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HUMBOLDT BAY, CALIFORNIA
A LITERATURE SURVEY

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FOREWORD

The Literature Survey of Humboldt Bay, California, has been completed by the Department of Oceanography of the University of Washington as authorized by the U. S. Navy Hydrographic Office Contract No. N62306s-303. The Department of Oceanography has provided a listing and analysis of published and unpublished literature.

The form of the paper is essentially that of an abstract of the current knowledge on each subject studied. These abstracts are not purported to be finished articles and should only be considered unpublished records subject to revision. Time allowed for preparation precluded refinement. Following each subject is an annotated bibliography of relevant publications and unpublished reports and data, whether used in the abstract or not.

Thirty-five copies of this report, including the annotated bibliography, were submitted to the U. S. Navy Hydrographic Office. A limited number of additional copies have been made. Only two reports, complete with all enclosures (drawings and original data), were assembled. One complete report was submitted to the U. S. Navy Hydrographic Office; the other is on file at the University of Washington.

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SECTION I

GEOGRAPHY

GEOGRAPHY

PHYSICAL GEOGRAPHY

LOCATION

Humboldt Bay, a harbor on the coast of northern California, is 216 nautical miles north of the San Francisco Lightship and about 180 nautical miles south of Coos Bay, Oregon.

Adjacent Harbors

Humboldt Bay is the only existing harbor of any commercial importance, or of value for refuge, to large vessels between San Francisco and Coos Bay, Oregon. The nearest improved harbors useful to small craft are at Nayo River, 95 nautical miles to the south, and at Crescent City, 64 nautical miles to the north.

DESCRIPTION OF THE AREA

The width of the bay varies from one-half to about four miles, and the length is 14 miles. The high and low water areas are 24.5 and 7.8 square miles, respectively. The entrance is protected by two rubble-mound jetties, which are about one-half mile apart, and extend from the ends of two long, narrow sand spits separating the bay from the ocean.

The southern portion of Humboldt Bay extends about four miles south from the entrance, widening gradually from one-half mile to two and one-quarter miles. A dredged channel extends for some two miles from the entrance to Fields Landing, which lies about midway along the east side of the South Bay.

North of the entrance, a fairly deep natural channel closely follows the north spit for about four miles to the junction of the Samoa and Eureka Channels. The latter channel, following Eureka Slough, is dredged for almost two miles along the waterfront of the city of Eureka. The northern or Samoa Channel is dredged across Indian Island Shoal for about one mile to Samoa on the north spit. A natural channel extends in a northeasterly direction from Samoa, through the shoal waters of Arcata Bay to a channel about one mile long originally dredged to serve the city of Arcata (U. S. Army Corps of Engineers 1951).

The Surrounding Area

Humboldt Bay is in a generally mountainous region forested with redwood, fir, pine, and other species. In the immediate vicinity of the bay are plains and low hills partially devoted to farming.

CULTURAL GEOGRAPHY

DISCOVERY OF HUMBOLDT BAY

Humboldt Bay was discovered by Captain Jonathan Winship in 1806, when temporarily in the service of the Russian American Company. The Bay was first named the Bay of Rezanof after the Russian Chamberlain whose agents had engaged him to make the voyage. The Indian name for the Bay was Qual-a-wa-loo (Davidsen 1891; Lewis 1943).

INDUSTRY BORDERING HUMBOLDT BAY

The bay serves as an outlet for the timber resources of Humboldt and Del Norte Counties and adjacent areas. These two counties have a population of 61,500 including 21,380 at Eureka, the largest city. They contain nearly 70 percent of the world's stand of redwood timber. Processing of forest products is the most important industry in the tributary area (U. S. Army Corps of Engineers 1951).

Pollution in Humboldt Bay

The California State Department of Public Works Division of Water Resources (1952) completed a survey of industrial waters entering the Bay and an investigation of waste discharges from the whaling station and community sewers at Fields Landing.

Field work consisted of sampling and flow measurements at hourly intervals for eight consecutive hours. Dissolved oxygen tests were made of all samples, following which they were composited in proportion to the rate of discharge. All samples were analyzed for suspended and volatile solids, five-day 20° C. biochemical oxygen demand, and mineral constituents. Waste from the plywood manufacturing plants was analyzed for phenol, while the tallow works effluent and the Fields Landing sewage were tested for ether-soluble matter and organic nitrogen. The following paragraphs are reproduced from the above mentioned reference:

Samples of industrial waste from the plywood factories displayed values of BOD ranging from 170 to 5,600 parts per million, suspended solids from 330 to 10,500 parts per million and phenol concentrations from 0.15 to 20 parts per million. It is evident that such wastes could be very troublesome if discharged in large amounts. Fortunately, the discharges are small (2 to 40 gallons per minute) and their capacity for harm is correspondingly limited. The following tabulation shows the population equivalents of the plywood and tallow plant wastes based on biochemical oxygen demand:

Mutual Plywood Company	165
Humboldt Plywood Corporation	235
Eureka Plywood Company	670
Eureka Tallow Company	120
Total	<u>1,190</u>

Waste discharges of the Eureka Tallow Company, Hunter and Poland's Fish Reduction Works and the village of Fields Landing were all weak and (except for the tallow plant) very small in volume. However, they are capable of causing localized pollution and nuisance due to odors, grease, discoloration, and unsightly floating and suspended matter. Such conditions were, in fact, observed near the outfall of Mutual Plywood, where a flocculent precipitate was seen; at Eureka Plywood where a black waste discolored the water within 50 feet of the point of discharge; and at Fields Landing, where odors, floating solids, and grease were found on the beach.

In general, good house keeping is observed by riparian lumber firms on Humboldt and Arcata Bays with respect to disposal of wood chips and bark. It is the prevailing practice to skim the log ponds regularly one or more times a week and to burn the material so removed in the plant sawdust burner.

HARBOR MODIFICATION PROJECTS

The following paragraph from the U. S. Army Corps of Engineers (1951) summarizes work done in the harbor:

The first Corps of Engineers' project for the improvement of Humboldt Bay was adopted by the River and Harbor Act of March 3, 1881. Work was begun under contract in 1881 and a channel dredged 10 feet deep, 240 feet wide, and 4,100 feet long in front of Eureka. Dredging of the Samoa and Arcata Channels as well as a channel to Hookton began shortly thereafter. The River and Harbor Act of July 5, 1884, provided for a single rubble-mound jetty along the south side of the Entrance Channel. This project was modified in 1888 and again in 1891 to provide for two parallel rubble-mound jetties, including shore protection enrockment. Construction of the south jetty began in 1889 and the north jetty in 1891. The original jetties have since been entirely rebuilt. The existing project provides for two rubble-mound jetties at the entrance, the north jetty about 4,500 feet in length and the south jetty 5,100 feet long, not including shore revetments; for an entrance channel 30 feet deep and 500 feet wide; for a channel 26 feet deep and 400 feet wide from deep water in Humboldt Bay to the foot of N Street, Eureka; a channel 26 feet deep and 300 feet wide across Indian Island Shoal to Samoa; a channel 18 feet deep and 150 feet wide to Arcata wharf; and a channel 26 feet deep and 300 feet wide to Fields Landing, with a turning basin

26 feet deep, 600 feet wide, and 800 feet long off the Fields Landing wharf. The project was completed in 1939.

Navigation

No navigation improvements other than those of the Corps of Engineers' project have been made (U. S. Army Corps of Engineers 1951).

Bridges

No bridges exist across any portion of Humboldt Bay proper (U. S. Army Corps of Engineers 1951).

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SECTION 2

CLIMATOLOGY

CLIMATOLOGY

PRECIPITATION

The rainfall in the Humboldt Bay area is typical for the coastal region of northern California. The well-known wet and dry season of the western slope of the Pacific Coast prevails. The winter months of December, January, and February, are the wettest with about 6.5 inches per month. The summer, June, July, and August, are dry with only about 0.3 inch per month. The spring and fall average 3.4 and 2.7 inches per month respectively. The heaviest rains occur in the winter with 52% of the days having precipitation of 0.01 inch or more per day. In the summer only about 10% of the days have 0.01 inch or more of rain. The spring and fall are intermediate.

The following tabulation from the U. S. Department of Commerce Weather Bureau (1952) concerns the maximum 24-hour precipitation for the town of Eureka, California, from 1888 to 1952:

Jan 1903 - 5.10"	Jul 1916 - 1.18"
Feb 1890 - 4.91"	Aug 1907 - 2.63"
Mar 1907 - 3.94"	Sep 1895 - 2.77"
Apr 1896 - 2.87"	Oct 1908 - 3.61"
May 1895 - 2.24"	Nov 1926 - 4.55"
Jun 1888 - 1.99"	Dec 1939 - 4.17"

The average monthly precipitation for Eureka, including snowfall, is tabulated in Table 2-1.

TEMPERATURE

The yearly temperature is mild, with extreme highs or lows being uncommon. The temperature ranges from a monthly average of 47° F. in January to 56° F. in July, August, and September. The lowest temperature recorded at Eureka, California, by the U. S. Department of Agriculture Weather Bureau (1934) was 20° F. in January 1888. The usual low for January is between 30° and 35° F. On the average, the temperature falls to 32° F. or below, only 3 days per year. The summer temperature seldom, if ever, reaches 90° F.

The average temperature data from 1887 to 1930 at Eureka, California, is tabulated in Table 2-2.

TABLE 2-1. Precipitation, Eureka, California. [In inches]

Month	Average	No. of Days with 0.01" or more	Total Amt. for Driest Yr.	Total Amt. for Wettest Yr.	Snowfall 24 hours	
					Average	Greatest Amount
Length of re- cord (Years)	53	44	53	44	44	44
Jan	7.0	17	4.3	5.2	0.2	3.0
Feb	6.3	15	2.1	16.1	0.1	1.5
Mar	5.1	15	2.3	19.0	0.1	1.8
Apr	3.4	12	2.6	5.1	Trace	0.1
May	1.7	9	0.1	1.0	0	0
Jun	0.7	5	2.4	0.6	0	0
Jul	0.1	2	Trace	0.8	0	0
Aug	0.2	2	Trace	Trace	0	0
Sep	1.0	5	0	1.4	0	0
Oct	2.3	9	0.2	2.7	0	0
Nov	5.0	13	Trace	4.4	0	0
Dec	6.2	16	7.1	8.2	Trace	Trace
Annual	39.0	120	21.1	64.5	0.4	3.0

Table compiled from U. S. Department of Agriculture Weather Bureau (1934).

TABLE 2-2. Monthly and Annual Averages and Extremes of Temperatures,
Eureka, California.

Month	Average	Average of Maxima	Absolute Maximum	Average of Minima	Absolute Minimum	Highest Monthly Average	Lowest Monthly Average
Length of record (Year)	44	44	44	44	44	44	44
Jan	47	53	77	41	20	51	42
Feb	48	54	85	42	24	52	41
Mar	48	54	78	42	29	53	44
Apr	50	56	79	44	31	55	46
May	52	57	78	47	35	55	49
Jun	54	59	85	50	40	59	52
Jul	56	60	73	52	43	58	52
Aug	56	60	79	52	45	60	53
Sep	56	61	82	50	36	58	53
Oct	54	60	84	48	35	57	50
Nov	51	58	81	45	27	56	48
Dec	48	54	70	42	24	52	43
Annual	52	57	85	46	20	—	—

Table compiled from U. S. Department of Agriculture Weather Bureau (1934).

VISIBILITY AND FOG

The records of the U. S. Department of Commerce Coast and Geodetic Survey (1951) show that the fog or low visibility maximum occurs during the summer and early autumn. The months of July through October average about 159 hours of fog signal operation at the Coast Guard Light Station. During the months of November through June the fog signal is used about 52 hours per month.

Table 2-3 gives the monthly hours of operation of the fog signal, the average occurrence of low visibilities, and the average occurrence of dense fog, as listed by the U. S. Department of Commerce Coast and Geodetic Survey (1951). Information concerning wind, direction and force, barometer readings, dry temperature, amount and type of clouds, visibility as well as direction and height of sea, is available from the log of the U. S. Coast Guard Lighthouse Station, Samoa, California.

The U. S. Army Corps of Engineers (1927) make the following statement concerning fog:

Fogs are liable to occur here at any time, but are more frequent from July to October. High fogs of long duration are frequent in the summer. These summer fogs are very persistent over the approaches to Humboldt Bay, sometimes continuing for weeks at a time, with an occasional lightening up in the middle of the day. The annual average number of hours of fog at the Humboldt Bay fog signal, which is located at the entrance, on the southern extremity of the north spit, based on records of the past 17 years, is 965 hours.

The recent records of the number of hours of foghorn operations, as taken directly from the log of Humboldt Bay Light Station, Samoa, California, is tabulated below. The visibility must be less than 8 miles before the foghorn will be put into operation.

Nov 1953 - 202 hours	Aug 1954 - 300 hours
Dec 1953 - 188 "	Sep 1954 - 153 "
Jan 1954 - 112 "	Oct 1954 - 327 "
Feb 1954 - 269 "	Nov 1954 - 265 "
Mar 1954 - 33 "	Dec 1954 - 115 "
Apr 1954 - 79 "	Jan 1955 - 182 "
May 1954 - 148 "	Feb 1955 - 131 "
Jun 1954 - 131 "	Mar 1955 - 107 "
Jul 1954 - 212 "	Apr 1955 - 58 "

According to the data compiled by the Landing Aids Experiment Station at Arcata Airport (Gardner and Halloway 1948), the highest incidence of fog is in August, September, and October, with each fog

TABLE 2-3. Fog and Use of Fog Signal, Humboldt Bay, California.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Occurrence of Low Visibilities (% hrs)													
0-1/4 mi	1.9	0.4	0.9	0.6	0.1	2.0	3.1	4.8	6.2	1.8	6.8	6.0	3.8
0-1/2 mi	2.2	0.4	1.2	0.6	0.1	2.3	3.8	6.1	7.3	13.1	7.1	7.2	4.4
0-2 mi	3.1	1.4	3.2	1.4	3.0	4.6	10.0	15.1	12.3	21.7	12.7	12.2	8.5
Average Occurrence of Dense Fog (% hrs)													
	1.9	0.4	0.9	0.6	0.1	1.9	3.1	4.8	6.1	11.8	6.8	5.9	3.7
Hours of Operation of Fog Signal (Mean)													
	42	61	81	28	44	81	148	160	209	190	92	35	1,171

Table from U. S. Department of Commerce Coast and Geodetic Survey (1951), Elevation 60 feet, record of 2 years.

averaging 7 hours in duration. During the rest of the year the fogs last on an average of 3 hours, the month of March having the lowest fog incidence. The foggiest part of the day is between 0600 and 0800; the least foggy between 1300 and 1600. About 70% of the fog is accompanied by a S., SW., W., NW., or calm wind; the remaining 30% occurs during N., NE., E., or SE., winds. At the Arcata Airfield in 1945, 134 fogs occurred in 110 days for a total of 810 hours of fog. In 1947, 140 fogs occurred in 105 days for a total of 504 hours.

The reports and information concerning the meteorological and fog dispersal data for the Landing Aids Experiment Station, at Arcata, California are held by:

Mr. Amos L. Lewis
Acting Chief--Visual Landing Aids
Bureau of Aeronautics. Code AE-10
Navy Department
Washington, D. C.

WIND AND WEATHER

The prevailing winds during the summer are generally from the north and northwest and during the winter from the southeast and southwest with the southeasterly direction being most common. The winds in the immediate region seldom exceed 40 miles per hour.

The Humboldt Bay Lifeboat Station at Samoa, California, logs the wind, weather, sea and visibility data. An approximate average of the above information for the 6 watches on the first, seventh, fourteenth, twenty-first and twenty-eighth day of each month during 1954-55 is tabulated in Table 2-4.

The wind data tabulated by the U. S. Department of Agriculture Weather Bureau (1934), shows that the prevailing winter winds are from the southeast, and the spring winds from the north. The summer and fall have prevailing northwest and north winds respectively (see Table 2-5).

The University of California Waves Research Laboratory obtained wind direction and velocity information in connection with surf studies made at Humboldt Bay in 1944 and 1945. This data is tabulated in Along-shore Transportation, Section 6, in Table 6-5. A Wind Rose for the year 1925, compiled by the U. S. Army Corps of Engineers, is shown on Enclosure 2-1.

Storms

The following quotation from the U. S. Army Corps of Engineers

TABLE 2-4. Humboldt Bay Lifeboat Station, Wind, Weather, and Sea Data.

Date	Wind	Weather ¹	Sea ²	Visibility ³
1 May 1954	E-NW 2	B, BC	M	7
7	Variable 1	F, CF	M	5
14	Variable 3	B, F	M	5
21	NW 5	BC	M	7
28	N-NW 2	BC	M	5
1 Jun	N 3	B, BC	L	7
7	N 2	BC, O, C	M	6
14	W 2	F, C	M	5
21	NE, NW 3	BC	M	6
28	SW-NE 3	B	L-M	7
1 Jul	W-N 4-5	B, BC	M	7
7	NW-Calm 2-3	O, C	M	6
14	N-NW 2	O	L	6
21	NW 4-5	BC, B	M	7
28	SW-NW 3	B, F	M-S	4
1 Aug	N-NW-W 2	OF	M	5
7	SW-N 2	F	M	4
14	E-N-W 1-2	OF, BC	L	7
21	W-N 1-2	F	L	4
28	SE-NE-N 2	BC	L	7
1 Sep	NW 2	FO	L	5
7	NW 2	BC	L	7
14	S-SE-E	RC	L-M	6
21	Calm-N-NW 2	O, C	M	5-6
28	SE-N-NW 3	BZ	S	6
1 Oct	NW-NE 2	F, B	M	3
7	SE-N-SW 3	B, C, F	R-S	5-6
14	Variable 2-3	BC	S-M	6
21	N-E-S 4	BC	M	5
28	E-2	BF	M-S	5
1 Nov	NE-S-SE 2	B, F, Q	M	6
7	E-SE 5	D, Q	M	7
14	SE 5	CQ, Cu, Op	M	7
21	Calm-SW 2	F	M	3
28	NW-SE-NE 3	B, C	M	8

TABLE 2-4. Humboldt Bay Lifeboat Station. Wind, Weather, and Sea Data.
(continued).

Date	Wind	Weather ¹	Sea ²	Visibility ³
1 Dec 1954	E 6	R	M	8
7	E 3	B, C	M	8
14	SE 1	B, C	M	6
21	NE-W-S-E 1	C, F	M	4
28	S-E-SE 4	C	L	7
1 Jan 1955	SE-N 6	B, R, G	S	6
7	E-N 2	BC, B	M	6
14	NE-E-S 2	B, O, C	M	7
21	SE-E 3	C, R, F	M	4
28	E-NE-N 1	F	L	4
1 Feb	SE-NW-E 1	BC, D, O	M	6
7	E-NW 2	F, BC	M	6
14	NE-N 2	F, OF, O	M	6
21	E-NW-N 2	B, BC	M	7
28	SW-SE 5	C, Q	M	7
1 Mar	SE-E-S 2	Q, OG, CF, C	R	7
7	SE-SW 2'	B, BL, BC, OF	M-L	8
14	NE-NW 2	BC	M-S	8
21	W-E-NW 2	B, C, BC	S-M	8
28	SE 4	Q, BC, D	L	8
1 Apr	W 3	R, RBC, P	M	7
7	SE-N 2	B, F, BC	L	8
14	E-SE-NW 3	BC, D, C	M	8
21	SE-NW 1	O, Cu, R, F	L-M	3-7
28	E-SE-SW 3	C, Q	L	6

¹ Symbols used in recording the weather in tabulated form:

- b = Blue sky, cloudless.
- bc = Blue sky with detached clouds.
- c = Sky mainly cloudy.
- d = Drizzling, or light rain.
- e = Wet air, without rain.
- f = Fog, or foggy weather.
- g = Gloomy, or dark, stormy-looking weather.
- h = Hail.
- l = Lightning.
- m = Misty weather.
- o = Overcast.

TABLE 2-4. Humboldt Bay Lifeboat Station. Wind, Weather, and Sea Data.
(continued).

- 1 Symbols used in recording the weather in tabulated form (continued):
 - p = Passing showers of rain.
 - q = Squally weather.
 - r = Rainy weather, or continuous rain.
 - s = Snow, snowy weather, or snow falling.
 - t = Thunder.
 - u = Ugly appearance, or threatening weather.
 - v = Variable weather.
 - w = Wet, or heavy dew.
 - z = Hazy weather.

- 2 L = light, 0-4 feet; M = medium, 4-8 feet; R = rough, 8-12 feet;
S = strong, above 12 feet.

- 3 Numerals used in recording visibility in tabulated form:
 - 0 = Prominent objects not visible at 50 yards.
 - 1 = Prominent objects not visible at 200 yards.
 - 2 = Prominent objects not visible at 500 yards.
 - 3 = Prominent objects not visible at $\frac{1}{2}$ mile.
 - 4 = Prominent objects not visible at 1 mile.
 - 5 = Prominent objects not visible at 2 miles.
 - 6 = Prominent objects not visible at 4 miles.
 - 7 = Prominent objects not visible at 7 miles.
 - 8 = Prominent objects not visible at 20 miles.
 - 9 = Prominent objects not visible above 20 miles.

Table compiled from U. S. Treasury Department Coast Guard (n. d. a).

TABLE 2-5. Wind Data, Eureka, California.

Month	Prevailing Direction	Average hourly wind velocity (mph)	Maximum Wind Velocity		
			Direction	Velocity	Date
Length of record (Years)	44	43	43	43	43
Jan	SE	7.3	SW	46	1914
Feb	SE	7.4	SW	40	1918
Mar	SE	8.1	SE	38	1904
Apr	N	8.7	N	46	1915
May	N	8.7	NW	37	1896
Jun	N	8.2	N	38	1892
Jul	NW	7.5	N	38	1908
Aug	NW	6.3	N	32	1909
Sep	N	6.2	N	37	1903
Oct	N	6.2	N	34	1906
Nov	SE	6.5	SW	36	1926
Dec	SE	6.8	SW	40	1892
Annual	N	7.3	SW	46	1914

Table compiled from U. S. Department of Agriculture Weather Bureau (1934).

(1927) concerns the frequency of storms and the condition of the inner harbor during such storms:

Storms are frequent in this locality from October to March. The period of greatest frequency is usually from the middle of December to the middle of February, when they are usually accompanied by heavy rains.

As noted above, violent storms are of rare occurrence and are from the southeast, south, and southwest. The south and southeast storms are generally of longer duration and the southwest storms are the most violent.

In the spring northerly storms with little rain are often experienced. These, however, usually last not more than three days and are seldom experienced more than two or three times in one season, whereas the southerly winter storms are often of long duration and one storm after another may be experienced over a period of several weeks, accompanied by heavy rains.

Very severe seas occur at the entrance to the bay, the worst seas occurring frequently as the result of offshore storms at times when conditions are calm locally.

Except for an entrance about 2,000 feet wide, the bay is a land-locked harbor with its major axes nearly north and south. During southerly and southwesterly storms, there is little to obstruct the wind, as the sand spits to the west are low except at the northerly end of the bay. The channel in front of Eureka, however, is nearly east and west and lies in the lee of the higher land on which the town is situated. Waves from onshore storms are broken up by the bar and the sand spits, and wave action within the bay, except near the entrance, is comparatively small. Hence, moderate and large-size vessels find good shelter in the bay, but the smaller craft must seek shelter usually in the nearby sloughs or in the channel in front of Eureka, the wharves of which lie under the lee of the shore during the worst storms.

The entrance channel is obstructed by a sand bar. The main channel through this bar is now 25 feet deep, which depth has been obtained by parallel jetties which have been recently rebuilt. The bar is subject to changes and in time of storm is a menace to navigators, due to heavy breakers. This condition has been greatly improved by the jetties and the channel has become deeper and more fixed. Nevertheless, few vessels now attempt to cross the entrance bar in time of storm.

Sky Conditions

In general the sky conditions are slightly more favorable during the summer months. The greatest amount of possible sunshine occurs between April and July. Table 2-6 summarizes the monthly sky conditions for Eureka, California.

SPECIAL PHENOMENA

The occurrence of solid moving masses has been repeatedly noted on the Ground-Control-Approach Radar at Arcata Airport, Arcata, California. These unidentified radar echoes, which have been called "Angels," occur on all AN/GPN-2 sets in the area. The following lists some of the characteristics of these echoes:

- (1) travel about 30 mph.
- (2) no relation to surface winds.
- (3) under 3000 feet in elevation.
- (4) not peculiar to the instrument since more than one was used.
- (5) magnetic heading of object 120° - 180° .
- (6) aircraft have been sent into region but nothing was ever spotted.
- (7) the reflectors on screen looked like "planes."

All information concerning this matter has been turned over to Mr. Lewis Alvarez at the University of California at Berkeley, California.

TABLE 2-6. Average Monthly Sky Conditions.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Clear days	6	6	7	8	8	9	7	6	9	9	7	7	89
Partly Cloudy days	8	7	9	10	11	11	13	12	10	9	8	8	116
Cloudy days	17	15	15	12	12	10	11	13	11	13	15	16	160
Average Cloudiness (0-10)	6.7	6.7	6.5	6.0	5.9	5.5	5.9	6.3	5.6	5.8	6.5	6.6	6.2
Average# hours of sunshine	117	129	176	216	242	253	230	187	186	164	120	119	2139
% possible sunshine	39	42	48	52	54	55	50	44	49	48	42	41	47

Table compiled from U. S. Department of Commerce Weather Bureau (1951).

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SECTION 3

HYDROLOGY

HYDROLOGY

SURFACE WATER

The drainage area tributary to Humboldt Bay comprises 223 square miles. The principal streams are Jacoby Creek, Mad River slough, and Eureka slough to the north and northeast, Elk River to the east, and Hookton slough to the south. Except for log rafting and the boating engaged in by sportsmen, the tributary streams are seldom used for navigation (U. S. Army Corps of Engineers 1951).

WATER SUPPLY RECORDS

Water Supply Papers published by the Geological Survey contain records for daily discharge of the Eel River at Scotia, Van Duzen River at and near Bridgeville, Mad River near Arcata, and Yager Creek near Carlotta. Miscellaneous measurements made on Jacoby Creek are available in the files of the U. S. Geological Survey in San Francisco. During 1955 a recording gage was placed on Jacoby Creek for the city of Eureka for which daily discharge records will be available.

In addition, the Eureka office of the U. S. Bureau of Reclamation has results of miscellaneous measurements on other small streams draining into Humboldt Bay (U. S. Department of the Interior Geological Survey 1955b).

CHEMICAL ANALYSES OF STREAM WATER

In addition to information published by the U. S. Geological Survey (Lohr and Love 1954) on chemical analyses of river waters, the Division of Water Resources of the State of California has obtained certain data. This Division has collected samples for water composition analysis at various points on the Mad River, between 1950 and 1953 as well as other streams tributary to Humboldt Bay (California State Department of Public Works 1955). This information, together with a sample location map, is provided as Enclosure 3-1.

GROUND WATER

The following information was provided by the U. S. Department of the Interior Geological Survey (1955a) concerning ground water:

In general, some ground water moves into Humboldt Bay from alluvial deposits along streams draining into the Bay. The principal ones are Salmon, Jacoby, and Freshwater Creeks and Elk

River. Some ground water also is discharged into the Bay from the alluvial plain north of the Bay, and a small amount may enter from the consolidated rocks bordering the Bay in the vicinity of Eureka. Information is not available to indicate the amount contributed by the various sources or the total.

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SECTION 4

REGIONAL GEOLOGY

REGIONAL GEOLOGY

PHYSIOGRAPHY

The Humboldt Bay region as well as the Eel and Mad River basins represent partially submerged fossil land surfaces. The oceans formerly penetrated far inland at least into the upper reaches of the Elk, Eel, and Mad Rivers, as well as Freshwater Creek. The land was rejuvenated and in fairly recent times was slightly submerged. This is in evidence by the drowned mouths of the Elk and Eel Rivers. The mouths of Freshwater, Jacoby, and Salmon Creeks, are also partially submerged. Arcata Bay and Mad River Slough represent the drowned mouth of the Mad River which formerly entered Humboldt Bay. Very recent local warping has isolated this from the present day Mad River (Ogle 1951, 1953).

Past land uplift due to warping is shown by the abundance of well developed river terraces on the Eel, Van Duzen, and Yager Rivers. The region from Grizzly Bluff to Rio Dell on the Eel River has numerous well developed gravel capped terraces (Ogle 1951, 1953).

From the Mad River south to Centerville Beach, a distance of about 25 miles, most of the coastal area is generally under 50 feet in elevations. Humboldt Bay, including mud flats, varies in width from about $\frac{3}{4}$ of a mile to more than $\frac{1}{2}$ miles and is approximately $\frac{1}{4}$ miles long. The northern portion, Arcata Bay, is the widest and rests in a flat plain about 6 miles wide. Here hills begin to rise about $\frac{1}{2}$ miles in from the bay shore. South Bay is approximately $2\frac{1}{2}$ miles wide. Humboldt Hill, on the east shore of South Bay, rises more than 500 feet above sea level; it is the west end of the Humboldt Anticline. The Bay region is separated from the Eel River by the Table Bluff Anticline, which has an elevation of about 350 feet and may be considered as a spur of the foothills.

The Eel River flats are less than 50 feet above sea level. This is largely a low flood plain approximately 9 miles wide at the coast and $2\frac{1}{2}$ miles wide at Fortuna, 8 miles inland.

South of Centerville Beach elevations of 250 feet and higher are found barely 500 feet from the shore. The alluvium of the Eel River disappears and outcrops of Tertiary sandstones and siltstones make up the shore cliffs. Farther to the south, by False Cape, harder sedimentary and igneous shear zone rocks form the shore cliffs. Here elevations of 1,000 feet are found about 1 to $1\frac{1}{2}$ miles inland. Marine terraces are present in this region.

To the north, near Trinidad Head, the coast is again abrupt with a gradual increase in elevation to about 1,000 feet at points approximately $\frac{1}{4}$ miles inland. The Coast Range which bounds the Humboldt Bay region on

the east is in excess of 4,000 feet, landslides and slumping have had important effects on the geomorphic features and are effective as erosion agents (Ogle 1953). On the coast there are numerous rock slides along the dip planes of the interbedded sandstones. Undercutting by the waves causes large blocks, including vegetation, to slip along the bedding planes and plunge into the ocean.

The shore from Centerville Beach north to the mouth of the Mad River consists of extensive sand beaches. The north and south spit form the west side of Humboldt Bay. The north spit is about 1/2 mile wide and 10 miles long. It is flat and barren near the south end and rises gradually to the north where heavily wooded dunes are present. The south spit extends southward to Table Bluff, the headland marking the southern end of Humboldt Bay. This spit varies in width from 300 to 3,000 feet, being low and barren in its entirety. For further discussion of the beaches see Section 6, RECENT SEDIMENTATION. The physiography of the region has been well considered by Lawson (1894), Watson, Cosby, and Smith (1926), Karinen (1948), and Ogle (1947, 1951, 1953).

STRATIGRAPHY

The immediate area of Humboldt Bay is blanketed with recent alluvium and upper Pleistocene gravels, sands, and clays. Older and more resistant sediments are found to the south, east, and north. The principal stratigraphic studies of the region have been made by Manning (1947), Manning and Ogle (1950), and Ogle (1947, 1951, 1953).

Pre-Tertiary Stratigraphy

The upper Jurassic and possibly lower Cretaceous Franciscan and Yager formations surround Humboldt Bay. These rocks are exposed at the higher elevations. At False Cape, south of the Eel River, the shear zone rocks are primarily Franciscan. The Jurassic Franciscan consists of graywacke, shale, chert, basalt, and shist. The Yager is composed of graywacke, shale, and conglomerate.

Tertiary Stratigraphy

An unconformity separates the Cretaceous and Tertiary strata; the lower Tertiary (Eocene and Oligocene) is missing. The Miocene Pullen formation, a mudstone with some basal sands, is exposed in a narrow strip near False Cape and thence to the east. The upper Pliocene contains three formations; the Eel River, Rio Dell, and Scotia Bluffs. The Eel River sediments are mudstones and sandstones; the Rio Dell contains mudstone, siltstone and thin sandstone while the Scotia Bluffs formation is a massive sandstone. The most extensive exposures of these differentiated

Tertiary sediments extend eastward from the area between False Cape and Centerville Beach. The undifferentiated Wildcat group consists of the entire Tertiary column and the lower Pleistocene Carlotta formation. This group is immediately inland from Humboldt Bay and makes up the foothills of the Coast Range.

Quaternary Stratigraphy

The lower Pleistocene Carlotta formation has small exposures at Table Bluff, Fields Landing, along the Elk River, and in other scattered locations near the shore of the bay. An unconformity separates the lower and upper Pleistocene. The upper Pleistocene deposits are the Hookton and Rohnerville formations composed of gravel, sand, and clay. Terrace deposits were also laid down during the upper Pleistocene. The Hookton and recent alluvium constitute the most common deposit along the shores of the bay. Presumably the recent bottom sediments in the bay rest on the Carlotta formation as well as the Tertiary Rio Dell and Scotia Bluffs formations.

GEOLOGIC HISTORY

Following the deposition of the Yager formation of the lower Cretaceous and upper Jurassic, the region was subjected to extensive erosion with the development of a peneplane. Marine deposition in the Tertiary basin began in the Miocene. This basin probably extended as far south as False Cape and up the present day Eel Valley for at least 20 to 25 miles. Around Humboldt Bay the basin was approximately 12 miles wide, narrowing to the north along an extension of Freshwater Creek. The Pullen, Eel River, Rio Dell, and Scotia Bluffs formations were deposited in this basin. Volcanism accompanied the deposition as is shown by the deposits of ash and basalt.

At the close of the Pliocene and into the Pleistocene, local warping and uplift was accompanied by the deposition of the predominantly non-marine Carlotta formation which also contains volcanic ash.

The mid-Pleistocene was a time of strong orogeny; folding and faulting occurred causing uplift and erosion. The Hookton sediments of upper Pleistocene were deposited in the broad valleys formed during this erosional period. Wave-cut marine terraces and stream terraces also developed. Regional uplift and warping occurred at the close of the Pleistocene (or early Recent); this initiated the formation of new valley plains. The present condition of Humboldt Bay began to develop. The drowned mouths of the rivers indicate that reemergence is not complete or that local sagging exists.

GEOLOGIC STRUCTURE

The most striking structural feature of the region is the eastward trend of the Tertiary sediments. A major structure is the Eel River syncline, which runs east-west and has its axis in the Eel River Valley. The Tomkins Hill, Table Bluff, Fowler, Humboldt, and Pine Hill anticlines all lie north of the Eel River and are all minor features having a westerly plunge.

The pre-Tertiary structure includes the Russ Fault, south of the Eel River, and Freshwater Fault, east of Freshwater Creek. These may well have defined the Tertiary sedimentation basin. Faulting also occurred in Tertiary times. In general, regional folding occurred after the deposition of the Carlotta formation and warping has continued to recent times.

ECONOMIC GEOLOGY

There are many oil seeps in the region, especially to the south of Humboldt Bay. Oil interests have put down exploratory wells. Some of these are located on Table Bluff and Humboldt Hill, both of which flank South Bay. A producing, commercial gas field is located on the Tomkins Hill Anticline (Table Bluff), two miles north of Fortuna.

Sand, gravel, clay, and possibly lignite, are also of some economic value.

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SECTION 5

GEOPHYSICS

GEOPHYSICS

SEISMOLOGY

The coastal region of northern California is an extremely active earthquake area. San Francisco Bay and Humboldt Bay are two of the most seismic areas on the West coast. The San Andreas Fault zone apparently reaches the border of the continental mass near 42° N., 126° W. (Byerly 1940). Most of the epicenters affecting the Humboldt Bay region fall on or near this fault zone.

Seismic Activity

From 1769 to 1952 there have been 255 recorded shocks in the region, 35 of which have been offshore. The force for 117 of these quakes has been scaled on the Rossi-Forel scale; a summation of this follows:

<u>Force</u>	<u>Occurrence</u>	<u>Force</u>	<u>Occurrence</u>
I	0	VI	21
II	6	VII	8
III	29	VIII	9
IV	18	IX	4
V	22	X	0

This data and the listing of the recorded earthquakes in Table 5-1 can be found in Holden (1898), McAdie (1907), Townley and Allen (1939), Clark (1944), and Wood and Heck (1951).

The following descriptions of the quakes of March 1, 1895, April 18, 1906, August 20, 1927, and June 6, 1932, are included to illustrate the severity of the shocks:

1895. March 1; at sea, off the Mendocino (Cal.) coast; longitude $125^{\circ} 20'$; latitude 40° .

The recent earthquake which was reported as having disturbed the inhabitants of Mendocino proved to be a veritable terror at sea, according to the stories told by the crew of the schooners Volant and C. T. Hill, which have just arrived from that section of the coast.

The Volant was about 52 miles off the Mendocino coast, in the vicinity of Shelter Cove, when she encountered the shake-up. It took place a few minutes before 1 o'clock on the morning of March 1.

TABLE 5-1. Earthquake shocks, Humboldt Bay, 1853-1952. [Rossi-Forel Scale]

Date	Intensity ¹	Date	Intensity ¹
24 Apr 1853	III	22 Nov 1873	VIII
23 Oct 1853	VIII	27 Aug 1877	
24 Oct 1853	III	3 Jan 1883	light
20 Aug 1854		27 Jan 1884	VII
17 Sep 1854		6 Apr 1884	III
26 Sep 1854		8 Apr 1884	III
2 Oct 1854		11 Apr 1884	III
9 Mar 1854	VI	12 Jun 1884*	
20 Mar 1855		4 Nov 1884*	
24 Apr 1853	III	3 Jan 1887	
23 Oct 1853	VIII	9 Jun 1887	light
25 Oct 1853	III	24 Jun 1887	VI
20 Aug 1854		2 Jun 1889	light
17 Sep 1854		12 Aug 1889	sharp
26 Sep 1854		20 Dec 1889	light
2 Oct 1854		25 Apr 1890	
19 Mar 1855	VI	4 Jul 1890	
20 Mar 1855		27 Jul 1890	moderate
5 Dec 1855		11 Aug 1891	
21 Dec 1855		22 Jan 1892	
12 Nov 1856	V	30 Jan 1892	
14 Jun 1857	VI	9 Jan 1893	sharp
12 Nov 1860	V	22 Feb 1893	light
26 Oct 1861		23 Feb 1893	light
1 Oct 1865		13 Apr 1893	light
3 Oct 1865	V	12 Jul 1893	
8 Oct 1865	VIII	22 Jul 1893	
26 Nov 1865*		30 Sep 1894	
12 Jun 1869		8 Jan 1895	heavy
6 Oct 1869*		1 Mar 1895*	
4 Dec 1870*		1 Mar 1895	
2 Mar 1871		1 Apr 1895	
12 Dec 1871	V	5 Oct 1895	light
26 Mar 1872	severe	15 Oct 1895	light
22 Nov 1873*		18 Nov 1895	light

TABLE 5-1. Earthquake shocks, Humboldt Bay, 1853-1952 (continued).
[Rossi-Forel Scale]

Date	Intensity ¹	Date	Intensity ¹
6 Dec 1895	heavy	7 Jun 1906	heavy
22 Apr 1896		13 Jun 1906	very light
9 Jun 1896		9 Jul 1906	
6 Mar 1897		30 Jul 1906	light
17 Sep 1897	severe	1 Aug 1906	light
28 Oct 1897	slight	7 Nov 1906	
25 Nov 1897	slight	25 Dec 1906	
27 Nov 1897	slight	14 Jan 1907	light
29 Jan 1898	light	25 Feb 1907	
14 Apr 1898	gentle	8 Aug 1907	light
9 Sep 1898	severe	11 Aug 1907	heavy
19 Oct 1898	light	12 Aug 1907	light
25 Nov 1898	light	23 Aug 1907	light
16 Apr 1899	severe	26 Aug 1907	slight
18 Apr 1899	light	7 Oct 1907	heavy
25 Dec 1899		14 Oct 1907	light
21 Jan 1900	light	23 Oct 1907	light
14 Apr 1900	light	28 Oct 1907	light
16 Apr 1900	light	22 Nov 1907	light
1 Oct 1900	light	3 Jan 1908	heavy
25 Feb 1903	slight	10 Jul 1908	light
9 Dec 1903	severe	18 Aug 1908	VIII
11 Jan 1904	light	8 Dec 1908	light
26 Mar 1904	heavy	17 May 1909	light
4 Dec 1904	severe	28 Jun 1909	light
6 Jul 1904	light	28 Oct 1909	heavy-IX
14 Sep 1904	light	1 Nov 1909	light
18 Apr 1906		18 Mar 1910	heavy
19 Apr 1906	slight	18 Mar 1910*	
20 Apr 1906	slight	4 Aug 1910	sharp
23 Apr 1906	severe	26 Aug 1910	light
27 Apr 1906		12 Dec 1910	
30 Apr 1906	slight	11 Mar 1911	
9 May 1906	slight	2 Feb 1914	
10 May 1906	slight	24 Nov 1913	

TABLE 5-1. Earthquake shocks, Humboldt Bay, 1853-1952 (continued).
[Rossi-Forel Scale]

Date	Intensity ¹	Date	Intensity ¹
10 Apr 1914	III, IV	31 Jan 1922*	
14 Aug 1914	IV	31 Jan 1922	VI
10 Dec 1914		4 Feb 1922	III
12 Dec 1914		17 Aug 1922	III
6 May 1915*	V	18 Sep 1922	III
6 May 1915	II	3 Nov 1922	III
22 Jul 1915	III	7 Nov 1922	III
31 Dec 1915*	destructive	22 Jan 1923*	IX
31 Dec 1915	III	22 Jan 1923	VII
6 May 1916	III	9 Feb 1923	II
4 Jul 1916	V	28 Mar 1923	III
23 Aug 1916	V or VI	3 Sep 1923	IV
26 Jun 1917	IV	17 Sep 1923	IV
12 Sep 1917	IV	9 Jan 1924	IV
26 Oct 1917	II	19 Jun 1924	II
23 Feb 1918	IV	17 Jul 1924	IV
2 Mar 1918	III	7 Sep 1924	III
16 Apr 1918	V	25 Jan 1925	II
16 Apr 1918*		2 Mar 1925	IV
14 Jul 1918*		3 Mar 1925	III
14 Jul 1918	VI	26 Jul 1925	III
21 Jul 1918	III	21 Sep 1926	IV
20 Aug 1918	IV	13 Oct 1926	slight
29 Nov 1918	V	27 Dec 1926	III
13 Jun 1919	IV	3 Jan 1927	IV
12 Sep 1919	V	12 Feb 1927	IV
15 Sep 1919	VII	16 May 1927	IV
4 Oct 1919	III	10 Aug 1927	V
20 Mar 1920	IV	20 Aug 1927	VIII
19 Apr 1920	III	6 Sep 1927	III
4 Oct 1920	V	16 Sep 1927	V
22 Mar 1921	III	8 Dec 1927	V
24 Apr 1921	IV	22 Sep '30(Eureka)	VIII
28 Aug 1921	III	27 Sep '30(Arcata)	
29 Nov 1921	II	15 Dec '30(Eureka)	III

TABLE 5-1. Earthquake shocks, Humboldt Bay, 1853-1952 (continued).
[Rossi-Forel Scale]

Date	Intensity ¹	Date	Intensity ¹
23 Dec 1930 (Eureka)		13 May 1941* (Eureka)	
25 Apr 1931 (Eureka)		3 Oct 1941 (Eureka)	VII
20 May 1931 (Eureka)		5 Oct 1941 (Eureka)	
8 Aug 1931 (Eureka)		11 Nov 1943* (Eureka)	
21 Aug 1931	III	12 Jan 1944*	V
23 Aug 1931	III	15 Jan 1944	V
6 Jun 1932 (Eureka)	VIII	21 Sep 1944 (Eureka)	IV
4 Mar 1933	IV	2 May 1945 (Eureka)	VI
20 Jun 1933		19 May 1945*	
10 Nov 1933		2 Aug 1946 (Eureka)	
17 Nov 1934 (Eureka)		23 Nov 1946 (Eureka)	
2 Jan 1935 (Eureka)*		18 Dec 1946* (Eureka)	VI
3 Mar 1935 (Eureka)*		29 Mar 1947*	VI
29 Jul 1935 (Eureka)		27 May 1947*	VI
27 Oct 1935 (Eureka)		23 Sep 1947 (Eureka)*	VII
3 Jun 1936 (Eureka)		19 Feb 1948* (Eureka)	
23 Aug 1936 (Arcata)		27 Mar 1948* (Eureka)	V
25 Sep 1936 (Eureka)		18 Aug 1948* (Eureka)	V
6 Feb 1937 (Eureka)		18 Aug 1948 (Eureka)	V
30 Aug 1938 (Samoa)		19 Aug 1948*	V
4 Sep 1938 (Eureka)		27 Oct 1949 (Eureka)	
9 Nov 1938 (Eureka)		14 Jan 1950 (Eureka)	VI
9 May 1939 (Eureka)		10 Feb 1950 (Eureka)	V
31 Dec 1939 (Eureka)		13 May 1950* (Eureka)	
13 Feb 1940 (Eureka)		2 Jun 1950 (Eureka)	
5 Mar 1930 (Eureka)		9 Jun 1950* (Eureka)	
19 Nov 1940 (Eureka)	VI	13 Jan 1951* (Eureka)	
20 Dec 1940 (Eureka)	VI	7 Oct 1951 (Eureka)	
23 Jan 1941	V	7 Oct 1951* (Eureka)	
9 Feb 1941*	VI	14 Nov 1951 (Eureka)	
		22 Sep 1952 (Eureka)	V-VI
		16 Nov 1952 (Eureka)	

¹ It was not always possible to distinguish the scale used. The Bulletin of the Seismological Society of America adopted the Modified Mercalli Scale in 1937 for Earthquake Notes from which a few recent listings were obtained, but the values were low and correlated with those of the Rossi-Forel Scale.

TABLE 5-1. Earthquake shocks, Humboldt Bay, 1853-1952 (continued).
[Rossi-Forel Scale]

* Sea quakes.

Table compiled from Holden (1898), McAdie (1907), Townley and Allen (1939), Wood and Heck (1951), and Earthquake Notes (Bulletin of the Seismological Society of America n. d.).

The sea had been quite calm all night, but the breeze kept up well. The first warning of the earthquake came in the form of a deafening roar which seemed to rise out of the sea. In an instant the ocean was lashed into a mass of foam, and in spots it rose in great geyser-like columns. The schooner stopped with a crash and then shook for fully two minutes. Every timber and bolt groaned and creaked, and it was thought for a moment that she was going down. Those on deck were knocked down. The schooner pounded up and down frightfully for a few minutes, just as if she were aground, and then all became still. We had scarcely recovered our senses when a second shock came, but it was not nearly so severe as the first. When this one was over the sea became as still as a mill pond, the wind died out, and everything was as quiet as death. The schooner C. T. Hill, which was carrying lumber, was also tossed about by the tremblor. She was only a few miles astern of the Volant at the time. Captain Forest's story of the experience is similar to that told by the crew of the Volant.

(Holden 1898, p. 237)

[Effect of Earthquake on Ships in Eureka Harbor.]

Mr. Buhne states that all ships in the harbor at Eureka felt the quake [April 18, 1906], but in South Bay it was heaviest. One vessel was hurled against the wharf time and time again, throwing down piles of lumber and shingles.

(Lawson 1908, p. 372)

1927 August 20, 11:30 a.m., 12:05 p.m. III and VIII. Humboldt Bay.

The first shock was reported only at Capetown, the second from Fort Seward on the south to the Oregon border on the north.

The second shock was very similar to other shocks in the Humboldt Bay region, which reach intensity VIII in the Eureka-Arcata district but are unfelt at distances of eighty or one hundred miles. At Arcata chimneys were destroyed, windows shattered, and the intensity was fully VIII; reported as more severe but of shorter duration than the 1906 earthquake. The same description applied well to the shock at Eureka. At Fortuna, the intensity was lower, VII to VIII; at Ferndale and Scotia about VII and south of Scotia no damage was reported.

At Westport, eighty-five miles south, the intensity was II, as it was at Crescent City, sixty-five miles north.

The shock recorded at a number of seismographic stations. Seismograms seemed to place the origin at sea some thirty miles from

Eureka, but the rapid decline of energy with distance manifested by this shock, taken with the high intensity at Arcata and Eureka, indicates that the origin was much nearer Humboldt Bay, very possibly inside of the coast line rather than offshore. Many strong but localized shocks at Eureka and Arcata point to the existence of a source at Humboldt Bay which characteristically generates shocks of intensity VI to VIII from some shallow focus very near Eureka. Refer to shocks of August 18, 1908; September 12 and 15, 1919; and later shock of September 22, 1930, which with this shock forms a remarkable group.

(Townley and Allen 1939, p. 249)

On the morning of June 6, 1932, about 44 minutes past midnight, the region about Humboldt Bay was severely shaken by an earthquake which attained a maximum intensity of VIII on the Rossi-Forel Scale. It was felt as far north as Coos Bay, as far south as San Jose, and as far east as Sierra County. It was the most severe shock felt in that region since 1922.

The most marked disturbance of the surface of the ground occurred on Cock Robin Island in the mouth of the Eel River where the soil on the island is marshy. A fissure . . . was twenty-eight inches wide, and extended for several hundred feet approximately parallel to the coast line. The center section in the foreground dropped 18 inches. There were many small cracks running in the same direction and a few at right angles. Several "mud craters" from a few inches to several feet in diameter, were developed in the bottom of the slough, which was near the fissure. The material in them was similar to quicksand. Prior to the earthquake there had been about three feet of water in this slough. It was apparently drained by the shock.

The occurrence of luminous phenomena was reported by Mr. Metzler, of Eureka. "During the earthquake," he said, "several of my friends and I saw to the east what appeared to be bolts of lightning travel from the ground toward the sky. The night was clear and a gentle wind was blowing." The possibility that these flashes were the arcing of electric lines is not excluded since there are power lines four miles outeast of Eureka.

No disturbance of the surface of the sea level accompanying this earthquake was noted on the tide gauges at Fort Point, San Francisco Bay, by the United States Coast and Geodetic Survey. The absence of a sea wave has been previously noted in the study of other earthquakes centering off the coast of northern California.

(Sparks 1936, pp. 13, 14, 15)

Unpublished data concerning the location of epicenters, force of quake, and some information on the tectonics involved in the region about Humboldt Bay is available. These data cover approximately the ten year period 1945 to 1955 and are in the possession of Dr. Donald Tocher, Seismographic Station, University of California, Berkeley, Calif.

Seismograph Stations

There are six active seismograph stations within 125 miles of the Humboldt Bay area. The Teleseismic stations are located at Humboldt State College, Arcata, Ferndale (private station), U. S. Coast and Geodetic Survey Latitude Observatory, Ukiah, and the Bureau of Reclamation Station at Shasta. The Strong Motion Seismographs are in the Federal Building at Eureka, and the City Hall in Ferndale, California.

VOLCANOLOGY

In general the volcanic history of this region is similar to that of the Coastal portion of Oregon. Volcanic glass is found in the sedimentary deposits of the Pliocene and Pleistocene. Mt. Shasta blew out ash in 1786; Cinder Cone, near Lassen Peak, discharged a basaltic lava in 1851 and Mt. Lassen, our most active volcano, erupted ash and lava from 1914 to 1917. There were about 220 eruptions of Mt. Lassen Peak between June 1914 and December 1915.

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SECTION 6

RECENT SEDIMENTATION

RECENT SEDIMENTATION

BEACHES

Beach Characteristics

The north and south spits separate Humboldt Bay from the Pacific Ocean. The south spit is the narrowest of the two; along most of its $\frac{1}{4}$ mile length it is under 1,000 feet wide. At the northern end it widens to approximately 3,000 feet. It is narrow, low, and characteristically devoid of much vegetation. The north spit is about 5,000 feet wide over most of its 10 mile length. The southern end is low and barren with only small sand dunes; the northern portion is higher with wooded dunes exceeding heights of 50 feet. A sand beach backed by low lands, extends southward past the mouth of the Eel River and its associated spit to approximately Centerville Beach, about $\frac{1}{4}$ miles south of the bay entrance. Here the beach becomes narrower, and is bordered by high bluffs. Northward from Humboldt Bay, a wide beach extends to the spit of the Little River, about $19\frac{1}{2}$ miles from the bay entrance. Farther north it is backed by bluffs and at Trinidad Head, rock headlands interrupt the continuity of the beach.

A beach area is located just inside the entrance on the east side of the bay. This sandy beach extends from the Elk River Spit to Buhne Spit. Point Humboldt, a 100-foot high knoll lies between these two spits.

The Fluid Mechanics Laboratory, University of California, Berkeley, set up 15 ranges at the Table Bluff beach area during the period of 17 December 1945 and 26 March 1945. One purpose of this study was to determine the beach profiles. A profile at each range was taken at least twice during the period of study. The location of the beach profiles is shown in Enclosure 6-1. The profiles for each range are in Enclosure 6-2. For the complete information concerning this study see Stump, Bascom, Foight, and Schorr (1947). The profiles indicate that in the vicinity of Table Bluff there may be a sand bar (at least during some seasons) located about 1,600 to 2,000 feet from the MLLW line. It is approximately 500 to 600 feet wide and 10 to 15 feet high and is covered by about 15 feet of water.

The U. S. Army Corps of Engineers in conjunction with their work on the improvement and maintenance of harbor facilities have investigated shoreline changes, erosion, and other aspects of the beach areas both on the ocean front and inside the bay.

Beach Sands

In conjunction with an investigation concerning a proposed canal between Southport Channel and McNulty's Slough, in the Eel River Valley, the U. S. Army Corps of Engineers (1909) made 60 borings along possible

canal routes. These samples include 54 beach samples located along the Pacific Ocean beach by Table Bluff, in South Bay, and in the northern coastal El River areas. The remaining six samples are of bottom sediments in South Bay. These six will be discussed under Bottom Sediments. The characteristics of the 54 beach and soil borings are given in Table 6-1. The 6 bottom samples are included in Table 6-4. The locations for all 60 test holes are on Enclosure 6-1.

In 1946 the U. S. Army Corps of Engineers collected 25 beach samples from the Elk River Spit to Buhne Spit. Samples from the top to the base of Point Humboldt located on the eastern bay shore just inside the entrance were included. Eight samples were also taken along the bay shore at the northern end of South Spit. The locations of these samples are in Enclosure 6-1 and the description of the beach samples in Table 6-2.

The Elk River Spit is composed primarily of a cohesionless gray sand; some locations have traces of shell and small gravel. They are essentially medium to fine, well sorted, sands of type 1 (see Enclosure 6-3). From the south end of Elk River Spit to the base of Point Humboldt the beach is composed of a cohesionless gray sand with some gravel. The sands are medium to fine, bimodal, of type 3 (Enclosure 6-3) and not as well sorted as on the spit. The samples on Point Humboldt and its immediate vicinity consist of sand, silt, clay, and some shale. The cumulative size distributions are types 1, 4, 5, 6, and 7 (see Enclosure 6-3). Buhne Spit and South Spit are primarily constructed of cohesionless gray sands of type 1.

The Fluid Mechanics Laboratory, Berkeley, California (Stump, Bascom, Foight, and Schorr 1947), studied 21 sediment samples from 2 ranges on the beach in the vicinity of Table Bluff. There, sediments are predominantly well sorted, medium, sands. The mechanical analysis data are given in Table 6-3; their approximate locations are shown on Enclosure 6-1; cumulative curves for the sand samples are in Enclosure 6-4.

SHORELINE CHANGES

Pacific Ocean Shoreline

A sandy shoal area known as "breaker flats" extended across the seaward side of the entrance to Humboldt Bay prior to the construction of the first jetties in 1888. The channel over the bar varied markedly from year to year (see Enclosure 6-5). "Breaker flats" disappeared when the original jetty was completed in 1889. The depth contours by the entrance also shifted seaward as a result of the jetty construction. Since its original construction the jetty has been maintained and lengthened. At present, the crest of the entrance bar lies 2,500 to 4,000 feet seaward of the end of the jetty. By comparing the 1886 edition of the U. S. Coast and Geodetic Survey chart No. 5832 and the present edition of the same chart it may be observed that the seaward movement of the 60 foot depth contour from 1886

TABLE 6-1. Borings Between Southport Channel, McNulty's Slough, 1909.

Sample No.	Description of Material
<u>Route No. 1</u>	
31+00	Brown Dirt 1 ft., Marsh Mud 14.5 ft., Sand & Mud 1 ft.
36+00	Brown Dirt 1 ft., Marsh Mud 13.0 ft., Sand & Mud 4 ft.
41+00	Brown Dirt 1.5 ft., Marsh Mud 10.5 ft., Sand & Mud 2 ft., Quick Sand 5 ft.
46+00	Marsh Mud 6 ft., Quick Sand 20 ft.
51+00	Sand 12 ft., Quick Sand 6 ft., Marsh Mud 8 ft.
56+00	Sand 9 ft., Quick Sand 9 ft., Hard Pan
59+00	Sand 10 ft., Quick Sand 2 ft., Hard Pan
62+00	Sand 11 ft., Sand & Mud 7 ft., Quick Sand 6 ft.
66+00	Sand 19 ft., Quick Sand 3 ft., Hard Pan
66+00 (20' Left)	Sand 12 ft., Quick Sand 6 ft., Hard Pan
66+00 (40' Left)	Sand 12 ft., Quick Sand with Mud 10 ft., Hard Pan
66+00 (60' Left)	Sand 12 ft., Quick Sand 6 ft., Sand & Mud 5 ft. Hard Pan
66+00 (80' Left)	Sand 16 ft., Quick Sand 6 ft., Hard Pan
66+00 (100' Left)	Sand 15 ft., Quick Sand 7 ft., Hard Pan
66+00 (120' Left)	Sand 14 ft., Quick Sand 6 ft., Hard Pan
66+00 (140' Left)	Sand 12 ft., Quick Sand 4 ft., Hard Pan
66+00 (160' Left)	Black Soil 1 ft., Yellow Soil 9 ft., Blue Clay 14 ft., Hard Pan
66+00 (180' Left)	Black Soil 1 ft., Yellow Soil 10 ft., Blue Clay 7 ft., Hard Pan
66+00 (20' Right)	Sand 14 ft., Quick Sand 6 ft., Hard Pan
66+00 (40' Right)	Sand 14 ft., Quick Sand 6 ft., Hard Pan
66+00 (60' Right)	Sand 14 ft., Quick Sand 6 ft., Hard Pan
66+00 (80' Right)	Sand 14 ft., Quick Sand 6 ft., Hard Pan
66+00 (100' Right)	Sand 12 ft., Quick Sand 8 ft., Hard Pan
66+00 (120' Right)	Sand 10 ft., Quick Sand 12 ft., Hard Pan
66+00 (140' Right)	Sand 8 ft., Quick Sand 12 ft., Hard Pan
66+00 (160' Right)	Sand 12 ft., Quick Sand 6 ft., Hard Pan
72+00	Sand 19 ft., Quick Sand 4 ft., Hard Pan
77+00	Sand 6 ft., Quick Sand 16 ft., Hard Pan
82+00	Sand 6 ft., Quick Sand 22 ft., Hard Pan
87+00	Sand 6 ft., Quick Sand 6 ft., Sand & Mud 2 ft., Quicksand 8 ft.
92+00	Sand 5 ft., Sand & Mud 1 ft., Quick Sand 22 ft.
97+00	Marsh Mud 1.5 ft., Sand 2.5 ft., Sediment 22 ft., Gravel 1 ft., Sediment
107+00	Marsh Mud 2 ft., Sand 10 ft., Quick Sand 8 ft., Marsh Mud 2 ft., Quick Sand 4 ft.
112+00	Sand 6 ft., Quick Sand 17 ft., Marsh Mud 1 ft.
117+00	Sand 6 ft., Quick Sand 12 ft., Marsh Mud 7 ft.

TABLE 6-1. Borings Between Southport Channel, McNulty's Slough, 1909.
(continued)

Sample No.	Description of Material
122+00	Marsh Mud 4 ft., Quick Sand 8 ft., Marsh Mud 6 ft., Quick Sand 6 ft.
127+00	Sand 6 ft., Quick Sand 10 ft., Marsh Mud 2 ft., Quick Sand 6 ft.
132+00	Marsh Mud 6 ft., Quick Sand 6 ft., Marsh Mud 6 ft., Quick Sand 7 ft.
137+00	Marsh Mud 6 ft., Quick Sand 6 ft., Marsh Mud 12 ft.
60+00 (40' Left)	Sand 8 ft., Quick Sand 14 ft., Hard Pan
(80' Left)	Sand 6 ft., Marsh Mud 3 ft., Quick Sand 11 ft., Marsh Mud & Land 2 ft., Hard Pan
(120' Left)	Sand & Yellow Clay 6 ft., Yellow Clay 6 ft., Blue Clay 12 ft., Hard Pan
(40' Right)	Sand 12 ft., Quick Sand 6 ft., Hard Pan
<u>Line B</u>	
0+00	Sand 6 ft., Quick Sand 18 ft., Marsh Mud 2 ft.
5+00	Sand 6 ft., Quick Sand 16 ft., Gravel
10+00	Gravel & Clay 8 ft., Yellow Clay 4 ft.
15+00	Yellow Clay 10 ft., Blue Clay 4 ft., Yellow Clay 6 ft.
20+00	Black Loan 1 ft., Yellow Clay 6 ft., Yellow Clay and Sand 13 ft.
25+00	Marsh Mud 8 ft., Yellow Clay 9 ft.
30+00	Marsh Mud 18 ft.
35+00	Marsh Mud 24 ft.
40+00	Marsh Mud 18 ft.
45+00	Marsh Mud 22 ft.
50+00	Black Loan 1 ft., Yellow Clay 10.5 ft., Hard Yellow Clay & Land 6 ft.

This table was compiled from data on U. S. Army Corps of Engineers, San Francisco (1909) map. See Enclosure 6-19.

TABLE 6-2. Description of Beach Sands:

Sample No.	Description	Laboratory Data ¹
S-1	Cohesionless gray sand	Mat. Type 1
S-2	Cohesionless gray sand	Mat. Type 1
S-3	Cohesionless gray sand; trace of shell	Mat. Type 1
S-4	Cohesionless gray sand with little rounded gravel; trace of shell	Mat. Type 3
S-5	Cohesionless gray sand	Mat. Type 1
S-6	Cohesionless gray sand	Mat. Type 1
S-7	Cohesionless gray sand with little small gravel	Mat. Type 3
S-8	Cohesionless gray sand with little small gravel	Mat. Type 3
S-9	Soft, wet, cohesive, gray clayey silt and decomposing gray brown shale	Mat. Type 4 W = 51.0% Sp. gr. 2.69
S-10	Soft, moist, cohesive, dark gray clayey silt with plant roots	Mat. Type 4 W = 67.5%
S-11	Compact, dry, cohesive, brown clayey silt with plant roots	Mat. Type 5 W = 4.9%
S-12	Slightly compacted, dry cohesive, light brown clayey silt with plant roots	Mat. Type 5 W = 6.4% Sp. gr. 2.62
S-13	Compact, dry, cohesive, light and dark brown clay silt	Mat. Type 5 W = 6.0%
S-14	Cohesionless gray sand with little shell	Mat. Type 1 Sp. Gr. 2.69
S-15	Cohesionless gray sand with trace of shell	Mat. Type 1
S-16	Cohesionless gray and black sand	Mat. Type 1
S-17	Cohesionless gray sand with some black sand	Mat. Type 1
S-18	Cohesionless gray sand	Mat. Type 1
S-19	Cohesionless gray sand with some black sand	Mat. Type 1
S-20	Cohesionless gray sand with some black sand and clay with roots	Mat. Type 1
S-21	Cohesionless black sand with some gray sand	Mat. Type 1
S-22	Soft, moist, cohesive, bluish gray clayey silt and gray brown silty sand	Mixed
S-23	Cohesionless gray sand with bluish gray clay pockets	Mat. Type 1

TABLE 6-2. Description of Beach Sands (continued).

Sample No.	Description	Laboratory Data ¹
S-24	Medium compact, moist, bluish gray clayey silt	Mat. Type 6 W = 20.4% Sp. gr. 2.71
S-25	Cohesionless gray and black sand	Mat. Type 1
S-26	Dry, cohesionless, brown sand with gray and blue clay chunks	Mat. Type 7 Sp. gr. 2.68
S-27	Slightly compact, moist, cohesive, bluish gray clayey silt with some brown sand	Mixed W = 43.1%
S-28	Soft, moist, cohesive, bluish gray clayey silt and organic matter	Mat. Type 4 W = 94.6%
S-29	Very loose, cohesionless, bluish gray silty sand with pieces of brown shale	Mat. Type 6
S-30	Cohesionless, bluish gray silty sand with little shell	Insufficient sample
S-31	Cohesionless, gray sand with some black sand and trace of shell	Mat. Type 1
S-32	Cohesionless gray sand with some black sand and trace of shell	Mat. Type 1
S-33	Cohesionless black sand with trace of shell	Mat. Type 1

¹ Mat., see Enclosure 6-3 for cumulative curves of each type. W = Water content expressed as % dry weight of sample.

Table from U. S. Army Corps of Engineers (1946).

TABLE 6-3. Analysis of Beach Sand in the Vicinity of Table Bluff.

FML ¹ Sample	Station No.	Range ²	Moisture (Dry Basis wt. %)	Sieve Analysis-Cumulative % Retained on Sieve Number									
				50"	38"	4	8	14	28	48	65	100	200
308	A	0+00	0.9	-	-	-	-	-	2	53	86	99	100
309	B	"	0.7	-	-	-	-	-	-	43	88	99	100
310	C	"	0.3	-	-	-	-	-	-	52	88	99	100
311	1	"	0.9	-	-	-	-	-	-	55	88	99	100
312	1A	"	0.8	-	-	-	-	-	-	59	89	99	100
313	1B	"	0.7	-	-	-	-	-	3	84	98	100	-
314	1C	"	0.6	-	-	-	-	1	10	88	99	100	-
315	2	"	0.6	-	-	-	-	1	16	90	99	100	-
316	2A	"	8.1	-	-	-	-	-	10	88	98	100	-
317	1	5+00N	0.7	-	-	-	-	-	1	44	83	98	100
318	1B	"	7.9	-	-	-	-	1	8	76	96	100	-
319	1C	"	1.1	-	-	-	-	2	12	86	99	100	-
320	2	"	0.6	-	-	-	-	4	21	93	99	100	-
320	2	"	0.6	-	-	3	100	-	-	-	-	-	-
320	2	"	0.6	-	-	-	2	6	22	93	99	100	-
321	2B	"	5.4	-	-	-	-	7	17	81	97	100	-
321	2B	"	5.4	5	19	59	100	-	-	-	-	-	-
321	2B	"	5.4	1	5	15	26	31	38	86	98	100	-
372	120 ³	"	1.2	-	-	-	-	-	-	49	89	99	100
373	210 ⁴	0+00	1.4	-	-	-	-	-	4	63	93	100	-
374	crest ⁵	0+00	1.9	-	-	-	-	1	2	40	75	97	100

¹ Fluid Mechanics Laboratory Number.

² The exact locations can be obtained from Fluid Mechanics Laboratory, Berkeley, California.

³ Hole 120 feet west of hub line.

⁴ Hole 210 feet west of hub line.

⁵ Crest of outer bar.

Table from Stump, Bascom, Foight, and Schorr (1947).

to 1948 has been about 2,500 feet.

A history of the shoreline changes between the Eel and Mad Rivers has been compiled by the U. S. Army Corps of Engineers (1950). This history consists of a comparative study of the highwater shorelines. The surveys of 1854, 1870, and 1929 were made by the U. S. Coast and Geodetic Survey, those of 1911, 1919, and 1940, are Corps of Engineers Surveys (see Enclosure 6-6). In addition a comparative study of the periodic surveys of the bar and entrance to the bay was also made. Changes in the entrance channel and configuration of the spits may be seen in Enclosures 6-7 through 6-12. A brief history of the shoreline as stated by the U. S. Army Corps of Engineers (1950) follows:

Between 1854 and 1870, the period prior to jetty construction, there was no significant change in the position of the highwater shoreline. Alternate accretion and erosion is indicated on the north spit for a distance of about five miles northerly of the present north jetty. Erosion occurred at the northerly tip of the south spit.

Comparison of the 1870 and 1911 surveys shows a seaward shift of the high-water shoreline from the north jetty to a point about 4,200 feet north of the north jetty, the maximum seaward movement being about 1,200 feet. North from this area of accretion to the northerly limits of the 1911 survey, a 4,600-foot length of shore shows erosion, with a maximum shoreward movement of approximately 400 feet. South of the south jetty to the limits of the 1911 survey, a total distance of about 5,600 feet, accretion occurred. The maximum seaward movement of the shoreline occurred on the south side of the south jetty where the shift amounted to approximately 2,400 feet. From the south jetty the movement tapered gradually to 600 feet at the southerly limit.

The 1919 survey delineated the shoreline for only about 3,000 feet on each side of the jetties. The portion of the shoreline shown by this survey is farther seaward of the 1911 position. North of the north jetty the seaward movement tapered from a maximum of 3,000 feet at the jetty to 500 feet at the northerly limit. South of the south jetty the seaward shift varied from a maximum of about 500 feet along the south side of the jetty to 300 feet at the southerly limit.

The 1929 position of the high-water shoreline immediately north of the north jetty was about 500 feet farther seaward of the 1919 position. South from the south jetty there was a 100-foot movement shoreward along a 1,200-foot length of shore, beyond which there was no apparent change between 1919 and 1929.

During the period 1929 to 1940, the shoreline north of the north jetty moved shoreward, tapering from about 325 feet immediately north of the jetty to zero at a point about 2,300 feet north of the jetty. North from this point for a distance of 12,000 feet, accretion is indicated, the maximum seaward movement amounting to 200 feet. Beyond this area of accretion for a distance of about 14,000 feet there was no significant difference in the 1929 and 1940 positions of the shoreline, except along a 3,500-foot length where the 1940 position is shown 200 feet shoreward of the 1929 position. From the south jetty to a shore point about four miles south of the jetty, the 1940 position of the shoreline is shoreward of the 1929 position by varying amounts. A maximum shoreward movement of about 400 feet occurred adjacent to the jetty.

The 1870 and 1929 surveys are the only two which completely delineate the shoreline from the mouth of the Mad River to that of the Eel River. Comparison of these two surveys shows that the 1929 position of the shoreline is farther seaward than the 1870 position for 10.5 miles of the approximately 15 miles between the north jetty and the Mad River by amounts varying from 50 to 3,800 feet. The maximum seaward movement has occurred immediately north of, and adjacent to, the north jetty. The only erosion, or shoreward movement of the high-water shoreline north of the north jetty indicated during this 50-year period begins at a point about 3 miles north of the north jetty and extends for a distance of approximately 2.5 miles, the maximum shoreward movement amounting to 200 feet.

The 1929 position of the ocean shoreline of the south spit is seaward of the 1870 position from the south jetty, where a 3,000-foot seaward movement is indicated, to a point on the shore seaward of Table Bluff, or about 4.5 miles southerly of the jetty, at which point the 1929 and 1870 positions intersect. South of this point to the mouth of the Eel River alternate stretches of erosion and accretion are shown. The maximum shoreward movement, of approximately 320 feet, occurred in the vicinity of the mouth of the Eel River and consisted of a shoreward migration of the Eel River Spit.

The net change in the position of the high-water shoreline in the vicinity of the jettied entrance to Humboldt Bay during the period 1870 to 1940 is an advance seaward both north of the north jetty and south of the south jetty. This seaward movement occurred along an approximate 3-mile reach of the north spit measured from the north jetty, and varied from a maximum of 3,400 feet adjacent to the jetty to zero, 3 miles north of the jetty. South of the south jetty the seaward movement extended along a 3.5-mile reach as measured from the jetty. The maximum seaward advance of 2,600 feet occurred adjacent to the south jetty.

Point Humboldt Shoreline

The Point Humboldt area is typical of the entire bay region in that alluvium is a common deposit. The ridges are composed of Pliocene marine deposits. The sediments of Point Humboldt are relatively soft sandstone and mudstones. They are easily eroded by the ocean waves which enter the bay through the entrance between the North and South Spits and impinge on the point. Aerial photographs taken by the Corps of Engineers, San Francisco, California, show that the wave action probably causes sand movement both north and south of Point Humboldt.

The U. S. Army Corps of Engineers (1950) studied the erosion of Point Humboldt by comparing the U. S. Coast and Geodetic Survey charts of 1854, 1870, and 1903, and the Corps of Engineers surveys of 1891, 1911, 1926, 1929, 1931, 1939-40 and 1946 (see Enclosures 6-13 through 6-16). In conjunction with this erosion study it is well to consider the shoaling of Fields Landing Channel. A part of the material responsible for this shoaling may have its origin at Point Humboldt and the Elk River (see Enclosures 6-17 and 6-18). The following quotation from the U. S. Army Corps of Engineers (1950) briefly discusses the history and erosion of Point Humboldt by comparing the MHHW lines:

The position of the high-water lines shown on figure 2 indicates that during the 92-year period, 1854 to 1946, the shoreline at Point Humboldt and points northeasterly and southwesterly thereof, has receded shoreward by amounts varying from 1,000 to 1,350 feet. The rate of this erosion has not been regular during equivalent intervals of time, but, except for the position of the 1903 high-water line, successive positions of the shoreline at Point Humboldt are generally shown as having moved farther shoreward. The 1911 survey indicates that Buhne Spit disappeared entirely except for a small islet at the southwestern tip of the spit. The 1926 survey shows the spit to have reformed 600 to 800 feet farther shoreward than its position in 1903. During the period 1926 to 1946, Buhne Spit, beginning at a point about 900 feet southwest of the bluff, advanced bayward as much as 400 feet. It is also to be noted that during the period 1928 to 1946 the erosion of the shoreline just to the northeast of the knoll, or bluff, has been much greater than during the period 1854 to 1926; a recession of 1,000 feet having occurred during the last 20 years compared with about 150 feet during the 72 years from 1854 to 1926. During the period from 1939 to 1946, it is estimated that 866,000 cubic yards of material were eroded from Point Humboldt.

Successive surveys made since 1911 show the formation and advance of a spit springing from shore at a point just south of the mouth of the Elk River. In the 35 years from 1911 to 1946, the spit has advanced a distance of about 6,200 feet in a northerly direction parallel to the shoreline. The 1946 survey shows the bayward tip of the spit to be

about 1,400 feet wide and that its bayward edge is from 300 to 1,100 feet farther out in the Bay than it was in 1939. It is estimated that the net accretion at Elk River Spit between 1939 and 1946 amounted to 461,000 cubic yards.

BOTTOM SEDIMENTS

Bay Sediments

From 1906 to 1948 the Corps of Engineers have collected and analyzed sediment samples from 109 locations in the bay. These are all borings which range from 1 foot to 32 feet long. The sediments comprising the surface materials on the bottom range from gravels to muds. About 40% of the samples are sand, another 40% are combinations of sand, clay, and mud. Mud comprises 15% of the samples and all other combinations of gravel, mud, sand, and shells about 5%. These sediment types are concentrated in definite areas. Table 6-4 presents the data for the surface sediments. The location of these samples is given in Enclosure 6-1.

The shallower flats adjacent to the Eureka channel from Dahy Island to the west end of Indian Island, consist of mud, sand, and some gravel as well as combinations of mud, gravel, and sand. The surface of the outer edge of the Eureka channel between the same two islands is composed principally of sandy mud. From Indian Island to the junction of the Samoa and Eureka channels, the sediments are primarily sand with some mud and clay. The surface veneer in Samoa Channel, west of Indian Island, is primarily a sandy material.

The bore samples taken in 1938 are from South Bay. From the Bay entrance to south of Buhne Spit the channel sediments are essentially sands and sandy muds. For 2,000 feet south of Buhne Spit the channel sediments are sands. For the next 2,500 feet hard sand, clay, and shell predominates. At Fields Landing, cross channel samples indicate mud deposits.

In 1946, 18 bore samples were collected by the Corps of Engineers in Southport and Hookton channels from the Bay entrance to Fields Landing (see Table 6-5). The Southport Channel surface samples are principally cohesionless gray sand of type 1 (see Enclosure 6-3). The sides of the channel are composed primarily of silty clay with sand and sandy clay. The Hookton Channel samples are mixtures of clay and silt of type 2 (see Enclosure 6-3).

The vertical distribution of sediment types as shown by all borings taken by the U. S. Army Corps of Engineers from 1906 to 1946 is illustrated in Enclosures 6-19 through 6-23.

TABLE 6-4. Description of Bottom Surface Sediments.

Location Number	Sediment ¹ Type	Location Number	Sediment ¹ Type	Location Number	Sediment ¹ Type
1906		1938 15	SC	1938 55	SM
2+20	S	16	SC	56	SC
6+70	S	17	SC	57	SCSh
11+70	S	18	S	58	S
16+20	S	19	S	59	S
20+70	SM	20	S	60	S
24+70	SM	21	S	61	S
		22	SC	62	HSS
1926 1	M	23	SC	63	HSCSh
2	HM	24	SM	64	HSCSh
3	HSM	25	SCM	65	HSCSh
4	M	26	SM	66	M
5	M	27	SM	67	HSM
6	M	28	SM	68	M
7	HSM	29	SM	69	M
8	M	30	M	70	M
9	M	31	SM	71	M
10	M	32	SM	72	SM
11	HMG	33	GSSh		
12	G	34	SC		
13	MG	35	GS		
14	HM	36	SM		
15	S	37	SM		
16	S	38	SM		
		39	SM		
1938 2	SC	40	SM		
3	SC	41	SM		
4	SCSh	42	M		
5	SC	43	GS		
6	SCSh	44	SM		
7	SCSh	47	S		
8	SCSh	48	S		
9	S	49	S		
10	S	50	S		
11	S	51	S		
12	S	52	SC		
13	S	53	S		
14	S	54	S		

¹ S = sand, C = clay, Sh = shell, M = mud, G = gravel, H = hard.
 Table from U. S. Army Corps of Engineers Drawing 5-1-2 (1909), 5-14-23 (1926), and 5-1-32 (1) (1938), 5-1-32 (2) (1938). (Enclosures 6-19, 6-20, 6-21, 6-22).

TABLE 6-5. Description of Samples from Borings (1946).

Sample No.	Hole No.	Elevation below MLLW (ft)	Sediment Type ¹
1-1	H-1	-17.9 to -35.9	S
2-1	H-2	-24.7	S
2-2	H-2	-29.7	S
2-3	H-2	-39.7	S
3-1	H-3	-19.5	S
--	H-3	-19.5 to -24.5	SSt
3-3	H-3	-32.5	S
4-1	H-4	-19.5	S
4-2	H-4	-24.5	S
4-3	H-4	-29.5	S
--	H-5	-20.0 to -22.0	CS
5-2	H-5	-38.0	S
6-1	H-6	-22.9	S
6-2	H-6	-27.9	S
6-3	H-6	-37.9	S
7-1	H-7	-23.1	S
7-2	H-7	-28.1	S
7-3	H-7	-33.1	S
8-1	H-8	-32.4	CSt
8-2	H-8	-42.4	S
9-1	H-9	-25.2	S
9-2	H-9	-30.2	S
9-3	H-9	-35.2	S
--	H-10	-26.3 to -29.3	StC
--	H-10	-29.3 to -41.3	StS
--	H-11	+ 1.2 to -0.8	S
11-1	H-11	-23.8	StC
12-1	H-12	-7.0	CSt
12-2	H-12	-14.0	S
12-3	H-12	-30.4	S
13-1	H-13	-3.8	S
13-2	H-13	-8.8	S
13-3	H-13	-13.8	S
14-2	H-14	-11.0 to -16.0	CSt
15-2	H-15	-10.8	StS
--	H-15	-15.8 to -21.8	CSt
16-1	H-16	-3.9	CSt
--	H-16	- 3.9 to -8.9	StC
--	H-17	- 0.1 to -5.1	StC
17-2	H-17	-10.1	CSt
18-1	H-18	-5.5	CSt
18-2	H-18	-10.5	S
18-3	H-18	-15.5	S

¹ S = Sand, St = silt, C = Clay

Table from U. S. Army Corps of Engineers (1955), Enclosures 6-3 and 6-23.

In 1954 the Corps of Engineers collected and analyzed 10 samples taken during their Hopper Dredge Operations in Humboldt Harbor. The location of these samples is not given (see Enclosure 6-24).

Offshore Sediments

The ocean sediments in the vicinity of Humboldt Bay have not been studied; however, the U. S. Coast and Geodetic Survey have described some offshore sediment samples (see Enclosure 6-1). Apparently sand, similar to the beach sands which make up the North and South Spits, extends out to about depths of 60 to 70 feet. Gray sands are present to at least depths of 180 feet.

ALONGSHORE TRANSPORT

The movement of sediment along a beach is dependent upon the waves and currents which carry, deposit, and erode the available sediments according to the competency of the water movement. According to the U. S. Army Corps of Engineers (1950) the direction of alongshore transport is southerly. They base this conclusion on a study of the survey taken previous to jetty construction and on the greater seaward advance of the shore of North Spit relative to that of the South Spit (see Enclosures 6-7 through 6-12). In 1921 the Corps of Engineers compiled information concerned with the shifting of sands at the bar and entrance to Humboldt Bay (see Enclosures 6-25, 6-26, and 6-27).

The following statement summarizes the opinion of the U. S. Army Corps of Engineers (1950) as to the prevailing direction of littoral transport:

Surveys of Humboldt Bay Entrance Channel in its natural state (1851 to 1883) show that it was a typical migrating bar channel, shifting radially through a regular cyclical period from the north to the south, and upon reaching the southern extremity of the bar, reopening suddenly at the north end to repeat the cycle. Surveys of 1851, 1858, 1870, and 1875 show the position of the channel in various phases of the cycle. Surveys of 1881, 1882, and 1883 show the rate of annual change. Study of all the surveys over this 32-year period indicates a usual cycle of about 5 years for channel migration at this inlet. This phenomenon is a clear indication that the predominant direction of littoral drift is from north to south. A comparison of periodic surveys of the Humboldt Bar and Entrance is shown on figure 5 of this appendix.

With the inauguration of jetty construction in 1890, there began a series of interruptions in normal littoral transport. With each increment in length of the jetties the bar was pushed seaward.

Consequent decrease in offshore depths caused the shore to advance on each side of the inlet. Interspersed with progressive lengthening of the jetties was their periodic partial destruction by storms. The periods during which the jetties functioned as important littoral barriers were relatively short and in each case ended when littoral transport was resumed in normal volume either through or around the jetties. Greater advance of the north shore as compared with the south illustrates the effect of dominance of downcoast drift during these periods when the jetties were functioning as littoral barriers. In 1917 the north jetty was rebuilt to within 500 feet of its ultimate seaward end. Based on surveys made since that time it is estimated that the annual rate of downcoast littoral drift is at least 500,000 cubic yards.

In 1934, a channel 35 feet deep and 500 feet wide was dredged across the bar. A study of the shoaling of this channel from October 1934 to May 1945 indicates that the average annual rate of shoaling was approximately 29,000 cubic yards during the 10½-year period. The maximum and minimum annual rates of shoaling in the channel were 113,000 cubic yards and 16,000 cubic yards, respectively.

There are other data which may be used in considering the direction of alongshore transport on the Pacific coast. The prevailing wind direction, the direction of wave approach, and the actual littoral current, have been considered in this region.

During the winter months, November through March, the prevailing winds are southerly (see Climatology, Section 2). The waves strike the coast from the southwest and logically a predominantly northerly littoral current should be set up. In the summer months the winds come essentially from a northerly direction and if Humboldt Bay may be compared to the Oregon coastline, then the wave action on the coast should be at a minimum (Twenhofel 1946). The summer littoral direction and force should thus be predominantly southerly and weaker than the northerly winter direction. Under such circumstances one would expect the primary alongshore transportation to be to the north. The development of the South Spit which trends northward from Table Bluff seems to indicate this. The North Spit, however, requires further explanation. According to Twenhofel (1946) the southerly trending spits of Oregon are due principally to wind transportation during the dryer summer months.

Personnel from the Fluid Mechanics Laboratory at Berkeley, California tabulated the littoral currents during the months of August through February 1944-45 (see Table 6-6). There is no readily available information for the months of March through July. From August 1944 through February 1945, 158 littoral current observations were made on the Pacific coast near the Humboldt Bay Life Boat Station. The littoral currents moved in a southerly direction during 154 days and toward the north for only 4 days. A comparison of 38 observations taken in December 1945 and January

1946 at Table Bluff shows 25 days of northerly littoral currents and 13 days of southerly currents. This information indicates one of two things: (1) local variation of the littoral current direction or (2) a year by year variation in the seasonal direction. In order to evaluate this information and the transportation capabilities of these currents further studies must be made.

TABLE 6-6. Data on Littoral Current, Swell, and Wind, for the Humboldt Bay Area.

Date	Swell 1	Littoral Current 2	Wind 3	Date	Swell 1	Littoral Current 2	Wind 3
Humboldt Bay				Humboldt Bay (continued)			
6 Aug 1944	WNW	S-W	WNW-7	22 Sep 1944	WNW	S-M	NNW-2
7 Aug 1944	NW	S-W	WNW-5	24 Sep 1944	WNW*	S-M	N-5
8 Aug 1944	NW	S-W	NW-8	25 Sep 1944	WNW*	S-M	NNW-5
9 Aug 1944	NW	S-W	NW-6	27 Sep 1944	WNW	S-M	NW-6
10 Aug 1944	WNW*	S-W	W-3	28 Sep 1944	WNW	S-W	WNW-6
11 Aug 1944	WNW	S-M	WSW-5	29 Sep 1944	WNW*	S-M	
12 Aug 1944	WNW	S-M	NNW-6	30 Sep 1944	WNW	S-M	NNW-5
13 Aug 1944	NW	S-M	NW-5	Humboldt Bay Life Boat Station			
14 Aug 1944	NW	S-M	WNW-6	1 Oct 1944	WNW	S-M	Calm
15 Aug 1944	NW	S-M	WNW-6	2 Oct 1944	WNW	S-M	WNW-3
16 Aug 1944	WNW*	S-W	WNW-5	3 Oct 1944	WNW*	S-M	NW-7
17 Aug 1944	WNW*	S-M	NW-9	4 Oct 1944	WNW*	S-M	E-5
18 Aug 1944	WNW*	S-M	NNW-6	5 Oct 1944	WNW*	S-S	Calm
19 Aug 1944	WNW*	S-M	Calm	6 Oct 1944	WNW*	S-M	E-3
20 Aug 1944	WNW*	S-M	WNW-7	7 Oct 1944	WNW	S-M	SW -3
21 Aug 1944	WNW*	S-W	WNW-7	8 Oct 1944	WNW	S-M	Calm
22 Aug 1944	WNW	S-M	NW-8	9 Oct 1944	WNW	S-M	NNW-5
23 Aug 1944	WNW	S-M	WNW-9	10 Oct 1944	WNW	S-M	ENE-7
24 Aug 1944	WNW	S-W	WNW-8	11 Oct 1944	WNW	S-M	NE-5
29 Aug 1944	WNW	S-S	WSW-5	12 Oct 1944	WNW	S-M	NW-6
30 Aug 1944	WNW	S-S	SE-5	13 Oct 1944	WNW	S-M	NW-5
31 Aug 1944	WNW	S-M	NW-5	14 Oct 1944	WNW	S-S	NW-8
2 Sep 1944	WNW	S-S	WNW-8	18 Nov 1944	W	S-S	WNW-3
3 Sep 1944	WNW	S-S	SW-7	19 Nov 1944	W	S-S	NW-3
5 Sep 1944	WNW	S-M	NNW-8	20 Nov 1944	W	S-M	WNW-3
7 Sep 1944	WNW*	S-M	NW-6	21 Nov 1944	W	S-M	N-1
8 Sep 1944	WNW*	S-M	NW-6	22 Nov 1944	W	S-M	N-1
10 Sep 1944	WNW*	N-M	NW-6	23 Nov 1944	W	S-M	--
11 Sep 1944	WNW*	N-M	NNW-9	24 Nov 1944	W	S-S	Calm
12 Sep 1944	WNW	S-M	NNW-3	28 Nov 1944	W*	S-M	S-3
13 Sep 1944	WNW	N-M	NW-5	29 Nov 1944	W	S-M	ESE-8
14 Sep 1944	WNW*	S-S	NNW-16	30 Nov 1944	W	S-M	SE-11
15 Sep 1944	WNW*	S-S	NW-8				
16 Sep 1944	WNW*	S-S	NW-5				
18 Sep 1944	WNW	S-S	N-3				
20 Sep 1944	WNW	S-S	E-1				
21 Sep 1944	WNW*	S-S	SW-12				

TABLE 6-6. Data on Littoral Current, Swell, and Wind, for the Humboldt Bay Area (continued).

Date	Swell ¹	Littoral ² Current	Wind ³	Date	Swell ¹	Littoral ² Current	Wind ³
Samoa Beach				Humboldt Bay Life Boat Station (continued)			
18 Nov 1944	W	S-S	W-2	19 Dec 1944	W	S-M	Calm
19 Nov 1944	W	W-S	NW-2	20 Dec 1944	W	S-M	Calm
20 Nov 1944	W	S-M	NW-4	21 Dec 1944	W	S-M	Se-4
21 Nov 1944	W	S-M	N-1	22 Dec 1944	W	S-M	Calm
22 Nov 1944	W	S-M	N-1	23 Dec 1944	W	S-M	Calm
23 Nov 1944	W	S-M	--	24 Dec 1944	W	S-M	Calm
24 Nov 1944	W*	S-S	Calm	25 Dec 1944	W	S-M	Calm
28 Nov 1944	W*	S-M	S-3	26 Dec 1944	W	S-S	Calm
29 Nov 1944	W	S-M	ESE-7	27 Dec 1944	W	S-S	E-6
30 Nov 1944	W	S-M	SE-10	28 Dec 1944	W	S-S	SE-10
Humboldt Bay Life Boat Station				Samoa Beach			
1 Dec 1944	W	S-M	SE-10	1 Dec 1944	W	S-M	SE-10
2 Dec 1944	W	S-M	SE-5	2 Dec 1944	W	S-M	SE-3
3 Dec 1944	W	S-M	SE-2	3 Dec 1944	W	S-M	SE-1
4 Dec 1944	W	S-M	Calm	4 Dec 1944	W	S-M	Calm
5 Dec 1944	W*	S-M	W-5	5 Dec 1944	W	S-M	Calm
6 Dec 1944	W*	S-M	Calm	6 Dec 1944	W*	S-M	Calm
7 Dec 1944	W	S-M	NW-5	7 Dec 1944	W	S-M	Calm
8 Dec 1944	W	S-M	Calm	8 Dec 1944	W	S-M	Calm
9 Dec 1944	W	S-M	Calm	9 Dec 1944	W	S-M	Calm
10 Dec 1944	W	S-M	Calm	10 Dec 1944	W	S-M	Calm
11 Dec 1944	W	S-M	Calm	11 Dec 1944	W	S-M	Calm
12 Dec 1944	W	S-M	Calm	12 Dec 1944	W	S-M	Calm
13 Dec 1944	W	S-M	Calm	13 Dec 1944	W	S-M	Calm
14 Dec 1944	W	S-M	Calm	14 Dec 1944	W	S-M	Calm
15 Dec 1944	W	S-M	Calm	15 Dec 1944	W	S-M	Calm
16 Dec 1944	W	S-M	E-4	16 Dec 1944	W	S-M	E-4
17 Dec 1944	W	S-M	Calm	17 Dec 1944	W	S-M	Calm
18 Dec 1944	W	S-M	Calm				

TABLE 6-6. Data on Littoral Current, Swell, and Wind, for the Humboldt Bay Area (continued).

Date	Swell ¹	Littoral Current ²	Wind ³	Date	Swell ¹	Littoral Current ²	Wind ³
Samoa Beach (continued)				Humboldt Bay Life Boat Station (continued)			
18 Dec 1944	W	S-M	Calm	22 Jan 1945	W	S-M	Calm
19 Dec 1944	W	S-M	Calm	23 Jan 1945	W	S-S	Calm
20 Dec 1944	W	S-M	Calm	24 Jan 1945	W	S-S	Calm
21 Dec 1944	W	S-M	Calm	25 Jan 1945	W	S-M	Calm
22 Dec 1944	W	S-M	Calm	26 Jan 1945	W	S-M	Calm
23 Dec 1944	W	S-M	Calm	27 Jan 1945	W	S-M	Calm
24 Dec 1944	W	S-M	Calm	28 Jan 1945	W	S-M	Calm
25 Dec 1944	W	S-M	Calm	29 Jan 1945	W	S-M	Calm
26 Dec 1944	W	S-S	Calm	30 Jan 1945	W	S-M	SSE-5
27 Dec 1944	W	S-S	E-5	31 Jan 1945	W	S-M	SSE-6
28 Dec 1944	W	S-S	SE-10	Samoa Beach			
29 Dec 1944	W	S-S	SE-8	1 Jan 1945	W	S-M	Calm
30 Dec 1944	W	S-S	Calm	2 Jan 1945	W	S-M	Calm
31 Dec 1944	W	S-M	Calm	3 Jan 1945	W	S-M	Calm
Humboldt Bay Life Boat Station				4 Jan 1945	W	S-M	Calm
1 Jan 1945	W	S-M	Calm	5 Jan 1945	W	S-M	Calm
2 Jan 1945	W	S-M	Calm	6 Jan 1945	W	S-M	Calm
3 Jan 1945	W	S-M	Calm	7 Jan 1945	W	S-M	Calm
4 Jan 1945	W	S-M	Calm	8 Jan 1945	W	S-M	Calm
5 Jan 1945	W	S-M	Calm	9 Jan 1945	W	S-M	Calm
6 Jan 1945	W	S-M	Calm	10 Jan 1945	W	S-M	Calm
7 Jan 1945	W	S-M	Calm	11 Jan 1945	W	S-M	Calm
8 Jan 1945	W	S-M	Calm	12 Jan 1945	W	S-M	Calm
9 Jan 1945	W	S-M	Calm	13 Jan 1945	W	S-M	Calm
10 Jan 1945	W	S-M	Calm	14 Jan 1945	W*	S-S	SSE-15
11 Jan 1945	W	S-S	SSE-4	15 Jan 1945	W*	S-S	WSW-7
12 Jan 1945	W	S-M	Calm	16 Jan 1945	W	S-M	Calm
13 Jan 1945	W	S-M	Calm	17 Jan 1945	W	S-M	NW-4
14 Jan 1945	W*	S-S	SSE-15	18 Jan 1945	W	S-S	Calm
15 Jan 1945	W*	S-S	SW-12	19 Jan 1945	W	S-M	N-5
16 Jan 1945	W	S-M	Calm	20 Jan 1945	W	S-M	Calm
17 Jan 1945	W	S-S	NNW-7	21 Jan 1945	W	S-M	Calm
18 Jan 1945	W	S-S	Calm	22 Jan 1945	W	S-M	Calm
19 Jan 1945	W	S-M	Calm	23 Jan 1945	W	S-S	Calm
20 Jan 1945	W	S-M	Calm	24 Jan 1945	W	S-S	Calm
21 Jan 1945	W	S-M	Calm	25 Jan 1945	W	S-M	Calm

TABLE 6-6. Data on Littoral Current, Swell, and Wind, for the Humboldt Bay Area (continued)

Samoa Beach (continued)					Samoa Beach (continued)				
Date	1 Swell	Littoral ² Current	3 Wind		Date	1 Swell	Littoral ² Current	3 Wind	
26 Jan 1945	W	S-M	Calm		3 Feb 1945	W	S-M	SE-5	
27 Jan 1945	W	S-M	Calm		4 Feb 1945	W*	S-S	SE-20	
28 Jan 1945	W	S-M	Calm		5 Feb 1945	W	S-M	Calm	
29 Jan 1945	W	S-M	Calm		6 Feb 1945	W	S-M	SE-5	
30 Jan 1945	W	S-M	SSE-5		7 Feb 1945	W	S-M	Calm	
31 Jan 1945	W	S-S	SSE-6		8 Feb 1945	W	S-M	Calm	
Humboldt Bay Life Boat Station					9 Feb 1945	W	S-M	Calm	
1 Feb 1945	W*	S-S	SSE-25		10 Feb 1945	W	S-M	Calm	
2 Feb 1945	W*	S-S	SSE-4		11 Feb 1945	W	S-M	Calm	
3 Feb 1945	W*	S-S	SE-6		12 Feb 1945	W	S-M	Calm	
4 Feb 1945	W*	S-S	SE-35		13 Feb 1945	W	S-M	Calm	
5 Feb 1945	W	S-M	Calm		14 Feb 1945	NW*	NW-S	NW-25	
6 Feb 1945	W	S-M	SE-6		15 Feb 1945	W*	NW-S	NW-5	
7 Feb 1945	W	S-M	Calm		16 Feb 1945	W	S-M	Calm	
8 Feb 1945	W	S-M	Calm		18 Feb 1945	W	S-M	NE-4	
9 Feb 1945	W	S-M	Calm		19 Feb 1945	W	S-M	NW-4	
10 Feb 1945	W	S-M	Calm		20 Feb 1945	W	S-M	NW-2	
12 Feb 1945	W	S-M	Calm		21 Feb 1945	W	S-M	Calm	
13 Feb 1945	W	S-M	Calm		22 Feb 1945	W	S-M	Calm	
14 Feb 1945	NW*	NW-S	NW-3		23 Feb 1945	W	S-S	NW-3	
15 Feb 1945	W*	NW-S	NW-5		24 Feb 1945	W*	S-M	N-4	
16 Feb 1945	W	S-M	Calm		Table Bluff				
17 Feb 1945	W*	S-M	NE-2		3 Dec 1945	15-S	N	SE -1	
18 Feb 1945	W	S-M	NE-2		4 Dec 1945	20-S	N	S-1.8	
19 Feb 1945	W	S-M	NW-2		5 Dec 1945	0-S	N	S-0-1	
20 Feb 1945	W	S-M	NW-2		6 Dec 1945	15-S	N	SW-2-3	
21 Feb 1945	W	S-L	Calm		7 Dec 1945	--	S	NE-0-1	
22 Feb 1945	W	S-M	W-1		8 Dec 1945	--	S	S-1	
23 Feb 1945	W	S-S	NW-3		9 Dec 1945	--	S	ESE-1	
24 Feb 1945	W	S-M	N-3		10 Dec 1945	--	S	ENE-1	
Samoa Beach					11 Dec 1945	--	S	SSE-1-2	
1 Feb 1945	W	S-S	SSE-20		12 Dec 1945	0-SN	S	NE-1-2	
2 Feb 1945	W*	S-M	SSE-4		13 Dec 1945	15-NW	S	S-1	
					14 Dec 1945	--	S	SSW-.5	
					15 Dec 1945	--	N	SE-5-1	

TABLE 6-6. Data on Littoral Current, Swell, and Wind, for the Humboldt Bay Area (continued).

Date	Swell ¹	Littoral ² Current	Wind ³	Date	Swell ¹	Littoral ² Current	Wind ³
Table Bluff (continued)				Table Bluff (continued)			
16 Dec 1945	12-2C-S		SSW	8 Jan 1946			NE
17 Dec 1945		S	SSW	9 Jan 1946	15-3	N	SSE-NE-1-15
18 Dec 1945	10-SW	S	SSE-1-2	10 Jan 1946		Varied	SE-1
19 Dec 1945		S	S-1	11 Jan 1946			NE
20 Dec 1945	10-S	N	S-SSE-0-3	12 Jan 1946		S	NE-W-1-3
21 Dec 1945		N	SE-0-1	13 Jan 1946	4-S	N	S-E-1-3
22 Dec 1945		N	SSW-2-3	14 Jan 1946	4-S	N	SSE-NNW-2
23 Dec 1945	10-SW	N	SW-2-3	15 Jan 1946	3-S		SSW-WSW
24 Dec 1945		N	E-2	16 Jan 1946		N	SW
25 Dec 1945	S	N	SW-WSW-3-4	17 Jan 1946	7-N		SSW
26 Dec 1945		N	SSW-1-2	18 Jan 1946		N	SW-1.5-2
27 Dec 1945		N	S-SW-2-3	19 Jan 1946	3-S	N	SW-NE-1
28 Dec 1945		N	S-1	20 Jan 1946		N	SEE-2-3
29 Dec 1945			NW	21 Jan 1946	8-S	N	SSE-SSW-2-3
30 Dec 1945	0-5-S	N	SSW-W-.5-1	22 Jan 1946	8-S		SE
31 Dec 1945	S	N	SSE-2-4	23 Jan 1946		N	S-SSE-4-5
1 Jan 1946	2-S	N	S-2-3	24 Jan 1946	2-N	N	SSW-E-2-5
2 Jan 1946	5-S	N	SW-1-2	25 Jan 1946	5-20-NW	S	E-NE-.25
3 Jan 1946	3-S	N	SE-0-1.5	26 Jan 1946	15-25-N	N	SSW-E-NE-1-3
4 Jan 1946		N	S-2-3	27 Jan 1946	3-N	N	WNW-1-2
5 Jan 1946		N	NE-.5	28 Jan 1946		N	NE-2-3
6 Jan 1946		N	WSW-S-1	29 Jan 1946			
7 Jan 1946	10-S	N	NE-NNE-1-2	30 Jan 1946			
				31 Jan 1946			

¹ Those with asterisk (*) are classified as "Chop."

² Littoral current given in direction of travel and relative velocity:
W = weak, M = moderate, S = strong.

³ Wind given in direction and velocity (knots).

Table compiled from Stump, Bascom, Foight, and Schorr (1947) and Stump (1945).

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1947. Beach and Surf Conditions on the Beaches of the Oregon and Washington Coasts Between October 9, 1946 and November 18, 1946. University of California, Department of Engineering, Fluid Mechanics Laboratory, Berkeley, Laboratory Memorandum No. HE-116-247, 54 pages, photos, profiles (typewritten).
(Includes profiles, surf conditions, tire impressions, sand samples, and water table profiles. Data for Humboldt Bay, Coos Bay, and Greys Harbor areas. Large number of photos obtained in survey which were not included in the report.)
- Stupp, Robert
1945. Comparison of Forecast and Observed Surf Conditions, California Coast from October 1944 through March 1945. University of California, College of Engineering, Berkeley, Report No. HE-116-95, 191 pages, tables, air photos, maps, diagrams (typewritten).
(Includes data obtained from three locations at Humboldt Bay.)
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1947. Beach and Surf Observations at Table Bluff, and a Comparison with Hindcasts: December 1945-February 1946. University of Calif., Department of Engineering, Fluid Mechanics Laboratory, Berkeley, Laboratory Memorandum No. HE-116-205, 83 pages, tables, photos, diagrams, maps (typewritten).
(Humboldt Bay area. Describes operations of field party and presents data obtained, also analysis of oblique daily observational photos of the surf zone and shows comparison of this data with hindcasts. Beach profiles, sieve analysis, and tire impressions, shown in tables, diagrams and photos.)
- Iwerthofel, W. H.
1946. Mineralogical and Physical Composition of the sands of the Oregon Coast from Coos Bay to the Mouth of the Columbia River. Oregon State Department of Geology and Mineral Industries, Bulletin no. 30, 64 pages (processed).
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1946. Notes on Reconnaissance of Miscellaneous Pacific Beaches May 21-September 29, 1945. Department of Engineering, Fluid Mechanics Laboratory, Berkeley, Laboratory Memorandum No. HE-116-223, 51 pages, maps, photos (typewritten). (Captions accompanying the photos constitute the report. Photos show surf conditions, beaches, and sand dunes in the various areas studied.)

U. S. Army Corps of Engineers

n. d. Quantity of Material Dredged from Humboldt Bay. On file in Operations Division, San Francisco District, San Francisco, California. (Unpublished.) (Dredge quantities are available from 1931 to date. Method of evaluation has been revised such that older estimates of material dredged are too large. Comparison of data not practical.)

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1950. Shore-Line Changes, Appendix I to Survey Report on Humboldt Bay California, February 10, 1950. San Francisco District, San Francisco, California, 73 pages, maps, diagrams (processed). (Comprehensive study of shore-line changes including depth changes, waves, littoral drift, geology, stream flow, soil samples, and dredging.)

1951. Humboldt Bay, Calif. House Document No. 143, 82d Congress, 1st Session, 38 pages, 1 map.

1954. Report of Soil Tests, Hopper Dredge Operations, Humboldt Harbor. South Pacific Division Laboratory, Sausalito, California, 2 pages, 3 plates (processed). (The samples analyzed were taken in the various channels of Humboldt Bay and serve only as a superficial index to the material involved in the dredging operations. Mechanical analysis of sediments included in graphic form.)

U. S. Army Corps of Engineers, San Francisco District, San Francisco, California [Humboldt Bay--Maps (Unpublished)]

n. d.a. Humboldt Bar and Entrance, Shift of Sand Above 30 Foot Depth. Map File No. 5-8-5. (Includes changes in cubic yards, 1916 to 1917.)

U. S. Army Corps of Engineers, San Francisco District, San Francisco, California [Humboldt Bay--Maps (Unpublished)]

n. d. b. Humboldt Bar and Entrance, Shift of Sand Above 30 Foot Depth. Map File No. 5-8-7.

(Includes changes in cubic yards, 1917 to 1920.)

n. d. c. Humboldt Bar and Entrance, Shift of Sand Above 30 Foot Depth. Map File No. 5-8-9.

(Includes changes in cubic yards, 1920 to 1921.)

n. d. d. Surveys of Bar and Entrance, 1851, 1858, 1870, 1875, 1881, 1882, 1883. Map File No. 5-2-70.

1909 Topographical Map of Land Between Southport, Humboldt Bay, Cal. and McNulty's Slough, Eel River Valley, Cal., Showing Several Routes for Canal. Map File No. 5-2-1.
(Includes table of borings.)

1926 Eureka Channel of Samoa Shoal. Map File No. 5-14-23.
(Includes log of borings in channel in front of Eureka.)

1929 Point Humboldt, Humboldt Bay, Calif., Relative Positions of High Water Line at Various Periods, 1854 to 1929. Map File No. 5-1-24.
(Surveys of 1854,-70,-91, 1903,-11,-26,-29 shown.)

1930 Erosion at Point Humboldt, 1851-1930. Map File No. 5-20-31.

1938a. Dredging in Fields Landing Channel. Map File No. 5-1-32/2.
(Includes log of borings.)

1938b. Dredging in Samoa and Eureka Channels. Map File No. 5-1-32/1.
(Includes log of borings.)

1939a. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/1.
(Surveys of 1851,-58,-70,-75,-81,-82,-83,-91 shown.)

1939b. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/2.
(Surveys of 1894,-96,-97,-98,-99, 1903,-05,-07 shown.)

1939c. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/3.
(Surveys of 1911,-12,-13,-14,-15,-16,-17,-19 shown.)

1939d. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/4.
(Surveys of 1920,-21,-22,-23,-24,-25,-26,-27 shown.)

U. S. Army Corps of Engineers, San Francisco District, San Francisco, California [Humboldt Bay--Maps (Unpublished)]

- 1939e. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/5.
(Surveys of 1917,-27,-31,-35,-37,-39 and U. S. Coast and Geodetic Survey of 1851,-58,-70,-82 shown.)
- 1950a. Changes in High Water Shore Line. Map File No. 5-51-1/2.
(The years 1854,-70, 1911,-19,-29,-40 shown.)
- 1950b. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78A.
(Surveys of 1929,-31,-35,-37,-40,-42,-44 included.)
- 1950c. Relative Positions of MHHW at Various Periods 1854-1926.
Map File No. 5-51-1/10.
- 1950d. Relative Positions of MHHW at Various Periods 1926-1946.
Map File No. 5-51-1/11.
- U. S. Army Corps of Engineers
1955 Personal communication on location of bottom samples. Letter from G. P. Reilly, Acting chief, Engineering Division, San Francisco District, to Peter M. McLellan, dated 7 July 1955.
(Concerns samples from drill holes obtained during soils exploration in October 1946.)

SECTION 7

HYDROGRAPHY

HYDROGRAPHY

BATHYMETRY

Humboldt Bay is typical of most of the northwestern coastal bays in that it is a shallow waterway, most of it less than 20 feet deep. In its original condition the entrance channel was about 600 feet wide with an average minimum usable depth at MLLW of about 12 to 15 feet. A continuous shifting of the entrance channel from north to south coupled with a changing configuration made passage difficult. The original channel at Eureka was about 10 feet deep at MLLW and averaged 150 feet in width. The construction of the jetties and their subsequent improvement has helped in stabilizing the channel entrance. Dredging of the inner channels has provided the necessary depths for ocean going vessels. The first dredging project, in 1881, was for improving the channel in front of Eureka to a depth of 12 feet and width of 200 feet as well as dredging the channel to Samoa and Eureka (U. S. Army Corps of Engineers 1951). Since that time the Eureka, Arcata, and Fields Landing channels have been improved and maintained. The following list is a tabulation of House Documents and Annual Reports of the Chief of Engineers, not included in the bibliography, which contain information on surveys and projects concerned with the improvement of Humboldt Bay:

- Annual Report, Chief of Engineers, 1871, (pp. 920-921).
 - Annual Report, Chief of Engineers, 1877, (p. 1052).
 - House Document No. 22, 45th Congress, 3d session, 1877.
 - House Document No. 59, 46th Congress, 3d session, 1878.
 - Annual Report, Chief of Engineers, 1881 (p. 2481).
 - Annual Report, Chief of Engineers, 1883 (p. 1986).
 - Annual Report, Chief of Engineers, 1891 (p. 3120).
 - House Document No. 528, 55th Congress, 2d session, 1898.
 - Annual Report, Chief of Engineers, 1898 (p. 2949).
 - House Document No. 228, 59th Congress, 1st session, 1905.
 - House Document No. 950, 60th Congress, 1st session, 1908.
 - House Document No. 204, 61th Congress, 2d session, 1909 (a).
 - House Document No. 326, 61th Congress, 2d session, 1909 (b).
 - House Document No. 226, 63th Congress, 1st session, 1913.
 - Annual Report, Chief of Engineers, 1915 (pp. 1982-1984).
 - House Document No. 1008, 65th Congress, 2d session, 1917.
 - House Document No. 1064, 65th Congress, 2d session, 1918.
 - House Document No. 755, 69th Congress, 2d session, 1926.
 - House Document No. 14, 74th Congress, 1st session, 1933.
 - House Document No. 11, 75th Congress, 1st session, 1936.
 - House Document No. 143, 82th Congress, 1st session, 1951.
- (Also Appendix I to Survey Report 1950)

Channel Characteristics

Portions of the channel are continuously changing in depth and configuration due to alongshore transportation and the shifting of sand at the entrance (see Enclosures 6-17, 6-18, and 6-24 through 6-26), the erosion of Point Humboldt (see Enclosures 6-13 through 6-16), and sedimentation from the rivers. Shoaling in Eureka, Samoa, Arcata, and Fields Landing channels are discussed by the U. S. Army Corps of Engineers (1927) as follows:

A comparison of surveys up to 1884 and of surveys up to 1919 shows but little change in the bay in general. There has been some shifting of the contours in places but no marked shoaling is noticeable in any portion of the bay. A narrowing of the channels in the south arm, particularly in the Fields Landing Channel, has taken place, but this narrowing in the channels in the northern section is not noticeable. A decided shifting of the shoals has occurred in the vicinity of the entrance, but this shifting is no doubt due to jetty and shore revetment work carried on between these dates. The changes in this vicinity, however, have for the greater part been for the good of the harbor and have caused the development of deeper and wider channels, the exception being the forming of a shoal at the mouth of the Fields Landing Channel, with a controlling depth of 17 feet as compared to 24 feet in 1884.

The various channels, which from time to time have been dredged show but little shoaling and in some cases show better depths than when last dredged. This condition is probably due partly to the drag of vessels in shallow water and in narrow channels. A statement as to the shoaling in each of the channels under discussion in this report follows:

Eureka Channel. This is the largest of the channels which have been dredged and shoaling is more rapid than noted in the other channels. Shoaling between the periods of dredging of 1920 and 1926 is estimated to be 84,000 cubic yards, or 14,000 cubic yards annually.

Samoa Channel. This channel was dredged 19 feet deep and 200 feet wide in 1914 and these dimensions still prevail.

Arcata Channel. This channel was dredged to 14 feet deep and 80 feet wide in 1915 and was dredged to 12 feet in 1920. The present channel has a controlling depth of 14 feet, and for the greater part, is wider and deeper than previously dredged.

Fields Landing Channel. This channel was dredged to 20 feet deep and 200 feet wide in 1915, was redredged to 17 feet in 1920, and still has a usable depth of 17 feet, but it is very narrow for a short distance near Buhne's Point. The section of channel near the south spit has greater depth and width than when last dredged, but a new bar has formed at the mouth.

The effect of shore line changes on the Pacific Ocean coast and at Point Humboldt in reference to the bar and channel entrance and shoaling in Fields Landing Channel are considered in the following statement by the U. S. Army Corps of Engineers (1951):

Effect of bar and entrance channel: The Humboldt Bar is characteristic of those which form at tidal inlets. The bar, created and fed by littoral material, serves as the path by which littoral material makes its way around the jettied inlet and continues its passage along the coast. The directions of littoral movement, in the vicinity of Humboldt Bay, is predominantly down-coast (north to south). The relative stability of the bar in recent years indicates that substantially all littoral drift is passing the entrance to Humboldt Bay and is maintaining the south spit and down coast shores. If the bar and entrance channel is enlarged as proposed, it is believed that littoral drift will encroach on the channel and will require the dredging of about 400,000 cubic yards annually as maintenance. If the littoral material dredged from the proposed channel is deposited south of the south jetty in a depth not greater than 30 feet, it will probably resume normal travel with no detriment to the shore. If deposited in deeper water it will remain, and the south spit will erode a corresponding amount.

The controlling depths at the entrance and in the inner channels is also considered by the U. S. Army Corps of Engineers (1954):

Controlling depths are 31 feet in Entrance Channel and channel between jetties, 26.5 feet in North Bay Channel, Eureka Channel, 20 feet to "D" Street, 12.5 feet to "N" Street, Eureka, 27 feet in Samoa Channel, 20 feet in Fields Landing Channel (June 1954), 18 feet in Arcata Channel (May 1937).

Soundings

The U. S. Army Corps of Engineers have periodically surveyed the bay in conjunction with the numerous projects of improvement and maintenance. Soundings for the entire bay and specific portions thereof are available from about 1881 to 1954. All charts pertinent to the bathymetry

of the bay and offshore areas are included as enclosures and are listed in Table 7-1. Additional charts concerned with specific projects and soundings can be obtained from the U. S. Army Corps of Engineers at Portland, Oregon.

SHIPWRECKS

Complete records of shipwrecks from about 1870 are available from the Records of Assistance Files kept by the U. S. Coast Guard Lifeboat Service and from the Record of Shipwrecks formerly maintained by the U. S. Coast Guard Light House Service. The following is a list of shipwrecks that occurred on or near the Humboldt Bar bar between the years 1850 and 1880 as taken from Elliott (1881):

- 1850 Eclipse, Brig San Jacinto, schooner Sarah Wardwell
- 1851 Bark, Jane, steamer Commodore Preble
- 1852 Steamer See Gull, bark Home, bark Cornwallis, brig John Clifford
- 1853 Schooner Mexican
- 1855 Schooner Piedmont, schooner Sierra Nevada
- 1858 Schooner Toronto
- 1859 Schooner J. W. Ryerson
- 1860 Bark Success, steamer Northerner (30 lives lost near Centerville)
- 1862 Schooner T. H. Allen (1 life lost), brig Eolus
- 1863 Steam tug Merrimac (13 lives lost, schooner Dashaway (14 lives lost)
- 1864 Bark Hartford
- 1876 Schooner Albert and Edward (5 lives lost, 1 saved)
- 1877 Schooner Marrietta (all saved)
- 1878 Schooner Laura Pike (7 lives lost)
- 1879 Scow Sara, (lost at sea off Crescent City)
- 1880 Schooner Edward Parker (2 lost, 4 saved)

TABLE 7-1. Listing of Enclosures on Bathymetric Information.

Enclosure No.	U. S. Army Corps of Engineers No.	Date	Subject
7-1	5-2-3	1907	Bucksport, Eureka, Samoa Channel soundings.
7-2a-J	5-2-17 (10 sheets)	1914	Channel soundings of entire Bay.
7-3	5-2-68	1931	Entrance channel soundings.
7-4a-J	5-2-69 (10 sheets)	1931	Channel soundings of entire Bay.
7-5a-H	5-1-34 (8 sheets)	1940	Channel soundings of entire Bay.
7-6a-C	5-2-94 (3 sheets)	1954	Channel soundings of entire Bay.
7-7	5-51-1 (Sheet 1)	1950	Depth contours to 100 feet.
6-20	5-14-23	1926	Samoa and Eureka channel soundings.
6-21	5-1-32 (Sheet 1)	1938	Samoa and Eureka channel soundings.
6-22	5-1-32 (Sheet 2)	1938	Fields Landing channel soundings.
6-7	5-2-78 (Sheet 1)	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-8	5-2-78 (Sheet 2)	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-9	5-2-78 (Sheet 3)	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-10	5-2-78 (Sheet 4)	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-11	5-2-78 (Sheet 5)	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-12	5-2-78A	1939	Comparison of Periodic Surveys at Bar and Entrance.
6-13	5-1-24	1929	Point Humboldt relative positions of High Water line 1854-1929.
6-15	5-51-1 (Sheet 10)	1950	Relative positions of MHHW, 1854-1926.
6-16	5-51-1 (Sheet 11)	1950	Relative positions of MHHW, 1926-1946.
6-17	5-51-1 (Sheet 8)	1950	Depth changes Fields Landing Channel 1939-1946.
6-18	5-51-1 (Sheet 9)	1950	Shoaling in Fields Landing Channel 1935-37, 1943-44.
6-24	5-8-5	1921	Shift of sand above 30 feet.
6-25	5-8-7	1921	Shift of sand above 30 feet.
6-26	5-8-9	1921	Shift of sand above 30 feet.

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 (For use by the Corps of Engineers. Reproduced to accompany the Annual Report of the Chief of Engineers presenting projects and their locations on reference maps.)
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 (Includes changes in cubic yards, 1916 to 1917.)

U. S. Army Corps of Engineers, San Francisco District, San Francisco, California [Humboldt Bay--Maps (Unpublished)]

- n. d. b. Humboldt Bar and Entrance, Shift of Sand Above 30 Foot Depth. Map File No. 5-8-7.
(Includes changes in cubic yards, 1917 to 1920.)
- n. d. c. Humboldt Bar and Entrance, Shift of Sand Above 30 Foot Depth. Map File No. 5-8-9.
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- 1907. Hydrographic Survey of Humboldt Bay, Cal. from Bucksport to Eureka. Map File No. 5-2-3.
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- 1911. [Hydrographic Survey of 1911.] Map File Nos. 5-2-17/index, 1 through 9.
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- 1926. Eureka Channel and Samoa Shoal. Map File No. 5-14-23.
(Includes log of borings in channel in front of Eureka.)
- 1929. Point Humboldt, Humboldt Bay, California, Relative Positions of High Water Line at Various Periods, 1854 to 1929. Map File No. 5-1-24.
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- 1930. Erosion at Point Humboldt, 1851-1930. Map File No. 5-20-31.
- 1931 a. Entrance Channels of Humboldt Bay, Cal. Map File No. 5-2-68.
(Includes wind rose.)
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- 1936. Dredging in Fields Landing Channel. Map File No. 5-1-30A.
- 1938 a. Dredging in Fields Landing Channel. Map File No. 5-1-32/2.
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(Surveys of 1851,-58,-70,-75,-81,-82,-83,-91 shown.)
- 1939 b. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/2.
(Surveys of 1894,-96,-97,-98,-99, 1903,-05,-07 shown.)
- 1939 c. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/3.
(Surveys of 1911,-12,-13,-14,-15,-16,-17,-19 shown.)
- 1939 d. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/4.
(Surveys of 1920,-21,-22,-23,-24,-25,-26,-27 shown.)
- 1939 e. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78/5.
(Surveys of 1917,-27,-31,-35,-37,-39 and U. S. Coast and Geodetic Survey of 1851,-58,-70,-82 shown.)
1940. [Hydrographic Survey of 1940.] Map File No. 5-1-34/index, 1 through 7.
(Showing bathymetry on a scale of 1 inch = 500 feet.)
- 1950 a. Wave Refraction Diagram. Map File No. 5-51-1/1.
(Off Shore bathymetry to 100 fathoms shown.)
- 1950 b. Changes in High Water Shore Line. Map File No. 5-51-1/2.
(The Years 1854,-70, 1911,-19,-29,-40 shown.)
- 1950 c. Comparison of Periodic Surveys of Bar and Entrance. Map File No. 5-2-78A.
(Surveys of 1929,-31,-35,-37,-40,-42,-44 included.)
- 1950 d. Depth Changes Between Fields Landing Channell and Elk River, 1939 and 1946. Map File No. 5-51-1/8.
(MHHW, 6, 12, 18, 24, 30 foot depths shown.)
- 1950 e. Plan of Improvement. Map File No. 5-51-1/4.
- 1950 f. Relative Positions of MHHW at Various Periods 1854-1926.
Map File No. 5-51-1/10.
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SECTION 8

PHYSICAL OCEANOGRAPHY

PHYSICAL OCEANOGRAPHY

TIDES

The tide in Humboldt Bay is of the mixed type with inequality in both the high and low waters but somewhat larger in the low. The mean and diurnal ranges increase, respectively, for 4.3 and 6.2 feet at the Bay entrance to a maximum to South Bay of 4.8 and 6.6 feet at Hookton Slough, and in Arcata Bay of 5.0 and 7.0 feet at Arcata Wharf. The time of tide becomes progressively later on passing inward from the entrance; at Hookton Slough and Arcata Wharf it is 20 minutes and 50 minutes later, respectively, than at the entrance. In the Bay, high tide occurs on the average during the hour preceding the upper and lower transits of the moon.

Tide Stations

Complete tidal predictions for Humboldt Bay at the South Jetty Landing are obtained and published annually as times and heights of high and low waters for each day of the year (U. S. Department of Commerce Coast and Geodetic Survey 1954). Tidal harmonic constants are published for this station (U. S. Department of Commerce Coast and Geodetic Survey 1942; International Hydrographic Bureau 1933).

Tidal data for the following stations:

1. Entrance
2. Fields Landing
3. Hookton Slough
4. Bucksport
5. Eureka
6. Arcata Wharf

consist of: the time of tide, height of high water, height of low water (1955), and ratio of ranges (prior to 1955) compared to the tide at the South Jetty Landing; the high water interval (prior to 1955), and mean range of tide and the diurnal range of tide (U. S. Department of Commerce Coast and Geodetic Survey 1954). Additional tidal data for the following stations:

1. South Jetty
2. Fields Landing
3. North Jetty
4. Eureka

consist of the elevations referred to mean lower low water of the following

planes: highest tide (estimated), mean higher high water, mean high water, half tide level, mean low water, mean lower low water, and lowest tide (estimated) (U. S. Department of Commerce Coast and Geodetic Survey 1946).

Monthly Tidal Variations

The tide in Humboldt Bay, as typified by that at the South Jetty Landing, follows the monthly lunar cycles in response to the Moon's changing phase, distance, and declination as follows:

<u>Lunar Cycle</u>	<u>Measure of Tidal Effects</u>	<u>Ratio</u>	<u>Lag of Maximum Effect in Hours</u>
Phase	Spring to neap range	1.5	19.7
Parallax	Perigean to apogean range	1.5	47.8
Declination	Tropic to mean diurnal inequality	1.5	15.5

This dependence on all three factors indicates a complicated monthly variation in tidal range. However, these variations are not large compared to the daily differences in range.

In addition, the time of tide relative to the moon's transit undergoes monthly change. A maximum deviation of about 2 hours from the mean can be expected.

Tidal Datum Planes

Mean lower low water, based on 19 months of automatic gage records, is the datum for the charts of the Humboldt Bay area (U. S. Department of Commerce Coast and Geodetic Survey 1946).

Sea level will undergo variations over periods of a day, month, year, and longer. The long-term trends of sea level can be expected to follow those for Seattle and San Francisco (Marmer 1949, 1951, 1952). The yearly variation will be somewhat similar to those at Crescent City and San Francisco (Marmer 1951) but will also depend on the local fresh water runoff. Shorter period fluctuations are generally unpredictable.

TIDAL CURRENTS

The tidal currents in Humboldt Bay follow the general direction of the channels. In the main channel, the average velocity at strength is less than 2 knots, and the maximum does not exceed 3 knots. Between the

jetties, the average velocity at strength is about 2 knots, with a maximum of about 4 knots (U. S. Department of Commerce Coast and Geodetic Survey 1931).

On the average, the current changes direction within $\frac{1}{2}$ hour after the times of high and low waters at the South Jetty Landing. Throughout the main navigation channels the times of current are within 15 minutes of one another.

Current Stations

Current tables list the time differences and velocity ratios for five stations in Humboldt Bay which makes it possible to derive their maximum flood and ebb current velocities and their times of maximum ebb, flood, and slack waters from the reference stations predictions. Also listed for each station are the intervals of time between maximum flood and moon's transit, the flood directions, and the average and tropic current velocities (U. S. Department of Commerce Coast and Geodetic Survey 1953a).

Surface Currents

Drift studies of the flood and ebb surface tidal currents at the Buhe property near the entrance to Humboldt Bay were made by the U. S. Army Corps of Engineers, Portland District (1930), in January 1930. Ebb currents to 5 knots and flood currents to $1\frac{1}{2}$ knots were obtained. The drift paths are shown in Enclosure 8-1.

Offshore Tidal Currents

Tidal current measurements have been made from five light vessels along the Pacific Coast of the United States in depths ranging from 20 to 30 fathoms (Marner 1926). At some locations the measured currents are strongly influenced by adjacent entrances to large inland bodies of water while at others there is no such effect. In all cases the currents were rotary. The maximum tropic velocities ranged from about 0.1 to 1.1 knots. It is estimated that at a depth of 20 to 30 fathoms off the entrance to the Humboldt Bay, the tropic velocity would be about 0.4 to 0.5 knot. At times of high water the set was generally in the northeast quadrant. The direction of maximum current followed the general trend of the local shoreline although the effect of onshore tidal flow was evident in some cases.

WAVES

Short-period waves occurring in Humboldt Bay may be generated either by the local wind or result from waves and swell entering from the Pacific Ocean. Since the Bay has limited fetches and is well protected from the Ocean, its waves, in general, can be expected to be moderate in size.

Off the adjacent coast in winter, seas greater than 8 feet and swells greater than 12 feet occur from the westerly directions about 20 and 30 percent of the time, respectively (U. S. Navy Hydrographic Office 1944).

Very severe seas occur at the entrance to the Bay, the worst seas occurring frequently as the result of offshore storms at times when conditions are calm locally (U. S. Army Corps of Engineers 1927).

Local Wind Waves

Wave conditions in the Bay can be derived from wind observations in the surrounding area.

The following are quoted from U. S. Army Corps of Engineers (1927):

The winds are generally moderate, seldom exceeding 30 to 40 miles per hour, the maximum velocity recorded in the last 36 years being 59 miles per hour as compared with 120 miles at Point Reyes, about 190 miles south of Humboldt Bay. The prevailing winds during the summer are from the north and northwest, and during the winter from the southeast and southwest.

See paragraph on Storms in Section 2, CLIMATOLOGY, for additional wind data. Wind roses are given in U. S. Army Corps of Engineers (1927, 1951).

Offshore Waves, Swell, and Surf

Data on the distribution of waves in the open ocean off the California coast, are available as follows:

1. Percentages of high and low seas and swell in winter and summer (Bigelow and Edmondson 1947).
2. The relative annual frequency of waves of different heights in the North Pacific (Bigelow and Edmondson 1947).
3. Percentages of high, medium, and low seas and swell from each direction for each month of the year (U. S. Navy Hydrographic Office 1944).

4. Percentage of total days from each of the westerly direction during 1936-1938 for which wave heights are less than 2, 4, 6, 8, 10, 15 and 20 feet and greater than 20 feet is shown in Enclosure 8-2. (U. S. Army Corps of Engineers 1950).
5. Percentages of waves in the approximate height ranges 0 to 3 feet, 3 to 8 feet, 8 to 20 feet, and over 20 feet for each month of the year (Maritime Safety Agency 1951; U. S. Navy Hydrographic Office 1943).

The U. S. Army Corps of Engineers (1950) have made a study of Wave action in the vicinity of the Humboldt Bay jetties by means of refraction diagrams (see Enclosure 8-3, 8-4, and 8-5). The following is quoted:

The characteristics of the waves used for the diagrams are for waves occurring most frequently as shown in the Scripps Institution of Oceanography, "Wave Report No. 68." The diagrams were constructed for present conditions of the bar seaward of the jetties and for an assumed condition in which the depths over the bar and areas adjacent thereto were increased to 40 feet. The refraction diagrams indicate that for present conditions waves are affected by the seaward submarine slope of the bar so that some wave convergence occurs before waves reach or pass over the bar crest. The crest of the bar produces additional convergence so that waves either break on the bar or advance toward the jettied entrance considerably higher than waves in comparable depths elsewhere. Waves with a height of 10 feet or greater, occurring most frequently in the Pacific Ocean area in the vicinity of Humboldt Bay, have an average period of 9 seconds. For the period the depth over the bar, assumed as 20 feet, has little effect on the wave height so that the effect of refraction determines the height of waves seaward of the jetties. Waves having a period of from 12 seconds to 16 seconds are increased in height from 15 percent to 30 percent, respectively, by the bar. This increase is in addition to the effect of refraction.

Present depths over the bar cause 9-second northwest waves and west waves to break when the deep-water wave height is about 12 feet and 15 feet, respectively. A 12-second wave from the northwest breaks on the bar when the deep-water wave height is about 9 feet or greater.

In 1925 the Corps of Engineers tabulated the sea conditions as either light, moderate, strong, rough, or rougher at the North Jetty, daily from January 1, 1885 to December 31, 1924 (see Enclosure 8-6). These data have been summarized to give the percentage of smooth, moderate, and rough seas throughout an average year and the extremes for each month (see Enclosure 8-7). In December, the seas are on the average

18 percent smooth, 46 percent moderate and 36 percent rough. In July, the seas are on the average 65 percent smooth, 31 percent moderate and 4 percent rough.

Surf observations have been made at selected times on the beaches adjacent to Humboldt Bay during 1944 and 1945. The following data have been tabulated: breaker height, period, number of lines of breakers, direction of wave approach, distance to breakers (University of California, Department of Engineering, Fluid Mechanics Laboratory Memoranda Nos. HE-116-40, HE-116-52, HE-116-95, HE-116-124, HE-116-133, HE-116-152, HE-116-160, HE-116-161, HE-116-162, HE-116-168, HE-116-169). A summary of the above data and an analysis of its accuracy appears in University of California (1946b), HE-116-203. Visual and photographic observations have also been obtained for the period December 1945 to February 1946 (Stump, Bascom, Foight and Schorr 1947, HE-116-205).

Tsunamis

Sea waves occur along the Pacific coast of the United States from seismic activity around the periphery of the North Pacific Ocean. Data are available on the tsunami of April 1, 1946 which resulted from an earthquake on the north face of the Aleutian Trench, south of Unimak Island, at $53\frac{1}{2}^{\circ}$ N, between 163° and 164° W, (Bascom 1946; O'Brien 1946; Roop 1946a, 1946b; Bulletin of the Seismological Society of America 1946; Transactions of the American Geophysical Union 1946). The times of arrival along the United States coast were within $2\frac{1}{2}$ hours of each other and can be explained by shallow water wave theory. The heights recorded ranged from 1 to 17 feet. There was no consistent variation of height along the coast; evidently the local bathymetry of the shelf is critical in this regard. In the tsunami of April 1, 1946, the largest heights were reached in those bays which had a southerly exposure.

Data on the tsunami of November 4, 1952, compared to the one in 1946, indicate a roughly similar distribution and magnitude in heights recorded at tide stations. These heights, however, are generally less than the maximum observed in the surrounding area (U. S. Department of Commerce Coast and Geodetic Survey 1953b).

Listings of other tsunamis are available in U. S. Department of Commerce Coast and Geodetic Survey (1953b), Heck (1947) and Holden (1898). See also section on Seismology.

WATER CHARACTERISTICS

Humboldt Bay is an estuary of the positive type where precipitation and runoff exceed evaporation. The source of fresh water is from several small streams entering at various points in the Bay. No data are available at present on the runoff pattern of these streams, but some measurements are now being made. The runoff pattern probably follows the local precipitation because the drainage basin is small (223 square miles) and very little snow falls in this region. Access to the ocean is through a narrow dredged channel flanked by jetties. No obstructions occur near the entrance.

Very little data exists on the water characteristics of Humboldt Bay. Temperatures and salinities were measured by Bonnot in the spring and summer months of 1935 and 1936 in connection with oyster raising experiments (Bonnot 1936, 1937).

Offshore data has been collected by the Scripps Institution of Oceanography at various times from 1930 to 1952 (University of California, Scripps Institution of Oceanography 1949-51; Sverdrup 1943) and one ocean section was obtained by the University of Washington off Humboldt Bay in August 1939 (Thompson n. d.) see Table 1. These data include salinity, temperature, dissolved oxygen, dissolved inorganic phosphate and other minor constituents.

Salinity Distribution

The section made by the University of Washington in August 1939 indicated rather uniform conditions in the upper 50 meters with an average salinity of about 33.2‰. Observations by the Scripps Institution of Oceanography at a station about 50 miles off Humboldt Bay indicated that only small changes occurred in the water from March through October of 1949. From April until July extensive upwelling occurs along the California coast as a result of northerly winds and then decreases with the diminishing winds of August and September. From November to February, a coastal counter current, the Davidson Current, sets north. Because of the upwelling in summer and northerly flow in winter, the water characteristics immediately offshore from Humboldt Bay are fairly uniform throughout the entire year. At Blunts Reef Lightship, 23 miles south of the Bay, the average annual variation in surface salinity from 1922 to 1941 was 0.9‰ and the average salinity was 33.4‰ (Department of Commerce, U. S. Coast and Geodetic Survey 1952a, 1952b).

Available data for Humboldt Bay (Bonnot 1936, 1937) indicated a lower salinity in May which reflected the end of the rainy season. In

June and July, the salinity increased and remained fairly steady between 33.5°/oo and 35°/oo until the end of September (Enclosures 8-8, 8-9, 8-10). The higher values are reported in Mad River Slough which is rather isolated from the main bay. It can be assumed that the salinity will remain fairly high until about the middle of October when the rainy season begins. Then the salinity will decrease, remain low during the winter months and will fluctuate with the changes in local precipitation.

Temperature Distribution

Offshore surface temperatures are also fairly uniform over the entire year. The Scripps Institution of Oceanography data indicated the surface temperatures about 50 miles offshore to vary from 10.3°C. in March 1949 to 12.9° C. in September 1949. The surface temperatures observed by the University of Washington in August 1939 varied from 12.7° C. five miles off Humboldt Bay to 14.8° C. 28 miles offshore. The upwelling along the coast tends to keep the summer temperatures lower than would be expected from seasonal warming. Because of summer upwelling and the winter Davidson current, the average annual surface temperature range in the area is small. At Blunts Reef Lightship, it was only 1.3° C. with an average surface temperature of 10.9° C.

Observed temperatures within the Bay will vary considerably from the oceanic temperatures because of local heating and cooling of the relatively isolated body of water. The observed surface temperatures increased from April to a summer maximum in early August and then decreased. The maximum temperature reported was 30° C. but the average summer surface maximum was 21° C. (Bonnot 1936, 1937). See Enclosures 8-9 and 8-10. The observed surface temperature pattern is similar to the air temperature pattern at Eureka and in general the water temperatures will tend to follow the air temperatures at Eureka.

TABLE 8-1. Oceanographic Data off Humboldt Bay.

Stat 1					Stat 3 (continued)				
Date 3 August 1939					DEPTH TEMP SAL O ₂ PO ₄				
Time 14:20					(m) (°C) (‰)(mg-at./l.)(/ug.at./l.)				
Lat 40°47'					100 8.19 33.80 0.312 1.86				
Long 12°21'					200 7.09 33.98 0.223 2.12				
Depth 30 fm.					300 6.35 34.07 0.133 2.24				
DEPTH TEMP SAL O ₂ PO ₄					400 5.86 34.14 0.087 2.52				
(m) (°C) (‰)(mg-at./l.)(/ug.at./l.)					500 5.52 34.18 0.067 2.68				
0 12.65 33.03 0.559 0.7					600 5.26 34.20 0.051 2.70				
10 11.39 33.33 0.557 0.8					700 4.95 34.29 0.036 2.76				
20 10.92 33.48 0.554 0.8					800 4.43 34.33 0.033 2.64				
30 10.19 33.57 0.472 0.9					900 3.98 34.36 0.026 2.80				
50 9.40 33.68 0.393 1.2					1000 3.67 34.42 0.030 2.50				
Stat 2					1200 3.16 34.49 0.042 2.68				
Date 3 August 1939					Stat 4				
Time 1610					Date 3 August 1939				
Lat 40°47'					Time 2210				
Long 124°35'					Lat 40°47'				
Depth 350 fm.					Long 125°05'				
DEPTH TEMP SAL O ₂ PO ₄					Depth 1520 fm.				
(m) (°C) (‰)(mg-at./l.)(/ug.at./l.)					DEPTH TEMP SAL O ₂ PO ₄				
0 13.76 32.90 0.549 0.20					(m) (°C) (‰)(mg-at./l.)(/ug.at./l.)				
10 12.30 32.90 0.575 0.25					0 13.40 33.31 0.564 0.5				
20 10.25 32.92 0.541 0.50					10 12.49 33.31 0.573 0.5				
30 9.16 33.15 0.467 0.90					20 12.35 33.37 0.575 0.7				
50 9.66 33.62 0.427 1.25					30 11.83 33.40 0.537 0.8				
75 8.91 33.78 0.355 1.66					50 9.48 33.46 0.441 1.20				
100 8.32 33.98 0.292 1.64					75 8.64 33.73 0.346 1.98				
200 7.65 34.00 0.229 1.70					100 7.69 33.84 0.261 2.14				
300 6.94 34.05 0.181 1.88					200 6.65 34.02 0.202 2.24				
400 6.17 34.09 0.122 2.00					300 5.89 34.09 0.120 2.30				
500 5.71 34.14 0.082 2.02					400 5.74 34.14 0.081 2.44				
600 5.08 34.23 0.050 2.60					500 5.38 34.22 0.057 2.56				
Stat 3					600 4.90 34.27 0.036 2.88				
Date 3 August 1939					700 4.62 34.34 0.028 2.86				
Time 1825					800 4.01 34.34 0.025 3.70				
Lat 40°47'					900 4.06 34.42 0.027 3.75				
Long 124°50'					1000 3.64 34.43 0.030 3.75				
Depth 726 fm.					1200 3.08 34.49 0.040 3.00				
DEPTH TEMP SAL O ₂ PO ₄					1500 2.64 34.54 0.082 3.10				
(m) (°C) (‰)(mg-at./l.)(/ug.at./l.)					2000 2.30 34.61 0.131 2.90				
0 14.85 32.81 0.534 0.3									
10 12.52 32.94 0.575 0.7									
20 11.98 32.97 0.565 0.8									
30 10.64 33.10 0.520 0.98									
50 9.11 33.21 0.456 1.18									
75 8.44 33.51 0.374 1.70									

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SECTION 9

MARINE BIOLOGY

MARINE BIOLOGY

BORING AND FOULING

Test boards installed in May 1948 at the U. S. Coast Guard Humboldt Bay Lifeboat Station showed attacks by Teredinidae each year, rating as a trace in 1948, moderate in 1949, very heavy in 1950 and 1951 (Brown 1954). The attacks proved so destructive in 1951 that the panels which were submerged 8 months were completely riddled and in many instances sections of panels only 1" x 2" x 2" remained of an estimated original size of 1" x 6" x 12". Therefore the period of submergence was reduced to 4 months in June and even then the attack continued to be very heavy during the remainder of the 1951 season.

In 1952 the continuity of the test was interrupted; however, a heavy attack was recorded. The attack in 1953 rated very heavy. Bankia setacea to 450 mm in length were observed. Limnoria also occurred each year, but the attacks have never exceeded traces.

Recent examination of test panels submerged in Humboldt Bay by the William F. Clapp Laboratories, Duxbury, Mass., has revealed the following as quoted from personal correspondence (Clapp 1955).

Teredinidae - Our records show a very heavy attack by the large and consequently extremely destructive molluscan borer, Bankia setacea. Specimens attaining a length of 450 mm or 18 inches in a 4 month submergence period have been recorded.

Limnoria - Trace attacks by Limnoria have been noted consistently.

Fouling - The test panels have been heavily fouled with Balanus crenatus and Balanus eburneus, with Algae, Hydroid, Serpula, Mytilus and Tunicates contributing factors.

Bonnot (1936) gives salinity data for Humboldt Bay measured by "Delicate specific gravity hydrometers," and reduced to parts per thousand for three stations for the months May to October, 1935. Water temperatures are graphed for a fourth station from April through September 1935. The pH content ranged from 7.6 to 8.6 which was considered normal. Bonnot (1937) graphed the salinity and temperature of Humboldt Bay water from May through September 1936 and also the tidal heights. These data are correlated with oyster propagation.

Papers of incidental interest include a survey of sonic fishes of the Pacific by Fish (1948). This report contains a summary of families of sound producing fishes of the North Pacific including the Eastern Pacific inshore regions.

A paper by Anderson and Peterson (1954) includes statistics on fish and shellfish landings and summarizes the equipment and personnel which were employed. The report refers to the California coast by districts.

PRESENT STUDIES

A study of the density and distribution of fish in Humboldt Bay is being conducted by John W. DeWitt, Humboldt State College, Arcata.

An investigation to ascertain the present condition of eel grass and to follow any relationships pertinent to oyster bed planting is now in progress by Charles F. Yocom, Humboldt State College, Arcata.

The ecology of the north spit at Humboldt Bay is being investigated by Raymond Dasmann, Humboldt State College, Arcata.

Fred Telenicher, Humboldt State College, Arcata, is studying the clam Schizotherus (Horse Clam). This study is principally on speciation and ecological factors such as location, position, and depth.

A personal communication from the California State Department of Fish and Game (1954) indicates that biological surveys have been started to guide the utilization of State owned water bottoms in Humboldt Bay. The preliminary work has been above the one fathom line. The natural beds of shellfish and eel grass as well as observations of surface sediment are being charted.

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APPENDIX A

SHORE-LINE CHANGES

This appendix has been reproduced from the text of the following document:

U. S. Army Corps of Engineers
1950 Shore-Line Changes, Appendix I to Survey Report
on Humboldt Bay, California, February 10, 1950.
San Francisco District, San Francisco, California,
73 pages, maps, diagrams (processed).

APPENDIX I

SHORE-LINE CHANGES

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APPENDIX I

SHORE-LINE CHANGES

PURPOSE AND SCOPE OF STUDY

1. Purpose of study. Section 5 of the River and Harbor Act, Public Law No. 409, Seventy-fourth Congress, approved August 30, 1935, is quoted as follows: "Every report submitted to Congress in pursuance of any provision of law for preliminary examination and survey looking to the improvement of the entrance at the mouth of any river or at any inlet, in addition to other information which the Congress has directed shall be given, shall contain information concerning the configuration of the shore line and the probable effect thereon that may be expected to result from the improvement having particular reference to erosion and/or accretion for a distance of not less than ten miles on either side of the said entrance." In accordance with the law quoted above, a study has been made to determine the probable effect upon the adjacent shore line of dredging a navigation channel across a portion of the Humboldt bar and of widening and deepening the existing navigation channel between the Humboldt Bay jetties. In addition, the erosion of Point Humboldt in Humboldt Bay has been studied with a view toward reducing the shoaling of the Fields Landing Channel even though no improvement of this channel is proposed at the present time.

2. Area considered. The Pacific Ocean shore line from the mouth of the Mad River to the mouth of the Eel River, a distance of approximately 22 miles, and the interior channels in Humboldt Bay have been considered within the scope of the study. Due to the different nature of the areas considered, the study has been made in two parts; the first part considers the ocean shore line; and the second part, the erosion of Point Humboldt, Humboldt Bay.

PART I -- PACIFIC OCEAN SHORE LINE

PRIOR REPORTS

3. No prior reports on the effect of shore structures in the immediate vicinity of the entrance to Humboldt Bay have been published. However, reports of the studies of the Entrance Channel conditions are contained in the Annual Reports of the Chief of Engineers for the fiscal years 1880 to 1899.

DESCRIPTION

4. Offshore depth changes. Humboldt Bay is separated from the Pacific Ocean by two low sand spits known as the north spit and the south spit. The entrance channel, from the ocean to the Bay, lies between the ends of these spits. The north spit, which is about one-half mile wide and ten miles long, is flat and barren near the southerly end, but rises gradually to the north to heavily wooded sand dunes. The south spit is narrow, low, and barren, varying in width from 300 to 3,000 feet, and extends south about four miles to Table Bluff, a high ocean headland which marks the southern extremity of Humboldt Bay.

5. Prior to the construction of the original jetties in 1888 at Humboldt Bay, a sandy shoal area, known as the "breaker flats", extended across the seaward side of the inlet between the spits. The channel across this shoal, or bar, varied in depth and position from year to year. An early edition of United States Coast and Geodetic Survey Chart 5832, published in 1886, and based on a hydrographic survey made between 1870 and 1884, indicates that the bar was located shoreward of the 18 foot depth contour. In the vicinity of the inlet, the depth contours seaward of the 18-foot depth were farther seaward than elsewhere, but the depth contours seaward of the 30-foot depth were, in general, parallel to the shore line extended.

6. During the period of jetty construction, 1888 to 1899, the "breaker flats" disappeared and the offshore ocean depth contours, in the vicinity of the jettied entrance to Humboldt Bay, shifted seaward by varying amounts. The latest edition of Chart 5832, based on surveys made in recent years by the United States Coast and Geodetic Survey and the Corps of Engineers, shows that the crest of the bar is from 2,500 to 4,000 feet seaward of the seaward ends of the jetties. Comparison of the depth contours seaward of the entrance to the Bay, shown on the 1886 edition of Chart 5832 and the latest edition of the same chart, indicates a considerable seaward shift. For example, it is estimated that the maximum seaward movement of the 60-foot depth contour during the period from about 1877 to 1948 was 2,500 feet. In recent years, however, the bar has been relatively stable and, except for alternate seaward and shoreward movements of the bar crest, the position of the bar with relation to the jettied entrance has remained about the same.

7. The original jetties, which had a crest elevation of +10 to +12 (MLLW), deteriorated rapidly until they were almost obliterated, and, coincidentally therewith, sand accumulated in the entrance. In 1914, practically the entire length of the north jetty was below mean lower low water, and the south jetty, which in 1911 had 2,400 feet of its seaward end below water, was being rebuilt. The rebuild-

ing of the south jetty was completed in 1916, and the north jetty was rebuilt to within 500 feet of the ultimate seaward end in 1917. Both jetties were rebuilt to a crest elevation of +18 (MLLW).

HISTORY OF SHORE-LINE CHANGES

8. A study of the changes in the shore line along the Pacific Ocean between the Mad River and the Eel River has been made by comparing the location of high-water shore line determined from surveys made by the United States Coast and Geodetic Survey and the Corps of Engineers. The surveys used in the comparison were made in 1854, 1870, and 1929 by the United States Coast and Geodetic Survey, and in 1911, 1919, and 1940, by the Corps of Engineers. The changes are shown on Figure 1.

9. Between 1854 and 1870, the period prior to jetty construction, there was no significant change in the position of the high-water shore line. Alternate accretion and erosion is indicated on the north spit for a distance of about five miles northerly of the present north jetty. Erosion occurred at the northerly tip of the south spit.

10. Comparison of the 1870 and 1911 surveys shows a seaward shift of the high-water shore line from the north jetty to a point about 4,200 feet north of the north jetty, the maximum seaward movement being about 1,200 feet. North from this area of accretion to the northerly limits of the 1911 survey, a 4,600-foot length of shore shows erosion, with a maximum shoreward movement of approximately 400 feet. South of the south jetty to the limits of the 1911 survey, a total distance of about 5,600 feet, accretion occurred. The maximum seaward movement of the shore line occurred on the south side of the south jetty where the shift amounted to approximately 2,400 feet. From the south jetty the movement tapered gradually to 600 feet at the southerly limit.

11. The 1919 survey delineated the shore line for only about 3,000 feet on each side of the jetties. The portion of the shore line shown by this survey is farther seaward of the 1911 position. North of the north jetty the seaward movement tapered from a maximum of 3,000 feet at the jetty to 500 feet at the northerly limit. South of the south jetty the seaward shift varied from a maximum of about 500 feet along the south side of the jetty to 300 feet at the southerly limit.

12. The 1929 position of the high-water shore line immediately north of the north jetty was about 500 feet farther seaward of the 1919 position. South from the south jetty there was a 100-foot move-

ment shoreward along a 1,200-foot length of shore, beyond which there was no apparent change between 1919 and 1929.

13. During the period 1929 to 1940, the shore line north of the north jetty moved shoreward, tapering from about 325 feet immediately north of the jetty to zero at a point about 2,300 feet north of the jetty. North from this point for a distance of 12,000 feet, accretion is indicated, the maximum seaward movement amounting to 200 feet. Beyond this area of accretion for a distance of about 14,000 feet there was no significant difference in the 1929 and 1940 positions of the shore line, except along a 3,500 foot length where the 1940 position is shown 200 feet shoreward of the 1929 position. From the south jetty to a shore point about four miles south of the jetty, the 1940 position of the shore line is shoreward of the 1929 position by varying amounts. A maximum shoreward movement of about 400 feet occurred adjacent to the jetty.

14. The 1870 and 1929 surveys are the only two which completely delineate the shore line from the mouth of the Mad River to that of the Eel River. Comparison of these two surveys shows that the 1929 position of the shore line is farther seaward than the 1870 position for 10.5 miles of the approximately 13 miles between the north jetty and the Mad River by amounts varying from 50 to 3,800 feet. The maximum seaward movement has occurred immediately north of, and adjacent to, the north jetty. The only erosion, or shoreward movement of the high-water shore line north of the north jetty indicated during this 50-year period begins at a point about 3 miles north of the north jetty and extends for a distance of approximately 2.5 miles, the maximum shoreward movement amounting to 200 feet.

15. The 1929 position of the ocean shore line of the south spit is seaward of the 1870 position from the south jetty, where a 3,000 foot seaward movement is indicated, to a point on the shore seaward of Table Bluff, or about 4.5 miles southerly of the jetty, at which point the 1929 and 1870 positions intersect. South of this point to the mouth of the Eel River, alternate stretches of erosion and accretion are shown. The maximum shoreward movement, of approximately 320 feet, occurred in the vicinity of the mouth of the Eel River and consisted of a shoreward migration of the Eel River Spit.

16. The net change in the position of the high-water shore line in the vicinity of the jettied entrance to Humboldt Bay during the period 1870 to 1940 is an advance seaward both north of the north jetty and south of the south jetty. This seaward movement occurred along an approximate 3-mile reach of the north spit measured from the north jetty, and varied from a maximum of 3,400 feet adjacent to the jetty to zero, 3 miles north of the jetty. South of the south jetty the seaward movement extended along a 3.5-mile reach as measured from the jetty. The maximum seaward advance of 2,600 feet occurred adjacent to the south jetty.

WAVES

17. A study of wave action in the vicinity of the Humboldt Bay jetties was made by means of refraction diagrams. The characteristics of the waves used for the diagrams are for waves occurring most frequently as shown in the Scripps Institution of Oceanography "Wave Report No. 68". The diagrams were constructed for present conditions of the bar seaward of the jetties and for an assumed condition in which the depths over the bar and areas adjacent thereto were increased to 40 feet. The refraction diagrams indicate that for present conditions waves are affected by the seaward submarine slope of the bar so that some wave convergence occurs before waves reach or pass over the bar crest. The crest of the bar produces additional convergence so that waves either break on the bar or advance toward the jettied entrance considerably higher than waves in comparable depths elsewhere. The refraction diagrams also indicate that waves advancing from any direction south of west-northwest will tend to produce upcoast littoral drift along the south and north spits.

18. Waves with a height of 10 feet or greater, occurring most frequently in the Pacific Ocean area in the vicinity of Humboldt Bay, have an average period of 9 seconds. For this period the depth over the bar, assumed as 20 feet, has little effect on the wave height so that the effect of refraction determines the height of waves seaward of the jetties. Waves having a period of from 12 seconds to 16 seconds are increased in height from 15 percent to 30 percent, respectively, by the bar. This increase is in addition to the effect of refraction.

19. Comparison of the refraction diagrams constructed for present conditions with those drawn for an assumed depth of 40 feet over the bar indicates that no appreciable reduction in the height of 9-second waves would occur with an increase in depth over the bar. The reason for this is that the seaward slope of the bar, in depths greater than 40 feet, causes wave convergence before the 40-foot depth is reached. However, the increase in depth would permit practically all 9-second waves from the northwest and the west to pass over the bar without breaking. Present depths over the bar cause northwest waves and west waves to break when the deep-water wave height is about 12 feet and 15 feet, respectively. For waves with periods of 12 seconds or greater, the comparison indicates that a bar depth of 40 feet would result in a decrease in wave height in the vicinity of the entrance channel. For example, a 12-second wave from the northwest now breaks on the bar when the deep-water wave height is about 9 feet or greater. When the depth over the bar is increased to 40 feet, 12-second northwest waves do not break on the bar. These waves are reduced in height about 12 percent at the bar and about 7 percent near the jettied entrance.

LITTORAL DRIFT

20. Surveys of Humboldt Bay Entrance Channel in its natural state (1851 to 1883) show that it was a typical migrating bar channel, shifting radially through a regular cyclical period from the north to the south, and upon reaching the southern extremity of the bar, reopening suddenly at the north end to repeat the cycle. Surveys of 1851, 1858, 1870, and 1875 show the position of the channel in various phases of the cycle. Surveys of 1881, 1882, and 1883 show the rate of annual change. Study of all the surveys over this 32-year period indicates a usual cycle of about 5 years for channel migration at this inlet. This phenomenon is a clear indication that the predominant direction of littoral drift is from north to south. A comparison of periodic surveys of the Humboldt Bar and Entrance is shown on Figure 5 of this appendix.

21. With the inauguration of jetty construction in 1890, there began a series of interruptions in normal littoral transport. With each increment in length of the jetties the bar was pushed seaward. Consequent decrease in offshore depths caused the shore to advance on each side of the inlet. Interspersed with progressive lengthening of the jetties was their periodic partial destruction by storms. The periods during which the jetties functioned as important littoral barriers were relatively short and in each case ended when littoral transport was resumed in normal volume either through or around the jetties. Greater advance of the north shore as compared with the south illustrates the effect of dominance of downcoast drift during these periods when the jetties were functioning as littoral barriers. In 1917 the north jetty was rebuilt to within 500 feet of its ultimate seaward end. Based on surveys made since that time it is estimated that the annual rate of downcoast littoral drift is at least 500,000 cubic yards.

22. In 1934, a channel 35 feet deep and 500 feet wide was dredged across the bar. A study of the shoaling of this channel from October 1934 to May 1945 indicates that the average annual rate of shoaling was approximately 29,000 cubic yards during the 10½-year period. The maximum and minimum annual rates of shoaling in the channel were 113,000 cubic yards and 16,000 cubic yards, respectively.

IMPROVEMENTS PROPOSED

23. The improvements proposed for the entrance to Humboldt Bay consist of deepening and widening the Bar and Entrance Channel to a depth of 40 feet and a width of 1,600 feet at the entrance, tapered to 500 feet between the jetties as shown on the plan of improvement map, Enclosure 1.

DISCUSSION

24. Except for periodic migration of the ends of the north spit and of the south spit at the inlet to Humboldt Bay, the history of shore-line changes prior to jetty construction indicates that the ocean high-water shore line in the vicinity of Humboldt Bay was geologically stable. The inlet channel varied in position and depth across the bar which, for the most part, lay shoreward of the 18-foot depth contour.

25. Since construction of the jetties in 1888, the Humboldt bar has shifted and reformed seaward of its 1870 position, and the ocean high-water shore line along the north spit has shifted seaward. The seaward advance of the north spit shore line was most pronounced upon reconstruction of the north jetty in 1917. The position of the ocean shore adjacent to the entrance to Humboldt Bay indicates that the predominant direction of littoral drift is from north to south, or downcoast. A measurement of the accretion north of the north jetty shows that the annual rate of downcoast drift is approximately 500,000 cubic yards. The shore line south of the south jetty also advanced seaward. However, it is believed that without the effects of offshore shoaling and frequent resumption of normal transport, serious erosion of the south spit would probably have occurred.

26. The Humboldt bar is believed to be characteristic of those which form at tidal inlets, created and fed by littoral material, and serving as the path by which the littoral material makes its way around the inlet and continues its passage along the coast. The position of the Humboldt bar relative to the seaward end of the Humboldt jetties has been maintained in recent years, and this seems to be indicative of the fact that the bar has reached a state of equilibrium.

27. As stated above, the bar is now believed to be approximately stable, and the inlet between the end of the south jetty and the southeast end of the bar is stable except as the tidal range varies. Substantially all littoral drift is passing the entrance and is maintaining the south spit and downcoast shores. If the inlet is enlarged to the dimensions proposed, littoral drift will encroach on the channel and will be dredged as maintenance. Because of the very severe wave action which prevails in this coastal area, it is believed that the volume of material movement in depths more than 30 feet is much greater than exists at less exposed coastal areas. Material deposited in depths of 30 to 35 feet, at a location 3,000 to 5,000 feet south of the south jetty would, it is believed, resume normal downcoast littoral transport. If littoral material dredged from the channel is deposited in water deeper than 30 to 35 feet the material will remain, and the south spit will erode a corresponding amount.

28. Although the annual rate of downcoast littoral drift is estimated to be in the order of 500,000 cubic yards, the maximum annual shoaling rate of record during a previous attempt to dredge a channel through the bar was considerably less than 500,000 cubic yards. Depth and width of the earlier dredged channel were somewhat less than those proposed in the improvement now being considered, and it is probable that a substantial part of the littoral material moved across the channel. Likewise, a portion of the littoral drift may be expected to move across the larger channel now being considered. On a conservative basis the annual rate of shoaling in the proposed enlarged Bar and Entrance Channel is estimated to be 400,000 cubic yards.

CONCLUSIONS

29. It is concluded that:

a. The predominant direction of littoral drift in the vicinity of Humboldt Bay is believed to be from north to south, or downcoast. The average annual rate of downcoast littoral drift is estimated to be in the order of 500,000 cubic yards.

b. The Humboldt bar is at present in equilibrium and serves as a path by which the littoral drift makes its way around the jettied inlet to maintain the south spit and downcoast shores.

c. The proposed Bar and Entrance Channel will require maintenance dredging of approximately 400,000 cubic yards annually.

d. The proposed improvement will have no harmful effect on the adjacent shore line provided the littoral material dredged as maintenance is deposited south of the entrance in a depth not greater than 30 feet.

PART II -- EROSION OF POINT HUMBOLDT, HUMBOLDT BAY, CALIFORNIA

PRIOR REPORTS

30. There have been two reports on the erosion of Point Humboldt (also known as Buhne Point), Humboldt Bay, California. One, dated May 31, 1929, was written in response to a letter to the Chief of Engineers from the Honorable Clarence F. Lea, Representative in Congress, 1st California District. The second report, dated March 7, 1930, was submitted in compliance with a resolution of the Committee on Commerce of the Senate, adopted December 24, 1929, which reads in part:

That the Board of Engineers for Rivers and Harbors be and is hereby requested, to review the report on Humboldt Harbor and Bay, California, submitted in House Document No. 755, Sixty-ninth Congress, Second Session, with a view to determining the effect of the jetties on the erosion of Point Humboldt, the effect of such erosion on navigable channels and the best method of shore protection.

31. The first report discussed the changes in the shore line at Point Humboldt during the period 1854 to 1929 but made no recommendations. The review report on Humboldt Harbor and Bay concluded that the construction of the jetties had accelerated the rate of erosion of Point Humboldt, but that erosion was going on before the jetties were built and would have continued had they not been constructed; that the erosion of Point Humboldt did not appear to have adversely affected the channels in the Bay to any great extent; that protective works must ultimately be built to prevent further erosion of the Point, but recommended that no modification to authorize such works be included in the project for Humboldt Harbor and Bay.

DESCRIPTION

32. Humboldt Bay and the entrance thereto are fully described in the text of the main report, in which there is also a map showing the location of Point Humboldt with reference to the entrance to the Bay (enclosure 1). Point Humboldt is a knoll on the eastern shore of Humboldt Bay directly opposite the jettied entrance to the Bay, and is about five miles south of the town of Eureka. The present height of the knoll is slightly greater than one hundred feet at the highest point. The bayward slope of Point Humboldt is steep and precipitous, its toe forming the high-water line. Shoreward of the highest point of the knoll, the ground slopes gently and gradually into a low, flat area that has a height of about ten feet above mean lower low water. A sand spit, known locally as Buhne Spit, extends southwesterly from Point Humboldt, the Spit varying in size and position from year to year.

GEOLOGY

33. The area adjacent to Point Humboldt is comprised of alluvium-filled valley floors between ridges of Pliocene marine deposits. Farther eastward, older rocks of the Franciscan formation are present. Point Humboldt is part of the Pliocene marine sediments and is made up of inter-bedded layers of fine-grained, reddish to buff-colored sandstone and blue mud rock. This formation is known to underlie

the area to the east and south from the logs of wells put down in search for oil and gas. The structure of the beds indicates that there is a broad anticlinal fold whose axis trends NW-SE and in general lies between Elk River on the north and Salmon Creek on the south. A fault follows the trend of the Salmon Creek Valley.

34. Point Humboldt is probably the last remnant of a once-more-extensive series of beds extending over the area. The flood plains adjacent to the knoll or bluff are made up of softer sedimentary rocks which have already been eroded to the grade of the present streams. The material comprising Point Humboldt is a relatively soft material, easily eroded by wave action.

SHORE-LINE CHANGES AT POINT HUMBOLDT AND VICINITY

35. A study of changes that have occurred in the shore line in the vicinity of Point Humboldt has been made by comparing the location of the high-water lines shown on United States Coast and Geodetic Survey and San Francisco District, Corps of Engineers, maps. Maps, from surveys made in 1854, 1870, and 1903 by the United States Coast and Geodetic Survey and from surveys made in 1891, 1911, 1926, 1929, 1931, 1939-40, and 1946, by the San Francisco District, are available. These surveys were plotted to a common scale and the high-water lines are shown superposed on Figure 2.

COMPARISON OF HIGH-WATER LINES

36. The position of the high-water lines shown on Figure 2 indicates that during the 92-year period, 1854 to 1946, the shore line at Point Humboldt and points northeasterly and southwesterly thereof, has receded shoreward by amounts varying from 1,000 to 1,350 feet. The rate of this erosion has not been regular during equivalent intervals of time, but except for the position of the 1903 high-water line, successive positions of the shore line at Point Humboldt are generally shown as having moved farther shoreward. The 1911 survey indicates that Buhne Spit disappeared entirely except for a small islet at the southwestern tip of the spit. The 1926 survey shows the spit to have reformed 600 to 800 feet farther shoreward than its position in 1903. During the period 1926 to 1946, Buhne Spit, beginning at a point about 900 feet southwest of the bluff, advanced bayward as much as 400 feet. It is also to be noted that during the period 1926 to 1946 the erosion of the shore line just to the northeast of the knoll, or bluff, has been much greater than during the period 1854 to 1926; a recession of 1,000 feet having occurred during the last 20 years compared with about 150 feet during the 72 years from 1854 to 1926. During the period from 1939 to 1946, it is estimated that 866,000 cubic yards of material were eroded from Point Humboldt.

ELK RIVER SPIT

37. Successive surveys made since 1911 show the formation and advance of a spit springing from shore at a point just south of the mouth of the Elk River. In the 35 years from 1911 to 1946, the spit has advanced a distance of about 6,200 feet in a northerly direction parallel to the shore line. The 1946 survey shows the bayward tip of the spit to be about 1,400 feet wide and that its bayward edge is from 300 to 1,100 feet farther out in the Bay than it was in 1939. It is estimated that the net accretion at Elk River Spit between 1939 and 1946 amounted to 461,000 cubic yards.

DEPTH CHANGES IN HUMBOLDT BAY

38. Depth changes in Humboldt Bay in the vicinity of Point Humboldt, Buhne Spit, and Elk River Spit, were studied by comparing hydrographic surveys made in 1870, 1939-1940, and 1946. The net change in the positions of the 6-, 12-, and 18-foot depth contours in the area east of the jettied channel between Point Humboldt and Elk River Spit, between 1870 and 1939, are summarized in the following subparagraphs:

a. 6-foot depth. The 6-foot depth contour advanced shoreward along a line about 3,200 feet long extending northeasterly from a point roughly 1,000 feet west and bayward of the present shore line at Point Humboldt. The maximum shoreward movement occurred off Point Humboldt and was about 500 feet. Erosion occurred along the east edge of the present deep-water channel connecting with the Eureka and Samoa Channels. In the vicinity of the present bayward tip of Elk River Spit, the 6-foot contour moved bayward along a 4,000-foot section, the maximum movement amounting to 600 feet. A deep area, with a maximum depth of 43 feet, east of the main channel and lying between Elk River Spit and Point Humboldt is shown by the 1939 survey to be almost entirely filled, the 6-foot contour having moved northerly about 7,000 feet.

b. 12-foot depth. Except for erosion, or scour, along the east edge of the deep-water channel leading to Eureka and Samoa Channels, the 12-foot contour moved bayward, indicating deposition, in the area between Point Humboldt and Elk River.

c. 18-foot depth. Along the east side of the deep-water channel connecting with the Eureka and Samoa Channels, the 18-foot depth contour moved easterly. In the area between Point Humboldt and the Elk River, the 18-foot depth contour moved bayward.

d. The significant changes in the water area between Point Humboldt and the present position of Elk River Spit during the period from 1870 to 1940 were a widening of the deep-water channel connecting the Eureka and Samoa Channels, brought about by scour along the east edge of the channel; the filling-in of a deep area located between Point Humboldt and the present tip of Elk River Spit; and a bayward movement of the 12- and 18-foot depth curves off Point Humboldt.

39. Comparison of the 6-, 12-, 18-, and 24-foot depth contours for the 1939-1940 and 1946 surveys, as shown on Figure 3, indicates that in the area between Point Humboldt and Elk River Spit, approximately opposite the entrance channel, the 6-foot to the 24-foot depth contour moved shoreward. The shoreward movement of the 6-foot depth contour was the most extensive. In two areas, one on the east side of the deep-water channel north of the entrance to the Bay, the second bayward of the northern end of Elk River Spit, the 6-foot to 24-foot depth contours have advanced bayward. In the first area, a shoal less than 6 feet in depth is shown detached from the 6-foot depth curve, and the 12-foot depth contour has moved a maximum of 300 feet along a 2,000-foot length. The corresponding movements for the 18- and 24-foot curves were 100 feet and 130 feet, respectively. In the second area, the greatest movements of the depth contours occurred near the north end of Elk River Spit. At this point, the 6-foot contour shifted 500 feet while the 12-foot and 18-foot contours moved about 350 and 200 feet, respectively. The movement of the 24-foot contour was not as pronounced and only extended over a 600-foot length. Between these two areas, along a 3,000 foot length of the east edge of the deep-water channel, scour occurred, and the 6- to 24-foot depth contours moved easterly toward the shore. The maximum movement was 300 feet and 150 feet for the 6-foot and 24-foot depth contours, respectively. During the 6-year period, it is estimated that there was a net loss of 543,000 cubic yards of material in this area.

FIELDS LANDING CHANNEL

40. Fields Landing Channel in the vicinity of Buhne Spit. Condition surveys of the Fields Landing Channel in the vicinity of Buhne Spit were compared and studied to determine whether the spit was encroaching on the channel. The surveys selected were made after the channel was dredged and before subsequent redredging, Figure 4 is a comparison of surveys made in 1935 and 1937, and surveys made in 1943 and 1944. Both comparisons show that shoaling, or movement of the depth contours toward the channel, occurred in the vicinity of Buhne Spit. Dredging records also indicate that Fields Landing Channel has a tendency to shoal in this area from year to year. This shoal has earned the name of Buhne Spit Shoal.

41. Middle Ground Shoal. Another area of recurrent shoaling is at the entrance to the Fields Landing Channel. This area is known as Middle Ground Shoal. The tendency here is for shoaling to occur completely across the channel. This area is shown on the vicinity map on Figure 4.

TRIBUTARY STREAMS

42. Three streams (Clark Slough, Elk River, and Salmon Creek) enter that part of Humboldt Bay south of Gunther, or Indian, Island. Clark Slough, a tidal slough, drains an area of about one square mile. Elk River and Salmon Creek drain areas of about 54 and 17 square miles, respectively. In so far as is known, no measurements have ever been made of the detritus carried into Humboldt Bay, by either Elk River or Salmon Creek, during flood periods. At one time the area drained by both streams was extensively logged. At the present time, Elk River drains an area comprised, for the most part, of second-growth timber lands on which selective logging is now practiced. Even during flood periods, Elk River is seldom able to break through Elk River Spit. Several attempts have been made to provide a channel across Elk River Spit but the River has not been competent to maintain such a channel.

43. Salmon Creek, at present, also drains a heavily timbered region so that it would be reasonable to expect that the stream carries very little debris. The owner of land adjacent to Salmon Creek, at its mouth, has constructed catchment works in an attempt to collect the debris carried by the Creek during floods in order to build up his land. The works, consisting of levees and tide gates, have been in operation for the past five years.

WAVE ACTION

44. The eastern shore of Humboldt Bay, from Buhne Spit to Elk River Spit, is exposed to ocean waves. These waves enter Humboldt Bay through the jettied entrance channel. Aerial photographs of the Bay in the vicinity of the entrance channel show waves impinging on Point Humboldt in a manner likely to cause sand movement both to the north and to the south of the point. The fact that Point Humboldt is still eroding indicates that the waves not only undermine the cliffs but, aided by tidal currents, also remove the material.

SOIL SAMPLES

45. Areas sampled. Mechanical analyses were made of soil samples obtained from a number of areas in Humboldt Bay. A description of the samples obtained in each of the areas is given in the following subparagraphs.

a. Elk River Spit. Samples were obtained from the upper two inches of the Elk River Spit along the length of the Spit at the mean tide line. Five of the seven samples consisted of coarse to very fine cohesionless gray sand with only a trace of shell. These samples had a median diameter of 0.25 millimeter. The remaining two samples consisted of a mixture of cohesionless gray sand and rounded gravel. The median diameter of the mixture was 0.42 millimeter. The specific gravity of each of the samples was 2.68.

b. Point Humboldt. Samples were taken from the face of the bluff and from the top of Point Humboldt. These samples consisted of a mixture of cohesionless gray and black sand, and compact, moist, bluish-gray clayey silt with bluish-gray clay pockets. The median diameters of these samples varied from 0.024 to 0.28 millimeter. Samples obtained from the top of Point Humboldt consisted of soft to compact brown clayey silt and clay with plant roots. The median diameters of the top samples varied from 0.014 to 0.035 millimeter.

c. Buhne Spit. The samples obtained from Buhne Spit were taken from the upper two inches of the Spit at the mean tide line. The samples consisted of coarse to very fine sand, gray to black in color, with a trace of shell. The median diameter of the samples was 0.25 millimeter.

d. South Spit. The samples obtained from the mean tide line along the South Spit consisted of coarse to fine gray sand with some black sand. The median diameter of the samples was 0.25 millimeter.

e. Shoals and flats. Offshore area samples were taken near Elk River Spit, Buhne Spit, and the South Spit. Except for two samples obtained in shallow water northwest of Buhne Spit, the material obtained was cohesionless gray sand, ranging from very fine to coarse, with a median diameter of from 0.25 to 0.42 millimeter. A trace of shell was found in several samples. The samples obtained in shallow water northwest of Buhne Spit consisted of bluish-gray, clayey silt and organic matter, and bluish-gray silty sand with pieces of brown shale. Grain size of both samples ranged from very fine sand to clay; median diameters varied from 0.015 to 0.025 millimeter.

46. Summary of soil sampling. With the exception of the samples obtained at Point Humboldt and in shallow water bayward of Buhne Spit, the samples consisted of sandy material with a trace of shell. In addition, the Elk River Spit samples contained some gravel. The topsoil of Point Humboldt is composed of clayey silt and organic material. The bayward face of Point Humboldt is composed of a mixture of sand and clay. On the basis of the soil sample analysis it is estimated that from 30 percent to 90 percent, or an average, say, of 50 percent, of the material composing Point Humboldt would be suitable beach material.

DREDGING IN HUMBOLDT BAY

47. The main channels to Eureka and Samoa, in the northerly part of Humboldt Bay, are relatively stable and, except for dredging to new project depths, have required very little maintenance dredging since 1930 when compared with the maintenance dredging of the Fields Landing Channel. During the period July 1940 through June 1947, a total of about 37,000 cubic yards were dredged from the Eureka and Samoa Channels, while about 556,000 cubic yards were removed from the Fields Landing Channel.

PRIOR PROTECTIVE ACTION

48. Several attempts were made to protect the low area northeast of Point Humboldt by timber bulkheads. These attempts proved unsuccessful as wave action undermined and washed out the structures. No further attempt to rebuild these bulkheads has been made since about 1935. The Northwestern Pacific Railroad Company's right-of-way parallels the Humboldt Bay shore line, starting at a point northeast of Point Humboldt and extending to the Elk River. By the placing of random riprap and the construction of bulkheads composed of old railroad ties, this company has been able to maintain its right-of-way against wave action. The maximum weight of stone used for riprap is approximately 5 tons.

49. In 1948, Buhne Spit was subdivided and developed as a small-boat anchorage. Since then, the local property owners have been forced to protect the Bay side of the spit from wave action, and have placed miscellaneous riprap along the Bay shore.

DISCUSSION

50. There are four possible sources of the material shoaling Fields Landing Channel. These are: (a) sediment brought into the Bay by tributary streams; (b) readjustment of material within the Bay by scouring of slopes and/or erosion of banks; (c) littoral material deposited in the channels by waves and tidal currents or by winds; and, (d) material eroded from Point Humboldt. Due to the nature of the areas drained by, and the size of the streams entering, Humboldt Bay, the amount of sediment carried by these streams is considered insignificant.

51. The most marked readjustment within the Bay in recent years occurred in the shallow-water area between Point Humboldt and Elk River Spit and at the Elk River Spit. The historical change in the water area has been one of shoaling. However, during the period 1939 to 1946 there was a net loss of approximately 543,000 cubic yards of bottom material in the water area, or about 78,000 cubic

yards annually. Elk River Spit has been advancing northerly since 1911, and in the period 1939 to 1946 there was an accretion of 461,000 cubic yards on the Spit, equivalent to about 66,000 cubic yards annually.

52. Littoral material may be deposited within the Bay by waves and tidal currents or by winds. The relative stability of the Humboldt bar and of the shore line of the South Spit, however, seems to indicate a fairly constant supply from littoral sources, so that any littoral materials deposited in the vicinity of the jettied channel ultimately are redeposited on the bar or move past the jettied entrance.

53. Point Humboldt has a history of erosion. In 1930 it was estimated that 2,500,000 cubic yards of material had been removed from the Point since 1854. Between 1930 and 1946, an additional 1,474,000 cubic yards were eroded. The average rate of erosion between 1939 and 1946 was approximately 124,000 cubic yards per year. Of the total amount of material eroded, it is estimated that about 50 percent is coarse enough to settle out and cause shoaling in the Bay. Therefore, Point Humboldt may be considered to have contributed about 62,000 cubic yards of shoaling material annually during the period 1939 to 1946.

54. The average annual rate of shoaling in Fields Landing Channel during the period 1940 to 1947 was about 80,000 cubic yards. The total measured losses and accretions in the vicinity of Point Humboldt are 140,000 cubic yards and 146,000 cubic yards, respectively. The close agreement between the two sums would seem to indicate that the shore line and offshore depth changes in the vicinity of Point Humboldt are local in character. It would also seem that the material shoaling Fields Landing Channel is derived either from Point Humboldt, from the water area between Point Humboldt and Elk River Spit, or from both areas.

55. It is believed that the erosion of both the offshore area near Point Humboldt and the point, itself, is due to wave action aided by tidal currents. Waves entering Humboldt Bay agitate the bottom material and then continue on to undercut the bluff and adjacent shore line. The coarser material eroded is transported by waves and currents to both Buhne Spit and Elk River Spit. Buhne Spit is considered only a temporary repository, and waves and currents eventually carry the material to the deeper waters of the Fields Landing Channel.

56. If this analysis is correct, the shoaling of Fields Landing Channel could be materially reduced by either revetting the shore line at Point Humboldt or by a barrier groin springing from a suitable point on Buhne Spit, provided the work could be economically justified.

The revetment would extend from the southerly end of the structures now protecting the railroad right-of-way to the southwest side of Point Humboldt, a distance of approximately 5,200 feet.

57. The barrier groin, springing from Buhne Spit, would extend bayward about 1,200 feet to the 12-foot depth contour. Both the revetment and the groin would stabilize the eroding shore. The groin, in addition, would impound material carried by the last remnant of the ebb flow from the north Bay which, considering the relative sizes of the north and south Bays, would continue after the flood had started both in the jettied entrance and in the Fields Landing Channel.

58. Although it is believed that the barrier groin would reduce the shoaling considerably in Fields Landing Channel, such an effect could not be expected immediately. In some respects the barrier groin would be an experiment and, if a 1,200-foot length of groin can be economically justified, it would be well to construct only a 600-foot length of groin initially. Should the 600-foot section prove successful, then the groin could be extended to its ultimate length.

CONCLUSIONS

59. It is concluded that:

a. The principal sources of the material shoaling Fields Landing Channel are Point Humboldt and the shallow-water area between Point Humboldt and Elk River Spit.

b. The material eroded from these sources is deposited in the Fields Landing Channel by wave and current action.

c. The shoaling of Fields Landing Channel could be materially reduced by either revetting a 5,200-foot length of the shore line of Point Humboldt or by the construction of a 1,200-foot barrier groin springing from Buhne Spit.

d. Both the revetment and the barrier groin would stabilize the eroding shore at Point Humboldt, and the groin would, in addition, impound material eroded from the shallow-water area between Elk River Spit and Point Humboldt.

e. Subject to the economic justification of the full 1,200-foot length of the barrier groin, a 600-foot length of groin should be constructed initially.

f. If the initial length of groin proves successful, the barrier groin should be extended to its ultimate length.

APPENDIX B

OCEANOGRAPHY OF COASTAL HARBORS

This appendix has been reproduced from the following document:

O'Brien, M.P.
n. d. [Oceanography of Coastal Harbors.] On file
U. S. Army, Corps of Engineers, Beach
Erosion Board, Washington, D. C. (Unpublished.)

HUMBOLDT BAY:

Humboldt Bay is formed of two tidal basins, of which the larger one is north of the entrance. On both sides of the entrance are low sand spits, an unusual circumstance. The south spit is 4 miles and the north spit is 7 miles in length. The entrance is approximately 22 miles north of Cape Mendocino, where the alignment of the coast changes abruptly and where the most northerly of the submarine valleys is located:

The fresh water run-off into Humboldt Bay is too small to have any effect on the currents but the debris brought down by the small creeks may be important in the effect on the tidal prism.

The mean annual precipitation at Eureka is 21 inches.

The bottom slopes seaward at about 10 fathoms to the mile directly west of the entrance. At the submarine valley between the entrance and Cape Mendocino, the slope is considerably greater. There are no reefs offshore. The bottom is shown as sand out to 30 fathoms beyond which fine grey sand and mud are shown.

WIND--The prevailing direction of the wind at Eureka is as follows:

<u>MONTH</u>	<u>DIRECTION</u>
JANUARY - MARCH	N
APRIL	W
MAY	N
JUNE	S W
JULY	N
AUGUST - SEPTEMBER	N W
OCTOBER - NOVEMBER	N
DECEMBER	S W
ANNUAL	S W

The average velocity is 5.3 miles per hour.

The wind "rose" on the chart of 1927 gives the following data on the direction and intensity of the winds.

<u>DIRECTION</u>	1 - 10 (m.p.h.)	10 - 20 (m.p.h.)	20 - 30 (m.p.h.)
	<u>NUMBER OF DAYS PER YEAR</u>		
N	49	27	7
N E	18		
E	18		
S E	57	13	2
S	27	14	1
S W	34	10	1
W	28	3	
N W	44	11	

TIDES and CURRENTS--The ranges of the tide at Humboldt Bay are as follows:

<u>LOCATION</u>	<u>MEAN RANGE</u>	<u>DIURNAL RANGE</u>
SOUTH JETTY	4.5	6.4
BUCKSPORT	4.6	6.5
FIELDS LANDING	4.6	6.5

The tide exhibits a diurnal inequality with the "long run-out" following the higher high water.

The tidal area of the bay at high water is 24.8 square miles. The tidal prism is approximately 120 square mile-feet between MHHW and MLLW. The corresponding mean velocity on the long run-out is 1.7 feet per second between the ends of the jetties.

The Coast Pilot contains no statement regarding littoral currents. The chart showing the survey of June 1923 carries current arrows indicating that the flood currents enter the channel between the jetties and that the ebb currents concentrate and flow westward from the end of the South Jetty. Persons familiar with the entrance stated that the flood currents come in rather evenly over the entire width between the jetties but that the ebb concentrates along the South Jetty. This current system was observed by the writer. Local residents also state that the summer littoral current is northward.

SUMMARY OF CHANGES AT ENTRANCE TO HUMBOLDT BAY.

<u>YEAR</u>	<u>MONTH</u>	<u>CONTROLLING DEPTH (FT.)</u>	<u>THROAT DEPTH</u>	<u>WIDTH AT MLLW</u>	<u>DIRECTION OF BAR CHANNEL</u>	<u>REMARKS</u>
1851		21	67	1500	N W	Entrance at about same location as in 1930
1858		22	66		W	
1870		14	72		N W	
1875	(APRIL JUNE)	10			W	
1881	OCTOBER	14	80		N W	
1882	MAY	12	89		W N W	
1882	SEPTEMBER	12	67		N W	
1883	MAY	15	63		W N W	Channel near south spit.
1911		19	50		N	Jetties started 1892.
1912		22	63		N	Distance between jetties, 2000 feet.
1913	JUNE	22	61		N N W	Jetties run about N W.
1914	JUNE	20	53		N N W	South Jetty reconstructed. Main channel follows South Jetty.
1914	DECEMBER	25	70		W	Channel follows South Jetty
1915	JUNE	25	70		N W	Channel follows South Jetty
1916	MARCH	20	72		N W	Erosion south of South Jetty. Shoals formed between jetties. North Jetty reconstruction started.
1916	(JUNE AUGUST)	19	80		N W	
1917	FEBRUARY	20			W N W	Channel follows South Jetty.
1917	JUNE	23	81		W N W	
1918	JANUARY	23	70		N W	
1921	JANUARY	19	62		W N W	Best Channel runs north.
		21			N	

<u>YEAR</u>	<u>MONTH</u>	<u>CONTROLLING DEPTH (FT.)</u>	<u>THROAT DEPTH</u>	<u>WIDTH AT MLLW</u>	<u>DIRECTION OF BAR CHANNEL</u>	<u>REMARKS</u>
1921	JUNE	24	62		N N W	Channel meanders between jetties.
1923	JUNE	25	59		W	Channel passes close to shore and of North Jetty then cuts across and follows South Jetty.
1926	JUNE	25	63		W	Shore line north of North Jetty has built out 2700 feet since 1917.
1927	JUNE	27	61		W	Slight accretion south of South Jetty. Bar skewed to northward of jetties.
1929	JUNE	27	67		W	Shoal between jetties holds main channel against South Jetty. Main channel follows shore end of North Jetty and then outer half of South Jetty.

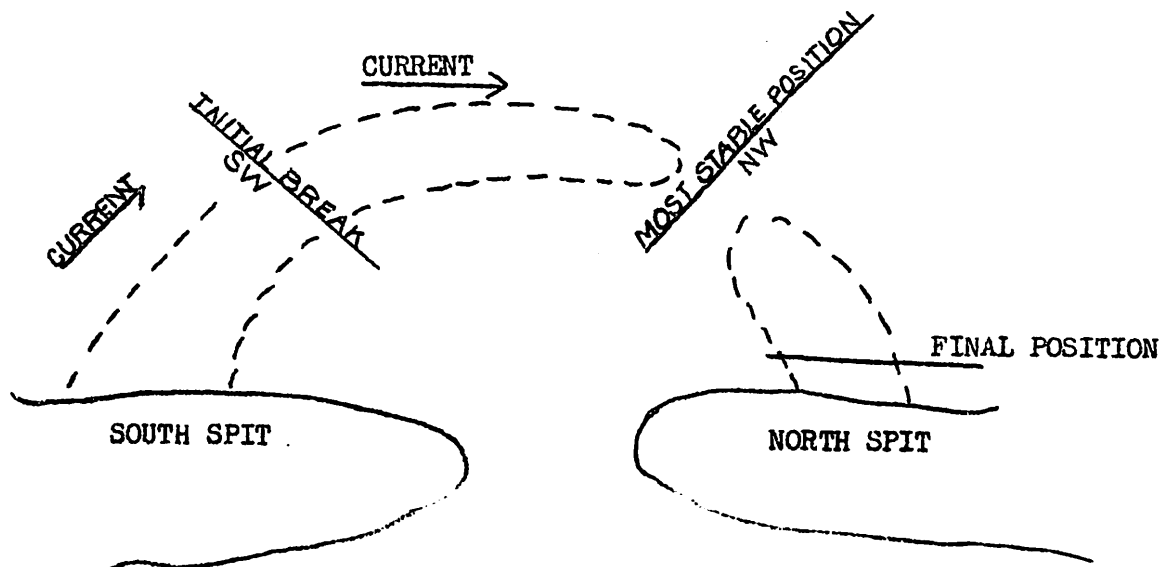
SAND SAMPLES and PROFILES--Sand samples from the beach on each side of the entrance but none were available from the bar. The sieve analysis showed the following results:

<u>LOCATION</u>	<u>DESIGNATION</u>	<u>MEDIAN DIAMETER</u> (INCHES)	<u>SLOPE</u> (DEGREES)
NORTH OF NORTH JETTY	26A	0.0152	7
SOUTH OF SOUTH JETTY	27	0.00795	

The sand has a much darker appearance than sand at any other location included in this report. A petrographic examination might easily establish its origin.

SAND MOVEMENT--Although attempts have been made to determine the direction of sand movement at this entrance, little success has been achieved which may indicate either no drift or a drift in each direction, depending on weather, of just sufficient magnitude to leave the net movement as zero. In the Proceedings of the American Society of Civil Engineers for 1901, C. H. McKinstry states that "at Humboldt Bay, there is said to be no well defined resultant drift, the movement to the south during the summer about counter balancing that to the north in winter."

Mr. E. D. Hughes, who was connected with the improvements at this harbor for many years, states that the bar channel exhibits a cyclic motion breaking through towards the southwest and then worked around to the northwest. The rate of drift of the bar channel was greatest near the original break and decreased as the channel swung northward. In its final position, the channel often paralleled the shore and a new break southwestward occasionally occurred while the north channel was still open. The channel seemed to be most stable when in the northwest direction.



This cyclic motion seems to have been established beyond a possibility of doubt by data obtained from pilots and by direct observation.

Following the construction of the jetties, accretion occurred on both sides of the entrance, the greater amount being on the north side. As the accompanying sketch shows, the accretion north of the entrance extended at least 6500 feet and had a maximum width of 2500 feet. The jetties make an angle of about 70° with the general trend of the shore line and it is to be noted that the greater fill occurred in the acute angle on the north side. The accretion on the south side had a maximum width of 200 to 300 feet. The writer is of the opinion that the fill on the north side occurred because of the protection of the North Jetty. Waves approaching parallel to the shore, race in along the south sides of both jetties while on the north side there is relatively calm water. The accumulation occurs in the most sheltered area.

The data presented indicate a northward sand movement but there is considerable uncertainty on this point.

An interesting feature of the improvement is the erosion at Point Humboldt, where the shore line has receded a maximum of 1200 feet since 1854. This erosion has been accompanied by the development of the Buhne Spit southward of the point. The vertical cliffs resulting from the erosion are 100 feet in height. In the natural condition of the entrance, Point Humboldt was partly protected from direct wave attack by the south spit. Since the improvement of the entrance, this protection has been removed and in addition the jetties seem to act as a funnel which directs the waves towards Point Humboldt, regardless of what their original direction may have been. The waves running in through the entrance not only grind away the base of the cliffs but also transport the material away along the shore, so that the rate of erosion does not decrease due to the accumulation of debris.

STRUCTURES--The entrance has been improved by means of two random-mound jetties, which are parallel over the greater portion of their length and 2000 feet apart. The main axis of the jetties makes an angle of about 70° with the general trend of the shore line.

The South Jetty was started in 1889 and completed in 1895. The North Jetty was started in 1892 and finished in 1896. By 1905, the outer third of each jetty had been beaten down by the sea to or below low water. In 1911, the condition was as indicated in the plan (on the following page) the section of each jetty seaward of the points marked "Elev 0.0" being at or below low water." The South Jetty was reconstructed between 1911 and 1915 and repaired in 1927. The North Jetty was repaired between 1915 and 1926.

Principal data on the jetties are:

SOUTH JETTY--Length 8000 feet
Height of crest +12' above MLLW.
Specifications for stone
Unit weight

NORTH JETTY--Length 8000 feet.
Height of crest +12' above MLLW.
Specifications for stone
Unit weight

The improvement of the entrance has been partially successful but the bar is dangerous in bad weather and probably will always be so. The distance between the jetties is too great for the tidal prism with the result that the channel meanders between them and the channel over the bar does not remain fixed in position.

The original height of the jetties at the completion of the last construction was approximately +12 feet above MLLW. The inner portion was held together by a concrete cap poured in place and a parapet was provided on the south side of each jetty. At the sea ends of both jetties, pre-cast blocks of concrete weighing 800 tons each were used.

As the accompanying photographs show, the concrete blocks at the sea ends have not been completely successful due to the removal of stone from beneath the blocks, allowing them to slide off the rockment. Inside the sea ends, the jetties appear to be stable but they have not been in place sufficiently long to decide this question.