SEDIMENT SOURCES AND SEDIMENT TRANSPORT IN THE REDWOOD CREEK BASIN: PROGRESS REPORT

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SEDIMENT SOURCES AND SEDIMENT TRANSPORT IN THE REDWOOD CREEK BASIN: A PROGRESS REPORT

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PREFACE

The following paper is a report of work in progress. As such, only those data available at the time of compilation (December, 1980) are presented, and the information it contains will be expanded and modified prior to more formal publication. We have as yet made little attempt to thoroughly assess our data, nor have we tried to tie together the different aspects of the study. However, the conclusions and interpretations outlined here are ones in which we feel confident, and we expect they will not be substantially altered by further analysis.

We have used both English and metric units in this progress report. Final publications resulting from this study will consistently use the metric system, but for the purposes of this report we did not attempt to convert all our compiled data to metric units.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

A. Redwood National Park and the Redwood Creek Basin

In March of 1978 through P.L. 95-250, Congress expanded Redwood National Park to include the lower 119 mi^2 of the 278 mi^2 Redwood Creek basin. Section 101 (a)(6) of the Law directs the Secretary of the Interior to "undertake and publish studies on erosion and sedimentation" within the Redwood Creek watershed, to "identify sources and causes, including differentiation between natural and man-aggravated conditions," and to "adapt his general management plan to benefit from the results of such studies." In keeping with this legislative mandate, Redwood National Park is undertaking a study of sediment sources and sediment transport within the basin.

Redwood National Park and the Redwood Creek basin have been the focus of political conflict over logging practices since the establishment of the park in 1968. A decade of controversy over the upstream effects of logging on the old-growth redwood ecosystem within the Redwood Creek portion of the park culminated in the park expansion. The history of events leading to the park expansion is well chronicled elsewhere (U.S. Department of Interior, 1975; U.S. House of Representatives, 1978; Weaver et al., 1979).

The Redwood Creek basin is one of the most highly erodible basins in the United States. The combination of naturally unstable terrain and infrequent, unusually severe storms, such as the one that occurred in northern California in December 1964, and intensive timber harvesting can trigger major episodes of erosion. Accurate assessment of the threat to downstream park resources in the wake of such an episode calls for a thorough understanding of sediment sources and sediment transport in the Redwood Creek watershed. This report describes the progress towards that understanding.

B. Land Use and Storm History in the Redwood Creek Basin

Although the lower 40% of the basin lies within Redwood National Park, timber harvesting is the major land use upstream of the park. The majority of the watershed from Redwood Valley upstream was logged in the 1950's and early 1960's in response to the housing boom following World War II. Timber in the upper watershed consists of Douglas-fir and a mixture of hardwoods. By today's standards, poor yarding methods were used and only better quality logs were taken. Consequently, tractor skid roads frequently crossed intermittent streams and traversed steep streamside slopes, and many cut and bucked trees were left on the hillslopes and at the margins of perennial streams.

Further down the basin, from Redwood Valley to Orick, logging activity started later. The lower basin, until the mid-1960's, consisted largely of vast tracts of old-growth redwood forest. However, by the early 1960's, lower Redwood Creek was being intensively logged.

Five major storms have occurred in northern California in the past 25 years (Table 1). The most significant storm was in December 1964. The 1964 storm brought immense changes to the upper portion of Redwood Creek, particularly the reach above State Highway 299. The obvious changes were the initiation or enlargement of streamside landslides and aggradation of stream channels (the filling in of the channels with gravel). Much of this channel sediment has moved downstream in succeeding years. The major hillslope changes caused by the 1964 storm occurred above what is now Redwood National Park. Later storms in 1972 and 1975 had significant impacts in lower Redwood Creek within the park.

The National Park Service is currently implementing a major land rehabilitation program on park lands in the lower watershed. Despite this rehabilitation program, the effects of major storms and land use practices on future erosion in the upper basin will be the primary determinants of sedimentation in the main channel of Redwood Creek within the park.

C. Previous Work

Integrated scientific studies of the hydrology and geology of the Redwood Creek basin began in 1972. At that time, political pressure was strong to investigate the effects of logging on the Redwood Creek channel within the national park. Most of these studies were conducted under the auspices of the Forest Geomorphology Project of the U.S. Geological Survey, and headed by Dr. Richard Janda. The USGS Forest Geomorphology Project looked into sediment transport in the whole basin, but concentrated on those processes that most directly threatened park resources. The USGS studies investigated a number of related topics: the effect of logging on fluvial sediment yield in tributary basins, the changes in streamside slope stability along the Redwood Creek channel and major tributaries since 1947, the recent channel geology of the Redwood Creek basin, sediment transport at selected USGS gage sites in the basin, movement rates of earthflows, and recent storm history in the basin. Through these studies, a large quantity of data is now available in published form on geomorphic processes in the basin and the effect of land use on these processes (Harden et al., 1978; Iwatsubo et al., 1975; Iwatsubo et al., 1976; Lee et al., 1975; Nolan et al., 1976a; Nolan et al., 1976b; Nolan, 1979; Nolan and Janda, 1981; Janda, 1975; Janda and others, 1975; Janda, 1976; Janda, 1978). Other studies from the USGS project are forthcoming and a 1:62,500 geologic map of the Redwood Creek basin in being printed.

D. Project Objectives and Plan of Study

The objectives of the sediment sources and transport study in the Redwood Creek basin are to document erosion and sedimentation that has

TABLE 1

PEAK DISCHARGES DURING MAJOR STORMS
IN THE
REDWOOD CREEK BASIN,
1950 - 1980

(Data from Table 4, Harden et al., 1978)

Date	Redwood Creek near Blue Lake		Redwood Creek at Orick	
	CFS*	CFS/mi^2	CFS	CFS/mi^2
January 18, 1953	-	-	50,000	180
December 22, 1955	12,100	179	50,000	180
December 22, 1964	16,400	243	50,500	182
January 22, 1972	6,900	102	45,300	163
March 3, 1972	13,700	203	49,700	179
March 18, 1975	12,200	180	50,200	181

* - Cubic feet per second.

occurred in the basin in the last three decades, to determine a sediment budget for the basin that will show sediment sources, sites of sediment storage and rates of sediment movement, to determine the extent to which land use in the basin effects erosion and sediment yield, and to make recommendations to park management concerning the status of erosion and sedimentation in the basin. The study results and recommendations to park management will be particularly useful in the review of timber harvest plans in sensitive areas, and for implementation of watershed rehabilitation projects in the upper basin with the cooperation of private landowners. The sediment transport study will also assess the status of aggradation and bank erosion along the entire main channel, particularly in the vicinity of the redwood groves on alluvial flats in the park.

The investigation of sediment sources and sediment transport involves several major study areas:

1. Main channel sediment storage and sediment transport studies include:

   a. Surveying channel cross-sections and the longitudinal stream profile.

   b. Field mapping sediment storage, bank stability and character of channel bed material.

   c. Measuring sediment transport by synoptic sampling at six main channel gaging stations during winter storm periods.

2. Analyses of landslides along the main channel includes:

   a. Measuring volumes of landslides that have contributed sediment to the main channel in the last three decades.

   b. Determining when landsliding occurred and relationship of timing to major storms and land use activities.

3. Studies of sediment storage in tributaries includes:

   a. Measuring sediment stored in tributary reaches.

   b. Determining the relationship of tributary storage to specific variables such as gradient, drainage area vegetative cover, land use, organic debris in channels.

4. Analysis of landslides along tributary channels includes:

   a. Measuring total volume of landslides that contributed sediment to the main channels of tributary basins.

   b. Determining times of landsliding and relationship of timing to major storms and land use activities.

5. Hillslope fluvial sediment yield studies include:

   a. Classifying the basin into different terrain types that have approximately equal sediment yield.

   b. Compiling the best estimates of sediment yield from different terrain types.

   c. Determining the effects of land use on hillslope sediment yields.

6. Compile sediment yield data at the downstream end of basin at Orick to determine total sediment leaving the basin.

Data from the above study areas will be incorporated into a sediment budget of the Redwood Creek basin. During the course of the study, the following general questions will receive the most attention:

1. Where are the major sediment sources which, in the past, have resulted in a high amount of sedimentation in the main channel of Redwood Creek?

2. How much sediment is currently in storage in the main channel of Redwood Creek and in the major tributaries?

3. Is it possible to predict how long it will take for the current excessive amount of sediment in the main channel of Redwood Creek within the park boundary to be flushed out of the basin?

4. Based on the studies, what specific recommendations can be made concerning management of watershed lands within and upstream of Redwood National Park?

The study is being carried out under the direction of a National Park Service geologist. The majority of the field work, data collection and surveying is being done by NPS professionals and staff. Collection of water discharge, sediment discharge, plus several other monitoring tasks are being done by the U.S. Geological Survey. The USGS data collection program is discussed in more detail in the next section.

E. Summary of Field Work Accomplished to Date

Field work for the project started in summer 1979. During that summer, our work consisted of main channel mapping within the park. During the winter of 1979 - 1980, we mapped landslide volumes in four tributaries and surveys of stored sediment were started in selected tributary reaches.

We accomplished the bulk of the field work to date during an intensive period of field investigations from June 1 through October 1, 1980. During most of that time, the sediment budget team systematically worked together down the main channel of Redwood Creek, starting in the headwaters at the Roddiscroft Road crossing of Redwood Creek.

1. Main Channel Sediment Storage

   a. One-hundred percent of the stored sediment mapped, measured and classified along the lower 103 km of channel (96% of the total length).

   b. A detailed longitudinal channel profile was surveyed over the full length of Reaches 1 - 15 (32.4 km). Twelve shorter profiles (average length 400 m) surveyed in Reaches 16 - 36.

   c. Sixty-five sites sampled for lithologic and particle size characteristics.

   d. Main channel geomorphic features systematically described and interpreted in Reaches 21 - 36.

   e. Initiation of a sediment transport-tracer experiment.

   f. Additional data obtained included dendrochronological determinations of minimum terrace age, and photographic records of all cross-sections (RNP and USGS) and other locations of geomorphic interest.

2. Tributary Sediment Storage

   a. Stored sediment measurements were made in 23 of 74 second order or higher tributaries.

   b. One-hundred percent of the stored sediment was measured in ten tributaries; three in the Park Protection Zone (PPZ) above Highway 299, and four above 299.

   c. The stored sediment in each of 58 randomly selected channel segments was also measured (average length 130 m). Segments were selected from 20 tributaries; 8 in the park, 4 in the PPZ, 4 between the PPZ and Highway 299, and 4 above Highway 299.

   d. Additional data obtained at selected sites along tributaries included detailed longitudinal profiles, detailed planimetric maps of selected segments, photographic records of selected sites, and dendrochronological determinations of minimum terrace age.

3. Main Channel Landslide Survey

   a. Volumes of 634 landslides and/or incidences of bank erosion were measured along 31 km (91%) of the channel upstream of Highway 299. Coverage of streamside landsliding was 100%.

b. Additional data obtained included measurements of slope angle and aspect, estimates of slide debris particle size, classification of slide revegetation, and a map of slide location. Pertinent observations concerning failure causes, land use and geology were also noted.

4. Tributary Landslide Survey

a. Volumes of 747 landslides and/or incidences of bank erosion were measured in 15 tributaries. Two of these were in the park (183 slides), 3 in the PPZ (246 slides), and 10 above Highway 299 (318 slides).

b. In most cases the additional data obtained was the same as that acquired during the main channel survey.

II. DATA COLLECTION BY U.S. GEOLOGICAL SURVEY

A. Introduction

A significant portion of the data collection for the sediment budget project is accomplished by the U.S. Geological Survey. The portion of the USGS-NPS cooperative program that directly supports the sediment budget project includes:

1. Operation of gaging stations along the mainstem.
2. Operation of gaging stations on selected tributaries.
3. Monitoring of channel cross-sections along the mainstem.
4. Collection of precipitation data at 18 storage precipitation gages and 3 recording precipitation gages.

B. Mainstem Redwood Creek Gaging Stations

Mainstem gaging stations serve to monitor sediment yield past different points along Redwood Creek (Table 2). The Orick continuous recording gaging station measures sediment yield out of the basin. Within the park, the Miller Creek and Harry Weir Creek periodic gaging stations sample sediment yield above these two respective points. The old South Park Boundary (SPB) continuous recording station, at the 1968 park boundary, will be discontinued at the end of water year 1982. The old SPB station monitored sediment yield into the original park from upstream private lands. The Panther Creek continuous recording station serves as the present (1978) South Park Boundary. The Panther Creek gaging station was a periodic recording station from water years 1974 to 1980 and was upgraded to a continuous recording station in October 1980. The Redwood Valley periodic gaging station is not presently in use. The O'Kane gaging station near the Route 299 bridge is a continuous recording station that measures sediment yield from the upper quarter of the Redwood Creek basin.

The three continuous recording stations (Orick, Panther Creek and O'Kane) constantly monitor water discharge. As changes in sediment yield occur above any of these stations, the change can be documented at the gage sites within that water year or the succeeding year.

The periodic mainstem gaging stations, in conjunction with the continuous recording mainstem stations, are sites of synoptic sampling events on Redwood Creek. Synoptic samplings, or "synoptics" have been held since 1976. The purpose of synoptics is to concurrently sample sediment yield at five or six points along the mainstem during peak storm periods, when Redwood Creek transports most of its annual sediment load. Analysis of synoptic results will indicate which reaches of Redwood Creek are the major sediment producers and which reaches are accumulating or storing sediment. To date, the USGS has conducted five mainstem synoptics in cooperation with the NPS (Table 3). Results and conclusions from these synoptics are being analyzed by the USGS as part of the fiscal year 1981 cooperative program.

TABLE 2

REDWOOD CREEK MAINSTEM GAGING STATIONS

Name and Gage Number	Drainage Area mi^2	Drainage Area km^2	Type of Gage	Period of Record
Redwood Creek at Orick 11482500	278.0	720.0	Continuous Recording	1953 to Current Year
Redwood Creek at Miller Creek 11482261	218.0	565.0	Periodic Record	1978 to Current Year
Redwood Creek above Harry Weir Creek 11482220	202.0	523.0	Periodic Record	1973 to 1976, 1978 to Current Year
Redwood Creek at South Park Boundary 11482200	185.0	479.0	Continuous Reading	1970 to Current Year
Redwood Creek above Panther Creek 11482120	150.0	389.0	Periodic and Continuous	1974 to 1976, 1978 to 1980 (Periodic) 1981 (Continuous Recording)
Redwood Creek at Redwood Valley Bridge 11482020	95.9	248.4	Periodic Record	1974 to 1976
Redwood Creek at O'Kane Bridge, near Blue Lake 11481500	67.7	175.3	Continuous Recording	1953 to 1958, 1972 to Current Year

TABLE 3

SYNOPTIC SAMPLING EVENTS ON THE MAINSTEM OF REDWOOD CREEK

Date	Stations Involved
February 25 - 27, 1976	Orick, Harry Weir, SPB, Panther, Redwood Valley, O'Kane
December 13 -15, 1977	Orick, Miller, Harry Weir, SPB, O'Kane
January 18 - 19, 1978	Orick, Miller, Harry Weir, SPB, O'Kane
February 28, 1979	Orick, Miller, Harry Weir, O'Kane
January 12 - 13, 1980	Orick, Miller, Harry Weir, SPB, Panther, O'Kane

C. Tributary Gaging Stations

Tributary sediment data has been collected since the 1974 water year. Four types of records have been collected at tributary sites:

1. Continuous-recording streamflow and periodic sediment sampling at four sites: Little Lost Man, Coyote, Panther, and Lacks Creeks.

2. Periodic streamflow and sediment sampling at one site (Lacks Creek, 1975-1980 water years).

3. Synoptic and instantaneous streamflow and sediment samples at six tributary sites.

4. Instantaneous streamflow and sediment sampling at an additional 18 tributary sites.

All water discharge and sediment data on tributary stations for the 1974 water year appears in Iwatsubo and others, 1975. All tributary data for the 1975 water year appears in Iwatsubo and others, 1976. Tributary data for 1976 and subsequent years appears in the annually released Water Resources Data for California, Pacific Slope Basins.

During the early phase of geomorphic studies in Redwood Creek, data collection was heavily weighted to synoptic and instantaneous sediment sampling of tributary basins adjacent to Redwood National Park. However, for the present sediment budget project, we consider the tributary basin water discharge and sediment data from the continuous streamflow stations to be of the most value because we are interested in obtaining best estimates of fluvial sediment yield from different terrain types. Each of the gaged tributary basins represent a different geomorphic terrain type (Table 4) and the basins will have different corresponding sediment yields.

D. Mainstem Channel Cross-Sections

The USGS established 48 channel cross-sections along the mainstem of Redwood Creek in 1973 or 1974. Seven more cross-sections were added in the fall of 1978 (cross-section 43A - 43G). The cross-sections are surveyed at least once a year, and graphic and tabular summaries of changes in stream channel cross-sections are available up through water year 1978 (Nolan and others, 1976; Nolan and others, 1979). We have interpreted the USGS cross-section data through 1979 in a qualitative manner to obtain an overview as to whether the cross-sections and the study reaches are either actively aggrading, degrading, or are relatively stable (Table 5).

TABLE 4

TERRAIN TYPES OF GAGED TRIBUTARY BASINS

Tributary Basin	Drainage Area mi^2	Drainage Area km^2	Type of Terrain	Period of Record of Continuous-Recording Stream
Little Lost Man Creek	3.64	9.43	Massive sandstone, bedded sandstone and siltstone; coherent rock types.	June 1974 to Present
Coyote Creek	7.88	20.41	Massive sandstone, bedded sandstone and siltstone; incoherent rock types predominantly, includes broken formations.	October 1979 to Present
Panther Creek	5.96	15.44	Schist	October 1979 to Present
Lacks Creek	17.0	44.03	Massive sandstone, bedded sandstone and siltstone; coherent rock types. Incoherent rock types in lower 25% of basin.	October 1980 to Present

TABLE 5

SUMMARY INTERPRETATION OF GRAPHIC CROSS-SECTION DATA
from Nolan et al., 1976 and 1979
for Water Years 1973 through 1979

Cross-Section Number	Behavior of Cross Section[1] 1973-78	Behavior of Cross Section[1] 1978-79	Descriptive Behavior of Cross-Section	Reach Number/Interpretation
1	D, A	D, A	Has become more braided.	1: Some aggradation continuing after past episodes of aggradation, some bank erosion occurring.
2	A, BE	d	Maintaining aggraded configuration.	
3	A, BE	S	Slowly aggrading.	
4	A, BE	S	Slowly aggrading.	
5	d, be	d	Slowly degrading.	
6	A	a	Aggrading.	2: Aggrading, some bank erosion.
7	A	d	Slight degradation after aggradation.	
8	A, BE	S	Aggrading.	
9	d, be	a	Somewhat stable at present.	3: Fairly stable banks, growth of larger mid-channel bars.
10	d, a	d, a	Becoming more braided.	
11	a, BE	d, a	Channel widening, some overall aggradation.	4: Aggradation, channel widening.
12	A, be	A	Aggrading.	
13	A, BE	a, d, a	Aggrading.	
14	A	A, D	Much aggradation.	5: Actively aggrading.
15	A, d	d, a	Aggrading.	
16	A, BE	d, a	Aggradation and bank erosion.	6: Aggradation, formation of mid-channel bars.
17	d, A, be	a, d	Growth of mid-channel	
18	A, be	a, d	Aggrading.	
19	A, be	d, a	Overall aggradation.	7: Aggrading.
20	A, be	d	Slight degradation after much aggradation.	8: Some degradation after much aggradation, some bank erosion since 1973.
21	A	d, A	Slight degradation after much aggradation.	
22	A, be	d	Slight degradation after much aggradation.	
23	A	d, a, be	Overall aggradation.	9: General aggradation.
24	-	-	- - - -	
25	d, a	S		
				10: Gorge section of Redwood Creek, no visible channel changes.

TABLE 5

SUMMARY INTERPRETATION OF GRAPHIC CROSS-SECTION DATA
from Nolan et al., 1976 and 1979
for Water Years 1973 through 1979

Cross-Section Number	Behavior of Cross Section[1] 1973-78	1978-79	Descriptive Behavior of Cross-Section	Reach Number/Interpretation
26	BE, A, D	a, d	Channel configuration is wider but approximately the same.	11: Relatively stable, some aggradation and bank erosion, scour in parts of channel.
27	A, be	d, a, be	Past aggradation stopped at present.	
28	d, a	be	Not much activity.	
29	D, BE	d	General degradation.	12: Overall degradation.
30	D, BE	be	Degrading.	13: Some degradation, bank erosion is active.
31	D, be	D, a	Degrading.	14: Most of bed is degrading.
32	D, be	D, a	Degrading.	15: General degradation of channel bed.
32a	BE, D	D, be	Degrading	16: Slight channel widening, channel degradation.
32b	A, D, be	d, a	Aggradation in thalweg, degradation on channel edge.	17: Some bank erosion, both aggradation and degradation.
33	D, be	a	Degrading	
				18: No channel cross-section in Study Reach 18.
34	D, be	D	Degrading.	19: Degradation after probable aggrada-
34a	D	d	Degrading.	
35	D	d	Degrading.	20: Degradation after probably aggradation.
36	D, be	1/2D, 1/2A	Degrading.	

TABLE 5

SUMMARY INTERPRETATION OF GRAPHIC CROSS-SECTION DATA
from Nolan et al., 1976 and 1979
for Water Years 1973 through 1979

Cross-Section Number	Behavior of Cross Section[1] 1973-78	1978-79	Descriptive Behavior of Cross-Section	Reach Number/Interpretation
37	D, be	a, S	Degradation, now inactive.	21: Past degradation, inactive at present.
38	D	None	Degradation, now inactive.	22-36: Degradation, now inactive.
39	D	S	One small bar built.	
40	D	d	Degradation, now inactive.	
41	D	S	Degradation, now inactive.	
42	D	a, d	Degradation, now inactive.	
43	d	S	Degradation, now inactive.	
44	A, D, BE	d	Small bar washed out	
45	a	a, d		

1: <u>Behavior of Cross Section</u> -

A: Large, obvious aggradation of channel.

a: Aggradation is evident but less than 1 foot deep.

D: Large, obvious degradation of channel bed.

d: Degradation is evident but less than 1 foot deep.

BE: Greater than 2 feet of bank erosion.

be: Less than 2 feet of bank erosion.

S: Stable.

E. Precipitation Data Collection by the USGS

The U.S. Geological Survey established 18 storage precipitation gages and 3 recording precipitation gages within or directly upstream from the park in 1973 and 1974 (Figure 1). The storage gages are emptied at least once each month, as well as after major storm periods. Records for the storage gages and recording gages have been tabulated for the 1975 - 1980 water years and the data is available in Redwood National Park files. Table 6 shows the approximate elevation, mean precipitation values and range of precipitation values for the storage gages. The precipitation data is useful in reconstructing rainfall distribution during synoptic storm events. The data will also be used to document rainfall amount and intensity of large storms that cause significant geomorphic change in the basin. Due to the relative inaccessibility of the upper basin and the expense of extending the precipitation network further up the basin, the precipitation gages are confined to the lower half of the basin. Four gages are above 2,000 feet and provide fairly good coverage of higher elevation sites.

Freshwater
Lagoon
Orick
101
Prairie
Creek
Larry Damm Cr
Little Lost Man Creek
Lost
Man
Hayes
Creek
McArthur
Creek
1
2
3
4
6
7

Figure 1: Location of precipitation gages

TABLE 6

PRECIPITATION STORAGE GAGES, REDWOOD CREEK BASIN

Name	Approximate Elevation (feet)	Date of Establishment	1976 - 1979 Mean Inches
1. Little Lost Man Creek Site #2	160	November 1974	52.7
2. Lost Man Creek at 18.5	1,000	October 1973	56.4
3. Lost Man Creek near Orick	400	October 1973	44.0
4. Freshwater Lagoon	250	October 1974	41.7
5. McArthur and Elam Divide	1,150	October 1977	- *
6. Hayes Creek	40	October 1973	49.9
7. Upper Little Lost Man Creek (Whiskey-40)	1,550	October 1973	62.7
8. Holter Ridge	2,250	October 1973	64.8
9. Bald Hills Road and C-Line	1,900	October 1974	58.6
10. Bond and 44 Creek Divide (A-Line)	1,350	October 1973	51.5
11. C-Line near Miller Creek	1,050	October 1973	56.3
12. C-50 Road upper Harry Weir Creek	1,000	October 1974	51.3
13. Head of Tom McDonald Creek	1,650	October 1974	65.5
14. M-Line and G-Line	750	October 1973	58.2
15. M-7-5 Road	1,100	October 1974	61.5
16. Shotgun Pass	2,000	October 1973	62.8
17. Copper Creek	800	October 1973	57.3
18. Little River-Redwood Creek Divide	2,000	November 1974	65.8

PRECIPITATION RECORDING GAGES

2225	Elk Camp	2,500	October 1973	- *
2120	K & K Road	450	October 1974	60.5
2020	Minor Creek	1,250	October 1974	- *

* Missing records.

III. MAIN CHANNEL STUDIES

A. Location Map and Photo Channel Strip Map

We catalogued all mainstem data by location according to reach numbers (Table 7). The reaches are delineated in Figure 2, and mainstem channel cross-sections and tributary streams are delineated in Figure 3. Exact locations of main channel field data, such as landslides, alluvial deposits, and notebook stations, are drafted onto photographic strip maps. The map scales are either approximately 1:3,000 or 1:1,500. More accurate scales for these photographs were determined in the field by measuring, at frequent intervals, actual distances between two points discernable on the photos. Total channel length and lengths between points along the channel were therefore determined from ground checks using photos rather than from 1:24,000 topographic maps. All river kilometer stations along the mainstem of Redwood Creek are distances downstream of the Roddiscroft Road crossing (end of Reach #36) near the headwaters of the basin.

B. Redwood Creek Channel: Description of Reaches above Minor Creek

Introduction

During the summer of 1980 we intensively mapped all geomorphic features along the main channel from the headwaters downstream to Minor Creek, a distance of 24 mi (38 km). The following is a narrative summary of field observations for this main channel reach, based on our field notes and discussions. The summary capsulates the major geomorphic processes operating in each stream reach and introduces the problems of interpretation of past erosional events in the main channel. The intent of the summary is to point out the variety of geologic, hydrologic and biologic factors that have contributed to erosion and deposition in the main channel since 1950. Many of the observations and interpretations mentioned in the summary will be studied further as our field data are analyzed and compared. Reaches discussed in the summary can be located on Figure 2; the reach-by-reach summaries include Study Reach numbers 21 through 36.

Roddiscroft Road Crossing to Confluence of Snow Camp Creek (Reach #36)

Along this channel reach, Redwood Creek follows the linear zone of sheared rocks that characterize the trace of the Grogan Fault. The east bank slopes are steeper than the west bank slopes because the east side of the creek is underlain by sandstone and siltstone bedrock, whereas the west slope is composed of the colluvial remains of a large prehistoric earthflow landslide that came down from the slopes of Snow Camp Mountain.

The most impressive characteristics of this reach are the abundance of both large boulders and logs in the channel bed. Log jams that developed where logs piled up against boulders in the channel are a common

TABLE 7

STUDY REACHES ALONG REDWOOD CREEK

Reach Number	Reach Location	Reach Length (km)	Cross Sections
1	Orick Bridge to McArthur Creek	5.66	1-5
2	McArthur Creek to Elam Creek	1.32	6-8
3	Elam Creek to Cloquet Creek	3.01	9-10
4	Cloquet Creek to Miller Creek	2.67	11-13
5	Miller Creek to Downstream End, Tall Trees Grove	1.98	14-15
6	Downstream End of TTG to Elbow Creek	2.06	16-18
7	Elbow Creek to Harry Weir Creek	1.85	18-19
8	Harry Weir Creek to Dolason Creek	2.54	20-22
9	Dolason Creek to Airstrip Creek (Mouth of Gorge)	1.19	23-25
10	Airstrip Creek to Slide Creek (Extent of Gorge)	1.87	- -
11	Slide Creek to cut off meander	2.25	26-28
12	cut off meander to Copper Creek	1.35	29
13	Copper Creek to Lyons Creek	1.55	- -
14	Lyons Creek to Devils Creek	1.29	30
15	Devils Creek to Coyote Creek	1.84	- -
16	Coyote Creek to Lacks Creek	9.79	31-32A
17	Lacks Creek to downstream end of meanders	2.90	32B-33
18	downstream end of meanders to Weepy Creek	7.37	- -
19	Weepy Creek to June Creek	5.90	34-34A
20	June Creek to Minor Creek	2.89	35-36
21	Minor Creek to Sweathouse Creek	4.45	37
22	Sweathouse Creek to Lupton Creek	3.40	38-39
23	Lupton Creek to Fern Prairie Creek	1.85	40-42
24	Fern Prairie Creek to Chicago Creek	2.60	43
25	Chicago Creek to Emmy Lou Creek	3.00	43A-43B
26	Emmy Lou Creek to Cool Spring Creek	2.35	43C-43D
27	Cool Spring Creek to Ayres Creek	3.50	- -
28	Ayres Creek to High Prairie Creek	1.55	- -
29	High Prairie Creek to Nisom Creek	1.80	- -
30	Nisom Creek to Lake Praire Creek	1.70	43E-43F
31	Lake Prairie Creek to Heustis Creek	2.05	- -
32	Heustis Creek to Pardee Creek	1.40	- -
33	Pardee Creek to Debris Torrent Creek	1.60	- -
34	Debris Torrent Creek to Last Gasp Creek	1.10	- -
35	Last Gasp Creek to Snow Camp Creek	2.20	43G
36	Snow Camp Creek to Roddiscroft Road	3.45	44
	TOTAL	99.28	

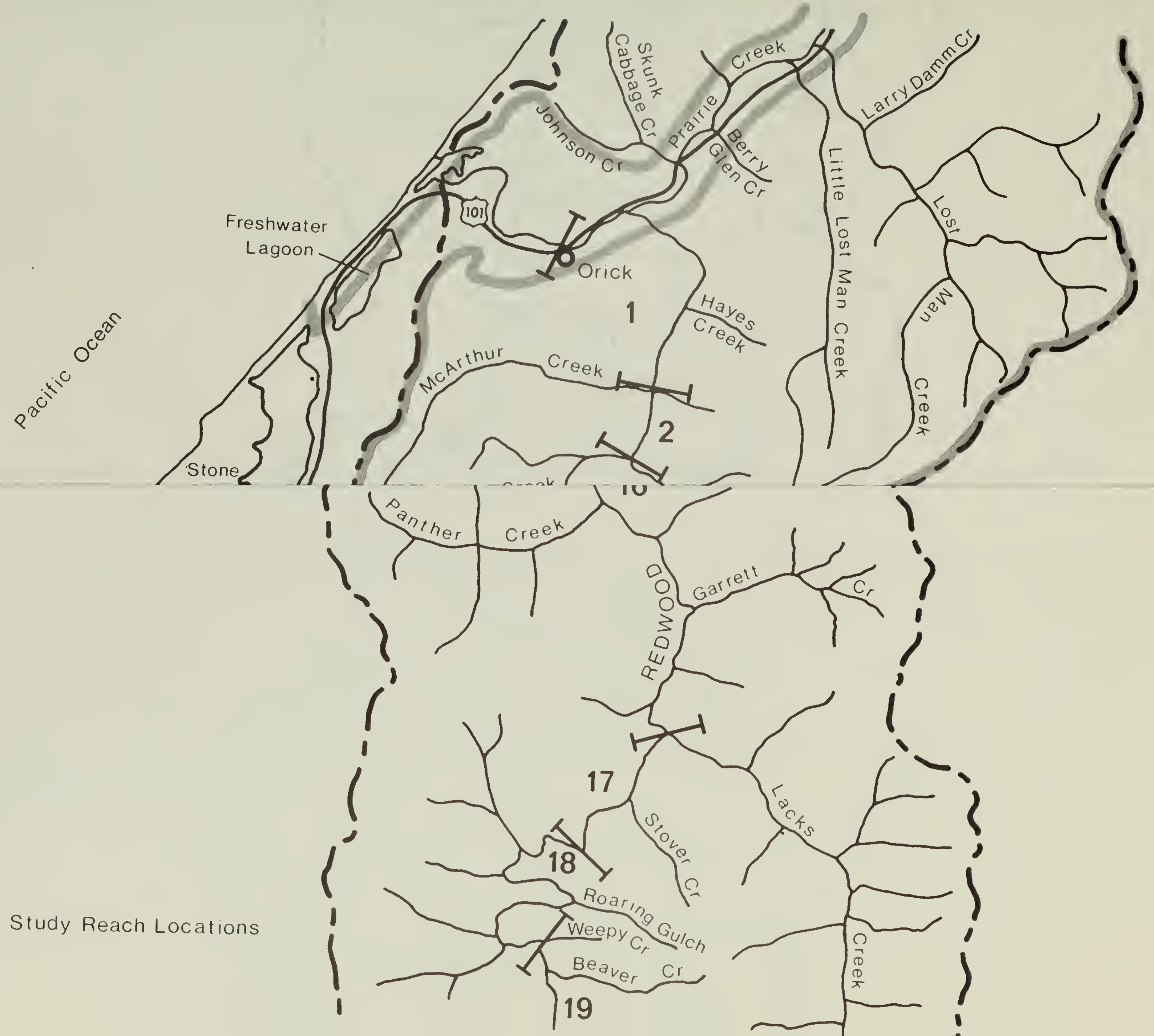

Figure 2: Study Reach Locations

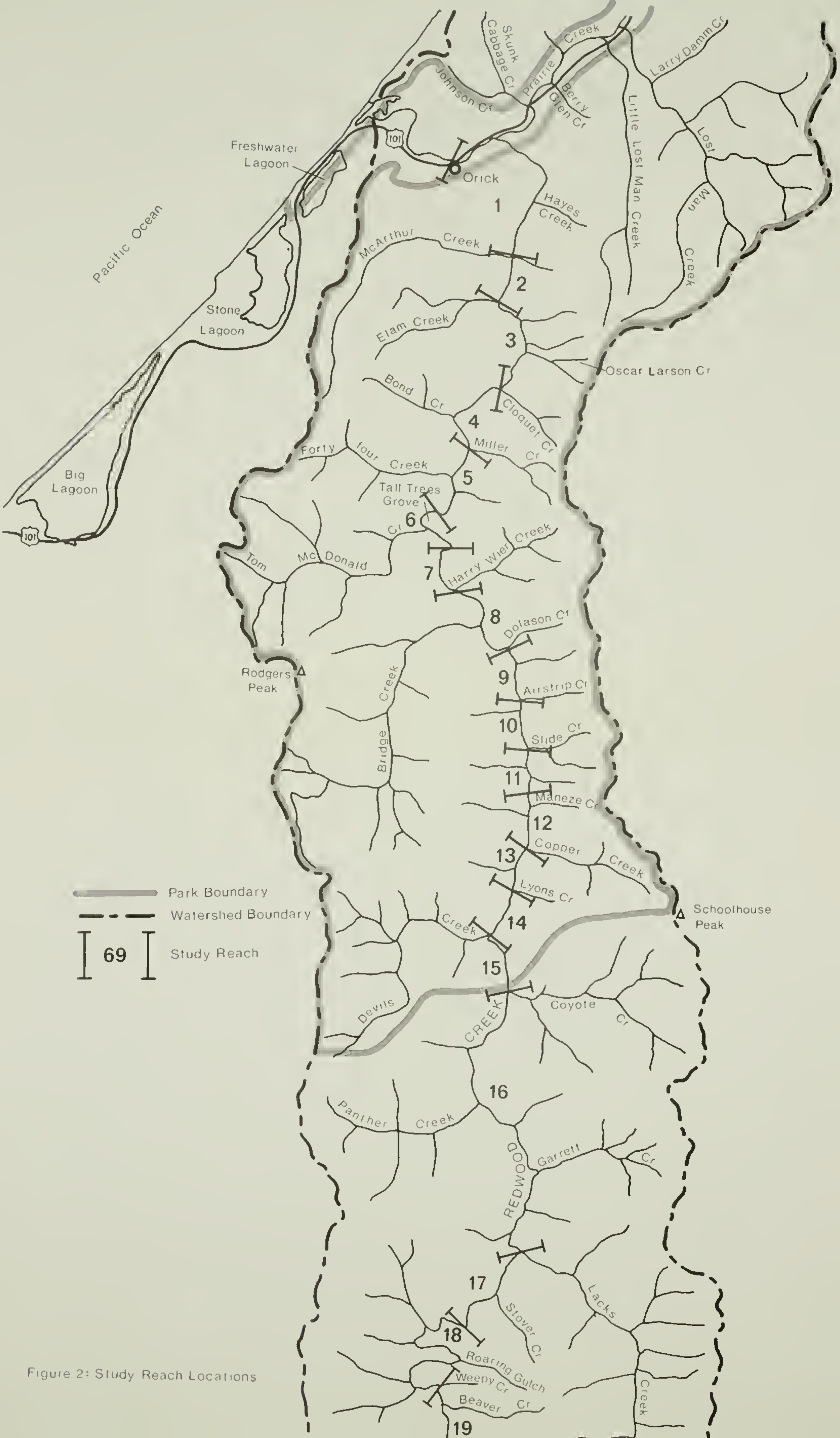

Figure 2: Study Reach Locations

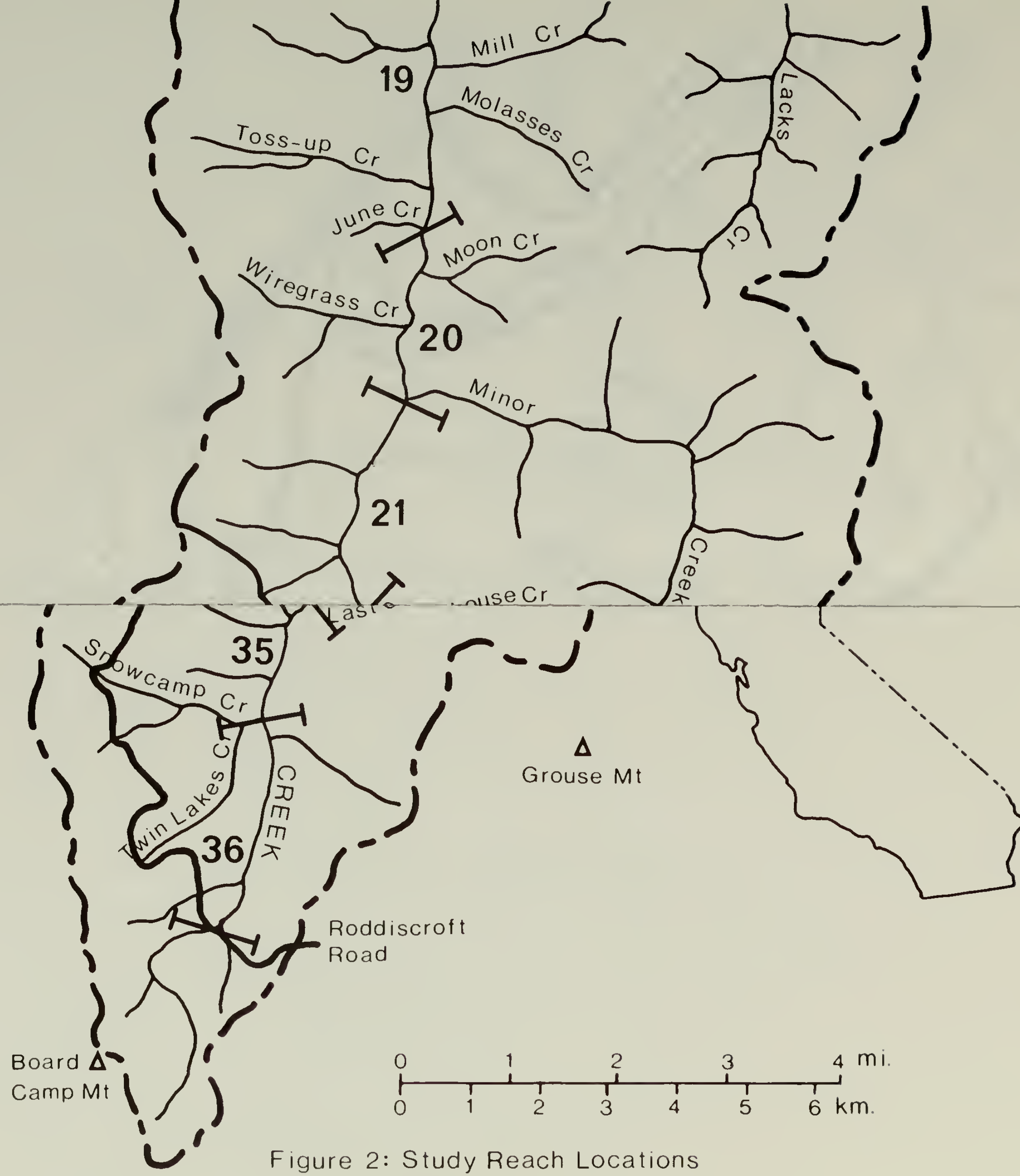

Figure 2: Study Reach Locations

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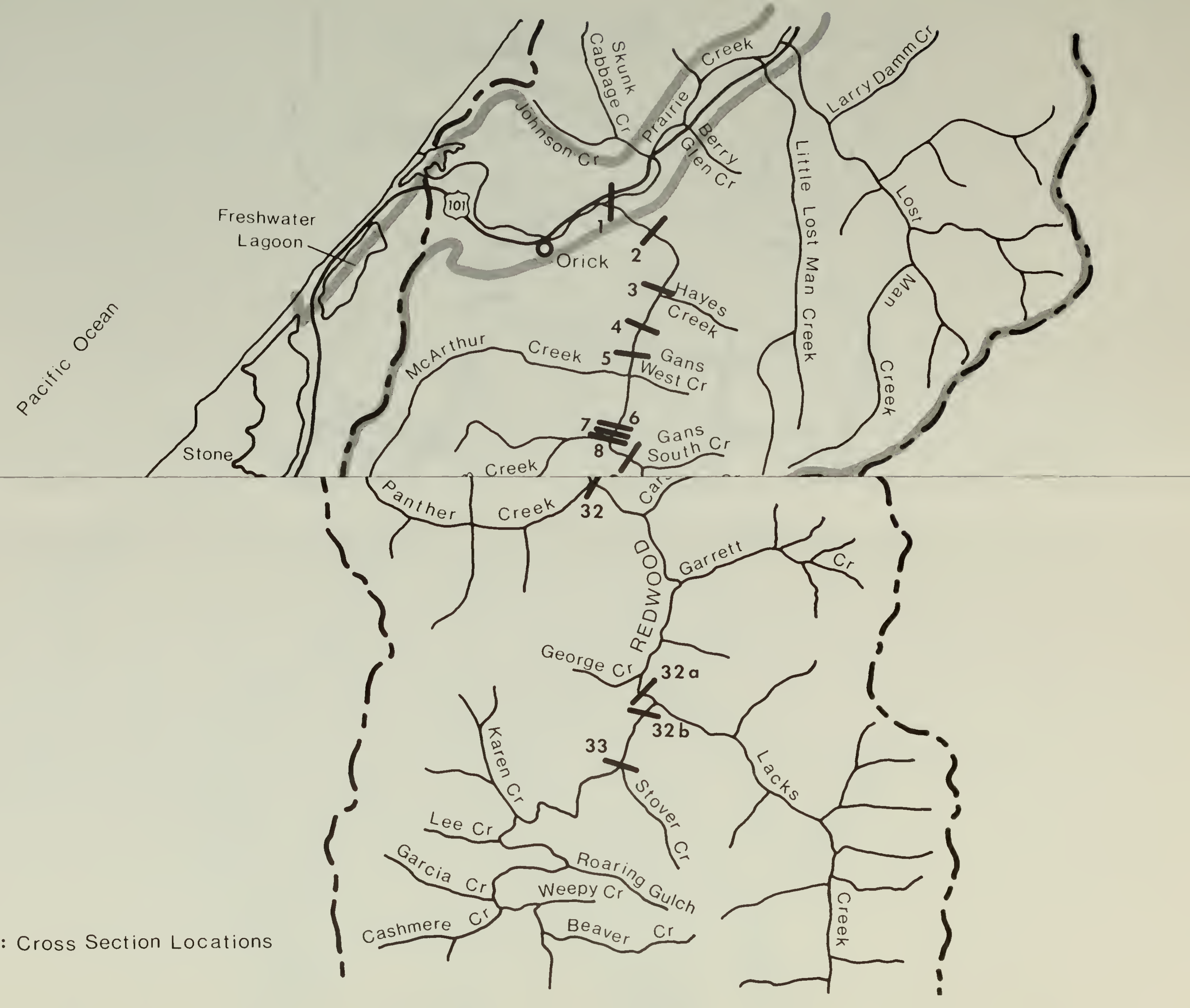

Figure 3: Cross Section Locations

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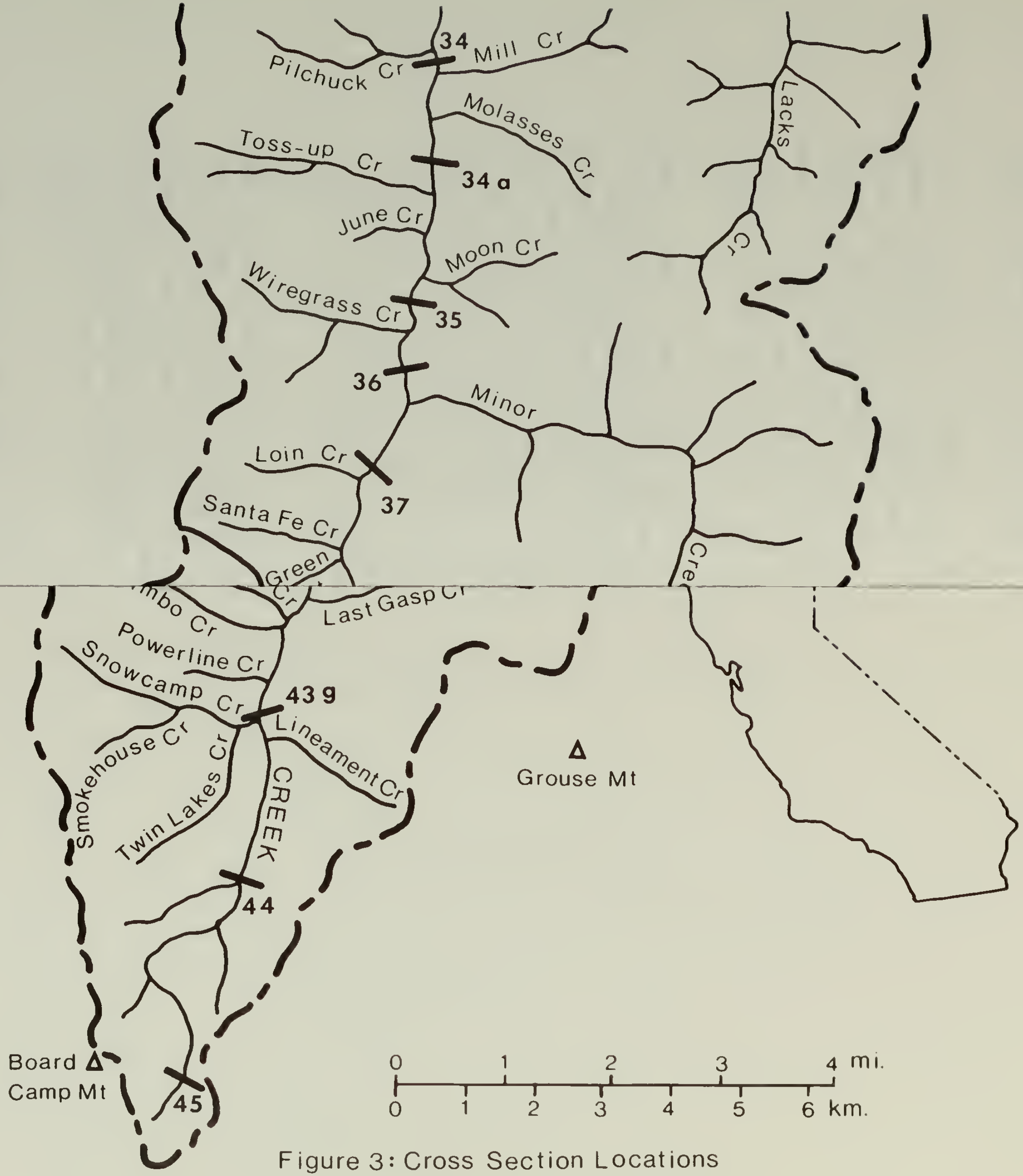

Figure 3: Cross Section Locations

Figure 3: Cross Section Locations

sight. The log jams are now partly collapsed, with an open-framework of logs. Logs are also strewn about singly or in clusters. Most logs have cut ends and cut stumps at streamside are also common. It is apparent that a tremendous quantity of bucked trees lying near, or in, the channel were mobilized by the 1964 flood and deposited in jams. The larger jams are essentially intact and store large quantities of sediment, though these jams have large holes in them.

Channel gradient is steep enough so that there are few large pockets of stored sediment; and what stored sediment remains is trapped behind the intact portions of log jams. The remnants of alluvial fill on the channel margins suggests that a large amount of degradation occurred after the channel was rapidly filled with sediment during the 1964 storm event. Bank erosion occurred concurrently with channel degradation. On the basis of roots exposed in streamside stumps and USGS cross-section data, 2 to 15 feet of bank erosion has occurred at many locations since 1964.

The channel reach has abundant streamside landslides. All the large landslides occur on the steep east bank. The slides are either debris or slump-translational slides and the underlying bedrock is siltstone or bedded sandstone-siltstone that is extensively sheared. By contrast, on the west bank, landslides are mainly slump flows or large earthflows that occur on the colluvial slope. These flow-type landslides transport dense crystalline boulders of greenstone and sandstone, as well as the finer-grained matrix material. The boulders remain in the channel because they are too large to be fluvially transported downstream. Consequently, the Redwood Creek channel is clogged with this lag deposit of boulders along much of this reach. The last 1,600 feet of the reach is a dramatically steep (1,000 feet/mile) boulder cascade consisting mainly of large massive sandstone boulders, though greenstones and some other unusual lithologies, discussed below, are also present.

The boulder-bedded channel abruptly ends below the confluence of Snow Camp Creek because the boulder-bearing geologic unit is faulted out at this point by the east-west trending Snow Camp Fault. Below Snow Camp Creek, the Grogan Fault juxtaposes Redwood Creek schist against a coherent unit of sandstone and siltstone. Textural descriptions of sedimentary and metasedimentary rocks within and adjacent to the Grogan Fault Zone follow a textural zonation introduced by Blake and others (1967).

Lithologies in the channel reach from Roddiscroft Road down to Snow Camp Creek include Franciscan rock types that are common to much of the east side of the Redwood Creek basin (sandstones, siltstones, cherts, greenstone) as well as Franciscan rock types that are more diagnostic of the Eel River-type melange terrain. Franciscan lithologies found in the Redwood Creek channel above Snow Camp Creek that appear in abundance <u>only</u> in this reach are:

1. High-grade blueschist.

2. A densely-veined, light greenish rock with coarsely crystalline, thick $CaCO_3$ vein fillings.

3. Densely crystalline blocks of textural zone two metagreywacke with fine white segregated quartz bands. This rock is much denser than the otherwise similar textural zone two rocks that occur along the Grogan Fault Zone.

4. Intricately bedded greenstone and siltstone blocks that show much post-depositional (or syn-depositional) deformation.

5. Greenstone conglomerate/breccia.

6. Bleached, whitish-green meta-chert.

Snow Camp Creek to Powerline Crossing (Upper Part, Reach #35)

The gradient of Redwood Creek below Snow Camp Creek is moderate and the channel is no longer boulder-clogged, although there are a couple of short, steep gradient reaches with large boulders. The clast sizes in the bed material are large cobbles to small boulders; and schist is a major component of the bed material (approximately 40%). Most of the schist in the channel appears to be of higher metamorphic grade (denser and greater amount of blue amphiboles) than the schist clasts in the channel reaches within Redwood National Park.

There are several large landslides on the west side along this reach. In contrast to slides further upstream, they have revegetated well with alder.

At the confluence of Snow Camp Creek, several large, thick (approximately 15 feet to 20 feet) fill terraces are deposited on the sides of Redwood Creek. These fills are 1964 flood deposits that settled out due to the sharp change in gradient at the confluence. The deposits accumulated in eddies and backwater areas while both upper Redwood Creek and Snow Camp Creek were at or near peak flood stage. While there are many such 1964 flood deposits in the uppermost sections of Redwood Creek, these fills are among the largest. The fills have largely been eroded away and the remnants are now nested on the channel sides or isolated on the inner edge of river bends.

Powerline Crossing to Last Gasp Creek (Lower Part, Reach #35)

In this channel reach, Redwood Creek flows on well-foliated, sheared metasiltstones and metasandstones of textural zone two that mark the NNW-trending trace of the Grogan Fault Zone. No outcrops of schist occur within the channel and debris slides on the west slope expose only the metasandstones and metasiltstones.

The channel has short reaches with large boulders, though most of the channel is composed of small boulders and large cobbles. Channel bed material includes metasandstones, metasiltstones, siltstones, and sandstones as the dominant lithologies. Other rock types are blue or slate-grey schist, foliated dense greenstones, unfoliated dense greenstones, and less dense massive greenstones. Notably absent in this channel reach, compared to upstream, are cherts, densely veined carbonate rock, and high-grade blueschist rocks.

Despite the increasing size of the stream, large log jams still occur along the steeper-gradient channel sections where boulders clog the channel bed. The continuing prevalence of large jams this far downstream along the main channel are due to: (1) the large quantity of logs left in or near the channel that were never taken after being felled, (2) additional organic debris delivered from slopes by streamside landsliding, and (3) the presence of large boulders in the channel that locally decrease effective channel width and cause logs to pile up. The number of log jams decreases with fewer large boulders in the channel.

Streamside landslides may contribute to log jam formation in two ways. A slide may occur and dump trees into the channel, forming a log jam that traps sediment. Alternatively, logs from upstream (cut logs in the case of Redwood Creek) get jammed on large boulders, then sediment accumulates and diverts streamflow towards a bank, causing bank erosion and a landslide. Both scenarios have occurred in different places along upper Redwood Creek.

Log jam stability appears to depend on their source. Old-growth Douglas-fir windfalls that are well keyed into the banks will have a long residence time compared to a jumble of cut logs and small debris. Sediment stored behind the different types of jams must be evaluated differently in terms of sediment residence time and transport potential.

The logs in the jams are now starting to decay and another major runoff event may break up many jams. As the logs further decay over the next decade, the jams will break during normal storm flows. The jams are still reasonably safe to walk on, but this condition may not persist after another 5 years. We are impressed that all the log jams are old and rotting and are probably of 1964 flood vintage. We observed no recent log jams composed of more solid, fresh debris. One jam appeared double-aged in that the downstream portion was old and rotting, whereas the upstream portion consisted of fresh organic debris. Old jams may apparently trap fresh debris and perpetuate themselves a bit longer. Since all the log jams are partially ruptured with an openframework of logs, most of the trapped sediment has moved downstream. An estimated 10% - 25% of the original sediment remains.

The channel banks show abundant evidence of sediment deposited by the 1964 flood. The highest flood bars bear vegetation (alder, Douglas-fir) whose ages suggest these bars were deposited about 1964. Other fill terraces associated with flooding occur on the insides of river bends or in large eddy deposits caused by an obstruction.

This channel reach has abundant landslides, and most are classic debris slides or combined slump-translational slides. Vegetation recovery is good on slides where the original ground surface slipped downslope intact by pure translation and part of the intact, soil-bearing surface remains. Slide revegetation also improves as slope gradient decreases. Where bare, meta-siltstone bedrock is exposed on the slide plane, recovery is generally poor to non-existent. Rilling and gullying are obvious on such surfaces, as well as retreat of the head scarp, but these erosional processes have contributed minor sediment compared to the initial mass failure. Some debris slides, which are partially revegetated, have fill terraces nested against their basal slopes. These fills suggest that the slides failed either during or before the 1964 flood, then the alluvial fill was laid down in the falling stages of the flood, and the slides have experienced no significant movement since 1964. Such slides make up a significant fraction (approximately 20%) of this channel reach.

After considering the condition of the log jams, the elevations of the fill terraces, and the re-emergence of the trees buried and killed by the initial channel aggradation, we believe that Redwood Creek has cut down to near the pre-1964 flood thalweg after a short period of channel aggradation. We see no obvious deeply-aggraded reaches, though fill terrace remnants of previous aggradation are abundant. However, roots of several Douglas-fir stumps are only 1 foot above the low water surface and about 2 feet of aggradation remains in the channel in many places. Channel bed material in this reach is boulder-cobbles and further degradation will occur slowly. This coarse bed deposit is probably a lag from the previous aggradation. The two USGS cross-sections in the vicinity show continuing degradation from 1974 to 1978. All these factors suggest most of the 1964 flood deposits have either eroded downstream or are now isolated as fills nested on channel margins, the channel is near the pre-1964 thalweg elevation, and degradation will continue in localized reaches, but at a much reduced rate.

Prior to major storms in 1955 and 1964 and prior to logging, this channel reach was probably a boulder/cobble stream with a minor amount of organic debris and a few areas of fine sediment stored behind boulders. Now, large volumes of finer-grained material are stored behind log jams, and this material has substantially changed the natural size distribution of sediment potentially available for transport.

Last Gasp Creek to Pardee Creek (Reach #33 - 34)

Below Last Gasp Creek, the channel is more open, bouldery reaches are less frequent, and the gradient decreases noticeably.

There are only a few log jams (or remainders of log jams) and they are found in the first half mile below Last Gasp Creek. The last effective log jam was just below Powerline Creek. The jams downstream of Last Gasp are old, rotting, and partially or totally broken up. All these jams appear to be of 1964 flood vintage. Below Pardee Creek, no concentrations of logs span the whole channel.

The gradient has moderated noticeably and the only steep gradient reaches are in a few scattered boulder-clogged channel reaches. Stored sediment is negligible and no remnant terraces occur in the boulder reaches. One of these bouldery reaches is at the base of an earthflow/slump landslide on the right bank (southwest-facing slope). This earthflow/slump failed during the 1964 storm.

A series of entrenched, tight meanders start just above Last Gasp Creek and numerous debris slides occur here. The slides are, for the most part, on the outsides of the river bends and occur in relatively competent metasandstones and metamudstones.

Approximately 3,500 feet below Last Gasp Creek are two large point bars on the insides of meander bends. Both bars resulted from 1964 flood deposition. The deposits buried and killed the old-growth Douglas-fir trees that were growing on the bars and the bars now have "snag forests" on them. These bars are the first evidence that Redwood Creek is becoming wide enough and has a moderate enough gradient to preserve large bars of sediment deposited during the waning stages of the 1964 flood.

Fill terraces nested on the channel margins are beginning to appear frequently. These fills indicate the original heights of aggradation. The minimum age of these deposits can be established by counting the annual growth rings of alders growing on the fills. Alders growing on the present low-water channel margin can establish the time elapsed since most post-flood downcutting occurred. Several channel fills show multi-level terraces. The highest terraces, 18 to 20 feet above the thalweg, date from 1964 and are composed of small pebbles and sand. A mid-level terrace, about 12 feet above the thalweg is common; this terrace fill has a more cobble-rich fraction and dates from 1970 to 1972.

On top of the eroded fill terraces, we found evidence of abandoned channels that date from 1966 and 1970, based on the aerial photos. Therefore, the main channel has downcut and shifted course in the last 10 years. In some reaches the channel pattern has become straighter, and in others, more sinuous.

Based on initial surveys, sediment storage is not going to correlate directly with channel gradient. A local high supply of sediment may be a more important contributor to terrace formation than a change in channel gradient. Also, just downslope and downstream of landslides, we often find large angular clasts that obviously have not been fluvially transported very far.

Bedrock exposures are more frequent below Last Gasp Creek and we get the impression that more channel reaches are entrenched between relatively competent sandstone slopes, compared to channel-hillslope characteristics upstream. Starting at about Last Gasp Creek and continuing downstream, the right bank (northeast side) of the creek borders a relatively competent zone of sandstone. The metasandstone-schist contact, which is approximately 500 feet to 1,000 feet up on the left bank hillslope, is in places near enough to the creek so that the upper portions of the longer slides are within the schist. However, Redwood Creek never flows on schist and has not flowed on schist at all since it first appeared on the hillslope above Snow Camp Creek.

The predominant strike of bedding attitudes in the channel bedrock exposures is N 05° W to N 20° W. Dips are almost all 70° to 90° and dips to the east are more common than dips to the west. There is no question that Redwood Creek's direction of flow is controlled by the strike and dip of the bedrock. The location of meanders may be controlled by relatively competent rock zones where a meander pattern, originally formed during uplift, became structurally frozen into the valley bottom as Redwood Creek entrenched itself deeper into the bedrock. We saw one outcrop where bedded metasiltstones graded into a green, bedded metachert unit. The resistant metachert formed the only instance of the channel flowing over bedrock in this channel reach, and this metachert is the only exposure of chert along the channel from Snow Camp Creek down to the Route 299 bridge.

The landslides are increasing in size, but are just as frequent as further upstream. Revegetation is becoming a major obstacle to measuring landslide volumes, especially for the slides on the northeast facing slopes (left bank). Revegetation started immediately after 1964 on the wetter sites and 15 years of growth has totally covered the original slide morphology. The 1966 aerial photos are an essential aid in measuring the slides accurately.

Pardee Creek to Lake Prairie Creek (Reach #31 - 32)

From Pardee Creek to Lake Prairie Creek, Redwood Creek is noticeably larger and visually different. The stream channel consists intermittently of small boulder-large cobble reaches or sand and small pebble reaches, but in only one place is there a distinctly steeper reach caused by a concentration of large boulders in the channel. Single large boulders are scattered along this reach; they are composed of either foliated meta-greenstone or dense, massive, meta-sandstones. Channel gradient is moderate and surprisingly consistent in elevation drop. The channel does not have a well developed pool-riffle pattern and deep pools are infrequent.

The remains of two large log jams occur along this reach, but we see no evidence that frequent, smaller jams once populated the streambed. The largest jam, 1,000 feet above Lake Prairie Creek, no longer blocks the channel, but older photos show that the jam was once continuous across the stream. Several nested fill terraces are deposited upstream of the jam; the top of the jam is 17 feet above the thalweg and the terraced fills are 19 feet above the thalweg. The terrace thins out upstream of the jam. Remnants of the second jam occur 500 feet above the first, and terrace deposition is evident above this jam as well. Both log jams occurred where large boulders along the right bank of the channel decreased channel width. Redwood Creek is now wide enough and carries sufficient water so that these large log jams are relatively short-lived and easily broken up by subsequent storm events.

Streamside landslides along this reach are just as frequent as above; and if anything, slide volumes are on the average even larger. Preliminary comparisons of the present channel with the channel in the 1966 photos show that a number of slides in this reach had not occurred by 1966. Post-1966 streamside landsliding is uncommon above Pardee Creek. The only major exception is a right bank slide just below Last Gasp Creek. The presence of post-1966 slides further downstream may be a function of the transport of sediment originally deposited in 1964, and of the storms in the 1970's, especially the two in 1972. Landslide revegetation is extensive on many slides, especially those with a northeast aspect. The presence of logging roads on steep slopes is the obvious cause of many of the 1964 failures, whereas further upstream, the relationship of road construction to slope failure was not as obvious. The total removal of these roads by slope failures testifies that slide depths were often well in excess of 8 feet along this reach. Some slides show intact logging roads across the slide surface. These slides probably occurred prior to the 1964 storm due to road building and smaller storm events, and the road was rebuilt to complete logging operations. The largest slides along this reach occur on the outside of tight river bends. The straighter reaches have only smaller slides.

The most impressive characteristic of this reach is the thickness and abundance of remnant fill terraces along the channel margins. Fill terraces are not higher than those upstream, but they are better preserved, especially on large point bars on insides of stream bends. Fill thicknesses of 15 to 20 feet are common. In two instances, the 1966 photos showed that the 1966 channel flowed on top of what are now perched, 20-foot-thick fills, implying the <u>entire</u> channel width was filled with sand and gravel to a depth greater than 20 feet. It really is hard to imagine the amount of sediment deposited in this reach by the waning stages of the 1964 flood. Along most of this reach, the channel was filled with 15 feet of sediment above the present thalweg. Some of the fills thin in the downstream direction, and others thin going upstream. Of equal surprise is how the age dates of alder growing near the present thalweg suggest early downcutting occurred at 1.5 to 3.0 feet per year and more recent downcutting has occurred at 0.5 to 2.0 feet per year. Recent photo documentation shows that downcutting is still occurring in several reaches. However, the majority of the fill was removed downstream in the first 5 to 7 years after the flood.

As one moves further downstream, we see more evidence that re-deposited alluvium moved downstream after 1965.

Some reaches strongly suggest channels are still aggraded compared to pre-1964 conditions. Just above Bradford Creek, large boulders are still partially buried in the channel, implying 1 to 3 feet of recent sediment deposition; in this reach, no pool-riffle pattern is present, and the channel is unusually straight.

Older terraces are beginning to appear along the channel with old-growth Douglas-fir growing on them. Deposition by the 1964 flood on these terraces was generally a sand-silt veneer of less than 1 foot, which did not kill the trees.

Three major tributaries enter in this reach: Pardee Creek (left bank), Bradford Creek (right bank), and Lake Prairie Creek (left bank). Air photos show both Pardee Creek and Bradford Creek suffered severe streamside landsliding before and/or during the 1964 storm and both delivered large volumes of sediment to this channel reach during the 1964 flood. Portions of both watersheds were harvested before 1964 and the steep slopes immediately adjacent to the channel were tractor-logged in places. Fill terraces of 1964 vintage along Redwood Creek just above Bradford Creek suggest that an alluvial delta at the mouth of Bradford Creek may have hydraulically dammed Redwood Creek temporarily during the 1964 flood.

From Pardee to Lake Prairie Creek, Redwood Creek flows entirely on bedded sandstones and mudstones. These rocks vary from a low textural zone two to a well developed zone two, but in no place is the bedrock schistose. A large component of the bedrock consists of sandy greywacke beds that are folded and fractured and show some cataclasis but are not pervasively sheared. These rocks show a close kinship to the competent sandstone and siltstone unit upslope to the northeast, but show no apparent kinship to the more fine-grained schist upslope to the southwest. The bedrock in this channel reach appears, in general, to be coarser grained (higher sandstone to siltstone ratio) than further upstream. Bedding strikes correspond very closely to the trend of the Redwood Creek canyon. The exceptions are where dips are shallow or approach horizontal. Meander zones are also present in this reach and the concentration of meanders separated by straight reaches is similar to the channel pattern from Last Gasp Creek to Pardee Creek.

We saw no exotic high-grade metamorphic blocks in the channel, although greenstones, foliated metagreenstones, and foliated metachert blocks are present. Sandstones and mudstones of textural zone one and two are by far the major rock types in the bed material, followed by schist. The greenstones are a minor, but persistent, component of the bed material.

Lake Prairie Creek to High Prairie Creek (Reach #29 - 30)

Redwood Creek has a moderate gradient throughout this reach, with a couple of steeper boulder reaches. A noticeable pool-riffle pattern is beginning to appear and some of the pools are quite deep (1 to 2 meters at low summer flow). Concentrations of flood-deposited logs are still occasionally present on channel margins, and locally they hinder sediment movement or divert streamflow. Almost all the log concentrations can be related to the failure of an adjacent forested slope. A large log jam may have spanned the whole channel where greenstone boulders form a constriction just above a large left bank debris avalanche which is 2,500 - 3,000 feet above High Prairie Creek.

There are very few of the fine-grained alluvial fill terraces nested on the channel margin that were so abundant directly below Pardee Creek. In this reach, the evidence for such fills resulting from primary deposition during the waning stages of the 1964 flood seems to die out. Below Minon Creek, there are few, if any, fine-grained remnant 1964 fills present. The fact that neither Lake Prairie Creek nor Minon Creek show evidence of any major streamside landsliding may contribute to the scarcity of fine-grained 1964 flood fills in this reach.

While fine-grained alluvial fills are diminishing downstream, several older terraces on the upper flood plains, with old-growth Douglas-fir, appear. These old terraces were affected by the recent flood events. A thin cover of fresh sand and silt is deposited at the base of old trees that are 14 to 18 feet above the thalweg. Old-growth Douglas-fir growing on terraces that are 12 feet or less above the thalweg were killed by thicker flood deposits. The recent flood deposition, however, did not significantly modify the original morphology of these older terraces.

Although channel-margin, fine-grained fills are not present, much evidence for aggradation exists in the form of gravel-cobble bars both on the channel margins and on point bars. These gravel-cobble bars, densely vegetated with alder, are a common feature in this channel reach. They are usually found along straight reaches of channel and the 1966 photos show these reaches comparatively contain less sediment from 1964 flood deposition, suggesting the reaches are relatively efficient conveyors of sediment. On some bars, alder growth is so vigorous that 6 to 12 inch diameter alder have formed a binding root mat on the bar that impedes bar removal by high flows. Alder roots have become exposed by downcutting of the bars, making root collars on the trunks clearly visible. The roots, however, still impede downcutting. The alders usually date from 7 to 10 years ago, suggesting the 1972 flood transported and reworked the 1964 deposits and left a lag of cobbles on the bars. We dug two or three holes on these bars and in each case there was a definite armor layer of cobbles protecting fine pebbles and sand below. A few of these cobble bars have two levels. The lower bars, 3.5 feet above thalweg elevation, date from 8 years ago (1972) and the higher bars date from 15 years ago (1965). The higher bars are only

4 to 7 feet above thalweg elevation and alders on these bars have root collars 1 to 2 feet above the bar level, suggesting that much fill was deposited on these bars in 1964 compared to point bar reaches, and not much downcutting has occurred since 1964.

These cobble bars clearly show the effects of reworking and transport of 1964 flood deposits by later flood events. The two large storms in 1972 are the most probable cause of the bar modifications. The cobble bars are significant modes of sediment storage because if a high flow event could mobilize the armor layer, the remainder of the bar could easily be flushed out.

In this channel reach, strath terraces start to be exposed on the channel margins. These terraces are floored with metasandstone and have a 1 to 2 meter veneer of gravel on top. Strath terraces continue downstream well beyond High Prairie Creek. Concurrent with the start of strath terraces along Redwood Creek, the valley width is becoming significantly greater. Valley width is now substantially wider than active channel width in most reaches. The Redwood Creek meanders are now no longer entrenched within the valley walls, but rather the meanders are cutting laterally into the banks of uplifted strath surfaces. The increase in valley width compared to active channel width and the disappearance of entrenched meanders suggest more stream power is now being expended on lateral erosion (bank corrasion) and less on channel downcutting. This change in the mode of erosion (exclusively downcutting to both downcutting and lateral cutting) occurs at about the same channel location where there is no longer any evidence of primary 1964 flood deposition of fine alluvium. In other words, lateral corrasion may begin to become an important channel-forming process in Redwood Creek at the same point where fluvial re-working of previously deposited bed material becomes a significant process. Interestingly, this same relation of valley form to the loci of original deposition of alluvium after the 1964 flood is present in the headwaters of the Van Duzen basin, further to the south (Kelsey, 1977).

Several pieces of evidence suggest this channel reach is still aggraded, although significant degradation has occurred. There are numerous abandoned, elevated channels at the back edges of point bars and terraces. However, evidence from tree roots suggest 1 to 3 feet of sediment still buries the pre-1964 thalweg. Snags of riparian hardwoods are presently in the channel at the low-flow water level. Also, the bed material of several channel reaches consists of large cobbles and small boulders of greenstone and dense metasandstone. This bed material is probably a lag deposit from previous aggradation. The lag deposit impedes downcutting and pushes the channel over to one bank where a narrow, steeper, and swifter channel can gradually erode into the lag material. In only one instance, a riffle in a straight reach below Minon Creek, is the channel literally flowing over bedrock.

From Minon Creek to High Prairie Creek, considerable tractor-yarded logging occurred on steep slopes adjacent to the Redwood Creek channel in the late 1950's and early 1960's. On these logged slopes, many large, 1964 flood-caused debris slides are directly attributable to tractor roads. The tractor roads frequently came down to the channel and connected with roads built across the higher gravel bars on the Redwood Creek valley bottom. Some of the tractor trail remnants on the right bank near the creek appear unstable and may fail in the near future.

From Lake Prairie Creek to High Prairie Creek, the channel flows through sandstones, mudstones, and their metamorphosed equivalents. The most common rock type is a meta-greywacke that consists of bedded greywacke sandstones and mudstones showing cataclasis and local shearing but hardly any phyllitic sheen to the mudstones. Bedding attitudes show a predominant NNW-trend and vertical to subvertical dip, though bedding variation is common. Redwood Creek flow direction is still influenced strongly by the strike and dip of the resistant, meta-sandstones. The schist contact is up on the slope above the left bank anywhere from 150 to 500 meters. The larger, left-bank landslides contribute massive quantities of schist directly to the channel, but the predominant lithology of the channel bed material is sandstone and metasandstone. In the NE-trending bend just above High Prairie Creek, the rock type in the channel is the closest to schist yet seen, but the Grogan Fault still remains up the slope to the west.

Streamside landslides continue to be a common hillslope feature on both sides of the valley. Slide sizes are larger but the frequency of channel bank affected by slides is less because more of the valley bottom is protected from lateral cutting by large point bars or strath terraces.

The largest slide in this reach occurs on the left bank approximately 450 meters upstream of High Prairie Creek. It consists of two arms that extend down from a topographic saddle. In 1966, the slide consisted of two long, narrow gully debris torrents. By 1978, both gully failures had enlarged to complex earthflow/debris avalanche failures and together have contributed over 5,000,000 ft^3 to Redwood Creek. The upper portion of both slides are earthflows that grade downslope into debris avalanche/flows. The Grogan Fault passes through the saddle where the slides join and schist bedrock makes up the upper headwalls of the slide. The slide offers the best exposed cross section of the Grogan Fault Zone that we have seen in the Redwood Creek basin. Between 1966 and 1970, a huge, house-sized greenstone block with a whitish, sheared talc rind slid down the northern landslide face and came to rest in the channel. The block came from the Grogan Fault Zone approximately 400 meters upslope.

A significant difference in stream bed character occurs above and below this large slide. Above, the channel is cobble bedded, whereas below, bed material is pebble-sand with boulders partially exposed. Despite the change in bed material at this locality, it is surprising how little aggradation appears to have occurred directly below the slide. Most slide debris has been transported further downstream.

High Prairie Creek to Ayres Cabin (Reach #28)

The channel in this reach has an even gradient with localized, steeper, more bouldery reaches. Dominant size of the channel-armoring bed material is large cobbles to small boulders.

The big sediment contributors are High Prairie Creek, Simon Creek, and a limited number of large landslides.

A log bridge crossed Redwood Creek at the mouth of High Prairie Creek. It apparently washed out before or during the 1964 flood. Based on tree roots and stumps next to the bridge, 6 feet of bank erosion and 1 to 2 feet of aggradation occurred.

All the large sediment bars appear to be re-worked 1964 flood deposits, or 1964 deposits that lost their original depositional morphology by subsequent downcutting and lateral bank erosion. The one notable exception is the deposition associated with severe debris sliding that occurred in Simon Creek during the 1964 storm. We estimate that 5,000,000 ft^3 of sediment was generated from these debris slides. A debris torrent swept down Simon Creek as a result of two large debris slides generated on steep, tractor-logged slopes. On Redwood Creek upstream of the Simon Creek confluence, a 15 foot high terrace remnant thins out going upstream. Fill remnants downstream of Simon Creek are 14 to 18 feet high, which is higher than fills further up the main channel near Lake Prairie Creek. Apparently, a delta of alluvium from Simon Creek backed up fill in Redwood Creek during the 1964 flood and subsequently deposited a large thickness of fill just downstream of the delta. Remains of the delta at Simon Creek are still clearly visible. A similar scenario occurred during the 1964 flood further up the main channel at the confluence of Bradford Creek. In the vicinity of Simon Creek, the rate of downcutting in the fill deposits has been about 1 foot per year since 1965. No large angular clasts are in these deposits, suggesting their origin was not nearby slides on Redwood Creek, but rather sediment transported down Redwood Creek or brought in by Simon Creek.

Strath terraces that are well above floodplain elevation are becoming a common channel-side feature. On one strath terrace just below Simon Creek, the average thickness of the alluvium above the bedrock strath was 15 feet; minimum thickness was 2 feet, maximum thickness was 25 feet. Lower strath terraces, less than 20 feet above the thalweg, have silt and sand deposited on them, probably of 1964 origin, and some old-growth trees were killed by this deposition.

Rocks in the channel at High Prairie Creek are highly metamorphosed sandstone (textural grade = high zone two) and are closely folded with lots of quartz veins.

Ayres Cabin to Noisy Creek (Upper Part, Reach #25; Reach #26 - 27)

The major characteristics of this reach are the abundance of strath terraces bordering the channel and the relatively open, even-gradient channel with only three notable bouldery reaches.

With the exception of the bouldery reaches, the channel bed is uniformly smooth with little variation in roughness. Pools are shallow and riffles are not steep. There are very few deep pools. No log jams are present, but in several instances, logs protrude from remnant fill material. Log accumulations may have been larger before channel degradation.

The bouldery reaches consist of greenstone boulders that appear to be metabasalts and meta-tuffs. The source of the greenstone boulders are debris slides upslope. In one instance (between Ayres Cabin and Cool Spring Creek), the boulder source is a coarse lag deposit sitting on a strath surface. The surface is about 150 feet above the channel and the boulders are coming from the alluvium atop the strath surface. Though not significant in bulk quantity, these dense greenstone boulders are an important component of the bedload because of their resistance to abrasion. As a bedload tool for downcutting, the role of greenstone clasts may far outweigh their relative percentage of the total bed material. We are not sure whether the greenstone boulders come primarily from the schist unit or the sandstone unit, or both. Most are unfoliated, suggesting they come from the Grogan Fault Zone or the sandstone unit.

There are noticeably fewer landslides along channel sideslopes in this reach because valley width in most cases far exceeds active channel width. Though they are revegetating, the landslides show both gullying and rilling.

As landslides decrease in frequency along channel margins, bank erosion of floodplain deposits is becoming a commensurately more significant erosion process. On both right and left banks, 10 to 20 feet of bank retreat is evident locally based on exposed roots and position of stumps.

In this reach, there is one cut-off meander just above Cool Spring Creek and an elevated, abandoned channel that forms a flat-bottomed notch in a ridge spur approximately 0.6 miles above Noisy Creek. The depth of the alluvial deposit in this abandoned channel ranges from 8 feet to 20 feet, and averages about 12 feet. A noticeable percentage (15% - 20%) of the cobbles in the abandoned channel were rounded greenstone, a far greater percentage than can be found in outcrops along the channel sideslope upstream.

Strath terraces are common along this reach and their presence may be due to a combination of the following factors. Channel banks are composed of relatively competent metasandstone that fails by debris sliding rather than by slumping or earthflow. Debris sliding is the most effective process for valley widening, whereas slumping and earthflow both tend to keep valley widths narrow. The bedrock is not highly resistant to erosion but it is reasonably homogenous in lithology, permitting fairly uniform retreat of competent slopes. Bed material is mostly of cobble size and smaller. It appears that the energy available to transport the sediment load approximately equals the load available, and downcutting occurs, but at a slow rate. At the same time, lateral erosion of banks, mainly by landsliding, is an important process. These two processes working together allow for the formation of strath surfaces and their subsequent preservation by downcutting.

The strath terraces are not paired, elevation-wise, directly across the valley from each other, suggesting the elevated surfaces do not indicate pulses of uplift followed by periods of stability. Often, old channel patterns can be followed downstream by tracing the meandering path and the gradual drop in elevation of a strath surface in the downstream direction.

Along this channel reach, Redwood Creek flows exclusively through the metasandstone unit (textural zone two). Bedding attitudes shows a strong structural control of channel directions, as is the case from at least Last Gasp Creek down to this point. The rocks are often intensively sheared and broken up, and impregnated with quartz veins, though less sheared zones are common. The dominant lithology is a bedded (2 inch to 10 inch beds) greywacke sandstone with thinner siltstone interbeds. Bedding tops are extremely difficult to identify.

We can document 1 to 3 feet of aggradation locally in this reach, except in bouldery reaches or where the channel is floored with bedrock. There are no thick, fine-grained fills along the channel margin, but small fill remnants up to 11 feet above the thalweg exist. Large flood bars are common and tree dating may establish an age for the larger bars. Along most of the active channel bordered by these bars, a dense fringe of 10 to 13 year old alders grow, indicating no flood event capable of removing these trees has occurred recently. However, we do see active lateral and vertical incision into these deposits despite the coarse clast size in many places. In the last 1.5 miles above Noisy Creek, at least three groups of 4 foot to 6 foot high, 12 inch diameter alder stumps are now exposed so that tree roots show. We therefore assume that after the 1964 flood event, the channel in this reach was filled-in with at least 6 feet of alluvium. Flood bar heights suggest even greater fill depths in localized areas such as point bars and eddy deposits on channel margins, but these point bar deposits are not as large nor as thick as those near Lake Prairie. Active downcutting in the past decade along this reach is evident in many localities. Downstream of Cool Spring Creek, photo documentation shows 6 feet of downcutting since the summer of 1970. Most of the downcutting probably occurred in the early to mid-1970's, because 1977 - 1980 were relatively dry winters.

Noisy Creek to Route 299 Bridge (Lower Part, Reach #25, Reach #24, Portion of Reach #23)

This is an even gradient reach with only a few bouldery sections. The boulders, most of which are greenstone, are smaller compared to the next upstream reach. Streamside landslides are few but are generally quite large. Bedrock is exposed in the channel bed five or six times between Noisy Creek and Route 299. No log jams occur; but in places, logs accumulate at bends and locally protect streambanks or divert flow into banks.

Just downstream of Noisy Creek, a section of tight meanders begins and continues for approximately 4,500 feet. The meanders are carved into a distinct, massive and cliffy greywacke sandstone with thin siltstone interbeds. Redwood Creek has become entrenched in this cliffy sandstone section, and the tight meandering ceases where the cliffy section dies out in the downstream direction.

In the latter half of this reach, Redwood Creek schist is exposed in the channel for the first time. From here downstream, schist exposures become increasingly more frequent.

Two earthflow/slump landslides enter from the right bank, the slide material being highly sheared mudstones. One of these earthflows, just downstream of Windy Creek, exposes dense angular greenstone chunks in the siltstone matrix. The outcrop suggests that the highly-sheared siltstone units in the Grogan Fault Zone are an important source for the dense greenstone boulders that make up most bouldery reaches. The greenstones are seldem seen in outcrop because the siltstone matrix is highly erodible, and the only time we see greenstone is as a lag deposit in the channel after the siltstone matrix is eroded away.

In this reach, at least two large, slow-moving (meaning with rates intermediary between creep and seasonal earthflow movement) forested earthflows occur on the left bank schist slopes above the channel. The upstream earthflow occupies the lower slopes of Noisy Creek, and its depositional lobe is encroaching on a strath terrace of Noisy Creek just above the Redwood Creek confluence. The other forested earthflow moves downslope from the vicinity of Christmas Prairie and enters Redwood Creek at a sharp bend below the cabin with the summertime-bulldozed pond in the channel. This latter earthflow has deposited a lag of schist boulders at its toe along the left bank of Redwood Creek.

The low water channels along the straight sections in this reach are alder fringed and most alders are 7 years old with some younger, 3 to 4 year old alders on more recent floodbars. There are two large flood bars downstream of Windy Creek. These floodbars were apparently deposited during the 1964 flood, based on aerial photo documentation. The 1972 and later storms have re-worked these floodbar surfaces, but the deposits were there prior to 1972.

Overall, we get the impression in this reach that the average channel bed elevation still reflects post-1964 aggradation, and that in most of the reach, the thalweg has not reached pre-1964 storm, nor pre-logging, elevations. Locally, at bedrock outcrops along the streambank, pools are absent where normally 4 to 5 foot deep pools would be present, suggesting the presence of recent aggradation. In 1966, the channel was 8 feet higher than today near Noisy Creek. Further downstream, the 1966 channel was 4 feet higher than at present. In all cases, vegetative evidence suggests the channel in this reach has not completely downcut to pre-1964 elevations. Recent sandy deposits lie on top of terraces with old-growth Douglas-fir stands. In some cases, sand deposition was thick enough to kill the trees. These terraces are 13 to 16 feet above the present thalweg. Streambank erosion, usually on the order of 5 to 10 feet, is apparent in several places; one reach locally shows approximately 20 feet of bank erosion, with riparian alder of pre-1964 vintage still buried.

A road traverses across the right bank slope from the Route 299 bridge upstream past Noisy Creek to the location of the meander cut-off. Though currently serviceable, the road has caused slope failures into Redwood Creek in four locations. This road is likely to remain a major access route to the east side of the basin, and we feel that rerouting or rebuilding segments of this road would significantly decrease sediment contributions to the channel.

Route 299 Bridge to Minor Creek (Lower Part, Reach #23; Reach #21 - 22)

This reach can be divided into the Chezem Ranch meander section, the relatively straight and well-vegetated reach below the meander section and above Sweathouse Creek, and the reach between Sweathouse Creek and Minor Creek where earthflow landslides become a major landform along the right bank.

Directly downstream of the Route 299 bridge, Redwood Creek starts a meandering course through the Chezem Ranch area. The channel at this point is flowing on schist but the Grogan Fault contact is just upslope to the east. This distinct set of meanders continues downstream for 9,600 feet. The meander reach is bordered for most of its length on both sides by strath terraces.

From the downstream end of the Chezem Ranch meanders to the right bank earthflow above Sweathouse Creek, the banks are vegetated and the channel continues to flow through schist. A forested, slow-moving earthflow comes in from the left bank (the schist side). The right bank earthflow above Sweathouse Creek is the first in a series of earthflows that enter from the right bank. A sparse scattering of boulders occur in channel at the base of this earthflow, and this is typical of boulder concentrations at earthflow toes further downstream.

A distinct set of terraces occurs along Redwood Creek, mainly on the left bank, in the vicinity of the confluence of Sweathouse Creek on the right bank and Bud Frankie's cabin on the left bank. The terraces record the downstream migration and periodic incision of the Redwood Creek stream bend that is still a part of the present channel pattern below Sweathouse Creek. The terrace deposit is unusually fine grained compared to the pebble-cobble veneer on most terraces.

Substantial left bank retreat has recently occurred at the base of the upper and middle terraces below Frankie's cabin. This retreat started about 1973 according to the landowner, and total bank erosion is approximately 50 feet. This bank erosion may have started, or at least been accelerated, when the thalweg started to degrade in a new channel position next to the left bank rather than along the right bank. Landowner Frankie says the thalweg was along the right bank prior to 1964, and the 1962 photos show the thalweg along the right bank. The 1964 high water mark at this site was 14 feet above present thalweg elevation, and the flood water just submerged the lowest terrace.

Earthflow landslides and generally unstable sheared mudstone colluvial stream banks are common features along the right bank starting just above Sweathouse Creek and continuing all along this reach down to Minor Creek. Hillslopes adjacent to the channel seem relatively gentle in this reach compared to further upstream, and the active channel becomes distinctly wider along the reach bordered by earthflows. Abundant earthflow activity begins near Sweathouse Creek because the relatively coherent sandstone unit that bordered the right bank from near Powerline Creek all the way down to Captain Creek is no longer present. Redwood Creek is eroding laterally into the more erosive incoherent mudstone and sandstone unit that borders Redwood Creek from Captain Creek downstream. Furthermore, the Grogan Fault in this reach is either in the channel or on the right bank side and the incompetent schist in most instances underlies both channel banks along the earthflow reach.

Despite the prevalence of earthflows along the Sweathouse to Minor Creek reach, the Redwood Creek channel is not clogged with boulders. Boulders that are present at earthflow toes consist of both foliated and unfoliated metavolcanics, massive sandstones, and a minor component of schist blocks. Although the local gradient of the earthflow reach is greater than upstream, it is less steep than earthflow reaches along the Mad, Van Duzen, and Eel Rivers. The lack of boulders and the relatively low channel gradient suggests these Redwood Creek earthflows do not transport as great a component of large dense blocks to the channel as other earthflows. The channel character as well as the slope morphology of most of the Redwood Creek earthflows further suggests they have not been as active in Holocene time as earthflows in the Mad, Van Duzen and Eel basins (Kelsey, 1977).

The following channel features suggest that this reach is still definitely above pre-1964 channel elevations but that the channel is now degrading following a post-1964 maxima: (1) pools are scouring but are not as deep as pre-1964 pools, according to local resident Bud Frankie;

(2) pools next to large channel boulders are less than 1 foot deep and typically such pools are much deeper in non-aggraded channels; (3) trees [hardwoods mainly] are still partially buried on channel margins; (4) the USGS gage downstream of the Route 299 bridge still shows some post-1964 aggradation though the channel bed is now degrading. We also saw some armored flood bars with a narrow channel cut deeply into one side suggesting degradation is occurring but is somewhat retarded by armoring with a coarse cobble-small boulder lag deposit.

A significant tributary sediment source along this reach, in addition to Sweathouse Creek and the earthflow terrain, is Loin Creek. Loin Creek enters on the left bank from the schist terrain and has a large alluvial delta at its mouth. Perusal of the airphotos may explain the source of this voluminous sediment output.

Cobble floodbars in this reach with alder growing on them and on their margins allow interpretation about the effects of the 1964 and 1972 flood events. Several cobble bars are 6 - 8 feet high with 13 - 15 year old alder on them, suggesting a 1964 flood origin. Lower cobble bars, averaging 4 feet above the thalweg, date from about 1972. We have not seen any flood deposits that unequivocally are primary 1972 deposits. Most 1972 floodbar surfaces appear to be a reworking of previously deposited material. In several instances we dated alders at 4 - 5 years old, so that 1975 flood waters may have re-worked some of the older deposits, leaving a fresh gravel surface open to alder invasion.

The highest fresh alluvial deposits (less than 25 years old) are 17 feet above the thalweg at the base of old trees, but most of these high deposits are 13 feet or less above the thalweg.

Pockets of fine sand deposits in back-eddy areas, associated with toppled or toppling hardwoods, are the sites of most severe bank erosion. On the straight, alder-fringed reaches, we have seen 1 to 2 feet of bank erosion on both banks, based on evidence of exposed roots of 7 to 10 year old alder trees.

A most noteworthy aspect of this entire channel reach is that schist is the most common bedrock type exposed in the channel, though exposures are quite poor compared to further upstream. The relative lack of exposures suggests the schist is more erodible than the sandstones of the Grogan Fault Zone and that the schist is not resistant enough to form abundant outcrops along the channel banks.

C. Main Channel Sediment Storage and Transport

Introduction

Sediment eroded from hillslopes enters Redwood Creek through several different processes: earthflows, landslides, fluvial hillslope erosion, bank erosion, soil creep and tributary transport. The relative importance of these processes varies throughout the Redwood Creek watershed. The timing and the amount of sediment input depends on the recurrence of large storms and on changing land use practices.

Sediment that enters the main channel of Redwood Creek is either stored temporarily or transported downstream. We categorized stored sediment in Redwood Creek, from its headwaters to its mouth, according to the method of storage, volume of sediment stored, and potential activity of the sediment. Sediment in the entire channel of Redwood Creek was mapped, measured and categorized during two field seasons (summers of 1979 and 1980). Sediment transport was determined by using U.S. Geological Survey flow and sediment records to estimate annual sediment yield from several reaches in Redwood Creek.

Tributaries were studied along with the mainstem. Even though the processes acting in tributary basins are similar to those in the main channel of Redwood Creek, their relative magnitudes and frequencies differ.

Modes of Storage in Gravel-Bedded Streams

Alluvial channels, by definition, have mobile beds of sand or gravel. This sediment, primarily transported as bedload during high flows, is temporarily stored in the stream channel during low flows. The residence time of sediment in the channel depends on its location and its mode of storage as well as on the frequency of storm events. Sediment is not evenly distributed throughout the channel; rather, it lies in various bed forms, or "storage compartments." The various types of storage compartments in Redwood Creek are listed below:

1. Channel Sediment:

   The channel bed consists of sediment that is mobilized and transported at high flows and deposited during recessional flows. Sediment above the average depth of scour is frequently mobilized. Sediment below the average depth of scour will be transported only during high magnitude/low frequency flood events, and in an aggrading system this sediment is inactive in a historical time frame. In a geological time frame and in an actively downcutting basin like Redwood Creek, all channel sediment is capable of being transported.

2. Point Bars:

   Above the channel bed, sediment is distributed in several forms. Point bars are a common stable bedform in a meandering stream located on the inside of meander bends. Sediment moves from point bar to point bar through the cross-over zone in the meandering thalweg. Even though individual particles composing the bar are continually in transit, the form of the point bar stays essentially the same through time. Over a long period of time, however, the active portion of a point bar migrates, and a well-vegetated stable deposit may be left.

3. Marginal Bars:

In straight reaches, bars form on alternating sides of the channel. As in point bars, the form of the marginal bar is relatively stable, while bed material particles are transported through them. However, sequential aerial photographs show that marginal bars shift more frequently than point bars.

4. Mid-Channel Bars:

In a braided channel, mid-channel bars are present. These bars are usually low, bare features that shift frequently, but they may be high and well-vegetated where the channel is not actively braiding.

5. Lag Deposits:

In some cases, large and heavy particles are sorted out and left behind as smaller, lighter ones are transported more rapidly downstream. As these larger particles are segregated, they create coarse lag deposits, which may take the form of point, marginal, or mid-channel bars. However, lag deposits are more persistent than other bars, and fewer particles are transported through bed forms armored by lag deposits.

6. Flood Berms and Fill Terraces:

A high magnitude flood may deposit large amounts of sediment in the channel in the form of flood berms or fill terraces. These berms are generally higher than "normal" gravel bars. The sediment that formed them is winnowed away slowly during more moderate flows. Because the surface of the berms is above the level of annual inundation, vegetation often becomes well established on them.

7. Debris Jams:

In forested watersheds, trees and other debris may cause debris jams which block the channel. Sediment is trapped upstream of the jam until the jam is broken by high flows or the debris decomposes. In Redwood Creek, debris jams are not found downstream of Lake Prairie Creek (drainage area above Lake Prairie Creek - 25mi^2 or 65 km^2).

8. Overbank Deposits:

Fine-grained alluvium is deposited on top of pre-existing bedforms or banks when floodwaters overtop the banks. Locally, splays of coarse material are also deposited on berms or banks, especially where the channel is severely aggraded.

9. Alluvial Flats:

In several locations, Redwood Creek has shifted laterally leaving point bars that are no longer being transported. These abandoned bars receive fine-grained overbank deposits during major storm events. They support magnificent groves of old-growth redwood and Douglas-fir, including the Tall Trees Grove. Alluvial flats are most common in the lower third of the basin. Under present conditions, alluvial flats are not a significant sediment source of erosion of previously deposited channel material.

10. Strath Terraces:

From Powerline Creek to downstream of Redwood Valley, alluvium is locally isolated in terraces underlain by bedrock. Due to regional tectonic uplift, Redwood Creek has incised into bedrock, leaving former floodplain deposits high above the present channel. This alluvium can only be reincorporated into the present channel by bank cutting into bedrock, causing sliding of the alluvium back down into Redwood Creek. Under present conditions, old alluvium on strath terraces contributes a miniscule amount of sediment to the Redwood Creek channel.

Classification of Stored Sediment by Transport Potential

We have categorized sediment stored in Redwood Creek according to its relative activity. Our qualitative assessments are based on elevation of bars above thalweg; particle size; amount, type and age of vegetation growing on bars; evidence of recent movement; and high water marks.

Active sediment is transported during moderate flows with a recurrence interval of 1 to 5 years. These are the discharges that define the bankfull channel. In terms of long term yield, they transport much of the sediment from a watershed. Weak or unstable debris jams collapse under such flows, and their trapped sediment is released. The surface particles of many point bars are active, and the channel bed itself is mobilized somewhat during moderate flows. Unvegetated marginal and mid-channel bars are also active.

Semi-active sediment is mobilized during moderately high flows, such as a 10 - 25 year flood. The channel bed scours to a greater depth. Sediment in bars with a cover of shrubs or young trees and in the active floodplain are mobilized. Some lateral erosion of fill terraces occurs. Fairly coherent debris jams may be partially or fully destroyed.

Non-active sediment is mobilized under high discharges, such as a 100-year flood. Besides moving the above mentioned bed forms, such flows may mobilize lag deposits, erode fill terraces, break log jams, and modify floodplain deposits.

Stable sediment is inactive in a historical sense. Sediment stored in alluvial flats and strath terraces that are well-vegetated with old-growth trees is not mobilized except during record floods. Some bank erosion occurs adjacent to the active floodplain, and mass movement occasionally reactivates sediment stored in terraces well above the present channel. The residence time of this sediment is at least 500 - 1,000 years, and may be influenced by climatic or tectonic changes.

Methods of Mapping Alluvial Storage Compartments in the Mainstem

When channel sediment was mapped, it was categorized according to mode of storage and potential activity, and the volume of sediment was measured. The relative accuracy of the measurements differs with the mode of the storage, and sediment fell into one of seven categories (Figure 4).

S_1 is sediment stored in the active floodplain above the 1980 thalweg. Gravel bars are usually flat, so we surveyed the height of a bar above the present thalweg with a hand level and stadia rod. Where there was a difference between the upstream and downstream portions of the gravel bar, we used an averge height. We measured the area of small bars in the field; for large bars we planimetered their areas from air photos. Accuracy of these measurements is excellent (within 2%). S_1 sediment is active or semi-active.

Debris jams occur frequently upstream of Pardee Creek. Sediment trapped upstream of debris jams was also classified as S_1. We calculated the volume of sediment stored upstream of log jams by treating the trapped sediment as a wedge, and measuring width and length of the deposit and the height of the jam (Figure 5). If a jam was partly broken through, we measured the height of the jam that was still effective in trapping sediment. Locally, terrace remnants indicated the original height of the deposit behind a log jam before it broke up.

S_2 deposits are remnants of alluvial fill deposited during the 1964 flood. Elevation of terraces were surveyed, and areas were measured in the field or planimetered from aerial photographs. The exact boundary of the fill with the underlying valley wall was unknown, so some error was introduced in estimating volume of fill deposits. In general, the visible portion of the valley walls were so steep that the maximum error due to estimating the buried boundary is about 15%, and is usually less than 10%. S_2 sediment is generally inactive.

S_3 sediment was deposited during the 1964 flood and has subsequently been eroded. In this case we measured the volume of the void rather than existing sediment. The total volume of 1964 sediment is the sum of $S_1 + S_2 + S_3 + S_6$. This estimate is subject to the same error as the one discussed in S_2. $S_2 + S_3$ were only calculated for the uppermost 14 km of Redwood Creek.

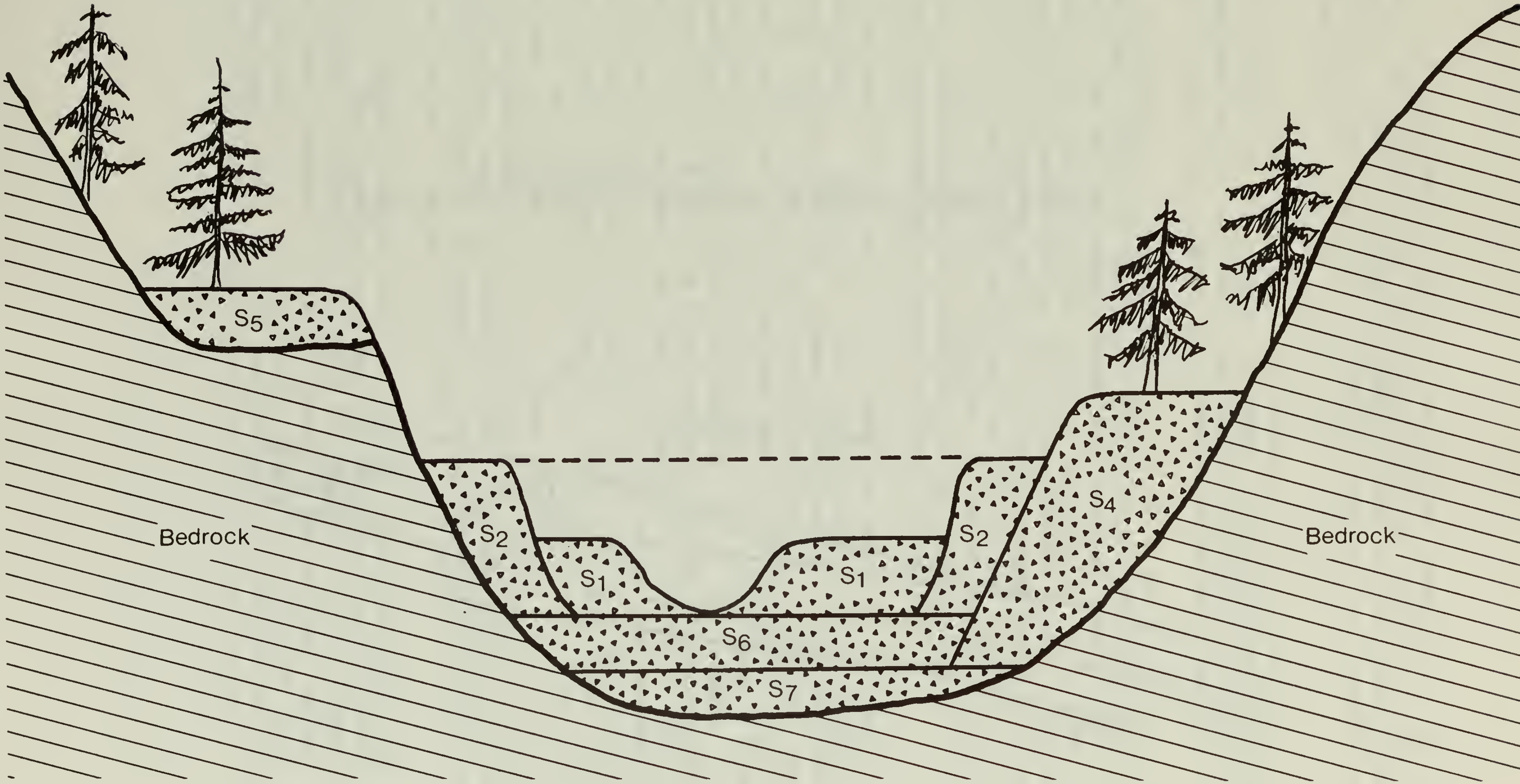

Figure 4: Schematic channel cross-section showing classification of sediment in storage compartments in the mainstem of Redwood Creek.

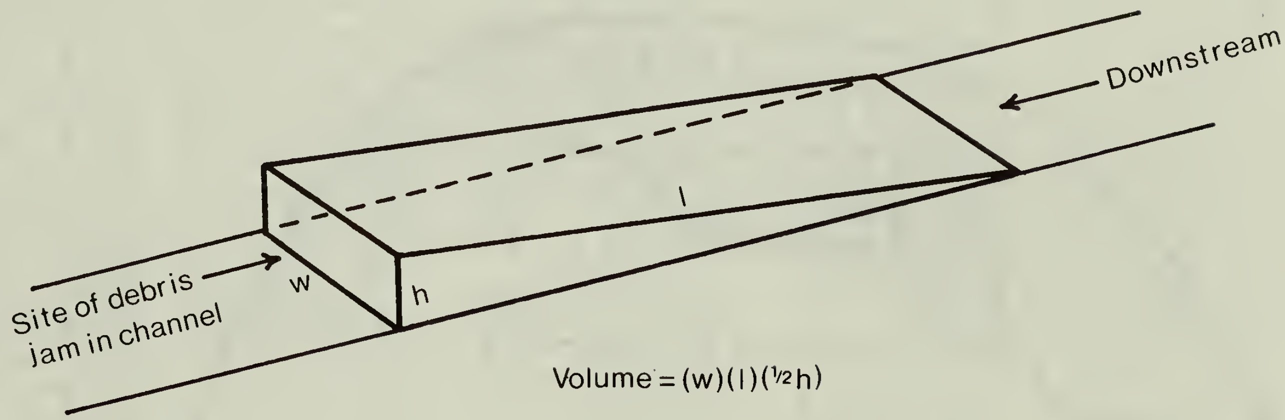

Figure 5: Calculation method of volume of sediment stored behind debris jams.

S_4 is alluvial fill outside of the active floodplain. The fill is stable and inactive and supports old-growth redwood and Douglas-fir forests. Error in volume estimates is due to not knowing where the bedrock/alluvium boundary lies. Volume estimates are probably accurate within 25%.

S_5 is alluvium underlain by bedrock strath terraces. Where cross sections of the terraces are bare, the alluvium/bedrock contact is clear, but this is not always the case. Estimates of alluvium stored in strath terraces are subject to the same error as those for S_4.

S_6 is sediment in the channel bed above a pre-disturbance thalweg elevation. Since the advent of logging and road construction in the 1950's, the bed of Redwood Creek has aggraded several feet in most reaches. In calculating the amount of aggradation, we assumed that the aggradation extended across the entire channel width. We were not trying to estimate the depth of fill in the channel bed down to bedrock. Drilling or geophysical techniques would have been necessary to discern that. Instead, we were attempting to locate the elevation of the thalweg under undisturbed conditions, before land use practices caused channel alteration and increased sediment loads (1947).

We used several approaches to estimate the amount of aggradation in any given reach. Talking to local landowners whenever possible about channel changes that they remembered was useful. In unpopulated parts of the creek, buried tree stumps, boulders, car bodies, and other objects which were slightly exhumed gave an indication of recent amounts of aggradation. Records from certain bridge sites show a history of aggradation and subsequent downcutting in a few reaches. Use of sequential air photos also helps determine channel changes through time; however, a thick canopy of trees obscures the channel in many places. In several instances on 1962 air photos we can see boulders in the channel which were totally buried in 1966 and are partly exposed in 1980. Locally, bedrock outcrops are exposed in the channel bed, so we know no aggradation exists there. Finally the USGS established permanent cross-sections along Redwood Creek in 1973 and 1974, so accurate measurements of recent changes are available. We extrapolated cross-section data to predict recent channel changes in adjacent reaches. Estimates of depth of active channel fill (S_6) were most subject to error, probably up to 100%.

S_7 is sediment stored above a bedrock base and below the active thalweg. This quantity is unimportant in a short-term sediment budget, and we made no attempt to estimate the depth of fill to bedrock. In the long term (hundreds of years) there is no sediment stored in S_7. Because Redwood Creek is most likely downcutting along the entire length of the upper basin, it will mobilize all of its bed and abrade the bedrock during the infrequent, high magnitude runoff events.

Total Volumes of Sediment Stored in Mainstem of Redwood Creek

Total storage volumes for Redwood Creek above the 1980 thalweg are listed by study reach in Table 8. Survey work for Reaches 1 - 15 was completed in fall 1979, and survey work for Reaches 16 - 36 was completed in the fall of 1980. During the 1979 field work, we did not distinguish between semi-active and non-active sediment, so these two storage categories are combined for Study Reaches 1 - 15 (Table 8). We include an estimate of stable sediment in this table, though the portion of stable sediment isolated on strath terraces has not yet been computed.

A significant component of sediment storage in the mainstem is the sediment stored below the present thalweg, but above the 1947 (predisturbance) thalweg (Table 9). We did not include this estimate in Table 9 because the error involved in this estimate is much greater than the error involved in measuring bed forms. Nevertheless, as an order of magnitude calculation, we think Table 9 has validity.

Our best estimate for total sediment below the present thalweg for the entire main channel is 3,000,000 tons. The real amount may possibly be as high as 6,000,000 tons or as low as 2,000,000 tons, but neither limit would significantly change the whole sediment budget.

Sediment Transport and Storage in Upper Redwood Creek After the 1964 Flood

Air photo coverage from 1936 to 1947 of the Redwood Creek channel shows that the channel in the 1930's and 1940's was considerably different than at present. In 1947, the channel was narrow and sinuous with a closed canopy. Locally, there were streamside slides or wide, alluviated reaches. Today, streamside landslides are abundant, the channel is wider with little canopy cover, channel aggradation and gravel berm deposition are ubiquitous, and the size of streambed material is probably smaller.

The channel changes are due to a combination of intense timber harvest, road construction, recent major floods in the basin, and unstable terrain. The headwaters of Redwood Creek were especially affected by the 1964 flood. Huge volumes of sediment entered Redwood Creek, exceeding its capacity to transport sediment. Much material was deposited, both upstream of debris jams and in relatively low gradient reaches. Today remnants of this primary (generally 1964 originating) fill exist upstream of Highway 299, but much of it has already been flushed downstream.

Upstream of Lake Prairie Creek, remnants of primary fill deposits from the 1964 flood are common. Further downstream recent alluvial deposits have a more complicated transport history because some of the 1964 deposits were reworked or eroded, and subsequent floods further modified the channel. Primary fill deposits that have been reworked have different characteristics than the original fill.

TABLE 8

VOLUME OF STORED SEDIMENT ABOVE 1980 THALWEG (ft^3)

Reach	Active	Semi-Active	Non-Active	Stable	Total	Cumulative Volume of Stored Sediment (ft^3)
36	95,220	152,840	137,020	39,980	425,060	425,060
35	142,055	439,600	1,164,895	150,875	1,897,425	2,322,485
34	272,375	111,320	849,240	644,100	1,877,035	4,199,520
33	121,555	546,310	516,665	329,170	1,513,700	5,713,220
32	283,520	83,100	764,230	575,340	1,706,190	7,419,410
31	356,620	1,382,555	1,859,655	593,290	4,192,120	11,611,530
30	238,720	689,545	690,895	160,920	1,780,080	13,391,610
29	93,530	645,925	112,000	357,985	1,209,440	14,601,050
28	336,140	1,285,800	1,358,950	1,659,335	4,640,225	19,241,275
27	666,300	2,270,220	2,198,735	1,056,790	6,192,045	25,433,320
26	299,750	2,153,290	1,138,715	98,635	3,690,390	29,123,710
25	302,360	2,876,990	1,510,395	528,785	5,218,530	34,342,240
24	771,340	2,310,790	896,430	892,360	4,870,920	39,213,160
23	401,615	894,570	698,220	- - -	1,994,405	51,207,565
22	571,905	900,215	252,540	640,860	2,365,520	43,573,085
21	1,175,310	3,482,285	459,775	2,274,095	7,391,465	50,964,550
20	2,119,095	4,741,705	5,659,775	- - -	12,530,575	63,495,125
19	3,183,995	5,501,025	1,630,105	1,840,625	12,165,750	75,660,875
18	3,279,425	487,130	108,030	- - -	3,874,585	79,535,460
17	2,411,795	737,095	- - -	- - -	3,148,890	82,684,350
16	3,172,190	2,014,905	976,130	136,445	6,299,670	88,984,020
15	191,430	930,717		298,260	1,420,407	90,404,427
14	101,250	110,970		- - -	212,220	90,616,647
13	152,010	784,809		1,430,943	2,367,762	92,984,409

TABLE 8

VOLUME OF STORED SEDIMENT ABOVE 1980 THALWEG (ft^3)

Reach	Active	Semi-Active	Non-Active	Stable	Total	Cumulative Volume of Stored Sediment (ft^3)
12	395,685	1,374,651		1,129,130	2,899,466	95,883,875
11	523,125	1,845,855		764,920	3,133,900	99,017,775
10	0	313,300		204,890	418,190	99,435,965
9	720,630	1,774,548		191,230	2,686,408	102,122,373
8	901,800	1,761,642		603,741	3,267,183	105,389,556
7	1,274,400	3,339,360		2,688,144	7,301,904	112,691,460
6	1,980,990	2,946,402		7,753,914	12,681,306	125,372,766
5	1,347,975	397,035		1,416,739	3,161,749	128,434,515
4	1,861,650	525,177		3,337,681	5,724,508	134,259,023
3	3,383,235	1,528,794		12,365,000	17,277,029	151,536,052
2	1,643,220	507,654		2,0867,110	4,236,984	155,773,036
1	7,195,230	13,992,372		51,124,119	72,311,721	228,084,757
1a	5,280,365	2,734,893		- - -	8,015,258	236,100,015

TABLE 9

VOLUME OF SEDIMENT STORED BELOW 1980 THALWEG AND ABOVE 1947 THALWEG

Reach	Channel Area (ft^2)	Estimated Depth of Fill (ft)	Sediment Stored in Channel Bed (ft^3)
36	209,400	1.7	354,700
35	626,450	1.5	952,900
34	167,700	1.0	167,700
33	231,632	0.8	196,600
32	344,706	1.5	522,400
31	674,797	2.0	1,349,600
30	565,794	1.1	586,600
29	398,680	0.8	341,100
28	691,837	1.3	915,000
27	429,500	1.5	644,000
26	870,431	2.0	1,740,000
25	1,060,024	1.5	1,590,000
24	1,069,437	2.5	2,670,000
23	726,298	1.0	730,000
22	1,103,863	2.0	2,210,000
21	1,152,700	2.5	2,880,000
20	2,544,252	3.0	7,630,000
18	2,541,811	0.5	1,270,000
17	3,310,278	1.5	4,970,000
16	3,823,701	1.0	3,820,000
15	205,830	0.5	100,000
14	98,505	0.0	0
13	167,760	1.0	170,000
12	184,545	1.0	180,000

TABLE 9

VOLUME OF SEDIMENT STORED BELOW 1980 THALWEG AND ABOVE 1947 THALWEG

Reach	Channel Area (ft^2)	Estimated Depth of Fill (ft)	Sediment Stored in Channel Bed (ft^3)
11	259,200	2.0	520,000
10	74,205	0.0	0
9	314,235	1.5	470,000
8	345,681	1.0	350,000
7	480,195	0.5	240,000
6	519,597	2.0	1,040,000
5	317,655	2.0	640,000
4	430,605	1.0	430,000
3	724,410	1.0	720,000
2	493,920	2.0	980,000
1	2,542,770	1.0	2,540,000
		TOTAL	50,350,000 ft^3

50,350,000 ft^3 = 3,000,000 tons

The texture of primary fill deposits is usually fine-grained, ranging from sand to fine pebbles. Locally, cobbles and some boulders are included. Boulders are angular, whereas small particles are subrounded. The deposits are poorly sorted. The primary fill is generally non-compacted and unweathered, especially when compared to older terrace deposits. Many of the terrace remnants are so porous and high above the channel bed that trees have been unable to grow on them.

Stratification of the primary fill deposits is common, but the depositional sequence varies. There is not a simple fining-upward sequence. Instead there are several coarse-grained layers, interspersed with more extensive fine-grained layers. Cross-bedding and local silt lenses also occur. The flood probably had several distinct peaks or surges, destroying any simple stratigraphic patterns. In addition, landsliding along the channel locally contributed sediment that influenced fill character and pattern. We sampled many of the terraces, and future analysis of this material will tell us more about the flow regime, degree of sorting, and probable size of the suspended load during the flood.

Primary fill deposits buried many individual logs and stumps, log jams and boulders which are slowly being exhumed. The fills are located along straight reaches above recent high water marks and on the inside of meanders. They are not well preserved near the present channel, nor on the outside of meanders.

Re-worked deposits result from transport or modification of primary fills. They lack the stratification typical of primary fills. Coarse-grained lag deposits are common. In some cases a lag of cobbles and boulders armor the surface of a bar, protecting finer particles below the surface from being transported. Reworked deposits are always lower than the height of the original deposits. They may or may not be nested within 1964 terrace remnants (Figure 4). Particles in reworked deposits are more rounded than those in primary deposits. Most coarse bars are well vegetated with dense alder fringes on their margins. These alder/cobble bars first appear upstream of Pardee Creek (drainage area = 14 mi^2 or 169 km^2).

To reconstruct the volume of sediment in the channel after the 1964 flood, we extended the height of primary fill terraces dating from 1964 across the entire channel width and multiplied the product of width and height by the length of the terrace. Primary fill deposits from the 1964 flood are most obvious near Snow Camp Creek, but remnants extend for 9 km down to Lake Prairie Creek. Deposits become lower and less distinct downstream of Last Gasp Creek, which is 2 km below Snow Camp Creek.

We have two pieces of evidence that support the view that during the 1964 flood the stream was actually flowing at or above the height of the terraces, and that the sediment was deposited in the entire active channel to the height of the terraces. Sequential air photos clearly show a huge slug of sediment in 1966, and in places the abandoned 1966 thalweg can now be identified on top of the fill terraces that are isolated by incision into the fill. Also, trees adjacent to fill terraces show silt lines as high water marks 9 - 10 ft above the surface of the terrace. Abrasion marks on the upstream side of tree trunks are also 9 - 10 ft above the surface.

Table 10 shows the values by reach for the volume of sediment stored in Redwood Creek directly after the 1964 flood. Most of the following discussion refers to the 11.8 km reach from the headwaters downstream to Lake Prairie Creek (Reaches 31 to 36). In the 5.1 km reach downstream of Lake Prairie Creek (Reaches 28 - 30), where primary fill deposits are rare, interpretation of these deposits is subject to greater error.

In Reaches 31 to 36, 29.6 x 10^6 ft^3 was deposited during the 1964 flood, of which 18 x 10^6 ft^3 or 61% was subsequently eroded and transported downstream. This represents a sediment yield for coarse bed material past Lake Prairie Creek of 2,825 tons/mi^2/year for the period 1965 - 1980. Airphotos show that most of the sediment was flushed out by 1973, so a more realistic rate of bed material sediment yield is 5,295 tons/mi^2/year. Much of this material would be transported as bedload in the upper 15 km of Redwood Creek but would be transported as suspended load by the time it reached the Blue Lake gaging station (km 32). Annual sediment yield at the Blue Lake station in recent years has been 3,000 tons/mi^2/year for bedload and 9,000 tons/mi^2/year for total load (J. Knott, USGS, written communication). Thus, a sediment yield of 3,000 - 5,000 tons/mi^2/year past Lake Prairie Creek (km 11.8) for bed material alone is a significant item in the current sediment budget.

Some reaches stored much more sediment after the 1964 flood than others; and in general, high-storage reaches lost a higher percentage of the original flood deposits. High-storage reaches are those with an abrupt decrease of channel gradient or those that have high-sediment load tributaries emptying into them. Most of the sediment transport out of these reaches since 1964 occurred at the expense of channel-side fill terraces rather than by erosion of the more stable point bars. For example, in Reaches 30 and 31 much of the remaining 1964 sediment is stored in stable point bars, and is not very active.

The potential for further erosion of fill from the upper 13.5 km of the main channel is suggested by the fact that 11,600,000 ft^3 (696,000 tons) still remains above the 1980 thalweg in Reaches 31 - 36, and may be transported at high flows. However, in 1980 most of the remaining fill terraces were well vegetated and we classified the sediment as not active. This sediment will be mobilized by only those very high flow conditions that recur, on the average, every 50 to 100 years.

An additional component to sediment storage in these reaches is sediment in the aggraded channel bed below the 1980 thalweg. We listed these volumes separately in Table 9 because there is a larger margin of error in these estimates. Upstream of Lake Prairie Creek, approximately

TABLE 10

SEDIMENT STORAGE IN UPPER REDWOOD CREEK AFTER THE 1964 FLOOD

Reach	Reconstruction of Volume of Sediment Deposited Due to the 1964 Flood		Volume of Sediment Flushed Out[1]	% Flushed Out	Approximate Volume of Sediment in Storage Below 1980 Thalweg
	ft^3	ft^3/km of Channel	ft^3		ft^3
36	1,558,288	395,000	1,133,222	73	354,700
35	10,329,106	4,695,000	8,431,681	82	952,900
34	3,567,300	3,243,000	1,690,273	47	167,700
33	1,940,345	1,213,000	426,642	22	196,600
32	5,178,136	3,677,000	3,441,941	67	522,400
31	6,079,721	3,966,000	1,936,962	32	1,349,600
Subtotal	29,592,453	- - -	18,030,277	61	3,543,900
30	2,234,333	1,396,000	454,254	20	586,600
29	1,366,317	739,000	140,382	10	341,100
28	7,259,979	4,684,000	2,619,752	36	915,000
Total	40,453,982 ft^3	- - -	21,244,665 ft^3	53	5,386,600

1: Probably the sediment was flushed out in the period 1965 - 1973, but survey of remaining stored sediment did not take place until 1980.

3.5×10^6 ft^3 (210,000 tons) is stored in the channel bed below the 1980 thalweg and potentially can be transported at high flows. Gradual degradation of the channel bed is occurring in the upper reaches. For example, the USGS cross sections indicate that the bed has degraded an average of 0.2 to 0.6 feet each year for the monitoring period 1974 to 1979.

In comparison, preliminary data show that 39×10^6 ft^3 of sediment has entered the main channel upstream of Lake Prairie Creek through streamside landsliding. In the same reach about 33.1×10^6 ft^3 was initially stored in the channel bed and in fill terraces. Additional sediment entered the mainstem through fluvial hillslope erosion, and at present we have no accurate estimates of that volume. In any case, the amount of sediment stored in the upper reaches of Redwood Creek after the 1964 flood was a significant percentage of total sediment input to those reaches by fluvial erosion and landsliding during the 1964 flood.

Sediment storage in the upper reaches had definite effects on downstream reaches. Initially, sedimentation in downstream reaches was postponed by temporary storage in the upper reaches. Post-1964 floods reworked sediment in upstream reaches and deposited it farther downstream.

Distribution of Stored Sediment in the Mainstem of Redwood Creek

Table 11 summarizes sediment stored in the entire main channel of Redwood Creek, exclusive of that sediment stored on stable terraces (S_5) and floodplains vegetated with old-growth forest (S_4). The table compares stored sediment for each reach on a per unit drainage area and on a per unit length basis. The two methods show similar trends, although they do not correspond totally. Reach 31 and Reaches 33 to 35 in the headwaters are high-storage areas. Here, large fill terraces were deposited and much sediment from the 1964 flood remains in the channel. Reaches 24 to 28 are also above average for sediment storage. The high 1964 fill terraces play a less important role here, but lower, broad terraces and point bars store a great amount of sediment. The floodplain is also wider here than in the upper reaches. Redwood Valley (Reaches 19 to 21) best exemplifies a wide valley floodplain storage site with tremendous amounts of sediment in low, broad bars. By far the highest concentration of sediment per unit length is found in Reach 20 of Redwood Valley; this concentration even surpasses the wide, alluviated area at the mouth of Redwood Creek (Reach 1).

Within park boundaries, the large sediment accumulation areas are from Copper Creek to Slide Creek, from the mouth of the "Gorge" to the downstream end of the Tall Trees Grove, and downstream of Cloquet Creek (Reaches 11 and 12, 6 - 8, and 1 - 3 respectively).

If sediment storage upstream of a specific point is compared with drainage area to that point, one can see a general pattern of increasing storage until Lacks Creek, and then a slight decrease to the mouth.

TABLE 11

SEDIMENT STORAGE, DRAINAGE AREA, CHANNEL LENGTH AND GRADIENT BY REACH

Reach	Drainage Area to Downstream end of Reach (km^2)	Channel Length In Reach (m)	Channel Gradient In Reach[1] (%)	Stored Sediment (A + SA + NA) In Reach/Drainage Area (m^3/km^2)	Cumulative Stored Sediment (A + SA + NA) to Downstream End of Reach/Drainage Area (m^3/km^2)	Stored Sediment Channel Length $m^3/100m$
14	453.56	1,287	0.55	13	4,886	467
13	458.301	1,545	0.45	58	4,897	1,717
12	468.40	1,352	0.72	107	4,897	3,709
11	474.64	2,253	0.40	141	4,973	2,978
10	478.89	1,867	1.26	13	4,940	324
9	484.80	1,191	0.29	149	5,028	6,062
8	520.12	2,543	0.30	145	4,831	2,967
7	530.54	1,851	0.25	247	4,984	7,060
6	550.71	2,060	0.25	251	5,050	6,775
5	561.67	1,979	0.22	87	5,039	2,497
4	573.065	2,671	0.20	110	5,061	2,530
3	584.12	3,010	0.18	240	5,203	4,623
2	593.01	1,320	0.14	64	5,225	4,615
1	718.65	5,660	0.17	831	5,148	10,602
1a	725.20	- -	0.12	313	5,410	- -

1: Accuracy of gradient depends on survey technique.

TABLE 11

Sediment Storage, Drainage Area, Channel Length and Gradient by Reach

Reach	Drainage Area to Downstream end of Reach (km^2)	Channel Length In Reach (m)	Channel Gradient In Reach[1] (%)	Stored Sediment (A + SA + NA) In Reach/Drainage Area (m^3/km^2)	Cumulative Stored Sediment (A + SA + NA) to Downstream End of Reach/Drainage Area (m^3/km^2)	Stored Sediment Channel Length $m^3/100m$
36	13.60	3,450	12	798	798	316
35	24.49	2,200	4	1,738	2,120	2,248
34	34.99	1,100	3.3	995	2,722	3,174
33	37.35	1,600	3	896	3,443	2,097
32	63.02	1,400	3.2	503	2,547	2,288
31	66.05	2,050	1.3	1,519	3,957	4,904
30	85.96	1,700	1.2	536	3,574	2,697
29	88.86	1,800	1.6	273	3,727	1,366
28	108.60	1,550	1.3	776	3,836	5,446
27	121.53	3,500	1.2	1,224	4,623	4,269
26	145.33	2,350	1.0	700	4,591	4,329
25	158.87	3,000	1.0	831	5,039	4,427
24	168.74	2,600	0.6	634	5,378	4,127
23	176.35	1,850	0.5	317	5,456	3,053
22	200.00	3,400	0.5	240	5,061	1,437
21	216.37	4,450	0.8	678	5,356	3,270
20	261.10	2,885	0.43	1,355	5,793	12,300
19	291.63	5,900	0.39	1,006	6,186	4,951
18	313.88	7,365	0.35	350	6,099	1,490
17	318.73	2,900	0.55	284	6,285	3,075
16	410.15	9,790	0.26	426	5,312	1,783
15	433.15	1,835	0.53	73	5,104	1,732

TABLE 12

DISTRIBUTION OF STORED SEDIMENT BY ITS MODE OF STORAGE, FOR STUDY REACHES 36 to 16 - HEADWATERS TO COYOTE CREEK

Reach	Side Bars (ft^3)	%	Fill Terrace (ft^3)	%	Log Jam (ft^3)	%	Point Bar (ft^3)	%	Mid-Channel Bar (ft^3)	%	Stable Terrace (ft^3)	%	Other (Fan, Boulders) (ft^3)	%
36	54,177	13	199,749	47	113,539	27	0	0	0	0	39,982	9	17,619	4
35	434,431	23	1,085,596	57	104,552	6	64,651	3	18,475	1	150,875	8	38,845	2
34	289,743	15	767,397	41	50,309	3	98,260	5	0	0	644,096	34	27,222	2
33	509,955	34	641,658	42	15,840	1	0	0	0	0	329,171	22	17,080	1
32	283,522	17	826,056	48	0	0	21,276	1	0	0	575,341	34	0	0
31	531,364	13	2,291,117	55	120,508	3	615,435	14	40,410	1	593,288	14	0	0
30	613,067	34	696,391	39	0	0	276,976	16	22,175	1	160,920	9	10,550	1
29	710,310	52	111,998	9	0	0	15,780	1	13,365	1	357,987	30	0	0
28	501,529	11	1,956,579	52	0	0	522,784	11	0	0	1,659,335	36	0	0
27	2,922,857	47	2,030,016	33	0	0	164,195	3	12,008	<1	1,056,792	17	6,178	<1
26	2,453,041	67	1,138,714	31	0	0	0	0	0	0	98,637	2	0	0
25	1,702,524	33	1,510,395	29	0	0	1,339,244	26	137,581	2	528,786	10	0	0
24	2,498,330	51	896,429	18	0	0	275,273	6	308,522	7	892,363	18	0	0
Total to Hwy 299	13,504,850	34	14,152,095	36	404,748	1	3,393,874	9	552,536	1	7,087,573	18	117,494	<1

Redwood Creek at Lacks Creek possibly represents a type of turning point in the watershed in terms of stream power (discharge x channel gradient). Upstream, although gradients are steeper, discharges are not sufficient to transport all the sediment supplied to a reach. Downstream of Lacks Creek the gradient decreases, but discharge is greater, so relatively less sediment is stored per unit drainage area.

Channel gradient only roughly correlates with the amount of stored sediment in a reach and sediment source areas may be the important determinant of storage quantities. For example, reaches upstream and downstream of Copper Creek show large differences in storage. The steeper, lower reach stores more sediment, probably because of the overriding influence of sediment contributions to the main channel from Copper Creek. Channel gradient and related factors will be discussed more fully in a later section.

Sediment storage in the mainstem is more evenly distributed on a per unit channel length basis than in the tributaries. In the mainstem, for Reaches 17 to 36, 95% of the sediment was stored in 85% of the channel length. In contrast, for the sampled tributary basins (see below), 95% of the stored sediment was found in 50% of the channel length.

Table 12 classifies stored sediment upstream of Coyote Creek according to its mode of storage. Some trends are evident from the data. Debris-stored sediment is important in Reach 36, but decreases in importance downstream. Reach 36 resembles a tributary more than the main channel, and its narrow channel is condusive to the formation of debris jams. (In tributaries, about 60% of stored sediment is associated with debris jams [John Pitlick, personal communication, November 1980]). Some of the fill terraces and side bars in Reach 36 were once debris-stored sediment, but now those log jams are almost gone. Thus the amount of debris-stored sediment directly after the 1964 flood was higher than we see today. No log jams are found downstream of Reach 31. This implies that given a drainage area of 66 km^2, channel width and stream power are sufficient enough to prevent the formation of debris jams.

Side bars are generally found in straight reaches and point bars in meandering reaches. They are both relatively stable bedforms, and their frequency depends on the local valley pattern which in turn depends on the underlying geology.

Fill terraces are most common in the upper reaches of Redwood Creek where the effects of the 1964 flood were most strongly felt. Reach 29 seems unusually low, but here a huge, post-1964 debris slide masked any previous deposits. Likewise, Reaches 19 and 20 seem high, but here the fill terraces are the result of many factors and later floods, and are not directly due to 1964 flood deposits.

Mid-channel bars are found in braided reaches, which can indicate channel bed instability. The percentage of mid-channel bars increases

TABLE 12

DISTRIBUTION OF STORED SEDIMENT BY ITS MODE OF STORAGE, FOR STUDY REACHES 36 TO 16 - HEADWATERS TO COYOTE CREEK

Reach	Side Bars (ft^3)	%	Fill Terrace (ft^3)	%	Log Jam (ft^3)	%	Point Bar (ft^3)	%	Mid-Channel Bar (ft^3)	%	Stable Terrace (ft^3)	%	Other (Fan, Boulders) (ft^3)	%
23	782,320	39	698,220	35	0	0	489,110	24	17,107	1	0	0	7,646	<1
22	1,459,076	62	49,052	2	0	0	97,094	4	42,436	2	640,860	27	77,274	3
21	4,710,217	64	0	0	0	0	290,874	4	116,277	1	2,274,094	31	0	0
20	5,196,390	41	5,659,776	45	0	0	1,586,465	13	87,947	1	0	0	0	0
19	8,079,055	66	1,064,244	9	0	0	1,023,743	9	148,008	1	1,850,625	15	0	0
18	2,645,001	68	108,031	3	0	0	360,867	22	260,687	7	0	0	0	0
17	2,456,841	78	0	0	0	0	580,339	18	111,708	4	0	0	0	0
16	3,097,757	49	976,130	15	0	0	1,966,262	31	123,078	2	136,445	2	0	0
Total to Coyote Creek	41,931,507	47	22,707,548	26	404,748	1	10,288,628	12	1,459,784	2	11,989,597	13	202,414	<1

somewhat downstream. Reaches having the largest volumes of mid-channel bars are usually those with wide, alluviated areas. Reach 18, the tight meanders, is an exception. There, recent channel shifting formed several mid-channel bars, and the lack of terraces emphasizes the relative importance of the mid-channel bars.

Stable terraces have not been fully categorized yet, but they seem to be most common and most significant between Last Gasp and Ayres Creeks. The reason for the increase is not clear. Strath terraces are not yet included in these figures.

An analysis similar to that of Table 12 has not been done yet for Redwood Creek within park boundaries (Reaches 1 - 15). Categories (except for debris jams) will remain the same. The frequency and magnitude of downstream storage compartments will be different, however.

Transport Potential of Stored Sediment in the Mainstem of Redwood Creek

It is important to recognize the transport potential of stored sediment in the upper reaches of Redwood Creek because of the possible downstream effects if a large quantity of sediment is deposited in the park reaches of Redwood Creek.

In absolute volumes, the amount of active sediment upstream of Highway 299 (Reaches 24-36) is 4,000,000 ft^3; however, from Highway 299 to Coyote Creek, the quantity is 16,000,000 ft^3. Within the park, we measured 22,000,000 ft^3 of active sediment. If a large flood event occurred (recurrence interval of 25 years, for example), semi-active sediment would be mobilized and transported downstream. In this size of flood, in addition to active sediment, the upper third of the watershed could provide an additional 16,000,000 ft^3 of sediment, the middle third 18,000,000 ft^3, and the lower third (within the park) about 32,000,000 ft^3 of semi-active sediment.

Under very high flow conditions (a 100-year flood, for example) Redwood Creek could mobilize active, semi-active and inactive sediment. High flows could also scour the channel bed to below the 1980 thalweg, mobilizing even more sediment (Table 9). The total amount of potential sediment coming from the upper third of Redwood Creek would then be 47,000,000 ft^3, and the middle third would be 72,000,000 ft^3. Thus 129,000,000 ft^3 could enter the park under extreme conditions, assuming none of the mobilized sediment was deposited upstream of the park. The potential amount that could enter the park (129,000,000 ft^3) is certainly significant when compared to what is already present, excluding stable terraces (70,000,000 ft^3). This is an extreme case, however, because it is unlikely that all the sediment transported in the upper watershed would actually reach the park boundaries, and any major flood event is also likely to remove sediment now stored in park reaches. Redwood Valley seems to act as a buffer system between the upper and lower thirds of Redwood Creek. Sediment is deposited in Redwood Valley during floods, and slowly re-worked during subsequent low-flow years.

Table 13 shows a distinct difference in the activity of sediment in different areas. The table shows the per cent of sediment in each reach that is in active, semi-active, inactive and stable storage. The mean percentage for active sediment in the upper third of Redwood Creek (Reaches 25 - 36) is 11%. For Reaches 19 - 24 the figure jumps to 20%, and in the lowest reaches (1a - 9) the mean is 35%. Not only is there more sediment in the lower reaches, but it is mobilized easier than that in the upper reaches. A similar trend, though not as striking, is seen in semi-active sediment. The mean for Reaches 25 - 36 is 34%; for Reaches 19 - 24 it is 43%. A higher degree of activity does not necessarily mean more rapid transport rates. Actually, the active coarse sediment currently on the channel bed in the park appears to be moving more slowly than the active sediment moved out of the upper basin in the past.

The section of creek from the headwaters to the Blue Lake gaging station (Reaches 23 to 36) stores 41,207,565 ft^3, or approximately 2,500,000 tons of sediment above the 1980 thalweg (Table 8). Annual bedload at the Blue Lake station is about 3,000 $tons/mi^2/year$, or 204,000 tons/year (Jim Knott, USGS, written communication). Thus, the equivalent of 12 years of bedload is stored in the mainstem upstream of Reach 23. We applied similar logic to data from the Orick station. About 228,000,000 ft^3 or 14,000,000 tons are stored upstream of Orick. Annual bedload plus coarse suspended sediment is 510,000 tons/year. The equivalent of 27 years of bedload and suspended sand discharge is stored in the mainstem of Redwood Creek.

The above discussion should not suggest that if all sediment input stopped today, Redwood Creek would flush itself clean of stored sediment in 27 years. A minimum of 3,000,000 tons additional sediment is stored below the present thalweg (Table 9), and this sediment raises the bedload-equivalent figure to 33 years. Sediment stored in different modes will not be mobilized at the same rate, and we have shown that some sediment will only be activated at extremely high discharges. In addition, there will always be a considerable natural background rate of sediment input to the main channel from streamside landsliding, from fluvial erosion from hillslopes, and from tributary channel-stored sediment. Sediment storage in tributary basins is an important potential source of sediment contribution to the mainstem. Tributary basins store approximately 2,161,000 tons of sediment (see below). If tributaries transported all this sediment to the mainstem, they would increase the mainstem sediment load by 16 %.

Determinants of Channel Gradient and the Relation of Gradient to Sediment Storage

The channel gradient of Redwood Creek is a semi-dependent variable; that is, it may adjust to changes imposed on it to a certain extent, but it

TABLE 13

PERCENT OF STORED SEDIMENT BY TRANSPORT POTENTIAL

Reach[1,2]	% Active (S_1)	% Semi-Active (S_1)	% Inactive (S_2)	% Stable (S_4)
36	22	36	32	9
35	7	23	61	8
34	15	6	45	34
33	8	36	34	22
32	17	5	45	34
31	8	33	45	14
30	13	39	39	9
29	8	54	9	29
28	7	28	29	36
26	8	58	31	3
25	6	55	29	10
24	17	44	19	19
23	20	45	35	--
22	24	38	11	27
21	16	47	6	31
20	17	38	45	--
19	26	45	13	15
18	85	13	2	0
17	77	23	0	--
16	50	33	15	2
15	13		66	21
14	48		52	--
13	7		33	60
12	14		47	39
11	17		59	24
10	0		51	49
9	25		66	7
8	28		54	19
7	18		46	37
6	16		23	61
5	43		13	45
4	33		9	58
3	20		9	71
2	39		12	49
1	10		19	71
1a	66		34	--

1: Sediment above 1980 thalweg for Reaches 16-36.

2: Sediment above 1979 thalweg for Reaches 1-15.

is constrained by other variables as well. A number of factors influence and are influenced by channel gradient. Tributaries influence channel gradient in the mainstem in varying ways. There is a sharp decrease in gradient at the mouths of Snow Camp, Bradford, Simon and Cool Spring Creeks, and to some extent at Minon Creek. Tributaries increase the contributing drainage area, and thus discharge, which is usually associated with a slight decrease in gradient. However, the slope of Redwood Creek at Bradford Creek changes from 0.93% to 0.78%, and at Simon Creek it changes from 1.48% to 1.08%. These are sharp discontinuities in gradient, and reflect more than an increased discharge. Both these streams carried very high loads of fine gravel and sand. The channel bed at the mouths of these creeks changes from a cobble-boulder bed to a sand-pebble bed, and the gradient changes reflect the change in particle size.

An opposite situation occurs at the mouths of Last Gasp, Lacks, Coyote, and Copper Creeks. Here the gradient steepens sharply. All these creeks transport boulders at their mouths and contribute relatively large bed material to Redwood Creek. Redwood Creek at the mouth of Lacks Creek is unusual in that the sharp increase in gradient is associated with a high sediment storage area.

The channel gradient downstream of Sweathouse Creek also increases sharply, due to an increase in the size of incoming sediment. In this case, though, the major contribution is coming from adjacent hillslopes rather than the tributary creek. Earthflows border much of the channel downstream of Sweathouse Creek. Large boulders enter Redwood Creek and cannot be transported under average flows. The channel steepens in such areas. A dramatic example of this occurs in Reach 10 at the foot of Counts Hill Prairie where the gradient more than doubles, from 0.50% to 1.26%. A similar phenomenon occurs locally upstream where greenstone boulders brought in from hillslope processes form resistant points in the channel bed and the channel gradient increases.

Channel gradient seems to be related to underlying bedrock as well as the material contributed by tributaries, earthflows and debris landslides. Reaches in the competent sandstone unit, for example, have narrower channels, and steeper gradients than those in less competent bedrock. Analysis of this data is not completed yet.

In general, channel gradient reflects the bed material at any given point. Larger bed particles are associated with higher gradients. Larger bed materials yields a higher roughness value "n." According to the Mannings equation:

$$\text{velocity} = \frac{(\text{depth}^{2/3})(\text{slope}^{1/2})}{n}$$

Slope and/or depth must increase with "n" to keep velocity constant. In the Redwood Creek channel, increases in roughness, equivalent to increases in bed material size, are associated with gradient changes.

Channel gradient does not correspond closely with channel pattern. In six cases where a longitudinal profile survey was done in a meandering section and in an adjacent straight reach, only three of the six profiles showed a decrease in gradient in the meanders. The more sinuous the reach, the more likely it was to have a decreased gradient. However, a meander increases the roughness of a reach, and to some extent channel gradient must increase to compensate. Unless a reach is quite sinuous, meanders will not have a more gentle gradient than adjacent straight reaches. Channel gradient is only a rough indicator of whether a reach will be a high or low storage area. The correlation coefficient of volume of stored sediment per unit reach compared to channel gradient in that reach was only 0.65.

The shape of Redwood Creek channel varies from reach to reach, and changes in channel geometry are also related to sediment storage and transport. Bankfull width and depth are sometimes difficult to determine, especially in upstream reaches where landslides obliterate evidence of the bankfull discharge. Nevertheless, some broad generalizations can be made.

The ratio of bankfull width-to-depth increases in a downstream direction, and ranges from 7.5 to 60. Channels that are narrower and deeper than adjacent reaches store less sediment in them. High width/depth ratios are associated with high storage reaches. For example, Reach 20 has the highest volume of sediment per unit length in Redwood Creek (12,300 m^3/100 m) and also has the highest width-depth ratio (60). In some cases, though, the present channel was shaped to a large extent by extremely large discharges, and may not realistically reflect the present hydrologic regime.

Bank erosion is apparent in many reaches. Channel widening is common in aggrading streams and is an adjustment by the stream to transport a higher sediment load. A wider channel bed provides a larger area upon which transport can occur. Also, channel widening is associated with a decrease in depth for a given discharge. This causes the gradient of shear velocity from the channel bed up into the main flow to increase, which causes higher transport rates. As stated above, channel widening through bank erosion is important to landslide activity as well.

Sediment Input from Streamside Landsliding Compared to Mainstem Sediment Storage

In Table 14, we compare the volume of sediment presently stored above the 1980 thalweg with the volume of sediment entering a reach from landslides. We did not include "stable" sediment in this analysis because it is unlikely stable terraces are greatly affected by recent landsliding. The contribution of tributary landslides was only calculated for tributaries actually mapped. We also took into account sediment in storage in tributaries. For example, if 15% of the landslide volume is in storage in the tributary at present, we only considered 85% of the total tributary landslide volume to have reached the mainstem of Redwood Creek (Table 14).

TABLE 14

Volume of Stored Sediment Compared to Volume of Landslide Material Delivered to the Mainstem of Redwood Creek

Reach	Stored Sediment in Reach (ft^3) (A + SA + NA)	Main Channel Landslides Entering Reach (ft^3)	Tributary Landslides Entering Reach (ft^3)[1]	Total Landslide Contribution to Reach (ft^3)	Landslide Material/km of Reach (ft^3)	Stored Sediment in Reach/Total Landslide Contribution to Reach (%)	Cumulative Stored Sediment to Reach/Cumulative Landslide Input to Reach (%)[2]
36	385,085	3,913,370	201,460	4,110,000	1.19×10^6	9	9
35	1,746,550	4,255,170	5,945,380	10,200,000	4.64×10^6	17	15
34	1,232,930	3,473,825	- -	3,470,000	3.15×10^6	36	19
33	1,184,535	6,039,480	- -	6,040,000	3.78×10^6	20	19
32	1,130,855	1,864,540	4,870,625	6,740,000	4.81×10^6	17	19
31	3,549,465	8,664,085	- -	8,660,000	4.22×10^6	41	24
30	1,619,160	3,335,490	1,583,850	4,920,000	3.08×10^6	33	25
29	867,950	7,065,390	- -	7,070,000	3.82×10^6	12	23
28	2,980,890	5,850,265	7,311,035	13,160,000	8.49×10^6	23	23
27	5,276,060	9,500,170	- -	9,500,000	2.64×10^6	56	27
26	3,591,755	3,249,775	- -	3,250,000	1.38×10^6	111	31
25	4,689,745	3,675,545	- -	3,680,000	1.23×10^6	127	35
24	3,789,260	6,387,715	3,099,990	9,490,000	3.34×10^6	40	36
23	1,994,405	1,514,215	- -	1,510,000	0.82×10^6	132	37
				91,800,000 ft^3			

1: Only mapped tributaries are included.

2: The cumulative volume of stored sediment includes all the sediment in a reach and in all reaches above it. This volume is divided by the cumulative volume of landslide contribution to that reach and all reaches above it.

In order to compare reaches of different lengths, the volume of landslide material entering a reach was divided by the length of the reach (Table 9). Reaches 24, 28 - 29, and 31 - 35 are high-landslide input reaches. High-storage reaches (Table 14) do not closely correspond to high-landslide input reaches, which suggests that, as of 1980, upstream of Highway 299 the transport capacity of a reach controls sediment storage more than sediment input to a reach.

Downstream of Reach 27 there is a sharp increase in the per cent of material stored in the channel compared to landslide input. The number of landslides drops off where strath terraces become abundant, such as in Reaches 25 and 26. Landslide input seems to be less directly related to total sediment storage for the channel downstream of Reach 27.

If the cumulative total stored sediment volume is compared to cumulative total landslide volume for a particular reach (Table 14), it is evident that the volume of stored sediment becomes larger relative to landslide input progressing downstream. The channel is wider downstream and is capable of storing more material. Concurrently, landslide input is generally decreasing per unit length going downstream.

The total volume of sediment contributed by landslides in Reaches 23 to 36 is 91.8 x 10^6 ft^3. Less than half that amount (41.2 x 10^6 ft^3) is presently stored in the active floodplain in these reaches. Most of the slides occurred from 1947 to 1966, and were associated with intensive timber harvest and high-magnitude floods during that time period.

The volume of sediment entering Redwood Creek through bank erosion has not been computed yet, but a rough estimate for Reaches 23-36 is 4,500,000 ft^3. Although this is a sizeable amount, it is small when compared to the total input from landslides in these reaches (92,000,000 ft^3). The importance of bank erosion lies not in its sediment volume contributed to Redwood Creek, but in its acceleration of landsliding by undercutting the toes of unstable hillslopes.

Characteristics of Coarse Bed Material Along the Redwood Creek Channel

Grain size distribution for the coarse bed material in the main channel of Redwood Creek shows a gradual increase in size going upstream (Figure 6). The grain size distribution of Figure 6 is based on 31 individual 100-sample pebble counts of clasts 4 mm or greater in diameter (Phi size = -2). Within the park reaches (Reaches 16 - 25) average clast size is slightly less than 64 mm, and in the upper reaches (Reaches 26-36) average clast size is slightly greater than 64 mm. Pebble counts do not sample material smaller than fine pebbles, and they do not indicate the frequency of boulder concentrations in the channel, but they do indicate the relative abundance of those clast sizes that make up the coarser fraction of the bedload.

We noted the lithology of each clast used for the pebble counts at each location and Figure 7 shows the ratio of schist to sandstone at each

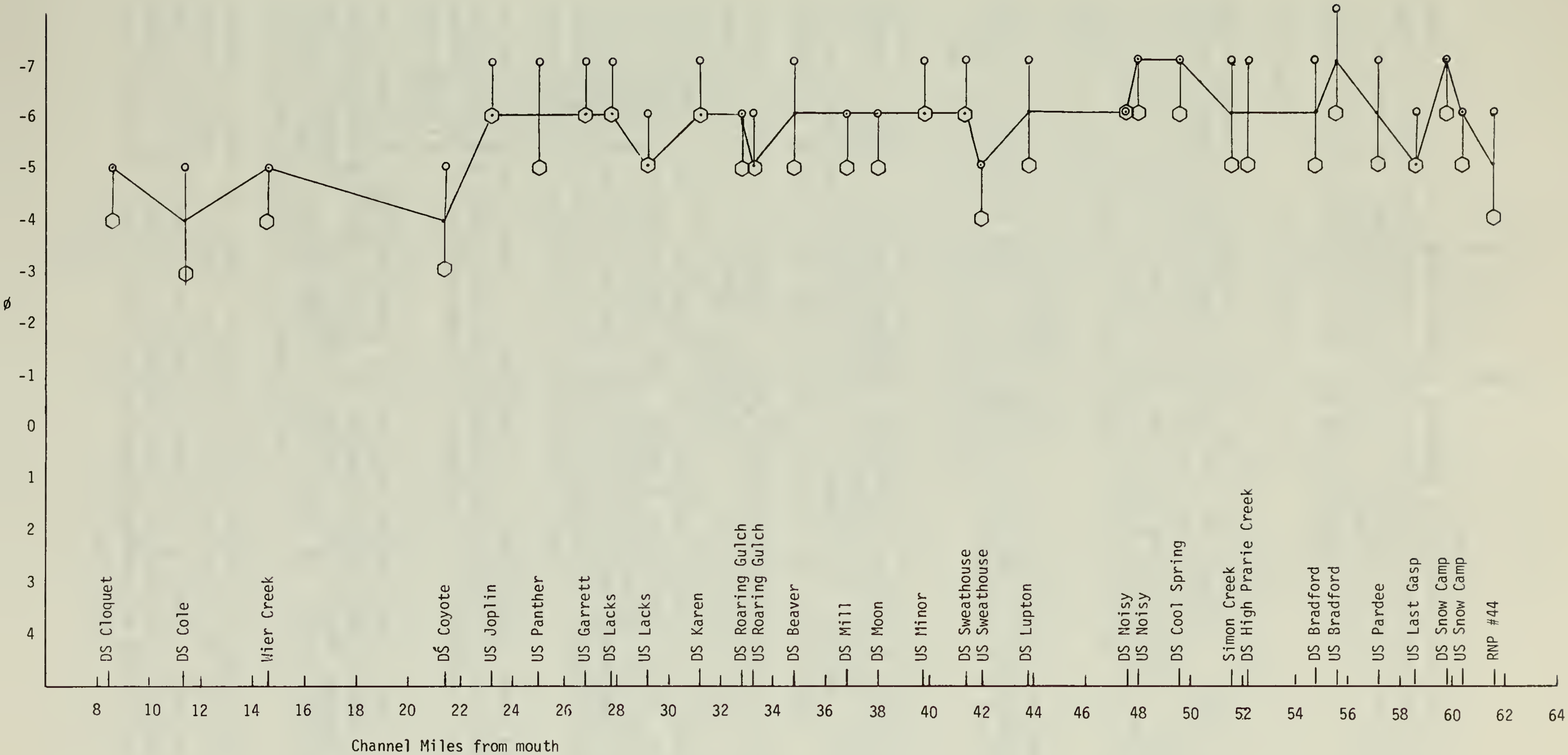

Figure 6: Redwood Creek Channel: grain size distribution for bed material > 4 mm diameter, based on 100-sample pebble counts
D_{25} = ⬡ (25% of the particle sizes are less than this diameter)
D_{50} = • (50% of the particle sizes are less than this diameter)
D_{75} = o (75% of the particle sizes are less than this diameter)

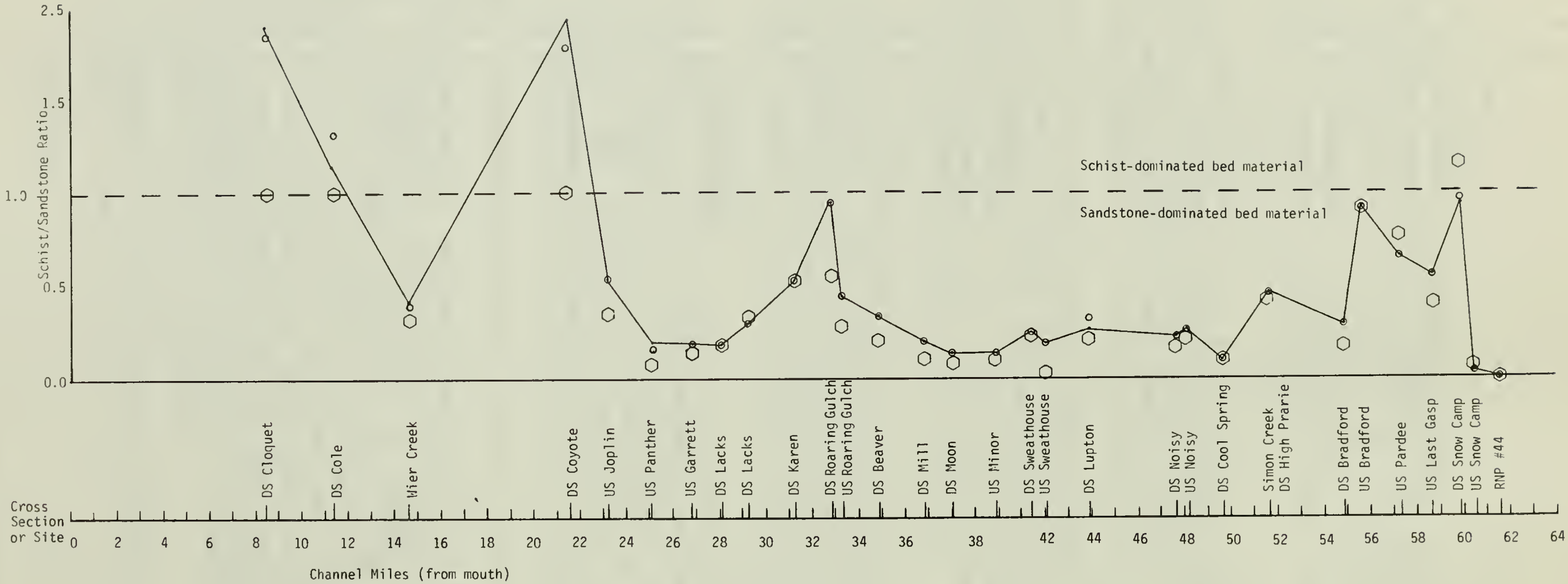

Figure 7: Redwood Creek channel: ratio of schist to sandstone for channel bed material > 4 mm diameter, based on pebble count data

⬡ = ratio of schist to sandstone for particle sizes ≥ -6 ϕ
o = ratio of schist to sandstone for particle sizes ≥ -4 ϕ
• = ratio of schist to sandstone for entire pebble count sample

pebble count site. Schist only becomes a dominant component of the bed material below Panther Creek (below Reach 16), because the drainage area of tributaries underlain by schist is relatively small down to Reach 16. Starting with Panther Creek, large schist tributaries enter Redwood Creek in the next 18 km along the main channel.

Conclusions

Approximately 236,000,000 ft^3 of sediment (14,000,000 tons) is stored in the Redwood Creek channel above the 1980 thalweg. About 47,000,000 ft^3 (2,800,000 tons) is active and an additional 91,000,000 ft^3 (5,000,000 tons) is semi-active or inactive. Another 50,000,000 ft^3 (3,000,000 tons) is stored below the 1980 thalweg but above the 1947 thalweg. A 100-year flood could mobilize active, semi-active and inactive sediment.

From the headwaters to Coyote Creek, 60% of the stored sediment lies in point and marginal bars. This mode of storage is also important downstream of Coyote Creek. Debris-stored sediment plays a major role only in the uppermost 6 km of Redwood Creek.

Deposits from the 1964 flood are still evident in the upper 12 km of Redwood Creek. Of the sediment originally deposited during the flood, 60% (1,300,000 tons) was eroded since 1964. Erosion of flood deposits is an important sediment source to downstream reaches, and this was especially true in the years directly after the 1964 flood.

Sediment input to Redwood Creek through landsliding is important in Reaches 23 - 36. About 92,000,000 ft^3 (5,520,000 tons) entered the channel by slides, and presently only 41,000,000 ft^3 of sediment (2,460,000 tons) is stored in Redwood Creek in these reaches. Considering a hypothetical case where a very large flood or poor land use caused a similar volume of sediment to enter the stream through landsliding, the present storage capacity of the stream would be greatly exceeded. Following such an event, large-scale channel adjustments and severe channel aggradation would probably occur.

Channel gradient generally decreases in a downstream direction. Local variations are associated with sudden bed material size changes. Bed material, in turn, is related to tributary influences and hillslope processes.

The channel of Redwood Creek has changed greatly since 1947. It widened through bank erosion, locally it became braided, and channel aggradation was widespread. The present sediment yield from Redwood Creek is probably much higher than in 1947, and the recent channel changes reflect the increase in sediment load.

Deposits from the 1964 flood are still evident in the upper 12 km of Redwood Creek. Of the sediment originally deposited during the flood, 60% (1,300,000 tons) has been eroded since 1964. Erosion of flood deposits is an important sediment source to downstream reaches, and this was especially true in the years directly after the 1964 flood.

Landslide Mapping Along the Main Channel

Introduction

We measured the volume of landslide debris contributed to the channel from the headwaters of Redwood Creek at the Roddiscroft Road crossing down to the Route 299 highway crossing, a channel distance of 29.6 km. In addition, landslides along approximately 1.4 km of the 4.8 km of channel above Roddiscroft Road were also measured, bringing the total length of the main channel survey to 31 km. Coverage of landsliding within this survey was 100%. Since both field and aerial photo observations of the remaining 3.4 km of unmapped channel (above 299) indicate that the volume of unmeasured landsliding is insignificant, the volumes reported here (Table 15 and the Upper Redwood Creek total in Table 16) represent all streamside landsliding along the upper 34.4 km of Redwood Creek. Most of the slides were debris slides or debris avalanches which failed during one or a few movement events and the raw scar was left exposed on the hillside after sliding. Large hillslope slumps or earthflow landslides form a minor percentage of the slides.

Field Techniques

We determined the volume of landslide erosion by measuring the voids left on the hillslopes after failure. Latest movement on most all the landslides post-dates the early 1960's, so landslide scars are still recognizable both in the field and on 1978 aerial photos, though extensive revegetation makes field measurement difficult in many instances. Both 1966 and 1978 photos were used during field work to insure that revegetation did not obscure the full extent of the landsliding. Landslide areas were measured using a tape and a rangefinder. For large, well-vegetated landslides, field measurement was an extremely time consuming task that took hours. For smaller slides, the area could be measured quickly from the channel. Landslide depth was estimated by mentally reconstructing the original hillslope shape prior to failure and estimating the average thickness of material lost. This procedure was usually rather straightforward. Only that material determined to have actually been delivered to the channel was counted, as there were numerous instances where substantial amounts of debris was still perched on the hillside.

Estimating depth was the greatest potential source of error, and individual slide volumes could conceivably vary by as much as 100% on those hillslopes where outlines of the original topography were no longer apparent. Ambiguities of this sort were the exception rather than the rule, however, and the actual measurement variability was probably closer to 25%. In addition, we feel that because of our tendency to be conservative when making depth estimates, the absolute values of our measurements may tend to underestimate rather than over estimate the actual slide volumes.

Compiliation of Mainstem Landslide Data

We have compiled data on all 634 mainstem landslide and/or incidences of bank erosion measured in the field. This data includes volume, area, average depth, aspect, slope angle, vegetative cover of the slide scar (most slides), estimated texture of landslide debris (most slides), length of the scar along the channel, landuse history, number of associated roads and location. This data is tabulated and on file in the Arcata Office of Redwood National Park. Interpretation of the data is still in the preliminary stages.

Preliminary Summary of Mainstem Landslides and Landuse

Total mainstem landslide volumes for Study Reaches 23 - 36, and the presence of primary or secondary logging haul roads on these landslides, is summarized in Table 15. Although our mainstem landslide data is essentially unanalysed as of yet, the close association of logging roads with streamside landslides is apparent. This close association largely reflects intensive, tractor-yarded logging of Douglas-fir on steep slopes directly adjacent to Redwood Creek. The timing of landslide activity in relation to timber harvesting, based solely on 1966 aerial photo interpretation and 1980 channel mapping is summarized in Table 16.

TABLE 15

STREAMSIDE LANDSLIDING ALONG THE MAINSTEM OF REDWOOD CREEK: VOLUMES AND PRESENCE OF ROAD

Reach Number	Downstream Distance From Roddiscroft Rd. (m)	Landslide in Reach ft^3	Number of Slides in Reach	Number of Slides With No Road	Number of Slides With One Road	Number of Slides With Two Roads	Number of Slides With Three or More Roads	Number of Slides for Which Landuse Not Known
36	000-3450	3,913,369	98	25	38	11	1	23
35	3451-5650	4,255,168	50	34	16	0	0	0
34	5651-6737	3,473,824	23	5	15	2	1	0
33	6738-8345	6,039,479	39	9	21	5	4	0
32	8346-9757	1,864,542	25	7	10	2	4	2
31	9758-11797	8,664,083	45	21	20	1	3	0
30	11798-13471	3,335,487	23	11	10	2	0	0
29	13472-15246	7,065,390	26	3	13	2	8	0
28	15247-16794	5,850,267	25	16	8	0	1	0
27	16795-20309	9,500,170	64	24	34	1	4	1
26	20310-22645	3,249,774	46	20	7	0	0	19
25	22646-25950	3,675,547	60	23	13	2	0	22
24	25951-28550	6,387,714	39	10	18	3	1	7
23	28551-29600	1,514,215	23	2	5	0	0	16

TABLE 16

Landuse of Mainstem Streamside Landslides
(Based on 1980 Channel Survey and 1966 Aerial Photo Interpretation)

Reach Number	Total Number of Slides in Reach	Landslides With Roads at Time of Failure							Landslides Without Roads at Time of Failure							Landslide History Unknown at this Time
		Total Number of Slides	Landslides Active Before 1966		Landslides Active After 1966		Time of Landslide Activity is Unknown		Total Number of Slides	Landslides Active Before 1966		Landslides Active After 1966		Time of Landslide Activity is Unknown		
			Cut Before 1966	Uncut in 1966	Cut Before 1966	Uncut in 1966	Cut Before 1966	Uncut in 1966		Cut Before 1966	Uncut in 1966	Cut Before 1966	Uncut in 1966	Cut Before 1966	Uncut in 1966	
36	98	50	36	6	3	2	2	1	25	15	2	1	1	5	1	23
35	50	16	10	6	0	0	0	0	34	4	26	0	0	0	4	0
34	23	18	7	8	0	1	2	0	5	0	3	1	0	0	1	0
33	39	30	26	0	3	0	1	0	9	7	0	0	0	2	0	0
32	25	16	12	0	1	0	3	0	7	0	5	0	2	0	0	2
31	45	24	12	3	1	1	6	1	21	0	15	1	5	0	0	0
30	23	12	0	9	0	0	2	1	11	0	4	5	0	0	2	0
29	26	23	12	0	10	0	1	0	3	0	0	3	0	0	0	0
28	25	9	9	0	0	0	0	0	16	3	11	0	0	1	1	0
27	64	39	19	11	1	0	8	0	24	2	7	5	0	6	4	1
26	46	7	2	2	0	2	1	0	20	8	7	0	2	0	3	19
25	60	15	8	5	0	0	2	0	23	3	4	0	4	6	6	22
24	39	22	21	0	0	0	1	0	10	3	3	0	0	4	0	7
23	23	5	4	0	0	0	1	0	2	2	0	0	0	0	0	0

V. TRIBUTARY STUDIES

A. Introduction

The Redwood Creek basin is unusually elongated in a north-northwesterly direction and has an elongation ratio of .34 (Janda and others, 1975). Redwood Creek roughly bisects the basin and its course is structurally controlled by the Grogan Fault. There are no major tributary forks of Redwood Creek and there are only a few tributaries that are substantially larger than the average (Figure 8). Tributaries to Redwood Creek are grossly separated into those underlain by schist to the west of the Grogan Fault and those underlain by sandstone to the east. Tributaries draining schist terrain have a more shaded aspect than those draining sandstone terrain. The vegetation in these basins strongly reflects the difference in aspect. Basins underlain by schist are almost totally forested, while sandstone tributaries have a significant percentage of oak woodland and open prairie, in addition to the coniferous forests. Thus the two tributary groups distinguished by different rock types are also distinguished by type of vegetative cover.

Tributary basins can supply voluminous amounts of sediment to the mainstem of Redwood Creek. As a first step in determining the timing and magnitude of sediment contributions from tributaries, we measured both streamside landslides and channel-stored sediment in many of these basins. Analysis of fluvial hillslope erosion from basins with differing geology, vegetation and land use is a forthcoming aspect of this project. Our final objective is to determine sediment yields from tributary basins given runoff events of varying magnitude and frequency.

B. Tributary Landslide Studies

In order to more fully evaluate the importance of streamside landsliding, landslide surveys were conducted along 16 tributaries. Most of these tributaries are larger than 5 km^2 in area, and have yielded sizeable amounts of landslide-derived sediment (see Figure 8 and Table 17). Landslide characteristics were similar to those observed along the mainstem, and the measurement techniques employed are the same as those described earlier under Main Channel Landslide Mapping. The type and accuracy of the data obtained were also comparable, though in general its collection was less comprehensive. The tabulated results of these surveys are on file in the Arcata office of Redwood National Park.

In addition to landslide mapping, for the three tributary basins in the Park Protection Zone, Coyote Creek, Lacks Creek, and Garrett Creek, we did a more detailed interpretation of land use history compared to landsliding (see Tables 18, 19, and 20, and the accompanying commentary on tabular data). In Tom McDonald Creek, we also did a more detailed analysis of the causes of landslide failure and the degree of revegetation (see Table 21 and accompanying comments).

A preliminary analysis of the contributions of different-sized landslides relative to the total sediment contribution by streamside landsliding is also available. In Copper Creek, where we measured 118 landslides, slides greater than 10,000 ft^3 account for approximately 90% of the total volume but only 24% of the total number (Figure 9). Data from Lacks Creek (157 surveyed slides) shows similar tendencies, with the exception that the 90th percentile occurs at around 100,000 ft^3. This size-to-volume relationship implies that only the largest streamside landslides need to be measured in order to obtain a realistic estimate of tributary basin landslide sediment production. Such an approach was used to generate the preliminary basin estimates shown in Table 17. Survey coverages were estimated using aerial photos.

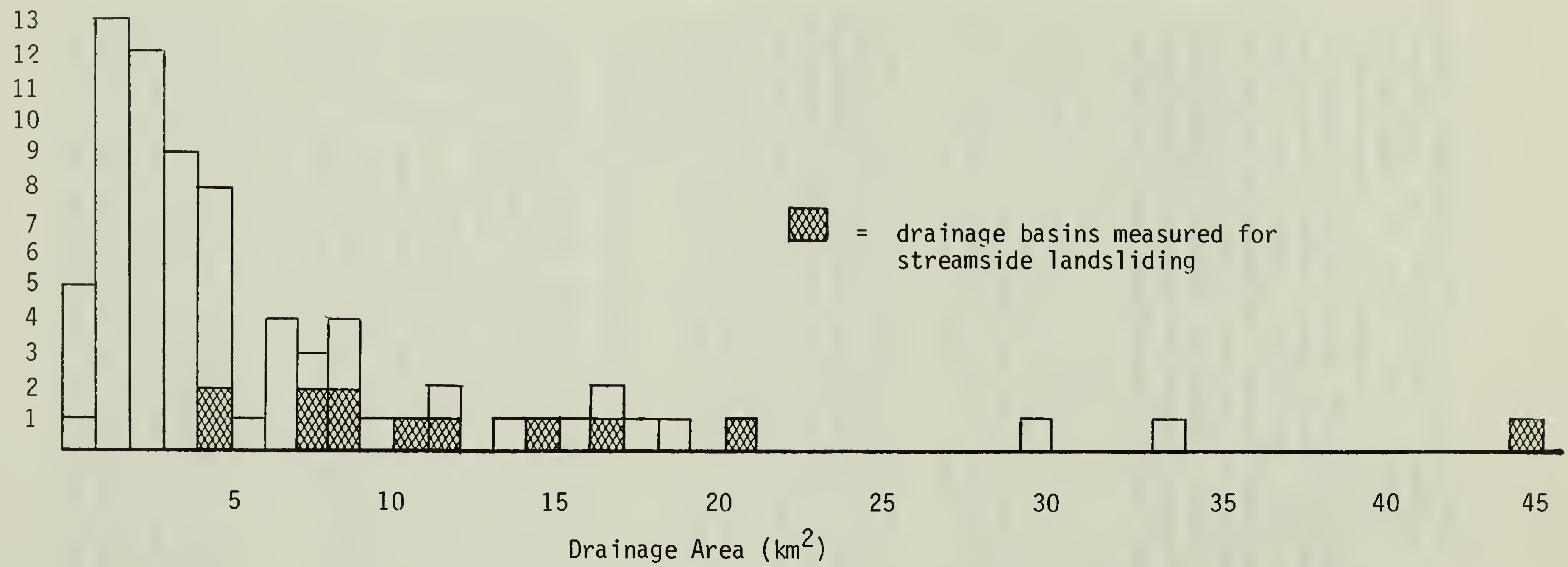

Figure 8: Distribution by drainage area of basins measured for streamside landsiding compared to distribution by drainage area of all tributaries.

TABLE 17

TRIBUTARY LANDSLIDE DATA

	Tributary	Drainage Area (km^2)	Number of Measured Landslides	Volume of Measured Landslides (ft^3)	Estimated Survey Coverage[1] (%)	Estimated Total[2] Landslide Production Entire Basin
1.	Tom McDonald Creek	17.95	65	1,818,775	98	1,855,790
2.	Copper Creek[3]	7.43	118	2,046,420[3]	85	2,407,550
3.	Coyote Creek	20.41	66	5,146,137	98	5,251,160
4.	Garrett Creek	10.75	23	2,715,821	85	3,195,080
5.	Lacks Creek	44.03	157	21,351,376	98	21,787,120
6.	Windy Creek	4.56	47	5,166,650	97	5,326,440
7.	Simon Creek	4.51	67	7,440,172	97	7,670,280
8.	High Prairie Creek	14.25	13	614,881	50	1,229,760
9.	Minon	11.06	15	1,130,888	70	1,615,550
10.	Lake Prairie Creek	8.75	59	452,960	65	696,861
11.	Bradford Creek	16.50	51	4,731,476	95	4,980,500
12.	Pardee Creek	8.13	8	588,556	65	905,470
13.	Powerline Creek	1.69	11	816,646	80	1,020,810
14.	Snow Camp Creek	8.16	38	5,078,734	95	5,346,040
15.	Lineament Creek	0.92	9	148,481	85	174,680
16.	Uppermost Redwood Creek (above Roddiscroft Rd.)	-	23	62,330	60	103,883

1: Survey coverage: The percentage of a basin's landslide-derived sediment production measured during a landslide survey.

2: $\text{Estimated Total Volume} = \dfrac{\text{Measured Volume}}{\text{Estimated Coverage}}$

3: Copper Creek landslide measurement is a preliminary figure subject to revision.

TABLE 18

TRIBUTARY LANDSLIDE STUDY - COYOTE CREEK - (20.41 km^2)

Total Measured Landslide Volume: 5,146,137 ft^3 (145,739 m^3)

Total Measured Landslide Mass: (density = 120 lbs/ft^3) 308,770 tons

Tributary Channel Study Length: 3.1 mi (4.99 km)

Timing of Landslide Sediment Contribution
(Based on Aerial Photo Research)

Time Period	ft^3	% of Total Volume
pre - 1962	778,615	15.1%
1962 - 1966	3,463,265	67.3%
1966 - 1980	904,257	17.6%

Land Use History and Landslide Volumes

Land Use	ft^3	% of Total Volume
Old-Growth Forest	220,909	4.3%
Clearcuts	2,224,328	43.2%
Road Construction	2,700,900	52.5%

Lithology (Bedrock Character of Hillslope) and Landslide Volumes

Lithology	ft^3	% of Total Volume of Identified Lithologies
Sandstone	2,789,243	66.2%
Siltstone	1,407,048	33.4%
Greenstone	10,913	0.3%
Chert	5,600	0.1%
(Not Mapped)	933,333	

Landslide History - Timing Compared to Land Use and Lithology

Time Period	Land Use (%)* Old Growth	Clear-cuts	Road Constr.	Lithology (%) Sandstone	Siltstone
pre - 1962	28.4	18.8	52.8	60.4	39.6
1962 - 1966	0.0	46.9	53.1	72.3	27.7
1966 - 1980	0.0	50.2	49.8	39.9	60.1

* - Land use percentages cumulatively total to 100% for each time period.

COMMENTS ON TABLE 18

COYOTE CREEK LANDSLIDE STUDY

1. Landslide volume contributions does not include earthflow contributions, which is a minor, but significant, percentage.

2. The major effect of the 1964 storm and flood event on initiating landslide activity in Coyote Creek is especially evident from the data.

3. Road construction stands out as a major cause of landslide failure along Coyote Creek.

4. A large debris slide, which was due to the failure of a road crossing, occurred during a March storm this winter (1980); this slide is not included in the volume measurements.

5. Revegetation of massive sandstone debris slides in this basin is minimal.

TABLE 19

TRIBUTARY LANDSLIDE STUDY - LACKS CREEK - (44.03 km^2)

Total Measured Landslide Volume: 21,351,376 ft^3 (604,671 m^3)

Total Measured Landslide Mass: (density = 120 lbs/ft^3) 1,381,080 tons

Tributary Channel Study Length: 7.5 mi (12.07 km)

Timing of Landslide Sediment Contribution
(Based on Aerial Photo Research)

Time Period	ft^3	% of Total Volume
pre - 1962	7,104,959	33.3%
1962 - 1966	8,181,383	38.3%
1966 - 1980	6,065,034	28.4%

Land Use History and Landslide Volumes

Land Use	ft^3	% of Total Volume
Old-Growth Forest	4,231,289	19.8%
Clearcuts	12,733,957	59.6%
Road Construction	4,386,130	20.5%

Lithology (Bedrock Character of Hillslope) and Landslide Volumes

Lithology	ft^3	% of Total Volume of Identified Lithologies
Sandstone	6,381,475	29.9%
Siltstone	14,964,009	70.1%
Terrace Deposits	5,892	0.03%

Landslide History - Timing Compared to Land Use and Lithology

Time Period	Land Use (%)* Old Growth	Clear-cuts	Road Constr.	Lithology (%) Sandstone	Siltstone
pre - 1962	49.5	33.1	17.3	25.6	74.4
1962 - 1966	3.3	76.3	20.4	41.4	58.9
1966 - 1980	7.4	68.1	24.5	19.8	80.1

* - Land use percentages cumulatively total to 100% for each time period.

COMMENTS ON TABLE 19

LACKS CREEK LANDSLIDE STUDY

1. Total landslide volume relative to drainage area (44.03 km^2) is high compared to other tributaries measured to date.

2. The presences of an "inner gorge" in Lacks Creek promotes streamside debris sliding and avalanching.

3. The data shows logging has had a profound adverse effect on slope stability. Though 51.7% of Lacks Creek remains either uncut or in prairie as of 1978, only 19.8% of the landslides occurred in old-growth forest and approximately 80% of these old-growth landslide events occurred before 1962 (i.e., before most logging and before the major storms).

4. The extent of revegetation of landslide scars varies from none on massive sandstone slopes to sparse on siltstone slopes. Steep slopes, persistent summer-time ravel and winter-time small failures, and lack of fertility of the exposed bedrock are the causes of slow revegetation.

5. Road construction within or just above the "inner gorge" has a demonstrably adverse effect on slope stability and should be avoided.

6. The Lacks Creek canyon is eroded along a shear/fault zone between incoherent Franciscan sandstones and siltstone and a much more competent Franciscan sandstone-siltstone unit. The presence of this shear zone probably contributes to slope instability.

7. Dating of young trees on landslide scars suggests most large landslides were triggered by one of the major storm events (1964 - 1972 - 1975) and in some cases, the trees show that a landslide was triggered by one event and then partially reactivated by a succeeding storm event.

8. The timing of landslide contribution to Lacks Creek shows a fairly even spread over the three time periods, suggesting that one cannot isolate the 1964 storm and flood as the single most influential event in this basin. Lacks Creek shows a great deal of recent (post-1970) landslide activity compared to other tributaries.

TABLE 20

TRIBUTARY LANDSLIDE STUDY - GARRETT CREEK - (10.75 km^2)

Total Measured Landslide Volume: 2,715,821 ft^3 (76,900 m^3)

(This total represents 90%, or greater, of total landslide volume along Garrett Creek).

Total Estimated Landslide Volume: 2,987,400 ft^3 (84,600 m^3)

Estimated Volume = Measured volume plus 10% of measured volume to account for contribution from slides under 10,000 ft^3 in size.

Tributary Channel Study Length: 7,400 ft (2,255 m)

Study length is from mouth of Garrett Creek to Landslide #19

Slope Gradient of Landslide Scar

Gradient Interval (%)	Number of Slides
Less than 60	1
60 - 69	2
70 - 79	6
80 - 89	3
90 - 99	1
100 - 109	2
110 - 119	2
120 - 140	3
Greater than 140	2

Cause of Failure[1]

Cause[2]	Number of Slides
CR	2
RD	5
LJ	1
UC-RS(?)	2
UC	9

1: Excludes bank erosion at toe, which undoubtedly contributed to, or triggered, the landslide event.

2: CR = Concentrated runoff onto slide from roads;
RD = Failure of road fill;
LJ = Log jam diversion of stream into bank;
UC-RS = Unclear, though loss of root strength due to logging is a good possiblity;
UC = Unclear

Land Use of Slope that Failed

Land Use	Number of Slides
Unlogged	6
Logged	14

Garrett Creek Landslide Study

1. Garrett Creek is grossly similar to Coyote Creek in topography and geologic rock types; and the two drainages probably have closely comparable sediment yields.

2. Garrett Creek headwater streams flow on an incoherent sandstone-siltstone unit that is highly prone to mass movement. Road building, especially near streams or on prairies, has led to increased gully cutting and small landslides in the past. The two main headwater stream channels that join to form Garrett Creek flow on either side of a large prehistoric earthflow landslide tongue that is now inactive. Just below this confluence, a main logging haul road runs just above the left (SE) bank and has caused three large debris slide failures.

3. The middle portion of Garrett Creek cuts through a coherent, massive sandstone and bedded sandstone-siltstone greywacke unit for approximately 2,500 feet of channel length. The canyon formed in this channel reach has slopes ranging from 70% to nearly vertical and averaging 80% to 100%. The canyon has many 10 to 15 foot waterfalls. The channel is inaccessible except from either end of the canyon and conifer trees on the steepest slopes near the channel have not been harvested. This canyon wall of redwood and Douglas-fir should never be harvested because of the added shear strength the roots probably impart to these steep slopes.

4. The lower portion of Garrett Creek flows through mixed coherent and incoherent rock units. Slope gradient is less steep than the canyon reach upstream. An active earthflow landslide currently enters the creek from the left (SE) bank. Timber harvesting has been active near this portion of the creek. Cable logging has not resulted in any obvious major erosion problems. However, construction of roads across prairies in this reach has caused drainage alterations that appear to be feeding more water onto the active earthflow.

5. There are a relatively small number of landslides on Garrett Creek compared to Copper Creek, Coyote Creek, and Lacks Creeks. The primary reasons for less landslides are probably: (1) major haul roads drop down near the channel only in one place, and (2) near-channel timber harvesting has not occurred in the canyon reach.

6. Upper slopes of Garrett Creek, especially on the southeast side, were initially logged in the 1950's and early 1960's. Failures of haul road fill crossings have occurred, and some of them are rather spectacular as to the length of the resulting sluiced-out channel. Three channelized debris torrents that start at haul road crossings, and are especially noticeable on the aerial photos, have total lengths of 1,300; 1,500 and 3,000 feet. These gully sluice-outs have been a significant sediment source in the past; and the volume of sediment involved is difficult to estimate and is not incorporated into the landslide volume estimates.

7. Currently the most problematical area in Garrett Creek is the haul road that runs parallel to the northernmost of the two major headwater tributary streams for portions opf the stream length. Crossings of this stream should be pulled after summer use. No permanent crossing should be left in except if a bridge is built.

TABLE 21

Tributary Landslide Study - Tom McDonald Creek - (17.95 km^2)

Total Measured Landslide Volume: 1,818,675 ft^3

(This total represents 90% or greater of all landslides along Tom McDonald Creek)

Total Estimated Landslide Volume: 2,000,000 ft^3 (56,640 m^3)

Tributary Channel Study Length: 18,500 ft (5,600 m)

Percent Delivery to Channel: 96.5% Released to stream
3.5% Debris still perched on slope

Status on Age and Revegetation of Measured Landslides

Relative Age*		Degree of Revegetation	
Old	39.5%	Well-vegetated	71.6%
Old-intermediate	2.6%	Semi-vegetated	16.7%
Intermediate	27.3%	Barely-vegetated	7.6%
Intermediate-young	4.7%	Non-vegetated	4.1%
Young	26.0%		100.0%
	100.0%		

* - Ages based on degree of revegetation and size of trees and/or understory revegetation:

Old = Well vegetated, large trees, landslide older than 1955.
Intermediate = Well-vegetated but no large trees, landslide younger than 1955, but no recent activity.
Young = Semi-vegetated to non-vegetated, landslide active at present.

Probable Cause of Failure of Landslide

Log dam flow diversion	543,827	29.9
Clearcutting and road construction	519,286	28.5
Log dam diversion or other natural cause	414,000	22.8
Natural	202,351	11.1
Windfall	42,183	2.3
Log dam diversion and windfall	39,320	2.2
Road construction	32,670	1.8
Clearcutting and log dam diversion	25,038	1.4
	1,818,675	100.0

COMMENTS ON TABLE 21

TOM McDONALD CREEK LANDSLIDES

1. Total landslide volume relative to drainage area (17.95 km^2) is low compared to other tributaries measured to date.

2. Tom McDonald Creek is totally underlain by schist bedrock. The schist is not as prone to large debris slides or avalanches as is the Franciscan sandstone and siltstone on the east side of the basin.

3. Rate of slope revegetation after failure is rapid compared to tributaries draining Franciscan sandstones on the east side of the basin. Rapid revegetation is probably due to: (a) slide scar composed of weathered clay-rich schist subsoil that can retain water, is reasonably fertile, and is soft enough for root penetration; (b) the N to ESE slope aspect results in wetter slopes for a greater time each year.

4. The main channel of Tom McDonald Creek below the forks was, in large part, not logged and an old-growth redwood buffer has prevented major logging-induced slope failure.

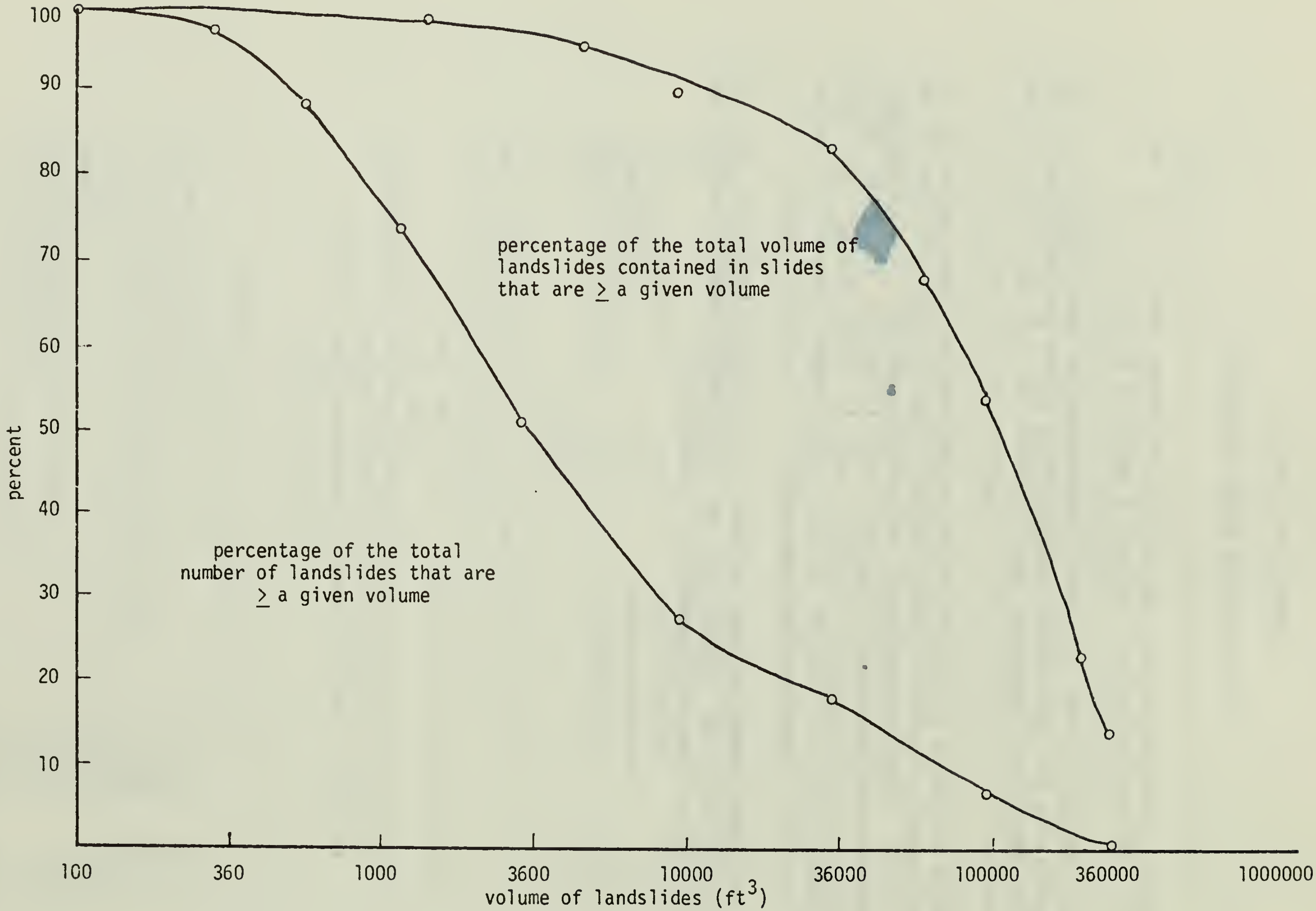

Figure 9: Copper Creek landsliding—relative contributions of different-sized landslides to total sediment contribution by landsliding

C. Stored Sediment in Tributary Basins

Introduction

The contribution of stored sediment from tributary stream channels to the mainstem of Redwood Creek is an essential element of the sediment budget study. There are 74 tributary basins drained by second order (after Strahler, 1957) or higher streams and these comprise nearly 600 km^2 or 83% of the Redwood Creek drainage basin. Our primary objective in this portion of the study is to define the amount of sediment in storage within tributary channels and to determine under what conditions and at what rate this sediment could be delivered to the mainstem of Redwood Creek. This knowledge forms an important base from which resource management decisions concerning park lands can be made. Secondly, we wish to define the relationships between the physical factors that control sediment storage or sediment transport in these watersheds. These factors include the physiographic and geologic setting, large organic debris derived from forested hillslopes, the degree of timber harvesting and the occurrence of infrequent, high intensity storm events.

Tributary Sampling

There are hundreds of miles of second order or higher tributary stream channels draining the Redwood Creek basin. This presents a significant data collection problem for determining the total contribution of tributary streams to sediment transport and storage. Measuring the entire length of every tributary stream would have been impossible given the scope of this project. We used two approaches to sample stored sediment. One approach was to map all the channel-stored sediment in a tributary and the other was to map randomly selected reaches in a tributary and then indirectly compute total stored sediment volumes. A comparison of the distribution, by drainage area, of all tributary basins to the distribution of basins sampled by one or both techniques is presented in Figure 10.

Data on stored sediment, channel gradient and channel geometry were collected for entire basins in ten cases. These basins were chosen in part because they were likely to have a large amount of stored sediment. In addition, landslide mapping has been completed in all but one of these tributaries.

Twenty basins were statistically sampled to arrive at an estimate of the total amount of sediment stored in the tributary streams. These tributaries represent a wide variety of physiographic settings and forest types. The selection of the study basins was based on probability proportional to drainage area. Three study reaches, one in each of the upper, middle and lower third of the tributary basin, were then chosen by simple random sampling with each study reach length being one forty-fifth of the total tributary drainage length. Estimates of the total amount of sediment in these tributaries was then made by:

$$SS = (1/3)(45) \sum_{i=1}^{3} SS_i$$

Where SS = Estimate of sediment stored in tributary.

SS_i = Measured amount of stored sediment in i^{th} reach of tributary.

Seven of the statistically sampled basins were also measured in their entirety.

Tributary Stored Sediment Data

Data for basins in which all stored sediment was mapped is presented in Table 22. Selected data for the 20 statistically selected basins is presented in Table 23, and the estimates of total stored sediment for these basins is given in Table 24. Table 25 gives a comparison of stored sediment volumes computed for basins measured by both sampling techniques.

Estimate of Total Stored Sediment in Redwood Creek Tributaries

We initially intended to compute total stored sediment using data from our randomly selected reaches (Table 23) but the consistent over-estimation of stored sediment using this approach (Table 25) led us to use the randomly selected reach data only when it was the only data available for a basin.

Our method for estimating total stored sediment in tributary channels involves integrating the data collected by both sampling techniques. Our computation method basically involves combining data on stored sediment in the sampled basins with the size distribution of tributary basins depicted in Figure 10. For each tributary drainage area class, we computed total stored sediment using data from basins measured in entirety and basins sampled by randomly selected reaches. By combining the data, we generated an estimate for total stored sediment in each drainage area interval. Our estimate of total stored sediment in tributary basins is 3,307,249 m^3 (36,015,946 ft^3) or 1,959,988 tonnes. In comparison to channel-stored sediment above the 1980 thalweg in the mainstem of Redwood Creek, the tributaries store 15% as much sediment.

Variables That Effect Sediment Storage and Timing of Sediment Transport in Tributaries

In addition to estimating total stored sediment in tributary watersheds, we looked at the factors which influence sediment transport into the main channel of Redwood Creek. The physical factors that work either independently or together in influencing sediment storage and/or transport are basin relief, basin geology, and the effects of large organic debris.

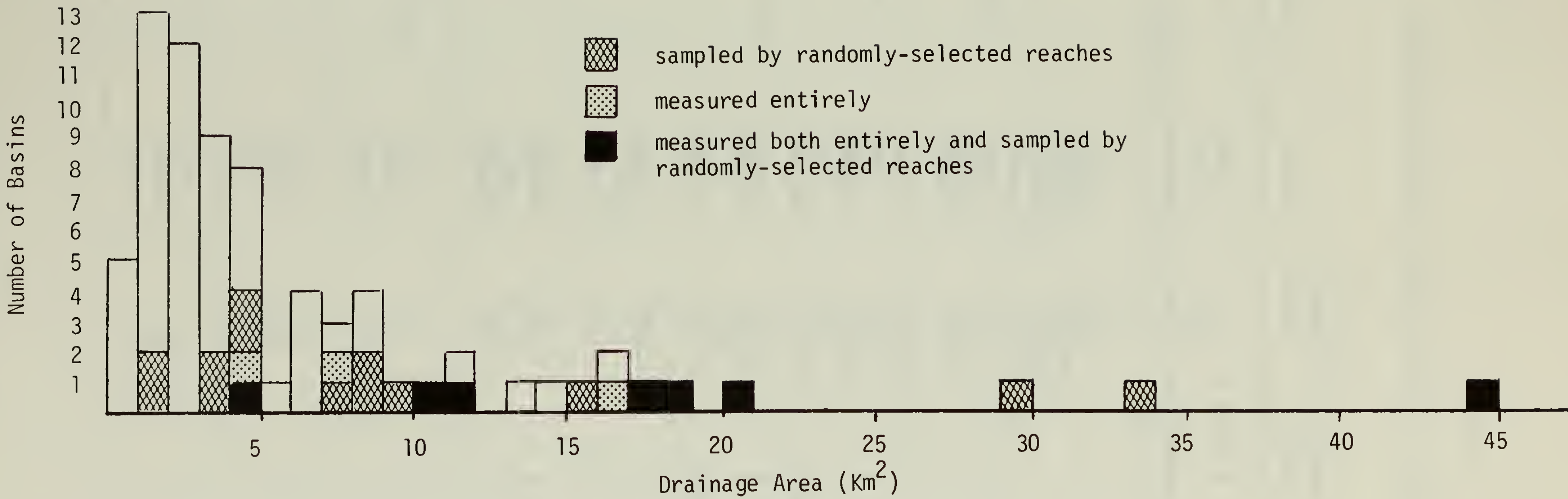

Figure 10: Distribution of 74 tributary drainage basins by drainage area. Shaded areas show distribution of basins sampled for volume of stored sediment.

TABLE 22

SELECTED DATA FOR BASINS IN WHICH ALL STORED SEDIMENT WAS MEASURED

Tributary	Drainage Area (km^2)	Total Stored Sediment (Tonnes)
Lacks Creek	44.03	120,000
Coyote Creek	20.41	22,000
Devils Creek	18.03	47,000
Tom McDonald Creek	17.95	65,000
Bradford Creek	16.50	25,000
Upper Redwood Creek	11.14	32,700
Garrett Creek	10.75	18,800
Copper Creek	7.43	18,700
Windy Creek	4.56	116,200
Simon Creek	4.56	44,700

TABLE 23

SELECTED DATA FOR STUDY REACHES OF STATISTICALLY SAMPLED BASINS

Tributary	Reach	Drainage Area (km^2)	Stream Order	Average Gradient	Stored Sediment (m^3/100m channel)
Bridge	Lower	22.25	4	.030	3,247
	Middle	9.51	3	.048	1,102
	Upper	1.71	1	.037	55
Lacks	Lower	44.03	5	.008	5,847
	Middle	22.02	4	.019	30
	Upper	1.06	2	.150	276
Sweathouse	Lower	3.47	3	.057	1,581
	Middle	.49	2	.38	88
	Upper	.02	1	.28	0
Cashmere	Lower	2.95	4	.17	336
	Middle	1.19	3	.17	383
	Upper	0.08	1	.23	0
Lake Praire	Lower	7.83	3	.10	356
	Middle	1.68	2	.25	50
	Upper	1.45	1	.067	93
Bond	Lower	3.65	3	.125	603
	Middle	1.42	3	.08	221
	Upper	.02	1	.12	0
Devil's	Lower	12.79	4	.012	1,236
	Middle	5.31	4	.03	1,564
	Upper	.52	2	.19	0
Harry Weir	Lower	5.39	4	.045	1,388
	Middle	4.17	4	.075	1,236
	Upper	.05	1	.42	0
Coyote	Lower	14.20	4	.088	80
	Middle	10.21	4	.094	612
	Upper	.17	1	.34	0
Powerline	Lower	1.21	2	.27	0
	Middle	.40	1	.23	106
	Upper	.20	1	.15	40

TABLE 23

SELECTED DATA FOR STUDY REACHES OF STATISTICALLY SAMPLED BASINS

Tributary	Reach	Drainage Area (km^2)	Stream Order	Average Gradient	Stored Sediment (m^3/100m channel)
McArthur	Lower	9.58	3	.089	974
	Middle	4.69	2	.012	0
	Upper	1.29	2	.010	335
Upper Redwood	Lower	10.44	3	.046	2,679
	Middle	4.12	2	.013	2,265
	Upper	.17	1	.073	0
Forty Four	Lower	8.11	3	.028	863
	Middle	5.18	3	.035	1,615
	Upper	.11	1	.25	0
Wiregrass	Lower	4.69	3	.091	0
	Middle	.78	2	.20	73
	Upper	.02	1	.076	0
Windy	Lower	4.47	3	.035	3,909
	Middle	3.61	3	.059	5,489
	Upper	.02	1	.17	0
Panther	Lower	14.43	4	.045	236
	Middle	11.34	3	.036	2,821
	Upper	1.48	2	.10	0
Tom McDonald	Lower	17.51	4	.018	3,644
	Middle	11.14	4	.054	1,019
	Upper	.44	1	.28	0
Minor	Lower	33.20	4	N/A	N/A
	Middle	22.30	4	N/A	N/A
	Upper	1.09	2	.22	84
Hayes	Lower	1.56	3	.032	155
	Middle	.49	2	.34	23
	Upper	.05	1	.47	0
Garrett	Lower	8.31	4	.12	0
	Middle	1.42	3	.075	268
	Upper	1.06	2	.23	645

TABLE 24

ESTIMATES OF TOTAL STORED SEDIMENT FOR STATISTACALLY SAMPLED BASINS

UPPER REDWOOD CREEK	Total Stored Sediment for Three Reaches (tonnes)	Estimate of Total Stored Sediment for Basin (tonnes)
Bridge Creek	24,178	362,664
Lacks Creek	35,720	535,800
Sweathouse Creek	2,159	32,383
Cashmere Creek	1,019	15,280
Lake Prairie Creek	1,061	15,917
Bond Creek	1,038	15,574
Devils Creek	9,530	142,950
Harry Weir Creek	4,965	74,480
Coyote Creek	1,925	28,871
Powerline Creek	170	2,552
McArthur Creek	4,217	63,259
Upper Redwood Creek	16,943	254,149
Forty Four Creek	5,342	80,128
Wiregrass Creek	113	1,690
Windy Creek	13,253	198,789
Panther Creek	7,308	109,624
Tom McDonald Creek	8,994	134,907
Minor Creek	N/A	N/A
Hayes Creek	153	2,295
Garrett Creek	1,771	26,560

TABLE 25

COMPARISON OF STATISTICALLY SAMPLED BASINS
AND
BASINS IN WHICH ALL STORED SEDIMENT WAS MEASURED

Tributary (listed in decreasing drainage area)	Statistically Sampled Basins: Estimated Stored Sediment (tonnes)	Basins Measured in Entirety: Measured Stored Sediment (tonnes)
Lacks Creek	535,800	120,000
Coyote Creek	28,871	22,000
Devils Creek	142,950	47,000
Tom McDonald Creek	134,907	65,000
Garrett Creek	26,560	18,800
Windy Creek	198,789	116,200
Upper Redwood Creek	254,149	32,700

Effects of Topography and Geology on Sediment Storage and Sediment Transport

The tributary streams within the Redwood Creek basin occupy well incised channels and have narrow floodplains or lack floodplains. Many tributaries have steep hillslopes adjacent to the main channel and more moderate slopes in the middle and upper portions. This "inner gorge" valley profile suggests the area has experienced recent uplift and denudational hillslope processes have not kept pace with downcutting by mainstem streams. The inner gorge is the most likely site for abundant streamside landsliding.

Incised tributary channels exhibiting an inner gorge are not common throughout the entire basin. On the western drainage divide, the headwater areas of streams such as McArthur, Noisy, High Prairie and Lake Prairie Creeks consist of low relief, broad ridges with shallowly-incised drainages. In these areas, creeks maintain low gradients; and hillslopes adjacent to the channel are moderate or gentle. Another type of stream lacking an inner gorge are creeks draining oak woodland and prairie terrain in the eastern portion of the Redwood Creek basin upstream of State Highway 299. The channel bed of these creeks often contain a lag deposit of very dense metavolcanic cobbles and boulders. This resistant bed material armors the channel and inhibits downcutting, resulting in relatively steep tributary stream gradients but only moderate hillslopes adjacent to the channels.

Many of the tributaries have steep profiles with average gradients ranging from less than .01 to .40. Channels are coarsely bedded (large gravels to large boulders) and lack thick alluvial fills, suggesting that the tributary streams transport a high proportion of the sediment delivered to them by hillslope processes relatively rapidly. Of the tributary streams in which all landslides and all stored sediment were measured, only two basins store more than 16% of the mass volume of sediment that has recently been delivered by streamside landslides (Table 26).

Sediment storage in the majority of streams is concentrated in the lower gradient reaches. Data from Table 27 indicates that on the average, 95% of the sediment stored in tributaries is found in the lower half of their drainage lengths. A specific example of the effect of stream gradient on sediment storage can be made by comparing data from Simon Creek and Windy Creek. These two basins are of equal size and drain very similar terrain but Windy Creek stores approximately two-and-a-half times as much sediment (Table 22) as Simon Creek. This is largely due to the differences in average gradient within their lower reaches where the majority of sediment is stored. The average gradients for these reaches in Windy and Simon Creeks are .027 and .074 respectively.

Variations in bedrock lithology are likewise important in determining the particle size of material that enters a stream channel and therefore its potential for being stored in the channel bed or being transported out of the basin. The dark grey, weakly cemented siltstone that underlies much of the east half of the basin is usually extremely friable and easily broken down. Likewise, the extensive well-foliated phyllites that are found within the schist are also easily reduced to small particle sizes. Both of these rock types therefore yield a high proportion of material which if it does not move in suspension immediately, does so with little abrasion or transport. This is illustrated indirectly by the data in Table 22 where the two basins with the largest amount of stored sediment have many debris slides that deliver coarse, massive sandstone bed material to the channels.

Coarse sediment delivered by debris slides from massive sandstone units can remain in the channel for long (hundreds of years) periods of time. Such coarse channel deposits can form a local nick point in the stream gradient, resulting in a moderate gradient reach upstream.

Effects of Organic Debris on Sediment Storage

Eighty-five percent of the Redwood Creek basin was forested prior to the initiation of timber harvesting. An accumulation of organic debris in streams within this type of watershed is common. Organic debris can accumulate in discreet jams comprised of several to hundreds of logs. The effect of these jams on stream morphology has been studied in detail by other investigators in both the old-growth redwood (Keller and Tally, 1969) and Douglas-fir forests (Swanson, Lienkaemper, and Sedell, 1976). These log jams are often very effective in ponding large amounts of sediment behind them. The resultant changes in stream morphology characteristically involve an abrupt step in the longitudinal profile at the jam with a decrease in gradient upstream of the jam, an increase in channel width associated with the decrease in gradient, and a decrease in particle size behind the jam.

Large organic debris (windfalls, cut logs, stumps, slash, etc.) that has accumulated in tributary stream channels has an important influence on sediment storage and sediment transport. Sediment stored directly by or influenced by the accumulation of organic debris is readily available for transport should the organic debris be moved and is a potential sediment source for downstream deposition in the mainstem of Redwood Creek.

Even the largest tributary streams in the old-growth redwood forest do not carry sufficient runoff under most conditions to move the old-growth redwood logs lying in channels. Consequently, the debris jams are massive and stable and remain in place for hundreds of years. In contrast, organic debris accumulation in the Douglas-fir forest tends to be less because the relatively smaller-sized debris can be moved more readily by high streamflows. Our findings indicate that in the oldgrowth redwood forest, organic debris directly or indirectly accounts for approximately 80% of the sediment stored in channels. In the Douglas-fir forest, only 40% of the stored sediment is associated with

TABLE 26

COMPARISON OF LANDSLIDE MASS AND SEDIMENT PRESENTLY IN STORAGE

Tributary	Drainage Area (km^2)	Landslide Mass (tonnes)	Total Stored Sediment (tonnes)	Percentage of Stored Sediment to Landslide Mass (%)
Lacks Creek	44.03	768,000	120,000	15.6
Copper Creek	7.43	111,400	18,700	16.8
Coyote Creek	20.41	240,000	22,000	9.2
Garrett Creek	10.75	162,500	18,800	11.6
Tom McDonald Creek	17.95	65,000	65,000	100.0
Windy Creek	4.50	281,200	116,200	41.3
Simon Creek	4.50	405,000	44,700	11.0
Bradford Creek	16.50	244,600	25,000	10.2
Upper Redwood Creek	11.14	206,500	32,700	15.8

TABLE 27

COMPARISON OF TOTAL TRIBUTARY LENGTH
TO
LENGTH OF CHANNEL WHERE MAJORTIY OF SEDIMENT IS STORED

Tributary	Total Drainage Length (TDL,m)	Length of Channel Storing 95% of Total Total Sediment (DL_{95},m)	DL_{95}/TDL
Bridge Creek	12,859	6,645	.52
Tom McDonald*	7,451	3,901	.52
Forty Four Creek	5,053	3,597	.71
Harry Weir Creek	4,426	2,256	.51
Lacks Creek*	13,600	9,656	.71
Windy Creek*	3,300	1,433	.43
Devils Creek	7,966	5,000	.63
Karen Creek	4,120	1,555	.38
Upper Redwood Creek*	8,030	3,475	.43
Simon Creek*	4,635	1,676	.36
Bradford Creek*	6,389	3,780	.58
Coyote Creek*	6,518	2,134	.33
Garrett Creek*	4,538	2,804	.62
Copper Creek*	4,748	2,377	.50

- Mean DL_{95}/TDL = .52

- Standard deviation = .12

* Basins in which all stored sediment was measured. DL_{95} for all other basins determined from qualitative field observations in conjunction with measured reaches in these basins.

organic debris and had high trap efficiencies, but the lifespan of log jams in such stream channels is short; in many cases, the lifespan was less than twenty years. In the lower gradient reaches of Douglas-fir tributaries that are free of log jams, the channel can store large quantities of coarse sediment below the thalweg. The amount of coarse bouldery sediment in storage at these sites is difficult to estimate and this bed material only moves during the more extreme runoff events. We have not yet incorporated this sediment into our storage volume estimates.

Effects of Organic Debris on Landsliding in Tributaries

The presence of large organic debris in channels may also induce small to large scale failures from adjacent hillslopes by diverting flow into banks and undercutting the toe of the slope. This is most obvious in the old-growth redwood forest. For instance, in Tom McDonald Creek, which flows through old-growth redwood, over 56% of the landslide volume delivered to the creek is related to flow diversion by log jams (Table 30). By comparision, only a fraction of the total sediment contribution from landslides in Coyote or Lacks Creek can be attributed to diverted flow around log jams where organic debris consists of smaller logs derived from a predominately Douglas-fir forest.

D. Conclusions

Our study of tributary drainage basins has focused on sediment delivery by streamside landslides and on sediment storage in mainstem reaches. The data presented in this report, although preliminary, does reveal some interesting relationships.

The estimated total amount of stored sediment as well as a brief discussion on the derivation of this quantity was presented earlier. It is our opinion that the given estimate of 1,960,000 tons is realistic. Comparisons between this value and the amount measured for the mainstem of Redwood Creek serve as the only gauge of its validity. The tributary streams store approximately 15 percent as much total sediment as Redwood Creek. The total miles of channel for all main stem tributary creeks is substantially more than the drainage length of Redwood Creek. Thus in terms of sediment storage per unit of drainage length, the tributary basins store only 10 percent as much sediment as Redwood Creek. Sediment source areas within these basins are as large and complex as those that supply sediment directly to the channel of Redwood Creek. The vast difference in sediment storage between tributary streams and Redwood Creek is not a reflection of supply; rather, it is a reflection of transport ability of the two systems. Data presented in Table 26 indicates that the majority of tributary streams are capable of transporting a high proportion of the sediment delivered to them. Earlier investigators (Janda, 1978) support this conclusion by showing that suspended sediment yields (per drainage area) for tributary streams are greater than for Redwood Creek during high runoff events, such as a storm with a recurrance interval of five years or greater. Thus these small order streams are very efficient agents of transport and it appears reasonable they they should store only 10% as much as Redwood Creek on a unit length basis.

Future Work

Further study of tributary streams will be conducted in the coming months. Total stored sediment will be measured for a minimum of four additional creeks both for the purpose of refining our estimate of total sediment and to serve as companion to hillslope erosion studies in those creeks. Additional study of the variables that control or affect sediment storage or sediment transport is also needed.

Our present understanding of the rates and conditions under which sediment moves through tributary channels is only cursory. Characterizing tributary sediment transport under a variety of runoff and landuse conditions is essential for predicting what the future contribution of tributary streams will be.

V. SUMMARY STATEMENT

A. Introduction

The data and analyses presented in this report are the result of a National Park Service research effort that began in the summer of 1979. The object of this research is to construct a sediment budget for the Redwood Creek watershed. When completed, this budget will outline the location and importance of the basin's major sediment source areas, the capabilities of the channel system to transport that sediment, and will address questions concerning the magnitude and variability of its total sediment yield. Over and above its intrinsic scientific value, this information will be of considerable utility in assessing future options concerning management of park resources.

Work to date has been directed along three general lines of inquiry. First, it has attempted to locate and measure the sediment now stored within the channel system. The results of these efforts are summarized in the sections dealing with tributary and main channel stored sediment. Second, it has begun evaluating the importance of streamside landsliding as a sediment source. Data concerning this question are contained in the sections on mainstem and tributary landsliding. The third area of emphasis has been the characterization of the basin's land use history. Initial findings are included as part of the main channel landslide section. Future work will involve refining and extending this data base, as well as generating the additional information and analyses needed to complete the budget.

The present state of the project's findings is summarized by Tables 28 through 31. They are followed by a preliminary sediment budget for those portions of the basin upstream of Highway 299, and an assessment of the impact our work has as regards the current land management policies of Redwood National Park. It should be noted that the work reported here is still in progress, and as such, the results are subject to revision prior to their final publication; however, we feel that its major contributions will not be changed.

TABLE 28

MAIN CHANNEL STORED SEDIMENT[1]

Approximate Location of Stored Sediment	Reach Numbers	Channel Length (km)	A+S+NA[2]	Between 1947 and 1980 Thalwegs	Stable[3]
Redwood Park	1a - 15	32.4	61,721,174	8,380,000	85,394,821
Park Protection Zone	16	9.8	6,163,225	3,820,000	136,445
Between the PPZ and Highway 299	17 - 22	26.9	36,711,205	25,390,000	4,765,580
Upsteam of Highway 299	23 - 36	30.2	34,120,000	12,760,000	7,087,565
TOTAL	1a - 36	99.3	138,715,604	50,350,000	97,384,411

1: All volumes given in cubic feet.

2: A = Active sediment.
S = Semi-active sediment.
NA = Non-active sediment.

These types of stored sediment are considered moveable during discharges up to and including those occurring during a very large flood; e.g., a 100-year event.

3: The minimum residence time of stable sediment is considered to be on the order of 500 - 1,000 years.

TABLE 29

TRIBUTARY CHANNEL STORED SEDIMENT

Tributary	Name	Drainage Area (km²)	Channel-Stored Sediment (tonnes) Measured	Channel-Stored Sediment (tonnes) Statistically Estimated	Ratio:[1] Percent DL95/TDL	Ratio: Percent Stored Sediment / Landslides
	Copper	7.43	18,700		50	14.3
	Tom McDonald	17.95	65,000	134,907	52	64.4
	Devils	18.03	47,000	142,950	63	
Redwood	Bridge	29.53		362,664		
Park	Forty Four	8.08		80,128		
	Harry Weir	7.77		74,480		
	McArthur	9.92		63,259		
	Bond	3.73		15,574		
	Hayes	1.56		2,295		
	Lacks	44.03	120,000	535,800	71	10.1
Park	Coyote	20.41	22,000	28,871	58	7.7
Protection	Garrett	10.75	18,800	26,560	62	10.8
Zone	Panther	15.44		109,624		
	Sweathouse	4.14		32,383		
Between	Cashmere	3.60		15,280		
the PPZ	Wiregrass	4.77		1,690		
and 299	Karen	7.87			38	
	Windy	4.56	116,200	198,789	43	40.1
	Simon	4.51	44,700		36	10.7
Upstream	Bradford	16.50	25,000		33	9.2
of 299	Upper Redwood	11.14	32,700	254,149	43	15.8
	Lake Prairie	8.75		15,917		
	Powerline	1.69		2,552		
Estimated Tributary Channel-Stored Sediment[2], Entire Basin			1,960,000			

1: DL95 = Length of channel containing 95% of the stored sediment.
TDL = Total channel length.

2: Estimation procedure combines statistical estimates and measured totals.

TABLE 30

MAIN CHANNEL LANDSLIDE/BANK EROSION SUMMARY

Slope Condition	Present in 1966 No.	Present in 1966 Vol.*	Initiated 1966 - 1980 No.	Initiated 1966 - 1980 Vol.*	Date of Initiation Uncertain No.	Date of Initiation Uncertain Vol.*	Initiation Date and Landuse Characteristics Not Determined No.	Initiation Date and Landuse Characteristics Not Determined Vol.*
Logged by 1966	260	42,355,145	38	5,127,853	82	1,683,487		
Unlogged in 1966	126	17,163,187	16	446,222	53	939,478		
TOTALS	386	59,518,332	54	5,574,075	135	2,622,965	56	266,327

Total Number of Slides and/or Incidences of Bank Erosion = 627

Total Volume = 67,981,699 ft^3

* Volumes measure in the summer of 1980 (cubic feet).

TABLE 31

TRIBUTARY LANDSLIDES/BANK EROSION SUMMARY

Tributary Location	Name	Drainage Area (km^2)	Number of Measured Landslides*	Estimated Total Landslide Volume* -Entire Basin-
Redwood	Tom McDonald	17.95	65	1,855,790
Park	Copper	7.43	118	2,407,550
Park	Coyote	20.41	66	5,251,160
Protection	Garrett	10.75	23	3,195,080
Zone	Lacks	44.03	157	21,787,120
	Windy	4.56	47	5,326,440
	Simon	4.51	67	7,670,280
	High Prairie	14.25	13	1,229,760
	Minon	11.06	15	1,615,550
Upstream of	Lake Prairie	8.75	59	696,861
Highway 299	Bradford	8.75	51	4,980,500
	Pardee	8.13	8	905,470
	Powerline	1.69	11	1,020,810
	Snow Camp	8.16	38	5,346,040
	Lineament	0.92	9	174,680

* Measurements made February - September, 1980. Volumes given in cubic feet.

B. Preliminary Upper Basin Sediment Budget

The long-term objective of this study is the development of a sediment budget for the Redwood Creek Basin that defines its major sediment sources, the sites of sediment storage, and the overall sediment yield. When all the data is collected and analyzed, we will attempt to outline a rather complex and sophisticated budget showing how sites of erosion and storage, as well as rates of sediment yield, have changed with time. A first step in this process is the calculation of a preliminary simplified budget for the 67.7 square mile upper basin above the USGS gaging station near State Highway 299 (Figure 2). This budget is for water years 1956 - 1980, which defines that period of time starting with the December 1955 flood. The chosen time period is somewhat arbitrary, as it could start as early as the later 1940's or as late as 1964. The only constraints on the time period, for our purposes, is that it should contain the effects of logging and the 1964 storm on erosion and sediment storage in succeeding years up to the present. The budget in Table 32 includes landslide and sediment storage volumes based on field measurements, an estimate of sediment yield based on limited sediment sampling (1973-1978) at the gaging station, and a value for fluvial hillslope erosion that is simply the calculated unknown quantity in the budget. The next stage of our study concentrates on trying to independently generate a value for fluvial hillslope erosion based on basin slope maps, terrain erodibility mapping, land use history, and the road network of the basin.

The budget clearly shows the importance of streamside landsliding as a sediment source and also shows the significant volume of sediment added to channel storage during the 25-year budget period. The input percentage attributed to fluvial erosion is much higher than either of these quantities. However; because it is only a calculated unknown, its value will change as refinements are made in other budget components. Further analysis of the data will allow estimates of residence time for channel bed material in different portions of the watershed. Such detailed tracking of sediment movement with time will be one of the unique and most interesting products of this study.

TABLE 32

SIMPLIFIED SEDIMENT BUDGET FOR 1956 - 1980 FOR THE REDWOOD CREEK BASIN ABOVE THE USGS GAGING STATION #11481500 AT STATE HIGHWAY 299 (DRAINAGE AREA = 67.7 mi^2 OR 175.3 km^2). ALL VALUES IN SHORT TONS. SEDIMENT YIELD VALUE ESTIMATED FROM EXISTING SEDIMENT MEASUREMENTS. FLUVIAL HILLSLOPE EROSION VALUE CALCULATED BASED ON THE OTHER KNOWN VALUES.*

Fluvial Erosion from Hillslopes		Streamside Landsliding Along Main Channel		Streamside Landsliding Along Tributary Channels		Additions to Alluvial Sediment Storage in Main Channel		Additions to Alluvial Sediment Storage in Tributary Channels		Sediment Yield Past USGS Gaging Station
12,470,000 tons	+	4,127,000 tons	+	1,842,000 tons	-	2,807,000 tons	-	421,000 tons	=	15,211,000 tons
68%	+	22%	+	10%	-	15%	-	02%	=	83%

Sediment Inputs to Channel ⟶ Must Equal ⟶ Sediment Stored in Channel or Discharged Out of Basin

* All values listed in the sediment budget are preliminary, and are subject to change.

C. Implications of Progress Report for Park Management

On the basis of our sediment transport and erosion data to date, we see no pressing need for changes in the National Park Service policies currently used in the management of Redwood National Park. We also see no immediate need for changing the current level of National Park Service involvement in the upper basin of Redwood Creek above the park.

Presently the Redwood National Park scientific staff has the opportunity to participate in, and submit written comments on, every timber harvest plan in the upper Redwood Creek basin that is submitted to the California Department of Forestry. We feel that this level of involvement with upper basin land management provides both an adequate and an effective means of minimizing the potential erosional problems resulting from future timber harvesting and road building. In addition, with further analysis of the data in this study, as well as of that obtained from the rehabilitation program (for example see Madej, et al., 1980), more site-specific recommendations for cooperative landowner-National Park Service erosion control projects may be forthcoming. However, such cooperative efforts, if undertaken, would be based on a clearly defined erosion-control need, and should be the result of mutual agreement.

The implications of the data in this progress report on the management of the current erosion control program in Redwood National Park (Kelsey et al., 1979; Madej et al., 1980) are summarized in a recently published report (Kelsey et al., 1981). The main thesis of this report is that in California coastal basins such as Redwood Creek, the major sediment source areas such as aggraded channels, landslides, and severely eroding gully systems, generally occupy small, inaccessible portions of the watershed. These inaccessible areas include the narrow channel bottoms confined between steep hillslopes, as well as the steep basal hillslopes themselves. The best available erosion control techniques, exemplified by those currently in use in Redwood National Park, are quite effective in dealing with erosional problems on most heavily disturbed hillslopes. However, because of the inaccessibility of many of the major sediment source areas, rehabilitative erosion control techniques are only effective up to a certain point. Our contention is that no matter what level of post-disturbance technological expertise or expense is devoted to erosion control in the highly modified basins of northern California, there is a limit to their effectiveness. This limit is set by the physical processes that erode, transport, and store sediment. It would therefore seem reasonable that rather than applying these techniques after the fact that it would be in the best interests of all concerned to incorporate erosion control measures into the design and implementation of responsible timber harvest plans. It is perhaps while serving as a guide for this process that the scientific studies described in this report will find their greatest value.

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