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GRAYS HARBOR, WASHINGTON
A LITERATURE SURVEY

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Executive Officer

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FOREWORD

The Literature Survey of Grays Harbor, Washington, 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 The Department of Oceanography has provided a listing and analysis of published and unpublished literature.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 These abstracts are not purported to be finished articles and should only be considered unpublished records subject to revision.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 Following each subject is an annotated bibliography of relevant publications and unpublished reports and data, whether used in the abstract or not.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 1

GEOGRAPHY

GEOGRAPHY

PHYSICAL GEOGRAPHY

LOCATION

Grays Harbor is a large estuary on the southwest coast of the State of Washington, 60 nautical miles north of the Columbia River Lightship, 17 miles north of Willapa Harbor and 118 nautical miles south of Cape Flattery at the entrance to the Strait of Juan de Fuca.

DESCRIPTION OF THE AREA

Grays Harbor is generally characterized by numerous mud flats, bare at low tide, with intervening channels formed by the discharge of tributary rivers. The most important of these channels are the North and South Channels extending from the deep water at the entrance to the Chehalis River. The North Channel, used by deep draft vessels, is maintained to a depth of 30 feet at mean lower low water over a width of 350 feet. Principal tributaries to the harbor other than the Chehalis River are the Humptulips, Hoquiam, Wishkah, Johns, and Elk Rivers. Except for the Chehalis River and the lower reaches of the Hoquiam River, these tributaries are unimportant from the standpoint of navigation (U. S. Army Corps of Engineers 1948).

The harbor diverges from the Chehalis River at Aberdeen, Washington, into a broad, shallow bay which further expands into North Bay and South Bay to a total width of 13 miles. Its length, from the entrance easterly to Aberdeen, is about 15 miles. The harbor is separated from the Pacific Ocean by two narrow, sandy peninsulas.

The harbor entrance is about 9,000 feet wide and lies between Point Brown on the north and Point Chehalis on the south. Point Brown is about seven miles long and Point Chehalis is four miles long. Both peninsulas vary in width from about one-half mile to nearly two miles, and both are covered with a dense growth of timber and other vegetation to within a mile of their ends, except for a strip of sand dunes and beaches, averaging about one-half mile in width on the seaward side. The last mile of each is composed mainly of loose sand and gravel. Two convergent rubble-mound breakwaters extend seaward from the points, constricting the entrance width to 6,500 feet. Beyond the jetties, an ocean bar composed of fine, gray sand lies convex to the sea. A survey made in September 1946 showed a minimum depth of 18 feet over the bar at mean lower low water. A navigation channel extends across the bar in a northeasterly direction from deep water to the entrance channel immediately west of the south jetty. It is maintained partly by tidal currents and partly by dredging under a Federal project. Within the entrance the channel extends along the south jetty for about two miles, then veers north-eastward to bypass Point Chehalis and join the North and South Channels leading to the Chehalis River at Aberdeen. The 1946 survey showed depths of at least 30 feet prevailing over a width of about 800 feet in the bar channel and depths from 37 to 89 feet over a width of about 1,200 feet in the entrance channel.

CULTURAL GEOGRAPHY

DISCOVERY OF GRAYS HARBOR

Grays Harbor was discovered on May 17, 1792, by Captain Robert Gray. The harbor was originally named Bulfinch Harbor. This, with the discovery of the Columbia River on May 11, 1792, later proved to be of prime importance in subsequent negotiations over possession of the northwest coast of America (Meany 1946).

INDUSTRIES BORDERING GRAYS HARBOR

Lumbering is the chief industry of the area. The vast stands of Douglas fir and cedar, much of it still virgin timber, provides the source of supply for the sawmills, wood product factories, and allied industries that dominate the region. Dairying is the major agricultural land-use and of lesser but significant importance are the fisheries and shellfish industries (Peterson 1951).

HARBOR MODIFICATION PROJECTS

The U. S. Army Corps of Engineers project provides for an entrance channel across the bar, 600 feet wide and 30 feet deep, to be secured by a south jetty 13,734 feet long and a north jetty 16,000 feet long, both at an elevation of 16 feet above mean lower low water, and by dredging. The project also provides for maintenance of a channel 30 feet deep and 350 feet wide from deep water in Grays Harbor to the Port of Grays Harbor Commission Terminal, a distance of 13¼ miles; thence 26 feet deep and 200 to 350 feet wide to the Union Pacific Railroad bridge at Aberdeen (2¼ miles), thence 18 feet deep and 200 feet wide to Cosmopolis (3 miles), thence 16 feet deep and 150 feet wide to Montesano (10 3/4 miles). In addition, the project provides for a channel 14 feet deep and 100 feet wide in South Bay to Bay City, for a rubble-mound breakwater, 1,000 feet long, at Westhaven Cove, and for a rockfill levee approximately 7,500 feet long, extending from shore end of the south jetty north-eastward along the beach at Point Chehalis. All depths refer to the plane of mean lower low water (U. S. Army Corps of Engineers 1951). A plan to construct an intercoastal system of canals and locks to connect the Columbia River, Willapa Bay, Grays Harbor, and Puget Sound has been proposed from time to time. See Enclosure 1-1.

Bridges

There are eleven highway, six railway and two pipeling bridges across tidal waters of Grays Harbor and tributaries, the plans for all of which have been formally approved by the War Department. Five of the bridges are on the Chehalis River in the portion from the mouth to an including Montesano, five over the Wishkah River at Aberdeen, three over Elliott Slough at Aberdeen, five over the Hoquiam River at Hoquiam and one across South Bay in the harbor (U. S. Army Corps of Engineers 1948).

STATUS OF POLLUTION IN GRAYS HARBOR

The condition in the river estuaries of Grays Harbor which results from the discharge of raw sewage from the cities of Aberdeen, Hoquiam, and Cosmopolis has been determined.

The results of the survey have shown that sewage and the accompanying bacterial contamination exists in the waters adjacent to these communities in concentrations many times that considered to be hazardous to the people living in the area, and that his sewage and other municipal wastes adversely affect their use for recreation, fisheries, shellfish culture, log rafting and booming (Peterson 1953).

Effect of Polluted Waters on Ships and Material in the Water

The deposition of organic waste materials on river and harbor bottoms causing the formation of sludge banks, often results in the creation of compounds which are harmful to the paint on marine craft and cause corrosion of metal parts which may be submerged. Industrial wastes, such as sulfite waste liquor, which are in themselves acidic, may have a similar effect if present in sufficient concentration. Organic materials promote the growth of slimes which may foul fishing gear and attach themselves to boats and underwater parts causing frequent and expensive maintenance. The removal of such materials from the harbor and rivers will no doubt appreciably reduce maintenance costs for fishermen and operators of other commercial and pleasure craft (Orlob, Jones, and Peterson 1951).

NUMBER OF SMALL BOATS OPERATING IN HARBOR

During 1950, approximately 48 gill-net boats were working inside the harbor. Trollers, crab-boats and drag boats, at times totaling approximately 450 craft, operated in and out of the harbor, most of them working in the ocean.

A total of 22 tow boats of various sizes operate within the harbor, ten of these boats being used by commercial tug boat compainies, four by general contractors, six by industrial plants, one by the Port of Grays Harbor and one by the log patrol (Orlob, Jones, and Peterson 1951).

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(Location and description of sediment samples, biological studies and water analyses.)

SECTION 2

CLIMATOLOGY

CLIMATOLOGY

INTRODUCTION

Grays Harbor is similar to other coastal harbors of the Northwest in that the climate is generally mild. The marine influence produces cool summers, mild winters, and considerable moisture. Local records show that there is an appreciable variation in wind direction and precipitation at various locations in the vicinity of Grays Harbor.

PRECIPITATION

The rainfall in the Grays Harbor area is typical for the Pacific Northwest coast. November, December, and January are the wettest months in Aberdeen and at Lone Tree; an average of 12.9 inches falls during each of these months. July and August are the driest months with an average of 1.1 inches of rain per month. The heaviest rains occur during the winter months with about 64% of the days having 0.01 inch of rain or more; during July and August only 16% of the days have 0.01 inch or more. The maximum recorded 24-hour rains occur between November and March. An isohyetal map encompassing the Grays Harbor area is included as Enclosure 2-1.

The following tabulation from 50 years of record kept by the U. S. Department of Commerce Weather Bureau (1952) gives the maximum 24-hour precipitation for the city of Aberdeen, Washington:

Jan 1935 - 5.25"	Jul 1932 - 1.82"
Feb 1932 - 3.76"	Aug 1912 - 2.03"
Mar 1932 - 4.50"	Sep 1920 - 2.31"
Apr 1938 - 3.59"	Oct 1942 - 4.87"
May 1941 - 2.36"	Nov 1911 - 4.07"
Jun 1933 - 2.00"	Dec 1943 - 5.07"

Table 2-1 presents precipitation data from Aberdeen and Lone Tree, Washington. Table 2-2 compares the average monthly precipitation for Aberdeen, Lone Tree, South Bend, and North Head, Washington.

TEMPERATURE

The yearly temperatures are mild, with extreme highs or lows being uncommon. In the period from 1892 to 1930 the lowest recorded temperature was 6° F., the highest was 105° F. (U. S. Department of Agriculture Weather Bureau 1936). In general, the temperature ranges from an average of about 39° F. in January, to 60° F. in August at Aberdeen, and 41° to

59° F. at Lone Tree. The North Head weather records show that on the average the temperature falls to 32° or less only 1 day in January and less than 1 day in November, December, February, and March. The summer temperatures seldom reach 90° F.

Table 2-1 presents temperature data from Aberdeen and Lone Tree, Washington. Table 2-2 compares the average monthly temperatures from Aberdeen, Lone Tree, South Bend, and North Head, Washington.

VISIBILITY AND FOG

The records (U. S. Department of Commerce Coast and Geodetic Survey 1951) indicate that the maximum fog or low visibility occurs during the late summer, autumn, and early winter. The months of July through November average about 95 hours of fog signal operations at the Coast Guard Light Station; the remainder of the year averages 46 hours of operation per month (U. S. Department of Commerce Coast and Geodetic Survey 1951). Table 2-3 gives the fog summary at the Grays Harbor Light Station. 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 Light Station, Westport, Washington.

WIND AND WEATHER

The prevailing winds in Aberdeen, Washington, during the spring, summer, and fall are generally from the west; during the winter the winds are from the east. At Lone Tree, on Point Brown, the spring, summer, and fall winds are prevailingly northwesterlies; the winter winds are primarily easterly and southeasterly. The velocity seldom exceeds 40 mph.

The U. S. Coast Guard Lifeboat Station at Westport, records wind, weather, sea, and visibility data. For wind data from Lone Tree and North Head, Washington, see Tables 2-4 and 2-5. A comparison of the prevailing winds from Aberdeen, Lone Tree, South Bend, and North Head is given in Table 2-6. Enclosure 2-2 consists of Wind Roses, indicating velocity and average duration of wind in days per year and a graphic presentation of wind velocity and duration.

<u>Storms</u>

The following quotation from the U. S. Army Corps of Engineers (1948) discusses the storms which affect the area:

TABLE 2-1. Precipitation and Temperature Data, Aberdeen and Lone Tree, Washington.

	Average No. of Days with 0.01" or more		Average Snowfall (inches)		Average Max. Temp.		Average Min. Temp.		Highest Temp.		Lowest Temp.	
	Aber.	L. T.	Aber.	L. T.	Aber.	L. T.	Aber.	L. T.	Aber.	L. T.	Aber.	L. T.
Length of record (Years)	38	12	36	12	38	12	38	11	38	12	38	12
Jan	20	24	6.8	4.0	44.6	44.7	33.3	37.0	61	57	8	21
Feb	17	19	4.2	0.4	48.5	46.9	34.3	38.0	73	59	13	28
Mar	18	20	0.8	0.3	52.9	50.4	35.5	39.9	82	70	18	27
Apr	15	17	0.3	Trace	57.4	43.0	38.1	43.0	88	73	25	32
May	12	13	0	0	61.9	57.2	42.5	47.3	92	86	29	38
Jun	9	10	0	0	65.7	60.6	46.9	50.5	100	82	32	44
Jul	5	8	0	0	69.7	63.4	49.6	53.2	105	85	34	46
Aug	5	7	0	0	70.5	64.2	50.5	53.4	98	83	36	47
Sep	10	11	0	0	67.9	68.2	46.9	52.3	93	80	30	44
Oct	14	17	0	0	61.1	56.9	43.0	47.9	85	71	24	33
Nov	19	22	0.7	0.4	51.7	51.0	38.5	42.7	73	69	18	31
Dec	20	23	2.1	0.2	46.0	46.6	34.6	38.8	63	60	6	17
Annual	164	191	14.9	5.3	58.2	54.8	41.2	45.3	105	86	6	17

Table compiled from the U. S. Department of Agriculture Weather Bureau (1936).

TABLE 2-2. Comparison of Average Monthly Precipitation and Temperature from Various Stations About Grays Harbor.

	Aberdeen		Lone Tree		South Bend		North Head	
	Precip. (Inches)	Temp. (° F)	Precip. (Inches)	Temp. (° F)	Precip. (Inches)	Temp. (° F)	Precip. (Inches)	Temp. (° F)
Length of record (Years)	40	38	13	12	36	33	29	44
Jan	12.08	39.0	13.25	40.8	12.71	40.2	7.62	41.6
Feb	9.45	41.4	8.01	42.4	9.75	42.4	5.75	43.0
Mar	8.10	44.2	7.04	45.2	8.81	44.8	4.74	45.0
Apr	5.93	47.8	4.83	48.5	6.32	48.4	3.16	47.8
May	4.03	52.2	3.00	52.2	4.22	53.4	2.36	51.3
Jun	2.89	56.3	2.31	55.6	2.91	57.2	1.92	54.8
Jul	0.95	59.6	1.13	58.3	0.97	61.4	0.62	57.4
Aug	1.26	60.5	1.07	58.8	1.55	61.6	0.96	58.1
Sep	4.00	57.4	3.00	57.6	3.72	59.0	2.43	56.7
Oct	6.88	52.0	6.93	52.4	6.77	53.2	4.12	53.4
Nov	13.18	45.1	12.71	46.8	12.42	46.5	7.26	48.3
Dec	12.83	40.4	10.57	42.7	13.20	41.8	7.90	43.9
Annual	81.58	49.7	73.85	50.1	83.35	50.8	48.84	50.1

Table compiled from the U. S. Department of Agriculture Weather Bureau (1936).

TABLE 2-3. Fog and Use of Fog Signal, Grays Harbor, Washington.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Hours of Fog Summary at Grays Harbor Light Station[1]													
1951-52	454.75	161.50	182.25	127.00	60.75	140.00	54.50	125.75	370.25	176.75	150.25	161.25	2165.00
1952-53	441.25	168.00	115.00	130.00	42.50	84.25	269.25	252.75	275.75	446.25	252.50	243.50	2712.00
1953-54	209.00	146.00	64.50	73.00	90.00	72.00	111.75	250.25	195.50	259.75	216.00	213.00	1900.75
Hours of Operation of Fog Signals[2]													
	69	52	57	25	25	40	83	138	92	81	82	56	800

[1] U. S. Treasury Department Coast Guard (n. d. a).
[2] U. S. Department of Commerce Coast and Geodetic Survey (1951).

The coastal area is subject to severe storms, particularly during winter months. Winter storm winds (November to February, inclusive) generally originate in the east or southeast, then swing to the south and southwest where they reach their greatest intensity. In summer the prevailing winds are northwesterly. Velocities up to 95 miles an hour have been recorded at the mouth of the Columbia River and 84 miles an hour at Tatoosh Island, off Cape Flattery. Data collected from various sources by the Shore Protection Board in connection with beach erosion studies at Point Chehalis indicated that wave heights exceeding 40 feet occurred along the coast, and that 75 percent of ocean swells (classified generally as of low or medium order) approach Grays Harbor in such direction as to permit their passage between the jetties into the harbor entrance. Fog may occur at any time of the year, but is most frequent during August on the coast.

Sky Conditions

The usual sky condition for the region is cloudy to partly cloudy; there is an average of only 5.5 clear days per month. The maximum cloudiness occurs during the months of November, December, and January. Table 2-7 summarizes the monthly sky conditions at North Head, Washington.

TABLE 2-4. Wind Data, Lone Tree, Washington.

Point from Which Wind Blows	Average Velocity (Miles per hour)	YEAR 1909-10	1915	1916	1919	Total Days	Average (Days per Year)
North	5-10	1	1	2	0	4	1
	10-20	4	0	1	0	5	1.25
	20-30	0	0	0	0	0	0
	30-40	0	0	0	0	0	0
	Over 40	0	0	0	0	0	0
Northeast	5-10	6	1	2	8	17	4.25
	10-20	6	1	2	22	31	7.75
	20-30	0	0	2	11	13	3.25
	30-40	0	0	0	0	0	0
	Over 40	0	0	0	0	0	0
East	5-10	1	4	6	3	14	3.5
	10-20	31	28	28	9	96	24
	20-30	11	21	24	1	57	14.25
	30-40	0	2	2	4	8	2
	Over 40	--	--	--	--	--	--
Southeast	5-10	4	2	4	4	14	3.5
	10-20	16	14	15	21	66	16.5
	20-30	4	14	10	18	46	11.5
	30-40	1	2	0	8	11	2.75
	Over 40	0	0	0	1	1	.25

TABLE 2-4. Wind Data, Lone Tree, Washington (continued).

Point from Which Wind Blows	Average Velocity (Miles per hour)	YEAR 1909-10	1915	1916	1919	Total Days	Average (Days per Year)
South	5-10	5	9	7	6	27	6.75
	10-20	23	15	28	21	87	21.75
	20-30	7	1	13	8	29	7.25
	30-40	0	1	8	5	14	3.5
	Over 40	1	1	1	0	3	.75
Southwest	5-10	24	13	17	24	78	19.5
	10-20	34	35	19	37	125	31.25
	20-30	6	13	9	7	35	8.75
	30-40	2	0	2	2	6	1.5
	Over 40	0	0	0	0	0	0
West	5-10	16	29	31	5	81	20.25
	10-20	14	23	18	3	58	14.5
	20-30	5	5	0	0	10	2.5
	30-40	1	0	0	0	1	.25
	Over 40	0	0	0	0	0	0
Northwest	5-10	32	33	26	24	115	28.75
	10-20	93	65	77	85	320	80
	20-30	9	7	6	10	32	8
	30-40	0	1	0	0	1	.25
	Over 40	0	0	0	0	0	0

Table rearranged from U. S. Army Corps of Engineers Seattle District (n. d. a).

TABLE 2-5. Wind Data, North Head, Washington. [True velocities]

	Average Hourly Velocity	Prevailing Directions	MAXIMUM Velocity (mph)	Direction	Date
Length of Record	44 years	44 years	--	34 years	--
Jan	15.9	E	112[1]	SE	1921
Feb	14.6	SE	69	S	1904
Mar	14.1	SE	73	S	1897
Apr	13.8	NW	65	SE	1907[2]
May	13.2	NW	60	SE	1911
Jun	12.8	NW	57	SE	1906
Jul	12.0	N	49	SE	1904
Aug	11.2	N	57	SE	1920
Sep	11.7	N	70	SE	1914
Oct	12.8	SE	69	S	1893
Nov	15.5	SE	70	S	1925
Dec	16.2	E	79	E	1884
Annual	13.6	NW	112[1]	SE	Jan 1921

1 Estimated.
2 Also other dates

Table compiled from U. S. Department of Agriculture Weather Bureau (1936).

TABLE 2-6. Comparison of Prevailing winds from Stations About Grays Harbor.

	Aberdeen	Lone Tree	South Bend	North Head
Length of record	38 years	12 years	21 years	44 years
Jan	E	SE	E	E
Feb	E	E	E	SE
Mar	W	NW	W	SE
Apr	W	NW	W	NW
May	W	NW	W	NW
Jun	W	NW	W	NW
Jul	W	NW	W	N
Aug	W	NW	W	N
Sep	W	NW	W	N
Oct	W	NW	E	SE
Nov	E	E	E	SE
Dec	E	E	W	E
Annual	W	NW	W	NW

Table obtained from U. S. Department of Agriculture Weather Bureau (1936).

TABLE 2-7. Sky Conditions at North Head, Washington.

	Average Hrs. of Sunshine (Days)	% Possible Sunshine	Average Cloudiness (0-10)	NUMBER OF DAYS Clear	Partly Cloudy	Cloudy
Length of record (Years)	42	42	54	60	60	60
Jan	78	27	7.9	4	5	22
Feb	110	37	7.3	5	6	17
Mar	155	42	7.1	5	8	18
Apr	197	49	7.9	5	9	16
May	223	48	6.9	5	10	16
Jun	228	48	6.8	5	9	16
Jul	240	50	6.4	7	10	14
Aug	202	46	6.5	7	9	15
Sep	180	48	6.2	8	8	14
Oct	137	40	6.8	7	8	16
Nov	89	31	7.6	5	5	20
Dec	74	27	7.7	4	5	22
Annual	1913	41	7.0	67	92	206

Sky cover 3/10 or less = clear, 4/10 to 7/10 = partly cloudy, 8/10 or more = cloudy.

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SECTION 3

HYDROLOGY

HYDROLOGY

RELATIONSHIP OF RIVERS TO BASIN TOPOGRAPHY

The Chehalis River is the principal stream entering Grays Harbor. It rises in the Willapa Hills, about 40 miles east of the Pacific Ocean and flows in a northerly and westerly direction for 110 miles to Grays Harbor at Aberdeen. Its basin ranges in altitude from sea level to a maximum of about 4,000 feet. The river is considered navigable to Chehalis, about 76 miles above the mouth of the Hoquiam River. Present navigation is limited to the tidal portion which extends to Elma, 31 miles above the mouth, although little commerce is carried above Montesano. The existing project for navigation improvement extends from Grays Harbor to Montesano, 16 miles above the junction of the North and South Channels in the Harbor. Surveys made in 1943 and 1945 showed controlling depths of 26 feet at mean lower low water below the Union Pacific Railroad bridge at Aberdeen, 21.1 feet below Cosmopolis, and 8.9 feet below Montesano over widths ranging from 150 to 200 feet.

The Hoquiam River joins the North Channel at Hoquiam, Washington. Although the river is considered navigable for several miles up each of two main forks, only 3½ miles from the forks to the mouth have been improved under a Federal project to a controlling depth of 17 feet at mean lower low water (U. S. Army Corps of Engineers 1948).

DRAINAGE AREA

The total drainage area of Grays Harbor is about 2,605 square miles, of which about 2,063 square miles are drained by the Chehalis River and its tributaries (U. S. Army Corps of Engineers 1948).

Effect of Drainage Basin on River Flow

The entire Chehalis system lies within an area noted for its tremendous stands of virgin Douglas fir. In recent decades, much of this timber has been cut with the resultant loss of the natural forest cover, which normally diminishes and delays the natural runoff. Loss runoff data is shown in Table 3-1. See Enclosure 3-1. This deforestation of an area which receives a considerable amount of rainfall but little snowfall because of its low altitude has resulted in the rapid runoffs, and the extended periods of low river flow which are characteristic of rainfall rivers. Gaging station data are shown in Table 3-2. See Enclosure 3-2. The mean annual flow for 1942, a year of near average precipitation, was approximately 5,500 cfs, while peak flows were recorded at 21,700 cfs (December 2, 1942) with a minimum of 806 cfs (October 25, 1942). Maximum discharge in 1950, a very wet year, was

47,400 cfs (December 24, 1950), while the stream flow dropped to 757 cfs in August of that year. Considerable correlation between rainfall and stream flow is apparent in comparison of flow and precipitation data (Orlob, Jones, and Peterson 1951). Range in suspended sediment loads for streams entering Grays Harbor is shown on Table 6-6. Enclosure 6-40 shows concentration of suspended sediment for the Chehalis River drainage. This subject is discussed further in Section 6, Recent Sediments.

A comprehensive study was made on flood problems in western Washington. Data from the Grays Harbor area is summarized in Table 3-3.

GROUND WATER IN THE GRAYS HARBOR AREA

Material provided by the U. S. Department of the Interior Geological Survey (1954) is reproduced as follows:

> Aquifers in the Grays Harbor area are of two general types. (1) consolidated sedimentary rocks and volcanic rocks, and (2) unconsolidated and semi-consolidated sedimentary rocks. The consolidated and volcanic rocks form the bedrock beneath the unconsolidated materials that underlie the Harbor, and the surrounding valley areas. The consolidated and volcanic rocks also form the surrounding hills. The unconsolidated and semi-consolidated rocks, consisting mostly of sand, silt, clay, and some gravel occur chiefly as valley fill deposits. The North and South Bays are also composed of unconsolidated materials.
>
> The consolidated and volcanic rocks, in general, have low permeability, and discharge relatively small amounts of ground water into Grays Harbor. The unconsolidated and semi-consolidated rocks are more permeable, and furnish the bulk of the ground water that is discharged directly into Grays Harbor. Moreover, a large component of the stream-flow, especially during the late summer and autumn periods of low stream-flow, is derived from ground-water discharge into these streams. The ground-water component of stream-flow probably is larger than the quantity of ground water that is discharged directly into Grays Harbor.

Ground Water Conditions in the South Bay District

Two principal aquifers are present in the Quaternary sediments of the South Bay district. They are (1) a little known sequence of sand and gravels in the Pleistocene (Satsop-type) strata of the Ocosta-Bay City District, and (2) a fresh-water body floating on salt water in the permeable sands of Recent age which comprise the southern bay-mouth bar of Grays Harbor and the contiguous barrier bars to the south. The extent, recharge, and possible yield of the aquifer in the Ocosta-Bay City District are not readily discernible; a more detailed study involving test drilling would be necessary to clarify this point.

The extent, recharge, possible yield, and quality of the fresh ground-water body in the sand of the Westport-Grayland area is more readily discernible. This body appears to be capable of sustaining a withdrawal of several hundred million gallons a year by properly constructed and dispersed pumping plants (Newcomb 1947).

TABLE 3-1. Normal Seasonal Precipitation Loss-Runoff Data for the Grays Harbor Area.

	Drainage Area	Runoff	Precip-itation	Loss
Chehalis River near Grand Mound	897	44.9	65.5	20.6
Satsop River near Satsop	315	93.9	116.8	22.9
Wynoochee River at Oxbow	65	164.9	178.9	14.0
Wynoochee River near Montesano	105	140.8	157.6	16.8

Table modified from U. S. Engineer data (U. S. Army Corps of Engineers Seattle District 1946).

TABLE 3-2. Gaging Station Data for the Grays Harbor Area.

GAGING STATION	DRAINAGE AREA (sq. mi.)	PERIOD of RECORD	DIVERSION	REGULATION	EXTREMES maximum sec. ft.	Date	minimum sec. ft.	Date	AVERAGE DISCHARGE sec. ft.	period yrs.
Johns River near Markham	18.9	1942-43	None	None	450	10/24/43	16	9/17-24 1942	--	--
Mewskah Creek near Aberdeen	8.0	1945-49	None	None	570	2/17/49	1.6	9/9-12, 28,1946	--	--
Charles Creek near Aberdeen	5.7	1945-49	None	None	436	2/2/47	0.3	9/11/46	--	--
Chehalis River at South Elma	1,420	1942-44 1946	Many minor diversions, domestic and irrigation	None	38,400	2/11/51	202	9/12/44	5,057	5
Satsop River near Satsop	290	1929	None	None	52,500	1/22/35	166	9/21/38	1,927	22
Wynoochee River near Montesano below Black Creek	179	1942-49	City of Aberdeen diverts 56 sec.ft.continuously	None	16,600	2/8/45	51	9/11/44		
Humptulips River near Humptulips	125	1933-35 1942	None	None	33,000	1/22/35	82	9/11/44	1,313	10

Table from Water Supply Papers (U. S. Department of the Interior Geological Survey Annual).

TABLE 3-3. Peak Flood Data from Three Gaging Stations in the Grays Harbor Area.

GAGING STATION	FACTORS USED IN THE MULTIPLE CORRELATION OF MEAN ANNUAL FLOOD TO BASIN CHARACTERISTICS.				
	Adjusted mean annual flood (cfs)	Drainage area (sq.mi.)	Altitude mean (ft.)	Area of lakes (%)	Geographical factor
Chehalis River at South Elma	28,600	1,420	700	0.14	120
Satsop River near Satsop	21,400	315	500	0.25	230
Wynoochee River below Black Creek near Montesano	15,200	179	900	0.01	230

GAGING STATION	DATA FOR HOMOGENITY TEST FOR GAGING STATIONS IN WESTERN WASHINGTON.					
	Q_{10} (cfs)	$Q_{2.33}$ (cfs)	$\frac{Q_{10}}{Q_{2.33}}$	$Q_{2.33}$ x ratio (cfs)	R.I. for $Q_{2.33}$ x ratio (yr)	Effective length of record (yr)
Chehalis River	41,500	28,600	1.45	47,500	21	22
Satsop River	32,700	21,400	1.53	35,500	15	31
Wynoochee River	21,000	15,200	1.38	25,200	32	24

TABLE 3-3. Peak Flood Data from Three Gaging Stations in the Grays Harbor Area (continued).

ANNUAL FLOOD PEAKS

CHEHALIS RIVER AT SOUTH ELMA		
Water Year	Date	Discharge (cfs)
1947	26 Jan 1947	28,000
1948	5 Jan 1948	24,400
1949	24 Feb 1949	35,600
1950	27 Feb 1950	34,500
1951	11 Feb 1951	38,800

WYNOOCHEE RIVER BELOW BLACK CREEK NEAR MONTESANO		
Water Year	Date	Discharge (cfs)
1942	3 Dec 1941	16,100
1943	2 Apr 1943	10,000
1944	3 Dec 1943	15,100
1945	8 Feb 1945	16,600
1946	11 Apr 1946	11,000
1947	14 Feb 1947	15,800
1948	19 Oct 1947	13,400
1949	22 Feb 1949	16,200
---	---	---
1951	9 Feb 1951	22,600

SATSOP RIVER NEAR SATSOP		
Water Year	Date	Discharge (cfs)
1930	23 Dec 1929	11,300
1931	23 Jan 1931	19,200
1932	26 Feb 1932	27,000
1933	8 Jan 1933	15,300
1934	21 Dec 1933	24,500
1935	22 Jan 1935	52,500
1936	4 Jan 1936	16,600
1937	14 Apr 1937	15,200
1938	28 Dec 1937	30,100
1939	1 Jan 1939	25,600
1940	15 Dec 1939	18,700
1941	18 Jan 1941	25,200
1942	19 Dec 1941	13,200
1943	1 Apr 1943	13,100
1944	3 Dec 1943	19,900
1945	7 Feb 1945	28,000
1946	11 Apr 1946	17,200
1947	25 Jan 1947	24,000
1948	19 Oct 1947	17,300
1949	22 Feb 1949	27,000
1950	28 Dec 1949	26,600
1951	9 Feb 1951	36,500

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SECTION 4

REGIONAL GEOLOGY

REGIONAL GEOLOGY

PHYSIOGRAPHY

Grays Harbor is situated in the northern limits of the physiographic province of the Willapa Hills. The Willapa Hills trend north and south through the area from Grays Harbor to the Columbia River. Most of the province is under 2,000 feet in elevation. In the vicinity of Grays Harbor elevations are seldom in excess of 600 feet.

The Olympic Mountains physiographic province lies immediately north of Grays Harbor. The topography of this province is extremely rugged. Elevations of the ridges and peaks culminate with Mt. Olympus (7,954 ft.) (Campbell 1953). This area forms a region of high relief available to the southward flowing subparallel rivers which empty into Grays Harbor.

The Grays Harbor-Chehalis River system is uniquely situated in a long narrow corridor of contrastingly low relief which extends eastwardly into the Puget-Willamette Trough. The Chehalis River occupies this valley as far east as the vicinity of Grand Mound. In this area the valley broadens considerably northeasterly and southeasterly into the Puget-Willamette Trough. Upstream from this region, the Chehalis River arcs rapidly south and west and heads in the Willapa Hills where some elevations are in excess of 2,000 feet.

Trending southwesterly from the mouth of the Chehalis River to Willapa Bay is a divide formed by hills which attain 600 feet in elevation. This divide considerably limits the drainage system of the south shore of Grays Harbor. The maximum distance for these northwesterly flowing streams from their source to the Bay is about 10 miles, the Elk River which empties into South Bay being the longest.

Terraces are reported at levels up to 300 feet in western Grays Harbor and also along the major streams (Newcomb 1947). No information is available as to their origin.

Aggradation at the mouths of the major streams and rivers is apparent from a cursory inspection of the topographic maps. Such aggradation may be due to the raising of the coast locally, to a decrease in water available upstream, or possibly to subsidence of upstream regions. The various agencies can work independently for each stream. The physiographic interpretation of the area will require considerable field work and study and cannot be made on the basis of present evidence.

STRATIGRAPHY

Pre-Tertiary

There are no known pre-Tertiary rocks in the Grays Harbor area.

Tertiary

A thick sequence of marine Tertiary rocks has been mapped in the area. Four formations of Tertiary strata are recognized.

Early Eocene Metchosin volcanics are exposed in the low hills between southwestern Grays Harbor and Willapa Bay. These rocks are basaltic lavas with intercalated shales, and tuffaceous sediments. The exposed portion of this formation is estimated to be between 500 and 3,500 feet thick.

Undifferentiated Oligocene sedimentary formations are located to the north and east of Grays Harbor. These lie unconformably upon the Metchosin volcanics. Exposures of the middle Oligocene Lincoln formation are mapped in the eastern portion of the Grays Harbor area. A thickness to 5,000 feet is recorded for the Oligocene strata. These rocks are all marine deposited, massive to stratified shaly sandstones.

The middle Miocene Astoria sandstones rest unconformably upon the Oligocene rocks. Thicknesses up to 2,500 feet are recorded for the local Astoria sandstones. The Astoria is a massive, fine to intermediate grained brownish sandstone, with intercalated sandy shales.

The lower Pliocene Montesano formation is mapped within two westerly plunging synclines in the eastern Grays Harbor area. The Montesano is a cross-bedded, medium-coarse grained sandstone with minor shales and some intercalated conglomerates. It is entirely a marine deposited formation. Its thickness varies from 1,700 feet on the south side to 2,200 feet on the north side of Grays Harbor. Possibly this formation is upper Miocene-lower Pliocene, as it rests with noted unconformity upon the eroded surface of the strongly folded pre-upper Miocene strata (Weaver 1937).

Pleistocene

Pre-glacial Pleistocene Satsop sediment occurrences are mapped along the Chehalis River, inland from Grays Harbor. The Satsop is also mapped in an area on the western side of the Wishkah River just north of Aberdeen; in this area the Satsop clays, sands, and gravels, are over 200 feet thick.

The terraces of the outer areas of Grays Harbor are underlain by accumulations of Saanich (Recent) marine sands. The materials underlying the upland terraces are Satsop-like clays, sands, and gravels. Both the Saanich sands and the older Satsop-like sands of the bars and beaches may total 800 to 900 feet in depth (Newcomb 1947).

GEOLOGIC HISTORY

Pre-Tertiary

As Grays Harbor has no known exposures of pre-Tertiary rocks, the interpretation of the geologic history of the area is inferred from the pre-Tertiary basement exposed elsewhere in Washington. Paleozoic and early Mesozoic volcanic, plutonic, and sedimentary rocks are known in western Washington, but their tectonic history is only partially known. Cretaceous shales, sandstones, and conglomerates form the deeply buried basement upon which the thick Tertiary deposits repose.

Tertiary

The visible geologic history of Grays Harbor begins with the Metchosin volcanics of the early Eocene. Some 3,300 feet of Metchosin basaltic lavas, tuffs, and agglomerates were deposited on the floor of the early Eocene embayment. Evidence for later Eocene history in the immediate area is lacking.

Minor occurences of Oligocene rocks are found on the northeastern flanks of the anticlinal zone of Metchosin volcanics along Elk and Johns Rivers. More extensive units of Oligocene rocks occur at some distance from the harbor. The Oligocene rocks present indicate the deposition of marine sediments upon a subsiding Eocene surface, the subsidence continuing through Oligocene time.

Early Miocene strata are unknown in the area. Deposition in moderately shallow water is suggested by the character of the middle Miocene marine sandstones of the Astoria formation. During Astoria time igneous activity was progressively greater to the southeast of Grays Harbor. In the Grays Harbor area a basalt flow 50 to 75 feet thick is intercalated in the lower 500 feet of the Astoria sandstone. This basalt has been quarried at a location about seven miles south of Aberdeen. No basalts within the Astoria are known north of the Chehalis River (Weaver 1937).

In western Washington and Oregon a series of diastrophic events produced numerous major northwest-southeast trending folds involving all pre-upper Miocene rocks. Deformation followed by extensive erosion occupied the remaining Miocene and early Pliocene. Regionally, Pliocene time closed with almost complete emergence of the Washington and

Oregon coast. A few minor marine embayments persisted through the late Miocene and early Pliocene. These occurred along the Olympic Peninsula coast, at Grays Harbor and Coos Bay, Oregon. The sediments of the Grays Harbor area accumulated during this time are mapped now as the Montesano formation of marine sandstones and conglomerates.

Thick terrace deposits of unconsolidated Pleistocene sediments conceal the Tertiary formations in parts of the area, as along the major rivers emptying into Grays Harbor and a rather wide area adjacent to the Pacific Ocean (Weaver 1937; Eardley 1951). Table 4-1 summarizes the formations of the Grays Harbor area.

GEOLOGIC STRUCTURE

Eastern Grays Harbor is located in a region of westerly plunging synclines. These synclines disappear beneath the Quaternary sediments of the western Grays Harbor area. Numerous subsidiary folds within the major structures provide the structural control for the present day topography. A northwest-southeast anticlinal zone of Eocene volcanics lies in the Johns and Elk Rivers region of western Grays Harbor.

The folds present are the product of two phases of deformation. Evidence suggests a late Miocene-early Pliocene phase of low to medium-intensity folding. Faults in these folds are not numerous and if present would be of the normal type.

Late Tertiary and early Pleistocene compressional movements produced broad north-south arching and sagging of the crust regionally. This folding was superposed on the Miocene westerly trending structures. Minor flexures have locally modified the major westerly trending folds of the Miocene.

Differential crustal movement of the Pleistocene and Recent has determined the present coast line and in places has elevated it from 20 to over 200 feet (Eardley 1951).

ECONOMIC GEOLOGY

Nonmetallic Minerals

The commercially worked nonmetallic minerals are the silica sands of the Montesano Quarry, the crushed stone operations of the Arctic, Newskah (Quiggs Bros. Construction Co.), and Hoquiam Quarries, and numerous sand and gravel pits. Minor occurrences of coal, limestone, clay and peat are in the area (Valentine 1949; Kauffman 1952).

Exploratory measures are being taken for oil and natural gas. No

TABLE 4-1. Formations of the Grays Harbor Area.

PERIOD	EPOCH	FORMATION
Quaternary	Recent	Saanich
	Pleistocene	Satsop
Tertiary	Pliocene	Montesano (lower Pliocene and possibly upper Miocene)
	Miocene	Astoria (middle Miocene)
	Oligocene	Lincoln (middle Oligocene)
	Eocene	Metchosin (lower Eocene)
Pre-Tertiary		none present

Table compiled from Weaver (1937).

natural gas discoveries are reported. One well with a strong showing of oil is reported at Ocean City (Valentine 1949). Several oil companies have conducted mapping programs and have, in some cases, considerable file data concerning the subsurface and surface geology of the Grays Harbor area (The Ohio Oil Company 1955; Richfield Oil Company 1955; Shell Oil Company 1955). Over 10 oil companies have had field parties in the area, but in general, all information is held within the companies' files and is not available for examination.

Metallic Minerals

The occurrence of metallic minerals for commercial use is insignificant.

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(Includes profiles, surf conditions, tire impressions, sand samples, and water table profiles. Data for Humboldt Bay, Coos Bay, and Grays Harbor areas. Large number of photos obtained in survey which were not included in the report.)

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(Includes sections on climate, flora, physiography, and geology in Grays Harbor area. Soil maps, 1:125,000, (in color), Olympia sheet and Port Townsend sheet. Land classification maps, 1:125,000, (in color), Olympia sheet and Port Townsend sheet.)

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(Grays Harbor County described on page 592.)

Western Gulf Oil Company
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(No work done by this company in the Grays Harbor area.)

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SECTION 5

GEOPHYSICS

GEOPHYSICS

SEISMOLOGY

In general, the state of Washington is not nearly as seismicly active as California. However, Washington does exceed Oregon in both number and severity of earthquakes. Most of the offshore and Coast Range epicenters cease north of 42° N. and then begin again off the coast of Canada (Byerly 1940, 1952).

Seismic Activity

From 1769 to 1953 there were 6 recorded land shocks and one offshore shock. These are listed from Holden (1898), McAdie (1907), Townley and Allen (1939), and Bulletin of the Seismological Society of America (n. d.). The Rossi-Forel scale of intensity is used. The 1939 shock had its epicenter offshore.

16 Mar 1904 - VIII to X (?)	14 Feb 1946 - V to VI
12 Nov 1939 - V	23 Jun 1946 - V to VI
6 Dec 1944 - VI	13 Apr 1949 - VII

The following is a description of the 1904 earthquake as given by Townley and Allen (1939):

> 1904 March 16. 8:18 p.m. VIII to X. Western part of Olympic Penninsula?
>
> This shock was felt in the region from Seattle to Victoria, B. C., as of about intensity VI. A report dated March 21, from Tacoma, appeared overdrawn, but indicated that possibly a very strong shock had taken place on the western shore of the Olympic Peninsula. It said: "Indians arriving today at Hoquiam on Grays Harbor bring news of strange happenings along the shore of the Pacific Ocean north of Quinault Indian Reservation from earthquake. They declare that last Wednesday night's shocks threw several rivers out of their channels forming several large lakes on the adjacent lowlands.
>
> "The beds of the Queets, Quinault, Wishkah, and Hoh Rivers, according to the Indians, were raised twenty to thirty feet, throwing a flood of water into the valleys lying between the Olympic mountain range and the Pacific Ocean."
>
> Clocks were stopped in Victoria, B. C. The shock was not felt in Portland, Oregon. In Seattle bottles were thrown from

shelves, chairs were moved, and people thrown from their feet. The intensity was at least VI in Seattle. --Reid's Scrapbook, 2, 30.

Seismograph Stations

There are three Strong-Motion Seismograph stations within a 100-mile radius of Grays Harbor. These are located in the Federal Building in Seattle, at the College of Puget Sound, Tacoma and in the Highway Testing Laboratory, Olympia. Two Teleseismic stations are located within 125 miles of the harbor. The University of Washington at Seattle houses one instrument; the other is at Victoria, B. C., Canada, in the Dominion Astrophysical Observatory.

VOLCANOLOGY

Volcanic activity is an important aspect in the geologic history of western Washington. The exposed volcanic rocks about the Grays Harbor area are early Eocene Metchosin. The Astoria formation deposited during the Miocene contains basalts. The shield volcanoes of the Cascade Mountains had their beginning during the Pliocene-Pleistocene epochs.

In investigating the Pleistocene and Recent peat bogs of the region, Rigg (1954) failed to find volcanic ash in the immediate vicinity of Grays Harbor. However, within a radial distance of 100 miles of Grays Harbor, numerous deposits of ash are found. These deposits, perfectly preserved within the peat bogs, offer a potentially valuable source of dating material.

Fargher Lake, a drained lake in Clark County to the southeast of Grays Harbor, shows four well separated layers of ash. One layer contains particles of pumice. Thirty miles to the east of Grays Harbor, Hicks Lake and Belmore Bog, both near Olympia, show one well-defined layer of ash. To the northeast the Chimacum Creek Peat area, shows volcanic ash in various locations and depths with one well-defined band close to the surface.

The bogs of the coastal area which contain no volcanic ash are in the sand dunes. These bogs are considerably more recent than the interior bogs and are subject to being destroyed by wave and wind action which constantly reworks the sand.

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SECTION 6

RECENT SEDIMENTATION

RECENT SEDIMENTATION

BEACHES

Beach Characteristics

From the mouth of the Columbia River northward to Point Grenville the shoreline is composed of sand beaches broken only by Copalis Head and the entrances to Willapa Bay and Grays Harbor. The entrance to Grays Harbor is formed by a north and south spit. The north spit is about 8 miles long and slightly more than 2 miles wide at the widest point. It narrows to approximately 3/4 mile in width at the northern end. Extending north-south down the center of the spit is a marsh which separates the east and west dune strip. Most of the dunes east of the marsh are well stabilized by forests. The south spit is approximately 5 miles long and 1-1/2 miles wide at the northern end. It narrows to slightly less than 3/4 mile wide at the southern portion. Most of the spit is well stabilized by vegetation.

A series of profile ranges on the ocean front beaches was set up in August and September of 1945 by personnel from the Fluid Mechanics Laboratory, Berkeley, California (Isaacs 1947). The beaches studied in the vicinity of Grays Harbor were from Point Grenville southward to the Columbia River. The north and south spits at Grays Harbor were not investigated. The beaches showed marked variations in slopes over the total investigated distance of about 43 miles. The type of sediments of the beach face varied as did the general smoothness and firmness of the beaches. Table 6-1 gives the average slopes and general characteristics for some of the beaches in this region. Enclosure 6-1 gives the location for some of the beaches studied and Enclosure 6-2, the profiles of these beaches.

The U. S. Army Corps of Engineers have made beach profile studies on the south spit in the vicinity of the south jetty. A periodic survey of 17 ranges has been made from 1936 to 1949. These profiles, located along the shore from about 1 mile to 3-1/4 miles south of the jetty, are shown in Enclosures 6-3 through 6-15. By comparing the various profiles it can be seen that for identical locations south of the jetty the elevations have increased appreciably between 1936 and 1949. The greatest elevation increase is in the region immediately south of the jetty. The greater the distance from the jetty the less the elevation increases. North of the jetty sediments have been removed and there has been a degradation of the shoreline.

The U. S. Army Corps of Engineers Seattle District (1939) have also compared two beach profiles from 1900 to 1933 which continue offshore for

TABLE 6-1. Characteristics of Beach Profiles.

Location	Slope		Remarks
Point Grenville	Overall Beach face -6 to -17 ft.	1:100 1:50 1:170	Beach regular.
Point Grenville South Station (2 mi. south of Cape)	Beach face	1:20	Beach face composed of gravel. High water reaches a clay bank. No berm present. Breaker zone irregular but offshore smooth and of gentle slope.
Copalis Beach	Beach face Beyond 12 ft., extremely flat	1:80	A number of distinct bars and berms present.
Ocean City Beach			Similar to Copalis Beach but very irregular from 0 to 10 ft.
Leadbetter Point	Beach face	1:90	2 well-defined offshore bars.
Solando Beach	Beach face	1:60	Offshore profile more irregular. Several offshore bars evident. Bar at 3,200 ft. offshore a bout 12 ft. high.
Ocean Park Beach			Offshore profile increasingly irregular. 3 well-defined bars exist. Bar at 2,500 ft. offshore about 12 ft. high.
Long Beach	Overall	1:60	One well-defined bar exists

Table compiled from Isaacs (1947).

depths of over 50 feet (see Enclosure 6-16). A range on the north and south spit is compared on profiles from 1900 to 1939 (see Enclosures 7-6 and 7-7).

Personnel at the Washington State Shellfish Laboratories have made a study of the ocean beaches in the vicinity of Grays Harbor in conjunction with their shellfish investigations (Washington State Department of Fisheries n. d.). They have constructed beach profiles at various locations on Copalis Beach, Twin Harbors Beach, and Long Beach (see Enclosure 6-1). These profiles, shown in Enclosures 6-17 through 6-30 indicate continual changes in the beach condition.

In a general study of beaches, Bascom (1951) shows that sand size and intensity of wave action are the factors controlling the slope of the beach face. All aerial photographs taken by personnel from the Fuild Mechanics Laboratory, Berkeley, California, are listed in Isaacs (1947) and Bascom and McAdam (1947). Dr. M. P. O'Brien, Department of Engineering, University of California, has information on file concerning the beach region of Grays Harbor, Washington.

Beach Sands

In conjunction with the beach profile study, the Fluid Mechanics Laboratory personnel (Isaacs 1947) collected 47 sediment samples from the beaches of Copalis, Ocean City, and Leadbetter Point. Most of these samples were collected above mean lower low water; however, a few were taken in shallow depths offshore. All of the samples were well sorted, fine sands, with median diameters ranging from 0.14 to 0.23 mm (see Table 6-2). The location of the profiles along which samples were collected is shown on Enclosure 6-1; the cumulative curves for the size analysis in Enclosure 6-31 .

The U. S. Army Corps of Engineers (1951b) in conjunction with beach erosion studies present the size analysis for 44 samples taken at 40 locations; four locations are bore holes with a sediment sample each. All the sediments were collected on the south spit in the vicinity of Point Chehalis. The median diameters ranged from about 3.0 mm (gravel) to 0.19 mm (fine sand). The sorting varied from good to poor (see Table 6-3). The cumulative curves for the mechanical analysis are given in Enclosure 6-32. The location of the samples is shown on Enclosures 6-1 and 6-33.

SHORELINE CHANGES

In 1862 the first Grays Harbor entrance survey showed the southern end of the north spit to be in part an island. By 1881 this island was connected to the spit and the channel had shifted from a northwest to a

TABLE 6-2. Median Diameters of Beach Sediments at Copalis Beach, Ocean City, and Leadbetter Point, Washington.

Location	Sample No.	Median Diameter (mm)
Copalis Beach	1	0.15
	1A	0.17
Range 0+00	2	0.18
	2A	0.18
	2B	0.18
	2C	0.19
	2D	0.18
	2E	0.16
	2F	0.19
	Bar seaward of 2G.	0.18
	Depression.	0.16(?)
	10' of water.	0.15

Location	Sample No.	Median Diameter (mm)
Ocean City	1	0.15
	1A	0.17
Range 0+00	2	0.17
	2A	0.17
	2B	0.17
	2C	0.17
	2D	0.17
	20' of water	0.16

Location	Sample No.	Median Diameter (mm)
Leadbetter Point	1A	0.185
	1B	0.175
Range 20+00S	1C	0.19
	1D	0.175
	1E	0.20
	2	0.175
	2A	0.18
	2B	0.19
	2C	0.20
	2D	0.22
	2E	0.20
	2F	0.20
	2G	0.21
Range 0+00	1	0.19
	1A	0.19
	1B	0.185
	1C	0.19
	1D	0.18
	2	0.18
	2A	0.19
	2B	0.19
	2C	0.21
	2D	0.23
	2E	0.18
	2F	0.23
	2G	0.21

Data from Isaacs (1947).

TABLE 6-3. Median Diameter of Beach Sediments in the Vicinity of Point Chehalis, Washington.

Sample No.	Median Diameter (mm)	Classification	Sample No.	Median Diameter (mm)	Classification
535-1	0.20	Fine sand	NOA	0.32	Medium sand
535-2	0.25	" "	NOB	0.32	" "
535-3	0.27	Medium sand	S25A	2.0	" "
535-4	0.27	" "	S25B	3.0	Gravel
535-5	0.26	" "	S20A	1.6	Very Coarse sand
535-6	0.50	" "	S20B	0.42	Medium sand
13B	1.2	Very coarse sand	S15A	5.5	Gravel
14B	0.44	Medium sand	S15B	0.26	Medium sand
15B	0.20	Fine sand	S10A	0.45	" "
16B	1.9	Very coarse sand	S10B	0.23	Fine sand
17E	0.40	Medium sand	S5A	0.19	" "
17N	3.00	Gravel	S5B	0.28	Medium sand
N25A	0.29	Medium sand	SOA	0.23	Fine sand
N25B	0.30	" "	SOB	0.19	" "
N20A	0.29	" "	Hole 1 elev -3.5'	0.29	Medium sand
N20B	0.30	" "	Hole 1 elev -7.0'	0.27	" "
N15A	0.30	" "	Hole 6 elev 5.0'	0.30	" "
N15B	0.30	" "	Hole 6 elev 3.0'	0.3[illegible]	" "
N10A	0.36	" "	Hole 7 elev 3.5'	0.23	Fine sand
N10B	0.40	" "	Hole 7 elev 0.0'	0.26	Medium sand
N5A	0.30	" "	Hole 9 elev -4.8'	0.28	" "
N5B	1.4	Very coarse sand	Hole 9 elev -2.3'	0.23	Fine sand

Data from U. S. Army Corps of Engineers (1951b).

southwest trend. Breakers and heavy surf line the channel. All the changes in entrance channel and shoreline from 1862 to 1953 for the north and south spit are shown in Enclosures 6-34 and 6-35. Between 1862 and 1891 the high water line of the west shore of the north spit retreated to the east by some 3,000 feet. This shore remained relatively stable until about 1906. After the construction of the north jetty there was a noticeable westward advance of both the high and low water lines. The mean lower low water line moved westward, due to sediment deposition, by about 2,000 feet between 1906 and 1909. The high water line showed a westerly advance of approximately 1,800 feet. By 1921 the high water and low water lines had moved seaward an additional 3,000 feet or more. Between 1921 and 1948 a seaward advance of approximately 1,000 feet was noted. On the average, the north spit advanced seaward at the rate of about 600 feet per year between 1906 and 1909, immediately after the construction of the jetty. The advance slowed to approximately 250 feet per year between 1909 and 1921. From 1921 to 1948 the average has decreased to about 37 feet per year.

There was no noticeable southern advance of the north spit until about 1917. Between then and 1921 the seaward edge of the high water line of the north spit had grown to the south by approximately 7,000 feet. From 1921 to 1948 the growth has been approximately only 1,000 feet.

The south jetty construction was begun in 1898; between then and 1909 a seaward movement of the high water line of about 2,800 feet occurred. A slow eastward retreat of the beach occurred between 1924 and 1936; since then the beach has moved slowly seaward. North of the jetty, Point Chehalis has been progressively retreating eastward and southwards since about 1935 (see Enclosures 6-36 and 6-37).

The erosion on Point Chehalis at Grays Harbor south jetty is discussed by the U. S. Army Corps of Engineers (n. d. b) as follows:

> 1. A study of the various maps showing the shoreline of the spit north of the South Jetty at Grays Harbor from 1900 to 1941 discloses that in 1900 the spit extended north from the jetty only 1800 feet at its widest part, whereas in 1940 it extended 4000 feet. In 1900 the area in the vicinity of the existing Port Wharf was water. Between 1940 and 1941 the point of the spit retreated about 400 feet.
>
> 2. The South Jetty was completed in 1902. It was supposed to be a high-tide jetty but the section was light, and in consequence the enrockment soon settled. By 1906 the outer end had settled to below low water. By 1913 nearly all of the enrockment was below midtide level. The report for 1916 states that the enrockment remains at or below extreme low water throughout practically its entire length.

3. The beach south of the base of the South Jetty moved out (westward) between 1900 and 1909, remained at about the same locality until 1924 and then retreated slowly towards the east until the reconstruction of the jetty was started in 1936, when the movement was reversed and the beach again moved to the west.

4. The above indicates that when the littoral drift from the south is stopped by jetty construction the shore south of the jetty builds out to the west.

5. Between 1900 and 1935 when reconstruction of the jetty was started, the shoreline north of the jetty was in prolongation of the shoreline south of the jetty; there was no effect at the jetty. This might indicate that the jetty section was so light that sufficient sand passed over and through it to maintain the beach north of the jetty.

6. Since 1935 the beach north of the jetty has moved to the east and there is a decided offset in the beach at the base of the jetty. This would indicate that the balance between accretion of material brought in by the littoral currents and the erosion by wave action had been upset and that erosion was the predominant force. The eastward movement of the beach is erratic. At times it is fast, at other times it is slow, depending on tidal currents and wave action. At times portions of the beach have moved to the west.

7. The erosion is generally greater during storms. During westerly winds the waves race along parallel to the jetty and break on the beach north of the jetty, causing erosion.

8. The shape of the spit clearly indicates a movement of material from the base of the jetty north and eastward.

9. The base of the spit measured parallel to the trace of the jetty is being decreased in width by the erosion of the beach near the jetty. The north and south dimension has decreased but little, probably because the material eroded is being transported along the beach to the north and eastward and deposited on the north end of the spit. This action cannot continue indefinitely as the material composing the spit is limited and the former supply has been cut off by the jetty enrockment.

10. Unless present conditions are modified in some way, either by Nature or the action of man, it is believed the greater portion of the spit will be eroded with the loss of Port wharf and the Coast Guard boathouse. As previously indicated, the shore connection of these structures was in 1900 to 1916 covered by water.

11. The foregoing study has been made to determine, if possible the reason for the erosion of the beach north of the jetty and to develop a means of preventing the loss of the spit and structures on it.

12. It appears that the loss of material from the spit is caused by the destruction of the balance of forces that existed before the jetty was reconstructed. Since the littoral movement of material was stopped, the equilibrium between the littoral drift and erosion no longer obtains--erosion is the predominant force.

BOTTOM SEDIMENTS

Bay Sediments

The U. S. Army Corps of Engineers (1951b) list 48 analyses of bay sediments exclusive of the beach sands. Most of the samples were collected by means of a grab sampler or during dredging operations. In the vicinity of Point Chehalis 9 borings were made. In general the interior of the bay is poorly sampled; most of the sediments analyzed have been obtained in the vicinity of Point Chehalis. The sediments range from fine sands to gravels near the entrance to the bay and in the region of Sand Island Shoal and North Channel shoal well sorted, fine sands occur. Table 6-4 gives the median diameter and classification of these sediments. The cumulative curves are in Enclosure 6-38. The location of samples is shown on Enclosure 6-1 and 6-33, and the log of the borings on Enclosure 6-39.

In conjunction with a pollution study of the waters about Hoquiam and Aberdeen the Washington State Pollution Control Commission (n. d.) collected and described 43 sediment samples in the Chehalis, Hoquiam, and Wishkah Rivers. Unfortunately mechanical analyses of the samples are not available; only field descriptions were recorded. The river sediments are primarily composed of soft muds and silts; sand is commonly found in the channels (see Table 6-5 and Enclosure 6-1).

In this survey no direct studies concerning the supply of river sediment to Grays Harbor have been found. It is possible to deduce, however, that most of the sediments derived from the headwaters of the rivers emptying into the harbor would not reach the sea. This is especially true of the coarser sediments. The beach sands are predominantly in the fine to medium size range (see Tables 6-2 and 6-3). This is also true of the bottom sediments at the entrance and those at Sand Island Shoal and North Channel Shoal (see Table 6-4). By considering the work of Twenhofel (1946) it is possible to conclude that these sediments may well originate from the eroding rocks of the shoreline and be transported by the waves and littoral currents.

TABLE 6-4. Median Diameter of Bottom Sediments of Grays Harbor, Washington.

Sample No.	Median Diameter (mm)	Classification	Sample No.	Median Diameter (mm)	Classification
1	0.45	Sand	1221	0.28	Medium sand
2	2.50	Sandy gravel	1222	0.28	" "
3	0.51	Gravelly sand	1 S.I. Shoal	0.28	" "
4	4.40	Sandy gravel	3-27-50 S. I. Shoal	0.2	Fine sand
5	3.10	" "	3-28-50 " "	0.2	" "
6	12.0	" "	3-29-50 " "	0.2	" "
7	3.0	" "	3-30-50 " "	0.2	" "
8	3.5	" "	3-31-50 " "	0.3	Medium sand
9	0.5	Medium sand	4-3-50 " "	0.2	Fine sand
10	0.33	Gravelly sand	4-4-50 " "	0.35	Medium sand
11	6.0	Sandy gravel	4-5-50 " "	0.2	Fine sand
12	12.0	Gravel	4-6-50 " "	0.2	" "
13	15.0	Gravel	4-7-50 " "	0.4	Medium sand
1119	0.2	Fine sand	2 N. C. Shoal	0.20	Fine sand
1120	0.2	" "	Hole 2		
1121	0.2	" "	elev -10.7' to -21.0'	?	Sand
1122	0.19	" "	Hole 3		
1123	0.18	" "	elev -17.6'	0.22	Fine sand
1127	0.19	" "	Hole 4		
1128	0.19	" "	elev -95' to -16.5'	?	Silty sand
1129	0.19	" "	Hole 5		
1130	0.19	" "	elev -16.6'	0.15	Fine sand
1131	0.15	" "	elev -19.6' to -20.1'	?	Gravelly sand
1132	0.20		elev below -20.1'	0.19	Fine sand
1218	0.24	Medium sand	Hole 8		
1219	0.29	" "	elev -4.5' to 8.0'	?	Sand
1220	0.27	" "			

Data from U. S. Army Corps of Engineers (1951b).

TABLE 6-5. Bottom Sediments Taken in the Vicinity of Aberdeen and Hoquiam, Washington.

Sample No.[1]	Location	Description[2]	Depth (ft)
HO 1	Mouth of Hoquiam River	Soft, muck ooze, sludge	35
HO 1a	Mouth of Hoquiam River (1/3 the way from east bank)	Mud over sand	28
HO 1b	Hoquiam River (1/3 the way from west bank)	Sludge, silt	-
HO 2	Hoquiam River (channel)	Sand (sides of channel mud with some sand)	25
HO 2a	Hoquiam River (midstream)	Muck, sludge	-
HO 2b	Hoquiam River (50 ft. from west shore)	Muck, sludge	-
HO 2c	Hoquiam River (30 ft. from east shore)	Sludge, clay	-
HO 3	Hoquiam River	Silt, sludge, blue-black mud	30
HO 3a	Hoquiam River (midstream)	Some rock, mud, silt	-
HO 3b	Hoquiam River (30 ft. from east bank)	Hard bottom, blue clay	-
HO 4	Hoquiam River(midstream)	Mud, silt	20
WI 1	Wishkah River (midstream	Sand	-
WI 2	Wishkah River (midstream)	Clay, silt, sand	-
WI 3	Wishkah River (midstream)	Silt, sand, some clay	-
WI 4	Wishkah River (east side)	Sludge, muck ooze, mud, silt	-
WI 5	Wishkah River (channel)	Rock bottom with silt and sand	20-25
WI 6	Wishkah River	Muck ooze, silt, sand	-
Aber 1	Chehalis River, Division St. (North side of channel)	Sludge, muck ooze, mud	4
Aber 2	Chehalis River, Division St. (midchannel)	Sand	30
Aber 3	Chehalis River, Lincoln St. (North side of channel)	Sludge, muck ooze, mud	12
Aber 4	Chehalis River, Park St. (North side of channel)	Sludge, muck ooze, heavy mud	15

TABLE 6-5. Bottom Sediments Taken in the Vicinity of Aberdeen and Hoquiam, Washington (continued).

Sample No.[1]	Location	Description[2]	Depth (ft)
Aber 5	Chehalis River, Union Stat. (North side of channel)	Sludge, muck ooze, mud	25
Aber 6	Chehalis River, Union Stat. (midchannel)	Fine sand	25
Aber 7	Chehalis River, "I" St. (North side of channel)	Sludge, muck ooze, mud	22
Aber 8	Wishkah River, Heron Bridge (East side of river)	Muck ooze, sludge	7
Aber 8a	Wishkah River, Heron Bridge (Middle of river)	Clean sand	-
Aber 8b	Wishkah River, Heron Bridge (West side of river)	Clean sand	-
Aber 9	Wishkah River, Wishkah Bridge (East side of river)	Sludge, clay	14
Aber 10	Wishkah River, Wishkah Bridge (Center of river)	Hard bottom	24
CHa	Chehalis River at mouth of Wishkah River (channel)	Sand	32
CHb	Chehalis River at mouth of Wishkah River (South side of channel)	Muck ooze, silt	-
CHC	Chehalis River at mouth of Wishkah River(North side of channel)	Muck ooze, sludge	-
(7a)	Chehalis River, foot of "I" St.	Hard bottom	30
(4a)	Chehalis River, foot of Alder (North side of channel)	Mud	-
(4b)	Chehalis River, foot of Alder (midchannel)	Sand, gravel	-
(4c)	Chehalis River, foot of Alder (South side of channel)	Mud (?)	-
(FCI)	Chehalis River, Fry Creek estuary (300' from bridge at head of estuary)	Mud	15
(FC2)	Chehalis River, Fry Creek estuary (400' from bridge at head of estuary)	Muck ooze, mud	27
(R1)	Chehalis River, 200 ft. from upper end of Rayonier Pulp Mill (not in channel)	Black muck ooze	-

TABLE 6-5. Bottom Sediments Taken in the Vicinity of Aberdeen and Hoquiam, Washington (continued).

Sample No.[1]	Location	Description[2]	Depth (ft)
(R2)	Chehalis River, 200 ft. from upper end of Rayonier Pulp Mill (in channel)	Sand, silt	-
(B1)	Chehalis River, Blassen Mill (midchannel)	Fine sand	30
(B2)	Chehalis River, Blassen Mill (close to Mill)	Muck	20
(B3)	Chehalis River, Blassen Mill (North side)	Sludge, mud, clay	12
-	Chehalis River, above Hoquiam Pulp Mill	Sand, silt, some clay	33
-	Chehalis River, above Hoquiam Pulp Mill	Muck ooze, mud, sludge	8

1 Sample Numbers in parentheses are not the official numbers, but merely used to locate samples on charts.

2 Muck and muck ooze are apparently descriptions for very soft, watery muds. Sludge consists of industrial and sewage wastes.

Data from Washington State Pollution Control Commission (n. d.).

The sediments of the Chehalis, Hoquiam, and Wishkah Rivers are primarily silts and muds (see Table 6-5). Though there are no direct studies concerned with the sediment transporting capacity of these rivers by traction, saltation or suspension, and its relationship to particle size and stream velocity, some deductions can be made. It is quite possible that the fine river sediments have been deposited by gravity settlement. Gravity settlement is aided by the prospects of flocculation due to salt water intrusion (see Water Characteristics, Section 8).

Barton (1951) reports on the concentration of suspended sediments of the Chehalis and tributary rivers (see Enclosure 6-40). This study is primarily concerned with the amount of suspended sediment; though it considers the factors which probably account for the variation of river load, it does not factually relate and evaluate each of them. Table 6-6 gives the range in suspended sediment load, based on about 15 samples at each of 7 stations.

According to the U. S. Army Corps of Engineers (1933) the 6,562,760 cubic yards of sediment were dredged from the inner Harbor and Chehalis River from 1923 to 1931 in order to maintain a channel 26 feet deep (see Table 6-7). An average of 729,195 cubic yards of sediment had to be removed each year to keep the inner harbor at the desired project dimensions. Though this gives some idea as to the magnitude of sediment deposition it does not necessarily imply that these sediments were supplied directly by the rivers to the channel during the nine years. Sediments may be added to the channel by transportation and redeposition of material previously deposited outside the channel area.

Offshore Sediments

This literature survey has not uncovered any investigations on the offshore sediments in the vicinity of Grays Harbor other than that shown by the U. S. Coast and Geodetic Survey on Chart 6195 and previous smooth sheets. Apparently the bottom sediment out to a least 100 feet is gray sands.

ALONGSHORE TRANSPORT

The south jetty was built in 1896 and the north jetty in 1907. These original jetties were about 13,000 and 17,000 feet long respectively and were intended to secure the entrance channel. The shifting of sands and division of the channel continued after jetty construction. In general, the history of the entrance bar shows a cycle of changes. The channel was deflected slowly northward until a sudden break across the bar to the south occurred. This sudden break was claimed as due to shoaling of the north channel and to an increasing distance to deep water

TABLE 6-6. Range in Suspended Sediment Loads for Streams Entering Grays Harbor, 1951. [In parts per million]

STREAM	MAXIMUM	MINIMUM	AVERAGE[1]
Chehalis	164	3	50
Skookumchuck (Bucoda)	98	2	41
Skookumchuck (Tenino)	88	1	37
S. Fk. Newaukum (Forest)	195	13	60
S. Fk. Newaukum (Alpha)	71	Trace	33
N. Fk. Newaukum (Water Intake)	65	Trace	30
N. Fk. Newaukum (Forest)	304	1/2	65

[1] The averages were based on approximately 15 samples per station.

Data from A Progress Report on Suspended Sediment Sampling in Several Western Oregon and Western Washington Streams (Barton 1951).

TABLE 6-7. Sediments dredged for Maintainance of Inner Harbor, 1923-31.

Year	Channel (cu. yds.)	Turning Basins (cu. yds.)	Port Slips (cu. yds.)	Chehalis River (cu. yds.)
1923	54,546	-	120,000	-
1924	444,232	258,424	229,061	-
1925	236,685	-	167,524	358,112
1926	796,279	70,400	249,026	137,139
1927	230,495	-	150,431	337,780
1928	-	-	259,352	212,744
1929	601,711	76,160	163,920	180,584
1930	-	22,794	204,411	-
1931	372,047	-	97,014	531,889
Total	2,735,995	427,778	1,640,739	1,758,248

Data from U. S. Army Corps of Engineers (1933).

(U. S. Army Corps of Engineers 1916). Jetty extensions were considered necessary since sediment transport at the entrance was of such a magnitude that a single storm could obliterate the results of any dredging operation (U. S. Army Corps of Engineers 1916).

A comparison of soundings may be used to exemplify the magnitude of sediment transport at the harbor entrance. In October 1924 a bar channel 32 feet deep was secured at the end of the year's dredging operations; when dredging was resumed in April 1925 this channel had shoaled to about 22-1/2 feet. By October 1925 the channel was dredged to a depth of 36 feet; in May 1926 it was only 25 feet deep (U. S. Army Corps of Engineers Seattle District 1926). The soundings of October 1949 and October 1950 indicate that approximately 1,100,000 cubic yards of sediment was deposited near the north end of Point Chehalis and about 200,000 cubic yards were removed above mean lower low water along the west shore. Approximately 1,000,000 cubic yards of sediments were transported out of the region between the south jetty and Point Chehalis (U. S. Army Corps of Engineers 1951b). The variations in soundings and elevations taken periodically at the entrance from April 1950 to March 1951 are shown in Enclosure 6-41. Changes in the high water line, 1862 to 1951, and 30-foot contour of the entrance bar from 1930 to 1951 are shown in Enclosure 6-42. A tabulation of dredging records at the entrance channel from 1900 to 1933 is given in Table 6-8.

The transportation and deposition of sands along any coast line is dependent upon the direction and competancy of the water movement, the availability of sediment, and the wind. Below the water line, transportation is conducted by the waves and associated littoral currents. Above the water line sand transportation and deposition depend upon wind and also the dryness and size of the sediment. The wind must be considered an important factor in the deposition of subaqueous coastal sediments.

According to the U. S. Army Corps of Engineers (1934) it appears that during the winter months a northerly moving littoral current predominates; in the summer there is an occasional and weaker littoral current to the south. This data was obtained by the Army Engineers from the observations of survey parties and from the logs of coastal steamers and sailing vessels. This in conjunction with the reported cyclical movement of the entrance channel to the north, leads them to believe that the effective alongshore transport is to the north.

The effect of storms on sediment transport is an important consideration. Though storm occurrence may be relatively low, ability to transport and rework sediments is high. During the winter months swells of 20 feet in height with periods of 16 to 18 seconds strike the shoreline about 2% of the time. These waves come from the west and northwest. From January through March heavy swells in excess of 12 feet strike the coast from the southwest, west, and northwest (U. S. Army Corps of Engineers 1951b). From this it is possible to consider that the effective sediment transportation by water may occur during the winter months.

During the months of May through September the precipitation is about 2.2 inches per month. For the rest of the year it is 9.0 inches a month. The percent of possible sunshine and the hours of sunshine is also higher during the summer months. The winds during these dryer periods are predominantly from the northwest (see Climatology, Section 2). Under such conditions it might be expected that the transportation of sediments above the high water line should occur during the summer months and the sediments be moved primarily to the south.

TABLE 6-8. Dredging on Grays Harbor Bar, and Condition of Channel.

DREDGING			CONDITION OF BAR						
			Width of channel of depth indicated						
Period	Cubic yards	Date of Survey	20	22	24	28	30	32	36
Fiscal year 1916	56,939	Jun 1916	3,100		300				
		Jan 1917	1,300						
Fiscal year 1917	22,512								
Fiscal year 1920	55,234	Jun 1920	2,000[1]						
Fiscal year 1921	39,923	Jul 1921	4,200						
Fiscal year 1922	89,295	Jun 1922	1,700						
Fiscal year 1923	92,222	Jun 1923	1,000						
		Nov 1923	1,000						
Fiscal year 1924	107,893	May 1924	1,200	600					
		30 Jul 1924			500				
Fiscal year 1925	927,281	6 Oct 1924	1,300	1,000	700	350	300		
		17 Nov 1924	2,000	900	500				
		15 Jan 1925			750				
		12 Mar 1925		[2]	[2]				
Fiscal year 1926	696,700	Jun 1925	6,300	5,000	700	400			
		22 Jul 1925	1,200	1,000	900	500	350		
		4 Aug 1925			1,000	600	500		
		27 Aug 1925			1,000	700	500		
		9 Sep 1925				700	500		
		30 Sep 1925				700	400		200
		26 Oct 1925			1,300	700	600		
		26 Feb 1926		2,900	2,100	1,200	500		
		27 Mar 1926		1,700	1,000	300			
		29 Apr 1926			1,700	800	300		
		Jun 1926	2,000	1,300	500	200			
Fiscal year 1927	748,759	4 Aug 1926			1,000	500			

TABLE 6-8. Dredging on Grays Harbor Bar, and Condition of Channel (continued).

DREDGING			CONDITION OF BAR						
			Width of channel of depth indicated						
Period	Cubic yards	Date of Survey	20	22	24	28	30	32	36
Fiscal year 1927		Oct 1926			700	300			
		11 Jan 1927		1,400	700				
		Jun 1927	2,200	700	400				
Jul 1927	186,794	13 Jul 1927				600	400		
Aug 1927	266,548								
Sep 1927	129,588	14 Sep 1927				400	350	300	
Oct 1927	98,433								
Nov 1927	71,561	Nov 1927	1,300	900	700	400	350	300	
Dec 1927	2,932								
Jan 1928	9,324	27 Jan 1928					300		
Feb 1928	64,046								
Mar 1928	87,020	2 Mar 1928					500		
Apr 1928	44,880	13 Apr 1928				800	300		
May 1928	121,575								
Jun 1928	264,238								
Jul 1928	209,198	Jul 1928	6,500	6,400	2,300	1,050	1,000	300	150
Aug 1928	227,414	1 aug 1928					450	400	200
Sep 1928	102,028	6 Sep 1928			2,100	800	700	650	600
Oct 1928	115,368								
Nov 1928	50,397								
Dec 1928	54,438								
Jan 1929	5,697								
Feb 1929	65,819								
Mar 1929	34,461	14 Mar 1929				1,500	600	200	
Apr 1929	73,525								
May 1929	169,434								
Jun 1929	238,882	4 Jun 1929				600	500	300	

TABLE 6-8. Dredging on Grays Harbor Bar, and Condition of Channel (continued).

DREDGING			CONDITION OF BAR						
			Width of channel of depth indicated						
Period	Cubic yards	Date of Survey	20	22	24	28	30	32	36
Jul 1929	189,641	4 Jun 1929							
Aug 1929	197,256	Aug 1929		4,800	1,400	1,050	1,000	400	200
Sep 1929	111,832								
Oct 1929	85,653								
Nov 1929	74,774								
Jan 1930	135,611	Jan 1930				800	700	500	
Feb 1930	6,723								
Mar 1930	41,389								
Apr 1930	227,462								
May 1930	194,233								
Jun 1930	176,073								
Jul 1930	260,872	Jul 1930			2,400	1,500	1,000	900	200
Aug 1930	269,274								
Sep 1930	100,832								
Oct 1930	102,438								
Nov 1930	104,940								
Dec 1930	15,808								
		31 Jan 1931				700	600		
Apr 1931	159,867	17 Apr 1931					1,000		
May 1931	125,942								
Jun 1931	239,033	Jun 1931					800		
Jul 1931	61,158	Jul 1931			2,100	1,300	700	400	
		28 Aug 1931					800		
Sep 1931	181,148								
Oct 1931	134,633								
Nov 1931	21,412								

TABLE 6-8. Dredging on Grays Harbor Bar, and Condition of Channel (continued).

DREDGING			CONDITION OF BAR						
			Width of channel of depth indicated						
Period	Cubic yards	Date of Survey	20	22	24	28	30	32	36
Dec 1931		14 Dec 1931				600	300		
Feb 1932	4,485								
Mar 1932	77,271								
Apr 1932	85,382								
May 1932	56,301								
Jun 1932	156,314	10 Jun 1932				750			
Jul 1932	297,751	18 Jul 1932			2,000	250			
Aug 1932	300,248	9 Aug 1932			2,500	250	100		
		13 Aug 1932				300	200		
		23 Aug 1932				500	200		
Sep 1932	221,138	9 Sep 1932			700	350	250		
		23 Sep 1932				350	300	200	100
Oct 1932	171,386								
		10 Dec 1932				700	500	400	
Mar 1933	34,400								
Apr 1933	47,912	10 Apr 1933				200	100		
Jun 1933	317,560	26 Jun 1933			3,500	500	250		
Jul 1933	336,571								
Aug 1933	301,034	4 Aug 1933				600	500	350	100
		30 Aug 1933				500	400	300	200
Sep 1933	176,101	25 Sep 1933				600	500	350	250
		3 Oct 1933					400		

[1]18 feet deep.
[2]Controlling depth, 23 feet.

Data from U. S. Army Corps of Engineers (1951b).

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1954. Grays Harbor and Chehalis River, Washington, Design Memo, No. 3, West Shore Revetment at Point Chehalis. On file, Seattle District, Seattle, Washington, 14 pages plus 6 plates and 6 figures. (Unpublished.)
(Recent erosion studies and sounding lines shown presenting history of change in bottom topography about Point Chehalis.)

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington [Grays Harbor, Washington--Maps (Unpublished)]

n. d.a. Grays Harbor, Wash., Seattle District Survey. Map File No. E-5-7-16/1 thru 54.
(Survey of bar and entrance from 1862 thru 1953; a total of 54 surveys, including all U. S. Coast and Geodetic Survey work.)

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

n. d.b. Shoreline Changes, Point Chehalis, 1936-1947. Map File No. E-5-6-88.

n. d.c. South Beach Profiles, Cross Sections of Beach. Map File Nos. E-5-6-74.2/1 thru 3.

1926. Comparative Sections at Entrance from 1900 to 1929. Map File No. E-5-7-48/1.

1933. Comparative Sections at Entrance from 1930 to 1950. Map File No. E-5-7-48/2.

1938. South Beach Profiles. Map File Nos. E-5-6-74/1 thru 5.

1939. Comparative Sections from 1900 to 1933. Map File No. E-5-6-79. (Adjacent to the Coast Guard Lookout Station on the south spit.)

1943. U.P.R.R. Bridge at Aberdeen to Cosmopolis, Condition August, 1943. Map File No. E-5-2-65/1 and 2. (Condition survey.)

1944a. South Beach Profiles, Plan of Beach Cross Sections. Map File No. E-5-6-74.1/1.

1944b. South Beach Profiles, South Jetty Profiles and Cross Sections. Map File No. E-5-6-74.1/2.

1944c. South Beach Profiles, Cross Sections of Beach. Map File Nos. E-5-6-74.1/3 thru 5.

1949. Bar and Entrance Condition, October 1949. Plate A-10, ref. U. S. Army Corps of Engineers (1951b).

1950. Bar and Entrance Condition, November 1950. Plate A-11, ref. U. S. Army Corps of Engineers (1951b)

1951a. Foundation and Embankment Exploration, Nov. 1949. Map File No. E-5-12-86.

1951b. Harbor Entrance Hydrography Showing Location of Samples. Map File No. E-5-1-44. (Samples described in text of reference U. S. Army Corps of Engineers (1951b).

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

1951c. Point Chehalis Soundings, Condition Mar. 4-5, 1950. Map File No. E-5-12-93.

1951d. Point Chehalis Soundings, Condition 12-14 April 1950. Map File No. E-5-12-94.

1951e. Point Chehalis Soundings, Condition June 12, 1950. Map File No. E-5-12-102.

1951f. Point Chehalis Soundings, Condition Jan. 1951. Map File No. E-5-12-110/1.

1951g. Point Chehalis Soundings, Condition Jan. 1951. Map File No. E-5-12-110/2.

1951h. Point Chehalis Soundings, Condition March 1951. Map File No. E-5-12-111/1.

1951i. Point Chehalis Soundings, Condition March 1951. Map File No. E-5-12-111/2.

1951j. Soundings and Elevations, August 10, 16, and 17, 1950. Map File No. E-5-12-103/1.

1951k. Soundings and Elevations, August 10, 16, and 17, 1950. Map File No. E-5-12-103/2.

1951l. Soundings and Elevations, Oct. 12 and 13, 1950. Map File No. E-5-12-107/1.

1951m. Soundings and Elevations, Oct. 31 and Nov. 1, 1950. Map File No. E-5-12-107/2.

1952. Entrance, Shoreline and Bar Changes. Map File No. E-5-7-122. (Entrance bar changes 1930,-40,-42,-44,-46,-48,-50,-51. High water line changes 1862,-83,-98, 1902,-09,-16,-20,-24,-30,-42,-46,-51.)

1954. Bar and Entrance, Condition August, 1954. Map File No. E-5-7-125.
(Condition survey.)

1955a. Cross Over Channel, Condition 18 May 1955. Map File No. E-5-13-92.
(Condition survey.)

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

1955b. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition Jan 25, 1955. Map File No. E-5-2-131. (Condition survey.)

1955c. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition April 4, 1955. Map File No. E-5-2-133/1. (Condition survey.)

1955d. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition June 1955. Map File No. E-5-2-134/1 thru 5. (Condition survey.)

1955e. North Channel, Condition 3 Feb. 1955. Map File No. E-5-2-130. (Condition survey.)

1955f. Sand Island Shoal, Condition 16 May 1955. Map File No. E-5-12-209. (Condition survey.)

Washington State Department of Fisheries

n. d. Report Manuscripts and File Data. On file at the Shellfish Laboratory, Aberdeen, Washington. (Unpublished.) (Data and charts on beach movements, plankton, shellfish population and distribution, and temperature and salinity of the water. Permanent stations visited were four at Copalis Beach, four at Twin Harbors Beach, and five at Long Beach.)

Washington State Pollution Control Commission

n. d. Report Manuscripts and File Data. On file at Olympia, Washington. (Unpublished.) (Location and description of sediment samples, biological studies and water analyses.)

SECTION 7

HYDROGRAPHY

HYDROGRAPHY

BATHYMETRY

Grays Harbor is a shallow coastal estuary predominantly less than 20 feet in depth. The channel depths range from approximately 80 feet, just inside the entrance to about 18 feet at Cosmopolis. Most of the bay is occupied by tidal mud flats. In order to keep the channel open to oceanic shipping the U. S. Army Corps of Engineers has conducted projects for maintenance and improvement since 1896.

Original Condition of Bay

The original condition of Grays Harbor is briefly described by the U. S. Army Corps of Engineers (1926):

> The outer end of the channel connecting the bay with the Pacific Ocean was obstructed by a bar convex to the sea over which several shifting channels having in general minimum depths of 12 to 13 feet at mean lower low water. The average width of the bar between the 18-foot curves was about 2,500 feet and between the 24-foot curves about 4,500 feet.
>
> The south channel of the inner harbor was shoal and little used. The north channel was obstructed by the two shoals, one below Hoquiam and one between Hoquiam and Aberdeen, which limited the draft to about 8 feet at mean low water.

Channel Characteristics

The characteristics of the channel have been changed from the original condition due to the continuing program of improvement. The construction of the south jetty in 1896 and the north jetty in 1907 has not resulted in the stabilization of an entrance channel (U. S. Army Corps of Engineers 1916). The channel continued to shift and divide and navigable depths varied between 12 and 26 feet. Dredging of the entrance was begun in 1916.

The U. S. Army Corps of Engineers (1934) described the entrance conditions to the bay as follows:

> The entrance throat is constricted at low tide to a width of 6,500 feet at the sea ends of two jetties that extend convergingly into the Pacific from the points named. An ocean bar composed of fine, gray sand lies beyond the jetties, convex to the sea, and extends each way to the sand spits on each side of the harbor throat.

In the vicinity of the buoyed channel, the bar has a breadth of about 4,000 feet between the depth contours of 30 feet in the ocean and in the harbor, but becomes broader with the distance northward of that channel. Depths upon the bar varied from 18 feet to 27 feet at mean lower low water in June 1933 except in the dredged channel where on October 3, 1933, there was a channel 30 feet deep by 400 feet wide. As shown by the survey of June 1933 depths over the southerly segment of the bar vary from 18 feet to 23 feet, while depths northward of the dredged cut are from 25 to 27 feet. The bar rises from the ocean floor at a fairly regular slope of about 6 feet in a thousand to its crest and descends on the harbor side into the end of a deep trough or gorge that follows close to south jetty and Point Hansen for about 4½ miles eastward. This gorge is about 3,000 feet wide near the bar and about 2,000 feet wide near its easterly end, and has depths that exceed 90 feet off Point Hansen. Opposite the easterly end of the gorge, the harbor expands to a breadth of about 13 miles into two bays named "North Bay and South Bay." These bays comprise extensive tide flats bare at low tide except where coursed by crooked channels from river mouths and sloughs. Eastward from North and South Bays the harbor narrows to the mouth of Chehalis River at Aberdeen, its total extent east and west being about 12 miles. Chehalis River enters the gorge by two channels across the tide flats.

The present condition of the channel is described by the U. S. Army Corps of Engineers (1954) as follows:

> Grays Harbor is a large pear-shaped estuary on the coast of Washington 45 miles north of the mouth of the Columbia River. From the Chehalis River at Aberdeen, it extends 15 miles to the coastline where it is separated from the ocean by 2 narrow, sandy peninsulas. The harbor entrance is about 9,000 feet wide between Points Brown and Chehalis. Point Chehalis is at the north end of the southerly peninsula and Westhaven Cove is in the bight formed by the eastward curvature of the point. The existing Federal project for the improvement of the harbor provides for an entrance channel across the bar 600 feet wide and 30 feet deep, to be secured by a south jetty, 13,734 feet long and a north jetty 16,000 feet long, both at an elevation of 16 feet above mean lower low water, and by dredging; for maintenance of a channel 30 feet deep at mean lower low water and 350 feet wide from deep water in Grays Harbor to the Port of Grays Harbor Commission terminal, a distance of 13.25 miles; thence 26 feet deep and 200 to 350 feet wide for 2.25 miles to the Union Pacific Railroad bridge at Aberdeen; thence 18 feet deep and 200 feet wide for 3 miles to Cosmopolis; thence 16 feet deep and 150 feet wide for 10.75 miles to Montesano, with a turning basin at Montesano of the same depth, 1,500 feet long and

200 to 500 feet wide; for a channel 14 feet deep at mean lower low water and 100 feet wide in South Bay to Bay City; for a breakwater 1,000 feet long at Westhaven Cove and for maintenance of the entrance channel to the cove; and for a rock-filled levee about 7,500 feet long for the protection of Point Chehalis. The diurnal range of tide is 9 feet in the vicinity of Point Chehalis. The improvements are completed except the 16-foot channel between Cosmopolis and Montesano, and the protective works on the west shore of Point Chehalis.

The controlling depths in Grays Harbor are also discussed by the U. S. Army Corps of Engineers (1951b). Over a width of 2,000 feet the bar channel is 31 feet deep. The lower harbor to the Port Terminal has a controlling depth of 29 feet and a width of 175 feet. From the Port Terminal to the Union Pacific Railroad bridge at Aberdeen and on to Cosmopolis the channel is 200 feet wide for depths of 22.6 feet.

Depth and Cross Sections

The U. S. Army Corps of Engineers and the U. S. Coast and Geodetic Survey have periodically surveyed the Harbor and offshore areas since about 1862. In conjunction with an entrance bar study, the Army Engineers have investigated and compared changes in several entrance bar cross sections from 1900 to 1939. Variations in the 30 foot depth line have also been recorded for the period between 1930 and 1951. See Enclosure 6-42. All included charts, cross sections, etc., pertinent to the bathymetry of Grays Harbor are listed in Table 7-1. Additional charts concerned with specific projects and area soundings can be obtained from the U. S. Army Corps of Engineers, Seattle District, Seattle, Washington. Table 7-2 lists U. S. Coast and Geodetic Survey smooth sheets covering Grays Harbor and entrance area out to a depth of 25 fathoms.

SHIPWRECKS

A listing of shipwrecks may be obtained from the Records of Assistance maintained by the U. S. Coast Guard Life Boat Service and Record of Shipwrecks formerly maintained by the U. S. Coast Guard Light House Service.

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

Enclosure No.	U. S. Army Corps of Engineers No.	Date	Subject
6-33	E-5-1-44	1951	Entrance
7-1	E-5-2-65/1	1943	Condition survey, Aberdeen to Cosmopolis.
7-2	E-5-2-65/2	1943	Condition survey, Averdeen to Cosmopolis.
7-3	E-5-2-130	1955	Harbor condition survey.
7-4	E-5-2-131	1955	Harbor condition survey.
7-5	E-5-2-133/1	1955	Harbor condition survey.
6-16	E-5-6-79	1939	Comparative sections on south spit.
6-34	E-5-7-16/1 thru 53	n. d.	Changes at entrance.
6-35	E-5-7-16/54	1953	Changes at entrance.
7-6	E-5-7-48/1	1926	Comparative sections at entrance.
7-7	E-5-7-48/2	1933	Comparative sections at entrance.
6-42	E-5-7-122	1952	Entrance, shoreline and bar changes.
7-8	E-5-7-125	1954	Bar and entrance condition.
7-9	E-5-2-134/1	1955	Harbor condition survey.
7-10	E-5-2-134/2	1955	Harbor condition survey.
7-11	E-5-2-134/3	1955	Harbor condition survey.
7-12	E-5-2-134/4	1955	Harbor condition survey.
7-13	E-5-2-134/5	1955	Harbor condition survey.
	--	1949	Bar and Entrance.
	--	1950	Bar and Entrance.
	E-5-12-93	1951	Point Chehalis condition survey.
	E-5-12-94	1951	Point Chehalis condition survey.
	E-5-12-102	1951	Point Chehalis condition survey.
	E-5-12-103/1	1951	Soundings and Elevations.
6-41	E-5-12-103/2	1951	Soundings and Elevations.
	E-5-12-107/1	1951	Soundings and Elevations.
	E-5-12-107/2	1951	Soundings and Elevations.
	E-5-12-110/1	1951	Point Chehalis condition survey.
	E-5-12-110/2	1951	Point Chehalis condition survey.
	E-5-12-111/1	1951	Point Chehalis condition survey.
	E-5-12-111/2	1951	Point Chehalis condition survey.
7-14	E-5-12-209	1955	Harbor condition survey.
7-15	E-5-13-92	1955	Cross Over Channel condition.

TABLE 7-2. Listing of U. S. Coast and Geodetic Survey Smooth Sheets Containing Bathymetric Information for the Grays Harbor Area.

Number	Date	Area of Survey
H-809	1862	Entrance Soundings.
H-1589A	1883	Entrance Soundings.
H-1589B	1883	Upper part of Harbor, Soundings.
H-2085	1891	Entrance Soundings.
H-2371	1898	Entrance Soundings.
H-3228	1911	South Channel Soundings.
H-3229	1911	South Channel Soundings.
H-3230	1911	South Bay Soundings.
H-4621	1926	Offshore Soundings.
H-4710	1927	Offshore Soundings.
H-4716	1927	Offshore Soundings.
H-4728	1927	Offshore Soundings.
H-4729	1927	Offshore Soundings.
H-4735	1927	Offshore Soundings.
H-6646	1940	South Bay Soundings.
H-6665	1940-41	Markham to Hoquiam, Soundings.

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Anonymous

1923. Wrecks in North Pacific, Bering Sea, and Artic Since 1853. The Marine Digest, vol 1, no. 33 and no. 34.

Jones, E. Lester

1918. The Neglected Waters of the Pacific Coast, Washington, Oregon, and California. U. S. Coast and Geodetic Survey, Special Publication no. 48, Serial no. 81, 21 pages.
(Gives relationships between the Pacific, Atlantic, and Southern Coasts shorelines, weather, and physiography. Summary of the major wrecks.)

LeConte, Joseph

1891. Tertiary and Post-Tertiary Changes of the Atlantic and Pacific Coasts; With a Note on the Mutual Relations of Land-Elevation and Ice Accumulation During the Quarternay Period. Bulletin of the Geological Society of America, vol. 2, pp. 323-330.
(Physical geography, orogenic history, and changes in rivers briefly discussed.)

Mason, W. A.

1952. Strandings and Wrecks of Vessels on the Coasts of California, Oregon, and Washington [Map]. San Pedro Blueprint Co., San Pedro, California.
(Certain wrecks and strandings are plotted with respect to general area of incidence. Not accurate as to location. Revised frequently.)

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.)
(Sections on Grays Harbor, Coos Bay, and Humboldt Bay include description, tides, tidal current, waves, wind, sand samples and profiles, sand movements, and structures.)

U. S. Army Corps of Engineers

1916. Grays Harbor, Wash. House Document no. 1729, 64th Congress, 2d Session, 48 pages, 10 maps.

1926. Grays Harbor, Wash. House Document no. 582, 69th Congress, 2d Session, 31 pages.

1934. Grays Harbor, Wash. House of Representatives, Committee on Rivers and Harbors, Document no. 2, 74th Congress, 1st Session, 36 pages.

U. S. Army Corps of Engineers

1938. Cross Sections, Grays Harbor, Surveys From June 1900 to June 1938. Original data, on file Seattle District, Seattle, Washington. (Unpublished.)
(Cross sections are of the gorge at the entrance of Grays Harbor. Sections are taken from a line projected from "Signal" Light House to a point 3,000 feet west of "Signal" Lone Tree. Station 0+00 of the projected line is "Signal" Light House.)

1940. Grays Harbor and Chehalis River, Washington, Bar and Entrance Condition October 1940. Original data, on file Seattle District, Seattle, Washington. (Unpublished.)
(The years 1936 and 1945 also available but with less detail.)

1951a. Grays Harbor and Chehalis River, Washington, Basis of Design for Protection of Point Chehalis and South Jetty, Appendix A, Beach Erosion Studies. Seattle District, Seattle, Washington, 7 pages plus 49 figures and 22 plates.
(Geomorphology, composition of beach and offshore zones, tides, local and offshore winds, waves and swells, storms and their effect, shore-line changes, offshore depth changes shown in tables, figures, and plates.)

1951b. Project and Index Maps. Seattle District, Seattle, Washington. (Processed.)
(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.)

1954. Grays Harbor and Chehalis River, Wash., Westhaven Breakwater. House Document no. 30, 84th Congress, 1st Session, 30 pages, 1 map.

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

n. d. Grays Harbor, Wash., Seattle District Survey. Map File No. E-5-7-16/1 thru 54.
(Survey of bar and entrance from 1862 thru 1953; a total of 54 surveys.)

1926. Comparative Sections at Entrance from 1900 to 1929. Map File No. E-5-7-48/1.

1933. Comparative Sections at Entrance from 1930 to 1950. Map File No. E-5-7-48/2.

1939. Comparative Sections from 1900 to 1933. Map File No. E-5-6-79.
(Adjacent to the Coast Guard Lookout Station on the south spit.)

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

1943. U. P. R. R. Bridge at Aberdeen to Cosmopolis, Condition August, 1943. Map File No. E.-5-2-65/1 and 2.
(Condition survey.)

1949. Bar and Entrance Condition, October 1949. Plate A-10, ref. U. S. Army Corps of Engineers (1951a).

1950a. Bar and Entrance Condition, November 1950. Plate A-11, ref. U. S. Army Corps of Engineers (1951a).

1950b. Harbor Entrance Hydrography and Tidal Currents. Map File No. E-5-7-118.

1951a. Harbor Entrance Hydrography Showing Location of Samples. Map File No. E-5-1-44.
(Samples described in text of reference U. S. Army Corps of Engineers (1951a).)

1951b. Point Chehalis Soundings, Condition Mar. 4-5, 1950. Map File No. E-5-12-93.

1951c. Point Chehalis Soundings, Condition 12-14 April 1950. Map File No. E-5-12-94.

1951d. Point Chehalis Soundings, Condition June 12, 1950. Map File No. E-5-12-102.

1951e. Point Chehalis Soundings, Condition Jan. 1951. Map File No. E-5-12-110/1.

1951f. Point Chehalis Soundings, Conditions Jan. 1951. Map File No. E-5-12-110/2.

1951g. Point Chehalis Soundings, Condition March 1951. Map File No. E-5-12-111/1.

1951h. Point Chehalis Soundings, Condition March 1951. Map File No. E-5-12-111/2.

1951i. Soundings and Elevations, August 10, 16, and 17, 1950. Map File No. E-5-12-103/1.

1951j. Soundings and Elevations, August 10, 16 and 17, 1950. Map File No. E-5-12-103/2.

1951k. Soundings and Elevations, Oct. 12 and 13, 1950. Map File No. E-5-12-107/1.

U. S. Army Corps of Engineers, Seattle District, Seattle, Washington
[Grays Harbor, Washington--Maps (Unpublished)]

1951l. Soundings and Elevations, Oct. 31 and Nov. 1, 1950. Map File No. E-5-12-107/2.

1952. Entrance, Shoreline and Bar Changes. Map File No. E-5-7-122. (Entrance bar changes 1930,-40,-42,-44,-46,-48,-50,-51. High water line changes 1862,-83,-98,-1902,-09,-16,-20,-24,-30,-42,-46,-51.)

1954. Bar and Entrance, Condition August, 1954. Map File No. E-5-7-125. (Condition survey.)

1955a. Cross Over Channel, Condition 18 May 1955. Map File No. E-5-13-92.
(Condition survey.)

1955b. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition Jan 25, 1955. Map File No. E-5-2-131.
(Condition survey.)

1955c. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition April 4, 1955. Map File No. E-5-2-133/1.
(Condition survey.)

1955d. Grays Harbor, Inner Portion and Chehalis River, Washington, Condition June 1955. Map File No. E-5-2-134/1 thru 5.
(Condition survey.)

1955e. North Channel, Condition 3 Feb 1955. Map File No. E-5-2-130.
(Condition survey.)

1955f. Sand Island Shoal, Condition 16 May 1955. Map File No. E-5-12-209.
(Condition survey.)

U. S. Department of Commerce Coast and Geodetic Survey

n. d. Index to Hydrographic Surveys, West Coast, United States. Washington, D. C.
(Loose leaf pages showing location and boundaries of surveys. Surveys from 1850 to 1947 for Grays Harbor area shown.)

U. S. Treasury Department Bureau of Customs

Annual. Merchant Vessels of the United States. Government Printing Office, Washington.
(Presents a complete listing of all vessels registered. "Vessels Lost" is of interest for ship wreck data. First volume published in [illegible].)

Wilkes, Charles
1858. U. S. Exploring Expedition, During the Years 1838-1842. Vol. 23, Hydrography, Chapter 16, Oregon Territory, pp. 303-327, C. Sherman, Printer, Philadelphia.
(Description of Grays Harbor from which original topography and bar structure may be visualized.)

SECTION 8

PHYSICAL OCEANOGRAPHY

PHYSICAL OCEANOGRAPHY

TIDES

The tide in Grays Harbor is of the mixed type with inequalities in both the high and low waters which are somewhat larger in the latter. The mean and diurnal ranges increase, respectively, from 6.9 to 9.0 feet at the harbor entrance (Point Chehalis) to a maximum of 7.8 and 9.9 feet at the Chehalis River mouth (Aberdeen) and then decrease up the river with 6.7 and 8.1 feet at Montesano. The time of tide becomes progressively later on passing inward from the entrance; at Aberdeen and Montesano it is 40 minutes and 2 hours and 10 minutes later, respectively, than at Point Chehalis. In the harbor, high tide occurs on the average within 45 minutes after the upper and lower transits of the moon.

The volume of the harbor at mean lower low water is about 16 billion cubic feet, while the volume of the harbor at a 10-foot tide at the Port Dock in Aberdeen (equivalent to a 9-foot tide in North and South Bays and the lower basin of the harbor) is about 34 billion cubic feet (Eriksen and Townsend 1940).

Tide Stations

Complete tidal predictions for Aberdeen 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 1954b). Tidal harmonic constants are published for this station (U. S. Department of Commerce Coast and Geodetic Survey 1942; International Hydrographic Bureau 1933).

Additional tidal data for the following stations:

1. Point Chehalis
2. Bay City
3. Markham
4. North Channel
5. Montesano

consists of: the time of tide, height of high water, height of low water (1955), and ratio of ranges (prior to 1955) compared to the Aberdeen tide (U. S. Department of Commerce Coast and Geodetic Survey 1954b); the high water interval (prior to 1955), the mean range of tide and the diurnal range of tide (U. S. Department of Commerce Coast and Geodetic Survey (1954b); and 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 1954b).

Monthly Tidal Variations

The tide in Grays Harbor, as typified by that at Aberdeen, follows the monthly lunar cycles in response to the moon's changing phase, distance and declination as follows:

Lunar Cycle	Measure of Tidal Effects	Ratio	Lag of Maximum Effect in Hours
Phase	Spring to neap range	1.7	35.5
Parallax	Perigean to apogean range	1.5	40.4
Declination	Tropic to mean diurnal inequality	1.4	12.8

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 from the mean of about 2 hours can be expected.

Tidal Datum Planes

Mean lower low water, based on 4 months of automatic gage records, is the datum for the charts of the Grays Harbor area (U. S. Department of Commerce Coast and Geodetic Survey 1954b).

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 Astoria (Marmer 1949,1952). The yearly variation will be somewhat similar to those at Seattle and Astoria, but will also depend on the local fresh water runoff and oceanographic conditions. Shorter period fluctuations are generally unpredictable.

The maximum probable high water at Aberdeen on a 50-year frequency is about 15.5 feet above mean lower low water or 5.6 feet above mean higher high water (U. S. Army Corps of Engineers 1951). The tidal datum planes are shown for five stations in Enclosure 8-1.

TIDAL CURRENTS

In Grays Harbor entrance, the average velocity of the flood or ebb tidal current is about 2½ knots, but velocities up to more than 5 knots may occur. In the channels through the bay, the velocities seldom exceed 3 knots (U. S. Department of Commerce Coast and Geodetic Survey 1951). The currents do not change appreciably with depth but may change considerably over small horizontal distances. In general, in the main channel, the ebb current is stronger than the flood.

Under normal conditions, the current at the bar changes at about the time of high and low water (U. S. Department of Commerce Coast and Geodetic Survey 1951). In the harbor, the times of current are within about 1 hour of that at the bar. In the Chehalis River, the times of slack water will depend on the discharge, but maximum flood and ebb occur on the average about 50 minutes earlier than at the bar.

Current Stations

Current tables furnish predictions for Grays Harbor entrance for each day of the year for times of slack water and times and velocities of maximum flood and ebb currents (U. S. Department of Commerce Coast and Geodetic Survey 1953a). Time differences and velocity ratios are listed for seven other stations in the harbor and entrance which make it possible to derive their maximum flood and ebb current velocities and their times of maximum ebb, flood, and slack waters from the reference station predictions. In addition, the time difference for maximum flood or ebb is given for the Chehalis River at Aberdeen.

The current tables give the intervals of time between maximum flood and moon's transit, the flood directions, the average and tropic current velocities for the harbor and entrance stations.

Additional current information has been obtained at one depth for 16 and at several depths for 10 current stations (U. S. Army Corps of Engineers 1951). Tabulated for most stations and depths are: the average times of slack and maximum currents referred to HW and LW at Aberdeen; and average direction, velocity, and duration of the flood and ebb currents. Average and maximum current curves for the Current Table reference station are given. Time differences and velocity ratios with respect to this station are listed for the other stations. A tidal current chart shows the magnitude and direction of the average flood and ebb currents at 15 feet (or half depth) for each station. Maximum calculated spring tide and observed velocities are indicated also. See Enclosure 8-2.

Tidal Excursion

Some float studies of tidal excursion have been made in the main channel (Eriksen and Townsend 1940). The distances that floats traveled during an ebb ranged from 8.59 to 9.72 miles while the distances on a flood ranged from 7.26 to 9.02 miles.

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 (Marmer 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. 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. The maximum tropic tidal velocities ranged from about 0.1 to 1.1 knots. It is estimated that at a depth of 20 to 30 fathoms off the Grays Harbor entrance, the tropic velocity would be about 0.4 to 0.5 knot.

Current measurements have been made at 4 depths at each of 3 stations over the offshore bar (U. S. Army Corps of Engineers Seattle District 1909). The results are shown in Enclosures 8-3, 8-4, and 8-5. The flood and ebb currents are in a general onshore-offshore direction. The maximum observed currents were about 2.5 knots at the surface and somewhat less at depth.

WAVES

Wind waves occurring in Grays Harbor may be either generated by the local wind or be the result of waves and swell entering from the Pacific Ocean. Winds from the morth, east, and southeast can be expected to produce maximum waves in the harbor, with a significant height and period of about 6 feet and 4 seconds, respectively, once in about 15 years (U. S. Army Corps of Engineers 1951). However, waves from the west occur with ocean swell from the southwest, west, or northwest directions. During the winter months these swell have heights greater than 12 feet about 30 percent of the time and greater than 20 feet with 16 to 18 second period about 2 percent of the time according to U. S. Army Corps of Engineers (1951). It is believed that this last extimate is too low and that these waves greater than 20 feet occur closer to 10 percent of the time (Bigelow and Edmondson 1947; U. S. Navy Hydrographic Office 1943). After these waves have broken across the bar and reached the harbor entrance, their height will have decreased to about 7 feet (U. S. Army Corps of Engineers 1951).

Local Wind Waves

Wave conditions in the harbor can be derived from wind observations in the surrounding area. The following wind information is summarized in the U. S. Army Corps of Engineers (1951):

1. Wind rose at Lone Tree, Washington, on Point Brown.
2. A summary of the prevailing and maximum winds observed at North Head. A wind diagram for North Head, Washington.
3. A velocity-duration curve for directions north, east and southeast for North Head, Washington. It is estimated that the graph represents the maximum winds that might be expected once in about 15 years.

Some of this wind information is summarized in the Climatology section of this report.

Offshore Waves, Swell, and Surf

Data on the distribution of waves in the open ocean off the Washington 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. Percentages of waves in the approximate height ranges 0-3 feet, 3-8 feet, 8-20 feet, and over 20 feet for each month of the year (Maritime Safety Agency 1951; U. S. Navy Hydrographic Office 1943).

The swell expected at the entrance to the harbor and along the adjacent shore can be computed from that offshore by means of suitable wave refraction diagrams. Refraction diagrams for waves with 15-second periods (approximately maximum storm conditions) and 10-second periods (more normal swell conditions) are given in U. S. Army Corps of Engineers (1951) (Enclosure 8-6). A photograph of storm waves breaking over the bar is enclosed as Enclosure 8-7.

Some photographs taken of surf along the Washington coast and a few heights and periods of the associated breakers, are given in Isaacs (1947) and Bascom and McAdam (1947).

Sea observations are recorded at the U. S. Coast Guard Light and Lifeboat Stations at approximate 4-hour intervals.

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

Listing 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

Grays Harbor is an estruay of the positive type where precipitation and runoff exceed evaporation. Fresh water comes from four rivers of which the Chehalis River, the largest, enters the harbor from the east and the Hoquiam, Wishkah, and Humptulips Rivers from the north. The annual runoff pattern for these rivers is discussed in Section 3, Hydrology, of this report. Access to the Pacific Ocean is through a narrow dredged channel flanked by partially submerged jetties. A small submerged bar lies on the ocean side of the entrance and has a depth of 37 feet comparable to the channel depths within the harbor. Inside the harbor several different channels exist, one of which is dredged. The others occur naturally and tend to shift from time to time.

Eriksen and Townsend made a comprehensive study of water characteristics in Grays Harbor measuring the salinity, temperature, dissolved oxygen, biclogical oxygen demand, and pH of the water at numerous stations from summer 1938 until fall 1939 (Eriksen and Towsend 1940). The Washington Pollution Control Commission surveyed the Lower Chehalis River and Grays Harbor measuring temperature, salinity, dissolved oxygen, pH, and sulfite waste liquor in the summer and fall of 1950 (Orlob, Jones, and Peterson 1951). The University of Washington measured temperature, salinity, dissolved oxygen, dissolved inorgainc phosphate, pH, and other minor constituents during the summers of 1938 and 1939 (Thompson n. d.). See Enclosure 8-8. Also, the Coast and Geodetic Survey measured temperature density at a tide gage station at Aberdeen (46°58.0'N., 123°51.2'W.) in 1934 and 1935 (U. S. Department of Commerce Coast and Geodetic Survey n. d., 1952a, 1952b). See Enclosure 8-9.

Temperature, salinity, dissolved oxygen, and other minor constituents outside the entrance to the harbor and seaward have been measured by the University of Washington during several summer cruises from 1938 to 1953 (Thompson n. d.; Paquette, Collias, and Love 1954). Temperatures and densities have been measured during a few summers along the ocean beaches on either side of Grays Harbor by the Washington State Department of Fisheries (Washington State Department of Fisheries, n. d.a).

Salinity Distribution

The salinity immediately off the entrance to Grays Harbor is affected by the runoff from land and the circulation patterns of the oceanic water. During the summer months higher salinities exist near the Coast than a short distance offshore, probably due to upwelling. Also water from the Columbia River may affect the surface salinity during periods of high runoff. University of Washington data indicate that the surface salinities during the summer months varied from 31.9°/oo to 32.5°/oo within 15 miles of the shore and the water at 50 meters was over 33.5°/oo. During the winter months the surface salinities may be lower than 30.0°/oo because of increased precipitation and river runoff.

The inflow of fresh water, entering principally through the eastern end of the harbor, tends to produce salinity gradients in the harbor both laterally and vertically. The water ranges from fresh at the eastern end of the harbor to Pacific Ocean water of 30°/oo to 31°/oo at the western end. The position and steepness of this gradient are regulated by the stage of the tide and the rate of discharge of the rivers (Enclosures 8-10 and 8-11). Incoming tides push the salt water farther eastward into the harbor and into the Chehalis, Wishkah, Hoquiam, and Humptulips Rivers, the magnitude of the movement varying with the height of the tide. On the other hand, increased river discharge tends to move this gradient seaward at all stages of the tide. During the summer months, the salinity in the upper harbor nearest the source of the greatest industrial pollution ranged from 16°/oo to 23°/oo. In winter the water in this region was almost completely fresh at all depths. The largest gradient with depth existed just west of Hoquiam and became very small off the mouth of the Chehalis River as shown in Enclosure 8-12.

According to Eriksen and Townsend, the volume of water in Grays Harbor indicates that there is considerable interchange of harbor water with each cycle of the tide. However, very little of this water is available for dilution of industrial wastes discharged into the upper part of the harbor as is shown by salinity data taken during the low water stages of the rivers from July through September in 1938 and 1939. During this period only about 1.2 percent of the upper harbor water was removed with each tidal cycle. This indicates that the average time of detention was about 80 tidal cycles or about 42 days. With increased river runoff during winter, the amount of fresh water available for dilution in the upper harbor is about five to ten times as great as in summer.

Temperature Distribution

The surface temperature of the ocean off Grays Harbor was found to vary from 13° to 15° C. during the summer months (Thompson n. d.; Paquette, Collias, and Love 1954). The summer temperatures are colder than would be expected from seasonal warming. In the winter of 1935, two sections were made 33 miles north of Grays Harbor to determine the temperature. The surface temperature in January 1935, during a period of local cooling, was 7.2° C. six miles offshore and increased to 9.1° C. 26 miles offshore. In February 1935, the surface temperature was 9.1° C. from about 6 to 45 miles off the coast.

Within the harbor most of the year, a temperature gradient was associated with the salinity gradient of the water (Eriksen and Townsend 1940). During the spring and summer months, the fresh water temperatures were found to be higher than those of the sea water and during the winter and spring months the fresh water was colder than the sea water. Occasionally in the summer, the brackish waters were found to be warmer than either the river water or sea water.

The maximum and minimum water temperatures observed by Eriksen and Townsend were 21.4° and 2.9° C. respectively; but the greatest variation in water temperature in the harbor on any one day was about 6° C. The temperatures observed by the Coast Survey at the tide gage station were from 23° to 0.4° C. Both the annual and short period variations in water temperatures followed rather closely the air temperatures at Aberdeen (Enclosure 8-13). During the spring and summer, water temperatures were often found to be higher than the air temperatures at Aberdeen. These elevated temperatures may be the consequence of insolation where extensive shoal areas are subjected to intense solar radiation.

Oxygen Distribution

Eriksen and Townsend found the oxygen concentration in Grays Harbor to be dependent upon the tide height, river stage, and the salinity and temperature of the water. As the river stage approached minimum, a marked deficiency in oxygen was observed off the towns of Aberdeen and Hoquiam (Enclosure 8-14). The amount of oxygen in the area of oxygen deficiency was often less than 2 ppm. Five parts per million is considered the minimum amount of oxygen necessary to sustain most fish life (Orlob, Jones, and Peterson 1951). As the tide changed, the location of the oxygen minimum moved up or downstream; on the flood, low oxygen water entered the various rivers feeding Grays Harbor. The salinity of the water containing the minimum oxygen was between 14.5 and 21.5^{o}/oo (Enclosure 8-15). As the river runoff increased, the oxygen minimum disappeared until it was almost absent at maximum river runoff. The oxygen minimum was definitely correlated with the operation of the paper pulp mill located in Aberdeen. On either side of the oxygen minimum zone, the oxygen increased to almost 100 percent saturation.

Pollution

The major source of pollution in Grays Harbor is the pulp mill of the Grays Harbor Division of Rayonier (Eriksen and Townsend 1940; Orlob, Jones, and Peterson 1951). Domestic pollution is a minor source even though raw sewage is dumped into all the rivers entering Grays Harbor and amounts to less than 10 percent of the total pollution load. The waste sulfite liquor is the cause of the oxygen deficiency at low river stage and the cause of high oxygen demand. Its principle effect is upon the fish that are migrating either up or downstream through this region. The reduction of the oxygen content of the water to below 5 part per million often kills the fish before thy can pass through this region. It has been shown that if the discharge of wast sulfite liquor can be prevented or reduced during periods of low river stages, the oxygen minimum will not become lower than that which fish can tolerate.

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SECTION 9

MARINE BIOLOGY

MARINE BIOLOGY

BIOLOGICAL FOULING

Report from William F. Clapp Laboratories indicates the following for the Grays Harbor area (Clapp 1950).

Aberdeen

U. S. Coast Guard has advised that there is some evidence of marine borer activity as far up Grays Harbor as the Hoquiam Fish Fleet moorings, 11.5 miles from the sea, but that this appeared only in 1947 after fishing vessels started using the moorings. They believe that there is very little borer activity above this point, as considerable fresh water reaches down that far. However they state that some fir pilings in the lower harbor where there is no fresh water have been eaten away in as short a period as eight months.

A regular Test Board operated by the U. S. Coast Guard at the City Fish Fleet mooring in the Chehalis River near where it empties into Grays Harbor, from May 1948 through 1949, has shown no activity of marine borers. Since the salinity at this location appears to range from 0°/oo to 10°/oo there appears to be no likelihood of their occurrence.

Westport

A regular Test Board operated at the U. S. Coast Guard from June 14, 1948 through 1949 has shown a set of Teredinidae in 1948, the attack rating but a trace. *Limnoria* occurred both years; the attack ratings were slight. *Chelura* was recorded in 1949.

PLANKTON

Studies made by the Washington State Pollution Commission are summarized below from a comprehensive report (Eriksen and Townsend 1940).

Phytoplankton samples were taken only at the surface in the harbor. Even for the quantitative samples taken from water of high chlorinity, there was little significance as regards pollution effects and the authors did not find it possible to correlate the results of numerous tow samples with any known factors. The phytoplankton as a whole based on cell counts, was always low when contrasted with that found in Puget Sound in the vicinity of the Pollution Laboratory. It was not possible, however, to definitely attribute this scarcity to either the pollution in the area or advection effects due to tidal exchange. Eriksen and Townsend found what they believed to be a strong positive correlation between the total number of diatom cells per liter and the chlorinity of the water as well as between the number of diatom cells per liter and the percent saturation with dissolved oxygen. However, they noted that the dissolved oxygen concentration elsewhere (in the North Channel) was so definitely associated with chlorinity that they deemed it probable that the chlorinity was the most important factor controlling the development of planktonic diatoms in the area. Other factors of possible control such as nutrient, light, etc. were not considered.

Periodic plankton tows were taken in the surf and in a lagoon in clearer water at three ocean beaches: Copalis, Twin Harbors, and Long Beach in June, July, August, and October 1954 and January 1955 by Tegelberg (Washington State Department of Fisheries n. d. b) to determine the composition of the plankton.

Results indicate that the noticeable brown water and frequent deposit of brown scum on the beaches are mainly composed of two genera of diatoms, Asterionella and Chaetoceras. Another diatom genus, Biddulphia, constituted the bulk of the material in early August. It is presumed by the investigator that this material is razor clam food and its abundance accounts for the rapid growth of these clams along Washington ocean beaches. The deposit of the scum on beaches is heaviest during winter and early spring months corresponding to rough ocean conditions which play a part in the deposition. The plankton composition appears to be the same at each beach though in lesser quantity at Long Beach.

KELP

The U. S. Department of Agriculture, Bureau of Soils has made the only known study of the kelp groves of the Pacific Coast. However, map numbers 13 and 16 covering the Grays Harbor Area were not published (Cameron 1914).

FISHERIES

Second to the forests in commercial importance are the fishing grounds of Grays Harbor and the Pacific coastal area extending from Willapa Harbor on the south to the vicinity of Destruction Island on the north. Commercial fishing and fish processing have been important industries since the turn of the century, but the greatest development has taken place since about 1940. Prior to 1934, the fishing industry depended primarily on salmon traps. In that year, fish traps were abolished by state law and the salmon fishery has since been dependent on gill netting in Grays Harbor waters and trolling in offshore waters. The annual catch has fluctuated with the runs of salmon. Since abolishment of salmon traps, the Grays Harbor fishing industry has shown increasing development in the catching and processing of other types of fish, fish products, and shellfish (U. S. Army Corps of Engineers 1948).

SHELL FISHERIES

Much of Grays Harbor is composed of tidal flats, partially exposed at low tide and somewhat protected from excessive winds and tidal action. Such lands are well suited to oyster culture and a rather large Pacific oyster industry has thrived in the Harbor area for many years, especially in the North and South Bays. However, approximately 34 percent of the total tide lands are restricted from oyster culture because of the proximity to domestic sewage discharge from Aberdeen and Hoquiam. The boundaries of this restricted zone were established by the State Health Department in accordance with the "Manual of Recommended Practice for Sanitary Control of the Shellfish Industry," U. S. P. H. S., 1946.

An estimated 439,000 pounds of oyster meat was harvested from Grays Harbor beds in 1952. An additional 691,325 pounds of razor clams and 1,373,708 pounds of crab meat were also marketed, bringing the total poundage of shellfish to 2,504,288 for 1952. The crab and razor clam fishery is largely confined to areas outside Grays Harbor proper (Peterson 1953).

EFFECTS OF GRAYS HARBOR WATER ON AQUATIC ORGANISMS

Extensive fish kills were observed in 1937, 1938, and 1939. Reports of fish kills in years prior to 1937 appear to be well authenticated (Eriksen and Townsend 1940).

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(Location and description of sediment samples, biological studies and water analyses.)

APPENDIX A

BEACH EROSION STUDIES

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

U. S. Army Corps of Engineers
1951 Grays Harbor and Chehalis River, Washington, Basis of Design for Protection of Point Chehalis and South Jetty, Appendix A, Beach Erosion Studies. Seattle District, Seattle, Washington, 7 pages plus 49 figures and 22 plates.

APPENDIX A - BEACH EROSION STUDIES

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A-17	Point Chehalis Soundings - October 1950 [Enclosure 6-41]
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A-19	Point Chehalis Soundings - January 1951 [Enclosure 6-41]
A-20	Point Chehalis Soundings - January 1951 [Enclosure 6-41]
A-21	Point Chehalis Soundings - March 1951 [Enclosure 6-41]
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GRAYS HARBOR, WASHINGTON

PROTECTION OF POINT CHEHALIS AND SOUTH JETTY

APPENDIX A

BEACH EROSION STUDIES

1. Introduction. - Pertinent data available for studies and basis of design are summarized in this appendix following the outline given in the Engineering Manual for Civil Works, Part CXXXIII, April 1947, "Beach Erosion Studies," chapter 2.

2. Geomorphology. - There is no knowledge of any report or study having been made of the geology of the area as related to the problems of shore protection along Point Chehalis.

3. Composition of Beach and Offshore Zones.- No detailed study is known to have been made of petrography or stream detritus. In connection with the present studies, and for the design of the Westhaven Breakwater, bottom samples have been taken and analyzed. The analysis of these samples mostly indicates medium sand with some coarser sands and gravels. Locations of these samples are shown on Plates A-1 and A-2 and the mechanical analyses are shown on figures A-1 through A-38.

4. Tides.- The U. S. Coast and Geodetic Survey has established bench marks and determined the tidal datum planes at the following stations in Grays Harbor:

a. Westport
b. Bay City
c. Markham
d. West Aberdeen
e. Aberdeen
f. North Hoquiam
g. West Hoquiam
h. Point Brown

Information furnished by the U. S. Coast and Geodetic Survey indicates the maxium probable high water at Aberdeen on a 50-year frequency is about 15.5 feet above MLLW or 5.6 feet above MHHW. However, it appears that the estimated highest tide of 12.00 feet above MLLW will seldom be exceeded at Westport or at the entrance to Grays Harbor. This value was therefore used in the design of proposed protective works. A graphical comparison of the various datum planes is shown on Plate A-3.

5. As part of the investigations to obtain basic data for the design and verification of the hydraulic model, arrangements were made with the U. S. Coast and Geodetic Survey to make an extensive current survey. This survey was accomplished during March and April 1950. The locations of 16 current stations, numbered 1-16, where observations were made with radio current buoys, are shown on Plate A-4. Stations numbered 17-26 indicate current observations at several depths. Stations 9 and 10 were observed simultaneously for a continuous period of 15 days. All other stations were each observed for a 100-hour continuous period. Current observations were made with the radio current meter and buoy at a uniform depth of 15 feet at stations 1-16, with the exception of 7 and 13. The meter was set at one-half the depth at these two stations. At stations 17-26 the current observations were made at three depths, 0.2, 0.5, and 0.8 of the depth of water at MLLW. The results of this survey are summarized in figures A-39 through A-44. The average and maximum velocities determined for the observation stations are shown graphically on Plate A-4. Copies of the plotted current curves as actually observed and the tabulation and reduction computations on Form 451, Department of Commerce, U. S. Coast and Geodetic Survey, are available in the Seattle District files.

6. Local and Offshore Winds.- A wind rose was prepared from the records at Lone Tree, Washington, on Point Brown, for the years 1910, 1915, 1916, and 1919, and is shown on figure A-45.

7. Local wind data are fragmentary and inadequate for a reliable determination of maximum velocities for the critical durations of 1 to 3 hours. The nearest weather station for which complete wind data are available is North Head, Washington. This station is about 45 miles south of Grays Harbor, but for the purpose of determining maximum probable wind conditions it is believed that the observations are directly applicable to the Grays Harbor area. A summary of the prevailing and maximum winds observed at North Head is shown in Table A-1. Figure A-46 is a wind diagram for North Head, Washington.

8. Firgure A-47, entitled, "North Head, Washington, Wind Velocity Duration Curve for Directions North, East, and Southeast," was prepared on the following basis. The wind velocity duration curves for North Head do not represent absolute maximum conditions since records were not available for a complete study. The data available in this office were daily maximum recorded velocities for the period 1931-1940. From these data, the two highest velociites for each of the directions, north, east, and southeast were used to suggest storms for further study in this connection. Hourly velocities for the peak hours of these storms were furnished by the weather bureau office at North Head, along with the highest recorded velocities for a 5-minute period from the east and southeast.

Table A-1 - WIND DATA, NORTH HEAD, WASHINGTON

NORTH	AVERAGE HOURLY VELOCITY	PREVAILING DIRECTIONS	HIGHEST		
			VELOCITY	DIRECTION	DATE
Record	46 YEARS	62 YEARS	62 YEARS	62 YEARS	62 YEARS
January	16.5	E	95	SE	1921
February	15.3	E	70	S	1937
March	15.2	S	73	S	1897
April	14.7	NW	77	S	1943
May	14.9	NW	65	SE	1937
June	14.4	NW	59	SE	1937
July	14.0	N	50	S	1934
August	12.5	N	57	SE	1920
September	12.4	N	70	SE	1914
October	13.5	S	87	SE	1934
November	15.7	SE	72	S	1937
December	16.6	E	84	S	1940
Year	14.7	N	95	SE	1921

The peak velocity from the north is lower than the maximum from the southeast but complete data are not readily available in this office. From these data, the curves were constructed. Winds used were continuously from the same direction during the duration periods with the exception that 45 degrees variation either way was allowed for one hour out of duration periods over 3 hours if it was thought that the wind was from the direction being considered over a major portion of the hour in question.

9. Although storms with greater velocity durations than indicated by the graph might occur, it is believed that they would not greatly exceed the values shown. It is estimated that the graph represents the maximum winds that might be expected once in about 15 years. The probability of a greater storm occurring at the time of extreme high tide (in order to obtain the maximum wave effect) is considered too remote for justification as a basis of design for the proposed project. The above graph has therefore been used in the determination of maximum wave heights generated.

10. The theoretical maximum deep water waves for the governing conditions of fetch and the wind velocity durations shown in figure A-47 were determined by the use of graphs contained in "The Bulletin of the Beach Erosion Board, Special Issue No. 1," dated July 1, 1948, as follows:

a. Easterly winds. The effective fetch from an easterly direction is about 10 nautical miles. The maximum height of wave would be about 8.0 feet with a period of 4.1 seconds and would be generated by a 43-knot (48.3 statute miles per hour) wind continuing for 2.1 hours.

b. Northerly winds. The effective fetch from a northerly direction is about 8 nautical miles. The maximum height of wave would be about 6.8 feet with a period of 3.8 seconds and would be generated by a 38-knot (43.6 statute miles per hour) wind continuing for 2.0 hours.

11. As noted, the heights of waves determined above are for deep water, which for the maximum length of waves would require a depth of at least 40 feet. Waves generated in shallower depths will not be as high as determined for deep water ("Wind Waves at Sea Breakers and Surf," U. S. Navy Department, Hydrographic Office, Pub. No. 602), but information is not available for determining accurately the reduced height of waves as generated in shallow water. As there are tide flats to the east of the project area with an average elevation approximately at MLLW, and with some areas over 6 feet MLLW, waves in the order of 5 feet cannot reach the area without breaking except at tidal stages above half tide. Even at

extreme high tide the depths are so limited that it is estimated that there would be a reduction of 2 to 3 feet from the theoretical deep water wave and that the maximum possible wave for any wind is between 5 and 6 feet high.

12. Offshore winds are shown in figure A-48 from data compiled by the Beach Erosion Board.

13. Waves and Swells. - As indicated above, storms from north, east, and southeast will seldom produce waves higher than 5.0 feet and it is not justified to design for higher waves from these directions. However, the maximum waves from the west are the result of ocean swells coming from the southwest, west, or northwest. In response to inquiry from this office, the Beach Erosion Board reported as follows:

"Examination of sea and swell charts for the ocean area contiguous to Grays Harbor leads to the conclusion that heavy swells (greater than 12 feet high) occur about 30 percent of the time from southwest through west to north directions during the period January through March. Reference to publications of the Scipps Institution of Oceanography indicates that swells of 20 feet height, and 16- to 18-second period will occur from the west and northwest during the winter months. So far as available information is concerned, this represents the maximum wave action to be expected and, in the opinion of this office, is a reasonable definition of maximum wave action for design purposes. The frequency of occurrence of such waves is low, of the order of 2 percent of the time, yet sufficiently high to justify their consideration as maxima."

Although there may be occasion for difference of opinion regarding the maximum wave height justifable for consideration in design or redesign of the South Jetty, it is believed that the effect on Point Chehalis of ocean swells greater than 20 feet high need not be considered, as greater swells will be at least partially broken up in crossing the entrance bar.

14. To aid in the study of wave effect on Point Chehalis, wave refraction diagrams have been prepared as shown on plates A-5 through A-9. Plates A-5, A-6, A-7, and A-8 show the refraction diagrams for waves with 15-second period and represent approximately the maximum storm conditions. Plates A-8 and A-9 show the refraction diagrams for waves of 10-second period and represent more or less normal swell conditions. It is believed that these diagrams indicate quite accurately the direction of approach of waves to the shore just before breaking. Attempts at the determination of the refraction coefficients have not been very satisfactory even when using the direct method of plotting orthogonals. It is apparent that the wave pattern in the harbor is complicated by intersecting wave fronts and secondary

waves. In general, it is concluded that waves in the vicinity of Point Chehalis will not be greater than about one-third the height of the ocean swell from which they originate. It is therefore believed that the maximum waves in the vicinity of Point Chehalis will be from the west and will seldom, if ever, exceed 7 feet in height.

15. Aerial photographs, figure A-49, are part of a flight of photographs taken during the storm of October 12, 1949. These photographs are on a scale of approximately 1 inch = 1,000 feet and were taken at 2:20 p.m. when the tide was at about +8.5 feet MLLW datum and the swells were coming in from azimuth 282° at about 15-second period. The deep water height of these waves is estimated at about 21 feet.

16. Storms and their Effect.- It is known in a general way that quite extensive movements of material have occurred during a single storm. However, no effort has been made to obtain a complete record of a particular storm and measure its effects.

17.. Shore-line Changes.- Condition surveys of bar and entrance to Grays Harbor are available on a scale of 1 inch = 2,000 feet for the years 1862, 81, 91, 94, 98, 1900-1904, inclusive, 1906, 1909-1917, inclusive, and 1920-1950, inclusive. A comparison between Plate A-10, "Condition - October 1949" and Plate A-11, "Condition - November 1950" shows only relatively small change.

18. Soundings in the vicinity of Point Chehalis and South Jetty are shown on Plates A-12 through A-22. The soundings and elevations shown on these plates were obtained by means of a fathometer on the Launch MAMALA and surveys on the shore areas. The soundings obtained are subject to some error because of wave action. This is especially the case for the winter months. Because of storm conditions, high velocity tidal currents, and the 5-foot draft of the survey boat, soundings near the shore and along the South Jetty are not obtained for distances nearer than 200 to 400 feet, as a rule.

19. A comparison between soundings of October 1949 and October 1950 shows a deposition of about 1,100,000 cubic yards in the vicinity of Point Chehalis, mostly on the north end. At the same time there was a removal of about 200,000 cubic yards of material above MLLW along the west shore, and about 1,000,000 cubic yards was scoured out north of the South Jetty in an area 2,000 to 6,000 feet west of the west shore of Point Chehalis. Since October 1950 there has been some additional scour above the low-water line on the west and northwest side of Point Chehalis but it has been more than balanced by deposition below the low-water line.

20. Offshore Depth Changes.- Condition surveys have been made in connection with maintenance of navigation channels and therefore do not, in general, extend beyond depths of about 60 feet. For this reason, offshore depth changes cannot be evaluated.

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.)

GRAYS HARBOR

Grays Harbor is a shallow bay extending approximately 17 miles east and west and 14 miles north and south. There are no headlands in the vicinity and the entrance channel passes between two low, heavily-wooded sand spits. The major portion of the tidal area lies north of a line running east and west through the entrance. Six small rivers enter the bay.

The 100 fathom line lies 35 miles and 10 fathom line 4.5 miles from shore. The slope of the bottom averages 3 fathoms per mile but the seaward slope of the bar is much steeper.

WIND and PRECIPITATION-- The mean annual precipitation at Aberdeen on the east shore of Grays Harbor is 80.85 inches.

The prevailing winds by months according to records of the Weather Bureau are:

December, January, February--------E
March to November, Inclusive------W
Annual----------------------------W

The accompanying blue print gives the number of days per year for different intensities and directions. It appears that moderate northwest winds occur about one-third of the time and that the strongest winds blow from the south, southeast, and east.

The winter storms begin usually in the east or southeast and swing around to southwest where they reach their greatest intensity. The direction gradually changes to northwest with diminishing velocity.

TIDES and CURRENTS-- The ranges of the tide at Grays Harbor are as follows:

LOCATION	MEAN RANGE (FEET)	DIURNAL RANGE (FEET)
WESTPORT	6.9	9.1
ABERDEEN	7.5	9.7
MONTESANO (CHEHALIS RIVER)	7.9	10.1

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

The area of the bay at high water is 94 square miles and at low water it is 36.7 square miles. The tidal prism is 518 square mile-feet between MLLW and MHHW. The average velocity between the ends of the jetties during the "long run-out" is 2.5 feet per second.

Measurements of currents shown on the survey of 1909 show that the ebb currents were stronger than the flood currents near the South Jetty but that the flood currents predominated near the North Jetty, which was then only partially completed. The ebb and flood currents were about equal at the whistling buoy. The ebb current near the South Jetty had a velocity of 3.2 feet per second while the flood current near the North Jetty attained only 2.9 feet per second.

During June 1913, float measurements of the currents were made both in the entrance channel and over the bar. Captain A. R. Ehrnbeck, who was in charge of the harbor survey made the following statement:

> "All through the survey when sounding outside of the channel between the jetties and across the bar a very strong northward current was found, which persisted during the fresh northwest winds in both ebb and flood stages of the tide. As shown by the float experiments, this current was so strong that it was impossible to make the floats enter the harbor even though they were released well to the southward of the opening between the jetties on the flood tide."

The results of these are shown in Figure , Appendix VIII.

In 1896, T. W. Symons (Proc. American Society of Civil Engineers, volume 36) stated that "in the vicinity of Grays Harbor there is a littoral current, the general resultant of which tends to the north. While the resultant littoral current is north it ordinarily follows the direction of the prevailing winds in the immediate vicinity of the land, moving to the south in summer and to the north in winter. Its intensity is said to reach as high as 2½ miles per hour either way."

In answer to a questionnaire sent out by the board, the U. S. District Engineer at Seattle made the following statement regarding the littoral currents:

> "The general resultant of the littoral current is to the north. In calm weather its velocity is about one mile per hour. The direction and velocity are affected by the prevailing winds. In summer it occasionally flows to the south, its maximum velocity in this direction being about one and one-half miles per hour. Its maximum velocity in winter, when it flows to the northward almost constantly, is about four miles per hour."
>
> 'From notes taken from logs of vessels it is probable that the increase in the velocity, of the current (between the jetties) since the construction of the jetties amounts to between one-half and three-quarters of a mile per hour."

Mr. E. L. Carpenter, who has been in charge of construction and maintenance at Grays Harbor for many years made the current sketch shown in

Figure 3, Appendix VIII, which represents average conditions. The ebb current follows the South Jetty to the end and is then deflected northward as if it has collided with a northward littoral current. The flood currents come in from all directions, over the jetties as well as through the main channel. The ebb current continues along the North Jetty for about an hour after the flood starts in along the South Jetty.

Additional circumstances pointing to a northerly current are:

(a) Muddy water presumable from Columbia River found off Grays Harbor in summer months in spite of northwest winds.
(b) Bodies of persons drowned in harbor found to north, if at all.
(c) Wrecks and drift wood move north.

It has been found that the water temperature in the channel gives a sine curve which follows the tide. The apparent explanation is that the water covering the broad flats is heated and then ebbs, to be replaced by colder ocean water but this would not apply if the measurements were made when the air and land were colder than the sea.

The existence of a prevailing northerly current running counter to prevailing northwesterly winds is very difficult to explain and throws some doubt on the possibility of correlation of wind and current data.

The depth to which wave action is effective in moving material is shown by the following circumstance. During 1925 and 1926, 1,800,000 cubic yards of material were dumped about 2000 feet west of the whistling buoy in 95 to 100 feet of water. The waves sharpened perceptible at this point and hump moved shoreward to a depth of 60 feet. At this point, it had flattened out so much that its further progress could not be traced.

SAND SAMPLES and PROFILES-- Analysis of the sand samples obtained in the vicinity of Grays Harbor showed the following sizes:

LOCATION	DESIGNATION	MEDIAN DIAMETER (INCHES)	SLOPE
Beach north of North Jetty.	N-1	0.00825	
Bar	N-2	0.00800	
Bar		0,0071	
1000 feet south of South Jetty	N-3	0.00734	1.5°
North of South Jetty (Channel side)	N-9	0.00767	2.0°
Slatz Road	N-10	0.00648	

The variation in size is not great but the variation is uniform and shows that the diameter decreases with distance southward.

At points in the harbor more than five miles from the throat, the bottom is entirely of mud and yet, in dredging on the bar, mud has been encountered but once.

The beach is composed of gray sand which packs very hard and makes an excellent road when wet. The surface of the beach near the South Jetty is covered with pea gravel and the same material was found a foot below the surface. Gravel was not observed at a point one mile south of the jetty.

SAND MOVEMENT-- In a paper previously referred to, T. W. Symons states that "as nearly as can be ascertained, there is a great cyclic change in the bar channel occurring in about 35 to 40 years and a lesser one at short and irregular intervals. There is a constant gradual movement of the channel from north to south." The same writer also states that in its natural condition there was a definite cycle of change at the end of the north spit. An island, shown as Eld Island on the chart of 1862, appeared first in deep water and then gradually moved northward and encircled Point Brown, as shown on the chart of 1891. The island then gradually wears away and a second island begins to form offshore. Such an island was said to be in process of formation in 1896.

Mr. Carpenter stated that the evidence supporting this cyclic motion of Eld Island is not conclusive. Old residents of the vicinity state that trees grew on Eld Island, indicating that it once enjoyed considerable permanency.

The charts of the entrance show that between 1881 and 1898, when the South Jetty was started the main channel swung around very slowly in a clockwise direction from its original southwest direction. From the surveys for the years 1900 to 1906, it appears that several large masses of sand traveled northward along the bar and attached themselves to the shoals around Point Brown. The surveys were made at intervals of a year and the apparently gradual movement may be merely a coincidence.

The survey of 1901 shows a fill south of the South Jetty estimated at eleven million cubic yards most of which occurred during one storm. Between the surveys of 1902 and 1903, the depth was reduced from 20 to 14 feet. The South Jetty was unable to stabilize or deepen the channel but the addition of the North Jetty, which provided a converging channel, effected a definite improvement.

A summary of the changes shown by the survey appears on the following page. Figure 4, Appendix VIII, shows profiles along the lines radiating from a point midway between the ends of the jetties. The quantity of material in the bar above elevation -30' has decreased since 1900 from 38 million to 10 million cubic yards. Between 1894 and 1929, the crest of the bar was pushed seaward approximately 3800 feet.

Following the construction of the South Jetty, the shore line at Point Hansen moved seaward approximately 2500 feet, attaining its maximum advance in 1912. Subsequently, erosion occurred and in 1928 the shore line was 1800 feet east of its most advanced position. Changes in Point Brown on the north side of the entrance have been much greater, the extension of the point amounting to 7500 feet between 1912 and 1928.

Dredging is usually done on the south side of the channel as the fill seems to occur most rapidly on this side.

Considering the charts and topographic maps of the shore north of the entrance, we find that Cranberry Creek, Copalis River and Bear Creek are deflected northward while the Moclips River follows the shore northward for some distance but finally bends southward slightly before discharging into the ocean. As these rivers cut through a sandy beach, the inference is that their mouths are deflected in the direction towards which the sand is moving.

The hydrographic charts show that the 30, 80 and 100 fathom contours diverge from the shore line with distance north of the Columbia River, which is to be expected if the debris brought down by this river is moved to the northward. The shape of the 100 fathom contour suggests that the delta, which would normally form directly off the entrance to Grays Harbor has been pushed northward by a strong littoral current.

The data presented point very clearly to a northward sand movement. This is in the same direction as the prevailing current but opposite to the prevailing wind. The accumulation of sand north of the North Jetty is probably due to a counter eddy generated by the northerly current and to the protection from southwesterly storm waves afforded by the jetties.

STRUCTURES-- The entrance to Grays Harbor has been improved by means of two random mound jetties intended to act both as training wall and as sand traps. The project depth is 24 feet below MLLW. At the sea ends, the distance between the jetties is 7000 feet.

Principal data on the jetties are as follows:

SOUTH JETTY-- Date of construction, 1897 - 1903.
Length, 13,784 feet.
Original height of enrockment, +8.4 above MLLW.
Present condition - Jetty down mid-tide at shore and to MLLW at outer end.
Total weight of stone originally placed, 655,996 tons.
Increase in total weight over estimate, 275%.
Unit weight of stone, 165 lbs.per cu. ft. (basalt)
Size delivered, 52% 4 tons to 14 tons.
30% 1000 lbs. to 4 tons.
18% 50 lbs. to 1000 lbs.
Original depth at outer end, 15 feet.
For sections and profile see Appendix VIII.

SUMMARY OF CHANGES AT ENTRANCE TO GRAYS HARBOR

YEAR	MONTH	CONTROLLING DEPTH (FT.)	DEPTH AT THROAT	DIRECTION OF BAR CHANNEL	REMARKS
1793		24	84	S W	George Vancouver
1862		16	100	N W	Eld Island has formed since 1795
1881		16	80	S W	Eld Island has disappeared.
1883		10	106	S W	
1891		14	105	S W	
1894		14	100	S W	
1898		15	112	W	South Jetty started.
1900		16	85	W	
1901		13	73	S W	
1902	JULY	20	115	S W	Channel very tortuous.
1903		14	109	S W	South Jetty completed.
1904		17	117	S W	Channel follows South Jetty.
1906		13	98	S W	
1907		12			
1908		17			North Jetty started.
1909		18	104	W	
1910		15	104	W	Deeper channel runs N W.
1911		18	95	W	
1912		17	105	W	
1913		18	100+	W	
1914		18	85	W	
1915	JUNE	17	85	W	
1916		24	100	W	North Jetty completed. Dredging started.
1920	JUNE	19	102	S W	
1923	JUNE	23	107	S W	
1925		23	105	S W	Bar dredged to 32 feet - October 1924.
1926		25	92	S W	Bar dredged to 36 feet - October 1925.
1927		23	90	S W	Bar dredged to 29 feet - August 1926.
1928		28	104	S W	Bar dredged to 36 feet - October 1927.
1929	AUGUST	34	96	S W	
1930	JANUARY	33		S W	Channel follows South Jetty to end and breaks S W.

NORTH JETTY-- Date of Construction, 1907 - 1913.
Length, 17,000 feet.
Original height of enrockment, mid-tide in 1913.
Raised to ord. H W in 1916.
Present condition - Sea end down to MLLW in 1928.
Major portion at +8 above MLLW.
Total weight of stone originally placed, 585,902 tons.
Unit weight of stone, 145 lbs./cu. feet (sandstone)
165 lbs./cu. feet (basalt)
170 - 175 lbs./cu. feet (diorite)
Sizes delivered, 45.7% 4 tons to 13 tons.
(original 30.8% 1000 lbs. to 4 tons.
construction) 23.5% 50 lbs. to 1000 lbs.
Sizes delivered, 42.6% 6 to 17 tons.
(maintenance) 7.5% 50 lbs. to 1000 lbs.
49.9% 1000 lbs. to 6 tons.
Diorite and basalt were used for maintenance. Sandstone was used below MLLW.
Original depth at outer end, 22 feet.
For section, see Appendix VIII.

Neither of the jetties extended out to the bar or to the depth of water desired and the writer is of the opinion that there was no necessity to do so. Maintenance, which is difficult and expensive with the present lengths, would have been almost impossible at a reasonable cost if the jetties extended across the bar. The tidal prism is sufficient to maintain a satisfactory channel and the decrease in the yearly amount of dredging indicates that a stable condition is being obtained.

From the curve showing the relation between the tidal prism and the area of the entrance section below MSL, the stable area for Grays Harbor is about 280,000 square feet. If the distance between the ends of the jetties had been less, the amount of dredging would probably have been decreased by a further concentration of the currents.

Interesting features of the construction were the use of brush mattresses where possible, the placing of an apron of stone ahead of the completed enrockment to prevent scour and the use of light sandstone below MLLW and basalt or diorite above that elevation.