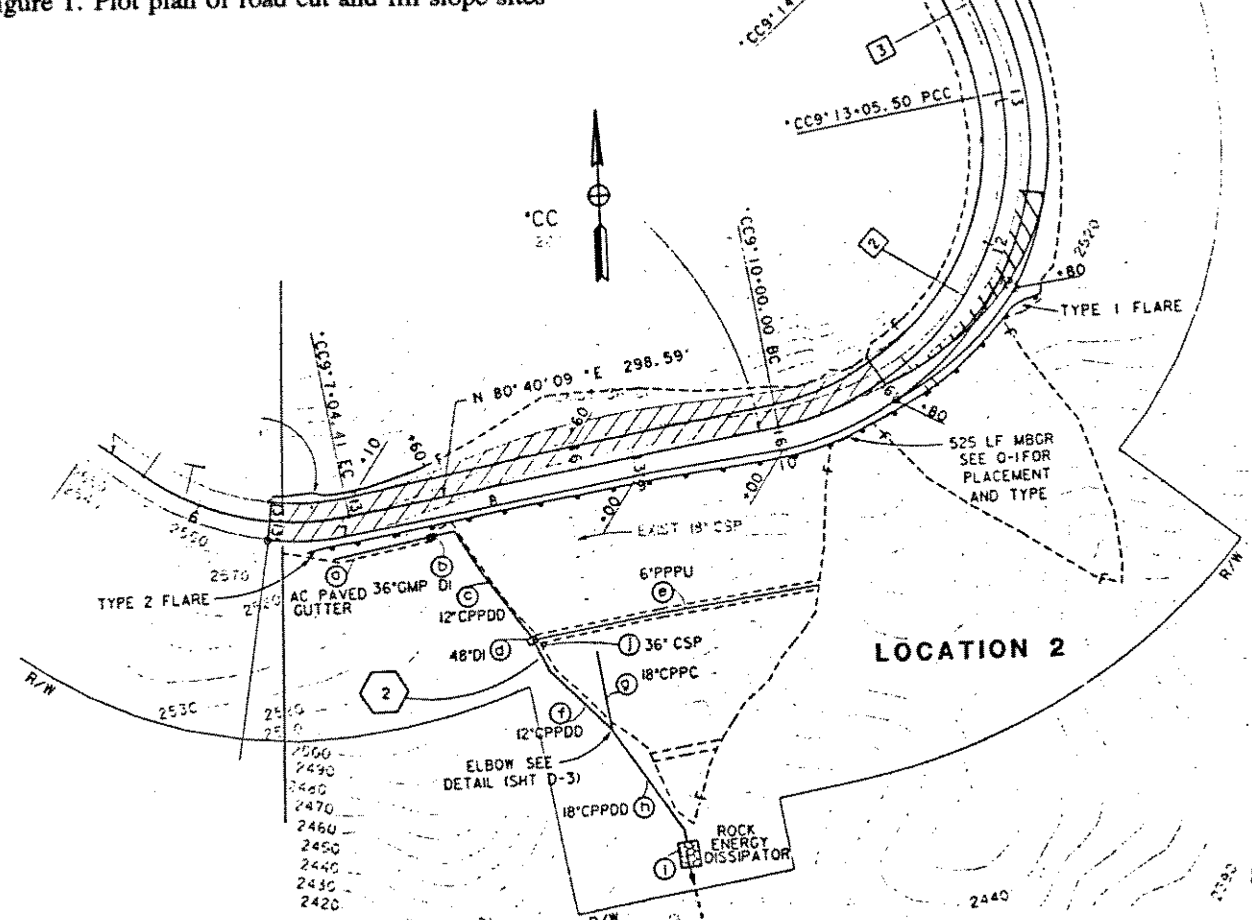


Figure 1. Plot plan of road cut and fill slope sites



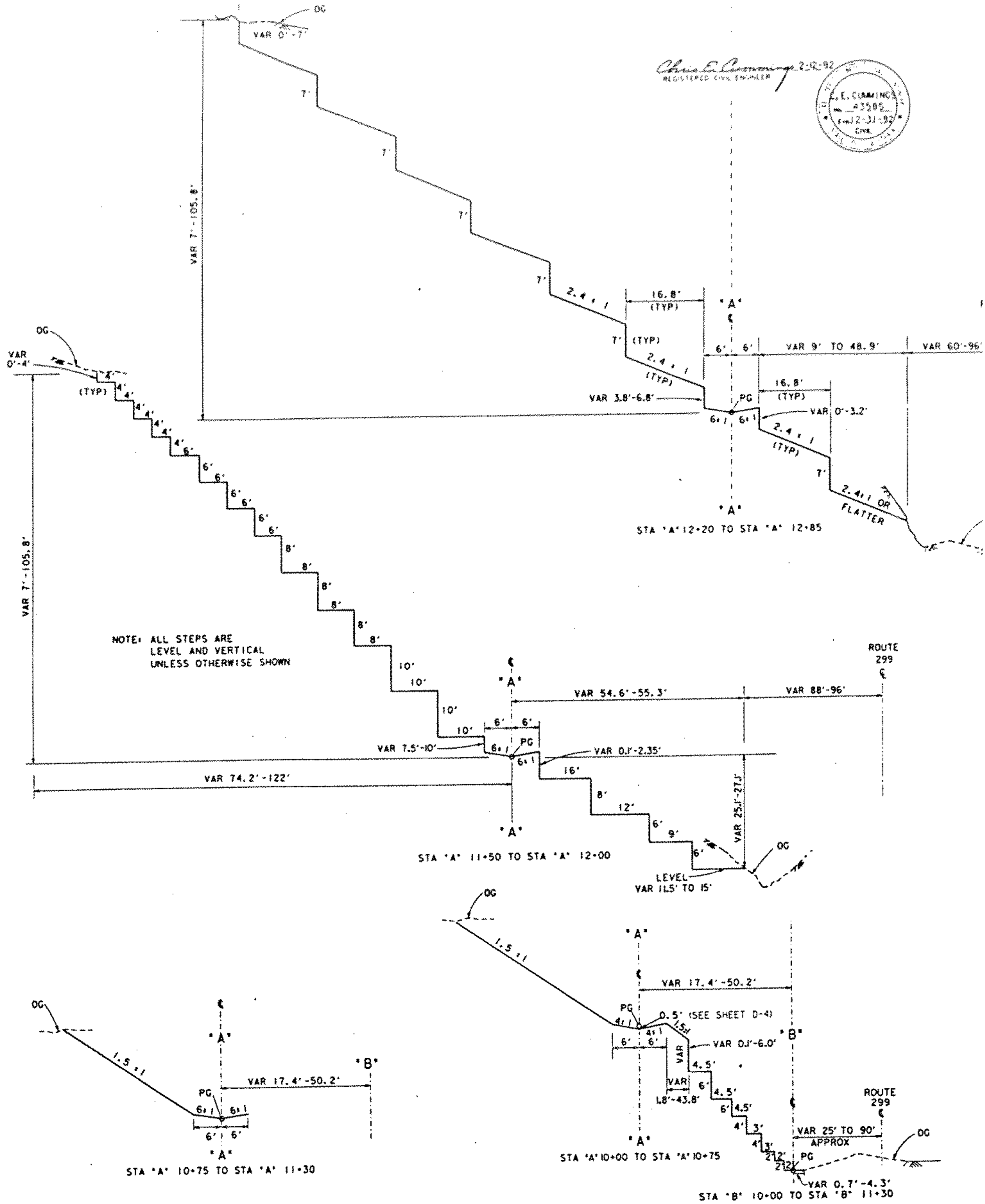
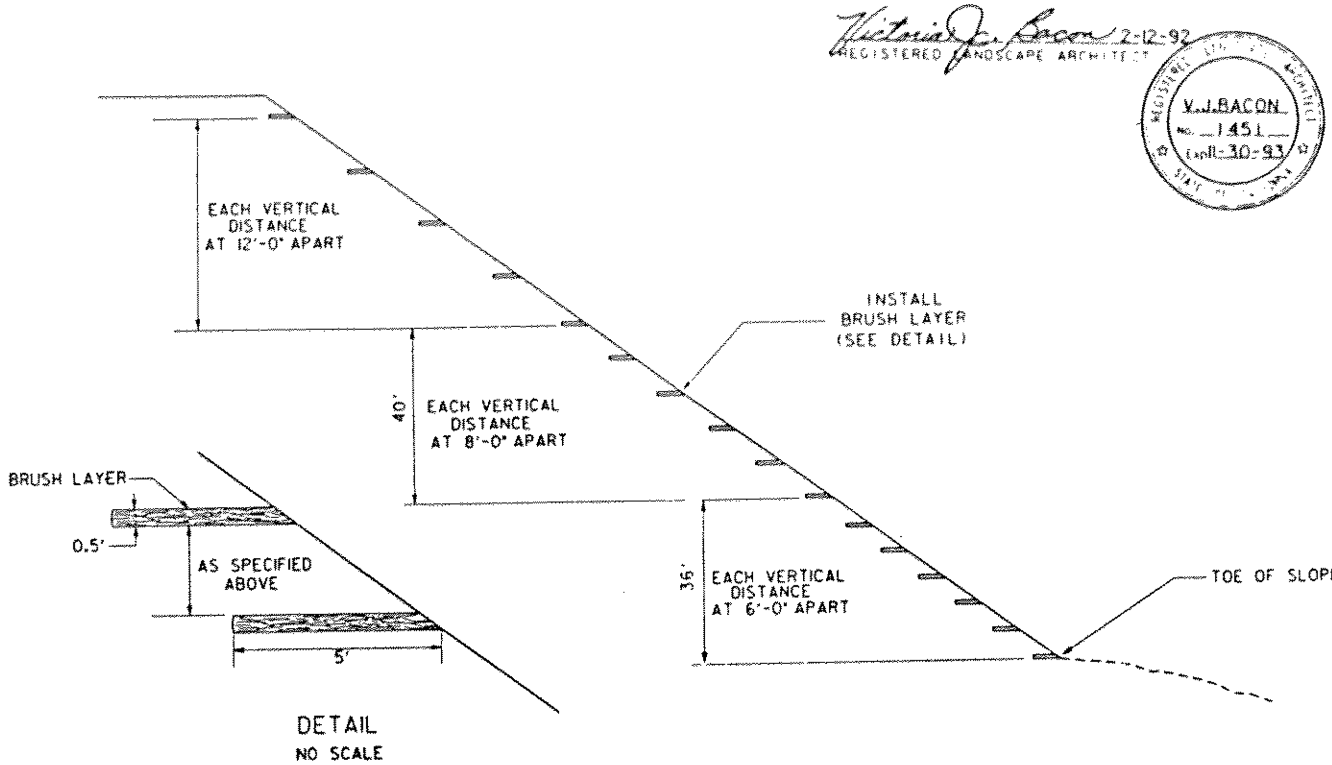
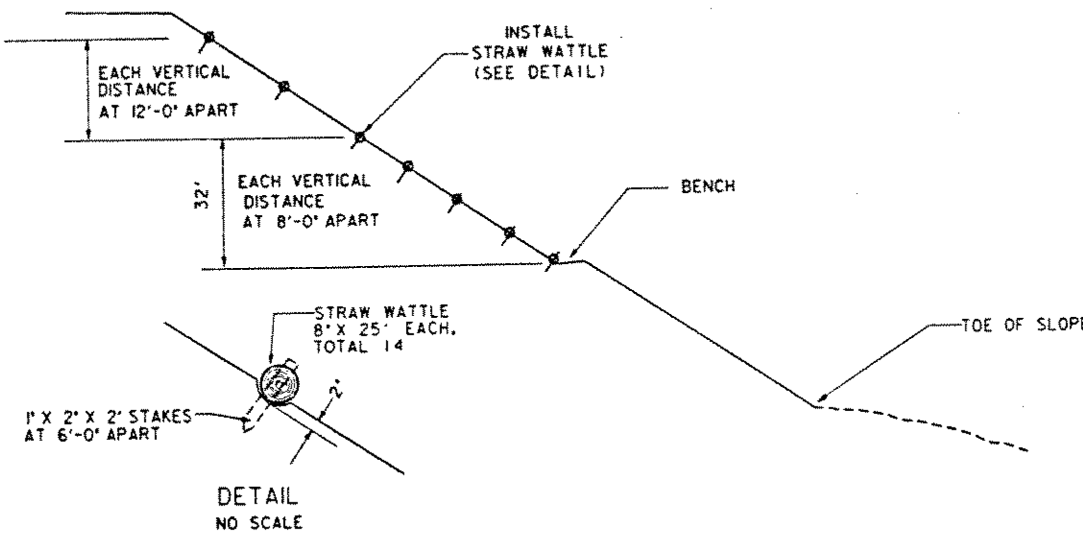


Figure 2. Typical cross-sections of experimental slope configurations



BRUSH LAYERING AT EROSION LOCATIONS "M" & "N"



STRAW WATTLE AT EROSION CONTROL LOCATION "I"

Figure 3. Brush layering and straw wattling designs for fill slope

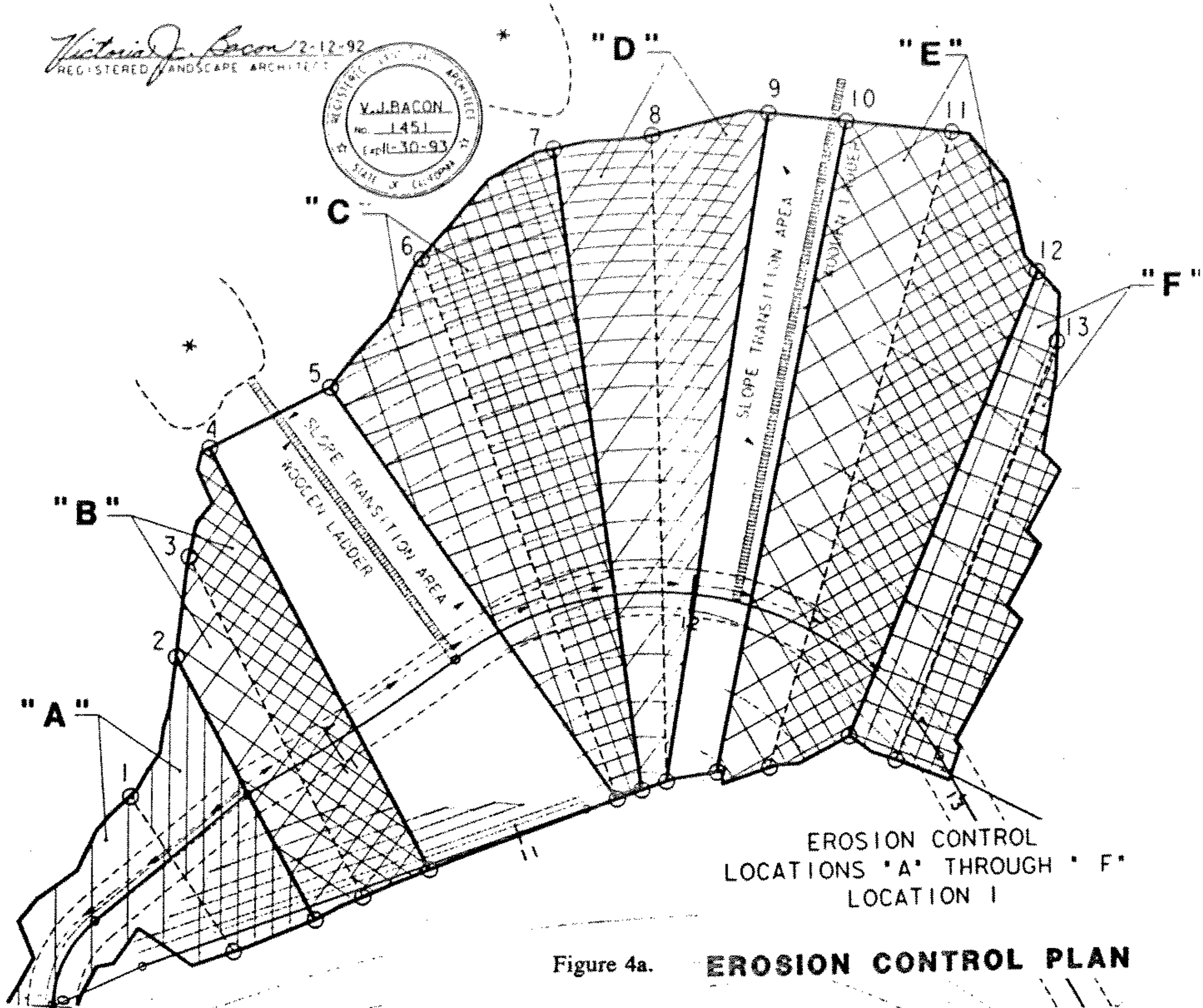


Figure 4a. **EROSION CONTROL PLAN**

LEGEND

- NO EROSION CONTROL TREATMENT
- TOPSOIL
- NO TOPSOIL
- DUFF
- NO DUFF
- MANURE
- NO MANURE
- * ALTERNATE DUFF STORAGE AREA
- SLOPE STEPS

AREAS FOR EROSION CONTROL MATERIAL (N)

LOCATION	IMPORTED TOPSOIL SF	MANURE SF	SPREAD DUFF SF	SEED (ER CTL) SF	COMMERCIAL FERTILIZER (ER CTL) SF	FIBER (ER CTL) SF	STRAW (ER CTL) SF	STABILIZING EMULSION (ER CTL) SF
A	1646			3142	3142			
B		2195		3491	3491	3491	3491	3491
C			3397	5506	5506	5506	5506	5506
D	2551			5392	5392	5392	5392	5392
E		1962		3625	3625	3625	3625	3625
F			3613	6519	6519			
G	3170			6597	6597			
H	3198			6465	6465			
I			2784	5568	5568	5568	5568	5568
J			3619	5578	5578	5578	5578	5578
K		6892		10114	10114	10114	10114	10114
L			2012	5590	5590	5590	5590	5590
M	3398			8448	8448	8448	8448	8448
N			5338	9312	9312	9312	9312	9312
ALTERNATIVE DUFF STORAGE AREAS				14088	14088	14088	14088	14088
TOTAL SF	13,963	11,049	20,763	99,435	99,435	76,712	76,712	76,712

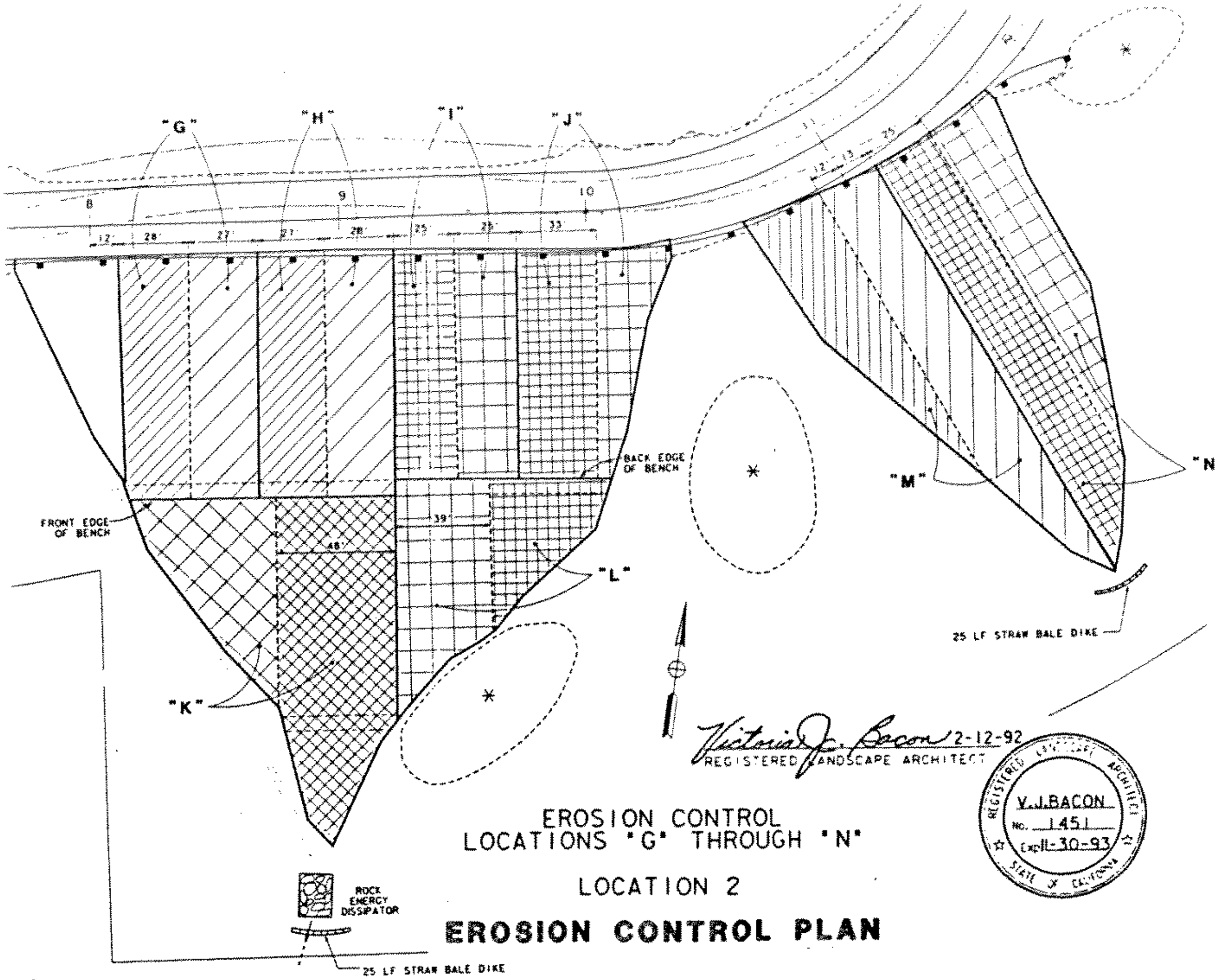


Figure 4b.

EROSION CONTROL LOCATION	EROSION CONTROL MATERIALS													EROSION CONTROL TYPE		
	TOPSOIL	MANURE	DUFF	LEGUME SEED	NON-LEGUME SEED	FERTILIZER-CHEMICAL ANALYSIS 16-20-0	FERTILIZER-CHEMICAL ANALYSIS 0-36-0-19	FIBER	STRAW	STABILIZING EMULSION	EROSION CONTROL MTL (BY OTHERS)	STRAW WATTLES (STATE FURNISHED)	BRUSH LAYERING-WILLOW BRANCHES (STATE FURNISHED)	(BLANKET)	(TYPE C)	(TYPE D)
A	X				X	X					X			X		
B		X		X	X	X	X	X	X	X						X
C			X		X	X		X	X	X						X
D	X			X	X	X	X	X	X	X						X
E		X			X	X		X	X	X						X
F			X	X	X	X	X				X			X		
G	X				X	X					X			X		
H	X			X	X	X	X				X			X		
I			X	X	X	X	X	X	X	X		X				X
J			X	X	X	X	X	X	X	X						X
K		X		X	X	X	X		X						X	
L			X		X	X		X	X	X						X
M	X				X	X		X	X	X			X			X
N			X	X	X	X	X	X	X	X			X			X
					X	X		X	X	X						X
ALT DUFF STORAGE AREA					X	X		X	X	X						X

control materials, practices and plant materials that can provide long-term slope stability. John and Neil are also sub-contractors to the Kavvas project and will collect sediment samples, make instrument readings and maintain the erosion control materials. They will be especially valuable for their constant visual monitoring of the various sites.

POST SCRIPT

Near the end of the construction project in November 1992, a major storm hit northern California. Almost ten inches of rainfall were recorded in Redding in five days; it is estimated the area of the project received even more. Most of the stepped slopes at the cut slope site have failed. Where the steps had been is now a talus slope on the wide bench filling to an angle of repose. The upper part of the slope is eroding to near vertical. The stepped slope below the bench had been covered with plastic and is still intact. It appears this slope configuration, or at least steps of the height designed, are not appropriate for this decomposed granite.

The Japanese terraces were failing on the bottom terraces, but the upper ones were still holding. This same configuration, with two to three foot high vertical faces and reduced terrace width, may be worth future evaluation. The 1 1/2: 1 slopes and the even steeper transition slopes had not suffered significant damage.

The fill slopes have also experienced failures. The erosion control materials had very recently been applied and plant growth had not started. The heavy rain saturated the slope, especially where the straw had been incorporated, and the top six to eight inches of straw and soil slid to the bench in the center of the slope. The bench had been fitted with an impermeable membrane to collect runoff. As the soil from above filled the bench, the water collected at low points and ran off, causing deep gullies below the bench. The top of the fill slope has been covered with a rock facing as emergency action to protect the newly-built roadway and guard rail. It is anticipated that at least the lower portion of the fill will have to be reconstructed. If the erosion control had been applied earlier, it is expected this may not have happened.

The fill slope that was constructed with the brush layering was also losing soil. The erosion started at the toe of the slope below where brush layers started and was working upslope. As the erosion reached the willows, it appeared they were stabilizing the slope. This slope will be closely monitored during the winter to see if the willows are sufficient to hold the slope together. If the slope can survive the winter, we believe the willows will grow sufficiently in the spring to provide a vegetative cover and stabilize the slope.

Future Research

We are now reevaluating our research. Because of the extensive slope damage, much of Kavvas' work is not possible. His effort will probably be downscoped to measuring subsurface flows and temperature variation for the freeze-thaw study. Claassen's work will remain about the same, except more of it will probably be conducted in the lab because most of the field plots have been destroyed. John McCullah's work is expected to increase greatly. One of our most important considerations now is to stabilize the cut slope site. It will be allowed to weather and mechanically stabilize during the winter. We believe that rather than reconstructing the site with heavy equipment, we can use a bio-engineering approach. Meetings are currently underway to assess the feasibility and practicality of this technique. If it is chosen, John McCullah will install the materials using California Conservation Corps (CCC) forces.

INVITED

PAPER

THE DIFFERENTIATION OF GRANITE IN THE SHASTA BALLY BATHOLITH AND THE MULE MOUNTAIN STOCK

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ABSTRACT

The term "granite" in decomposed granite refers to a quartz-bearing igneous rock made up of individual crystals. The actual rock type may be one of several classifications under the broad category "granite". Understanding the origin, composition, crystal size, and structure of an igneous rock is an important step to understanding the erosional processes of an associated decomposed granite. The Shasta Bally Batholith and Mule Mountain Stock are two examples of "granitic" bodies in northwestern California. Although they are close geographically, they are compositionally and structurally dissimilar.

INTRODUCTION

What is granite? To a geologist, it is a specific classification of an igneous rock with a composition of 10-50% quartz and an alkali feldspar content making up 65-90% of the total feldspars in the rock. To those with some scientific background, it probably means a quartz-bearing rock with crystals large enough to see with the eye. There are severeal classifications under the term "granite": granodiorite, quartz syenite, monzonite, and diorite are just a few. Why is the classification important? The classification of a rock give information about the origin, composition, and crystal size (Raguin, 1965).

There are many terms to describe a body of rock. An example of this is the Shasta Bally Batholith. The term batholith refers to the geometric shape and the relative size of the body. Sill, stock, dike, and laccolith also refer to geometric shapes and relative sizes. These terms provide additional information about a particular igneous intrusive rock, or pluton (Hamilton and Myers, 1967).

If a mineral name precedes the rock type name, such as hornblende granodiorite, it is because that mineral exists in sufficient quantity to be a characteristic of the rock. If the terms grus or saprolite follow the rock name, then the rock is decomposed. Grus refers to a disintegrated crystalline rock resulting in coarse granular fragments. Saprolite refers to completely decomposed igneous or metamorphic rock which results in a clay-rich, soft material. Saprolites are less of a problem in natural resource management because they are less erodible due to the higher percentage of clay.

GRANITIC ORIGINS

The Molten Body

Plutons originate deep within the earth's crust or upper mantle as molten bodies. Because of a density differential, the melted material starts migrating up through the crust. As it moves up there is a decrease in pressure and the body expands. The molten pluton cools as it approaches the surface.

Composition

As the pluton cools, it chemically differentiates. The high temperature minerals, such as olivine, pyroxene, and calcic plagioclase, crystallize first. As these crystals fall out of the melt and the temperature drops, other lower temperature minerals begin to form. The lower temperature minerals may form at the expense of the higher temperature minerals; the higher temperature minerals may get reabsorbed. The low temperature minerals are the last to form and are the most stable at surface conditions. These are quartz, muscovite, and potassium feldspar. Since melts have various bulk compositions, final compositions of plutons are also different. The pluton, if cooled slowly, will form the most stable minerals possible from the available ions in the melt.

The center, or core, of a pluton wil crystallize last, causing compositional differences or zoning of the body. The lower temperature, more stable minerals should, theoretically, be found at the center of the pluton. This process explains gradational changes in composition within individual plutons.

Crystal Size

Crystal size is directly related to the rate of cooling. If cooling was rapid, then crystal sizes will be small or there will be a glassy texture. A slow rate of cooling will result in large crystal development. Weathering of coarse crystalline rocks becomes accelerated if crystal boundaries are not intricately locked.

Structure

The local structure and structural history of a pluton can be a critical factor in the weathering process. If the pluton has been fractured or faulted, then water transport through the body will be increased. The presence of water increases chemical weathering. Thrust faulting may also affect the movement of water in a pluton by trapping it above or below the plane of the fault.

Another structural feature is unloading. Unloading is the expansion of a pluton occurring because overburden removed by erosion reduces pressure. The expansion can cause abundant fractures and joints which expose the inner pluton to water-induced chemical weathering (Twidale, 1982). Exfoliation, spalling, spheroidal weathering, or "onion skin", are surface expressions of the unloading, expanding process. Thin, concentric layers of rock are successively stripped away from the surface of a bare rock. This process is visually distinctive.

Any structural feature that modifies a pluton will potentially have an effect on the weathering process. The extent and type of effect depends upon the specific pluton and its structure.

THE SHASTA BALLY BATHOLITH

This granitoid pluton is located mainly in Trinity County and partly in Shasta County, about 30 miles west of Redding, California (Lydon and Klein, 1969).

Age and Emplacement

The Shasta Bally Batholith is 127 ± 4 million years old and is related to many other granitic intrusions in the Klamath Province (Murphy et al, 1969). Of the numerous plutons in the Klamath Mountains, the Shasta Bally is thought to be the youngest of the granitic intrusions (Hotz, 1971). This age difference explains why the batholith has a lower percentage of secondary solution deposits such as quartz veins.

Composition and Crystal Size

The crystal size within the Shasta Bally Batholith is variable, but generally the batholith is coarse-grained with crystals visible to the unaided eye. Compositionally, the Batholith is a biotite-hornblende quartz diorite with extremes ranging from gabbro to granodiorite (Lydon and O'Brien, 1974). This quartz diorite contains quartz, hornblende, biotite, plagioclase, and some pyroxene. According to Hotz (1971), parts of the batholith are a trondjemite (a high mica quartz diorite) with a biotite component of 13%. This biotite content is very high because accessory minerals generally compose only two to five percent of the total rock composition.

Water and Weathering

Numerous springs in the Shasta Bally Batholith are the result of a complex set of fractures and an abnormally high water table. After six years of drought, springs are still active even at higher elevations. It is possible that a structural obstruction has perched the water table far above the normal ground water level for the area.

Physical breakdown of the batholith because of unloading and fracturing has resulted in the increased transport capability of the rock. This increased capability, in turn, allows water to attack the rock on a much greater surface area. The water reacts with biotite to form hydrobiotite, and hydrobiotite reacts with the water to form vermiculite, chlorite, or kaolinite. Vermiculite is an expandable clay and in the presence of water will expand to twice its dry state (Dixon and Weed, 1977). This microexpansion causes the rock to break down into monocrystalline fragments, resulting in grus.

MULE MOUNTAIN STOCK

This smaller granitoid pluton is located in Shasta

County, about 8 miles west of Redding, California.

Age and Emplacement

The Mule Mountain Stock has not been precisely dated. It is thought to be related to the Pit River Stock based on structure and composition. Davis (1966) dated the Mule Mountain Stock at 218 million years, which is similar to the age of the Pit River Stock.

The Mule Mountain Stock is one of the older intrusive units in the Klamath Province. It has been dramatically altered by magmatic solutions associated with the emplacement of the nearby Shasta Bally Batholith and is believed to have formed mainly by metasomatism (alteration of a rock by chemically active liquids) (Lydon and O'Brien, 1974).

Crystal Size and Composition

The crystal size of the Mule Mountain Stock is fine to medium. The Stock is mostly trondjemite composed of sodic plagioclase, quartz, epidote, and chlorite. The introduction of silica and soda has altered parts of the Stock to an albite (feldspar) granite. It is characterized by secondary mineralization and numerous quartz veins (Lydon and O'Brien, 1974).

Water and Weathering

The fractures in the Mule Mountain Stock that occurred during unloading have been filled with secondary solution deposits (quartz veins). These deposits limit the transport capability within the rock, also limiting internal chemical weathering. The mineral chlorite, a mica, is the most susceptible to weathering.

CONCLUSION

Climate, topography, vegetation and rock type are all factors in the weathering process. The controlling factor varies for each situation, but when plutons are geographically close, then rock type becomes an important determinant in differential weathering. A study of the origin, composition, and structural history of the pluton provides pertinent information for the determination of a geologic controlling factor. A basic understanding of "granitic" rocks is valuable for individuals who deal with and study decomposed granite.

The Shasta Bally Batholith and Mule Mountain Stock are excellent examples of decomposed granitic terrains. Although their origins, structures, and compositions are different (Table 1), they pose similar natural resource problems. The way in which these problems are dealt with should be linked with their individual histories. Erosion control practices that are successful on the Mule Mountain Stock may fail when used on the Shasta Bally Batholith. The geology of these two plutons must be taken into consideration as a part of the whole erosional system.

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Table 1. Comparison of certain granitic characteristics of two neighboring plutons.

	SHASTA BALLY BATHOLITH	MULE MOUNTAIN STOCK
AGE	127 mil.yrs.	218 mil.yrs.
TYPE	quartz diorite	trondjemite
CRYSTAL SIZE	coarse	medium to fine
MINERALS	quartz	quartz
	hornblende	epidote
	biotite	chlorite
	plagioclase	sodic plagioclase
	pyroxene	

POSTER SESSION ABSTRACTS

MIDDLE CREEK COORDINATED RESOURCE MANAGEMENT PLAN (CRMP)

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Poster Abstract

Located within the Sacramento River Basin, the Middle Creek watershed is 2,700 acres in size and is of primarily granitic parent material. Rural subdivisions have extended into this area in recent decades as part of the outward growth around the City of Redding in Shasta County. Road and homesite construction in the 1980s has caused widespread soil erosion, leading to sedimentation in Middle Creek and Sacramento River. Soil Conservation Service (SCS) geologists have estimated soil loss rates as high as 150 tons/acre/year from disturbed sites.

To help control this accelerated erosion and the resulting sedimentation of aquatic habitat, a local/state/federal partnership was created in January 1992 in the form of the Middle Creek Coordinated Resource Management and Planning (CRMP) effort. A Resource Management Plan is under development, as are a number of activities to raise public awareness and appreciation of the fish habitat. The Middle Creek CRMP has conducted sediment trapping and removal projects and is currently planning instream rehabilitation efforts. Landowners and land users alike are being encouraged to implement erosion control measures on existing disturbed areas identified in the SCS's erosion inventory. Public information meetings and a tour of the area have been held for Middle Creek watershed landowners. In addition, a video and informational flyer were also developed to help raise public awareness.

A $142,000 non-point source pollution control grant from the State Water Resources Control Board to treat the worst areas identified in the SCS erosion inventory was recently awarded to the Western Shasta Resource Conservation District (RCD). Grant funds will also be used to establish model demonstration sites to showcase erosion control methods to landowners and the development community. This two year program will greatly benefit the ongoing CRMP efforts to mobilize landowners to take proactive steps to prevent erosion. Technical assistance to landowners will be available through the Western Shasta RCD and the Redding Field Office of the Soil Conservation Service.

Portions of this watershed, located 5 miles west of Redding, will be seen during the Friday Field Trip.

ECONOMICAL TECHNOLOGY FOR REDUCING STORM-ASSOCIATED COARSE SEDIMENT PRODUCTION FROM ROADS IN HIGH RELIEF, HIGH PRECIPITATION FOREST LAND

KENNETH S. BALDWIN
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Klamath National Forest
Happy Camp CA 96039

Poster Abstract

Analysis of coarse sediment production to streams in the central Klamath Mountains indicates that erosion and landsliding of road fill is a major component of the sediment production attributable to timber harvest activities. In intensively managed basins, harvest-associated sediment results in doubling of natural sediment production.

Reinforcement of road fill with geotechnical fabric results in a significant improvement in shear strength of the fill. From the pattern of past episodes of erosion and landsliding, application sites can be identified along new and existing roads. The technology can also be applied to the repair of fill. Assumptions about predictive success allow analysis of cost and benefit of application to new roads and of existing roads.

NUTRITIONAL CHARACTERISTICS OF DECOMPOSED GRANITE

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* California Department of Transportation -
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Poster Abstract

Soil fertility of decomposed granite (DG) fill and cut slopes was analyzed for promotion of revegetation by native species. Soil samples from four sites along State Highway 299 east of the Shasta/Trinity county line were collected and analyzed for macro and micronutrients, acidity, cation exchange, organic matter and waterholding capacity. Tissue samples from plants growing on these sites were analyzed for nutrient composition. The sites included bare cut and fill slopes, revegetated cut and fill slopes, and native topsoils and subsoils adjacent to construction areas. A greenhouse bioassay was constructed using Sudan grass to measure plant growth in DG. The treatments were irrigated with solutions containing all sufficient nutrients except: 1) minus N, 2) minus P, 3) minus S, and 4) minus micronutrients, with complete nutrients in a control treatment.

Plant tissue analysis from field samples indicated potentially low N, P, S, B, Cu, and Mo. The greenhouse assay indicted low nitrogen, phosphorus and sulfur, but no obvious micronutrient response. As expected on these low organic matter substrates, nitrogen was severely limiting to plant growth. Plants in the minus N treatment also showed phosphorus deficiency, evidently caused by the lack of sufficient root development required for P uptake. Plants growing without phosphorus showed some limitation on growth and P deficiency symptoms. Phosphorus may become limiting as the soil weathers further and P fixation increases. Minus sulfur treatments showed yellowing of the leaves, but little reduction in plant growth.

Experimentation is now underway to develop treatment for long term prevention of growth limitation by N, P, and S on DG cut and fill slopes. The objectives are to provide a slow release N form to provide for initial growth and to establish nitrogen fixing plants for long term nitrogen inputs. Phosphorus occurs in the rock matrix, but its availability appears to be limited. Organic amendments are planned which will reinoculate the soil with mycorrhizae and soil bacteria, will help to generate the organic mat which protects the slope from surface erosion, and will increase the organic N and P pools available for increased plant uptake.

GRASS VALLEY CREEK WATERSHED RESTORATION PROGRAM

JAN DYBDAHL
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Weaverville CA 96093

Poster Abstract

Controlling sediment sources in the Grass Valley Creek watershed is one of the top priorities of the Trinity River Restoration Program, a Congressionally-funded interagency effort to restore the river's salmon and steelhead populations. Grass Valley Creek is mainly composed of decomposed granitic terrain in the Shasta Bally Batholith. Excessive amounts of the sand-sized sediment which results from its erosion is one of the major causes of the loss of quality spawning habitat in the upper Trinity River.

The USDA Soil Conservation Service and the Trinity County Resource Conservation District recognized that the decomposed granitic soils in the Grass Valley Creek watershed required unique and significant land treatments. The first step for a land treatment program is to locate sediment sources and identify types of needed treatments. This poster is a six (6) minute slide set and audio tape, developed in 1990, which illustrates some of the sediment sources and then proposes an acre by acre inventory of specific sites (completed in 1991).

Temporary sediment control measures already installed in the watershed by the Trinity River Restoration Program include sediment ponds at the mouth of the creek and the Buckhorn Debris Dam in the upper watershed. These two sites will be viewed during the Friday Field Trip.

THE TRINITY COUNTY ADOPT-A-WATERSHED PROGRAM

JAN DYBDAHL
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Trinity County Resource Conservation District
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Poster Abstract

The Trinity County Office of Education has created a K-12 curriculum for an Adopt-A-Watershed Program, as part of the Trinity River Restoration Program's educational outreach. Helping students develop a sense of stewardship toward our local watersheds and the resources within them should improve chances for long-term restoration success.

Kindergarten students adopt a specific watershed and then study and follow changes in that watershed as the focal point of their science curriculum through the twelfth grade. This program gives students the opportunity to observe up to thirteen years of change in one watershed and develop their ability to recognize the effects of this change on their lives.

The objective is to provide a thread that ties the entire science curriculum together for the teachers and the students, as well as to assist students in learning science skills with a program that is local and directly applicable to their lives. For example, if first grade science teaches animal life cycles, the class could incubate steelhead eggs in the classroom, learn about anadromous fish life cycles, or take part in a fisheries restoration project in their watershed. Other examples include studies in animal habitats, soil erosion, geology or meteorology, to name just a few. Each grade level will complete experiments about different aspects of their watershed. The data from these experiments will be compiled and will build from one year to the next.

The Adopt-A-Watershed scope, sequence, and curriculum is based on the most recent California State Science Framework. It will also integrate the life, physical, and earth sciences. The program will be coordinated and integrated with the California State Social Science and Language Arts Framework.

Copies of an 8 minute "Adopt-A-Watershed" video are available on a free, two week loan basis.

GRANITIC TERRAIN MANAGEMENT: LANDSLIDE HAZARD RATING AND RELATIONSHIP TO FAILURE MODES

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Poster Abstract

Granitic terrain provides the simplest case for the use of a specialized geotechnical method for assessment of landslide activation risk due to impact generated by logging and road construction. This technique involves the determination and assignment of ACTIVITY LEVELS (relative factors of safety) and upslope ZONES OF INFLUENCE (primarily groundwater) for all landslide prone terrain. The assessment and assignment of HAZARD LEVELS for the at-risk ground is completed for both natural (future) and altered (logging and construction) conditions. This data allows the preparation of terrain RISK TABLES (estimated percentage risk of failure) for each HAZARD ZONE delineated. In addition, estimates are made of potential impact: both cubic yards of sediment produced (and delivered) and acres of surface area lost for several rotations of timber production. The land management decision-making process can thus be readily quantified and projects put on a sound footing. High risk granitic terrain can be avoided since the technique provides identification and protection of potentially unstable land.

The failure of granitic soil (generally non-cohesive sandy material) is essentially liquid-like, whether in the form of a "landslide/debris slide/avalanche/torrent" (due to the effect of a rapidly flowing zone of groundwater) or at the surface (due only to gravity, not water). This factor allows the above described technique to be highly effective. In addition, the natural stabilizing process is completely used to advantage because the influence area concept allows easy avoidance of management impact. In the natural stabilizing process, all vegetative roots/rootlets form an interlocking "filter" network in combination with the sandy decomposed granitic soils (peds, aggregates, and particles).

Road cutslopes and, especially, fillslopes of DG soils are the most failure prone and potentially destructive features of all mountainous terrain land management/logging activities. Minimization of aggravated damage requires that fillslopes, for example, will not fail when subjected to concentrated groundwater discharge. Recreating the natural process of stabilization described above can be accomplished by use of a rock blanketed filter fabric on cut/fill slopes. These "buttress-filters" can be designed and constructed so that native vegetation (natural or planted) will eventually resume the slope stabilization process.

USING A GEOGRAPHIC INFORMATION SYSTEM TO CONSTRUCT A SEDIMENT BUDGET: A PRELIMINARY STUDY ON GRANITICS OF THE SCOTT RIVER BASIN

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Tierra Data Systems
Reedley CA 93654

Poster Abstract

A geographic information system (GIS) aided in landscape stratification, data extrapolation and modeling of soil loss on about 57,000 acres of granitic hillslopes (out of a 215,500 acre study area) in our report, Scott River Basin Granitic Sediment Study (1990). Maps of rate-controlling variables such as climate, slope, soil type, vegetative canopy cover, timber harvest history and roads were digitally overlaid, along with erosion sites digitized from sets of historical aerial photos. Erosion features and sediment storage areas could then be related to watershed variables. Soil loss and sediment models were run with the ability to draw on thousands of data points from the map layers, which interacted with tabular data collected from the field. This facilitated rapid characterization of erosion processes for the entire study area.

The following is a brief summary of how a GIS can be used in the development of sediment budgets.

Characterization of the watershed: Once the database is established, it is very efficient to find areas, lengths, and counts of multiple layers and associations and to re-categorize data into new statistics.

Landscape stratification: Stratifying an area into homogenous units based on slope, level of road use, or stream order can greatly reduce the sample size required.

Data collection: Erosion features can be digitized from sets of historical aerial photos, registering the various scales either manually or with a stereoplotter. Once in the database, erosion features can be easily related to watershed variables.

Extrapolation of results: Using digital elevation models to map elevation, slope and aspect and combining these with other resource layers allows the user to rapidly and easily extrapolate site-specific data to similar areas of the watershed based on whatever resource category or association of categories desired.

Sediment modeling: The multi-layered map database and associated tabular datasets from inventory and monitoring programs can be combined with GIS tools for correlating land use to water quality, routing sediment and many other kinds of analysis.

Iteration of results and sensitivity analysis: Variables can be calibrated, refined and adjusted as more information is gathered or new decisions about how to process data are made.

LAKE TAHOE EROSION CONTROL

LAKE TAHOE BASIN MANAGEMENT UNIT
U.S. Forest Service
South Lake Tahoe CA 96150

Poster Abstract

Lake Tahoe, one of the world's largest high altitude lakes, is famous for its remarkable clarity and great depth. The drainage basin is composed of granitic and volcanic rocks and is relatively small (309 sq.mi.) in comparison to the lake's size (193 sq.mi.). The rock type, altitude and limited drainage area are largely responsible for the lake's clear waters. Urbanization has changed the Basin's environment, causing increased discharges of sediment and nutrients into the lake and its tributaries. As a result, the clarity of Lake Tahoe has declined significantly in recent decades.

The Lake Tahoe Basin Management Unit has as its highest priority the protection of the water quality of Lake Tahoe and its tributary lakes and streams. It administers two watershed programs to restore and stabilize disturbed lands.

On Forest Lands: The Forest Service (USFS) manages about 148,000 acres (75%) of the basin's land area. Over 40,000 of these acres have been purchased through the Burton/Santini Land Acquisition Act of 1980 and other purchase programs. Many of these lands have serious existing erosion problems. In 1980, the USFS began an aggressive watershed restoration program to manage disturbed forest lands. Since then, the watershed restoration program has resulted in the improvement of 3,600 acres of disturbed lands at an investment of about $500,000 per year. This program is one of the largest, most complex and technical watershed restoration programs in the nation. Projects have included streambank stabilization, harsh site revegetation, drainage improvements and run-off control, and wetlands restoration.

On Urban Lands: The USFS also administers an Erosion Control Grants Program which provides federal financial assistance to local governments for water quality improvement in the developed portion of the Basin. Between 1984 and 1991, $12.3 million were distributed to fund a total of 60 projects. State and local funding provided $28 million to match these federal grants. The primary focus of this program is urban restoration. Typical measures include biological and structural roadside slope stabilization, road and storm drainage improvements, and some streamzone stabilization.

These programs have been a success because of the cooperation and planning efforts of the local/state/federal governing bodies, regulatory agencies, and land management agencies in the Basin.

FINE SEDIMENT IN POOLS: AN INDEX OF MOBILE SEDIMENT SUPPLY

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Poster Abstract

As sediment inputs into a stream increase, the bed surface becomes finer and more mobile. In a channel with a high sediment supply, there is abundant fine sediment (sand and fine gravel) in transport over much of the bed surface at high flow. As flow decreases, the fines are winnowed from riffles and deposited as a distinct layer in pools. In a channel with low supply, there is less fine sediment available on the bed surface to accumulate in pools at low flow.

The volume of fines in pools relative to the potential pool volume (minus the fines) thus provides an index of the amount of mobile sediment in the system. As an indicator of habitat condition, fine sediment in pools can be linked to embeddedness and sedimentation of spawning gravels, as well as pool habitat condition.

V^* is the fraction of residual pool volume that is filled with fine sediment. Fines volume is measured by probing the depth of fines with a metal rod across transects, and residual water volume is measured by sounding across transects. V^* can be used to monitor and evaluate channel condition and to detect and evaluate sediment sources.

TRINITY COUNTY RESOURCE CONSERVATION DISTRICT PHOTO DISPLAY

JOHN McCULLAH
Trinity County Resource Conservation District
Weaverville, CA 96093

Poster Abstract

To help restore the quality of salmon and steelhead habitat in the Trinity River Basin, the Trinity County Resource Conservation District (RCD) has been working closely with the USDA Soil Conservation Service (SCS) on various watershed rehabilitation projects located on private lands. These sites are predominantly in decomposed granite areas since they are producing the most sediment in the upper Basin. Projects are designed by SCS, with funding provided by the Trinity River Basin Fish and Wildlife Task Force (through the U.S Bureau of Reclamation and U.S. Fish and Wildlife Service).

The RCD photo display depicts this work being performed. Roads were reconstructed using contracted equipment and labor. Trinity River Conservation Camp inmates and the California Conservation Corps crews applied various critical area treatments: scattering seed, fertilizer, and mulch, and planting trees, shrubs and willows. Temporary straw bale and log sediment dams, grade stabilization structures, and energy dissipators have also been constructed. Excavating road crossing diversions and lining the crossings with rock represent other completed projects.

Educational efforts have included taking high school students on "job shadowing" projects as part of the Adopt-a-Watershed Program, as well as producing a video on how Off Road Vehicles (ORVs) can kill fish. In addition, ORV exclusion signs were placed throughout the Grass Valley Creek watershed and erosion control measures were implemented.

Some of the above sites will be visited on the Friday Field Trip.

FIRE PLANNING IN GRANITIC TERRAIN

MARTY MAIN AND NEIL BENSON*
Small Woodland Service, Eagle Point OR
* U.S. Forest Service, Ashland OR 97520

Poster Abstract

The upper Hamilton Creek watershed is a 750 acre area located just south of the Ashland city limits in southwestern Oregon. It is located in steep, highly dissected topography typical of the Siskiyou Mountains. Intentional fires early in the century coupled with an effective fire exclusion policy in the ensuing years have created an increasingly flammable vegetational composition. A severe wildfire in 1973 consumed approximately one-third of the watershed, causing significant resource damage and contributing to flood destruction in Ashland the following year. Highly flammable brush species have reinvaded the burn area and, coupled with increasing fuel loadings elsewhere in the water-shed, have greatly increased the likelihood of another major wildfire - one which would inflict even greater resource damage not only to the Hamilton Creek watershed, but potentially to the adjacent city of Ashland watershed. Its location within the urban-wildland interface and its subsequent heavy public usage not only greatly increases the likelihood of ignition, but represents a significant threat to the lives and property within the adjacent city of Ashland.

In response to this threat, a coordinated plan has been developed by the eight property owners within the upper Hamilton Creek watershed. With the guidance of the USDA Soil Conservation Service (SCS), the owners (City of Ashland, US Forest Service, a local land trust, and 5 small woodland owners) have produced a Hamilton Creek Coordinated Resource Management Plan (CRMP) similar to that often employed by the SCS to assist in managing rangelands throughout the west.

The owners have met numerous times in 1991 and have collectively formulated objectives, problems/concerns and solutions. A subsequent list of projects is being jointly developed by the owners, including prescribed burning, fuelbreak construction and other fuel reduction techniques, and soliciting public awareness and cooperation. This is thought to be the first time that this process has been used to manage watersheds in multiple ownership such that cumulative impacts from wildfire can be reduced. We believe this process represents a significant opportunity for managing interface ecosystems on a landscape level, particularly where fire ecology and management is of such critical importance.

REDUCING SEDIMENT YIELD FROM DISTURBED GRANITIC LANDS: EXAMPLES FROM THE SALMON RIVER WATERSHED, KLAMATH NATIONAL FOREST

ROBERTA VAN DE WATER
Salmon River Ranger District
Klamath National Forest
Etna CA 96027

Poster Abstract

A variety of management practices on national forest granitic land over the years have led to accelerated erosion rates and reduced site productivity. This display highlights recent practices which show promise for turning around the legacy left by poorly designed roads and abandoned minesites. The examples are taken from the Salmon River watershed, of which 30 percent is underlain by granitic rock.

Development of Road Construction and Reconstruction Practices

By the late 1970s, standard road design specifications on the Forest had evolved from insloped roadbeds with ditch-and-pipe drainage to outsloped surfaces. In the early 1980s, the design standard included an aggregate surface on virtually all new roads in decomposed granitic lands.

Older, problem roads located on granitics became the object of attention by the Forest during the 1980s. In 1990 and 1991, watershed condition surveys in the upper South Fork Salmon watershed identified insloped roads to be a significant source of sediment. Several roads were reconstructed with the objective of reducing potential sediment delivery to the South Fork, which is the most extensive habitat for spring chinook salmon remaining in the Klamath River Basin. Reconstructed road segments are being monitored using photo points and soil troughs.

Abandoned Hydraulic Minesite Reclamation

Another major sediment producing area was a 30 acre site adjacent to the river which had been mined in the 1800s. About 15 to 20 feet of the river terrace overburden was removed, leaving behind the granitic parent rock. A century of weathering has resulted in a thin skeletal soil only sparsely vegetated. Sheet and gully erosion yield sediment directly to the South Fork.

Following the installation of gully stabilization structures, the long-term strategy for the site called for native plant revegetation. A soil amendment monitoring and evaluation project began in the summer of 1992. A half acre area was divided into several plots with varying combinations of treatments using wood chips, fertilizer, tillage, and native grass. Soil and vegetation response will be monitored for the next five years to help develop a reclamation plan for the rest of the site.

AN INVESTIGATION ON THE USE OF DECOMPOSED GRANITE AS AN EARTHFILL MATERIAL

A.S. KASHYAPA YAPA, JAMES K. MITCHELL, AND NICHOLAS SITAR
Dept. of Civil Engineering, University of California
Berkeley CA 94720

Poster Abstract

Decomposed granite, usually a gravelly sand with low or no plasticity, can be an excellent earthfill material for many applications. A review of past experience indicates the suitability of decomposed granite for compacted fills governed by particle breakage and its impact on the shear strength and settlement characteristics of the material. The purpose of our investigation is to evaluate the mechanical properties of decomposed granite from the Shasta Bally batholith near the Buckhorn Summit on State Highway 299, which is an earthfill proposed by Caltrans for 300+ foot high embankments forming a part of the realigned highway.

The material can be classified as completely weathered rock to residual soil and, according to the Unified Soil Classification, as well-graded sand to silty sand (SW-SM). A laboratory test program, consisting of triaxial and oedometer tests, has been initiated to evaluate the shear strength and settlement characteristics in specimens compacted at 90% and 95% Modified AASHTO maximum density, under the full range of possible field stress conditions. The applied confining pressures in the triaxial tests and the normal pressures in the oedometer tests range from 100 KPa to 1500 KPa. The hydrocompression effects on decomposed granite are also studied in oedometer tests. Particle breakage is measured at the end of each test. A concurrent test program investigates the feasibility of steepening the embankment side slopes with geosynthetic reinforcements. Direct shear and pullout tests, using geogrids embedded in compacted decomposed granite specimens, are being conducted under normal pressures up to 700 KPa.

Preliminary results from both the triaxial and the direct shear tests indicate friction angles of about 40 degrees in the specimens compacted to 95% density at confining pressures up to about 200 KPa.

Acknowledgements

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FIELD

TRIP

ITINERARY

DECOMPOSED GRANITIC SOILS CONFERENCE

FIELD TRIP - FRIDAY, OCTOBER 23rd

8:00 a.m. LEAVE from Red Lion Inn parking lot in Redding. Driving west on State Highway 299 to Trinity County.

Observe subdivision roads and highway road cuts in granitic terrain on way to first stop. Drive by Whiskeytown Reservoir, storing Trinity River water as part of the water delivery system for the Central Valley Project.

Grass Valley Creek Watershed, Trinity County

9:00 a.m. STOP # 1 - Trinity River at confluence with Grass Valley Creek; Sediment ponds at mouth of Creek

- o Bill Brock, Watershed Ecologist, U.S. Fish and Wildlife Service, Weaverville
- o Russ Smith, Trinity Project Manager, U.S. Bureau of Reclamation, Weaverville

9:40 a.m. STOP # 2 - ORV damage and rehabilitation site

- o John McCullah, Project Manager, Trinity Co. Resource Conservation District, Weaverville

10:10 a.m. STOP # 3 - Little Grass Valley Creek: rehabilitation of damage from old logging practices

- o John McCullah, Trinity Co. R.C.D.
- o Jim Komar, Soil Conservationist, S.C.S., Weaverville

11:20 a.m. STOP # 4 - Grass Valley Creek Debris Dam and new road

- o Jim Spear, Soil Conservationist, SCS, Weaverville
- o Russ Smith, Trinity Project Manager, U.S. Bureau of Reclamation, Weaverville

12:00 p.m. LUNCH

1:00 p.m. STOP #5a - Recent timber harvest site (Joe's Peak THP) Special CDF Mitigation Rules

- o Dan Fisher, Forester, Champion International, Redding
- o Steve Dunlap, Forester, Calif. Dept. of Forestry and Fire Protection, Weaverville
- o Jim Komar, Soil Conservationist, U.S. Soil Conservation Service, Weaverville
- o Tom Spittler, Geologist, Calif. Div. Mines and Geology

1:45 p.m. STOP # 5b - Monitoring sediment trends

- o Bill Weaver, Geologist, Pacific Watershed Consultants
- o Tom Lisle, Geomorphologist, U.S. Forest Service, Arcata

2:40 p.m. STOP # 6 - Erosion control research on Highway 299

- o John Haynes, Erosion Control Specialist, CalTrans, Sacramento
- o John McCullah, Trinity County RCD, Weaverville

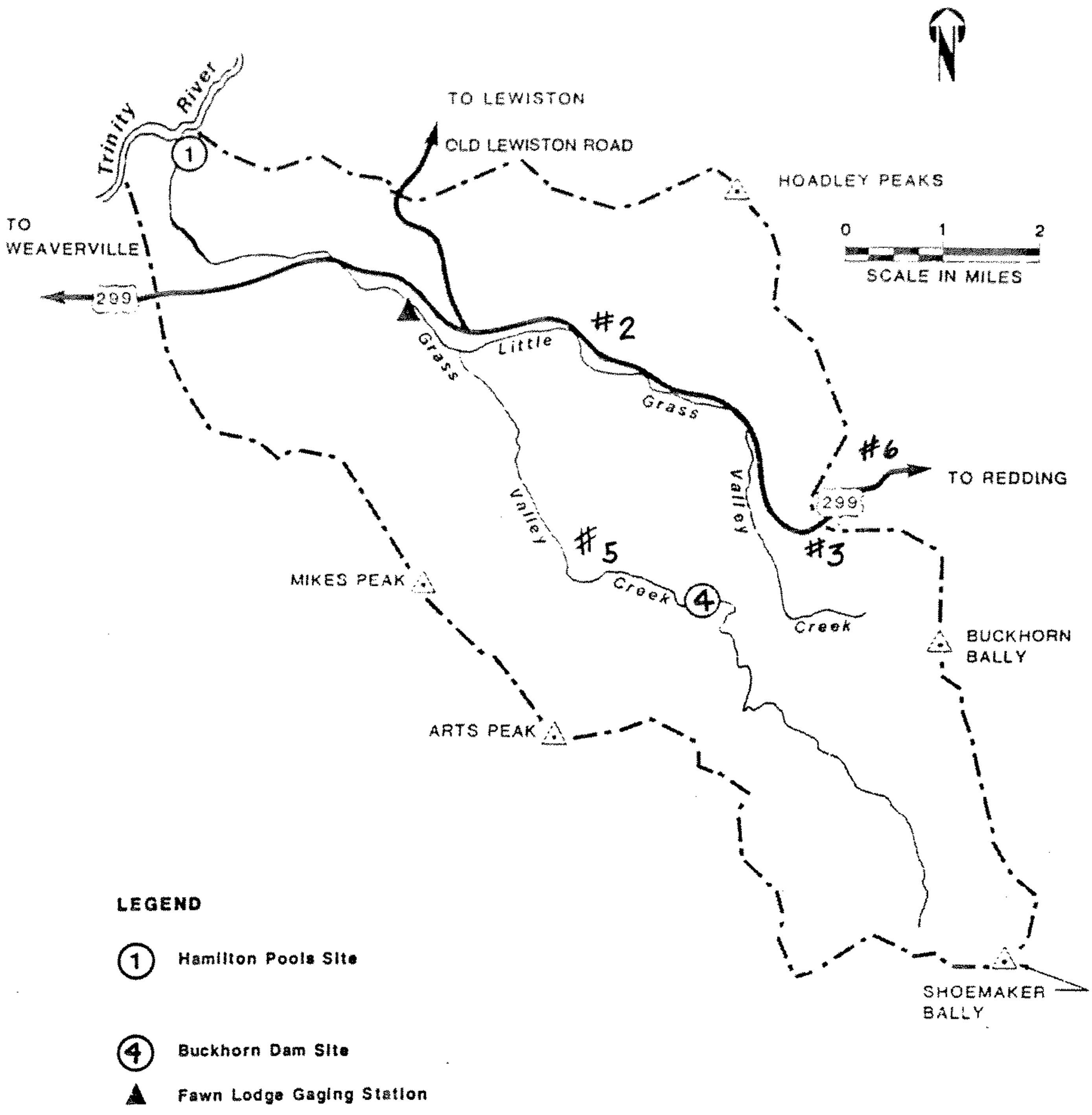
Middle Creek Watershed, Shasta County

3:45 p.m. STOP # 7 - Erosion control in rural subdivisions; Middle Creek CRMP

- o Bob Bailey, District Conservationist, SCS, Redding

4:30 p.m. ARRIVE at Red Lion Inn

FIELD TRIP - FRIDAY, OCTOBER 23rd



GRASS VALLEY CREEK WATERSHED

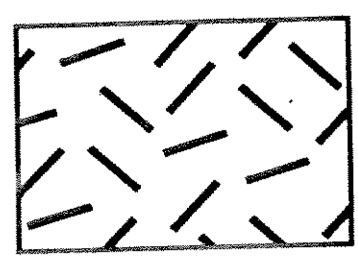
PUBLICATIONS

BY

W.F. MEGAHAN

ON

GRANITICS



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