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SEDIMENT ROUTING IN TRIBUTARIES OF THE REDWOOD CREEK BASIN: NORTHWESTERN CALIFORNIA

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SEDIMENT ROUTING IN TRIBUTARIES OF THE REDWOOD CREEK BASIN: NORTHWESTERN CALIFORNIA

by John Pitlick

Redwood National Park
P.O. Box SS
Arcata, California 95521

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ABSTRACT

Detailed studies of 16 streams draining diverse terrain indicate that tributaries have been major sediment sources for Redwood Creek since the early 1950's. Low frequency high intensity storm events and timber harvesting resulted in sediment production by landslides along tributary channels comparable in magnitude to that along the channel of a much larger stream, Redwood Creek. In the majority of tributaries, the amount of sediment in storage is low relative to sediment supply and the residence time of sediment in tributary channels is necessarily short. Over short periods of time, sediment yield from these small steepland watersheds is largely dependent on sediment supply rather than water discharge.

INTRODUCTION

Traditionally, studies of sediment yield from small steepland watersheds have relied heavily on data obtained from a gaging station located at the outlet of a study basin. The significance of such studies is often limited by the availability of reliable data collected over a long period of time. Furthermore, such an approach tells very little about the complex interaction between the processes which mobilize and transport sediment. Several workers (Mosley, 1978; Dietrich and Dunne, 1978; Kelsey, 1980; Lehre, 1981; Trimble, 1981) have recently presented detailed analyses of changes in sediment source areas and sediment transport through both natural and disturbed watersheds. A point highlighted in much of this work is the disparity between the measured erosion rates of selected geomorphic processes and the downstream sediment discharge. In many watersheds, sediment storage on hillslopes and in channels has been identified as an important link between the mobilization and transport processes. Given this knowledge, a thorough understanding of the spatial and temporal changes in sediment mobilization and storage is necessary to put information on sediment yield in proper perspective.

In focusing on channel and hillslope processes centered along the main stem of Redwood Creek, previous studies (Colman, 1973; Harden, et al., 1978; Janda, 1978) were fundamental in documenting the recent acceleration in erosion rates within the 720 km² Redwood Creek basin (Figure 1). Much of this effort was directed to the collection of water and sediment discharge data along the mainstem of Redwood Creek and at selected tributary localities. In summarizing this work, Janda (1978) concluded that "at discharges that are likely to occur several times in any given decade...tributaries may indeed be major contributors of suspended sediment to Redwood Creek..." In a contrasting view, Winzler and Kelly Engineers (1975) pinpointed massive landsliding along the main stem channel as the primary source of sediment for Redwood Creek and concluded that "the contribution of sediment from the individual tributary streams....is insignificant compared to the load carried by Redwood Creek." The data presented in this paper were generated as part of more recent studies on sediment source areas and sediment transport in the Redwood Creek basin (Kelsey, et al., 1981b). Through detailed studies of 16 diverse basins, I have attempted to quantify the amount of sediment delivered from streamside landslides, to determine the extent to which major storm events and changes in land use have generated landslides and to assess the role of sediment storage and large organic debris in tributary channels.

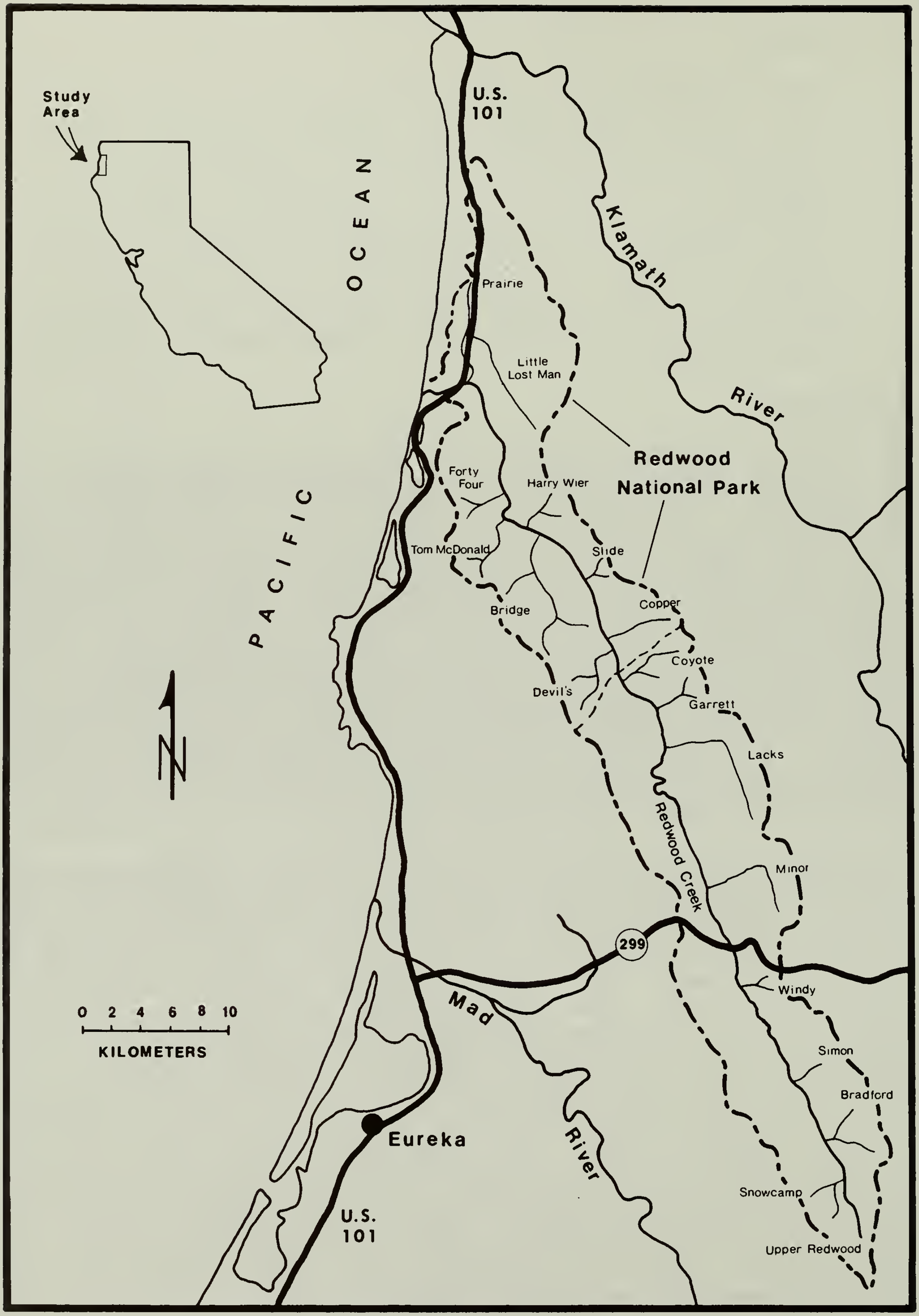

Figure 1. Location map of the Redwood Creek watershed, Redwood National Park, and the tributary basins of this study.

STUDY AREA

The physical setting of the Redwood Creek basin has been described in detail by previous authors (Janda, et al., 1975). While the Redwood Creek basin offers us an opportunity to study a large number of low order streams within a physiographically similar region, the basin is not without inherent variability. Factors such as geology, climate, vegetative cover and land use locally play important roles in the mobilization and storage of sediment in tributaries.

Geology and Physiography

The Redwood Creek basin is underlain by rocks of the Franciscan assemblage (Bailey, et al., 1964; Harden, et al., 1981), which is a Mesozoic to early Cenozoic accumulation of weakly indurated and pervasively sheared continental margin deposits which are highly susceptible to fluvial erosion and mass wasting. The Grogan Fault, expressed as a well-defined, NNW-trending lineament, roughly bisects the basin and juxtaposes unmetamorphosed and slightly metamorphosed clastic sedimentary rocks to the east against metamorphic schistose rocks to the west. Tributary streams are nearly equally divided between those draining sedimentary rocks and those draining metamorphic rocks. The soils developed on these rock types are moderately coarse in texture. They have high infiltration capacities but possess little cohesion and very low shear strength.

The course of Redwood Creek is structurally controlled by the Grogan Fault and the unusually elongate geometry of the basin is a strong reflection of this (Figure 1). As a result, there are no major tributary forks to Redwood Creek[1] and only a few tributaries are larger than the majority (Figure 2). In all there are 74 tributary basins drained by second order (after Strahler, 1957) or higher streams flowing directly into Redwood Creek. Most tributaries are characteristically low order, high gradient streams draining small watersheds. Their channels are, in general, deeply incised and have narrow, discontinuous flood plains (Figure 3). Average stream gradients range from .05 to .30 meters/meter (Appendix Tables A1 and A2). Average hillslope gradients within these basins range from .25 to .35 meters/meter. Topographic relief and average stream gradient is greater in tributaries draining the eastern portion of the watershed. Many tributary basins exhibit steep hillslope segments adjacent to channels and more moderate gradients at middle and upper slope positions. This incised inner valley is particularly susceptible to mass wasting by shallow debris slides and debris avalanches.

Vegetation and Land Use History

Tributary watersheds are distinguished by predominant forest type and degree of timber harvesting. Eighty-five percent of the Redwood Creek basin was forested prior to the initiation of logging (Janda, et al., 1975). Under natural conditions, the coastal northern third of the basin supported

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1. Prairie Creek is the largest tributary to Redwood Creek. It drains approximately 104 km² and enters the main stem of Redwood Creek just upstream of Orick. However, due to the marked differences between the physiography and geology of this tributary and the remainder of the watershed, I have not included it in the present study.

Figure 2. Distribution of tributary drainage basins by drainage area. Shaded areas indicate basins in which streamside landslides and channel stored sediment were measured.

Figure 3. Lacks Creek channel exhibiting steep sideslopes, coarse bed material, and narrow flood plain.

mixed stands of old-growth redwood and Douglas-fir (here called "redwood dominated" forests) while the inland, southern two-thirds supported primarily mixed Douglas-fir and hardwood forests (here called "Douglas-fir dominated" forests) (Figure 1). The distribution of forest types is in part, a reflection of the variation in micro-climate throughout the basin. Redwood is less tolerant of summer drought and winter cold than Douglas-fir and hence is found in the more temperate areas near the coast. Today, over 65 percent of the basin has been logged with the majority of this occurring over the last 25 years. Most units have been clear-cut and tractor yarded. Twenty percent of the basin, virtually all within the Redwood Creek unit of Redwood National Park, remains as uncut virgin forest and the remaining 15 percent consists of prairie and oak woodland (Janda, et al., 1975).

Climate

The climate of Redwood Creek is characterized by a strong seasonal variation. The basin receives an estimated mean annual precipitation of 80 inches (Harden, et al., 1978) with the majority of this occurring between October and April. Rainfall during the summer months is very infrequent.

Major flood-producing storms occurred throughout northern California in 1953, 1955, 1964, 1972 and 1975. Peak discharges of greater than 45,000 cubic feet per second were recorded near the mouth of Redwood Creek for each of these floods (Harden, et al., 1978). The storm of December 1964 resulted in widespread landsliding and changes in channel morphology. Other storms occurring since the early 1950's, although similar in magnitude, did not have the geomorphic impact of the 1964 storm.

STUDY METHODS

As a first step in determining the magnitude and timing of sediment contribution from tributaries, streamside landslides and channel stored sediment were measured conjunctively in 16 basins (Table 1). These basins cover a wide range of drainage areas and terrain types. The amount of sediment delivered from streamside landslides was determined by detailed field measurements of the hillslope void. The surface area of the landslide scar was measured using a tape and rangefinder. Landslide depth was determined from measurements or estimates of side or head-scarp heights. More than 1,000 landslides were measured along a total channel length of 70 km. Based on review of aerial photographs, an estimated 80 to 98 percent of the total sediment production from streamside landslides was measured during the field surveys of individual tributaries.

Sediment stored in fill terraces and in association with large organic debris was measured along a total of 67 km of tributary channel length (Appendix Tables B1 - B19). The volume of material stored in terraces was determined by measuring the surface area of the feature and the average height above the present thalweg. The amount of sediment stored upstream of a debris jam was determined by treating the trapped sediment as a wedge. The surface area of the deposits associated with the debris was measured and the depth of stored sediment taken as one-half the height of the debris jam. Buried tree stumps, root wads, boulders, and other objects which are now partially exhumed, were used to determine the depth recent aggradation.

Table 1.

GENERAL INFORMATION FOR STUDY BASINS

TRIBUTARY	DRAINAGE AREA (km^2)	AVERAGE GRADIENT (m/m)	PREDOMINANT ROCK TYPE (1)	PREDOMINANT FOREST TYPE (2)
Lacks Creek	44.0	.06	SS	DF
Minor Creek	33.6	.08	SS	DF
Bridge Creek	29.4	.06	SH	RW
Coyote Creek	20.4	.13	SS	DF/RW
Devils Creek	18.0	.08	SH	RW
Tom McDonald Creek	18.0	.07	SH	RW
Bradford Creek	16.5	.18	SS	DF-O-P
Upper Redwood Creek	11.1	.11	SS	DF-O-P
Garrett Creek	10.8	.18	SS	DF
Snowcamp Creek	8.2	.17	SS/SH	DF
Forty Four Creek	8.1	.10	SH	RW
Harry Weir Creek	7.8	.16	SS/SH	RW
Copper Creek	7.4	.18	SS	RW/DF
Windy Creek	4.5	.19	SS	DF-O-P
Simon Creek	4.5	.23	SS	DF-O-P
N. Fork Slide Creek	1.6	.26	SS	RW

(1) SS: Unmetamorphosed and slightly metamorphosed sedimentary rocks of the Franciscan Formation.
SH: Quartz-mica schist of the Franciscan Formation.

(2) RW: Predominately redwood forest with minor amounts of hardwood and Douglas-fir.
RW/DF: Predominately redwood forests with significant amounts of Douglas-fir.
DF/RW: Predominately Douglas-fir forests with significant amounts of redwood.
DF: Predominately Douglas-fir with associated hardwoods.
DF-O-P: Nearly equal amounts of Douglas-fir forests, oak woodland, and prairie.

Temporal changes in slide activity were documented by reviewing sequential aerial photos taken in 1954, 1958, 1962, 1966, 1970, 1974 and 1978 at scales ranging from 1:20,000 to 1:6,000. For each slide measured in the field and visible on air photos, I noted the period during which the slide was initiated and any increase in the size of the slide. On sites that had been logged, I noted the timber harvesting methods and amount of roads at time of failure. Photos were of little use in documenting changes in stream morphology because a dense vegetative cover usually obscured tributary channels.

STREAMSIDE LANDSLIDNG IN TRIBUTARIES

The natural instability of Franciscan terrain, a clustering of major storm events, and timber harvesting have been cited (Janda, 1978, Kelsey, 1980) as the main contributors to the acceleration in erosion rates of the northern California Coast Ranges over the last 30 years. Streamside landslides have previously been identified (Janda, 1978; Kelsey, 1980) as major sources of sediment for northern California streams and rivers. In the Redwood Creek basin, debris slides, debris avalanches and complex earthflows are the most common mass movement features. Although they comprise a small percentage of the basin area (Table 2), these types of sediment sources can contribute a significant amount of the total sediment load in northern California rivers (Kelsey, 1980).

Table 2.

EROSIONAL LANDFORMS IN THE REDWOOD CREEK BASIN
(data from Harden *et al.*, 1978)

Features active in 1974:	Percent of drainage area
Debris slides	1.0
Debris avalanches	0.2
Earthflows	10.0
Very active earthflows	2.0
Unstable streambanks	3.0
Total, active features	16.2

Debris slides and debris avalanches are episodic types of failures which are characteristically shallow (less than 3.0 meters deep) and move predominantly by translation resulting in relatively rapid and direct sediment contributions to stream channels. Earthflows are large-scale, deep-rooted features that characteristically exhibit both rotational and translational movement. Earthflows are more persistent in delivering sediment to channels.

Streamside landslides in tributary watershed are as large and complex as similar landslides along the main channel of Redwood Creek. The 20 largest streamside slides in the tributary basins of this study have contributed a total of 1,470,000 tonnes. By comparison, of the 566 landslides measured along the main stem of Redwood Creek upstream of State Highway 299 (Figure 1), the largest 20 slides have delivered 1,353,000 tonnes. In individual tributaries, sediment production from streamside landslides is highly variable, but in terms of mass per drainage area, tributary landslide contribution does not differ substantially from the contribution due to landsliding along the main stem of Redwood Creek upstream of Highway 299 (Table 3).

Timing of Streamside Landsliding

The data from the surveys of tributary landslides emphasize several important points (Table 4). First, slightly less than half of the total measured mass of landslide material was delivered during the 1964 storm and the tributary basins south of Highway 299 were particularly affected during this storm. Second, the total amount of landslide material delivered to tributaries during the other intervals varies significantly; that is, the standard deviation is nearly equal to or higher than the mean percentage of material delivered in all cases except the 1962 - 1966 interval.

The marked differences between the amount of landsliding initiated during the 1964 storm and during other storms of similar magnitude may be due to the following factors. The exceptional amount of erosion which occurred in the upper 175 km² of the watershed suggests that the 1964 storm was more intense at higher elevations in the upper basin. Although the recorded peak discharge of Redwood Creek at Orick was nearly the same as during other storms, the peak discharge of Redwood Creek at Highway 299 during the 1964 storm was 20 percent higher than any other storm recorded (Harden, et al., 1978). Secondly, storms and land use practices of the 1950's were important in "conditioning" the basin for an event such as the 1964 storm (Harden, et al., 1978). They reported that an exceptionally large number of landslides which were visible on 1958 photos, increased in size during the 1964 storm. The most extensive logging in the basin was conducted during the 1950's, with nearly half the streamside area along Redwood Creek having been at least partially logged. Finally, storms of the 1970's did not initiate slides as large or as numerous as in 1964 simply because the slopes most susceptible to sliding had already failed.

Landslides and Land Use

Numerous studies (Brown and Krygier, 1971; Rice, et al., 1972; Beschta, 1978; Harr, 1976) have shown that the hydrologic and erosional consequences of logging are highly variable and dependent on physical factors such as soils,

Table 3.

TRIBUTARY LANDSLIDE DATA

TRIBUTARY	DRAINAGE AREA (km^2)	LANDSLIDE MASS[1] DELIVERED BETWEEN 1954-81 (Tonnes)	LANDSLIDE MASS PER UNIT DRAINAGE AREA (Tonnes/km^2)
Lacks Creek	44.0	917,700	20,900
Minor Creek	33.6	465,500	13,900
Bridge Creek	29.5	311,000	10,600
Coyote Creek	20.4	231,800	11,400
Devils Creek	18.0	53,900	3,000
Tom McDonald Creek	18.0	50,000	2,800
Bradford Creek	16.5	213,100	12,900
Upper Redwood Creek	11.1	169,800	15,300
Garrett Creek	10.8	108,300	10,000
Snowcamp Creek	8.2	215,500	26,300
Forty Four Creek	8.1	29,900	3,700
Harry Weir Creek	7.8	47,500	6,100
Copper Creek	7.4	92,000	12,400
Windy Creek	4.6	241,600	52,500
Simon Creek	4.5	323,200	71,800
N. Fork Slide Creek	1.6	36,700	23,000
MEAN:			18,600
STANDARD DEVIATION:			18,800
Mainstem of Redwood Cr. upstream of State Highway 299:	175.3	3,736,800	21,400

[1]Landslide mass computed by taking the product of the measured volume and assumed soil density of 1.6 grams/cm^3 (100 lbs/ft^3) (James Popenoe, N.P.S., personal communication). The reported values represent data from only those slides measured during the tributary landslide surveys. Survey coverage accounted for between 80 and 98 percent of the total sediment production from landslides in individual basins.

Table 4.

DISTRIBUTION OF SEDIMENT
DELIVERY FROM TRIBUTARY LANDSLIDES THROUGH TIME

Tributary	Total Measured Slide Mass (Tonnes)	Percentage of Total Landslide Material Delivered to Individual Tributaries During Specific Intervals						
		78-74	74-70	70-66	66-62	62-58	58-54	PRE 54
Lacks	967,000	10.5	10.6	1.8	44.0	9.4	18.6	5.1
Minor	490,400	8.1	1.0	2.2	59.4	--	24.3	5.0
Bridge*	372,000	1.3	16.8	--	55.4	--	10.1	16.4
Coyote	233,200	9.6	7.3	6.0	65.2	10.8	0.5	0.6
Devils*	146,800	3.1	16.4	5.8	10.9	--	0.5	63.3
Tom McDonald*	82,500	--	26.0	4.6	27.3	--	2.6	39.5
Bradford	214,400	--	11.1	7.6	56.9	20.5	3.3	0.6
Upper Redwood	171,300	1.7	11.6	7.3	71.4	1.9	5.2	0.9
Garrett	123,100	--	43.4	7.3	19.2	--	18.1	12.0
Snowcamp	264,800	3.2	5.3	--	67.0	5.3	0.6	18.6
Forty Four*	41,400	4.2	4.2	--	38.3	--	25.4	27.9
Harry Weir	56,400	12.7	31.5	8.2	29.6	2.3	--	15.7
Copper	98,100	29.9	43.6	1.0	19.3	--	--	6.2
Windy	241,600	--	5.7	--	68.9	11.4	14.0	--
Simon	337,400	--	3.8	3.7	85.2	3.1	--	4.2
N. F. Slide*	36,700	26.0	15.6	16.6	9.3	--	32.5	--
	MEAN:	6.9	15.9	4.5	45.5	4.0	9.7	13.5
	STANDARD DEVIATION:	9.2	13.5	4.4	23.9	6.0	10.9	17.4

Note: In the majority of basins, most slides were visible on all photo sets. Basins in which the forest canopy obscured more than 20 percent of the landslides are denoted with an asterisk (*). The accuracy of this analysis depends greatly on slide visibility.

geology, climate and degree of ground disturbance. The importance of road construction and timber harvesting is illustrated in Table 5. The number of slides occurring on unlogged slopes as opposed to logged slopes is nearly the same. However, slides associated with roads or initiated on cut slopes are substantially larger and account for nearly 80 percent of the total landslide erosion. Failures associated with roads (and not necessarily timber harvesting) are the most frequent and produce the largest total amount of sediment from landslides in logged areas. There is little difference between the frequency and total mass of slides generated on tractor yarded, clear cut slopes and cable yarded, clear cut slopes. Cable yarding is a commonly used procedure in the timber harvesting of steeper slopes. Slides initiated on this type of site illustrate the importance of slope as a factor in hillslope failure. Landslides initiated in selectively cut, tractor-yarded areas are the least important in terms of sediment production. Tractor yarding is usually restricted to more moderate slopes and selection cutting generally results in less ground disturbance.

Table 5
INVENTORY OF TRIBUTARY LANDSLIDES LARGER THAN
450 TONNES AND SITE CONDITIONS PRIOR TO FAILURE

	UNLOGGED[1]	LOGGED			
		ROAD-RELATED[2] FAILURES	CLEAR-CUT		SELECTION-CUT
			TRACTOR-YARDED	CABLE-YARDED	TRACTOR-YARDED
Number of slides larger than 450 tonnes measured	222	109	47	46	37
Total mass of sediment delivered (tonnes)	687,867	1,199,698	606,761	464,319	243,812
Average slide mass	3,099	11,006	12,910	10,094	6,590
Percent of total inventoried slide mass	21.5	37.5	18.9	14.5	7.6

[1]Slides occurring in unlogged areas may be related to upslope or upstream timber harvesting. However, in most cases, the association between the slide and timber harvesting is not direct or obvious.

[2]Road related failures are those types of slides associated with failure of the road fill and/or the cut-bank upslope and are not necessarily associated with timber harvesting.

SEDIMENT STORAGE AND SEDIMENT TRANSPORT IN TRIBUTARIES

Quantifying the amount of sediment stored in stream channels is a basic component of any sediment routing study. Storage elements attenuate the effects of relatively instantaneous inputs of sediment to a channel from adjacent hillslopes by providing a compartment that slowly releases sediment to downstream reaches. In the Redwood Creek basin, large organic debris and local variations in bedrock lithology exert strong control on tributary channel morphology. Unlike the main channel of Redwood Creek, tributary streams do not show a uniform downstream increase in the amount of stored alluvium because of the variability in sediment supply, stream gradient and organic debris loading of any particular reach. Sediment storage in tributaries is restricted to lower gradient reaches and behind accumulations of large organic debris.

The effects of large organic debris (LOD) on channel morphology have been studied in detail by other investigators (Swanson and Lienkaemper, 1978; Keller and Tally, 1979; Mosley, 1981). Lowest (first and second) order streams lack sufficient power to move most LOD and the debris tends to remain where it entered the channel. Logs and other woody debris are found within and proximal to the channel in almost any configuration. In third and fourth order streams, logs are mobilized more frequently and there is a tendency for debris to accumulate in jams comprised of several to hundreds of logs. Higher order streams, such as the main stem of Redwood Creek, have sufficient power under high flow conditions to move even the largest debris and hence LOD accumulation tends to be neglible and often confined to channel margins.

Organic debris and, especially, log jams alter the hydraulics of a reach by impeding flow, which reduces the available stream power and results in deposition of sediment behind the jam. The changes in channel morphology commonly involve an abrupt step in the longitudinal profile at the jam with an associated decrease in gradient upstream of the jam, an increase in channel width upstream of the jam, and a decrease in particle size behind the jam.

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

Although sediment source areas in tributaries are as large and complex as similar features along the much larger stream, Redwood Creek is a much larger storage cell (Figure 4). Comparison between the amount of sediment stored in tributary channels and that stored in the main stem of Redwood Creek illustrates the relative transport capability of these streams. To estimate the total amount of sediment stored in tributary channels, I have combined the sediment storage data from the study tributaries with the distribution of drainage basins by drainage area (Figure 2). The amount of stored sediment

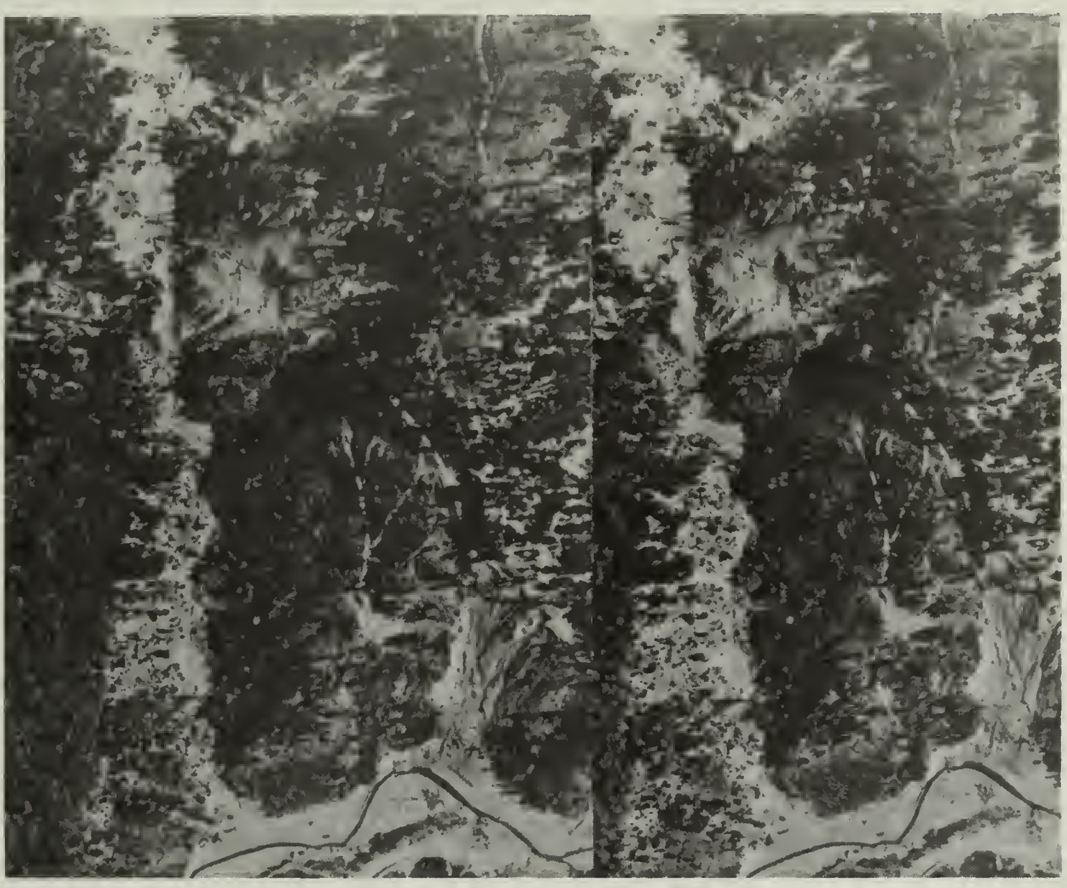

Figure 4. 1966 1:12,000 stereo photo of confluence of Simon Creek and Redwood Creek. Note that the landslides along both the tributary and main-stem channel are of similar size but the amount of sediment stored in the narrow, deeply incised tributary is negligible compared to the amount stored in Redwood Creek.

for individual drainage area classes was computed by taking the product of the average amount of stored sediment for basins in a class and the number of basins in the class. My estimate of the total amount of sediment stored in the 74 tributary basins is 1,050,000 m^3 or approximately 2,000,000 tonnes. This is only 15 percent of the total amount stored in the main stem of Redwood Creek (M.A. Madej, N.P.S., personal communication). On the average, 95 percent of the sediment stored in tributaries is found in the lower half of their drainage lengths (Table 6). In contrast, 95 percent of the sediment stored in Redwood Creek is distributed over 85 percent of its length (M.A. Madej, N.P.S., personal communication).

A comparison between the amount of landslide material delivered to the study streams since 1954 and the amount of sediment presently in storage serves as another measure of tributary sediment transport or storage efficiency (Table 7). Tributaries characterized by high relief and Douglas-fir dominated forests store a significantly smaller proportion of sediment supplied by streamside landslides than do redwood dominated tributaries even though sediment production from streamside landslides is much higher on the average in the former type of basin. Of the 74 tributaries draining the Redwood Creek basin, only a handful would be characterized as low relief, redwood dominated tributaries. The more typical, high relief Douglas-fir and redwood dominated tributaries represent streams in which the sediment transport regime is limited only by sediment supply. The data from Table 7 also implies that the residence time of sediment in the higher gradient tributary channels is necessarily short.

Changes in stored sediment provide only an incomplete measure or record of sediment transport through a watershed. Continuous and periodic sampling of water, suspended sediment and bedload discharge generate data on sediment yield more directly. Nolan and Janda (1981) used water and suspended sediment discharge records to assess the impacts of timber harvesting on sediment transport in Redwood Creek tributary basins characterized by diverse terrain and land use history. They found that suspended sediment concentrations for tributaries exceeded those for Redwood Creek at discharges with a recurrence interval of approximately five years or greater. In other words, at higher discharges, tributaries become major sediment source areas and transport more sediment per unit drainage area than the main stem of Redwood Creek.

Table 6.

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

Tributary	Total Drainage Length of longest channel (TDL,m)	Length of Channel, measured from mouth, Storing 95% of Total Sediment (DL_{95},m)	DL_{95}/TDL
Bridge Creek	12,859	6,645	.52
Tom McDonald Creek	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

* Basin in which DL_{95} was determined from qualitative field observations and measured reaches in this basin.

Table 7

DATA ON CHANNEL STORED SEDIMENT FOR THREE GROUPS OF STUDY BASINS: REDWOOD-DOMINATED, LOW RELIEF (TOP), REDWOOD-DOMINATED, HIGH RELIEF (MIDDLE), AND DOUGLAS-FIR DOMINATED, HIGH RELIEF (BOTTOM)

Tributary	Drainage Area (km^2)	Total Stored Sediment as of 1981[1] (Tonnes)	Stored Sediment per Unit Drainage Area as of 1981 (Tonnes/km^2)	Total Landslide Mass Delivered to Tributary Channels, 1954-1981[2] (Tonnes)	Landslide Mass per Unit Drainage Area Delivered 1954-1981 (Tonnes/km^2)	Percentage of Present Stored Sediment Mass to Post-1954 Land Slide Mass	Percentage of Sediment Stored by Large Organic Debris
Bridge[3]	29.5	381,000	13,000	311,000	12,700	123	N/A
Devils	18.0	50,400	2,800	53,900	3,000	94	91
Tom McDonald	18.0	80,000	4,400	50,000	2,800	160	56
Forty Four	8.1	81,800	10,100	29,900	3,700	274	83
Mean:			7,575		5,600	163	77
Standard Deviation:			4,785		4,782	79	18
Harry Wier	7.8	29,200	3,700	47,500	6,100	61	76
Copper	7.4	18,700	2,500	92,000	12,400	20	82
N.F. Slide	1.6	24,300	15,200	36,700	23,000	66	57
Mean:			7,130		13,800	49	72
Standard Deviation:			7,010		8,500	25	13
Lacks	44.0	120,000	2,700	917,700	20,900	13	49
Minor[4]	33.6	219,300	6,500	465,500	13,900	47	13
Coyote	20.4	22,000	1,100	231,800	11,400	9	52
Bradford	16.5	27,000	1,600	213,100	12,900	13	16
Upper Redwood	11.1	32,700	2,900	169,800	15,300	19	27
Garrett	10.8	18,800	1,700	108,300	10,000	17	70
Snowcamp	8.2	28,200	3,400	215,500	26,300	13	94
Windy	4.6	116,200	25,800	241,600	52,500	48	19
Simon	4.5	74,700	16,600	323,200	71,800	23	29
Mean:			6,920		26,100	22	41
Standard Deviation:			8,560		21,586	15	27

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

[2] Landslide mass computed by taking the product of measured volume and an assumed soil density of 1.6 grams/cm^3 (100 lbs/ft^3). (James Popenoe, N.P.S. Personal Communication).

[3] Data on sediment storage in Bridge Creek provided by David Leslie, Department of Earth Sciences, University of California, Santa Cruz.

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

CONCLUSIONS

The Redwood Creek watershed provides an opportunity to study hillslope and channel processes operating in a large number of small, steepland drainage basins. Data from 16 tributaries draining diverse terrain show that these basins are major sediment source areas for the main stem of Redwood Creek.

Streamside landslides in tributary watersheds are as large and complex as similar landslides along a much larger stream, the main channel of Redwood Creek. In individual tributaries, sediment production from streamside landslides is highly variable in space and time but, on the whole, does not differ substantially from the rate along the upper 34 km of the main channel of Redwood Creek. Landslides initiated or enlarged during the 1964 storm delivered as much sediment to tributary channels as all other slides initiated over the 27 year period of this study. Other storms occurring during the study period, although of similar magnitude, did not have the erosional impact of the 1964 storm.

The frequency of landsliding is nearly the same for unlogged versus logged slopes but slides occurring in cutover areas are substantially larger and account for nearly 80 percent of the total landslide erosion measured in this study. Failures associated with roads are the most frequent and produce the most sediment from logging-related landslides. Slide frequency and landslide sediment production on clear cut, tractor yarded slopes and on clear cut, cable yarded slopes is nearly the same. This illustrates the importance of both the degree of ground disturbance and hillslope gradient as factors in contributing to slope failure. Landslides on tractor yarded, selectively cut slopes are the least important in producing sediment.

Tributary streams are capable of transporting a high percentage of the material supplied to them. The total amount of sediment stored in tributary channels is estimated to be only 15 percent of the amount stored in the main channel of Redwood Creek. The majority of tributary stored sediment is found in the lower half of their main channel drainage lengths and is associated with large organic debris and low gradient reaches. In a comparison of the mass of landslide material delivered to the study streams since 1954 and the mass of sediment presently in storage, tributaries characterized by Douglas-fir forest types and high relief transported, over a period of less than three decades, an average of 78 percent of the sediment supplied by streamside landslides. These tributaries represent streams in which the sediment transport regime is limited by sediment supply and the residence time of sediment is necessarily short. This conclusion is supported by earlier studies (Nolan and Janda, 1981) that contrast the sediment transport characteristics of Redwood Creek and its tributaries.

Large organic debris can be an important determinant of channel form and process in the old-growth redwood forests. On the average, tributaries draining redwood forests have a higher proportion of debris-stored sediment than tributaries draining Douglas-fir forests or prairie-woodland terrain. Organic debris accumulation in the redwood forests is greater because large redwood logs are mobilized less frequently, are highly resistant to decay and may remain in the channel for hundreds of years.

RECOMMENDATIONS

These conclusions provide a conceptual base from which to approach the management of tributary streams of the Redwood Creek basin and possibly, other small steepland watersheds in the Northwestern California coast ranges. Sediment source areas in tributary watersheds provide a significant amount of the total sediment load of a larger stream over a short period of time. Management of these watersheds should therefore focus on controlling or abating the amount of sediment generated from the most active source areas.

Streamside landslides are very important in supplying sediment to tributary channels. In the Redwood Creek basin, most landslides are shallow, episodic failures that deliver sediment rapidly (often in one storm) to channels. After-the-fact treatment of such sites will in most cases have little effect on downstream sediment yield. Rather, emphasis should be placed on preventing or minimizing such a disturbance. In the discussion of landslide causes, I pointed out the importance of timber harvesting in generating larger failures.

Road cuts and road fills generate substantial amount of sediment as a result of landslides. Road layout and construction should therefore be carried out with a maximum of foresight and care. The data from Table 5 suggests that there is as high a risk of generating landslides from steep cable yarded slopes as there is from more moderate tractor yarded slopes with high ground disturbance. Of all timber harvesting techniques, selection cutting on moderate slopes has the least amount of slide activity associated with it. 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. This level of involvement with upper basin land management provides both an adequate and an effective means of minimizing the potential impact associated with future timber harvesting and road building.

Stored sediment in tributary channels is not a major sediment source for the main channel of Redwood Creek. Removal of tributary channel stored sediment will therefore have little effect on downstream sediment yield. In a previous paper (Pitlick, 1981), I discussed the role of organic debris in stream channel processes as well as the merits of debris removal. Where streambank stability is reduced by diversion of flow around a jam, debris removal should be considered as a rehabilitative measure.

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APPENDIX A

Through the course of this study, a substantial amount of data on tributary basins has been compiled. This data is included in the following appendices for general use.

Tables A1 and A2 present general information for eastside and westside tributaries.

Figures A1, A2 and A3 describe general relationships between drainage basin parameters of drainage area, drainage length, stream order and average gradient.

Drainage basin area is the area on a map enclosed by the basin boundary and measured with a planimeter. Drainage length is defined as the length of the main channel from its outlet to the basin divide. The stream ordering system used in this report is that of Strahler (1957). First order streams are defined by the smallest crenulations on 1:24000 scale topographic sheets. Average stream gradient is defined as the ratio of drainage basin relief to drainage basin length.

Information on the aerial photography used for this study is provided in Appendix C.

Table A1

GENERAL INFORMATION FOR EASTSIDE TRIBUTARIES

EASTSIDE TRIBUTARIES	Drainage Area (Mi²)	(Km²)	Drainage Length (Mi)	(Km)	Average Gradient (m/m)
1. Hayes	0.6	1.5	1.3	2.0	.24
2. Gans West	0.3	0.7	1.3	2.1	.30
3. Gans South	0.5	1.2	1.2	2.0	.27
4. Chris	0.5	1.2	1.3	2.1	.27
5. Oscar Larson . . .	0.7	1.8	1.3	2.1	.27
6. Cloquet	1.2	3.0	1.7	2.8	.22
7. Miller	1.3	3.5	2.0	3.3	.20
8. Cole	0.3	0.8	1.1	1.7	.29
9. Harry Wier	3.0	7.8	2.8	4.4	.16
10. Dolason	0.8	2.2	1.6	2.5	.28
11. "G"	0.8	2.0	1.5	2.4	.30
12. Airstrip	0.4	1.1	1.4	2.3	.30
13. Slide	1.2	3.1	1.6	2.6	.26
14. Childs	0.3	0.7	1.3	2.2	.23
15. Maneze	0.3	0.8	1.3	2.1	.23
16. Copper	2.9	7.4	3.0	4.8	.18
17. Big Tree	0.3	0.8	1.4	2.3	.32
18. Coyote	7.9	20.4	4.1	6.5	.13
19. Carson	0.6	1.6	1.4	2.3	.31
20. Garrett	4.2	10.8	2.8	4.5	.18
21. Lacks	17.0	44.0	8.5	13.6	.06
22. Stover	0.9	2.3	1.8	2.9	.28
23. Roaring Gulch . . .	0.7	1.8	1.6	2.5	.31
24. Beaver	0.8	2.1	1.8	3.0	.26
25. Mill	1.4	3.5	2.1	3.3	.24
26. Molasses	1.7	4.4	2.3	3.7	.21
27. Moon	1.1	2.8	1.9	3.0	.25
28. Minor	13.0	33.6	6.5	10.5	.08
29. Sweathouse	1.6	4.1	1.9	3.0	.24
30. Captain	2.1	5.3	2.2	3.5	.24
31. Negro Joe	1.2	3.2	1.7	2.8	.24
32. Windy	1.8	4.6	2.1	3.3	.19
33. Squirrel Tail . . .	1.6	4.3	2.4	3.8	.25
34. Emmy Lou	2.6	6.7	3.3	5.4	.22
35. Cut Off Meander . .	0.9	2.4	2.0	3.2	.26
36. Gunrack	2.4	6.1	3.4	5.4	.20
37. Simon	1.7	4.5	2.9	4.6	.23
38. Minon	4.3	11.1	3.1	4.9	.24
39. Bradford	6.4	16.5	4.0	6.4	.18
40. Last Gasp	1.6	4.1	1.8	2.9	.25
41. Lineament	0.9	2.4	1.4	2.3	.26

Table A2

GENERAL INFORMATION FOR WESTSIDE TRIBUTARIES

WESTSIDE TRIBUTARIES	Drainage Area (Mi²)	(Km²)	Drainage Length (Mi)	(Km)	Average Gradient (m/m)
1. Mc Arthur	3.8	9.9	4.7	7.5	.05
2. Elam	2.5	6.5	2.6	4.2	.09
3. Bond	1.4	3.7	1.8	3.0	.14
4. Forty Four	3.1	8.1	3.1	5.1	.10
5. Tom McDonald . . .	6.9	18.0	4.6	7.5	.07
6. Bridge	11.4	29.5	8.0	12.9	.06
7. Elf	1.0	2.0	1.5	2.5	.29
8. Devils	7.0	18.0	5.0	8.0	.08
9. Panther	6.0	15.4	3.5	5.6	.11
10. George	1.1	2.8	1.7	2.7	.24
11. Karen	3.0	7.9	2.6	4.1	.15
12. Lee	0.5	1.3	1.7	2.7	.21
13. Garcia	1.4	3.5	2.3	3.6	.16
14. Cashmere	1.4	3.6	2.1	3.3	.23
15. Pilchuck	1.8	4.5	2.6	4.1	.18
16. Toss-Up	2.6	6.8	2.7	4.3	.19
17. Wiregrass	1.8	4.8	2.2	3.6	.21
18. Loin	0.9	2.4	1.5	2.4	.26
19. Sante Fe	0.8	2.1	1.5	2.4	.20
20. Green Point	0.5	1.3	1.3	2.1	.25
21. Lupton	5.2	13.5	4.7	7.5	.09
22. Fern Prairie . . .	0.8	2.0	1.3	2.1	.25
23. Christmas Prairie .	0.6	1.6	1.5	2.4	.20
24. Noisy	6.3	16.4	4.7	7.5	.08
25. Cool Spring	1.2	3.0	2.1	3.4	.20
26. Six Rivers	1.3	3.2	2.1	3.3	.20
27. High Prairie . . .	5.5	14.3	3.8	6.1	.11
28. Lake Prairie . . .	3.4	8.8	3.1	5.0	.12
29. Pardee	3.1	8.1	3.2	5.2	.18
30. Marquette	0.8	2.1	2.1	3.4	.25
31. Powerline	0.7	1.7	1.7	2.8	.29
32. Snowcamp	3.4	8.2	2.8	4.5	.17
33. Upper Redwood . . .	4.3	11.1	5.0	8.0	.11

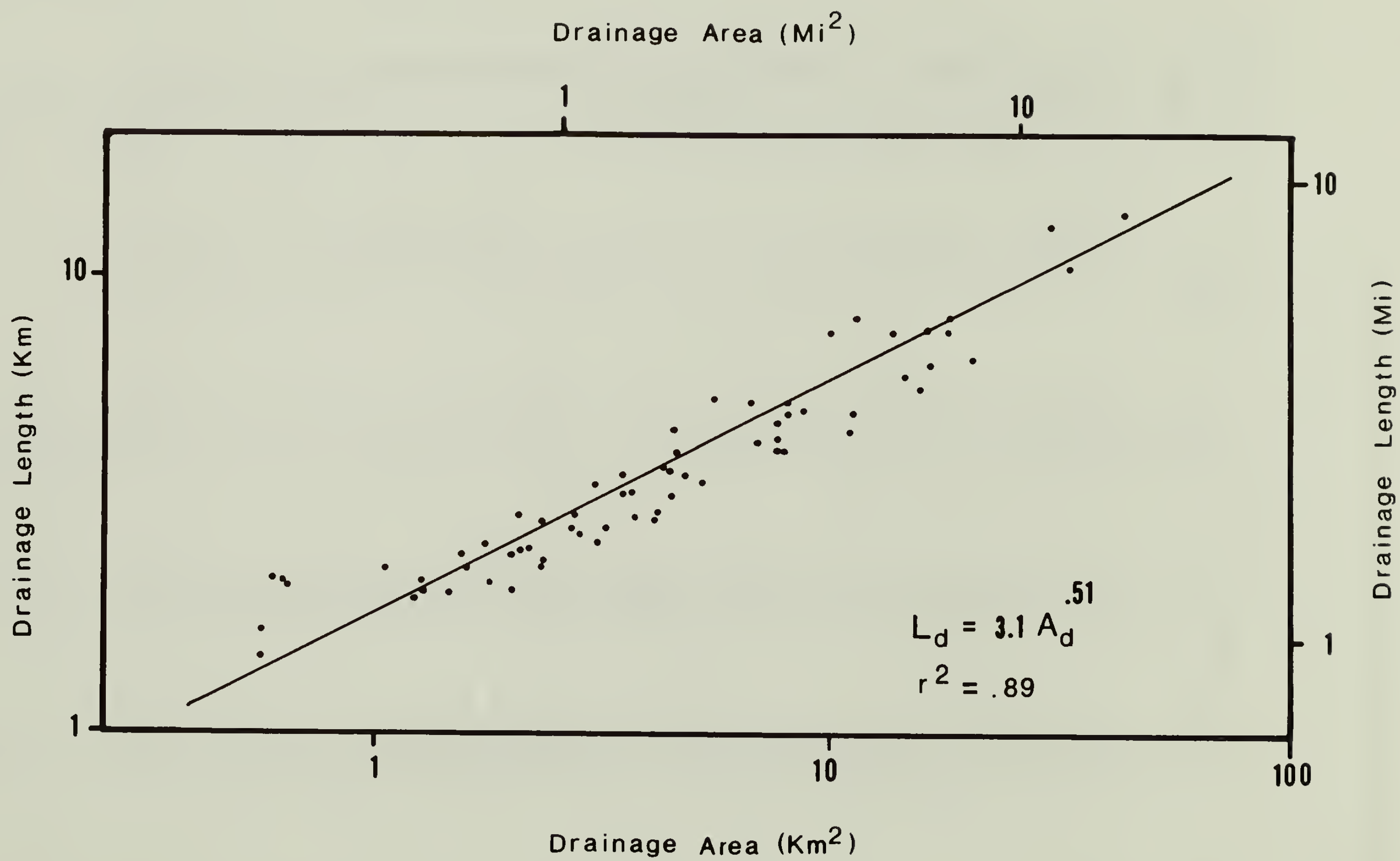


Figure A1. Relationship for drainage area (A_d) and drainage length (L_d) for tributaries of Redwood Creek.

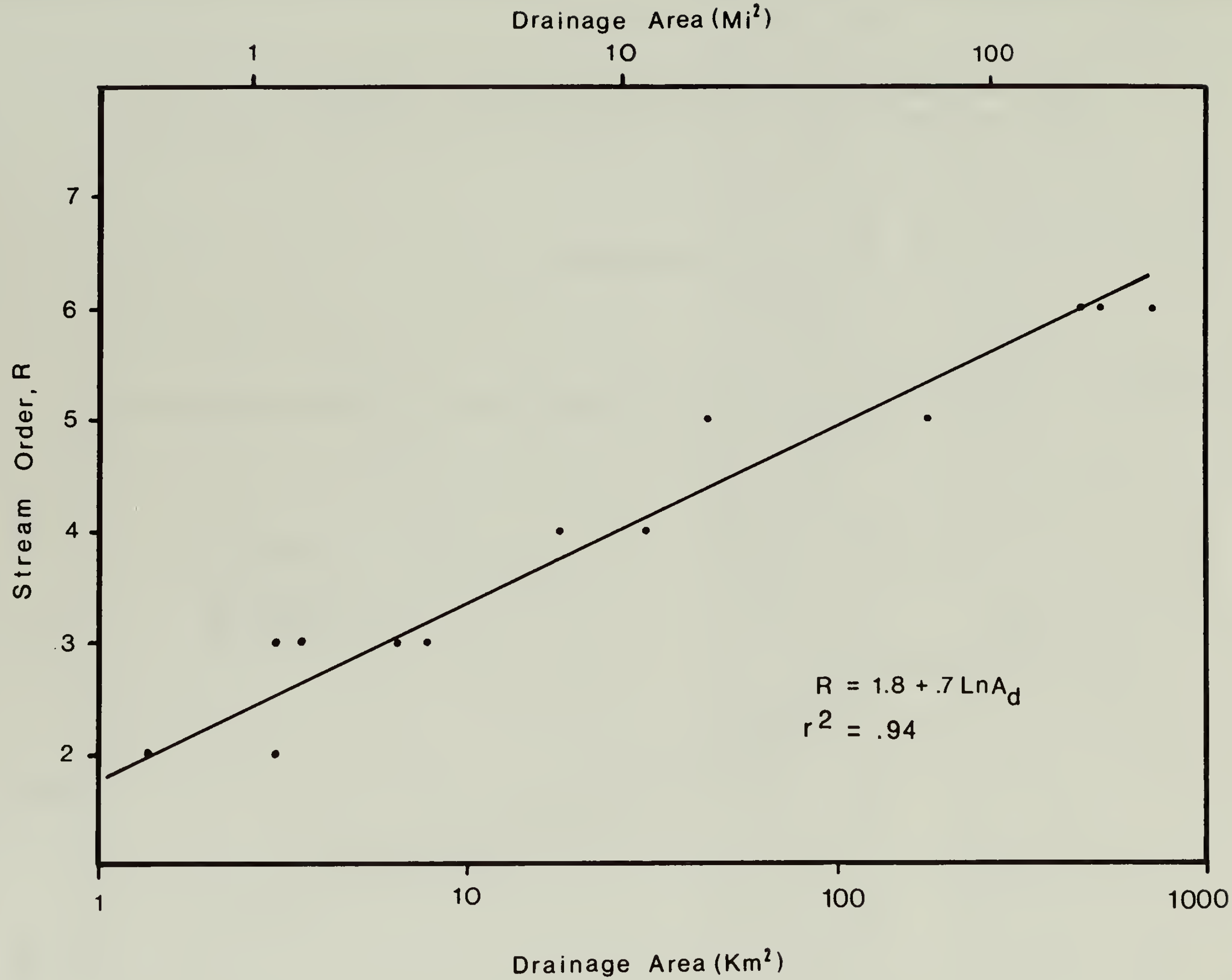


Figure A2. Relationship for drainage area (A_d) and stream order (R) for Redwood Creek and selected tributaries (Data from Iwatsubo, R.T., et al., 1976).

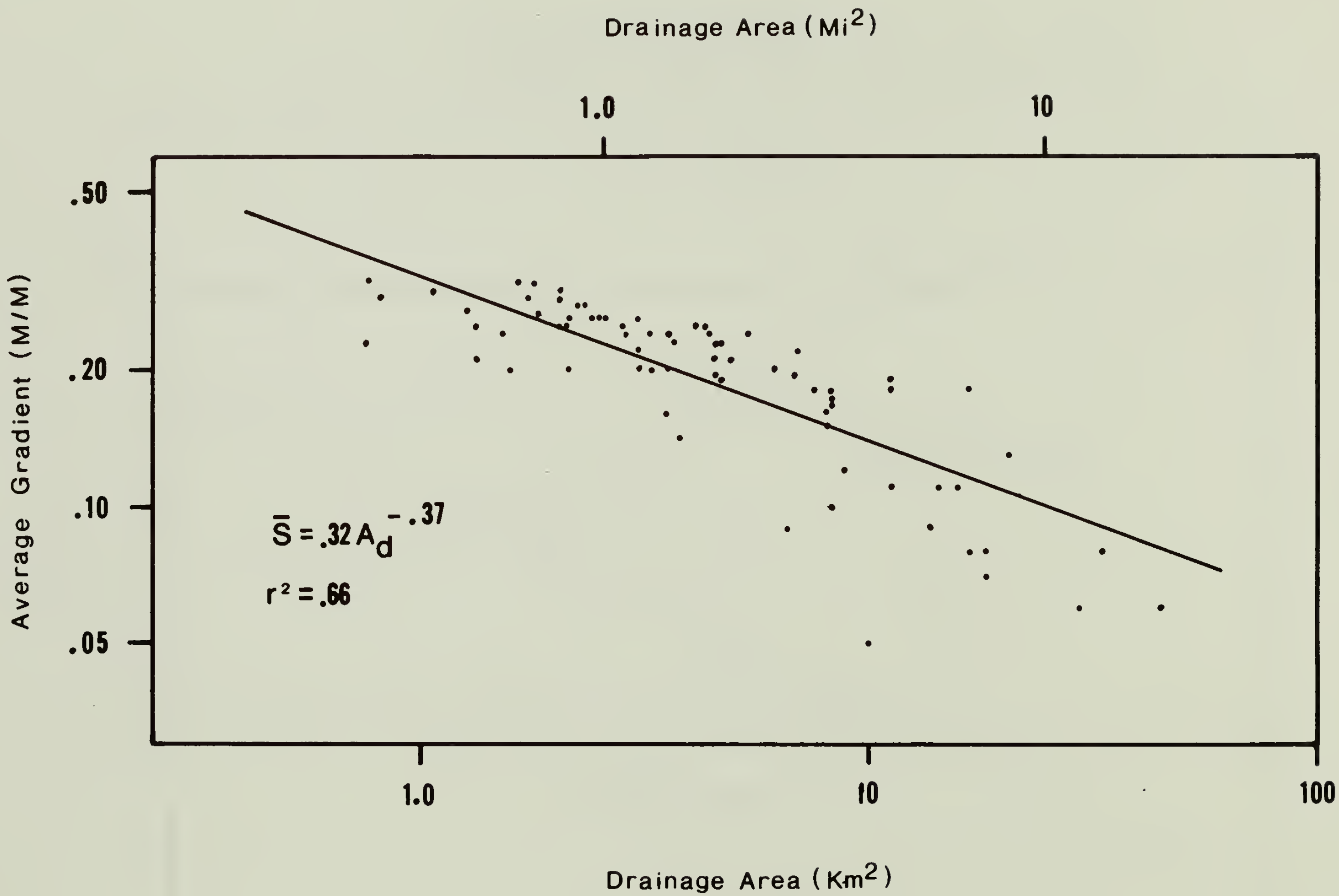


Figure A3. Relationship for drainage area (A_d) and average stream gradient (S) for tributaries of Redwood Creek.

APPENDIX B

Figures B1 through B17 depict the locations of mapped reaches, longitudinal profiles and large log jams. For each reach designated as a "mapped reach", a morphologic map of the channel has been constructed at a scale of 1 inch = 20 feet. Longitudinal profiles were also surveyed for each of these mapped reaches. The locations of additional longitudinal profiles for which there are no morphologic maps are also shown. Data from stream surveys (plotted profiles, morphologic maps, tabulation and description of stored sediment) is on file at the Arcata Office of Redwood National Park. Only the largest log jams are depicted on the location maps. Numerous smaller jams are found on many stream reaches and these are generally not shown.

Tables B1 through B19 present tabulated stored sediment data. The total amount of sediment stored in the main tributary channels is broken down by 300 meter (1,000 ft) reaches measured from the mouth. In most tributaries, the volume of stored sediment was determined by field measurement of consecutive reaches. Reaches where stored sediment was estimated by using air photos or extrapolating data from adjacent reaches are noted under "remarks".

FIGURE B1

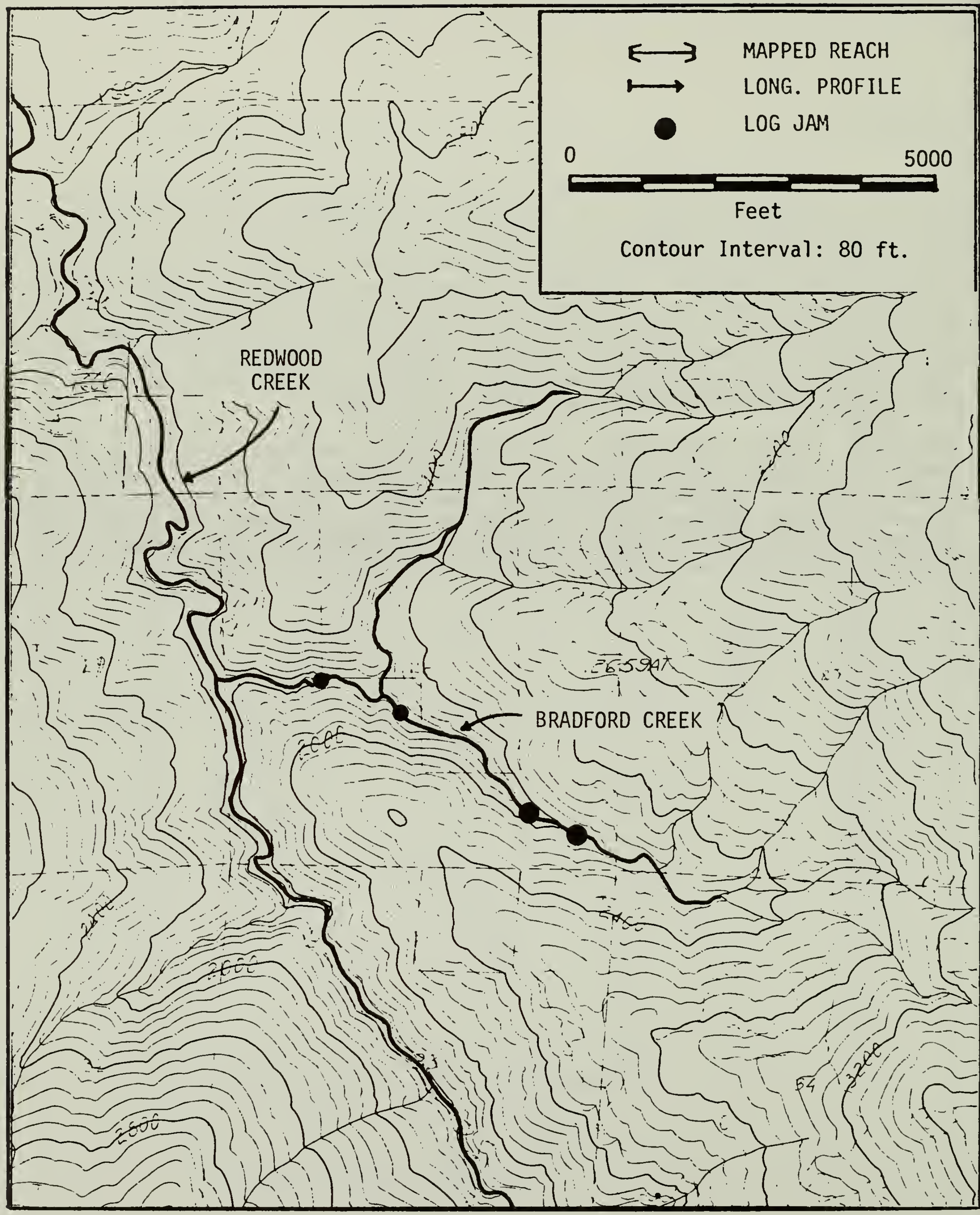
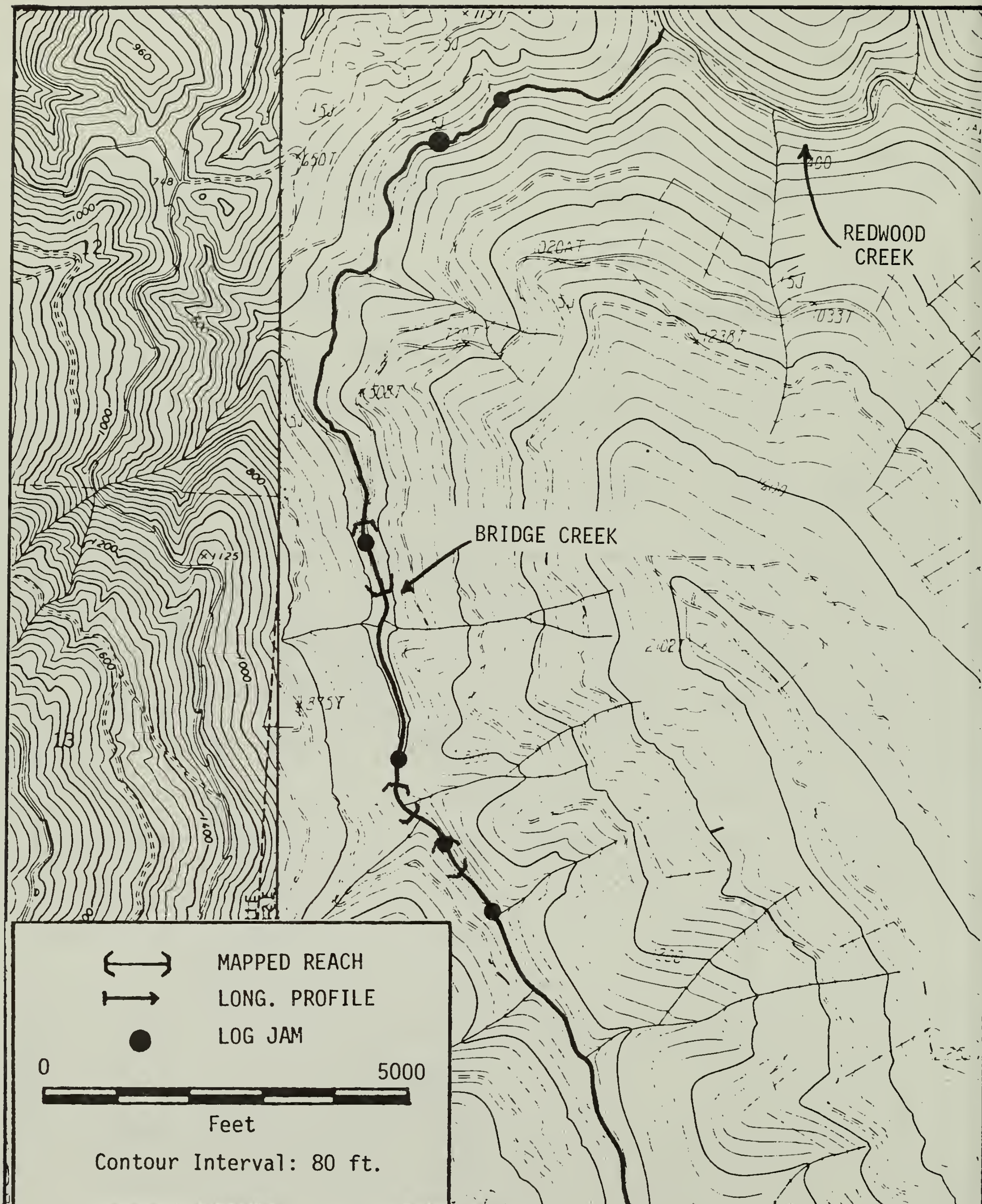

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
REDWOOD CREEK
BRADFORD CREEK

TABLE B1

TRIBUTARY: BRADFORD CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	8,865	Majority stored as backwater terraces at confluence w/ Redwood Cr.
2	2,926	
3	0	Coarsely bedded high gradient reach
4	1,281	Large jam
5	993	Large jam
TOTAL	14,064	

FIGURE B2



REDWOOD CREEK
BRIDGE CREEK
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B2

TRIBUTARY: BRIDGE CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
TOTAL	200,000	Data on sediment storage provided by David Leslie, Department of Earth
		Sciences, University of California, Santa Cruz

FIGURE B3

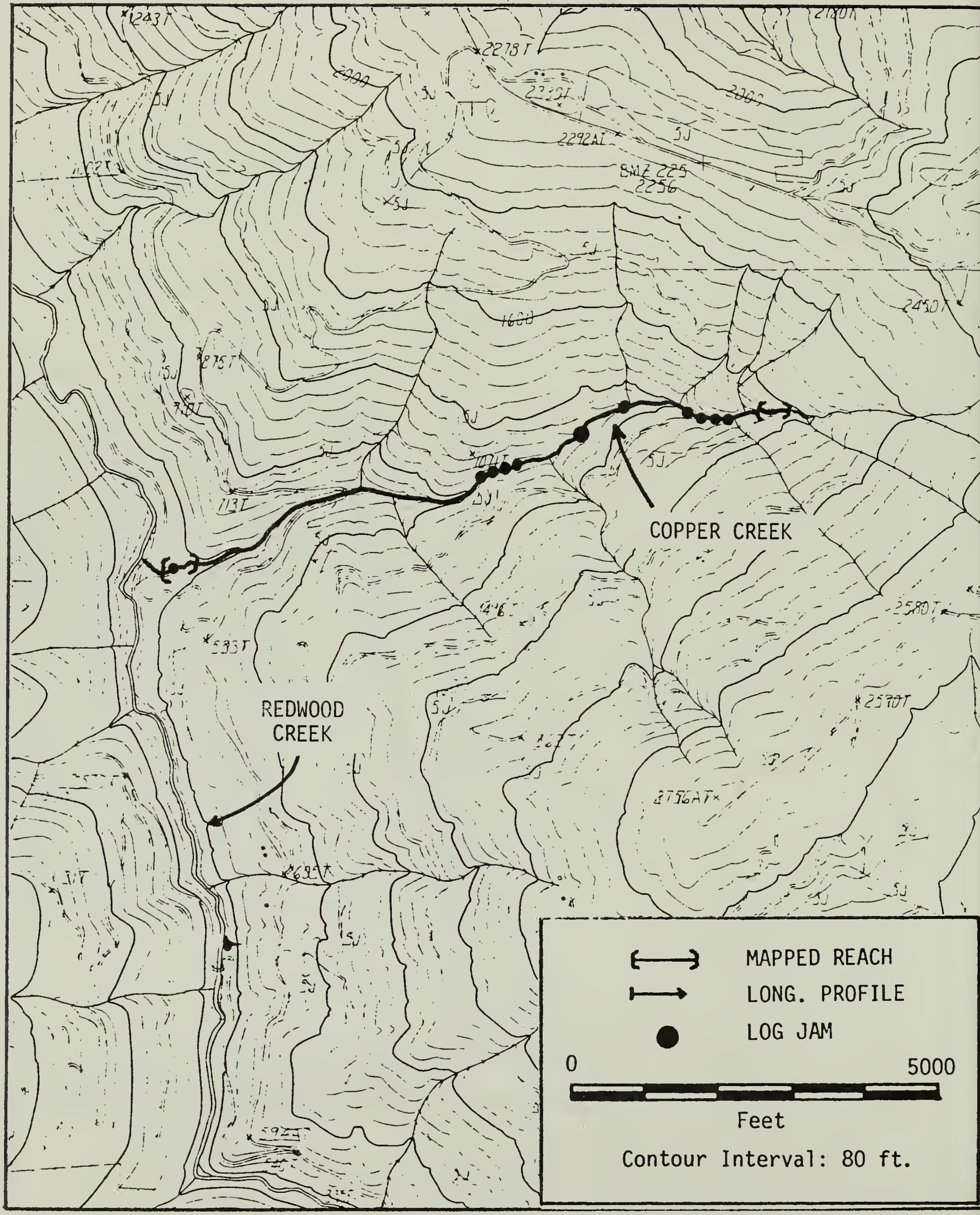

COPPER CREEK
REDWOOD
CREEK
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B3

TRIBUTARY: COPPER CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	4,322	mapped reach
2	0	Steep, boulder-bedded reach
3	0	" " " "
4	704	
5	704	
6	1,011	numerous small log jams
7	1,278	
8	634	
9	590	
10	453	
TOTAL	9,696	

FIGURE B4

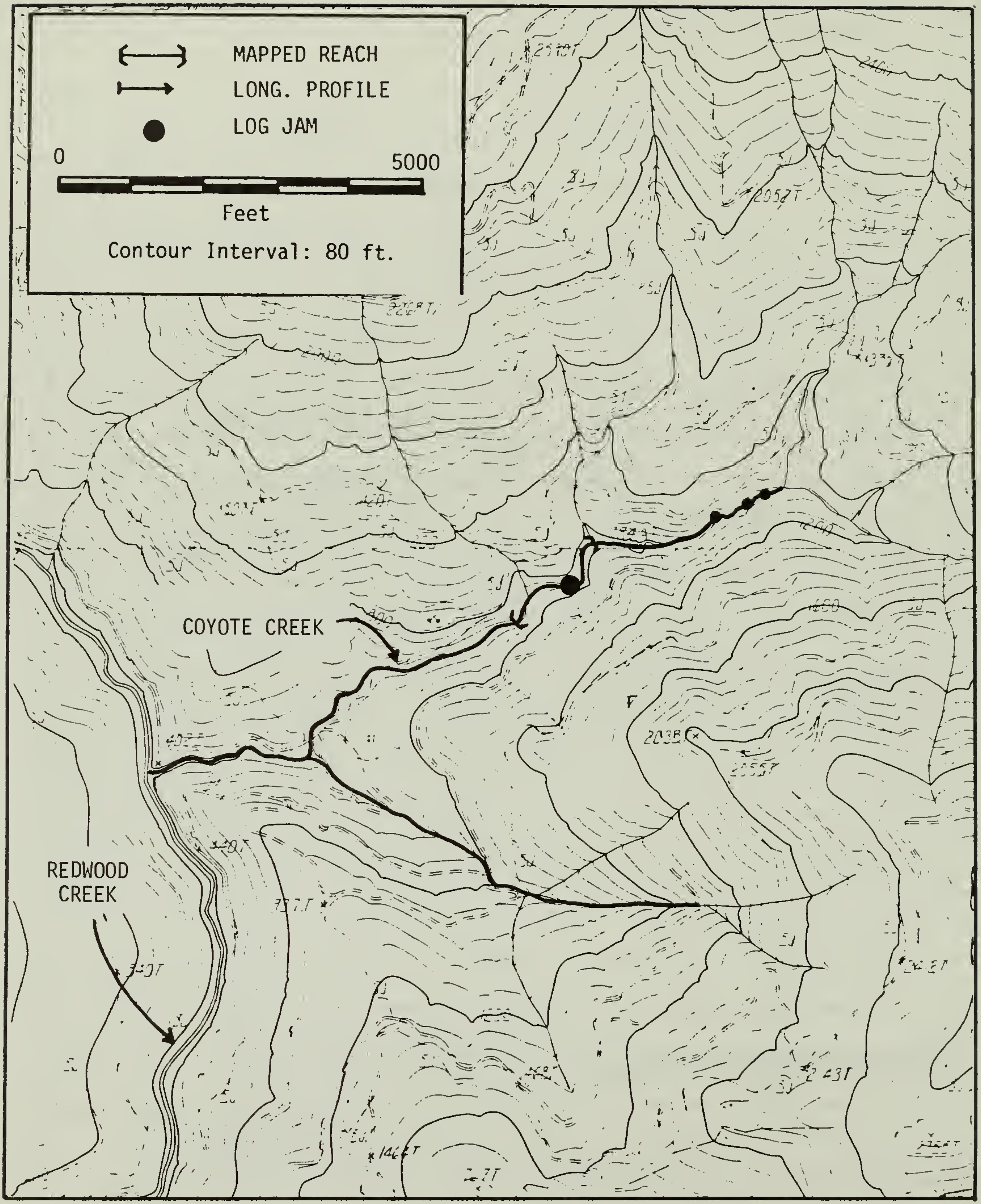

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
COYOTE CREEK
REDWOOD
CREEK

TABLE B4

TRIBUTARY: COYOTE CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1		
2		
3		Coarsely-bedded, moderate gradient reaches; little organic debris
4		
5		
6		Narrow, steep reach
7	164	
8	4,429	Very large log jam (mapped)
9		Narrow, steep reach
10		" " "
11	1,371	Numerous log jams

Comments: Total basin estimate was taken from field and air photo measurements.

FIGURE B5

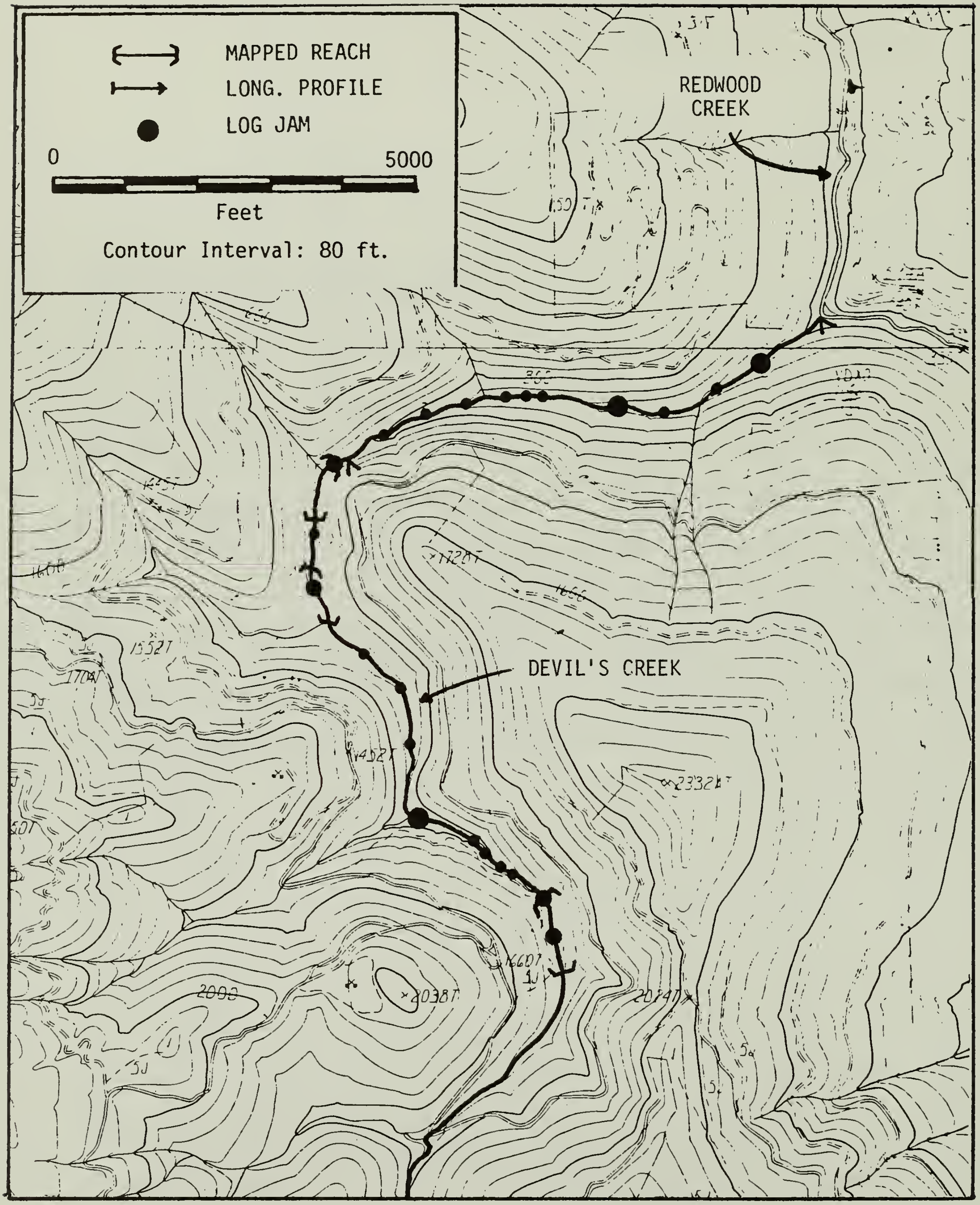

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
REDWOOD CREEK
DEVIL'S CREEK

TABLE B5

TRIBUTARY: DEVIL'S CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	0	V. steep boulder-bedded reach
2	1,856	
3	1,578	
4	312	
5	833	Moderate-high gradient reaches in Old-growth. Numerous debris jams.
6	1,058	
7	1,203	
8	3,161	
9	3,866	Mapped reach
10	2,612	Mapped reach
11	1,012	
12	605	Moderate-high gradient reaches in Old-growth. Numerous debris jams.
13	1,558	
14	713	Adjacent to cable cut
15	551	
16	1,867	
17	1,313	Mapped reach
18	533	Mapped reach
TOTAL	24,632	

FIGURE B6

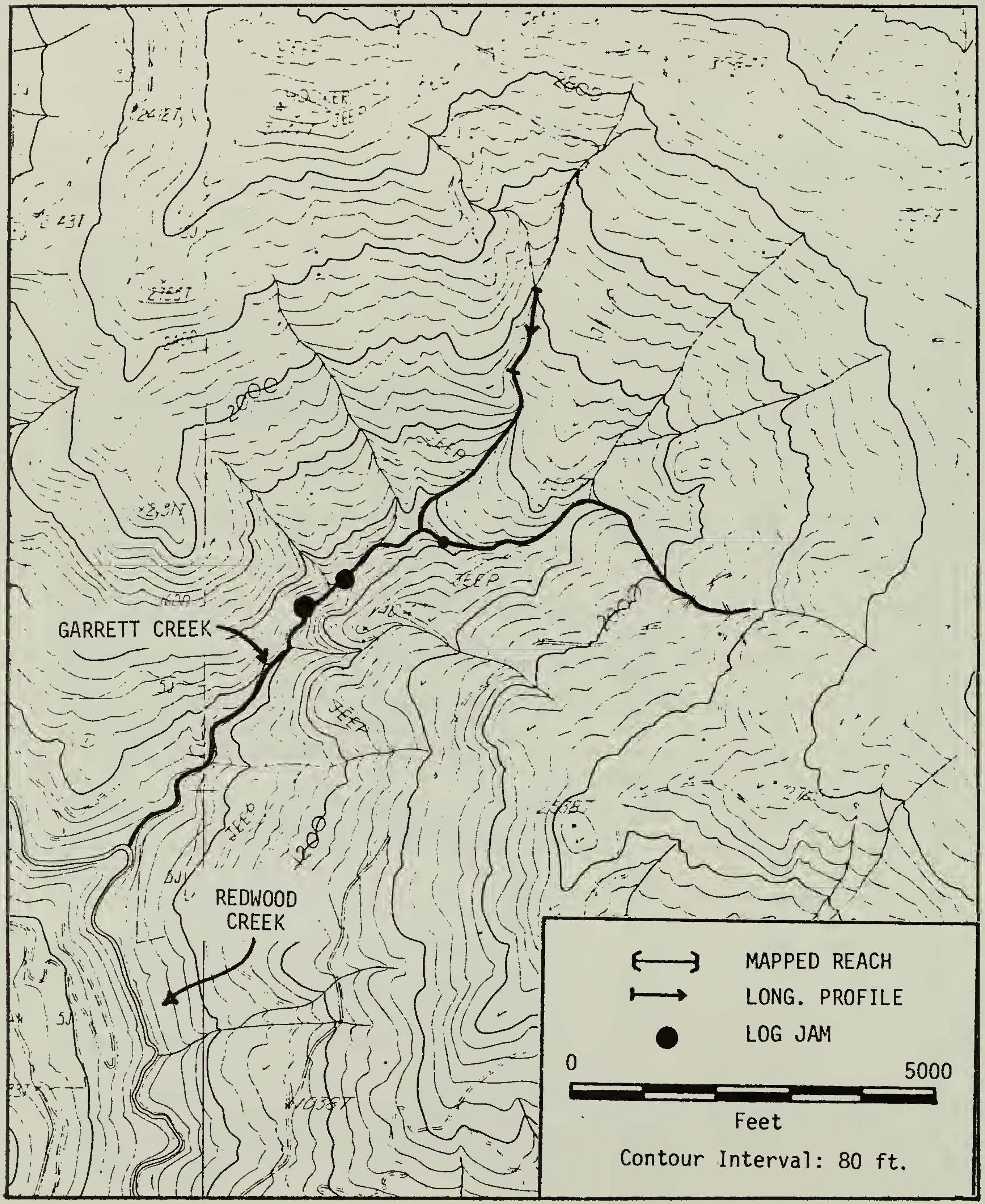
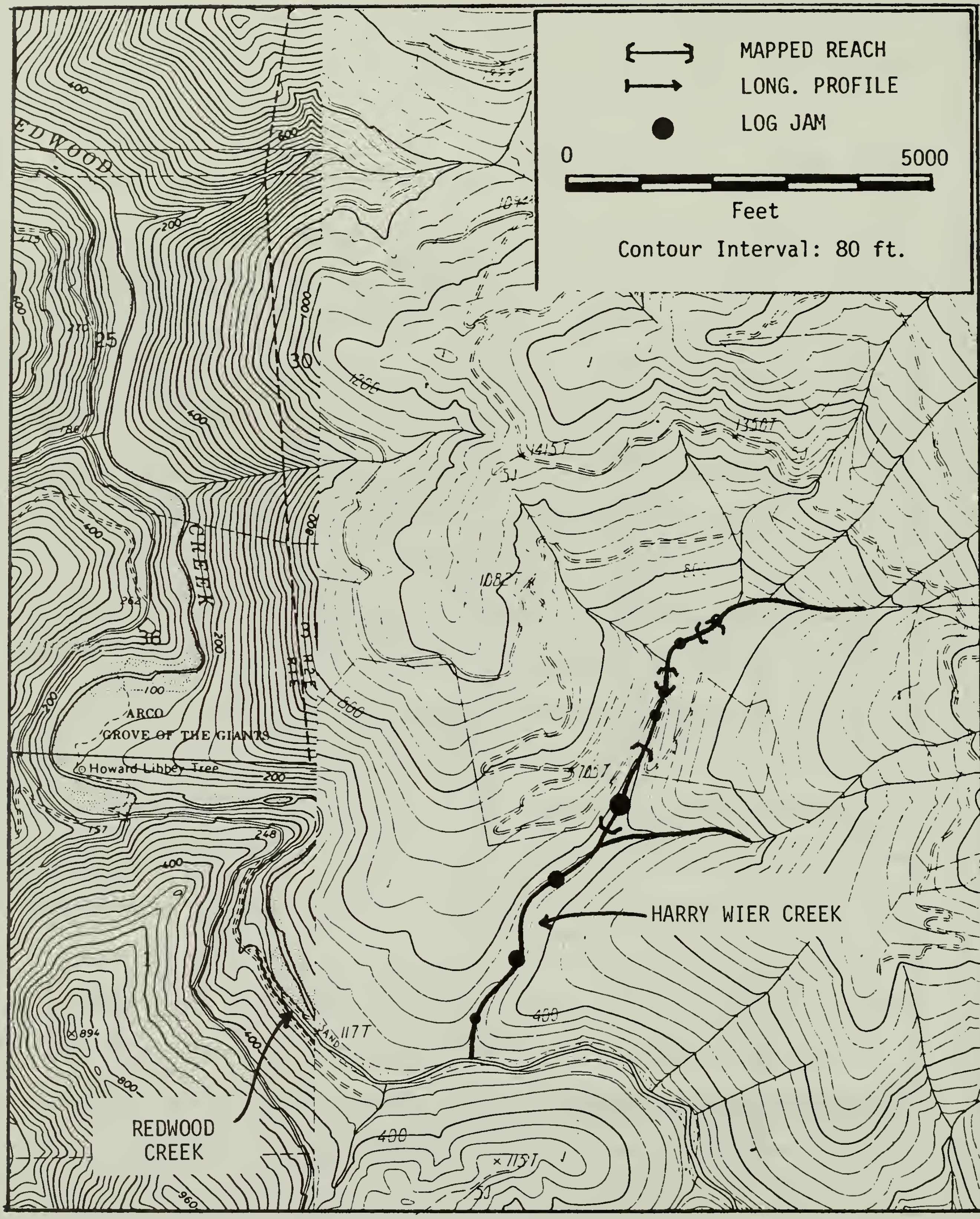

GARRETT CREEK
REDWOOD CREEK
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B6

TRIBUTARY: GARRETT CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	0	
2	0	Coarsely bedded, moderate gradient reaches; very little organic debris
3	0	Deeply incised, narrow, high gradient reaches.
4	515	
5	767	
6	1,535	
7	789	Steep reaches; numerous log jams
8	1,716	
9	270	
10	1,464	
11	737	
TRIBS:	2,002	Measured in forks
TOTAL	9,795	

FIGURE B7



MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
HARRY WIER CREEK
REDWOOD
CREEK
ARCO
GROVE OF THE GIANTS
Howard Libbey Tree

TABLE B7

TRIBUTARY: HARRY WIER CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	1,271	
2	710	
3	2,028	
4	967	Moderate-high gradient reaches in old growth; numerous debris jams
5	2,220	Mapped reach
6	1,456	
7	2,976	Mapped reach
8	309	
9	0	
10	239	
TRIB	2,997	
TOTAL	15,172	

FIGURE B8

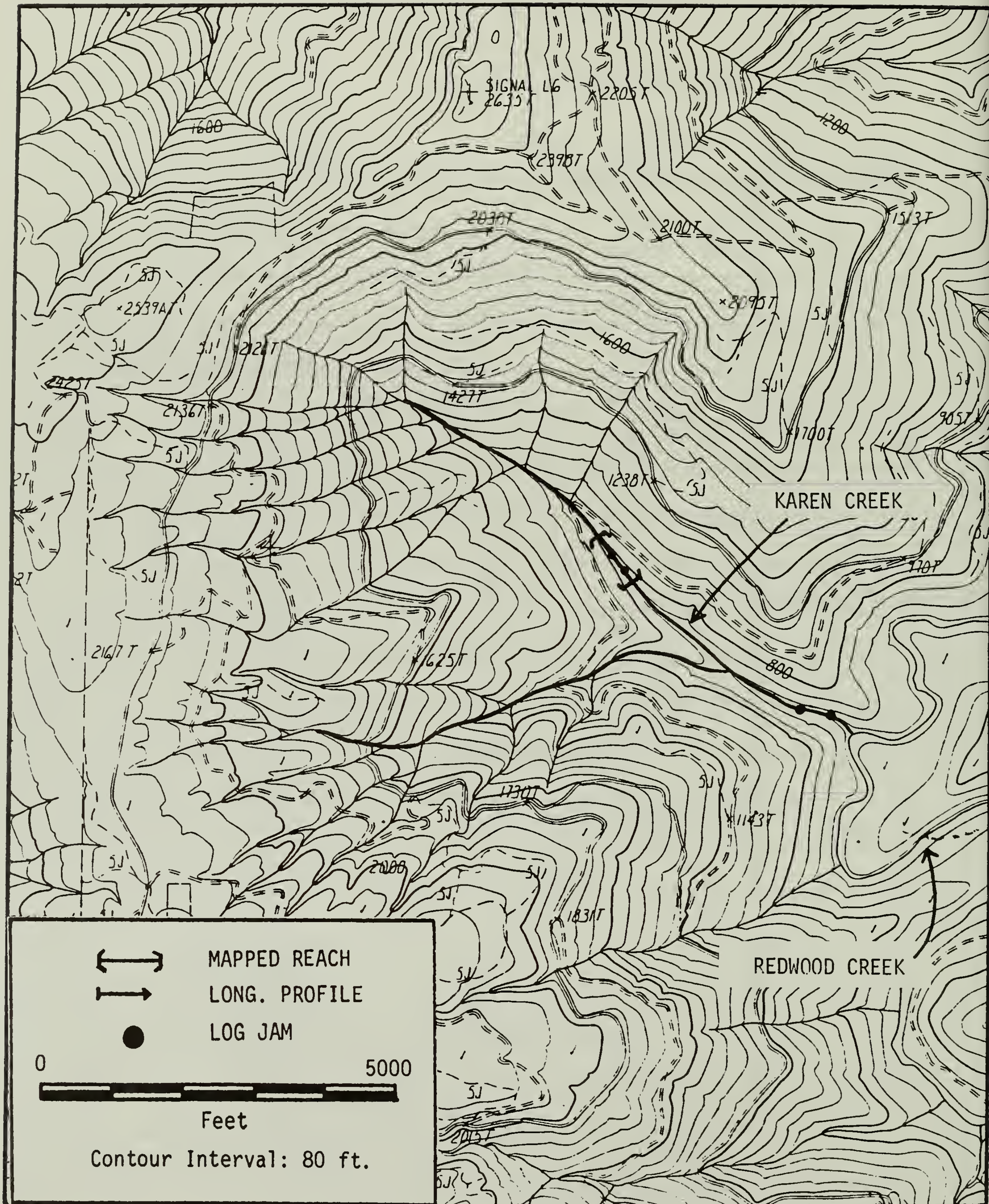

SIGNAL LG
2635T
2205T
1600
1200
2398T
2030T
2100T
1513T
5J
2539AT
2095T
2128T
1600
1427T
2136T
1700T
905T
1238T
KAREN CREEK
2167T
1625T
800
1730T
1143T
2000
1831T
REDWOOD CREEK
2055T
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B8

TRIBUTARY: KAREN CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1-3	--	No stored sediment data collected
4	3,793	Mapped Reach
5	2,611	Mapped Reach
		No estimate made of total stored sediment.

FIGURE B9

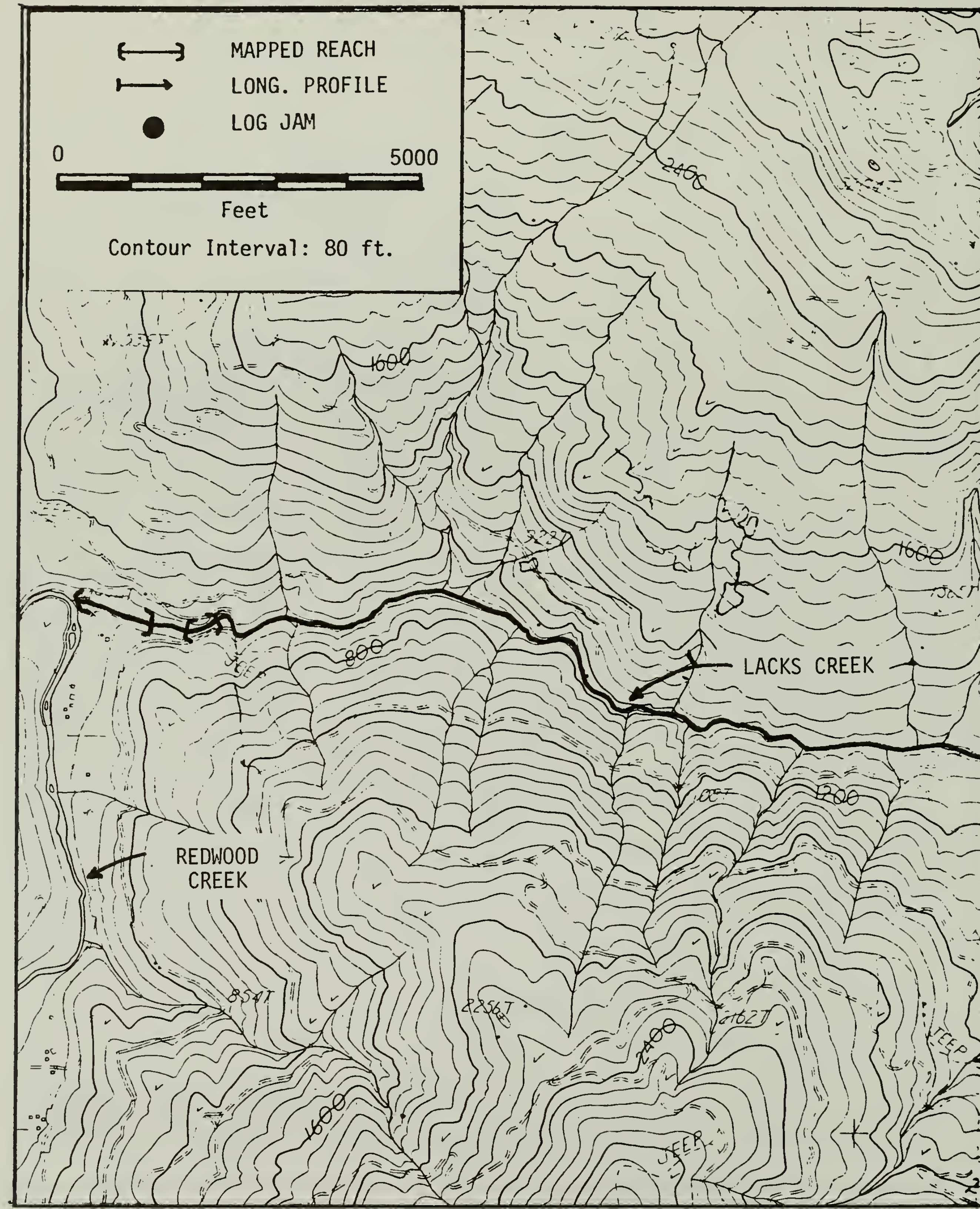

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
LACKS CREEK
REDWOOD CREEK
1600
800
1200
2400

FIGURE B10

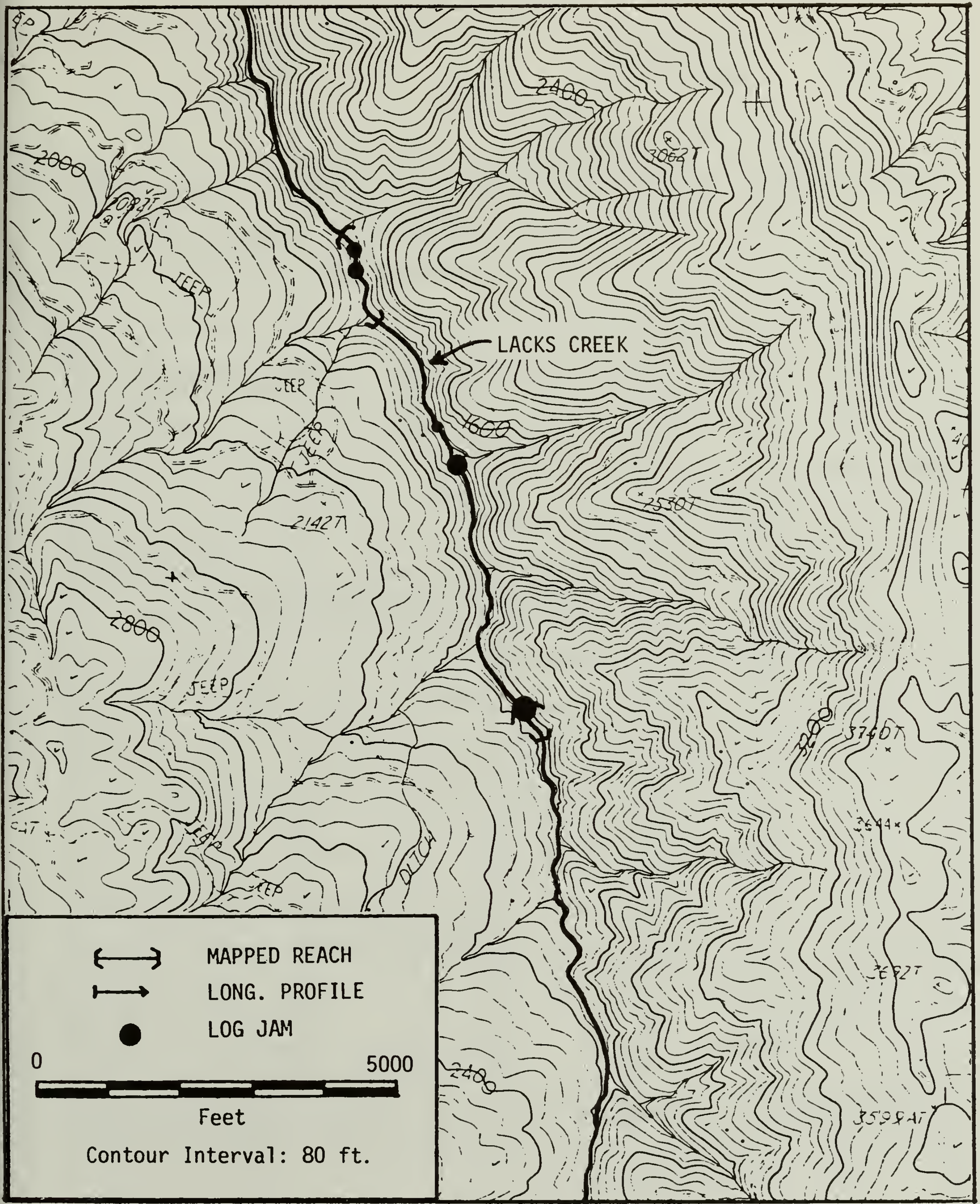
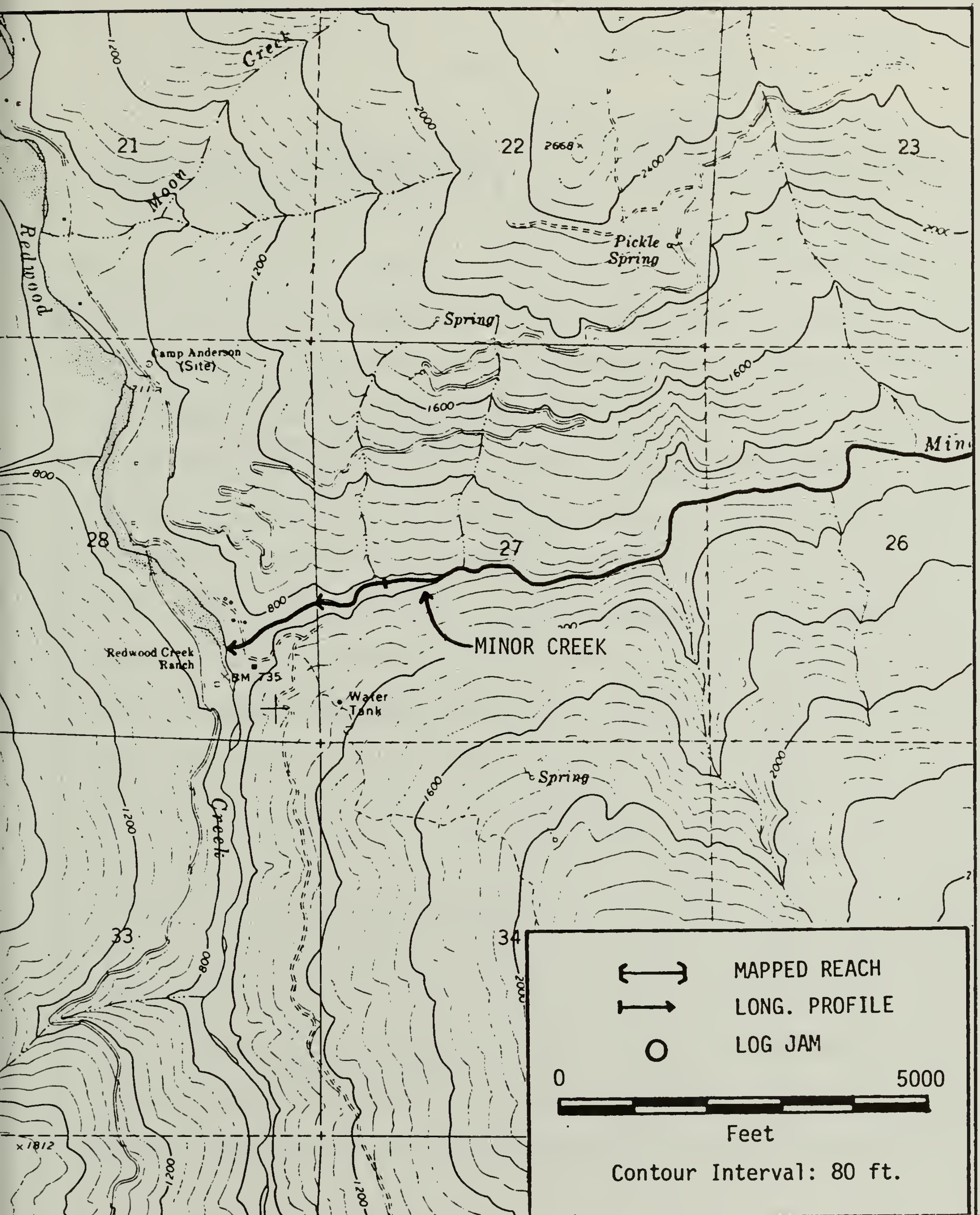

LACKS CREEK
2400
2000
1600
2800
2142T
JEEP
DITCH
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B9

TRIBUTARY: LACKS CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	17,825	Mapped reach; hydraulically-stored sediment
2-8	0	Narrow, mod. gradient reaches with little organic debris.
9	1,303	
10	295	
11-14	0	Narrow, mod. gradient reaches.
15	425	
16-17	0	
18	97	
19	0	V. narrow deeply incised reach; little organic debris
20	1,189	Large terrace
21	0	Deeply incised reach
22	2,130	Mapped reach
23	9,898	Low gradient, aggraded reach
24	2,719	
25	510	
26	1,274	Moderate gradient reaches with frequent jams
27-28	1,133	
29	566	
30	12,702	One large jam (mapped)
31-42	10,082	Average value based on mapped reach.
TOTAL	62,290	

FIGURE B11



Creek
Moon
Redwood
21
22
2668
2400
23
2000
1200
Pickle
Spring
Spring
Camp Anderson
(Site)
1600
1600
Min
800
28
27
26
800
Redwood Creek
Ranch
BM 735
MINOR CREEK
Water
Tank
Spring
2000
1600
1200
Creek
33
34
800
x 1812
1200
1200
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B11

TRIBUTARY: MINOR CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	2,252	long. profile shot from mouth
2	1,556	
3	5,785	
4	3,537	
5	1,538	
6	2,952	Moderate gradient reaches with frequent fill terraces.
7	8,021	
8	5,930	
9	6,187	
10	3,476	
11	6,039	
12	15,718	Wide, aggradded reach
13	0	
14	726	
15	0	
16	14,443	Stored in tributary
17	5,197	
18	7,718	
19	10,875	Stored in tributary
20	5,206	

TABLE B10

TRIBUTARY: MINOR CREEK (cont.)

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
21	0	
22	1,187	
23	3,517	
24-headwtrs	2,266	Average based on mapped reach
TOTAL	114,126	

FIGURE B12

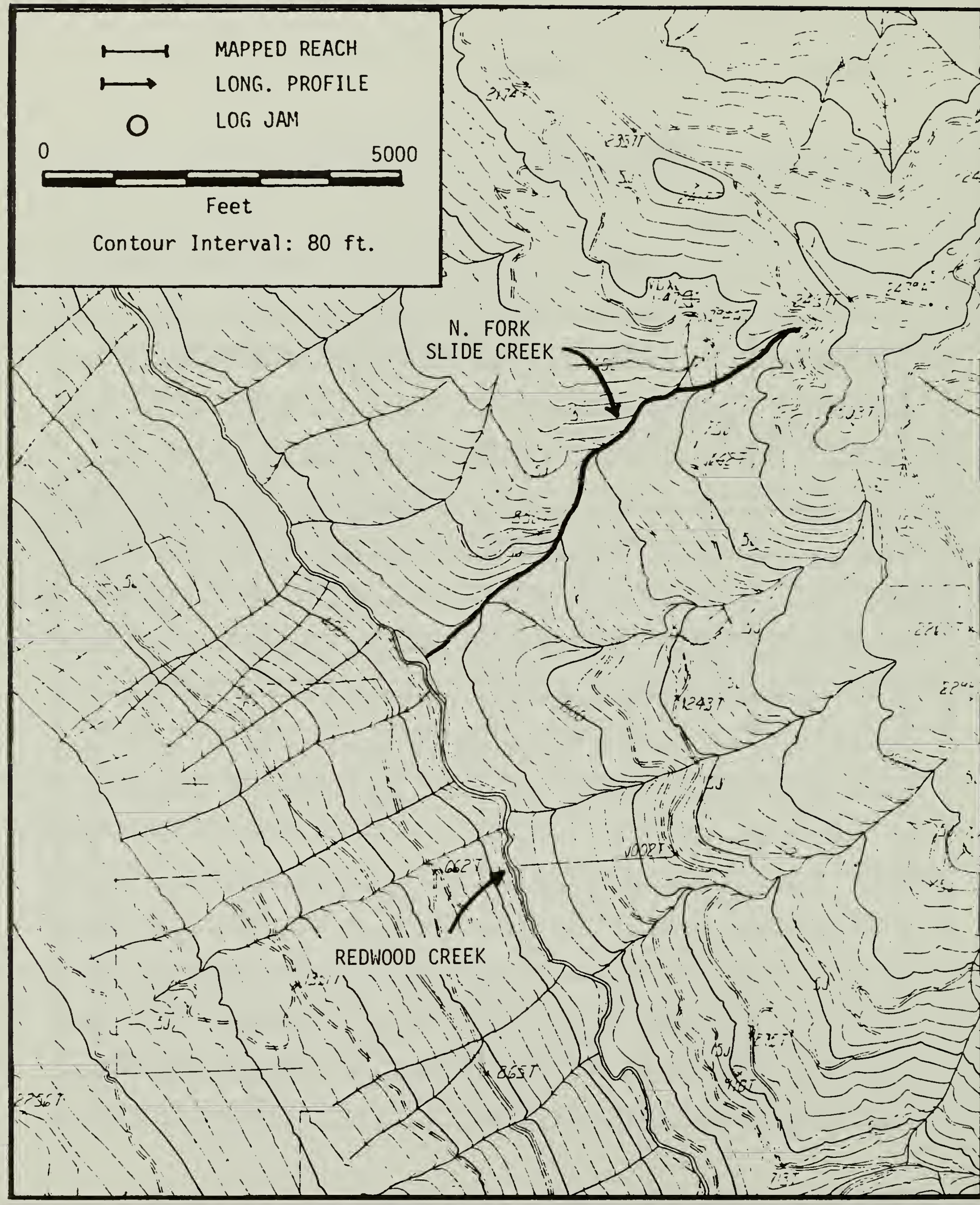

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
N. FORK
SLIDE CREEK
REDWOOD CREEK

TABLE B12

TRIBUTARY: N. FORK SLIDE CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	4,247	In old growth
2	2,605	Numerous small jams in clear-cuts
3	4,209	
4	1,606	
TOTAL	12,668	

FIGURE B13

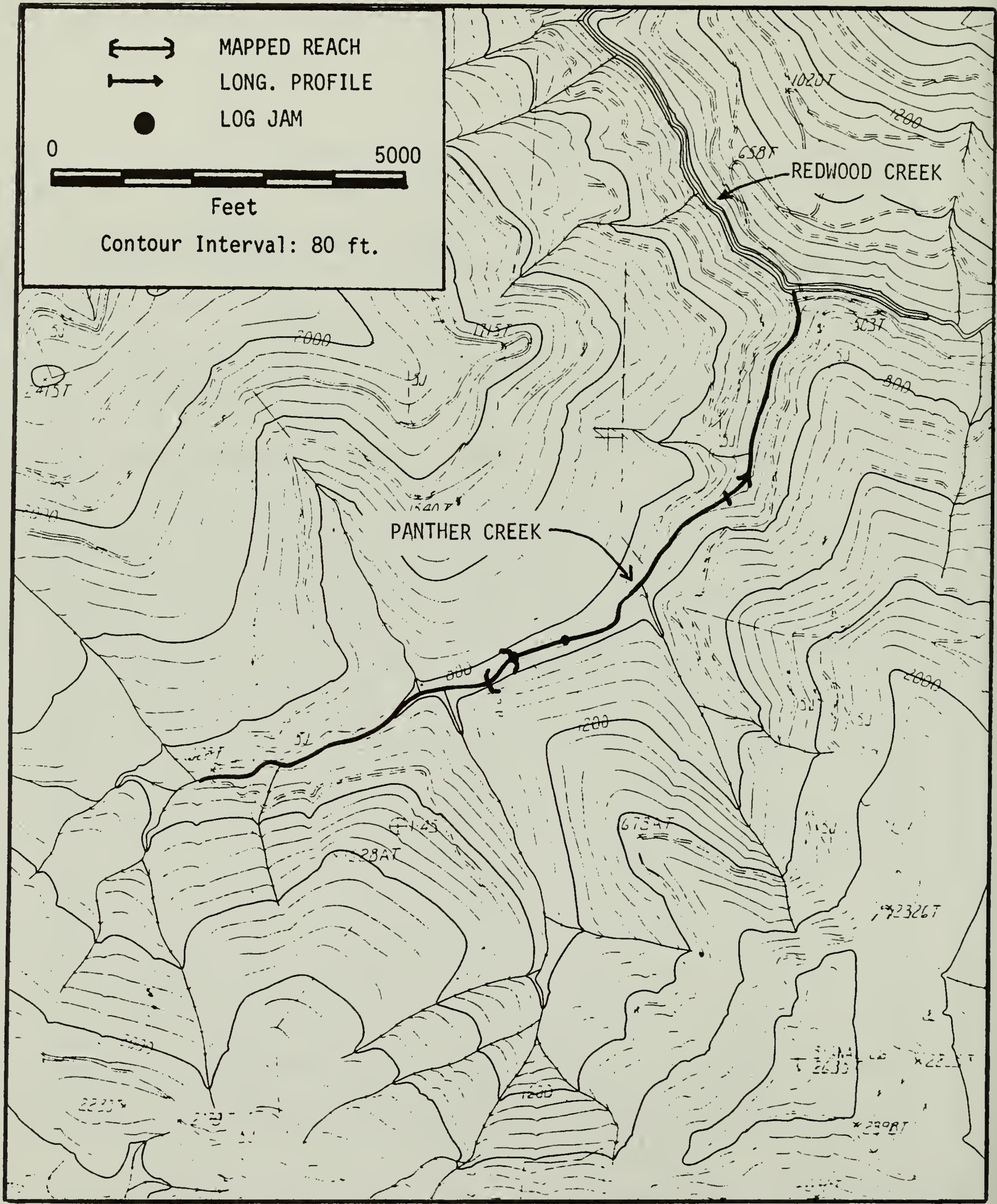
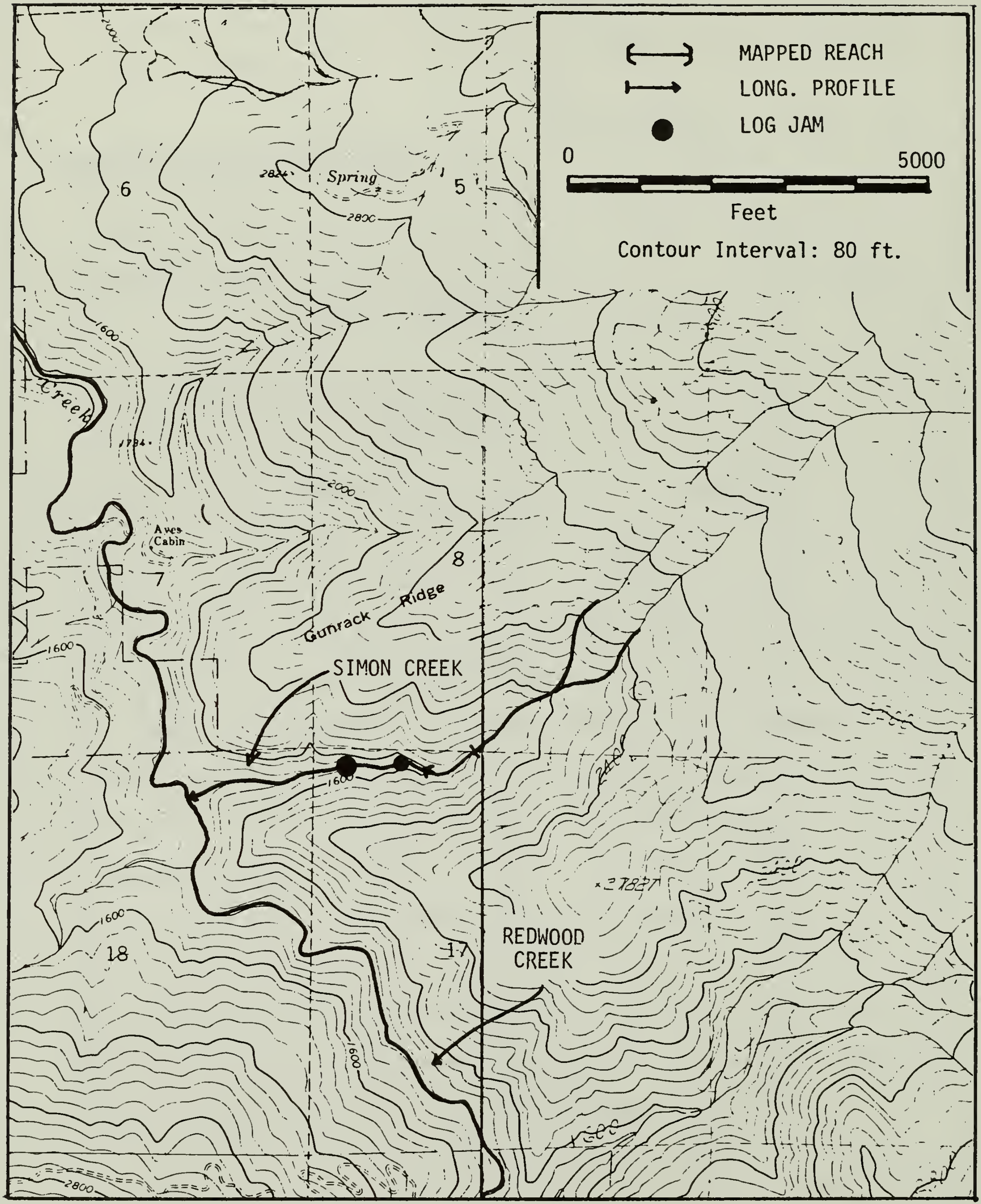

MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
REDWOOD CREEK
PANTHER CREEK

TABLE B13

TRIBUTARY: PANTHER CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1,2	--	No stored sediment data collected
3	294	Long profile shot
4-7	--	No stored sediment data collected
8	4,386	Mapped section
		No estimate made of total stored sediment

FIGURE B14



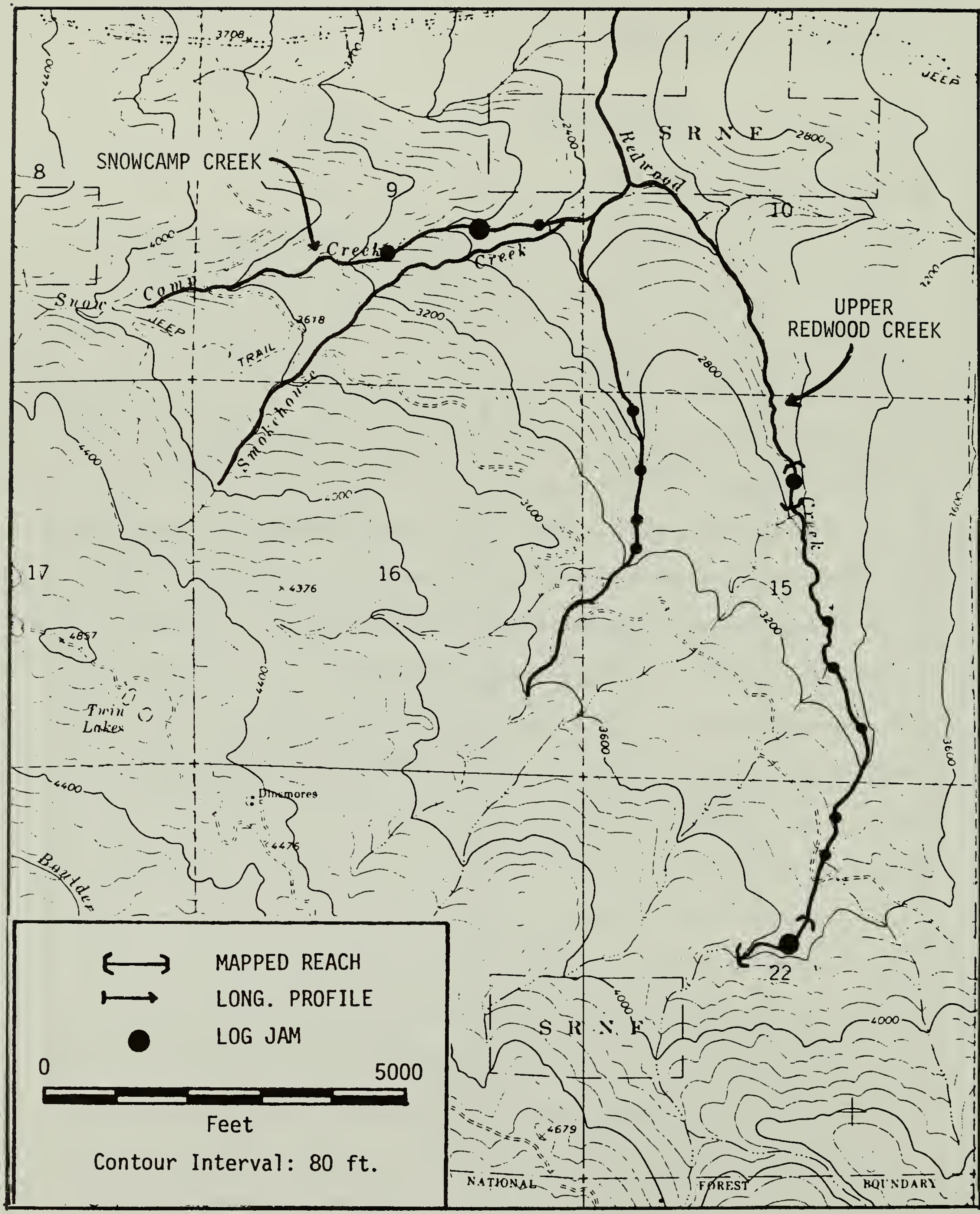
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
Spring
2800
6
5
Creek
1600
Aves Cabin
7
8
Gunrack Ridge
2000
SIMON CREEK
REDWOOD CREEK
18
17

TABLE B14

TRIBUTARY: SIMON CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	6,112	
2	5,389	
3	21,383	Very large debris jam; caused by slide.
4	4,513	
5	1,479	
TOTAL	38,876	

FIGURE B15



SNOWCAMP CREEK
UPPER
REDWOOD CREEK
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.

TABLE B15

TRIBUTARY: SNOWCAMP CREEK

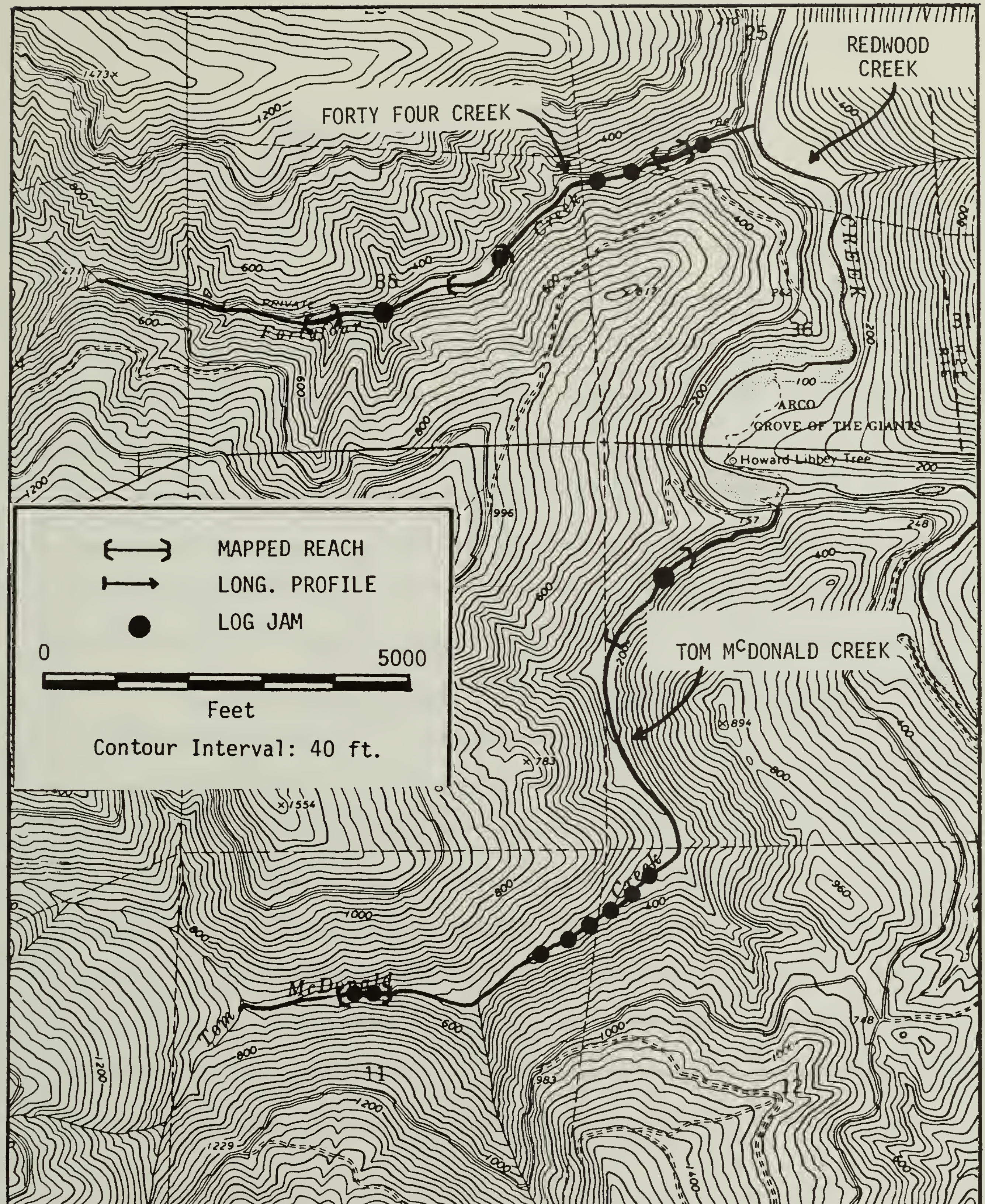
REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	1,333	
2	0	Steep boulder-bedded reach
3	3,149	
4	1,806	
5	662	
6	671	
TRIB	7,059	Stored in Twin Lakes Creek
TOTAL	14,680	

TABLE B16

TRIBUTARY: UPPER REDWOOD CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	583	Steep boulder-bedded reach
2	5,164	
3	2,943	Moderate gradient reaches with numerous debris jams
4	3,164	Mapped section
5	341	Mapped section
6	520	
7	960	
8	69	
9	0	
10	2,858	Mapped section
11	1,219	Mapped section
12	2,390	
TOTAL	20,211	

FIGURE B16



REDWOOD
CREEK
FORTY FOUR CREEK
TOM M^C DONALD CREEK
MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 40 ft.
ARCO
GROVE OF THE GIANTS
Howard Libbey Tree

TABLE B17

TRIBUTARY: TOM McDONALD CREEK

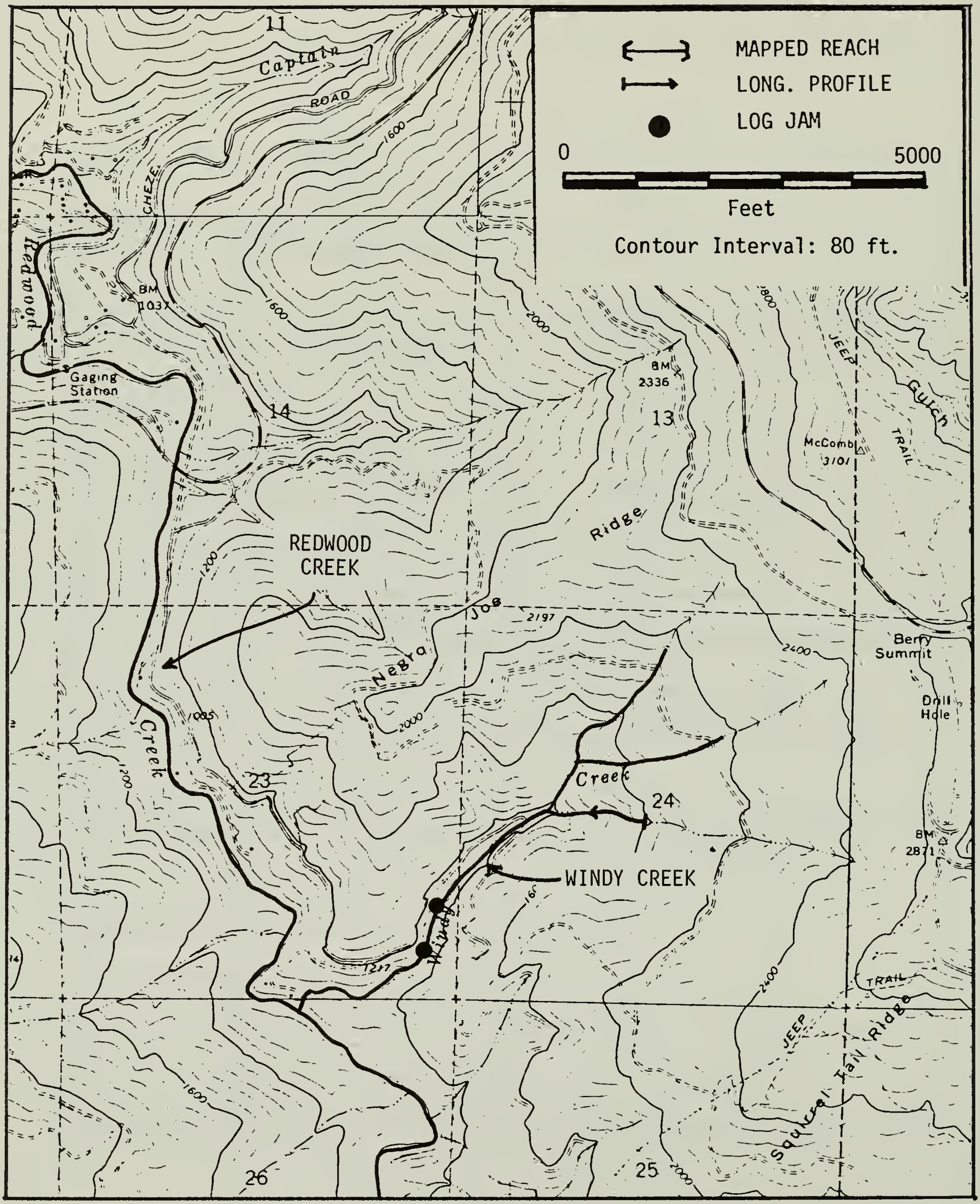
REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	4,616	
2	6,379	Mapped reach
3	4,616	
4	4,616	Low gradient, wide, alluviated reaches with occa sional jams.
5	4,616	
6	3,115	
7	1,614	
8	1,614	High gradient reaches with numerous jams
9	1,614	
10	0	
11	1,874	Mapped reach
12-headwtrs	7,000	based on average value
TOTAL	41,676	Much of the stored sediment in this
		creek was estimated.

TABLE B18

TRIBUTARY: FORTY FOUR CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	2,283	Mapped section
2	1,116	Low gradient reaches with numerous large, debris jams.
3	2,391	
4	6,917	Mapped section
5	3,292	
6	7,251	
7	12,228	Very wide low gradient reach
8	1,311	
9	4,783	
10	900	Narrow incised reach
TOTAL	42,472	

FIGURE B17



MAPPED REACH
LONG. PROFILE
LOG JAM
0
5000
Feet
Contour Interval: 80 ft.
REDWOOD CREEK
WINDY CREEK
Captain
ROAD
CHEZE
Redwood
Creek
Gaging Station
BM 1037
BM 2336
Negra Joe Ridge
McComb 3101
Jeep Gulch Trail
Berry Summit
Drill Hole
BM 2871
Windy Creek
Squirrel Tail Ridge
JEEP TRAIL
11
13
14
23
24
25
26

TABLE B19

TRIBUTARY: WINDY CREEK

REACH (300 M)	VOLUME OF STORED SEDIMENT (M^3)	REMARKS
1	7,444	
2	6,002	
3	14,291	Wide, aggraded reaches with 1-1.5 meters of fill.
4	16,487	
5	11,750	
6	4,509	
TOTAL	60,482	

APPENDIX C

AERIAL PHOTOGRAPHY USED IN THIS STUDY

1954
U. S. Department of Agriculture
Symbol CVL
1:20,000
Available from: U. S. Department of Agriculture
Agriculture Stabilization and Conservation Service
Aerial Photography Field Office
P.O. Box 30010
Salt Lake City, Utah 84125

On file: Agriculture Stabilization and Conservation Service
of Humboldt - Del Norte County
5630 South Broadway
Eureka, California 95501
Coverage: Enlargements of entire basin

Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Main channel, Hwy 299 to Orick

1958
Humboldt County Timber Assessor
Symbol HU
1:12,000
Available from: Air Data Systems
1134 Main Street
Fortuna, California 95540

On file: Humboldt County Timber Assessor
c/o Dave Goodwin
County Court House
Eureka, California 95501
Coverage: Entire basin

Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Main channel, headwaters to Tom McDonald Creek;
Lacks Creek basin; Minor Creek basin

1962 aerial photographs of Humboldt County
Humboldt County Timber Assessor
Symbol HCN
1:12,000

Available from: Air Data Systems
1134 Main Street
Fortuna, California 95540

On file: Humboldt County Timber Assessor
c/o Dave Goodwin
County Court House
Eureka, California 95501
Coverage: Entire basin

Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Main channel, headwaters to Lacks Creek; lower 1/3 of basin

1965 aerial photographs of Humboldt County
U. S. Department of Agriculture
Symbol CVL
1:20,000

Available from: U. S. Department of Agriculture
Agricultural Stabilization and Conservation Service
Aerial Photography Field Office
P.O. Box 30010
Salt Lake City, Utah 84125

On file: Agricultural Stabilization and Conservation Service of Humboldt - Del Norte County
5630 South Broadway
Eureka, California 95501
Coverage: Enlargements of entire basin

Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Main channel, Hwy 299 to Orick

1966
Humboldt County Timber Assessor
Symbol HC
1:12,500

Available from:	Air Data Systems 1134 Main Street Fortuna, California 95540
On file:	Humboldt County Timber Assessor c/o Dave Goodwin County Court House Eureka, California 95501 Coverage: Entire basin
	Redwood National Park, Arcata Office Sediment Budget Project Arcata, California 95521 Coverage: Main channel headwaters to Hwy 299; Minor Creek channel; Lacks Creek channel; Coyote Creek basin; Copper Creek basin

1970
Humboldt County Timber Assessor
Symbol CH70
1:12,500

Available from:	Air Data Systems 1134 Main Street Fortuna, California 95540
On file:	Humboldt County Timber Assessor c/o Dave Goodwin County Court House Eureka, California 95501 Coverage: Entire basin
On loan:	Redwood National Park, Arcata Office Sediment Budget Project Arcata, California 95521 Coverage: Entire basin

1974
Redwood National Park
Symbol 5900
1:10,000

Available from: Air Data Systems
1134 Main Street
Fortuna, California 95540

On file: Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Redwood National Park;
Main channel, Redwood Creek

1978
Redwood National Park
Symbol RNP 78 7/20/78 & RNP 78 7/9/78
1:6,000;12,000

One file: Redwood National Park, Arcata Office
Sediment Budget Project
Arcata, California 95521
Coverage: Entire basin