MAGNITUDE AND FREQUENCY
OF
SEDIMENT TRANSPORT
IN
THREE NORTHERN CALIFORNIA COASTAL STREAMS

by

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ABSTRACT

The relative effectiveness in geomorphic processes of a discharge event with given magnitude and frequency can be measured in terms of the relative amounts of "work" done on the landscape. The amount of suspended sediment transported out of a basin by various discharges serves as a quantifiable measure of the relative "work". The relationship between magnitude and frequency of sediment transport was determined from records of five gaging stations on Eel River, Mad River, and Redwood Creek, north coastal California.

At the five stations, 50 percent of the total suspended sediment load was transported below flows which are equalled or exceeded an average of 1.9 days per year. Ninety percent of the total suspended sediment load was transported below flows that are equalled or exceeded an average of one day every 12.5 years. The highest one percent of flows transport an average of 61 percent of the total suspended load, while the highest 10 percent of flows transport an average of 92 percent. The data indicate that infrequent flows accomplish a majority of the geomorphic "work" in these basins.

Infrequent flows transport a greater percentage of total suspended load when compared to other studies. The highly skewed, kurtotic distributions of streamflow of the study streams contribute to the effectiveness of infrequent flows. Results also suggest that, for a given combination of climate and terrain, the most effective channel shaping event is associated with the most efffective sediment transporting event.

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INTRODUCTION

Problem Description

The concept of magnitude and frequency of forces in geomorphic processes was first considered by Wolman and Miller (1960). These authors proposed that the relative effectiveness of an event, in terms of work done on a landscape, is a function of an event's magnitude and frequency. By combining flow-duration curves with sediment transport curves, Wolman and Miller were able to determine the percentage of the suspended sediment load carried by flows of various magnitudes. Data from Brandywine Creek in Pennsylvania and the Rio Puerco in New Mexico indicated that 50 percent of the total suspended load was transported below flows which occur, on the average, one day or more per year (Table 1, column 4). Ninety percent of the sediment transported out of the basins was moved by flows which recur at least once every five years (Table 1, column 6). For these two streams, the authors concluded that the greatest portion of the total suspended load during the period of record was carried by small to moderate flows and not by catastrophic floods.

As flow variability increases, a larger

Table 1. Percentage of Suspended Sediment Transported by Flows of Different Magnitudes (from Wolman and Miller, 1960).

(1)	Distribution Measure of Flow used in Analysis (2)	Magnitude of Flow below Which 50 Per Cent of Total Sediment is Transported (3)	Frequency of Occurrence of Flow in Col. 3 (4)	Magnitude of Flow below Which 90 Per Cent of Total Sediment is Transported (5)	Frequency of Occurrence of Flow in Col. 5 (Per Year) (6)
Rio Puerco, near Bernardo, N.M.	Daily discharge, Duration curve	950 CFS	Equalled or exceeded 6 days/year	3,400 CFS	0.7 days
Brandywine Creek, at Willmington, Del.	"	1,900 CFS	Equalled or exceeded 11 days/year	8,200 CFS	0.2 days

percentage of the total suspended load is more likely to be transported by infrequent events. However, Wolman and Miller concluded that even for many small streams with variable flow, a large percentage of the total suspended load is carried by flows which recur at least once every five years. These arguments were restated and the methodology explained in greater detail by Leopold, Wolman, and Miller (1964). They concluded that if sediment discharge is used as a measure of work done on a landscape, the data iindicate that a large proportion of the work is done by relatively frequent events of moderate magnitude. This is considered the "geomorphic work principle" (Baker, 1977) of Wolman and Miller.

The concept that the maximum work on a landscape, in terms of sediment transport, occurs at a moderate range of flows can be conceptualized using the example of river mechanics (Wolman and Miller, 1960; Leopold, Wolman, and Miller, 1964; Baker, 1977; Andrews, 1980). Using this example, the magnitude of an event is represented by the sediment transport rate, which varies with discharge (Curve A, Figure 1). The frequency of an event is represented by the distribution of streamflow (Curve B, Figure 1). The overall effectiveness of a given discharge is represented by the product of the magnitude and frequency curves (Curve C, Figure 1). For equal periods, low magnitude flows transport very little

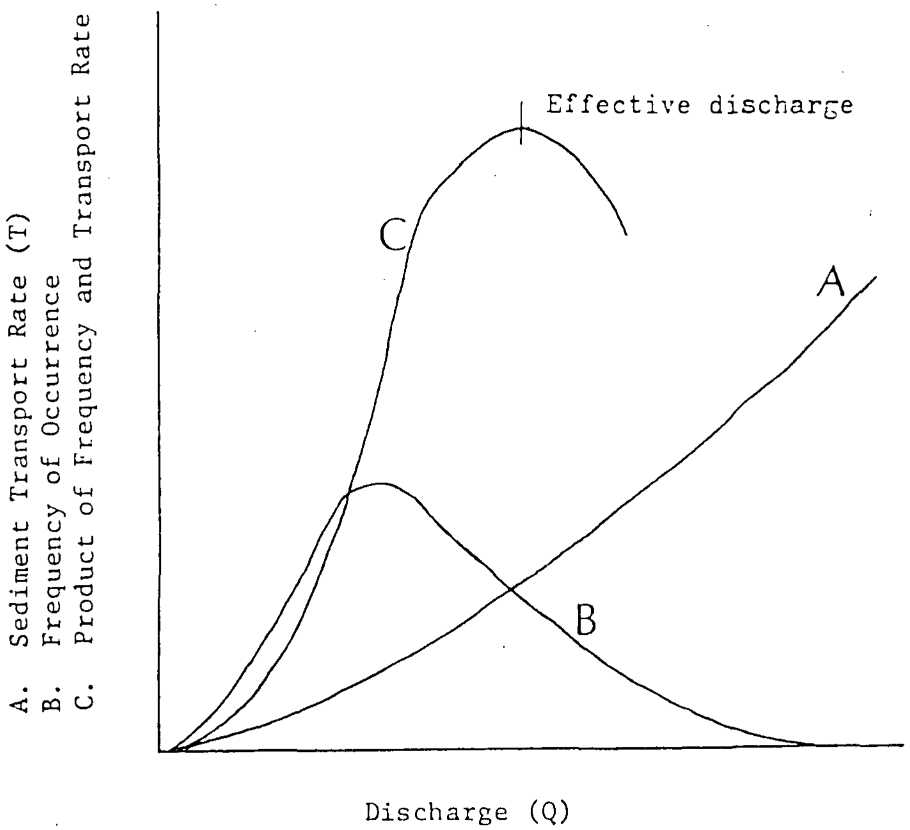

Figure 1. Relations Between Discharge and Sediment Transport Rate, Frequency of Occurrence, and the Product of Frequency and Transport Rate (after Andrews, 1980).

sediment, while the high magnitude flows transport large amounts of sediment. Because of the combination of magnitude and frequency, intermediate flows are the most effective sediment transport events.

The principles suggested by Wolman and Miller (1960) have gained wide acceptance, but field investigations have often been inconclusive (Andrews, 1980). Piest(1965) studied the relative sediment contributions from discharges of various return periods in 72 small watersheds (542 to 0.29 sq.mi., 1403 to 0.75 sq.km.) in 17 midwestern, southern, and eastern states. He found that sediment yield of large storms (storms with a return period greater than two years) varied from 3 to 46 percent of total suspended sediment yield; the yield from moderate storms (storms with a return period between one and two years) ranged from 3 to 22 percent of the total; frequent storms (with return periods less than one year) accounted for 34 to 92 percent of the total suspended sediment yield. Although not quantifiable, Piest identified several trends in his data. The data suggested that suspended sediment yields resulting from very large storms are proportionally greater in the semiarid Great Plains than in the more humid Southeast. Also, the relative sediment contribution of any given large storm tends to decrease with increasing watershed size.

Dickinson and Wall (1976) studied the temporal patterns in suspended sediment load of six rivers in southwestern Ontario. Suspended sediment yield closely parallels the seasonal distribution of flood occurrences in southern Ontario, with more than 55 percent of the annual load being transported in the months of March and April. The data indicated that suspended sediment loads are more highly skewed than streamflow distribution. The authors consider the movement of suspended sediment to be a discrete process, dependent on extreme events. Fifty percent of the suspended material is transported in less than five percent of the time; 80 percent is moved downstream in less than 10 percent of the time. As a result of the variability of suspended sediment loads, infrequent severe runoff events contribute significant sediment yields for streams tributary to the lower Great Lakes.

Using examples from central Texas, Baker (1977) demonstrated how streams with a high sediment transport threshold and highly variable streamflow apparently violate the geomorphic work principle of Wolman and Miller (1960). The effect of a sediment transport threshold on the frequency of the most effective discharge was demonstrated graphically by Baker (Figure 2). A higher discharge is required to initiate sediment transport (Curve A1 to A2), such that the majority of sediment transport is occurring during a minority of the flows. Sediment contribution (Curve C2, Figure 2) is

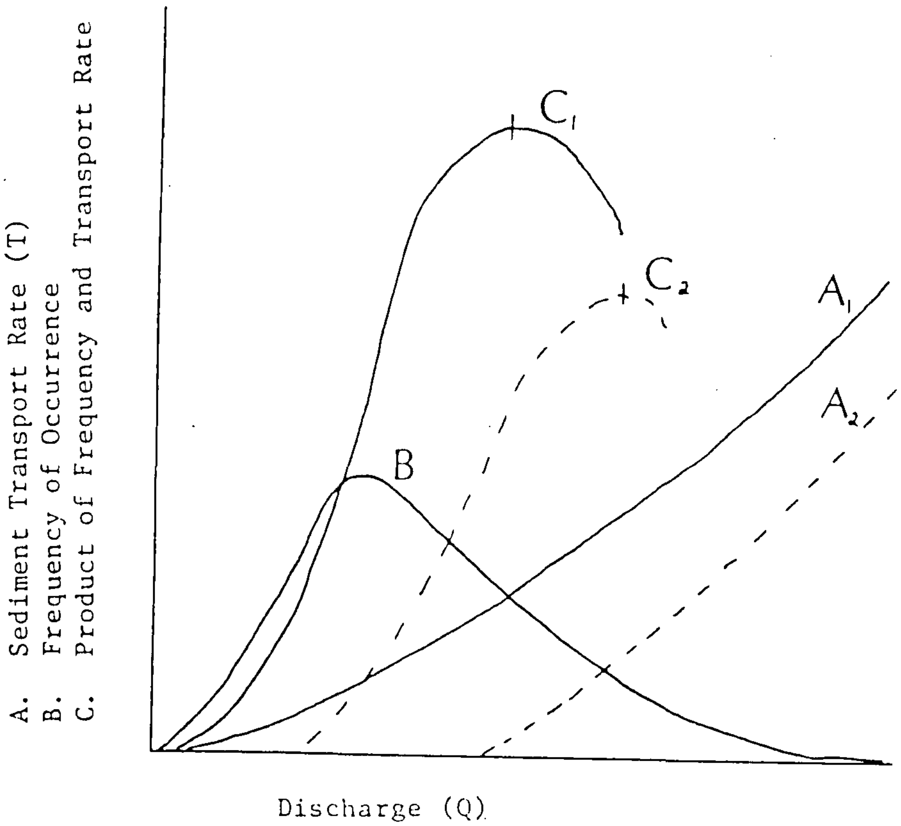

Figure 2. Effect of a Sediment Transport Threshold on the Frequency of the Effective Discharge (after Baker, 1977).

greatest at a higher but less frequent flow. If the effect of a sediment transport threshold is significant enough, the most effective discharge will be considerably less frequent than once every five years. Flow variability has a similar effect (Figure 3). When flow distributions become highly skewed (Curve B2) many more flows occur in a range of discharge that transports very little sediment. When the two curves in Figure 3 are combined (Curve A and B2), the product of the magnitude and frequency (Curve C2) is greatest at a less frequent flow. Therefore, Baker (1977) showed rare large magnitude storms are the major sediment transporting events in central Texas.

Dunne (1979) reported that Kenyan catchments yield an average of 41 percent of their sediment during the highest one percent of flows. This average is based on a range of values that varied from 35 percent for forested watersheds to 75 percent in grazed watersheds. The highest 10 percent of flows transported an average of 80 percent of the mean annual sediment yield. Within a single large basin, the relative importance of the highest flows decreases with increasing drainage area. Although Dunne does not draw conclusions in terms of how his observations fit Wolman and Miller's (1960) geomorphic work principle, he does indicate that the highest one percent and 10 percent of streamflows mentioned above represent catastrophic floods that

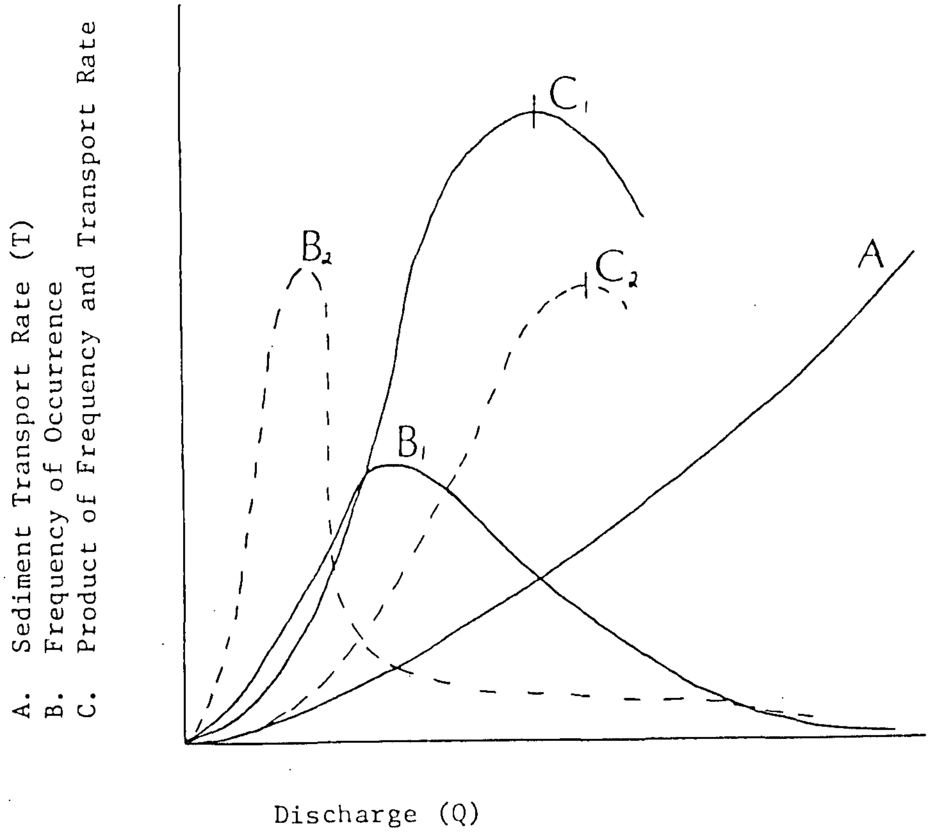

Figure 3. Effect of Variable Flow on the Frequency of the Effective Discharge (after Baker, 1977).

occurred in late 1961 and early 1962. In one large basin the equivalent of 4.75 years of sediment transport was accomplished during the month of highest flows. This yield accounted for 22 percent of all sediment lost during the 21 year period of record.

Andrews (1980) determined the duration of the effective discharge for 15 gaging stations in the Yampa River basin, Colorado and Wyoming. The effective discharge is defined as the increment of discharge that transports the largest fraction of a stream's annual sediment load over a period of years. Andrews found the streamflow duration of the effective discharge ranged from 0.4 to 3.0 percent of the time, or from 1.5 to 11 days per year. In addition, he found that for the Little Snake River near Dixon gage, 73 percent of the annual sediment load was transported by flows that were equalled or exceeded on the average between 8.8 and 0.2 percent of the time. For the Little Snake River, neither the common flows nor the rare floods were effective sediment transporting events. These observations agree with the conclusion of Wolman and Miller (1960) that the effective discharge is a relatively frequent flow that occurs on an average of several days per year.

Purpose and Justification of the Study

The objective of this study is to evaluate the relationship between the magnitude and frequency of sediment transport for selected northern California coastal streams in terms of Wolman and Miller's (1960) geomorphic work principle. Previous studies of sediment yields and flood frequency (Brown and Ritter, 1971; Knott, 1971; Brown, 1973; Kelsey, 1977; and Janda, 1978) have not examined sediment discharge in terms of this principle. However, these studies did suggest that a majority of the sediment transport occured during major discharge events. The highly erosive terrain and high sediment yields that characterize northern California streams are significantly different from watershed conditions in the studies that have considered the geomorphic work principle of Wolman and Miller (1960). Evaluating local relationships in this context will allow comparisons with previously studied areas outside the north coast region of California, and will provide a different perspective on the effectiveness of local floods as geomorphic forces. This objective was accomplished by applying the methodology described by Leopold, Wolman, and Miller (1964) to streamflow and sediment data from selected gaging stations on three northern coastal California streams.

Study Area

The study area includes the Mad River, Eel River, and Redwood Creek basins, located primarily in Humboldt County, but with portions of the watersheds in Trinity and Mendocino Counties, California. Five U.S. Geological Survey gaging stations within these three watersheds were selected for this study (Table 2, Figure 4).

The climate of the study area is Mediterranean, with dry summers and cool, wet winters. Mean annual precipitation in the study area ranges from 40 to 90 inches (1010 to 2280 mm.) (Rantz,1968). Orographic lifting of moist air masses has a considerable influence on the amount and intensity of rainfall in the study area. Most of the areas above 3,000 feet (914 m.) annually receive 70 or more inches (1778 mm.) of precipitation (Elford and McDonough, 1974).

The study area is predominantly underlain by the Franciscan Assemblage described by Baily, Irwin, and Jones (1964). The Franciscan Assemblage comprises thick graywacke sequences containing minor interbeds of dark shale, interlayered mafic volcanic rocks, chert, limestone, and unusual metamorphic rocks containing minerals such as glaucophane, jadite, and lawsonite. Additionally, ultramafic rocks, largely serpentinites, are an integral part of the tectonic melange.

Table 2. Summary of the Five Gaging Stations.

Station Name	U.S.G.S. I.D. Number	Drainage Area		Period of Record[a]
		(sq.mi.)	(sq.km.)	
Eel River at Fort Seward	4750	2,107	5,457	WY 56 to 81
Middle Fork Eel River near Dos Rios	4739	745	1,930	WY 65 to 81
Mad River near Arcata	4180	485	1,256	WY 11 to 13 WY 51 to 81
Redwood Creek at Orick	4825	278	720	WY 54 to 81
Redwood Creek near Blue Lake	4815	68	176	WY 54 to 58 WY 73 to 80

[a] Water Year (WY) 19-- to 19--

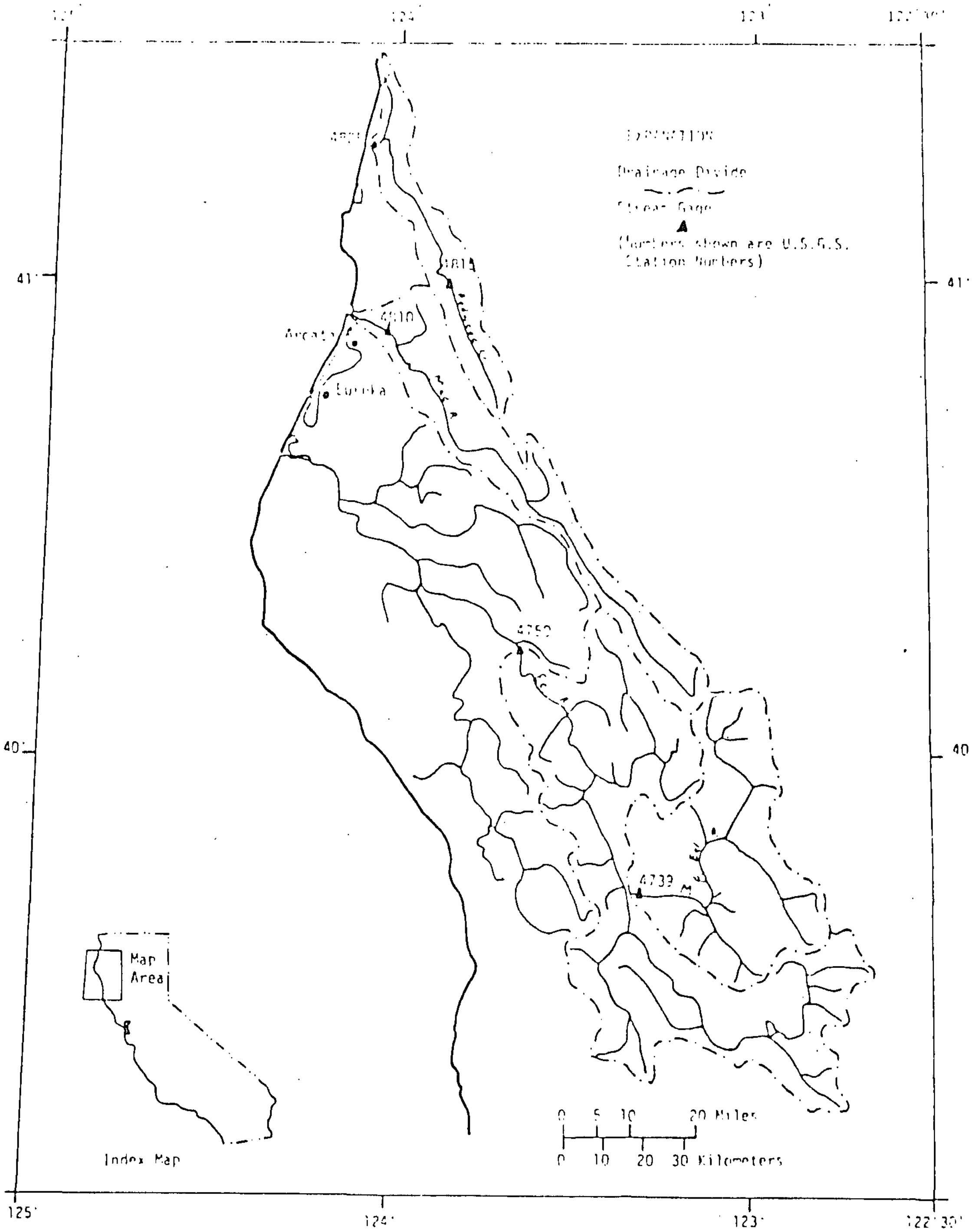

Figure 4. Study Area.

Structurally, the unit is complexly and intensely sheared. Faults trend predominantly northwesterly in the Coast Range. These faults are associated with broad shear zones that consist of blocks of the different harder varieties of Franciscan rocks embedded in a more sheared matrix. Because of the sheared nature of this zone, landslides are a common feature.

Vegetation types in the study area are predominantly commercial forests of Redwood and Douglas Fir, but also include prairies, hardwood stands, and chaparral. Elevation in the study area ranges from sea level to 7500 feet (2290 m.).

Streamflow in the study basins is characterized by long periods of minimal base flow during the summer months and high winter runoff associated with area-wide storms. Sediment yields from the study watersheds (Table 3) are very high. Redwood Creek and the Eel River have the highest sediment yield per unit area of any river of comparable size or larger in the U.S. (Judson and Ritter, 1964). Janda (1978) attributes the exceptionally rapid erosion rates implied by the suspended sediment yields to a combination of (1) intricately dissected, moderately steep to steep terrain, (2) readily erodible rocks and soil, (3) frequent prolonged moderately intense winter storms and, (4) recent major changes in land use, particularly timber harvest and road construction. While average

Table 3. Measured and Estimated Suspended Sediment Yields at the Five Gaging Stations.

Station Name	Period of Record	Suspended Sediment Yield (tons/sqmi)	(tons/sqkm)
Eel River at Fort Seward	WY 58 to 68	6,872	2,406[a]
	WY 66 to 76	4,569	1,600[b]
Middle Fork Eel River near Dos Rios	WY 58 to 68	5,698	1,995[a]
		2,660	931[c]
Mad River near Arcata	WY 58 to 70	5,590	1,957[d]
	WY 58 to 74	5,712	2,000[b]
Redwood Creek at Orick	WY 71 to 76	7,480	2,620[e]
	WY 71 to 77	6,462	2,262[b]
	WY 73 to 77	4,683	1,639[b]
Redwood Creek near Blue Lake	WY 73 to 77	4,798	1,680[b]

[a] Brown and Ritter (1971)
[b] Janda (1979)
[c] Weighted Long Term Estimate, Knott (1971)
[d] Brown (1973)
[e] Janda (1977)

sediment yields are high, annual sediment yields can have a wide range. For example, suspended sediment yield ranged from 777 to 25,000 tons/sq.mi. (272 to 8753 tons/sq.km.) on the Middle Fork Eel River in the 10 year period starting in 1958 (Knott,1971). Individual storm events can transport tremendous amounts of sediment. The equivalent of 1.15 years of suspended sediment was transported past the Mad River near Arcata gage on December 22, 1964, during the peak of the Christmas floods of 1964 (Brown, 1973). These characteristics are common to all the watersheds in this study.

METHODS

The effectiveness of discharge events at the five gaging stations was determined by the flow-duration, sediment transport curve method described by Leopold, Wolman, and Miller (1964). My procedure consisted of: 1) data compilation, 2) constructing streamflow-duration curves for each station, 3) calculating a suspended sediment transport equation for each station, and 4) combining the streamflow-duration curves with the suspended sediment transport equation to determine the relative contribution of various discharges to the total suspended load.

Data Compilation

Data compilation began with the selection of gaging stations after a review of the available U.S. Geological Survey streamflow and sediment data. My criteria for selecting stations were: 1) similar geology, climate, and vegetation, and 2) measured daily suspended sediment discharge values during a common period of record. Using these criteria I selected the five stations analyzed in this study.

Data used in this study were supplied by the U.S. Geological Survey (U.S.G.S.). Data on streamflow-duration were supplied by the Menlo Park Office, Water Resource Division, U.S.G.S., and data on the suspended sediment discharge were supplied by the U.S.G.S. Eureka Field Office. Yearly records of mean daily discharge were obtained from records in Water Resource Data for California, published annually by the U.S. Geological Survey. The data were grouped by station, and each group was separated into three sets. The first data set contained five years of mean daily discharge values, the second set contained the data for the flow-duration curves, and the third set contained data for the suspended sediment discharge curves.

Streamflow-Duration Curves

Streamflow-duration curves, commonly called flow-duration curves, have been in general use since 1915 (Searcy, 1959). The flow-duration curve is a cumulative frequency curve that shows the percentage of time specified discharges are equalled or exceeded during a given period. If a representative period of streamflow is used, the relationship describes the average or probable frequency of the various discharges during a year (Andrews, 1980).

The accuracy of the flow-duration curve in predicting the expected probability of streamflows depends on the representativeness of the period of record used, and also on the time units of discharge used to plot the curve. Flow-duration curves become more representative when long periods of record and short time units of discharge are used (Miller, 1951; Searcy, 1959). This study used the available period of record for each station, and mean daily discharge as the time unit.

The 1827 values of mean daily discharge contained in the first data set of each station were analyzed using the SPSS Frequency program on file at the U.S.D.A. Computer Center at Fort Collins, Colorado. This program computed basic statistics such as mean daily flow, standard deviation, kurtosis, and skew. These statistics are used to characterize the distribution of streamflow.

The second data set (Appendixes A through E) for each station was organized into discharge classes, and the relative frequency for each class was calculated. Cumulative frequency was also calculated to determine the exceedence probability of flows of various magnitudes.

Sediment Transport Equations

The majority of the total sediment load of northern California coastal streams is composed of clastic sediment (Kelsey, 1977). Bedload was not used in this study for two reasons. The first is that reliable measurements of daily bedload transport were not available for the five stations used in this study. The second reason is that the suspended sediment load usually comprises 85 to 90 percent of the total sediment discharge for the streams in this study (Knott, 1971; Kelsey, 1977), with the exception of the Redwood Creek near Blue Lake station, where bedload may comprise as much as 30 percent of the total sediment load (Janda, 1978). For this study, suspended sediment discharge accounts for the majority of debris movement out of a basin and is an adequate measure of the total sediment yield.

Sediment transport rates can be expressed as a power function of discharge by the equation $T=kQ^n$,where T is the sediment transport rate in tons/day, k a constant related to the availability of sediment (Nolan, personal comm.), Q the discharge in cubic feet per second (CFS), and n an exponent that describes the rate of increase of T with relation to Q. The second data set for each station, containing paired values of mean daily discharge (in CFS), and sediment transport rate (in tons/day) (Appendixes F through J), was fit to this power function, and values were calculated for k, n, and r^2 (to indicate the goodness of fit).

The data pairs used in this analysis were selected from several years of record. Sediment transport curves are more accurate when they are developed from data sets that cover the observed range of discharge, so an effort was made to select data pairs throughout the entire range of recorded discharge. Appendix K lists the equations used to fit the data to the power function.

Combined Duration-Transport Computation

The calculation that combines flow-duration with sediment transport rates relies on the assumption that a given sediment transport rate will occur with the same frequency as the discharge it is associated with. Based on this assumption, the flow duration curves can be multiplied piecewise with the sediment transport equations to calculate the relative contribution of each discharge class to the total suspended sediment load.

The procedure was relatively simple. The sediment transport rate for each discharge class was first computed using the sediment transport equation. The sediment transport rate for each discharge class was then multiplied by its frequency. This product was multiplied by 365 days to give the average annual suspended sediment yield for the discharge class. The sum of the suspended sediment yields of all discharge classes estimated the average annual suspended sediment yield.

The relative contribution of each discharge class to the annual suspended sediment yield was computed. The cumulative gragh showing the relative contribution of various discharges to annual suspended load was plotted with the graph of streamflow-duration. The magnitude and frequency of flows below which 50 percent and 90 percent of the total suspended sediment load was transported was determined from these curves.

RESULTS

Streamflow-Duration Curves

Frequency analysis results are summarized in Table 4. While these results do not directly affect the computation of the most effective discharge, they do provide basic statistics that characterize streamflow distribution. The study streams are characterized by positively skewed distributions dominated by summer low flows. The range of discharge values is very wide, with high winter flows commonly three or four orders of magnitude greater than summer low flows.

Streamflow-duration results are summarized in Tables 5 through 9. Results from this analysis directly influence the results of the most effective discharge computation. Specifically, frequency of the extreme high flow class is of critical importance. This is because extreme high flows produce great rates of sediment transport, and errors in determining their frequency may significantly bias the effective discharge calculation. Factors that affect the flow-duration analysis are: 1) length of the period of record, 2) storm history during the period of record, and 3) influence of recent floods and land management on runoff.

Miller (1951) and Searcy (1959) indicated that a

Table 4. Summary of Results from the Frequency Distribution Analysis.

Station Name	I.D. Number	Drainage Area (sq.mi.)	Period of Record	Mean Daily Q (CFS)	Modal Daily Q (CFS)	Kurtosis	Skewness	Range (CFS)
Eel River at Fort Seward	4750	2,107	WY 72 to WY 76	4,746	28	104.8	8.0	230,976
Middle Fk. Eel River n. Dos Rios	4739	745	WY 72 to WY 76	1,718	12	85.4	7.3	72,090
Mad River near Arcata	4810	485	WY 72 to WY 76	1,562	20	35.6	4.9	36,954
Redwood Creek at Orick	4825	278	WY 72 to WY 76	1,221	21	86.3	7.4	40,090
Redwood Creek near Blue Lake	4815	68	WY 73 to WY 77	234	11	63.5	5.8	8,360

Table 5. Results of the Discharge Class Frequency Analysis, Eel River at Fort Seward.

Discharge Class	Class Value (CFS)	Relative Frequency (%)	Cumulative Frequency (%)
1	6	0.5	99.5
2	37	18.0	90.0
3	110	16.8	70.9
4	240	7.4	61.2
5	360	3.7	57.2
6	520	4.5	53.6
7	760	5.1	49.1
8	1,100	5.3	44.0
9	1,600	6.1	38.7
10	2,400	5.7	32.6
11	3,500	6.2	26.9
12	5,100	5.9	20.6
13	7,500	4.4	14.7
14	11,000	3.4	10.3
15	16,000	2.4	6.9
16	23,000	2.0	4.4
17	34,000	1.3	2.5
18	50,000	0.6	1.1
19	73,000	0.3	0.5
20	110,000	0.1	0.2
21	160,000	0.08	0.1
22	230,000	0.02	0.04
23	330,000	0.02	0.02

Table 6. Results of the Discharge Class Frequency Analysis, Middle Fork Eel River Near Dos Rios.

Discharge Class	Class Value (CFS)	Relative Frequency (%)	Cumulative Frequency (%)
1	11	5.4	96.8
2	46	26.4	71.9
3	110	9.0	62.6
4	200	6.5	56.3
5	270	3.0	52.7
6	360	4.0	49.7
7	480	4.0	45.7
8	650	3.5	41.8
9	870	4.3	38.3
10	1,200	5.2	34.0
11	1,600	6.2	28.8
12	2,100	6.5	22.7
13	2,800	5.8	16.1
14	3,800	3.7	10.3
15	5,000	2.1	6.6
16	6,800	1.4	4.5
17	9,100	1.1	3.1
18	12,000	0.6	2.0
19	16,000	0.6	1.4
20	22,000	0.3	0.7
21	29,000	0.3	0.4
22	39,000	0.1	0.1
23	53,000	0.02	0.02

Table 7. Results of the Discharge Class Frequency Analysis, Mad River Near Arcata.

Discharge Class	Class Value (CFS)	Relative Frequency (%)	Cumulative Frequency (%)
1	1	0.1	99.9
2	6	0.8	99.5
3	18	7.9	97.3
4	41	18.4	81.8
5	62	6.1	72.8
6	92	6.2	66.7
7	140	5.3	60.5
8	210	4.6	55.2
9	310	5.0	50.6
10	460	5.1	45.5
11	690	6.4	40.4
12	1,000	8.1	33.9
13	1,500	8.3	25.7
14	2,300	6.5	17.4
15	3,500	4.6	10.9
16	5,200	2.9	6.4
17	7,700	1.9	3.4
18	12,000	0.8	1.5
19	17,000	0.6	0.7
20	26,000	0.2	0.2
21	39,000	0.02	0.04
22	58,000	0.02	0.02

Table 8. Results of the Discharge CLass Frequency Analysis, Redwood Creek At Orick.

Discharge Class	Class Value (CFS)	Relative Frequency (%)	Cumulative Frequency (%)
1	27	13.2	91.3
2	91	22.5	69.0
3	200	10.9	56.9
4	320	8.6	49.3
5	420	4.2	44.8
6	540	4.3	40.6
7	690	5.6	36.3
8	890	6.3	30.7
9	1,200	4.6	24.3
10	1,500	4.0	19.8
11	1,900	4.5	15.7
12	2,500	3.2	11.2
13	3,200	2.6	8.0
14	4,100	2.1	5.4
15	5,300	1.3	3.3
16	6,800	0.8	2.0
17	8,800	0.4	1.2
18	11,000	0.4	0.8
19	15,000	0.2	0.4
20	19,000	0.06	0.2
21	24,000	0.02	0.1
22	31,000	0.05	0.06
23	40,000	0.02	0.02

Table 9. Results of the Discharge Class Frequency Analysis, Redwood Creek Near Blue Lake.

Discharge Class	Class Value (CFS)	Relative Frequency (%)	Cumulative Frequency (%)
1	7	14.0	91.4
2	23	21.1	68.2
3	48	10.2	58.0
4	78	7.6	50.7
5	100	3.7	47.0
6	130	3.7	43.3
7	160	5.7	39.6
8	210	5.8	33.9
9	260	6.4	28.1
10	340	5.1	21.7
11	430	4.5	16.7
12	550	3.2	12.2
13	700	2.7	9.0
14	890	1.7	6.2
15	1,100	1.6	4.6
16	1,400	1.0	3.0
17	1,800	0.8	2.0
18	2,300	0.8	1.3
19	3,000	0.2	0.4
20	3,800	0.08	0.2
21	4,900	0.08	0.1
22	6,200	0.0	0.04
23	7,900	0.04	0.04

period of several years provided an adequate record if it covered a representative period of streamflow. Andrews (1980) considered a length of five years to be the minimum acceptable period of record. This study used the available record for each station, which spans from 13 to 34 years (Table 2).

Storm history forms the basis for the representativeness of the period of record. The records for the Eel River at Fort Seward, Mad River near Arcata, and Redwood Creek at Orick cover essentially the same period of time, Water Years (WY) 1951 to 1981. Plotting yearly mean discharge and the five year moving mean of yearly mean discharge for these three stations (Figures 5 through 7) provides an indication of streamflow trends during the period of record. Years with high mean discharge represent years with one or more large storm events. When the five year mean drops below the mean discharge for the period of record, it usually indicates a period of few storms and relatively low discharge. The Redwood Creek and Mad River basins experienced two periods of heavy runoff (1951 to 1960, and 1972 to 1976), one low runoff period (1977 to 1981), and one "near average" period of runoff (1961 to 1971). The Eel at Fort Seward experienced two heavy runoff periods (1956 to 1960, and 1965 to 1976), and two low runoff periods (1961 to 1964, and 1977 to 1981). These types of streamflow variation may be relatively normal

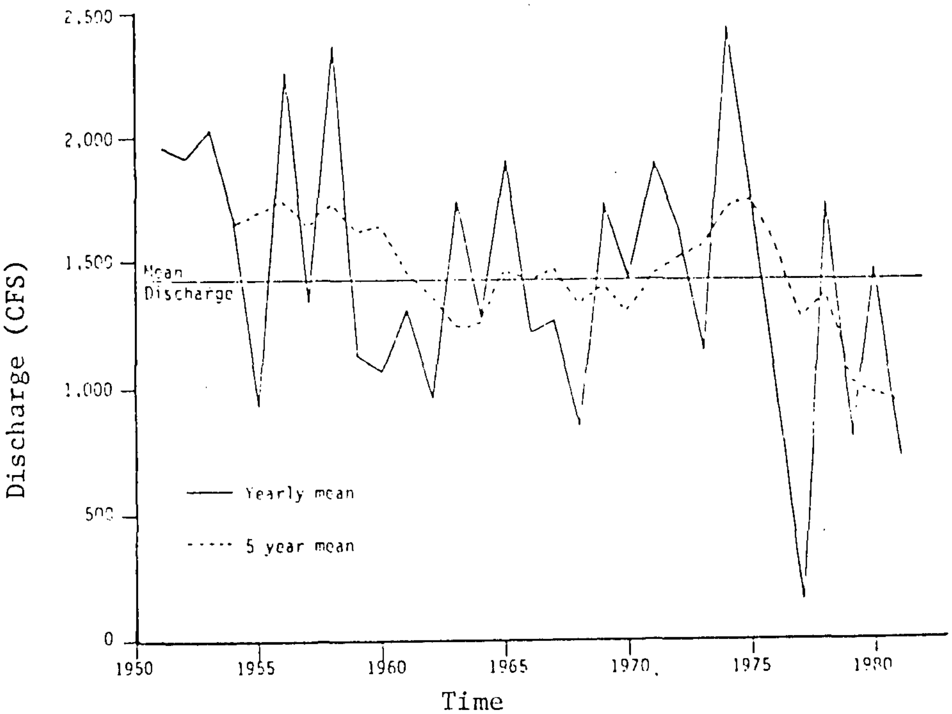

Figure 5. Graph of Yearly Mean Discharge and Five Year Moving Mean Discharge, Mad River near Arcata.

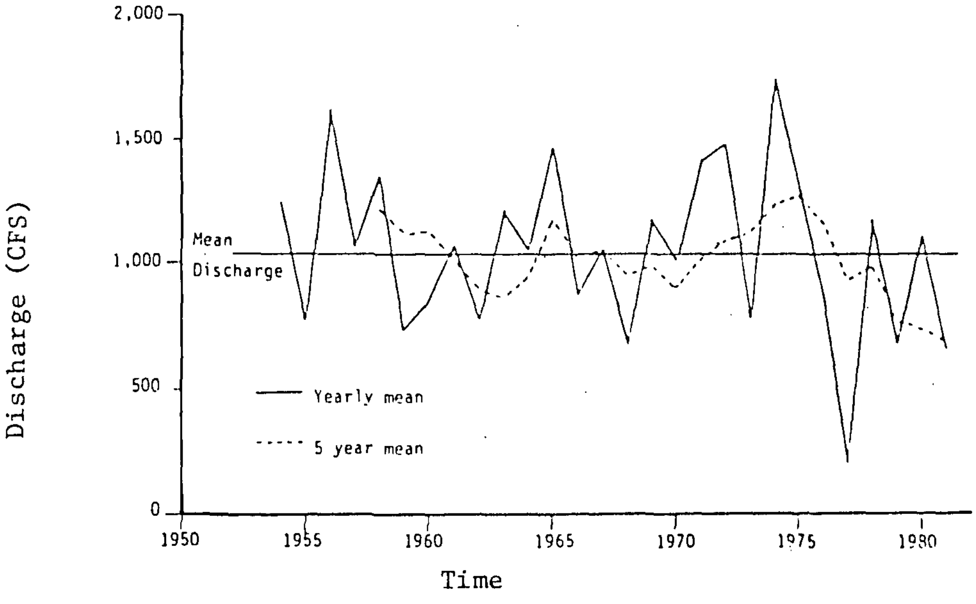

Figure 6. Graph of Yearly Mean Discharge and Five Year Moving Mean Discharge, Redwood Creek at Orick.

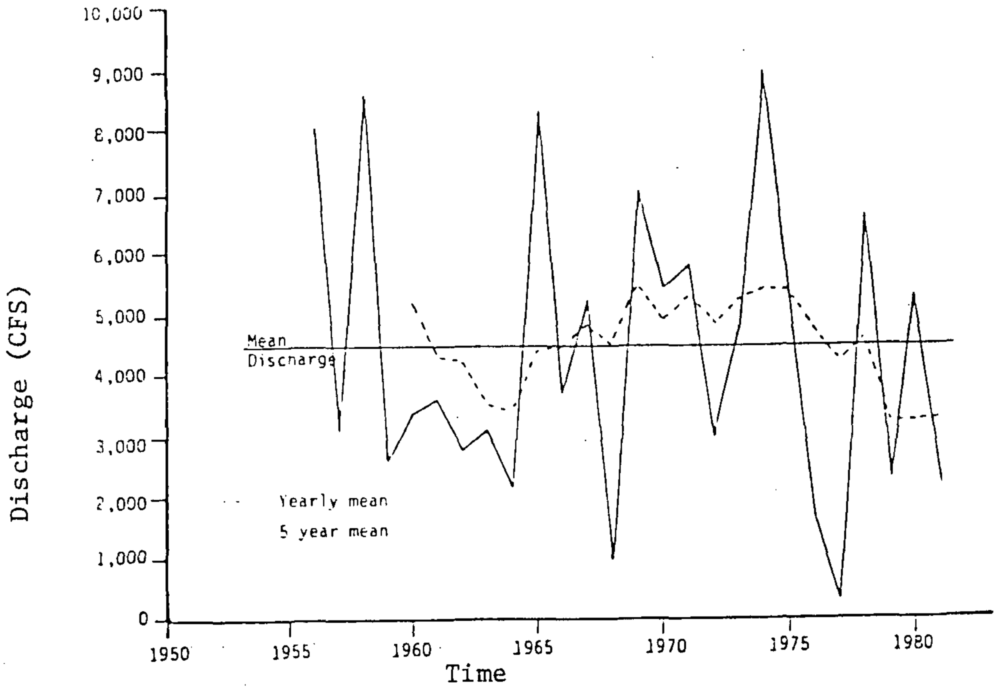

Figure 7. Graph of Yearly Mean Discharge and Five Year Moving Mean Discharge, Eel River at Fort Seward.

in a long-term context. However, after comparing recent discharge statistics with historical observations, Coghlan (1982) concluded "statistics from 20th century runoff data should be viewed only as rough approximations to their long-term values".

Discharge records for the Middle Fork Eel River near Dos Rios and Redwood Creek near Blue Lake cover only a portion of the longer records and may not accurately represent the overall runoff history during this period. Knott (1971) found that flow-duration curves based on short term records (10 years) from a predominantly wet period of high runoff overestimated the exceedence probability of high flows. The records for these two stations cover short, predominantly wet periods. It can be assumed that the flow-duration curves tend to overestimate the frequency of high flows at these stations.

The Christmas flood of December 1964 and recent land use activities have caused changes in the duration of streamflow for several northern California coastal streams. Kelsey (1977) reported increased frequency of high flows on the Van Duzen River after the 1964 flood. The change in post flood flow-duration curves was attributed to an increase in the area of impermeable ground in the watershed. The increase in impermeable area was a result of inner gorge debris avalanching that removed the soil mantle adjacent to stream channels.

Similar storm damage was extensive in the headwater portions of the study area (Harden, Janda, and Nolan, 1978). The increase in peak flows would be more significant on the records of the Redwood Creek near Blue Lake and Middle Fork Eel River near Dos Rios stations, which cover the period after the flood.

Lee, Kapple, and Dawdy (1975) report a 20 percent increase in runoff in the Redwood Creek basin as a result of "changes in hydrology". These changes in hydrology took place in the 1960's, a period of intensive land use practices and the severe 1964 flood. These changes caused an increase in peak flows for both Redwood Creek stations.

The long term records of the Eel River at Fort Seward, Mad River near Arcata, and Redwood Creek at Orick are the most representative records of streamflow in the study. The effect of storm history, recent floods, and land use is the greatest on the records of the remaining two stations. The trend is an overestimation of the frequency of the high flows.

Suspended Sediment Transport Equations

Estimates of k and n determined for the suspended sediment transport equation are summarized in Table 10. A strong relationship exists between discharge and sediment transport rates. As is the case for most

Table 10. Summary of the Results for the Suspended Sediment Transport Rate Equations.[a]

Station	Period of Record	Number of Data Pairs	r^2	k	n
Eel River at Fort Seward	WY 73,75,76	82	0.96	$4.7x10^{-5}$	2.08
Middle Fork Eel River Near Dos Rios	WY 73,75,76	80	0.96	$4.5x10^{-5}$	2.22
Mad River Near Arcata	WY 73,74	65	0.97	$1.4x10^{-4}$	2.16
Redwood Creek At Orick	WY 74,75,76	67	0.96	$3.1x10^{-5}$	2.36
Redwood Creek Near Blue Lake	WY 74,75,76	69	0.94	$2.2x10^{-4}$	2.32

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[a] $T = k Q^n$

Where: T = suspended sediment transport rate
k = coefficient
Q = discharge
n = exponent of rate of increase of T relative to Q

streams, suspended sediment discharge increases exponentially with water discharge, indicating a relatively greater input of sediment than water to the stream system with rising flow (Janda and Nolan, 1979). The rate of increase of suspended sediment transport relative to discharge (the n coefficient) is within the commonly observed range of 2.0 to 3.0 (Leopold, Wolman, and Miller, 1964). However, suspended sediment transport rates on a per area basis are exceptionally high (Janda and Nolan, 1979).

Out of necessity, the equations developed from a few years of data are assumed to represent a stable suspended sediment discharge relationship that can be applied to the entire period of record. In reality, however, suspended sediment discharge relationships are highly responsive to anomolous peak flows and watershed alterations by man (Brown, 1973). They would not be expected to remain stable over a long period.

Combined Duration-Transport Computation

The relationship between discharge frequency and contribution of suspended sediment is summarized in Figures 8 through 12. On the average, flows below which 50 percent of the total suspended sediment yield is transported are equalled or exceeded 1.9 days per year (Table 11). Flows below which 90 percent of the total

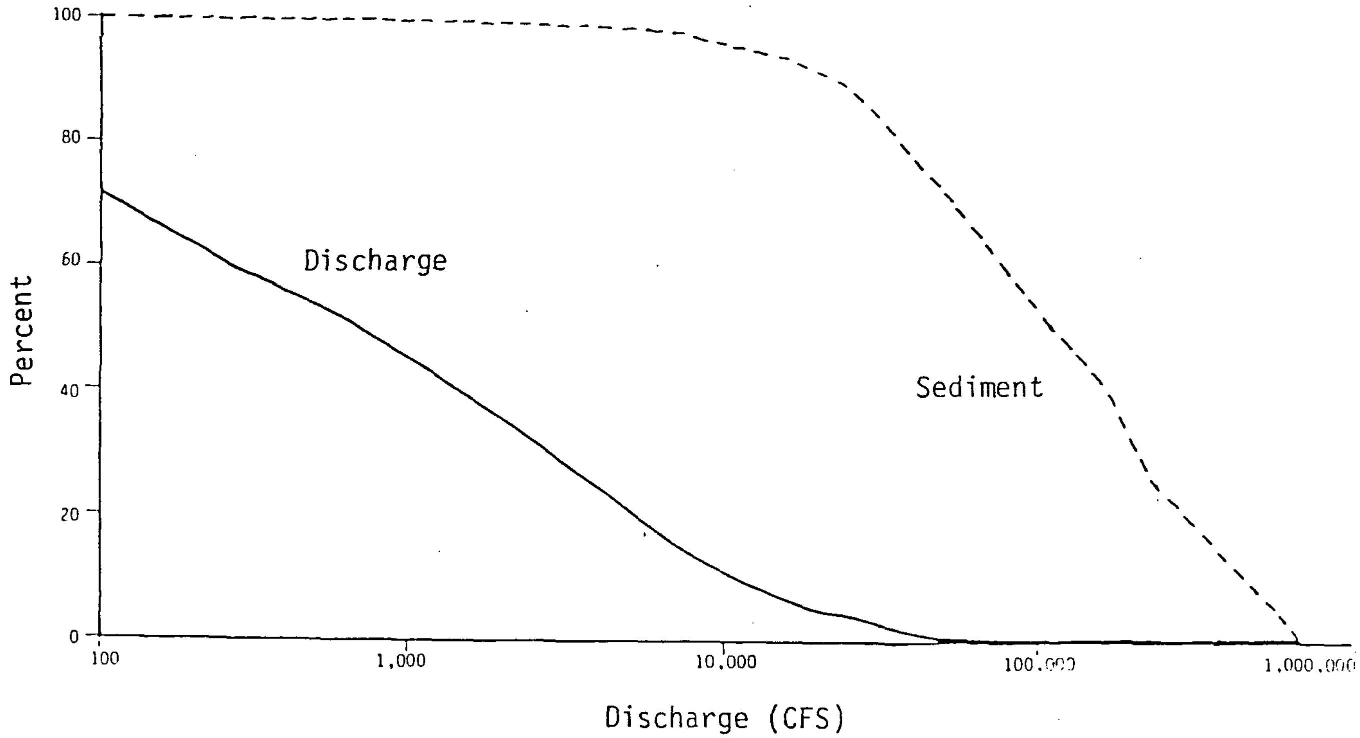

Figure 8. Cumulative Percent of Discharge Duration (Percentage of Time a Specified Discharge is Equalled or Exceeded) and Suspended Sediment Yield (Percentage of Total Suspended Sediment Load Transported Above a Specified Discharge), Eel River At Fort Seward.

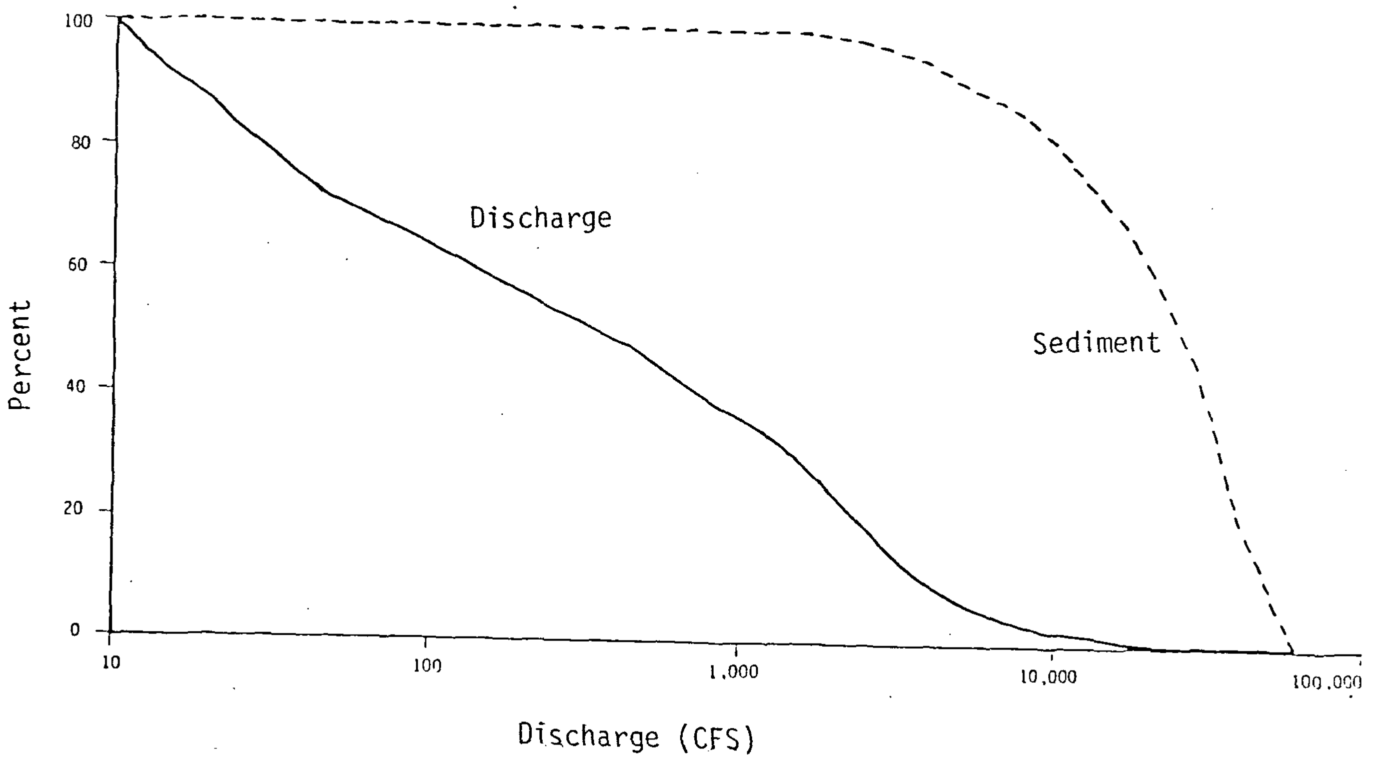

Figure 9. Cumulative Percentage of Discharge Duration (Percentage of Time a Specified Discharge is Equalled or Exceeded) and Suspended Sediment Yield (Percentage of Total Suspended Sediment Load Transported Above a Specified Discharge), Middle Fork Eel River Near Dos Rios.

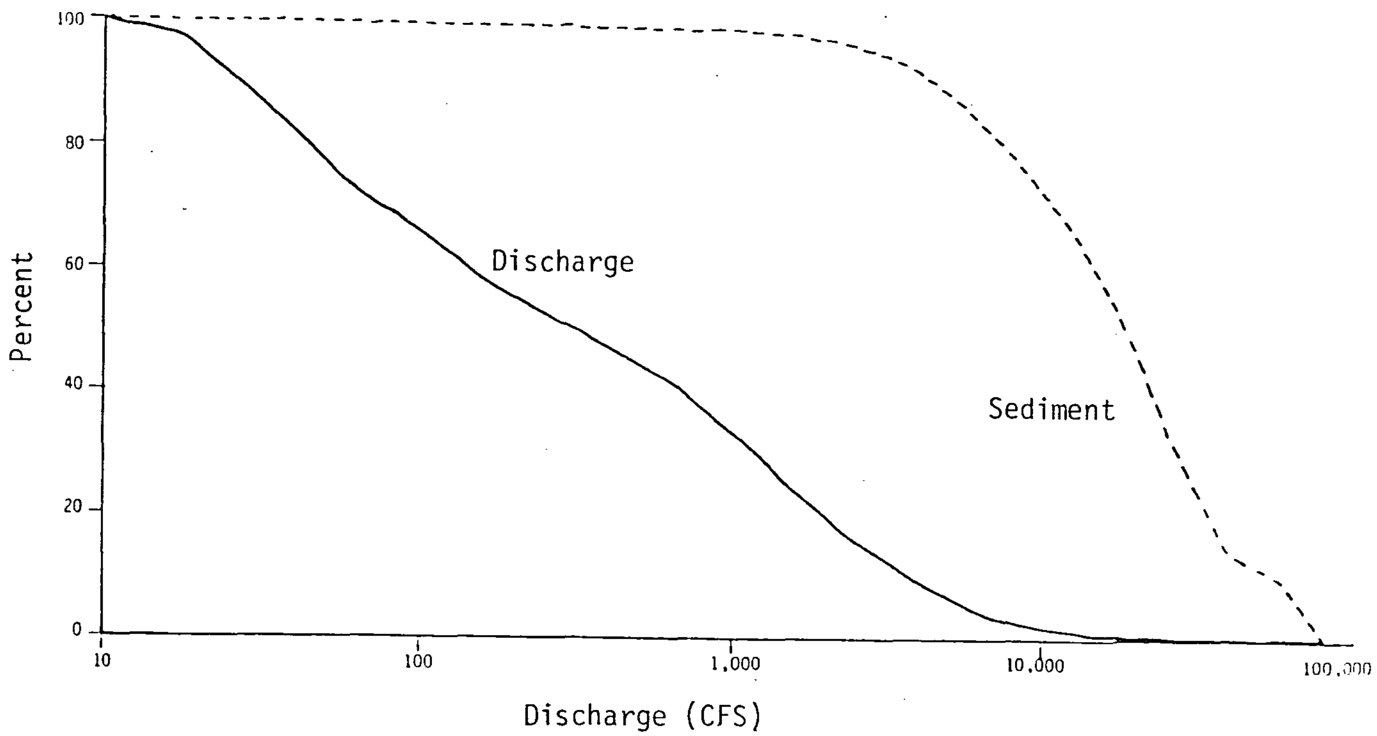

Figure 10. Cumulative Percentage of Discharge Duration (Percentage of Time a Specified Discharge is Equalled or Exceeded) and Suspended Sediment Yield (Percentage of Total Suspended Sediment Load Transported Above a Specified Discharge), Mad River Near Arcata.

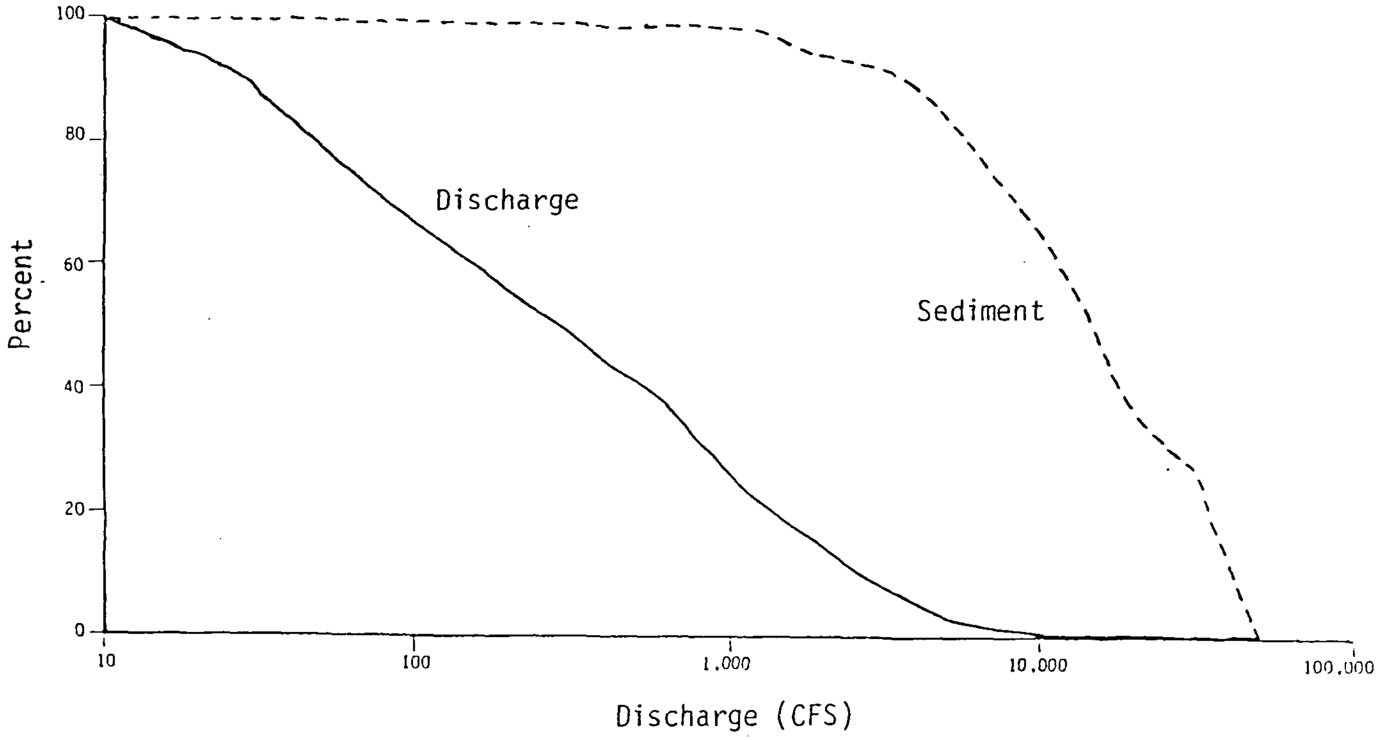

Figure 11. Cumulative Percentage of Discharge Duration (Percentage of Time a Specified Discharge is Equalled or Exceeded) and Suspended Sediment Yield (Percentage of Total Suspended Sediment Load Transported Above a Specified Discharge), Redwood Creek At Orick.

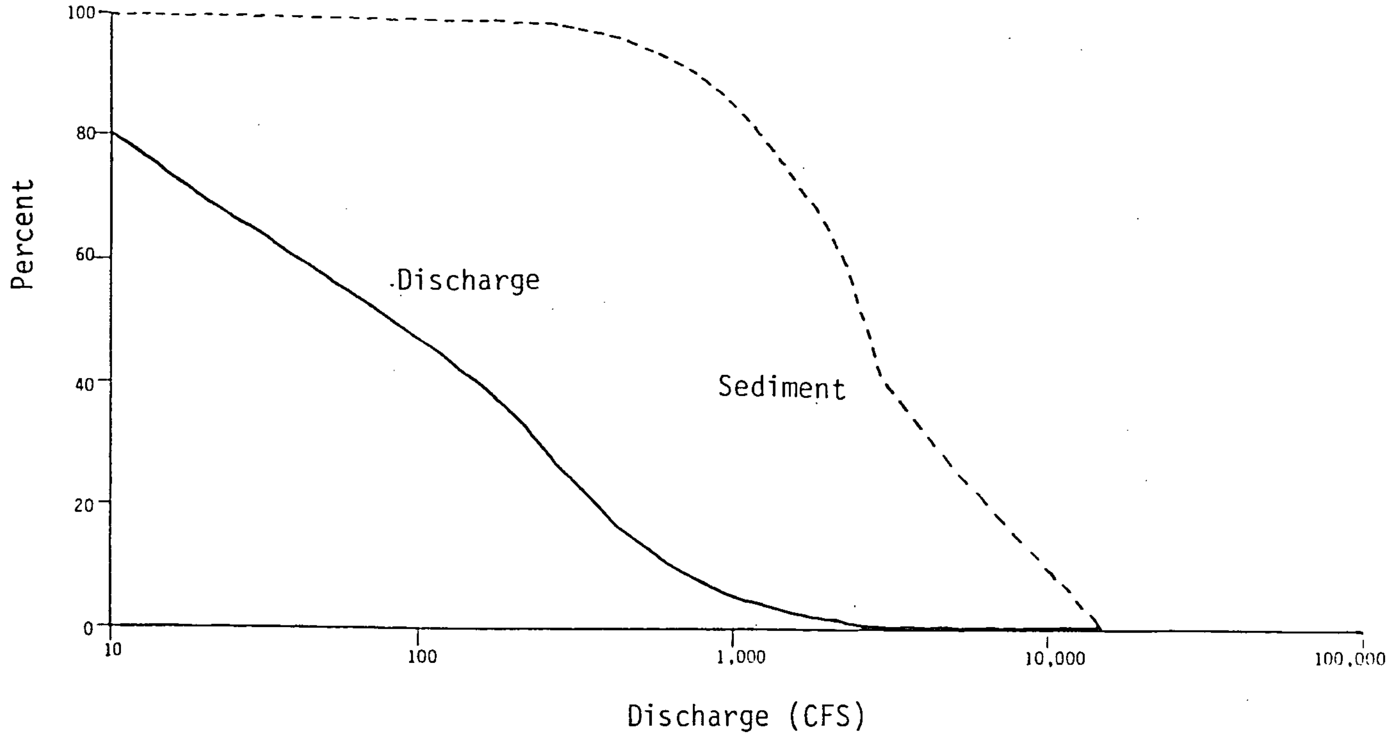

Figure 12. Cumulative Percentage of Discharge Duration (Percentage of Time a Specified Discharge is Equalled or Exceeded) and Suspended Sediment Yield (Percentage of Total Suspended Sediment Load Transported Above a Specified Discharge), Redwood Creek Near Blue Lake.

Table 11. Percentage of Suspended Sediment Transported by Flows of Different Magnitudes.

(1)	Distribution Measure of Flow used in Analysis (2)	Magnitude of Flow below Which 50 Per Cent of Total Sediment is Transported (3)	Frequency of Occurrence of Flow in Col. 3 (4)	Magnitude of Flow below Which 90 Per Cent of Total Sediment is Transported (5)	Frequency of Occurrence of Flow in Col. 5 (per year) (6)
Eel River at Fort Seward	Daily discharge Duration	115,000 CFS	Equal. or Exced. 0.5 days/yr.	450,000 CFS	0.04 days
Middle Fork Eel Near Dos Rios	"	26,000 CFS	Equal. or Exced. 2.0 days/yr.	49,000 CFS	0.15 days
Mad River near Arcata	"	18,500 CFS	Equal. or Exced. 2.0 days/yr.	58,000 CFS	0.07 days
Redwood Creek at Orick	"	15,000 CFS	Equal. or Exced. 1.0 days/yr.	41,000 CFS	0.04 days
Redwood Creek Near Blue Lake	"	2,600 CFS	Equal. or Exced. 4.0 days/yr.	10,000 CFS	0.10 days

suspended sediment yield is transported are equalled or exceeded, on the average, one day every 12.5 years (Table 11). The highest 1.0 percent and 10.0 percent of flows transport an average of 61.0 and 94.0 percent respectively of the total suspended sediment load (Table 12).

Table 12. Percent Contribution to the Average Annual Suspended Sediment Yield by Discharges of Various Ranges.

Station Name	Discharge Highest 1%	Highest 10%
Eel River at Fort Seward	63	87
Middle Fork Eel River near Dos Rios	67	91
Mad River near Arcata	58	89
Redwood Creek at Orick	72	93
Redwood Creek near Blue Lake	58	92

DISCUSSION

The results of this study indicate that a large portion of the geomorphic work in northern California coastal streams is accomplished by relatively infrequent flows. The support for this statement is the low frequency of occurrence of flows below which 90 percent of the total suspended sediment yield is transported. Wolman and Miller (1960) demonstrated that these flows occur at least once every five years. By comparison, Redwood Creek at Orick and Eel River near Fort Seward transport 90 percent of their suspended sediment at flows below a magnitude equalled or exceeded once every 25 years. The three remaining stations in this study transport 90 percent of their total suspended load below flows which occur once every seven to 14 years.

Infrequent flows transport a greater percentage of total suspended load in the study streams when compared to other studies. Dickinson and Wall (1976) reported infrequent flows contributed significant sediment yields in Great Lake basins. They found 50 percent of the total suspended load was transported by the highest five percent of flows. In the California streams, 61 percent of the suspended load, on the average, was transported by the highest one percent of flows. The northern California coastal streams in this study transported, on the average, more sediment in the highest one percent and 10 percent of flows than the average sediment contribution by the same range of flows in the Kenyan catchments studied by Dunne (1979).

Comparisons with the observations of Piest (1965) and Andrews (1980) are complicated by differences in data presentation. Piest evaluated the contribution of sediment from storms with various return periods. This study used the duration of mean daily discharge, which is quite different. Andrews divided the range of discharge values into 25 equal classes. The effective discharge, or the "most work" discharge, was defined as the discharge class that transported the largest percentage of the total sediment load. This study used unequal discharge classes, following the standard practice for constructing flow-duration curves and the methodology described by Leopold, Wolman, and Miller (1964).

Some observations can be compared. Andrews reported that for the Little Snake River near Dixon gage, 73 percent of the total sediment load was transported by flows that were equalled or exceeded between 8.8 and 0.2 percent of the time. Andrews concluded that this demonstrated the relative unimportance of both the common low flows and infrequent high flows as sediment contributors. Analyzing results of this study along those same lines shows that an average of 52 percent of the total suspended sediment load is transported within this range of flows. Low flows transport less than 10 percent of the suspended load, indicating that the high flows of the study streams transport a significantly greater portion of the total suspended load.

The observations of Baker (1977) provide a conceptual model to explain why infrequent flows may contribute a larger percentage of the total suspended load. Baker found that the combined effect of a sediment transport threshold and a highly variable flow regime caused catastrophic floods to become the most effective sediment transporting events in arid central Texas. Sediment transport occurs throughout the range of discharge values for the California streams, indicating flow variability should account for any deviation from the geomorphic work principle of Wolman and Miller (1960). When the data from the Eel river at Fort Seward is plotted (Figure 13) along the same format as Figures 1 through 3, it is apparent that flow variability will explain why infrequent flows contribute so much sediment. In Figure 13 the distribution of streamflows is positively skewed, that is, most of the population is concentrated at the left of the gragh with a long "tail" extending to the right. The streamflow distribution is also highly kurtotic, which means that the peak of the distibution is very narrow. The vast majority of the flows, which occur where sediment

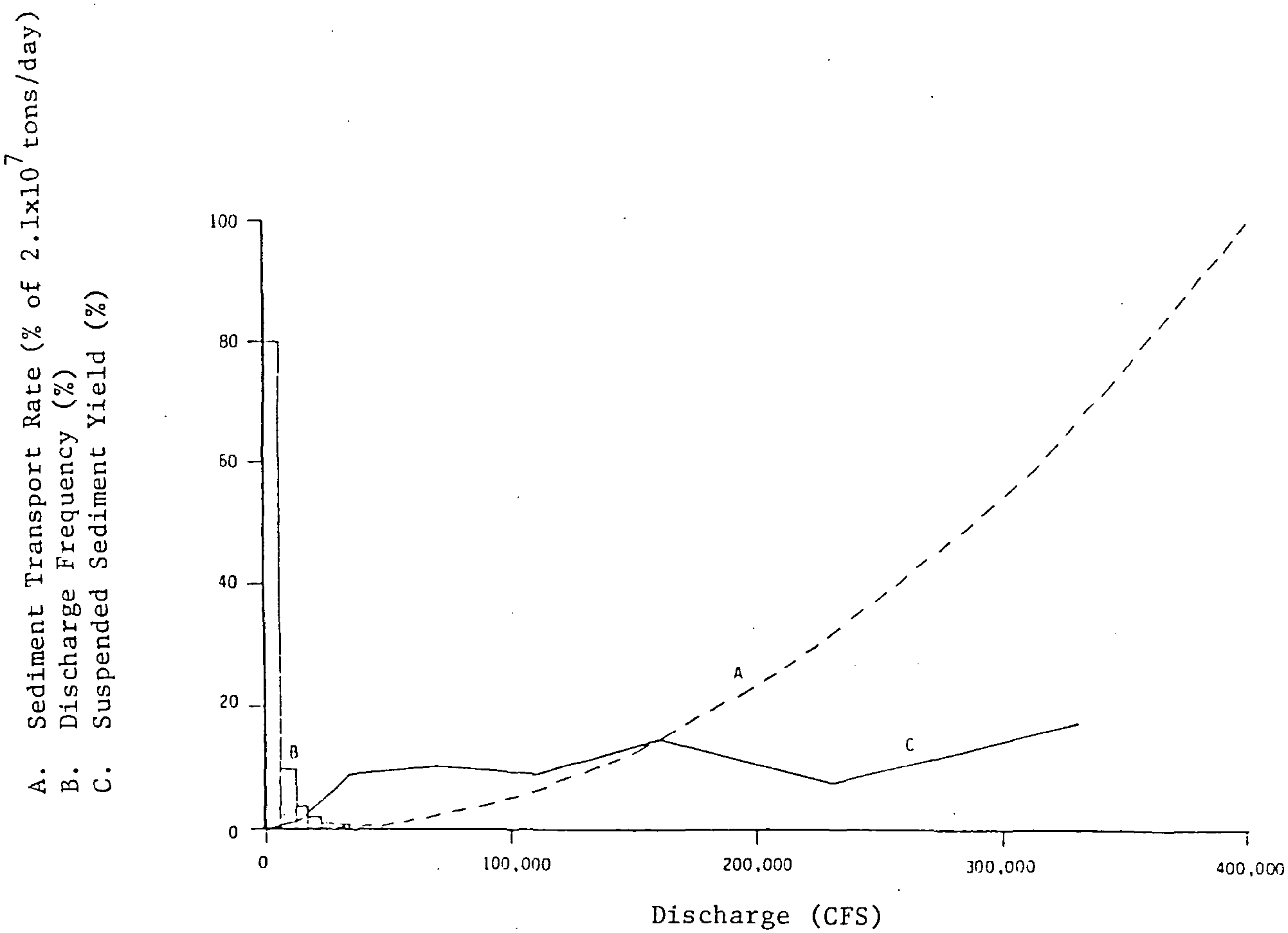

Figure 13. Relationship Between Suspended Sediment Transport Rate, Frequency of Discharge, and the Product of Frequency and Transport Rate, Eel River at Fort Seward.

transport rates are very low, account for a very small percentage of the total suspended sediment load. With this type of flow distribution, the large increase in sediment transport rates at the extreme end of the distribution more than compensates for the infrequency of the flows. The infrequent high flows transport, in this example, the largest percentage of the total suspended load. Both Redwood Creek at Orick and the Eel River at Fort Seward stations have highly kurtotic, positively skewed flow distributions, with very effective infrequent flows. The Mad River near Arcata gage has a less skewed, less kurtotic flow distribution with slightly less effective infrequent flows. The variability of flow in the study streams provides an adequate explanation for the effectiveness of infrequent flows. The effect of flow variabiltiy fits within the geomorphic work principle of Wolman and Miller (1960), although the effect in this study seems to exceed the expectations of the Wolman and Miller.

Previous studies have considered the significance of the most effective sediment transporting discharge in shaping stream channels. Wolman and Miller (1960) discussed this topic, and through several examples demonstrated that the most work discharge is the same as "bankfull" discharge. The authors found the relatively frequent bankfull discharge is responsible for a large portion of an alluvial channel's shape and dimensions. Andrews (1980) also observed an excellent correlation between the effective discharge and bankfull discharge, lending further support to this concept. Expanding on this topic, Wolman and Gerson (1978) stated that the effectiveness of events which sculpture the landscape is measured, in part, relative to the processes that restore the landscape to the original form. They found that in temperate regions, river channels widened by infrequent floods often regained their original form within months or years. Widened channels in arid channels may never recover because of the lack of streamflow and vegetation. In this example, a catastrophic flood in an arid region would be more effective in shaping a stream channel than a flood of equal frequency in a humid region. Lisle (1981) studied the recovery of aggraded gaging sections at nine gaginng stations in northern California and southern Oregon to determine the effectiveness of an infrequent climatic event (the 1964 flood) in shaping stream channels. The study suggests that stream channels draining areas with highly erosive terrain, non-alluvial channels, and great seasonal variability of precipitation will recover more slowly from catastrophic floods than alluvial channels draining stable, humid regions. The author states "Under these conditions, infrequent, large floods are far more effective in determining channel size and form than in less erosive humid environments." This conclusion compliments the observation that, in northern California, infrequent flows are more effective sediment transporting events. It would appear that, for a given combination of climate and terrain, the most effective channel shaping event is associated with the most effective sediment transporting event.

Summary

This study examined the relationship between the magnitude and frequency of suspended sediment transport of three northern California coastal streams. The results of this analysis were evaluated using the geomorphic work principle proposed by Wolman and Miller (1960). The evaluation indicated that most of the geomorphic "work" was accomplished by infrequent flows of large magnitude. The effectiveness of infrequent flows was greater in northern coastal California than was found in other studies. The highly skewed, kurtotic distributions of streamflow contributed to the effectiveness of the infrequent flows.

Several studies that consider the effectiveness of discharge events on channel size and form were discussed. It appears that the most effective channel forming discharge is commonly linked to the most effective sediment transporting event.

The results of this study suggest that

infrequent flows are effective suspended sediment transporting events in areas with highly erosive terrain, seasonal rainfall, and high annual precipitation.

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APPENDIX A

Table 13. Streamflow Duration Data, Eel River at Fort Seward (from U.S.G.S.).

Class	Value	Total	Percent
1	0.0	0	100.0
2	1.1	21	100.0
3	1.8	8	99.8
4	2.6	7	99.7
5	3.7	8	99.6
6	5.5	7	99.5
7	8.0	22	99.5
8	12.0	138	99.2
9	17.0	170	97.8
10	25.0	568	96.0
11	37.0	808	90.0
12	54.0	522	81.5
13	78.0	483	76.0
14	110.0	591	70.9
15	170.0	329	64.7
16	240.0	378	61.2
17	520.0	349	57.2
18	750.0	428	53.6
19	1100.0	502	44.0
20	1600.0	580	38.7
21	2400.0	544	32.6
22	3500.0	590	25.9
23	5100.0	561	20.8
24	7500.0	419	14.7
25	11000.0	324	10.3
26	16000.0	230	6.9
27	23000.0	186	4.4
28	34000.0	128	2.5
29	50000.0	57	1.1
30	73000.0	35	0.5
31	110000.0	12	0.2
32	160000.0	4	
33	230000.0	2	
34	330000.0	2	

APPENDIX B

Table 14. Streamflow Duration Data, Middle F. Eel R. (from U.S.G.S.).

Class	Value	Total	Percent
1	0.0	0	100.0
2	3.3	28	100.0
3	4.4	18	99.5
4	5.9	67	99.2
5	8.0	60	97.9
6	11.0	123	96.9
7	14.0	372	94.6
8	19.0	377	87.8
9	26.0	234	80.9
10	34.0	263	76.7
11	46.0	203	71.9
12	62.0	166	68.2
13	88.0	140	65.1
14	110.0	183	62.6
15	150.0	162	59.2
16	200.0	197	56.3
17	270.0	161	52.7
18	360.0	221	49.7
19	480.0	213	45.7
20	650.0	194	41.8
21	870.0	233	38.3
22	1200.0	288	34.0
23	1600.0	333	28.8
24	2100.0	359	22.7
25	2800.0	318	16.1
26	3800.0	203	10.3
27	5000.0	113	6.6
28	6800.0	75	4.5
29	9100.0	62	3.1
30	12000.0	35	2.0
31	16000.0	35	1.4
32	22000.0	19	0.7
33	29000.0	16	0.4
34	39000.0	7	0.1
35	53000.0	1	

APPENDIX C

Table 15. Streamflow Duration Data, Mad R. near Arcata (from U.S.G.S.).

Class	Value	Total	Percent
1	0.0	0	100.0
2	0.1	2	100.0
3	0.2	2	100.0
4	0.3	2	100.0
5	0.5	1	100.0
6	0.7	3	99.9
7	1.1	4	99.9
8	1.7	4	99.9
9	2.5	15	99.9
10	3.7	33	99.7
11	5.5	44	99.6
12	8.3	66	99.1
13	12.0	156	98.6
14	18.0	765	97.3
15	28.0	1154	91.1
16	41.0	1129	81.8
17	62.0	756	72.8
18	92.0	767	66.7
19	140.0	658	60.2
20	210.0	574	56.2
21	310.0	627	50.6
22	460.0	618	45.5
23	690.0	601	40.4
24	1000.0	1010	33.9
25	1500.0	1032	25.7
26	2300.0	806	17.4
27	3500.0	673	10.9
28	5200.0	365	6.4
29	7700.0	240	3.4
30	12000.0	98	1.5
31	17000.0	69	0.7
32	26000.0	20	0.1
33	39000.0	2	
34	58000.0	2	

APPENDIX D

Table 16. Streamflow Duration Data, Redwood Cr. at Orick (from U.S.G.S.).

Class	Value	Total	Percent
1	0.0	0	100.0
2	9.2	45	100.0
3	12.0	91	99.6
4	15.0	281	98.7
5	20.0	466	95.9
6	26.0	469	91.3
7	33.0	492	86.8
8	43.0	492	81.9
9	55.0	451	77.1
10	71.0	385	72.7
11	91.0	478	69.0
12	120.0	141	68.1
13	150.0	415	60.9
14	200.0	358	56.9
15	250.0	413	53.4
16	320.0	468	49.3
17	420.0	425	44.8
18	540.0	441	40.6
19	690.0	577	36.3
20	890.0	647	30.7
21	1200.0	467	24.3
22	1500.0	412	19.8
23	1900.0	461	15.7
24	2500.0	325	11.2
25	3200.0	262	8.0
26	4100.0	218	5.4
27	5300.0	136	3.3
28	6800.0	84	2.0
29	8800.0	45	1.2
30	11000.0	40	0.7
31	15000.0	22	0.4
32	19000.0	6	0.2
33	24000.0	3	0.1
34	31000.0	5	
35	40000.0	2	

APPENDIX E

Table 17. Streamflow Duration Data, Redwood Cr. near Blue Lake (from U.S.G.S.).

Class	Value	Total	Percent
1	0.0	0	100.0
2	2.5	27	100.0
3	3.3	76	99.4
4	4.2	76	97.8
5	5.4	228	96.2
6	6.9	256	91.4
7	8.8	199	86.0
8	11.0	293	81.8
9	14.0	200	75.7
10	18.0	155	71.5
11	23.0	157	68.2
12	30.0	162	64.9
13	38.0	165	61.5
14	48.0	158	58.0
15	61.0	186	54.7
16	78.0	176	50.7
17	100.0	176	47.0
18	130.0	176	43.3
19	160.0	273	39.6
20	210.0	274	33.9
21	260.0	302	28.1
22	340.0	241	21.7
23	430.0	212	16.7
24	550.0	151	12.2
25	700.0	129	9.0
26	890.0	79	6.2
27	1100.0	75	4.6
28	1400.0	47	3.0
29	1800.0	36	2.0
30	2300.0	41	1.3
31	3000.0	12	0.4
32	3800.0	3	0.1
33	4900.0	4	0.1
34	6200.0		
35	7900.0	2	

APPENDIX F

Table 18. Data Pairs, Mean Daily Discharge (MDD) and Suspended Sediment Discharge (SSD), Eel River at Fort Seward.

MDD	SSD	MDD	SSD
90	.49	203	2.7
176	2.4	151	1.2
724	37	754	10
1100	30	2370	192
7250	21500	4430	3170
1510	128	6820	61000
10500	11300	15800	27700
25500	168000	26500	157000
52900	670000	10700	65400
18000	57000	37600	380000
64700	507000	57900	358000
29700	120000	69600	802000
35200	144000	18900	56100
15000	20300	14000	11700
10000	12700	7140	2180
5300	758	5040	885
2930	316	2150	99
1900	77	465	5
198	1.6	100	.81
58	.3	41	.1
26	.1	124	3.3
30	.2	179	1
2530	7440	10700	29500
2070	363	3210	364
13100	545400	23800	146000
14700	11900	7440	5320
42800	176000	95100	801000
47000	114000	34900	200000
46900	518000	31400	81900
17500	10300	96100	1020000
73100	31400	85200	70100
11000	8910	5520	1420
2490	296	179	1.9
63	.17	2680	3210
1810	459	10100	28500
4600	2360	12300	41800
3950	3610	42800	376000
38700	218000	29100	118000
15400	23700	2250	103
8080	14300	1250	13
481	2.6	203	3.8
60	.32	26	.14

APPENDIX G

Table 19. Data Pairs, Mean Daily Discharge (MDD) and Suspended Sediment Discharge (SSD), Middle Fork Eel River near Dos Rios.

MDD	SSD	MDD	SSD
34	.09	62	1
174	3.3	408	53
1520	1690	1320	1220
2550	1650	569	9.2
555	19	5290	51400
18200	184000	6990	13000
3560	1890	1980	364
4660	18400	17500	172000
22900	165000	19700	111000
34300	346000	16400	77100
5350	7630	8310	26900
3640	2750	2100	391
1780	231	1450	94
263	.71	81	.22
40	.11	21	.06
15	.04	13	.04
12	.03	62	1.3
209	1.7	3910	21500
1200	4550	324	8.7
2530	7900	8580	83800
10100	79100	1100	208
7140	14800	16900	201000
26000	266000	10800	47500
12500	53700	24900	164000
9390	23800	26700	205000
3530	4480	1430	328
2570	1800	1670	586
573	37	346	6.5
202	4.4	137	1.5
57	6.2	37	.5
26	.07	54	1.5
127	5.8	19	.05
1220	2250	1730	2.5
408	3.3	192	1

APPENDIX H

Table 20. Data Pairs, Mean Daily Discharge (MDD) and Suspended Sediment Discharge (SSD), Mad River near Arcata.

MDD	SSD	MDD	SSD
80	1.7	123	3.3
62	.33	468	228
8960	101000	4350	20800
1280	1020	5610	34000
7549	44300	12700	86400
11900	56500	7040	16700
5040	5580	18100	241000
16100	143000	9370	44300
5850	11400	8030	25300
36600	709000	22500	319000
11400	108000	2141	1650
11100	113000	10500	86100
2700	3350	1330	445
24500	374000	12500	96200
21200	27500	13000	83500
1020	162	449	34
305	5.8	47	.63
19	.26	40	.32
127	4.1	571	398
407	152	725	430
204	9.4	1140	1170
9660	162000	6420	43700
6690	52000	2950	3820
10100	71500	8740	69800
10800	113000	5760	34600
3250	5660	1420	1330
2000	1100	1500	535
4310	5180	1000	329
460	39	276	7.5
153	1.2	73	.6
69	.6	17	.1
22	.2		

APPENDIX I

Table 21. Data Pairs, Mean Daily Discharge (MDD) and Suspended Sediment Discharge (SSD), Redwood Creek at Orick.

MDD	SSD	MDD	SSD
50	.1	92	.25
848	2320	9670	167000
5370	33200	9270	52500
8700	41800	14000	128000
10800	58900	2240	1630
5120	16800	788	234
13200	122000	1600	799
8180	74400	4060	29800
11000	124000	5830	18900
16400	226000	331	7.1
203	1.6	149	1.2
100	.8	10	.2
318	31	2440	16000
4070	24300	3210	7280
2580	4810	9920	76500
10600	100000	38500	1070000
18100	254000	14300	192000
1130	497	590	131
330	34	140	2.3
106	1.7	41	.44
4240	37400	4690	39400
7900	60800	932	277
3940	22500	1540	943
7370	62300	6290	30800
9070	78800	4720	12800
2070	1740	1070	255
2070	3470	1400	636
934	122	176	1
72	.4	25	.2
6430	23400	5040	10900
8890	66000	9380	51600
3050	4600	6000	73500
7560	58400	6560	40700

APPENDIX J

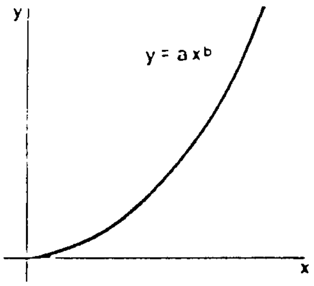
Table 22. Data Pairs, Mean Daily Discharge (MDD) and Suspended Sediment Discharge (SSD), Redwood Creek near Blue Lake.

MDD	SSD	MDD	SSD
5	.1	12	.6
62	73	57	30
954	7550	394	319
544	1010	186	28
255	24	1070	2710
127	6	180	74
1500	4690	210	14
917	1400	823	667
101	1.4	79	.4
1920	11400	2010	10900
2030	13900	1010	1360
345	28	211	3.4
100	.8	20	.1
25	.3	8	.1
73	4	68	6
394	642	145	23
1110	2650	681	506
2250	21600	2580	23600
3140	16800	1890	8000
2450	16200	2710	23300
2430	15700	3270	57500
1950	13900	8360	276000
3410	32200	3180	36700
409	232	220	36
596	177	111	4
50	2	7	.1
2470	50900	1200	4730
2030	12400	3670	53900
2820	30500	3560	63200
1200	3240	1760	15200
1250	8070	2130	18300
2070	9200	2710	23700
3710	51100	332	260
126	17	50	.4

APPENDIX K

03-04

Power Curve Fit



$$b = \frac{\Sigma(\ln x_i)(\ln y_i) - \dfrac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}}{\Sigma(\ln x_i)^2 - \dfrac{(\Sigma \ln x_i)^2}{n}}$$

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - b\,\frac{\Sigma \ln x_i}{n}\right]$$

$$r^2 = \frac{\left[\Sigma(\ln x_i)(\ln y_i) - \dfrac{(\Sigma \ln x_i)(\Sigma \ln y_i)}{n}\right]^2}{\left[\Sigma(\ln x_i)^2 - \dfrac{(\Sigma \ln x_i)^2}{n}\right]\left[\Sigma(\ln y_i)^2 - \dfrac{(\Sigma \ln y_i)^2}{n}\right]}$$

Remarks:

Negative and zero values of x_i will cause a machine error for logarithmic curve fits. Negative and zero values of y_i will cause a machine error for exponential curve fits. For power curve fits both x_i and y_i must be positive, non-zero values.

Registers R_0–R_9 are available for user storage.

It is not necessary to key in the x value if it corresponds to the counter returned to the display (see example 1).

As the differences between x and/or y values become small, the accuracy of the regression coefficients will decrease.

Figure 14. Power Function Fitting Equations.