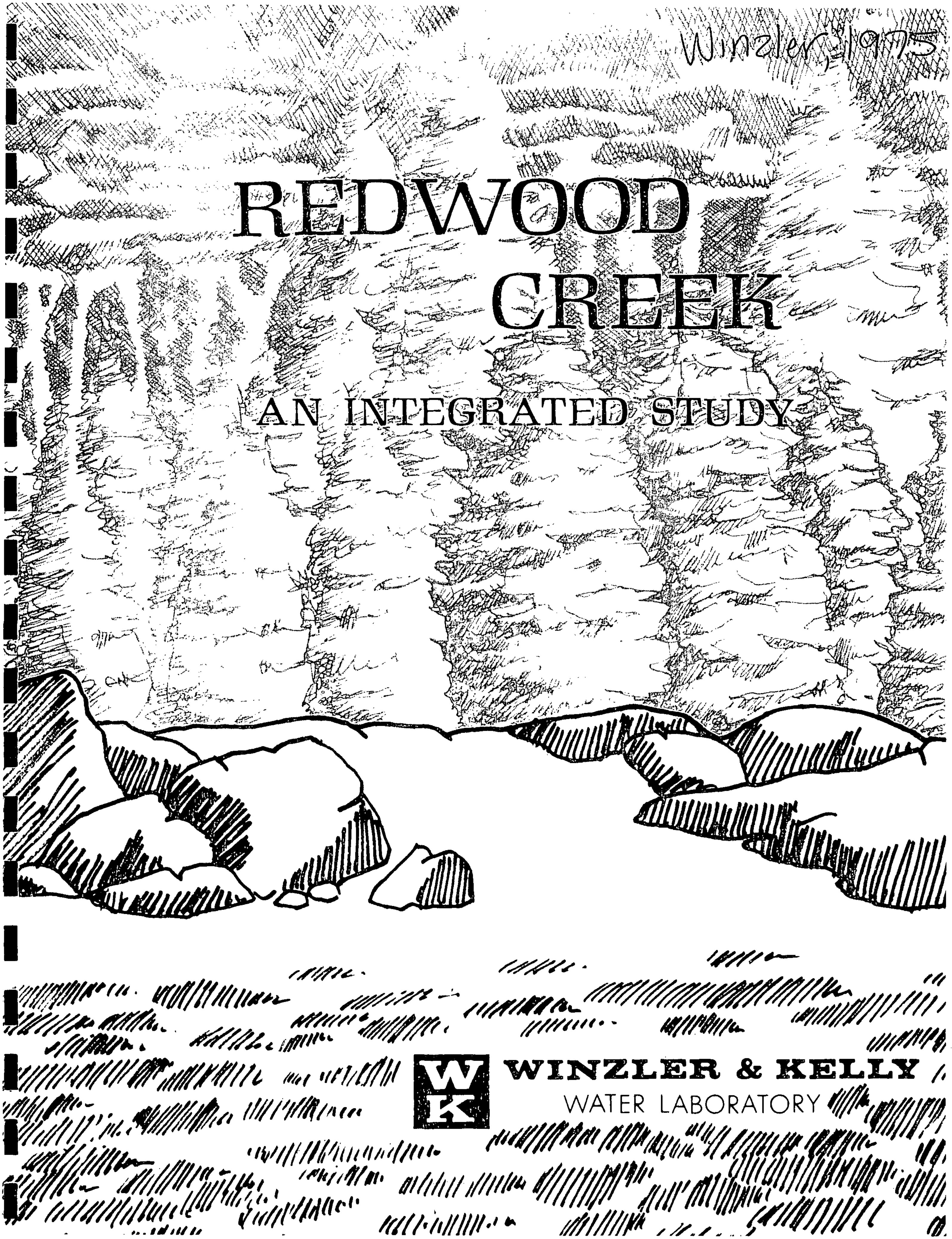
Winzler, 1975



REDWOOD CREEK

AN INTEGRATED STUDY

WINZLER & KELLY
WATER LABORATORY

1973 - 1974

REDWOOD CREEK SEDIMENT STUDY

WINZLER AND KELLY ENGINEERS
WATER LABORATORY
P. O. Box 1345
Eureka, California 95501

April 1975

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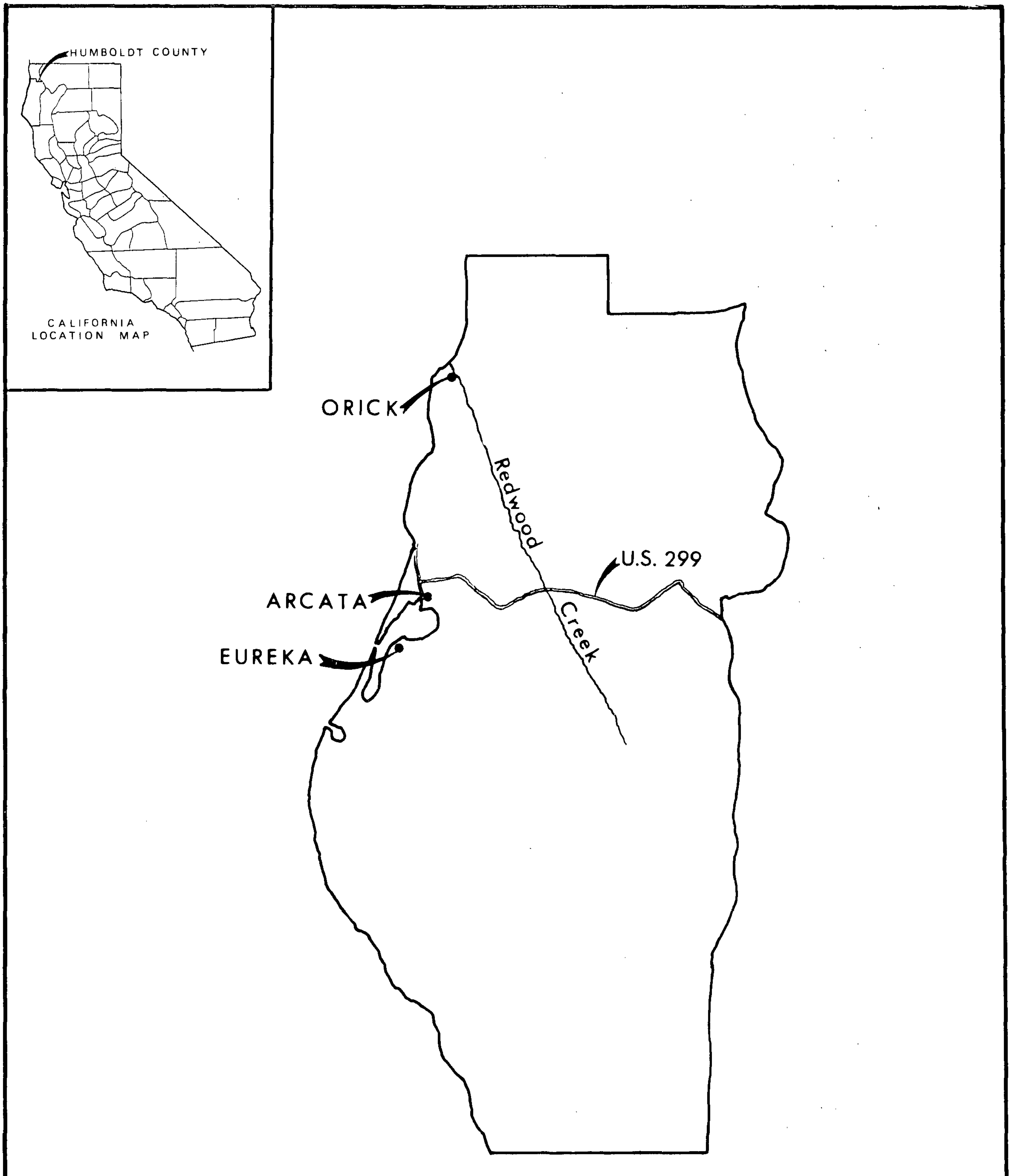
INTRODUCTION

Commencing with the 1973 rainy season, the firm of Winzler and Kelly Consulting Engineers and Laboratories began a study designed to assess certain environmental characteristics related to water quality and sedimentation within the Redwood Creek Basin (Figure A). It is expected that the overall study program, when completed, will provide data that will improve current timber harvesting operations and aid in long-range planning for future operations.

The present study focuses on sediment production and transport within the Redwood Creek Basin and assesses the relative contributions of natural processes and timber harvesting operations downstream of the Chezem Bridge to sediment production in the Basin. This assessment required coordinated studies of water quality and soils.



HUMBOLDT COUNTY

VICINITY MAP

FIGURE A

WATER QUALITY STUDY

This portion of the overall study program involved monitoring various measures of sediment load at different points within the Basin. This study also included monitoring Redwood Creek and several of its tributaries for a number of water quality parameters throughout the course of two storms. This specific work effort provided data which formed the basis of an estimate of the contribution to sediment load of various areas of the Basin, both within and outside the boundaries of current logging operations. Another facet of the investigation involved the determination of the Redwood Creek stream gradient and compared this important controlling factor to the scour-deposition regime established by the U.S. Geological Survey. In addition, the water monitoring study was tailored to allow immediate response to situations which were causing or could cause undue sediment damage to streams. Upon identification of a correctable problem, responsible persons were immediately contacted so that maintenance crews could respond with appropriate corrective action.

SOILS STUDY

This study attempted to identify areas of greatest sediment production by a more direct "fingerprinting" method. Comparative observations of soil mineralogy and morphology of streambed sediments and of soils from various sites within the drainage basin permitted the location of those areas which were primarily responsible for sediment generation to be delineated. The results in this investigatory effort were then considered in relation to known slope stability characteristics of various soils as well as a field examination running the entire length of Redwood Creek.

THE STUDY TEAM

The Redwood Creek Study Team was composed of Winzler and Kelly Consulting Engineers and Laboratories permanent staff, supplemented as required with consulting experts. Key study team members were:

	Affiliation	Education	Expertise
Jerry K. Ficklin	Director Winzler and Kelly Water Laboratory	B.S. Humboldt State University	Study Team Coordinator Water Quality Limnology
Ronnie N. Clifford	Winzler and Kelly Consulting Engrs.	B.S. Colorado State University	Slope Stability Erosion Control Road Design
Chester T. Youngberg	Professor, Soils Science Department Oregon State Univ.	Ph.D. Univ. of Wisconsin	Soils, Slope Stability Forest Soils
Moyle E. Harward	Professor, Soils Science Oregon State Univ.	Ph.D. North Carolina State University	Soils, Soil Chemistry Clay Mineralogy
Rollin C. Jones	Univ. of Hawaii	Ph.D. Univ. of Arizona	Clay Mineralogy
George Wingate	Winzler and Kelly Water Laboratory	M.S. Humboldt State University	Forest Management, Watershed Management,

	Affiliation	Education	Expertise
			Forest Hydrology, Water, Soil, Plant Relationships, R.F.P.#1572
Martin Lay	Winzler and Kelly Consulting Engrs.	B.S. Humboldt State University	Environmental Engineering, Soils, Hydrology
Edward Schillinger	Winzler and Kelly Consulting Engrs.	B.S. U.C. Berkley M.S. Ohio State University	Hydrologic Systems, Open Channel Hydraulics, Road Design, Surveying
Anthony K. Chan	Winzler and Kelly Water Laboratory	B.S. U.C. Berkeley	Analytical Chemistry
Henry Mauro	Winzler and Kelly Consulting Engrs.	Rensselaer Polytechnic Institute 1963-1965	Engineering Technician, Illustrator
Ernest G. Leo	Winzler and Kelly Water Laboratory	Natural Resources College of the Redwoods	Field Technician

The members of the Winzler and Kelly field team were given intensive training sessions on storm monitoring techniques. During the actual storm events, the staff was expanded by the hiring of additional temporary personnel, primarily students from the Natural Resources program at Humboldt State University. These temporary employees were distributed among the various storm monitoring stations, where all were under the close supervision of permanent Winzler and Kelly staff members.

In addition to the above personnel, major input was received from the Company foresters, whose knowledge of the specific area was invaluable.

SUMMARY OF FINDINGS

Our research and studies support the following conclusions:

1. The contribution of sediment from the individual tributary streams observed is insignificant compared to the load carried by Redwood Creek.

2. The upper watershed of Redwood Creek (well above the Chezem Bridge) is a significant source of sediment.

3. Dominant geomorphic processes are deep-seated rather than surficial. Streamside slides are the dominant contributors of erodible materials in the Redwood Creek Basin.

4. Dominant geomorphic processes in the Redwood Creek Basin appear to have been similar through at least the historical past. These same processes will continue in the future regardless of changes in the land management of the watershed.

5. Deposition in areas of the Redwood National Park, particularily near the Tall Trees Flat, appears to be a response to the stream gradient.

STREAM SEDIMENT MONITORING

METHODOLOGY

This portion of the program was directed towards obtaining general trends and a qualitative evaluation of the sediment characteristics within the Basin. The data were obtained primarily through weekly monitoring of stream stations throughout the drainage. The stations were located both in Redwood Creek and on major tributaries, above and below current timber harvesting operations, at intermediate points within operations, and at selected boundary lines within the Basin (Figure 1).

In addition to the weekly monitoring program, two storm events were monitored at selected sites to obtain quantitative data on flow and sediment loads through a storm cycle. The initial intent was to establish monitoring stations in drainages that were unlogged, previously logged, or were areas of current timber harvesting activity. Also to be monitored were areas of massive land movement, streamside slides, and areas of accelerated bank-cutting. Quantitative measurements of sediment from each station were then used to delineate inputs from natural and man-related sources. After careful evaluation, including preliminary field observations, this methodology was rejected for certain theoretical and practical reasons:

1. Because the tremendous amount of natural land movement within the drainage forms an intrinsic matrix upon which all other activities are superimposed, a discrete erosional process in the Basin is an extreme rarity.

2. The degree and variability of man's activities within the Basin, both in kind and time.

3. The overlapping of various human activities such as differing timber harvesting methods, road building and maintenance, grazing, etc.

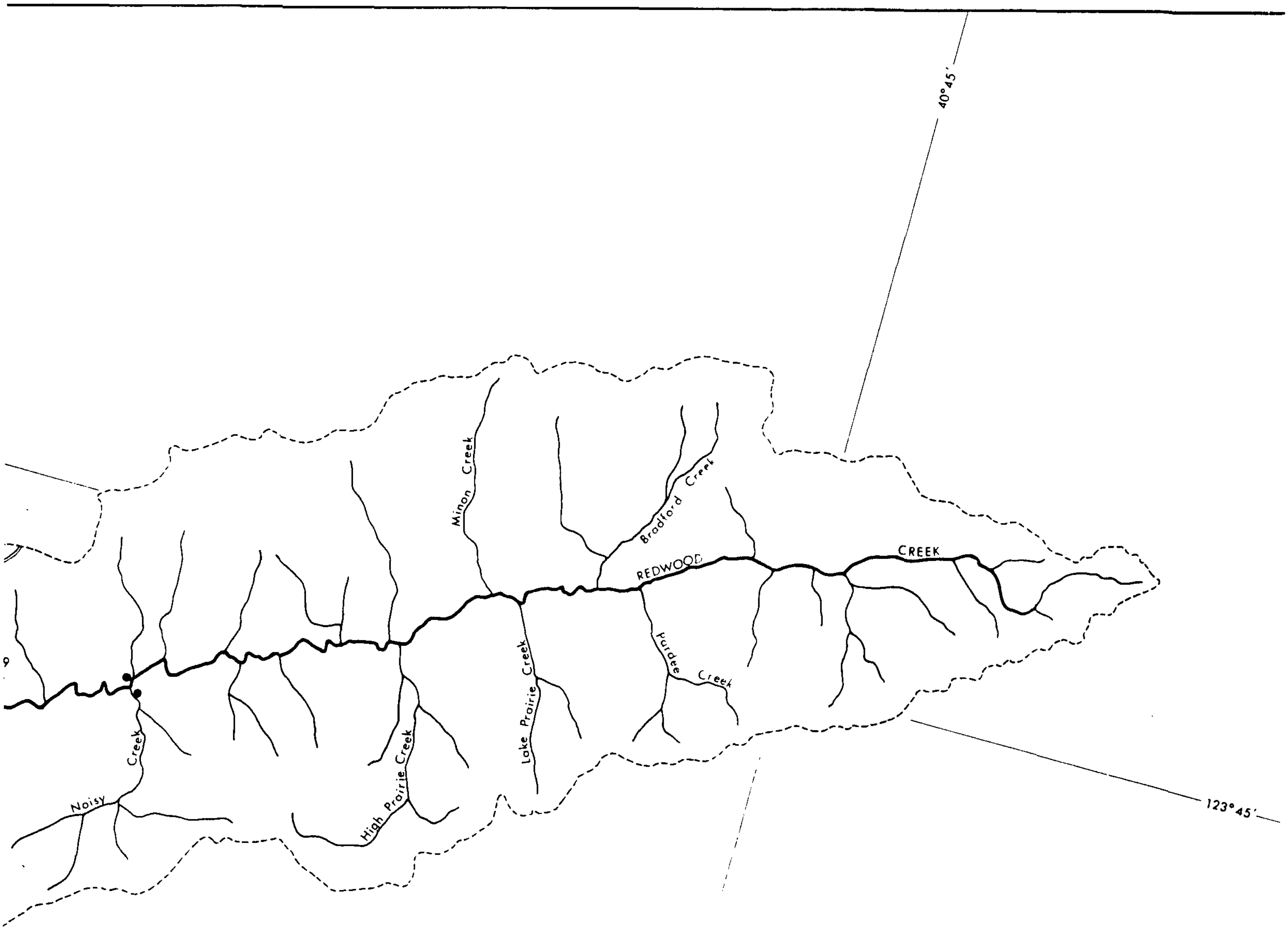
4. The physical incapability of being able to measure enough of the different processes to be able to make valid extrapolations.

5. The general lack of access, particularly during periods of intense precipitation.

6. To measure the sediment transport effectively would have required installation of semi-permanent facilities both on tributaries, in Redwood Creek, and bracketing areas of mass movement, an activity well beyond any conceivable economic framework.

Because of these difficulties, an approach was adopted which would provide sufficient data to allow relative comparisons between different tributaries, between tributaries and Redwood Creek, and between routine monitoring trends and storm processes. This approach, in combination with the Soils Study, allowed the investigators to draw reliable conclusions about sediment sources.

Sampling stations were established on Redwood Creek and its tributaries between July and August, 1973, and subsequently manned on a weekly basis (Figure 1). Grab samples were obtained on a weekly basis from each of fifty-four stations, as shown in Figure 1. The samples were obtained from representative locations, based upon stream channel and flow characteristics, accessibility, operational areas, time requirements and geographical

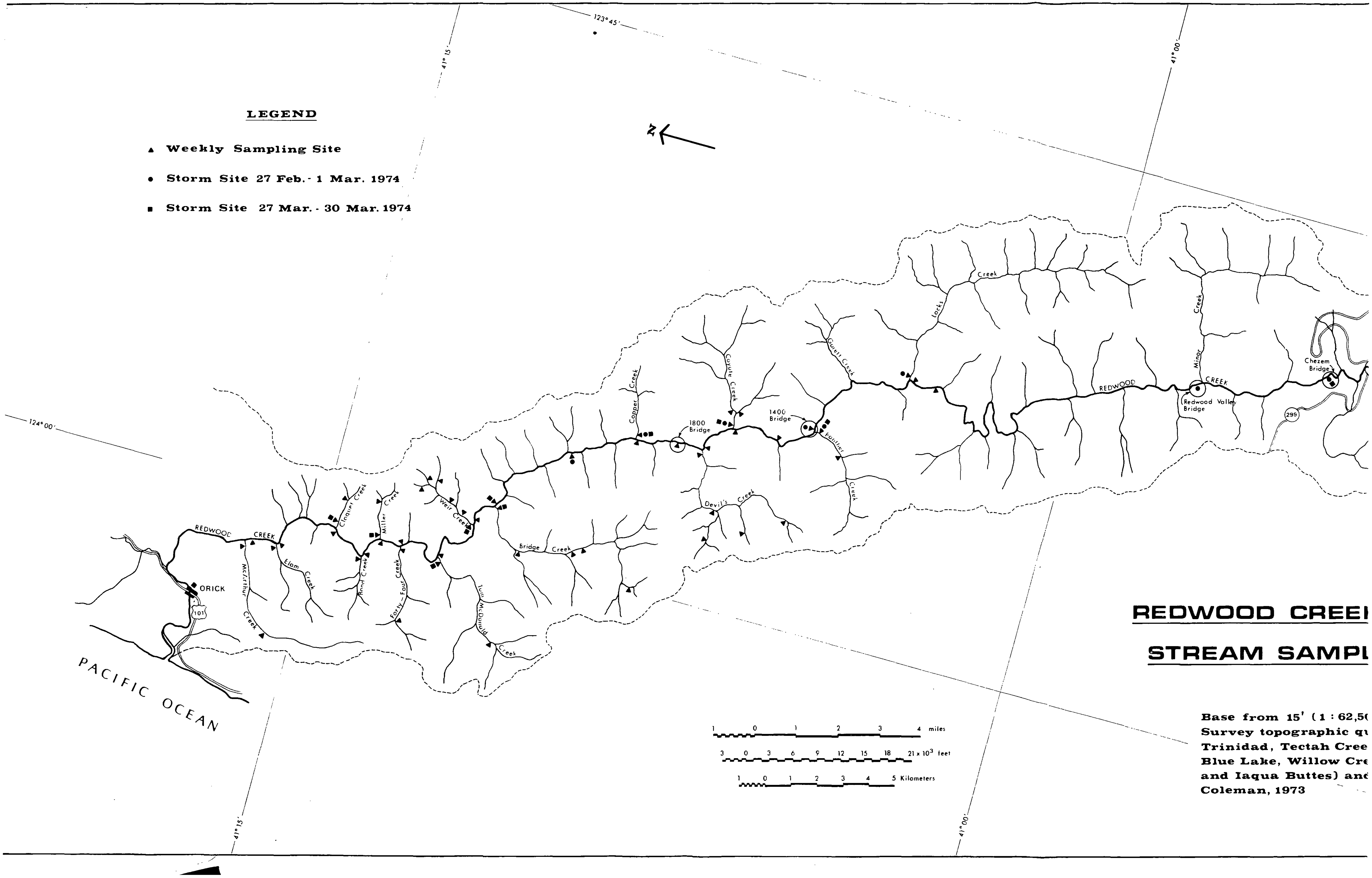


RAINAGE

G SITES

.S. Geological
ngles (Orick,
yote Peak,
ilot Peak,
by S. M.

FIGURE 1



REDWOOD CREE

STREAM SAMP

Base from 15' (1 : 62,5
Survey topographic q
Trinidad, Tectah Cree
Blue Lake, Willow Cre
and Iaqua Buttes) an
Coleman, 1973

considerations, i.e. property boundaries, park boundary, and location in the Basin. The samples were collected from as near mid-depth - mid-flow stream locations as practical, based upon the stream volume and velocity. Considerable effort was expended in determining sampling locations. Large scale maps were closely examined and generalized sampling sites were determined. Subsequently, each sampling area was examined in the field in order to locate specific sampling sites from which representative data could be obtained. Tributary sampling stations were located in close proximity to Redwood Creek in order to reflect their overall contribution, but were also situated so that they were removed from any backwater influence by Redwood Creek. Specific criteria used in selecting the sampling sites included considerations of: flow characteristics, channel geometry, stream configuration, i.e. straight or curved reach of the stream, stream obstructions, containment of the total flow, and accessibility during all flow conditions.

Dissolved oxygen and temperature information was obtained *in situ* by IBC Dissolved Oxygen and Temperature Monitor, Field Units, Catalogue Number 490-051. The oxygen detector consisted of a polarographic sensor which, utilizing a semipermeable membrane, measures the partial pressure of oxygen in a gas or liquid. The instrument is temperature compensating to correct for the varying solubility of oxygen in water of varying temperatures. The instruments were calibrated routinely through the sampling day in an atmosphere of known humidity, temperature, and pressure. Less frequently, the meters were calibrated in the Laboratory by Winkler titrations.

Temperature measurements were obtained through a thermistor incorporated into the dissolved oxygen probe. The thermistor was routinely checked with a mercury bulb thermometer.

Turbidity measurements were performed in the laboratory utilizing a Hach Model 2100A Turbidimeter. The instrument was standardized against formazin suspensions of known turbidities prior to and during each series of turbidity determinations. Samples with turbidities of greater than 40 JTU were diluted to within that range.[1]

Suspended solid measurements were also performed in the laboratory in accordance with the procedures outlined in the 13th Edition of Standard Methods.[2] Suspended solid determinations were not conducted on water samples of less than 1 JTU turbidity.

Specific conductance determinations were accomplished in the laboratory in accordance with the procedures specified in the 13th Edition of Standard Methods. The instrument used was YSI, Model 31, Conductivity Bridge. All readings were corrected to 25° C.

To obtain a very general indication of the bacterial quality of water within the Basin, occasional samples were taken for the determination of Total and Fecal Coliform bacteria. The procedure for Coliform Group determinations was the Multiple-Tube Fermentation technique carried through to the confirmed stage, again in conformance with Standard Methods, 13th Edition.

In addition to the weekly sampling at fifty-four stations, synoptic monitoring of two storm events was conducted at specific locations (Figure 1). Samples collected were analyzed for turbidity and suspended sediment. Measurements were also taken at specific locations in the field to obtain flow and bedload data.

Velocity determinations were made using Price AA current meters, following procedures outlined in the U.S. Geological Survey publication, "Discharge Measurements at Gauging Stations."[3] Measurements for velocity were accomplished every two to four hours. Velocity determinations were performed at multiple points at each flow measuring station. The actual number of measuring points at a particular station depended upon the stream width, depth, and flow characteristics. Velocity determinations were generally made at 0.2 and 0.8 of the water depth; where the stream depth was less than 2.5 feet, a single measurement was obtained at 0.6 of the depth. Horizontally the measuring points were established so that no single vertical station represented more than ten percent of the total flow. Stage height readings were recorded at the time of each velocity and bedload determination. In conjunction with the velocity measurements, the stream cross section was determined on a four-hour basis at each station. Water samples at all stations were taken on an hourly basis to determine suspended sediment concentrations and turbidity.

Bedload determinations were made at four of the synoptic sampling stations, using either a hand-held or cable-suspended Helly-Smith type bedload sampler.[4] Of the data collected, the bedload data are the most difficult to assess. The orientation of the sampler on the stream bottom during sampling could have an extreme effect on the sample obtained, and control over the bottom orientation for cable-suspended samplers, especially under high velocity flow conditions, was difficult. During periods of particularly high flows, it was difficult to ascertain accurately the time the sampler was on the bottom. These difficulties could introduce considerable error, particularly for sampling times of a fraction of a minute duration. For these reasons the bedload information has been treated separately and not incorporated into the basic data analysis.

SEDIMENT LEVELS

Since routine reports on all stations were developed on the data generated from the weekly sampling, this report will concentrate on parameter values obtained in Redwood Creek only, except for those tributary streams that were monitored over a storm event.

Increases in sediment concentration in Redwood Creek correlated very closely with increases in rainfall. Also from field observations, it was visually evident that Redwood Creek was nearly *as turbid* above all current logging activity as it was downstream below all current operations. A regression analysis of the turbidity data obtained weekly during the entire rainy season from November 1973 through April 1974, gives an equation for turbidity versus distance of: $T = -0.017x + 129.5$ (T = Turbidity in JTU's and X = Distance in miles). The statistical analysis of 423 turbidity measurements obtained from 18 stations located from the U.S. 299 Bridge to the confluence of Redwood and McArthur Creeks, a distance of approximately 37 miles, indicates that there was no statistical increase in turbidity over this major reach of Redwood Creek; rather, there was a slight decrease. The data confirms the preliminary field observations.

A similar analysis performed on suspended sediment values from the same samples indicates an increase of the average suspended sediment concentration of only 17.5 percent, again over a stream reach of approximately 37 miles. The equation generated by the average suspended sediment value is: $SS = 2.01x + 337.2$ (where SS = Suspended sediment in Mg/l and X = Distance in miles).

Figure 2 contains graphs of the calculated suspended sediment concentration and turbidity curves. It is noteworthy that both parameters have essentially gained their maximum values at the U.S. 299 Bridge a point well upstream of any current timber harvesting activity. The results plotted on the two curves point to that portion of the watershed above the U.S. 299 Bridge as an area of significant sediment input to Redwood Creek.

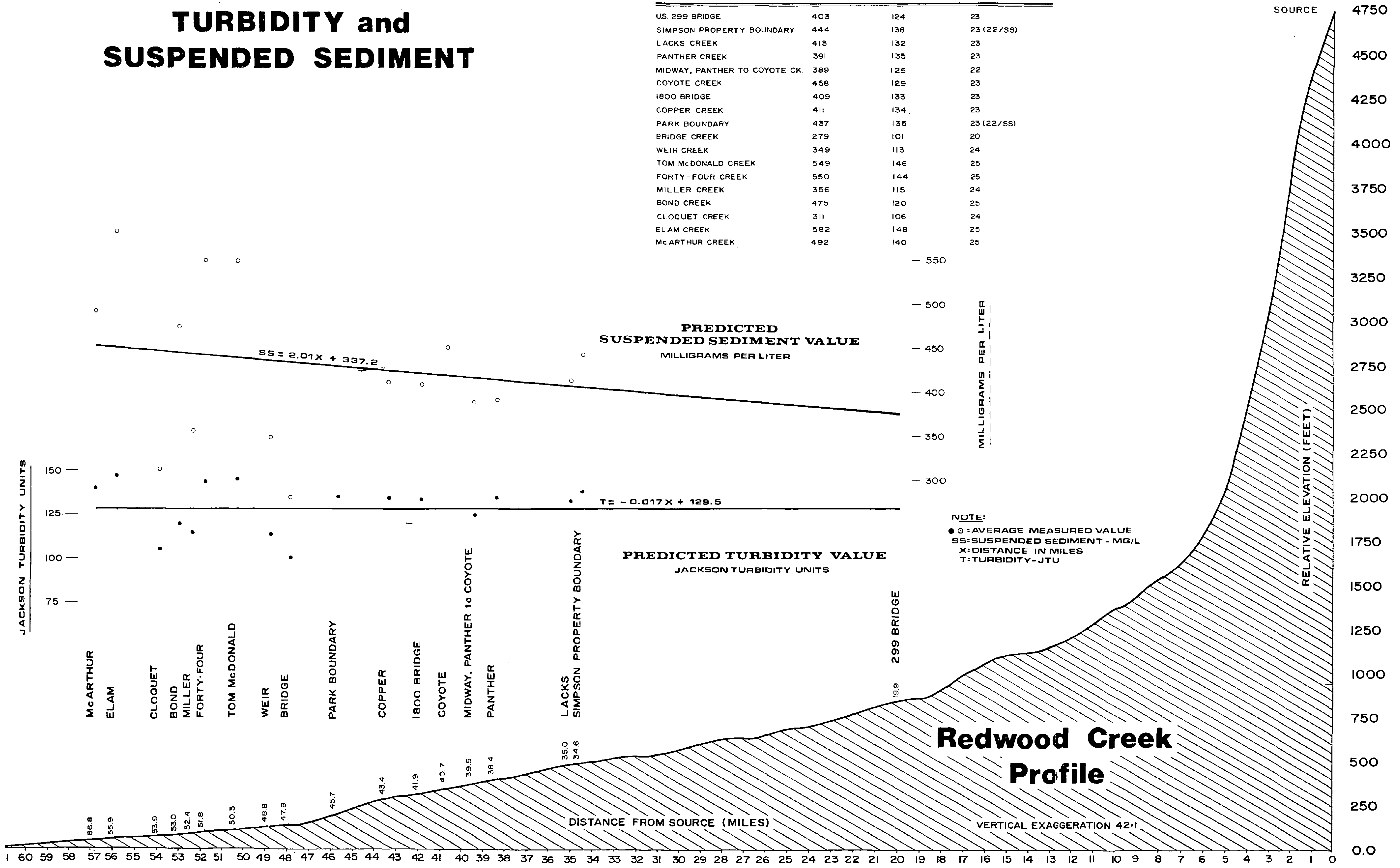
Figure 3 delineates the suspended sediment concentration and turbidity obtained at weekly intervals at four locations in Redwood Creek. The values between stations fluctuate to the point that it would be difficult to establish which station consistently had higher sediment concentration. Differences between stations could relate to localized differences in

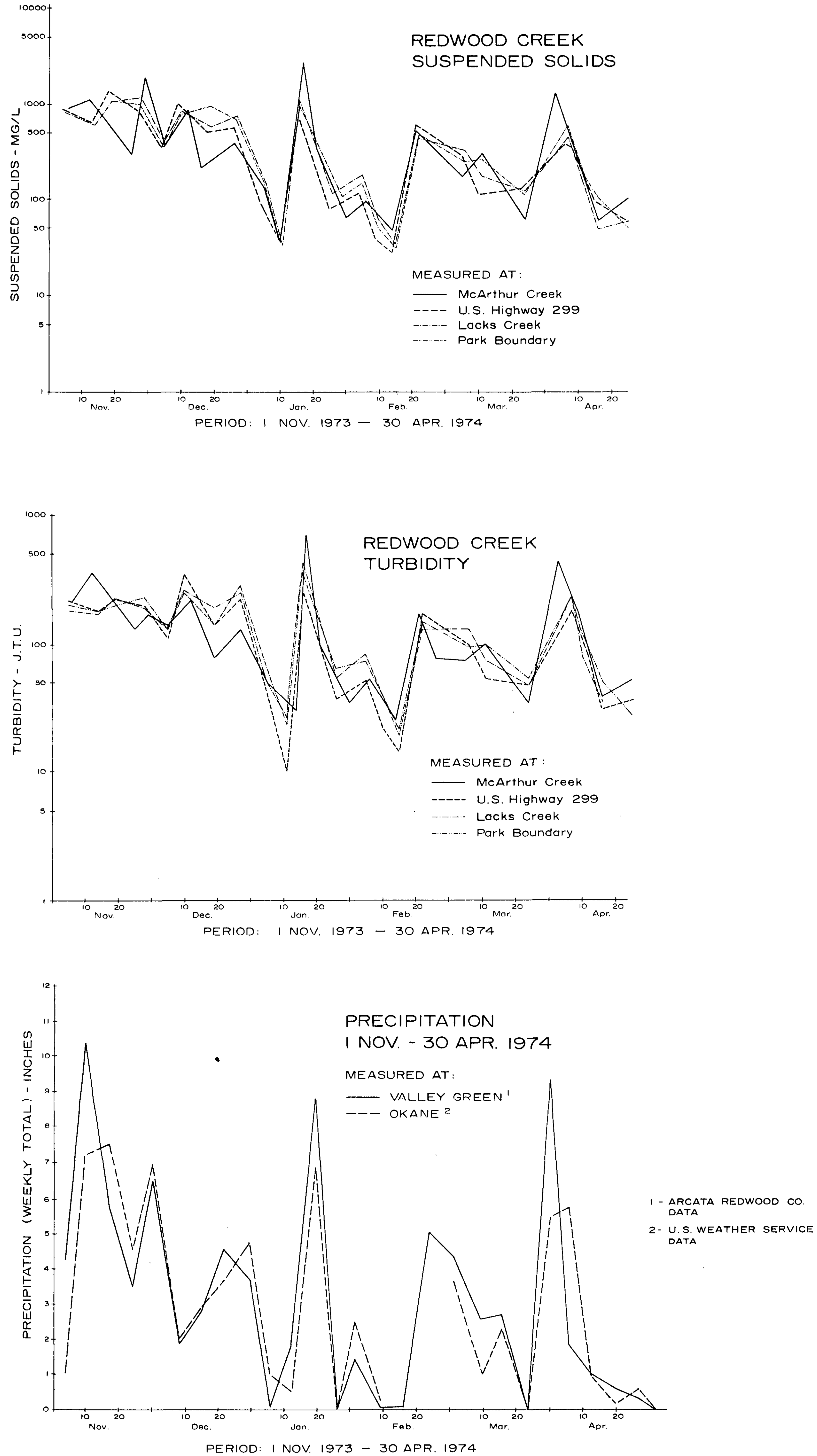
TURBIDITY and SUSPENDED SEDIMENT

WINZLER & KELLY
CONSULTING ENGINEERS

AVERAGE MEASURED VALUES - NOVEMBER 1973 - APRIL 1974

STATIONS, REDWOOD CREEK AT:	SUSPENDED SEDIMENT Mg/L	TURBIDITY JTU	NUMBER OF MEASUREMENTS
US. 299 BRIDGE	403	124	23
SIMPSON PROPERTY BOUNDARY	444	138	23 (22/SS)
LACKS CREEK	413	132	23
PANTHER CREEK	391	135	23
MIDWAY, PANTHER TO COYOTE CK.	389	125	22
COYOTE CREEK	458	129	23
1800 BRIDGE	409	133	23
COPPER CREEK	411	134	23
PARK BOUNDARY	437	135	23 (22/SS)
BRIDGE CREEK	279	101	20
WEIR CREEK	349	113	24
TOM McDONALD CREEK	549	146	25
FORTY-FOUR CREEK	550	144	25
MILLER CREEK	356	115	24
BOND CREEK	475	120	25
CLOQUET CREEK	311	106	24
ELAM CREEK	582	148	25
Mc ARTHUR CREEK	492	140	25





1 - ARCATA REDWOOD CO. DATA

2 - U.S. WEATHER SERVICE DATA

FIGURE 3

Location	Period of Measurement		Total Rainfall (Inches)
Redwood Creek at Panther Creek	1900 2-27-74 1400 2-28-74	to	1.77 inches
Valley Green near Orick**	2-27-74 3-03-74	to	3.46 inches

* United States Weather Service, Eureka, California, data
** Arcata Redwood Company data

The flow information obtained from this storm event was rather sporadic and not intensive enough to allow for a definitive analysis of the important parameters. There is, however, enough information to allow for a comparison of the magnitude of differences between Redwood Creek and several tributaries upstream from the Park Boundary. As determined from field observations and from the peak sediment concentrations shown on Figure 4, the flow measurements taken in Redwood Creek at 0630, 28 February at the Redwood Valley Bridge and at 1920, 28 February at the Chezem Bridge closely bracket the peak storm flow. (Table II).

The flow for Lacks Creek also closely approximates the peak flow condition, while the measurements made on Copper, Coyote and Panther Creeks reflect rising and descending stages. The discrete characteristics of these tributary streams cannot be commented on in the absence of a more accurate hydrograph, but the values obtained can be used for rough comparisons of the magnitude of their flow and sediment load to those of Redwood Creek. The measured flow and sediment values are shown in Table II.

TABLE II

FLOW AND SEDIMENT VALUES - STORM I

27 February 1974 - 1 March 1974

Location	Time	Date	Flow(CFS)	Instantaneous Suspended Load (Tons/Day)
Redwood Creek at Chezem Bridge	1800	2-27-74	860	450
Redwood Creek at Chezem Bridge	1920	2-28-74	3300	11900
Redwood Creek at Chezem Bridge	0130	3-1-74	3200	9100
Redwood Creek at Redwood Valley Bridge	0630	2-28-74	3600	33700
Redwood Creek at Redwood Valley Bridge	0300	3-1-74	3100	11000

Location	Time	Date	Flow(CFS)	Instantaneous Suspended Load (Tons/Day)
Lacks Creek at Railroad Car Bridge	0400	2-28-74	220	40
Copper Creek at Redwood Creek	1630	2-27-74	9	1
Copper Creek at Redwood Creek	2030	2-27-74	7	0.6
Copper Creek at Redwood Creek	1300	2-28-74	40	50
Panther Creek at Redwood Creek	1000	2-28-74	100	12
Coyote Creek at Redwood Creek	1800	2-27-74	100	7

As can be seen in Table II, Redwood Creek at Redwood Valley Bridge, well above any current timber harvesting operations, carries a tremendous sediment load, with a high instantaneous suspended sediment load of nearly 34,000 tons per day. This compares to tributary instantaneous suspended sediment loads of 40 tons per day at Lacks Creek, 50 tons per day at Copper Creek, 12 tons per day at Panther Creek, and 7 tons per day at Coyote Creek. For comparison, the combined high instantaneous suspended loads for Lacks, Copper, Panther and Coyote Creek is only 0.3% of the amount of suspended sediment load carried in Redwood Creek at the Redwood Valley Bridge, which is a considerable distance upstream from the tributaries. Table III summarizes some of the relationships found between the Redwood Creek Basin above the Redwood Valley Bridge, and the four tributary Basins monitored:

TABLE III

A COMPARISON OF THE REDWOOD CREEK BASIN ABOVE THE REDWOOD VALLEY BRIDGE TO SELECTED DOWNSTREAM TRIBUTARIES

		Percentage of the Redwood Creek Basin above the Redwood Valley Bridge*		
Stream	Drainage Area Square Miles	Drainage Area (%)	Flow (%)	Suspended Load (%)
Redwood Creek at Redwood Valley Bridge	94	100	100	100
Lacks Creek	17.9	19	6	0.12
Panther Creek	6.2	6.6	2.0	0.04

Stream	Drainage Area Square Miles	Percentage of the Redwood Creek Basin above the Redwood Valley Bridge* Drainage Area (%)	Flow (%)	Suspended Load (%)
Coyote Creek	8.6	9.1	2.0	0.02
Copper Creek	3.1	3.3	1.0	0.15

*Based upon highest values measured 27 February - 1 March 1974

It can readily be seen from Table III that both the flow and sediment load values of tributary streams are insignificant compared to the flow and sediment load values of Redwood Creek measured 8 to 16 miles higher in the drainage. This result is particularly striking if one notes that the four tributaries drain an area equivalent to 38% of the Redwood Creek drainage above the Redwood Valley Bridge.

Figure 4 depicts the suspended solids concentration and turbidity values obtained in Noisy Creek and in Redwood Creek at two locations, the first in Redwood Creek at the southern Park Boundary, the second at the confluence with Noisy Creek, during the period of February 27 to March 1, 1974. Samples taken on one hour intervals defined the suspended sediment concentrations over the storm period. The plots of values obtained in Redwood Creek at Noisy Creek compared to Redwood Creek at the Park Boundary are different only in that the peak values are displaced on the time axis as would be expected. The magnitudes of the peak suspended solid concentrations and the turbidity levels at the two stations, approximately 25 miles apart, are nearly identical. As the station in Redwood Creek at Noisy Creek is approximately 23 miles above any current timber harvesting activity, it can be concluded from the near identical values that the natural erosional forces active within the drainage are dominant; that man's activity does not seemingly have an effect sufficient to produce any significant difference in the data as measured.

Storm II

The second storm event was monitored during the period 27 to 30 March 1974. During this storm more emphasis was placed on obtaining a larger instantaneous picture of hydrologic conditions within the Basin. Stations were established at two points in Redwood Creek, one high and one low in the Basin, to obtain flow and sediment data. Additionally, more tributary streams were monitored for both flow and sediment data. The stations were maintained from the Chezem Bridge to Orick covering the major length of Redwood Creek, and at points where the influence, if any, of current timber harvesting activities could be established (see Figure 1 for actual storm stations).

The 27 - 30 March storm was considerably more severe than the previous storm, and, in fact, became too intense to monitor some of the stations during the peak flow conditions. Monitoring stations on Bridge, Tom McDonald and Weir Creeks had to be abandoned when the peak stream flows caused extremely treacherous wading conditions. The station on Weir Creek was abandoned when the Redwood Creek cable crossing become unpassable due to the extremely high flow in Redwood Creek. A graph of the cumulative rainfall received at Panther Creek is shown on Figure 5. Precipitation totals are given in Table IV.

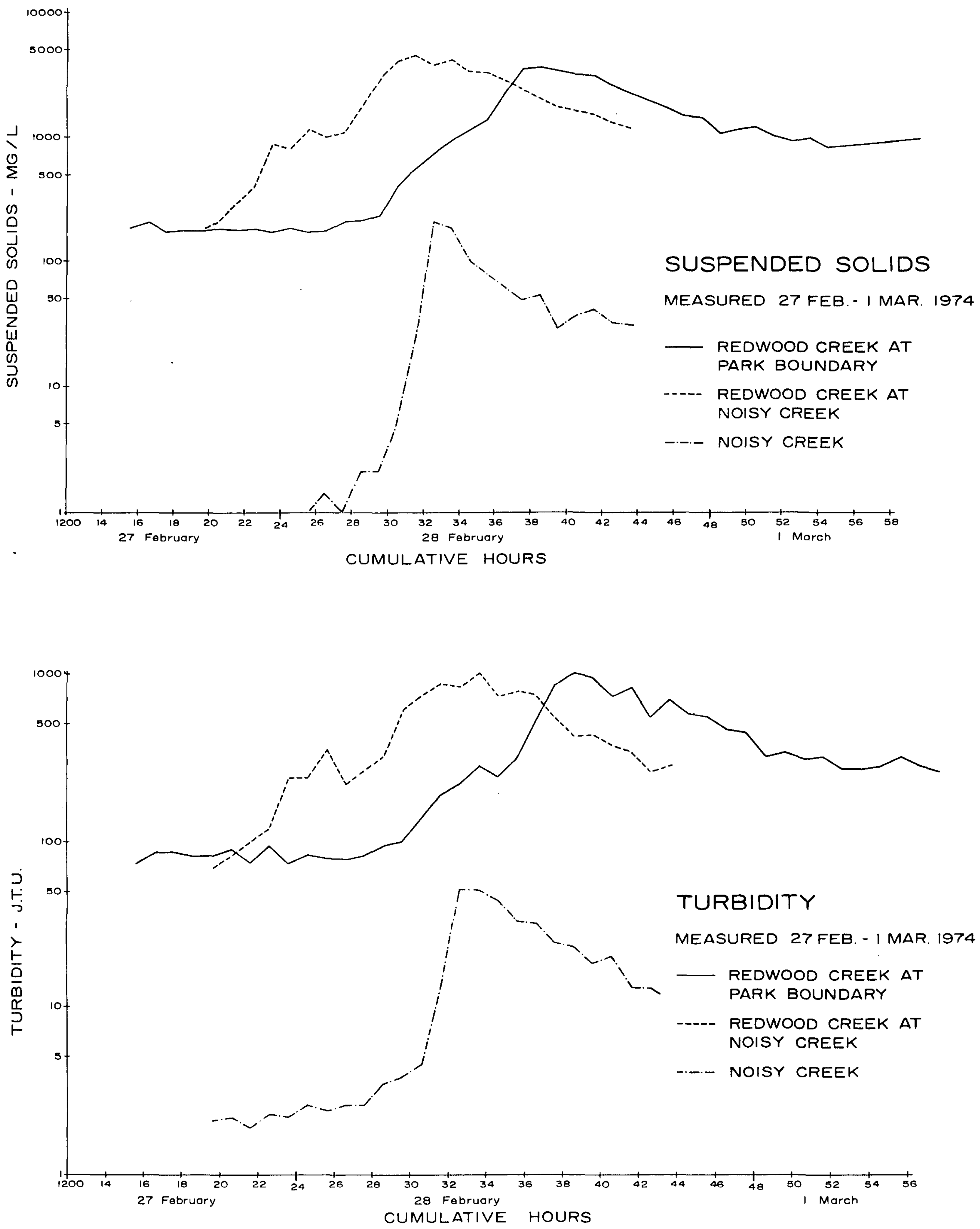

SUSPENDED SOLIDS
MEASURED 27 FEB.- 1 MAR. 1974
REDWOOD CREEK AT PARK BOUNDARY
REDWOOD CREEK AT NOISY CREEK
NOISY CREEK
SUSPENDED SOLIDS - MG/L
10000
5000
1000
500
100
50
10
5
1
1200 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58
27 February
28 February
1 March
CUMULATIVE HOURS
TURBIDITY
MEASURED 27 FEB. - 1 MAR. 1974
REDWOOD CREEK AT PARK BOUNDARY
REDWOOD CREEK AT NOISY CREEK
NOISY CREEK
TURBIDITY - J.T.U.
1000
500
100
50
10
5
1
1200 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
27 February
28 February
1 March
CUMULATIVE HOURS

FIGURE 4

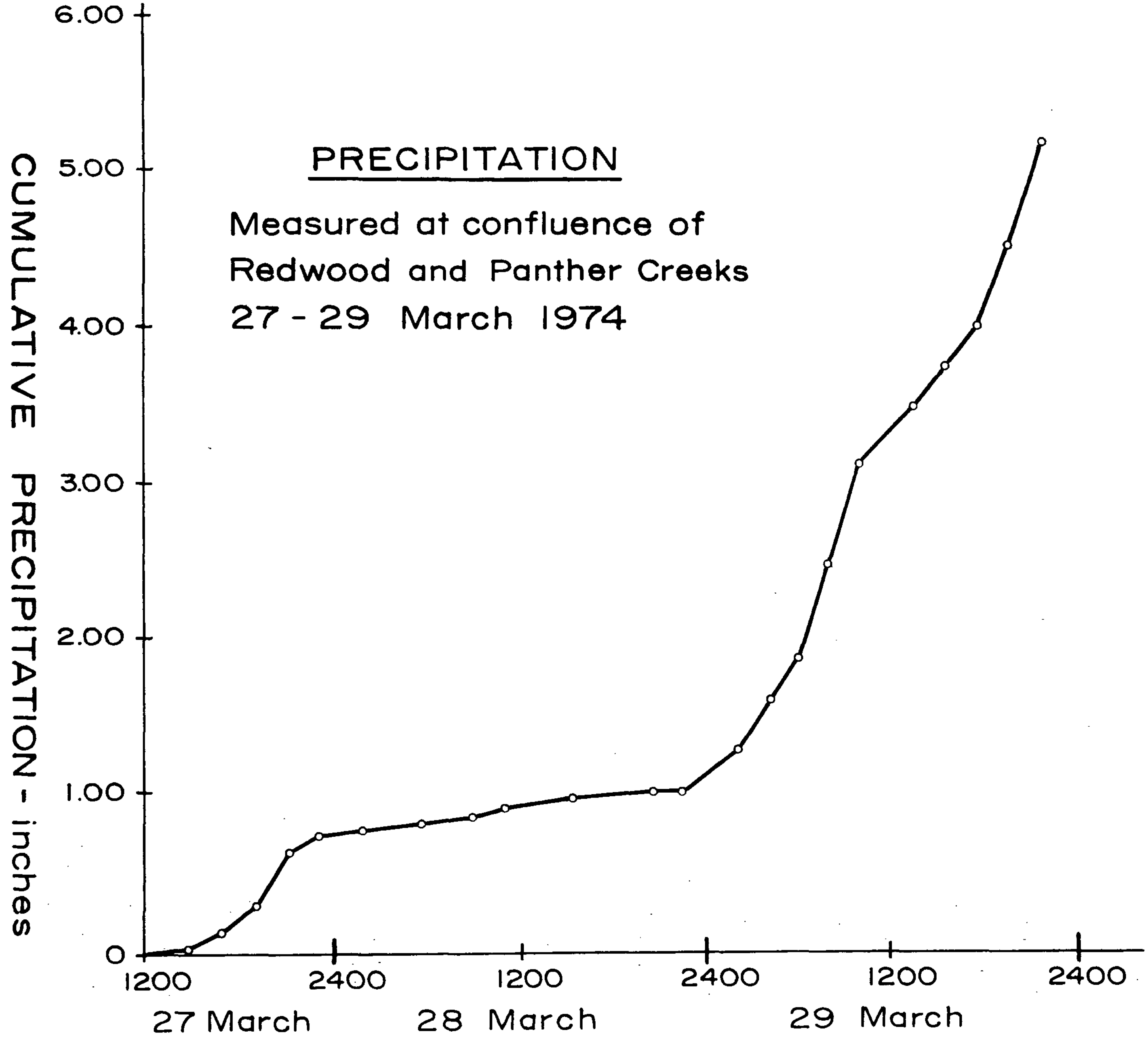

PRECIPITATION
Measured at confluence of
Redwood and Panther Creeks
27 - 29 March 1974
CUMULATIVE PRECIPITATION - inches
6.00
5.00
4.00
3.00
2.00
1.00
0
1200
2400
1200
2400
1200
2400
27 March
28 March
29 March

FIGURE 5

TABLE IV

TOTAL PRECIPITATION - STORM II

Location	Period of Measurement	Total Rainfall (Inches)
Redwood Creek at O'Kane*	28-30 March 1974	3.9 Inches
Redwood Creek at Panther Creek	1245 - 3-27-74 to 2150 - 3-29-74	5.22 Inches
Bridge Creek at M-7 Road	1300 - 3-27-74 to 1200 - 3-30-74	6.62 Inches
Valley Green near Orick**	27-31 March 1974	9.15 Inches
Junction of 800 and K & K Roads***	27-30 March 1974	5.35 Inches

* U.S. Weather Service, Eureka, California, data.
** Measured by Arcata Redwood Company Personnel.
*** Measured by Simpson Timber Company Personnel.

The 27-30 March storm confirmed that tremendous amounts of sediment are carried in Redwood Creek. Table V lists the high flow and instantaneous suspended sediment loads.

TABLE V

HIGH FLOW AND SUSPENDED SEDIMENT LOADS
STORM II
27-30 March 1974

Location	Time	Date	Flow CFS	Instantaneous Suspended Load (Tons/day)
Redwood Creek at Chezem Bridge	2100	3-29-74	4100	36,200
Redwood Creek at Orick	0225	3-30-74	20100	145,000
Bridge Creek at Redwood Creek	1530	3-29-74	480	900
Tom McDonald Creek at Redwood Creek	1415	3-29-74	200	170

Location	Time	Date	Flow CFS	Instantaneous Suspended Load (Tons/day)
Weir Creek at Redwood Creek	0325	3-29-74	18	1.4
Weir Creek at Redwood Creek	0705	3-29-74	14	6.5
Miller Creek at Redwood Creek	1600	3-29-74	37	140

The data from Weir Creek have been included in Table V and on Figure 8, but no comparative analysis will be attempted because the extremely difficult access to the Weir Creek station caused it to be manned less frequently and abandoned sooner than the other stations monitored.

Applying the same percentage calculations to the 27-30 March storm as were applied to the 28 February - 1 March storm, some significant figures are generated which are given in Table VI.

TABLE VI

A COMPARISON OF REDWOOD CREEK PARAMETERS TO THOSE OF SELECTED TRIBUTARIES*

Location	Drainage Area Square Miles	Percentage of Basin		Percentage of Flow		Percentage of Instantaneous Suspended Load	
		% of Total	% Above Chezem	% of Total	% Above Chezem	% of Total	% Above Chezem
Redwood Creek at Orick	278	100	-	100	-	100	-
Redwood Creek at Chezem	72	25.6	-	20.4	-	24.0	-
Bridge Creek	11.2	4	15.6	2.4	11.7	0.6	2.5
Tom McDonald Creek	6.9	2.5	9.6	1.0	4.9	0.1	0.5
Miller Creek	1.4	0.5	1.9	0.2	0.9	0.1	0.4
Total of Tributaries	19.5	7.0	27.1	3.6	17.5	0.8	3.4

*Based Upon Maximum Values Determined

The Redwood Creek Basin above the Chezem Bridge comprises 25.6% of the total drainage area, yields 20.4% of the total flow, and carries 24% of the total suspended load. (Table VI). This again is at a point many miles upstream from current timber harvesting activities. Comparison of this to the tributary data set forth in Table VI shows that the total high instantaneous suspended sediment loads carried by the three tributaries comprised 0.8% of the high instantaneous suspended sediment in Redwood Creek and only 3.4% of the high instantaneous suspended sediment load carried in Redwood Creek at the Chezem Bridge. Placed in another perspective, 7.0% of the total drainage produced but 0.8% of the high instantaneous suspended sediment load. Considering just the drainage above the Chezem Bridge, the three tributaries (Tom McDonald, Bridge Creek and Miller Creek) drain an area equal to 27.1% of that drainage and produced only 3.4% of the high instantaneous suspended sediment load measured at Chezem Bridge.

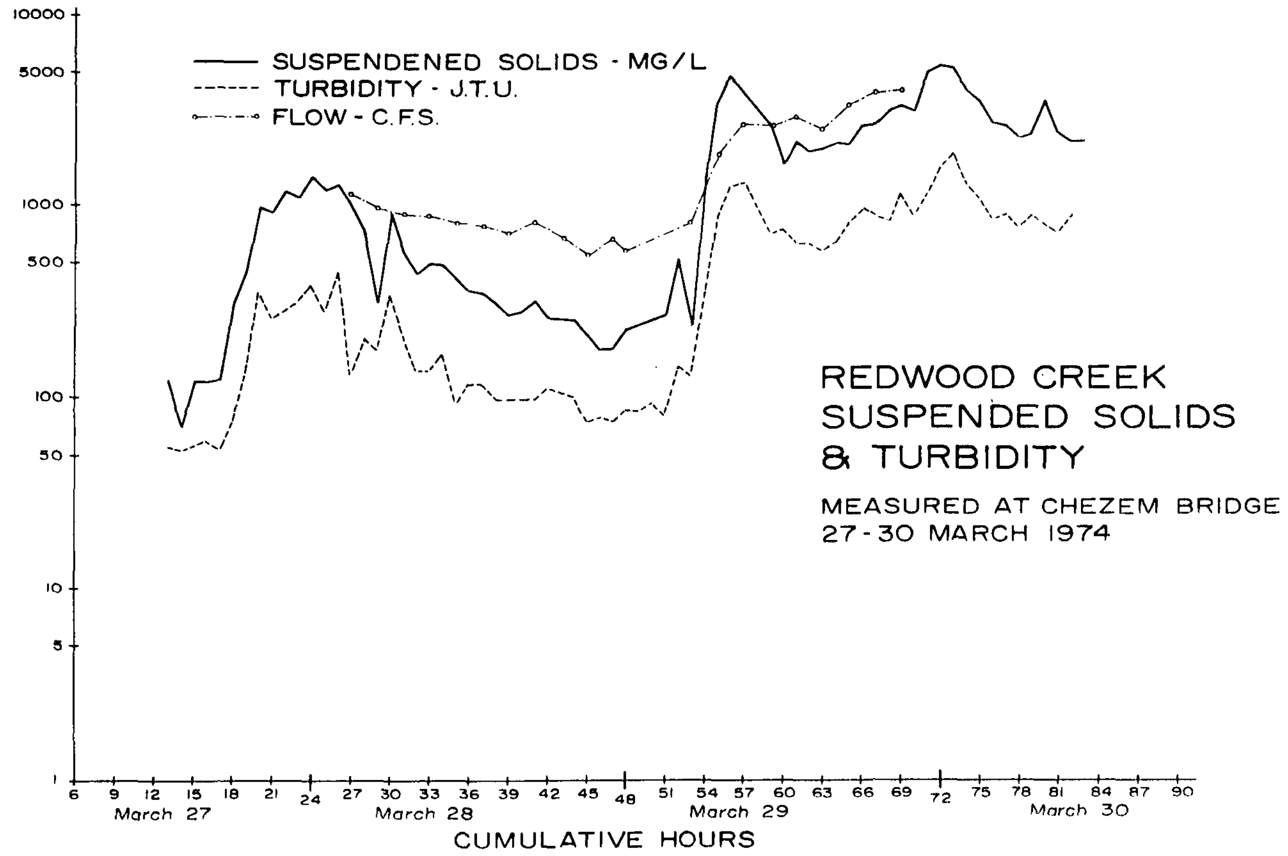
Figure 6 contains three graphs depicting the flow, suspended sediment concentration, turbidity values, and a ratio of the suspended load to flow for Redwood Creek during Storm II. The two points of measurement, the Chezem Bridge and Orick, one high and one low in the drainage, began the storm cycle with suspended solid concentrations of near 100 milligrams per liter. The curves for suspended solid concentrations at the two locations are quite similar. The station at the Chezem Bridge showed that the parameters were more responsive to storm conditions than were the curves generated at Orick. The instantaneous peaks at the Chezem Bridge are of a higher magnitude than those measured at Orick, which points to the dampening effect of being further downstream in the drainage.

It is difficult to compare the sediment concentrations and suspended loads of different streams since these parameters are uniquely related to drainage area, stream gradient, soil types and other watershed characteristics that may vary from stream to stream. A method utilized by the U.S. Geological Survey involves comparisons on the basis of sediment load per square mile or acre. This method of comparing sediment loads in different streams can lead to misinterpretations. Sediment transport results recorded in terms of tons per square mile are derived from only the planar area within certain boundaries on a map and do not give consideration to vertical elevations. A mountainous region may, in fact, have many times the surface drainage area that would be determined from the planar area. To avoid this difficulty, this study used the instantaneous sediment load of the stream expressed in tons per day as a ratio to the instantaneous flow expressed in cubic feet per second (see Figure 6). This ratio shows the quantity of sediment carried per cubic foot of water. The ratio allows a direct comparison of dissimilar streams, thus permitting comparison of the sediment characteristics of a large stream such as Redwood Creek with a smaller tributary stream such as Miller Creek. Using this procedure, it was established that the sediment load per cubic foot of water in Redwood Creek measured at the Chezem Bridge when approaching peak flow is nearly twice that at Orick. This may well relate to channel profile as is discussed later, but it is of considerable importance here since it refers to processes occurring in the upper portion of the Basin.

Figure 7 contains three graphs of Bridge and Tom McDonald Creeks depicting the suspended solid concentration, turbidity, and flow values for Storm II. The third graph depicts suspended sediment load per cubic foot of flow for both creeks. From the standpoint of sediment load per unit volume, the tributaries transported 300 to 400 percent less sediment than Redwood Creek.

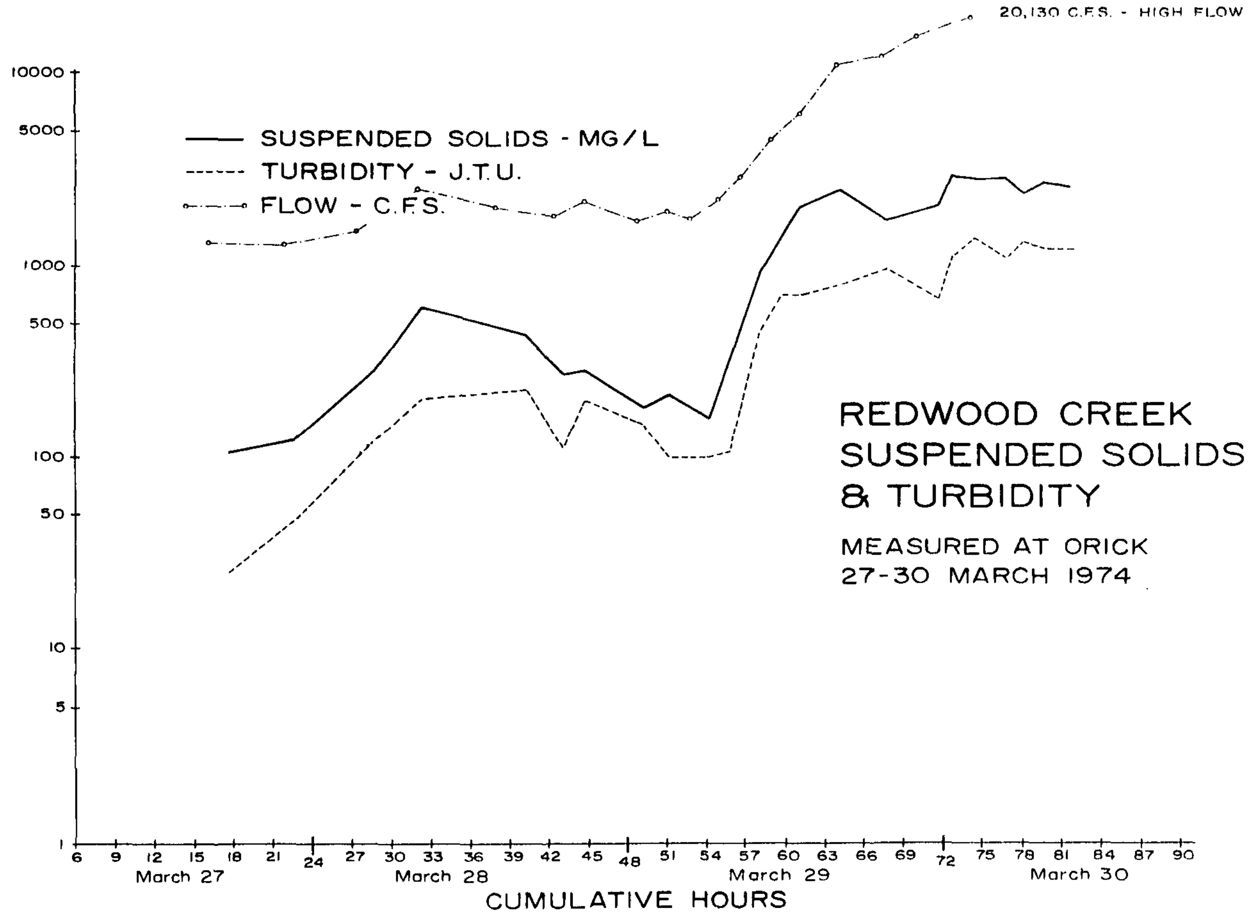
Figure 8 lists the suspended sediment concentration, turbidity, and flow values for Weir and Miller Creeks. The samples were obtained in Miller Creek on an hourly basis and more clearly define the changes in turbidity and suspended sediment concentration over the storm cycle. Weir Creek samples were taken on a two to four hour frequency, until sampling had to be discontinued due to extreme flow conditions quite early in the event.

A comparison of suspended load to flow for Miller Creek and Redwood Creek shows



REDWOOD CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED AT CHEZEM BRIDGE
27-30 MARCH 1974



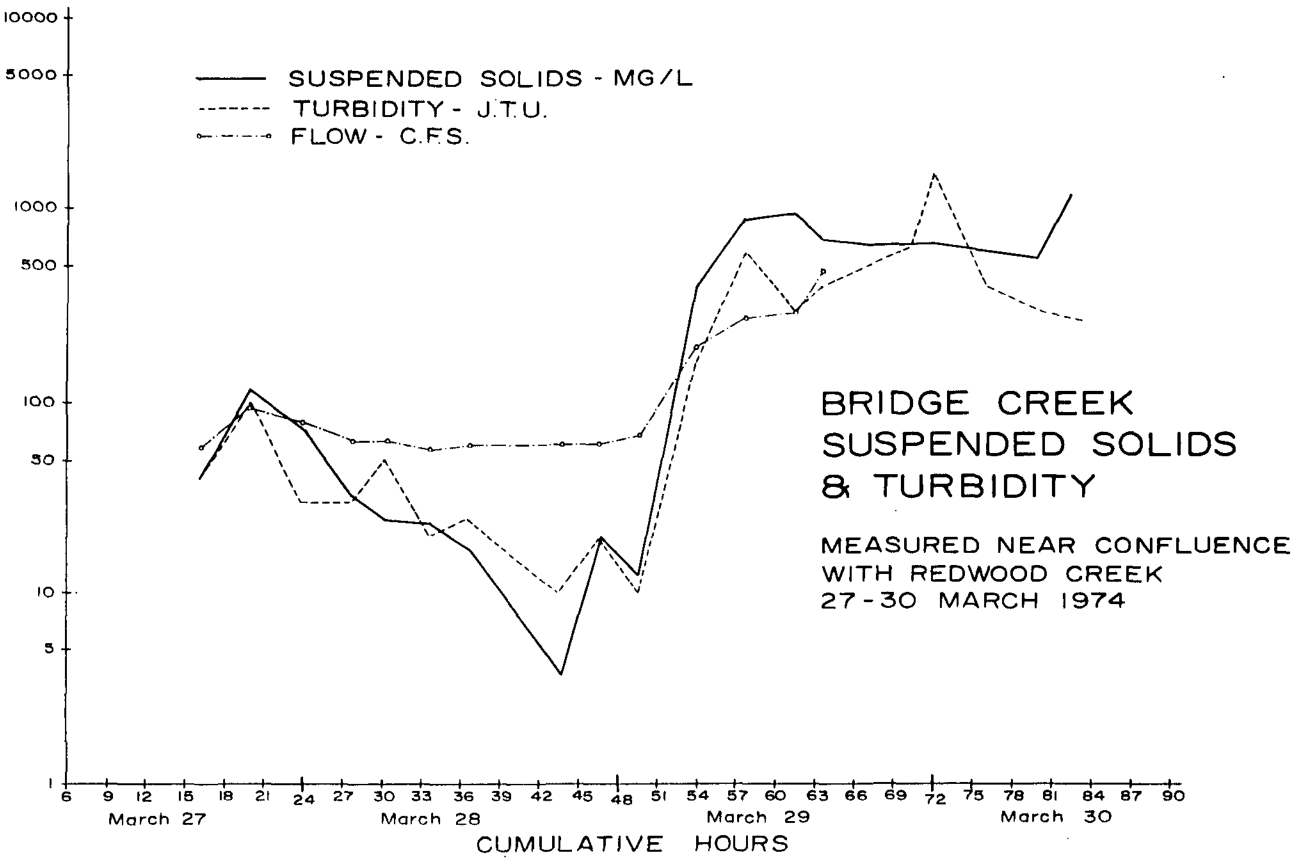
REDWOOD CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED AT ORICK
27-30 MARCH 1974

REDWOOD CREEK
SUSPENDED LOAD TO
FLOW RATIO

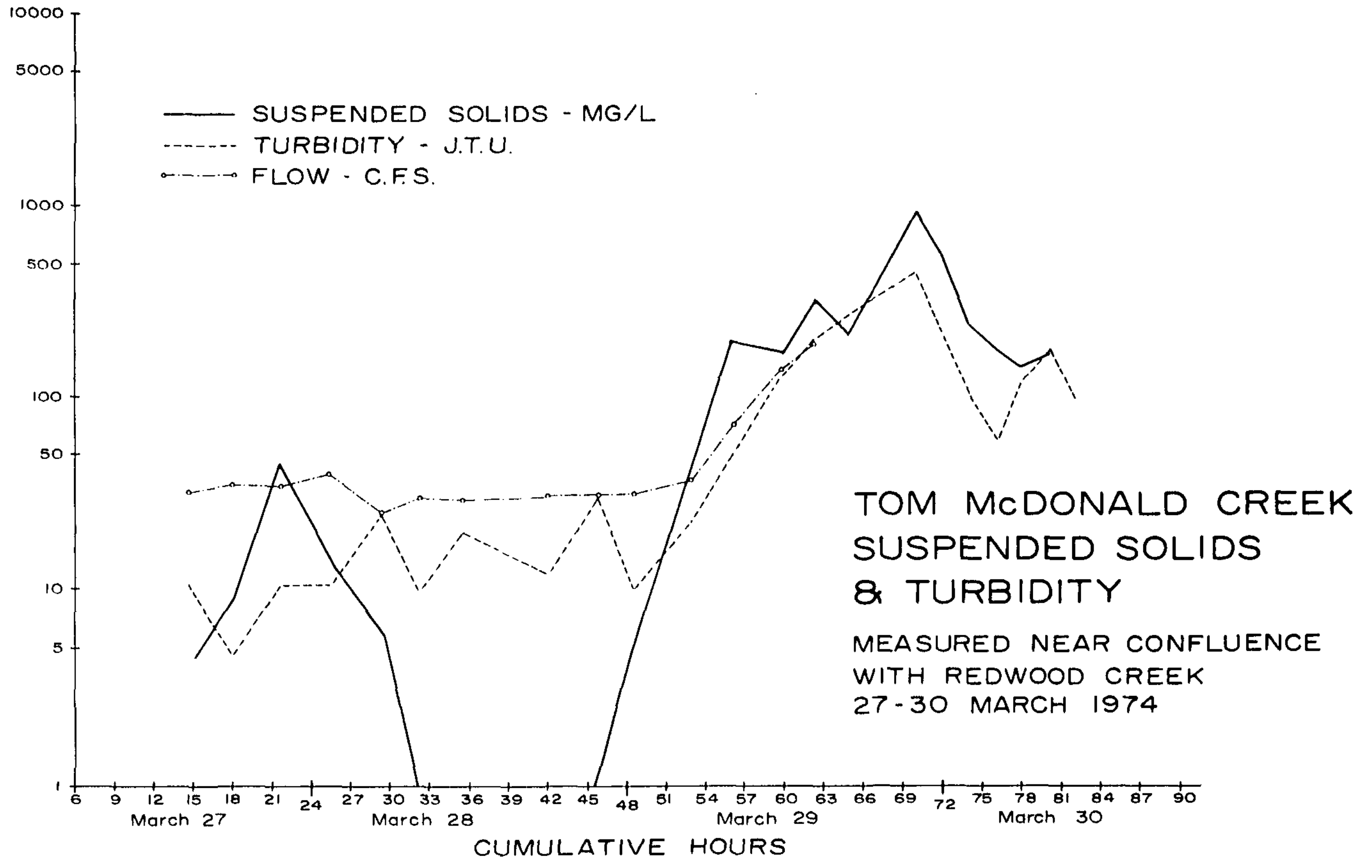
MEASURED 27-30 MARCH 1974

FIGURE 6



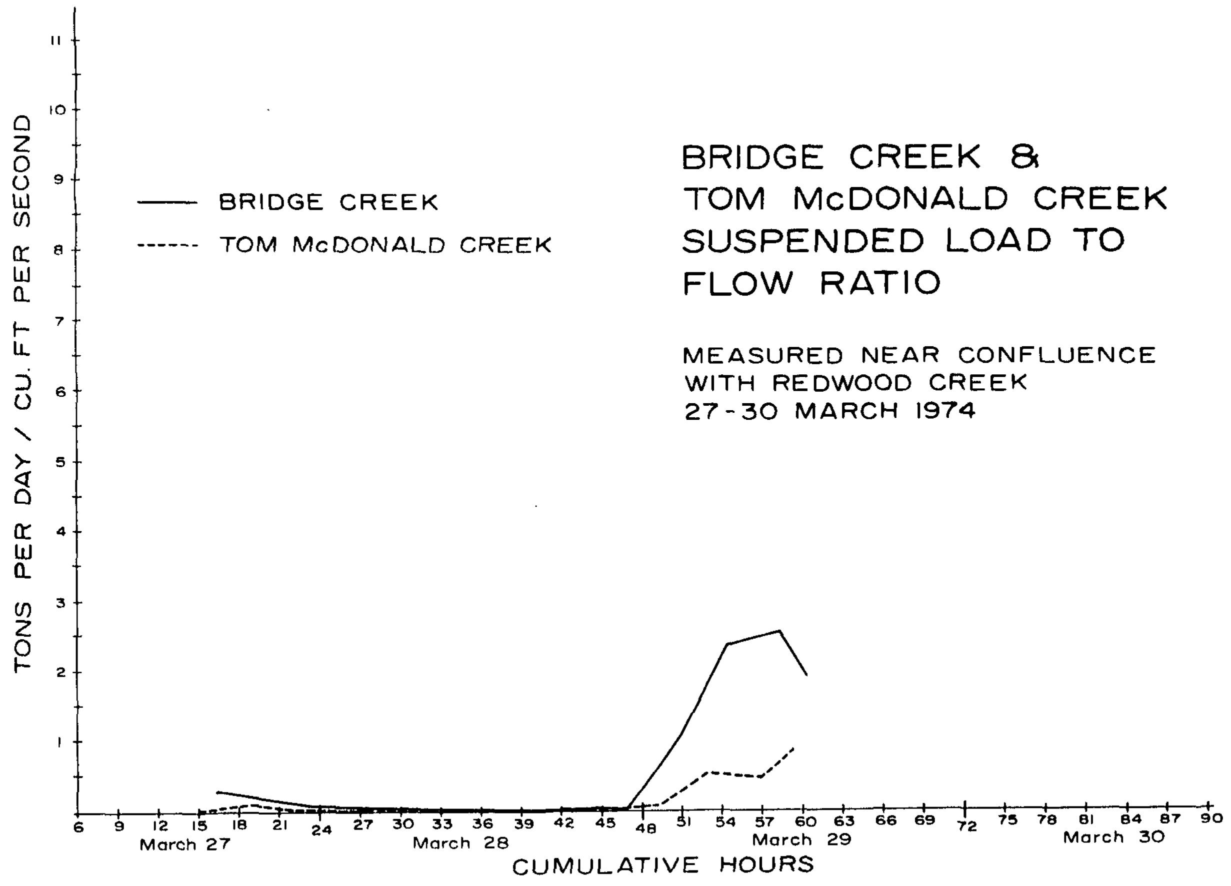
BRIDGE CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974



TOM McDONALD CREEK
SUSPENDED SOLIDS
& TURBIDITY

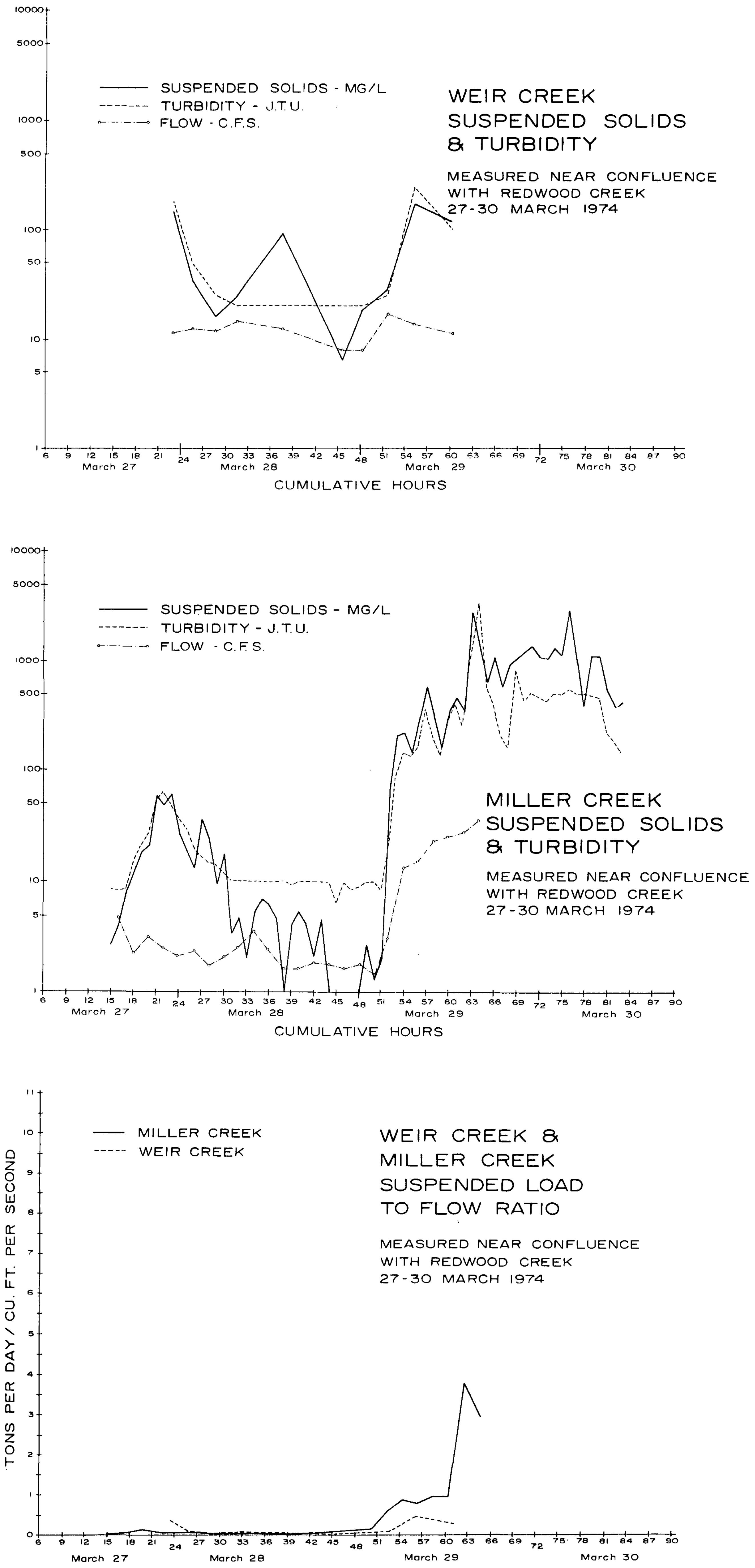
MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974



BRIDGE CREEK &
TOM McDONALD CREEK
SUSPENDED LOAD TO
FLOW RATIO

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

FIGURE 7



WEIR CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

MILLER CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

WEIR CREEK &
MILLER CREEK
SUSPENDED LOAD
TO FLOW RATIO

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

FIGURE 8

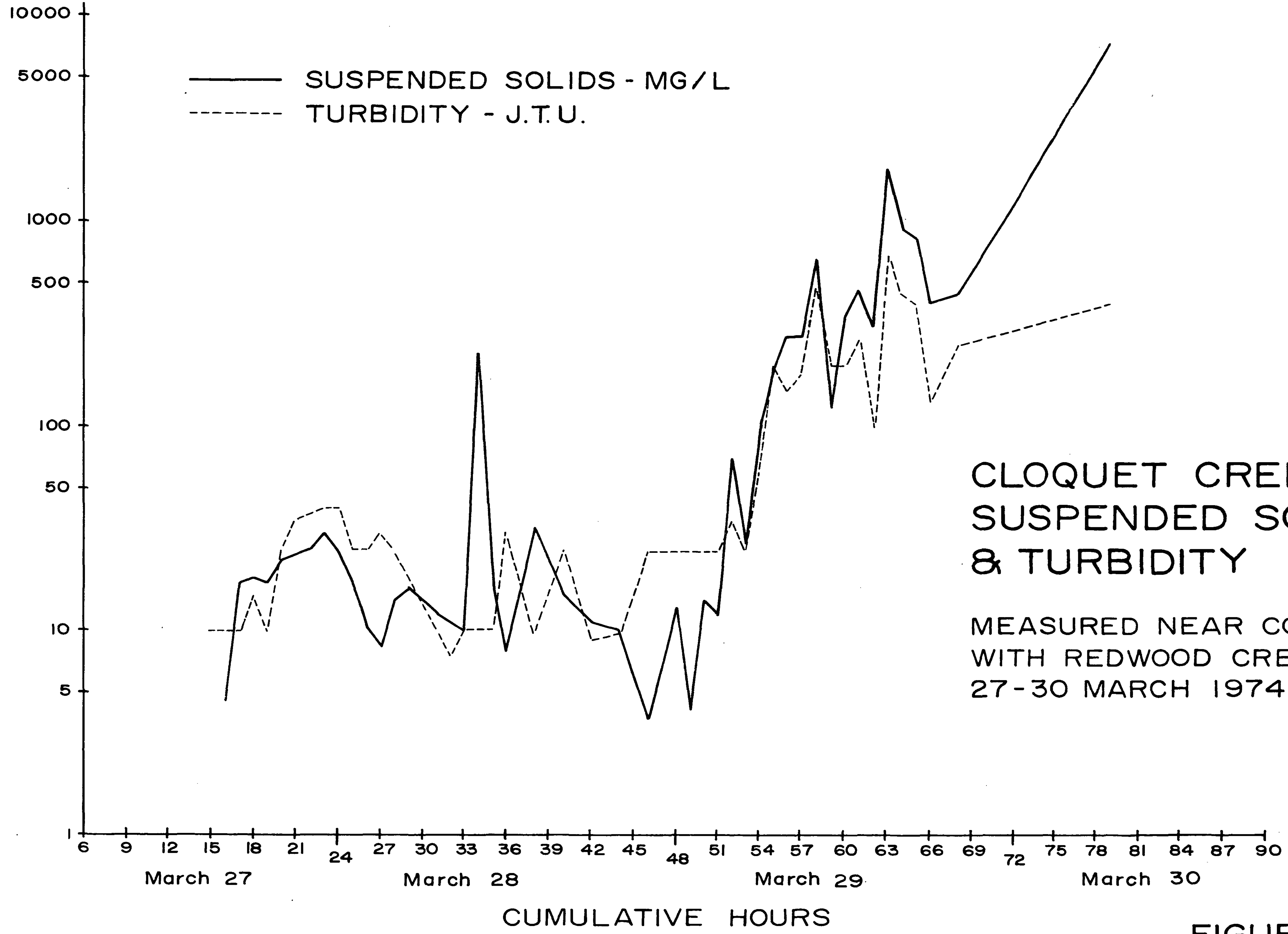
that Redwood Creek transports approximately 300% more sediment per cubic foot of water at the Chezem Bridge than does Miller Creek at its mouth.

No flow measurements were taken in Cloquet Creek during Storm II, but the stream was sampled near its confluence with Redwood Creek on an hourly basis for suspended sediment concentration and turbidity. Figure 9 shows the general relationship between turbidity and suspended sediment concentration. It also illustrates that a "one to one" relationship does not exist between suspended sediment and turbidity. Generally, turbidity values are not as closely related to stream velocities as are suspended sediment concentrations. This is due to the fact that turbidity values are related to functions other than stream velocity. The measurement of turbidity is dependent upon the light scattering, or reflecting, properties of the particular materials suspended in the water. Therefore, turbidity measurement is dependent upon the particle size, particle shape, surface roughness, and particle color of the suspended material. Suspended sediment, however, is related directly to the "energy" or carrying capacity of the stream. The magnitude of the suspended sediment concentration in Cloquet Creek was again considerably less than in Redwood Creek.

Stream flow was not measured in Panther, Coyote or Copper Creeks during Storm II, but samples for both turbidity and suspended sediment concentration were obtained from each stream near its confluence with Redwood Creek on a two-hour interval (Figure 10). The prestorm turbidity and suspended solids levels were approximately 10 Jackson turbidity units and 10 milligrams per liter for both Copper and Coyote Creeks. The prestorm turbidity and suspended solids concentrations for Panther Creek were both less than one JTU and one milligram per liter. The sediment curves for these three creeks more clearly define the nature of Storm II which encompassed two storms, the first a rather mild event followed by an intense rain storm of nearly two and one half days duration. All three streams exhibited two sharp increases in sediment concentration bracketing a recovery period where the concentrations returned to near prestorm conditions. This underscores the rapid storm recovery rate of the streams. The concentrations of suspended solids peaked at 434 milligrams per liter in Panther Creek while the peak values in Coyote and Copper Creeks were 3160 and 7080 milligrams per liter, respectively. The rapid rise in the sediment concentration emphasized the intensity of the storm and the fact that these are small, steep drainages.

Figure 11 is a graph of the instantaneous sediment loads in all of the streams where flow was monitored during Storm II, which includes Redwood Creek at the Chezem Bridge, Redwood Creek at Orick, Miller Creek, Weir Creek, Bridge Creek and Tom McDonald Creek. The suspended sediment loads are plotted in instantaneous tons per day. Because of the extreme range in values, a logarithmic plot had to be used. For example, the range of instantaneous suspended load in Redwood Creek at Orick was from a low of 390 tons per day to a high of 145,000 tons per day. The six plots have been combined on one graph to emphasize that the sediment loads in Redwood Creek range from several hundred to several thousand times the values found in tributary streams. Because a logarithmic plot masks the differences between the high and low loads, a bar graph is included on the right-hand side of this figure, showing the maximum sediment loads obtained at each of the six stations. This bar graph dramatically shows that the tributary sediment load is insignificant compared to loads carried in Redwood Creek at both sample sites, one well above current logging operations and the other at Orick.

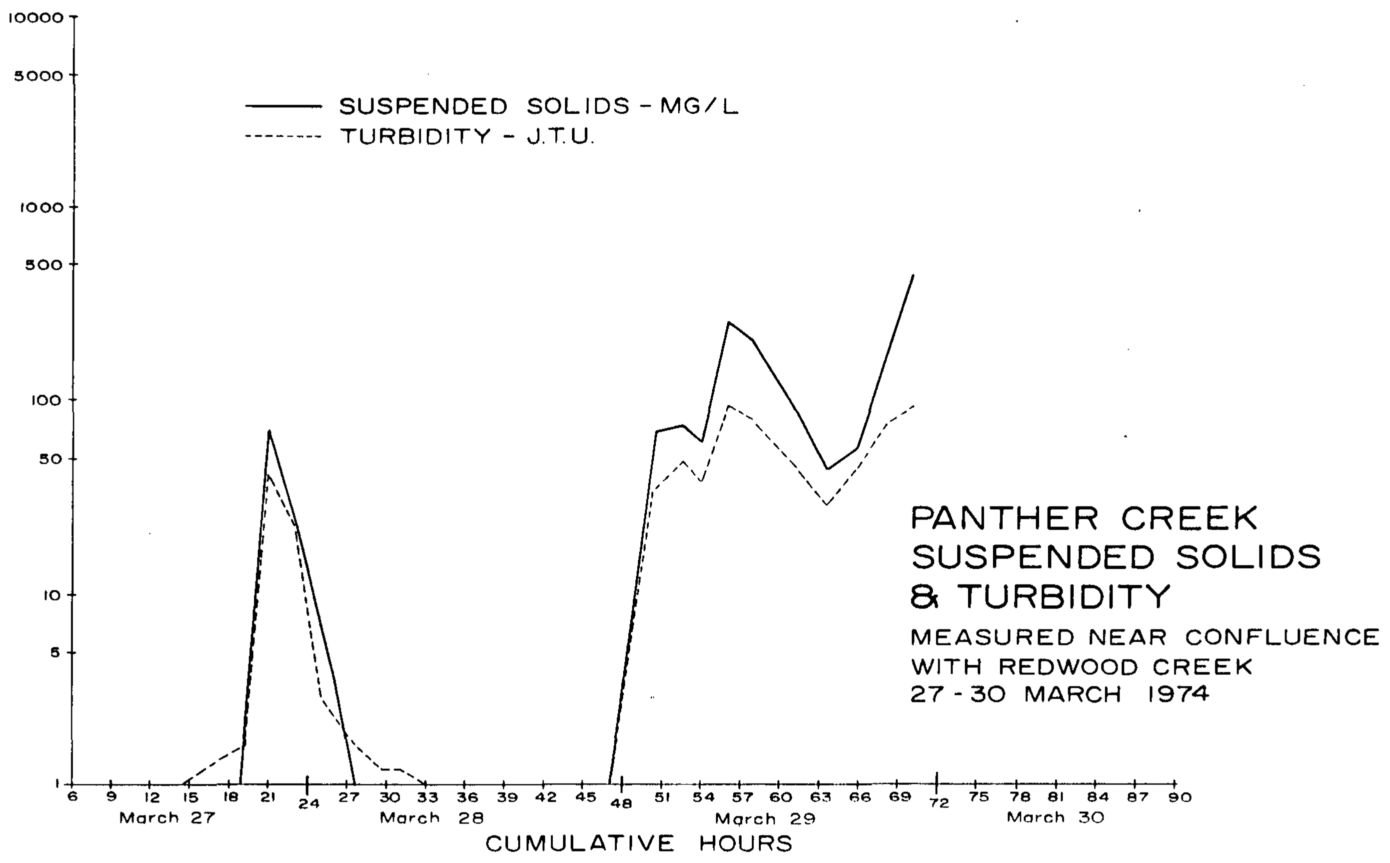
While the magnitude of sediment carried by Redwood Creek at Orick is several times that carried by Redwood Creek at the Chezem Bridge, by referring back to the Suspended Load to Flow Ratio shown on Figure 6, the amount of sediment carried per cubic foot of water is considerably less at Orick than at the Chezem Bridge. This indicates that the relative contribution of sediment and the carrying capacity of Redwood Creek are both considerably greater in the upper portion of the Basin.



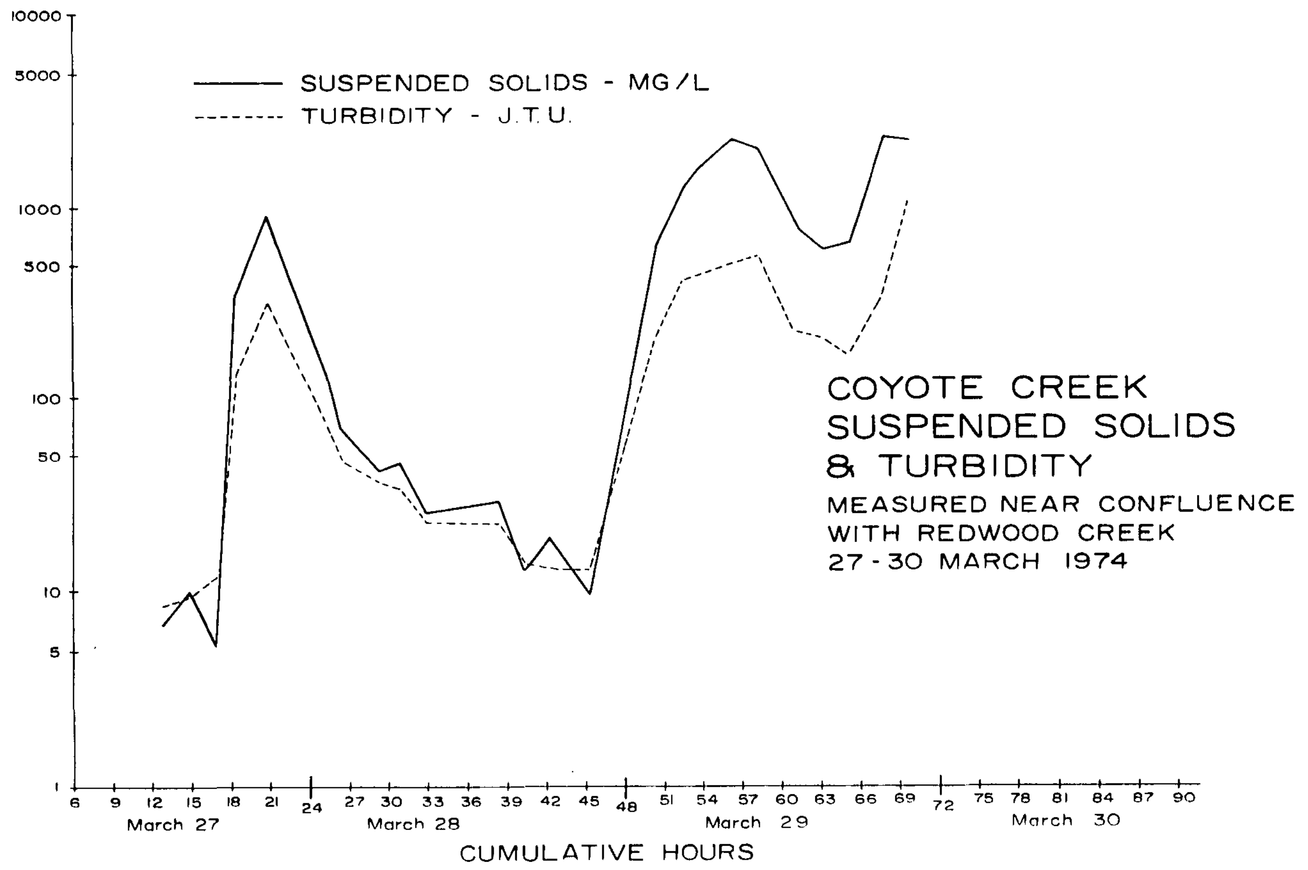
CLOQUET CREEK
SUSPENDED SOLIDS
& TURBIDITY

MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

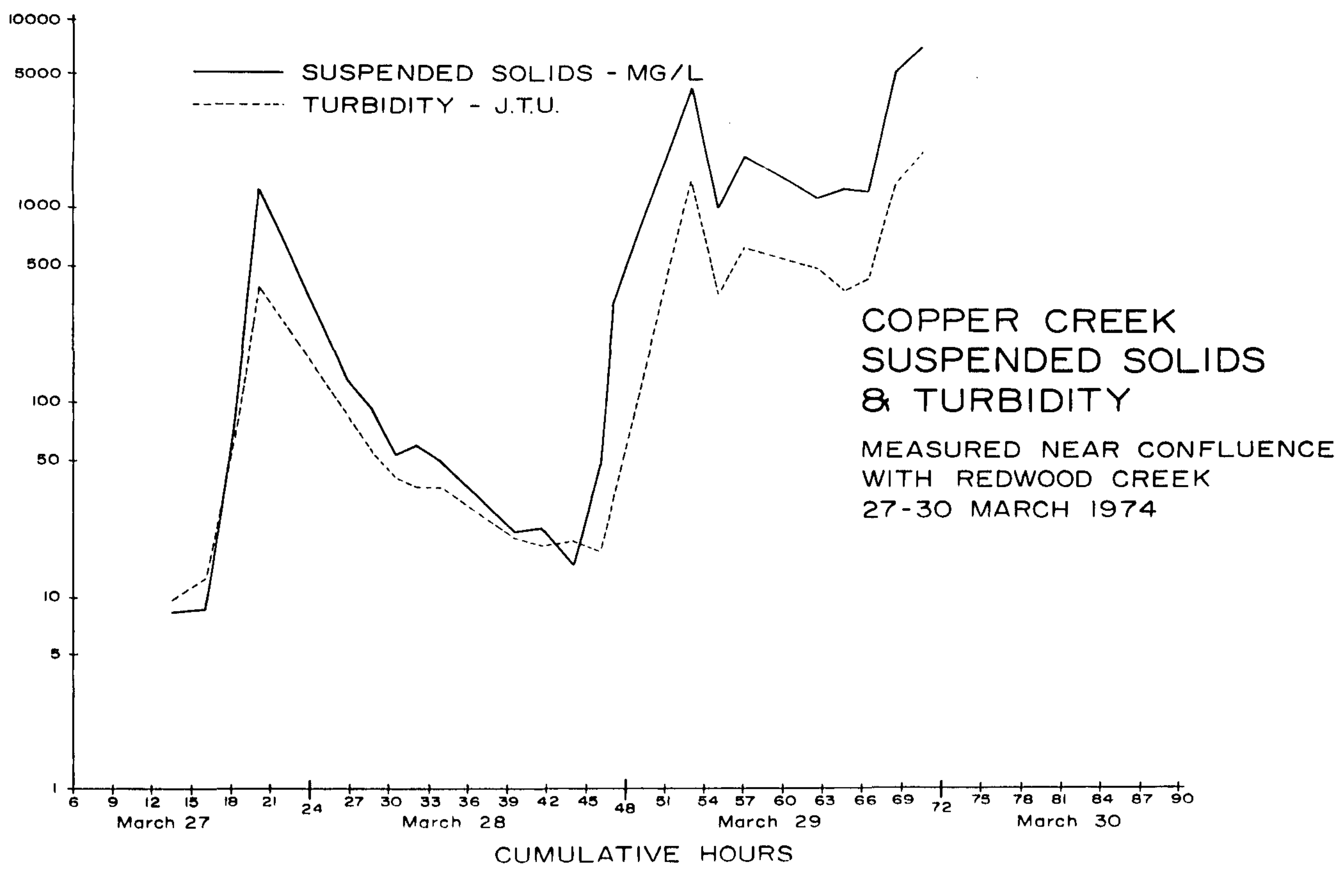
FIGURE 9



PANTHER CREEK
SUSPENDED SOLIDS
& TURBIDITY
MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27 - 30 MARCH 1974



COYOTE CREEK
SUSPENDED SOLIDS
& TURBIDITY
MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27 - 30 MARCH 1974



COPPER CREEK
SUSPENDED SOLIDS
& TURBIDITY
MEASURED NEAR CONFLUENCE
WITH REDWOOD CREEK
27-30 MARCH 1974

FIGURE 10

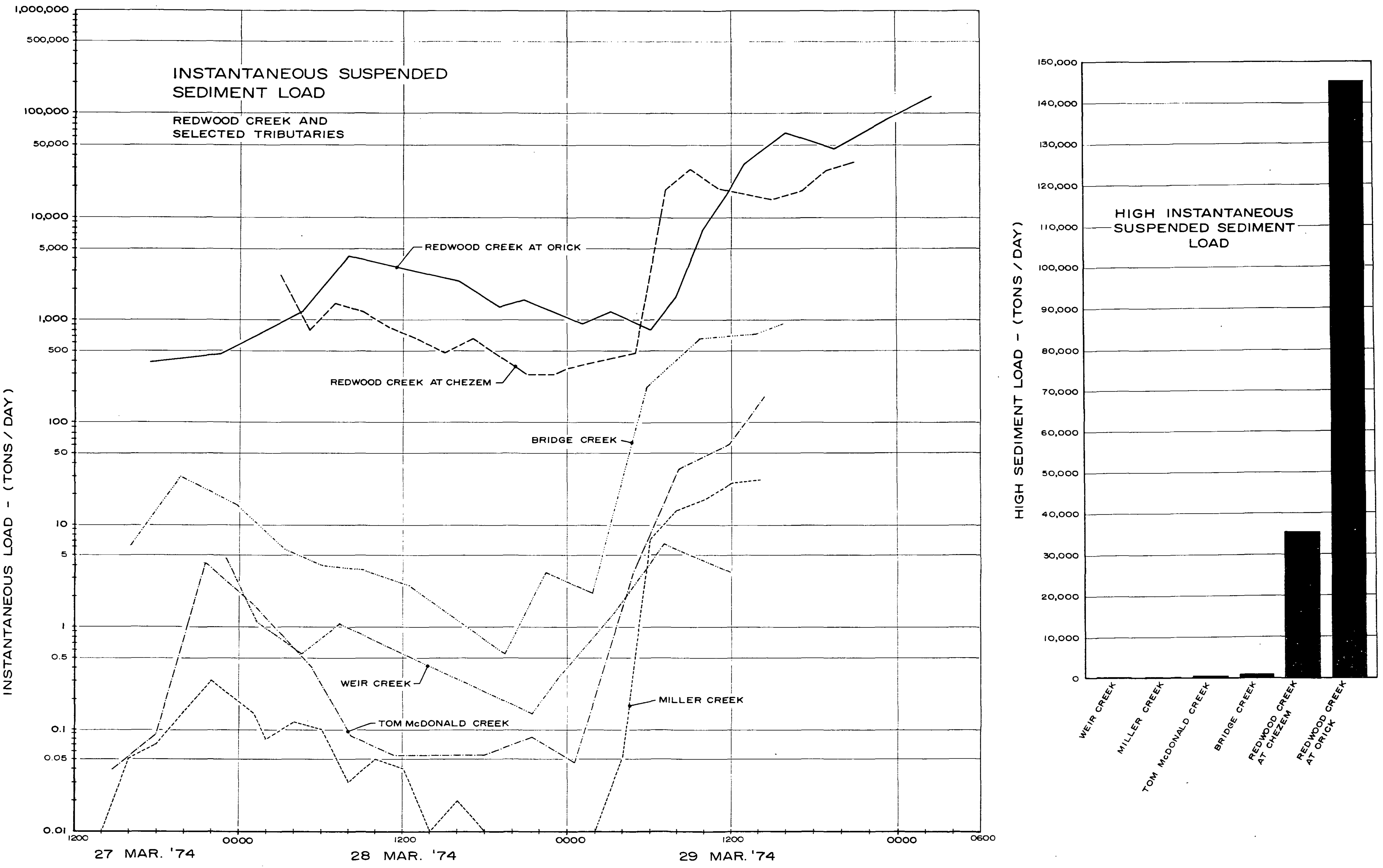

INSTANTANEOUS SUSPENDED SEDIMENT LOAD
REDWOOD CREEK AND SELECTED TRIBUTARIES
INSTANTANEOUS LOAD - (TONS / DAY)
1,000,000
500,000
100,000
50,000
10,000
5,000
1,000
500
100
50
10
5
1
0.5
0.1
0.05
0.01
1200
0000
1200
0000
1200
0000
0600
27 MAR. '74
28 MAR. '74
29 MAR. '74
REDWOOD CREEK AT ORICK
REDWOOD CREEK AT CHEZEM
BRIDGE CREEK
WEIR CREEK
TOM McDONALD CREEK
MILLER CREEK
HIGH INSTANTANEOUS SUSPENDED SEDIMENT LOAD
HIGH SEDIMENT LOAD - (TONS / DAY)
150,000
140,000
130,000
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
WEIR CREEK
MILLER CREEK
TOM McDONALD CREEK
BRIDGE CREEK
REDWOOD CREEK AT CHEZEM
REDWOOD CREEK AT ORICK

FIGURE 11

The total tons of suspended sediment transported at various locations within the Basin during the period 27-30 March 1974 are summarized in Table VII.

TABLE VII

TOTAL SUSPENDED SEDIMENT STORM II

Location	Total Suspended Sediment (Tons)	Rate of Transport (Tons/hours)	Percent Of Total Transport Rate	Drainage Area (Sq. Mile)	Percent of Total Basin Drainage
Redwood Cr at Orick	19500	342	100	278	100
Redwood Cr at Chezem Bridge	7750	172	50.3	72	25.9
Bridge Cr	136	2.8	0.82	11.2	4.0
Tom McDonald Cr	11.2	0.24	0.07	6.9	2.5
Miller Cr	10.8	0.22	0.06	1.35	0.5

This data shows that the total contribution of sediment from Bridge, Tom McDonald and Miller creeks is less than one percent of the total sediment load transported by Redwood Creek at Orick. The same tributaries comprise 7 percent of the total drainage. Redwood Creek at the Chezem Bridge, a station high in the drainage, has a rate of transport equal to fifty percent of the transport rate in Redwood Creek at Orick.

CONCLUSIONS

1. Increases in sediment loads in Redwood Creek and its tributaries correlate closely to increases in rainfall.

2. Sediment concentration in Redwood Creek is nearly as great well above any current harvesting operations as it is downstream from all timber harvesting.

3. Suspended sediment concentration and turbidity values from stations along Redwood Creek indicate a generalized sediment input rather than major input from specific source areas.

4. Suspended sediment loads carried by monitored tributaries were insignificant compared to those carried by Redwood Creek, both above and below current timber harvesting operations.

5. Suspended sediment loads expressed as a ratio to flow were higher in Redwood Creek than in measured tributaries where timber companies are currently operating.

REDWOOD CREEK STREAM GRADIENT

RELATION OF STREAM PROFILE TO THE SCOUR-DEPOSITION REGIME

Many different factors influence the erosional or depositional regime of rivers, and most are superimposed upon the controlling factor of stream gradient. Figure 12 shows the profile of Redwood Creek from its source near Board Camp Butte to a point near its mouth at Orick. The stream gradient was plotted from elevations shown on 15 minute (1:62,500) U.S. Geological Survey topographic quadrangles. Although the gradient was generated from small-scale maps, the resulting profile does allow for a generalized interpretation of the changes in gradient which affect stream velocity and therefore the stream's capacity to carry sediment. The deposition or scour regimes suggested by this profile do not take into account features such as channel width, temporary sediment storage due to partial stream blockages, substrata composition, etc. However, this profile will give an indication of the areas where one would expect a scour or a depositional environment in a long-term geological sense. It can be seen that there are essentially three broad gradient regimes. The first is a steep slope near the headwaters that extends downstream 6 to 8 miles. Next are the intermediate slopes which extend from mile 6 or 8 to approximately mile 47. Finally, there is an area of noticeably flatter stream gradients from mile 47 to the mouth. It is interesting to note that from approximately mile 43 through mile 47 there is a pronounced increase in the stream gradient followed by a marked flattening of the stream profile. Based upon the assumption that the stream profile controls the primary erosional/depositional regime of the creek, the three delineated areas could be designated very broadly as an area of pronounced cutting and erosion, an area of more moderate erosion and transport, and an area of deposition and transport.

U.S. GEOLOGICAL SURVEY CROSS-SECTION DATA

The United States Geological Survey in the Redwood Creek study monitored approximately forty cross-sections in the main stream of Redwood Creek during the period October 1973 through May 1974.[5] The data obtained from their cross-sectional measurements supports the delineation of the stream into erosion, transport and depositional areas. Superimposed upon Figure 12 is the plot of the USGS cross-sectional data on which positive values represent a net increase in cross-sectional area (scour) and negative values a decrease (deposition). Except for three anomalous points, the USGS cross-sections show an increase in channel area or scour from above the U.S. 299 Bridge downstream through to approximately mile 48. At mile 48 the character of the stream becomes depositional, with two exceptions, through to mile 56. This depositional area coincides with the flattening of the stream profile and begins just upstream from the Big Trees Flat.

CONCLUSIONS

The Redwood Creek profile and the data generated from the USGS cross-section measurements indicate that, regardless of land practices, Redwood Creek above mile 48 is essentially erosional and below mile 48 is essentially depositional.

An area of primary interest to the National Park is the depositional area which begins near mile 48. The beginning of the depositional regime is immediately upstream from the Big Trees

Flat, an area where deposition of stream-borne sediments is occurring and where deposition would be expected as shown by the stream profile. It was this type of depositional environment that created the alluvial flat upon which the Big Trees grew, and it is now the same depositional environment that some feel threatens those same trees.

This evidence strongly suggests the importance of the main stream relative to the tributaries in the production of stream-borne sediment. The data also points to the importance of the upper watershed. Figure 12, based upon U.S. Geological Survey data, indicates that scour is occurring quite generally in Redwood Creek upstream from Mile 47.

BEDLOAD DATA

DISCUSSION

The bedload data obtained suggest, in a very general way, the pattern noted for the suspended load. Of the four stations measured, that at Orick is most suited for bedload measurements. The channel bottom is fairly flat, with a gravel substrata and no large boulders to severely disrupt the velocity vectors. Figure 12A illustrates the resemblance of the bedload data to the suspended sediment information. However, when the bedload data is plotted as a percentage of the suspended load (Figure 12C), it is noted that an increase in suspended load is accompanied by an almost geometric decrease in the percentage bedload. This decrease may be related to the increased stream velocity, but the near-flood conditions during the March 1974 storm prevented our obtaining additional peak and recession data that might have supported this conclusion. The percentage bedload curve may geometrically increase to some undetermined level with decreasing flows.

Although the Chezem Bridge data also generally follows the suspended load pattern, it is too variable to analyze in detail, probably because of the channel geometry and resulting velocity vectors (Figures 12A and 12C). Flow conditions at this station also made it extremely difficult to determine the time that the sampler was actually on the bottom.

The bedload data obtained from Tom McDonald Creek varied from 9.5% to 600% of the suspended load measured, averaging 200%. The variation may be due to a great extent to the very low suspended sediment and bedload values obtained (Figure 12B).

At Bridge Creek, the relationship between bedload and suspended load follows a pattern opposite to that observed at the Redwood Creek Orick station. The percentage of bedload to suspended load hovered in the 5—10% range during intermediate flows and then markedly increased during higher stream flows (Figure 12B).

Obviously, the inconsistencies in the bedload data make any evaluation hazardous. Considerably more data regarding the performance of the Helly-Smith sampler will be needed before it will be generally useful for obtaining reliable information. The sketchy data obtained here suggests that the sampler may be useful only under rigorously controlled conditions seldom found in the field.

PHYSICAL AND BACTERIOLOGICAL CHARACTERISTICS

DISCUSSION

While the main objectives of this investigation were concerned with the sediment regime of the Basin, measurements were also taken at each station of the temperature, dissolved oxygen, specific conductance, and total and fecal coliform concentrations. The information, while not directly applicable at this time, should provide a needed background data base for future reference.

WINZLER & KELLY
CONSULTING ENGINEERS

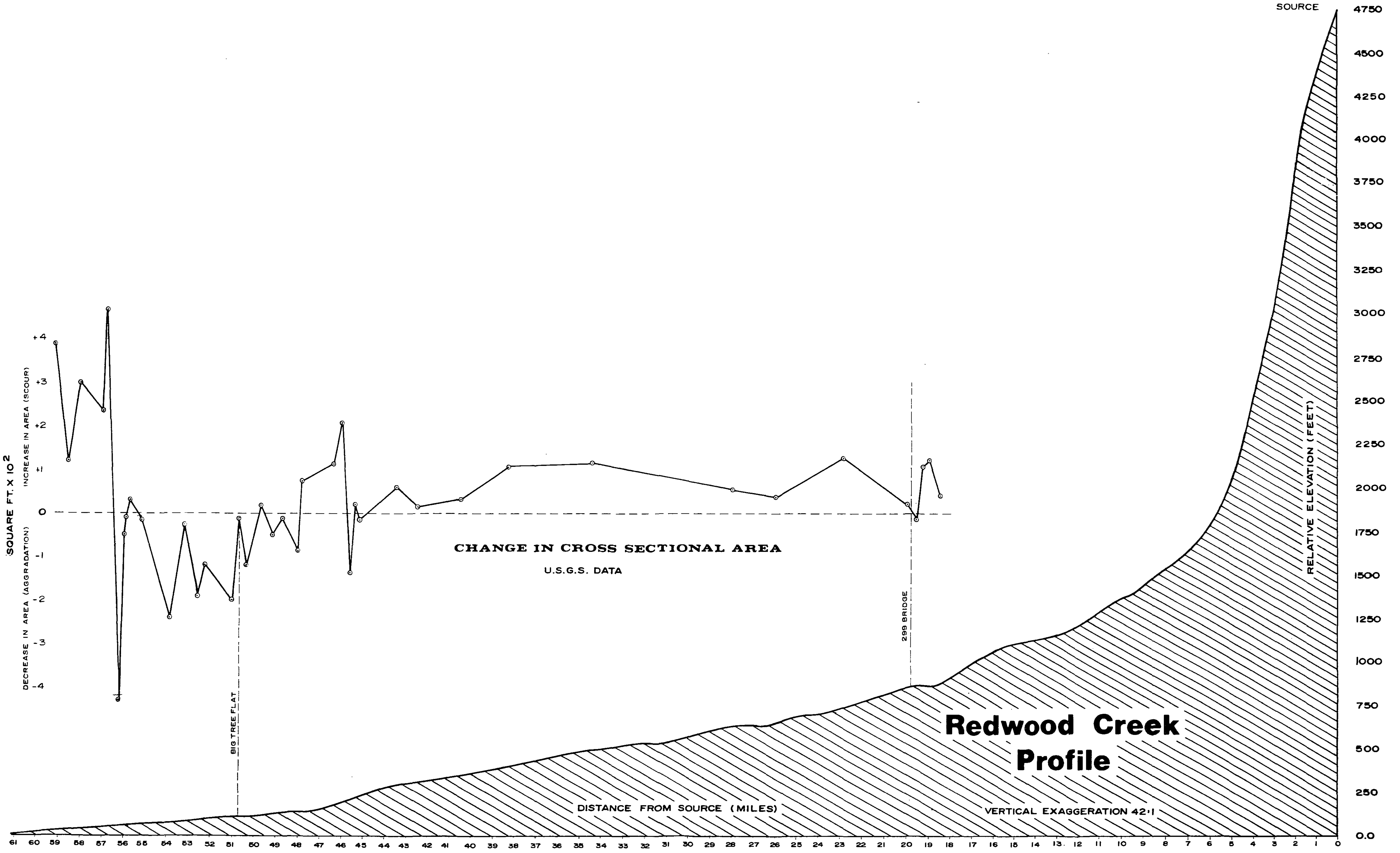


FIGURE 12

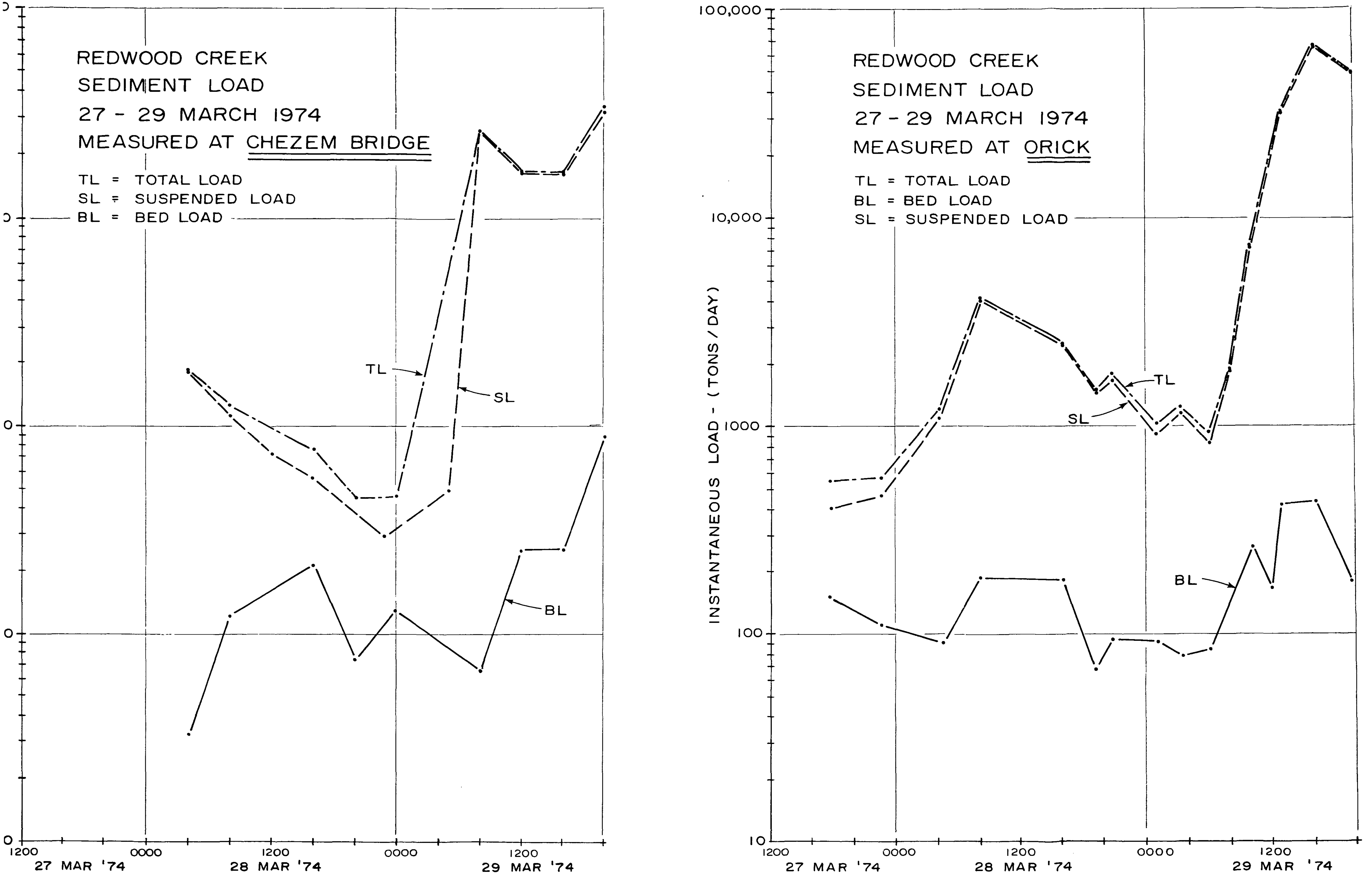
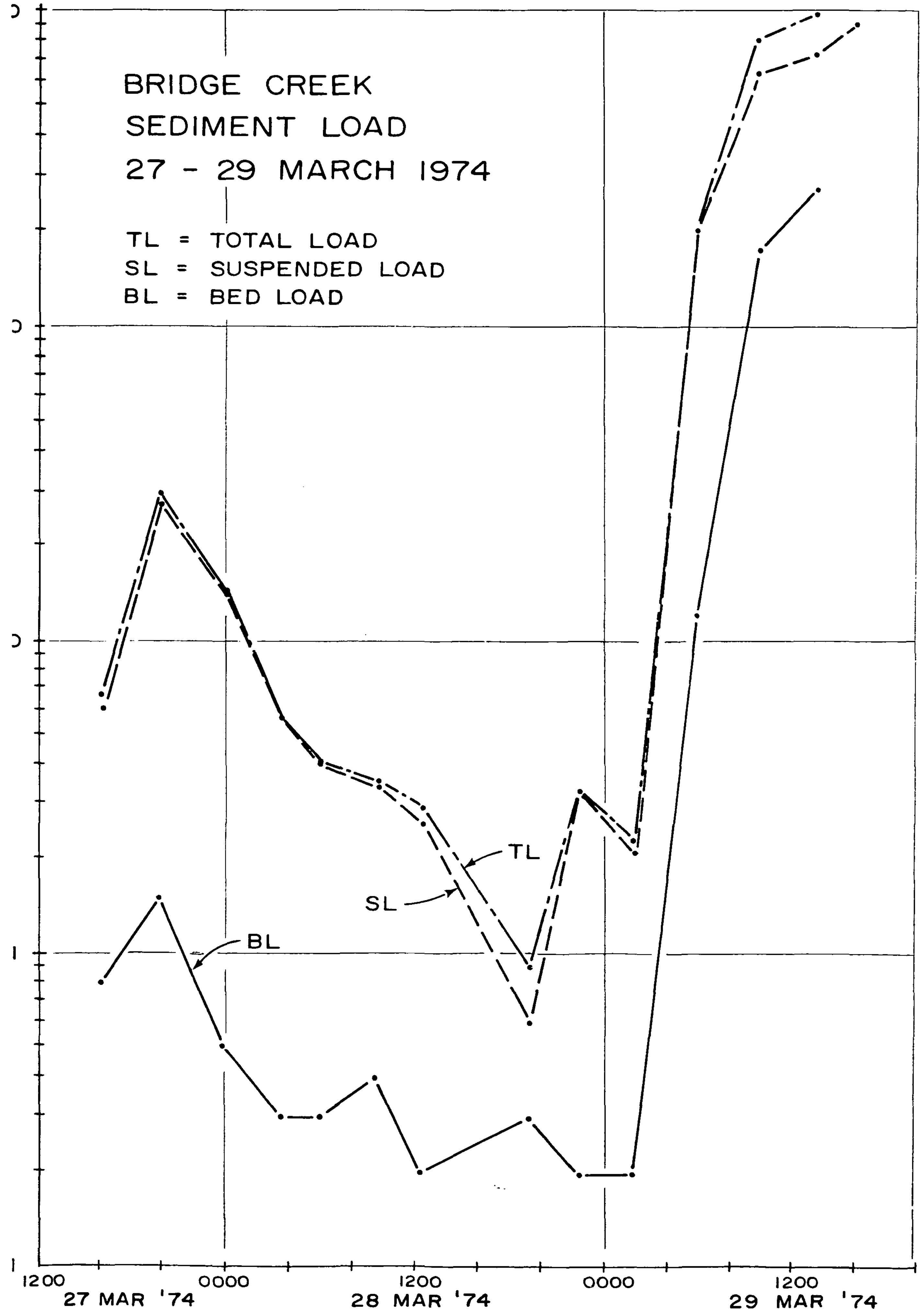
REDWOOD CREEK
SEDIMENT LOAD
27 - 29 MARCH 1974
MEASURED AT CHEZEM BRIDGE
TL = TOTAL LOAD
SL = SUSPENDED LOAD
BL = BED LOAD
TL
SL
BL
0
0
0
0
0
1200
0000
1200
0000
1200
27 MAR '74
28 MAR '74
29 MAR '74
REDWOOD CREEK
SEDIMENT LOAD
27 - 29 MARCH 1974
MEASURED AT ORICK
TL = TOTAL LOAD
BL = BED LOAD
SL = SUSPENDED LOAD
INSTANTANEOUS LOAD - (TONS / DAY)
100,000
10,000
1000
100
10
TL
SL
BL
1200
0000
1200
0000
1200
27 MAR '74
28 MAR '74
29 MAR '74

FIGURE 12 A


BRIDGE CREEK
SEDIMENT LOAD
27 - 29 MARCH 1974
TL = TOTAL LOAD
SL = SUSPENDED LOAD
BL = BED LOAD
TL
SL
BL
1
1200
27 MAR '74
0000
1200
28 MAR '74
0000
1200
29 MAR '74

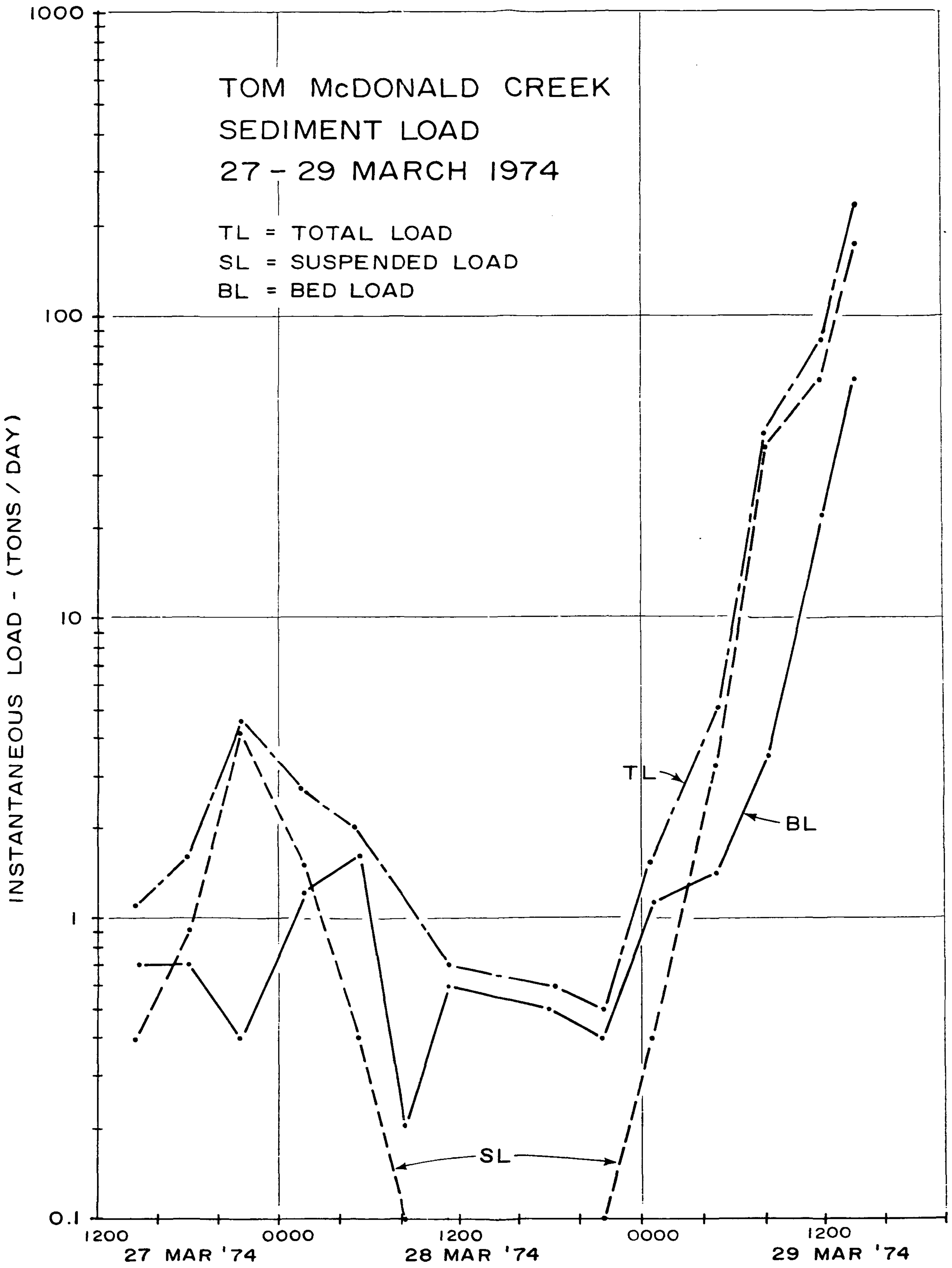

TOM McDONALD CREEK
SEDIMENT LOAD
27 - 29 MARCH 1974
TL = TOTAL LOAD
SL = SUSPENDED LOAD
BL = BED LOAD
INSTANTANEOUS LOAD - (TONS / DAY)
1000
100
10
1
0.1
TL
BL
SL
1200
27 MAR '74
0000
1200
28 MAR '74
0000
1200
29 MAR '74

FIGURE 12 B

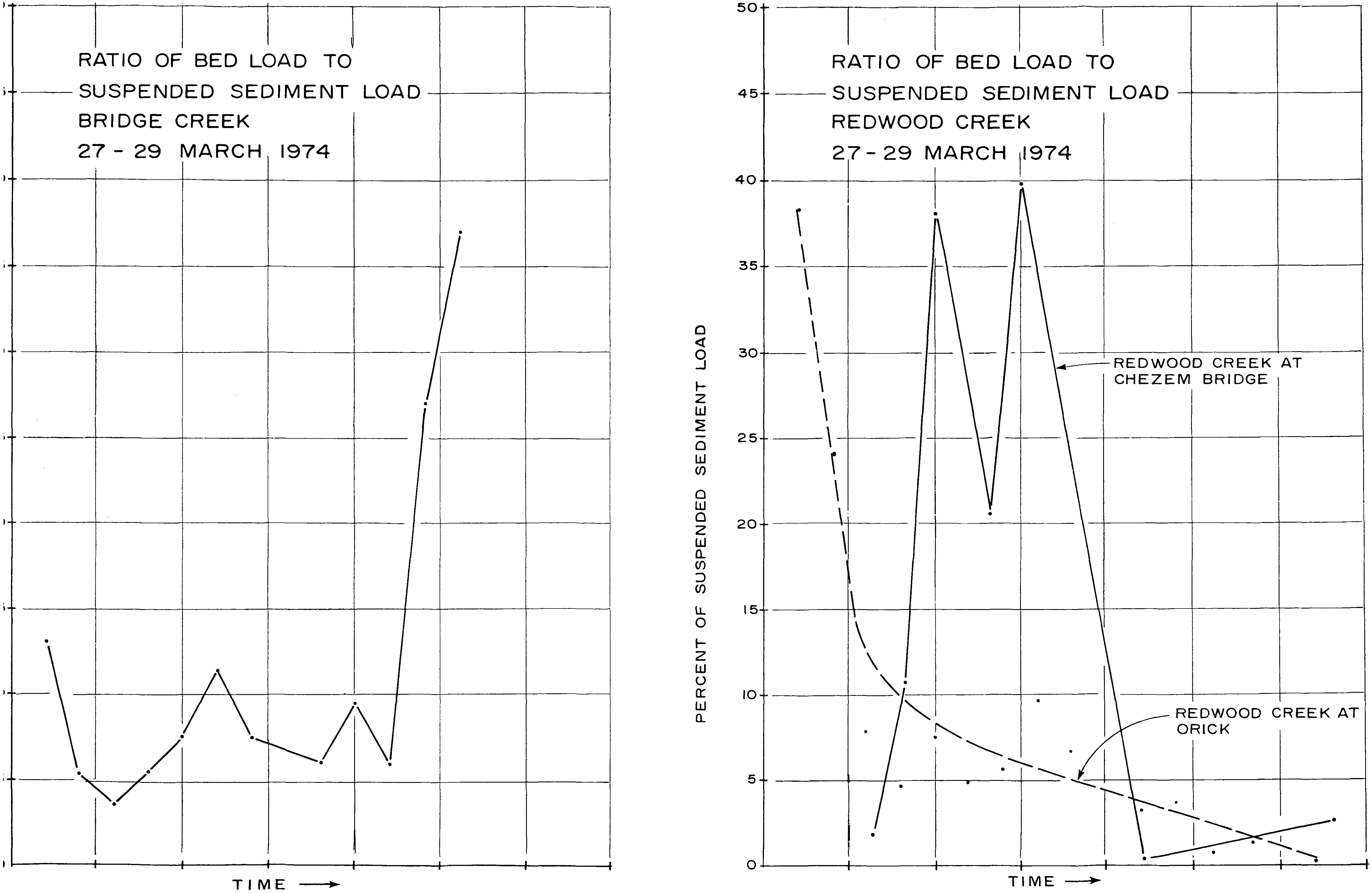

RATIO OF BED LOAD TO
SUSPENDED SEDIMENT LOAD
BRIDGE CREEK
27 - 29 MARCH 1974
TIME →
RATIO OF BED LOAD TO
SUSPENDED SEDIMENT LOAD
REDWOOD CREEK
27 - 29 MARCH 1974
PERCENT OF SUSPENDED SEDIMENT LOAD
50
45
40
35
30
25
20
15
10
5
0
REDWOOD CREEK AT CHEZEM BRIDGE
REDWOOD CREEK AT ORICK
TIME →

FIGURE 12 C

The temperatures found in Redwood Creek were, as expected, directly proportional to the degree of insolation. Mid-reaches of Redwood Creek, where the stream is more open to direct radiation, exhibited slightly higher temperatures than the upper and lower reaches (Table VIII).

Dissolved oxygen levels were nearly always at or above saturation except during low flow, late summer month periods when some stations exhibited lower than saturated dissolved oxygen concentrations. Water turbulence resulting from the stream gradient appeared to be the controlling factor in maintaining dissolved oxygen levels. Temperature effects were secondary, and in areas where decaying organic material would be expected to have some effect, none was noted (Table VIII).

Specific conductance measurements were obtained on a monthly basis. The resulting average values are somewhat lower than published median conductivity values for Redwood Creek, probably because the present sampling was mostly during the rainy season (Table VIII).

Samples for coliform bacteria were not taken intensively enough to allow other than very sketchy conclusions (Table VIIIA). The samples taken, however, do not indicate any gross bacterial contamination of Redwood Creek. Additional sampling should be accomplished in order to relate bacterial densities to such factors as stream flow, temperature, storm runoff and livestock grazing. The following tables summarize the results of the temperature, dissolved oxygen, specific conductance, and bacterial sampling accomplished in Redwood Creek during the period September 1973 through July 1974.

TABLE VIII

REDWOOD CREEK PHYSICAL CHARACTERISTICS

	Specific Conductance Micromhos/cm @ 25°C			Temperature °C			Oxygen (Mg/1)		
Redwood Creek at:	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
U.S. 299 Bridge	60	101	210	3.0	10.3	19.5	8.4	11.1	13.6
Lack's Creek	66	90	136	2.5	11.2	21.5	7.8	10.8	13.7
Panther Creek	58	104	181	3.5	11.6	24.0	8.3	10.8	13.1
Coyote Creek	62	104	190	3.5	11.7	23.5	7.0	10.7	13.2
Devil's Creek				3.5	13.0	24.5	7.0	10.8	13.3
1800 Bridge	58	97	198	3.0	11.8	24.0	8.0	10.8	13.7
Copper Creek	57	99	198	3.0	12.1	26.5	7.8	10.8	13.4
Park Boundary	58	78	132	3.0	12.8	25.0	7.4	10.8	13.1
Bridge Creek	63	90	139	3.5	12.5	21.0	8.3	10.6	13.0
Weir Creek	59	86	142	4.5	11.6	20.5	8.2	10.9	13.4
Tom McDonald Creek	58	88	149	3.5	12.1	21.0	7.6	10.7	13.2
Forty-Four Creek	57	84	135	3.5	11.8	21.0	7.9	11.0	13.0
Miller Creek	57	90	144	4.5	11.1	20.0	7.3	11.0	13.4
Bond Creek	45	85	132	3.5	11.9	22.0	7.9	11.0	13.7
Cloquet Creek	59	90	140	4.5	11.6	19.0	7.9	10.9	13.2
Elam Creek	56	87	138	3.5	11.7	21.0	7.2	10.8	13.5
McArthur Creek	54	86	138	3.5	12.2	22.0	6.9	10.7	13.6
Number of Determinations per station		8-10			44			44	
Redwood Creek Average	58	91	156	3.5	11.8	22.1	7.7	10.8	13.4

Specific conductance determinations were performed monthly. Temperature and dissolved oxygen readings were conducted weekly.

TABLE VIIIA

TOTAL AND FECAL COLIFORM CONCENTRATIONS* REDWOOD CREEK

REDWOOD CREEK SAMPLING LOCATIONS

Date	U.S. 299 Bridge		Lack's Creek		1800 Bridge		Copper Creek		Park Boundry		Bridge Creek		Below McArthur Creek	
	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal	Total	Fecal
20 July 1973	920	14			350	<2	130	33						
3 Oct. 1973	79	5	23	8					49	2			130	<2
13 Nov. 1973													170	49
15 Nov. 1973	46	49							920	9				
4 Dec. 1973	31	23							31	2				
9 Jan. 1974													13	8
18 Jan. 1974													240	
30 April 1974											2	<2	11	2
9 May 1974	49	5							70	5				
Average	225	19							270	5			110	15

Average Total Coliform Density in Redwood Creek: 180 MPN/100 ml
(18 Determinations)
Average Fecal Coliform Density in Redwood Creek: 13 MPN/100 ml
(17 Determinations)

* All values are expressed as the Most Probable Number per 100 Milliliters.

SEDIMENT ANALYSIS

METHODS OF SEDIMENT ANALYSIS

The determination of the sources and amounts of suspended sediments in streams is being given major consideration in water quality investigations. Obtaining an exact measure of suspended sediment requires the construction of weirs and the use of automatic proportionate water samplers. This requires a large capital outlay and can be justified only for long-term research projects. Pinpointing the exact source of sediments requires observation of active erosion processes on site. This is obviously impossible in terms of placing observers in the right place and at the right time. For the present study, it was desired to know the sources of materials carried by Redwood Creek.

The work of previous investigators[6] has demonstrated the utility of using the occurrence and nature of clay minerals taken in water samples as an aid in tracing and identifying the sources of sediments. As an example, tributary streams to the Middle Fork of the Willamette River in the Oregon Cascades were classified as to their suspended sediment loads during between-storm periods as well as during storm events. Soil and slide samples were collected from the watersheds of turbid streams. For comparison, water and soil samples were also collected from non-turbid streams and their watersheds. Clay mineral analysis of the suspended sediments from the stream samples and analysis of soil and slide materials were then used to "fingerprint" or identify the probable sources of sediment. These techniques were applied to this study of the Redwood Creek Drainage Basin.

The nature of suspended sediments in the streams of a watershed reflects the character of the geologic formations and soils on the drainage system. It also reflects the nature of the weathering and mass movement processes active in a watershed. Soil creep has been described as the major source of erosion in the Northern California Coast Range.[7] Creep is the slow continuous down-slope movement of soil material resulting on slopes with deep, cohesive soils. Down cutting by streams results in over steepening of the banks causing slumping of bank material into the stream. This in turn accelerates the soil creep and accompanying slope failures and mass movement on adjacent slopes. These processes are also accelerated by major storm events.

Redwood Creek is bordered nearly its entire length by active stream side slides. During the rainy season the toes of the slides are continually eroded causing a constant influx of sediment into Redwood Creek. Based upon the work of Kojan,[8] these natural processes probably account for seventy percent or more of the natural sediments reaching Redwood Creek and its tributaries. This natural occurrrence of erosion proceeds at a faster rate in some geologic formations than in others. In the Redwood Creek drainage, the Kerr Ranch schist and the Franciscan Melange are the dominant geologic formations. Creep and mass movement proceed at a more rapid rate in the Kerr Ranch schist than in the Franciscan formation. Within the latter formation, these processes proceed at a more rapid rate in shear zones than in non-shear zones.

A preliminary reconnaissance was made of the watershed to observe geologic and soil materials and areas where soil movement was evident, especially on stream banks.

Following the preliminary reconnaissance and study of soil-vegetation maps,[9] sites representing major soils and geologic materials were selected for sampling (Table IX). Soil samples were taken from genetic horizons, sealed in plastic bags in field-moist conditions, and submitted to Dr. R.C. Jones of the University of Hawaii for analysis. Dr. Jones was informed of the type of analysis desired and the methods to be followed but was not informed as to what the samples represented. The coded data were returned for analysis and interpretation. The methods of sample preparation and analysis and the criteria used in the interpretations are given in Appendix A.

Water samples collected by Winzler and Kelly personnel were also submitted to Dr. R.C. Jones. They were analyzed in the same way as the soil samples except that they were not sonicated or wet-seived.

TABLE IX

DESCRIPTION AND LOCATION OF SOIL AND SLIDE SAMPLES

Sample Numbers	Depth (inches)	Soils Horizon or Material	Location	Ownership
		SLUMPS AND SLIDES		
11-Z		Masterson C horizon	Bridge Creek drainage SW -1/4 Sec 4 T9N R2E	LP
2-1		Masterson - road slump	Simpson 2000 Road SW -1/4 Sec 36 T6N R3E	Simpson

Sample Numbers	Depth (inches)	Soils Horizon or Material	Location	Ownership
3-1		Bank Slide - schist	Head of operations SE -1/4 Sec 36 T6N R3E	Simpson
16-1		Bank slide - schist	Redwood Valley Road NW -1/4 Sec 21 T7N R3E	?
MASTERSON SOIL				
1-1	2-10	A3	Noisy Creek Drainage	
1-2	20-43	B21	NE -1/4 Sec 35 T6N R3E	Simpson
1-3	43-59	B22g		
11-1	7-16	B1		
11-2	16-25	B21	Bridge Creek Drainage	
11-3	25-39	B22	SW -1/4 Sec 7 T9N R2E	LP
11-4	39-55	B3		
KERR SOIL				
	20-24		Alluvial terrace near Orick SW -1/4 Sec 33 T11N R1E	Pvt. farm
OTHER SOILS				
5-1	15-33	Hugo B2	Weir Creek Drainage	ARCO
5-2	33-52	Hugo B3	NE -1/4 Sec 31 T10N R2E	
6-1	17-20	Orick B21	Weir Creek Drainage	ARCO
6-2	20-33	Orick B22	NW -1/4 Sec 6 T9N R2E	
9-1	9-18	Orick A3	McArthur Creek Drainage	LP
9-2	33-47	Orick B21	SW -1/4 Sec 21 T10N R1E	
9-3	47-69	Orick B22		
7-1	0-27	Kneeland A11	Weir Creek Drainage	Pvt. ranch
7-2	38+	Kneeland C	SW -1/4 Sec 28 T10N R2E	
8-1	3-9	Atwell A3	Copper Creek Drainage	Simpson
8-2	9-13	Atwell B21g	SE -1/4 SEC 22 T9N R2E	
8-3	32-49	Atwell B22g		
15-1	6-22	Atwell B1	Stover Ranch-US Ply. Rd.	Stover
15-2	22-38	Atwell B21g	NE -1/4 Sec 17 T8N R3E	
10-1	5-10	Sites A3	Bridge Creek Drainage	LP
10-2	17-33	Sites B21	NW -1/4 Sec 17 T9N R2E	
14-1	3-13	Yorkville A3	Stover Ranch-US Ply. Rd.	Stover
14-2	22-35	Yorkville B22	SE -1/4 Sec 19 T7N R3E	

Of the water samples collected, only the sample collected at "head of operations" (E 1/16 between Section 36 and 1, T5 &6N R3E H.B.& M.) was a single grab sample taken during a non-storm period. All other water samples collected were composite samples taken over the entire storm events monitored during the periods 28 February - 1 March and 27 - 30 March, 1974.

Selected samples were analyzed by electron transmission microscopy to characterize the morphology of particles, and with a quantometer (electron spectroscope) to determine elemental composition.

RESULTS

X-Ray Diffraction Analysis

The components in the stream samples are given in Table X. All samples from Redwood Creek exhibited strong lines corresponding to chlorite. This was indicated by the invariant 001 spacing of about 14 Å regardless of treatment. Strong "10 Å" lines were also observed, indicating the presence of mica. Some samples exhibited a doublet (about 10 and 9.4 Å) in the diffraction peak for mica. The 9.4 Å peak plus chemical data for sodium on related samples (Table XIV to be discussed later) suggest the presence of paragonite. This component is listed separately from the other micas in the tables because of its usefulness as a "tracer". The samples from the different areas of Redwood Creek appear quite uniform. The X-ray pattern for the W-1 sample from the upper quarter of the watershed (which was above current logging operations) is qualitatively the same as the sample taken at Orick, even though a large number of tributaries enter between these points. Figure 13 contains tracings of the X-ray diffraction patterns for the Redwood Creek stream samples.

The samples from the tributaries to Redwood Creek (Table X) exhibit the same general features as those from the main stream. Chlorite and mica are dominant components. The samples from Panther, Bridge and Tom McDonald Creeks are most like those from Redwood Creek. Samples from Coyote, Copper, Weir, Miller and Cloquet Creeks gave 10 Å mica lines which were somewhat broader than the others (See Figures 14 and 15). The latter samples also appeared to have some chloritic intergrades present.

TABLE X

CLAY MINERALS IDENTIFIED FROM X-RAY DIFFRACTION PATTERNS OF SUSPENDED SOLIDS FROM WATER SAMPLES[1]

Samples	Chlorite	Chloritic Intergrade	10Å Mica	Paragonite	Vermiculite	Interstratified	Kaolin[2]
Main Stream							
W-1, Redwood Cr. Above Opn's	S		S	M			
Redwood Cr. at Noisy Cr.	S		S	W			
Redwood Cr. at Chezem Cr.	S		S	W			

SUSPENDED SEDIMENTS IN REDWOOD CREEK

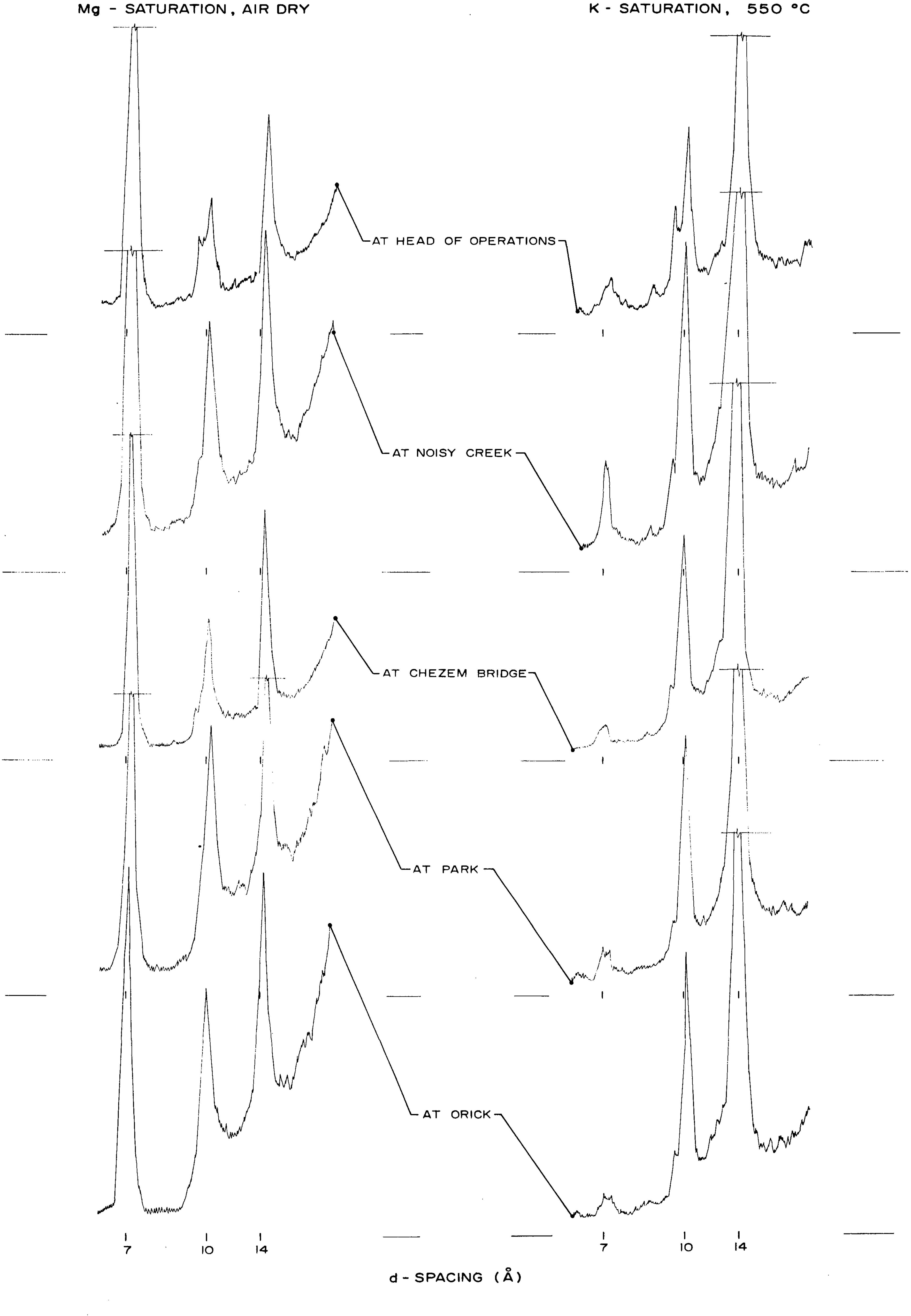
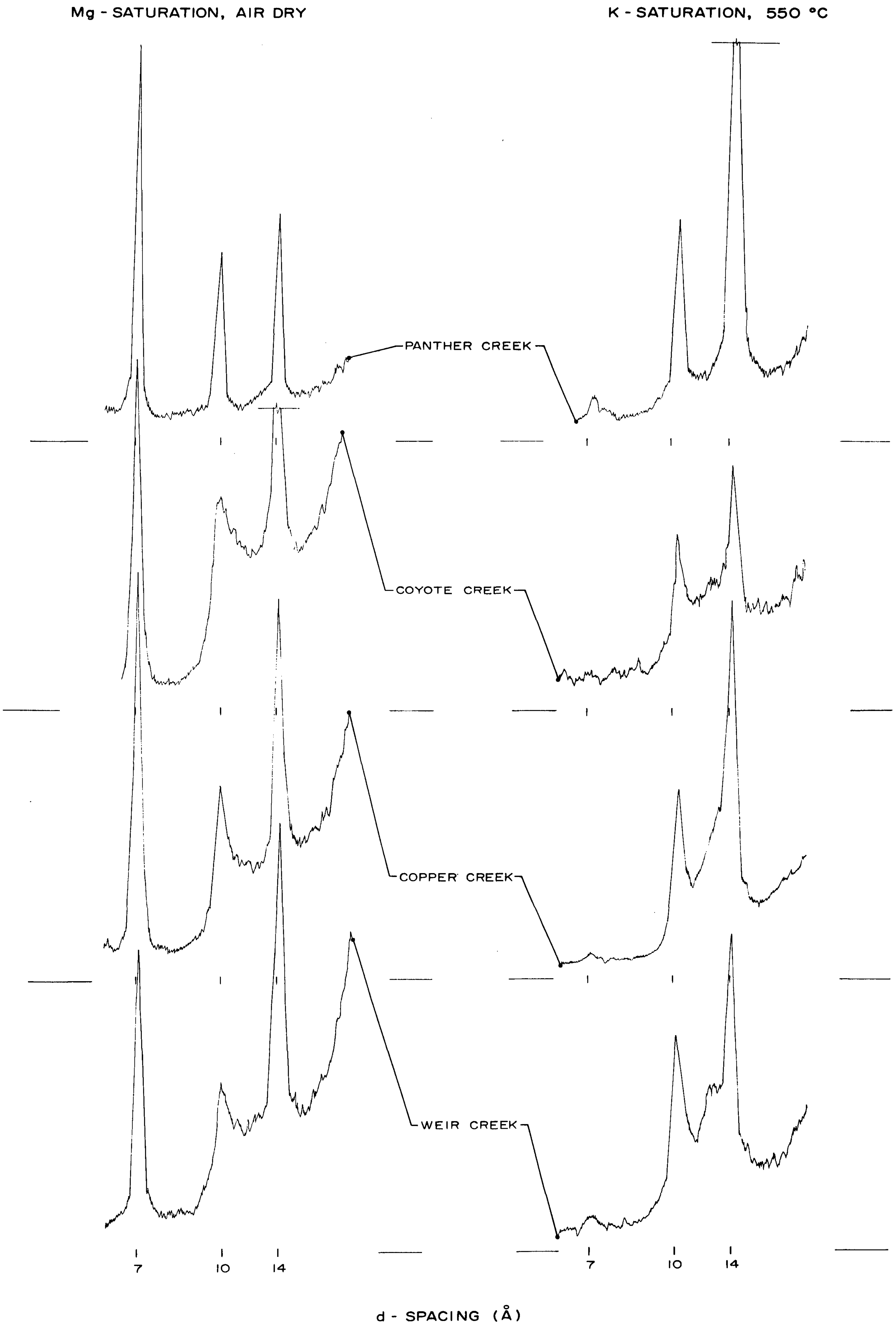


FIGURE 13

SUSPENDED SEDIMENTS

-IN-

TRIBUTARIES



Mg - SATURATION, AIR DRY

K - SATURATION, 550 °C

FIGURE 14

SUSPENDED SEDIMENTS
- IN -
TRIBUTARIES

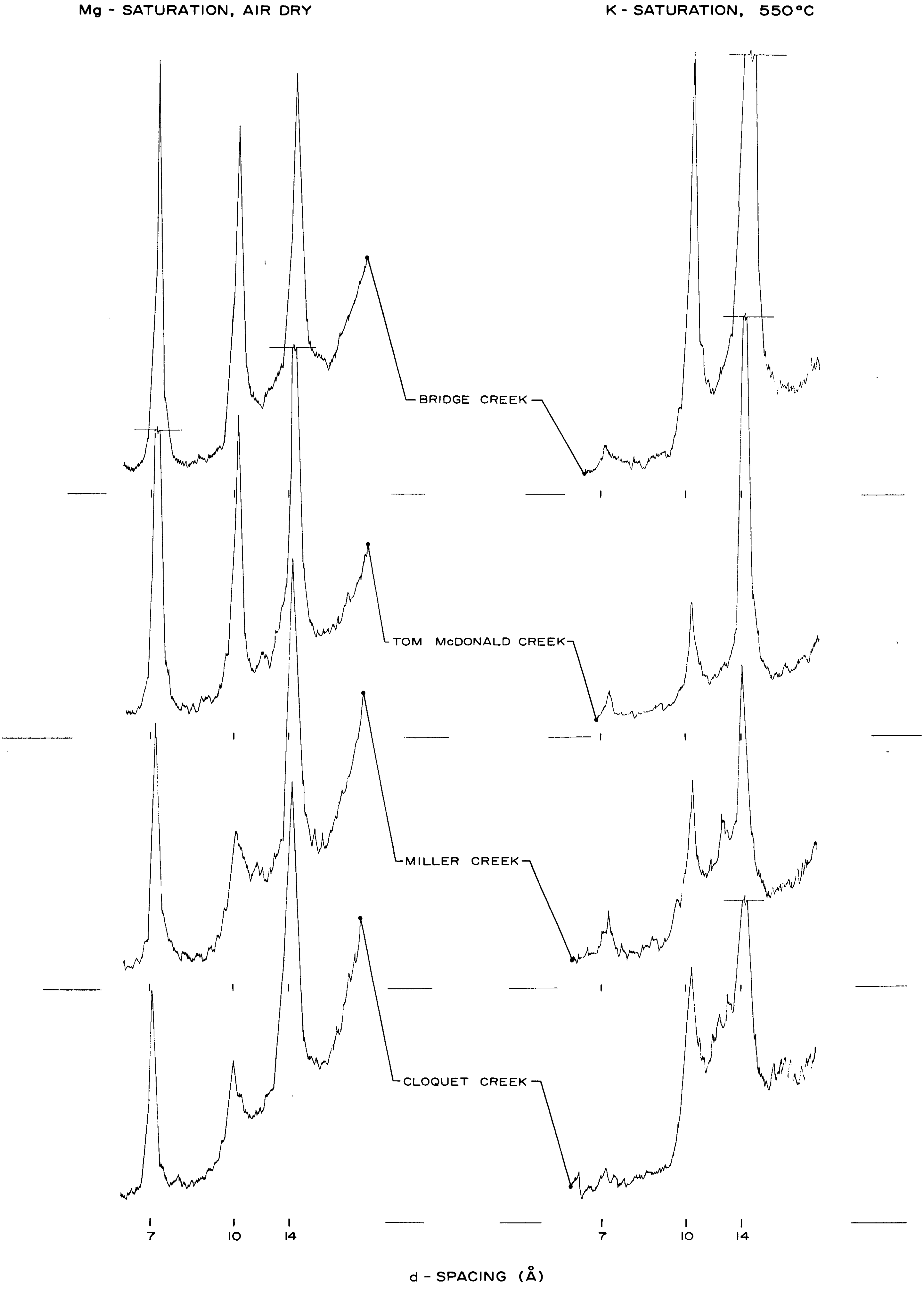


FIGURE 15

Samples	Chlorite	Chloritic Intergrade	10Å Mica	Paragonite	Vermiculite	Interstratified	Kaolin[2]
Redwood Cr. at Park	S		S				
Redwood Cr. at Orick	S		S	M			
Tributaries							
Panther Creek	S		S				
Coyote Creek	S		M[3]		W		
Copper Creek	S—M[3]		M[3]				
Weir Creek	S	M—W	M[3]				
Bridge Creek	S		S				
Tom McDonald Cr.	S		S				
Miller Cr.	S	M—W	M[3]				
Cloquet	S	M--W	M				

[1] S = strong; M = moderate; W = weak
[2] Kaolinite is possible but doubtful in all samples - see discussion
[3] Broader peak than many other samples

Sediments from the streambed of Redwood Creek (Table XI) were qualitatively the same as the suspended sediments obtained from water samples. The samples from a back eddy deposit above current logging operations is very similar to the sample downstream at the Redwood Valley Bridge. The coarse sample is qualitatively the same as the finer material although the peaks for the latter are less sharp and intense. This difference may be due to the effect of particle size and degree of crystallinity.

Samples obtained from slumps and slides gave strong lines for chlorite and mica (Table XI). There was little difference between slide samples and streambed or water samples (Figure 16).

TABLE XI

CLAY MINERALS IDENTIFIED FROM X-RAY DIFFRACTION PATTERNS OF SOIL AND GEOLOGIC SAMPLES[1]

Samples	Chlorite	Chloritic Intergrade	10Å Mica	Paragonite	Vermiculite	Interstratified	Kaolin[2]
Streambed Sediments							
3-2 Back eddy of Redwood Cr. above operations	S		S				

COMPARATIVE X-RAY DIFFRACTION PATTERNS

DEPICTING SIMILARITY BETWEEN SOURCE, TRANSPORTED AND DEPOSITED SEDIMENT MATERIAL

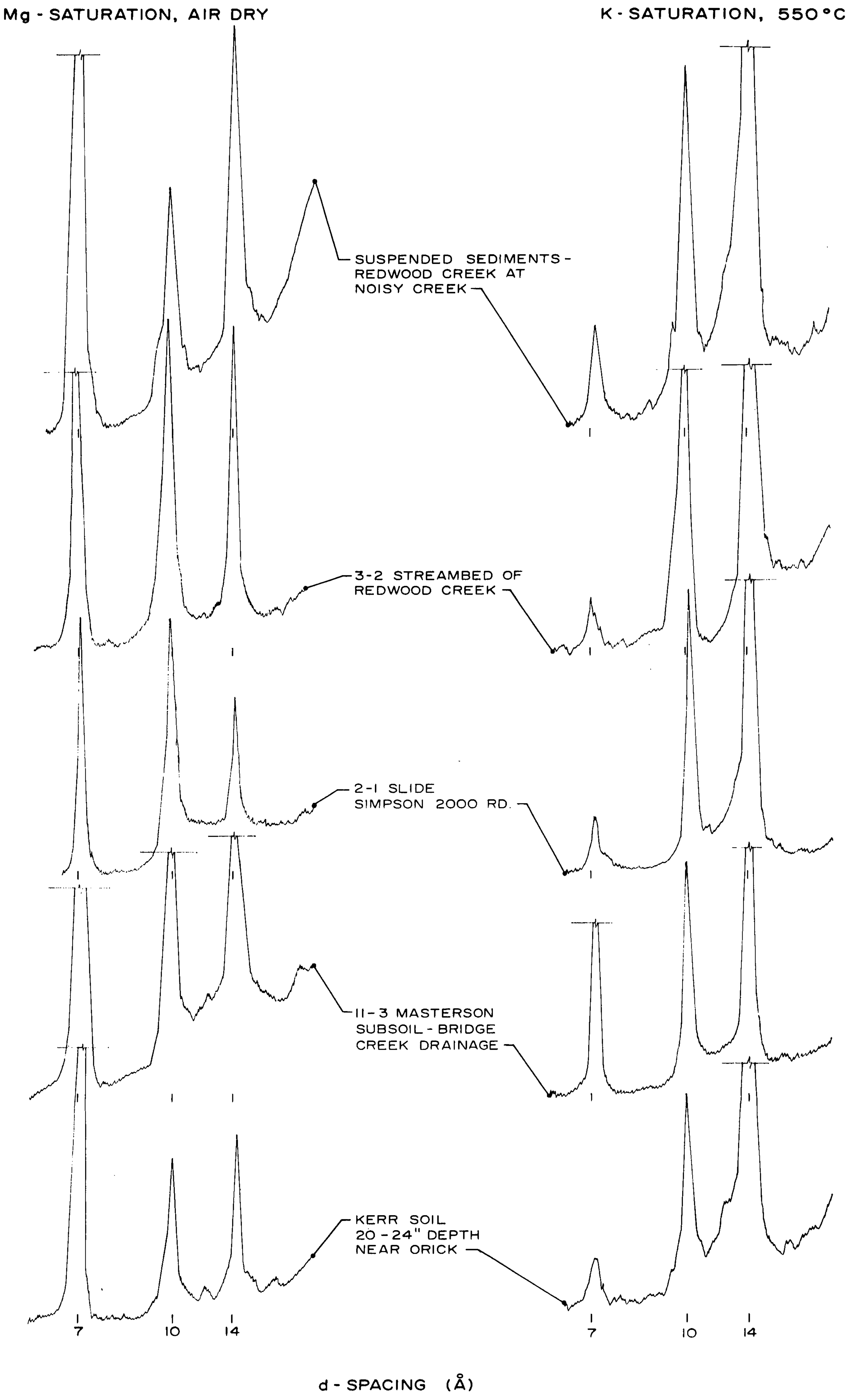


FIGURE 16

Samples	Chlorite	Chloritic Intergrade	10Å Mica	Paragonite	Vermiculite	Interstratified	Kaolin[2]
13-1 Streambed of Redwood Cr. at Redwood Valley Road - fine material	M		M	W			
13-2 Same as 13-1 except more coarse	S		S				
Slides and Slumps							
2-1 Simpson 2000 rd.	S		S				
3-1 Fluid portion of *Slide above Simpson* operation	S		M				
16-1 Slide on Redwood Valley Rd.	S		S				
11-Z Slump in C horizon Bridge Cr. Drainage	S		S				
Masterson Soil							
1-1 A3 Noisy Cr.	S	S	M	M		M	
1-2 B21 Noisy Cr. Drainage	S	M	S	S		M	
1-3 B22g Noisy Cr. Drainage	S	M—W	S	S		M	
11-1 B1 Bridge Cr. Drainage	S	M	M—W	W		W	
11-2 B21 Bridge Cr. Drainage	S	W	M—S				
11-3 B22 Bridge Cr. Drainage	S		S				
11-4 B3g Bridge Cr. Drainage	S		S				
Kerr Soil							
20-24" Near Orick	S		S				
Hugo Soil							
5-1 B2 Weir Cr. Drainage	M	M					
5-2 B3 Weir Cr. Drainage	M	M	W				
Orick Soil							
6-1 B21 Weir Cr.	S	M	W				
6-2 B22 Weir Cr. Drainage	S	W				W	
9-1 A3 McArthur Creek Drainage	W	M	W				

Samples			Chlorite	Chloritic Intergrade	10 Å Mica	Paragonite	Vermiculite	Interstratified	Kaolin[2]
9-2[3]	B21	McArthur Creek Drainage	M	M	W				
9-3	B22	McArthur Creek Drainage		W	W				W[4]
Kneeland Soils									
7-1	All	Weir Cr. Drainage	M—W	M—W	W				
7-2	C	Weir Cr. Drainage	M	M—W	M—W				
Atwell Soil									
8-1	A3	Copper Cr. Drainage	M—S					M	
8-2	B21g	Copper Cr. Drainage	M		W		M	M—W	
8-3	B22g	Copper Cr. Drainage	S				M—S	M—S	
15-1	B1	Stover Ranch	S		M		W	M	
15-2	B22g	Stover Ranch	M		M		S	M	
Sites Soil									
10-1	A3	Bridge Cr. Drainage	W	M					
10-2	B21	Bridge Cr. Drainage		M				M	W[4]
Yorkville Soil									
14-1	A3	Stover Ranch	M				M	M—W	
14-2	B22	Stover Ranch	W	M			M	M	

[1] S = strong; M = moderate; W = weak

[2] Kaolinite is possible but doubtful in all samples - see discussion

[3] Another portion which did not settle on centrifugation contained chlorite and amorphous materials

[4] Probably halloysite

Almost all of the soil samples examined contain chlorite, and micaceous components are fairly common. A number of samples contain chloritic intergrades. This is indicated by properties exhibited in response to K-saturation and heat treatments; properties are intermediate between chlorite and vermiculite. Interstratified (mixed-layer) systems occur in a number of cases. In the presence of chlorite, it is sometimes difficult to determine kaolinite because of overlapping diffraction lines. On the basis of X-ray data alone, one would have to recognize the possible presence of kaolinite. However, the characteristic shape of kaolinite particles was not observed in the electron micrographs (discussed later), so their presence in those samples is doubtful. X-ray diffraction tracings for soils and

COMPARATIVE X-RAY DIFFRACTION PATTERNS

FOR SOILS OF THE REDWOOD CREEK BASIN

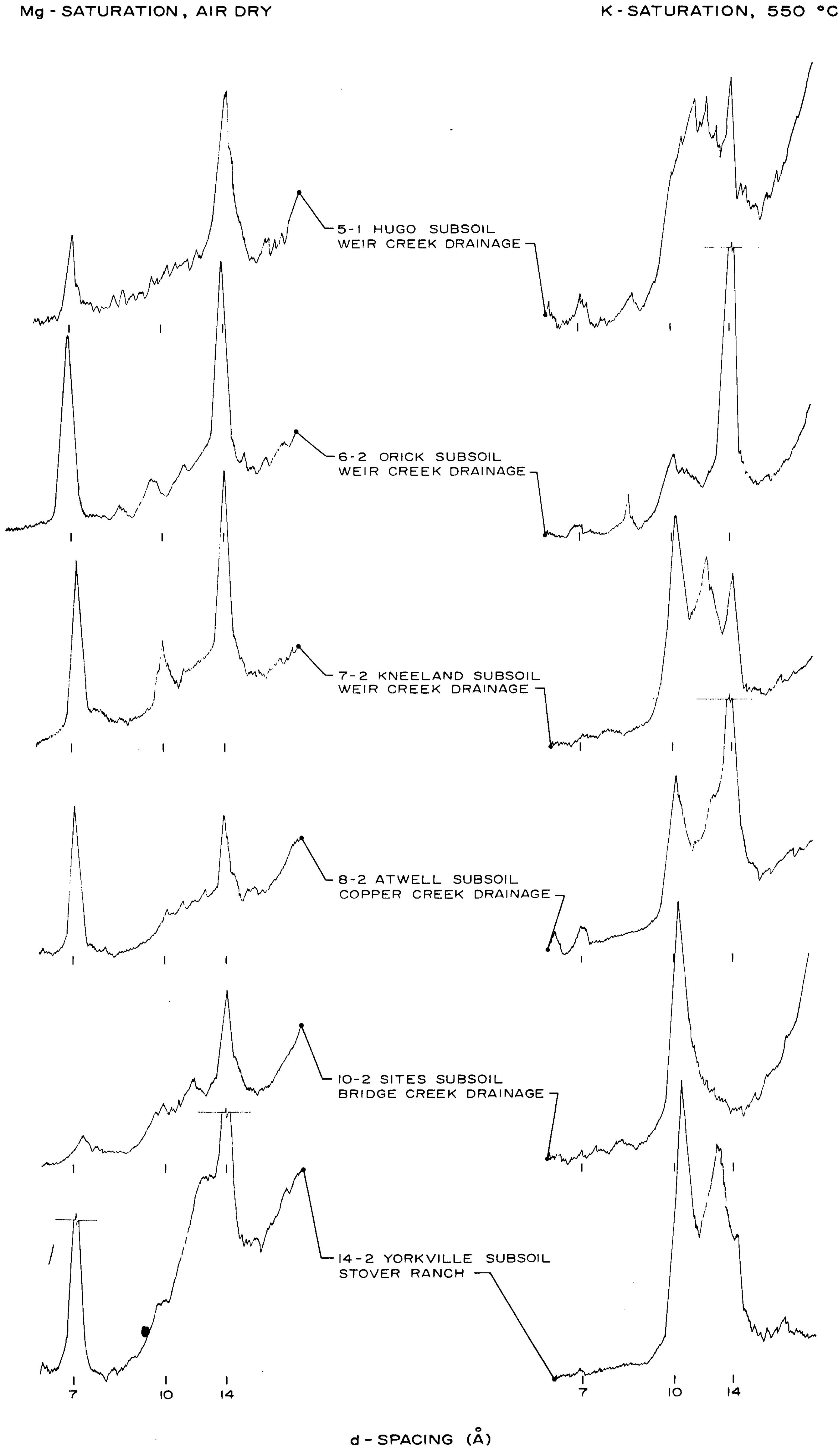


FIGURE 17

representative horizons of the soils found in the Redwood Creek Basin are shown in Figures 18 through 23 in Appendix B.

Some differences exist between horizon samples (depth) within a given soil as well as between soil series. Generally, the surface horizons tend to be more complex with respect to clay mineral suites. Peak intensities for chloritic intergrades decrease with depth; degree of crystallinity as indicated by shape and size of diffraction peaks increases with depth.

The X-ray diffraction patterns for some of the soil-slide samples and the suspended solids in the stream samples are qualitatively the same. Particularly striking is the similarity of samples from the Masterson sub-soil, the Kerr soil, slides, creek sediments, and suspended material from water samples. All contain strong lines for chlorite and strong to moderate lines for mica. Paragonite was observed in the Masterson samples, in a streambed sample, and in some of the water samples from Redwood Creek. It was not observed in other soil samples. The similarity of these samples is strikingly shown in Figure 16.

The X-ray data for other soil samples are generally different from the water and streambed samples. The Hugo soil exhibits only moderate peaks for chlorite and, significiantly, the lines for mica are weak or absent (Figure 17). The Orick samples also exhibit weak mica lines. The Atwell samples did not exhibit mica lines; they contained vermiculite and interstratified components which were not observed in the stream and sediment samples. The chlorite lines in the Sites samples were weak or absent. The Yorkville sample is similar to the Atwell in the presence of vermiculite. The difference between these soils and the sediments in Redwood Creek can be observed by comparing Figures 16 and 17.

Although there is some direct contribution of sediment from prairie areas, e.g. earth flow from a Yorkville soil moving directly into Minor Creek, the clay mineral data indicate their contribution is masked by the preponderance of material from the banks of Redwood Creek and its tributaries. Examination of the aerial photographs reveals that there are 43 prairie areas adjacent to or within 2,000 feet of Redwood Creek that are potential contributors of sediment. These prairies have soils developed from non-schist parent materials and their contribution during the sampling period is completely masked by the greater mass of material coming from schist materials.

The nature (intensity and shape) of the diffraction peaks themselves provide additional clues as to the sources of sediments in Redwood Creek. Intensities (counts per second for peaks minus background) for some of the characterization treatments are shown in Table XII. The amounts of specimen on the slides prepared for X-ray diffraction analysis were not controlled. The amount of suspended material separated from the water samples was sometimes limited so that different amounts of sample were exposed to the X-ray beam. Consequently, it would not be expected that the intensities of soil and "water" samples coincide. In spite of this, the correlation of slides of the Masterson and Kerr soils with sediments and suspended solids is striking. This is probably due to the overriding influence of degree of crystallinity of the samples. In orders of magnitude, the intensities of 14, 10 and 7 Å lines for the above samples are greater than those for other soil samples. The correlation is especially strong for the 14 Å chlorite lines after K-saturation and heating to 550° C.

TABLE XII

INTENSITIES (PEAK-BACKGROUND) OF X-RAY DIFFRACTION PEAKS AFTER CHARACTERIZATION TREATMENTS

	Mg - sat'n, dry air				K - sat'n 550°C
Sample	14Å	10Å	9.4Å	7Å	14Å
Suspended Solids from Redwood Creek					
W-1 Above Operation	150	96	60	500	408
Above confluence with Noisy Creek	268	172	50[2]	576	440
Chezem Bridge	784	448	136	1,552	640
Park Boundary	232	152		528	436
Orick	418	276	64[2]	162	264
Suspended Solids from Tributaries					
Panther Creek	166	134		488	260
Coyote Creek	192	100[1]		406	39
Copper Creek	108	50		188	292
Weir Creek	328	140		386	115
Bridge Creek	752	640		1,712	784
Tom McDonald Creek	236	150		552	204
Miller Creek	280	108		414	59
Cloquet Creek	448	176		336	67
Streambed Sediments					
3-2 Backeddy of Redwood Cr. above operations	124	134		390	1,008
13-1 Redwood Valley Road - fines	85	65	30	296	160
13-2 Redwood Valley Road - coarser	162	160		420	376
Slumps and Slides					
2-1 Masterson soil, Simpson 2000 Road	260	408		424	928
3-1 Redwood Creek above operations	73	54		340	476
11-Z Masterson C, Bridge Cr. Drainage	284	436		512	832
16-1 Redwood Valley Road	158	178		600	576
Masterson Soil					
1-1 A3 Noisy Creek Drainage	129	25	33	253	348
1-2 B21 Noisy Creek Drainage	168	160	127	716	528
1-3 B22 Noisy Creek Drainage	128	62	56	464	440
11-1 B1 Bridge Creek Drainage	344	38	28	522	392

	Mg - sat'n, dry air				K - sat'n 550°C
Sample	14Å	10Å	9.4Å	7Å	14Å
11-2 B21 Bridge Creek Drainage	234	91		612	764
11-3 B22 Bridge Creek Drainage	256	124		656	732
11-4 B3 Bridge Creek Drainage	280	304		624	652
Kerr Soil					
Sub-soil 20-24" Near Orick	67	62		240	224
Hugo Soil					
5-1 B2 Weir Creek Drainage	37	--		17	37[1]
5-2 B3 Weir Creek Drainage	75	24		47	41
Orick Soil					
6-1 B21 Weir Creek Drainage	92	11[1]		153	152
6-2 B22 Weir Creek Drainage	106	16		165	196
9-1 A3 McArthur Creek Drainage	204	--	9	11	---
9-2 B21 McArthur Creek Drainage	200		18	59	56
9-3 B22 McArthur Creek Drainage	22[1]	30[1]		36[1]	---
Kneeland Soil					
7-1 All Weir Creek Drainage	44	13		32	---[2]
7-2 C Weir Creek Drainage	91	32		78	---[2]
Atwell Soil					
8-1 A3 Copper Creek Drainage	27	12[2]		52	164
8-2 B21g Copper Creek Drainage	44	14[2]		66	119
8-3 B22g Copper Creek Drainage	181	64[2]		121	166
15-1 B1 Stover Ranch	242	116[2]		336	220
15-2 B21g Stover Ranch	236	102[2]		476	96[2]
Sites Soil					
10-1 A3 Bridge Creek Drainage	178	--		12	11
10-2 B21 Bridge Creek Drainage	52	16[2]		12	---
Yorkville Soil					
14-1 A3 Stover Ranch	103	---[2]		112	41
14-2 B22 Stover Ranch	130	25[2]		113	---[2]

---

[1] Broad

[2] Peak not entirely discrete

A further check on interpretations can be made by comparing intensities of various lines in a given sample with the same ratios for other samples. This minimizes differences due to amount of sample on the slide. Ratios of intensities were calculated for some of the patterns and are given in Table XIII. The ratios of the 10 Å mica line to the 14 Å chlorite line for slide, sediments and suspended solids of Redwood Creek and the subsoils of Masterson and Kerr soils are generally high, and, with the exception of one sample, range from about 0.48 to 1.57. With the exception of the Orick B22, which apparently represents a profile discontinuity, the 10/14 ratio for all of these other samples is less than 0.43 similarly, the ratio of the second order 7 Å to the first order 14 Å chlorite lines range from 1.5 to 4.6 for the Masterson, Kerr, slide, sediment, and Redwood Creek samples while the values for other samples range from 0.2 to 2.0.

TABLE XIII

RATIOS OF INTENSITIES OF X-RAY DIFFRACTION PEAKS AFTER CHARACTERIZATION TREATMENTS

	Mg - sat'n and air dry			After 550°C
Sample	10+/14+	9.4/14+	7+/14+	7+/14+
Suspended Solids from Redwood Creek				
W-1 Above operation	0.64	0.40	3.3	0.05
Above confluence of Noisy Creek	.64	[1]	2.15	.10
Chezem Bridge	.57	.17	1.98	.03
Park Boundary	.66		2.28	.03
Orick	.66	[1]	1.37	.05
Suspended Solids from Tributaries				
Panther Creek	.84		2.94	.05
Coyote Creek	.52[3]		2.11	----
Copper Creek	.46[3]		1.74	.03
Weir Creek	.43		1.18	.06
Bridge Creek	.85		2.28	.02
Tom McDonald Creek	.64		2.34	.06
Miller Creek	.39		1.48	.20
Cloquet Creek	.39		.75	.07[2]
Streambed Sediments				
3-2 Backeddy of Redwood Creek above operations	1.08		3.15	.02
13-1 At Redwood Valley Road "fine" material	.76	.35	3.48	.42
13-2 Same as 13-1 except more coarse	.99		2.59	.05
Slump and Slides				
2-1 Slump, Masterson Soil, Simpson 2000 Road	1.57		1.63	.10
3-1 Slide, fluid portion, above operation	.74		4.66	.03
11-Z Slump, Masterson Soil, Bridge Cr. Drainage	1.54		1.80	.06
16-1 Slide, Redwood Valley Road	1.13		3.80	.03

Sample	Mg - sat'n and air dry			After 550°C
	10+/14+	9.4/14+	7+/14+	7+/14+
Masterson Soil				
1-1 A3 Noisy Creek Drainage	.19	.26	1.96	.04
1-2 B21 Noisy Ceeek Drainage	.95	.76	4.26	.08
1-3 B22 Noisy Creek Drainage	.48	.44	3.63	.21
11-1 Bl Bridge Creek Drainage	.11	.08	1.52	.12
11-2 B21 Bridge Creek Drainage	.39		2.62	.08
11-3 B22 Bridge Creek Drainage	.48		2.56	.80
11-4 B3 Bridge Creek Drainage	1.09		2.23	.18
Kerr Soil				
Sub-soil 20-24" Depth, Near Orick	.93		3.58	.09
Hugo Soil				
5-1 B2 Weir Creek Drainage	----		.46	.19
5-2 B3 Weir Creek Drainage	.32		.63	----
Orick Soil				
6-1 B21 Weir Creek Drainage	.12[4]		1.66	.03
6-2 B22 Weir Creek Drainage	.15[4]		1.56	.03
9-1 A3 McArthur Creek Drainage	----	.04[2]	.05	----
9-2 B21 McArthur Creek Drainage		.09[2]	.30	.18
9-3 B22 McArthur Creek Drainage[4]	1.36		1.64	----
Kneeland Soil				
7-1 All Weir Creek Drainage	.34[4]		0.73	----
7-2 C Weir Creek Drainage	.35		.86	----
Atwell Soil				
8-1 A3 Copper Creek Drainage	.44[5]		1.94	----
8-2 B21g Copper Creek Drainage	.32[5]		1.50	.08
8-3 B22g Copper Creek Drainage	.35[5]		.67	----
15-1 B1 Stover Ranch	.48[5]		1.39	.04
15-2 B21g Stover Ranch	.43[5]		2.02	.08
Sites Soil				
10-1 A3 Bridge Creek Drainage	----		.07	----
10-2 B21 Bridge Creek Drainage	.31[5]		.23	----
Yorkville Soil				
14-1 A3 Stover Ranch	[1]		1.09	.1[2]
14-2 B22 Stover Ranch	.19[5]		.87	----

[1] No discrete peak; presence indicated by "shoulder"

[2] Increase above background is small

[3] Peak is broad rather than sharp

[4] Peak is small and broad

[5] No discrete 10 Å Peak; components interstratified

Chemical Composition of Selected Samples

It became possible during analysis to obtain estimates of relative chemical compositions of selected samples by use of a quantometer (Table XIV). Inspection of the data indicates that streambed sediments are most like the slide samples with respect to sodium, phosphorus, sulfur, and manganese. The Masterson sample is similar to the sediment and slide samples with respect to magnesium and potassium. It is possible to obtain a value which reflects the degree that one sample agrees with another by selecting one as a reference and expressing the composition of other samples relative to it. The data in Table XV were obtained by calculating the ratio of compositions of other samples relative to the sediments of Redwood Creek. In the ratios for each element, aluminum and silicon were omitted since their abundance exceeded the capabilities of the instrument without dilution. Sulfur and calcium were not included because of lack of good agreement between duplicate determinations of related samples. The values for all elements in a given sample were then averaged to obtain one figure which expresses the agreement with the sediment samples. Values near 1 indicate good agreement with stream bed sediments. The Masterson and slide samples correlate with the sediment sample better than the Hugo, Atwell or Orick samples.

TABLE XIV

CHEMICAL ABUNDANCES IN SAMPLES FROM REDWOOD CREEK DRAINAGE - VALUES RELATIVE TO BORIC ACID STANDARD. MEAN OF DUPLICATE DETERMINATIONS.

Sample	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Fe
13-1 Sediments from steambed of Redwood Cr. at Redwood Valley Rd. - fine material	6387	4886	4000	4000	2304	237	1259	953	495	500	2375
3-1 Fluid slide on Redwood Cr. above Simpson operation	4836	5424	4000	4000	2229	534	2431	536	590	531	3020
11-3 Masterson B22, Bridge Cr. Drainage	3710	5459	4000	4000	861	6	2465		598	282	3211
5-1 Hugo B2, Weir Creek Drainage	2096	2101	4000	4000	1444	80	744	122	490	186	2329
8-2 Atwell B21 Copper Creek Drainage	3883	3052	4000	4000	1471	29	1696	62	377	173	2562
9-2 Orick B21, McArthur Creek Drainage	2847	2157	4000	4000	647	69	441	427	700	129	3010

TABLE XV

CHEMICAL ABUNDANCES RELATIVE TO SEDIMENTS FROM STREAMBED OF REDWOOD CREEK (SAMPLE X/SAMPLE 13-1)

Sample	Na	Mg	P	K	Ti	Mn	Fe	Average
3-1 Fluid slide on Redwood Creek above Simpson operation	.76	1.11	.97	1.93	1.19	1.06	1.27	1.18

Sample		Na	Mg	P	K	Ti	Mn	Fe	Average
11-3	Masterson B22, Bridge Creek Drainage	.58	1.12	.37	1.96	1.21	.56	1.35	1.02
5-1	Hugo B2 Weir Creek Drainage	.3	.43	.63	.61	.99	.37	.98	.62
8-2	Atwell B21, Copper Creek Drainage	.61	.62	.64	1.35	.76	.35	1.08	.77
9-2	Orick B21, McArthur Creek Drainage	.45	.44	.28	.35	1.41	.26	1.27	.64

Electron Microphotographs

Selected samples were analyzed with a transmission electron microscope. The image enlargement of the particles range from 60,000 to 180,000 times, permitting an examination of particle sizes and shapes. Dr. Jones provided comments on the plates, and a large part of the following interpretation is his.

Samples 3-1 from the slide, 11-3 for Masterson subsoil, and 13-1 from the streambed of Redwood Creek exhibit similar morphologies (Photographs 1 through 3). The materials are generally crystalline and well ordered with thin mica-like sheets. Samples 3-1 and 13-1 both contain rod or lath shaped particles believed to be amphiboles, and fine grained material which may be clusters of amorphous silica. Samples 5-1 (Photograph 4) for the Hugo soil and 9-2 (Photograph 6) for the Orick are similar. Both exhibit rolling of thin sheets at the edges and on the surface of longer particles. The material in samples 5-1, 8-2 (Photograph 5) and 9-2 appear to be more heterogeneous than 3-1, 11-3, and 13-1. Sample 8-2 appears to be highly weathered and contains aggregates of smaller particles.

Photo 1. Photomicrograph from electron microscopic examination of sample 13-1, sediments from stream bed of Redwood Creek. Magnification 60,000 X.

Photo 2. Photomicrograph from electron microscopic examination of sample 3-1 fluid portion of slide above logging operations on Redwood Creek. Magnification 60,000 X.

Photo 3. Photomicrograph from electron microscopic examination of sample 11-3, Masterson B 22 horizon, Bridge Creek Drainage. Magnification 60,000 X.

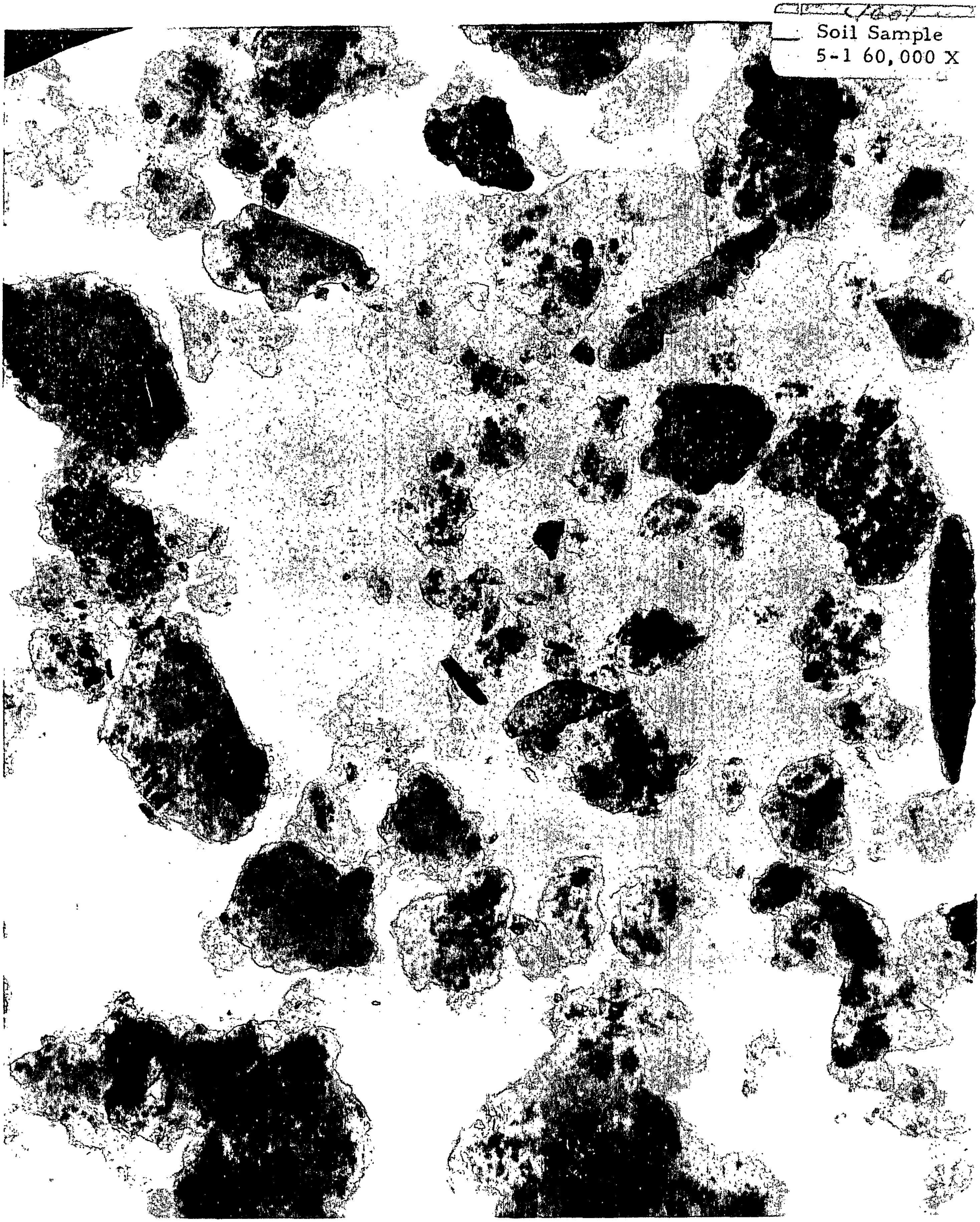


Photo 4. Photomicrograph from electron microscopic examination of sample 5-1, Hugo B 2 horizon, Weir Creek Drainage. Magnification 60,000 X.

Photo 5. Photomicrograph from electron microscopic examinations of sample 8-2, Atwell B 21 g horizon, Copper Creek Drainage. Magnification 60,000 X.

SLOPE STABILITY IN THE BASIN

The evidence presented in the clay mineralogy section indicates that the greatest mass of suspended sediment carried by Redwood Creek comes from bank-cutting of schistose material (parent material for Masterson soil) along Redwood Creek and major tributary streams. Table XVI summarizes the distribution of the dominant soils on the banks of the major tributaries as well as in the tributary watersheds. The X-ray diffraction patterns for the stream bank slides and the lower B and C horizons of the Masterson soils indicate that deep cutting accompanied by slope failures resulting in mass movement is a potential source of sediment. The Masterson soil has been observed to be especially unstable.

TABLE XVI

DOMINANT STREAM BANK AND WATERSHED SOILS IN REDWOOD CREEK TRIBUTARIES

Creek	Dominant Soils	
	Stream Bank	Watershed
McArthur	Orick	Orick
Elam	Orick	Orick
Cloquet	Orick, Hugo/s[1]/ Melbourne/s[1] /	Orick, Hugo/s, Hugo
Bond	Masterson	Orick, Masterson
Miller	Masterson, Hugo/s	Hugo/s, Hugo
Fortyfour	Masterson	Masterson, Orick
Tom McDonald	Masterson, Orick	Masterson, Orick
Weir	Masterson, Hugo/s Hugo	Hugo/s, Hugo Melbourne
Bridge	Masterson	Masterson, Orick
Copper	Atwell, Hugo	Hugo/s, Hugo, Tyson
Devils	Masterson	Masterson, Orick
Coyote	Masterson, Hugo/s	Hugo, Hugo/s, Tyson, Kneeland
Panther	Masterson	Masterson
Garrett	Atwell, Hugo	Atwell, Hugo, Yorkville
Lacks	Atwell, Hugo	Atwell, Hugo, Yorkville Sedimentary Colluvial land
Toss-up	Masterson	Masterson
Minor	Atwell, Hugo	Atwell, Hugo, Tyson, Yorkville, Kneeland
Lupton	Masterson	Masterson, Atwell
Noisy	Masterson, Sites	Masterson, Sites
High Prairie	Masterson	Masterson
Lake Prairie	Masterson	Masterson
Minon	Masterson, Hulls	Masterson, Tyson Tyson(s)[2],Hulls, Hugo

Photo 6. Photomicrograph from electron microscopic examination of sample 9-2, Orick B 21 horizon, McArthur Creek Drainage. Magnification 60,000 X.

Creek	Dominant Soils	
	Stream Bank	Watershed
Bradford	Hugo, Masterson	Hugo, Tyson, Masterson
Pardee	Masterson	Masterson
Twin Lakes	Hugo	Hugo

[1] Underlain by Kerr Ranch schist.

[2] Schist variant.

Slope stability is a function of geology, soil properties, slope, precipitation, vegetation and land management practices. Some soils tend to be naturally unstable with slope failures occurring in the absence of man's activities. Slope failures are generally more frequent during high intensity storms. The frequency of slope failures on these soils tends to increase when they are disturbed, especially by road building. Practices that alter drainage patterns cause changes in the frequency of slope failures. Undercutting of stream banks causing steepening of adjacent slopes also results in increased slope failure.

Slope failures are not normally confined to surface soils, but occur in subsoil or weathered parent materials. Thus, the properties of these materials, including texture, mineralogy, and moisture characteristics, play an important role. Perhaps the most important soil properties are the amount and kind of clay. The Franciscan materials generally weather to form materials that are more stable than materials weathered from Kerr Ranch schist. On steep topography, colluvium derived from Franciscan rock is sometimes underlain by schist. Since slope failures are generally deepseated, soils formed in Franciscan colluvium underlain by schist are more unstable than those over Franciscan rock. In this case, the failure is in the schist rather than in the Franciscan colluvium.

There are numerous faults and shear zones in the Redwood Creek Basin. Where the shear zones occur in Franciscan rock, the weathered materials are much higher in clay content than in non-shear zone areas, and the soils tend to be much more unstable.

The soils in the Redwood Creek Basin have been placed in four stability classes: very unstable, unstable, moderately stable, and stable. Appendix C outlines the characteristics of each of these stability classes and Appendix D classifies the pertinent soils into these stability ratings.

The soils in these classes have been delineated on Soil-Vegetation Map sheets. In reference to these maps, it should be noted that the black lines delineating the Kerr Ranch schist area are only approximate, having been "transferred" from general geology maps for the area. As a result, where Hugo and Melbourne mapping unit ratings are higher because these soils occur over schist, the higher rating is carried over the Kerr Ranch schist boundary. A miscellaneous land type, colluvial land of sedimentary rock material, designated 700 (cK), occurs in association with the Hugo soils in the Lacks Creek and Minor Creek drainages. It has been rated in the same stability class as the Hugo soil with which it is associated.

An examination of these maps and the summary of dominant soils in tributary watersheds (Table XVI) reveals that a very high proportion of the basin is mantled by unstable soils. Future road location, construction, drainage, and logging methods should be planned with this fact in mind. With the exception of the McArthur Creek and Elam Creek watersheds, all of the tributary watersheds have a high proportion of unstable soils. In the watersheds west of Redwood Creek, Masterson is the dominant series. On the east side, Atwell, Hugo underlain by schist, Yorkville, Kneeland, and Tyson accompany Masterson as the dominant unstable soils. Yorkville, Kneeland and Tyson are prairie soils. In the Lacks Creek and Minor Creek watersheds there are numerous areas mapped as colluvial land of sedimentary rock material. Although these areas have not been visited, the description of the unit suggests instability. Examination of aerial photos also indicates the instability of these units.

The only portion of the Basin that does not have a high proportion of unstable soils is the first two to three miles at the Headwaters.

CONCLUSIONS

Throughout the investigation, there were strong indications of a close relationship between the material in the slides and the sediments in Redwood Creek. Occurrence of clay minerals, intensities of individual diffraction peaks, relative chemical compositions, and the morphology of particles all indicate that the samples of sediments for Redwood Creek and the slide samples are alike. The slides occur throughout the length of the watershed and many extend down into the streambeds, and thus the slides are commonly undercut by the streams, particularly in flood situations. No difference could be found between the nature of sediments above logging operations and the material at the Park or Orick. Photo interpretation, observations on slide occurrence, and water quality measurements all indicate the importance of the upper watershed.

The Masterson soil, particularly the lower horizons (underlying materials), closely resembles the slides, suspended materials, and streambed sediments. The slides in the watershed of Redwood Creek occur most commonly on the Kerr Ranch Schists. This is also the parent material for the Masterson soils. The slides commonly occur on soils mapped as Masterson.

The clay materials in lower horizons of the Masterson soils correlate better with the stream sediments than do the upper horizons. This indicates that movement of materials into stream channels is not primarily surface or sheet erosion, but that the mechanism is more deep-seated and involves mass movement. Again, the importance of slides is indicated.

Soils other than the Masterson did not show strong correlations with the sediments in Redwood Creek. Some of the other soils which tend to be unstable could be contributors. However, the amounts are not sufficient to alter the X-ray diffraction patterns. This is undoubtedly due to the predominant influence of the slides.

The sample of the Kerr series near Orick represents a soil formed on alluvial materials from Redwood Creek. The sample from the 20-24" depth exhibited X-ray diffraction patterns essentially identical with the sediments and the slides. The Kerr soil has formed over a considerable period of time. It is a reasonable assumption that the material at the 20-24" depth was deposited prior to settlement and cultural activities in the area. This indicates the importance of phenomena involving unstable landscapes which have been occurring since before man's activity in the Basin.

DISCUSSION OF FINDINGS

The Redwood Creek Basin in a large drainage. The subdrainages within the Basin are unique, and extrapolating data from one subdrainage to another without knowledge of the specific drainage characteristics could be very misleading. Management decisions based upon extrapolated or assumed data could lead to either unfortunate environmental results on the one hand, or to unwarranted restrictions being placed on timber harvesting practices on the other hand. The opportunities for classical whole-watershed studies are limited due to the complex logging history of the Redwood Creek Basin. Where uncut timber stands occur, geologic and soil characteristics of subbasins differ significantly. The opportunity for necessary watershed calibration periods is not available.

Because of the complex natural matrix of unstable landscapes and the history of land use in the Basin, it is difficult to assess the impact of man's activities on mass soil movement and stream bank slides. Current activities such as timber harvesting and grazing combine to render difficult any quantitative, objective comparison of the sediment generation, e.g., a comparison of harvested and unharvested areas or of various timber harvesting methods.

Because of these difficulties, this study has concentrated on methods which allow a comparison of the relative sediment contributions of different parts of the Basin. Specific research conclusions are as follows:

1. Suspended sediment samples in Redwood Creek well above timber harvesting activity were mineralogically the same as samples taken near the mouth of Redwood Creek at Orick.

2. X-ray diffraction patterns for suspended sediment, streambed sediment, slides along Redwood Creek, and deposited flood plain soil near Orick are essentially the same. All of them contain well-crystallized mica and chlorite.

3. The subsoil of the Masterson soil has mineralogy like the stream sediment and slides. The slides have developed predominantly on the Kerr Ranch schist. Kerr Ranch schist is also the parent material for the Masterson soil. The predominant soil adjacent to Redwood Creek and its tributaries is also Masterson.

4. The mineralogy of surface horizons of the Masterson soil is different from the suspended and deposited sediment found in Redwood Creek. The similarity of the Redwood Creek sediment to the subsoil and not the topsoil suggests that the dominant geomorphic processes are deep-seated, occurring in the soil parent material rather than in the solum.

5. Other representative soils of the Redwood Creek watershed have clay mineral suites which differ from the slide and sediment material. Although these soils could contribute to the sediment load of Redwood Creek, the amounts are not sufficient to be detected in the presence of the predominant suite of chlorite and mica from the Masterson subsoil.

6. The clay mineralogy of sediment being transported by Redwood Creek at the present time does not differ significantly from sediment deposited at depths in the flood plain near Orick, indicating deposition prior to man's activity in the Basin. Geomorphic processes and sediment sources appear to have been similar through at least the last several hundred years. The same processes will continue in the future regardless of the changes in the land management of the watershed.

7. The amounts of suspended sediment in upper Redwood Creek (well above current timber harvesting operations) are in the same orders of magnitude as in the lower portions of the stream. The upper watershed is a significant source of sediment.

8. The contribution of sediment from individual tributary streams is insignificant compared to the load carried by Redwood Creek.

9. The upper watershed is undergoing stream bank cutting and channel scour while a large section of the stream in and near the Redwood National Park is undergoing deposition, particularly that area through the Tall Trees Flat. This appears to be in response to the stream gradient.

10. Based upon sediment composition and the number and location of slides, mass movement phenomena represent the dominant geomorphic response to processes within the Redwood Creek Basin. Stream-side slides are the principal source of sediment within the Basin.

11. Owing to the general occurrence of erodible slide materials along Redwood Creek and its tributaries, sediment influx to the Creek is not readily attributable to point sources, either in terms of specific slide locations or tributary input.

Examination of the soil-vegetation maps and the clay mineral data definitely indicates that bank cutting on Redwood Creek and the majority of the tributary streams is the main contributor to the sediment in Redwood Creek. These natural geomorphic processes within the Basin emphasize the need for well planned land management practices. The companies operating within the basin must assess the comparative erodibility of projected harvesting areas and continually monitor their actions in order to minimize their operational impact upon the Basin.

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APPENDIX A

Vermiculite

Mg-sat'n; 54% R.H.	14.3 Å
Mg-sat'n; solvation with ethylene glycol does not result in expansion to more than mono-interlayer complex	14.1 Å
K-sat'n; 105 C; Dry Air	10.3 Å
K-sat'n; 54% R.H.	10.4 Å

A small 14 Å line may also be observed on hydration, particularly for vermiculites with lower charge. Both the 10 and 14 Å components are integral.

K-sat'n; 500°C; Dry Air	10 Å

Chlorite

14 Å spacing does not vary with ethylene solvation or K-saturation and heating. The intensity of the first order line intensifies and the second order decreases or is lost after heating to 550°C.

Chloritic Intergrades

Properties are intermediate between chlorite and vermiculite or smectite. The predominant feature is resistance to collapse upon K-saturation and heating. As amount and stability of hydroxy-interlayers increases, the lattice is more difficult to collapse. Samples toward the chlorite end of the spectrum may also exhibit resistance to expansion upon solvation.

Micaceous

Presence of 7.2-7.5 Å component regardless of saturating cation, humidity or solvation. Well crystallized kaolinite has 001 spacings of 7.15 Å with sharp peaks. Halloysite (metahalloysite) exhibits spacings on 7.2-7.5 Å which may expand slightly on rehydration or solvation; the peaks are normally broader than for kaolinite.

In the presence of chlorite and chloritic intergrades, possible confusion between the second order chlorite line and first order kaolin should be recognized.

APPENDIX B

The following Figures, 18 through 23, are X-ray diffraction tracings for soils and representative horizons of the soils found in the Redwood Creek Basin.

MASTERSON SOIL

BRIDGE CREEK DRAINAGE

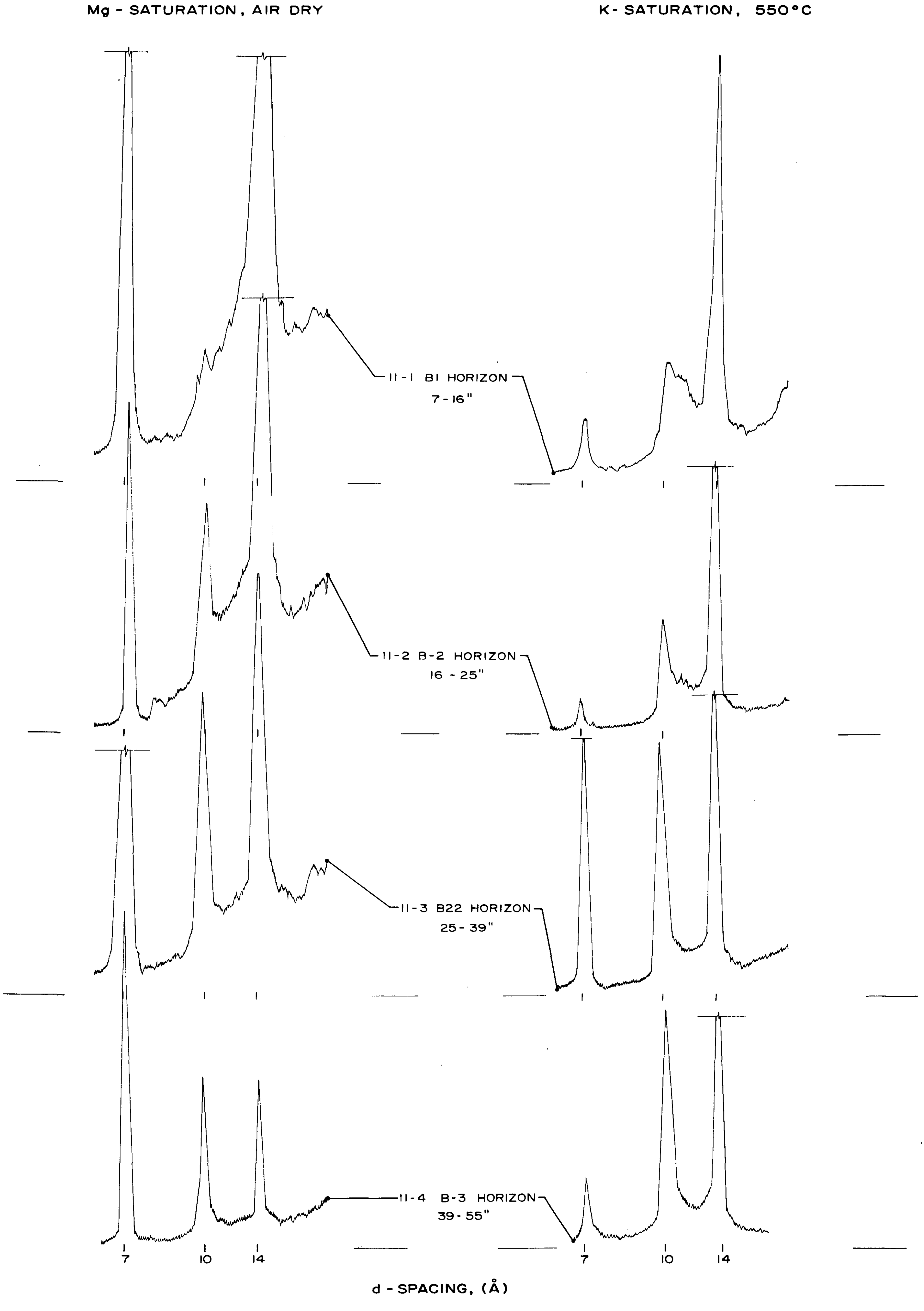

FIGURE 18

MASTERSON SOIL

NOISY CREEK DRAINAGE

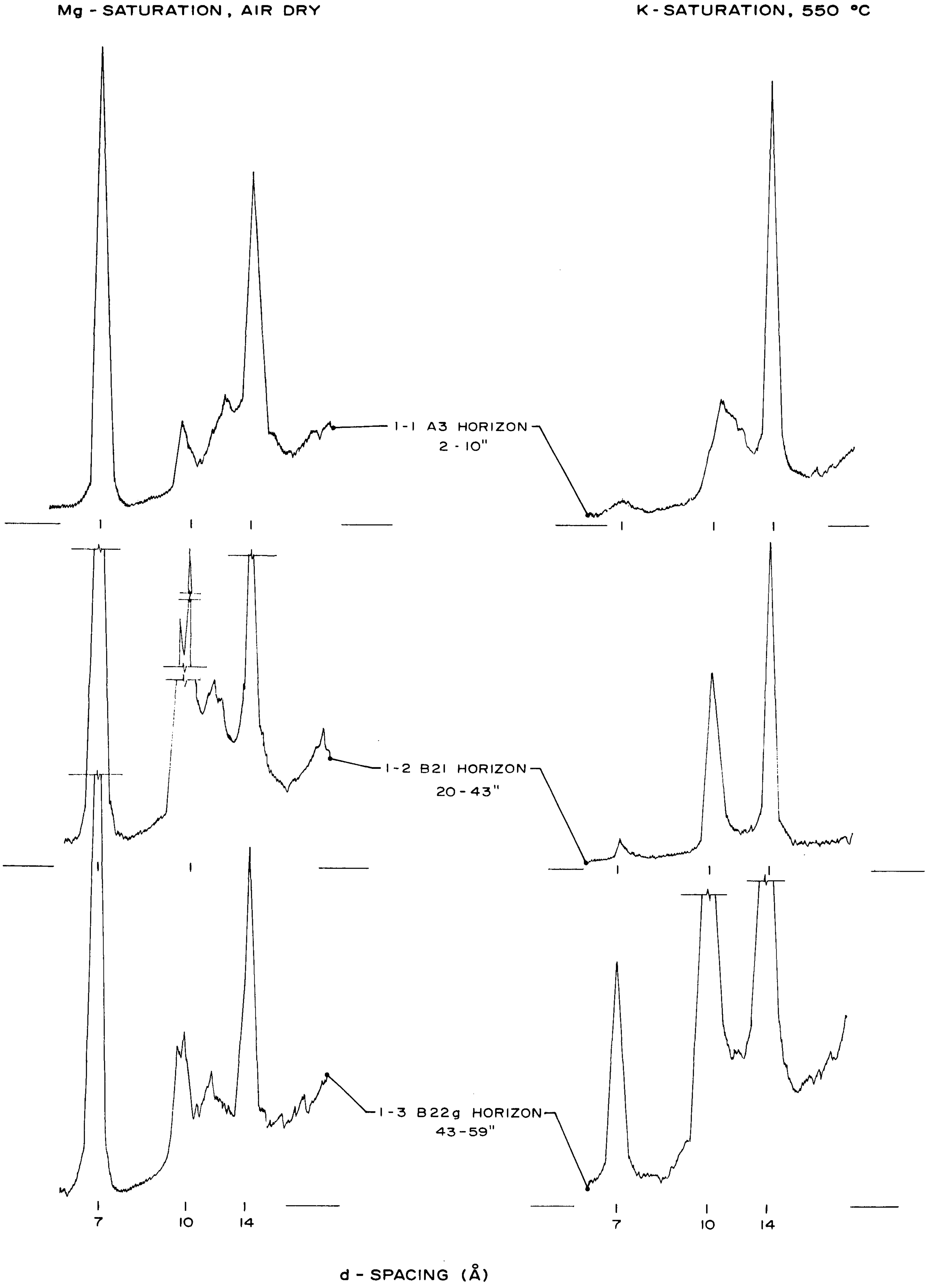

FIGURE 19

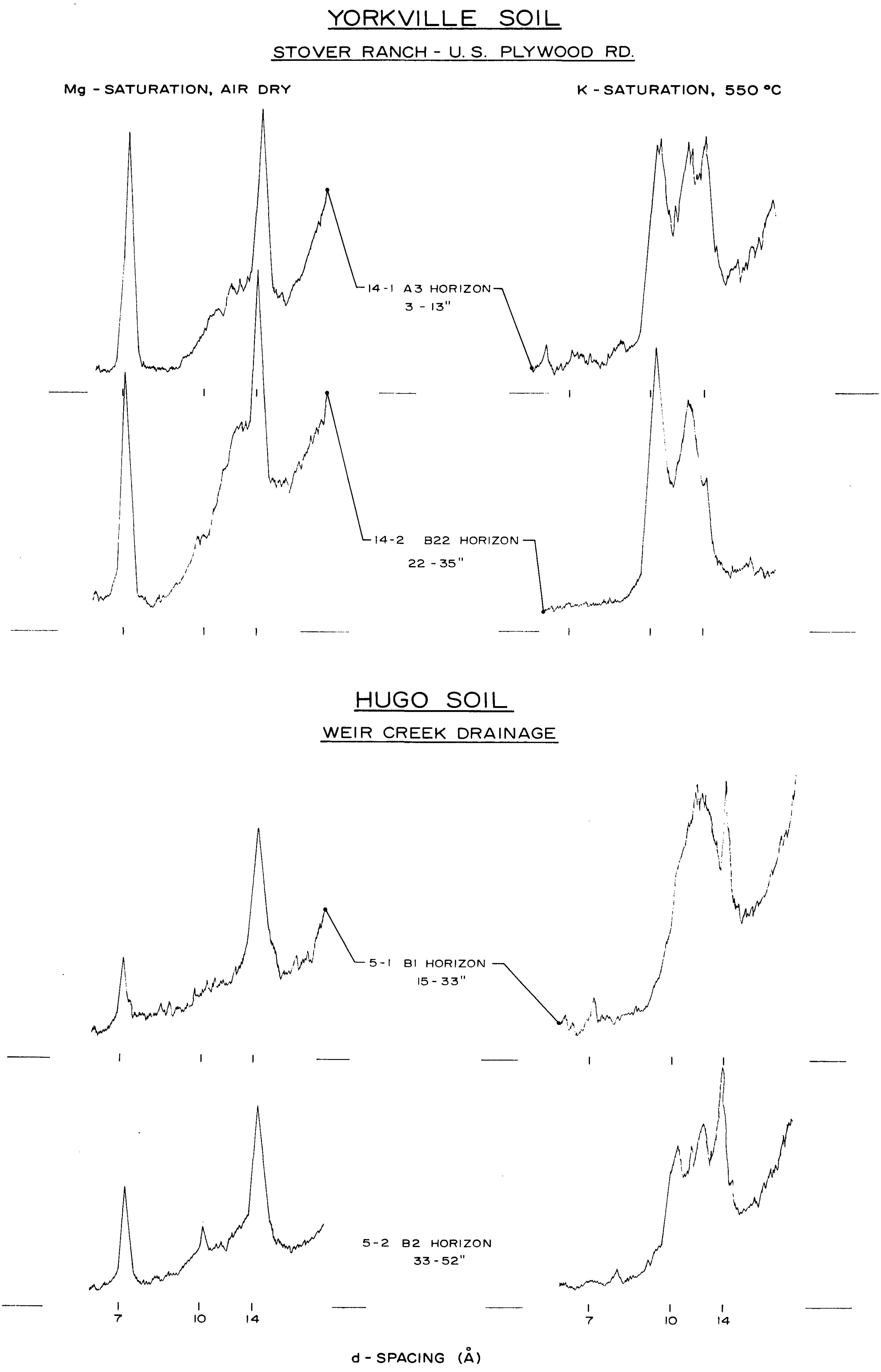
YORKVILLE SOIL
STOVER RANCH - U. S. PLYWOOD RD.
Mg - SATURATION, AIR DRY
K - SATURATION, 550 °C
14-1 A3 HORIZON
3 - 13"
14-2 B22 HORIZON
22 - 35"
HUGO SOIL
WEIR CREEK DRAINAGE
5-1 B1 HORIZON
15 - 33"
5-2 B2 HORIZON
33 - 52"
7
10
14
7
10
14
d - SPACING (Å)

FIGURE 20

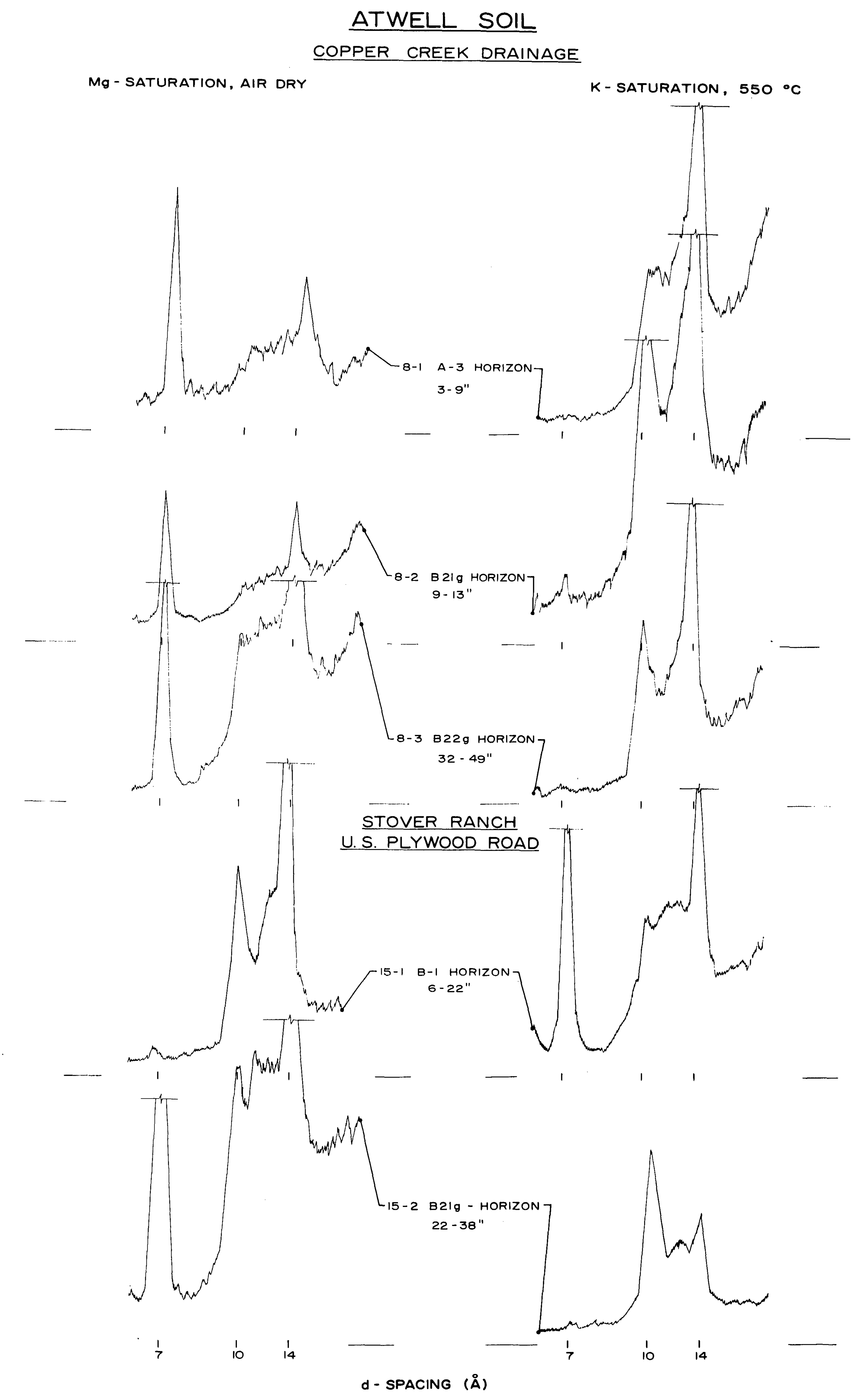
ATWELL SOIL
COPPER CREEK DRAINAGE
Mg - SATURATION, AIR DRY
K - SATURATION, 550 °C
8-1 A-3 HORIZON
3-9"
8-2 B21g HORIZON
9-13"
8-3 B22g HORIZON
32 - 49"
STOVER RANCH
U. S. PLYWOOD ROAD
15-1 B-1 HORIZON
6-22"
15-2 B21g - HORIZON
22-38"
7
10
14
7
10
14
d - SPACING (Å)

FIGURE 21

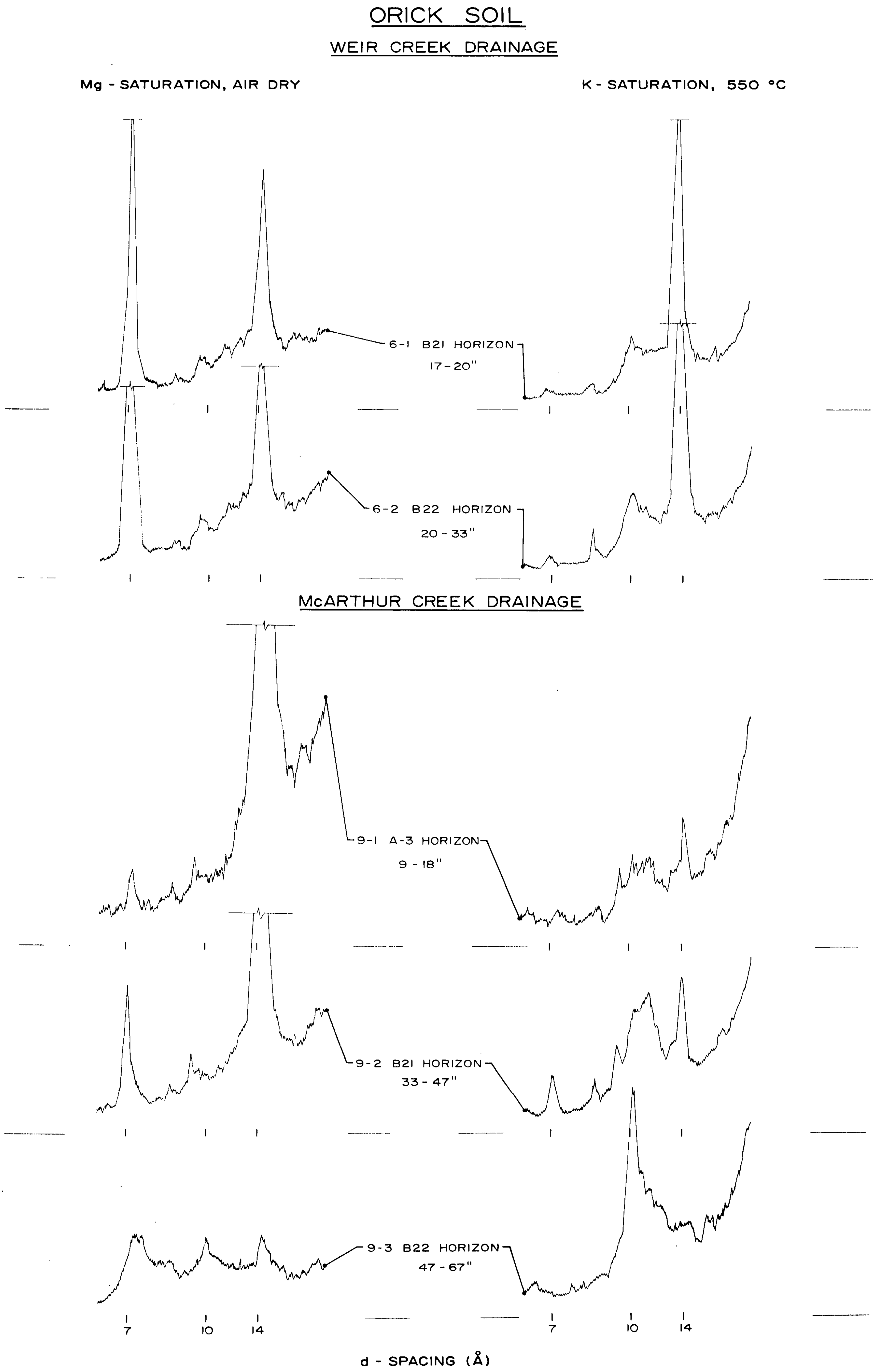
ORICK SOIL
WEIR CREEK DRAINAGE
Mg - SATURATION, AIR DRY
K - SATURATION, 550 °C
6-1 B21 HORIZON
17-20"
6-2 B22 HORIZON
20 - 33"
McARTHUR CREEK DRAINAGE
9-1 A-3 HORIZON
9 - 18"
9-2 B21 HORIZON
33 - 47"
9-3 B22 HORIZON
47 - 67"
7
10
14
7
10
14
d - SPACING (Å)

FIGURE 22

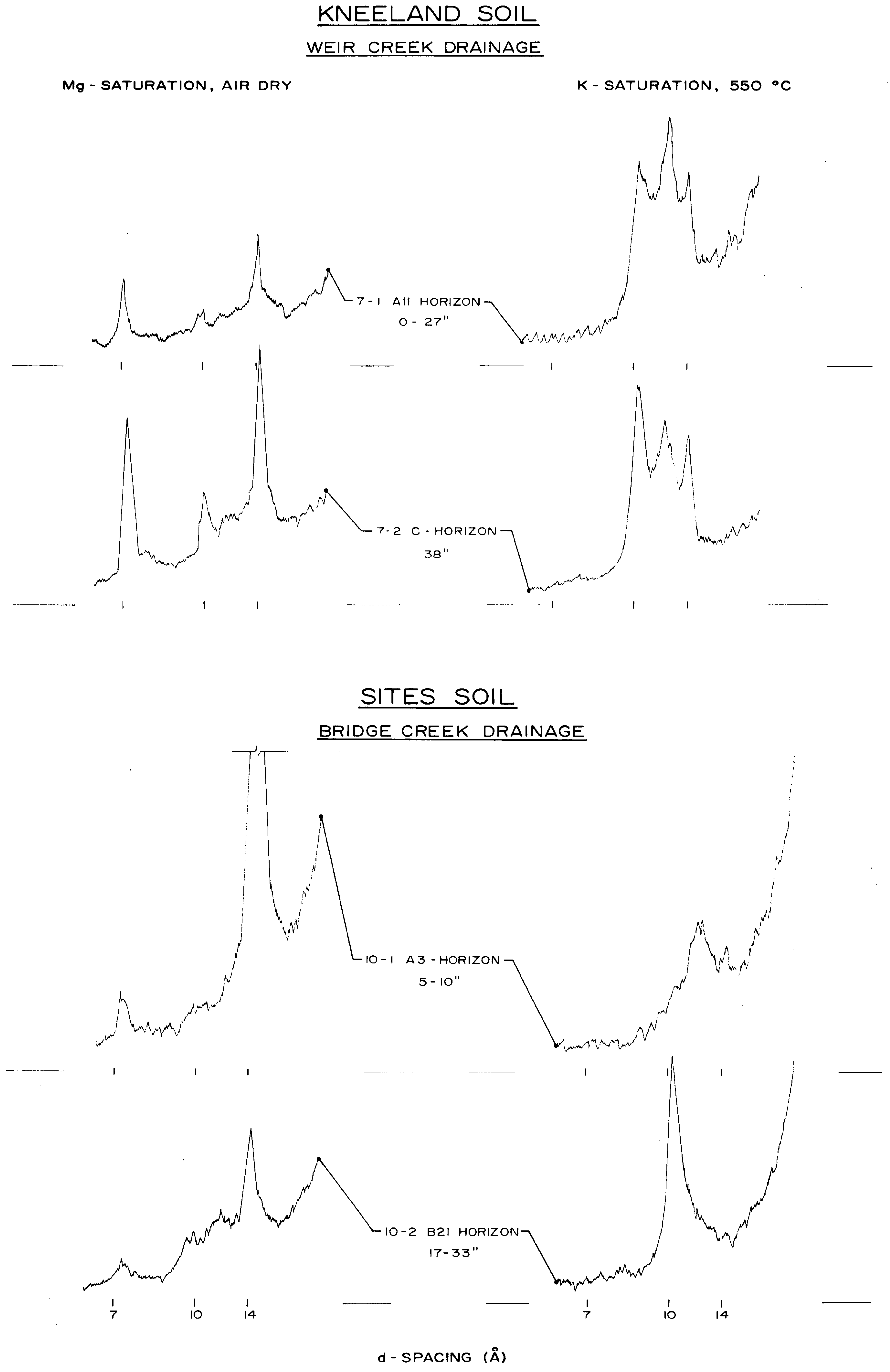
KNEELAND SOIL
WEIR CREEK DRAINAGE
Mg - SATURATION, AIR DRY
K - SATURATION, 550 °C
7-1 A11 HORIZON
0- 27"
7-2 C - HORIZON
38"
SITES SOIL
BRIDGE CREEK DRAINAGE
10-1 A3 - HORIZON
5-10"
10-2 B21 HORIZON
17-33"
7
10
14
7
10
14
d - SPACING (Å)

FIGURE 23

APPENDIX C

SLOPE STABILITY CLASSES

Very Unstable — These are areas in which mass movement in the form of slumps, slides, slip-outs and earth flows occurs frequently. They are characterized by uneven hummocky surfaces and headwall and bench topography. Undercutting of stream banks during storm events is very common. Trees are pistol-butted and often lean in random directions. Surface seepage is common and is indicated by the presence of rushes and horsetail in open areas and by heavy stands of alder after logging. Cutbank and fill failures along roads are very frequent. Included in this class are soils on slopes greater than 30% which have developed on schistose parent materials (Kerr Ranch schist), except Orick and Sites. In addition, Hugo and Melbourne soils which have developed in Franciscan sandstone colluvium but are underlain by Kerr Ranch schist and occur on slopes over 50%, are included in this class. The approximate boundaries of the Kerr Ranch schist are outlined on the Soil-Vegetation maps. Where there is only one line, the Kerr Ranch schist occurs west of the line except on Map sheets 10D-1 and 26B-2 where the line is the west boundary.

Unstable — These are areas where mass movement in the form of slumps, slides, slip-outs and earth flows occasionally occurs. Uneven and hummocky surfaces are present but are less common than in the very unstable areas and there is also less pistol-butting and random leaning of trees. Surface seepage is generally confined to toe slope positions. Undercutting of stream banks during storm events is common. Man's activity increases the frequency of mass soil movement through road-cutbank-and-fill failures, especially on the soils on steep slopes. Soils included in this class are those on slopes in the 0-30% slope class that have developed on schistose parent materials, except Orick and Sites. Also included are Hugo and Melbourne on 30-50% slopes if they are underlain by Kerr Ranch schist.

Moderately Stable — These are areas where some mass movement has occurred in the past but fresh or recent slope failures are infrequent. Slopes are generally smooth, trees are generally straight and not pistol-butted. Stream bank undercutting during storm events is infrequent. Few cutbank and road failures occur on these areas and where they do it is usually on the soil units on slopes greater than 50%. Soils included in this class are generally those on slopes less than 50% (except Hugo, Melbourne, Mendocino and Laughlin 50-70%).

Stable — These are areas where slope failures have been very infrequent and the chance of cutbank and road fill failures are very slight. Slopes are gentle (usually less than 30%) and smooth. Trees are straight and not pistol-butted. The only soils on slopes greater than 30% included in this class are Hugo, Melbourne and Laughlin.

APPENDIX D

RATING OF SOILS IN SLOPE STABILITY CLASSES

VERY UNSTABLE

Yorkville $\frac{752}{-2}$, $\frac{752}{-3}$[1]

Hugo $\frac{812}{-3}$, $\frac{812}{-4}$ (where underlain by Kerr Ranch Schist)[2]

Hugo (schist) $\frac{812m}{-2}$, $\frac{812m}{-3}$

Orick $\frac{813}{-4}$

Melbourne $\frac{814}{-3}$, $\frac{814}{-4}$ (where underlain by Kerr Ranch schist)[2]

Josephine (schist) $\frac{815m}{-2}$

Unnamed $\frac{81Y}{-2}$

Masterson $\frac{821}{-2}$, $\frac{821}{-3}$, $\frac{821}{-4}$

Atwell $\frac{823}{-2}$, $\frac{823}{-3}$, $\frac{823}{-4}$

Atwell (schist) $\frac{823m}{-2}$, $\frac{823m}{-3}$

Hulls $\frac{834}{-2}$

Kneeland $\frac{835}{-3}$

McMahon $\frac{839}{-2}$, $\frac{839}{-3}$

Wilder (schist) $\frac{840m}{-2}$, $\frac{840m}{-3}$

Laughlin (schist) $\frac{847m}{-2}$

Tyson $\frac{849}{-4}$

Tyson $\frac{849}{-2}$, $\frac{849}{-3}$ (where underlain by Kerr Ranch schist)

Tyson (schist) $\frac{849m}{-2}$, $\frac{849m}{-3}$

Larabee $\frac{914}{-3}$

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[1] 823 - Series designator
—2 - Slope designator
Slope Classes - 1—0 = 30%
2—3 = 50%
3—5 = 70%
4 > 70%

Variants designated by "V" in numerator included in same class.

[2] Outlined in black line boundaries on S-V maps.

UNSTABLE

Yorkville $\frac{752}{-1}$

Hugo $\frac{812}{-4}$

Hugo $\frac{812}{-2}$ **(where underlain by Kerr Ranch schist)**

Hugo (schist) $\frac{812m}{-1}$

Orick $\frac{813}{-3}$

Melbourne $\frac{814}{-4}$

Melbourne $\frac{814}{-2}$ **(where underlain by Kerr Ranch schist)**

Josephine $\frac{815}{-3}$

Josephine (schist) $\frac{815m}{-1}$

Masterson $\frac{821}{-1}$

Atwell $\frac{823}{-1}$

Atwell (schist) $\frac{823m}{-1}$

Unnamed $\frac{81Y}{-1}$

Hulls $\frac{834}{-1}$

Kneeland $\frac{835}{-2}$

McMahon $\frac{839}{-1}$

Wilder $\frac{840}{-3}$

Wilder (schist) $\frac{840m}{-1}$

Laughlin (schist) $\frac{847m}{-1}$

Tyson $\frac{849}{-3}$

Tyson $\frac{849}{-1}$ **(where underlain by Kerr Ranch schist)**

Kinman $\frac{855}{-2}$

Larabee $\frac{914}{-2}$

MODERATELY STABLE

Hugo $\frac{812}{-3}$

Orick $\frac{813}{-2}$

Melbourne $\frac{814}{-3}$

Josephine $\frac{815}{-2}$

Sites $\frac{816}{-2}$

Kneeland $\frac{835}{-1}$

Wilder $\frac{840}{-2}$

Laughlin $\frac{847}{-2}$, $\frac{847}{-3}$

Tyson $\frac{849}{-2}$

Kinman $\frac{855}{-1}$

Larabee $\frac{914}{-1}$

Mendocino $\frac{915}{-2}$, $\frac{915}{-3}$