AN ABSTRACT OF THE THESIS OF

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Title: SEASONAL VARIATIONS IN TIDAL DYNAMICS, WATER QUALITY AND SEDIMENTS IN THE ALSEA ESTUARY

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During 1973 data was collected to analyze the seasonal variations of the tidal dynamics, water quality and sediments of the Alsea Estuary. A summary of historical information with a list of all known alterations to the estuary was made. A complete physical description, including the geographical setting and mixing classification of the estuary, was done.

Times of high and low water and tidal ranges at three locations were measured. Tide measurements made at Waldport indicated that the published tide predictions for that location were reliable. At a location upstream of the estuary embayment noticeable damping of the tidal wave amplitude was detected during periods of high river flow and high tidal range. High water lag times were found to decrease during periods of high river flow, but low water lag times were unaffected by river flow. The tide motion was found to be a damped, partially standing wave, which altered its behavior according to the volume of water in the estuary.

The high and low tide water quality parameters of salinity, temperature, dissolved oxygen, turbidity and pH were measured at 10 to 18 locations during each season to determine any seasonal changes in them. The parameters at a given location were found to be a function of river flow and tidal range.

Winter and summer sediment samples were analyzed for grain size distribution, volatile solids and porosity. The sediments from the main channel exhibited characteristics of a high velocity regime and those of the north channel, a low velocity regime.

SEASONAL VARIATIONS IN TIDAL DYNAMICS, WATER QUALITY AND SEDIMENTS IN THE ALSEA ESTUARY

by

David Roller McKenzie

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A_{hw} = estuary high water surface area

A_{lw} = estuary low water surface area

C = wave celerity

D_{10} = 10% grain size

D_{50} = median grain size

D_{60} = 60% grain size

g = acceleration of gravity

h = mean water depth

$\bar{h}$ = mean water depth between two points

L = basin length

P_m = measured period of a tidal cycle

P_n = natural period of a tidal cycle

Q = river flow

$\bar{Q}_D$ = mean daily river flow

RM = river mile from mouth

R_m = measured tide range

R_p = predicted tide range

t = time of tidal wave travel between two points

T_f = flushing time

T_m = measured time (PST) of high or low water

T_p = predicted time (PST) of high or low water

ΔT = $T_m - T_p$, tidal lag time

U = D_{60}/D_{10}, uniformity coefficient

V_f = fresh water volume

V_p = tidal prism volume

x = distance from estuary mouth

ENGLISH-METRIC CONVERSION TABLE

To convert	To	Multiply by
inches (in)	centimeters (cm)	2.540
feet (ft)	meters (m)	0.305
miles (mi)	kilometers (km)	1.610
square feet (sq ft)	square meters (m^2)	0.093
acre (acre)	square meters (m^2)	4047.000
square miles (sq mi)	square kilometers (km^2)	2.590
cubic feet (cu ft) or cubic feet per second (cfs)	cubic meters (m^3) or cubic meters per second (m^3/sec)	0.028
acre-feet (acre-ft)	cubic meters (m^3)	1233.000

SEASONAL VARATIONS IN TIDAL DYNAMICS
WATER QUALITY AND SEDIMENTS
IN THE ALSEA ESTUARY

I. INTRODUCTION

Purpose of the Study

The most widely accepted definition of an estuary used by marine researchers is a semi-enclosed coastal body of water, usually the extension of a river, which has a free connection with the open sea and within which sea water is measurably diluted with fresh water from land drainage (Pritchard). In addition to the obvious function of serving as outlets through which fresh water is returned to the ocean, estuaries are also areas of high biological productivity. Marx (1967) states that Dr. Eugene Odum, a University of Georgia ecologist, has concluded from his own studies that "...estuaries are twenty times as productive as the open sea, seven times as productive as an alfalfa field and twice as productive as a corn field." Estuaries, therefore, play a critical role in the cycles that support life on this planet.

It has only been recently that intensive scientific investigations of estuaries have been initiated. Because there are numerous time and space dependent variables that influence the processes which occur within the boundaries of all estuaries, they are among the most complex of all natural systems. Furthermore, no two estuaries, although sharing similar geological, climatological and marine environments, are alike.

At the present time there is an insufficient amount of information describing the physical and chemical characteristics of Oregon's estuaries. This input is necessary for intelligent, far-sighted coastal planning in the Pacific Northwest. Therefore, there is a need to gather and analyze reliable, useful data on the physical and chemical properties of Oregon's estuaries to better understand, protect and utilize these systems.

The Alsea is a medium-sized estuary (by Oregon standards) located on the Central Oregon Coast (see Figure 1). The Oregon State Division of State Lands (1973) reports that the total area of the estuary, including tidelands, is 2,146 acres. Its main tributary is the 48.7 mile long Alsea River (Oregon State Water Resources Board) which has its source in the Coast Range Mountains. The largest population center along the estuary is the city of Waldport located on the south shore at the mouth of the bay. Today, the primary use of the estuary is for recreational purposes, including sport fishing, clamming, crabbing and boating. There is only a small amount of commercial crabbing and no industrial activity on the estuary. However, there is extensive logging being conducted throughout the estuary's drainage basin, much of which lies in the Siuslaw National Forest. Although the Alsea and its environs have been used by the White Man for over 100 years the estuary remains pristine and unpolluted. It is hoped that the additional information provided by this study will prevent this unspoiled river and bay system from being improperly exploited in the future.

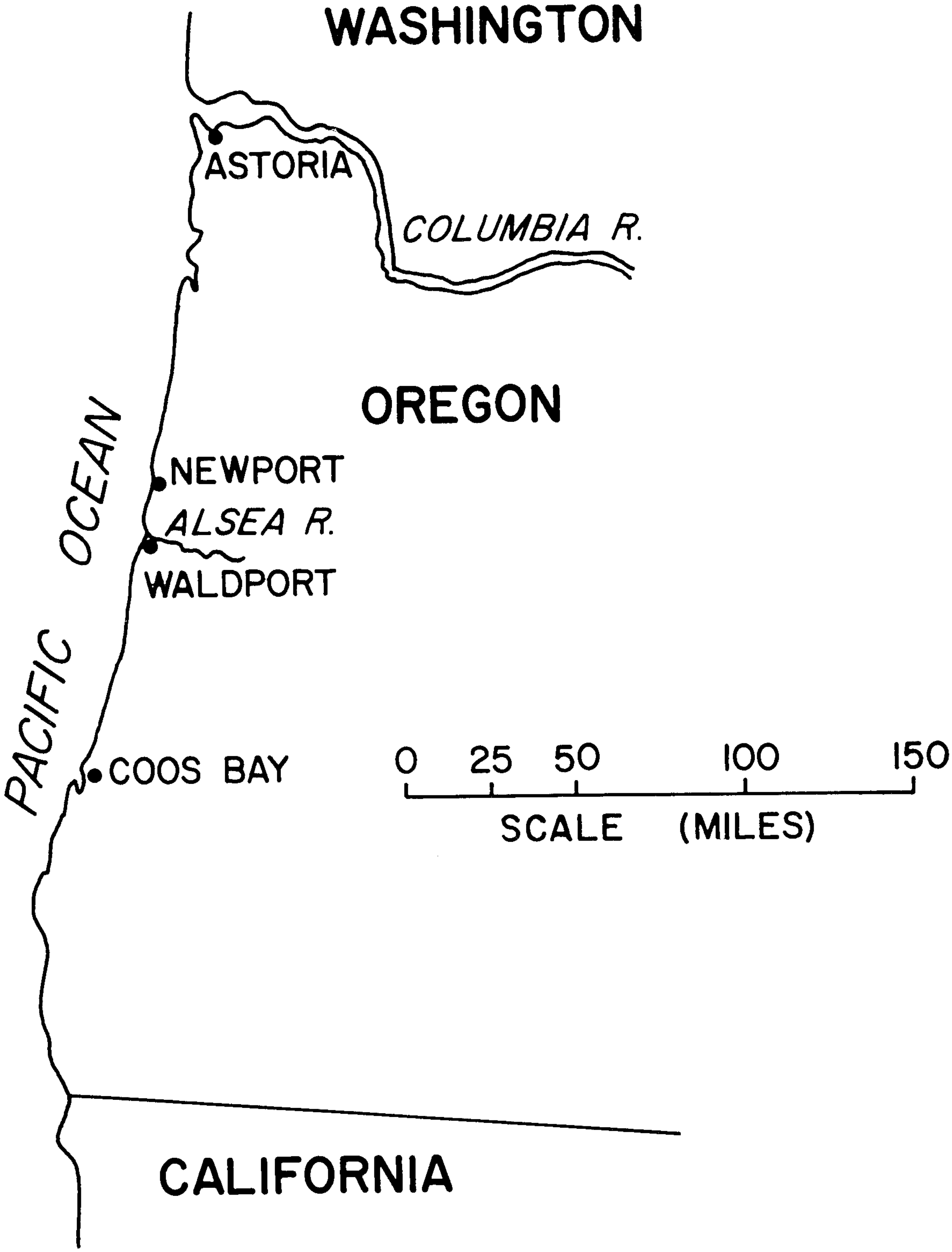


Figure 1. Location at the Alsea Estuary.

The purpose of this study was fourfold. The first goal was to provide a summary of the known geographical, geological, historical and physical information of the Alsea Estuary. The second goal was to collect, reduce and analyze quantitative data on the seasonal variations of (a) the water quality (salinity, temperature, dissolved oxygen, pH and turbidity), (b) the tidal dynamics (tidal ranges, tidal peak times, tidal damping, tidal lag and tidal current flows), and (c) the sediment characteristics of the Alsea estuary. The third goal was to interpret the collected information and develop a description of the estuary's behavior throughout an entire year. The fourth goal was to make a thorough presentation of the information in such a way that coastal residents and planners could easily apply it to the wise utilization of the Alsea Estuary environment.

Previous Studies

Other studies have been conducted entirely, or in part, on the Alsea Estuary. Listed below in chronological order are brief descriptions of the major studies:

(1) Burt, W. V. and W. B. McAllister (1959) - This paper discusses estuarine classification according to mixing, presents a method of classifying estuaries on the basis of salinity change from top to bottom and classifies the Alsea at four different times of the year by the method presented.

(2) Chapman, D. W. *et al* (1961) - The purpose of this study on the Alsea Watershed was "... to learn how to obtain maximum productivity of a river basin for public good." It includes (a) a

water survey of fresh water yield, water quality and rainfall; (b) a soil-vegetation survey; and (c) a logging-aquatic resources study "... to determine the effects of two logging methods on physical and biotic characteristics of small coastal streams."

(3) Goodwin, C. R., E. W. Emmett and B. Glenne (1970) - This report summarizes the following tidal and physical characteristics data collected on the Alsea in the summer of 1969 by the Oregon State University Department of Civil Engineering: tidal elevations and peak times, tidal current velocities, estuary cross-sectional areas, tidal lag times, tidal prism volumes and tidal amplification factors.

(4) Giger, R. D. (1972) - This paper discusses the influence of estuary geometry, salinity, and temperature on the summer distribution and movements of upstream-migrating adult cutthroat trout in the Alsea and two other Oregon estuaries. It presents plots of salinity gradients from the mouth to the head of tide for a low and a high tide in winter, spring, and summer and a plot of the temperature gradient from the mouth to the head of tide for a summer high tide on the Alsea.

(5) Matson, A. L. (1972) - This study presents physical and chemical data (depth, temperature, salinity and dissolved oxygen) and zooplankton population statistics gathered in the Alsea Bay from September, 1966 to September 1968. It describes the relationships between these populations and the measured physical and chemical parameters.

(6) Percy, K. L. et al (1973) - This publication serves as a summary of known information concerning the physical, chemical and biological parameters as well as the natural resources of Oregon's estuaries. It also provides an extensive number of references in which to locate more detailed information.

(7) Oregon State Division of State Lands (1973) - This publication provides the following material on the larger Oregon estuaries including the Alsea: mean high tide and mean low tide surface areas, ownership and deed information, drainage basin areas and fresh water yields. It also contains a tideland map of the Alsea Bay, as well as maps of the other estuaries discussed.

(8) Schlicker, H. G. (1973) - This bulletin published by the Oregon Department of Geology and Mineral Industries presents geographical and geological information on the Alsea Estuary and its drainage basin. It includes a discussion on the topography, vegetation and land use of the Alsea Basin and the surrounding area and contains several maps depicting geological formations in the basin.

(9) Boley, S. L. (1974) - The purpose of this study was to determine a discharge coefficient value for the mouth of Alsea Bay. It also discusses circulation patterns and provides a tidal analysis of the bay.

(10) Weise, H. G. (1974) - This study presents a computer program which uses oblique aerial photographs of surface dye patches placed in estuaries to analyze estuarine circulation patterns

and diffusion. The program has been used with existing photographs of dye patches on the Alsea.

(11) Goodwin, C. R. (1974) - This study develops a one-dimensional computer model which uses a finite difference technique to predict the following estuarine tidal hydraulic parameters: tidal height, tidal lag time and maximum tidal current velocities. Data from the Alsea Estuary taken during a previous study, Goodwin, Emmett and Glenne (1970), were used to verify the model.

Although these other studies provide for much useful information on the Alsea Estuary no single report attempts to document historical, geological, tidal, physical and chemical data together. None of the water quality research previously conducted correlates salinity, temperature and dissolved oxygen data with the measured stage of the tide and the river flow. Previous research on the tidal dynamics of the estuary utilized data collected only during a short period in the summertime. Furthermore, there has been no study of the sediments in the lower portion of the estuary.

This report was intended to fill in some of the missing information as well as to provide a convenient compilation of the known information. In order to achieve these goals it was necessary to conduct the research in a specific manner and to review numerous documents. Tidal measurement data from four seasons was collected to verify NOAA tide prediction and to analyze more thoroughly tidal dynamics. Water quality data for each season was directly correlated to actual tide measurements and known river flows. Core samples of the bottom sediments were collected and analyzed for the winter and summer seasons. Finally, a summary of historical facts, a discussion of the geological setting and a physical description (which includes a list of all the known alterations) of the Alsea Estuary was assembled.

II. HISTORY

Geographical Setting

The Alsea Estuary, the ninth largest estuary on the Oregon Coast (Oregon State Division of State Lands), is located at 124°04'45" W. Longitude and 44°26'22" N. Latitude (Matson), approximately 130 miles south of the Columbia River (Percy)(see Figure 1). Water from the Alsea River and its tributaries drains through Alsea Bay to the Pacific Ocean. The mean surface area is approximately 1650 acres and the total estuary length is 15 miles. Table 1 gives information on the five population centers located along the estuary.

Table 1. Population centers along the Alsea Estuary (Percy, Oregon State Water Resources Board)

Name	Location (River Mile)	Population
Waldport, City of	South Shore Alsea Bay (0.1 to 2.7)	700
Bayview	North Shore Alsea Bay (2.2)	Rural
Little Albany	Alsea River (10.6)	50
Tidewater	North Bank Alsea River (11.7)	150
Little Switzerland	North Bank Alsea River (12.7)	Not Listed

Exploration and Settlement

Alsea is probably a corruption of Alsi the name of the Yakonan Indian tribe that originally inhabited the area adjacent to Alsea Bay (McArthur). The Alsea Indians were a peaceful tribe living in some

20 villages located on both sides of the bay (Johnson, J. E.). They hunted and fished the abundant game that lived along and in the bay. The 1750 population of Alsea Indians in the bay area was estimated at 6000, but by 1930 it was reduced to 9; the last full-blooded Alsea died in 1950 at Siletz, (Johnson, J. E.).

No doubt Captain Cook sighted the mouth of Alsea Bay when he sailed along the Oregon Coast in 1778. One of the first white men to explore the region on foot was Army Lt. Theodore Talbot who passed through the area in 1849 (Carey). In 1850 Lcdr. McArthur, captain of the survey ship "Ewing," examined Alsea Bay as part of the first survey of the Pacific Northwest Coast (U.S. Forest Service).

White settlers were slow to come to the region because the area along the coast from the Yaquina River south to the Yachats River was an Indian Reservation. In 1860 the first white settler, an Indian agent, came to the lower Alsea. Several more settlers came in 1865 to the bay and in 1871 a school was built (Fagan). By 1875 the Indians living in the portion of the reservation south of the Alsea River were forced to leave and the area was opened to homesteading (Johnson, J. E.). In 1881 the town of Waldport was officially established with its first post office (McArthur). The city name is believed to be a combination of the German word "wald" meaning forest and the English word "port" (Johnson, J. E.).

Settlement of the region along the upper reaches of the Alsea River preceded that of the area along the bay by nearly twenty years. As early as 1852 settlers came to the area near the present site of the town of Alsea on the North Fork, about fifty river miles from the coast. These early settlers engaged in farming and logging and built several saw mills (Fagan).

Early Use of the Alsea Bay

Prior to World War I commercial fishing was the principle occupation along Alsea Bay in addition to a small amount of logging and farming (Johnson, J. E.). Crabbing and salmon fishing were carried on in the bay, but, because of the shallow bar at the mouth, the bay was not used as a port for ocean-going fishing boats.

For several reasons early logging along the bay, and throughout the drainage basin as well, was on a small scale. Prior to 1850 wide-spread fires (among them the "Umpqua Fire" of 1846 which covered 450,000 acres including the present Waldport District) swept the Coast Range (U.S. Forest Service). As a result of these fires no large body of old growth timber remained to support profitable logging operations. Also, transportation of logs was extremely difficult because of lack of adequate roads and the fact that the Alsea River was not particularly suitable for log towing. Thus early logging was, by necessity, restricted to small, isolated stands of mature timber near usable water transportation (U. S. Forest Service). Nevertheless, several saw mills (the first in 1884) were built in or near Waldport (Johnson, J. E., Kauffman) and some logs were transported on the bay (Kauffman).

World War I created a demand for Sitka spruce lumber to be used in aircraft construction, so for the first time major organized logging operations started in the areas along the coast. Because only timber with straight grain was desired a form of selective logging was practiced and no extensive clear-cutting occurred. In order to transport the spruce timber from the Blodgett tract, 13,400 acres between the Alsea and the Yachats Rivers, to the mill at Toledo, the twenty-four mile long "Alsea Southern Railroad" was constructed from South Beach on the Yaquina River to Waldport in 1917. A wooden trestle bridge for the railroad was built across Alsea Bay at River Mile (RM) 1.8, just upstream of the mouth of Lints Slough. The bridge construction was a formidable task because of the difficulty of transporting timbers to its site on the bay. With the end of the war the demand for the spruce declined considerably, but the railroad was operated until 1936 when the track was torn up (U.S. Forest Service).

Transportation was a serious problem for the early residents of the lower Alsea region. No adequate roads connected Waldport with the outside world for a long time after the first settlers arrived. Newport was reached from Waldport by first taking a ferry across the bay and then traveling north along the beach wherever possible. Travel to the south was hindered by rocky Cape Perpetua. Farmers who lived along the upper Alsea brought their farm products down the river during periods of high flow in barges especially built for that purpose. These barges were torn apart and sold for lumber in Waldport (Johnson, J. E.). In 1872 residents from the upper Alsea blazed a trail to Tidewater and from there adequate depth made the river passable to Waldport (Johnson, J. E.). In 1919 the first wagon road along the Alsea was completed (U.S. Forest Service).

Maritime commerce was hindered by the bar at the mouth of the bay, but smaller, shallow-draft vessels occasionally visited Waldport. Several of these small vessels were built on Alsea Bay (Johnson, J. E., Fagan). Waldport never developed as a prosperous maritime trading port, however.

Some small industries flourished in the Waldport area for a time. In addition to the saw mills mentioned above there were at one time (1915) two salmon canneries, a creamery, a planning mill and an oar factory (Johnson, J. E.). Other early residents engaged in farming, ranching and dairying along the river and on the nearby coastal plains (Schlicker).

Present Use of Alsea Bay

Today Alsea Bay is utilized quite differently from its original use by the first white settlers. Commercial salmon fishing was outlawed in all streams south of the Columbia River by an Initiative Petition in November, 1956, thus ending that industry on the bay. A small amount of commercial crabbing is still being done on the bay; the annual yields for 1970 and 1971 both being slightly in excess of 3000 pounds (Percy). There are no longer any canneries in Waldport, and no ocean-going commercial fishing boats operate from the bay.

In the immediate vicinity of the bay there is not much logging at this time, but throughout the remainder of the drainage basin extensive logging operations are being conducted. It is estimated that over 90% of the basin is forested (Chapman, Matson & Percy) and much of that is part of the Siuslaw National Forest. No figures are available on the amount of timber annually harvested from the drainage basin, but Robert Maley, Timber Staff Officer of the U.S. Forest Service, estimates that the annual sustained productive capacity of the basin would be 65,000,000 board feet based on an estimated forested area of 250,000 acres. Alsea Bay has not been used for log rafting or towing since the last saw mill along the bay ceased operation in 1954 (Kauffman).

Logging operations in the Coast Range forests did not become large scale until World War II. It was not until this time that the second growth timber, which got its start between 1850 and 1870 after the great fires, was mature enough to harvest profitably. Also, it was not until World War II that the demand for second growth timber and the advent of truck logging along with improved roads made logging worthwhile in the Coast Range (Maley).

Probably the most significant change that has come to the Alsea Bay-Waldport area is the vastly improved highway system. Transportation to and from the region is no longer an ardous venture. The construction of the highway bridge across the bay at RM 0.9 in 1934 (DeSouza) and the completion of U.S. Highway 101 along the middle portion of the Oregon Coast in 1936 (Johnson, J. E.) made the area easily accessible. By 1940 an adequate highway, State Route 34, was completed along the river.

The new highways brought with them a new industry to Alsea Bay, recreation. The Alsea is the most popular stream of the Oregon

Mid-Coast Basin for sport fisherman (Percy). The estimated annual harvest of salmonoid fish (salmon, sea-run cutthroat and steelhead trout) from the estuary and river is 19,830 and of non-salmonoid fish from the estuary is 15,000 (Percy). Crabbing and clamming are also popular pastimes on the bay. There are several motels, trailer parks and restaurants in the bay area to accomodate tourists. Several commercial marinas, in addition to the Waldport city dock, and numerous private boat docks are located along the estuary from Waldport to Tidewater.

Besides the tourist-related businesses there are several other industries, mainly lumber-oriented, in the Alsea Bay vicinity. These businesses include: four logging companies, a cutting contractor, a plywood company, a manufacturer of railroad spike-hole plugs and a ready mix concrete company (Percy). None of these industrial-type activities make direct use of the estuary. The City of Waldport Zoning Ordinance of 1972 does discuss the permitted uses of Marine Industrial Zones, however the present City Zoning Map has no such zones designated.

In recent years farming in Lincoln County has declined because of higher costs. The high acidity and low nutrient value of the soil in many areas makes soil preparation expensive (Schlicker). At present only 25% of the land in the county suitable for agriculture is in fact being farmed (Schlicker).

An Oregon State Game Commision fish hatchery is located on Lints Slough. A dam located approximately one-half mile up the slough was completed in 1963 to impound the waters of the slough for the hatchery.

A series of sluice gates on the dam is used to regulate the depth and salinity of the pond. The purpose of the hatchery is to conduct the experimental raising of salmonoids in salt water (Keiski).

Also located on Lints Slough, downstream of the fish hatchery dam, is the City of Waldport Sewage Treatment Plant. The original plant built in 1949 at the same location provided primary treatment only. However, the new plant, completed in May, 1973, is a secondary activated sludge system which operates well within the limits established by the Oregon State Department of Environmental Quality (Becker). The outfall for the plant is located on Lints Slough just upstream of the Highway 34 bridge. There are no other legal sewage outfalls located on the bay.

Today, only recreational boaters and fisherman and the facilities to support their activities make direct use of the estuary. No industrial concerns actively use the bay; however, the effects of the wide-spread logging operations along the upper reaches of the watershed cannot be ignored. More discussion on this will come later.

III. PHYSICAL DESCRIPTION

Geological Setting

The geological setting of the Alsea River and Bay system is thoroughly described in the State of Oregon, Department of Geology and Mineral Industries Bulletin 81, Environmental Geology of Lincoln County, Oregon. The Alsea River Basin, which lies on the western slopes of the Coastal Range, is described in this publication as a region of "... rugged mountains with steep-sided stream valleys in the uplands ..." and "... narrow flood plains in the interior..." The Alsea River widens into the Alsea Bay near the mouth of Drift Creek at River Mile (RM) 5.1. The bay reaches its widest part at about RM 2.5 and narrows down again at the mouth to approximately 20% of its maximum width. In the widest section of the bay (7500 feet), at approximately RM 2, the main channel divides into two separate ones, the north and the south channels. The north channel, the smaller of the two, rejoins the larger south channel at RM 4.4 (see Figure 2, taken from the Oregon State Division of State Lands, Tideland Map of Alsea Bay).

Marine terraces composed of semi-consolidated uplifted beach sand border both sides of the bay from the mouth to approximately RM 5.1. These terraces are interrupted at several locations by siltstone deposits. In the bay itself there are numerous tidal flats composed of saturated fine sand and clayey silt deposits (Schlicker). These tidal flats, which are frequently submerged by high tides,

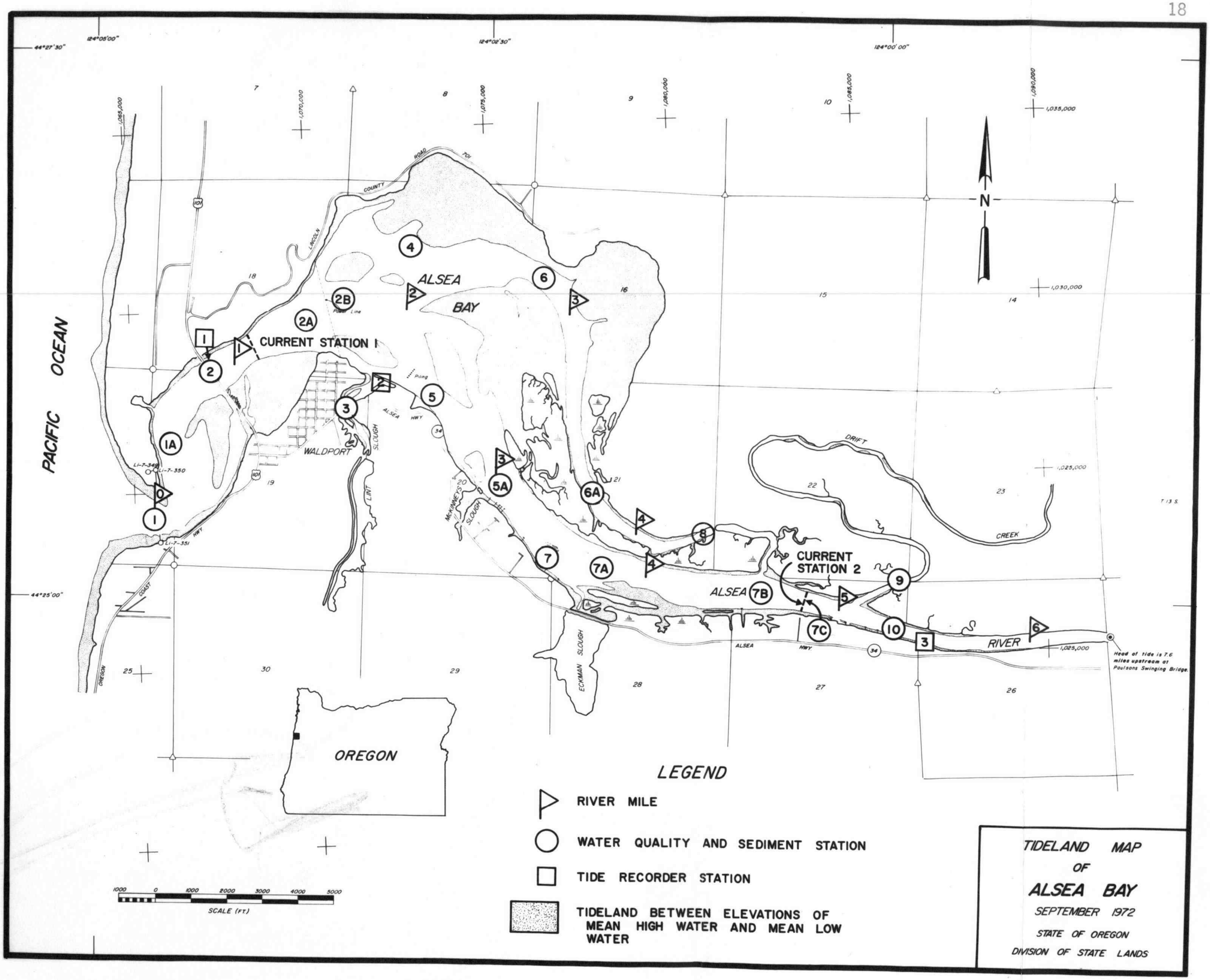


Figure 2. Map of the Alsea Estuary.

cover a large portion of the lower bay on both sides and extend upstream past the mouth of Drift Creek. A spit approximately 4000 feet long and 1000 feet wide extends from the north shore of the bay at the mouth. This spit, which is composed of unconsolidated fine to medium grain beach and dune sand, is an extension of the beach lying along the ocean shore just to the north of the mouth (Schlicker). The ocean shorelines immediately to the south and to the north of the mouth of Alsea Bay are both areas of critical marine erosion problems (Schlicker). J. W. Johnson (1973) describes the inlet of Alsea Bay as being "open", i.e. having free access to the ocean, and as being fully exposed to wave forces.

Physical Dimensions

The physical dimensions of an estuary at any given time are determined by the volume of water in the estuary at that time. This volume of water is, of course, a function of the fresh water flow into the estuary and the stage of the tide. Therefore, considerable variations in an estuary's widths and depths can occur during the short period of time from peak high tide to peak low tide, as well as from season to season.

Table 2 gives surface area values of Alsea Bay taken from the State of Oregon State Division of State Lands publication Oregon Estuaries. These areas were determined by planimeter from the State Lands' Tideland Map of Alsea Bay. All mapping and measurements were completed between February 1967 and March 1973.

Table 2. Reported surface areas of Alsea Bay (Oregon Division of State Lands)

Surface area (acres)	Measured at	Tidelands acres	Tidelands percent	Submerged lands acres	Submerged lands percent
2,146	MHT	979	46	1,168	54
1,168	MLT				

J. W. Johnson (1972) reported the surface area as 2140 acres at high water and Marriage (1958) reported the surface area, as affected by tidal action, to be 2,227 acres.

Figure 3, taken from Goodwin, Emmett and Glenne (1970) gives a plot of cross-sectional area versus river mile at mean higher high water (MHHW), mean lower low water (MLLW), and mean tide level (MTL). The value of the mouth cross-sectional area, 6.8×10^3 square feet, at mean tide level is in close agreement with J. W. Johnson's (1973) value of the throat cross-sectional area, 7×10^3 square feet at mean sea level.

Table 3 gives several values of estuary width at high water taken from the Division of State Lands (1973) Tidelands Map.

Table 3. Alsea Bay high water widths (Oregon Division of State Lands)

River Mile	Width (ft)	Location Description
0.0	1500	Mouth of bay
0.9	2600	Highway 101 bridge
1.8	6500	Mouth of Lints Slough
2.5	7500	Widest part of bay
3.0	1500	Mouth of Eckman Slough
5.1	700	Mouth of Drift Creek

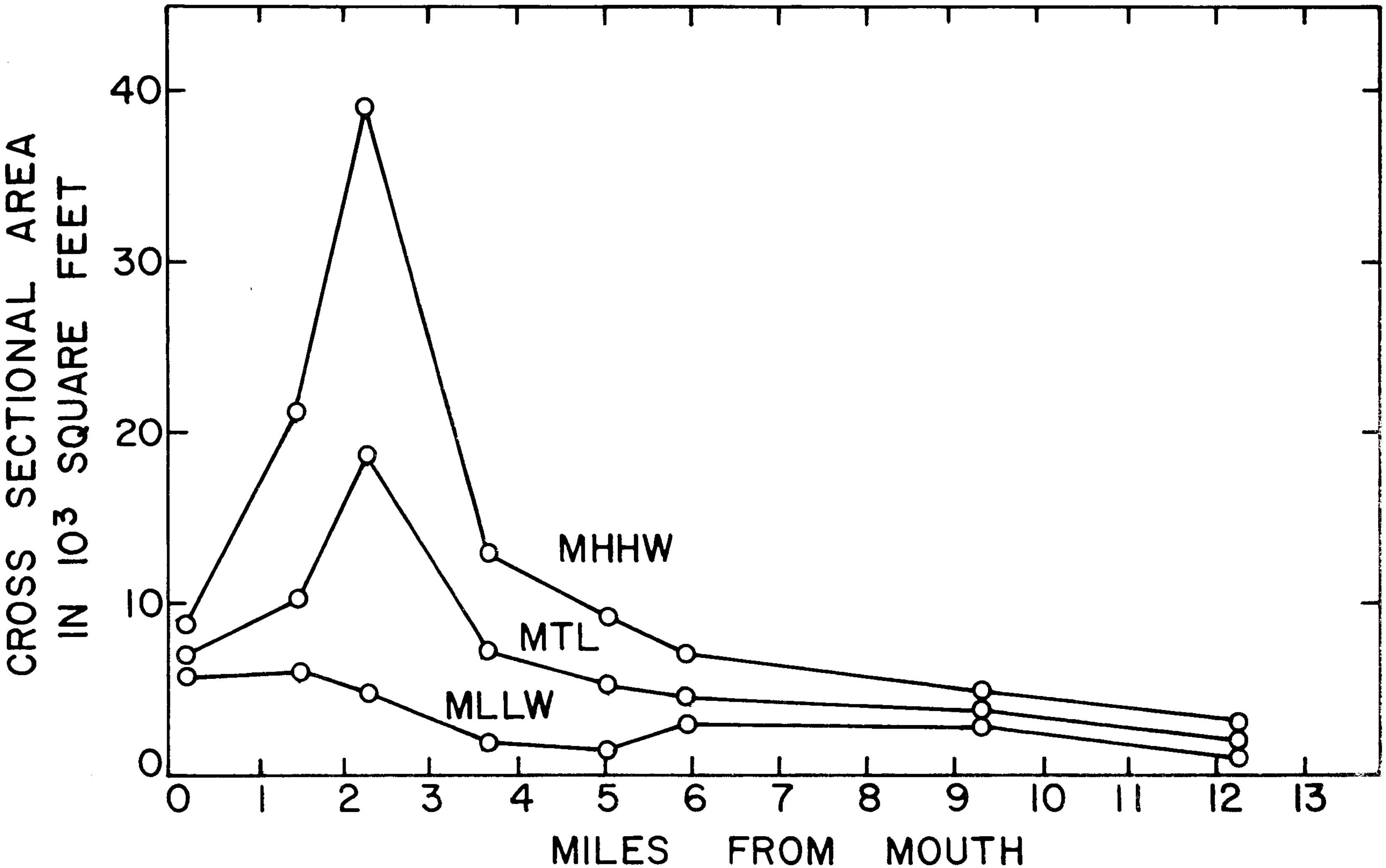


Figure 3. Cross sectional area vs. distance (Goodwin, C. R., E. W. Emmett and B. Glenne)

In general Alsea Bay is shallow throughout most sections, even along the channels. The deepest part of the bay is at the mouth where depths in excess of 35 feet were measured during the research. Matson (1973) also indicates measuring a depth in excess of 35 feet at the same location. Except for the channel that runs along the south shore of the bay, most of the section between RM 1.6 and RM 2.5 (the widest part of the bay) is very shallow with measured depths of less than 5 feet on high tides. During low tides much of this section is exposed tidal flat. The section near McKinney Slough, RM 3.0, can become quite shallow and even become impassable in a small boat at low tide during periods of low river flow (less than 100 cfs). Upstream of Eckman Slough, RM 3.8, in the narrower portion of the bay the depths increase making small boat passage easier. Upstream of Drift Creek, RM 5.1, depths were measured from 6 to 14 feet, depending on the tide stage and the river flow. The downstream end of the north channel, RM 2.5, is quite shallow all of the time since it passes through the section of the bay covered by tidal flats. Once upstream of the tidal flats the north channel deepens. Just downstream of the dam on the north channel, RM 4.44, depths were measured from 6 to 10 feet. More information on water depths is shown in Figures 16 through 19 which give the bottom depths of the water quality measurement stations.

The overall length of the Alsea River is 48.7 miles from the mouth to the confluence of the North and South Forks (Oregon State Water Resources Board). The bay portion of the estuary extends from the mouth to approximately RM 5.1. Several values for the distance to head of tide, the nominal head of the estuary, are given. Goodwin et al (1970) report this distance as 16 miles from the mouth. The U.S. Army Corps of Engineers (1973) reports a value of 15 miles. The Tideland Map of the Division of State Lands (1973) gives a value of 14.2 miles. Matson (1972) reports a value of 12+ nautical miles which is 13.7+ statute miles. These values have an approximate mean of 15 miles for the distance to head of tide. The exact distance to head of tide at any time is undoubtedly a function of tidal range and river flow.

Tides

The mean tide range, the difference in height between mean high water and mean low water, is 5.8 feet. The diurnal range, the difference in height between mean higher high water and mean lower low water, is 7.7 feet. The mean tide level, a plane midway between mean low water and mean high water, is 4.1 feet based on the U.S. Pacific Coast datum of mean lower low water (U.S. National Ocean Survey).

J. W. Johnson (1973) estimates the estuary's tidal prism, based on the volume of water between mean lower low water and mean higher high water, as 5×10^8 cubic feet. Goodwin et al (1970) gives the same value also based on the same definition, the volume between MLLW and MHHW. It should be pointed out that the actual volume of a tidal prism over a particular tidal cycle can be quite different from the value given above since tidal prism volume is a function of tidal range.

Drainage Basin

The 474 square mile drainage basin of the Alsea River and its tributaries includes portions of three counties: Lincoln, Benton and Lane. Except to the west, the basin is bounded on all sides by the Coast Range Mountains, with elevations ranging from sea level to 3000 feet (Percy). Adjacent river basins are the Yaquina to the north, the Willamette to the east and the Siuslaw to the south (Matson). Much of the basin lies in the Siuslaw National Forest; altogether, 62% of the basin is federally owned (Chapman et al). 94% (446 square miles) of the basin is covered by forests; 3% (14 square miles) is devoted to range and other uses (Percy). The dominate type of trees are conifers which include Western hemloc, Western red cedar, Sitka spruce and Douglas fir (Schlicker).

The annual fresh water yield of the drainage basin is estimated at 1,500,000 acre feet based on data collected from 1937 to 1963 (Percy). Precipitation in the basin is heavy, averaging 80 to 90 inches annually. Generally, the amount is lower along the coast where it averages 60 inches per year and it increases to 110 inches per year in the upper portions of the basin (Percy).

One U. S. Geological Survey stream gaging station is located at river mile 21.0 (drainage area 334 square miles) on the Alsea River. Another station was located on Drift Creek at mile 21.8 (drainage area 20.5 square miles), but its use was discontinued in 1970 (Percy). Table 4 summarizes stream flow records from these stations.

Table 4. Flow rates of the Alsea River and Drift Creek (Percy)

Stream	Complete water years of record	Flow rate (cfs) maximum	minimum	mean
Alsea River	1939-1970	41,800 12/64	45 9/65	1,534
Drift Creek	1957-1963 1966-1970 (discontinued)	2,500 10/62	3.8 9/58	120

During this study, for the periods when tide recorders were installed, Alsea River flows ranged from 95 cfs on July 26, 1973 to 20,700 cfs on November 16, 1973 (U. S. Geological Survey).

In addition to the Alsea River there are several other streams that contribute fresh water to the Alsea Estuary. The larger of these include: Lints Slough with its mouth at RM 1.8, Eckman Slough with its mouth at RM 3.8 and a drainage area of 10 square miles, and Drift Creek with its mouth at RM 5.1 and a drainage area of 69 square miles. Eleven smaller streams also drain into the estuary from the mouth to the head of tide (Oregon State Water Resources Board).

Classification

Several schemes have been developed to classify estuaries. Some of these methods make use of geological and geometrical parameters to define different types of estuaries. These approaches can be useful for some kinds of studies, but from a hydraulic point of view the best classification system is based on saltwater - fresh water mixing patterns.

There are three general types of estuaries in the Mixing Characteristic Classification System: (a) stratified (two-layered), (b) partially-mixed and (c) well-mixed (vertically homogenous). These descriptions are highly qualitative and the divisions between different types are somewhat arbitrarily selected.

In a stratified estuary the fresh water tends to flow over the top of the intruding saltwater, creating two distinct layers with a definite density interface between them. Because of this sharp gradient there is only slight vertical mixing. Above the interface the fresh water flow is always downstream, but below it there is an upstream saltwater flow during flood tide that may persist during ebb tide (Simmons).

In a partially-mixed estuary vertical mixing is more pronounced, although an interface (less well defined than in the stratified case) still exists. The current normally flows flood and ebb and the saltwater advances and retreats during the tidal cycle (Simmons).

The well-mixed estuary, too, has a barely detectable density interface, even though tidal forces dominate over fresh water flow. Salinities generally decrease upstream from the mouth and bottom salinities exceed surface ones by only 15-25%. The current flows ebb and flood and the point of maximum saltwater intrusion is determined by tidal forces (Simmons).

An estuary's mixing classification type can be determined by using two different criteria: either (a) the flow ratio or (b) the difference between surface and bottom salinities at a specified location.

The flow ratio is the volume of fresh water which enters an estuary during a tidal cycle divided by the tidal prism (Simmons). The tidal prism is the volume of sea water which is temporarily stored in an estuary during high tide and drains back to sea as the tide ebbs. The tidal prism volume, then, is a function of the tidal amplitude (Ippen I). A stratified estuary has a flow ratio value equal to or greater than one. A partially-mixed estuary has a flow ratio between 0.2 and 0.5. A well-mixed estuary has a flow ratio value of 0.1 or less (Simmons).

In the "salinity difference" method, which is outlined by Burt and McAlister (1959), the difference between bottom and surface salinities is measured during high tide at a location nearest the point in the estuary where the mean salinity is 17 parts per thousand (ppt), i.e. the point where the water is half fresh and half salt. An estuary with a difference equal to or greater than 20 ppt is stratified; one with a difference between 4 and 19 ppt is partially-mixed; and one with a difference equal to or less than 3 ppt is well-mixed.

The advantages of the flow ratio method are (1) no knowledge of salinity distribution is required; (2) fast, easy calculations can be made knowing only estuary surface areas, tidal ranges and periods (measured or predicted) and river flows; and (3) it gives an overall description of the estuary. The preciseness of the flow ratio calculation is limited by the accuracy of the input measurements, particularly the values of surface area. Also, it gives no information on specific locations within the estuary and says nothing about salinity gradients or density interfaces. Finally, the dividing lines between well-mixed and partially-mixed estuaries and between partially-mixed and stratified estuaries are rather broad.

The salinity difference method provides some information on salinity gradients, however, its meaningfulness is dependent upon the number and quality of salinity measurements. By presenting information at only one location along the estuary nothing is said about what is happening at other locations. Also, tide ranges and river flows are not taken into account.

Neither method considers the possibility that an estuary's characteristics may change along its length. For example, near the mouth, where turbulence is usually greatest, the estuary is likely to be well-mixed; but stratification may occur upstream, particularly where depth variations can cause saltwater to be trapped in pockets. Such saltwater "lenses", as found on the Alsea just upstream of Drift Creek, can create the false impression of stratification in an otherwise well or partially-mixed system if the mean salinity at the lens is near 17 ppt.

Estuary mixing characteristics are a function of the relative magnitudes of the tide and river momentum flux at a particular point and time. The energy required to mix salt and fresh water in an estuary is of tidal origin and this energy is approximately proportional to the square of the tidal range (Burt and McAlister). When river flow dominates tidal flow the estuary tends to become stratified, but when the tidal flow is much greater than the river flow the estuary tends to become well-mixed. Because of the temporal variations of both tidal and river flows, an estuary's classification can easily change from season to season. Even during a given season, when river flow may remain fairly constant, the classification of an Oregon estuary can change because the tidal range along the Pacific Northwest Coast can vary by a factor of four, or greater, from spring to neap tides.

Table 5 presents the mixing classification types of the Alsea Estuary on the four days in 1973 when water quality data was collected. It shows a comparison of the results between the flow ratio and the salinity difference methods. Values for the tidal prism in the flow ratio method were estimated by multiplying the mean of the Oregon State Division of State Lands (1973) high and low water surface areas by the measured tide ranges (from high to low) taken at the tide recorder station 2 and then subtracting from that product the volume of fresh water flow during the tidal cycle. Expressed mathematically the tidal prism, V_p, is:

$$V_p = \left(\frac{A_{hw} + A_{lw}}{2}\right)R_m - \bar{Q}_D P_m \qquad (1)$$

Where A_{hw} is the high water surface area, A_{lw} is the low water surface area, R_m is the measured tidal range, $\bar{Q}_D$ is the mean daily river flow and P_m is the measured period of the tidal cycle. The mean estuary surface area was found to be 72,178,920 square feet. Measured ranges from recorder station 2, RM 1.8, were used because this station was nearest the widest portion of the estuary. In order to make a meaningful comparison the flow ratios were estimated for the tidal cycle that included the high tide when salinity measurements were taken.

Table 5. Mixing classifications of the Alsea Estuary.

			Flow ratio method				
Season (date)	Range R_m (ft)	Period R_m (hrs)	Mean daily flow (cfs)	Total fresh water (ft^3)	Prism P_t (ft^3)	Flow ratio	Classification
winter 2/18/73	8.1	12.58	737	3.34×10^7	5.51×10^8	.061	well-mixed
spring 4/26/73	4.65	12.42	736	3.29×10^7	3.03×10^8	.11	well-mixed to partially-mixed
summer 7/17/73	3.8	11.75	104	4.40×10^6	2.70×10^8	.016	well-mixed
fall 12/4/73	5.3	13.72	3210	1.59×10^8	2.24×10^8	.71	partially-mixed to stratified

		Salinity difference method		
Season (date)	River mile	Mean salinity (ppt)	Salinity difference (ppt)	Classification
winter 2/18/73	5.34(s)	18.4	11.7	partially-mixed
spring 4/26/73	2.45(s)	20.3	21.8	stratified
summer 7/17/73	5.34(s)	20.9	9.4	partially-mixed
fall 12/4/73	2.45(s) 2.75(n)	21.5 17.9	22.7 27.5	stratified

The results in Table 5 indicate that the Alsea Estuary is well-mixed in the winter, well to partially-mixed in the spring, well-mixed in the summer and partially-mixed to stratified in the fall according to the flow ratio criteria. By comparison, the salinity difference criteria indicates that the estuary is partially mixed in the winter and summer and stratified in the spring and fall. It is interesting to compare the winter and spring results because these two seasons have identical fresh water flows of nearly 740 cfs, however the winter tide range of 8.1 is almost twice the spring range of 4.65. The effect of a varied tide range on a constant river flow can clearly be seen using either criteria. The high winter tide range dominates the river flow and the estuary tends to move towards a well-mixed system; whereas the low spring tide range allows the river flow to dominate and the estuary tends to move away from a well-mixed system.

Burt and McAlister (1959), using the salinity difference criteria, classify the Alsea Estuary as partially-mixed at four different times of the year. The months and the locations (in nautical miles from the mouth) of the station nearest to where mean salinity was 17 ppt are as follows: January, 1 nm; March, 2 nm; April, 3 nm; and October, 8 nm. The data was collected in 1957 and 1958 but the values of tidal range and river flow at the time of the measurements are not given.

Matson (1972) concludes from data taken throughout his two year study at all stages of the tide that the system is well-mixed at the mouth but tends to become stratified upstream.

High tide salinity gradient plots from the mouth to the head of tide shown in Giger (1972) indicate that the estuary tends toward stratification during the winter (2/9/68) and tends toward well-mixed during the summer (8/22/67). No river flow or tidal range data are given, however.

It would be improper to generalize about an estuary's seasonal classifications from one day's worth of data per season, particularly along the Oregon Coast. The tide records taken indicate that in a 14 day period tidal ranges can vary from 1.3 to 9 feet. River discharge records show that a change in river flow of 12,000 cfs can occur within twenty-four hours (U. S. Geological Survey). Such large changes in tidal range and river flow will have a significant effect on an estuary's mixing characteristics.

In spite of the large variations of tidal range and river flow which can occur during a season it is still possible to draw some conclusions about the Alsea's classification. The estuary tends toward stratification when the river flow is high (greater than 3000 cfs) and the tidal range is low (less than 4 feet). The estuary tends toward well-mixed when the river flow is low (less than 500 cfs) and the tide range is high (4 to 8 feet). Also, the estuary will always be stratified when river flow exceeds 14,000 cfs regardless of tidal range; and it will always be well-mixed when river flow is less than 300 cfs regardless of tidal range. The value of 14,000 cfs for the minimum river flow above which the estuary is always stratified was determined by estimating the maximum possible tidal prism volume

volume (based on a 9 foot tidal range), equating this to the total fresh water volume (i.e., the flow ratio value = 1) and solving for river flow. Likewise, the value of 300 cfs for the maximum river flow below which the estuary is always well-mixed was determined by estimating the minimum possible tidal prism volume (based on a 2 foot tidal range), equating this to 10 times the total fresh water volume (i.e., the flow ratio value = 0.1) and solving for river flow.

Alterations to the Estuary

No major man-made alterations have occurred to the Alsea River or the Alsea Bay. On the river itself there are no damns, hydro-electric plants or extensive floodworks such as levees or floodwalls (U. S. Army Corps of Engineers). There are no jetties at the mouth and dredging in the bay has been minimal. Because there has never been a great demand for maritime or riverine commerce on the Alsea, modifications have not been needed. Much of the information on the alterations that have taken place was provided by Larry Kauffman, former Port Commissioner of the Port of Alsea and long time resident of the Alsea Bay area. Other sources also provided information. All the known modifications are listed below in chronological order. The dates which are only approximate are so indicated. Refer to Figure 2 for locations.

1880's - Docks and seawalls were built along the south shore of the bay at the site of "old town" (RM 1.6), the center of early Waldport. In addition, some filling was done in this area as the settlement grew (Johnson, J. E.).

c.1914 - A wooden groin extending from the south shore two-thirds of the way across the bay was constructed just upstream of Eckman Slough, RM 3.8. Its purpose and by whom it was built are unknown. The last remaining pilings from this structure were removed in 1958 (Kauffman).

1917 - A wooden railroad trestle bridge was built across the bay just upstream of the mouth of Lints Slough, RM 1.8. Use of the bridge for rail traffic was discontinued in 1936 when the tracks were torn up (U.S. Forest Service). Apparently no attempt was made to remove the bridge and it was allowed to deteriorate naturally. Only remnants of the original pilings, which can be seen at low tide, still remain and present a hazard to navigation.

1934 - The U. S. Highway 101 bridge, with over 30 piers, was completed at RM 0.9 (DeSouza).

1940 - The Oregon Highway 34 bridge, with 2 piers, was completed at RM 8.4 (DeSouza).

1946 to 1971 - During this time span a portion of the tideland area around the mouth of Lints Slough was filled (Kauffman). Percy (1973) reports that altogether 24.75 acres of submersible land on the Alsea Estuary have been filled, primarily to improve marine recreational facilities on the east side of Waldport.

1948 - An attempt was made to blast open a channel along the south side of the estuary near the city docks, RM 1.6, to meet the existing south channel upstream (Percy, Matson).

1956 - One of the most significant alterations made to Alsea Bay was the damming of the upstream end of the north channel at RM 4.44 with an earthen dam. The purpose of this dam, which was financed by the Port of Alsea, was to divert the main river flow through the south channel and thus deepen it by hydraulic scouring. A year later wooden dikes were placed across two openings through the island which separates the south channel from the north one. With the addition of the dikes the upstream end of the north channel was completely blocked off (Kauffman).

c.1957 - The Oregon Highway 34 wooden trestle bridge across the mouth of Eckman Slough was replaced by an earthen dike with a flood gate (DeSouza). The impounded waters of the slough are now used for recreational purposes.

1963 - Using a clamshell dredge Kauffman dredged the south channel from RM 2.5 to the mouth of Lints Slough, RM 1.8. In this same year several small boat channels were excavated on the bay side of the spit at the mouth. These channels lead into a main channel which enters the bay at RM 0.5 (Kauffman). Also, at this time, the dam on Lints Slough was built to impound the water for the fish hatchery (Keiski).

1968 - A jetty parallel to the bay's south shore was built on the east side of the mouth of Lints Slough by the Owner of McKinley's Marina to improve his small boat moorage. By 1970 he filled much of the tide flat shoreward of the upstream end of the jetty (Kauffman).

1972 - The entrance to Lints Slough (RM 1.8) between the Highway 34 bridge and McKinley's Marina was dredged and spoils were placed on adjacent low lying areas to the North for mobile home plots (Sollitt).

IV. DATA COLLECTION AND REDUCTION METHODS

Tide Measurements

The tidal motion of the Alsea was measured with several goals in mind. First, it was desired to verify the accuracy of the NOAA Tide Table predictions. To do this it was necessary to locate a tide recorder at or near the location upon which the tide predictions are based. Second, tidal damping and tidal lag were to be measured. In order to examine these phenomena several tide recorders located along the estuary axis were required. Finally, it was necessary to measure the tide at several locations so that the water quality data and the tidal current flow data could be correlated with the actual stage of the tide.

The placement of tide recorders was limited by several factors. A tide recorder site had to be fairly accessible, always have water at all stages of the tide and had to be along the main channel of the estuary, if possible. Also, it was desirable to place the recorders where they would not be in danger of being tampered with by the general public. Three tide recorder stations were selected for this study (see Figure 2). Tide Recorder (TR) Station 1 was located at River Mile (RM) 0.9 on a main span pier of the Highway 101 Bridge. TR Station 2 was located at RM 1.8 on a dock at McKinley's Marina in the mouth of Lints Slough. This station was just upstream of the site of the predicted tides at RM 1.6. TR Station 3 was located at RM 5.47 on a dock at Oakland's Marina, just above the site of the farthest upstream water quality station and above Drift Creek. At

TR Station 1 a Bass pressure sensing tide recorder was used for the winter and spring periods and a Bristol "bubbler" recording tide gage, on loan from the National Oceanic and Atmospheric Administration (NOAA), was used for the summer and fall periods. Unfortunately, due to recorder malfunctions, only tide data for the summer season was recovered at TR Station 1. Leupold and Stevens float and chain tide recorders were used at TR Stations 2 and 3 for all seasons.

Tide data was collected for a minimum of 14 days during each season in order to ensure the measurements were taken for both spring and neap tides. The tide recorders were placed in operation prior to the intended day that water quality and current velocity measurements were to be taken since it was essential to have tidal data for that particular day. Because tidal ranges and times of tidal peaks (both high and low) were of primary interest it was not necessary to level in the recorders; therefore, absolute water level heights were not obtained. A local resident was employed to reset the two Stephens recorders each day of operation. Daily monitoring of the Bass and "bubbler" recorders was not required. All tide records were reduced and tabulated by hand.

Water Quality Measurements

The five water quality parameters measured were salinity, temperature, dissolved oxygen, turbidity and pH. In addition to providing information on the chemical nature of the estuarine waters, knowledge of these parameters also helped to explain other characteristics of the estuary as well. Salinity measurements are quite useful for determining an estuary's mixing patterns. To a lesser degree temperature measurements can also be used to examine mixing. Dissolved oxygen data provides important information on an estuary's ability to support life. Turbidity values provide a measurement of the amount of suspended matter in the estuary water. Since pH is affected by the chemical actions of plants and animals, measurement of it gives an indication of the degree of biological activity in the water. In order to determine the longitudinal variations of the water quality parameters, measurements were taken at various locations along the the axes of both the main (south) and north channels of the estuary. Because of time limitations the upstream extent of these measurements was approximately five miles.

Water quality data was collected from a fast, shallow draft aluminum boat. In situ measurements were taken at the bottom, mid-depth and surface with a Hydrolab Surveyor 5, an electronic device which measures water temperature, dissolved oxygen (DO), pH, and conductivity (salinity). Except for simple corrections to the DO values and conversion of the conductivity values to salinity values, the Hydrolab data required no further reduction. In addition to the Hydrolab measurements, a 4 bottle DO sampling canister was used to collect water samples from the bottom and mid-depth in 250 ml BOD bottles. Surface samples were collected by filling the 250 ml bottles directly with surface water after they were thoroughly rinsed. Samples were analyzed in the laboratory for salinity using a Bisset-Berman Hytech Model 6220 lab salinometer; for pH using a Leeds and Northrup lab pH meter; and turbidity using a Hach Model 1860A lab turbidimeter. DO was determined by the Winkler titration method as outlined in Standard Methods (American Public Health Assoc.).

Ten primary (Hydrolab and sample) and eight secondary (Hydrolab only) water quality stations were selected along the length of the estuary from the mouth, RM 0, to RM 5.34. See Table 6 and Figure 2 for the exact location of each station. Three of the primary and one of the secondary stations were located along the north channel. One of the primary stations was located up Lints Slough and another up Drift Creek. The remainder of the primary and secondary stations were located along the center line of the south or main channel.

Table 6. Alsea Estuary water quality stations.

Station number	Type (P or S)	River mile	Station Description
1	P	0.00	mouth of bay
1A	S	0.43	main channel
2	P	0.90	Highway 101 bridge
2A	S	1.46	main channel
2B	S	1.68	main channel
3	P	1.80	0.28 miles up Lints Slough
4	P	2.15	entrance to north channel
5	P	2.45	south channel
6	P	2.75	north channel
5A	S	3.06	south channel
7	P	3.47	south channel
7A	S	3.77	south channel
6A	S	3.88	north channel
7B	S	4.40	south channel
8	P	4.44	north channel (immediately downstream of dam)

Table 6. (cont.)

Station number	Type (P or S)	River mile	Station Description
7C	S	4.81	main channel
9	P	5.10	0.23 miles up Drift Creek
10	P	5.34	main channel

Water quality parameters were measured once each season for both a high and a low tide. The day selected for data collection was determined by the times of tidal peaks, since it was desirable to collect all the data during daylight hours. Therefore, each data collection day had a peak tide (either high or low) occurring shortly after sunrise and the next consecutive peak occurring in the early afternoon. Some consideration was given to choosing only data collection days with similar tide ranges, but the practical problems of daylight scheduling and manpower availability made this a secondary factor. In order to collect the water quality data as closely as possible to the time of peak tide occurrence at each station the water quality boat proceeded to the mouth prior to predicted peak time there and then headed upstream to the other stations with minimum delays enroute. In this way it was possible to proceed with the tidal wave as it progressed up the estuary and to sample high or low tide conditions at all stations.

Tidal Flow and Velocity Measurements

On the same day that water quality data was collected ebb and flood tidal current velocities were measured at two locations (see Figure 2) on the estuary in order to compare river and tidal flows, measure tidal lags and determine current reversal times. The lower current station was located at RM 1.12, upstream from the Highway 101 bridge. The upper current station was located at RM 4.81 just downstream from the mouth of Drift Creek. At each station four to five floats were placed approximately equidistant from each other on a line running laterally across the estuary. One and a half hours after the morning peak tide occurrence the measurement boats arrived at the two current stations and began making velocity measurements. The boats proceeded across the estuary stopping at each float to measure currents near the bottom, at 1 to 5 intermediate depths and near the surface. The total number of velocity measurements taken at each float depended on the overall depth at the float. Upon completion of a transit across the estuary, the boats returned to the first float and continued the process for a minimum of three hours or until a noticeable decrease in current velocities was detected. The same procedure was then repeated one and a half hours after the afternoon peak tide. Generally at least five transits were completed at both stations for an ebb tide and a flood tide during each season. By measuring currents during a three hour period midway between times of slack water it was possible to gather the necessary data with which to determine the time and the amount of peak tidal flow.

Depending upon the operating status and availability of equipment, a Gurley Model 667 saltwater (Price) current meter was generally used at the lower station and a Hydroproducts (Savonius) current meter system, composed of a Model 460A speed sensor and a Model 465B current direction sensor was used, at the upper station. The Price meter, which measures velocities by counting rotor revolutions over a set time period, provides no direction information unless its visible. The Savonius meter, however, provides an instantaneous measurement of both current velocity and direction. For these reasons the Savonius meter was used at the upper station whenever possible because of the greater likelihood of counter currents there.

Since the purpose of measuring current velocities was to gather data for calculating tidal flows, it was necessary at both stations to determine the distance from shore to each float, overall estuary width and bottom bathymetry. This was accomplished by using a transit to shoot horizontal angles from a measured baseline to determine station position and a sounding line to determine depths.

The selection of the current velocity stations was decided by several factors. A straight, level shoreline at least 500 feet long on which to lay out a satisfactory surveying baseline was necessary for both stations. Also, an estuary section that was not excessively wide and where flow was parallel to the channel center line was desired. In addition, an upper station downstream of Drift Creek and a lower station downstream of the last fresh water source, Lints Slough, were preferred. A suitable upper station was located at RM 4.81, but a suitable lower station was more difficult to establish. The estuary section from the Highway 101 bridge to the mouth was undesirable because of its great width and frequent choppiness. The section upstream of the public boat dock (RM 1.59) to Lints Slough was also too wide. In addition, it was necessary to stay away from the sections close to the public boat dock where the estuary converges and close to the Highway 101 bridge to avoid the flow interferences these two constrictions create. Thus the most suitable location was at RM 1.12. Unfortunately, the south shore at this section is a tidal flat, nearly 2000 feet wide, which is exposed at low tide, but is covered by approximately one foot of water at high tide. Because it would have been extremely difficult to measure flows in the sector over the tidal flat at high tide it was necessary to ignore its contribution to the flow. This is not an unreasonable assumption since the predominant flow is through the main channel north of this tidal flat.

In order to determine the tidal flow for each transit across the estuary it was first necessary to divide the estuary cross-section into separate segments whose dimensions were based upon the positions of the floats and the depths at which the velocities were measured. For example, all segments beneath float "n" had a width that extended between two vertical lines each of which was drawn halfway between "n" and the adjacent floats "n - 1" and "n + 1". The height for any segment encompassing a velocity measured at depth "m", was bounded by two horizontal lines, the bottom line equidistant between depth "m" and the next lower velocity measurement depth "m + 1" and the top line equidistant between depth "m" and the next higher velocity measurement depth "m - 1" (see Figure 4). The flow through a given segment was found by multiplying the one, and only one, velocity measured in that segment by its area. The flow values

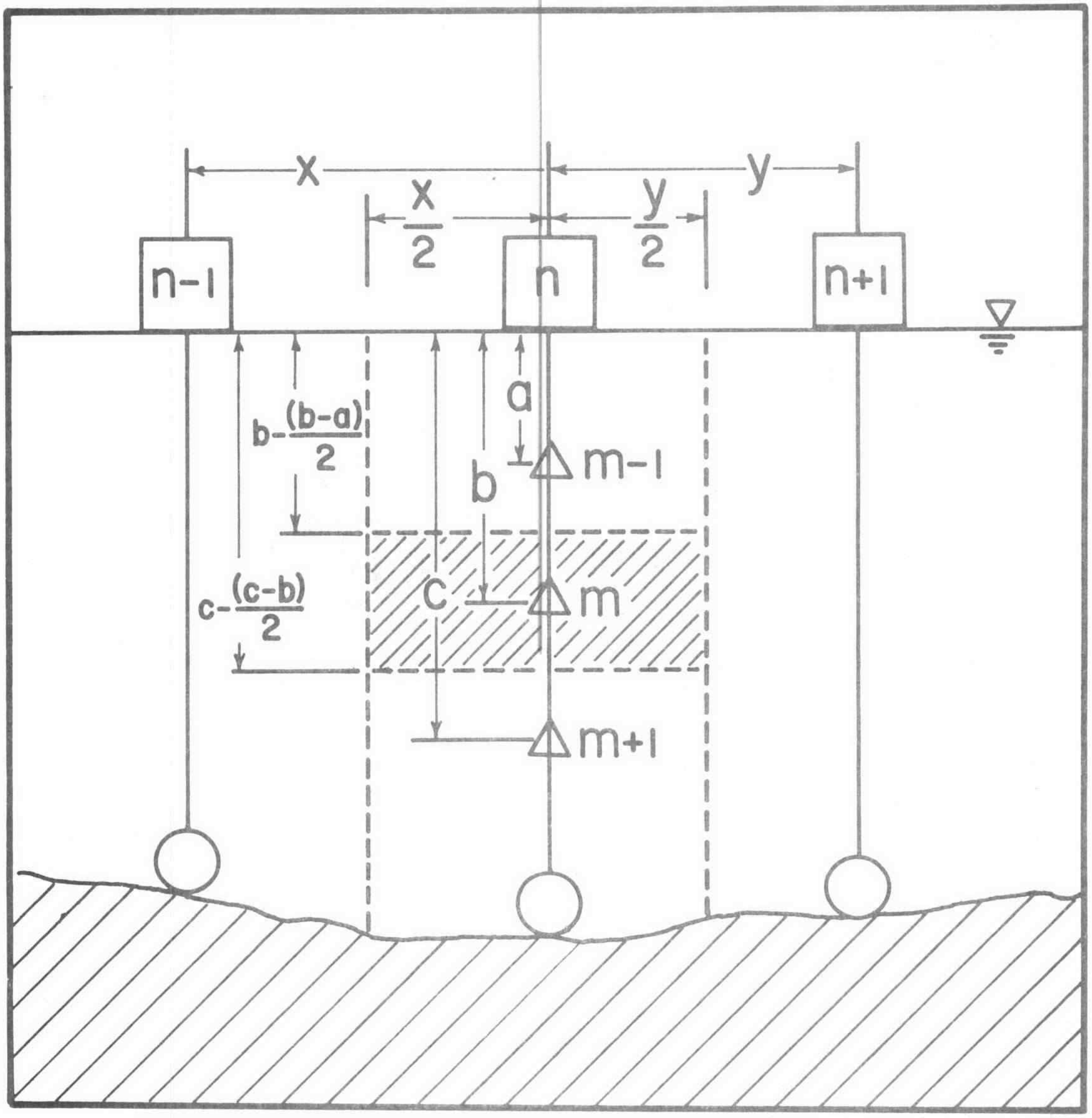


Figure 4. Diagram depicting area used to compute tidal flow.

for each segment of a particular transit were summed to give the total flow of that transit. The time assigned to the flow value of each transit was the mean of all the velocity measurement times taken during that transit. The average time to complete a transit was approximately thrity minutes. Use of a computer program written by C. E. Rauw (1975) greatly simplified the flow calculations.

Sediment Samples

In order to better understand the character and distribution of the Alsea's sediments, core samples were taken during the winter and summer seasons using a gravity coring device mounted on a specially built catamaran work boat. The core sample stations were identical to the primary water quality stations since these stations were known to be easily accessible during high tide and fairly evenly spaced along the center lines of the estuary channels. The core samples were sealed in acrylic liner tubes until they were ready to be analyzed in the laboratory for grain size distribution, volatile solids, specific gravity and porosity.

In preparation for analysis, after removal from its liner, each sample was cut into four inch lengths which were then air dryed and weighed. Because of time limitations only the top four inches of each core sample were analyzed. Each of these top segments were then divided into separate portions to be used for the grain size, volatile solid and specific gravity analyses. The grain size analysis was performed in accordance with the American Society for Testing and Materials (ASTM) standards, using a constant temperature hydrometer technique and seiving. Samples analyzed for volatile solids were first oven dryed at 110°C to eliminate hygroscopic moisture, weighed, then burned at 600°C to oxidize volatile materials, and then weighed again. Certain samples were analyzed for specific gravity using the standard ASTM method of water displacement in a pre-calibrated pyncometer. The porosity of each sample was calculated from its known volume, its air-dryed weight and its specific gravity.

Data Collection Difficulties

Malfunctions of data collecting devices and supporting equipment occasionally caused problems which handicapped the retrieval of data. As previously mentioned, the Bass tide recorder located at TR Station 1 failed to operate properly for two seasons and a "bubbler", also located there, worked improperly during another season. Consequently, tide data for that station was recovered for only one season. Infrequent problems with the Stevens tide recorders, such as a clogged pen or hungup cable, caused the loss of some data at TR Stations 2 and 3. However, because these stations were monitored daily the problems were readily corrected so that data loss was kept to a minimum.

Temporary failure of the Price current meters occurred several times, but timely repairs allowed the continuous measurement of currents during the critical portions of the tidal cycles. The Savonius current meter operated for the first three seasons, but malfunctioned during the last one and was replaced by a spare Price meter.

The Hydrolab Water Quality Monitor proved to be a highly reliable and sturdy piece of equipment. It functioned properly for all collection periods. However, the resulting data obtained did not always correlate with alternative laboratory analysis results.

Three portable citizen's band radios were a necessary part of the support equipment. They were used to assist with the surveying and to relay other important and emergency messages. Frequent weak batteries, however, often rendered them useless, thus hampering the research effort. Occasional boat motor breakdowns also hindered data collection; but, considering the severe operating conditions often encountered, these motors performed surprisingly well.

Fortunately, adverse weather conditions severe enough to require postponement of a data collection operation were encountered only once. A storm, accompanied by high winds, caused a one week delay of the fall water quality and data collection day. Concurrent research projects during the fall data collection period also placed a heavy strain on equipment and manpower assets. Because of the shortage of spare equipment and people during this period extraordinary demands were placed on research personnel.

V. TIDAL DYNAMICS

Introduction

Tide, the periodic rise and fall of the water level along sea coasts, is produced by the gravitational attraction of the sun and moon on the oceanic masses of water. Since the moon is much closer to the earth than the sun it exerts the dominant influence on the tides. When the sun and moon are in phase (full or new moon) spring tides occur resulting in greater than average tide ranges. However, when the sun and moon are not in phase (first and third quarter moon) neap tides occur resulting in smaller than average tide ranges. Spring tides occur approximately every two weeks.

The tides are extremely long waves with periods determined by the period of the primary forcing function, the moon's gravitational force. Because the length of the tidal waves is so great compared to the water depth, h, these waves can be regarded as shallow water waves that travel at a celerity $C = \sqrt{gh}$, where g = acceleration due to gravity and h = mean water depth. In general, the tidal waver period is approximately semi-diurnal with a value of 12.42 hours. The period of a tidal wave may be, however, modified by other factors, the most important of which is the natural fundamental period of the particular ocean basin involved. This natural period, P_n is determined by the geometry of the basin through the relationship $P_n = \frac{2L}{gh}$ where L is the basin length and h is the mean depth of the basin. The East Coast of the United States experiences semi-diurnal tides, the Gulf Coast experiences diurnal tides, and the West Coast has mixed tides, neither diurnal nor semi-diurnal.

Although mixed tides have two high waters and two low waters per day, as do semi-diurnal tides, they often have great inequalities in heights of successive tides. The sequence mixed tides follow is: higher high (HH) water to lower low (LL) water to lower high (LH) water to higher low (HL) water and then back to higher high water, starting the pattern over again. During part of the tidal month diurnal tides prevail causing the second tide of the day to be only a slight vertical movement of the water level, but at other times semi-diurnal tides prevail and the range of successive tides is approximately equal.

The height of a tidal wave is also affected by several factors. As previously mentioned, tidal height, in part, is determined by the position of the moon. Another important factor influencing tide height on a coast is the geometry of the adjacent ocean basin. A third factor that can alter tide heights is the amplification caused by storm surges. The effects of the moon's position and the ocean basin geometry are taken into account when predictions of tide height are made, but it is not always possible to account for meteorlogical conditions.

Tides have an important influence on estuaries. The vertical motion of water causes the development of horizontal currents which can become quite strong near estuary entrances. During the rising tide, water is forced into the estuary and a "flood" current moving in the upstream direction develops. During the falling tide, water is removed from the estuary and an "ebb" current moving in the down-is given by the integral (Harleman):

$$t = \int_0^x \frac{dx}{gh(x)} \tag{3}$$

During the flooding tide river water is stored in the estuary, thus causing an increase in the water depth; but, as soon as the tide begins to ebb this excess water is released and the water depth decreases. Therefore, the mean water dpeth, h, is greater during the flood tide than during the ebb tide. The amount of the increase in estuary mean water depth from the ebb to the flood tide depends upon the river flow. Equation (2) shows that the tidal wave travels faster during a flooding tide when mean water depth is greater than during an ebbing tide when mean depth is less. Furthermore, it can be seen from Equation (3) that, as a result of the difference in mean water depths, the duration of the ebb tide is longer than the duration of the flood tide.

If there is an impermeable barrier or a reduction in depth below critical depth at all stages of the tide, the incident tidal wave is reflected. The reflected wave travels down the estuary and is affected by estuary geometry and friction. The resultant tidal motion is the summation of the incident and reflected waves. The time of high water still occurs progressively later in the upstream direction, but in general the time difference is less than given by Equation (3). Such a tidal movement, where an incident and reflected wave are added together, is known as a cooscillating tide (Harleman). This type of tide would be expected to occur to some extent on the

Alsea, with its dam across the north channel and its series of rapids located at Tidewater.

The amplitude of a tidal wave traveling up an estuary is affected by the estuary's geometry in several ways. In a gradually converging estuary the wave amplitude tends to increase due to power conservation requirements. On the other hand, very rapid convergence can cause reflection from estuary side walls and reduce tidal wave amplitude. Finally, there is a reduction in amplitude due to the energy loss through boundary friction (Harleman). High river flows tend to modify estuary geometry and interfere directly with the wave propagation rate.

During the summer of 1969 Goodwin, Emmett and Glenne (1970) conducted research on the tidal dynamics of the Alsea Estuary. Using Stevens type tide recorders they measured tides during a 25 day period in August at three separate locations along the estuary: RM 1.9, RM 5.6 and RM 11.7. Also, on one day during that period they measured tidal current velocities over an entire tidal cycle at the tide recorder stations. Although they do not report the river flow for their research period it is presumed to be approximately 100 cfs based on the reported August mean of 104 cfs. Their report includes plots of cross sectional area, tidal observations, tidal amplification factors and tidal currents. The plot of tidal amplification versus distance from the mouth, which is reproduced in this study in Figure 5, is of particular interest. Tidal amplification factor, as defined by them, is the local tidal range divided by the tidal range at or near the mouth. This plot has six amplification factor curves

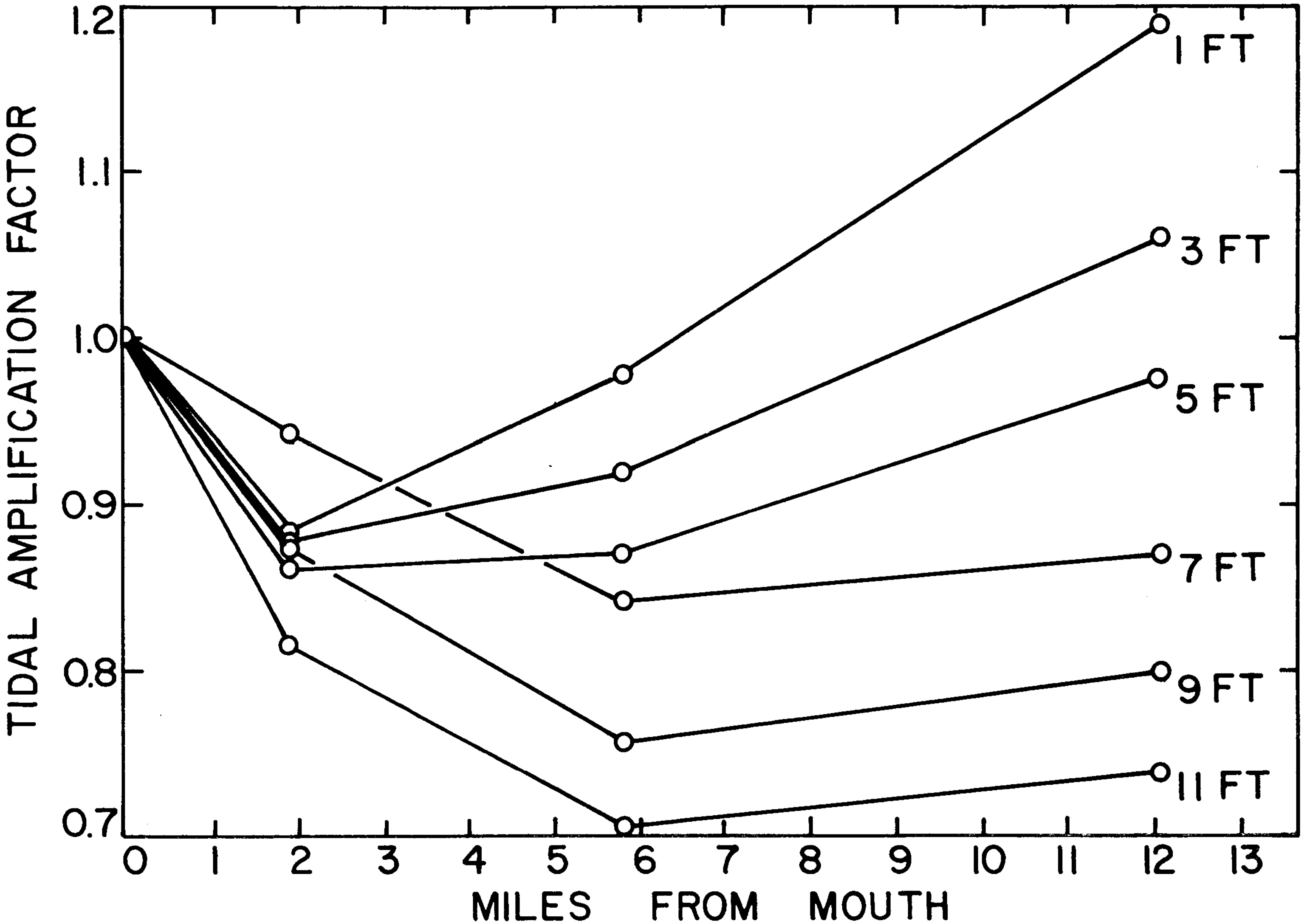


Figure 5. Tidal amplification factor vs. distance (Goodwin, C. R., E. W. Emmett and B. Glenne)

for tide ranges from one to eleven feet. These curves indicate a "choking", or reduction in tidal range compared to tides at the mouth, up to RM 5.6. It must be pointed out, however, that they did not measure tides at the mouth of the Alsea but compared their measured Alsea tides to the measured tides at Newport, nearly two miles upstream from the mouth of the Yaquina River. This fact creates doubts about the validity of this plot. Nevertheless, such a reduction in tidal amplitude could certainly be expected to occur near RM 1.9, as shown, since the estuary rapidly diverges into a large embayment at this point.

Evaluation of NOAA Tide Predictions

One of the purposes of this study was to investigate the reliability of the tidal range and tidal peak time predictions which are annually published in the National Oceanic and Atmospheric Administration (NOAA) Tide Tables, West Coast of North America and South America. These Tide Tables include the time and elevation (based on mean lower low water) of all high and low water for the Alsea throughout the calendar year. For smaller bays and estuaries, such as the Alsea, tide elevations are determined by applying correction factors to the predictions of a larger, primary station. The Alsea's correction factors are applied to the predictions for Humboldt Bay, California. These correction factors are: +25 minutes and +1.3 feet for high water, and +31 minutes and 0.0 feet for low water. It is apparent that this method cannot account for the effects of seasonal variations in meteorlogical conditions and river flow, since these factors vary with location and watershed characteristics.

The present day predictions of the Alsea tide height and time listed in the NOAA Tide Tables are based on U.S.C. & G.S. tide measurements made from April, 1933 to March 1934 at Waldport. The station at which the measurements were taken was located on the south side of the bay at RM 1.6 on the abandoned ferry dock.

Although, for this study, a tide recorder was not installed at the same site as the original U.S.C.&G.S. site, a recorder(TR Station 2) was installed 0.2 miles upstream on the same side of the bay, just inside the mouth of Lints Slough at McKinley's Marina, RM 1.8. It was felt that this recorder was sufficiently close to the site on which the predictions were based to make a reasonable comparison. Naturally, some difference could be expected since the study recorder was at a different location and not on the main channel. Altogether, 70 days' of tide records were collected during all four seasons of 1973. Occassionally, records were incomplete because of temporary tide recorder malfunction. As previously stated only ranges and peak times were measured by the recorders, and no absolute water levels were determined since the recorders were not leveled in.

Of the 114 ranges (high to low water only) measured at TR Station 2,104, or 91%, were within one foot of the predicted range; nine, or 8%, were within two feet of the predicted range; and only one, or less than 1%, was within three feet. Only 26, or 23%, of the measured ranges were greater than the predicted; and all of these were less than one foot greater. Table 7 gives the seasonal and overall means of the mean daily river flow, $(\bar{Q}_d)$, tidal range ratios and tidal lag times for all three tide recorder stations. The tidal range ratio for a particular station is defined as the measured range, R_m, for that station divided by the NOAA predicted range at Waldport, R_p, i.e. the range ratio is R_m/R_p. The tidal lag time, ΔT, for a particular station is defined as the measured time of high or low water for that particular station, T_m, minus the NOAA predicted time of high or low water at Waldport, T_p, i.e. $\Delta T = T_m - T_p$.

Table 7. Alsea estuary seasonal means of mean daily river flows, tidal range ratios and tidal lag times.

Season (Dates)	Mean of Q_d's (cfs)	Sta 1 (RM 0.9) Mean of R_m/R_p	Sta 1 (RM 0.9) Mean of $T_m - T_p$ (mins) HW	LW	Sta 2 (RM 1.8) Mean of R_m/R_p	Sta 2 (RM 1.8) Mean of $R_m - T_p$ (mins) HW	LW	Sta 3 (RM 5.6) Mean of R_m/R_p	Sta 3 (RM 5.6) Mean of T_m-T_p (mins) HW	LW
Winter 2/13/73-3/6/73	1071	-	-	-	.91	14	28	.92	36	85
Spring 4/12/73-4/26/73	900	-	-	-	.93	6	14	.90	21	86
Summer 7/10/73-7/26/73	110	.94	4	1	.92	2	14	.90	36	80
Fall 11/15/73-12/5/73	6867	-	-	-	.93	-12	16	.69	4	89
Overall	2442	-	-	-	.92	2	18	.83	27	85

The mean range ratio values given in Table 7 for TR Station 2 indicate that there is little change throughout the year from the overall mean of 0.92. However, the results of Figure 6, which is a

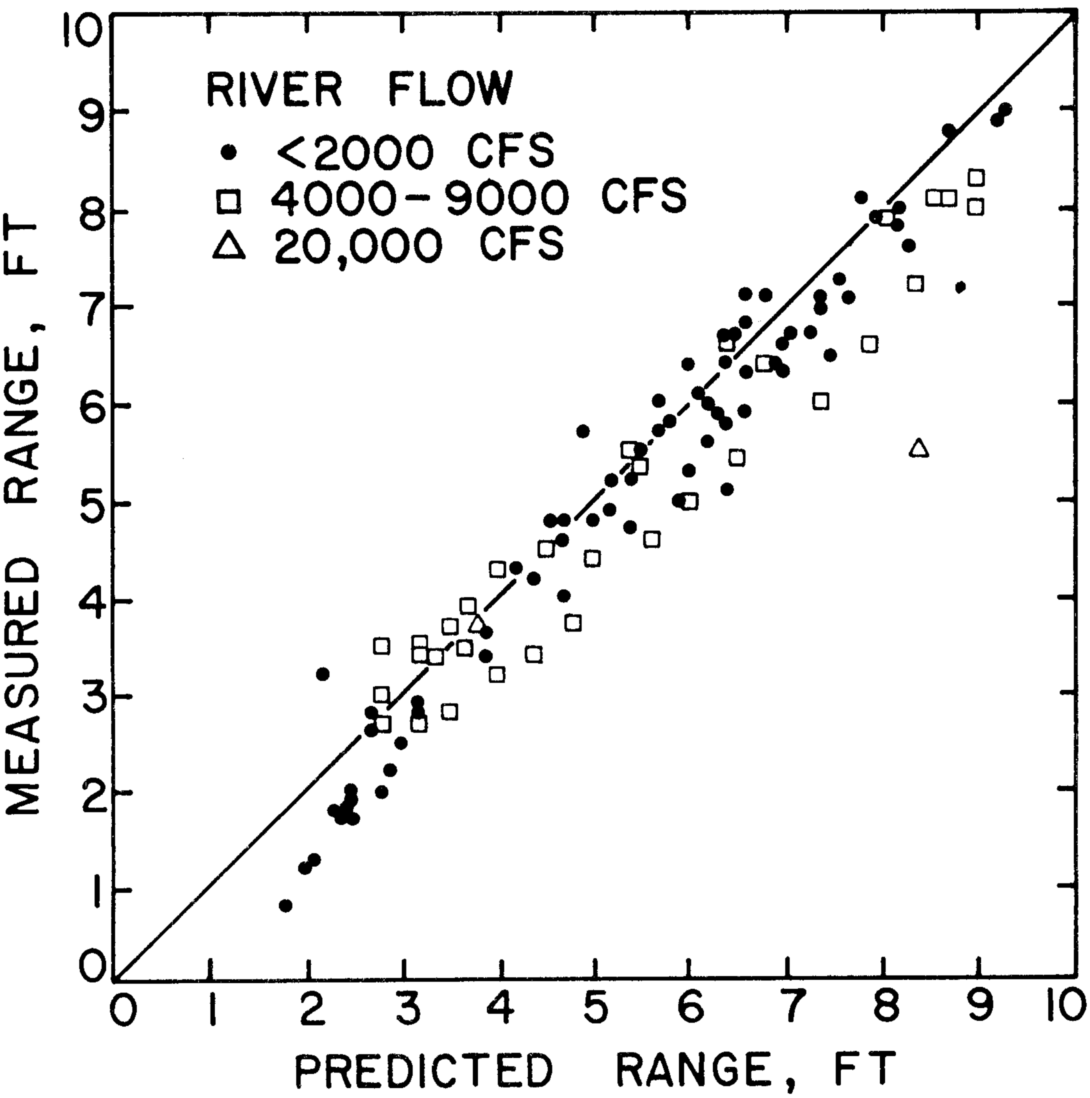


Figure 6. Measured range, TR Station 2 vs. predicted range, Waldport.

plot of measured range at TR Station 2 versus the NOAA predicted range at Waldport (with three river flow regimes indicated) for the entire year, must be considered. Generally, this figure supports the values given in Table 7 in that it shows the majority of points falling just below the $R_m = R_p$ line. The only point falling well below this line occurred at a predicted range of 8.4 feet when the river flow was 20,000 cfs. The only other point at 20,000 cfs is for an $R_p = R_m = 3.8$ feet. This would seem to indicate that high ranges (greater than four feet) are significantly damped at TR Station 2 by very high river flows, but more evidence than one data point is needed to confirm this. Table 7 does show that the mean range ratio for the fall, the period of highest river flow is 0.93; however, nearly all the tide records for that period were taken when the river flow was between 3000 to 4000 cfs, and only two ranges were measured at 20,000 cfs. Therefore, in general, when the river flow is less than 10,000 cfs the actual tide ranges in the lower portion of the estuary can be expected to be approximately 90% of the predicted value and to be within one foot of the predicted value 90% of the time.

Figure 7, a frequency histogram of the TR Station 2 lag times, shows the distribution of high and low water lag times throughout the entire year. This figure shows that 54% of the high water lag times were within ± 15 minutes of the predicted high water times, 79% were within ± 25 minutes and 100% were within ± 45 minutes. For the low water lag times it shows that 41% were within ± 15 minutes of the predicted low water time, 59% were within ± 25 minutes and 100% were

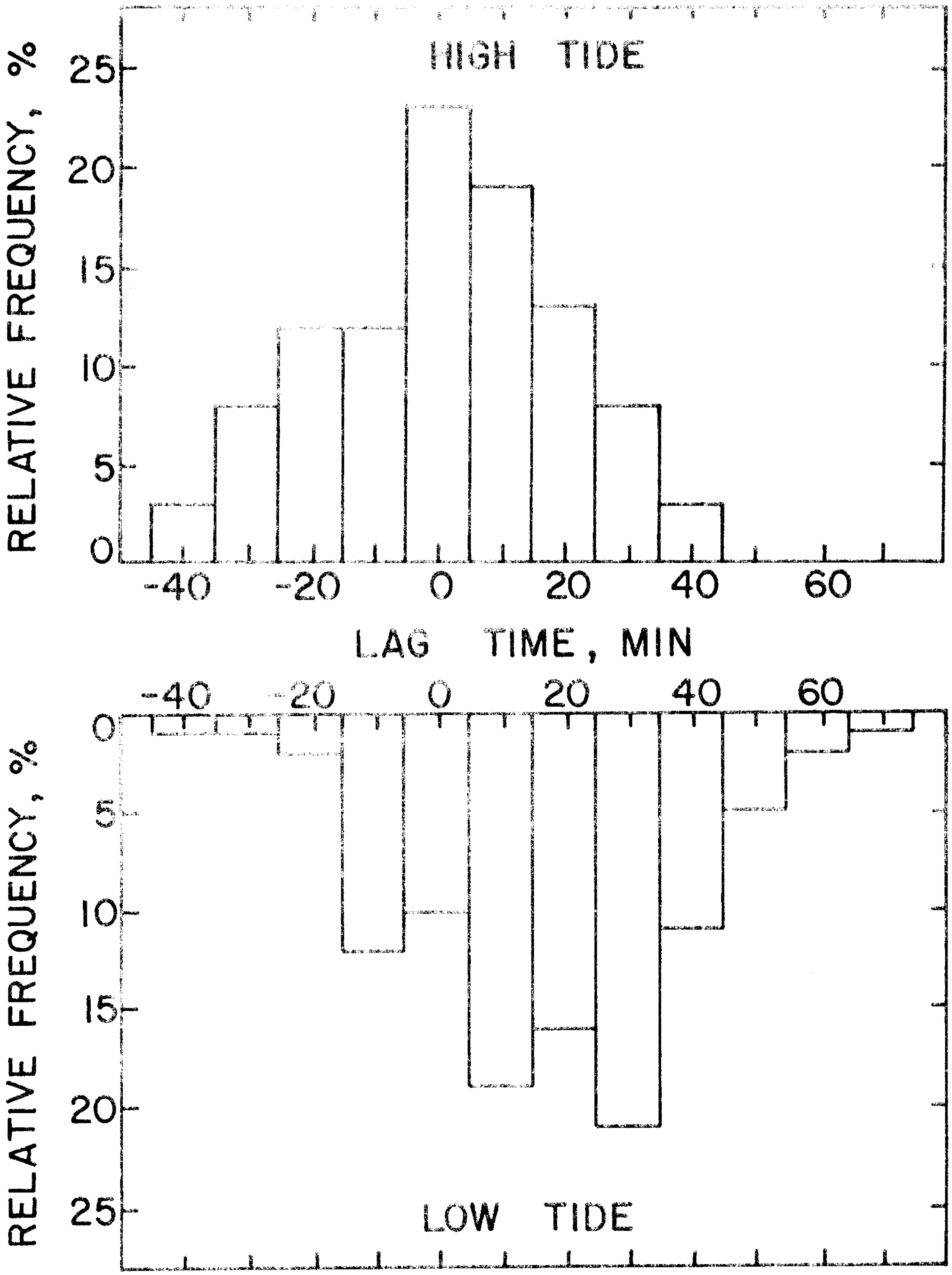


Figure 7. Frequency histogram of tidal lag time, TR Station 2.

within +75 minutes and -45 minutes. 56% of the low water lag times fell between +5 to +35 minutes. The means of the high water lag times for TR Station 2 shown in Table 7 indicate some seasonal variation from the overall mean of +2 minutes. This variation is particularly evident for the fall when the mean was -12 minutes. This fall mean value can be explained by the fact that during this period of higher river flow the depths in the estuary were greater than normal causing the tidal wave to travel faster than it did during low river flow periods. This resulted in high water times that occured earlier than predicted. On the other hand, during the summer low river flow period the mean of the high water lag times was only +2 minutes. The seasonal means of the low water lag times show much less variation than the means of the high water lag times, indicating that the seasonal variations of low water depths have little effect on low water lag times. Except for the fall mean of the high water lag times all the lag time means were positive, a result that was expected since TR Station 2 is upstream of the location on which the predictions were based. Also, the means of the low water lag times were greater than the high water means since apparently the tidal wave celerity decreases during the ebbing tide when the estuary mean water depth is less.

The tide measurements made at TR Station 2 strongly support the predicted values given in the NOAA Tide Tables. With the possible exception of high ranges (greater than four feet) at very high river flows (greater than 10,000 cfs), the predicted range values are quite accurate for the lower portion of the estuary. The 10% reduction in measured ranges from predicted ranges can be explained by noting from Figure 2, the map of the estuary, that TR Station 2 is located where the estuary is approximately 3900 feet wide at high water and the site of the predicted tides is located where the estuary is approximately 2100 feet wide at high water. This divergence of the estuary would cause the amplitude of the tidal wave to be less than predicted. Also, the map shows that the high water width at TR Station 1 is approximately 2700 feet. The mean of the summer range ratios at that station was 0.94 indicating that the tidal wave range was also generally less than the predicted value. It is possible that the amplitude of the tidal wave increases as it passes through the narrower point of the estuary at RM 1.6, the site of the predicted tides.

The predicted times of high and low water are generally a reliable estimate of the actual times of high and low water. A slight adjustment, however, should be made to high water times for periods of very high river flow, since during these periods high tide generally occurs earlier than predicted. It should be noted that when an individual tide range and peak time is considerably different from the predicted values it is not always possible to determine whether the difference is the result of an inherent error in the prediction process or the result of some other factor such as storm surge at sea or unusual river flow.

Tidal Damping

The change in amplitude of a tidal wave as it propagates up the estuary depends upon the estuarine geometry and the boundary friction.

Friction dissipates the energy in the wave and thus reduces the amplitude. Convergence tends to increase tidal wave amplitude, but too rapid convergence causes reflections which reduce amplitude (Harleman). Divergence tends to reduce tidal wave amplitude.

Figure 6, the measured range at TR Station 2 versus the Waldport predicted range indicates that there is little damping of the tidal wave in the lower portion of the estuary with the possible exception of high ranges (greater than four feet) at very high river flows (greater than 10,000 cfs). Since TR Station 2 is downstream of the major portion of the embayment section, the tidal ranges there apparently are not affected by river flow unless it is extremely high. However, Figure 8, TR Station 3 (RM 5.6) measured range versus the NOAA Waldport predicted range for the entire year, shows definite damping of high tide ranges (greater than four feet) when river flow exceeds approximately 3000 cfs. Table 7 shows little variation from 0.90 in the TR Station 3 range ratio means for the winter, spring and summer seasons when river flow was always less than 2000 cfs, but there is a definite decrease of the seasonal mean to 0.69 for the fall when river flows ranged from 3000 to 20,000 cfs. Table 8 gives the TR Station 3 seasonal mean range ratios for predicted ranges less than or equal to four feet and predicted ranges greater than four feet. Also given in this table are the combined results of spring and winter, the two periods which had very similar river flows. The values shown in Table 8 indicate that there is little significant difference between the range ratios for predicted tides less than or equal to four feet and predicted tides greater than four feet for all three

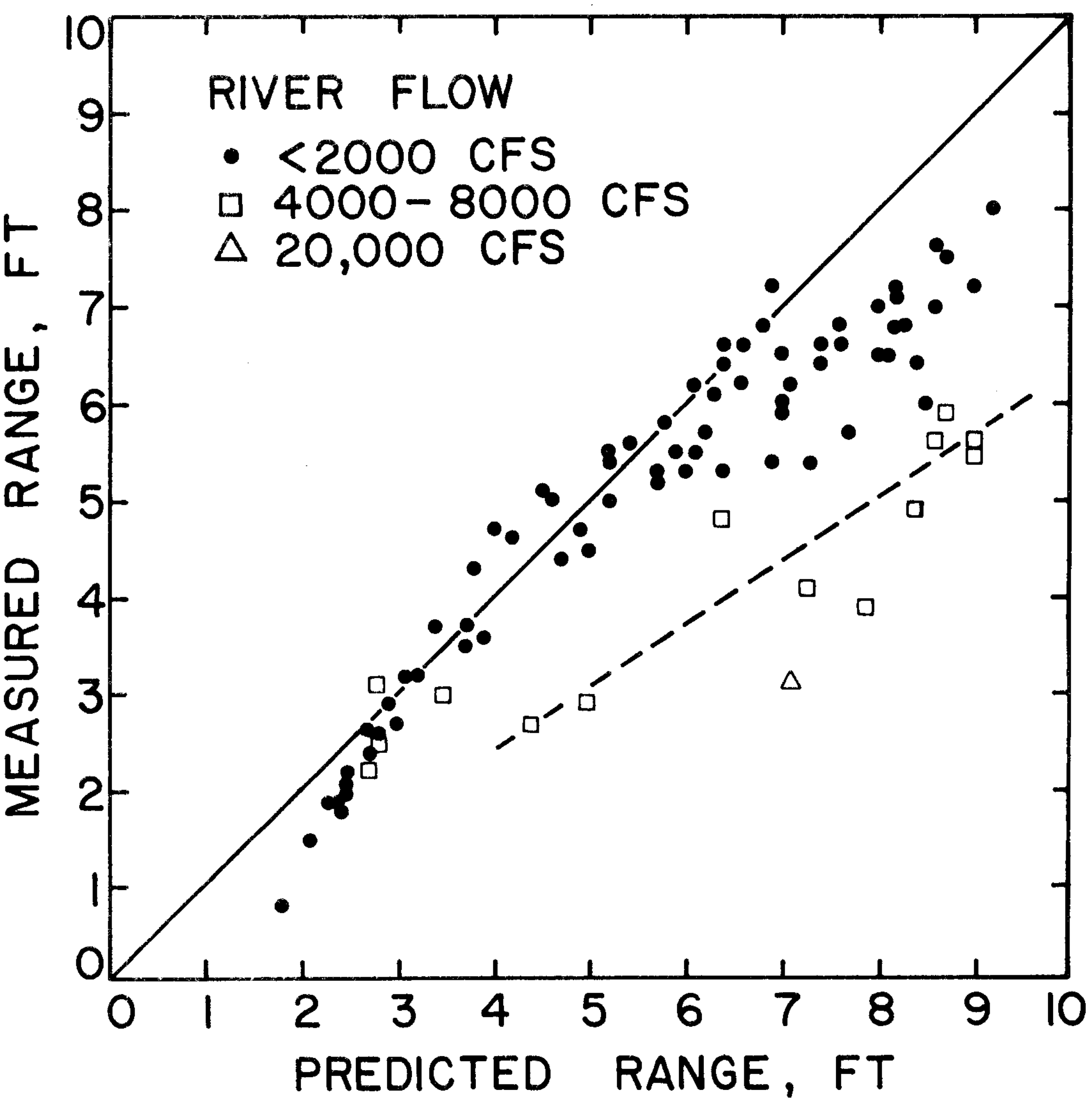


Figure 8. Measured range, TR Station 3 vs. predicted range, Waldport.

periods when river flow is less than 2000 cfs. However, a noticeable drop in range ratios for tides greater than four feet is apparent during the fall when river flows ranged from 3000 to 20,000 cfs.

Table 8. Seasonal means of range ratio at TR Station 3 (RM 5.6).

Season	Mean of $\overline{Q}_d$'s (cfs)	Mean of R_m/R_p $R_p \leq 4$ ft	Mean of R_m/R_p $R_p > 4$ ft
Winter	1071	.84	.95
Spring	900	.97	.88
Winter & Spring	1002	.90	.91
Summer	110	.92	.86
Fall	6867	.86	.59

When river flow exceeds 3000 cfs more water remains in the estuary throughout the tidal cycle, particularly in the large embayment between RM 2.0 and RM 3.0 (see Figure 2). Much of the tideland that is exposed during the low tides of normal river flow periods is probably covered during the low tides of high river flow periods, thus greatly modifying the low water geometry of the estuary. This larger than normal volume of fresh water plus the amount of sea water brought in by a tide with less than a four foot range, however, does not provide a sufficient total volume of water to alter the high water geometry to the point where it significantly influences the tidal wave amplitude. But tides in excess of a four foot range bring in enough sea water, which when added to the large amount of fresh water already present, provide enough total water to noticeably change the high water geometry of the embayment. The larger than normal volume of water in the embayment during these high tide range, high river flow conditions spreads out and increases the surface area of the embayment. This results in an increased shoreline length of the embayment, particularly on the north side where the shore has a shallow slope.

This altered geometry affects the incident tidal wave in several ways as it proceeds up the estuary into the embayment section. First, the wave experiences a reduction in amplitude caused by the divergence of the estuary. This reduction is probably more pronounced than usual since, due to the added fresh water, the cross-sectional width is greater than the normal low tide cross-sectional width. Second, the greater shoreline length and additional area covered by a very shallow layer of water increase the frictional losses of the tidal wave, causing further damping. Finally, because the cross-sectional width of the embayment is greater than normal it converges more rapidly than usual at the upstream end, RM 3, where the estuary width is fairly constant at all river flows. This rapid convergence probably causes refelctions which also diminish the transmitted tidal wave. Thus, the damping that was noted at TR Station 3 when the predicted tide range exceeded four feet and the river flow exceeded 3000 cfs occurred because the greater than normal amount of water contained in the embayment between RM 2 and RM 3 acted to absorb a significant portion of the propagating tidal wave's energy. No noticeable damping was detected at TR Station 2, which is downstream of the embayment, except for the reduced amplitude of the only measured range exceeding four feet at 20,000 cfs. At this river flow it is possible that the damping effects of the embayment are even felt at TR Station 2.

Tidal Lag

In an estuary where no reflection occurs, a tidal wave propagates upstream as a progressive wave and is eventually damped out by friction. In such a case an estimate of the wave's celerity between any two points along the estuary axis can be determined from the shallow water wave celerity expression $C = \sqrt{g\bar{h}}$ where $\bar{h}$ equals the mean depth between the two points. Knowing the wave celerity and the distance, x, between the two points the time of wave travel is easily calculated by the expression $T = x/C$. To determine high water lag time between the two points the mean water depth that exists during flood tide is used; and to determine low water lag time the mean water depth that exists during ebb tide is used.

If perfect reflection of the tidal wave occurs a standing wave is set up in the estuary. In this case high water occurs everywhere throughout the estuary at the same time, as does low water. At the locations which coincide with the nodes of the standing wave there will be no change in the water level whatsoever.

In order to determine whether or not the tidal wave behave like a progressive wave, the measured celerities between TR Station 2 and TR Station 3 were used to compute calculated mean depths between the stations for the tides occurring on the data collection days. Each calculated mean depth was then compared to the measured mean depth between the stations. The measured celerities were found by dividing the known distance, 20,000 feet, by the measured time differences of the high or low waters between the stations. Each measured mean depth used in the comparison was determined for each tide by taking the mean of the bottom depths observed during that tide at all the main channel water quality stations between the two tide recorder stations. The results of this comparison are shown in Table 9.

Table 9. Alsea measured tidal wave celerity, calculated mean depth and measured mean depth.

Season (date)	Tide (H or L)	Time difference (mins)	Wave celerity (fps)	Calculated mean depth (ft)	Measured mean depth (ft)
winter	H	13	25.6	20.4	15
2/18/73	L	73	4.6	0.7	10
Spring	H	-	-	-	7
4/26/73	L	-	-	-	6
Summer	H	10	33.3	34.5	10
7/17/73	L	75	4.4	0.6	7
Fall	H	-	-	-	15
12/4/73	L	55	6.1	1.1	11

It is readily apparent from the comparison of calculated mean depths to measured mean depths that the tide behavior in the Alsea does not follow the motion of a progressive wave. Since comparison between tide measurements made at TR Station 2 and TR Station 3 show that at TR Station 3 the time of high water can occur as much as one hour later and the time of low water can occur as much as two hours later than at TR Station 2, it is also apparent that the tide wave is not a standing wave either. In fact, the tide is some complex, multi-reflected, variably-damped wave that does not behave according to simple theoretical analysis. Furthermore, any changes in estuarine geometry brought about by river flow and tide range variations tend to modify the wave's behavior from day to day.

Figure 9 is a frequency histogram of the TR Station 3 lag times (T_{m3} - T_p) for the entire year. This figure shows that 68% of the TR Station 3 high water lag times fall between +5 and +45 minutes and that 100% of the high water lag times fall between -35 to +85 minutes. Table 7 shows there is little variation for the seasonal mean of the TR Station 3 high water lag times for the winter, spring and summer when river flows were all less than 2000 cfs. However, in the fall when river flows ranged from 3000 to 20,000 cfs, the seasonal mean of the high water lag times dropped down to +4 minutes from the previous values which were all greater than +20 minutes. The greater water depths in the estuary during this period of higher river flows caused an increase in the celerity of the tidal wave crest so that high water times at TR Station 3 occurred sooner than normal.

As shown in Figure 9, the distribution of the low water lag times at TR Station 3 was more spread out than the high water lag times. This figure shows that 48% of the low water lag times at TR Station 3 occur between +85 to +125 minutes and 100% occur between -5 to +165 minutes. The Table 7 seasonal means of the TR Station 3 low water lag times indicates there is little seasonal variation from one period to another. These means all range from +80 to +89 minutes,

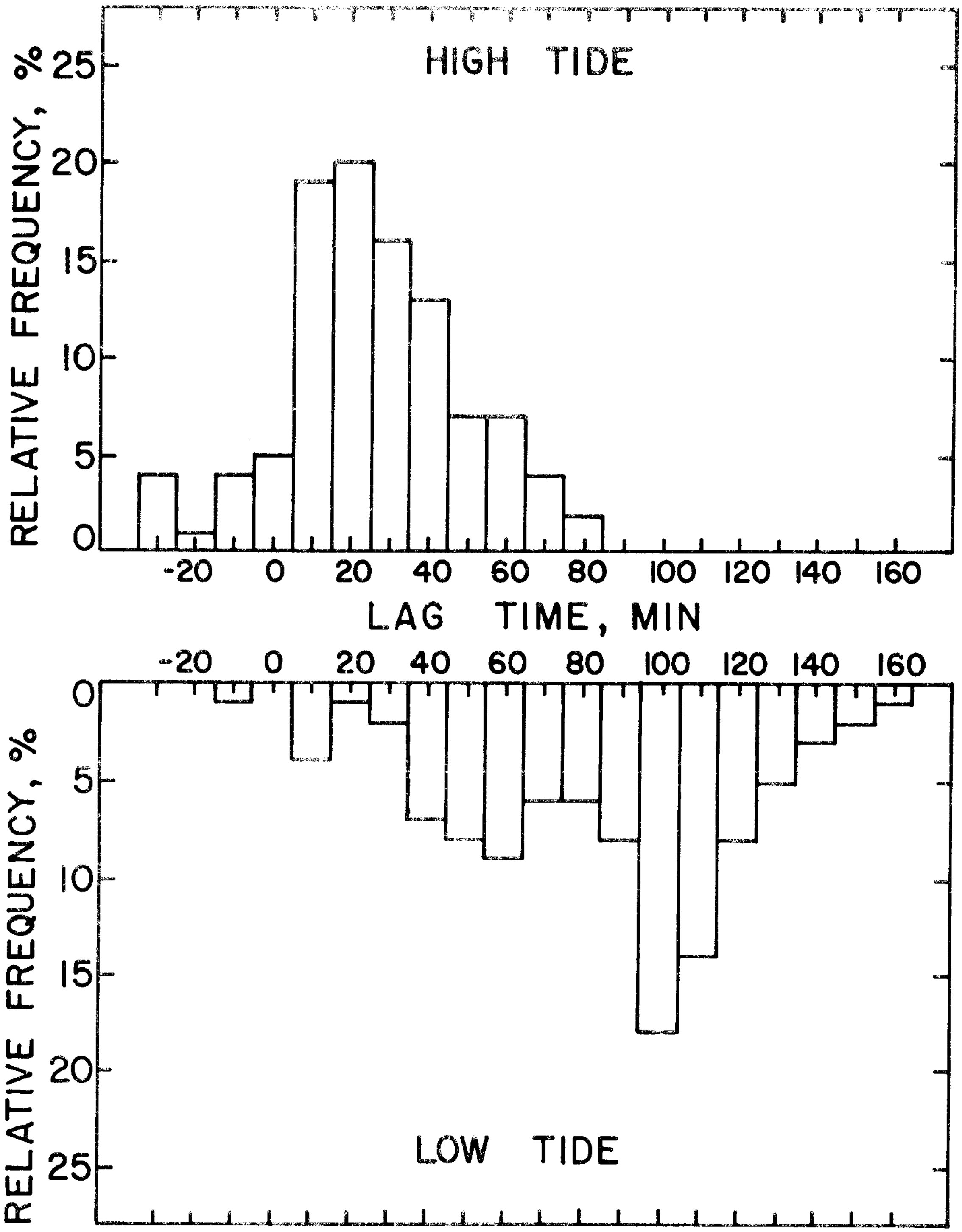


Figure 9. Frequency histogram of tidal lag time, TR Station 3.

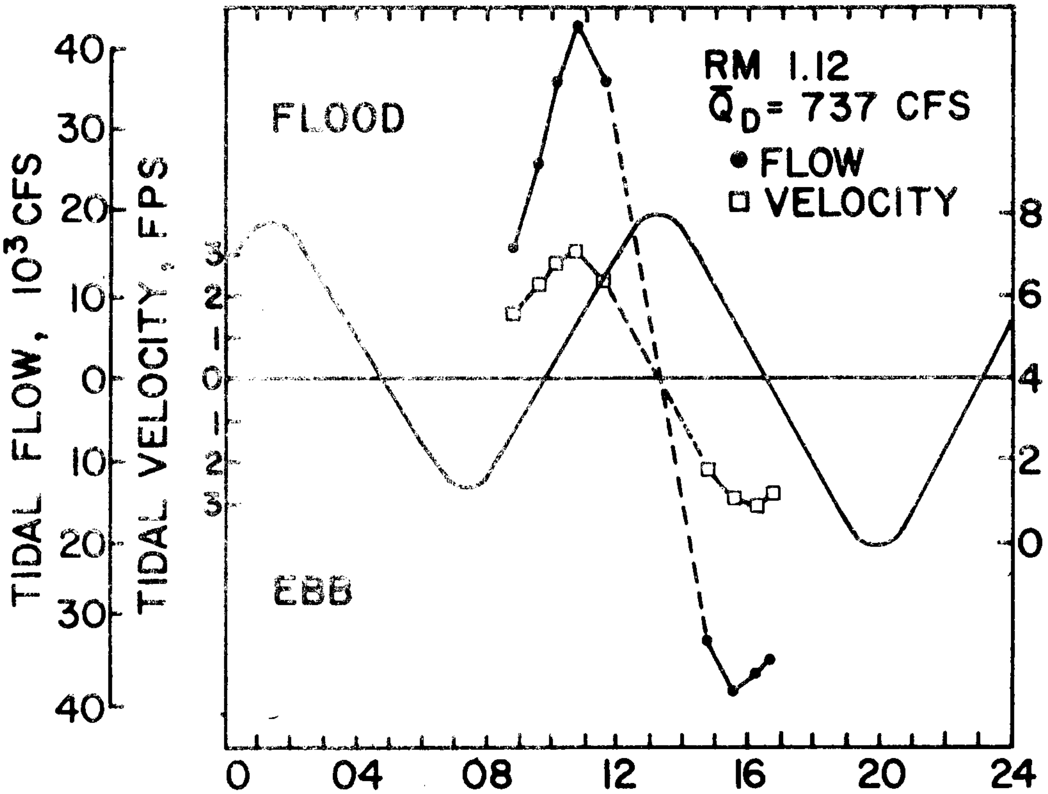
even for the fall high river flow period. This indicates that the TR Station 3 low water lag times, unlike the high water lag times, were unaffected by river flow.

Only very general conclusions can be made about the tidal lag in the Alsea Estuary from the data collected. From the seasonal mean values and the frequency histogram it can be seen that high water at Oakland's (TR Station 3) most likely occurs 15 to 30 minutes after predicted high water at Waldport, except during periods of high river flow (greater than 3000 cfs) when the lag is approximately five minutes. Low water at Oakland's most likely occurs 85 to 105 minutes after predicted low water at Waldport and is unaffected by river flow.

Tidal Flow

The phase relationship between amplitude and tidal current velocities (and flows) depends upon the type of tidal motion occurring in the estuary. If tidal behavior follows a progressive wave the current velocities are in phase with the amplitude. In this case the maximum flood current velocity and flow occur at high water and the maximum ebb current velocity (but not necessarily the flow) occurs at low water. Slack water occurs when the amplitude is zero. If the tide is a standing wave resulting from perfect reflection, the current velocity is 90^{0} out of phase with the amplitude. In this case slack water occurs at high and low waters, maximum flood velocity occurs midway between low and high water and the maximum ebb velocity occurs midway between high and low water. Since flow is the product of velocity and cross-sectional area it is more difficult to determine the relationship between flow and amplitude, but maximum flow could be expected to occur at nearly the same time as maximum velocity. Bascom's (1964) description of tidal currents, previously mentioned, best fits that of a standing wave. An imperfect reflection resulting from a damped partially standing wave could be expected to have characteristics which lie between the extreme conditions just described.

Figures 10 through 13 present the results of the tidal current and flow measurements made during each season. The upper plot in each figure is for the downstream current station (RM 1.12) and the lower plot is for the upstream current station (RM 4.81). The tidal elevation curve shown in both the upper and the lower plots is the measured tide at TR Station 2. Since absolute water elevations were not measured, the tide heights for each plot were based on a datum of the lower low water which occurred during the day the current measurements were made. The tide curve for the spring plots (Figure 11) uses one predicted high water value since the measured record for that day was imcomplete. Where sufficient data permit, dashed lines connect the ebb and flood velocity and flow curves in order to determine the approximate time of slack water. It is assumed that the tide measurements made at TR Station 2 adequately describe the tide motion at the downstream current station, since the distance between these two locations is only 0.68 mile. Summer tide records from TR Station 1 (RM 0.9) confirm that there is only a small difference between the tide range and times at that station and TR Station 2. However, the upstream current station is three miles upstream from TR Station 2 and, as it has already been shown, there is a definite lag in the



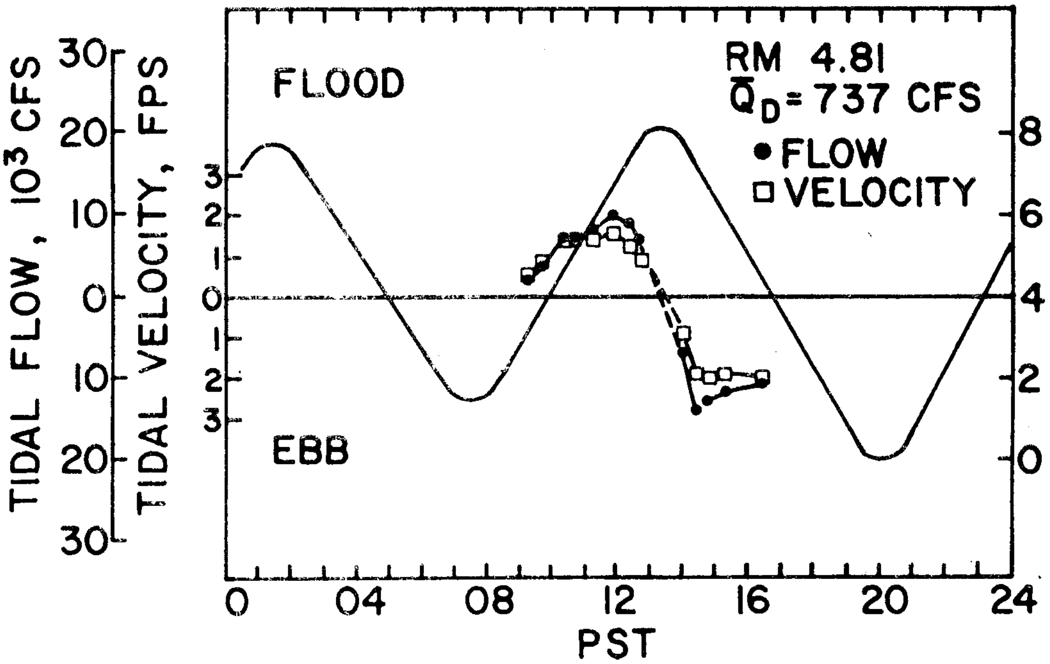


Figure 10. Tidal flow and velocity, February 18, 1973.

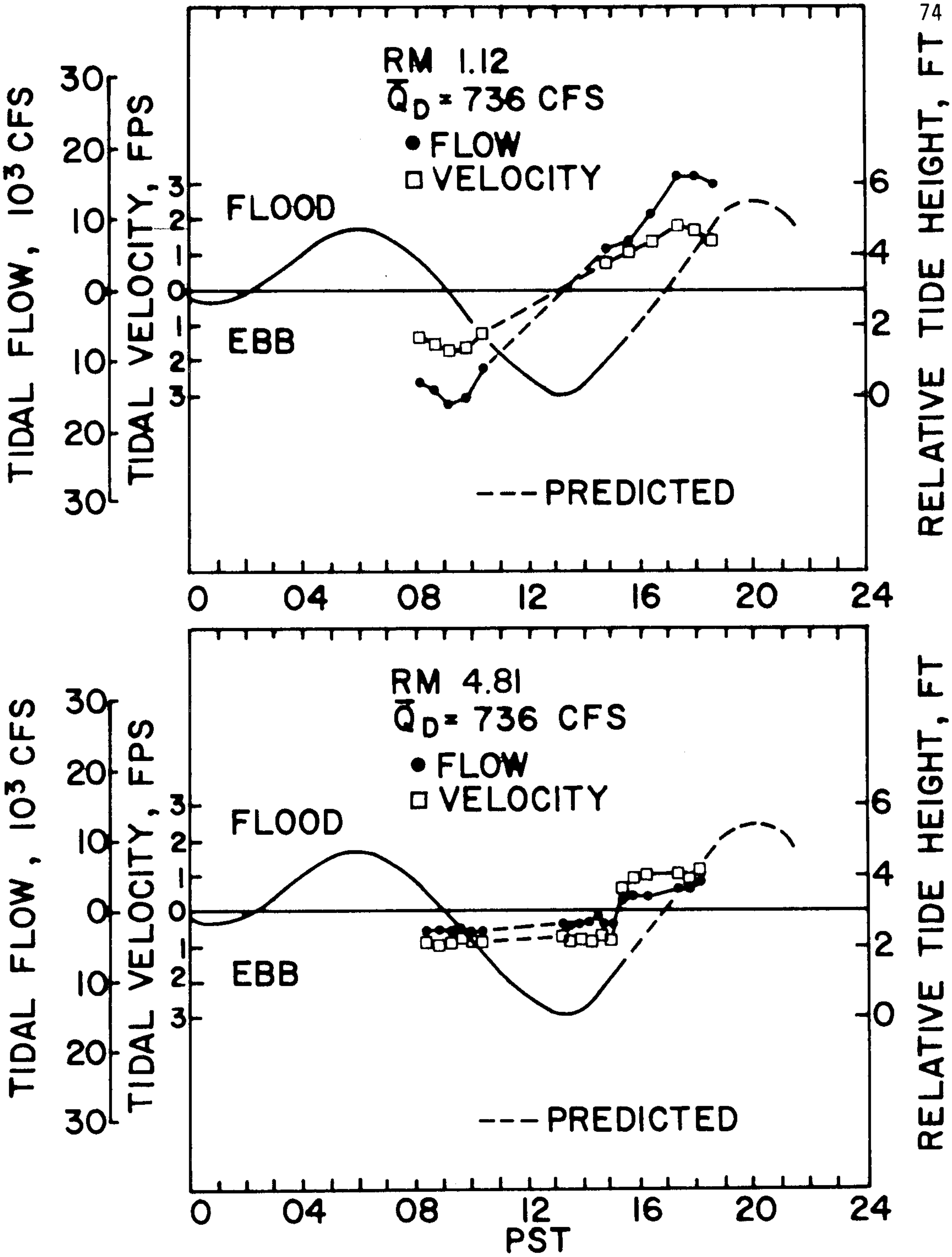


Figure 11. Tidal flow and velocity, April 26, 1973.

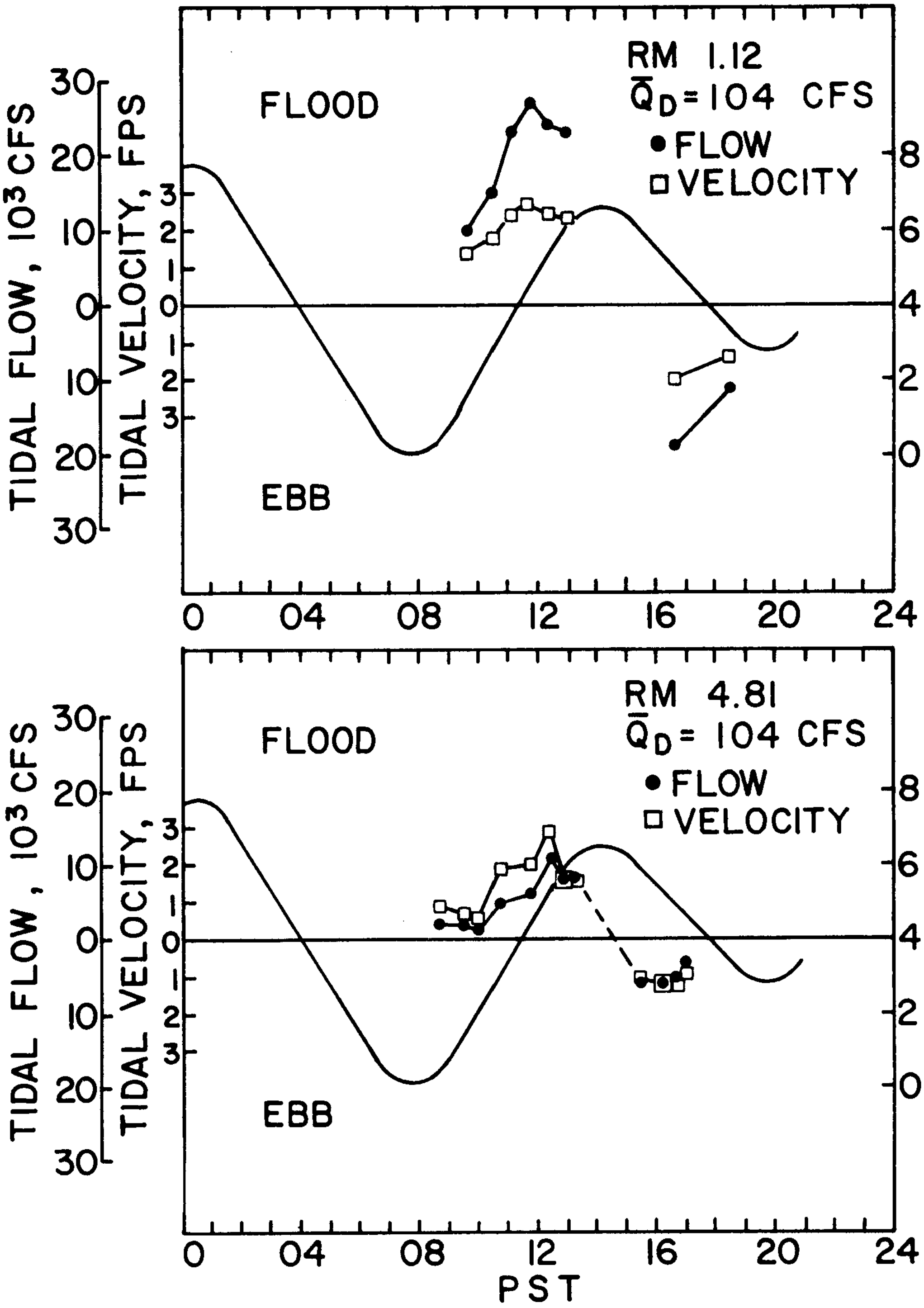


Figure 12. Tidal flow and velocity, July 17, 1973.

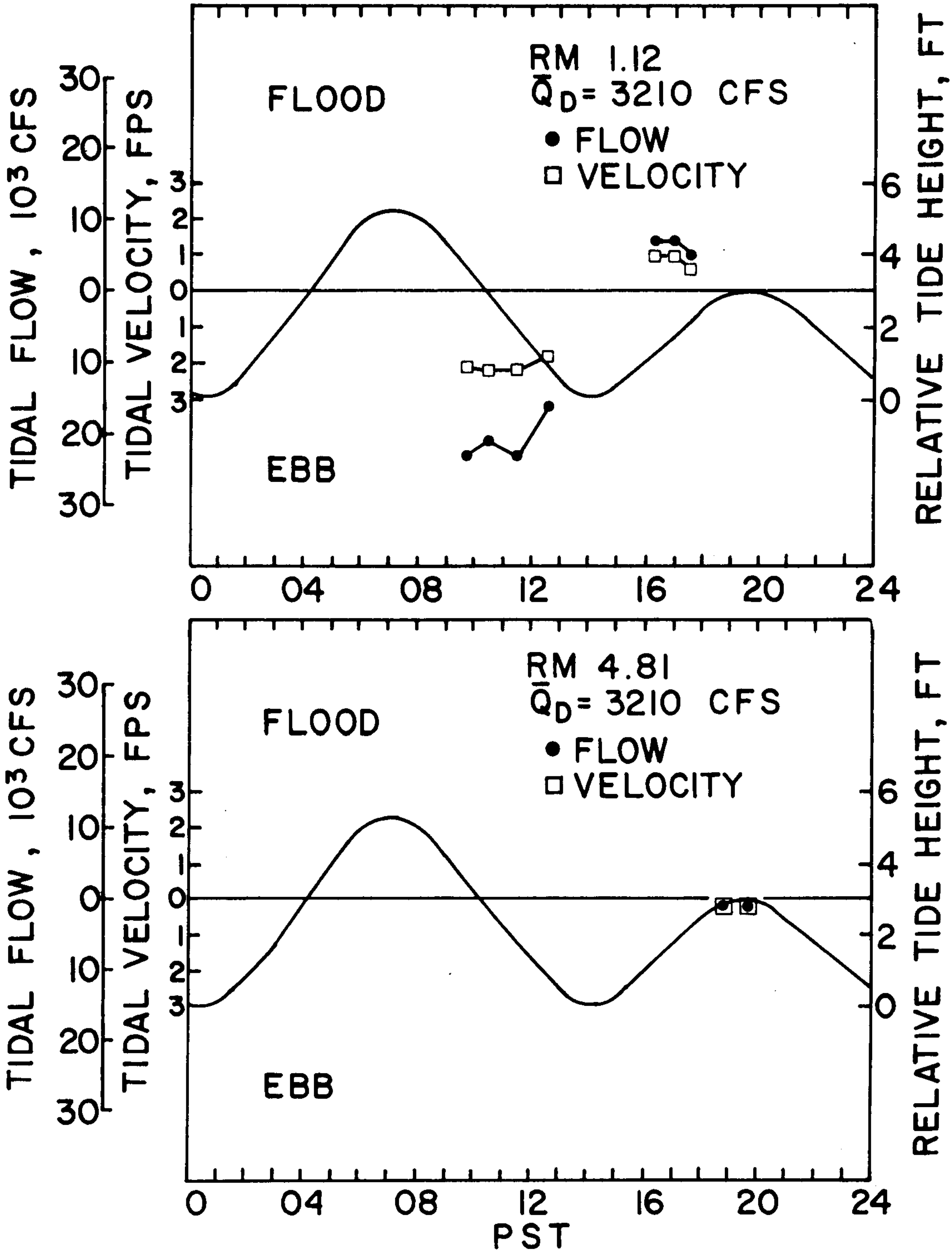


Figure 13. Tidal flow and velocity, December 4, 1973.

times of high and low water this far up the estuary.

At the downstream current station the peak flood flow occurred from 3.3 to 4.0 hours after low water during the winter, spring and summer, but in the fall the peak flood flow occurred approximately 2.0 to 2.5 hours after low water. The time of the maximum average flood velocities coincided with the time of the peak flood flows for each season. The higher river flow in the fall may have caused the time of peak flood flow and velocity to occur earlier than it did during the periods of lower river flow. Or, the fall 3.0 foot low-to high tide range, which was approximately half the low-to-high range of the other seasons, may have affected the time of maximum flood flow and velocity occurrence. Without additional data it is not possible to say whether either of these, or a combination of both, significantly influence the time at which peak flood flow and velocity occurred. In all cases maximum flood flow and velocity occurred when the water level was changing the fastest. In all four seasons peak ebb flow and velocity occurred between 2.3 to 3.6 hours after high water, which was when the water level was changing the fastest. The time of maximum ebb flow and velocity occurrence does not appear to be affected by river flow or the height of the high-to-low tide range.

The winter downstream velocity plot (Figure 10) indicates that the flood velocity goes to zero (high slack water) at approximately the same time as high water and the summer velocity plot (Figure 12) indicates that the ebb velocity goes to zero (low slack water) at approximately the same time as low water. The phase relationship between the tidal currents and amplitudes at the downstream current station closely follows the behavior of a standing wave as described by Bascom (1964).

At the upstream current station the maximum flood flows and velocities occurred between 4.4 to 4.7 hours after TR Station 2 low water during the winter, spring and summer seasons. In the fall no current was detected moving in the upstream direction during the flood portion of the tidal cycle. The small low-to-high tide range on the fall measurement day did not provide enough tidal flow to overcome the high river flow and cause a current reversal that far up the estuary. However, as shown on the fall upstream plot (Figure 13) the momentum of the incoming tide did reduce the net downstream flow to approximately 1000 cfs. During the winter and summer the maximum ebb flow occurred between 1.1 to 1.6 hours after TR Station 2 high water. Because of the flat flow curve for spring it is not possible to say at what time the peak happened during that season. Unfortunately the fall ebb flow data at the upstream station were not recovered. The winter upstream high slack water occurred at approximately the same time as high water at TR Station 2. The spring low slack water occurred approximately 1.5 hours after low water at TR Station 2.

Comparison with the upstream plots for the same season shows that tidal flows were much greater at the downstream current station. Evidently much of water brought into the estuary during the flood tide is stored in the large embayment between RM 2 and RM 3. The time of maximum flood flow happened earlier downstream than upstream; but, as the winter and summer plots (Figures 10 and 12) indicate, the time of maximum ebb flow occurred earlier upstream than downstream. The latter may be due to a slow response in emptying the large downstream shallow embayment. Since the time of zero velocity between the flood and the ebb currents (high slack water) occurred at approximately the same time at both current stations as shown in the winter and summer plots, it can be concluded that the current reversed from flood to ebb at nearly the same time along the lower five miles of the estuary. However, the spring plot shows that low slack water, the time of zero velocity between the ebb and flood currents, occurred nearly 1.5 hours later upstream, thus indicating that the tidal current reversed from ebb to flood at a later time upstream. The tide data show that the lag time between the two current stations was approximately 20 to 30 minutes for high water and 60 to 70 minutes for low water. Therefore, due to the one hour low water lag, the reverse from ebb to flood occurred later upstream, whereas, because of the short high water lag, the reverse from flood to ebb occurred at nearly the same time.

Figure 14, a plot of the downstream peak tidal flow versus the measured range at TR Station 2, shows the relationship between tidal flow and tidal range. It can be seen from this plot that tidal flow is proportional to tidal range; although the exact relationship is not possible to predict, it appears to be approximately linear. Since the volume of water brought into or removed from an estuary is proportional to the flood (low-to-high) range or ebb (high-to-low) range, respectively, such a relation as shown in Figure 14 between tidal flow and range was expected.

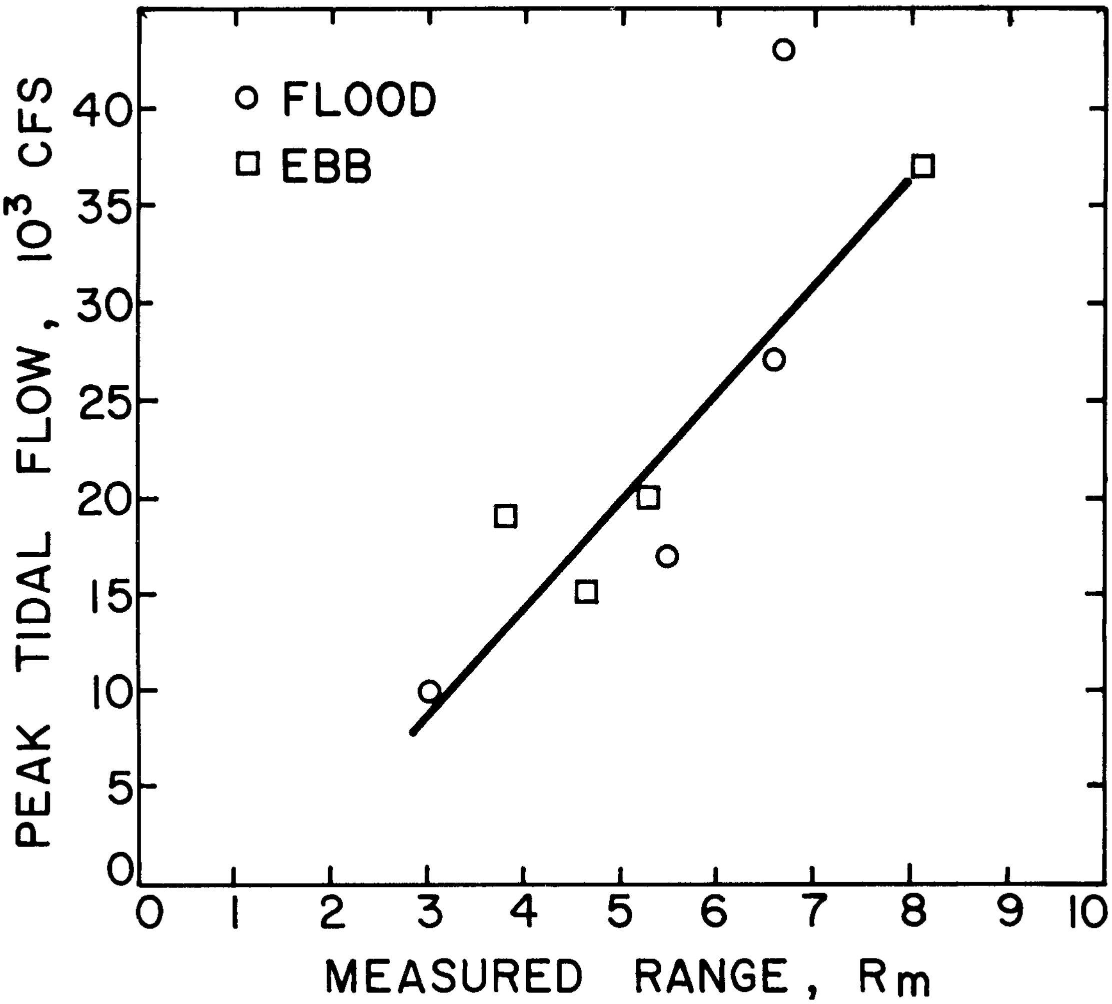


Figure 14. Peak tidal flow vs. measured range, TR Station 2.

Circulation Patterns

Several observations about the Alsea's general circulation features have been made. It was noted on occasion that, even after the onset of flood tide, water continued to drain from the northern portion of the large embayment (located between RM 1.6 and RM 2.5) into the main channel along the south side of the estuary. This ebb flow from the embayment continued during the flood until the water level in the main channel became high enough to force water to flow back into the embayment. Aerial photographs revealed that during both the ebb and the flood tides a shear layer developed between the water flowing in the main channel and the water flowing in the embayment. This shear layer occurred because the flow velocity is much slower in the shallower embayment region than the flow velocity in the deeper channel portion of the estuary.

Boley (1974) placed tide recorders on the south side of the bay at Lints Slough, RM 1.8, the same location as this study's TR Station 2, and on the north side of the bay near the location of this study's Water Quality Station 6, RM 2.75 (N). From his measurements he determined that high tide occurred at approximately the same time at both locations, but that low tide occurred on the north side before it did on the south side. From these results he concluded that the north and the south sides of the bay fill at the same time, but that the northern portion of the bay starts to empty before the southern portion.

Unpublished tide data indicate that the water surface level at the upstream end of the north channel (immediately below the dam) can be as much as one foot higher than the water surface level of the south channel just across the island separating the two channels. This would seem to indicate that the tide motion in the dammed-up north channel is not in phase with the tide motion of an immediately adjacent location on the south channel.

Figure 15 is an example of a computer drawn sketch of the Alsea Estuary flood tide surface current patterns. This sketch was made by inputting the data taken from oblique aerial photographs of surface dye dye patches to a computer program developed by H. Weise (1974). The triangles represent the centroids of the dye patches and the vectors extending from the triangles represent the direction and velocity of the surface currents. The numbers along the bottom and side of the sketch are coordinates. Table 10 gives the time period during which the dye was photographed, initial and final coordinates and the velocity of the currents.

Table 10. Alsea computer sketch tidal current velocities, 29 June 72 AM.

Vector	Photo Time (PST)	Initial Coords	Final Coords	Velocity (fps)
1	1057 1059	3082/11551	3727/11856	5.9426
2	1057 1059	3319/11405	3870/11720	5.2874
3	1057 1059	3713/11263	4162/11699	5.2065
4	1059 1116	3727/11856	4080/12099	0.1254
5	1059 1116	3870/11720	4493/12060	0.2075
6	1059 1116	4162/11699	4732/11901	0.1770
1	1103 1107	7380/12672	7615/12597	1.0247
2	1103 1107	7441/12883	7624/12764	0.9073

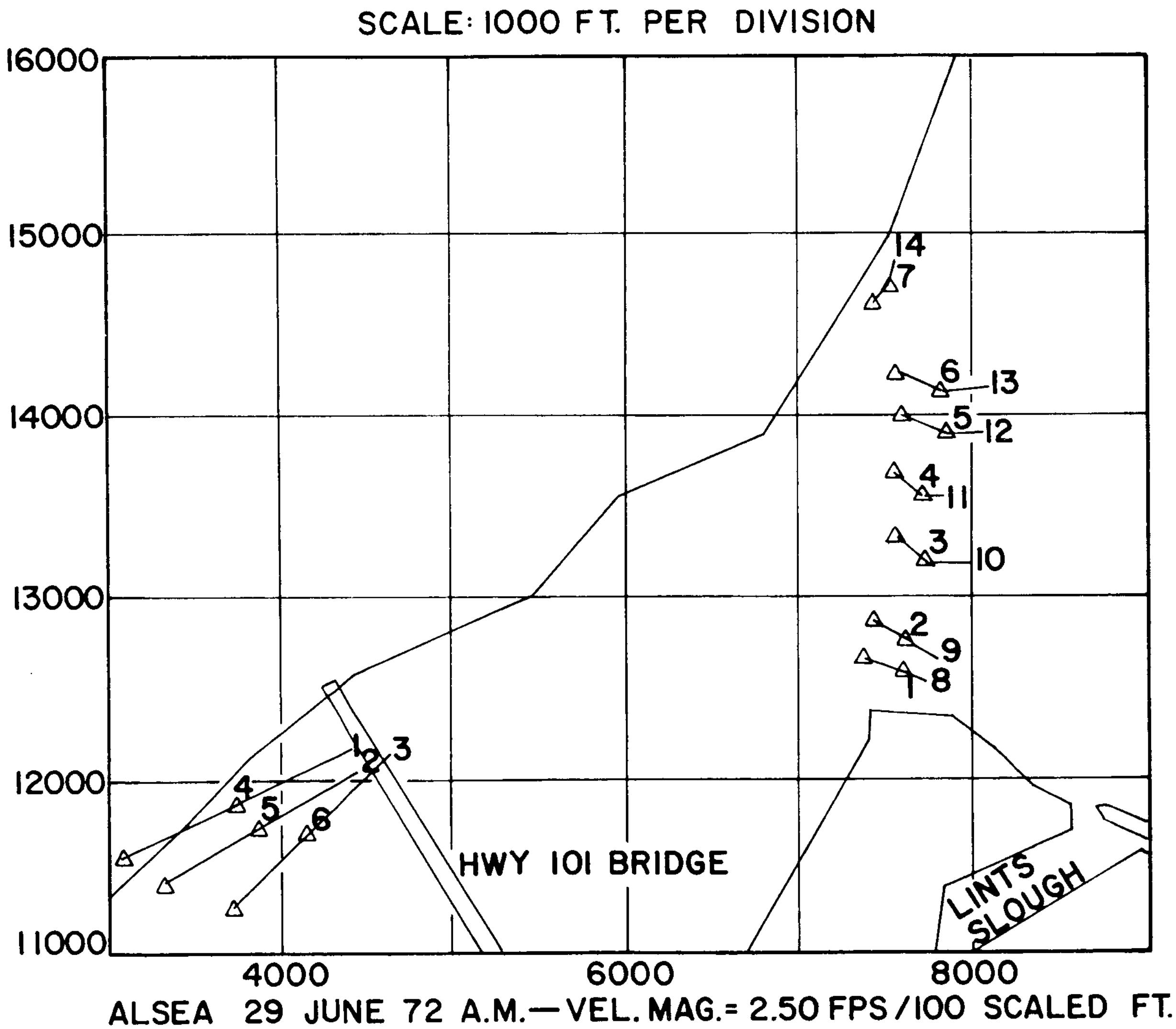


Figure 15. Computer sketch of Alsea flood tide current patterns, June 29, 1972.

Table 10. (cont.)

Vector	Photo Time (PST)	Initial Coords	Final Coords	Velocity (fps)
3	1103 1107	7566/13322	7739/13186	0.9151
4	1103 1107	7562/13688	7714/13563	0.8210
5	1103 1107	7602/14006	7866/13898	1.1885
6	1103 1107	7568/14241	7821/14133	1.1475
7	1103 1107	7453/14601	7528/14711	0.5563
8	1107 1116	7615/12597	7844/12484	0.4681
9	1107 1116	7624/12764	7945/12552	0.7055
10	1107 1116	7739/13186	8110/13165	0.6798
11	1107 1116	7714/13563	7981/13543	0.4903
12	1107 1116	7868/13898	8200/13924	0.6136
13	1107 1116	7821/14133	8363/14199	0.9993
14	1107 1116	7528/14711	7611/15103	0.7347

The particular flood tide depicted by the sketch occurred on the morning of June 29, 1972. The NOAA predictions for that day were a -1.0 foot low water at 0821 PST and a +6.3 foot high water at 1506 PST. The sketch, which includes the portion of the estuary from RM 0.6 to RM 1.8, shows flood currents in excess of 5 fps parallel to the channel occurring just before 1100 in the section approximately 0.3 miles downstream from the Highway 101 bridge. At RM 1.6, where the estuary begins to widen into the large embayment, currents with velocities ranging from 0.47 fps to 1.19 fps are shown occurring just after 1100. All these current vectors are parallel to the south shore except the northernmost one which is parallel to the north shore. Since the photographs were taken at a time approximately midway between low and high water, the surface current vectors shown should be representative of peak flood tide currents. This method of analyzing tidal current circulation patterns is particularly useful when data is available all along the estuary length at different times during the tidal cycle.

Flushing

Flushing, in an estuary, is the exchange of fresh water with the sea. Dyer (1973) defines flushing time as "... the time required to replace the existing fresh water in the estuary at a rate equal to the river discharge." Expressed mathematically the flushing time, T_f, is (Dyer).

$$T_f = \frac{V_f}{Q} \qquad (4)$$

where V_f is the total volume of fresh water in the estuary, or a segment of the estuary, and Q equals the river flow into the estuary. As shown by Equation (4) the flushing time decreases as the river flow increases. Knowledge of an estuary's flushing time is necessary in order to estimate the time duration that a pollutant, such as an oil spill, will remain in the estuary.

Several schemes have been devised to estimate flushing times. In one method the fractional fresh water concentration is multiplied by the total volume of the estuary to determine the total fresh water volume. Once the fresh water volume and the river flow are known the flushing time is calculated. A more thorough approach is the Ketchum modified tidal prism method as described by Dyer (1973). In this procedure the estuary is divided into segments starting at a location upstream of which there is no salt water intrusion. The length of each segment is determined by the average distance a water particle travels during the flood tide. The high tide volume of any segment equals the low tide volume of the adjacent downstream segment. From the known high and low tide volumes of any segment and the known river flow, a flushing time for that segment is calculated. The flushing time for the entire estuary is the sum of the flushing times for each segment.

Matson (1972), as part of his research, made three separate estimates (based on three different river flows) of the flushing time of the Alsea estuary using the Ketchum modified tidal prism method. The river flows used for his calculations were 63 cfs, 421 cfs and 3000 cfs. In all three cases he used a tidal height of six feet to calculate tidal prism volumes. His results are presented in Table 11.

Table 11. Flushing time of the Alsea Estuary at various river flows using the Ketchum modified tidal prism method (Matson).

Segment Number	Segment Length (ft)	Tidal Prism (10^7 ft^3)	Low Tide Volume (10^7 ft^3)	Flushing Time (tidal cycles)
		River flow - 63 cfs		
		Start - 12.5 nautical miles upstream		
0		0.28	0.00	1.0
1	2410	0.27	0.28	2.0
2	5240	0.46	0.55	2.2
3	7310	0.79	1.01	2.3
4	8020	1.16	1.80	2.6
5	10570	1.42	2.96	3.1
6	11240	2.13	4.38	3.1
7	20410	15.11	6.51	1.4
8 partial	10800	21.61	4.63	0.3
	76000			18.0

Table 11. (cont.)

Segment Number	Segment Length (ft)	Tidal Prism (10^7 ft^3)	Low Tide Volume (10^7 ft^3)	Flushing Time (tidal cycles)
		River Flow - 421 cfs		
		Start - 8 nautical miles upstream		
0		1.88	3.04	2.6
1	14220	2.23	4.92	3.2
2	22510	12.15	7.15	1.6
3 partial	11910	25.32	9.83	0.7
	48640			8.1
		River Flow - 3000 cfs		
		Start - 4.5 nautical miles upstream		
0		13.40	12.74	2.0
1 partial	27360	35.37	13.79	0.7
				2.7

The results in Table 11 show that for a river flow of only 63 cfs the flushing time, 18 tidal cycles (nearly ten days), is quite long. As the river flow increases, however, the flushing is noticeably reduced. At a river flow of 421 cfs the flushing time has decreased to 8.7 tidal cycles (approximately 100 hours); and at a flow of 3000 cfs, nearly 50 times the 63 cfs flow, the time has reduced to 2.7 tidal cycles (33 hours). Thus since flushing time is inversely proportional to river flow, a pollutant could be expected to remain in the estuary for a much longer time during the summer than during the winter.

VI. WATER QUALITY

Introduction

This chapter presents graphical displays and discussions of the spatial and temporal variability of several estuarine water quality parameters. The parameters measured during this study were salinity, temperature, dissolved oxygen, turbidity and pH. Also included are plots of the bottom depths measured at each water quality station. All Hydrolab and bottle sample data values for each season are listed in Appendix A, Table A2.

Water Quality Station Depths

Figures 16 through 19 are plots, one for each season, of the bottom depths, measured in feet, at each water quality station during both high and low tides. The depths were measured using markings on the Hydrolab cable, in the same manner a sounding line is used. The purpose of the plots is to provide a quick reference to determine the depth at any water quality station for a given season and tide. In no way are these plots intended to be an accurate hydrographic survey of the estuary. They give only a very general indication of the estuary profile.

Occasionally, the low tide depth for a given station was greater than the high tide depth for the same season. This occurred because, in some instances, the degree of accuracy in relocating a station each time was estimated to be a 500 foot radius circle (i.e. it was possible to expect to be within 500 feet of the exact station

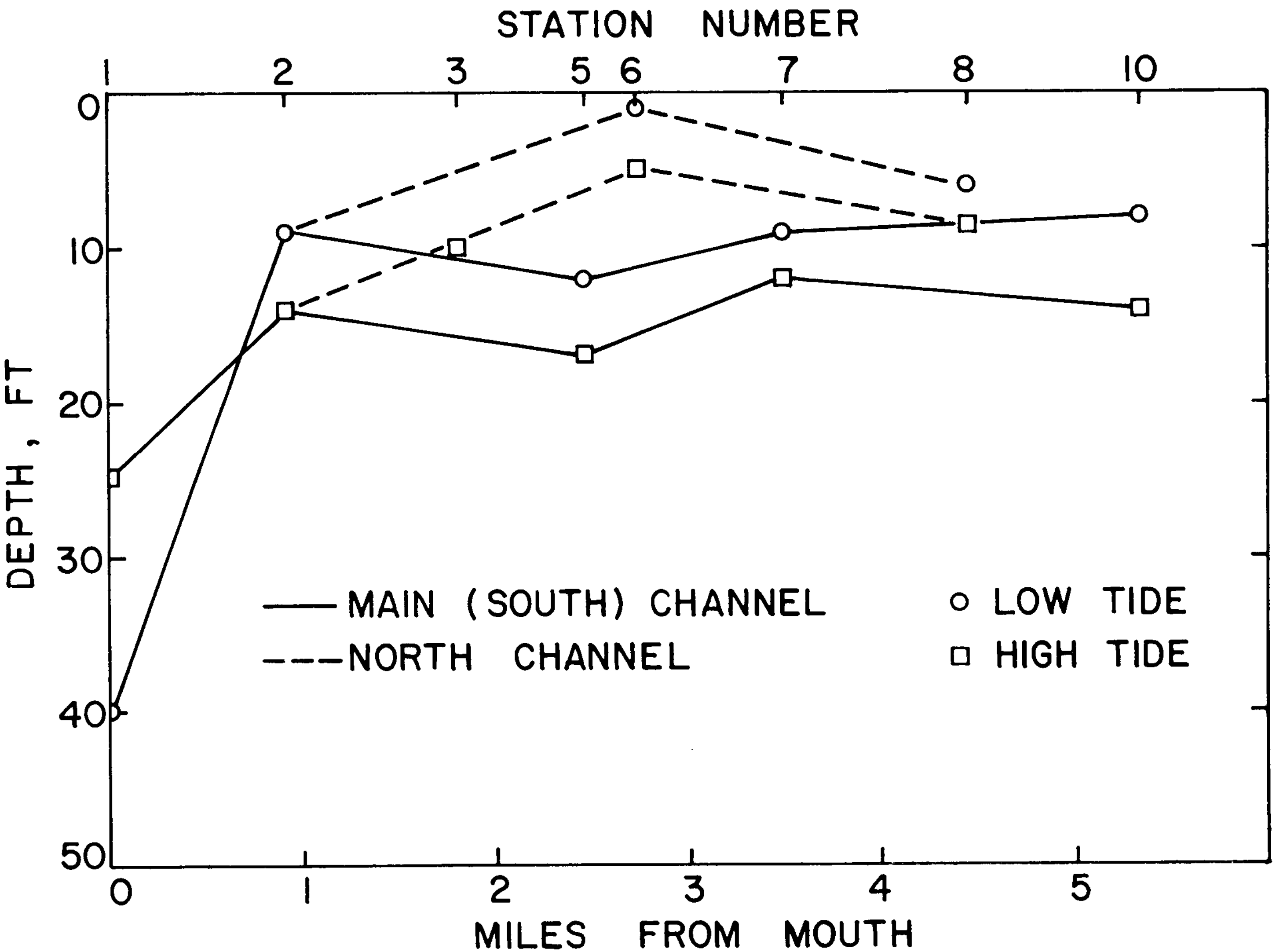


Figure 16. Water quality station depths vs. distance, February 18, 1973.

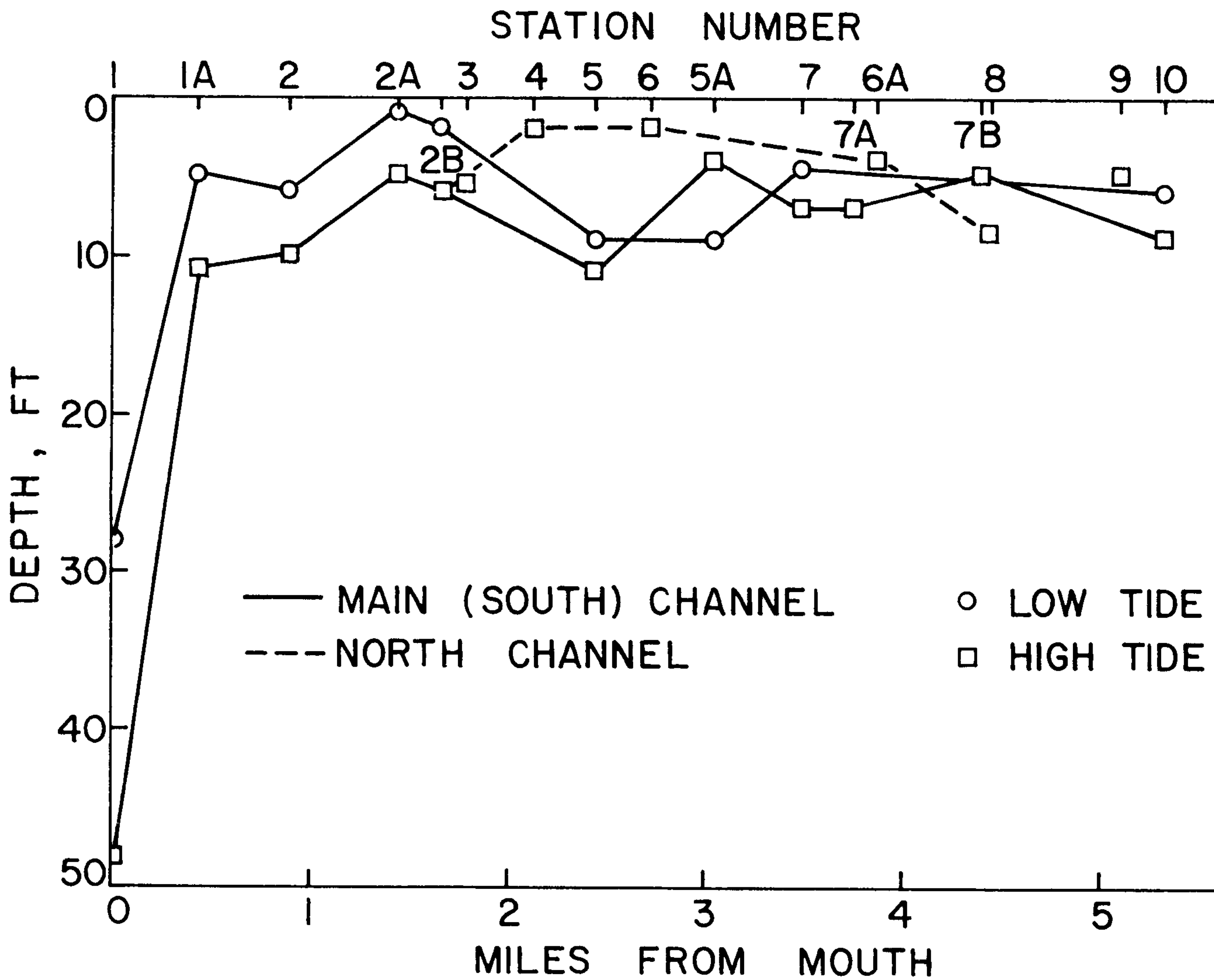


Figure 17. Water quality station depth vs. distance, April 26, 1973.

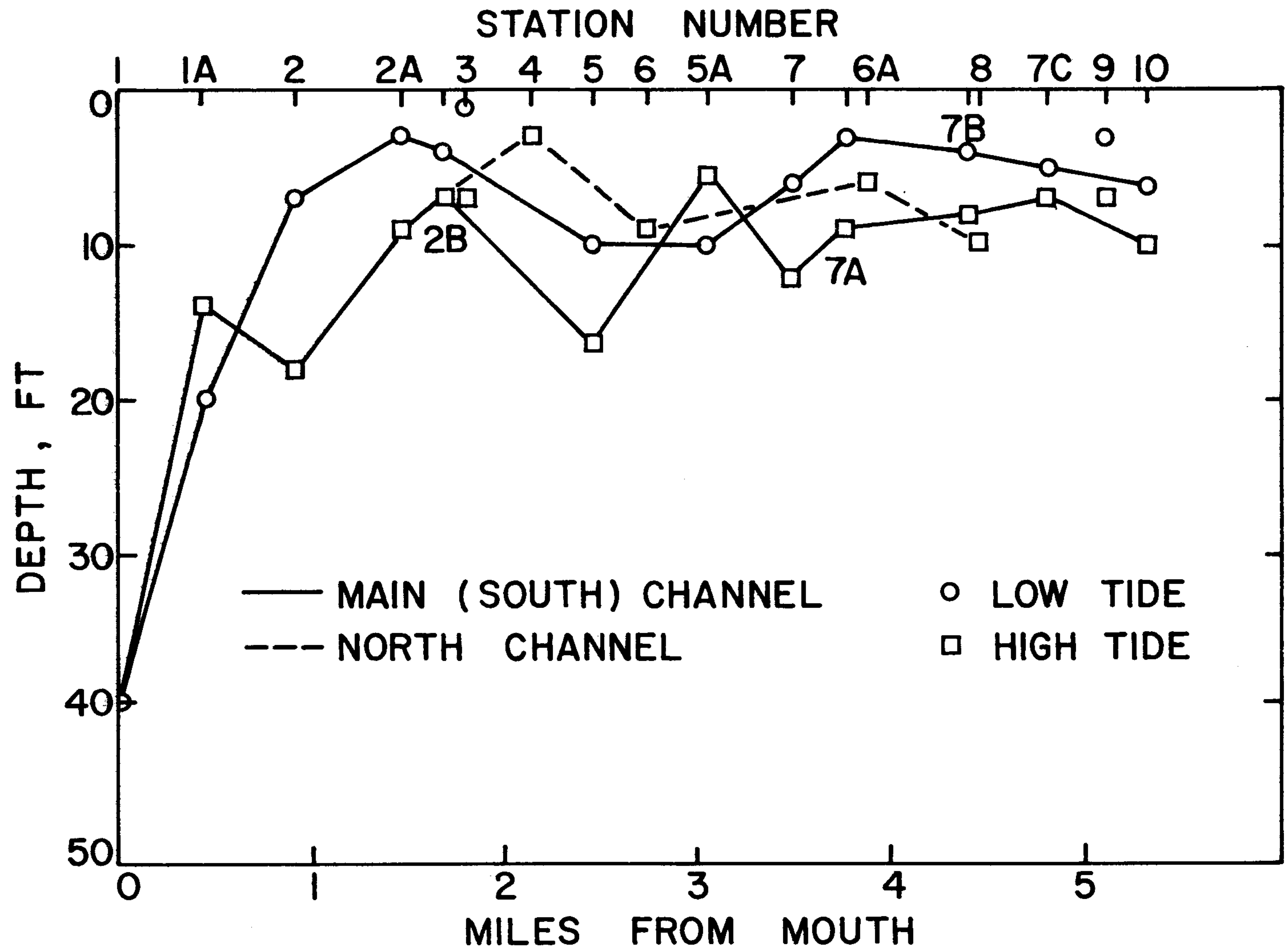


Figure 18. Water quality station depths vs. distance, July 17, 1973.

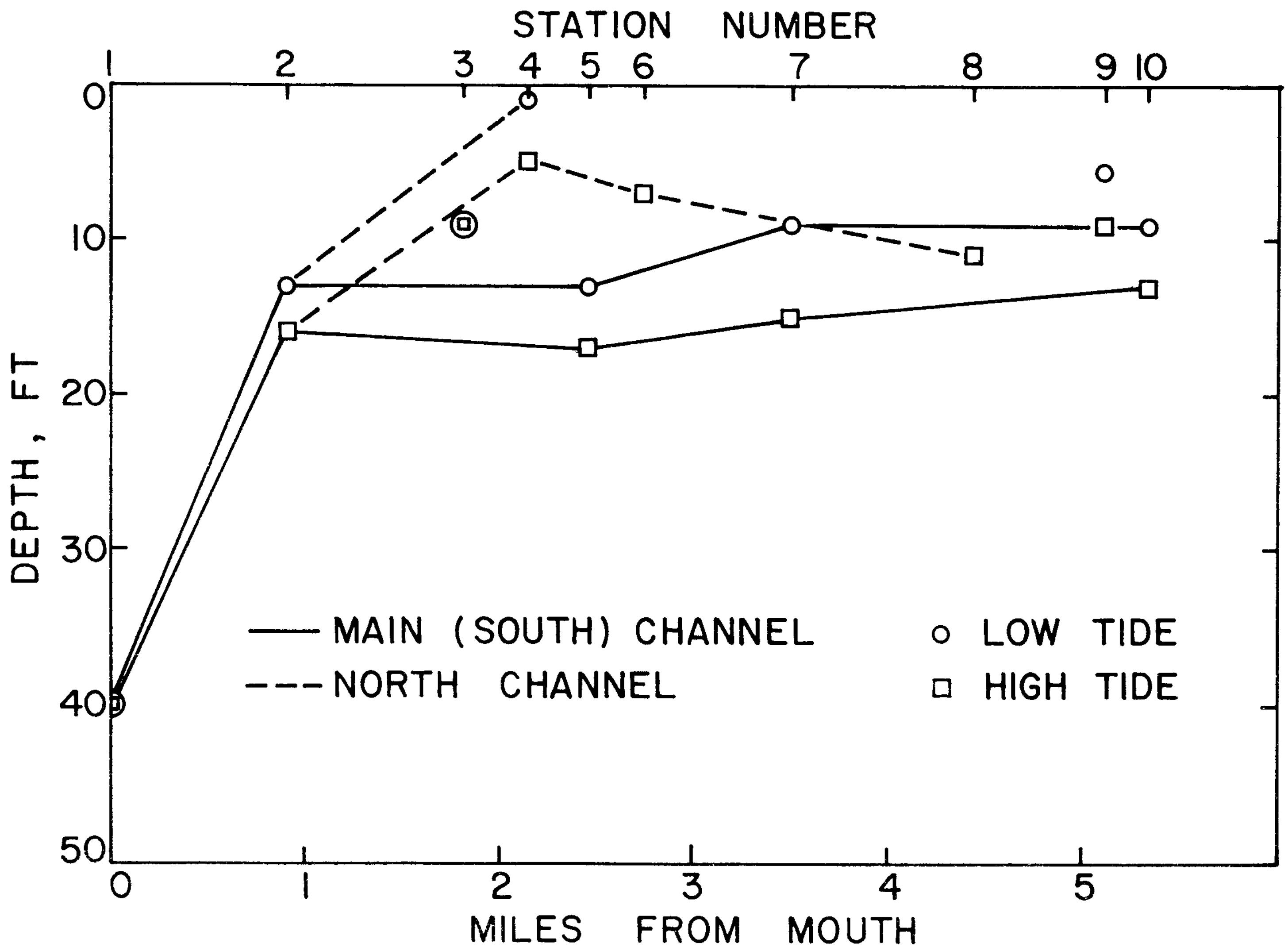


Figure 19. Water quality station depths vs. distance, December 4, 1973.

location). Therefore, within a 500 foot circle it was quite possible that contours varied enough to account for measuring deeper low tide depths than high tide depths. This was particularly true at the mouth where surf conditions dictated whether or not the water quality boat could approach the station located there. Because several of the water quality stations were located near prominent landmarks, such as the Highway 101 bridge piers, it was possible to return to within 20 feet of the exact location of these particular stations.

Salinity

Measurement of the vertical salinity gradients at various locations along an estuary axis provides the best information for determining how the intruding sea water mixes with the fresh water within the estuary. The following factors affect estuarine salinity distribution: tide range, fresh water flow, density difference between fresh and sea water, turbulence, estuary geometry, and Coriolis force. The importance of the relative magnitudes of tidal flow and fresh water flow has already been discussed in the section on classification. As Burt and McAlister (1959) pointed out, much of the energy needed to mix salt water with fresh water is provided by the tidal forces. The available energy in a tidal cycle is approximately proportional to the square of the tide range. When the tidal flow dominates the river flow the estuary tends to become well-mixed, but when the river flow dominates the tide forces the estuary tends to become stratified.

Although the tidal and river flows are the primary forces that determine an estuary's mixing characteristics the influence of other factors cannot be ignored. The density variation between fresh and salt water has a definite effect on the vertical salinity gradient. The density of water is directly proportional to its pressure and dissolved solid content and inversely proportional to its temperature. In the shallow depths of Oregon's estuaries water can be considered incompressible, therefore the pressure effect on water density can be ignored. The temperature of the ocean water along the Oregon Coast is generally constant throughout the year with a value near $10^{O}C$. The temperature of the fresh water flowing into the estuaries along the Oregon Coast does vary throughout the year; however, data collected in this study indicates it does not get more than $2^{O}C$ colder than the ocean water. Temperature induced density differences are small compared to salinity induced density differences, particularly when the fresh water temperature is only slightly less than the sea water temperature. The sea level density of fresh water at $4^{O}C$, the temperature of its maximum density, is 1.0 gm/cm^3; whereas the sea level density of sea water with a salinity of 35 ppt and a temperature of $10^{O}C$ is 1.02697 gm/cm^3, and, as it cools, it gets denser (Williams). In general, though, the temperature of the fresh water is approximately equal to or greater than the temperature of the ocean water. Thus, the density difference between the sea water and the fresh water depends primarily upon the salinity of the sea water; and the sea water will always be denser than the fresh water. The density of sea water is always greater than 1.0 gm/cm^3 (the density of pure fresh water), but is never as great as 1.1 gm/cm^3 (McLellan). Therefore a given volume of sea water weighs more than an equal volume of fresh water and tends to sink to the bottom when the two are mixed.

Turbulence in estuaries is generated by several mechanisms. If incoming ocean waves are sufficiently large, as along the Pacific Northwest Coast, they can produce enough turbulence to thoroughly mix the estuarine waters near the mouth. Strong winds acting over estuarine sections with high width to depth ratios can create waves and currents which help to mix the water within those sections. Very high river flows generate turbulence and create vortices and eddies which all contribute toward mixing the estuarine waters.

An estuary's geometry plays a definite role in influencing its mixing characteristics. Channel width and depth, as well as the relative magnitudes of tidal and river flows, determine the ability of the denser sea water to intrude up the estuary. Width also determines the importance of Coriolis force which, in the Northern Hemisphere, causes the saltwater-fresh water interface to slope down to the right when looking toward the sea (Bowden). The Alsea, like other Oregon estuaries, is not sufficiently wide, however, for the effects of Coriolis force to become significant.

From this discussion on the factors affecting estuary mixing characteristics it is easy to see how man's alterations to an estuarine system can greatly affect that system. Dams change the fresh water input and tend to dampen out seasonal variations in the fresh water flow. Structures, such as jetties and breakwaters, modify an estuary's geometry and influence the generation of waves and currents.

Dredging deepens channels and thus favors salt water intrusion. Also, agriculture and logging practices in the drainage basin affect sediment input, which in turn affects geometry. Although no major alterations have been made to the Alsea Estuary, some man-made changes have been affected. The most important modification is the damming of the north channel at RM 4.44. Several attempts were made to dredge the main channel between RM 1.8 and RM 2.5. Dredging was also done in the mouth of Lints Slough, RM 1.8, and the spoils were used to fill adjacent tidelands. In addition, the waters of Lints Slough were impounded for a fish hatchery. As already stated, extensive logging is taking place in the drainage basin.

Figures 20 through 23 are plots, one for each season, of bottom, mid-depth and surface salinities in parts per thousand (PPT) versus river mile at both high and low tide. The salinity values used are those measured in the laboratory from the water samples collected. Bottle sample data were used instead of Hydrolab data because it was possible to continually standardize the lab salinometer while measuring the samples. This was not practical to do with the Hydrolab. The correlation between bottle sample and Hydrolab data was good. In the high salinity measurement region (greater than 30 PPT) the bottle sample values were approximately 5 PPT greater than the Hydrolab values at the same locations, but in the low salinity regions the two values were approximately equal. Since the lab salinometer cannot measure salinities below 2.846 PPT, Hydrolab values were plotted where salinity values less than this occurred. This was considered satisfactory because Hydrolab and sample values were in close agreement in

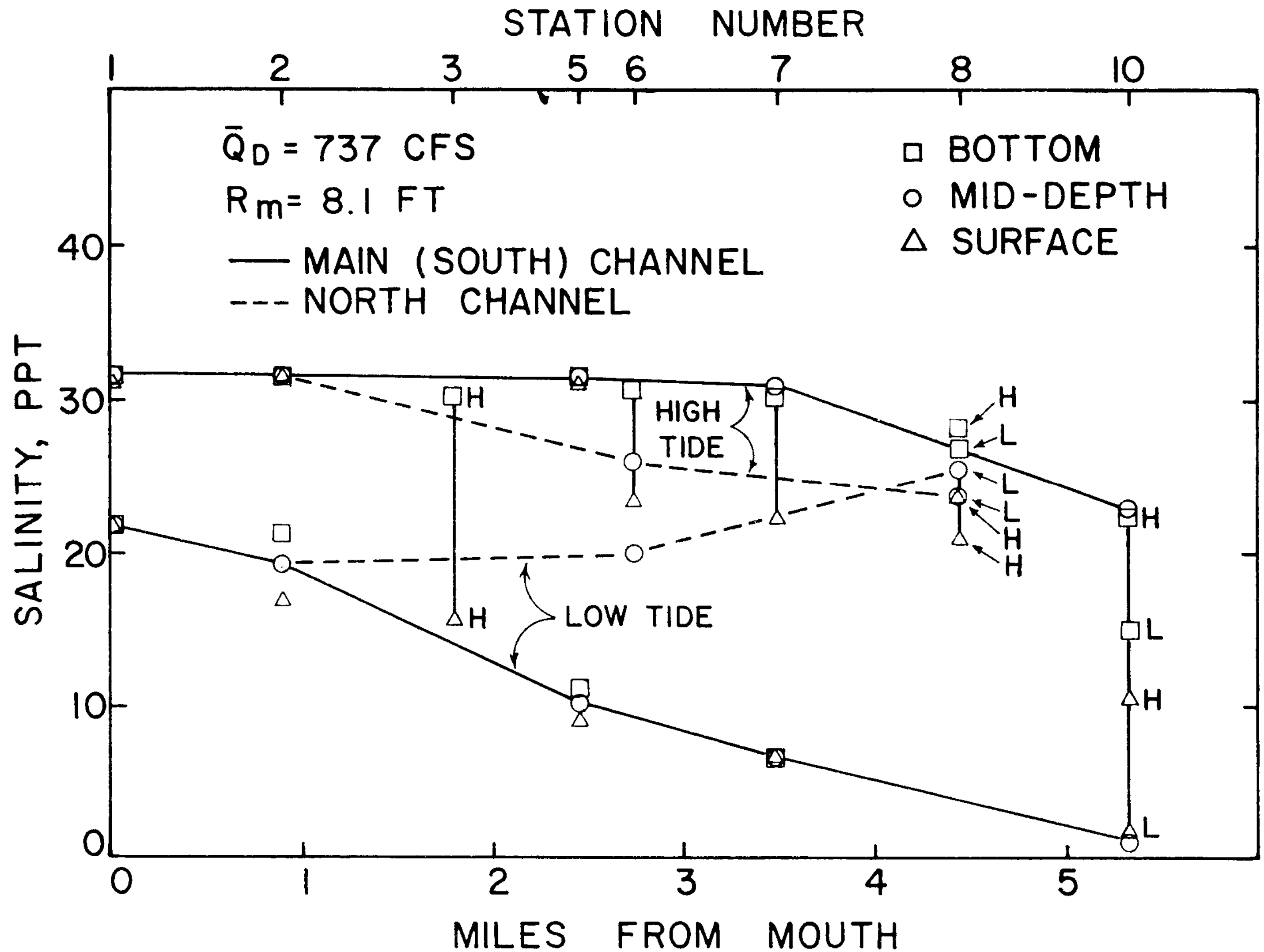


Figure 20. Salinity vs. distance, February 18, 1973.

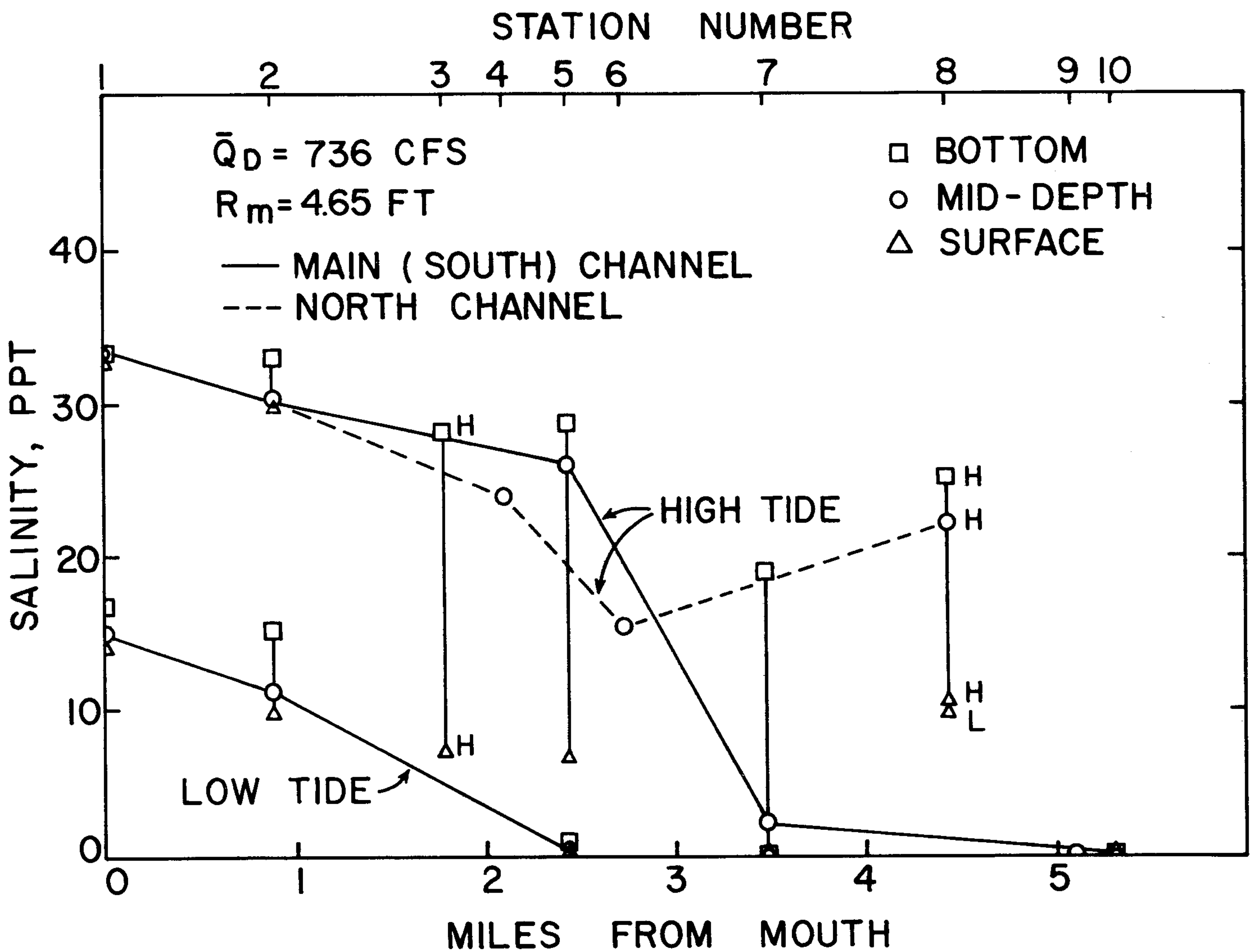


Figure 21. Salinity vs. distance, April 26, 1973.

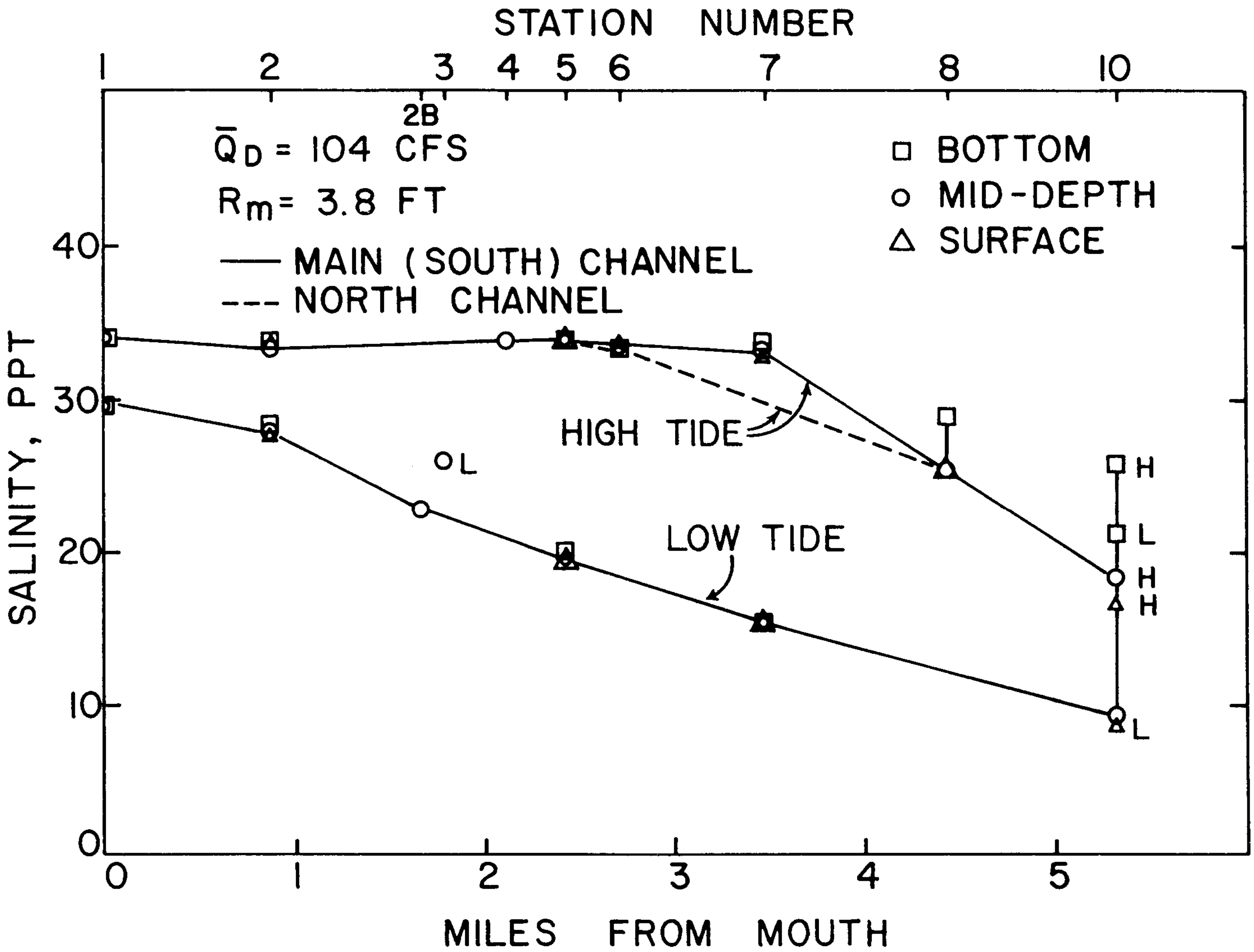


Figure 22. Salinity vs. distance, July 17, 1973.

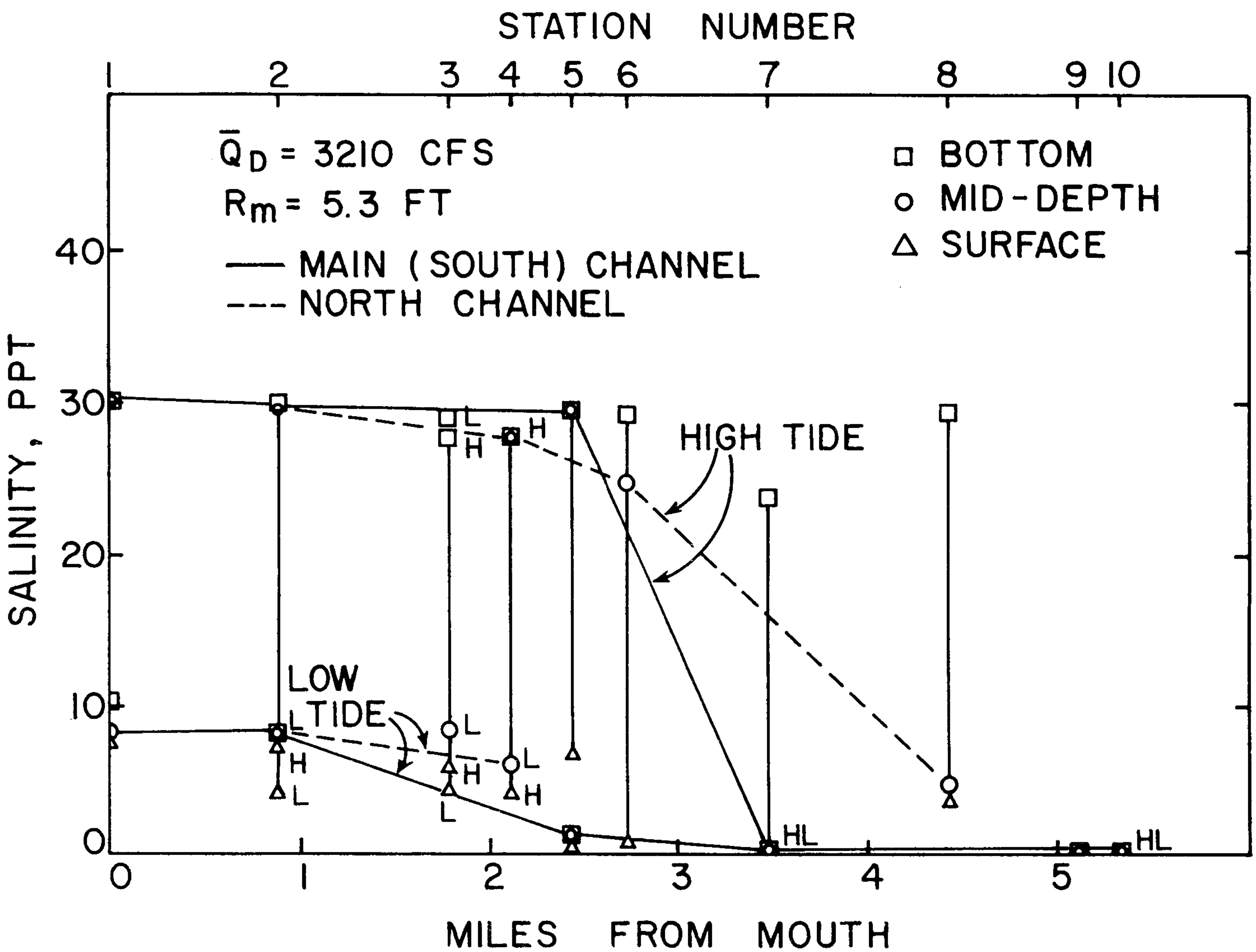


Figure 23. Salinity vs. distance, December 4, 1973.

the low salinity region. Otherwise bottle sample values were used throughout.

Vertical "range bars" were used to connect bottom and surface values at each station where sufficient difference between these values warranted it. The depth variation of salinity shown on these plots emphasizes the mixing condition of the Alsea for each given river flow and tide range. In the following discussion, the values given for the percentage of sea water at specified locations are based upon the mean Pacific Ocean salinity value of 34.62 PPT as given by McLellan (1965).

Winter (Figure 20)

The winter (2/18/73, $\bar{Q}_D$ = 737 CFS, R_m = 8.1 ft) plot shows an example of tidal forces dominating river flow. During the high tide the main channel was well-mixed at the mouth and became partially-mixed near RM 3. The north channel was partially-mixed along its entire length. The water in the main channel at the mouth was 91% sea water at all depths and at Station 10, RM 5.34, was 68% sea water on the bottom and 31% on the surface. The water immediately below the dam on the north channel (Station 8), RM 4.44, was 81% sea water on the bottom and 60% on the surface.

During low tide the main channel was well-mixed at the mouth and became partially-mixed above RM 5. The north channel was well-mixed along its entire length. The water in the main channel at the mouth was 65% sea water at all depths and at Station 10 was 44% sea water on the bottom and 3% on the surface. The fact that stations downstream from Station 10 were well-mixed and had lower bottom salinities indicates that partially diluted sea water was trapped in a "lens" or pocket located above RM 5. The water at Station 8 in the north channel had a mean value of 75% sea water.

Spring (Figure 21)

The spring (4/26/73, $\bar{Q}_D$ = 736 CFS, R_m = 4.65 ft) plot shows an example of river flow dominating tidal forces. During high tide the main channel was well-mixed at the mouth but became stratified past RM 2. The north channel was partially-mixed at the upstream end, Station 8. The water in the main channel at the mouth was 96% sea water at all depths and at Station 10 was fresh at all depths. The water at Station 8 on the north channel was 72% sea water on the bottom and 30% on the surface with an overall mean of 55%.

During low tide the main channel was well-mixed at the mouth changing to partially-mixed by RM 0.9 and becoming almost completely fresh by RM 2.45. Because shallow depths made the entrance to the north channel impassable the only salinity sample taken along this channel during low tide was collected on the surface from the shore at Station 8 after researchers walked across the island separating this location from the south channel. The low tide surface salinity in the north channel was 9.420 PPT, only slightly less than the high tide value of 10.235 PPT. The water in the main channel had a mean value of 44% sea water at the mouth dropping to 2% by RM 2.45.

Summer (Figure 22)

The summer (7/17/73, $\bar{Q}_D$ = 104 CFS, R_m = 3.8 ft) plot shows another example of tidal forces dominating river flow. During high tide the main channel was well-mixed from the mouth to Station 10, where it became partially-mixed. The north channel was well-mixed along its entire length. The water in the main channel was 98% sea water at the mouth at all depths and at Station 10 was 75% sea water on the bottom and 47% on the surface, with an overall mean of 60%.

During low tide the main channel remained the same, well-mixed from the mouth to Station 10 where it was partially-mixed. No water quality data were collected along the north channel during low tide because of shallow depths. The water in the main channel was 86% sea water at the mouth at all depths and at Station 10 was 60% sea water on the bottom and 25% on the surface, with an overall mean of 42%. The appearance of a vertical salinity gradient at a location over 5 miles upstream in an otherwise thoroughly well-mixed system is again indicative of a salt water lens.

Fall (Figure 23)

The fall (12/4/73, $\bar{Q}_D$ = 3210 CFS, R_m = 5.3 ft) plot shows another example of river flow dominating tidal forces. During high tide the main channel was well-mixed at the mouth but became stratified by RM 0.9 and remained so until it became fresh at a point between RM 3.5 and RM 5. The north channel was stratified along its entire length. The water in the main channel was 86% sea water at the mouth at all depths and at RM 3.47 was 67% sea water on the bottom and fresh water on the surface, with an overall mean of 22% there. The main channel was fresh water at all depths by Station 10. In the north channel the water at Station 8 was 83% sea water on the bottom and 9% on the surface, with an overall mean of 35%.

During low tide the main channel was well-mixed from the mouth to RM 3.47 where it became fresh. Again, no water quality data were collected along the north channel, except at the entrance, because of the shallow depths. The water in the main channel had a mean of 24% sea water at the mouth and became fresh at all depths by RM 3.47.

Conclusions

The winter and spring plots, Figures 20 and 21, provide and excellent opportunity to study the effect of a varied tide range on a constant river flow. For both seasons the river flow is nearly 740 cfs, but the winter tide range of 8.1 feet is almost twice the spring range of 4.65 feet. On the winter plot there is considerably less stratification evident than on the spring one. The point of extreme salinity intrusion during the spring high tide was not beyond RM 5.34, but at that same point during the winter high tide the water still had a mean value of 53% sea water, indicating that the location of extreme saline intrusion was well upstream from this point. Comparison of these two plots demonstrates how a high river flow relative to the tidal flow pushes the point of extreme salinity intrusion downstream and favors stratification; and how a high tidal flow relative to the river flow pushes the point of extreme salinity intrusion upstream and favors mixing.

Although complete low tide salinity data are only available for the winter season there is enough evidence to indicate that the upstream portion of the north channel is not well flushed out. Winter salinity values at Station 8 show no change in the percentage of sea water at that location from high to low tide. Spring surface salinity values at Station 8 also show no significant change from high to low tide. The shallow depth at the downstream end and the dam at the upstream end are ample reasons for the poor flushing characteristics of the north channel. The fall data indicate some fresh water does get into the north channel during high tide. This fresh water could have been pushed up the north channel from the lower bay during the flooding tide or could be primarily from precipitation and local runoff.

The existence of a salt water "lens" in the main channel above the mouth of Drift Creek, RM 5.1, is verified by the winter and the summer salinity data for Station 10. In both these cases the tide dominated the river flow so that the intruding salt water was pushed past the mouth of Drift Creek. The low tide salinity plots for these two seasons show a well-mixed system from the mouth to RM 5.34, where it abruptly changes to a partially-mixed one. Also, in each case bottom salinity values at RM 5.34 are greater than bottom values at Station 5, nearly 3 miles downstream. The depth immediately downstream of Drift Creek is considerably shallower than the upstream depth, probably due to the sediment load of the creek dumped into the estuary and the fact that the river widens into the bay at that point.

This area of greater depth, upstream of the creek, serves to trap salt water brought upstream during the flooding tide. The less dense fresh water flows over the top of the trapped salt water during the ebbing tide and fails to flush it out.

Another noteworthy observation about the salinity data is that during both high and low tides for all seasons the estuary was always well-mixed at the mouth. This is not surprising when considering the "open" condition of the Alsea's mouth which is fully exposed to the high energy waves of the North Pacific Ocean. Extremely turbulent conditions are a semi-permanent characteristic of the water at the Alsea's mouth. This turbulence dominates all other mixing factors to produce well-mixed estuarine water at the mouth nearly all the time.

Temperature

The surface temperature of the North Pacific Ocean water flowing into the Alsea Estuary varies much less throughout the year than the temperature of the fresh water flowing into the estuary. Based on data accumulated by Bourke _et al_ (1971) from 1965 to 1969 the mean annual temperature of ocean surface water along the coast at Depoe Bay, approximately 25 miles north of Alsea Bay, was 11.5^{o}C with a minimum monthly average of 8.3^{o}C occurring in March and a maximum monthly average of 16.8^{o}C occurring in August. Percy (1973) reports fresh water temperatures ranging from 0.6^{o}C to 25.6^{o}C measured at RM 21 by the U.S. Geological Survey between 1947 and 1966 in 110 spot observations. Both the sea and fresh water temperatures are warmer in the spring and summer and colder in the fall and winter.

Occasionally summer ocean water temperatures are colder than would be expected because upwelling brings deep ocean water to the surface along the coast. Temperature can be used as a parameter for measuring estuarine mixing characteristics provided the ocean and fresh water temperatures are not the same.

Figures 24 through 27 are plots, one for each season, of in situ water temperatures in ^{o}C as measured by the Hydrolab at the bottom, mid-depth and surface. In the following discussion it was assumed that bottom temperatures measured at the mouth during high tide closely approximate the ocean surface temperature and that the low tide surface temperatures measured at Station 10, RM 5.34, closely approximate undiluted fresh water temperatures.

Winter (Figure 24)

The winter (2/18/73) fresh water temperature of $8.5^{o}C$ was $1.5^{o}C$ colder than the sea water temperature, $10^{o}C$. During both high and low tides there was negligible variation both vertically and along the length of the estuary. The high tide temperature was $10^{o}C$ throughout the estuary with only a slight decline at Station 10, indicating the estuary was predominantly sea water as shown in the winter salinity plot Figure 20. The low tide temperature was approximately $8.5^{o}C$ throughout the estuary. The north channel temperatures were nearly identical to the main channel ones and showed no vertical variation for either high or low tides.

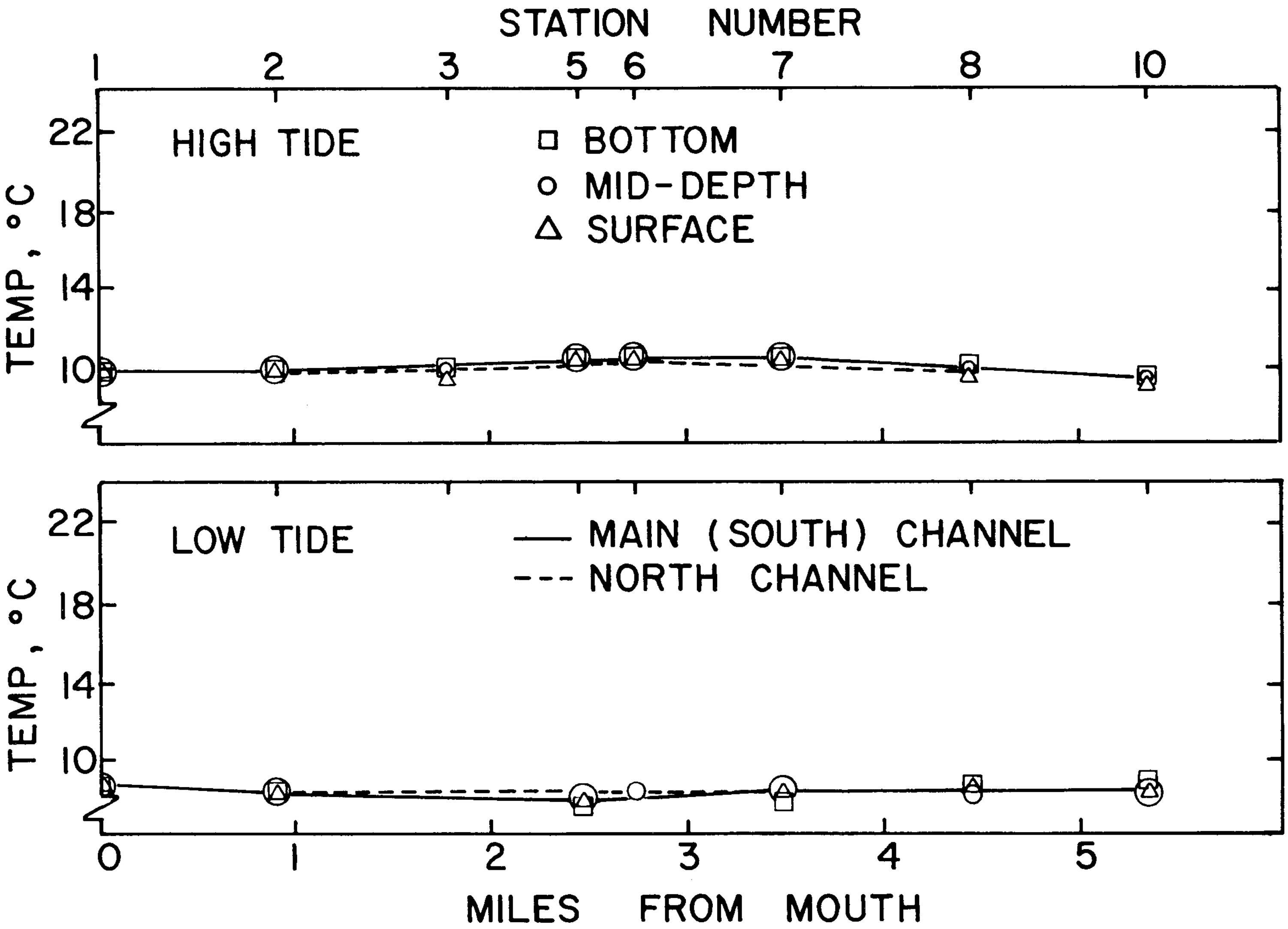


Figure 24. Temperature vs. distance, February 18, 1973.

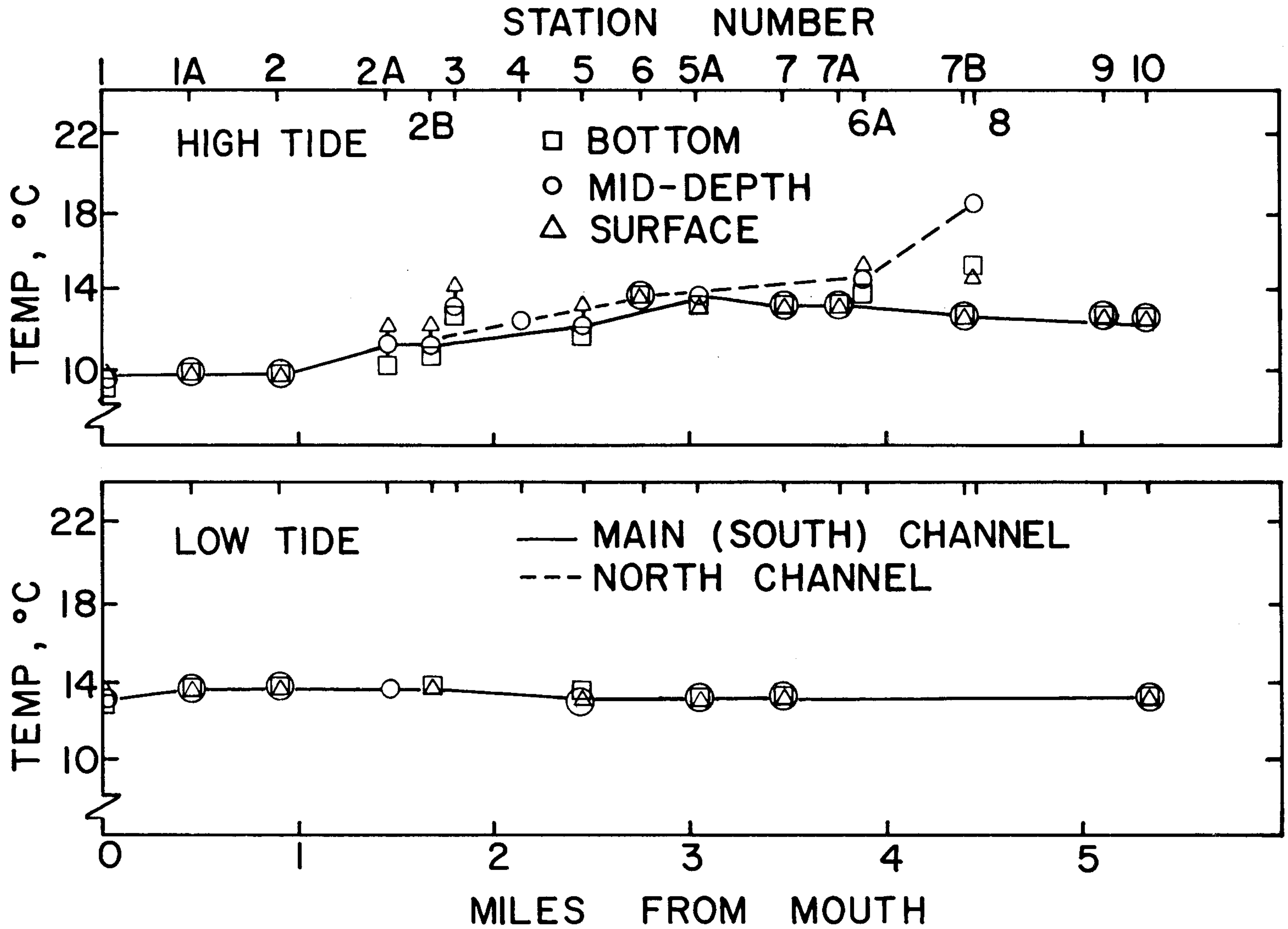


Figure 25. Temperature vs. distance, April 26, 1973.

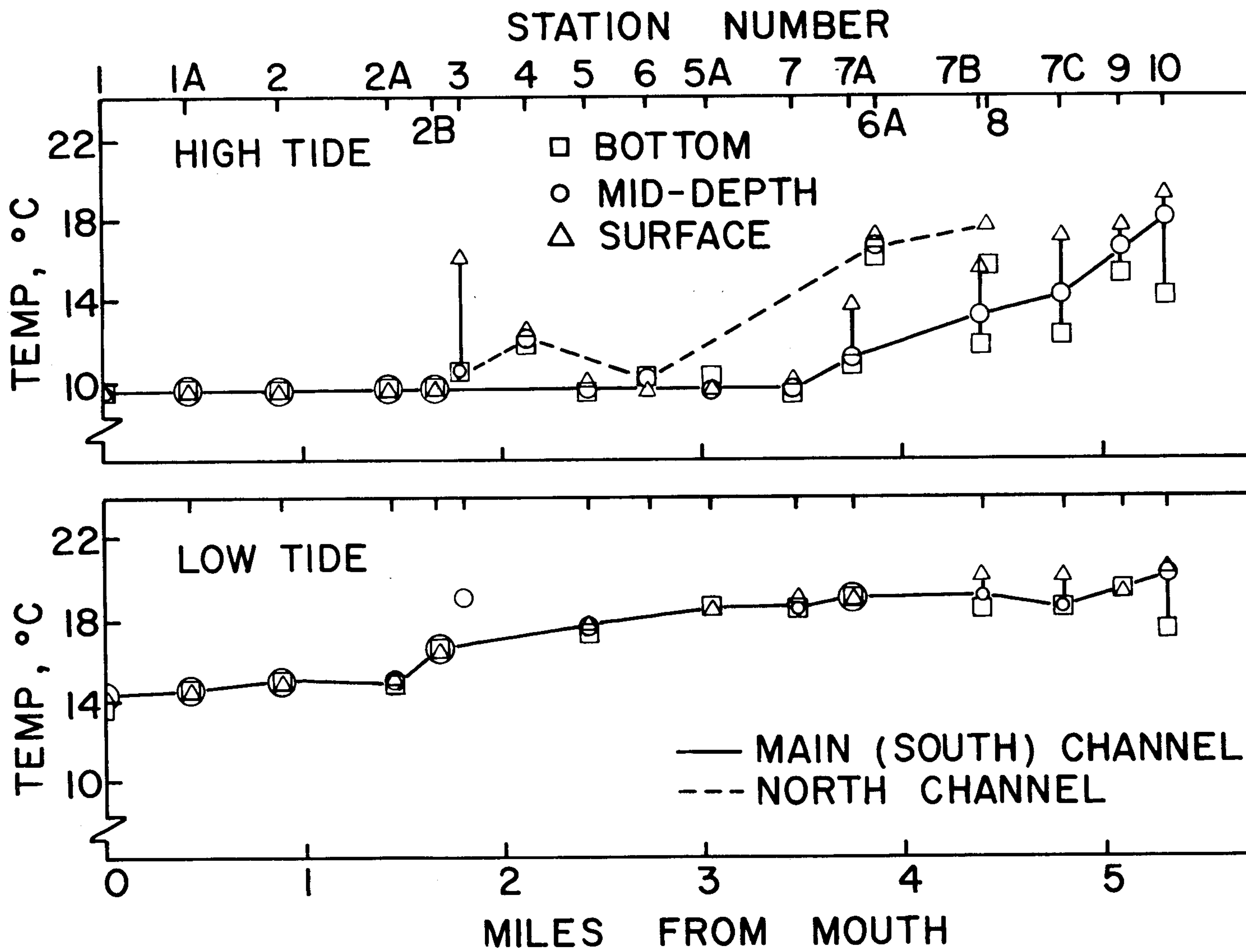


Figure 26. Temperature vs. distance, July 26, 1973.

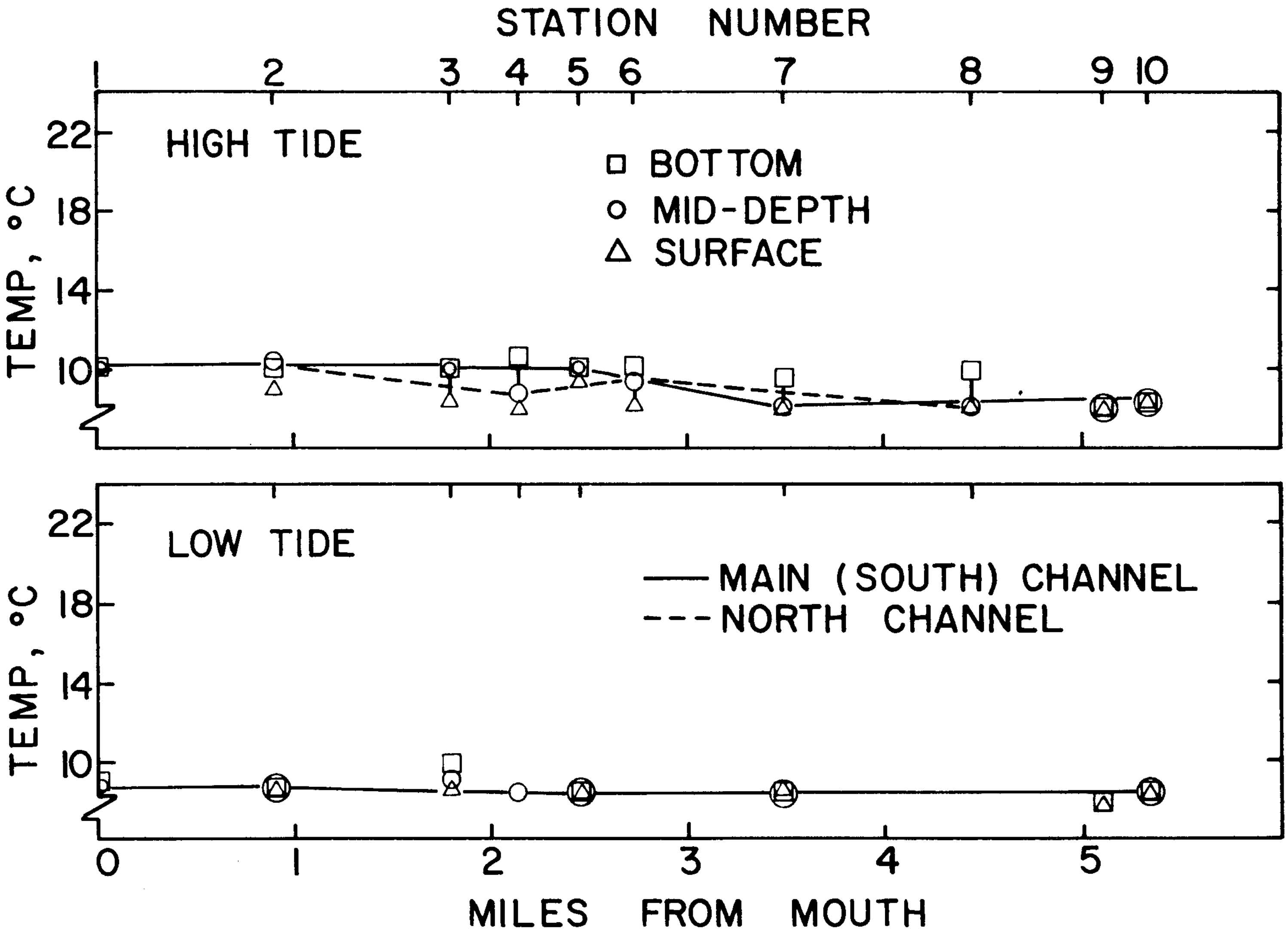


Figure 27. Temperature vs. distance, December 4, 1973.

Spring (Figure 25)

The spring (4/26/73) fresh water temperature, $13^{\circ}C$, was $3.5^{\circ}C$ warmer than the sea water temperature, $9.5^{\circ}C$. During high tide there was no vertical or longitudinal variation for the first mile above the mouth. Upstream of this point the temperature increased to nearly $14^{\circ}C$ at one location and surface water $2^{\circ}C$ warmer than bottom water was noted at some stations. In general, however, there was little vertical variation. Because the spring tide range was smaller than the winter range the spring plot shows more dominance by fresh water than the winter plot. The north channel temperatures were slightly higher than the main channel ones.

During low tide there was little vertical or longitudinal variation throughout the estuary. The temperature was about $13^{\circ}C$ along the entire length, with only a slightly lower temperature at the mouth.

Summer (Figure 26)

The summer (7/17/73) ocean temperature remained at $9.5^{\circ}C$ but the fresh water temperature increased to $20.4^{\circ}C$. During high tide there was no vertical or longitudinal variation of the $9.5^{\circ}C$ temperature from the mouth to RM 3.47. Upstream of this location the mid-depth temperature increased to $18^{\circ}C$ and the surface values were as much as $5^{\circ}C$ warmer than the bottom ones. Comparison with the summer salinity plot, Figure 22, shows that RM 3.47 is the point where the fairly constant salinity value of 33 PPT noticeably declines. The north channel temperatures showed little vertical variation and were generally 4^{o}C warmer than the main channel ones.

During the low tide the temperatures were higher, ranging from 14^{o}C at the mouth to 20^{o}C at Station 10. There were no vertical temperature variations from the mouth to RM 4.4. At Station 10 the surface temperature became 2.5^{o}C warmer than the bottom temperature, indicating colder water was trapped in the salt water lens there.

Fall (Figure 27)

The fall (12/4/73) fresh water temperature was 8.5^{o}C and the ocean temperature was 10^{o}C. During high tide there was little vertical variation in the 10^{o}C temperature from the mouth to RM 2.45, but upstream of that point the surface temperatures were about 2^{o}C colder than the bottom ones which remained near 10^{o}C. The north channel temperatures were nearly the same as the main channel and showed the same 2^{o}C vertical variation with the colder temperature on the surface.

The low tide temperatures were constant along the estuary length at approximately 8.5^{o}C and had no vertical variation. The low tide plot shows how the fresh water flow dominated the estuary.

Conclusions

In general, plots of temperature distribution verify the mixing characteristics already depicted by the salinity plots. However, the larger vertical and longitudinal variations of the salinity plots make them much more useful for analyzing mixing than the temperature plots. Expansion of the temperature scale would make any temperature variations more apparent, but this is impractical when large temperature differences exist between fresh and salt water. Also, whenever the temperatures of the salt and fresh water are nearly equal no variation of any kind would exist. The fact that during spring and summer the temperatures measured in the north channel were higher than the main channel temperatures is additional evidence that the north channel is not well flushed. The higher temperatures in the north channel resulted because this essentially non-flowing body of water was heated by solar radiation and, unlike the main channel, was not cooled by a steady inflow of lower temperature water. There was no noticeable temperature difference between the water in the two channels during fall and winter, however, since sufficient solar radiation was not available to raise the temperature of the north channel during those two seasons.

Dissolved Oxygen

Since the atmospheric gases of nitrogen and oxygen are poorly soluble in water, and since they do not react chemically with it, their solubility in water is determined by Henry's Law which states that the amount of gas that dissolves in a liquid at a given temperature is almost directly proportional to the partial pressure of the gas (Phelps). Not only is the saturation value of dissolved oxygen (DO) in a body of water a function of the water temperature and atmospheric pressure above the water, it is also affected by the salinity of the water (Phelps). At a constant temperature, an increase in atmospheric pressure increases the solubility of oxygen, likewise, an increase in water temperature at a constant pressure reduces the solubility. An increase in salinity at a constant temperature and pressure reduces the solubility (Phelps). Therefore, fresh water has greater solubility than sea water at the same pressure and temperature conditions. The level of DO in a body of water always tends toward the saturation value for the given pressure, temperature and salinity in order to achieve equilibrium with the atmosphere, unless affected by some other factor. In a stratified estuarine system where fresh water overlays salt water there is negligible diffusion across the interface between layers, consequently each layer tends to retain its own DO saturation value and the bottom layer cannot come into equilibrium with the top one or with the atmosphere.

The importance of DO in a body of water cannot be overemphasized because it is DO that supports aquatic life. Different species of marine life have different acceptable minimum levels of DO necessary for their survival. An example of a minimum desirable DO level appropriate to Oregon estuaries is 6 parts per million (PPM), which is the minimum allowable value for assuring good salmonoid production (Tarzwell). Another need for maintaining the highest DO levels possible is to assure aerobic conditions so that liquid wastes are oxidized by aerobic organisms which produce innocuous end products and not by anaerobic organisms (Sawyer and McCarty).

Unlike salinity, DO is a non-conservative substance that has sources and sinks within the estuary. One of the main sources of DO in estuarine waters is the process of direct solution from the atmosphere, known as reaeration. The rate at which oxygen is dissolved in water is directly proportional to the oxygen deficit of water. This means that the rate of solution for water that is 80% saturated (20% deficit) for a given pressure, temperature and salinity is twice as fast as the rate for water that is 90% saturated (10% deficit) for the same conditions (Phelps). If the water is 100% saturated there is no reaeration and if it is greater than 100% saturated oxygen is given off by the water. Since atmospheric oxygen can only enter the water at the surface it must rely on diffusion to carry it to the lower depths in order to equalize the concentration throughout the water. Mixing caused by turbulence greatly aids the process of diffusion to achieve an equilibrium concentration so the DO level could be expected to decrease with increasing depth in waters where there is little or no turbulence.

Another primary source of DO in an estuary is photosynthesis, the process in which green plants produce carbohydrates and oxygen from carbon dioxide and water through the action of sunlight on chlorophyll as shown by the reaction (Phelps)

$$CO_2 + H_2O = HCOH + O_2. \qquad (5)$$

The amount of oxygen produced by photosynthesis depends upon the season, the amount of sunlight available, the turbidity of the water and the amount of green plant life in the water. Photosynthesis in Oregon estuaries is greatest in the spring and summer when the amount of sunlight is highest. The prescence of a large amount of green plant life can create supersaturated DO levels under the favorable conditions that exist in the spring and summer (Matson).

In addition to the DO provided by reaeration and photosynthesis both the fresh and sea water flowing into the estuary contain DO. The DO content of the fresh water is primarily a function of its temperature and salinity. For both cases the atmospheric pressure can be considered the same. If the salt water is coming in from the deep ocean bottom through upwelling (which usually occurs in the summer) it may be undersaturated in DO (Matson). However, the turbulence at the mouth, which aids reaeration, would help to raise the DO level of undersaturated ocean water. Likewise, turbulent conditions in the river would favor reaeration of incoming fresh water that was undersaturated.

There are several mechanisms which act to remove DO from an estuary. The respiration of animal life removes DO, the total amount lost this way depending upon the type and number of animals present. It is not likely that the DO depletion caused by marine animals is serious in an estuary that has a continual DO input from several sources.

The oxidation and bacterial decomposition of organic matter which is in solution, in suspension, or in bottom deposits plays an important role in DO removal. The sources of organic matter in an estuary can include the following: industrial pollution, municipal sewage, logs, input from the ocean, wastes from aquatic life and decay of dead aquatic organisms (Gameson and Burnett). Depending upon the use of the estuary, several, or all of these sources of organic material can be available. Fortunately, on the Alsea, there is no industrial pollution, the sewage is now treated by a secondary plant and there is no log rafting or towing.

Another way in which DO is removed is through the oxidation of reduced inorganic compounds diffusing from anaerobic bottom deposits (Phillips). Anaerobic decomposition, which produces these bottom deposits, happens in non-polluted water as a result of processes using matter naturally occurring in that water. Often these deposits are found in pools, or other areas where the water is slow moving (Phelps).

There is DO contained in the water that flows through the estuary mouth during the ebb tide; however, the loss of DO in this manner may be compensated for by the DO brought in during the flood tide and by the DO in the continually flowing fresh water.

Figures 28 through 31 are plots, one for each season, of the bottom, mid-depth and surface dissolved oxygen values in parts per million (PPM) versus river mile. The DO's were determined by analyzing the water samples using the Winkler titration method. Sample data were felt to be more reliable than Hydrolab data because salinity adversely affects the DO probe, thus causing possible inaccuracies in in-situ electrode DO measurements. Also, it was not practical to continually recheck the Hydrolab DO calibration in the field. Since the DO samples were "fixed" immediately in the field and titrated within 24 hours using a thiosulfate solution which was standardized after its use, more reliability is placed on the sample DO values. The plots show vertical and longitudinal variation along the estuary. The measured DO values are compared on the plots to the surface DO

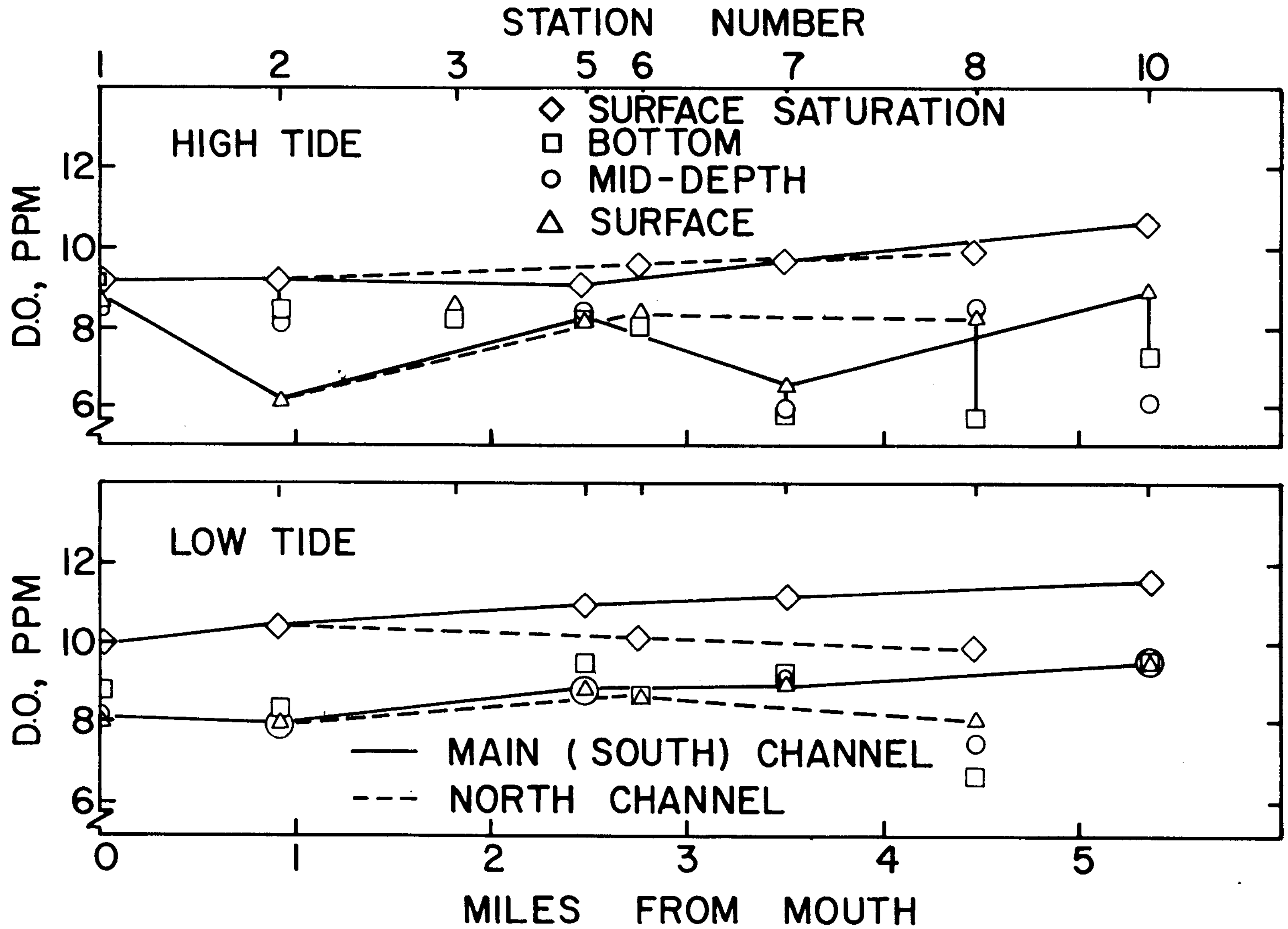


Figure 28. Dissolved oxygen vs. distance, February 18, 1973.

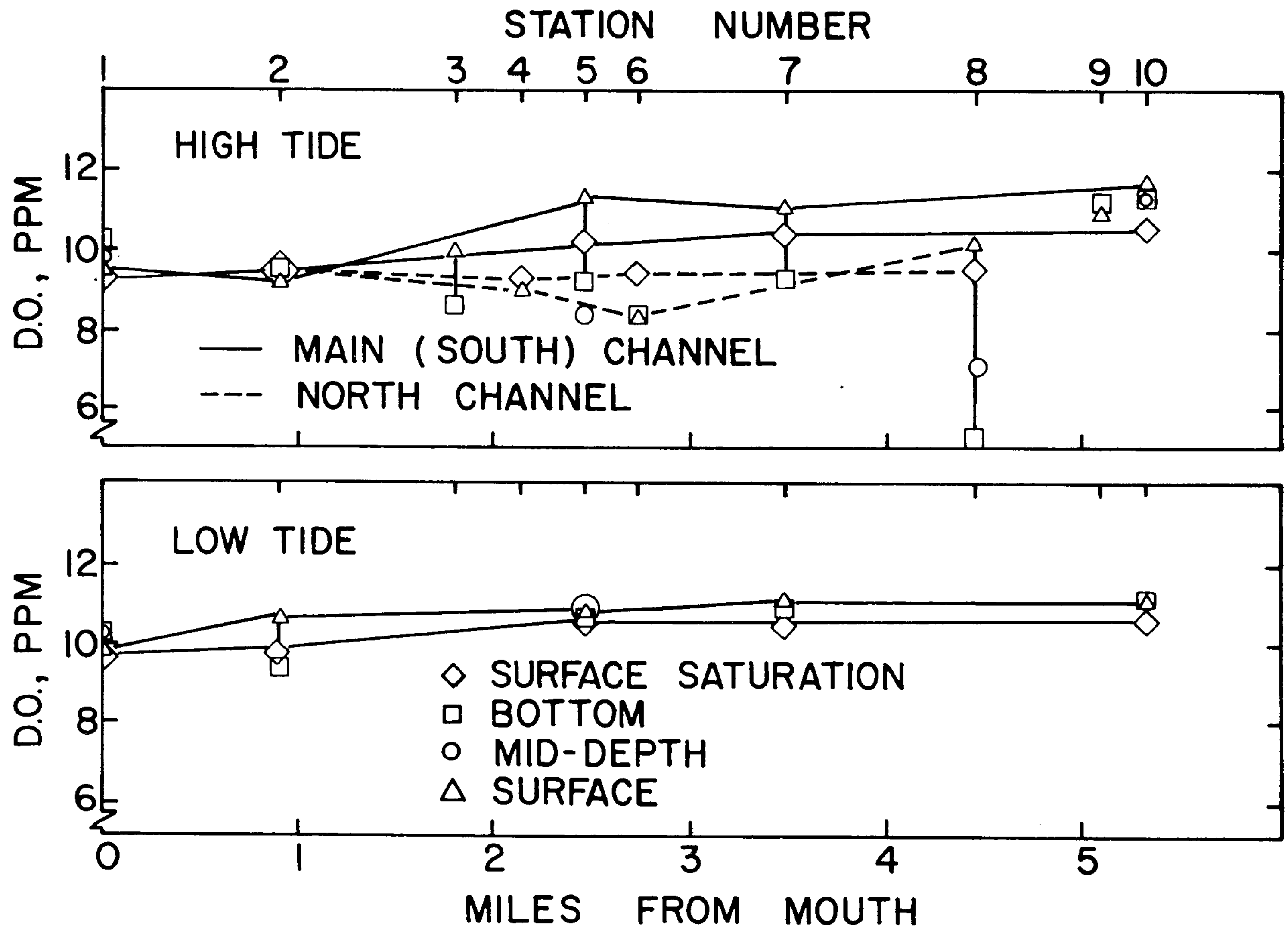


Figure 29. Dissolved oxygen vs. distance, April 26, 1973.

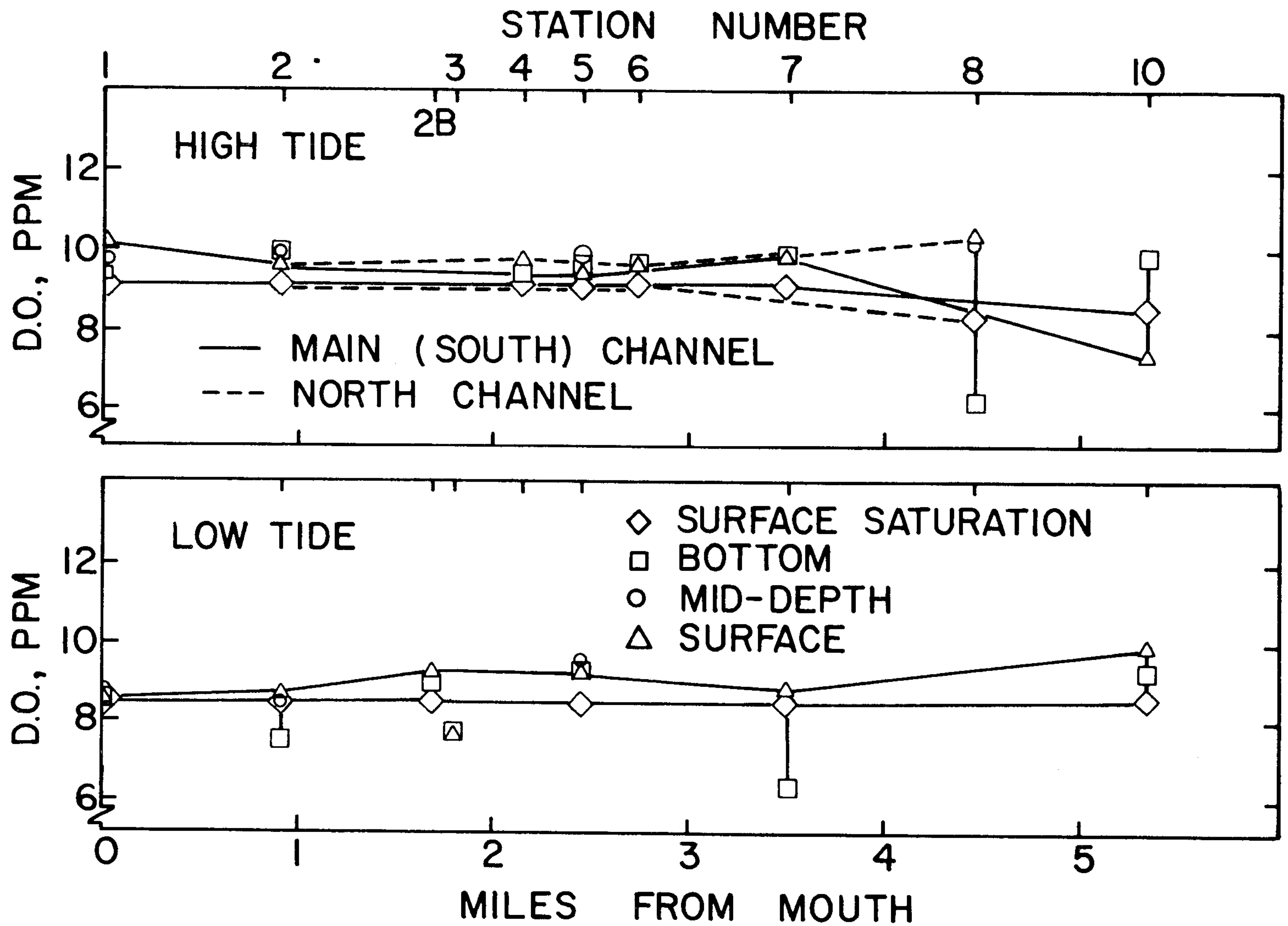


Figure 30. Dissolved oxygen vs. distance, July 17, 1973.

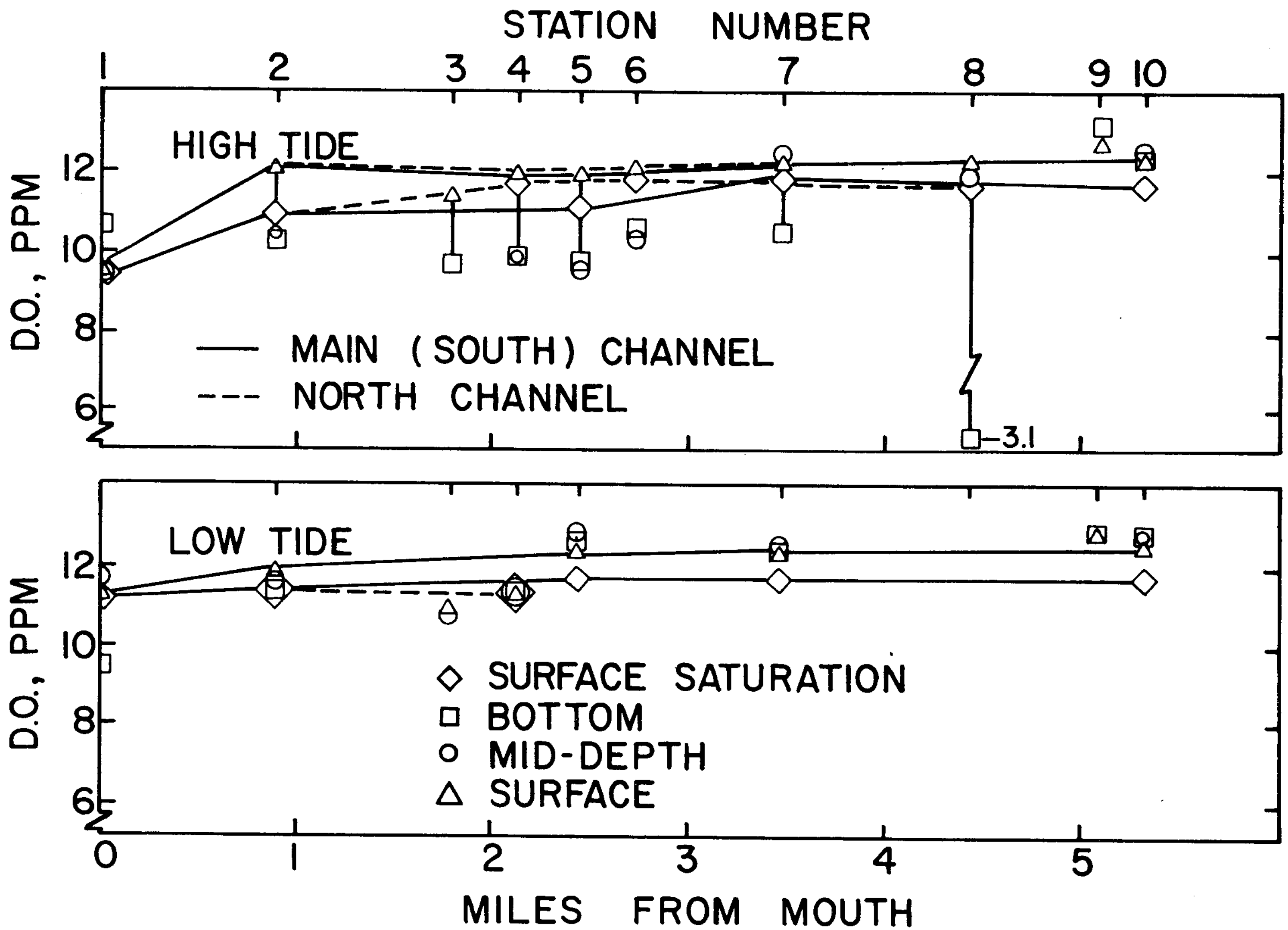


Figure 31. Dissolved oxygen vs. distance, December 4, 1973.

saturation values which were determined from the measured salinity (sample) and temperature values, assuming standard barometric pressure, by using the DO solubility data table in Appendix C of <u>Wastewater Engineering: Collection, Treatment and Disposal</u>.

<u>Winter (Figure 28)</u>

During high tide the water at the mouth was nearly saturated. Generally the measured DO values in the main channel followed 1 to 2 PPM below the surface saturation curve which increased upstream toward the colder, fresher water. Little vertical variation was noted in the well-mixed water except at Station 10 where bottom and mid-depth DO's were 2 to 3 PPM, respectively, less than the surface DO. Salinity stratification, unlike the downstream portion of the estuary, also occurred at this station. The north channel DO values also followed 1 to 2 PPM below the surface saturation curve. No vertical variation was noted except at Station 8 where the bottom value of 5.8 PPM was nearly 3 PPM less than the mid-depth and surface values.

During low tide, when the estuary was well-mixed, the main channel DO values followed nearly 2 PPM below the surface saturation curve and showed no vertical variation. The north channel values followed 2 PPM below the surface saturation curve and showed only slight vertical variation at Station 8 where the bottom value, 6.7 PPM, was 2 PPM below the surface value.

Spring (Figure 29)

During high tide the main channel DO values followed the surface saturation curve which increased gradually upstream toward the fresher water. From the mouth to Station 2, RM 0.9, there was no vertical variation and the DO values were saturated. However, from Station 5 through 7, RM 2.45 to 3.47, where salinity stratification existed, vertical variation occurred with the surface values supersaturated by nearly 1 PPM and the bottom values undersaturated by 1 PPM. By Station 10, where the water was all fresh, there was no longer any vertical variation, and all values were 1 PPM above saturation. In the north channel, where the water was well-mixed, the DO generally followed the surface saturation curve with slightly undersaturated values having no vertical variation. At Station 8 some stratification existed and there was large vertical variation with the 10.6 PPM surface DO .6 PPM above saturation and the bottom value at 5.3 PPM.

During low tide the DO values followed the surface saturation curve, which increased slightly upstream, and showed no vertical variation except at Station 2, RM 0.9, where some salinity stratification existed in an otherwise well-mixed system. At Station 2 the surface DO was 1 PPM greater than the bottom DO. At the mouth the DO's were saturated, but upstream from there all values (except Station 2 bottom) were supersaturated by approximately .5 PPM.

Summer (Figure 30)

During high tide the main channel DO values generally followed the surface saturation curve which decreased gradually upstream where the water was much warmer. There was no vertical variation in the well-mixed water until Station 10, where some stratification occurred at the salt water lens there. At Station 10 the bottom DO exceeded the surface DO by nearly 3 PPM. Bottom DO in excess of surface DO can be explained by the fact that the $5^{0}C$ colder bottom temperature induces a higher DO value in the bottom water than the 10 PPT greater bottom salinity would induce in the surface water. The DO showed values supersaturated by .5 PPM along the estuary length except for the 1 PPM undersaturated surface DO at Station 10. The north channel DO's followed the surface saturation curve with no vertical variation at the lower stations and then diverged away from the curve at Station 8 where vertical variation was also evident. All values were supersaturated except the Station 8 bottom DO of 6.2 PPM.

During low tide the main channel DO's followed the nearly horizontal surface saturation curve and showed no vertical variation except at Station 7, RM 3.47. The DO's were saturated from the mouth to Station 2 above which they were nearly 1 PPM supersaturated except for the Station 7 bottom DO.

Fall (Figure 31)

During high tide the main channel DO's followed the surface saturation curve as it increased upstream toward the colder, fresher water. At the mouth there was only slight vertical variation of the well-mixed water, but from Station 2 through 7, RM 0.9 to 3.47, the supersaturated surface DO's exceeded the slightly undersaturated bottom values by nearly 2 PPM. At Station 10, where the estuary was all fresh water, there was no vertical variation and the DO values were 1 PPM above surface saturation. The north channel DO's also followed the surface saturation curve and showed a 2 PPM vertical variation with the surface values slightly above saturation and the bottom values undersaturated. At Station 8 an extremely low bottom DO of 3.1 PPM was measured.

During low tide there was no vertical variation of the DO's in the well-mixed estuary water. The DO's followed the increasing surface saturation curve and, except for the saturated DO at the mouth, the DO's along the estuary were 1 PPM above saturation.

Conclusions

In nearly every case when well-mixed conditions existed there was little to no vertical variation in the DO distribution, but when salinity stratification occurred so did vertical DO variation. Generally, in a stratified situation such as the fall high tide, the DO in the bottom saline water was less than the DO of the surface fresh water. However, when the affect of temperature difference exceeded the influence of salinity difference, as in the summer high tide at Station 10, the inverse occurred and the bottom DO was greater than the surface DO.

Saturated DO's occurred at the mouth in every case but the winter low tide. This was an expected result since the high degree of turbulence usually found at the mouth is a great aid to reaeration. The tide range and river flow seemed to have no effect on the DO levels, which were almost always at or near saturation.

There were noticeably lower bottom DO values at the upstream end of the north channel, Station 8. Bottom water samples collected at this station always contained large amounts of sediments which were stirred up when the DO sampler struck the bottom. Phillips (1974) suggested that the extremely low DO values (less than 6 PPM) were probably the result of the DO sampler collecting a portion of the deoxygenated water which is mixed in with the top layer of the anaerobic bottom deposits existing at this location. Because of the very fine nature of these deposits it was not always possible to collect bottom water samples without disturbing the deposits and putting them into suspension. Therefore, the low DO values measured at the bottom of Station 8 are not necessarily an indication of water undersaturated in DO, but of the prescence of interstitial deoxygenated water in the surface layer of bottom deposits.

The estuary DO saturation level was found to be higher in the fall and winter when the temperatures were colder and the fresh water flow was higher. With the exception of the fall high tide bottom DO at Station 8 no values less than 5 PPM and only a few less than 6 PPM were measured. This was not surprising since there are no serious harmful mechanisms at work to deplete DO in the Alsea Estuary.

The supersaturated values occurring in spring and summer do not seem unlikely, since these are the seasons when there is sufficient sunlight to favor photosynthesis. Matson (1971) reported supersaturated DO values for May through September of 1967 and 1968, occurring primarily after 1200 PST. The supersaturated DO's reported in this author's study were measured during both the morning and the afternoon. Phillips (1974) was of the opinion that supersaturated values measured in the fall were in error, particularly considering the fact that the skies were periodically overcast during the data collection day.

There is a possibility of a systematic error in the DO measurements made from the bottle samples. This error could be induced through the sample collection method, and not through the laboratory analysis procedures. Phillips (1974) suggested that the diameter of the DO sampler intake pipes may have been too large and caused the water to be aereated as it was collected. Also, the technique of lowering the sample bottle by hand to collect the surface water sample may have aereated the water as it entered the bottle if proper care was not taken. Both of these factors would tend to increase the measured DO value of the water.

Unfortunately, there was little correlation noted between the Hydrolab DO values and the sample DO values when they were compared for the same stations. The Hydrolab data showed fewer supersaturated values, and those were primarily in the summer. The Hydrolab data did not indicate any seriously low values and generally showed much less variation with depth. It is felt that the sample DO values, although possibly too high (particularly in the fall), do accurately indicate vertical DO variations and confirm that there are no large areas within the estuary having depleted DO levels.

Turbidity

Sawyer and McCarty (1967) define turbid as "The term ... applied to water containing suspended matter that interferes with the passage of light through the water or in which visual depth is restricted." Turbidity can be the result of many different suspended materials, the size of which ranges from colloidal to coarse suspensions. The degree of turbulence, of course, affects the size of material that can be placed in suspension. This suspended material can be either organic or inorganic.

Estuaries have natural and man-caused sources of turbidity. The ocean water brought in during the flood tide contains micro-organisms and other suspended matter, but generally the fresh water source brings in the larger amounts of suspended material. The amount of riverborne turbidity-causing matter varies with the flow and depends upon the geological nature and usage of the drainage basin. Activities such as farming, ranching, logging, and disposal of industrial wastes and domestic sewage influence the character and amount of material carried by the river. Whatever is dumped into the upstream reaches eventually passes through the estuary. The fine clay minerals, which are carried by the river water in a collidal or semi-collidal state floculate when the intruding sea water mixes with the fresh water. Often the floculated particles are large enough to settle out as deposits, but if there is sufficient turbulence these flocs remain in suspension.

The estuary itself provides material which contributes to its own turbidity. This may be matter originally brought in by another source and deposited during low water on tide flats and marshes only to be resuspended during high tide; or it may be material deposited directly into the estuary from debris sloughed off of cliffs located on the estuary margins. Also, microorganisms native to the estuary may add to the turbidity.

Winds can supply substantial amounts of material to an estuary, particularly if there is an adequate source, such as sand dunes, nearby. This material may settle or remain in suspension, depending upon its size and the water turbulence.

Man induced turbidity can be caused in many ways. The same activities that occur upstream, as mentioned above, can also happen along the estuary as well, In addition to those sources, use of the estuary for rafting and towing logs, use by vessels, dredging and construction add to the turbidity of the water.

The turbidity of water is important for several reasons. Aesthetically turbid water detracts from water recreational activities. The other undesirable qualities are the negative effects high turbidity has on photosynthesis and aquatic animals, which in turn have a negative influence on biological productivity, as well as recreation. Turbidity is an important consideration for water to be used as a public water supply, however it is unlikely an estuary would be used for that purpose.

Turbidity is measured by an arbitrary standard which is:

$$1 \text{ mg } SiO_2/\text{liter} = 1 \text{ unit of turbidity}$$

and commonly referred to as the Jackson Turbidity Unit (JTU). The name comes from the Jackson candle turbidimeter, the original standardizing instrument. The silica used for standardization must meet certain grain size specifications. A turbidimeter which is calibrated against a standard source measures the scattering effect that the suspended matter has on a light source transmitted through a water sample (Sawyer and McCarty).

Turbidity can range from 0 JTU's in pure water to several thousand JTU's in highly turbid river water. The Public Health Service has established a maximum permissible value of 5 JTU's for public water supplies (Sawyer and McCarty).

Figures 31 through 33 are plots, one for each season (except winter), of turbidity in JTU's versus river mile. The turbidity values were measured in the laboratory from the collected water samples. Because of the disturbance to the sediments caused by the DO sampler when it was lowered to the bottom, turbidity measurements of the bottom samples must be regarded as highly unreliable. The following discussion considers only the mid-depth and surface turbidity values. All winter values were considered unreliable because of improper operation of the laboratory turbidimeter.

Spring (Figure 32)

During high tide both the main and north channel surface turbidities were all less than 5 JTU's. There was a gradual decrease of values in the upstream direction. Mid-depth turbidities were slightly greater than surface ones.

During low tide the main channel surface turbidities increased from a low value of 0.8 JTU's at the mouth to 9.0 JTU's at Station 5, RM 2.45, then decreased again to 2.0 JTU's or less upstream of Station 7.

Summer (Figure 33)

During high tide the main channel surface and mid-depth turbidities were all less than 5 JTU's and showed no definite variation along the estuary length. The north channel turbidity at the downstream end was also less than 5 JTU's, but increased to 8 JTU's by Station 8 at the upstream end.

During low tide main channel surface and mid-depth turbidities fluctuated between 6 and 9 JTU's from the mouth to Station 7, RM 3.47, and then decreased to 3 JTU's by Station 10.

Fall (Figure 34)

During high tide the main channel surface and mid-depth turbidity values all were at or below 5 JTU's. The north channel surface turbidities were all very close to 5 JTU's and the mid-depth turbidities showed an increasing trend in the upstream direction, ranging

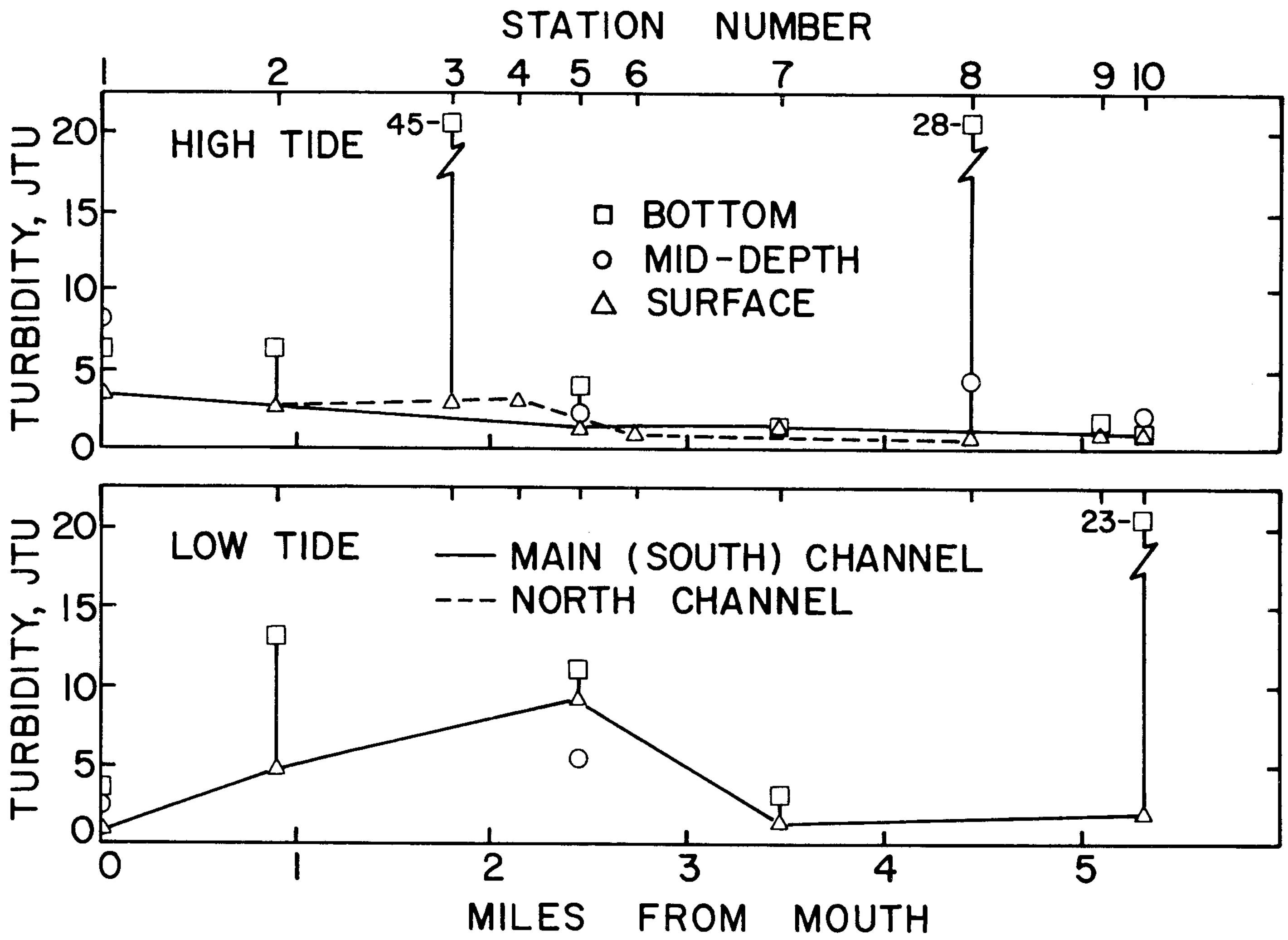


Figure 32. Turbidity vs. distance, April 26, 1973.

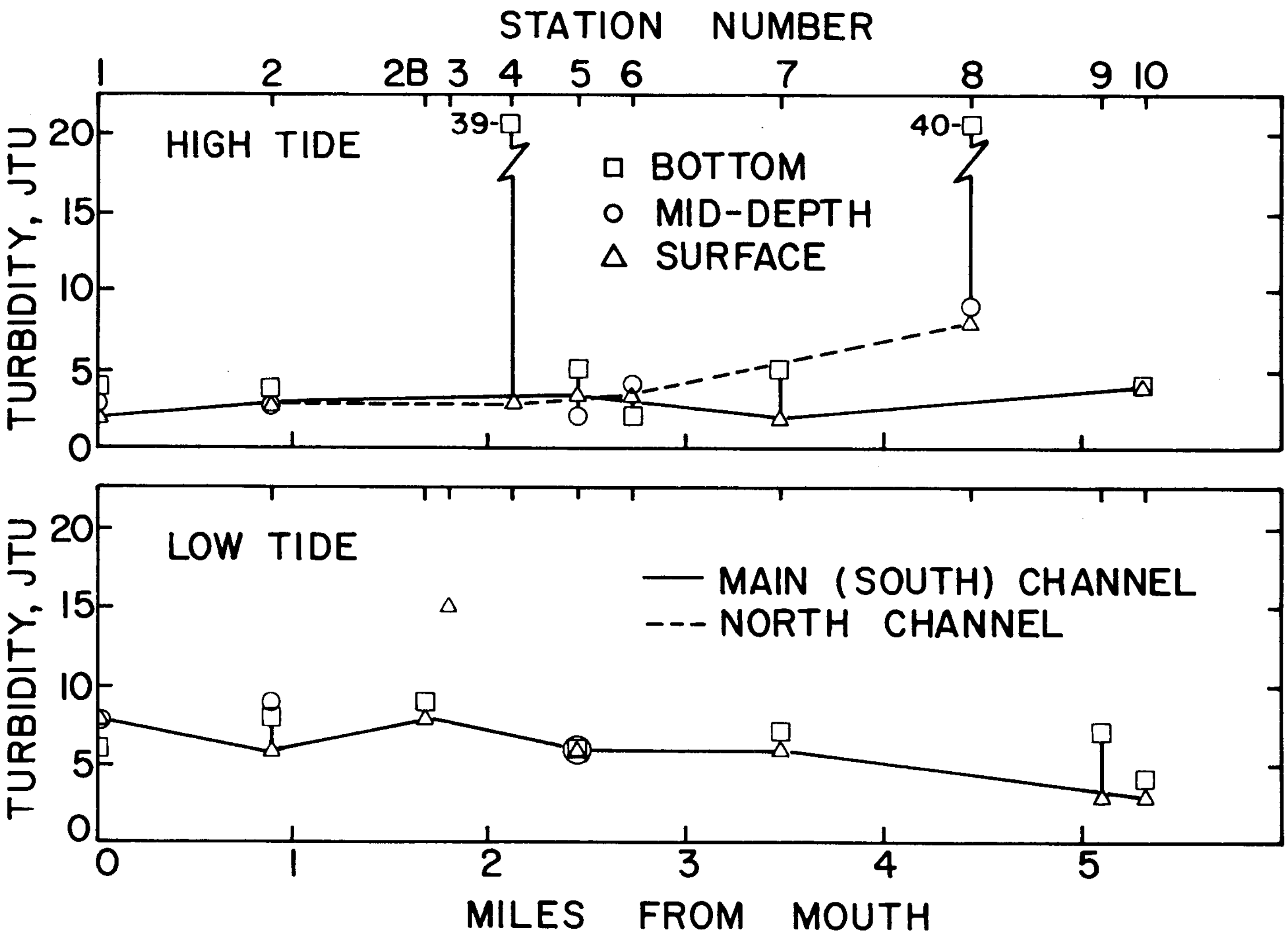


Figure 33. Turbidity vs. distance, July 17, 1973.

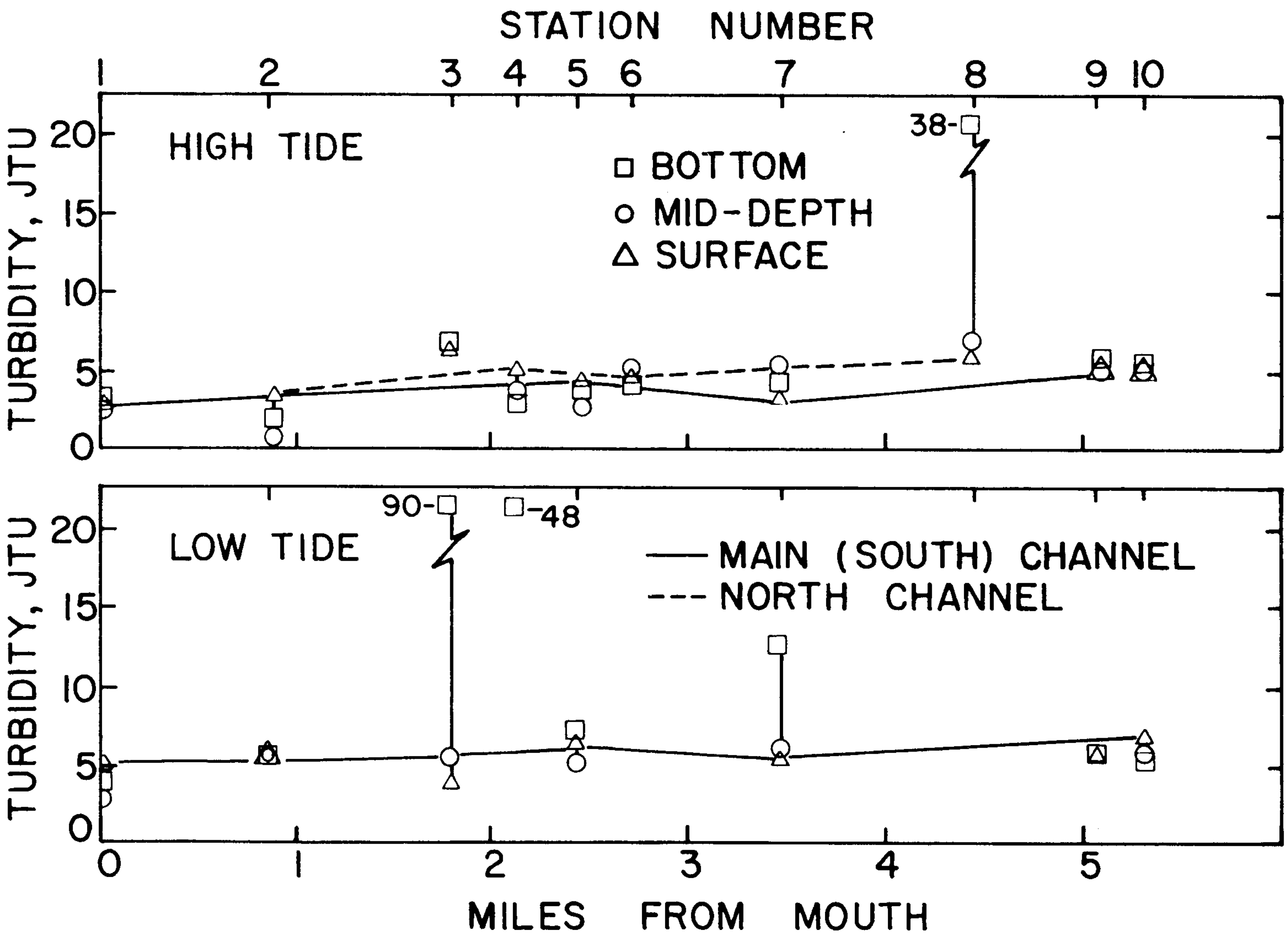


Figure 34. Turbidity vs. distance, December 4, 1973.

from 3.4 JTU's at Station 4, RM 2.15, to 6.8 JTU's at Station 8.

During low tide the main channel surface turbidities ranged from 5 JTU's at the mouth to 6.9 JTU's at Station 10. Mid-depth turbidities ranged from 2.8 JTU's at the mouth to 5.7 JTU's at Station 10.

Conclusions

The water of the Alsea exhibited low turbidity values during the periods when the samples were collected. The values measured during the fall, the period having the highest flow, were in the same range as the summer low flow values. However, the fall flow of 3210 cfs was not an exceptionally high flow for that season. On March 14, 1974 the author personally observed from the air very turbid water in the Alsea, as well as several other nearby estuaries. The turbid fresh water made a distinctive plume as it entered the ocean. At this time the river flow was 5600 cfs. Therefore, even though only low turbidities were measured in the Alsea visual evidence indicates that during periods of high flow (greater than 5000 cfs) much higher turbidities can occur.

Sample evidence indicates in all three cases that low tide turbidities were on the average slightly higher than the high tide turbidities. This was an expected result for spring and fall when the more turbid river water dominated the estuary during low tide. During the high tide, not only was the turbid fresh water diluted by salt water, but flocculation may have caused some of the colloidal particles to fall out of suspension in the more saline water. An increase in turbidity at low tide conditions was not expected during the summer when much salt water remained in the estuary during low tide and the river flow was low. Evidently the Alsea river water continues to transport a significant amount of suspended matter, relative to the amount carried by the ocean water, even at low flow conditions.

pH

pH refers to the hydrogen ion concentration of a water solution and is defined by the equation:

$$pH = \log \frac{1}{[H+]}$$

Generally pH values are considered to range from 0 to 14, although values greater than 14 and less than 0 are possible. A pH of 7 represents neutrality, as in pure fresh water, a pH less than 7 is an acidic condition and a pH greater than 7, an alkaline condition. The pH of ocean water is usually near 8.0, with values often ranging from 8.1 to 8.3. The pH of ocean water depends in part upon the concentration of carbonate and bicarbonate ions which are basic in nature (Williams).

The pH of both sea and fresh water is affected by the amount of biological activity in the water. The consumption of CO_2 by plants (photosynthesis) results in an excess of CO_3 in the water thus raising the pH. Whereas the production of CO_2 by animals (respiration) removes CO_3 from the water and lowers the pH (Williams).

No attempt was made to plot the pH data because significant variations were not noted. All pH (Hydrolab and bottle sample) data are listed in Table A2 of Appendix A. In general, there was a slight decreasing trend in the pH values in the upstream direction. High tide pH values near the mouth were usually near 8.0 and low tide values at Station 10 were usually near 7.0, indicating the ocean water was more basic than the fresh water. pH appears not to be a particularly useful tracer for measuring estuarine mixing conditions.

VII. SEDIMENTS

Introduction

Sources of estuarine sediments vary according to a particular estuary's geological, climatological and tidal environments. The manner in which these sediments are deposited is influenced partly by the mixing characteristics of the estuary. In general, there are four natural sources of sediments in estuaries: (1) the ocean (marine), (2) the river (fluviatile), (3) the wind (aeolian), and (4) the immediately adjacent land, in particular, the lower slopes bordering the estuary (Klingeman and Kaufman, Guilcher). A fifth source of sediments found on many estuaries is from man-made waste discharges.

The intruding salt water transports marine sediment material into the lower reaches of an estuary. The amount of material transported and the distance extended upstream depend upon the flow ratio and the estuary geometry. Marine sediment may consist of sand carried across the mouth from adjacent beaches by longshore currents or of ocean bottom mud brought in from farther out at sea (Kulm and Byrne, Guilcher). The fluviatile sediment material is clay, silt and sand eroded from the land making up the river's drainage basin and then carried downstream by the river. The wind can carry large amounts of sediment material if there is a nearby source, such as sand dunes (Kulm and Byrne). Tidal action, waves and precipitation erode the land bordering and estuary, thus producing additional sediments for the estuary. This source of sediments can be important if the estuary shoreline is easily eroded. Tidal flats that are periodically covered with water provide another notable source of estuarine sediment (Klingeman and Kaufman). The man-made wastes may either be solids ranging in size from tiny particles to automobiles, or liquid chemicals that produce precipitates which settle out as potentially undesirable sediments.

Estuarine sediments are transported either as bed load material, or as suspended load. The bed load material, consisting of sand-sized or larger particles, is transported in close proximity to the bottom. In order for these particles to be transported as bed load the current velocity near the bottom must exceed the entrainment velocity for the particular sized particles involved. The bed load sand particles are primarily composed of quartz (Turekian).

Particles smaller than sand are held in suspension by turbulence. In some cases very fine clays behave as colloids (Klingeman and Kaufman). This suspended material ranges in size from silts to very fine clays. The principle silt material is calcium carbonate and the clay minerals are kaolinite, montmorillionite, illite and chlorite (Turekian).

In nearly every major river of the world the greatest quantity of sediment is transported as suspended load. Turekian (1968) estimates the quantity of suspended load carried by these rivers to be 3×10^{16} grams per year. Although it is not possible to determine precisely, he estimates the bed load transported to be approximately 10% of the suspended load. The Columbia River, however, is a unique exception because its sediment consists primarily of bed load sand with a median grain size of one-half millimeter (Ippen II).

Geologists have developed empirical relationships to show the critical erosion velocity at which a particle of a given size is picked up and moved by flowing water. The particle settles to the bottom when the water flow decreases to that particular particle's lowest transportation (deposition) velocity. Both the values of critical erosion velocity and deposition velocity increase with particle size, except for small diameter unconsolidated clays and silts (Postma). Turbulence tends to keep particles in suspension when a continuous source of material is available, as in an estuarine system. Therefore, since turbulence in part depends upon velocity, the quantity of turbulence suspended material, as well as the quantity of material carried as bed load, is proportional to velocity. During the portion of the tidal cycle when current velocities exceed a particular particle's critical erosion velocity it is transported with the current, either as bed load, or in suspension, depending upon its size. As soon as the current velocity drops below the deposition velocity the particle settles. Thus, during a tidal cycle sediment transportation and deposition fluctuate with the changing strength of the tidal currents.

Clay-sized sediment particles in a colloidal or semi-colloidal state are deposited through the complex process of flocculation. The clay minerals of illite, montmorillionite and kaolinite flocculate more readily than other minerals, such as quartz. These tiny clay particles often have an electric charge which is usually negative because of (1) preferential absorption of anions (usually hydroxol ions), (2) cationic substitutions within the crystal lattice and (3) residual valences at particle edges. Double layers of hydrated cations held in place by electrostatic attraction surround the particles and balance the negative charge. The thickness and electrolytic potential of these double layers depend upon the total ion concentration, pH and temperature of the surrounding water, as well as the valence of the particles' sorbed ions (Postma).

As long as the clay particles have thick double layers they are stable and, because of like charges, tend to repel when they approach each other through their Brownian movement. When the thickness of these double layers is reduced below a certain value the particles lose stability, no longer repel each other and begin to coagulate. The addition of electrolytes to the water, as in the case of salt water intrusion, decreases the thickness of the double layers surrounding the collidal particles and causes these clay particles to flocculate. Therefore, river-borne collidal clay particles begin to flocculate when they come into contact with sea water in the estuary. Flocculation is extremely unlikely in fresh water unless polyvalent cation or organic wastes are present (Postma).

An understanding of the hydraulic and chemical properties of estuaries leads to several general conclusions about estuary sedimentation. Because of the net upstream bottom current in the lower portion of an estuary, sediments deposited there tend to be transported upstream. Kulm and Byrne (1966) described the region upstream of the mouth where ocean sediments predominated as the marine realm of the estuary. Shoals tend to form near the point of farthest salt water intrusion, or where the net bottom velocity is at or near zero. The intensity of the shoal formed at the end point of the salt water intrusion depends upon the mixing characteristics of the estuary. The well-mixed estuary generally has more dispersed shoaling in this area than the highly stratified one (Ippen II).

Activities of both man and nature can have long term effects on estuarine sedimentation processes. Seasonal variations in climatic conditions have an important effect on the supply and deposition of sediments. Precipitation, which can vary considerably during a year, determines river discharge. Discharge, in turn, affects river velocity and estuarine mixing characteristics, thus influencing sedimentation processes. Shifts in direction and changes in velocity of prevailing winds affect circulation and mixing. In addition, wind direction shifts can cause a change in direction of the ocean's longshore current adjacent to the estuary mouth. This longshore current affects littoral sand drift which is a source of marine sediment (Kulm and Byrne).

Man's alterations to the ocean and river environment can have serious consequences on estuary sedimentation processes. Altering fresh water influx into an estuary, either through building upstream dams or diverting additional fresh water sources into an estuary, changes circulation and sediment flow. Deepening channels through dredging also influences mixing and circulation. Unwise disposition of dredge spoils can have undesirable after effects. Jetty construction, which usually disrupts littoral drift of sand, can dramatically increase or decrease the supply of marine sediment, depending upon the location of the jetty and the direction of the drift. Logging practices in an estuary's watershed can have a severe impact on the sediment loads carried by the estuary's tributaries. Logging, itself, in a forested watershed increases the streamflow. The road systems constructed to support the logging operations and the necessary slash disposal can cause unusual erosion problems which result in higher than normal quantities of sediments (Brown). Finally, discharge of electrolytic or organic wastes affects the process of flocculation and may produce unwanted precipitates (Postma).

Alsea Sediments

Since there is no industrial waste discharge occurring on the Alsea, the three sources of sediments for the estuary, excluding the tidal flats and bordering land, are the ocean, the river and the wind. The manner and the degree to which these three primary sources provide sediments to the estuary are largely decided by meteorlogical conditions, which may vary seasonally. In addition to climatic influences, tidal range, which affects mixing and circulation patterns, also plays a major role in determining which sediments are deposited where.

The supply of marine sediments going into the bay is influenced by littoral drift, which is the flow of ocean sediment material parallel to the ocean shoreline. This longshore littoral drift of sand is caused by wave-induced currents which are set up parallel to the shore when waves strike the coastline obliquely. The direction of littoral drift is determined by the direction from which the waves approach the shore. The direction of this wave advance is, in turn, determined by the direction of the prevailing winds. Kulm and Byrne (1966) concluded from wave hindcast data that the direction of littoral drift along the Oregon Coast is northward from November or December to March and southward from April to October or November. Thus, the direction of littoral drift along the Oregon Coast is southward for 67% to 75% of the year. There is an ample supply of sand on the ocean beaches adjacent to the mouth of the Alsea, particularly to the north, to establish a high volume flow of sediment material past the estuary entrance.

As this sediment material is carried past the mouth by the littoral currents it is brought into the estuary by the intruding salt water. The greatest amount of material is transported into the bay during the flood tide, although some material is probably brought in during the ebb tide if an upstream bottom current persists throughout the entire tidal cycle. The amount of material carried in by the flood tide depends, in part, upon the flood tide flow, which is proportional to the low-to-high tide range (see Figure 14). The distance upstream the material is carried is determined by the length of the salt water intrusion. Kulm and Byrne (1966) concluded that, on the Yaquina, the maximum upstream sediment intrusion should occur during the winter and spring when river flow is highest (due to greater precipitation) and the estuary approaches a stratified condition. They believed that under these conditions of stratification the salt water wedge intruded to its farthest extent and the flood current velocity was greatest. However, the results of this research indicate that the point of extreme salt water intrusion is determined by the relative magnitudes of the river flow and the tidal flow. The summer salinity plot (Figure 22) shows that during the high tide when the river flow was 104 cfs and the tide range was 3.8 feet, the water at Station 10 (RM 5.34) had an overall mean of 60% sea water; whereas, during the fall high tide (Figure 23) when the river flow was 3210 cfs and the tide range was 5.6 feet, the water at Station 10 was all fresh. Comparison of the winter and spring salinity plots (Figures 20 and 21) show the difference in the extent of salt water intrusion resulting when the same river flow experiences two greatly different tide ranges. Therefore, the point of extreme salinity intrusion, and thus of marine sediment intrusion, depends upon the tidal range as well as the river flow. The amount of marine sediments brought into the estuary and the distance they are carried upstream do not necessarily vary with changes in precipitation, but depend upon whether the tide flow or the river flow is dominating the system.

The amount of fluviatile sediment material carried into the estuary depends upon the river flow, which is a function of the precipitation occurring in the watershed. Thus the Alsea River transports a greater sediment load downstream during the period of highest rainfall, which generally lasts from October through March. The characteristics of the river-borne sediments are determined by the geological nature and the usage of the watershed. A heavily forested drainage basin, such as the Alsea's, provides less sediment material than one in which most of the land is devoted to agriculture. Logging operations in a forested watershed do, of course, increase the amount of sediments since the removal of vegetation increases both erosion and stream flow (Brown). Therefore, the logging carried on in the Alsea's drainage basin is bound to have an impact on the amount of sediments transported into the estuary by the Alsea River and other tributaries. Brown (1972) concludes that the primary causes for soil erosion resulting from logging operations are slash disposal and road building, and not clear-cutting.

Tiny clay particles constitute much of the material carried as riverborne sediments (Ippen II). When the fresh water mixes with the intruding salt water these clay particles often flocculate to form particles large enough to settle to the bottom. If the flocculation is confined to a small area, as in the case where there is a well-defined, arrested salt water wedge, a large shoal can develop. In the Alsea, however, where the fresh and salt water are often partially or well-mixed and the location of extreme salt water intrusion varies widely, severe shoaling at a single location resulting from flocculation would not be expected.

Although no measured sediment loads of the Alsea River have been reported, and accurate estimates are difficult to make, Percy (1973) does provide an estimate that 249,000 tons are deposited annually in the estuary by the Alsea River and other tributaries. Percy qualifies this estimate by stating in the introduction to her report that it was based on a map presented in 1954, and since that time conditions in the watershed have changed significantly. Therefore, this estimate cannot be regarded as being too accurate. Its validity is also made questionable by the fact that, in the same report (Percy's), the estimate for the Siuslaw Estuary, based on the same map, was 103,000 tons annually. The Siuslaw, which is 30 miles south of the Alsea, has a similar geological and climatological environment, but its drainage basin is over 100 square miles larger than the Alsea's and its fresh water yield is nearly twice that of the Alsea. Yet despite this, the Siuslaw's annual sediment load was estimated at less than half that of the Alsea's.

Since there are no large sand dune formations in the immediate vicinity of the Alsea, it is felt that wind carried particles do not constitute more than a minor portion of the estuary's sediments. No doubt, however, some sediment material is blown into the lower reaches of the estuary by onshore winds from the sandspit located on the north side of the mouth.

In their report Kulm and Byrne (1966) divide the Yaquina Estuary into three sedimentation realms: marine, marine-fluviatile (transition) and fluviatile. The marine realm, which extends from the mouth to 1.5 miles upstream, is characterized by "... waters of the normal marine salinity and vigorous wave or tidal action." They described the sediments of this realm as "... similar to the sediments of adjacent beaches and coastal dunes." The transition realm extends from 1.5 miles to 6 miles upstream and includes a portion of the river channel and a large embayment containing two tidal flat areas. The water in this realm ranged from marine to brackish and the sediments were of both marine and fluviatile origin. The fluviatile realm extended from 6 miles upstream to the freshwater head of tide. It was characterized by brackish water and sediments of fluviatile origin. Since the Yaquina shares a similar geological, meteorological and tidal environment with the Alsea such a division into three distinct regions of sedimentation could also be expected to occur in the Alsea. In order to determine precisely where the boundaries between these realms are located on the Alsea, it would have been necessary to collect many more samples and to perform mineralogical analyses of them.

Results of Sediment Analysis

Sediment core samples were collected for the winter (3/6/73) and the summer (9/4/73) seasons only. These samples were collected during high tide at the same locations as the water quality stations, which were along the channel centerlines. It was necessary to collect the samples at high water in order to ensure an adequate depth for the coring boat. No difficulties were encountered during the winter sample collection period, but several problems occurred at the two downstream stations during the summer sample collection effort. Because of the strong currents encountered near the mouth (Station 1) a sample was not recovered at the channel centerline there. Instead, it was necessary to move to the south side of the channel centerline and slightly upstream from the desired location. The core sample collected at this site was quite small (less than four inches) and composed of many mollusk shell fragments. Since this sample was collected in a region of slower velocities than encountered in the main channel it was felt that its composition was not representative of the sediments which would be found in the main channel. At Station 2 (RM 0.90) numerous attempts to collect a sample there were all unsuccessful because the bottom deposits were so loosely consolidated that they would not remain in the acrylic core liner inside the steel coring barrel. A core sample, however, was successfully retrieved upstream at Station 2A (RM 1.46).

The top four inches of each core sample were air dryed and then analyzed for grain size distribution and volatile solids content. From the grain size distribution plots median grain diameter, D_{50}, and uniformity, $U = D_{60}/D_{10}$, were determined. Porosity was calculated from the air-dryed weight, total volume and specific gravity. In addition, the winter four to eight inch segments of samples taken at Station 5 (RM 2.45) in the main (south) channel and Station 6 (RM 2.75) in the north channel were analyzed for specific gravity. The specific gravity of the Station 5 sample was found to be 2.71 and the specific gravity of the Station 6 sample was found to be 2.60. No attempt was made to measure estuarine sedimentation rates or to do a mineralogical analysis of any of the samples. All sediment test data is presented in Appendix A, Table A3. Grain size distribution plots are given in Appendix B.

Median Grain Size

Figure 35 presents the median grain size, D_{50}, in millimeters (mm), versus river mile, for both the winter and summer. Fifty percent, by weight, of the particles in a sample have smaller diameters than the median grain size. The median grain size of a sediment sample gives a good indication of the water velocities at the location where the sample was taken, and also gives an idea of the source from

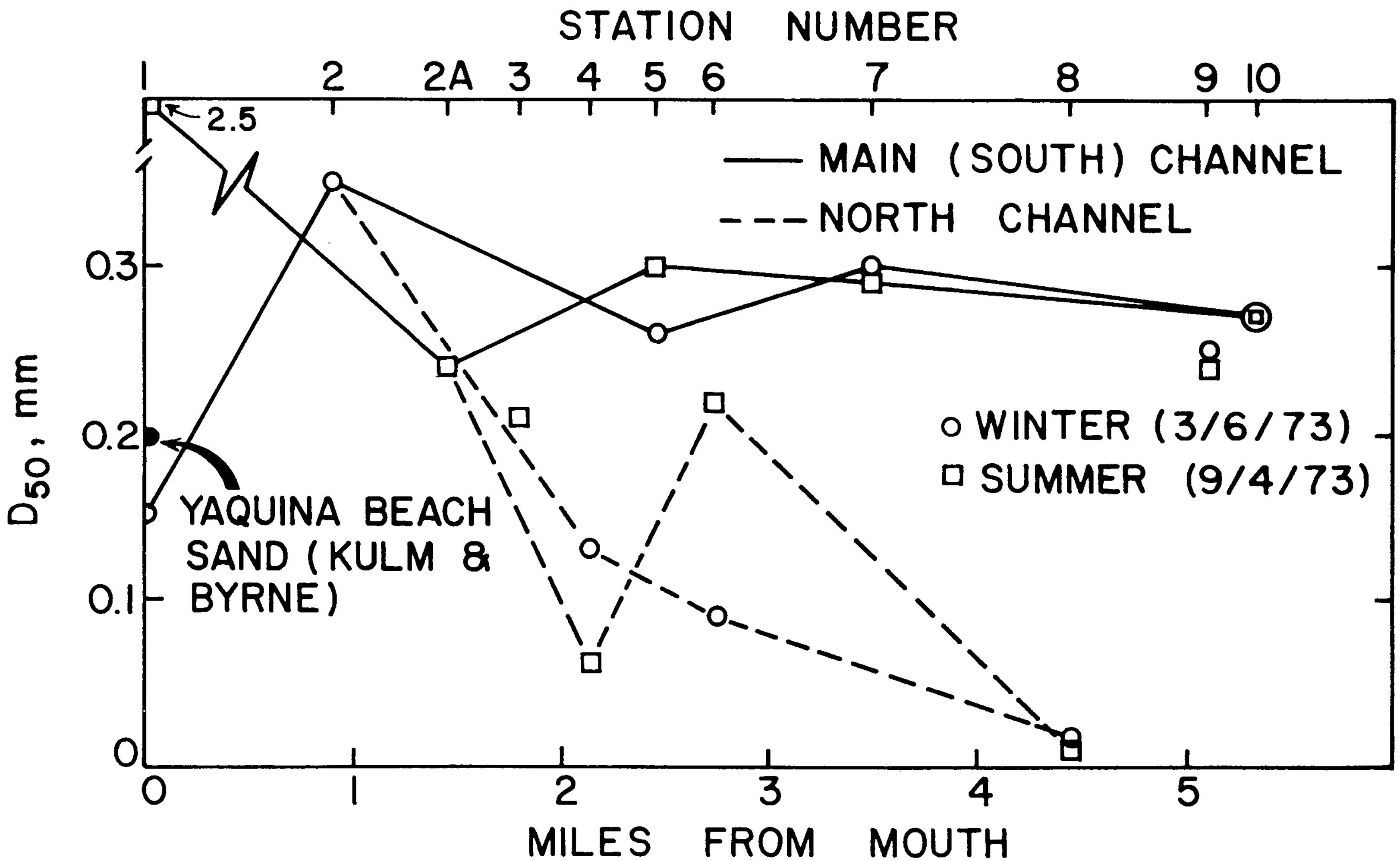


Figure 35. Median grain size, D_{50} vs. distance.

which the sediments came. Since both the critical erosion and the deposition velocities are proportional to grain size, a sediment's D_{50} value is partly determined by the velocity of the water flowing over it. In areas where water velocities are high, D_{50} values can be expected to be high, since much of the finer material is carried away by the flowing water. Likewise, in a region of low velocities, the finer material remains and the sediment has a smaller D_{50} value. The D_{50} value can also reflect the presence of a nearby source of sediments, such as a sand dune or a beach.

The D_{50} values for the main channel during the winter ranged between 0.15 mm at the mouth to 0.35mm at Station 2,thus falling into the fine sand category. The values upstream of Station 2 showed even less variability, ranging from 0.26 mm to 0.30 mm. Closer to the entrance (Station 2) the D_{50} increased as would be expected, since this is an area of high tidal current velocities; but at the mouth (Station 1) it decreased to the lowest value detected on the main channel. This lower D_{50} value at the mouth in a region of high velocities may have occurred because the sediments there are predominately composed of sand from nearby beaches. Although no grain size analysis was made of the sand from the beaches adjacent to the Alsea's entrance, the D_{50} value of 0.15 mm at the mouth compares favorably with the average grain size value, 0.198 mm, found by Kulm and Byrne (1966) for the upper foreshore dune sands near the Yaquina. They also found that the lower foreshore beach sands there had diameters ranging from 0.186 mm to 0.254 mm.

With the exception of the D_{50} value at the mouth, all the median grain size values for the main channel during the summer were in the fine sand category and ranged from 0.24 mm at Station 2A to 0.30 mm at Station 5. Because the sample taken near the mouth was not from the main channel and contained numerous shell fragments, the results of its analysis cannot be regarded as representative of the channel centerline. Upstream of Station 2A there was little variation between the summer and the winter D_{50} values.

The winter D_{50} values in the north channel decreased from 0.13 mm (fine sand) at the downstream end (Station 4) to 0.017 mm (silt) at the upstream end (Station 8). During the summer, however, the D_{50} increased from 0.064 mm (silt) at Station 4 to 0.22 mm (fine sand) at Station 6, then decreased to 0.012 mm (silt) at Station 8. The smaller D_{50} values in the north channel are indicative of the lower velocities that are known to exist there. This is particularly noticeable at the upstream end where the flow appears to be nearly zero. There is little variation between the winter and the summer values except at Station 6 where the summer D_{50} was over twice as large as the winter value. Although the higher summer value may only be a local anomaly, it is possible that that location was experiencing higher velocities during the summer.

Uniformity

The uniformity coefficient, U, is defined as the ratio of D_{60} to D_{10} (i.e. $U = D_{60}/D_{10}$). D_{60} is the particle diameter which 60%, by weight, of the particles are finer, and D_{10} is the particle diameter which 10%, by weight, are finer. The uniformity coefficient of a sediment sample indicates how much variation there is in the sizes of the particles composing the sample. A sample with a value of U less than two is considered very uniform. Such a sample would be described as well sorted. A sample with a U greater than 10 is non-uniform and therefore considered poorly sorted.

Figure 36 is a plot of uniformity versus river mile for both the winter and the summer. From Station 2 upstream the main channel sediments were very uniform (well sorted) during both the winter and the summer, with negligible seasonal variation. At the mouth, however, both winter and summer samples had high uniformity coefficients, indicating that there was a large variation of the particle sizes found there. A possible explanation for this is that smaller beach sand particles were continually being added to the larger particles carried into this area by the high velocities that often occur there.

The uniformity of the north channel samples changed from being fairly uniform at the downstream end (Station 4) to being non-uniform at the upstream end (Station 8), during both seasons. There was little seasonal variation in the uniformity coefficient. More variation in particle size, as indicated by the higher uniformity coefficients, would be expected in the north channel since water velocities high enough to wash away the fine material do not occur there.

Volatile Solids

Measurement of a sediment's volatile solids content determines how much organic material is present in the sample. This organic

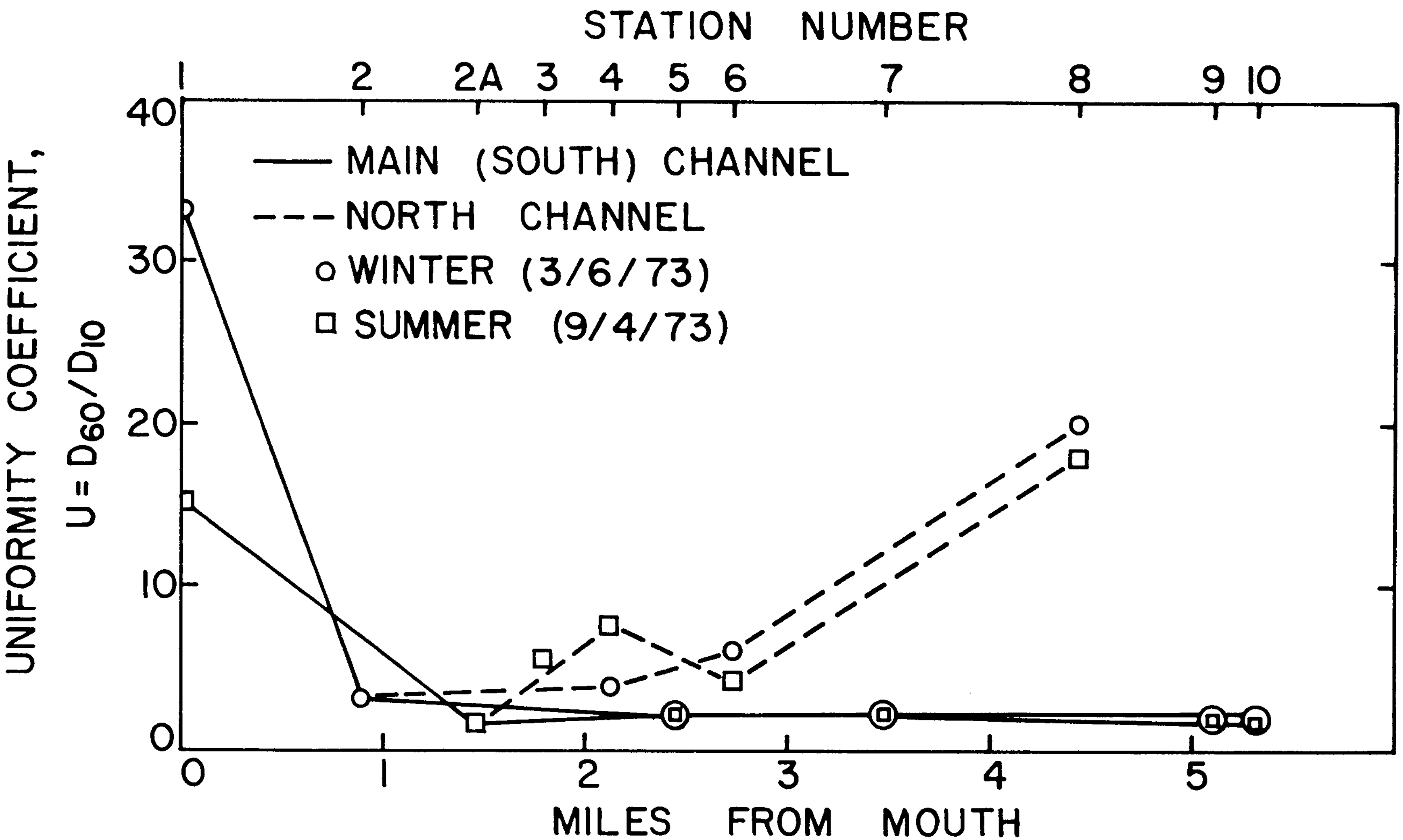


Figure 36. Uniformity vs. distance.

matter may consist of wood chips, plant fibers, biological wastes, dead marine organisms or any other organic debris. Since this organic material is lighter than the minerals found in sediments much of it is washed out of the bottom deposits in regions of faster water velocities.

Figure 37 is a plot of volatile solids, in percent by weight, versus river mile, for both the winter and the summer. All the samples in the main channel from Station 2 upstream, during both seasons, had volatile solids content of less than 3% of their weight, with little seasonal variation noted. But at the mouth, the winter sample had a 7.5% volatile solids content and the summer sample had a 4.3% content. With this limited information it is not possible to explain why the samples at the mouth had higher volatile solid contents than those samples from all the other stations along the main channel, since, if anything, the velocities at the mouth are higher than anywhere else in the main channel.

Volatile solids content in the north channel ranged from 1.9% at Station 4 to 13.4% at Station 8 in the winter and from 3.0% at Station 4 to 12.5% at Station 8 in the summer, thus showing little seasonal variation. The noticeably higher volatile solids content at the upstream end of the north channel was expected because of the low flow in that portion of the estuary.

Porosity

Sediment porosity is the ratio of the volume of voids in a sample to the total volume of the sample. The porosity of a sample

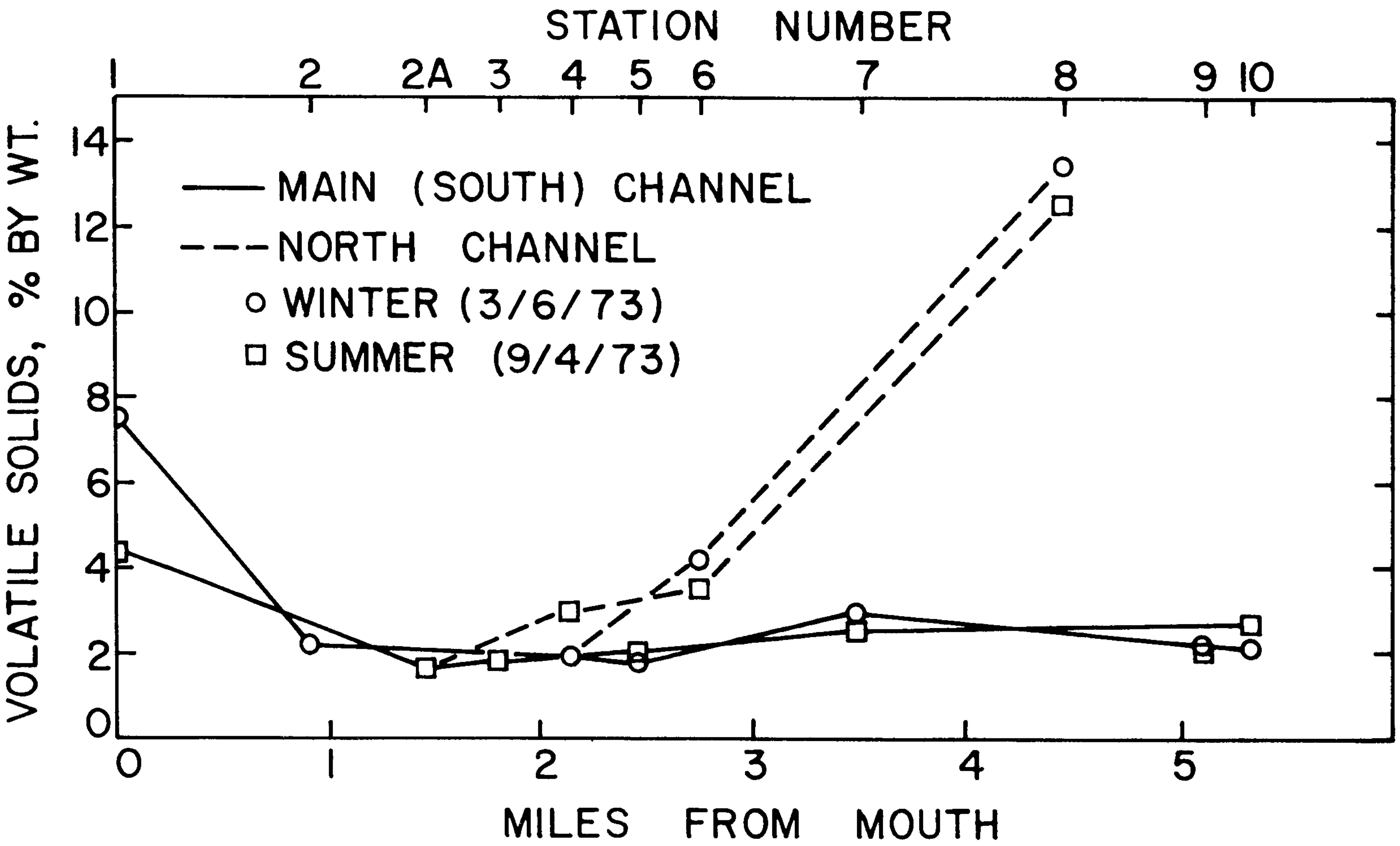


Figure 37. Volatile solids vs. distance.

gives an indication of how well the sediment has consolidated. Sand generally has low porosity values since it is well consolidated. Sediments containing a large amount of fine material which is frequently stirred up, but not washed away, are poorly consolidated and have high porosities. However, if the fine material is washed away, the remaining coarser material consolidates and the porosity decreases. High uniformity also tends to decrease porosity because small particles fill the voids between large particles.

Figure 38 is a plot of porosity, in percent, versus river mile for both the winter and the summer. In the winter the main channel porosity decreased from 67% at the mouth to values ranging from 44% to 51% at the upstream stations. The higher porosity at the mouth may have been the result of the high velocities at that location constantly stirring up the very fine grain beach sand which is continually brought there by the littoral drift. The summer main channel porosities varied from 36% to 49%, generally slightly less than the winter values. Because of the poor quality of the summer sample taken at the mouth no porosity was calculated for it.

In the north channel the winter porosities increased from 52% at Station 4 to 85% at Station 8. The summer porosities decreased from 55% at Station 4 to 45% at Station 6 then increased to 84% at Station 8. With the exception of Station 6 there was only slight seasonal variation of the north channel porosities. The lower summer porosity at Station 6 is consistent with the higher summer D_{50} measured there. The high porosities measured at Station 8 were an expected result, again because of the fine sediment composition.

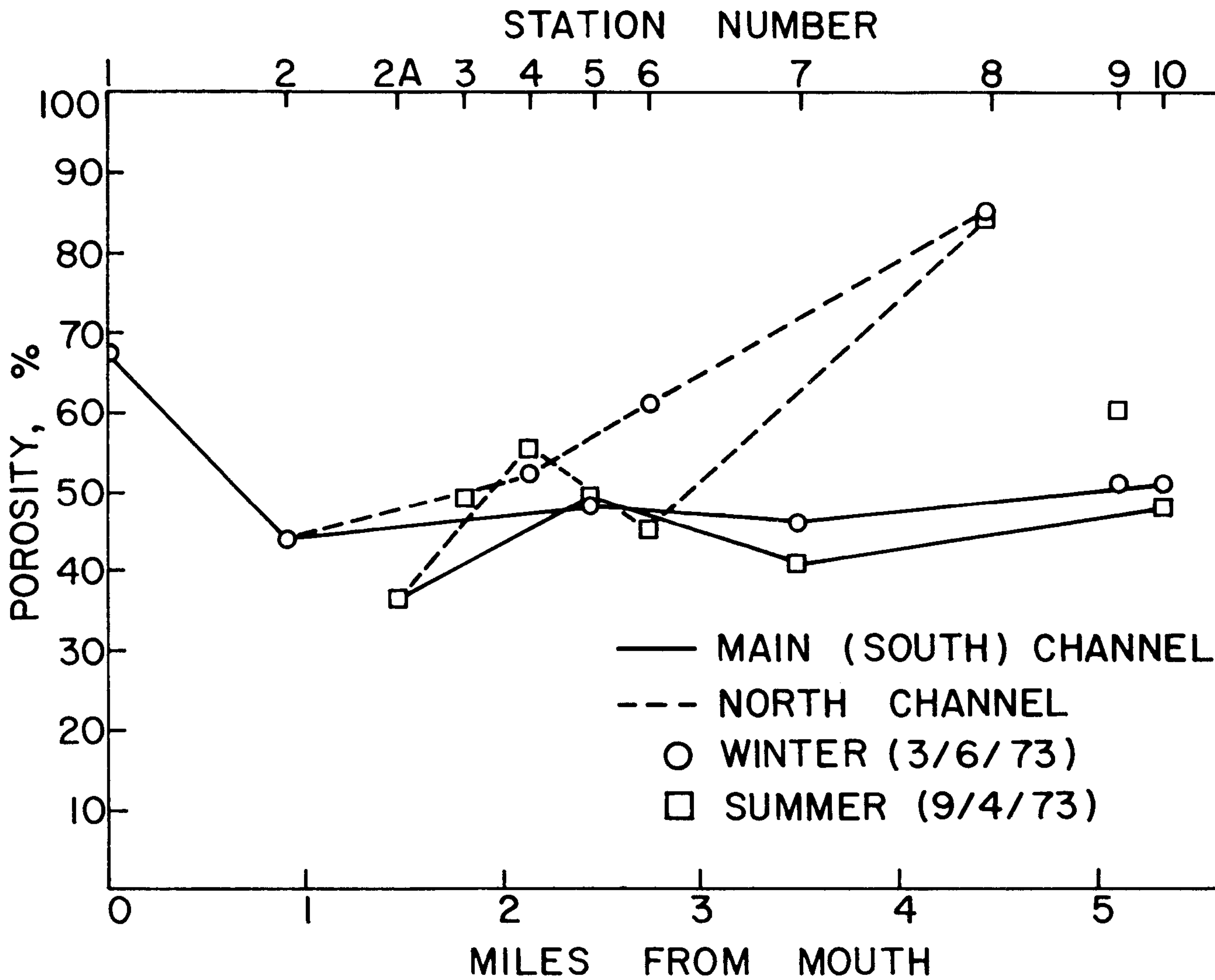


Figure 38. Porosity vs. distance.

It should be pointed out that the porosity plots follow the same general trend as the volatile solids plots. This probably occurs because the organic material composing the volatile solids portion of the sediment samples are less dense than the minerals in the sediment. Therefore, samples with high volatile solid contents would also tend to indicate high porosity values.

Conclusions

The main channel sediments have a median grain size in the fine sand category. In general, there was little longitudinal or seasonal variation of the measured D_{50} values, except at the mouth, where a D_{50} value lower than the other main channel values was detected in the winter. Although this smaller D_{50} was not repeated in the summer sample at Station 1, this sample was not representative of the channel centerline. The sediments at the mouth are probably composed predominately of nearby beach sand, which evidently has a smaller median grain size than the coarse fraction of sediments in the upstream portion of the estuary. In addition, the main channel sediments are all uniform (well sorted), have low volatile solids content and low values of porosity. All of these things are indicative of the high velocity regime existing in the main channel. Again, the only exception is the winter sample at the mouth, which was non-uniform, had higher volatile solids content and had a higher porosity value. These characteristics are not necessarily in agreement with the high velocities which are known to exist at the entrance. The poor sorting of the entrance sample indicates that, although the sediments are probably dominated by beach sands, a large variety of particle sizes occurs there.

The north channel sediments show a decreasing trend in median grain size from the downstream end, during both seasons. The north channel sediments were noticeably finer than the sediments in adjacent locations on the main channel. The smallest D_{50}'s measured in the estuary were found at Station 8, at the upstream end of the north channel. The only significant seasonal variation in north channel D_{50} values occurred at Station 6 where the summer D_{50} was over twice as large as the winter D_{50}, indicating the flow regime there may have had higher velocities in the summer. In general, the nature of the sediments found in the north channel is consistent with the low flow velocities and poor flushing characteristics of that portion of the estuary.

Since no mineralogical analysis was made of the sediments it was not possible to determine the boundaries between the marine and transition realms and between the transition and fluviatile realms. However, a knowledge of the estuary geometry makes it possible to estimate where these boundaries are located. The marine realm probably extends from the mouth upstream to approximately RM 1.6 where the estuary widens into the embayment. At this point the flood tide flow experiences a decrease in velocity because of the increase in cross sectional area and, as a result, most of the remaining marine sediments settle out. Likewise, the river flow experiences a similar velocity decrease at approximately RM 2.5, where the river widens into the embayment, thus causing the deposition of fluviatile sediments.

The embayment itself is the transition realm, consisting of both marine and fluviatile sediments. This is similar to the manner in which the realms were separated in the Yaquina Estuary, as found by Kulm and Byrne (1966).

VIII. SUMMARY AND CONCLUSIONS

Utilization of Alsea Estuary

The present day use of the Alsea Estuary is primarily limited to the recreational activities of boating and sport fishing. There is no direct industrial exploitation of the estuary, but large scale logging operations in the drainage basin certainly have an impact on the estuary's characteristics. The damming of the north channel is probably the single most important alteration to the estuary. The only major alteration to the estuary foreseen in the future is a proposed recreational boat moorage to be located on the south side of the bay at Waldport. The 210 boat basin, which was authorized under the River and Harbor Act of 1960, would have a fifty food wide, six foot deep entrance channel protected by a breakwater. The plan for the marina is approved, but construction is awaiting funding and availability of local cooperation (U.S. Army Corps of Engineers).

It is unlikely that any major alterations will be undertaken on any of the tributaries in the Alsea River Basin. After completing a study authorized in 1966 on the feasibility of making improvements for flood control and multiple-purpose water use in the Alsea Basin, the U.S. Army Corps of Engineers (1973) recommended that "... No structural improvements for water and related resources development be undertaken at this time by the Corps of Engineers in the Alsea River Basin." This applies to dams and other floodworks, but not to the proposed recreational boat basin at Waldport. Because of the advent of permit requirements and Environmental Impact Statements any alterations to the estuary proposed in the future will be thoroughly investigated prior to any work. If the Alsea River is to remain a major fishery spawning area then careful consideration must be given to each proposed alteration.

Summary of Results

The mixing classification of the estuary depends upon the relative magnitudes of the tidal flow and the river flow. The volume of sea water brought into the estuary during a flooding tide is proportional to the low-to-high tide range, and the river flow is a function of the precipitation in the drainage basin. The Alsea tends to become stratified when the river flow is high (greater than 3000 cfs) and the tide range is low (less than four feet). However, when the river flow is low (less than 500 cfs) and the tidal range is high (greater than four feet) the system tends to become well-mixed.

The predictions of high and low water times and tidal ranges published in the NOAA Tide Tables are reliable estimates of those tidal parameters in the lower portion of the estuary (downstream of the embayment). All of the measured high waters at RM 1.8 were within ±45 minutes of the predicted times and all the measured low waters were within +75 and -45 minutes of the predicted times. The measured tidal ranges were approximately 90% of the predicted ranges. There was a tendency during periods of very high river flow for the time of high water at Waldport to occur earlier than predicted. Because of tidal damping and lag the tide predictions for Waldport do not accurately reflect the times of high and low water, or the tidal ranges, at locations upstream of the embayment.

Noticeable damping of the tidal wave amplitude was detected at RM 5.6 during periods of high river flow when the tide range exceeded four feet. This damping probably occurred during these periods of high flow and tide range because the greater than normal volume of water stored within the estuary significantly altered its geometry. As the tidal wave propagated up the estuary it encountered a much less efficient cross section than normal and, because the friction and other damping effects were greater, its amplitude was more noticeably reduced than usual. Under conditions of very high river flow (20,000 cfs) there was an indication that the tidal wave amplitude was even damped at RM 1.8.

At both RM 1.8 and RM 5.6 a noticeable decrease in the high water lag times was measured during periods of high river flow. No effect from river flow on low water lag times, however, was detected at either location. It was felt that, because the incoming flow of the flooding tide prevents the discharge of river water, much of this fresh water is stored within the estuary until the tide starts to ebb. During periods of high river flow the storage of more fresh water than usual increases the mean water depth, h, of the estuary above its normal value. This causes the celerity of the tidal wave to increase and high water to occur at an earlier time than normal.

The tidal current velocity and flow measurements, when correlated with the measured times of high and low water, indicated that the tidal motion in the estuary followed the behavior of a damped, partially standing wave. Such a tidal motion is described as a cooscillating tide.

Salinity serves as an excellent trace for following the intrusion of sea water and determining in what manner it mixes with fresh water in an estuary. The salinity data gathered during this research made it possible to determine whether the sea water or the fresh water was dominating the system under the given set of conditions. Vertical salinity gradients indicated whether the water a a particular location was stratified or well-mixed. Comparison of the winter and spring salinity measurements distinctly showed the different mixing characteristics that occurred at identical locations when the same river flow was affected by tide ranges differing in magnitude by a factor of two. The salinity measurements also confirmed the existence of a salt water "lens", a region of trapped salt water, at RM 5.34, just upstream from the mouth of Drift Creek.

Temperature measurements can also be used to analyze an estuary's mixing characteristics, providing that there is a detectable difference between the temperature of the sea water and the fresh water. The temperature measurements made during this study showed how the temperature of the fresh water varied quite noticeably throughout the year; whereas, the ocean temperature showed much less seasonal variation. The summer temperature measurements pointed out that the water in the north channel can get considerably warmer than the water at an adjacent location on the main channel.

The dissolved oxygen content of a body of water is a measure of that water's ability to support aquatic life. In the Alsea no areas of DO depletion were detected. The low DO values measured in the bottom water at the upstream end of the north channel probably resulted because a quantity of the deoxygenated interstitial water contained in the surface layer of sediments was collected in the samples. In general, the measured DO's were almost always at or near the level of DO saturation, which varied with the local salinity and water temperature. Photosynthesis may have helped to cause the supersaturated DO's measured in the spring and the summer.

The turbidity of water is determined by the kind and the amount of suspended matter in the water. No high values of surface or mid-depth turbidity were measured during any of the seasons. Also, there appeared to be no seasonal variation in the turbidity, although no measurements were made during periods of very high river flow when higher turbidities could be expected. The average of the low tide turbidity values, in all cases, exceeded the average of the high tide values, probably because river-borne sediments were diluted and removed from suspension by flocculation during the high tide.

With the exception of the samples analyzed at the mouth, the sediments of the main (south) channel had a mean grain size ranging between 0.24 mm to 0.35 mm (fine sand), were uniform (well sorted), had low volatile solids content and low porosity values, during both the winter and the summer. The winter sediment sample at the mouth had a smaller D_{50} (0.15 mm), was less uniform, had a higher volatile solids content and a higher porosity value than all the other samples taken in the main channel. This smaller D_{50}, larger uniformity coefficient and higher porosity occurred because the sediments at the mouth are probably composed of nearby beach and dune sand, which evidently has a smaller mean grain size than the sediments carried downstream by the river. It is not possible to explain the high volatile solids content found at the mouth, however.

The sediments in the north channel decreased in mean grain size and increased in uniformity coefficient, volatile solids content and porosity from the downstream end to the upstream end. The smallest D_{50} values (silt size) and the highest volatile solids contents and the highest porosities in the estuary were measured at the upstream end of the north channel, indicating that area experiences very low velocities. No significant seasonal variation was noted in the north channel sediment characteristics, except at RM 2.75, where a larger D_{50} was measured in the summer. This may have been a local anomaly, or the result of higher velocities occuring there in the summer.

The water quality data verified the poor flushing characteristics of the north channel. On the occasions when it was possible to make water quality measurements in the north channel during consecutive high and low tides little significant difference was detected in the salinities. During the summer the temperatures in the north channel noticeably exceeded the ones in the main channel. These findings, along with the very fine sediments taken from the upstream end of the north channel, confirm that the water in the north channel is not frequently replaced.

Undoubtedly the closing off of the north channel at the upstream end significantly modified the hydraulic characteristics of the estuary. The most apparent change would be the reduction in longitudinal flow through the northern side of the bay and the prevention of the flushing of the north channel water. Since there is little hydrographic information available from the time prior to this closure, it is not possible to say how successful it was at bringing about an increase, if any, in the depth of the south channel.

Long Term Changes

There is some concern among local residents that the lower portion of the estuary is filling in with sediments. This could very well be possible on the northern side of the embayment where flow velocities are quite low. Sediments carried by the river water which is impounded in the embayment during the flooding tide are very likely to be deposited in the low velocity areas there. Also, marine sediments brought in by the intruding sea water could readily deposit in the low velocity areas. Prior to the closure of the north channel there may have been sufficient flow through the northern side of the embayment to produce velocities high enough to prevent large volumes of sediment accumulation in that part of the estuary.

The severity of the sedimentation, if if is occurring at all, is difficult to estimate without the benefit of accurate hydrographic records, which are not available. Fagan (1885) does, however, provide excerpts of an 1878 Army survey report on the Alsea Bay. This report, which is quoted, in part, below gives an excellent qualitative description of the bay, as well as its dimensions and depths as they existed at that time.

> The tide extends twelve miles from the head of the bay to the foot of a line of rapids, where my personal examination ended. Here the stream is eighty feet wide and from three to six feet deep at low tide. Above it is a mountain stream, navigated only by Indian canoes, with a swift current and a rocky bed. Below it is a tidal channel with no perceptible river current, widening gradually down to the mouth of Drift Creek, where it is three hundred feet across. The depth along this section at low tide varies from four to six feet, the bottom being very uneven, and in some places, rocky. The bay is three and one-half miles long and from two thousand to seven thousand feet across at high tide. At low tide a large extent of mud flats is left bare, forming islands between which the channels are so shallow as to admit only small boats and scows. For a mile inside the bar there is a good anchorage, with a depth of from twelve to twenty feet at low water, constituting a harbor of about eighty acres in area, sheltered on all sides. Immediately inside the bar is a deep hole two thousand feet long and three hudnred feet wide, at the curve, of eighteen feet depth, in which no bottom was found at thirty-six feet.
>
> The above data concerning the bay were obtained from the chart of survey made in 1875 under the direction of Major N. Michler. At the head of the bay, in the principle channel, there is a bar half a mile long, on which I found only three feet at low water.

The description of the Alsea Bay in this one hundred year old report sounds much the same as it is today, particularly at low tide; yet it was written when the surrounding region had been open to settlement by the white man for only a short time. Therefore it would seem that the shallow depths in the bay are a condition that existed prior to any man-made alterations.

Recommendations for Further Studies

It is recommended that any future studies on the Alsea Estuary not be of such a general nature as this one. A more thorough investigation into each of the areas covered by the research is desirable. For example, an extensive, year-long water quality monitoring program at some specific location along the estuary, correlated with tide and river flow measurements, would provide much more precise information on seasonal variations and give a good indication of the estuary's response time to changes in the tidal and meteorlogical variables. A network of tide recorders installed from the mouth to the head of tide and designed to gather data based on a common datum could be used to analyze more thoroughly the tidal damping and lag phenomena of the estuary. In particular, more tidal data during periods of high river flow is needed. To ascertain if sedimentation problems are, in fact, developing, sedimentation rates at suspected areas should be measured. In addition, a mineralogical analysis of sediments should be made to determine the exact source of the various sedimentation realms.

At the present time the Alsea Estuary is in no serious danger of being foolishly exploited. Since the bay does not lend itself to commercial use and since it is unlikely that the Alsea River Basin will ever become a center of industrial activity, the chances are favorable that the estuary will retain its relatively unspoiled state for many years to come.

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APPENDICES

APPENDIX A

Data Tables

Table A1. Predicted and measured tides, Alsea Estuary, 1973.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
2/13	812	0209	3.4	TIDE RECORDER INOPERATIVE			L		L
			(5.1)						
		0814	8.5				H		H
			(8.9)						
		1553	-0.4			1628	L	1730	L
			(6.7)						5.95
		2240	6.3				H	2250	H
			(3.1)						3.20
2/14	789	0323	3.2			0338	L	0400	L
			(5.4)						5.28
		0920	8.6			0928	H	1000	H
			(9.2)						8.00
		1643	-0.6			1720	L	1850	L
			(7.3)				7.00		
		2322	6.7			2335	H		H
			(3.9)				3.55		
2/15	759	0425	2.8			0450	L	0530	L
			(5.8)				5.48		

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	NOAA Pred. Tides Waldport, RM 1.6 Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	TR Sta. 1 101 Br., RM 0.9 Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	TR Sta. 2 McK. Mar. RM 1.8 Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	TR Sta. 2 Oak. Mar. RM 5.6 Range (Range)
		1022	8.6			1027	H	1055	H
			(9.3)				9.00		
		1729	-0.7			1820	L	1945	L
			(7.7)				7.37		
		2400	7.0			0020	H		H
			4.7				4.80		
2/16	719	0523	2.3			0557	L		L
			(6.3)				6.35		
		1111	8.6			1135	H	1205	H
			(9.2)				8.90		
		1811	-0.6			1905	L	2020	L
			(8.0)				7.89		7.17
2/17	730	0036	7.4			0057	H	0120	H
			(5.5)				5.50		5.85
		0612	1.9			0650	L	0735	L
			(6.5)				6.50		6.75
		1204	8.4			1225	H	1250	H
			(8.7)				8.80		7.45
		1849	-0.3			1930	L	2053	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(7.9)				7.85		
2/18	737	0110	7.6			0130	H	0143	H
			(6.0)				6.35		
		0702	1.6			0730	L	0843	L
			(6.4)				6.70		
		1252	8.0			1315	H	1328	H
			(7.8)				8.10		
		1924	0.2			2005	L	2120	L
			(7.5)				7.72		7.05
2/19	691	0141	7.7			0200	H	0217	H
			(6.4)				6.73		6.60
		0747	1.3			0822	L	0935	L
			(6.2)				6.68		6.59
		1336	7.5			1400	H	1435	H
			(6.8)				7.10		6.80
		1959	0.7			2037	L	2140	L
2/20	663	0213	7.8			0222	H		H
			(6.6)				7.10		
		0838	1.2			0915	L		L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	(Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(5.8)				5.97		
		1428	7.0			1450	H	1515	H
			(5.7)				5.97		5.30
		2032	1.3			2110	L	2210	L
			(6.5)				6.79		6.60
2/21	636	0242	7.8			0305	H	0335	H
			(6.6)				6.83		6.60
		0920	1.2			0955	L	1110	L
			(5.3)				5.69		5.50
		1512	6.5			1547	H	1615	H
			(4.7)				4.54		4.35
		2107	1.8			2120	L	2215	L
			(5.9)				6.00		
2/22	619	0316	7.7			0330	H		H
			(6.5)				6.75		
		1011	1.2			1030	L		L
			(4.8)				4.60		
		1605	6.0			1635	H	1650	H
			(3.6)				3.40		3.65

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		2142	2.4			2210	L	2240	L
			(5.2)				5.10		5.32
2/23	599	0351	7.6			0420	H	0435	H
			(6.4)				6.40		6.28
		1106	1.2			1140	L	1245	L
			(4.4)				4.22		3.61
		1712	5.6			1730	H	1730	H
			(2.8)				2.03		2.60
		2220	2.8			2210	L	2235	L
			(4.7)				4.46		4.81
2/24	594	0434	7.5			0440	H	0450	H
			(6.3)				5.85		6.05
		1210	1.2			1235	L	1320	L
			(4.1)				3.70		3.35
		1838	5.3			1840	H	1835	H
			(2.1)				1.30		1.50
		2309	3.2			2302	L	2320	L
			(4.1)				3.55		3.77
2/25	1460	0526	7.3			0525	H	0520	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(6.2)				5.55		5.62
		1320	1.1			1335	L	1410	L
			(4.2)				3.51		2.33
		2018	5.3			1943	H	2020	H
			(1.8)				0.75		0.83
2/26	1550	0018	3.5			2338	L	0005	L
			(3.8)				2.40		2.58
		0631	7.3			0553	H	0625	H
			(6.4)				5.12		5.25
		1425	0.9			1415	L	1510	L
			(4.6)				3.96		
		2133	5.5			2130	H		H
			(2.0)				1.15		
2/27	1400	0135	3.5			0145	L		L
			(3.8)				2.51		
		0737	7.3			0745	H		H
			(6.6)				5.90		
		1520	0.7			1555	L	1635	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		2218	5.8			2213	H	2230	H
			(2.4)				1.65		1.80
2/28	1260	0246	3.4			0323	L	0520	L
			(4.0)				2.87		3.10
		0840	7.4			0843	H	0900	H
			(7.0)				6.27		6.00
		1606	0.4			1655	L	1815	L
			(5.7)				5.60		5.30
		2253	6.1			2310	H	2330	H
			(3.0)				2.45		2.65
3/1	1570	0345	3.1			0425	L	0435	L
			(4.5)				4.30		4.70
		0932	7.6			1005	H	1030	H
			(7.4)				7.10		6.60
		1648	0.2			1710	L	1750	L
			(6.2)				5.65		5.15
		2320	6.4			2328	H	2350	H
			(3.7)				3.40		3.54

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
3/2	1930	0432	2.7			0510	L	0555	L
			(5.0)				4.52		4.59
		1021	7.7			1030	H	1100	H
			(7.5)				6.50		
		1720	0.2			1815	L		L
			(6.5)				6.44		
		2345	6.7			0030	H		H
			(4.4)				4.22		
3/3	1740	0518	2.3			0610	L		L
			(5.5)				5.59		
		1106	7.8			1150	H		H
			(7.6)						
		1756	0.2				L	2000	L
			(6.8)						6.26
3/4	1560	0010	7.0				H	0105	H
			(5.2)						5.48
		0600	1.8				L	0750	L
			(5.9)						5.80
		1148	7.7				H	1300	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(7.4)						6.38
		1828	0.3				L	2025	L
			(7.1)						6.44
3/5	1400	0035	7.4				H	0120	H
			(6.1)						6.16
		0640	1.3				L	0830	L
			(6.3)						6.30
		1233	7.6				H	1330	H
			(7.0)						6.50
		1859	0.6				L	2055	L
			(7.1)						7.25
3/6	1350	0103	7.7				H	0205	H
			(6.9)						7.15
		0725	0.8				L	0935	L
			(6.5)						6.33
		1319	7.3				H	1430	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
				SPRING					
4/12	732	0220	2.3				L		L
			(4.4)						
		0804	7.7				H		H
			(6.4)						
		1449	0.3			1518	L	1630	L
			(6.6)				6.30		5.75
		2125	6.9			2125	H	2200	H
			(5.2)				4.90		4.95
4/13	735	0326	1.7			0330	L	0430	L
			(4.9)				4.70		4.75
		0916	6.6			0920	H	0945	H
			(6.1)				6.05		5.45
		1539	0.5			1605	L	1725	L
			(6.7)				6.35		5.80
		2205	7.2			2225	H	2240	H
			(6.2)				6.00		5.70

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
4/14	691	0422	1.0			0455	L	0555	L
			(5.6)				5.40		5.10
		1019	6.6			1045	H	1100	H
			(5.7)				5.70		5.15
		1624	0.9			1638	L	1740	L
			(6.6)				6.50		6.10
		2238	7.5			2243	H	2252	H
			(7.1)				6.75		6.15
4/15	655	0509	0.4			0523	L	0630	L
			(6.2)				6.20		5.62
		1115	6.6			1123	H	1125	H
			(5.4)				5.20		5.60
		1706	1.2			1735	L	1830	L
			(6.4)				6.50		6.40
		2310	7.6			2335	H	2344	H
			(7.6)				7.25		6.75
4/16	707	0552	0.0			0550	L	0730	L
			(6.5)				6.40		5.95
		1205	6.5			1140	H	1230	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(4.9)				5.65		4.70
		1741	1.6			1803	L	1835	L
			(6.1)				6.15		6.20
		2341	7.7			2348	H	2357	H
			(8.0)				7.90		7.00
4/17	923	0631	-0.3			0658	L	0810	L
			(6.7)				6.70		5.80
		1252	6.4			1253	H	1305	H
			(4.5)				4.40		5.05
		1816	1.9			1835	L	1925	L
			(5.8)				5.95		6.05
4/18	1070	0010	7.7			0020	H	0025	H
			(8.2)				8.00		7.20
		0710	-0.5			0720	L	0847	L
			(6.7				6.85		6.10
		1333	6.2			1335	H	1340	H
			(4.0)				4.65		4.65
		1851	2.2			1915	L	1952	L
			(5.5)				5.45		5.35

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	NOAA Pred. Tides Waldport, RM 1.6 Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	TR Sta. 1 101 Br., RM 0.9 Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	TR Sta. 2 McK. Mar. RM 1.8 Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	TR Sta. 2 Oak. Mar. RM 5.6 Range (Range)
4/19	1430	0037	7.7			0020	H	0100	H
			(8.2)						6.75
		0748	-0.5				L	0945	L
			(6.6)						4.90
		1415	6.1				H	1425	H
			(3.6)						3.70
		1923	2.5			1935	L	2040	L
			(4.1)				5.10		4.90
4/20	1270	0108	7.6			0120	H	0140	H
			(8.0)						6.48
		0824	-0.4				L	1040	L
			(6.3)						3.98
		1500	5.9				H	1525	H
			(3.1)						3.15
		1958	2.8			1955	L	2105	L
			(4.6)				4.42		4.25
4/21	1080	0139	7.4			0150	H	0155	H
			(7.7)				7.10		5.65
		0906	-0.3			0935	L	1108	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	NOAA Pred. Tides Waldport, RM 1.6 Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	TR Sta. 1 101 Br., RM 0.9 Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	TR Sta. 2 McK. Mar. RM 1.8 Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	TR Sta. 2 Oak. Mar. RM 5.6 Range (Range)
			(6.0)				5.20		3.95
		1546	5.7			1545	H	1555	H
			(2.7)				2.55		2.60
		2035	3.0			2035	L	2133	L
			(4.2)				4.10		4.01
4/22	971	0216	7.2			0230	H	0245	H
			(7.3)				6.70		5.35
		0951	-0.1			1022	L	1148	L
			(4.7)				5.45		4.25
		1638	5.6			1650	H	1647	H
			(2.5)				1.95		2.10
		2120	3.1			2125	L	2215	L
			(3.9)				3.20		3.25
4/23	898	0258	7.0			0305	H	0310	H
			(6.9)				6.40		5.35
		1037	0.1			1047	L	1215	L
			(5.5)				4.75		3.80
		1734	5.6			1730	H	1745	H
			(2.3)				1.75		1.90

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		2218	3.3			2215	L	2255	L
			(3.4)				2.65		2.70
4/24	830	0347	6.7			0400	H	0410	H
			(6.4)				5.75		4.70
		1131	0.3			1145	L	1317	L
			(5.4)				4.75		
		1836	5.7			1830	H		H
			(2.5)				1.70		
		2331	3.2			2330	L		L
			(3.2)				2.30		
4/25	782	0449	6.4			0445	H		H
			(5.9)				5.00		
		1226	0.5			1225	L		L
			(5.4)				4.60		
		1925	5.9			1940	H		H
			(2.9)				2.20		
4/26	736	0051	3.0			0100	L		L
			(3.1)				2.10		
		0602	6.1			0605	H		H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(5.4)				4.65		
		1319	0.7			1325	L		L
			(5.5)						
		2007	6.2				H		H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			SUMMER						
7/10	133	0325	0.2				L		L
			(5.0)						
		1005	5.2				H		H
			(2.3)						
		1419	2.9			1438	L		L
			(4.7)						
		2036	7.6				H		H
			(7.8)						
7/11	130	0414	-0.2			0448	L		L
			(5.6)				4.95		
		1104	5.4			1130	H	1158	H
			(2.4)				1.66		1.85
		1518	3.0			1535	L	1608	L
			(4.7)						4.00
		2122	7.7				H	2153	H
			(8.1)						6.45
7/12	125	0456	-0.4			0535	L	0728	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(6.0)				5.37		6.45
		1152	5.6			1152	H	1222	H
			(2.5)				1.98		2.25
		1610	3.1			1625	L	1700	L
			(4.7)						4.25
		2206	7.8				H	2240	H
			(8.4)						6.35
7/13	120	0537	-0.6			0555	L	0730	L
			(6.4)				3.38		4.07
		1228	5.8			1220	H	1250	H
			(2.7)				3.15		2.42
		1656	3.1			1645	L	1730	L
			(4.7)						4.55
		2245	7.8				H	2300	H
			(8.6)						6.95
7/14	117	0613	-0.8			0720	L	0810	L
			(6.7)				6.20		5.34
		1300	5.9			1300	H	1330	H
			(2.9)				2.70		2.92

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		1738	3.0			1745	L	1820	L
			(4.8)						4.78
		2320	7.8				H	2345	H
			(8.6)						7.62
7/15	110	0648	-0.8			0750	L	0930	L
			(6.9)				6.37		5.53
		1332	6.1			1410	H	1437	H
			(3.2)				2.92		3.21
		1818	2.9			1915	L	1957	L
			(4.9)						4.81
		2359	7.8				H	0122	H
			(8.5)						6.00
7/16	107	0718	-0.7			0730	L	0755	L
			(6.9)				6.65		5.90
		1400	6.2			1345	H	1415	H
			(3.4)				3.50		3.65
		1901	2.8	1901	L	1910	L	1950	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(4.8)		4.70		4.75		5.50
7/17	104	0034	7.6	0042	H	0025	H	0055	H
			8.2		7.90		7.75		7.10
		0750	-0.6	0746	L	0805	L	0920	L
			7.0		6.90		6.60		6.05
		1426	7.4	1423	H	1420	H	1430	H
			(3.8)		3.90		3.80		4.30
		1943	2.6	1949	L	1950	L	2020	L
			(4.7)		4.50				4.89
7/18	102	0113	7.3	0127	H		H	0146	H
			(7.6)		7.50				6.55
		0819	-0.3	0831	L	0830	L	1008	L
			(6.9)		6.90		6.63		5.96
		1450	6.6	1440	H	1437	H	1520	H
			(4.2)		4.30		4.26		4.55
		2029	2.4	2030	L	2020	L	2130	L
			(4.6)		4.30		4.38		4.62
7/19	103	0155	7.0	0202	H	0200	H	0235	H
			(7.0)		6.70		6.60		5.93

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		0851	0.0	0900	L	0925	L	1030	L
			(6.8)		6.80		6.60		6.00
		1519	6.8	1511	H	1530	H	1553	H
			(4.6)		4.80		6.60		4.95
		2117	2.2	2131	L	2140	L	2228	L
			(4.3)		4.20		4.78		4.40
7/20	105	0237	6.5	0305	H	0315	H	0338	H
			(6.0)		5.80		5.33		5.30
		0922	0.5	0933	L	0945	L	1115	L
			(6.6)		6.40		6.42		6.02
		1550	7.1	1558	H	1610	H	1645	H
			(5.2)		5.20		5.22		5.36
		2213	1.9	2216	L	2245	L	2355	L
			(4.1)		4.00		3.87		3.94
7/21	107	0336	6.0	0354	H	0405	H	0500	H
			(5.0)		4.80		4.75		4.49
		0958	1.0	1002	L	1007	L	1125	L
			(6.3)		6.10		6.15		6.00
		1625	7.3	1635	H	1630	H	1710	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(5.8)		5.70		5.75		5.80
		2312	1.5	2313	L	2322	L	0045	L
			(4.0)		3.80		3.70		3.69
7/22	106	0441	5.5	0443	H	0452	H	0547	H
			(3.9)		3.60		3.44		3.59
		1036	1.6	1021	L	1028	L	1140	L
			(6.0)		5.70		5.75		5.85
		1707	7.6	1706	H	1700	H	1745	H
			(6.6)		6.30		6.32		6.20
7/23	105	0021	1.0	0008	L	0008	L	0210	L
			(4.2)		3.70		3.66		3.40
		0604	5.2	0612	H	0608	H	0710	H
			(3.1)		2.60		2.56		2.60
		1125	2.1	1120	L	1110	L	1205	L
			(5.7)		5.20		5.22		5.40
		1755	7.8	1745	H	1735	H	1815	H
			(7.4)		7.10		7.02		6.55
7/24	103	0130	0.4	0125	L	0120	L	0320	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(4.6)		4.20		4.08		2.95
		0742	5.0	0719	H	0722	H	0745	H
			(2.5)		1.90		1.88		1.95
		1224	2.5	1215	L	1202	L	1230	L
			(5.6)		4.80		4.80		5.05
		1851	8.1	18456	H	1822	H	1852	H
			(8.3)		7.90		7.60		6.78
7/25	101	0236	-0.2	0242	L	0230	L	0423	L
			(5.4)		5.20		4.85		4.90
		0913	5.2	0906	H	0900	H	0940	H
			(2.4)		1.80		1.80		1.80
		1333	2.8	1317	L	1310	L	1350	L
			(5.5)		4.80		4.85		6.00
		1953	8.3	2001	H	1940	H	2010	H
			(9.0)		8.60		8.30		7.18
7/26	95	0337	-0.7	0359	L	0355	L	0600	L
			(6.3)		5.00		5.55		4.44
		1022	5.6	1009	H	1032	H	1100	H
			(2.7)						

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		1446	2.9		L		L		L
			(5.7)						
		2054	8.6		H		H		H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
				FALL					
11/15	20,100	0437	6.7				H		H
			(3.5)						
		0944	3.2			1025	L	0953	L
			(4.7)				4.90		
		1517	7.9			1540	H		H
			(8.4)				5.45		
		2243	-0.5			2315	L		L
			(7.3)				4.70		
11/16	20,700	0536	6.8			0510	H		H
			(3.8)				3.70		
		1101	3.0			1157	L	1330	L
			(4.2)				2.55		0.70
		1623	7.2			1627	H	1645	H
			(7.1)						3.05
		2339	0.1				L	0208	L
			(7.0)						
11/17	8,830	0631	7.1				H		H
			(4.5)						

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		1225	2.6			1305	L	1352	L
			(4.0)				3.15		
		1746	6.6			1750	H		H
			(6.0)				4.95		
11/18	5330	0036	0.6			0105	L	0227	L
			(6.8)				5.95		
		0720	7.4			0705	H		H
			(5.4)				5.46		
		1342	2.0			1407	L	1515	L
			(4.2)				3.40		2.20
		1918	6.2			1912	H	1930	H
			(5.0)				4.38		2.85
11/19	3720	0130	1.2			0142	L	0315	L
			(6.5)				6.20		4.50
		0809	7.7			0742	H	0815	H
			(6.4)				6.58		4.75
		1449	1.3			1507	L	1630	L
			(4.8)				4.90		3.45
		2043	6.1			2057	H	2107	H

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(4.4)				3.40		2.70
11/20	4160	0225	1.7			0257	L	0345	L
			(6.3)				6.10		5.52
		0851	8.0			0842	H	0907	H
			(7.4)				6.00		
		1546	0.6			1517	L		L
			(5.5)				5.40	2147	
		2157	6.1			2134	H		H
			(4.0)				4.30		
11/21	6930	0314	2.1			0332	L		L
			(6.1)				5.45		
		0931	8.2			0917	H		H
			(8.1)				7.92		
		1635	0.1			1717	L		L
			(6.1)				5.47		
		2258	6.2			2225	H		H
			(3.7)				3.85		
11/22	6200	0403	2.5			0427	L		L
			(5.8)				5.85		

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		1007	8.3			1002	H	1020	H
			(8.6)				8.08		5.58
		1721	-0.3			1729	L	1927	L
			(6.6)				6.12		3.70
		2352	6.3			2322	H	2335	H
			(3.5)				3.69		3.00
11/23	5040	0445	2.8			0457	L	0540	L
			(5.6)				5.50		4.80
		1042	8.4			1035	H	1053	H
			(9.0)				7.95		5.57
		1759	-0.6			1820	L	1945	L
			(7.0)				6.24		
		0039	6.4			0005	H		H
			(3.4)				3.36		
11/24	5280	0527	3.0			0527	L		L
			(5.3)				5.02		
		1116	8.3			1100	H		H
			(9.0)				8.25		
		1837	-0.7			1905	L	2032	L

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
			(7.1)				7.30		
11/25	5760	0124	6.4			0103	H		H
			(3.2)				3.48		
		0606	3.2			0617	L		L
			(5.1)						
		1148	8.3				H	1205	H
			(9.0)						5.50
		1913	-0.7				L	2050	L
			(7.1)						4.20
11/26	6310	0203	6.4				H	0135	H
			(3.0)						2.72
		0641	3.4				L	0720	L
			(4.7)						4.42
		1220	8.1			1230	H	1245	H
			(8.7)				8.10		5.90
		1949	-0.6			2020	L	2130	L
			(6.9)				6.60		4.50
11/27	6020	0242	6.3			0215	H	0207	H
			(2.8)				3.50		3.10

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		0721	3.5			0800	L	0825	L
			(4.5)				4.15		3.78
		1256	8.0			1245	H	1355	H
			(8.4)				7.15		4.90
		2027	-0.4			2045	L	2155	L
			(6.7)				6.45		4.20
11/28/	7440	0321	6.3			0300	H	0310	H
			(2.8)				2.97		2.45
		0803	3.5			0850	L	0910	L
			(4.2)				3.32		2.86
		1331	7.7			1340	H	1350	H
			(7.9)				6.60		3.94
		2106	-0.2			2130	L	2245	L
			(6.5)				5.70		3.13
11/29	7920	0359	6.3			0320	H	0330	H
			(2.7)				2.78		2.20
		0848	3.6			0915	L	0942	L
			(3.8)				3.26		2.65

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	NOAA Pred. Tides Waldport, RM 1.6 Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	TR Sta. 1 101 Br., RM 0.9 Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	TR Sta. 2 McK. Mar. RM 1.8 Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	TR Sta. 2 Oak. Mar. RM 5.6 Range (Range)
		1410	7.4			1415	H	1419	H
			(7.3)				5.96		4.05
		2144	0.1			2215	L	2312	L
			(6.3)				5.38		3.35
11/30	6140	0438	6.4			0410	H	0412	H
			(2.8)				2.70		
		0946	3.6			0940	L		L
			(3.4)				2.80		
		1455	7.0			1525	H		H
			(6.5)				5.40		
		2224	0.5			2220	L		L
			(6.1)				5.50		
12/1	4790	0520	6.6			0440	H		H
			(3.2)				3.42		
		1050	3.4			1057	L		L
			(3.1)				2.2		
		1551	6.5			1542	H		H
			(5.6)				4.63		

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		2307	0.9			2315	L		L
			(5.9)				5.08		
12/2	3910	0559	6.8			0530	H		H
			(3.7)				3.45		
		1206	3.1			1200	L		L
			(3.0)				2.20		
		1656	6.1			1700	H		H
			(4.8)				3.65		
		2349	1.3			2340	L		L
			(5.8)				5.60		
12/3	3560	0638	7.1			0615	H		H
			(4.5)				4.45		
		1313	2.6			1300	L		L
			(3.1)				2.68		
		1819	5.7			1815	H		H
			(4.0)				3.18		
12/4	3210	0037	1.7			0037	L		L
			(5.7)				5.30		

Table A1. Continued.

Date	Mean Daily River Flow Tidewater (crs)	NOAA Pred. Tides Waldport, RM 1.6 Time (PST)	Height (Range) (ft)	TR Sta. 1 101 Br., RM 0.9 Time (PST)	Range (Range)	TR Sta. 2 McK. Mar. RM 1.8 Time (PST)	Range (Range)	TR Sta. 2 Oak. Mar. RM 5.6 Time (PST)	Range (Range)
		0718	7.4			0700	H		H
			(5.5)				5.30		
		1415	1.9			1420	L	1515	L
			(3.7)				3.00		2.50
		1946	5.6			1935	H	1952	H
			(3.5)				2.80		
12/5	2860	0128	2.1			0120	L		L
			(5.7)				5.30		
		0757	7.8			0725	H		H
			(6.8)				6.40		
		1510	1.0			1505	L		L
			(4.7)				4.30		
		2107	5.7			2105	H		H
			(3.2)				2.72		
12/6	6867	0218	2.5			0205	L		L

Table A2. Water quality data, Alsea Estuary, 1973.

Date: 2/18/73
Tide: High
River Flow: 737 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{0}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	25.0	10.0	8.7	27.6	8.1	9.3	31.6	7.9	DATA
1235	12.5	10.0	9.1	27.6	8.1	8.6	31.6	8.0	NOT
0.00	1.0	10.1	9.4	27.6	8.1	8.9	31.0	8.0	VALID
2	14.0	10.0	9.6	27.0	8.1	8.6	31.7	8.0	
1250	7.0	10.0	9.8	27.0	8.1	8.3	31.6	8.1	
0.90	1.0	10.1	10.0	27.0	8.1	6.3	31.5	8.1	
3	10.0	10.0	9.6	25.5	8.1	8.3	30.3	8.0	
1310	5.0	10.0	9.6	25.5	8.1				
1.80(LS)	1.0	9.5	10.6	13.0	7.9	8.7	15.5	7.9	
5	17.0	10.5	9.6	27.0	8.1	8.4	31.2	7.9	
1430	8.5	10.5	9.7	27.0	8.1	8.6	31.1	8.0	
2.45(S)	1.0	10.5	10.0	27.0	8.1	8.4	30.9	8.0	
6	5.0	10.5	9.7	26.5	8.1	8.2	30.5	7.8	
1405	2.5	10.5	9.9	22.5	8.1				
2.75(N)	1.0	10.5	10.1	19.5	8.1	8.5	23.2	7.8	
7	12.0	10.5	9.8	27.0	8.1	5.9	30.3	7.9	
1355	6.0	10.5	10.0	26.5	8.1	6.0	31.0	8.0	
3.47(S)	1.0	10.5	10.2	25.5	8.1	6.7	22.2	8.0	

Table A2. Continued

Date: 2/18/73 Tide: High River Flow: 737 CFS			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^oC)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
8	11.0	10.3	7.2	24.8	7.7	5.8	28.0	7.4	DATA
1415	5.0	9.8	8.8	21.0	7.9	8.6	23.8	7.8	NOT
4.44(N)	1.0	9.5	9.3	18.5	8.0	8.4	20.8	7.8	VALID
10	14.0	9.5	9.5	20.5	8.1	7.4	22.0	8.0	
1335	7.0	9.5	9.6	19.1	8.1	6.2	22.8	7.9	
5.34	6.0	9.2	10.1	18.0	8.0				
	5.0	9.2	10.1	17.0	8.0				
	4.0	9.2	10.3	15.0	8.0				
	3.0	9.2	10.2	15.0	8.0				
	2.0	9.5	10.7	10.0	7.9				
	1.0	9.3	10.3	9.0	7.9	9.0	10.3	7.7	

Table A2. Continued

Date: 2/18/73
Tide: Low
River Flow: 737 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	40.0	9.0	9.8	19.1	8.1	8.9	22.0	7.7	DATA
0700	20.0	9.0	9.9	19.1	8.1	8.4	21.9	7.8	NOT
0.00	1.0	9.0	10.1	19.1	8.1	8.3	21.5	7.9	VALID
2	9.0	8.5	9.6	18.0	8.1	8.5	21.1	7.9	
0725	4.5	8.5	9.7	17.1	8.1	8.1	19.3	7.8	
0.90	1.0	8.5	10.2	15.0	8.1	8.1	16.8	7.8	
5	12.0	8.0	11.0	8.5	7.9	9.6	10.1	7.6	
0820	6.0	8.2	11.2	8.5	7.9	9.0	10.0	7.6	
2.45(S)	1.0	8.3	11.2	8.5	7.9	9.0	9.9	7.6	
6	1.0	8.5	10.7	17.0	8.0	8.8	20.0	7.8	
1000									
2.75(N)									
7	9.0	8.0	11.3	5.5	7.8	9.3	6.4	7.6	
0900	4.5	8.5	11.3	5.5	7.7	9.2	6.6	7.5	
3.47(S)	1.0	8.5	11.3	5.5	7.7	9.1	6.2	7.5	
8	6.0	9.0	8.2	25.5	7.8	6.7	26.8	7.2	
1025	3.0	8.5	8.8	24.0	8.0	7.6	25.4	7.8	
4.44(N)	1.0	9.0	9.1	22.0	8.0	8.2	23.8	7.6	

Table A2. Continued

Date: 2/18/73
Tide: Low
River Flow: 737 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
10	8.0	9.0	10.9	14.3	7.8	9.7	14.9	7.6	DATA
0915	7.5	8.7	11.2	8.0	7.8				NOT
5.34	7.0	8.5	11.1	9.0	7.8				VALID
	6.0	8.5	11.6	2.9	7.6				
	5.0	8.5	11.6	2.0	7.6				
	4.0	8.5	11.7	1.8	7.6	9.5	<2.8	7.5	
	1.0	8.5	11.7	1.0	7.6	9.6	<2.8	7.5	

Table A2. Continued

Date: 4/26/73
Tide: High
River Flow: 736 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (°C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	48.0	9.0	7.2	28.4	7.8	10.2	33.3	8.3	6.2
0605	24.0	9.5	8.1	28.4	7.8	9.8	33.2	8.3	8.3
0.00	1.0	9.5	8.1	28.4	7.9	9.6	32.8	8.4	3.7
1A	11.0	9.5	7.2	28.4	7.8				
0620	5.5	9.5	7.2	28.4	7.8				
0.43	1.0	9.5	7.4	28.4	7.9				
2	10.0	9.5	7.1	27.5	7.8	9.6	32.8	8.0	6.3
0625	5.0	9.5	7.2	28.4	7.8				
0.90	1.0	9.6	7.6	27.0	7.8	9.2	29.8	8.7	2.7
2A	5.0	10.0	7.8	27.5					
0637	2.5	11.0	8.2	24.8	7.9				
1.46	1.0	12.0	8.4	20.5	7.7				
2B	6.0	10.5	8.0	25.5	7.8				
0641	3.0	11.0	8.3	24.5	7.9				
1.68	1.0	12.0	8.7	17.1	7.8				
3	5.5	12.5	7.4	21.2	7.8	8.6	27.9	7.2	45.0
0540	2.5	13.0	7.9	19.1	7.8				
1.80(LS)	1.0	14.0	8.7	13.0	7.8	10.1	7.0	7.8	2.9

Table A2. Continued

Date: 4/26/73
Tide: High
River Flow: 736 CFS

			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
4	2.0	12.3	7.2	22.0	7.7	9.0	23.7	8.6	3.2
0650									
2.5(N)									
5	11.0	11.5	7.5	25.0	7.8	9.2	28.4	9.5	4.0
0745	5.5	12.0	7.8	22.6	7.8	8.4	25.9	9.2	2.2
2.45(S)	1.0	13.0	9.2	6.2	7.8	11.3	6.6	8.3	1.4
5A	4.0	13.0	8.7	15.9	7.8				
0753	3.5	13.0	8.6	13.9	7.8				
3.06(S)	3.0	13.5	9.0	13.0	7.7				
	2.5			10.7					
	2.0	13.5	9.5	3.3	7.5				
	1.0	13.0	9.6	2.2	7.5				
6	2.0	13.5	6.3	16.4	7.6	8.4	15.0	9.0	1.0
0655	1.0	13.5	6.5	15.9	7.6				
2.75(N)									
6A	4.0	15.0	6.1	17.9	7.4				
0729	2.0	14.5	8.2	11.0	7.9				
3.88(N)	1.0	13.5	9.3	10.5	8.0				

Table A2. Continued

Date: 4/26/73 Tide: High River Flow: 736 CFS		Field Measurements (Hydrolab)				Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^oC)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
7	7.0	13.0	8.2	16.4	7.8	9.3	18.7	8.4	1.4
0803	6.0	13.5	8.6	12.5	7.8				
3.47(S)	5.0	13.5	9.0	7.0					
	4.0	13.5	9.1	4.5	7.6				
	3.5	13.0	9.4	2.2	7.6				
	1.0	13.0	9.7	1.8	7.4	11.1	<2.8	8.6	1.4
7A	7.0	13.0	8.2	20.0	7.7				
0812	3.5	13.0	8.4	14.5	7.7				
3.77(S)	3.0	13.0	9.4	1.8					
7B	5.0	12.5	9.9	0.5	7.6				
0820	2.5	12.5	9.6	0.5	7.5				
4.40(S)	1.0	12.5	9.7	0.3	7.5				
8	8.5	14.5	6.1	18.5	7.4	5.3	24.9	8.5	28.0
0715	4.0	18.3	10.3	16.0	8.1	7.2	21.8	9.0	4.4
4.44(N)	1.0	15.0	9.7	11.0	8.2	10.2	10.2	8.4	0.86
9	5.0	12.5	9.6	0		11.1		7.6	1.7
0840	2.5	12.5	9.5	0					
5.10(DC)	1.0	12.5	9.5	0		11.0		7.5	1.0

Table A2. Continued

Date: 4/26/73
Tide: High
River Flow: 736 CFS

			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
10	9.0	12.5	9.7	0		11.4		8.4	1.1
0845	4.5	12.0	9.7	0		11.4		8.1	2.2
5.34	1.0	12.5	9.8	0		11.7		7.3	1.0

Table A2. Continued

Date: 4/26/73
Tide: Low
River Flow: 736 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	28.0	12.7	8.1	15.0	7.8	10.1	16.7	8.2	3.5
1154	14.0	13.0	9.0	11.9	7.8	10.1	14.8	8.1	2.5
0.00	1.0	13.3	9.0	11.9	7.8	9.8	14.0	9.0	0.8
1A	5.0	13.5	9.0	11.9	7.8				
1202	2.5	13.5	9.0	11.0	7.8				
0.43	1.0	13.5	9.1	10.5	7.9				
2	6.0	13.5	8.0	12.4	7.8	9.5	14.8	9.2	13.0
1210	3.0	13.5	8.8	11.0	7.8				
0.90	1.0	13.5	9.4	8.5	7.8	10.7	9.6	9.5	4.8
2A	1.0	13.5	9.6	5.5	7.7				
1216									
1.46									
2B	2.0	13.5	9.6	7.3	7.9				
1224	1.0	13.5	9.7	5.0	7.7				
1.68									
5	9.0	13.2	9.6	1.0	7.5	10.7	<2.8	8.2	11.0
1245	4.5	13.0	10.0	0.5	7.4	10.8	<2.8	8.4	5.6
2.45(S)	1.0	13.0	10.0	0.5	7.9	10.8	<2.8	7.8	9.0

Table A2. Continued

Date: 4/26/73 Tide: Low River Flow: 736 CFS			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
5A	9.0	13.0	10.0	0.8	7.5				
1255	4.5	13.0	10.0	0.8	7.4				
3.06(S)	1.0	13.0	10.0	0.5	7.4				
7	4.5	13.0	9.9	0	7.4	11.0		7.8	3.2
1307	2.0	13.0	10.0	0	7.4				
3.47(S)	1.0	13.0	9.9	0	7.4	11.1		8.4	1.4
8									
1410									
4.44(N)	1.0	16.0			8.1		9.4	8.2	43.0
10	6.0	13.0	9.2	0	7.5	11.1	<2.8	6.6	23.0
1505	3.0	13.0	9.7	0	7.3				
5.34	1.0	13.0	9.7	0	7.3	11.0	<2.8	6.8	2.0

Table A2. Continued

Date: 7/17/73
Tide: High
River Flow: 104 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	40.0	9.5	7.8	30.0	7.8	10.2	33.7	7.6	4.0
1440	20.0	9.5	8.3	30.0	7.8	9.8	33.8	7.7	3.0
0.00	1.0	9.5	7.7	30.0	7.8	9.4	33.8	7.6	2.0
1A	14.0	9.5	7.7	30.0	7.8				
1453	7.0	9.4	8.2	30.0	7.8				
0.43	1.0	9.7	8.5	29.5	7.9				
2	18.0	9.5	8.3	30.0	7.8	10.0	33.8	7.6	4.0
1458	9.0	9.5	8.5	30.0	7.8	10.0	33.1	7.6	3.0
0.90	1.0	9.5	8.6	30.0	7.8	9.6	33.8	7.5	3.0
2A	9.0	9.5	8.1	30.0	7.8				
1507	4.5	9.5	8.3	30.0	7.8				
1.46	1.0	9.5	8.6	30.0	7.8				
2B	7.0	9.5	8.1	30.0	7.8				
1512	3.5	9.5	8.5	30.0	7.8				
1.68	1.0	9.5	8.5	30.0	7.8				
3	7.0	10.5	8.2	29.0	7.8				
1531	3.5	10.5	8.5	29.0	7.8				
1.80(LS)	1.0	16.0	10.6	22.0	7.9				

Table A2. Continued

Date: 7/17/73
Tide: High
River Flow: 104 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (°C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
4	3.0	12.5	7.7	30.0	7.8	9.4	33.6	7.2	39.0
1338	1.0	11.5	8.1	30.0	7.8	9.8	33.7	7.6	3.0
5	16.5	9.5	8.5	30.0	7.8	9.7	33.8	7.3	5.0
1517	8.5	9.5	8.6	30.0	7.8	9.9	33.7	7.6	2.0
2.45(S)	1.0	10.0	8.9	29.5	7.8	9.4	33.6	7.7	3.0
5A	5.5	10.0	8.1	30.0	7.8				
1542	3.0	9.5	8.5	30.0	7.8				
3.06(S)	1.0	9.5	8.6	29.5	7.8				
6	9.0	10.0	7.2	29.0	7.8	9.8	33.5	7.5	2.0
1348	4.5	10.0	7.6	29.0	7.8	9.7	33.1	7.5	4.0
2.75(N)	1.0	9.5	8.0	28.5	7.8	9.7	33.9	7.7	3.5
6A	6.0	16.0	7.5	23.5	7.7				
1400	3.0	16.5	7.8	22.0	7.8				
3.88(N)	1.0	17.0	8.1	21.0	7.8				
7	12.0	9.5	8.3	29.5	7.8	9.9	33.5	7.7	5.0
1546	6.0	9.5	8.6	29.5	7.8				
3.47(S)	1.0	10.0	9.0	29.5	7.8	9.9	32.3	7.6	2.0
7A	9.0	10.5	8.4	30.0	7.8				

Table A2. Continued

Date: 7/17/73
Tide: High
River Flow: 104 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Field Measurements (Hydrolab) Salinity (PPT)	Field Measurements (Hydrolab) pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Laboratory Measurements (Samples) Salinity (PPT)	Laboratory Measurements (Samples) pH	Laboratory Measurements (Samples) Turbidity (JTU)
1600	4.5	11.0	8.7	30.0	7.8				
3.77(S)	1.0	13.5	9.7	25.5	7.9				
7B	8.0	11.5	8.7	26.0	7.8				
1608	4.0	13.0	9.4	24.0	7.8				
4.40(S)	1.0	15.5	10.4	21.0	7.7				
7C	7.0	12.0	8.5	27.5	7.8				
1614	3.5	14.0	9.5	25.5	7.8				
4.81	1.0	17.0	10.7	20.5	7.9				
8	10.0	15.5	4.1	26.0	7.3	6.2	28.4	7.2	40.0
1405	5.0	17.5	9.8	22.5	8.0	10.2	25.3	7.0	9.0
4.44(N)	1.0	17.5	9.6	21.5	8.0	10.4	25.0	7.0	8.0
9	7.0	15.0	8.8	25.5	7.8				
1619	3.5	16.5	10.1	20.0	7.9				
5.10(DC)	1.0	17.5	10.3	19.0	8.0				
10	10.0	14.0	8.3	25.5	7.8	9.9	25.6	7.6	4.0
1653	5.0	18.0	10.3	18.0	8.0				
5.34	1.0	19.0	11.2	14.0	8.1	7.4	16.2	7.8	4.0

Table A2. Continued

Date: 7/17/73 Tide: Low River Flow: 104 CFS			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^{O}C)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	>40.0	13.7	8.2	27.0	7.8	8.6	29.8	7.7	6.0
0608	20.0	14.0	8.3	26.5	7.8	8.8	29.7	7.6	8.0
0.00	10.0	14.2	8.3	26.5	7.8				
	1.0	14.3	8.2	26.0	7.8	8.6	29.5	7.6	8.0
1A	20.0	14.6	8.0	25.5	7.8				
0630	10.0	14.6	8.0	25.5	7.8				
0.43	1.0	14.5	8.0	25.5	7.8				
2	7.0	15.0	7.8	25.0	7.8	7.6	28.2	7.6	8.0
0635	3.0	15.0	7.9	25.0	7.8	8.5	27.7	7.2	9.0
0.90	1.0	14.9	7.9	25.0	7.8	8.7	27.8	7.6	6.0
2A	3.0	14.7	7.9	25.0	7.8				
0645	1.0	15.0	8.3	22.5	7.8				
1.46									
2B	4.0	16.6	9.0	19.5	7.9	9.1	22.6	7.4	9.0
0655	1.0	16.7	8.8	19.5	7.8	9.3	22.5	7.6	8.0
1.68									
3	1.0	19.0	8.5	21.5	7.8	7.8	25.8	7.5	15.0
0708									
1.80(LS)									

Table A2. Continued

Date: 7/17/73
Tide: Low
River Flow: 104 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (°C)	Field Measurements (Hydrolab) Dissolved Oxygen	Field Measurements (Hydrolab) Salinity (PPT)	Field Measurements (Hydrolab) pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Laboratory Measurements (Samples) Salinity (PPT)	Laboratory Measurements (Samples) pH	Laboratory Measurements (Samples) Turbidity (JTU)
5	10.0	17.5	8.3	16.5	7.8	9.2	19.7	7.5	6.0
0719	5.0	17.8	8.2	16.5	7.8	9.6	19.2	7.6	6.0
2.45(S)	1.0	17.9	8.1	16.5	7.8	9.3	19.3	7.6	6.0
5A	10.0	18.5	9.3	14.5	7.8				
0755	5.0	18.5	9.1	14.5	7.8				
3.06(S)	1.0	18.5	9.0	14.5	7.8				
7	6.0	18.5	9.1	13.0	7.7	6.4	15.2	7.2	7.0
0804	3.0	18.5	9.0	13.0	7.7				
3.47(S)	1.0	10.0	8.6	13.0	7.7	8.9	15.1	7.4	6.0
7A	3.0	19.0	9.1	12.0	7.7				
0820	1.0	19.0	9.0	12.0	7.7				
3.77(S)									
7B	4.0	18.5	8.7	15.0	7.7				
0827	1.0	20.0	9.4	9.0	7.7				
4.40(S)									
7C	5.0	18.5	8.3	14.5	7.8				
0834	3.0	18.5	9.3	7.0	7.7				
4.81	1.0	20.0	8.6	7.0	7.4				

Table A2. Continued

Date: 7/17/73
Tide: Low
River Flow: 104 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{O}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
9	3.0	19.5	7.9	7.0	7.2	7.7	6.6	7.3	7.0
0846	1.0	19.5	7.6	4.0	7.1	7.8	4.0	7.1	3.0
5.10(DC)									
10	6.0	17.2	7.9	22.0	7.8	9.3	20.8	6.8	4.0
0923	3.0	20.0	9.7	8.5	7.8				
5.34	1.0	20.4	9.7	7.0	7.8	10.0	8.2	7.3	3.0

Table A2. Continued

Date: 12/4/73
Tide: High
River Flow: 3210 CFS

			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	40.0	10.0	11.0	21.0	7.5	10.6	30.0	7.9	2.8
0730	20.0	10.5	10.7	22.0	7.5	9.4	29.8	8.1	2.0
0.00	1.0	10.0	10.7	20.5	7.6	9.6	29.7	8.2	2.3
2	16.0	10.0	10.2	24.8	7.5	10.3	29.8	8.1	1.7
0747	8.0	10.3	10.0	25.0	7.5	10.5	29.3	8.1	0 6
0.90	1.0	9.0	10.2	14.0	7.5	12.1	6.9	7.7	3.2
3	9.0	10.0	10.3	22.0	7.5	9.7	27.1	7.6	6.3
0710	5.0	10.0	11.3	19.4	7.6				
1.80(LS)	1.0	8.7	10.9	3.2	7.0	11.4	5.4	7.2	6.0
4	5.0	10.7	10.1	22.8	7.4	9.9	27.3	7.9	2.7
0800	3.0	8.7	10.5	5.6	7.0	9.9	27.1	7.9	3.4
2.15(N)	1.0	8.0	10.6	3.8	6.9	12.0	<2.8	7.4	4.9
5	17.0	10.0	10.0	23.0	7.5	10.7	29.1	8.1	3.5
0848	8.0	10.0	9.7	22.8	7.4	10.6	29.0	8.0	2.7
2.45(S)	1.0	9.5	10.0	18.0	7.5	11.9	6.4	7.7	4.0
6	7.0	10.0	10.4	24.0	7.4	10.6	28.5	7.9	3.4
0810	4.0	9.5	9.3	21.0	7.4	10.2	24.1	7.9	5.0
2.75(N)	1.0	8.0	10.9	1.0	7.1	12.1	<2.8	7.4	4.5

Table A2. Continued

Date: 12/4/73
Tide: High
River Flow: 3210 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Field Measurements (Hydrolab) Salinity (PPT)	Field Measurements (Hydrolab) pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Laboratory Measurements (Samples) Salinity (PPT)	Laboratory Measurements (Samples) pH	Laboratory Measurements (Samples) Turbidity (JTU)
7	15.0	9.5	11.2	20.5	7.5	10.6	23.1	8.0	3.7
0900	7.0	8.0	12.1	0	7.0	12.5	<2.8	7.4	5.2
3.47(S)	1.0	8.0	12.3	0	6.8	12.3	<2.8	7.2	3.0
8	11.0	9.8	7.4	20.0	7.0	3.1	28.8	7.0	38.0
0825	6.0	8.0	9.4	4.0	7.1	11.9	4.4	7.3	6.8
4.44(N)	1.0	8.0	10.3	3.5	7.0	12.3	3.1	7.3	5.9
9	9.0	8.0	11.8	0.4	6.2	13.2	<2.8	7.5	3.1
0933	5.0	8.0	11.7	0.3	6.1	12.7	<2.8	7.2	2.3
5.10(DC)	1.0	8.0	11.2	0.2	6.1	12.7	<2.8	7.1	2.5
10	13.0	8.2	12.0	0	5.6	12.4	<2.8	7.4	5.5
0917	6.0	8.5	11.9	0	5.4	12.5	<2.8	7.2	5.2
5.34	1.0	8.5	11.9	0	5.0	12.4	<2.8	7.3	5.2

Table A2. Continued

Date: 12/4/73 Tide: Low River Flow: 3210 CFS			Field Measurements (Hydrolab)			Laboratory Measurements (Samples)			
Station Time (PST) River Mile	Depth (ft)	Temp. (^oC)	Dissolved Oxygen	Salinity (PPT)	pH	Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
1	40.0	9.0	11.5	5.6	6.8	9.5	9.6	7.5	4.0
1337	20.0	8.7	11.5	4.5	6.8	11.7	7.6	7.5	2.8
0.00	1.0	8.5	11.5	5.4	6.8	11.3	7.3	7.5	5.0
2	13.0	8.8	11.0	6.8	7.1	11.3	7.8	7.7	4.8
1350	6.0	8.8	11.1	4.5	7.0	11.6	7.9	7.4	4.7
0.90	1.0	8.8	11.6	3.4	6.9	11.9	3.8	7.3	5.0
3	9.0	10.0	10.6	21.5	7.3		28.2	7.4	90.0
1434	5.0	9.2	10.5	12.0	7.1	10.7	7.1	6.0	5.2
1.80(LS)	1.0	8.3	10.3	3.5	6.6	10.9	3.8	6.8	3.7
4	1.0	8.5	10.8	5.2	6.7	11.3	5.9	7.0	48.0
1545									
2.15(N)									
5	13.0	8.5	11.7	1.0	6.0	12.7	<2.8	3.3	6.5
1445	7.0	8.5	11.3	1.0	5.9	12.8	<2.8	6.2	4.8
2.45(S)	1.0	8.5	11.4	0.8	5.9	12.3	<2.8	3.5	5.9
7	9.0	8.5	11.5	0.9	6.0	12.4	<2.8	6.8	12.0
1455	5.0	8.5	11.4	0.5	5.9	12.5	<2.8	6.9	5.8
3.47(S)	1.0	8.5	11.5	0.5	5.7	12.4	<2.8	7.4	5.2

Table A2. Continued

Date: 12/4/73
Tide: Low
River Flow: 3210 CFS

Station Time (PST) River Mile	Depth (ft)	Temp. (^{o}C)	Field Measurements (Hydrolab) Dissolved Oxygen	Salinity (PPT)	pH	Laboratory Measurements (Samples) Dissolved Oxygen (PPM)	Salinity (PPT)	pH	Turbidity (JTU)
9	5.5	8.0	11.4	0.4	6.3	12.9	<2.8	6.6	2.7
1515	1.0	8.0	11.5	0.4	6.0	12.9	<2.8	4.1	2.8
10	9.0	8.5	11.5	0.4	6.1	12.8	<2.8	7.0	5.4
1507	5.0	8.5	11.6	0.4	6.0	12.7	<2.8	6.3	5.7
5.34	1.0	8.5	11.5	0.3	5.8	12.5	<2.8	4.5	5.9

Table A3. Test data on the top four inches of the sediment samples

Station River Mile	Season Date	D_{50} (mm)	Uniformity (D_{60}/D_{10})	Porosity (%)	Volatile Solids (% by wt.)	Remarks
1 0.00	Winter 3/6/73	0.15	33.0	67	7.47	Black, slightly grainy, wood chips throughout, lower .5 in. sandy.
2 0.90	Winter 3/6/73	0.35	3.0	44	2.19	Black, shell frags., coarse sand, wood chips, sulfide odor.
4 2.15(N)	Winter 3/6/73	0.13	3.7	52	1.90	Black silt.
5 2.45(S)	Winter 3/6/73	0.26	1.8	48	1.76	Black on top, coarse sand, sulfide odor.
6 2.75(N)	Winter 3/6/73	0.09	6.0	61	4.23	Black, slightly grainy, some plant fibers.
7 3.47(S)	Winter 3/6/73	0.30	2.3	46	2.85	Coarse sand, wood chips on top and throughout.
8 4.44(N)	Winter 3/6/73	0.017	20.0	85	13.38	Black, very mushy, very fine silt.
9 5.10(DC)	Winter 3/6/73	0.25	1.9	51	2.17	Coarse sand, few wood chips and plant fibers.
10 5.34	Winter 3/6/73	0.27	2.1	51	2.13	Coarse sand, some wood chips.

Table A3. Continued.

Station River Mile	Season Date	D_{50} (mm)	Uniformity (D_{60}/D_{10})	Porosity (%)	Volatile Solids (% by wt.)	Remarks
1 0.00	Summer 9/4/73	2.5	15.0	-	4.26	Black, feels "rock" hard, many shell frags., sulfide odor.
2A 1.46	Summer 9/4/73	0.24	1.6	36	1.59	Coarse sand.
3 1.80(LS)	Summer 9/4/73	0.21	5.3	49	1.83	Med. coarse to fine sand, thin layer of silt on top.
4 2.15(N)	Summer 9/4/73	0.063	7.5	55	3.00	Black to gray, fine sand and silt, some shell frags, very few plant fibers.
5 2.45(S)	Summer 9/4/73	0.30	2.1	49	3.03	Coarse sand, very few wood chips.
6 2.75(N)	Summer 9/4/73	0.22	4.3	45	3.46	Coarse sand, some shell frags., some wood chips on top.
7 3.47(S)	Summer 9/4/73	0.29	2.1	41	2.53	Coarse sand.
8 4.44(N)	Summer 9/4/73	0.012	18.0	84	12.53	Black, fine silts, some plant fibers.
9 5.10(DC)	Summer 9/4/73	0.24	1.8	60	2.00	Coarse sand.
10 5.34	Summer 9/4/73	0.27	1.9	48	2.68	Coarse sand, some wood chips.

APPENDIX B

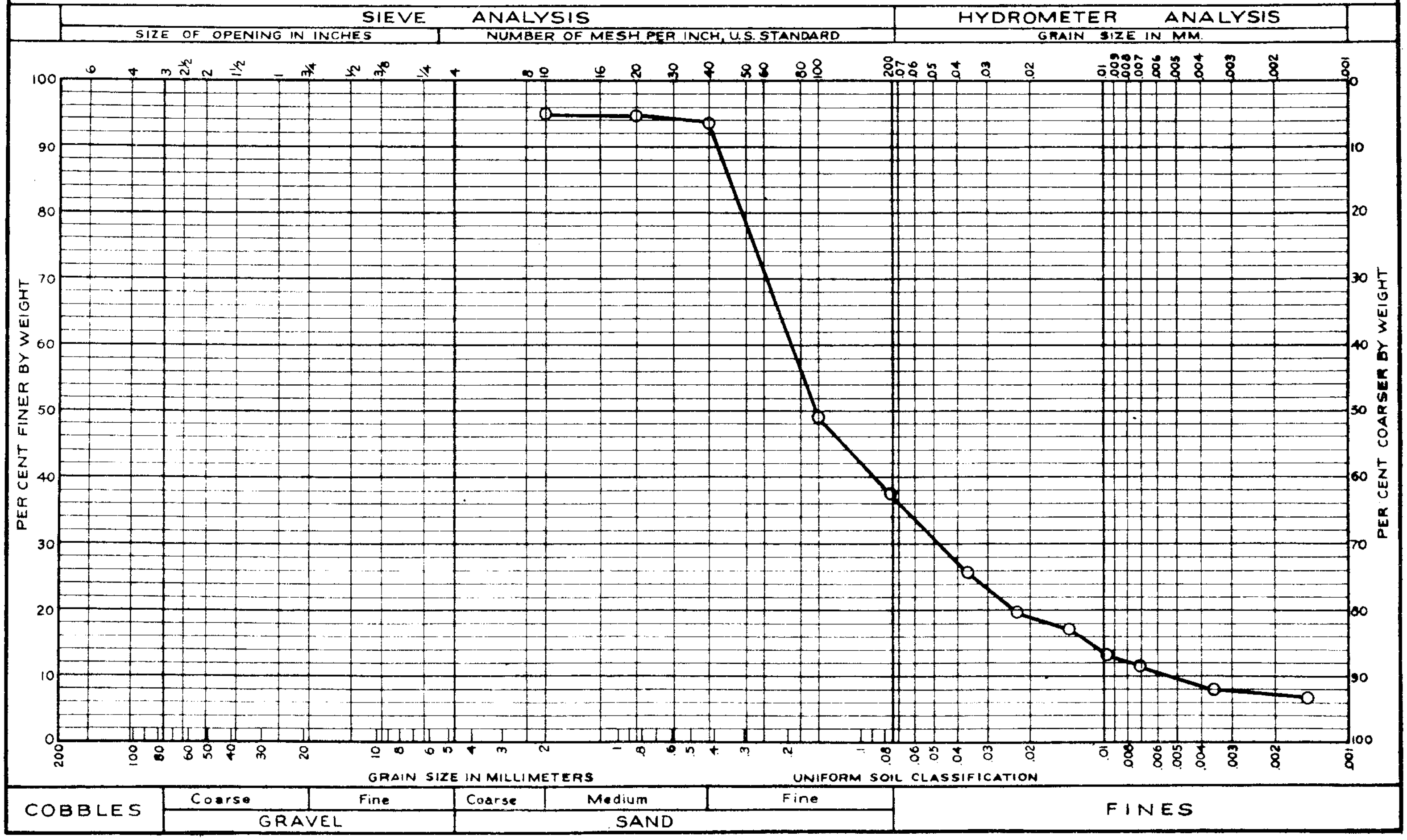
Sediment Grain Size Distribution Plots

GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 1, Rm 0.0

TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4 in.



GRAIN SIZE ANALYSIS

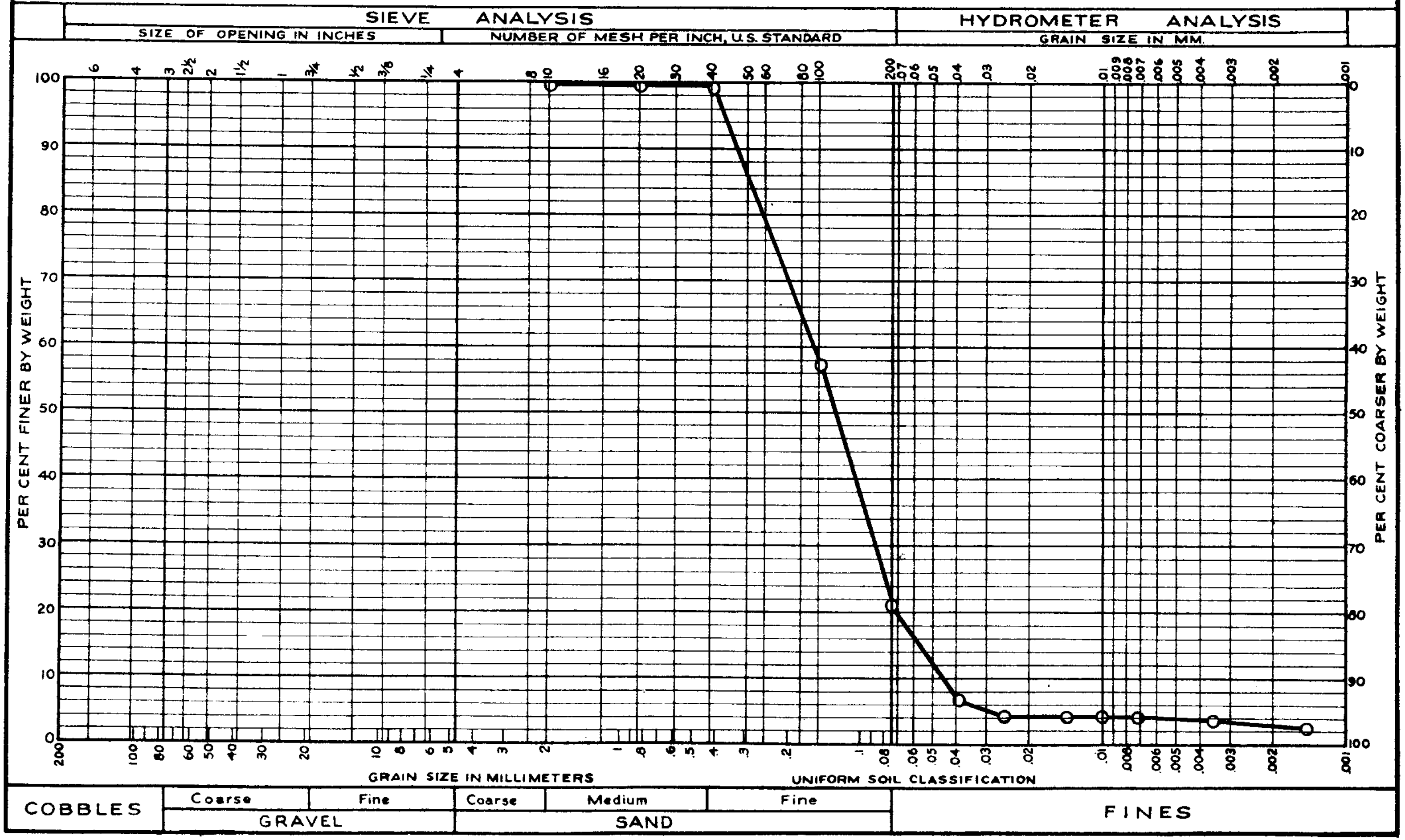
TEST FOR Alsea Estuary, Sta. 2, Rm 0.9

TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4 in.

GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 4, Rm 2.15(N)
TEST BY Utt and Crane DATE 3/6/73
SAMPLE DESCRIPTION Top 4 in.

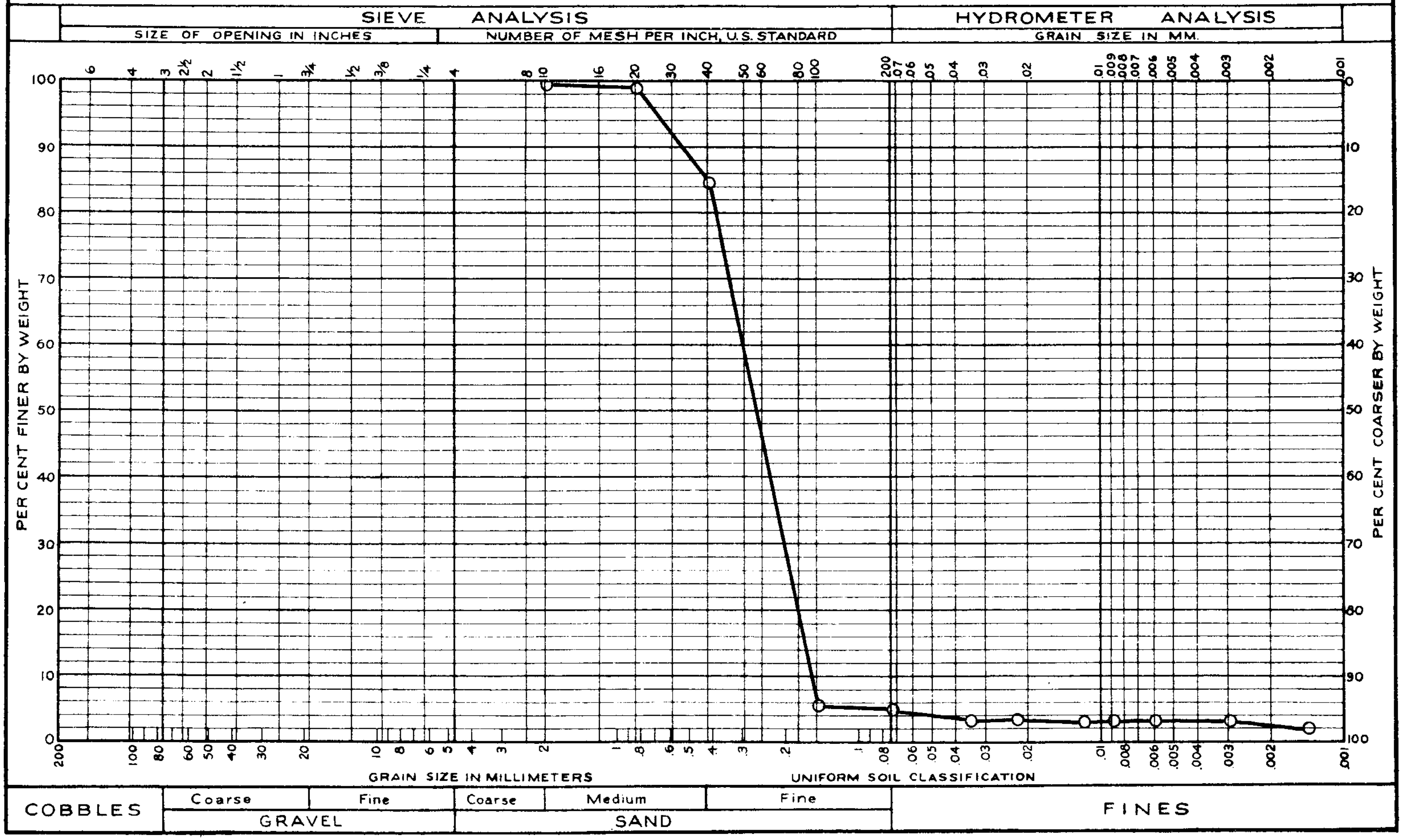


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 5, Rm 2.45(S)

TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4 in.

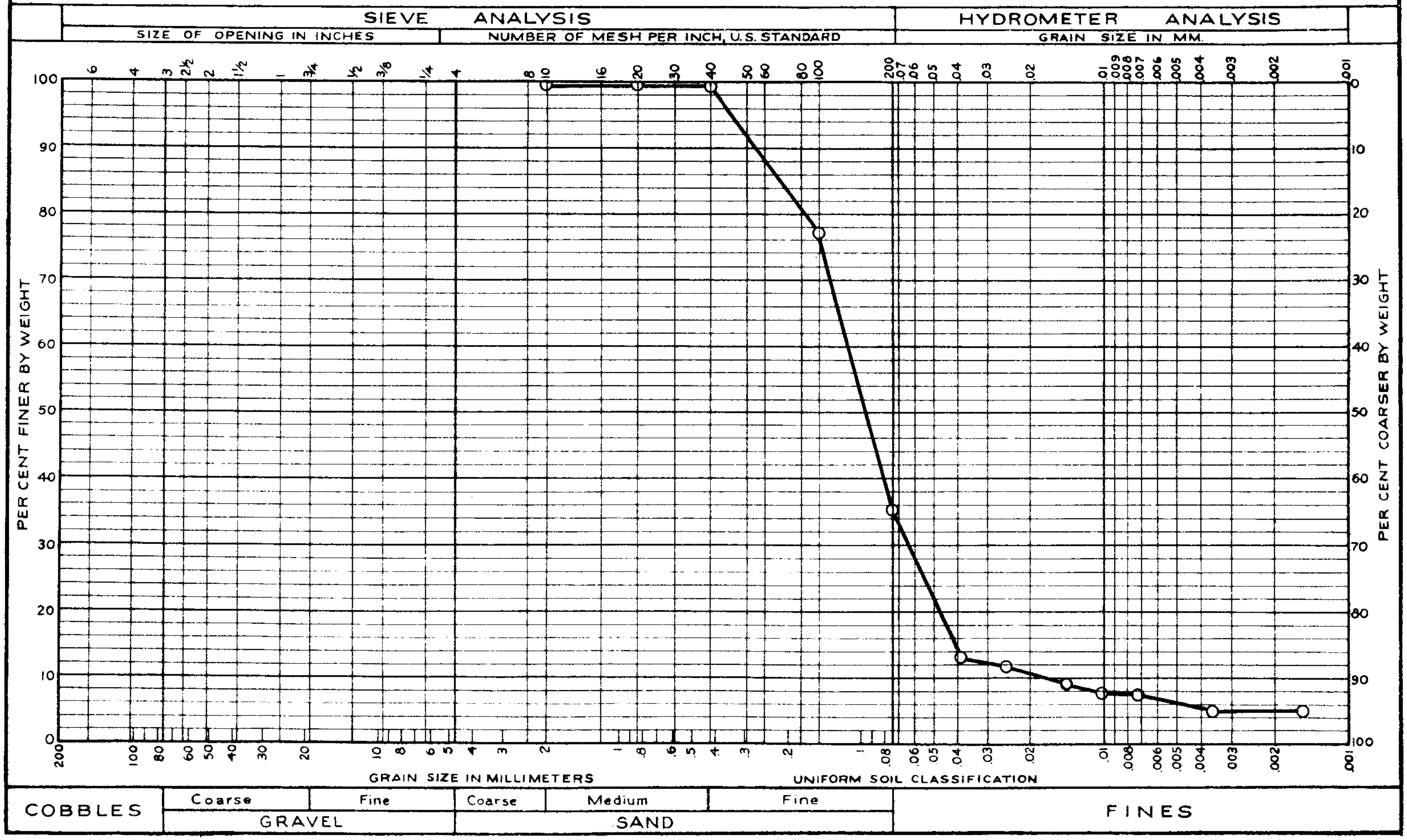


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 6, Rm 2.75(N)

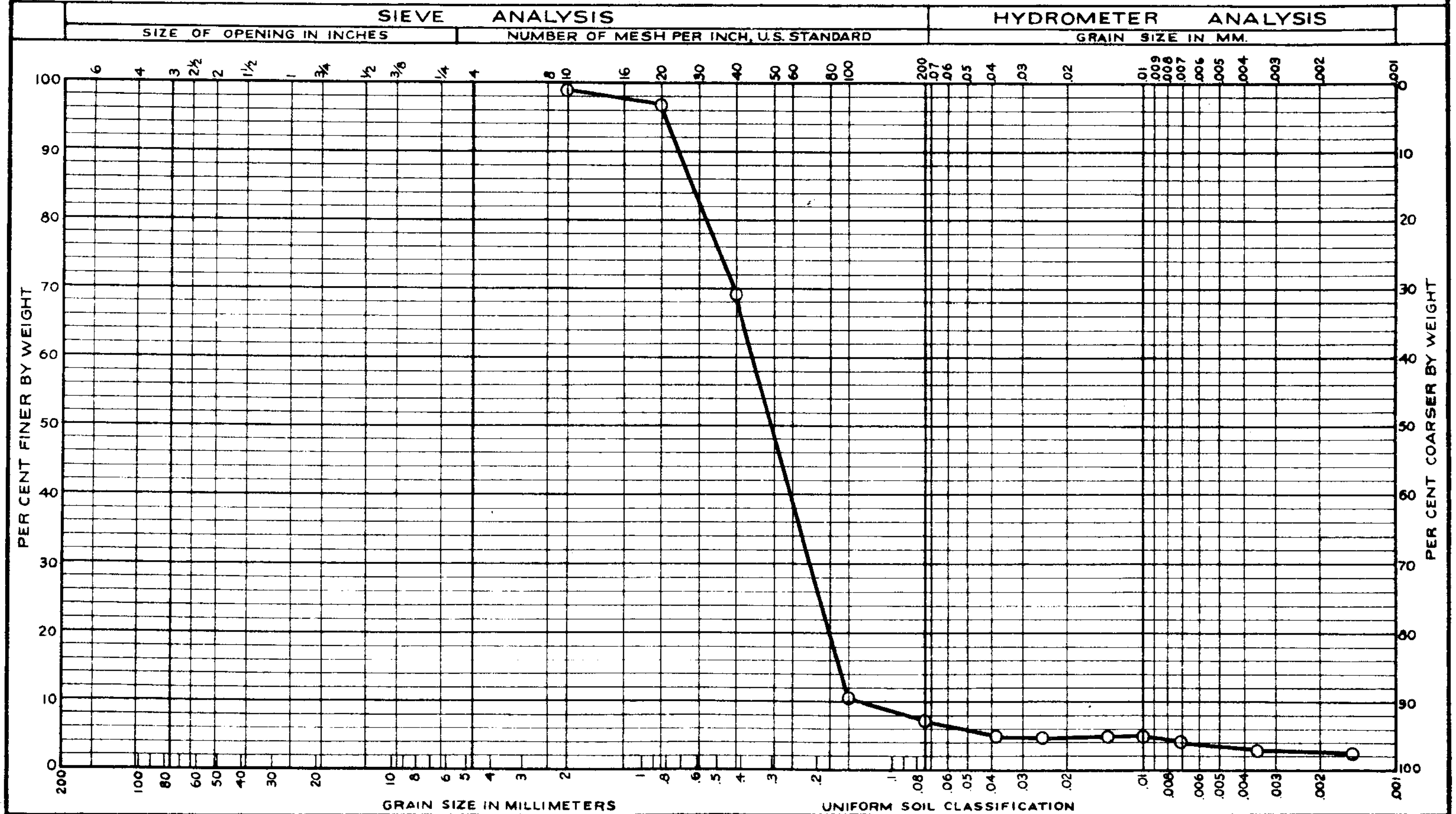
TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4 in.



GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 7, Rm 3.06(S)
TEST BY Utt and Crane DATE 3/6/73
SAMPLE DESCRIPTION Top 4 in.



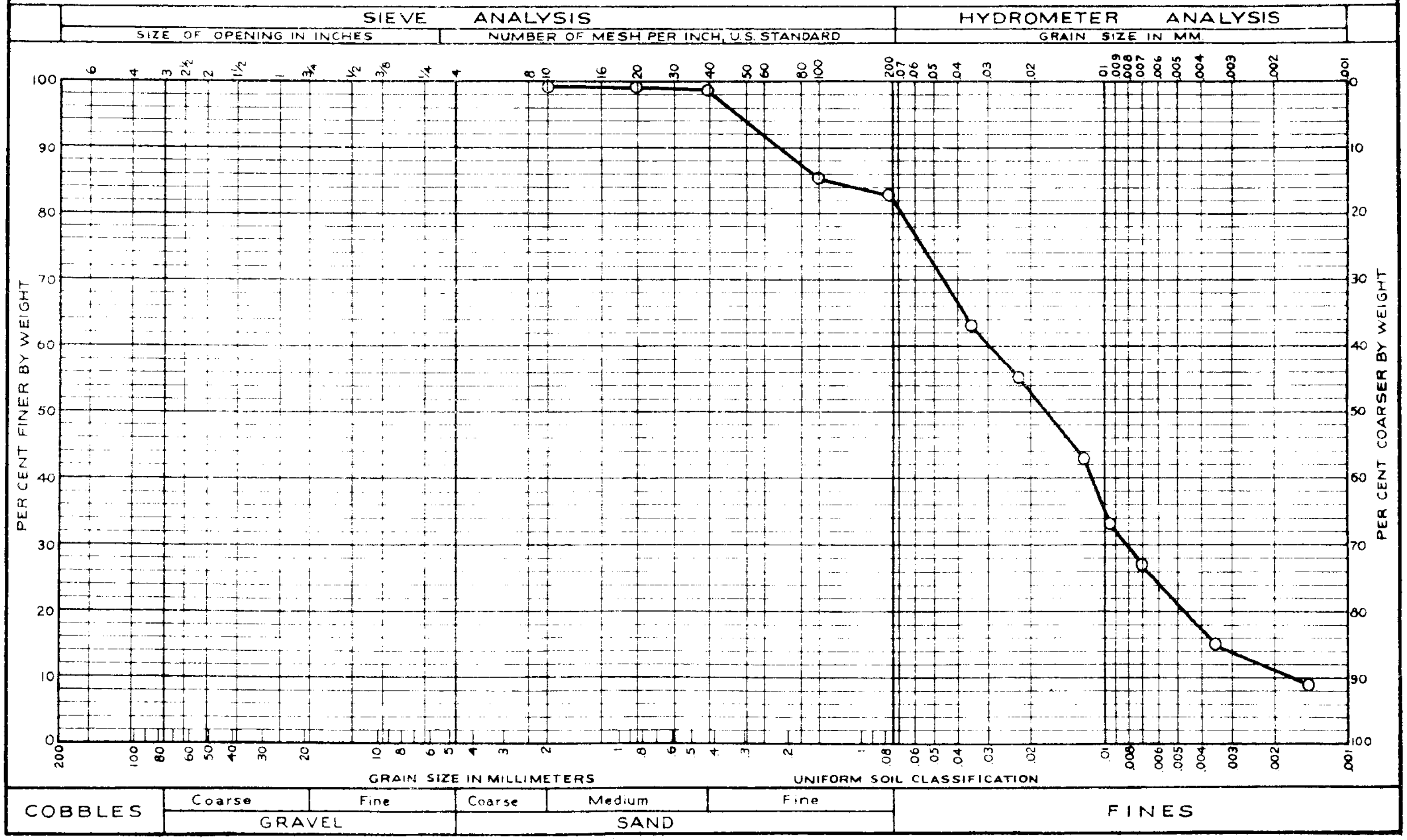
COBBLES	GRAVEL		SAND			FINES
	Coarse	Fine	Coarse	Medium	Fine	

GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 8, Rm 4.44(N)

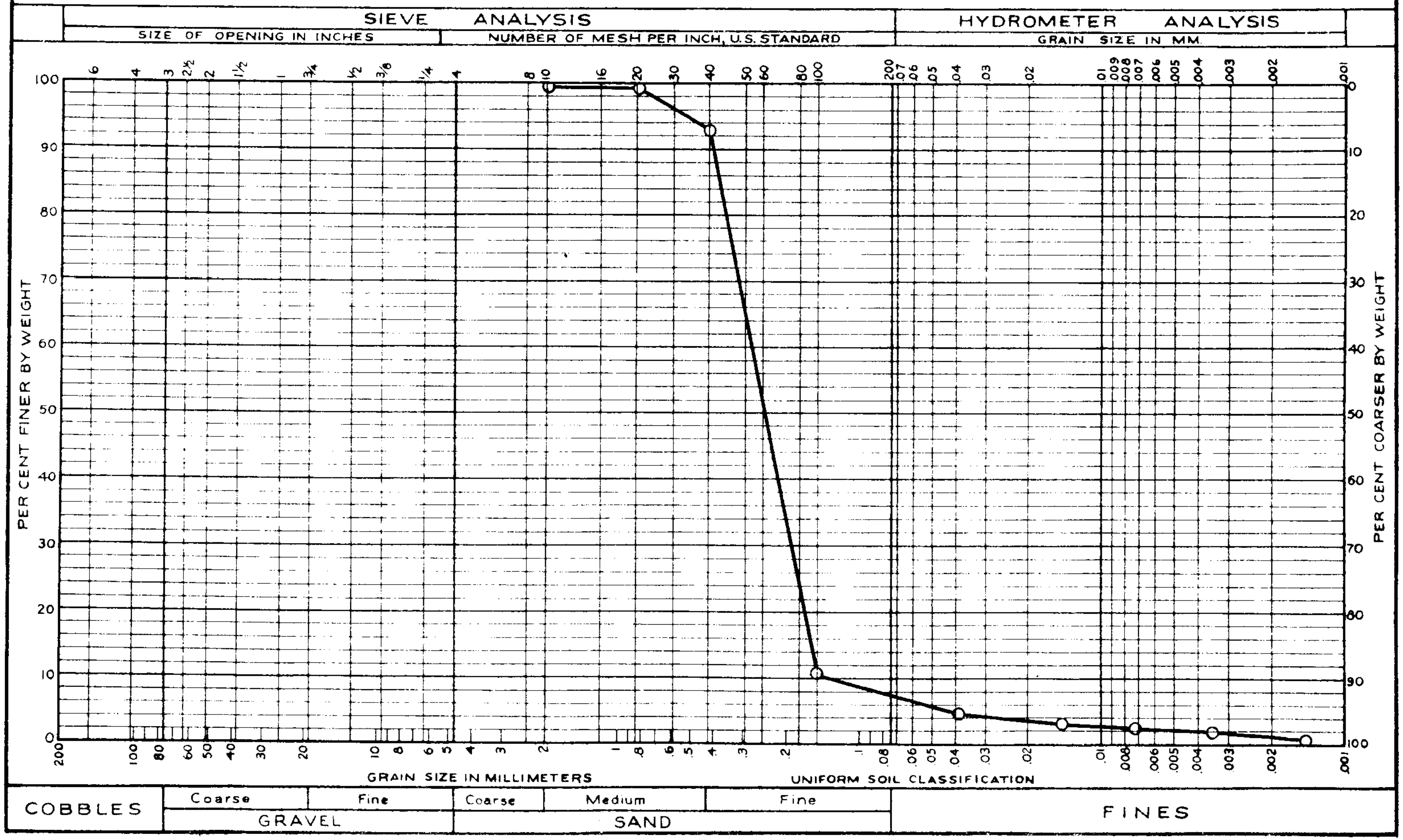
TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4 in.



GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 9, Rm 5.1 (Drift Creek)
TEST BY Utt and Crane DATE 3/6/73
SAMPLE DESCRIPTION Top 4 in.

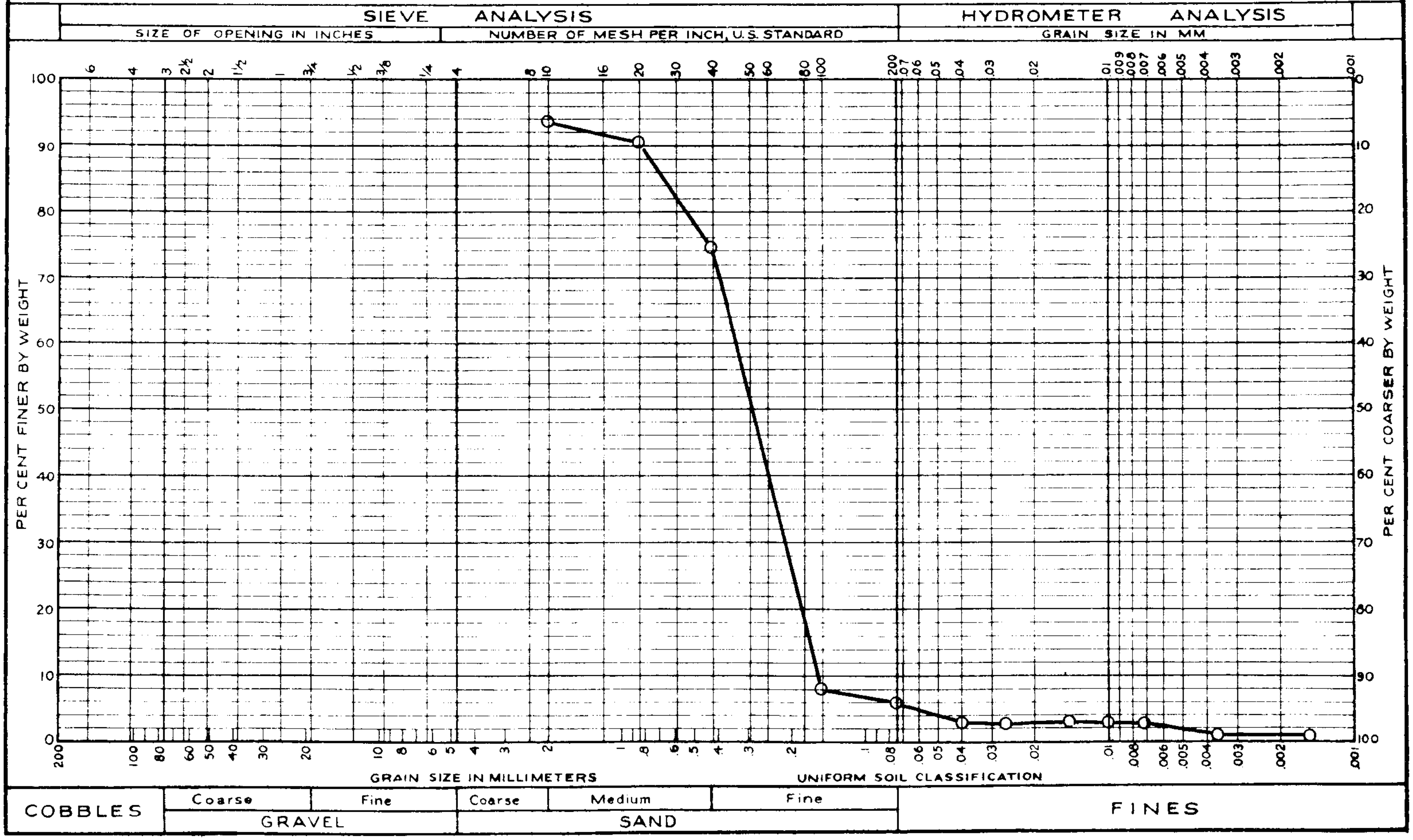


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 10, Rm 5.34

TEST BY Utt and Crane DATE 3/6/73

SAMPLE DESCRIPTION Top 4in.

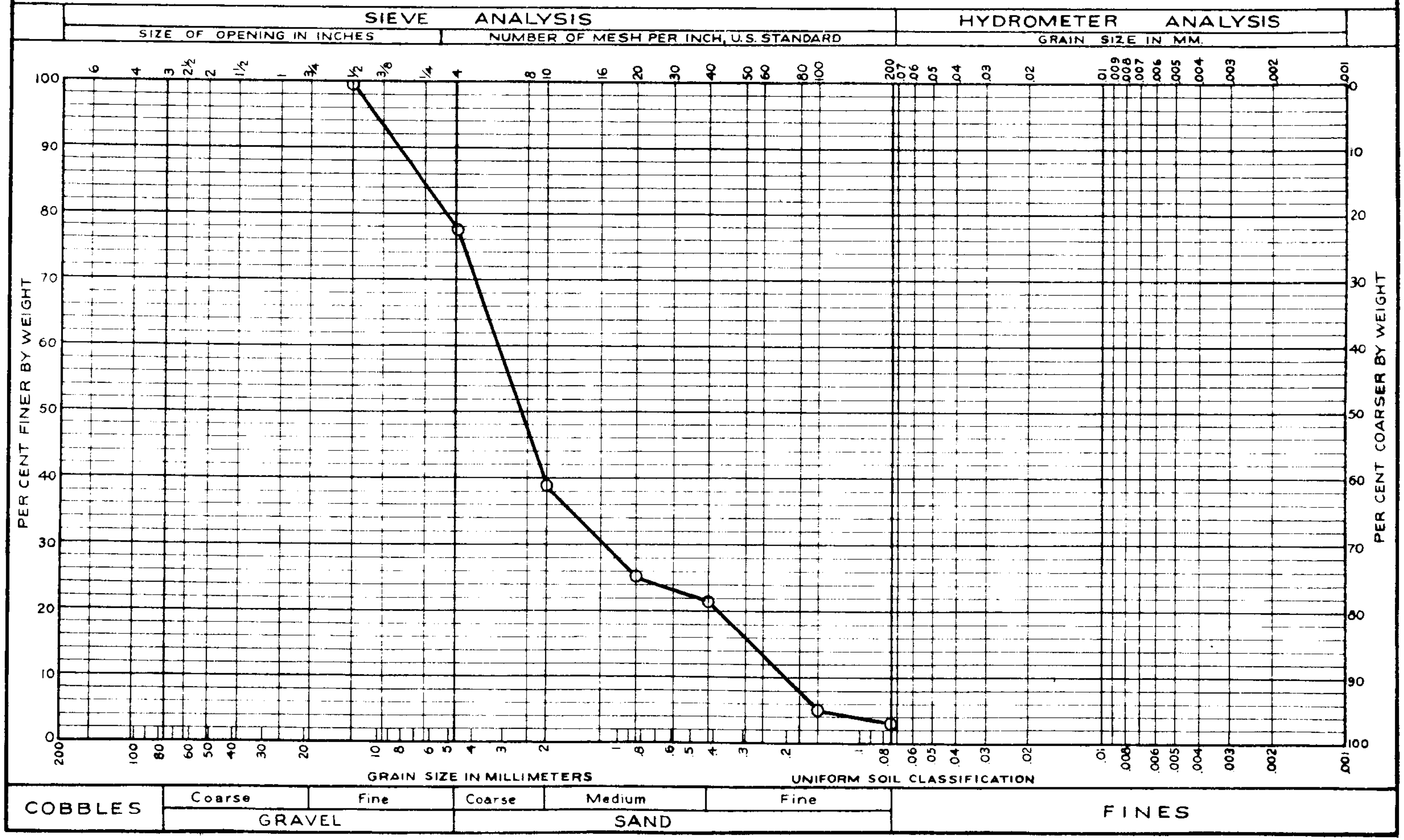


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 1, Rm 0.0

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

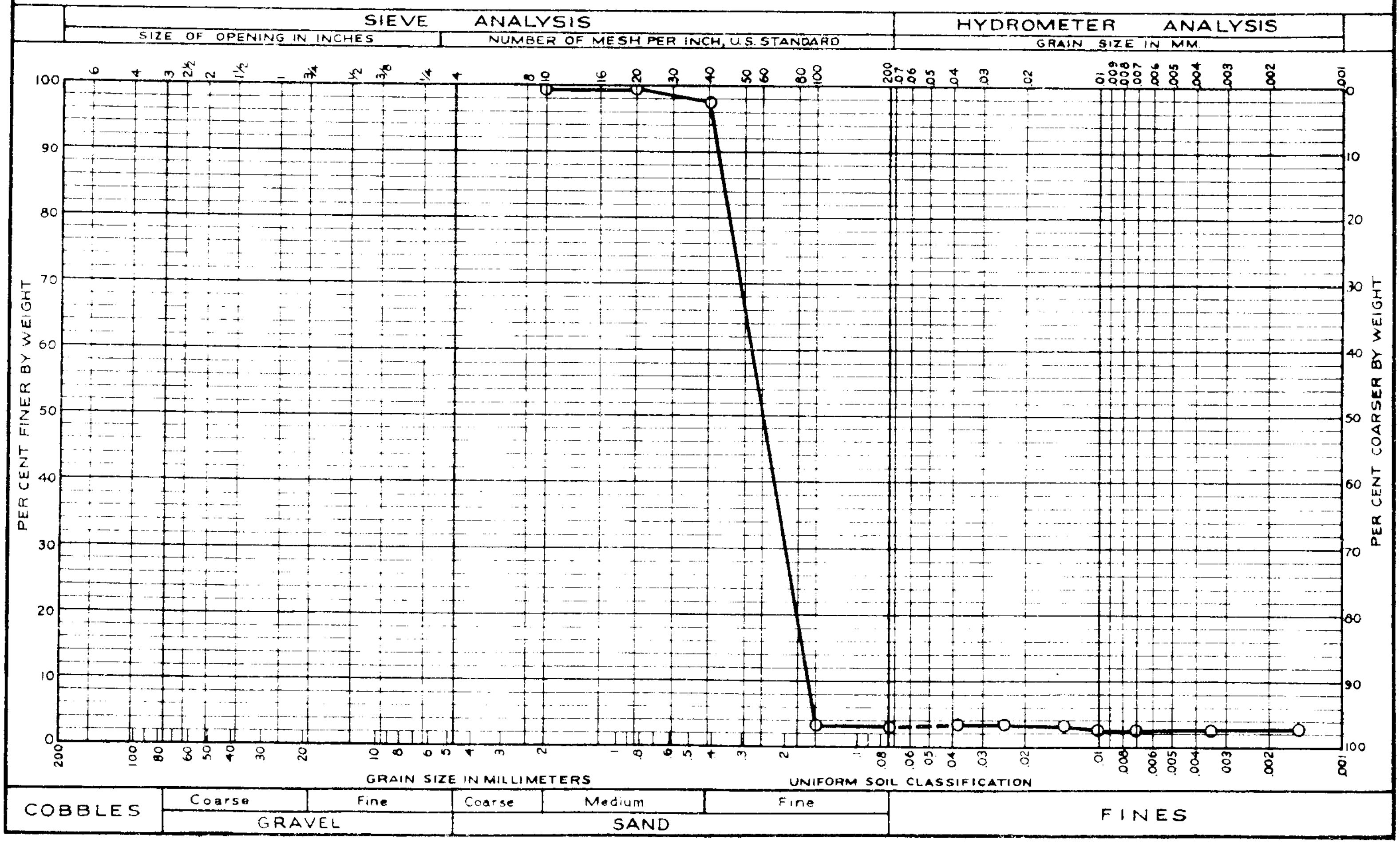


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 2A, Rm 1.46

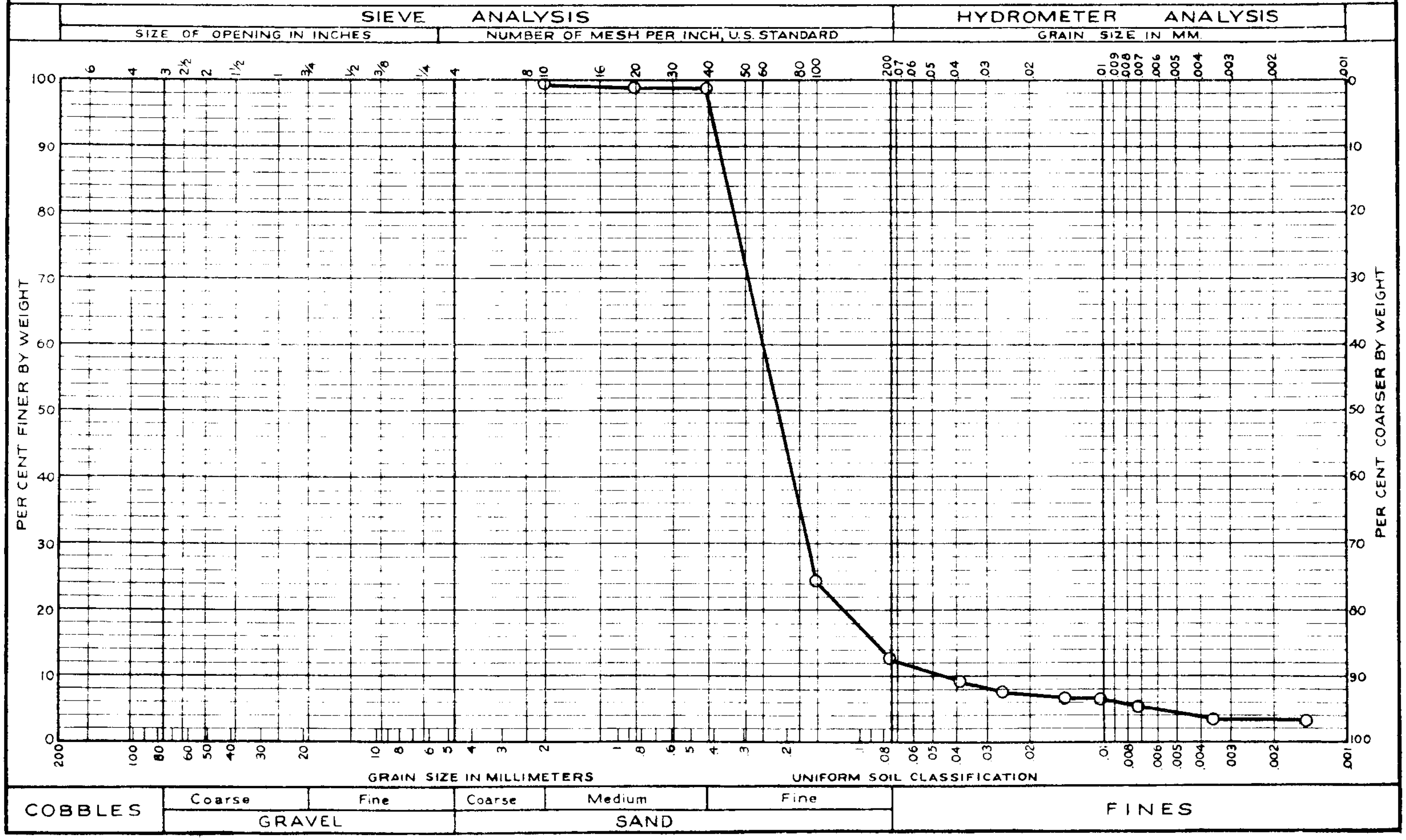
TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.



GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 3, Rm 1.8 (Lints Slough)
TEST BY Utt and Crane DATE 9/4/73
SAMPLE DESCRIPTION Top 4 in.

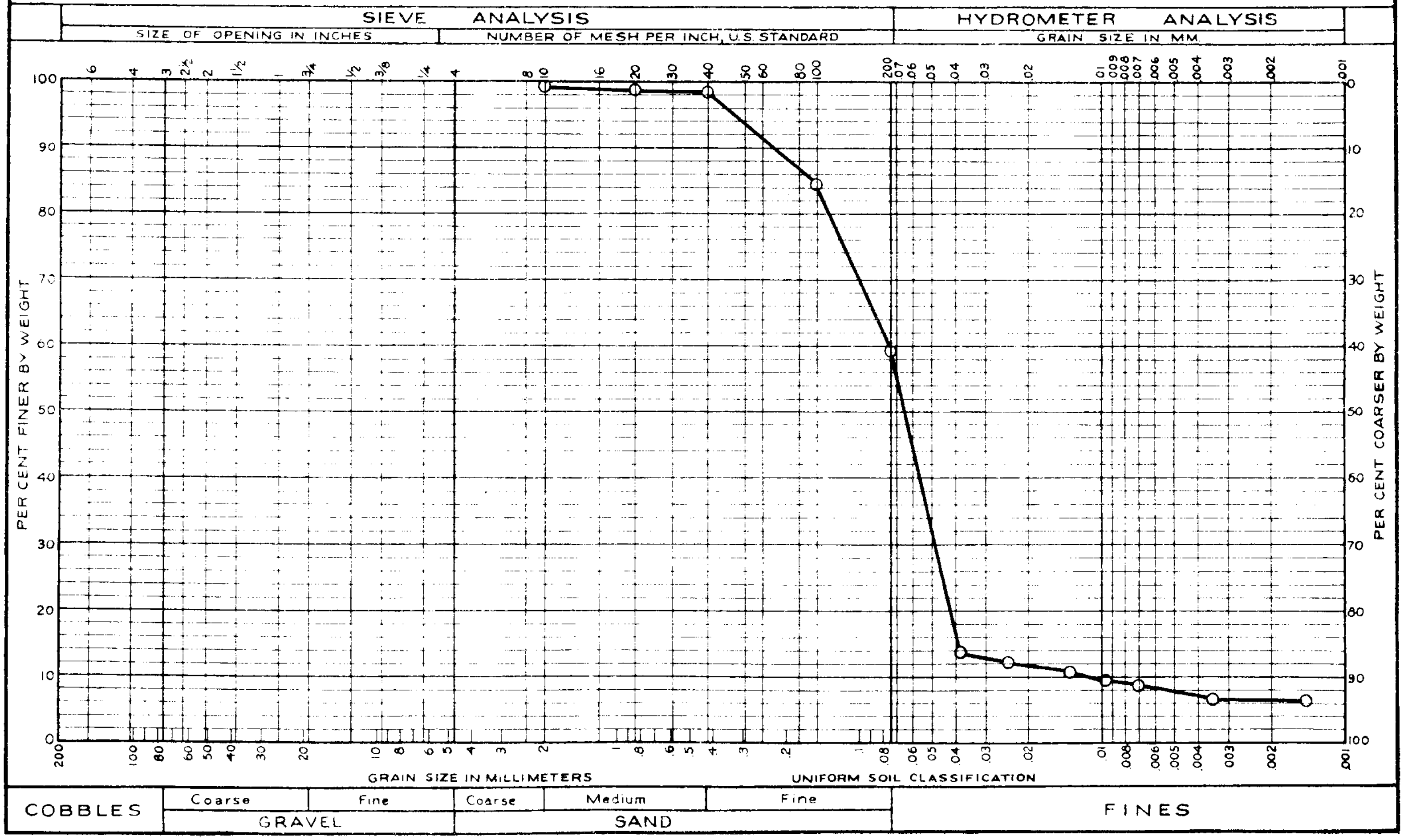


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 4, Rm 2.15(N)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

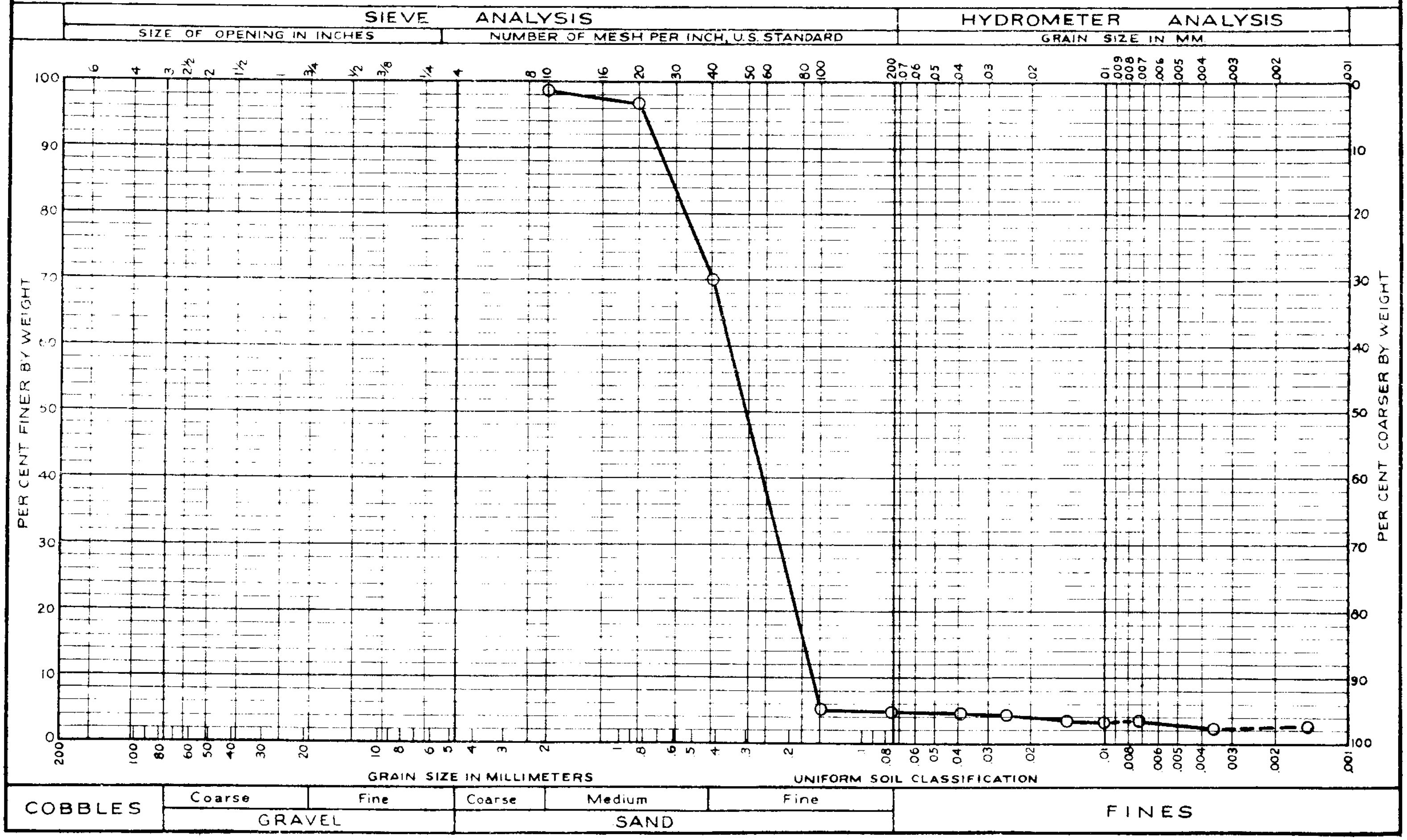


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 5, Rm 2.45(S)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

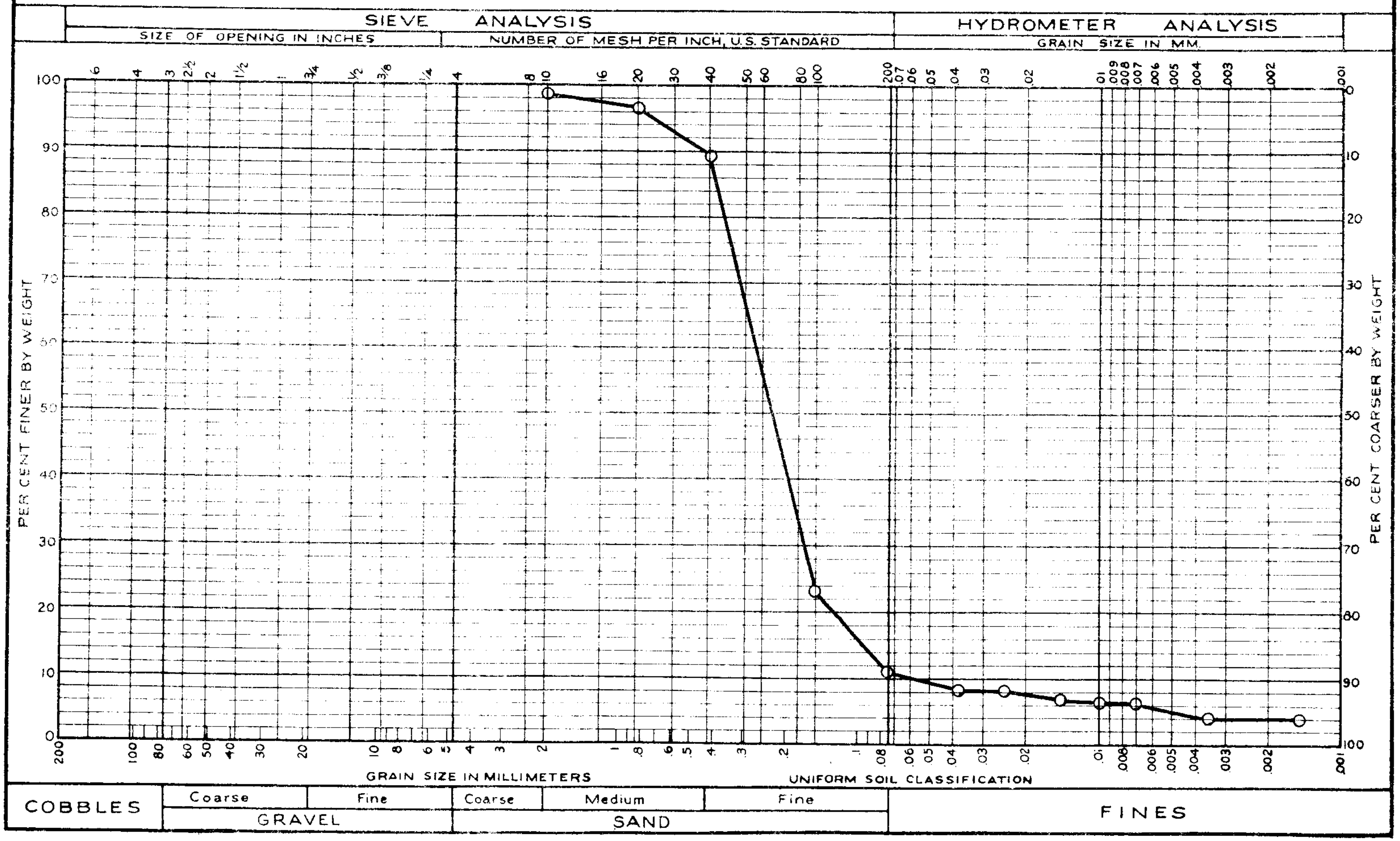


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 6, Rm 2.75(N)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

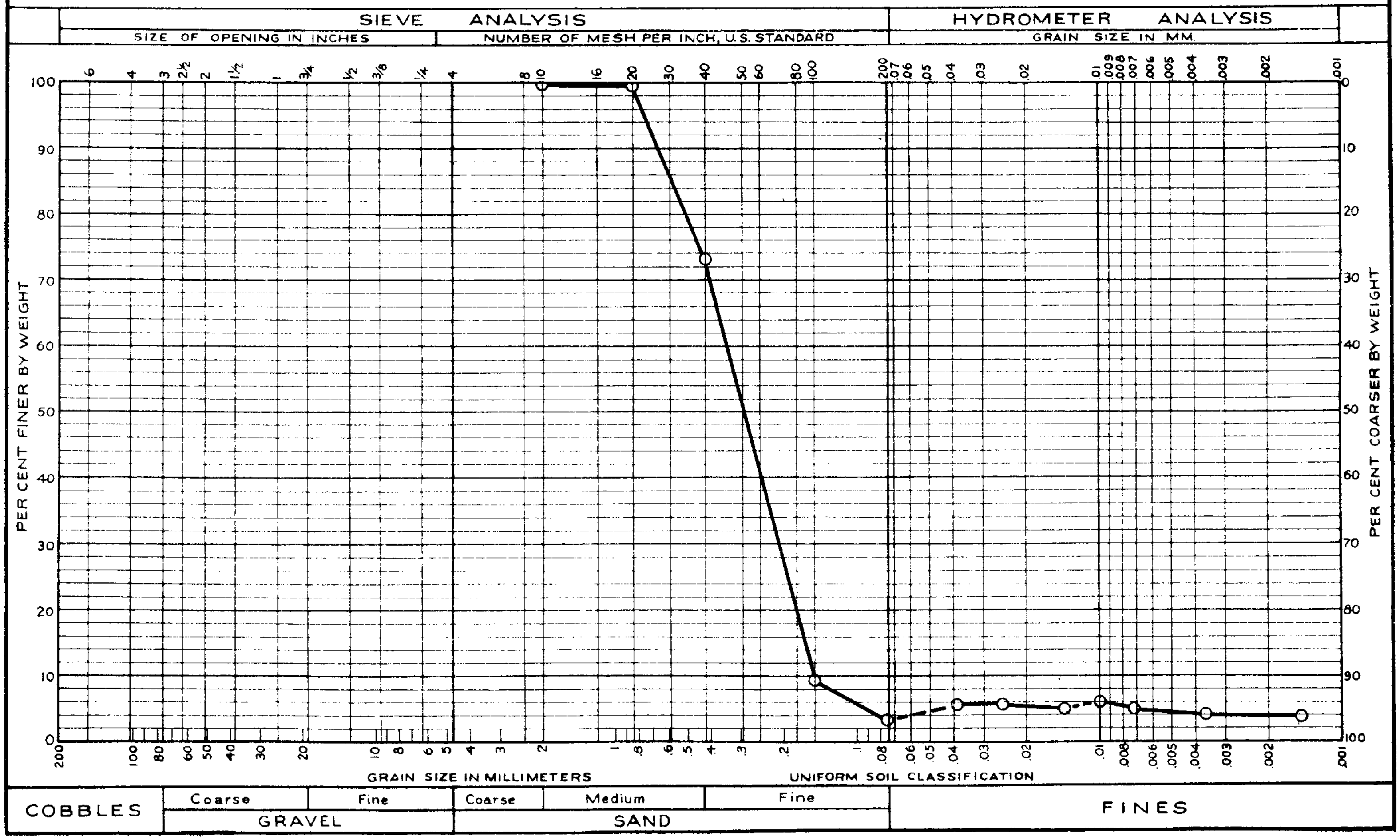


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 7, Rm 3.47(S)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

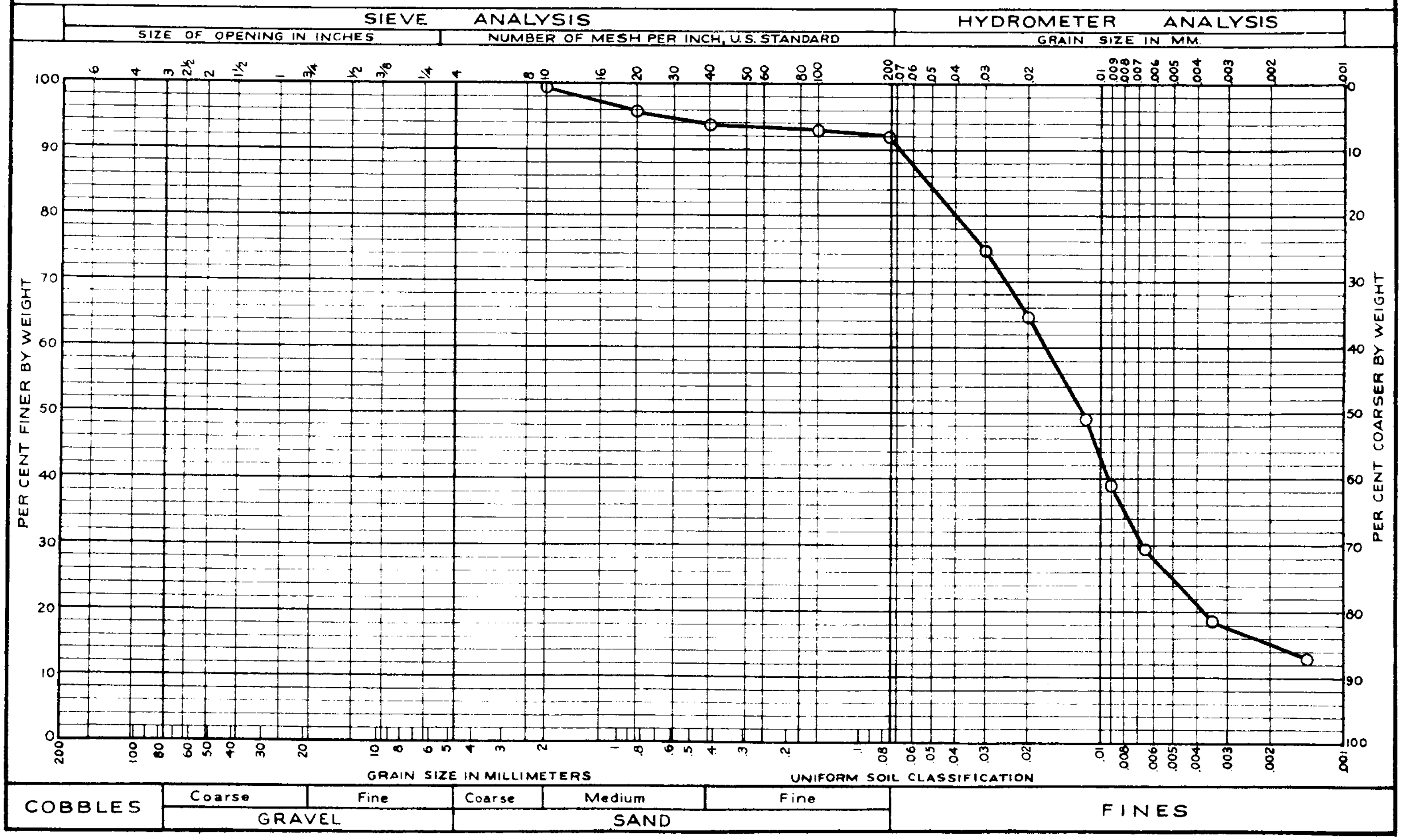


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 8, Rm 4.44(N)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.

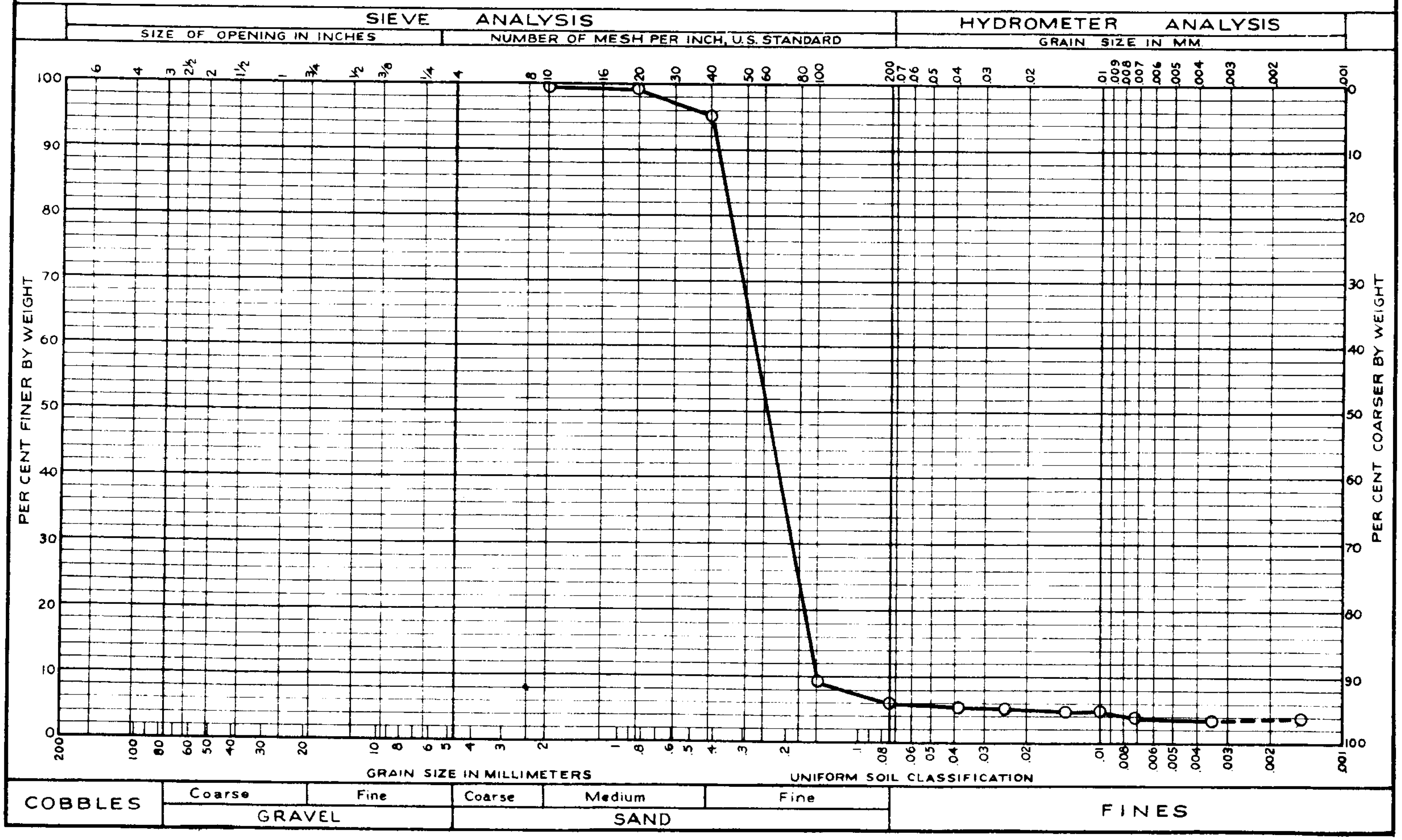


GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 9, Rm 5.1 (Drift Creek)

TEST BY Utt and Crane DATE 9/4/73

SAMPLE DESCRIPTION Top 4 in.



GRAIN SIZE ANALYSIS

TEST FOR Alsea Estuary, Sta. 10, Rm 5.34
TEST BY Utt and Crane DATE 9/4/73
SAMPLE DESCRIPTION Top 4 in.