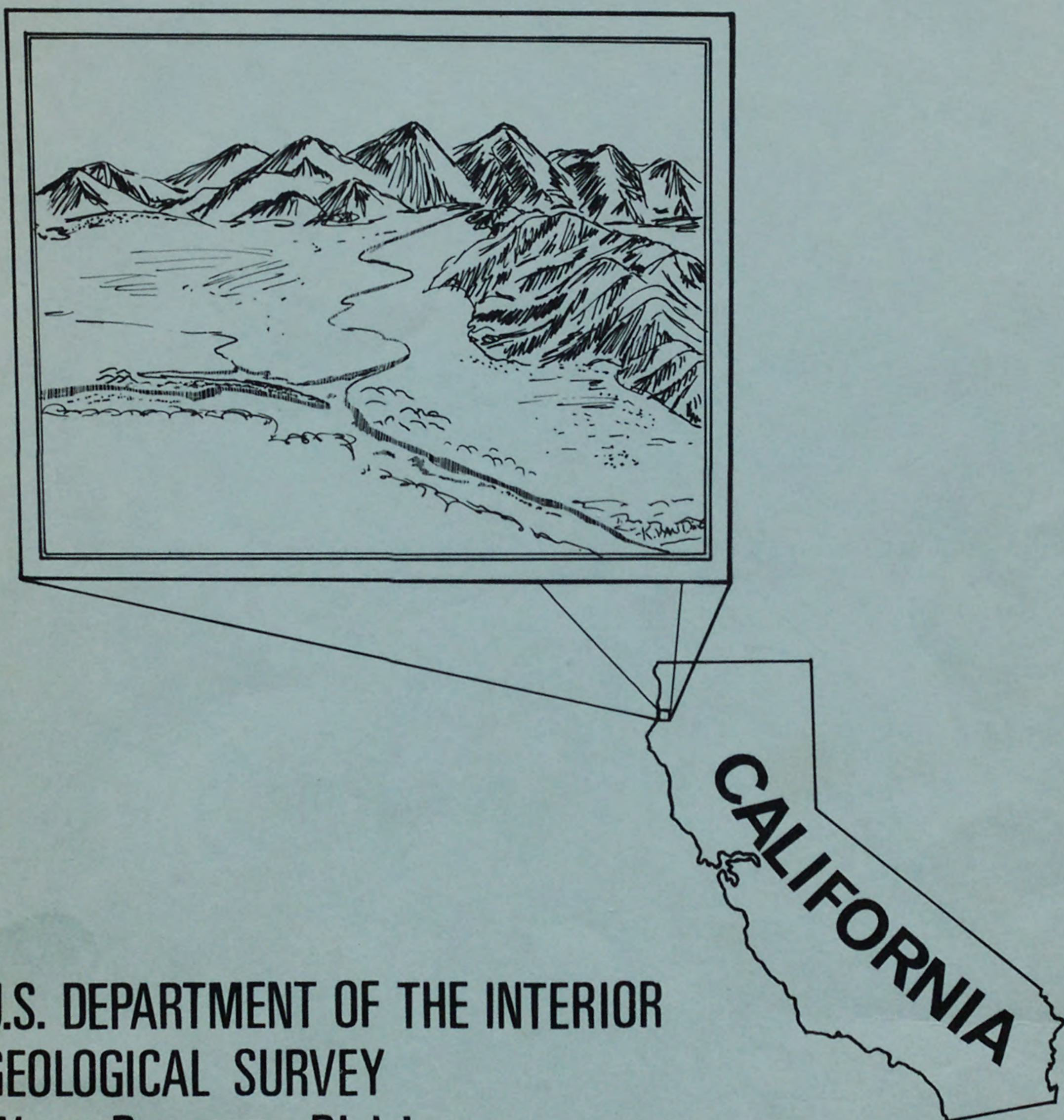
SAND TRANSPORT by the EEL RIVER and ITS EFFECT on NEARBY BEACHES



U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

Menlo Park, California, 1972
OPEN-FILE REPORT
PREPARED IN COOPERATION WITH THE
CALIFORNIA DEPARTMENT OF WATER RESOURCES

Cover design--Karen Van Dine

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Water Resources Division

SAND TRANSPORT BY THE EEL RIVER AND ITS EFFECT ON NEARBY BEACHES

By

John R. Ritter 1922-

Prepared in cooperation with the
California Department of Water Resources

OPEN-FILE REPORT

Menlo Park, California
December 19, 1972

CONTENTS

ILLUSTRATIONS

TABLES

SAND TRANSPORT BY THE EEL RIVER AND ITS EFFECT ON NEARBY BEACHES

By John R. Ritter

ABSTRACT

The Eel River basin has one of the largest sediment yields per unit area in the world. Sand composes about 25 percent of the total sediment transported by the river into its estuary. The annual sand load averages about 4,600,000 tons, equivalent to a deposition of about 2,100 acre-feet of sand per year.

Most of this sand probably enters the ocean, some is deposited in the estuary, and the amount furnished to nearby beaches probably is small. Of the sand and finer sediment debouched by the Eel River into the ocean, the major part is scattered over the continental margin, some is trapped by the Eel Canyon (not shown in fig. 1), and some is deposited offshore near the Eel River mouth. The Eel River probably supplies most of the sand found along the beaches between Centerville Beach and the entrance to Humboldt Bay. The Mad and Little Rivers probably supply most of the sand found along the beaches between the entrance to Humboldt Bay and Moonstone Beach.

INTRODUCTION

Streams that empty into the ocean are major sources of the sand[1] found on nearby beaches, and thus the sediment yields of the drainage basins of the streams are factors in the maintenance of the beaches. Disruption of the fluvial transport of sand from coastal basins may cause serious erosion of beaches by depriving them of the sand needed for replenishment of materials lost through natural processes. One such disruption is caused by dams on streams tributary to the ocean. The possible detrimental consequences of the damming of many coastal streams in southern California were discussed by Norris (1964).

The beaches near Eureka, California, extend a total of 34 miles, with interruptions at the mouths of the Eel, Mad, and Little Rivers and at the entrance to Humboldt Bay (fig. 1). The supply of sand for the beaches probably comes from those three rivers. The Eel River, by far the largest of the three streams, annually discharged an average of about six times more water and 11 times more suspended sediment than the Mad River and about 64 times more water than the Little River over a 13-year period (table 1). The data (table 1) for the Eel River are conservative because they do not include the water and suspended-sediment discharge of the Van Duzen River which has a drainage basin of 429 square miles and enters the Eel River downstream from the measuring site at Scotia. The Eel River basin has one of the largest recorded sediment yields per unit area in the world (Judson and Ritter, 1964; Holeman, 1968; and Brown and Ritter, 1971) and thus has a potential to contribute a considerable quantity of sand to the nearby beaches.

TABLE 1.--*Water discharge and suspended-sediment discharge at the data-measuring site farthest downstream on Eel, Mad, and Little Rivers (1958-70)*

Data-measuring site	Distance upstream from mouth (miles)	Drainage area (sq mi)	Average annual		
			Water discharge (acre-feet)	Suspended-sediment discharge (tons)	Suspended-sediment yield (tons/mi^2)
Eel River at Scotia	16	3,113	6,100,000	29,700,000	9,540
Mad River near Arcata	5	485	1,030,000	2,700,000	5,570
Little River at Crannell	2	44	95,000	---	

[1]Sand is defined in this report as sediment having an intermediate diameter of 0.062-2.0 mm (millimeter). See table 5.

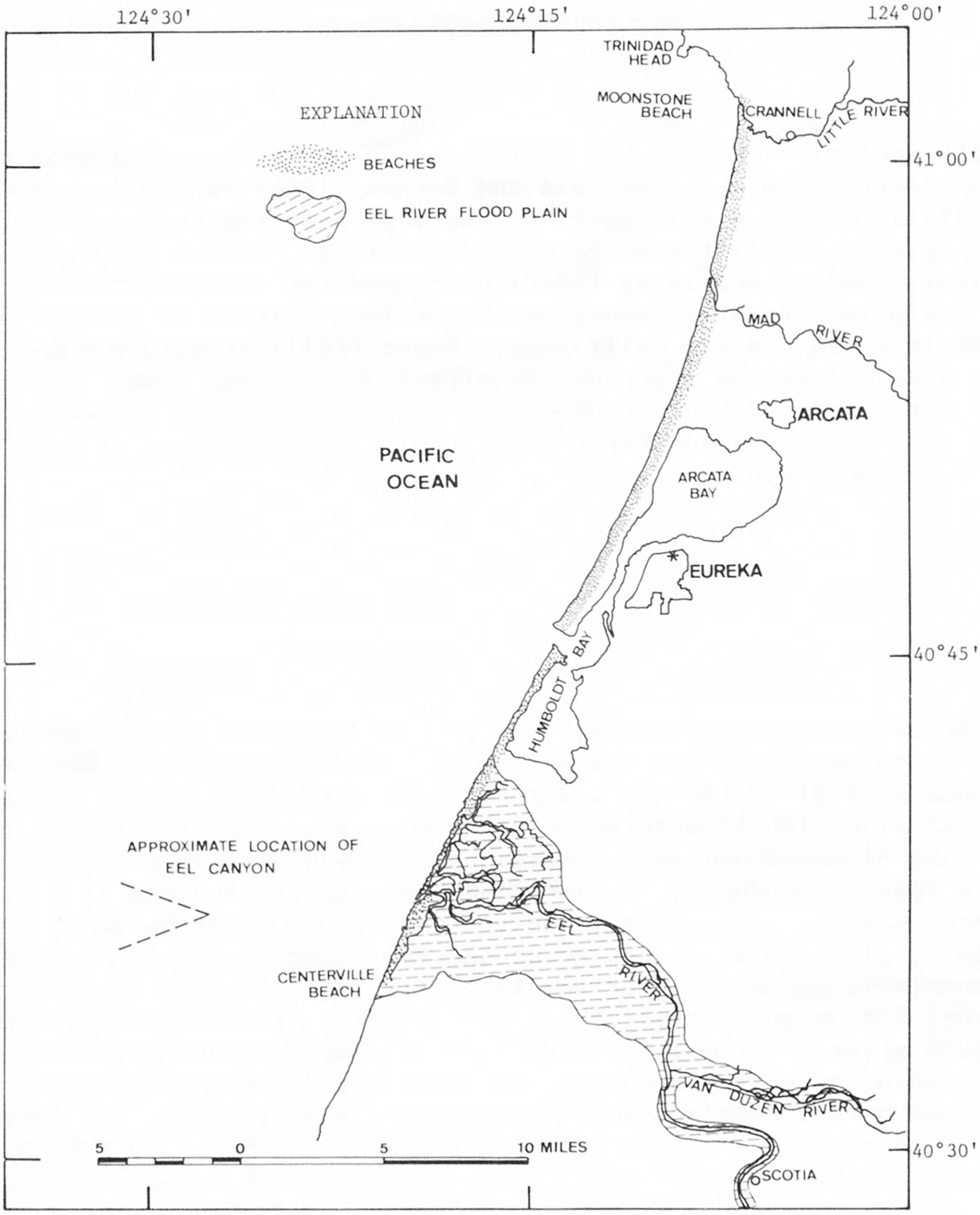


FIGURE 1.--Map of coastal area near Eureka, California.

The purpose of this study, made by the U.S. Geological Survey in cooperation with the California Department of Water Resources, was to determine the quantity of sand transported by the Eel River to its estuary and to determine the importance of the Eel as a source of sand to nearby beaches. Results may provide an insight to the possible consequences to the coast if the sand being discharged by the Eel River is interrupted by works of man, such as dam on its lower reaches or dredging operations at its mouth.

PREVIOUS INVESTIGATIONS

The Geological Survey has published five reports on sediment transport in the Eel River basin. Porterfield and Dunnam (1964) reported on the sedimentation of Lake Pillsbury, a reservoir near the headwaters of the Eel River. Ritter (1967) investigated bed-material movement in the Middle Fork Eel River. Hawley and Jones (1969) discussed the sediment yield in the Eel River basin as part of a report on the sediment yields of the basins of streams in north coastal California. Knott (1971) studied sediment transport by the Middle Fork and its possible effect on proposed dams. Brown and Ritter (1971) described sediment transport and turbidity in the entire Eel River basin. None of the above reports dealt with the discharge of sand by the Eel River into the ocean.

SAND TRANSPORT BY THE EEL RIVER NEAR ITS MOUTH

The suspended-sand discharge of the Eel River at Scotia was determined from sand-transport curves drawn from plots of instantaneous measurements of suspended-sand discharge and water discharge (fig. 2). Those curves were used in conjunction with flow-duration data to compute annual and long-term discharges of suspended sand. More than one sand-transport curve had to be used because the quantity of suspended sediment transported at a given water discharge was increased considerably after the flood of December 1964. For example, a given water discharge at the Eel River at Scotia carried twice as much suspended sediment after the flood (1965-68) than it did before the flood (1958-64) (Brown and Ritter, 1971, p. 32). The rate of sand transport also increased after the flood. Figure 2 shows that the postflood curve is much higher than the preflood curve. In other words, at a given water discharge many times more suspended sand was transported during Dec. 23, 1964-Sept. 30, 1965 (postflood) than at the same discharge during Dec. 19, 1956-Dec. 22, 1964 (preflood). The curve for the 1966-68 data is about midway between the preflood curve and the postflood curve, and the 1969-70 curve is almost the same as the preflood curve. The suspended-sand discharge, therefore, increased considerably immediately after the December 1964 flood and then decreased during the next few years until by 1969 the suspended-sand discharges equalled the preflood suspended-sand discharges at a given water discharge.

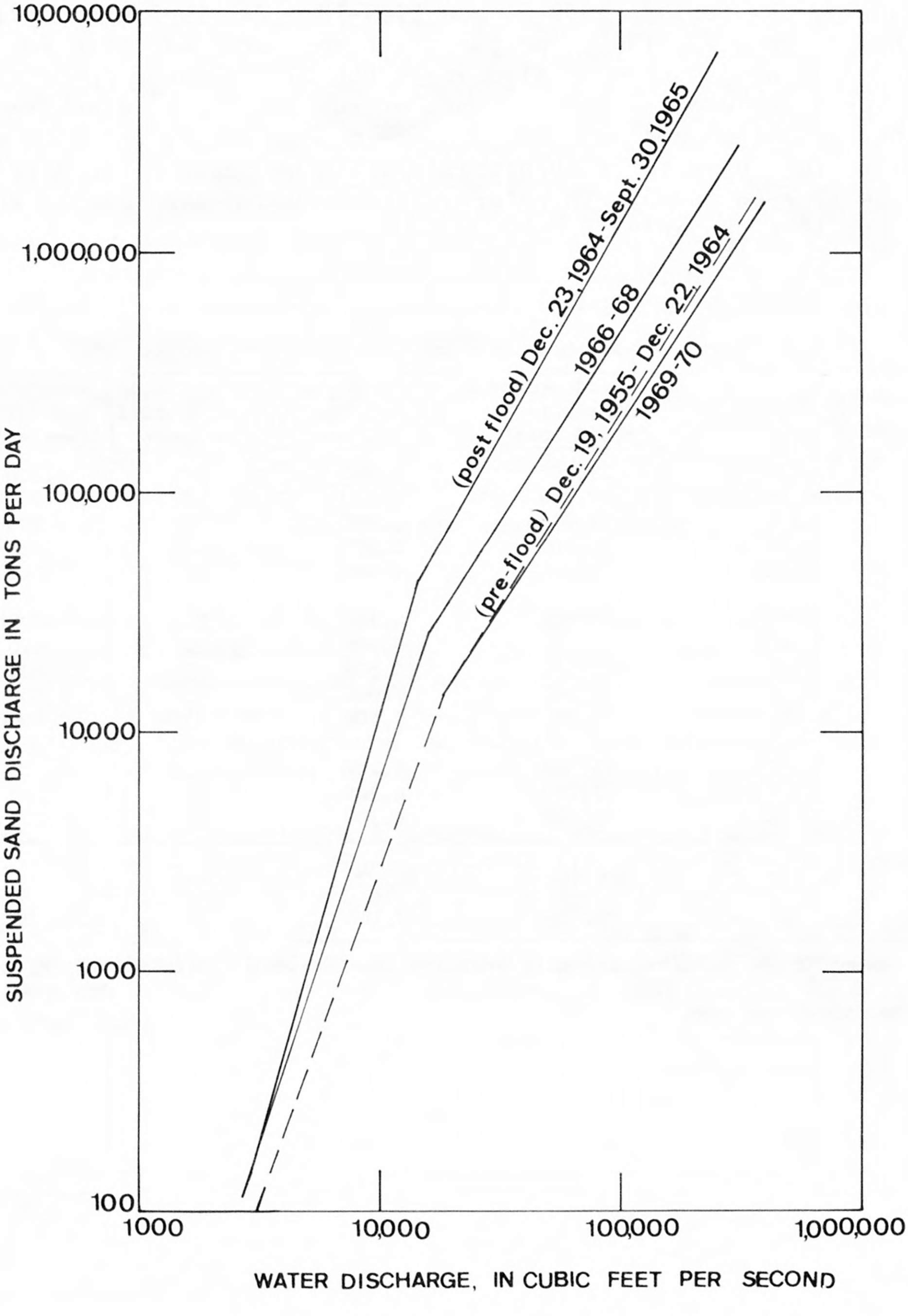


FIGURE 2.--Sand-transport curves for Eel River at Scotia, 1956-70. The preflood curve is based on 122 measurements; the postflood curve on 15 measurements; the 1966-68 curve on 21 measurements; and the 1969-70 curve on 23 measurements.

To calculate the annual suspended-sand discharges shown in table 2, the preflood curve (fig. 2) was used in conjunction with the flow-duration data for each year during the periods 1958-64 and 1969-70. For 1965 the preflood curve was used through Dec. 22, 1964, and the postflood curve was used for the rest of the year. The suspended-sand discharges for 1966-68 were computed from the 1966-68 curves. Because few measurements of suspended-sand discharge were made in 1966, they were combined with the 1967-68 measurements, which were fairly similar. The true curve for 1966 probably would be between the postflood curve and the 1967-68 curve. Therefore, the suspended-sand discharge calculated for 1966 probably is low.

TABLE 2.--*Suspended-sediment discharge, Eel River at Scotia, 1958-70*

Water year	Water discharge (1,000 acre-ft)	Suspended-sediment discharge (1,000 tons)	Suspended-sand discharge (1,000 tons)	Percent sand in suspended sediment	Suspended sand yield[1] (tons/mi^2/yr)
1958	11,600	29,000	8,500	29	3,100
1959	4,000	9,900	2,200	22	800
1960	4,500	15,000	3,200	21	1,200
1961	5,200	8,300	2,400	29	870
1962	3,800	4,800	1,500	31	540
1963	6,900	21,000	4,300	20	1,600
1964	3,300	5,600	1,300	23	470
1965	9,200	170,000	80,000	47	29,000
1966	5,000	28,000	7,000	25	2,500
1967	6,400	24,000	7,700	33	2,800
1968	4,100	11,000	4,100	36	1,500
1969	8,500	27,000	6,200	23	2,200
1970	7,300	33,000	6,100	18	2,200
Total	79,800	386,600	134,500	--	--
Average	6,100	29,700	10,300	[2]35	[2]3,700

[1]Based on the 2,764-square-mile drainage area between Scotia and Van Arsdale dam.

[2]Weighted average.

The largest annual quantity of suspended sand was transported in 1965, the year of the flood; the smallest quantity in 1964, a year of little runoff. Perhaps it is significant to note that the year with the highest water discharge (1958) was not the year with the highest suspended-sand discharge. This fact emphasizes that sediment transport in the Eel River basin is not influenced as much by the annual runoff as by the intensity and duration of individual rainstorms and the consequent runoff peaks. Sediment transport also was influenced by the increased availability of transportable sediment after the December 1964 flood. For example, almost as much suspended sediment was transported during both 1966 and 1967 as was transported during 1958 even though the annual water discharges were about half those of 1958. The average annual suspended-sand discharge for 1958-70 was 10,300,000 tons or 35 percent of the total suspended-sediment discharge.

The total suspended-sand discharge for the 58-year period of flow measurement, 1911-14 and 1917-70, was calculated by adding the suspended-sand discharge for 1958-70 to the suspended-sand discharge computed from the preflood sand-transport curve (fig. 2) and the flow-duration data for the years 1911-14 and 1917-57. The average suspended-sand discharge for 1911-14 and 1917-70 was 4,100,000 tons per year.

The flood during the 1965 water year, however, was shown by Pearson type III analysis to have a recurrence interval of about 180 years. The long-term average suspended-sand discharge adjusted to that flood frequency was 3,200,000 tons per year. Thus the suspended-sand discharge calculated from the period of flow measurement (4,100,000 tons per year) was excessively large because the frequency of the major flood was not considered.

Bedload was estimated to be 4 percent of the total load (bedload plus suspended-sediment discharge) transported by the river at Scotia (Hawley and Jones, 1969), and in this report most of the bedload was assumed to have been sand. Therefore, the total sand discharge was the sum of the suspended-sand discharge and bedload. On these assumptions, the long-term average total sand discharge was estimated to be 3,800,000 tons per year, about 25 percent of the total sediment load.

The long-term average sand yield of the Eel River basin above Scotia and below Van Arsdale dam (fig. 3) is 1,400 tons per square mile per year. This yield was calculated by dividing the average annual sand discharge (3,800,000 tons) by 2,764 square miles per year, the drainage area between Scotia and Van Arsdale dam. Van Arsdale dam probably effectively stops sand transported to the reservoir and thus the drainage area upstream from the dam does not contribute any of the sand transported at Scotia.

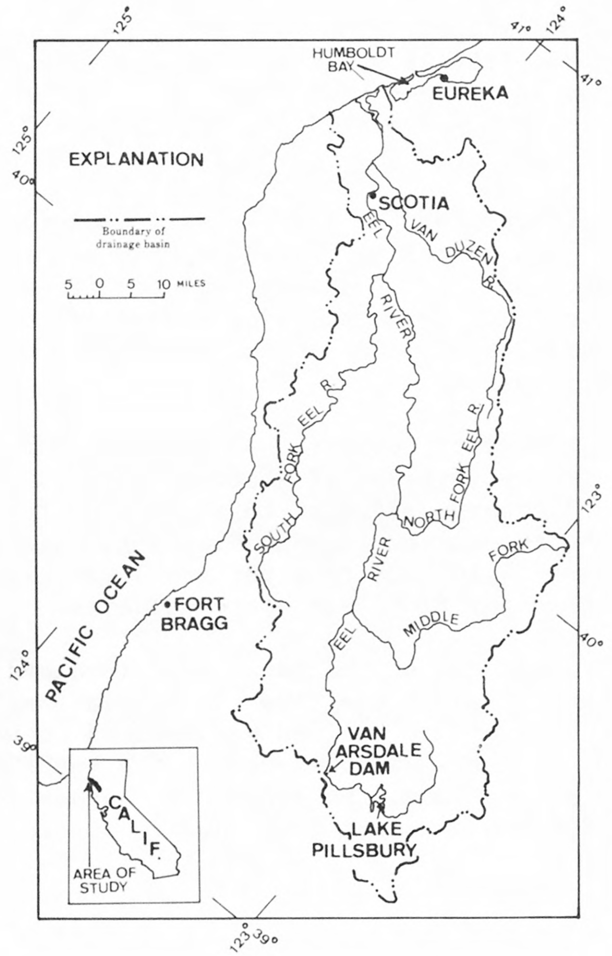


FIGURE 3.--Eel River basin.

The drainage area of the Eel River from its mouth to Van Arsdale dam is 3,273 square miles. If the entire area downstream from the dam is assumed to have a long-term average sand yield of 1,400 tons per square mile per year, the total sand contributed by the Eel River basin would average 4,600,000 tons per year. The depositional volume of this sediment would be 2,100 acre-feet if the specific weight of the deposited sand is assumed to be 100 pounds per cubic foot.

DEPOSITION OF SAND TRANSPORTED BY THE EEL RIVER

The sand transported by the Eel River to the coast may be deposited in the river's estuary, on the continental margin, or on the nearby beaches.

The estuary at the mouth of the Eel River has several islands, channels, and sloughs, and there is evidence of deposition in the estuary in recent years (Shepard and Wanless, 1971, p. 345, 347). The river itself is tidal for about 4 miles inland (Evenson, 1959, p. 6), and the area of the estuary at high water is 2.6 square miles or 1,660 acres (Johnson, 1972, p. 109). If the average annual long-term sand load (4,600,000 tons) was deposited only in the estuary, the bottom of the estuary would be elevated at a rate of about 1.3 feet per year. The area flooded in December 1964 below the confluence of the Eel River with the Van Duzen River was about 47 square miles and, of course, included the estuary. If the sand load for the 1965 water year at Scotia (80,000,000 tons, table 2) was deposited in the estuary and the adjacent flood plain, the average elevation of those areas would have been raised 1.2 feet. The actual amount of deposition in the estuary and on the flood plain is unknown, but the rates of possible deposition that were calculated above do not seem realistic; therefore, much of the sand transported by the Eel River probably passes through the estuary and into the ocean.

Sediment deposition off the mouth of the Eel River is indicated by the contours of the ocean bottom. Although the 30- and 60-foot contours parallel the shoreline, the contours from 120 to 240 feet show a convex bulge. The present sediment loads also may be spread over the continental margin as a blanket deposit, or they may form a submarine fan similar to the fan that was formed in Pleistocene time (Silver, 1971, p. 2969).

Along the California Coast, submarine canyons are major traps or conduits for littoral sediment. Although the Eel Canyon comes within 7 miles of the mouth of the Eel River, Silver (1971, p. 2969) reported that the fan at the mouth of the canyon was surprisingly small in view of the large sediment loads carried by the river. On the other hand, Greene and Conrey (1966), interpreting seismic records near the head of the canyon, found a buried canyon that extended shoreward from the present-day canyon. This buried canyon consisted of two branches. One other branch was oriented toward the south part of Humboldt Bay. In the past, sediment deposited by the Eel River may have filled this part of the canyon and now perhaps is filling the head of the present canyon.

The stretch of beaches along the coast north and south of the mouth of the Eel River at Humboldt Bay would seem to be an obvious place for deposition of the stream-borne sand. In order to determine whether the Eel River is contributing a major amount of the beach sand, 31 sand samples were collected from the beaches during November 12-15, 1964 (fig. 4).

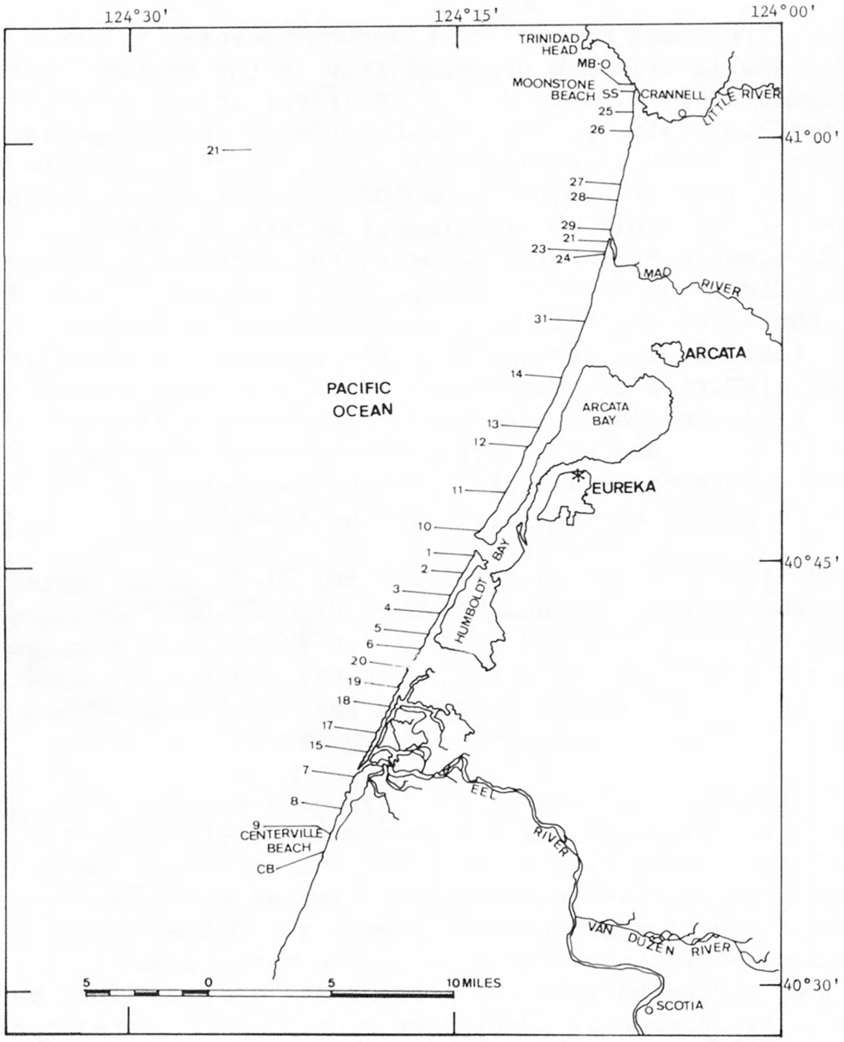


FIGURE 4.--Beach-sampling sites.

The grain-size parameters and mineral content of the sand were determined to try to find clues to the source of the sand. One set of samples, however, may show only the prevailing conditions at the time of sampling and not the general conditions. However, Snow (1962) collected samples from eight sites along the beaches at various times during 1958-60 and demonstrated that the temporal variation in median size of the samples was not appreciable. Therefore, a single sampling may well be representative. The set of samples collected during November 12-15, 1964, from that part of the beach subject to wave action at midtide stage was seived at half-phi[1] intervals; statistical parameters of the grain size (table 3) were determined in the manner described by Folk (1961, p. 43-47). The graphic mean grain sizes of the sampled beach sediment ranged from fine sand to coarse sand (table 4) except for sample 24, the mean grain size of which was in the pebble class. That sample, taken about 100 feet south of sample 23, was collected only to show localized coarseness and was the only sample not selected randomly. Because of this bias, sample 24 was not used in the statistical analysis of the data.

TABLE 3.--*Grain-size parameters and percentage of heavy minerals of samples collected along the coast between Centerville and Moonstone Beaches*
[See figure 4 for location of samples.]

Sample	Graphic mean (ϕ)	Primary mode (ϕ)	Inclusive graphic standard deviation (ϕ)	Inclusive graphic skewness	Graphic kurtosis	Heavy minerals (percent)
			Centerville Beach to mouth of Eel River			
CB	1.46	1.45	0.30	-0.02	1.01	9.7
9	1.20	1.15	.38	-.06	.97	4.1
8	1.43	1.45	.34	-.08	.97	3.7
7	1.66	1.65	.33	-.04	1.10	40.5
			Mouth of Eel River to entrance to Humboldt Bay			
15	1.37	1.35	.37	.12	1.03	.9
17	1.66	1.60	.30	.00	1.03	8.9
18	1.70	1.70	.33	-.03	1.09	4.6
19	1.45	1.55	.42	-.12	1.00	4.2
20	1.16	1.15	.43	-.08	.99	2.2
6	1.73	1.65	.31	.03	1.06	14.8
5	1.47	1.60	.51	-.28	1.23	5.9
4	1.64	1.65	.33	.02	1.04	14.5
3	1.96	1.95	.30	.06	1.00	12.3
2	1.89	1.90	.28	.03	1.02	4.4
1	2.14	2.10	.29	.05	1.00	5.3
			Entrance to Humboldt Bay to mouth of Mad River			
10	2.11	2.10	.31	-.04	.99	6.7
11	1.61	1.55	.32	-.02	.99	2.2
12	1.78	1.80	.29	.03	1.02	2.5
13	1.88	1.85	.30	.03	1.00	2.8
14	2.11	2.10	.28	-.03	1.02	4.0
31	2.23	2.20	.26	-.01	1.05	8.0
24	-3.18	-3.10	.55	.01	.99	---
23	2.07	2.05	.36	-.10	1.00	2.5
21	.22	-.60	1.41	.23	.78	4.2
			Mouth of Mad River to Moonstone Beach			
29	1.82	2.10	.83	-.55	1.82	2.8
28	2.22	2.20	.26	-.01	1.05	8.0
27	2.22	2.20	.30	-.02	1.00	4.2
26	2.47	2.45	.22	-.07	.97	2.9
25	2.50	2.55	.23	-.12	1.04	5.8
SS	2.50	2.55	.24	-.10	.98	6.0
MB-0	2.53	2.55	.22	-.03	1.00	5.9
Range	-3.18 to 2.53	-3.10 to 2.55	0.22 to 1.41	-0.55 to 0.23	0.78 to 1.82	0.9 to 40.5
Average	1.65	1.65	.37	-.04	1.04	6.6
Median	1.78	1.80	.30	-.02	1.00	4.3

TABLE 4.--*Grade scales of particles*

Wentworth (1922) size classification	Phi	Millimeter
Boulder		
	-8	256
Cobble	-7	128
	-6	64
	-5	32
Pebble	-4	16
	-3	8
	-2	4
Granule		
	-1	2
Sand: Very coarse		
	0	1
Sand: Coarse		
	+1	1/2
Sand: Medium		
	+2	1/4
Sand: Fine		
	+3	1/8
Sand: Very fine		
	+4	1/16
Silt: Coarse		
	+5	1/32
Silt: Medium		
	+6	1/64
Silt: Fine		
	+7	1/128
Silt: Very fine		
	+8	1/256
Clay		

[1]Phi (ϕ) = $-\log_2 D$ where D is the intermediate particle diameter in millimeters (Krumbein and Pettijohn, 1938, p. 84, 244).

Among the samples, the graphic mean and the primary mode were the only grain-size parameters that showed differences. The mode and mean were approximately the same for most samples and, therefore, only the mean grain size was used to determine significant changes.

According to data shown in figure 5, the mean grain size of the beach sand became finer as the distance from the mouth of the Eel River increased. Most samples south of the entrance to Humboldt Bay had mean grain sizes coarser than the median mean grain size of all the samples; conversely, the mean grain sizes of the sediment north of the entrance were mostly finer than the median. The tau test for linear trends indicates that there is a significant trend ($p<0.05$) toward finer sand in a northward direction. This trend suggests that the source of the sand is the Eel River because sediment normally tends to become finer with distance from its source area. Snow's (1962, p. 23-24) sampling at eight sites along the beaches during 1958-60 also showed that the sand south of the Eel River was coarser than the sand to the north. However, the accumulation of sediment along the north jetty at the entrance to Humboldt Bay is larger than the sediment accumulation along the south jetty, an indication that littoral drift is chiefly toward the south (Noble, 1971; Shepard and Wanless, 1971, p. 347). The long sand spit just north of the mouth of the Eel River also suggests a predominantly southward drift. Littoral drift is chiefly to the south along most of the California Coast. The diminishing sizes of sand particles from south to north, thus, may be caused by factors other than distance from the sand source. These factors include differences in wave energy, protection by the coastline from wave action, and differences in sources for the sediment deposited in different areas. Wave energy may change along a shore because of the offshore topography, and areas of the beaches where more wave energy is expended usually have coarser sediment (King, 1959, p. 163). Except near the mouth of Little River where Trinidad Head probably provides some protection from waves approaching from the north, the beaches are open to relatively uniform wave attack.

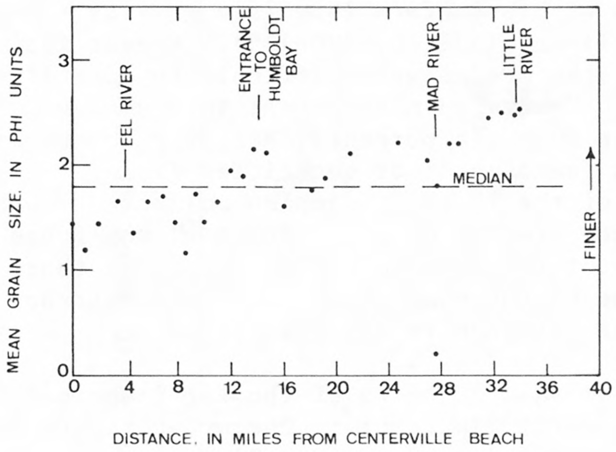


FIGURE 5.--Graph of relation of mean grain size of beach samples to distance from Centerville Beach.

Statistical analyses (T-test, rank test) showed that there was a significant difference ($p<0.05$) in the means of the grain sizes of the beach sand sampled north and south of the entrance to Humboldt Bay. This difference perhaps can be explained as sediment coming from two different sources. The sediment north of the entrance to Humboldt Bay may come from the Mad and Little Rivers, whereas the sediment south of the entrance to the bay may come from the Eel River. Even though the predominately southward direction of littoral drift would favor transportation to the study beaches of sediment discharged by the Mad and Little Rivers, the littoral drift may reverse direction often enough for the Eel River to supply the beaches between the river's mouth and the entrance to Humboldt Bay. This hypothesis assumes that Humboldt Bay and the jetties at its entrance provide effective barriers to the interchange of large quantities of sand from the Eel and Mad Rivers. Humboldt Bay probably does not entrap much of the sand carried by the Eel River. The areal extent of Humboldt Bay at high water is about 28 square miles (Johnson, 1972, p. 105). If the bay captured a large part of the sand discharge of the Eel River, it would be filling at the rate of about 0.1 foot per year and would be filled within a hundred years.

The beach samples and samples taken from the Eel, Van Duzen, Mad, and Little Rivers were analyzed for heavy-mineral composition. The heavy minerals were separated from the light minerals with bromoform (specific gravity - 2.87) by standard methods (Krumbein and Pettijohn, 1938, p. 320-325). Except for garnet, which occurred as pink shards, the grains were difficult to identify mineralogically. The Eel River sediment averaged more garnet in its heavy mineral suite (12 percent) than the Van Duzen (4 percent), Mad (1 percent) and Little (1 percent) Rivers. Garnet was found in minor quantities (1 to 3 percent) in the heavy minerals of 9 of the 15 beach samples collected south of the entrance to Humboldt Bay; garnet, also in minor quantities, was found in 5 of the 15 samples collected north of the entrance. This suggests that the Eel River contributes more sediment to the beaches south of the entrance to the bay than to beaches north of the entrance to the bay.

Of the four rivers sampled, fluvial-sand deposits of the Eel River had the highest percentage of heavy minerals (11.7 percent). The other rivers had less than half that much (Van Duzen River, 5.8 percent; Mad River, 3.2 percent; and Little River, 3.5 percent). Except for the Mad River these averages were made on grain counts of one sample only; not enough to draw more than tentative conclusions. The indication is, however, that the sand transported by the Eel River contains a higher percentage of heavy minerals than the other rivers.

The heavy minerals in the sampled beach sand ranged from 0.9 to 40.5 percent and averaged 6.6 percent. Figure 6 shows that 10 of the 15 samples collected south of the entrance to Humboldt Bay had a heavy-mineral composition larger than the median percentage and conversely the heavy-mineral composition of only 5 of 15 samples collected north of the bay entrance was larger than the median. The heavy-mineral composition of the samples collected south of the bay entrance averaged 9.1 percent and even averaged 6.8 percent when the sample containing 40.5 percent heavy minerals was omitted. The samples from north of the bay entrance averaged 4.1 percent heavy minerals. The rank test ($p<0.10$) suggested that there was a significant difference between the amount of heavy minerals in the samples collected north and south of the entrance to Humboldt Bay. Therefore, the total heavy-mineral content of the beach sands provided another indication that the sources of the sand north and south of the bay entrance were different.

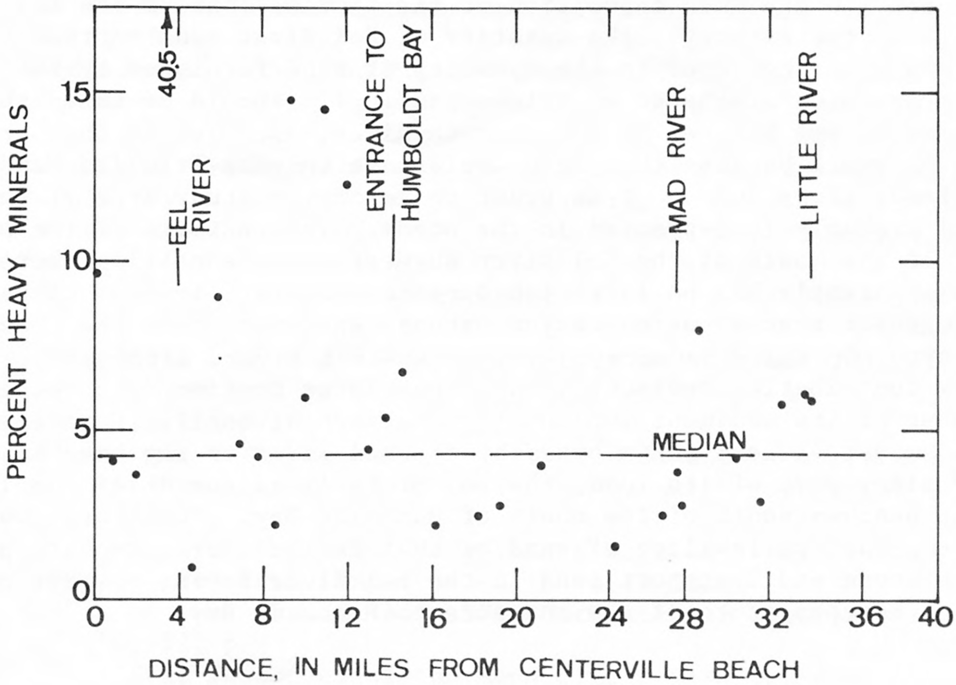


FIGURE 6.--Graph of relation of percentage of heavy minerals in beach samples to distance from Centerville Beach.

The differences in mean grain size, amount of garnet, and heavy-mineral composition of the samples from north of the entrance to Humboldt Bay, compared to samples from south of the bay entrance, indicate that sand from south of the bay entrance may have come mostly from the Eel River basin and that the sand from north of the bay entrance may have come from the Mad and Little Rivers. Certainly the beaches in each area are different. The beaches north of the bay entrance are more extensive, are wider, and are backed by large dunes--some rising 80 feet above mean sea level (Cooper, 1967, p. 31). Dunes south of the bay entrance rise less than 10 feet above mean sea level. Thus, it would seem that if the Eel River is the source of most of the sand on the beaches south of the bay entrance, the volume of sand deposited is not as much as the volume deposited on beaches north of the bay entrance or it is being removed more rapidly. It is not readily apparent why the amount of sand on the beaches south of the Eel River mouth is so scanty. Southward littoral drift along the coast should supply enough sand to make the beaches much wider and the dunes much higher.

In conclusion, the dimensions of the Eel River estuary are not large enough to accommodate much deposition of the fluvial load of the Eel River without filling the estuary. The quantity of Eel River sand carried to the beaches seems minor compared to the quantity of sand furnished by the Mad and Little Rivers, which discharge much less sand. (It should be noted that the sand supplied to the beaches by the Klamath River, 35 miles to the north, is assumed to be small because the sand would have to pass Trinidad Head and other headlands along the coast in order to reach the study area.) Thus, most of the sand probably is deposited in the ocean. The contours of the ocean floor west of the mouth of the Eel River suggest some deposition there. The Eel Canyon apparently has no large fan deposits (Silver, 1971), but geophysical evidence suggests that a buried canyon extends shoreward from the head of the present canyon (Greene and Conrey, 1966). The Eel River, although undoubtedly contributing sediment to all the places mentioned above, clearly deposits most of its sediment load on the continental shelf. However, even though the amount of sand contributed by the Eel River to the beaches may be a relatively minor part of its load, the Eel probably is the chief supplier of sand to the beaches south of the mouth of Humboldt Bay. Therefore, works of man that decrease availability of sand or that decrease or attenuate peak flows which erode and transport sand in the Eel River basin, may affect the condition of beaches south of the entrance to Humboldt Bay.

REFERENCES

Brown, W. M., III, and Ritter, J. R., 1971, Sediment transport and turbidity in the Eel River basin, California: U.S. Geol. Survey Water-Supply Paper 1986, 70 p.

Cooper, W. S., 1967, Coastal dunes of California: Geol. Soc. America Memo. 104, 131 p.

Evenson, R. E., 1959, Geology and ground-water features of the Eureka area, Humboldt County, California: U.S. Geol. Survey Water-Supply Paper 1470, 80 p.

Folk, R. L., 1961, Petrology of sedimentary rocks: Austen, Texas, Hemphill's, 154 p.

Greene, H. G., and Conrey, B. L., 1966, Seismic investigation of Eel Submarine Canyon, Humboldt County, California (abs.): Am. Assoc. Petroleum Geologists bull., v. 50, no. 3, p. 648.

Hawley, N. L., and Jones, B. J., 1969, Sediment yield of coastal streams in northern California, 1958-64: U.S. Geol. Survey open-file rept., 19 p.

Holeman, J. N., 1968, The sediment yield of major rivers of the world: Water Resources Research, v. 4, p. 737-747.

Johnson, J. W., 1972, Tidal inlets on the California, Oregon, and Washington coasts: California Univ., Berkeley, Hydraulic Engineering Lab., Rept. HEL-24-12, 156 p.

Judson, Sheldon, and Ritter, D. F., 1964, Rates of regional denudation in the United States: Jour. Geophys. Research, v. 69, no. 16, p. 3395-3401.

King, C. A. M., 1959, Beaches and coasts: London, Edward Arnold, 403 p.

Knott, J. M., 1971, Sedimentation in the Middle Fork Eel River basin, California: U.S. Geol. Survey open-file rept., 60 p.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts, 532 p.

Noble, R. M., 1971, Shoreline changes, Humboldt Bay, California: Shore and Beach, v. 39, no. 2, p. 11-18.

Norris, R. M., 1964, Dams and beach-sand supply in Southern California *in* Papers in marine geology (Shepard commemorative volume): New York, MacMillan, p. 154-171.

Porterfield, George, and Dunnam, C. A., 1964, Sedimentation of Lake Pillsbury, Lake County, California: U.S. Geol. Survey Water-Supply Paper 1619-EE, 46 p.

Ritter, J. R., 1967, Bed-material movement, Middle Fork Eel River, California: U.S. Geol. Survey Prof. Paper 575-C, p. C219-C221.

Shepard, F. P., and Wanless, H. R., 1971, Our changing coastlines: New York, McGraw Hill, 592 p.

Silver, E. A., 1971, Tectonics of the Mendocino triple junction: Geol. Soc. America Bull., v. 82, p. 2965-2978.

Snow, D. T., 1962, Beaches in northwestern California: California Univ., Inst. of Engineering Research Tech. Rept., ser. 14, issue 25, 74 p.

Wentworth, C. K., 1922, A scale of grade and class terms of clastic sediments: Jour. Geology, v. 30, p. 377-392.

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849