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CHANNEL CHANGES AT CROSS SECTIONS IN REDWOOD CREEK, CALIFORNIA

REDWOOD NATIONAL PARK

RESEARCH AND DEVELOPMENT

TECHNICAL REPORT 12

OCTOBER 1984

SEDIMENT BUDGET PROJECT

In 1978, the National Park Service initiated a study project to formulate a sediment budget for the Redwood Creek basin. This investigation documents and quantifies sediment source areas in the watershed, changes in sediment storage in tributary and mainstem stream channels, and sediment transport out of the basin.Results are presented in a series of Technical Reports and Data Releases, and condensed versions will be published in scientific journals.

NOTICE

This document contains information of a preliminary nature, and was prepared primarily on an interim basis. This information may be revised or updated.

CHANNEL CHANGES
AT CROSS SECTIONS
IN REDWOOD CREEK, CALIFORNIA

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October 1984

ABSTRACT

Between 1973 and 1978, 58 cross sections were established along 108 kilometers of the Redwood Creek stream channel, Humboldt County, California. All cross sections have been resurveyed at least annually since they were established. Major aggradation has been documented throughout the length of Redwood Creek since 1964. Since 1973, the uppermost reaches of Redwood Creek have experienced pervasive scour of the channel bed, with changes in net area and thalweg elevations adjusting accordingly. The streambed elevations of some of these cross sections are approaching pre-aggradation levels. In contrast, the downstream reaches have undergone widespread aggradation. In Water Year 1982, the mean net change in cross-sectional area was 2.1 m^2 of scour. The mean change in thalweg elevation based on cross section data indicated slight scour (0.1 m). The cross sections that did experience aggradation in Water Year 1982 were mostly located in the wide, alluviated downstream reaches of Redwood Creek within the boundaries of Redwood National Park.

Annual water yield and frequency of major runoff events were compared to the percent of cross sections experiencing major change for the Water Years 1974 to 1983. The number of cross sections showing major changes in channel form during a given year is related to the frequency of major runoff events during that year, and to a lesser extent is related to the annual water yield for that year.

In 1975, the location of maximum aggradation was downstream of the gorge (80.3 km downstream of the watershed divide). By 1982 this location was downstream of Forty-Four Creek (91.0 km), which represents a downstream shift of about 11 km. If no large sediment inputs from hillslope processes or major aggradation occur in the near future, the recovery of the main channel of Redwood Creek will be determined primarily by the frequency of moderately high and high runoff events.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following persons and organizations for granting access to or across their property: Joe Massei, Tom Stover, James Russ, the Kerr Ranch and Timber Company, and the Simpson Timber Company. In addition, Mike Nolan of the United States Geological Survey was most helpful in providing information and consultation. I thank Ted Powers for his assistance in the field; Bill Weaver, Danny Hagans, Ron Sonnevil, Ken Utley, Mary Ann Madej, and Mark Haley for reviewing the report; Vicki Ozaki, Mark Haley, and Tom Marquette for preparing graphics; Colleen O'Sullivan for editorial assistance; and Ron Knickerbocker and Susan Richey for typing. Finally I want to thank the support staff at the Arcata office of Redwood National Park. Without the help and support of the above people and companies, the report would not have been possible.

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I. INTRODUCTION

The channel configuration and flow characteristics of the main stem of Redwood Creek, in north coastal California (Figure 1), have changed greatly since the mid-1950's (Janda *et al.*, 1975). A series of intense storms and the advent of widespread timber harvest during this time have been recognized as the major source of this change in Redwood Creek and other nearby north coast streams (Hickey, 1969; Denton, 1974; Kelsey, 1977; Kennedy and Malcolm, 1978; Lisle, 1981). Consequently, recent suspended sediment discharge rates for Redwood Creek are probably 7.5 times greater than the natural erosion rate (Anderson and Brown, 1982; Janda, 1977). Also, there has been a 40 percent increase in the volume of stored sediment in the main channel of Redwood Creek since 1947 (Madej, 1984). Channel characteristics reflecting this increase in stored sediment include a widespread increase in channel width, increased elevation of the streambed, increased channel braiding and a large increase in streamside landsliding (Janda *et al.*, 1975).

Redwood National Park encompasses the lower 40 percent of the Redwood Creek basin. Included here are some of the tallest known trees in the world. Major impacts of recent increases in channel stored sediment on park resources include a drastic decline in anadromous fish populations and habitat. This is due to elevated and widened channels, siltation, loss of streamside canopy and pools, increases in water temperature, loss of streamside shelter for fish, and decreased summer flows (Anderson and Brown, 1982). Also, loss and injury of riparian vegetation has occurred along the main channel of Redwood Creek from abrasion and undermining by deflected stream flow, burial, and drowning by elevated water tables associated with the aggraded stream channel (Figure 2) (Nolan and Janda, 1979).

In 1973, the National Park Service, in cooperation with the U.S. Geological Survey (USGS), initiated sediment studies in Redwood Creek to help formulate management priorities directed at preserving park resources (Janda *et al.*, 1975). Between 1973 and 1978, a total of 58 cross sections were installed along the entire length of Redwood

Creek, producing the longest basin-wide record of channel response available in the region to date (Nolan and Marron, 1984).

The purpose of this study is to document the changes in the channel configuration and elevation of the streambed of Redwood Creek at cross sections during Water Year 1982 (WY 1982). It also summarizes previous work and provides interpretations of channel response during the nine years of record.

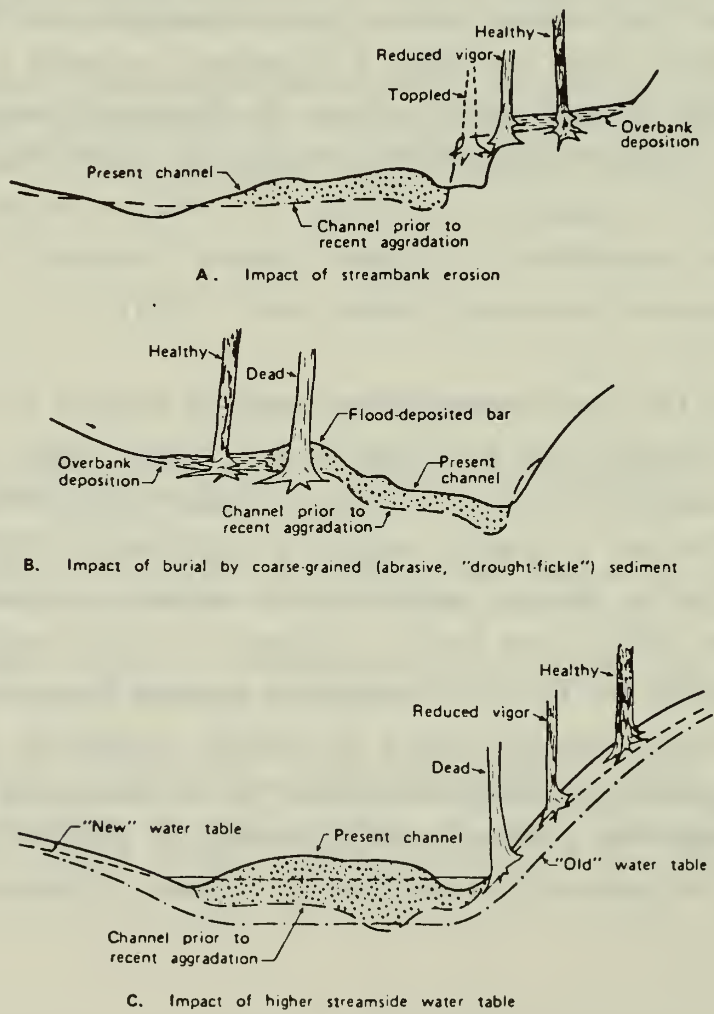

Figure 2: Schematic representation of some adverse impacts of recent channel geometry on streamside vegetation. (Nolan and Janda, 1979).

Figure 1; Cross Section Locations

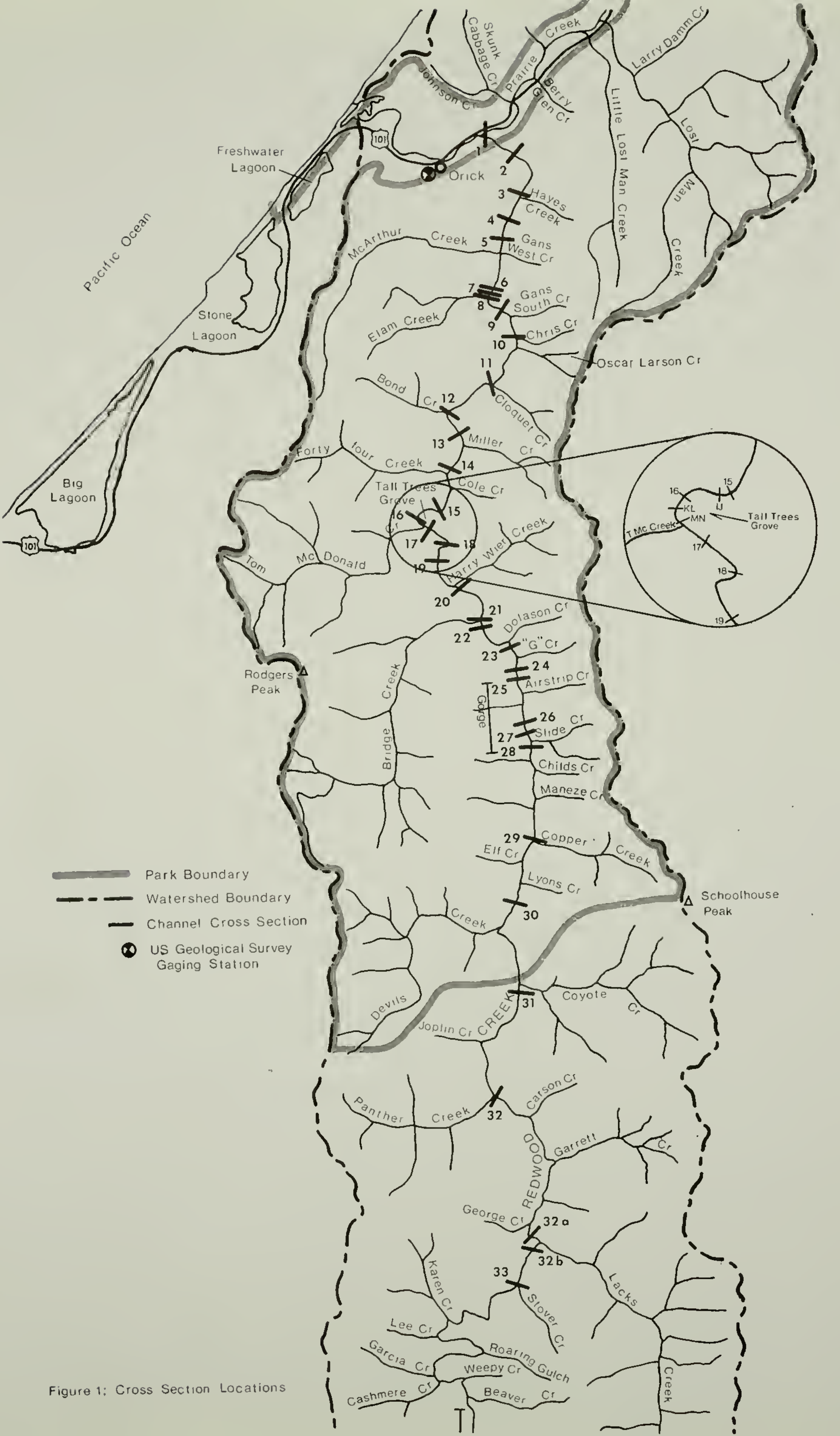

Figure 1: Cross Section Locations

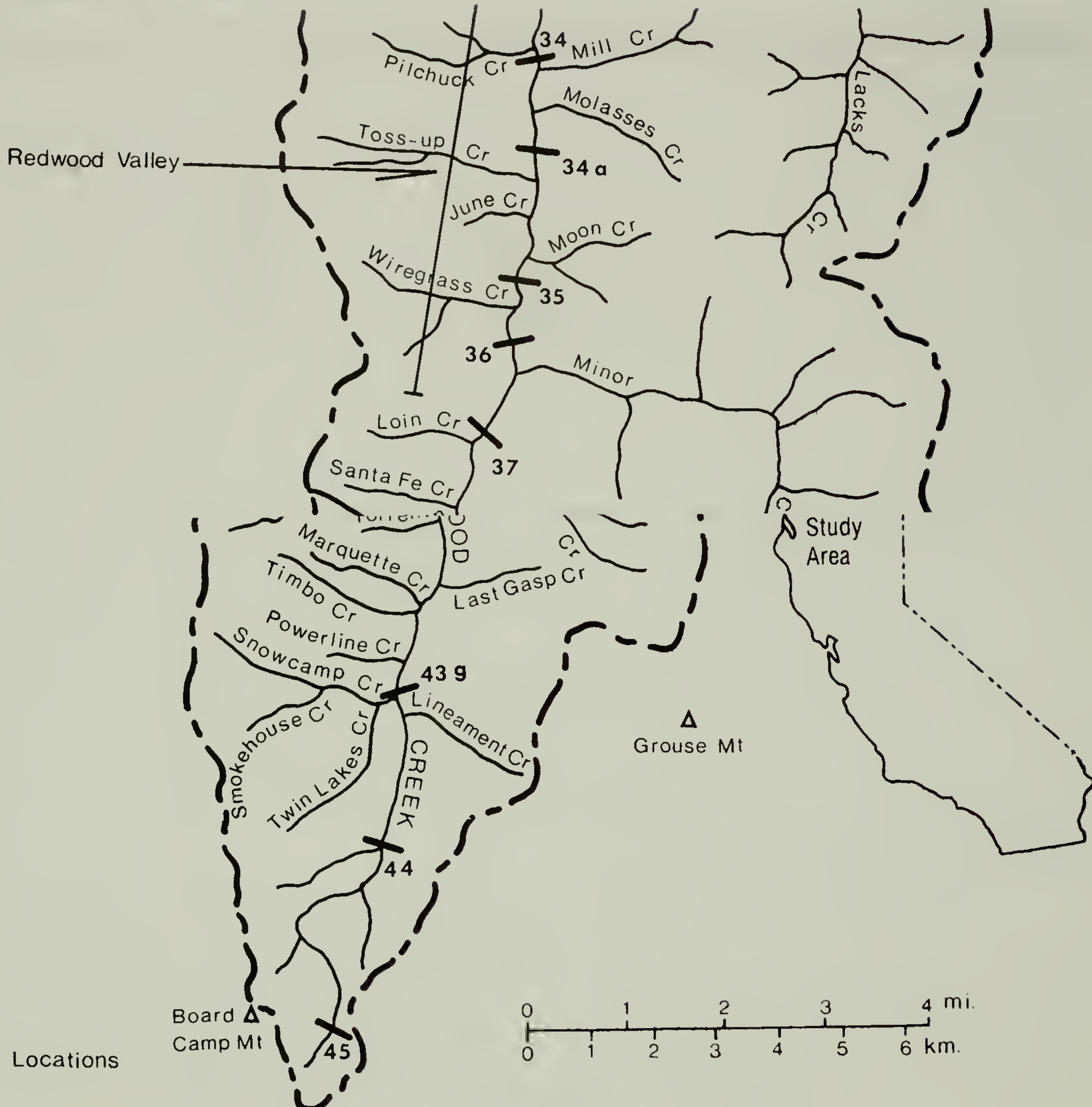

Figure 1: Cross Section Locations

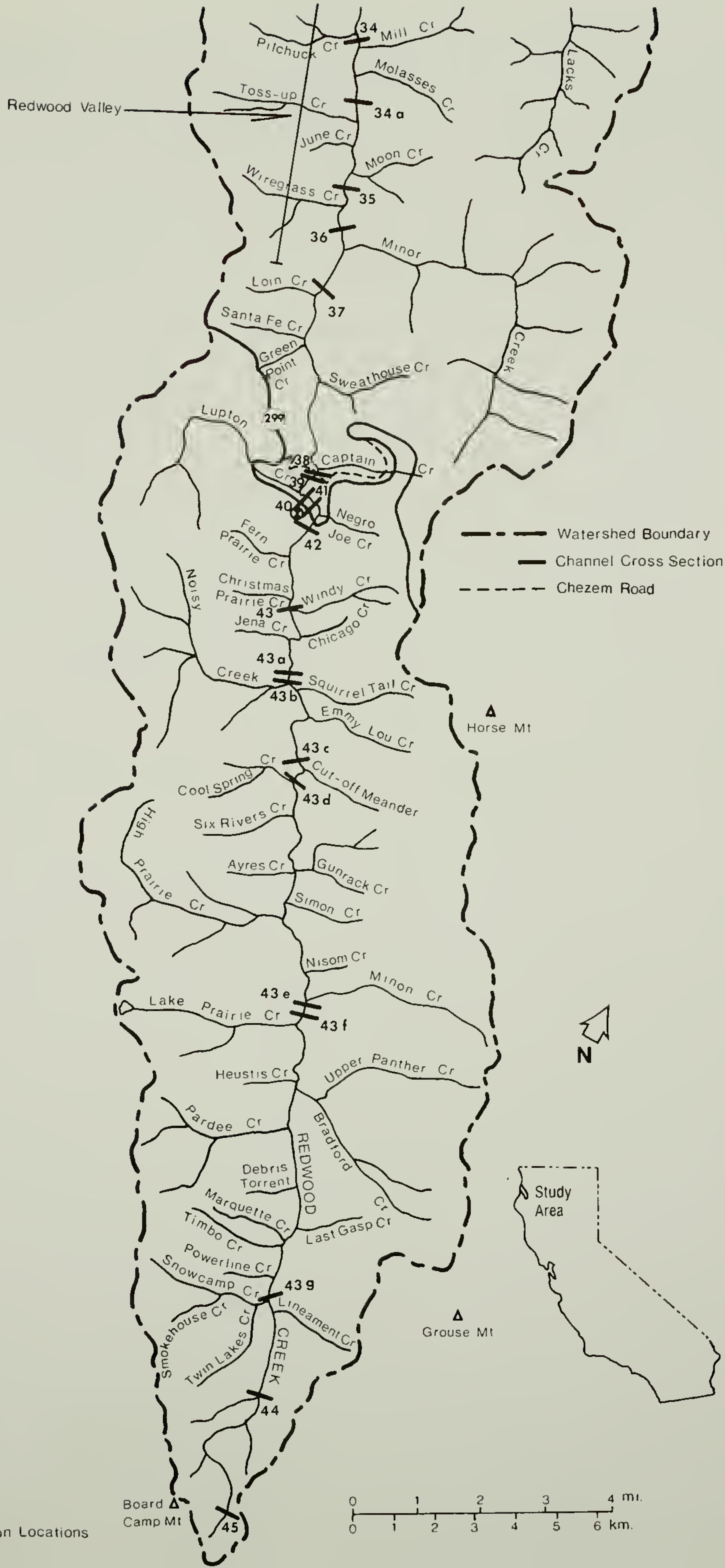

Figure 1: Cross Section Locations

II. PREVIOUS STUDIES

From 1973 to the summer of 1981, the U.S. Geological Survey conducted cross section surveys of Redwood Creek and interpreted the results. For example, Janda *et al.*, (1975) described the major characteristics of the main channel and the hydrologic and physical effects of major storms and land use since 1947. They relied on the use of sequential aerial photographs and stream gaging records. Iwatsubo *et al.*, (1976) published data on main channel cross sections for WY 1974. Nolan (1979) and Nolan and Janda (1979) interpreted the cross-sectional data from 1973 to 1978. Nolan and Marron (1984) provide and interpret data from the cross-sectional surveys measured between 1973 and 1981.

III. STUDY AREA

The main channel of Redwood Creek drains a 720 km^2 area in northwestern California (Figure 1). Basin-wide average rainfall is approximately 2,000 mm, 80 percent of which falls between the months of October and March (Janda, 1975). Total basin relief is 1,615 m. Figure 3 is a longitudinal profile of Redwood Creek.

Most of the Redwood Creek basin is underlain by two distinct rock types of the Mesozoic Franciscan assemblage. The eastern side is underlain by unmetamorphosed sandstones and siltstones, while the western side is underlain by a quartz-mica schist. For most of its 108 km length, Redwood Creek flows along the trace of the Grogan Fault, which juxtaposes the two rock types.

The average gradient for the creek is 1.35 percent. During periods of low and moderate discharge, Redwood Creek flows within an "inner floodplain" that is typically two and one-half to seven times wider than the low water channel (Janda *et al.*, 1975). Winter flows typically occupy the entire inner floodplain for most of the winter season. The inner floodplain either abuts directly against colluvial hillslopes or occasional "upper floodplains." These upper floodplains are inundated by flows during major storms, often resulting in 0.15 to 0.30 m of sand and silt deposition (Janda *et al.*, 1975).

Aerial photographs taken in 1936 and 1947 show the basin covered primarily with old growth redwood forests in the downstream reaches and old growth Douglas-fir forests in the upstream reaches. The main channel had a thick canopy cover in the narrow reaches. Wide alluviated reaches were apparent in Redwood Valley and near the mouth of Redwood Creek (Figures 1 and 3). Many of these alluvial deposits were vegetated with conifers and hardwoods (Madej, 1984). Widespread timber harvest and road construction began in the 1950's. By 1962, 49 percent

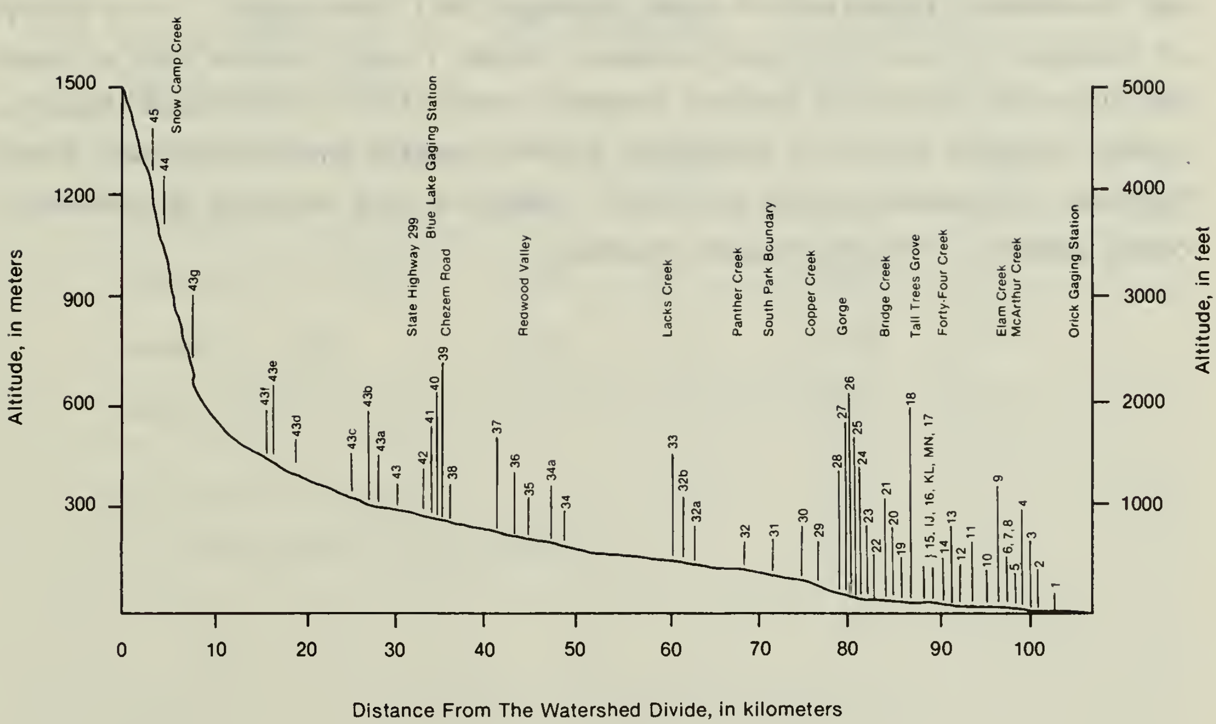

Figure 3: Longitudinal Profile of Redwood Creek showing location of monumented stream channel cross section, major tributaries and roads, and stream gaging stations.

of the old growth coniferous forest upstream of Prairie Creek (102.8 km)* had been logged. By 1978 the figure rose to 84 percent (Best, in press).

Large floods occurred in 1953, 1955, 1964, 1972 and 1975 (Table 1). The 1964 flood caused widespread aggradation, particularly in the upper reaches of Redwood Creek upstream of State Highway 299 (35.0 km). The most prevalent deposits were gravel berms up to 9 meters high consisting of coarse gravel (Madej, 1984). Storms of 1972 and 1975 caused additional aggradation and moved much of the sediment stored in the headwaters (upstream of State Highway 299) downstream. In a study of changes in channel stored sediment, Madej (1984) reports that at least 800,000 cubic meters of bedload sediment derived from 1964 flood deposits passed through the U.S. Geological Survey gaging station site near State Highway 299 between 1965 and 1973. Some of this material is presently being stored in the downstream reaches.

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* - *Kilometer distances following locations and cross sections refer to the distance from the watershed divide of Redwood Creek.*

TABLE 1

Peak Discharges During Major Storms
in the Redwood Creek Basin, 1950-1980 (Harden *et al.*, 1978)

Date	Redwood Creek near Blue Lake		Redwood Creek at Orick	
	cms*	cms/km²	cms	cms/km²
January 18, 1953	-	-	15,240	34
December 22, 1955	3,688	34	15,240	34
December 22, 1964	4,999	46	15,392	34
January 22, 1972	2,103	19	13,807	31
March 3, 1972	4,176	38	15,149	34
March 18, 1975	3,719	34	15,301	34

* - *cubic meters per second.*

IV. METHOD OF STUDY

A technique commonly used to measure stream channel changes is a cross section surveyed between two permanently mounted end points (Emmett, 1974). Annual surveys determine changes in channel width, bed elevations and thalweg position. This provides the basic data needed to quantify channel response to hydrologic and physical variables and the movement of streambed sediment.

Currently, 58 monumented cross sections are distributed along the entire channel of Redwood Creek (Figures 1 and 3). Two of the cross sections were established at the beginning of WY* 1973 along lower Redwood Creek by the National Park Service; 40 additional cross sections were established early in WY 1974; six more cross sections were established by WY 1975 by the U.S. Geological Survey (Nolan, 1979). By WY 1978, an additional ten cross sections were established by the U.S. Geological Survey and the National Park Service.

Cross sections were monumented with 1.2 m lengths of 9.5 mm steel bar or by reference marks on concrete bridge abutments. Steel monuments were driven one meter into the ground and referenced to at least two other triangulation points. Triangulation was by tape and compass. Relative altitudes between end points were established by leveling (Nolan, 1979; Emmett, 1974). Cross sections were surveyed during the summer months with an automatic level and stadia rod or a theodolite and electronic distance meter. Cross section plots and calculations of scour and fill between the summers of 1981 and 1982 were accomplished with the assistance of the U.S. Forest Service Pacific Southwest Laboratory's computer facilities. Some error (≤5 percent) is inevitable while surveying long distances or during poor weather conditions. Information and photographs on the condition of survey monuments, specific erosional or depositional features, bed forms, and bed material were obtained while surveying to assist in the interpretation of cross-sectional changes.

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* *WY represents "Water Year," which extends from October to September (i.e. WY 1982 in October 1, 1981 to September 30, 1982).*

Figure 4 illustrates the terms used in describing changes at the cross sections. The thalweg is the lowest point in the streambed in cross-sectional profile. The streambed is the area that becomes completely

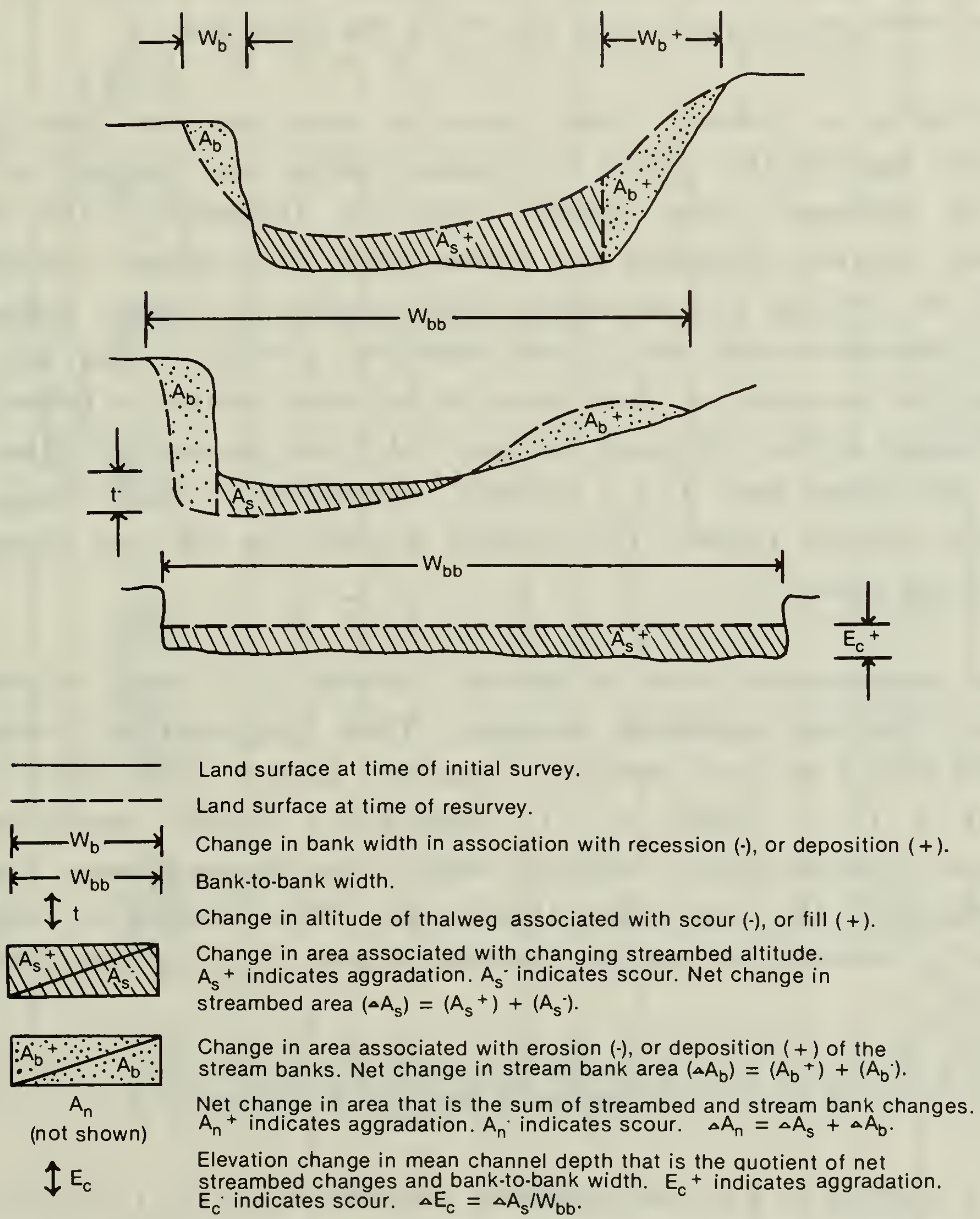

Figure 4: Explanation of cross-sectional change shown in Table 2 and Figure 5. (Modified from Nolan and Janda, 1979).

inundated by winter flows. The width of the streambed may vary from year to year, depending on the magnitude of winter flows and bank erosion. In Redwood Creek, the streambed represents 80 to 95 percent of the entire cross-sectional profile and therefore is the most important factor in computing area change. Net streambed area change (ΔA_s) is the net difference between scour and fill in the streambed.

Stream banks in Redwood Creek consist of either alluvium from upper floodplain deposits that rise 2 to 3 meters above the streambed or the base of hillslopes rising directly from the streambed. The exact boundary between streambed and stream bank is sometimes subjective. Criteria for locating this boundary include vegetation breaks, highwater marks, breaks-in-slope and upper floodplain surfaces. The distance between this boundary on both sides of the cross section is termed the bank-to-bank width. Net area changes (ΔA_n) are the sum of streambed (ΔA_s) and stream bank (ΔA_b) changes. Summaries of these changes at the cross sections between the summers of 1981 and 1982 are shown in Table 2 and Figure 5.

Another characteristic used to describe variation at a cross section is change in the mean streambed elevation. Table 2 provides the change in net area (ΔA_n) at cross sections. However, bank-to-bank widths vary from 12 to 144 m (Table 3). To compare the relative importance of change at cross sections of different widths, the change in mean streambed elevation (ΔE_c) was used (Figure 6). This normalized value is derived by dividing net change in streambed area (ΔA_s) by bank-to-bank width (W_{bb}):

$$\Delta E_c = \Delta A_s / W_{bb}$$

Thus, a lowering of the mean streambed elevation of 0.15 m (ΔE_c = 0.15 m, scour) has the same percent change in a 10 m wide cross section as it has in a 100 m wide section, even though more material moves through the wider cross section.

TABLE 2

Net changes in the Redwood Creek stream channel at cross sections from the summer of 1981 to the summer of 1982.[1]

			CHANGE IN AREA						
					At Left Bank		At Right Bank		
			Associated With Streambed Altitude		Change in Width	Change in Area	Change in Width	Change in Area	
Cross Section Number	Interval of Measurements	Change in Altitude of Thalweg	Aggradation $A_s+(m^2)$	Scour $A_s-(m^2)$	$W_b(m)$	$A_b(m^2)$	$W_b(m)$	$A_b(m^2)$	Net Change in Area $A_n(m^2)$
1	6/15/81 - 7/21/82	0.4	41.2	36.5	0	0	0	0	4.7
2	6/16/81 - 7/21/82	-0.6	43.8	49.4	0	0	0	0	-5.6
3	6/18/81 - 7/21/82	-0.1	5.1	27.2	0	0	0	0	-22.1
4	7/27/81 - 7/22/82	-0.1	7.6	18.7	0	0	0	1.9	-9.2
5	7/27/81 - 7/15/82	-0.1	26.2	21.7	-1.2	1.4	0	0	4.7
6	7/30/81 - 7/15/82	0.1	14.9	10.3	-0.8	-0.7	0.6	1.1	5.0
7	7/30/81 - 7/15/82	0.1	9.9	4.7	0	0	0	-0.7	4.5
8	7/30/81 - 7/14/82	0.2	26.0	9.7	0	0	0	0	16.3
9	7/30/81 - 7/14/82	-0.4	11.4	18.2	-0.6	-0.9	0	0	-6.8
10	7/30/81 - 7/13/82	0.1	25.9	7.5	0	0.4	0	0.7	19.5
11	7/31/82 - 7/13/82	0.3	13.5	2.2	0	0	0	-0.1	11.2
12	7/29/81 - 7/13/82	-0.5	12.3	6.4	0	0.3	0	-0.4	5.8
13	7/29/81 - 7/13/82	0.7	41.7	1.9	0	0	0	-0.1	39.7
14	7/31/81 - 6/30/82	-0.2	7.7	5.1	0	0.3	0	0	2.9
15	7/23/81 - 8/20/82	0.5	3.8	15.8	0	0	0	0	-12.0

1 - *See Figure 4 for explanation of terms.*

TABLE 2

Net changes in the Redwood Creek stream channel at cross sections from the summer of 1981 to the summer of 1982.[1]

Cross Section Number	Interval of Measurements	Change in Altitude of Thalweg	CHANGE IN AREA: Associated With Streambed Altitude: Aggradation $A_s+(m^2)$	Scour $A_s-(m^2)$	At Left Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	At Right Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	Net Change in Area $A_n(m^2)$
IJ	7/23/81 8/20/82	-0.2	54.2	50.4	0	0	0	0	3.8
16	7/23/81 - 6/30/82	-1.0	22.3	17.4	BANK FAILURE		0	0	4.8
KL	7/23/81 - 6/28/82	-0.6	14.2	33.2	0	0	0	0	-19
MN	7/23/81 - 6/02/82	-0.3	28.7	8.4	0	0	0	0	20.3
17	7/21/82 - 6/22/82	0.5	3.6	16.5	0	0	0	0	-12.9
18	7/21/81 - 10/04/82	-0.6	7.3	18.1	0	-0.3	BANK FAILURE		-11.1
19	7/24/81 - 7/01/82	-0.1	15.9	52.7	0	-3.1	0	1.4	-38.5
20	7/24/81 - 6/29/82	1.7	16.2	9.7	0	0.4	0	0	6.9
21	7/22/81 - 6/29/82	0.1	6.4	18.5	BANK FAILURE		0	-0.2	-12.3
22	7/22/81 - 6/29/82	-0.5	5.8	15.3	0.3	0	1.2	1.0	-8.5
23	7/22/81 - 7/21/82	-0.6	1.0	26.4	0	-0.3	-1.0	-2.1	-27.8
24	7/22/81 - 7/12/82	-0.3	5.8	17.1	0	0	0	0	-11.3
25	7/22/81 - 7/12/82	-0.2	1.4	16.6	0	0.2	0	0	-15.2
26	6/25/81 - 8/23/82	-0.3	4.8	34.7	0	-0.1	0	0	-29.9
27	6/25/81 - 6/23/82	-0.1	2.8	17.6	0	-0.1	0	0	-14.8

1 - *See Figure 4 for explanation of terms.*

TABLE 2

Net changes in the Redwood Creek stream channel at cross sections from the summer of 1981 to the summer of 1982.[1]

Cross Section Number	Interval of Measurements	Change in Altitude of Thalweg	CHANGE IN AREA: Associated With Streambed Altitude: Aggradation $A_s+(m^2)$	Scour $A_s-(m^2)$	At Left Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	At Right Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	Net Change in Area $A_n(m^2)$
28	6/25/81 - 8/28/82	0.1	2.7	4.5	0	-0.1	0	1.0	-0.9
29	6/24/81 - 8/24/82	0.4	16.4	1.8	0	0	0	0	14.6
30	6/14/81 - 8/24/82	-0.1	2.6	2.9	0	0	0	-0.2	0.5
31	7/07/81 - 8/25/82	0.3	0.5	2.1	0	0	0	0.1	-1.5
32	6/23/81 - 8/25/82	-0.3	0.9	8.3	10	0	0	0.3	-7.1
32a	6/22/81 - 7/08/82	-0.2	3.8	10.6	0.6	1.2	0	0.3	-5.3
32b	6/22/81 - 7/08/82		BULLOOZED SUMMER OF 1982						
33	6/23/81 - 7/08/82	-0.1	5.0	5.4	0	0.8	0	-1.7	-1.3
34	6/23/81 - 7/07/82	-0.4	0.3	11.8	0	-0.7	0	0.6	-12.8
34a	8/05/81 - 7/07/82	-1.1	30.2	26.0	0	1.2	0	0	5.4
35	6/18/81 - 7/05/82	-0.1	0.4	5.7	0.2	0.6	0	0	-4.7
36	6/18/81 - 7/06/82	-0.3	1.5	11.4	0	0.5	0	0	-9.4
37			OATA NOT AVAILABLE						
38			OATA NOT AVAILABLE						
39	6/18/81 - 7/06/82	-0.4	0.7	8.7	-0.6	-1.2	0	0	-9.2

1 - *See Figure 4 for explanation of terms.*

TABLE 2

Net changes in the Redwood Creek stream channel at cross sections from the summer of 1981 to the summer of 1982.[1]

Cross Section Number	Interval of Measurements	Change in Altitude of Thalweg	CHANGE IN AREA: Associated With Streambed Altitude: Aggradation $A_s+(m^2)$	Scour $A_s-(m^2)$	At Left Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	At Right Bank: Change in Width $W_b(m)$	Change in Area $A_b(m^2)$	Net Change in Area $A_n(m^2)$
40	6/18/81 - 7/05/82	-0.3	1.5	6.7	-0.3	-0.9	1.6	-0.6	-6.7
41	6/17/81 - 7/05/82	-0.1	1.0	0.7	0	0	0	0	0.3
42	6/30/81 - 7/05/82	-0.2	2.3	3.3	0	0	0	0.1	-0.9
43	6/29/81 - 8/09/82	0	2.1	9.5	0	0	0	0	-7.4
43a	6/30/81 - 8/04/82	-0.1	6.2	6.1	0	0.6	0	-0.2	0.5
43b	6/30/81 - 8/04/82	0	4.8	6.4	0	0	0	0	-1.6
43c	6/29/81 - 8/03/82	-0.5	3.9	5.7	-1.4	-2.8	1.4	2.1	-2.3
43d	6/29/81 - 8/03/82	-0.4	1.7	8.9	0	-0.4	0	0	-7.6
43e	8/19/81 - 8/02/82	-0.1	0.7	5.7	0	0.1	0	0	-4.9
43f	8/19/82 - 8/02/82	0	3.4	5.1	0	-0.3	0	0.4	-1.6
43g	8/19/81 - 8/10/82	-0.4	1.7	4.0	-0.9	-2.5	-1.1	-1.1	-5.9
44	8/20/81 - 8/10/82	-0.1	1.2	4.8	0.4	0.5	-0.7	-0.8	-3.9
45	8/19/81 - 8/10/82	0	0.1	0.6	0	0	0	0.2	-0.3

1 - *See Figure 4 for explanation of terms.*

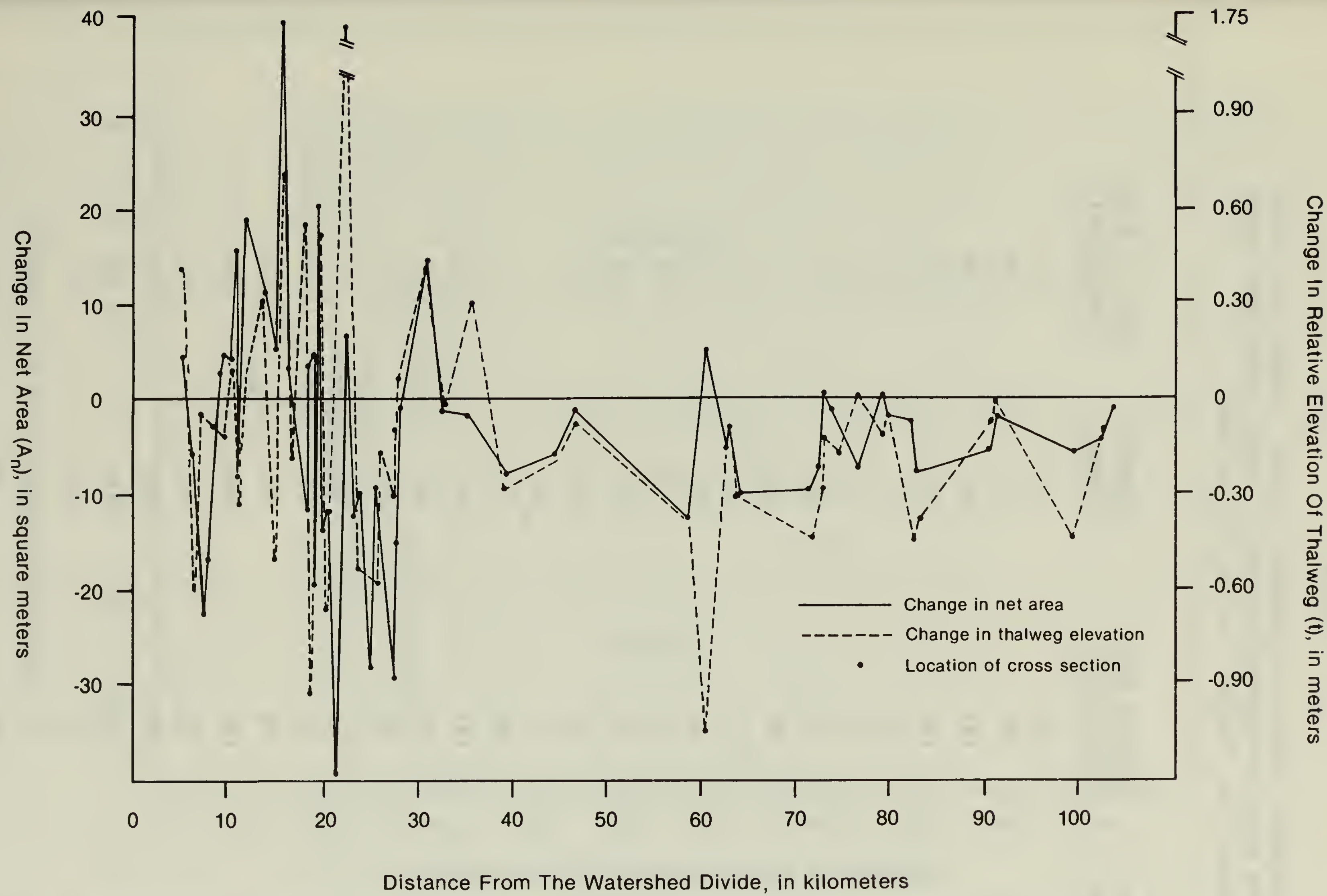

Figure 5: Summary of net area changes (An) and changes in thalweg elevation (t) in the Redwood Creek stream channel at cross sections for WY 1982.*

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* *The lines connecting the observation points have no physical meaning, but are shown to indicate the sequence of observations along the Redwood Creek stream channel.*

TABLE 3

Bank-to-bank width of Redwood Creek channel at cross sections as of the summer of 1982. These values were used to calculate the change in mean channel depth.

Section Number	Bank to Bank Width (m)	Section Number	Bank to Bank Width (m)
1	133	27	44
2	142	28	90
3	127	29	66
4	144	30	37
5	108	31	25
6	112	32	35
7	58	32a	71
8	88	32b	-
9	111	33	43
10	96	34	67
11	67	34a	85
12	75	35	48
13	70	36	40
14	61	37	-
15	60	38	-
IJ	137	39	30
16	85	40	32
KL	74	41	27
MN	113	42	33
17	73	43	49
18	76	43a	56
19	120	43b	59
20	57	43c	47
21	69	43d	40
22	58	43e	48
23	72	43f	31
24	67	43g	49
25	45	44	15
26	47	45	12

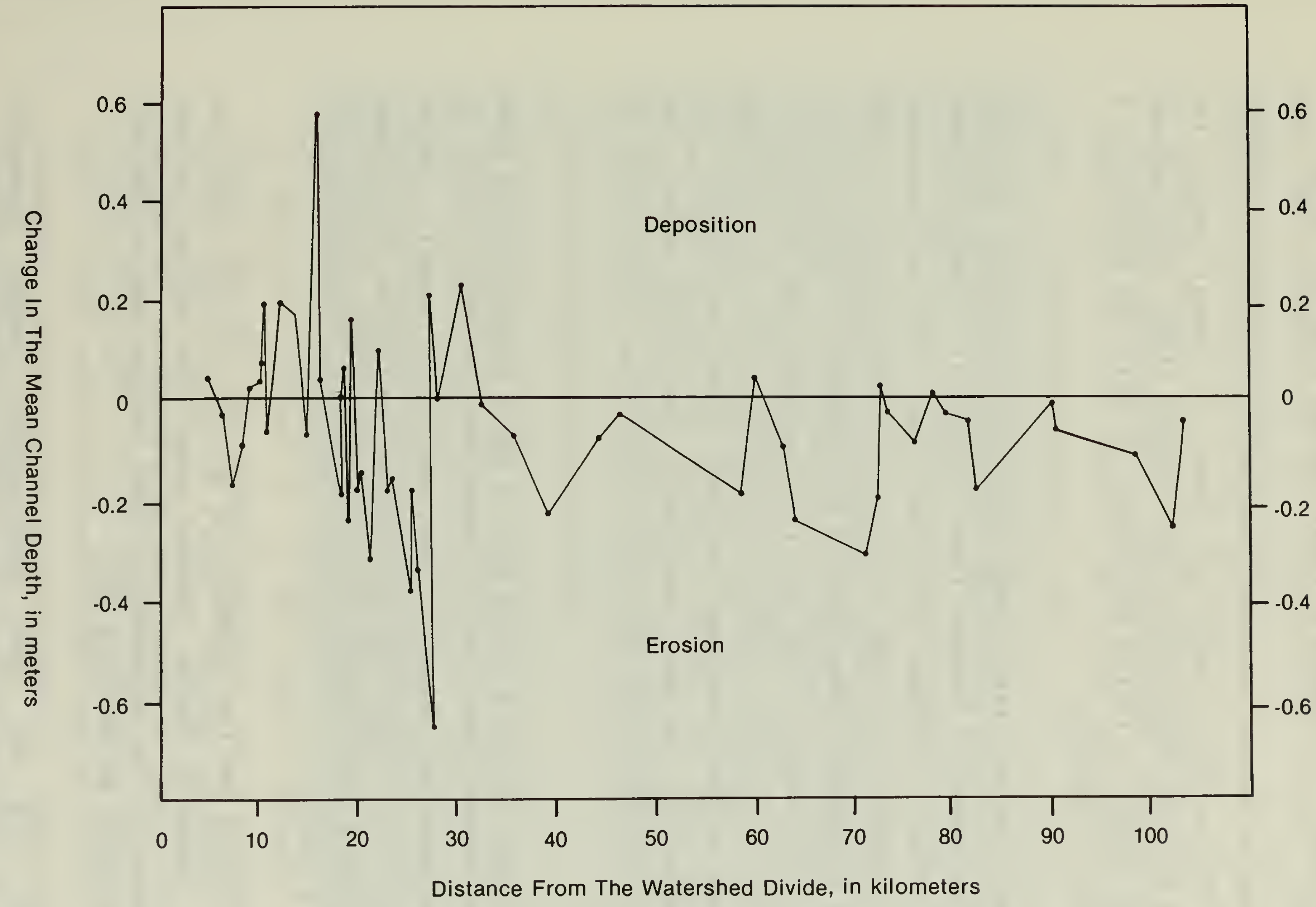

Figure 6: Summary of net changes in the streambed elevation (ΔE_c) of the Redwood Creek stream channel at cross sections between the summers of 1981 and 1982.*

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* *The lines connecting the observation points have no physical meaning, but are shown to indicate the sequence of observations along the Redwood Creek stream channel.*

V. DISCUSSIONS AND RESULTS

A. Summary of Changes at Cross Sections From 1973 to 1981

The U.S. Geològical Survey conducted cross-sectional surveys in Redwood Creek from 1973 to 1981. Nolan and Marron (in press) discuss the history of the channel changes since the initiation of the cross-sectional surveys in the summer of 1973 to the summer of 1981. The following is a summary of their conclusions.

1. During WY 1974 and 1975, large quantities of sediment aggraded reaches downstream of Panther Creek (Figure 1), whereas channel scour was dominant upstream of Panther Creek. This may represent removal of sediment deposited in upstream reaches during the 1964 storm and subsequent redeposition of this material in lower reaches. The mean net change in area (ΔA_n) at measured cross sections for WY 1975 was 7.2m² (fill). Bank erosion occurred at over two-thirds of the cross sections throughout the basin during this period. The area experiencing the most aggradation and bank retreat was immediately downstream of the rocky gorge below Cross Section 26 (Figure l).

2. Channel changes during WY 1976 were of lesser magnitude than those during the previous years due to exceptionally low flows during the year. The mean net change in area was 2.2 m² (scour). Despite this reduction in magnitude, the spatial distribution of changes appears to have been roughly similar to those observed during the preceding 2 years.

3. During continued low flow conditions of WY 1977 and 1978, there was a greater tendency towards channel scour than during previous years. However, the magnitude of these changes was considerably less than those of WY 1974 and 1975.

4. During WY 1979 and 1980, cross-sectional changes apparently returned to conditions similar to those which existed during WY 1974

and 1975 when channel fill dominated downstream reaches. The magnitude of changes during 1979, however, continued to be far less than those recorded for WY 1974 and 1975. In WY 1979 the mean change in net area was 0.68 m^2 (fill).

5. Although changes during WY 1981 were relatively minor, they showed an overwhelming tendency toward pervasive channel scour with the mean ΔA_n = 2.1 m^2 (scour). Of the 50 cross sections measured that year, 27 were characterized by scour.

B. *Cross-Sectional Changes in Redwood Creek by Reach From 1973 to 1982*

The morphology of the Redwood Creek channel changes dramatically throughout its 108 km length, varying from narrow high gradient areas to wide, alluviated, gentle reaches. In the following discussion, the main channel has been divided into ten separate reaches, separated on the basis of channel width, channel gradient and locations of cross sections. Preliminary data provided by Nolan and Marron (in press) on cross sections from 1974 to 1981 have been used in the following interpretations.

1. Upstream of Highway 299, Cross Sections 43 (31.6 km) - 45 (4.7 km)

The distribution of the ten cross sections in this reach is sparse and inferences based on cross-sectional data are rather general. Bank-to-bank width varies from 12 m to 84 m with an average width of about 45 m (Figure 7). In WY 1982, all sections, except Cross Section 43a (29.1 km) showed net scour (ΔA_n) ranging from 0.3 to 7.6 m^2 with a mean of 3.9 m^2. Thalweg elevations at six cross sections also decreased while four showed no change. These elevation changes ranged from -0.1 to -0.5 m, averaging -0.2 m. The trend in scour in this reach has generally been evident since 1974, although scattered locations experienced occasional fill. Major annual changes in mean streambed elevation (ΔE_c) of up to -0.29 m of scour did occur throughout the years of record, but locations were variable.

Figure 7: Channel configurations in the long reach above State Highway 299 are highly variable. Configurations range from small valleys with low gradients to steep and narrow channels clogged with boulders up to 4 m in diameter. In general, bed material sizes tend to be large and channel widths narrow, as in this photograph near Cross Section 43g.

2. Highway 299 to Chezem Road, Cross Sections 38[1] (36.5 km) - 42 (34.4 km)

There are five cross sections in this 2.0 km length of the channel. This area is typified by a narrow channel (W_{bb} = 29 to 35 m) with high, steep banks (Figure 8). All sections scoured during WY 1982 except one, which showed minor fill. All had decreasing thalweg elevations, with Cross Section 39 (36.5 km) decreasing as much as 0.4 m. Two of the scouring cross sections experienced a major change in mean streambed elevation (ΔE_c) of -0.20 and -0.31 m. This is a continuing trend that has been evident since 1974. Thus, in this reach, all major streambed changes (defined as $\Delta E_c \geq 0.15$ m) have been scour.

In 1958 and 1973, cross-sectional information was obtained from USGS stream gaging records from the Blue Lake gaging station on Redwood Creek [located at Cross Section 40 (35.5 km)]. Records show that between 1958 and 1973, the mean streambed elevation (ΔE_c) rose more than 1.0 m and that the thalweg rose more than 1.2 m (Figure 9)(Nolan and Janda, 1979)[2]. In the 1982 water year, the thalweg was less than 0.5 m above the 1958 level, having lowered nearly 0.3 m during WY 1982.

The area between the headwaters and this reach was the area most severely affected by the 1964 storm and flood (Kelsey *et al.*, 1981). The close spacing of cross sections in this reach probably best documents the channel scour observed throughout the creek upstream of the Blue Lake gaging station.

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1 Cross section 38 is not included in the WY 1982 analysis due to surveying errors.

2 The total amount of aggradation following the 1964 flood may have been considerably greater than this, but documentation is lacking since gaging station records were discontinued between 1958 and 1973 (Nolan and Janda, 1979).

Figure 8: Much of the Channel between Highway 299 and Chezem Road has a consistent width of 30 to 40 m. Records from the U.S.G.S. gaging station near Blue Lake (located at Cross Section 40) together with cross section data indicate stream degradation since 1973 in both this reach and the reach above Highway 299.

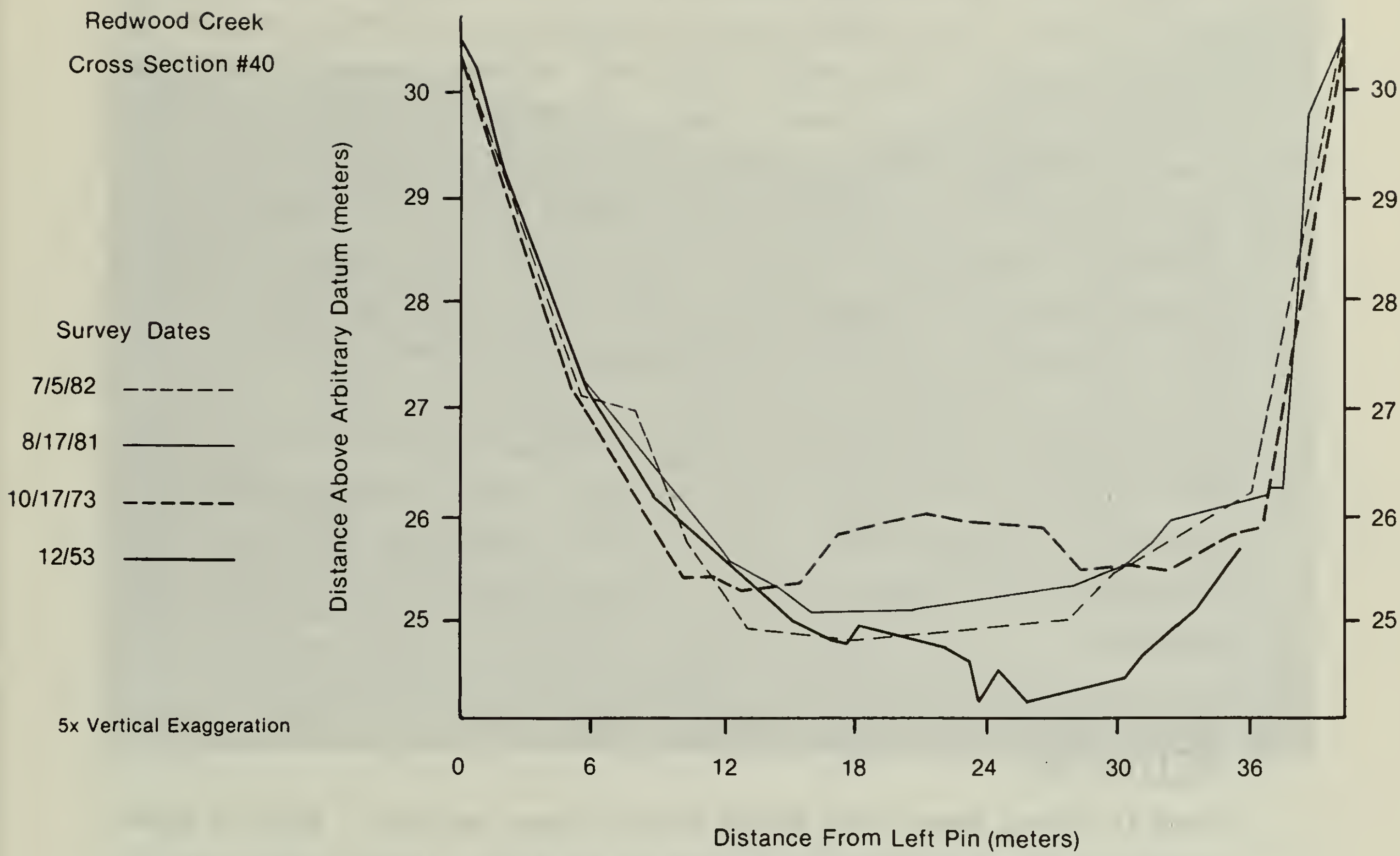

Figure 9: Cross Section at the U.S.G.S. gaging station on Redwood Creek near Blue Lake. Cross sections at or above this location have shown persistent scour for nine years.

3. Redwood Valley, Cross Sections 34 (49.1 km) - 37[3] (42.8 km)

In this reach the channel becomes wider, with valley widths of 50 to 150 m (Figure 10). Bank-to-bank widths are up to 100 m (from 40 to 130 m) narrower since some of the older sediment storage bars have not been affected by recent flows. In WY 1982, three of the four cross sections surveyed showed net scour(ΔA_n) up to 12.8 m². All thalweg elevations lowered by an average of 0.2 m. Cross Section 34a (48.0 km)(Figure 11) showed only a minor rise in mean streambed elevation (ΔE_c = 0.04 m) but did experience major channel shifting and a large decrease in the thalweg elevation (1.1 m).

In this reach, the values for ΔE_c were high ($\geq$0.15m) for the high flow years of 1974 and 1975, but they often fluctuated annually between scour and fill. The low flow water of 1978 also had unusually high values for ΔE_c, reflecting scour at three of the cross sections.

4. Stover Creek to Copper Creek, Cross Sections 29 (77.2 km) - 33 (61.4 km)

This is a long reach with widely spaced cross sections. Bank-to-bank widths at cross sections vary from 25 to 70 m. Valley walls tend to be steep, with little room for extensive storage bars. The creek flows through a rocky channel with a moderate gradient (0.35 percent) (Figure 12).

Change in thalweg elevations ranged from 0.4 m fill to -0.3 m scour during WY 1982, with four of the six cross sections here experiencing lowered thalwegs. In five cross sections, net area change (ΔA_n) resulted in scour, averaging 3.4 m². Cross Section 29 (72.2 km) showed a net fill (A_n) of 14.6 m². Data from cross section 32b was unavailable due to channel disturbance.

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[3] *Cross section 37 is not included in the WY 1982 due to surveying errors.*

Figure 10: In Redwood Valley, channel widths up to 180 m are common and the streambed gradient is gentle. The lack of older vegetation on the storage bar indicates recent inundation by high flows.

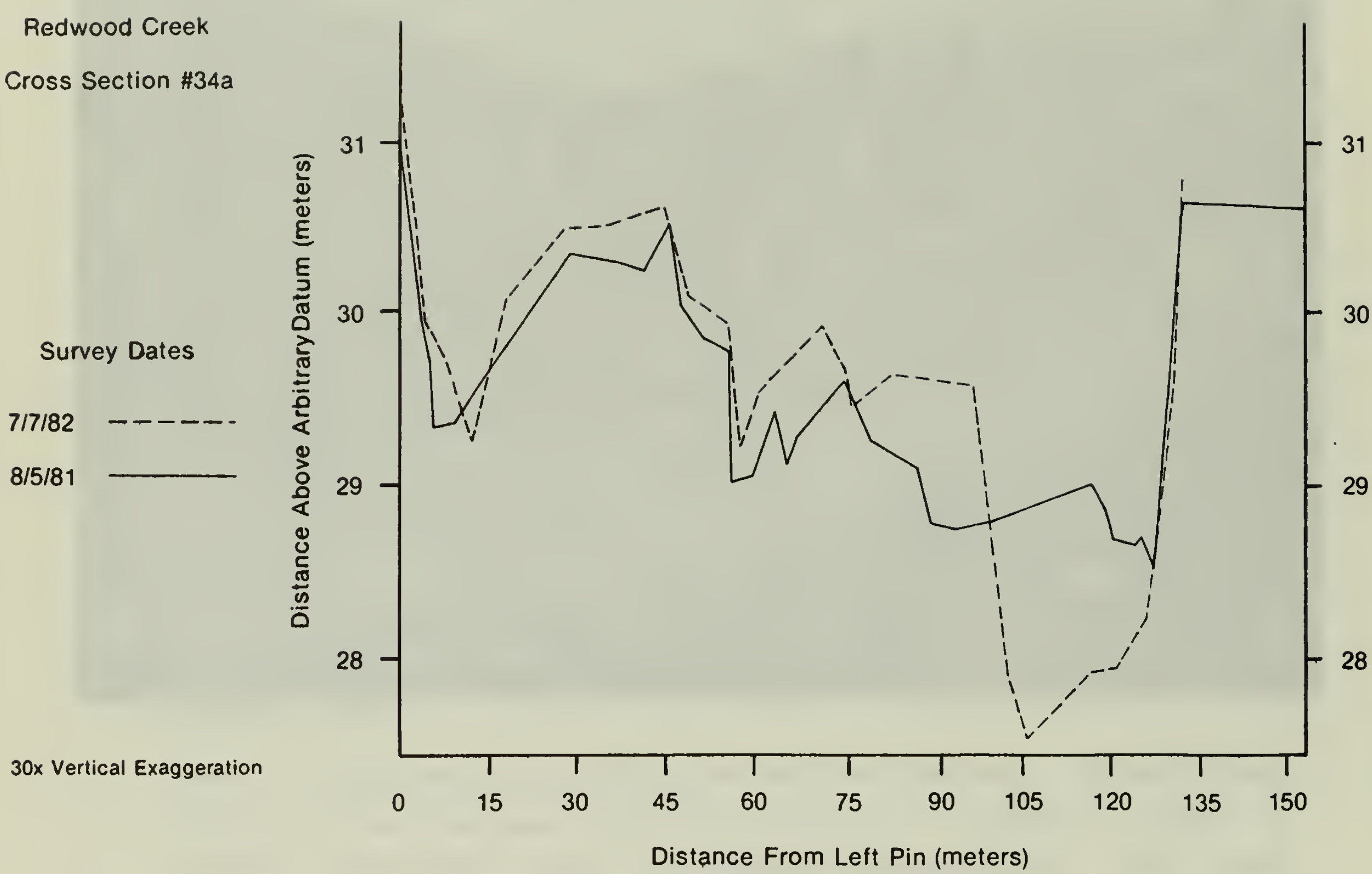

Figure 11: Although this cross section showed a small net area change, there were major changes in thalweg shifting and thalweg elevation.

Figure 12: In the reach between Stover and Copper Creeks, the channel again becomes narrow. This photograph is looking upstream from Cross Section 32.

5. Upstream End of the Gorge, Cross Sections 26 (80.3 km) - 28 (80.0 km)

This area occupies the upper end of what is generally referred to as the gorge. Large earthflows entering the creek from the east side have resulted in a narrow, extremely rocky channel with a steep gradient (1.4 percent). These cross sections exhibit an atypically wide reach for this area (47 to 90 meters)(Figure 13) and may serve as a temporary storage area (Cross Section 26, Figure 14). As a consequence, these cross sections may have had no trend in scour or fill. In WY 1982, values for ΔE_c at two of the cross sections were -0.22 m (scour) and -0.65 m (scour) with the remaining cross section showing no ΔE_c. Values for change in thalweg elevations, however, ranged only up to -0.3 m (scour) in WY 1982.

Figure 13: This reach provides space for temporary sediment storage. Earthflows (left) entering from the east side of the channel are major sediment contributors. This photograph is looking upstream from Cross Section 28.

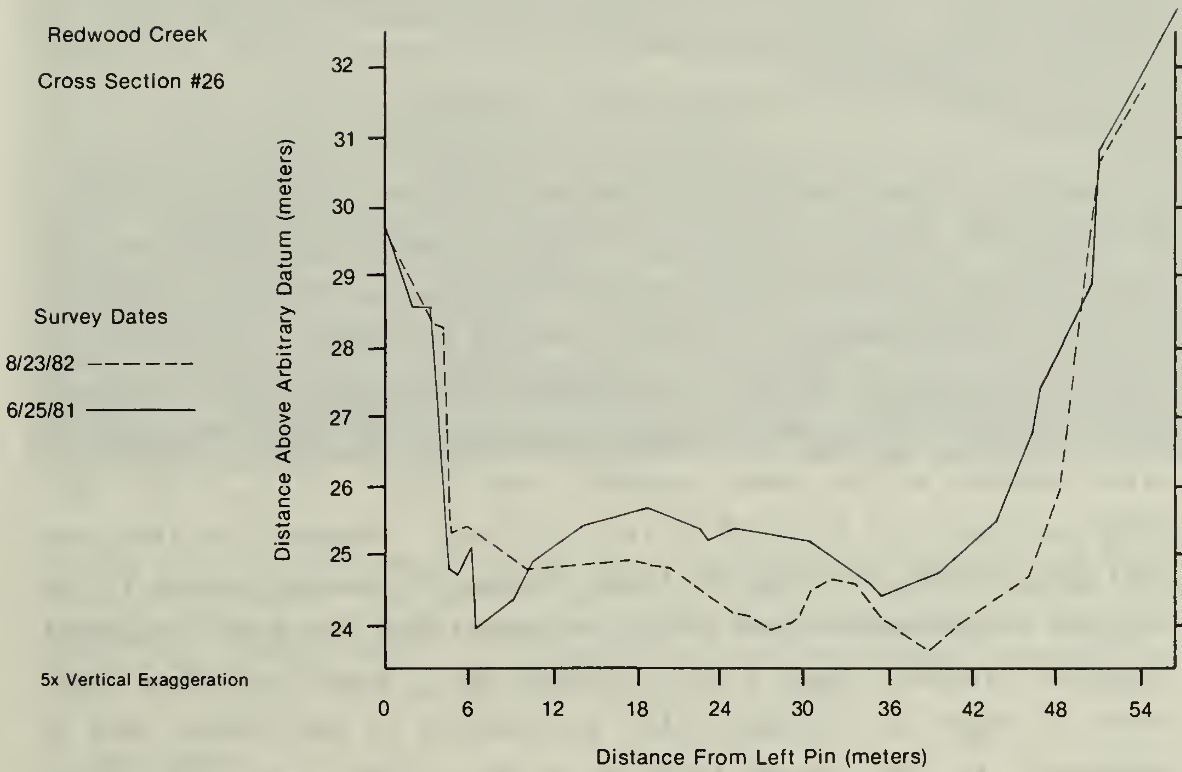

Figure 14: Major changes in mean channel depth in the area immediately above the gorge are common.

6. Base of Gorge to Bridge Creek, Cross Sections 22 (84.3 km) - 25(82.1 km)

The base of the gorge marks the beginning of the wide alluvial channel typical of lower Redwood Creek (Figure 15). Bank-to-bank widths (W_{bb}) at these four cross sections range from 45 to 72 m. In WY 1982, ΔA_n at all four cross sections showed scour, averaging 15.9 m². All thalwegs scoured (up to -0.6 m.).

Due to the abrupt increase in channel width and decreasing channel gradient, ΔE_c at these cross sections are usually the highest for the entire channel. In WY 1975 this reach experienced major aggradation, with ΔE_c values ranging up to 1.4 m and averaging 0.64 m for the four cross sections in this reach. Since then, these cross sections have generally experienced scour. During WY 1981 and WY 1982, all cross sections in this reach scoured, with values of ΔE_c in WY 1982 ranging from -0.16 to -0.38 m ($\bar{x}$ = 0.25 m). Between WY 1975 and 1982 the thalweg elevation at Cross Section 25 lowered about 1.3 m and the accumulated values of ΔE_c indicated that the mean streambed elevation lowered about 1.0 m (Figure 16). Based on these data alone, it might be concluded that this section of the channel bed is returning to its pre-aggradation levels. This was the reach considered to be the locus of maximum aggradation in 1976 (Nolan and Janda, 1979).

7. Bridge Creek to the Tall Trees Grove, Cross Sections 18 (87.7 km) - 21 (84.6 km)

This reach is characterized by a wide alluvial channel, with bank-to-bank widths ranging from 57 to 120 m. In WY 1982 changes in net area (ΔA_n) at Cross Section 20 resulted in 6.9 m² of fill, while the other three cross sections scoured, up to 38.5 m². Thalweg elevation changes ranged from 1.7 m fill to -0.6 m scour.

Figure 15: Downstream of the gorge, the riparian vegetation of Redwood Creek is typically old growth redwood forest. The streambed is also characterized by a wide alluviated channel. Between the base of the gorge and Bridge Creek, E_c values have been the highest recorded in the basin. Presently, the streambed is scouring here.

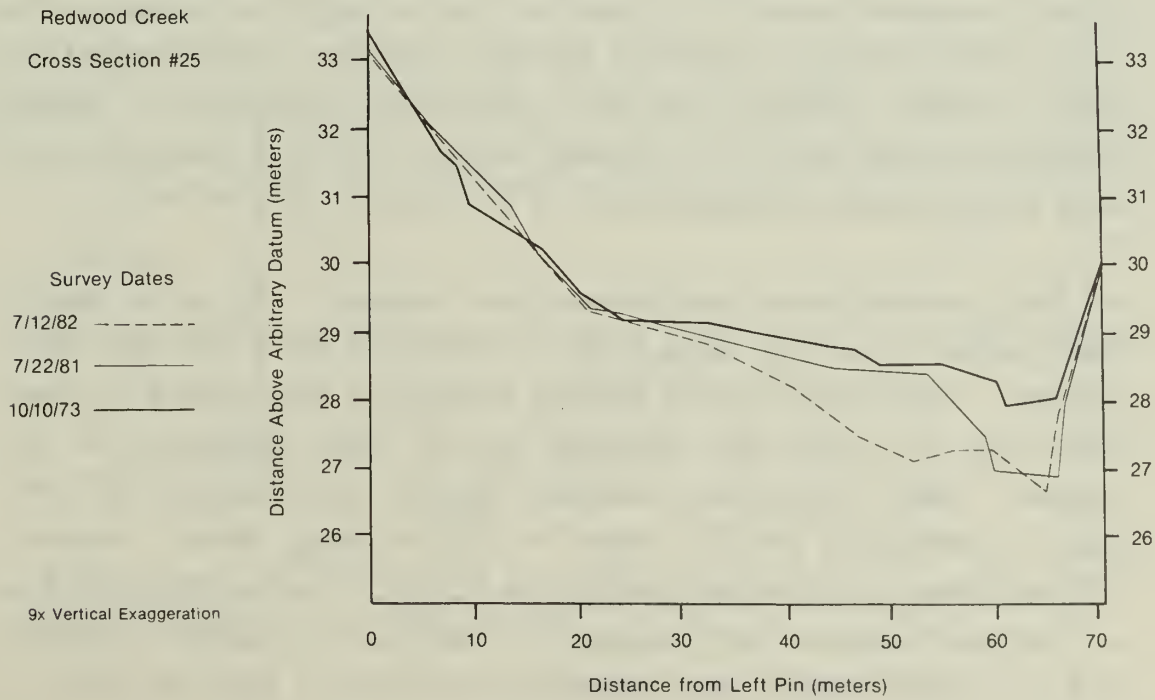

Figure 16: Cross sections immediately below the gorge have been degrading since 1975, following a period of major aggradation.

Beginning 2.0 km upstream of Bridge Creek and continuing downstream to near McArthur Creek (99.0 km), riparian vegetation is typically an old growth redwood forest. Recent aggradation of the streambed has resulted in elevated groundwater tables, burial of the base of some streamside trees, and thalweg shifting which has caused bank erosion (Figure 17). Two of the four cross sections here suffered stream bank failures in WY 1982. The degree of thalweg shifting can be seen in Cross Section 19 (Figure 18).

A very definite trend of channel fill can be seen from 1974 to 1977, with values of ΔE_c ranging up to 0.29 m. Thereafter, scour has dominated, with ΔE_c values ranging up to -0.32 m in 1982. Wide, low gradient reaches, as Cross Section 19 shows, can easily experience major changes through lateral shifting of the thalweg.

8. <u>Tall Trees Grove, Cross Sections 15 (89.8 km) - 17 (88.5 km)</u>

Six cross sections currently monitor the channel and banks around the Tall Trees Grove (Figure 19). Here, Redwood Creek flows around a low, occasionally flooded terrace that supports an old-growth redwood grove, with some of the tallest known trees in the world. Bank-to-bank widths in this area are large (up to 140 m) and major thalweg shifting has been observed. Changes in thalweg elevations range from -1.0 m scour to 0.5 m fill and changes in net area (ΔA_n) similarly range from 19.0 m^2 scour to 20.2 m^2 fill.

In 1982, several areas experienced bank erosion, with up to 24 m of bank retreat occurring along a 300 m stretch on the north side of the terrace. This portion of the terrace supports a dense stand of alders less than 20 years old, attesting to the past instability of this section. Major filling was recorded at most cross sections in 1974, with no distinctive trend in scour or fill occurring since. However, ΔE_c are often $\geqq 0.15$ m and as high as 0.25 m. During WY 1982, four of the six sections had changes in the mean streambed elevation (ΔE_c) of about 0.20 m, with no distinctive trend in scour or fill.

Figure 17: View downstream from Cross Section 20, located between Bridge Creek and the Tall Trees Grove. The fallen redwood tree on the right fell in WY 1981 as the result of effects related to streambed aggradation (see Figure 1).

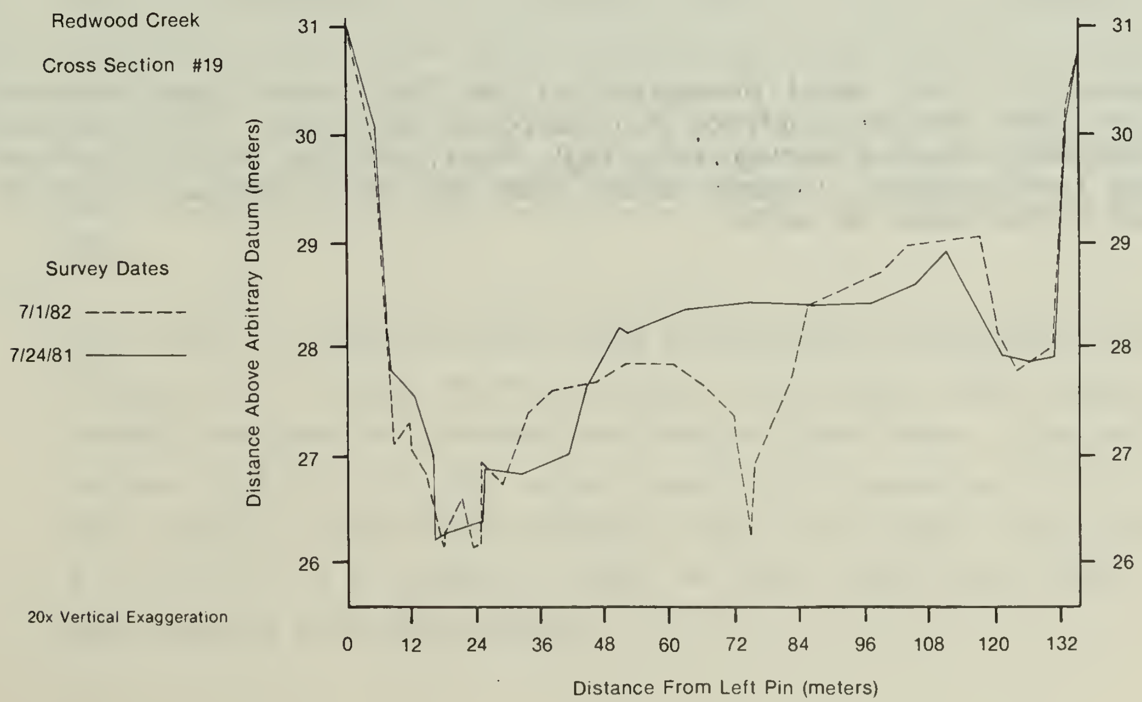

Figure 18: In this cross section just above Tall Trees Grove, thalweg shifting is apparent, a common feature in reaches with low gradient and wide channels.

Figure 19: 1981 aerial photograph of the Tall Trees Grove. Redwood Creek flows around a terrace that supports the grove. The terrace is occasionally flooded during very high flows and has recently suffered some bank erosion. Channel widths here are very wide, up to 150 m. Flow is from south to north.

9. <u>Forty-Four Creek to Elam Creek, Cross Sections 6 (97.5 km) - 14 (91.4 km)</u>

The nine cross sections here are spaced about 1.0 km apart, except Cross Sections 6 through 8, which are 0.1 km apart. Bank-to-bank widths range from 58 to 112 m, averaging about 80 m (Figure 20).

Since 1974, the upper and lower ends of this reach have experienced the most change, with cross sections often alternating between scour and fill. Major changes in mean streambed elevation ($\Delta E_c \geqq 0.15$ m) generally have recorded episodes of fill in this reach.

In 1982, the occurrence of multiple, braided channels in this reach suggested a high input of sediment. In WY 1982, eight of the cross sections filled, with the average $\Delta A_n = 13.0$ m². Thalweg elevations in these filling cross sections rose an average of 0.1 m. Cross Section 9 showed net scour ($\Delta A_n = 6.8$ m²). In general, cross sections located between the confluences of Forty-Four Creek and McArthur Creek showed a very definite trend in net fill, elevated thalwegs, and braiding, suggesting major aggradation in 1982. General aggradation of the channel may be occurring upstream of Forty-Four Creek, but cross-sectional data do not show it to be a definitive trend.

10. <u>Elam Creek to Prairie Creek, Cross Sections 1 (102.8 km) - 5 (98.8 km)</u>

This reach is very wide, with most bank-to-bank widths near 140 m (Figure 21). Thalweg shifting has been very common here, sometimes eroding the bases of terraces and inactive gravel bars. Changes in net area (ΔA_n) in WY 1982 varied from 22.1 m² scour to 4.7 m² fill, and changes in the thalweg elevation were fairly large, ranging from 0.4 m fill to -0.6 m scour. Since WY 1974, distinctive trends in scour and fill were not apparent.

Figure 20. The channel between Forty-Four and Elam Creeks is heavily alluviated, as in most of Redwood Creek, and the presence of multiple channels may reflect abnormally high sediment loads.

Figure 21: Channel shifting is common in the broad, alluviated reach between Elam and Prairie Creeks.

C. *Quantification and Analysis of Changes at Cross Sections During WY 1982*

During the summer of 1982, all 58 cross sections were surveyed along the mainstem of Redwood Creek (Table 2 and Figure 5). Three of these cross sections are not considered in this report because of recent bulldozing in the channel [Cross Section 32b (62.6 km)] or because of surveying errors greater than 5 percent [Cross Sections 37 (42.8 km) and 38 (36.5 km)].

1. Streambed Changes

Values for net area change in the streambed (ΔA_s) at individual cross sections are extremely variable. This is due to such factors as differences in hydraulic geometry (mean width, depth and stream velocity), bed materials, proximity to tributaries and land use activities. For the 55 usable cross sections, the mean net change in streambed area (ΔA_s) was 2.1 m^2 of scour in WY 1982. However, individual changes showed high variability with a standard deviation of 10.9 m^2, or 519 percent of the mean. The largest amount of net scour in the streambed was 36.8 m^2 at Cross Section 19 (86.7 km) and the largest amount of fill was 39.8 m^2 at Cross Section 13 (92.0 km). Both of these extremes are located in the wide alluviated reaches near the Tall Trees Grove (89.0 km, Figure 2).

The distribution of cross sections showing scour in net area change (ΔA_n) and those showing fill suggest a very general trend of upper basin scour and lower basin fill. Above Bridge Creek (84.6 km), 27 of 31 cross sections scoured. The remaining four cross sections showing fill occurred at widely scattered locations. Below Bridge Creek, 10 of 24 cross sections scoured. The majority of the 14 cross sections showing fill in this area occurred at, or downstream of, the Tall Trees Grove.

Changes in thalweg elevations were also highly variable. The mean change in thalweg elevations during WY 1982 was -0.1 m of scour, with a standard deviation of 0.4 m or 400 percent of the mean. The thalweg at Cross Section 34a (48.0 km) lowered the most (1.1 m). The thalweg at Cross Section 20 (85.8 km) elevated the most (1.7 m). Changes in thalweg elevations suggest a trend of upper basin scour. Above Panther Creek (68.8 km), all but four cross sections showed lower thalweg elevations than the previous year. In the reaches below Bridge Creek, 13 of 24 sections had lower thalwegs.

Thalweg elevation changes usually reflect the net area change in the streambed. In WY 1982, 42 out of 55 sections experienced thalweg changes conforming to the net area change in the streambed. Contrary situations most commonly occurred in very wide, low gradient reaches where thalweg shifting and/or braiding was apparent.

A braided stream is one that has multiple channels separated by islands or bars. This situation commonly occurs when there is a supply of sediment which tends to aggrade the channels and causes a braided pattern (Matthews, 1974). Cross-sections of Redwood Creek show braiding by the appearance of two or more low water channels (Cross Section 14, Figure 22). By this definition, braiding was observed at 16 cross sections in WY 1982, all of which were located in wide, low gradient reaches. Thirteen of these occurred at or down-stream of the Tall Trees Grove (89.0 km).

2. Stream Bank Change

Stream bank erosion occurred at seven cross sections in WY 1982, mostly in the form of slumping at widely scattered locations. Slumping at three of the sections resulted in loss of survey monuments. Compared to previous years with similar yearly discharge (1974, 1975), it appears that bank erosion was much less significant in 1982. During the summer of 1974, Janda *et al.* (1975) reported stream bank erosion along 41 percent of the channel below the gorge. Although bank erosion was not quantified for the entire length of Redwood Creek in WY 1982, field observations indicate that bank erosion along the mainstem of Redwood Creek was much more frequent than indicated at cross section locations.

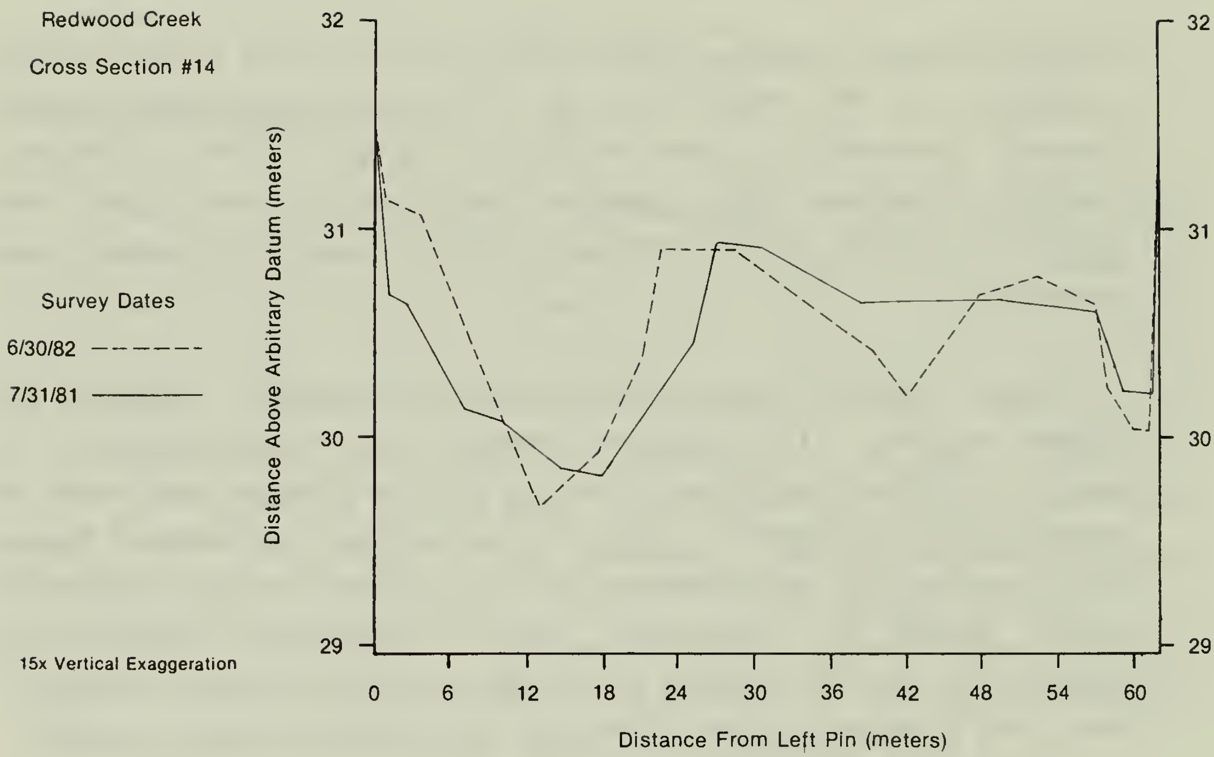

Figure 22: This braided cross section is characteristic of the reaches below the Tall Trees Grove where most cross sections are aggrading.

D. Magnitude of Change

The change in mean streambed elevation (ΔE_c) is used to compare the relative magnitude of change at cross sections of different widths. For WY 1982, the average change in mean streambed elevation (ΔE_c) was -0.07 m scour, with a standard deviation of 0.18 m or 257 percent of the mean. Cross Section 13 (92.0 km) showed the largest mean fill, with ΔE_c = 0.57 m while Cross Section 26 (80.3 km) showed the largest mean scour, with ΔE_c = -0.64 m.

High magnitude, mean streambed elevation changes ($\Delta E_c \geqq 0.15$ m of scour or fill) during the 9 years of cross-sectional record are used as an indicator of major change. This year, eight cross sections showing a net decrease in cross-sectional area (fill) had E_c values of $\geqq 0.15$ m. Eighteen cross sections had ΔE_c values of $\geqq 0.15$ m that showed a net increase in cross-sectional area (scour).

E. Significance of Channel Adjustments in the 1982 Water Year

Table 4 gives the values for annual water yield and the number of days mean daily discharge exceeded 235 m^3/s (8,300 m^3/s) for Redwood Creek at Orick, California for WY 1974 through 1982. Notes from successive discharge measurements at the Orick gaging station indicate that the streambed is extensively mobilized at a flow of 235 m^3/s. This flow is exceeded about 1.35 percent of the time, based on an unpublished flow duration curve by the U.S. Geological Survey (Figure 23). For this reason the number of days with flows equal to or exceeding 235 m^3/s was chosen as an index of how often the streambed was mobilized.

The 1982 water year was significant in that winter storms produced some of the highest flows and annual water yield since WY 1975. Also, the number of cross sections experiencing high magnitude change [ΔE_c $\geqq 0.15$ m (scour or fill)] was greater than it had been since 1975. Table 4 compares the number of cross sections with $\Delta E_c \geqq 0.15$ for WY 1974 through 1982.

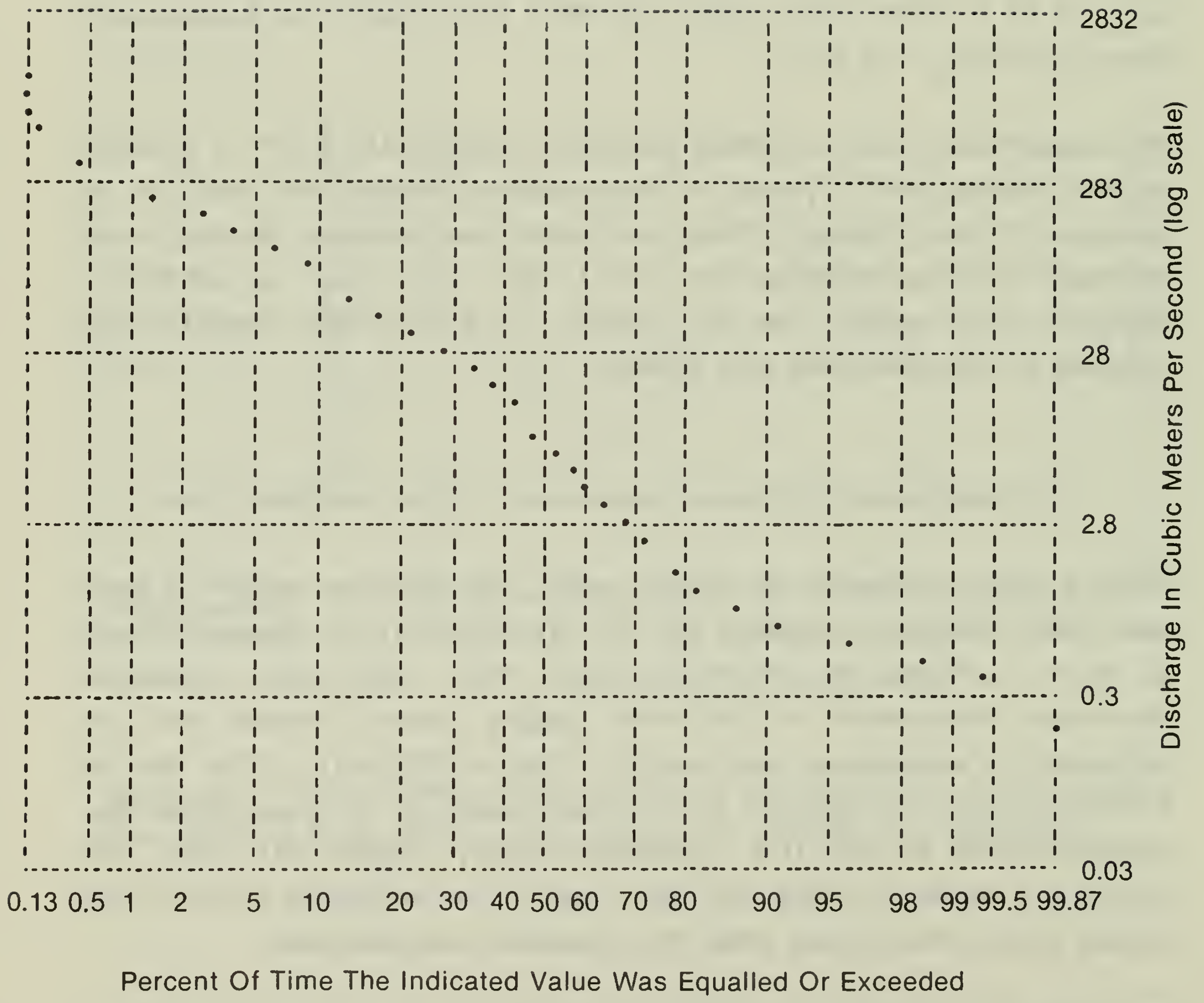

Figure 23: Flow duration plot of daily data for Water Years 1954-1981. Redwood Creek near Orick (station #11-485.00). (Source U.S. Geological Survey, unpublished data).

The relationship between the percent of cross sections with ΔE_c of ≥ 0.15 m to the annual water yield is shown in Figure 24. The coefficient of determination (r^2) is 0.62 and the correlation is significant at the 95 percent confidence level. The relationship between high magnitude change and number of days in which flows exceeded 235 m^3/s is somewhat better ($r^2 = 0.74$, Figure 25) and is also significant at the 95 percent confidence level with 9 years of data. The number of moderately high runoff events appears to be somewhat more important than the total annual runoff in effecting changes of large magnitude.

These relationships assume that the entire streambed is mobilized when the Orick gaging station is recording 235 m^3/s. Scour and fill data presented by Madej (1984) suggest this is true at Cross Sections 40 and 20, and is probably valid for most of the channel.

The locus of maximum aggradation is a qualitative assessment defined by features such as changes in net area and mean channel depth, channel widening, stream braiding and shifting, and bank retreat. Several of these loci may occur throughout the main channel, but the term "locus of maximum aggradation" refers here to the center of the longest reach consistently showing major aggradational features.

The area where aggradation is the dominant characteristic in a channel reach has changed since cross-sectional surveys were initiated in 1974. In 1975, the locus of maximum aggradation began immediately below the gorge (82.0 km) (Nolan and Janda, 1979) and may have extended as far as the upstream end of the Tall Trees Grove (88.5 km). In the 1982 water year, the locus of maximum aggradation appeared to extend from near the Forty-Four Creek confluence (91.4 km) to the Elam Creek confluence (98.0 km). This represents a downstream movement of 9 to 10 km. The years between 1975 and 1982 were characterized by relatively low annual water yield and lack of flows that would have extensively mobilized the streambed (Table 4). Major changes in the streambed were not as apparent during these years. As a result, the locus of maximum aggradation either did not exist or was too subtle to detect with available data.

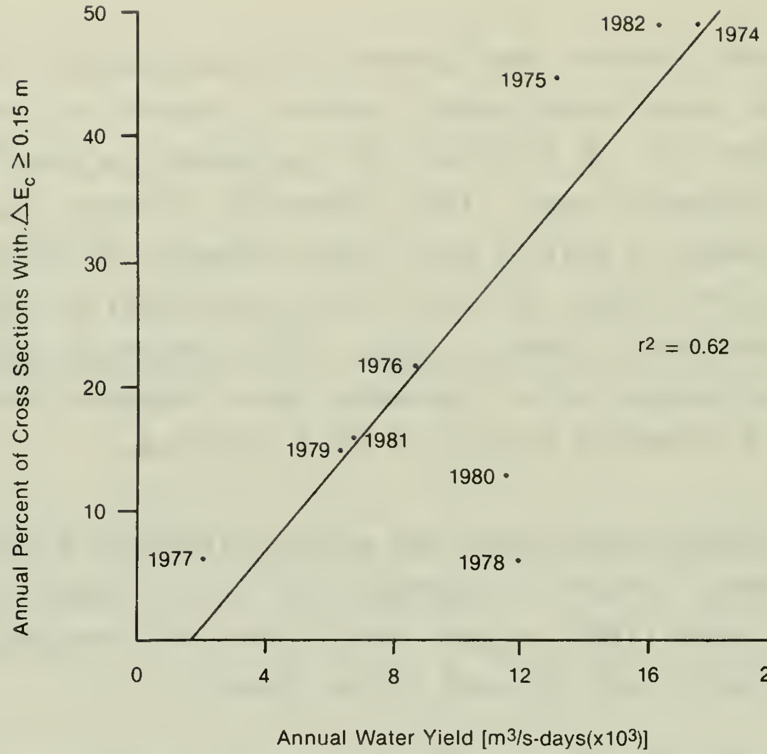

Figure 24: Relationship of annual percent of cross sections with a magnitude of change ≧0.15m to annual water yield at the Orick, CA gaging station.

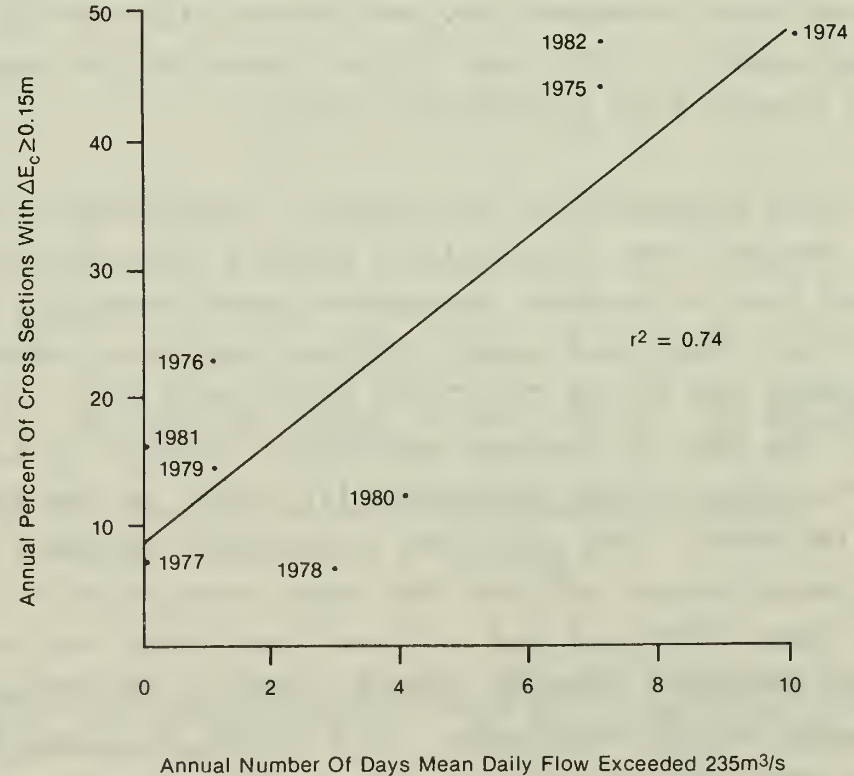

Figure 25: Relationship of annual percent of cross sections with a magnitude of change ≧0.15m to annual number of days mean daily flow exceeded 235 m^3/s (8300 ft^3/s) at Orick, CA.

TABLE 4

Comparison of annual water yield and number of days mean daily flow exceeded 235 m^3/s (8,300 ft^3/s) at the USGS Gaging Station at Orick, California[1] to the number of cross sections that equalled or exceeded a change in mean channel depth of 0.15 meters for the Water Years 1974-1982.

Year	Annual Water Yield cms-day	Number of Days Mean Daily Flow Exceeded 235 cms[1]	Number of Cross Sections Showing E_c of ≥ 0.15 m[2]: Fill	Scour	Percent
1974	17,837	10	6	13	47
1975	13,481	7	12	9	42
1976	8,740	1	2	8	22
1977	1,985	0	1	2	6
1978	12,060	3	0	3	6
1979	6,542	1	4	2	14
1980	11,448	4	2	3	12
1981	6,673	0	1	6	15
1982	16,561	7	8	18	47

[1] - *From U.S. Geological Water Resources Data (1983).*

[2] - *The total number of cross sections analyzed each year varied from 40 in 1974 to 55 in 1982.*

The locus of maximum aggradation is a qualitative assessment defined by features such as changes in net area and mean channel depth, channel widening, stream braiding and shifting, and bank retreat. Several of these loci may occur throughout the main channel, but the term "locus of maximum aggradation" refers here to the center of the longest reach consistently showing major aggradational features.

The area where aggradation is the dominant characteristic in a channel reach has changed since cross-sectional surveys were initiated in 1974. In 1975, the locus of maximum aggradation began immediately below the gorge (82.0 km)(Nolan and Janda, 1979) and may have extended as far as the upstream end of the Tall Trees Grove (88.5 km). In the 1982 water year, the locus of maximum aggradation appeared to extend from near the Forty-Four Creek confluence (91.4 km) to the Elam Creek confluence (98.0 km). This represents a downstream movement of 9 to 10 km. The years between 1975 and 1982 were characterized by relatively low annual water yield and lack of flows that would have extensively mobilized the streambed (Table 4). Major changes in the streambed were not as apparent during these years. As a result, the locus of maximum aggradation either did not exist or was too subtle to detect with available data.

The 1982 survey showed a persistent trend of continued upper basin scour and downstream shift of aggradation at cross sections. Assuming no major aggradational event will occur in the near future, complete recovery of the Redwood Creek stream channel from the major aggradational event of 1964 will depend on the magnitude and frequency of runoff events capable of mobilizing the streambed.

VI. SUMMARY

In the 1982 water year, Redwood Creek experienced major changes at cross sections relative to the 9 years of record. In the reaches of Redwood Creek above Bridge Creek (84.6 km) net scour occurred in 27 of 31 cross sections. Evidence at the USGS gaging station near Blue Lake (35.5 km) indicated that the streambed above State Highway 299 was approaching the 1958 (pre-major aggradation) level. In the lower reaches, the locus of maximum aggradation has moved downstream 9 to 10 km since 1975 (below the Tall Trees Grove). The number of cross sections that experienced major changes in mean streambed elevation (ΔE_c) was similar to 1974 and 1975. Common characteristics of the 1974, 1975 and 1982 water years include relatively high annual water yields and the number of runoff events exceeding 235 m^3/s at Orick, California. If no large sediment inputs from hillslope processes or major aggradation occur, recovery of the Redwood Creek main channel from the aggradational event of the 1964 flood will progress at a rate determined mostly by the frequency of moderately high runoff events.

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