ORGANIC DEBRIS IN TRIBUTARY STREAM CHANNELS OF THE REDWOOD CREEK BASIN

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Abstract. Data from 14 study basins indicates that tributary watersheds are major sediment sources for Redwood Creek. This is a reflection of both the magnitude of point source contributions within these basins and the relative efficiency with which these streams transport the supplied load. The majority of these tributaries are characteristically low order, high gradient streams with narrow, discontinuous flood plains. The accumulation of large organic debris in these streams is common and plays an important role in channel and hillslope processes. The effect of organic debris is most pronounced in the old-growth redwood forests where woody debris remains in the stream channel longer than in a Douglas-fir counterpart. Given the present understanding of basin-wide dynamics, organic debris should be removed from streams only in cases where it presents a barrier to anadromous fish or where it contributes to hillslope failure.

INTRODUCTION

The accumulation of large organic debris (LOD) in low order streams is common to both natural and disturbed watersheds. In a natural system, woody debris is delivered to the channel by a variety of mechanisms including blowdown and hillslope failure. In a logged watershed, additional debris can be delivered to the channel as a direct or indirect consequence of timber harvesting operations. Stream crossings are commonly constructed by placing large logs in the channel, parallel to the flow, and covering with road fill. Known as "Humboldt crossings", they often deteriorate and form a jam. Additional debris such as slash and cut logs often enter streams during or after falling or yarding operations.

Lowest (first and second) order streams lack sufficient power to move most LOD and hence it tends to be randomly distributed. Logs and slash are found within and proximal to the channel in almost any configuration. In third and fourth order streams, logs are mobilized more frequently and there is a tendency for debris to accumulate in jams comprised of several to hundreds of logs. Jams are commonly oriented perpendicular to flow and often span the entire width of the channel. Higher order streams, such as the mainstream of Redwood Creek, have sufficient power under high flow conditions to move

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even the largest debris and hence LOD accumulation tends to be negligible and often confined to channel margins.

The effects of LOD on channel morphology has been studied in detail by other investigators (Swanson and Lienkaemper 1978; Keller and Tally 1979). Organic debris and specifically log jams alter the hydraulics of a reach by impeding flow. Characteristically, this reduces the available stream power and results in deposition of sediment behind the jam. The changes in channel morphology commonly involve:

(1) An abrupt step in the longitudinal profile at the jam with an associated decrease in gradient upstream of the jam;

(2) An increase in channel width upstream of the jam, and;

(3) A decrease in particle size (roughness) behind the jam.

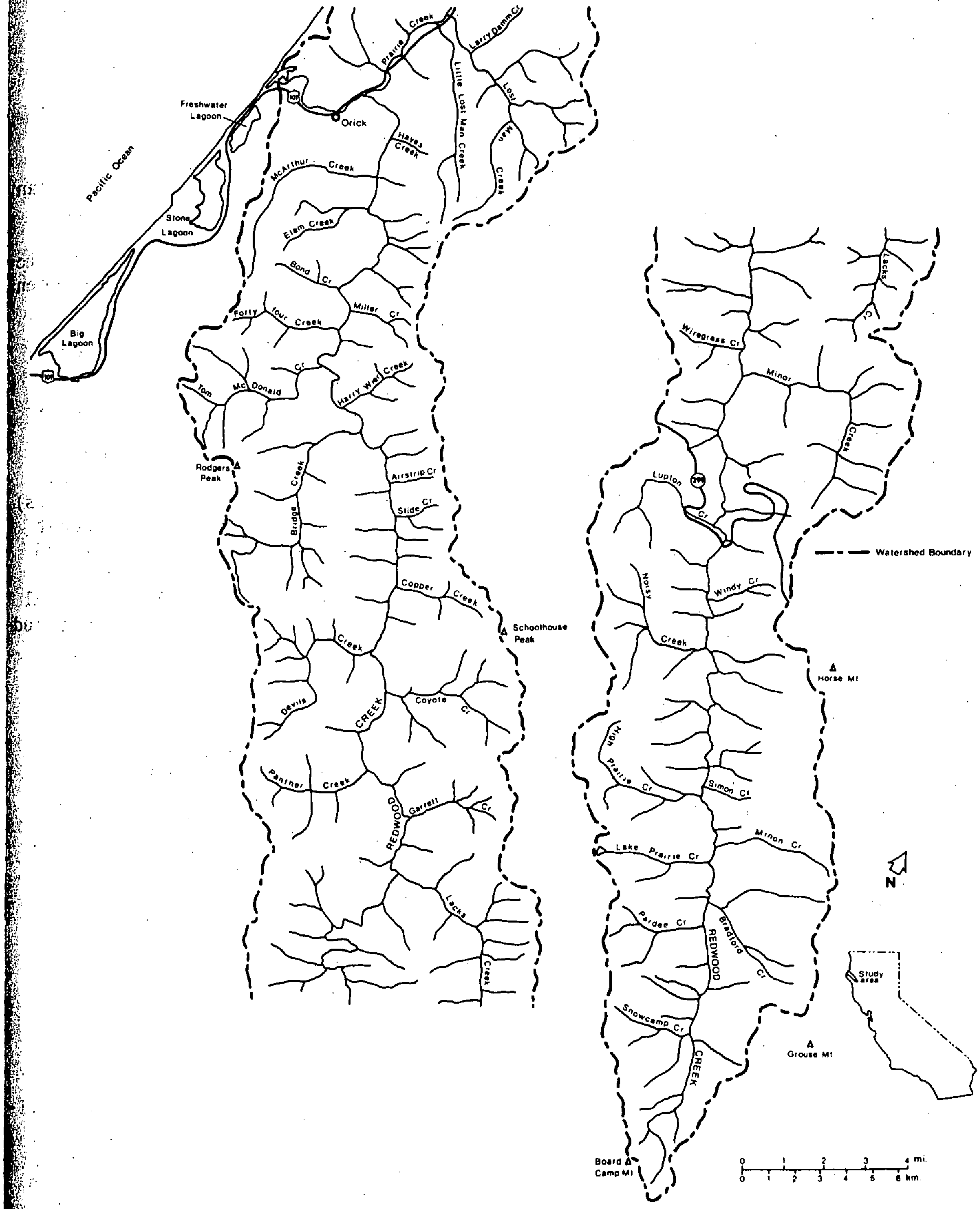
Log jams can be important sites of sediment storage in low order streams. They often serve to attenuate the effects of a relatively instantaneous input of sediment to the channel from adjacent hillslopes by providing a storage compartment that may remain stable for many decades. Debris jams may also induce small to large scale failures from adjacent hillslopes by diverting flow into the banks and undercutting the toe of the slope. Finally, they present barriers to anadromous fish and in many cases prevent their upstream migration. Thus, log jams are an important determinant of the interaction between hillslope, channel and biological processes. As such, they merit careful study in any comprehensive program of watershed management.

The identification of severe and complex erosion processes and their potential threat to the resources of the Redwood Creek basin led to the expansion of Redwood National Park in 1978. Previous studies (Janda, et al., 1975, Coleman 1973) have focused on channel and hillslope processes centered around the main stem of Redwood Creek. The expansion legislation (Public Law 95-250) clearly states the need for a basin-wide study of sediment source areas and sediment transport. This paper reports the initial results of a study on sediment routing in the tributaries of Redwood Creek. Specifically, I would like to: 1) describe the present understanding of sediment routing in tributary streams with the Redwood Creek basin, 2) describe the role of organic debris in storing sediment and initiating landslides, and 3) to present a conceptual approach to determining when it is appropriate to remove large organic debris as part of stream channel restoration.

STUDY AREA

Sediment storage and sediment transport in tributaries of Redwood Creek are strongly influenced by three basin characteristics. First, the main stem channel of Redwood Creek is structurally controlled by the Grogan Fault and the unusually elongate geometry of the basin is a strong reflection of this (Figure 1). As

Figure 1: Location map of the Redwood Creek Basin



a result, there are no major tributary forks[1] to Redwood Creek and only a few tributaries are larger than the majority (Figure 2). Therefore, most tributaries are characteristically low order, high gradient streams draining small watersheds (Figure 3). Their channels are in general deeply incised and have narrow, discontinuous floodplains. In all, there are 74 tributary basins drained by second order or higher streams.

Secondly, the weakly indurated and pervasively sheared rocks underlying the Northern California Coast Ranges are highly susceptible to erosion and mass wasting. The Redwood Creek basin is underlain by rocks of the Franciscan assemblage (Bailey, et al., 1964, Harden, et al., 1981). The Grogan Fault roughly bisects the basin and juxtaposes unmetamorphosed and slightly metamorphosed clastic sedimentary rocks on the east against quartzofeldspathic-mica schist to the west. Tributary streams are nearly equally divided between those draining sedimentary rock and those draining metamorphic rocks.

Finally, tributary watersheds are distinguished by predominant forest type and degree of timber harvesting. Eighty-five percent of the Redwood Creek basin was forested prior to the initiation of logging (Janda, et al., 1975). Under natural conditions, the northern third of the basin supported mixed stands of mature old-growth redwood and Douglas-fir (here called "redwood dominated" forests) while the southern two-thirds supported primarily mixed Douglas-fir and hardwood forests (here called "Douglas-fir dominated" forests). Logging was initiated in the basin as early as 1936. Today, over 65 percent of the basin has been logged with the majority of this occurring the last 25 years. Most units have been clear-cut and tractor yarded. Twenty percent of the basin, virtually all within the Redwood Creek unit of Redwood National Park, remains as uncut virgin forest and the remaining 15 percent is comprised of prairie and oak woodland (Janda, et al., 1975).

STUDY OBJECTIVES AND METHODS

The data presented in this paper are part of a more general study on sediment source areas and sediment transport in the Redwood Creek basin (Kelsey, et al., 1981b). As a first step in determining the magnitude and timing of sediment contribution from tributaries, streamside landslides and channel-stored sediment were measured conjunctively in 14 basins. These tributaries represent a wide variety of physiographic settings, forest types and drainage areas. Basic data for these basins are given in Table 1.

SEDIMENT SOURCE AREAS AND SEDIMENT TRANSPORT IN TRIBUTARY STREAMS

Sediment routing in tributary watersheds involves a complex set of interactive hillslope and channel processes. Source areas adjacent or proximal to perennial streams mobilize sediment most effectively. The most common

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[1] Prairie Creek is the largest tributary to Redwood Creek. It drains approximately 104 km^2 and enters the main stem of Redwood Creek just upstream of Orick. However; due to the marked differences between the physiography and geology of this tributary and the majority, we have not included it in our study to date.

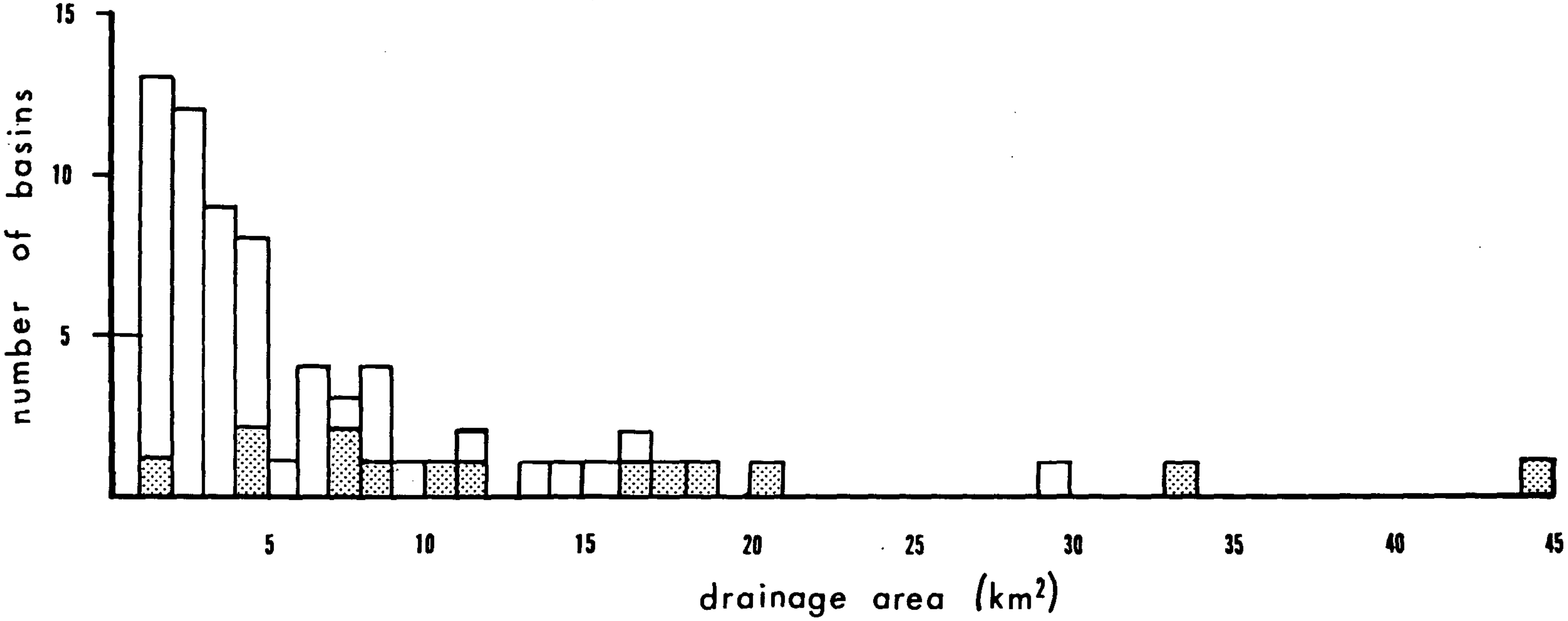

Figure 2: Distribution of tributaries by drainage area. Shaded areas indicate basins sampled for stored sediment and stream-side landslides.

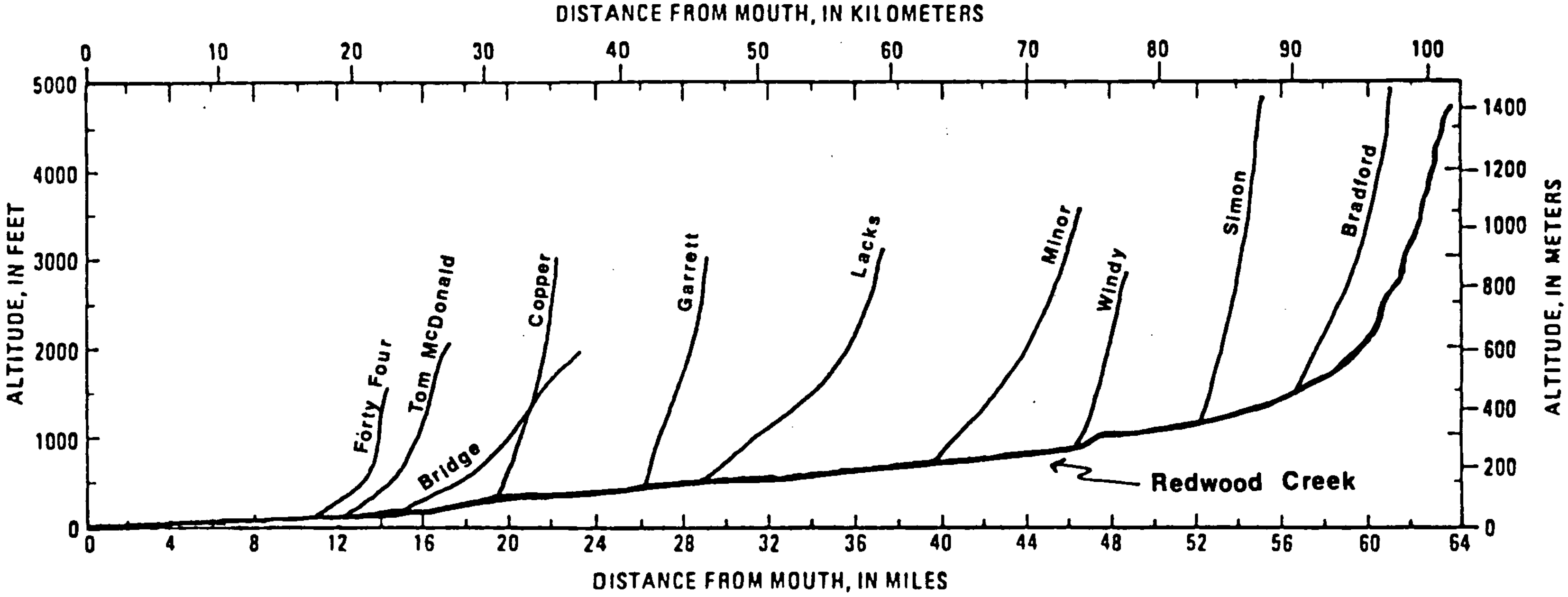

Figure 3: Longitudinal profile of Redwood Creek and selected tributaries

TABLE 1

GENERAL INFORMATION FOR STUDY BASINS

TRIBUTARY	DRAINAGE AREA (km^2)	PREDOMINANT ROCK TYPE (1)	PREDOMINANT FOREST TYPE (2)
Lacks Creek	44.03	SS	DF
Minor Creek	33.57	SS	DF
Coyote Creek	20.41	SS	DF/RW
Devils Creek	18.03	SH	RW
Tom McDonald Creek	17.95	SH	RW
Bradford Creek	16.50	SS	DF-O-P
Upper Redwood Creek	11.14	SS	DF-O-P
Garrett Creek	10.75	SS	DF
Forty Four Creek	8.08	SH	RW
Harry Weir Creek	7.80	SS/SH	RW
Copper Creek	7.43	SS	RW/DF
Windy Creek	4.50	SS	DF-O-P
Simon Creek	4.50	SS	DF-O-P
N. Fork Slide Creek	1.55	SS	RW

(1) SS: Unmetamorphosed and slightly metamorphosed sedimentary rocks of the Franciscan Formation.

SH: Quartz-mica schist of the Franciscan Formation.

(2) RW: Predominately redwood forest with minor amounts of hardwood and Douglas-fir.

RW/DF: Predominately redwood forests with significant amounts of Douglas-fir.

DF/RW: Predominately Douglas-fir forests with significant amounts of redwood.

DF: Predominately Douglas-fir with associated hardwoods.

DF-O-P: Nearly equal amounts of Douglas-fir forests, oak woodland, and prairie.

mass movement mechanisms in these basins are complex earthflows, slumps, debris slides and debris avalanches. Large gullies and rills resulting from fluvial transport of soil and regolith are the most obvious surface erosion features. Sediment storage in stream channels occurs behind accumulations of large organic debris, in fill terraces nested against adjacent hillslopes, in point bars or as aggraded bed material.

Streamside landslides in tributary watersheds are as large and as complex as similar landslides along the main channel of Redwood Creek. The 20 largest streamside slides in the tributary basins of this study total 1,591,000 tons. By comparison of the 634 landslides measured along the main stem of Redwood Creek upstream of State Highway 299, the largest 20 slides have delivered 1,624,000 tons to the channel.

Massive aggradation in the lower reaches of Redwood Creek illustrates the inability of a stream to transport the available load. Sediment transport in tributary channels, however, differs markedly from the main stem of Redwood Creek. A comparison between the amount of landslide material delivered to the channels of the tributary study basins and the amount of sediment remaining in storage serves as a partial gauge of the transport efficiency of these streams (Table 2). A majority of the study streams store a relatively small (less than 20 percent) proportion of the material supplied to them by streamside landslides. Those tributaries which store proportionally more than 20 percent either drain old-growth redwood forest or are small basins which were severely effected by landsliding. The fact that tributaries transport a high proportion of the sediment delivered to them is largely a reflection of their steep gradients (Figure 3). Average gradients in the reaches of Redwood Creek downstream of Snowcamp Creek (Figure 1) range from .04 to .001. Average gradients for reaches in tributaries are seldom less than .01 and often exceed .20.

Stored sediment provides only an incomplete measure or record of sediment transport through a watershed. Continuous and periodic sampling of water, suspended sediment and bedload discharge, however, generate data on sediment yield more directly. The U. S. Geological Survey has, in cooperation with the National Park Service, operated gaging stations on selected tributaries since the 1974 water year (Iwatsubo, and others, 1975, 1976; Water Resources Data for California, Pacific Slope Basins, published annually). Nolan and Janda (1981) used water and suspended sediment discharge records to assess the impacts of timber harvesting on sediment transport in Redwood Creek tributaries characterized by diverse terrain and land use history. They found that suspended sediment concentrations for tributaries exceeded those for Redwood Creek at discharges with a recurrance interval of approximately five years or greater. In other words, at higher discharges, tributaries become major sediment source areas and are more efficient agents of sediment transport than the main stem of Redwood Creek.

The final gauge on the relative importance of sediment storage in tributary basins is provided by comparison with field measurements of stored sediment in the main stem of Redwood Creek. Data from the study basins may be used in conjunction with the distribution of basins by size (Figure 1) and thus to arrive at an estimate of the total amount of sediment stored in all tributaries. Such extrapolation indicates that the tributary streams store approximately 15 percent as much total sediment as Redwood Creek (Kelsey, _et al_., 1981a)

LARGE ORGANIC DEBRIS: ITS EFFECT ON SEDIMENT TRANSPORT AND MASS MOVEMENT

Under most conditions, these low order streams lack sufficient discharge to purge their channel of large organic debris. Thus, channel process and channel morphology in Redwood Creek tributaries are strongly influenced by organic debris. This point is highlighted in the work of Keller and Tally (1979). In their studies of old-growth redwood streams, they found that variables such as pool and riffle spacing, elevation drop and channel area were, in large measure controlled by the presence of LOD. The relative size of organic debris determines the degree to which debris influences channel form and process. Old-growth redwood trees are renowned for their girth and resistance to decay. Even the largest streams do not carry sufficient runoff under any conditions to move massive redwood logs. Consequently, debris jams tend to be stable and may remain in place for hundreds of years and they influence channel morphology for periods of time on the order of 1,000 years (Kelly and Tally 1979).

Accumulations of LOD serve to attenuate the effects of a relatively instantaneous input of sediment to the channel from adjacent hillslopes by providing a storage compartment that may remain stable for long periods of time. LOD, and particularly log jams, are the most important sites of sediment storage in old-growth tributaries (Table 2). The mean percentage of total sediment which is stored by LOD in the six streams draining redwood forests is 74.5 percent. Of the basins dominated by Douglas-fir and prairie-woodland vegetation, the mean percentage of sediment stored by LOD is 37.5. Organic debris accumulation in the latter types of basins tends to be less because Douglas-fir deteriorates more rapidly than redwood and because the relatively smaller sized debris can be moved more readily by high streamflows. Commonly, the majority of sediment in the Douglas-fir and prairie-woodland tributaries is stored in the lower gradient reaches near their mouths as backwater terraces deposited concurrently with high stages in Redwood Creek.

Organic debris in channels can have marked effect on hillslope processes as well. Debris may induce small to large scale failures by diverting flow into streambanks and undercutting the toe of the slope. The importance of organic debris in contributing to slope failure is illustrated in Table 2. The percentage of sediment supplied from landslides induced by flow diversion around large organic debris is higher on the average for tributaries draining old-growth redwood forests than for those draining Douglas-fir forests. This is again a reflection of the larger size and greater resistance to decay of redwood debris compared to Douglas-fir.

REMOVAL OF ORGANIC DEBRIS FROM CHANNELS

As a rehabilitative measure, the merit of removing organic debris from stream channels must be approached on a site-specific basis. Previous reports (Kelsey, et al., 1981a, 1981b), as well as this report, stress the fact that the amount of sediment in storage in tributary streams is substantially less than that in the main channel of Redwood Creek. Therefore, removing a jam for the sole purpose of removing the sediment behind the jam will have a minimal effect on basin-wide sediment yield. In the Redwood Creek watershed, the reasons for removing a jam are to reduce stream bank instability caused by flow diversion around the jam and/or to remove a barrier to anadromous fish.

TABLE 2

DATA ON SEDIMENT SOURCE AREAS AND CHANNEL-STORED SEDIMENT FOR TWO GROUPS OF STUDY BASINS: REDWOOD DOMINATED (TOP), AND DOUGLAS-FIR DOMINATED (BOTTOM)

TRIBUTARY	TOTAL LANDSLIDE MASS DELIVERED TO TRIBUTARY CHANNELS (TONNES) [1]	TOTAL STORED SEDIMENT (TONNES) [2]	PERCENTAGE OF STORED SEDIMENT TO LANDSLIDE MASS	PERCENTAGE OF TOTAL SEDIMENT STORED BY LARGE ORGANIC DEBRIS	PERCENTAGE OF TOTAL LANDSLIDE VOLUME CONTRIBUTED FROM ORGANIC DEBRIS RELATED SLIDES
Devils Creek	156,000	50,400	32.6	91.3	19.7
Tom McDonald Creek	84,200	80,000	95.0	55.7	56.3
Forty Four Creek	42,300	81,800	193.4	82.8	18.4
Harry Wier Creek	57,500	29,200	50.8	75.5	34.2
Copper Creek	109,200	18,700	17.1	82.0	N/A [3]
North Fork Slide	38,700	24,300	62.8	56.9	11.5
	MEAN		75.2	74.0	28.0
	STANDARD DEVIATION		63.5	14.6	17.8
Lacks Creek	988,100	120,000	12.1	48.9	1.2
Minor Creek [4]	564,400	219,300	39.0	13.4	0.9
Coyote Creek	238,200	22,000	9.2	52.1	7.4
Bradford Creek	225,800	27,000	12.0	16.2	19.4
Upper Redwood Creek	172,100	32,700	19.0	27.0	29.7
Garrett Creek	144,900	18,800	13.0	69.5	1.6
Windy Creek	241,600	116,200	48.0	18.5	2.6
Simon Creek	347,800	74,700	21.5	29.3	4.4
	MEAN		21.7	37.4	9.5
	STANDARD DEVIATION		14.2	19.8	10.9

[1] Landslide mass computed by taking the product of the measured volume and an assumed soil density of 1.6 grams/cm^3 (100 lb/ft^3)(Jim Popenoe, Personal Communication).

[2] Stored sediment mass computed by taking the product of the measured volume and an assumed density of 1.9 grams/cm^3 (120 lb/ft^3)(Jim Popenoe, Personal Communication).

[3] Causes of slides not noted during collection of data.

[4] Data on sediment delivery from Minor Creek earthflow provided by Mike Nolan, U.S. Geological Survey, Water Resources Division, Menlo Park. An additional 169,000 tonnes of sediment were delivered to Minor Creek by large gullies.

The approach to determining the feasibility of removing a log jam for the purpose of reducing stream bank instability centers around producing a quantitative statement of the erosion potential of the site. The procedures for evaluating a site involve simple field measurements and are outlined below:

(1) Assess the stability and composition of the jam keeping in mind that jams comprised of redwood logs are, in general, more stable and decay-resistant than Douglas-fir jams.

(2) Survey a longitudinal profile of the channel, extending downstream and upstream of the site using a tape, rod, and hand level. The survey provides an estimate of the depth and channel length of stored sediment associated with a jam.

(3) Establish monumented cross sections across the channel and onto the adjacent hillslopes beyond the possible limits of excavation or failure.

(4) Construct a morphologic map of the area showing channel perimeter, distribution of organic debris and other pertinent hillslope and channel features.

(5) Estimate the depth and length of channel fill from the longitudinal profile. In cases where excavation of material off hillslopes is necessary to insure stability, the amount of material to be removed from the hillslopes can be estimated from the cross sections and from field observations.

(6) Measure planimetric areas of channel and hillslope features from the morphologic map. The total volume of sediment in storage within the channel and on the slope can be computed by taking the product of the surface area of the feature and the estimated depth of sediment as determined by the profile or cross-section.

(7) The amount of work necessary to remove the jam is evaluated at this point. The costs of excavating material off hillslopes and from the channel can be determined knowing the volumes of sediment. The feasibility of treating this site over others is then weighed in terms of the projected amount of sediment saved from introduction into the channel. The potential impact on aquatic habitat is an additional factor that although not as easily assessed should be taken into account.

In the event that the jam is pulled, it is useful to make some simple measurements while work is in progress to determine if the excavation is adequate or beyond what was prescribed.

The longitudinal profile and cross-sections are resurveyed following the rehabilitation work and again after subsequent winter seasons. The net gain or loss of sediment from the site is again computed as per (5) and (6) above. With this information, the rehabilitator can accurately say what amount of sediment has been removed from the site both through and after treatment and judge the effectiveness of the work in reducing the amount of sediment available for downstream transport.

A case example will serve to illustrate both the conceptual and methodological approach to evaluating the removal of organic debris from a perennial stream channel. A series of moderate-sized jams were removed from the main stem of Copper Creek during site-specific rehabilitation work in late summer, 1979. A "Humboldt crossing" constructed in 1969 had deteriorated over the last decade and the logs had moved downstream to form three debris jams. The jams and the ponded sediment associated with them were diverting flow into the streambanks and were inducing several streamside failures in the road fill prism adjacent to the channel. At this site, Copper Creek is a second-order stream and drains 1.4 km^2.

The longitudinal profile of the stream and six channel cross-sections were surveyed on four separate occasions: prior to rehabilitation, immediately after heavy equipment work, and after the subsequent two winter seasons. A tape and compass map of the area was also made prior to rehabilitation. These data were then used to compute the volume of material removed during heavy equipment work and during subsequent winter seasons. A total of 1,100 m^3 of sediment was excavated by heavy equipment; 450 m^3 of alluvium was removed from the channel and 650 m^3 was removed from the oversteepened hillslopes adjacent to the channel. As a result of 1980 winter storms, 430 m^3 of sediment left the site with all of this loss being associated with channel scour. An additional 50 m^3 was lost during the 1981 winter. The hillslopes have remained stable through both winter seasons. The minimal amount of sediment lost since the first winter season suggests the site is rapidly approaching stability and that the primary objective of stabilizing the hillslopes, has to this point in time, been reached.

During heavy equipment work, it became exceedingly difficult for the equipment to operate in the channel and the projected "stable" channel bed was never reached. Subsequent winter storms downcut through the remaining sediment only to expose more large organic debris. Although the existing channel is more stable, the possibility exists for new jam formation at the same site. This problem was also noted in the evaluation of stream clearance at the Airstrip Creek rehabilitation unit (Kelsey and Stroud, 1981). It appears that partial removal of organic debris has limited effects as in many cases, additional debris soon becomes exposed or lodged and thus forms a new jam. A full evaluation of these efforts will be possible only with the passage of time and collection of additional data. Nonetheless, it appears reasonable to consider removing large debris jams when they contribute to massive slope failure.

CONCLUSIONS

The tributary drainage basins within the Redwood Creek watershed are major sediment source areas. Sediment routing in these basins involves a complex set of interactive hillslope and channel processes. Data from 14 study basins draining diverse terrain suggests that the majority of these streams are capable of transporting a high percentage of the sediment supplied to them. This conclusion is supported by earlier studies (Nolan and Janda, 1981; Kelsey *et al.*, 1981b) which contrast the sediment transport characteristics of Redwood Creek and its tributaries. In addition, the amount of sediment stored in tributaries is estimated to be only 15 percent of the amount stored in the main stem of Redwood Creek.

Large organic debris plays an important role, particularly in the old-growth redwood forests in determining channel form and process. On the average, tributaries draining redwood forests store a higher proportion of sediment than tributaries draining Douglas-fir forests or prairie-woodland terrain. In addition, the amount of sediment delivered by landslides whose cause is related to flow diversion around large organic debris is higher for old-growth streams than for Douglas-fir or prairie-woodland streams. Organic debris accumulation in the redwood forests tends to be greater because redwood is more resistant to decay and because of its size, mobilized less frequently, if at all. Thus, debris tends to be stable and may remain in place for hundreds of years.

The above conclusions form an important conceptual base from which to view the removal of large organic debris as a rehabilitative measure. Organic debris accumulation in the tributary stream channels within the Redwood Creek basin is important primarily in its effect on slope stability and on the migration of anadromous fish. A preliminary evaluation of debris jam removal at Copper Creek suggest that in the case of the former, the erosion potential of a site can be reduced substantially by such a treatment.

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