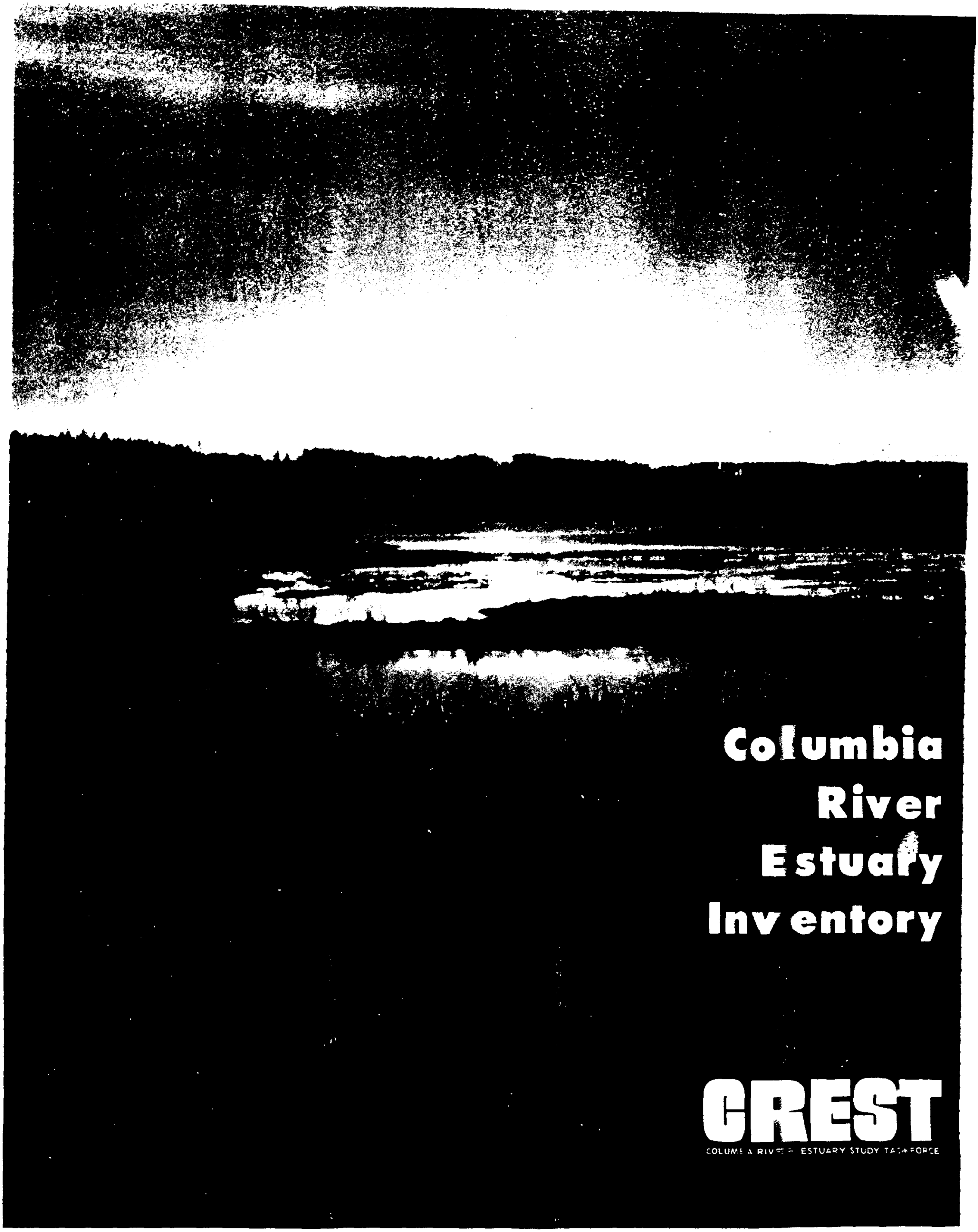

Columbia River Estuary Inventory

CREST

COLUMBIA RIVER ESTUARY STUDY TASKFORCE

1/31/78/jc

CREST INVENTORY ERRATA SHEET

Acknowledgements, 2nd Pg., Paragraph 1

READS: Jan vanZander

SHOULD READ: Janet Zander

Pg. 306-9, Paragraph 3, Sentence 3 & 4

READS: From Jan-May, those from low salinity areas feed mainly on the bottom dwelling amphipod *Corophium sp.* Those from higher salinity areas feed on *Corophium*, *Neomysis sp.* (a shrimp-like organism), and Chironomids ...

SHOULD READ: From January to May, those from high salinity areas feed mainly on the bottom dwelling amphipod *Corophium sp.* Those from lower salinity areas feed on *Corophium*, *Neomysis sp.* (a shrimp-like organism),...

Pg. 306-10, Paragraph 2, Sentence 5

READS: Juveniles spend one year...

SHOULD READ: Naturally produced juveniles spend one year...

Pg. 306-14, Paragraph Ø, Sentence 3

READS: Record low counts of summer...

SHOULD READ: Record low numbers of summer...

Your CREST Inventory is missing Figures 210-2, 210-3 and 210-4. The Table of Contents for Section 210 indicates where the figures should be inserted. An errata sheet has also been enclosed.

1/31/78/jc

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COLUMBIA RIVER ESTUARY INVENTORY OF PHYSICAL, BIOLOGICAL AND CULTURAL CHARACTERISTICS

EDITED BY

MARGARET H. SEAMAN

WITH CONTRIBUTIONS BY

ROBERT E. BLANCHARD,
KURT D. BUCHANAN,
JAMES W. GOOD,
DAVID JAY
AND
GEORGE POTTER

PREPARED FOR

THE COLUMBIA RIVER ESTUARY STUDY TASKFORCE

The preparation of this report was financially aided through grants from the Oregon Land Conservation and Development and the Washington State Department of Ecology with funds obtained from the National Oceanic and Atmospheric Administration, and appropriated for Sections 305 and 306, respectively, of the Coastal Zone Management Act of 1972.

FOREWARD

This Inventory contains summaries of the physical, biological and cultural characteristics of the Columbia River estuary area. It is intended to be a primary resource for the development of the CREST Land and Water Use Plan and contains information pertinent to the planning process. It represents the first attempt to compile a document containing summaries of known information about the Columbia River estuary.

The Inventory was originally conceived as a brief summary of existing information about the estuary, but it has evolved into a lengthy search for and review of available literature and data. Although a great deal of effort has gone into the Inventory, there may be information that has not been included.

While compiling the document, CREST has attempted to provide a tool that will be helpful to a wide range of users. As a result, it is recognized that some may view the Inventory as too technical, while others may perceive it as too general.

The subjects of the technical reports included in this Inventory are listed in the Table of Contents. Each technical report has a more detailed Table of Contents, as well as a list of figures and tables relating to it. Many of the figures and tables summarize the text, and it is hoped they are useful for general reference and planning.

It is important for the reader to recognize that there are facets of the estuary that have never been studied, and there are subjects that have been researched for only limited areas of the estuary. Much research and analysis remain to be done to provide a total picture of the estuary area and information regarding impacts of actions within the region.

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ACKNOWLEDGEMENTS

The Inventory was compiled by the CREST staff. Mr. David Jay was primarily responsible for the section on physical characteristics, Mr. James W. Good for the section on biological characteristics and Mr. Robert E. Blanchard for the section on cultural characteristics. Mr. Kurt Buchanan prepared the section on Fishes. These staff members gratefully acknowledge the assistance they received from estuary area residents and state and federal agency personnel in the location and review of material about specific places and subjects summarized in the Inventory. The staff wishes to thank everyone who contributed to the Inventory and particularly those individuals listed below:

Physical Characteristics

Stan Hamilton of the Oregon Division of State Lands provided the tidal data shown in Figure 203-4.

R.C. Coykendall of the Washington Department of Natural Resources provided information concerning ownership of tidelands and bedlands in the State of Washington.

Terry Durkin of the National Marine Fisheries Service provided information for Section 204.

Dan Silver and Ray Petersen of the U.S. Environmental Protection Agency, Seattle, Washington, provided the data on municipal and industrial waste discharges in the Columbia and Willamette Rivers for Section 205.3.

J.L. Glenn and D.W. Hubbell of the U.S. Geological Survey, Denver, Colorado, provided unpublished sediment transport data for Tables 208-3 and 208-4.

J. Craeger and R. Sternberg of the University of Washington and R. Moulton of the U.S. Army Engineers, Portland District provided information on which Section 208.6 is based.

Don Leach of the Clatsop County Soil Conservation Service, Bernie Rufener of the Pacific County Soil Conservation Service, Rich Bainbridge of the Wahkiakum County Soil Conservation Service and Mike Moore of the Cowlitz-Wahkiakum Governmental Conference provided information for Section 210.

Walt Lindstrom, Bob Blanchard, Don Mathison and Jan vanZander did the drafting for the entire physical section.

Biological Characteristics

Norman Kujala of Oregon Ocean Services, Inc., provided an extensive background report and distribution maps of estuary fishes and invertebrates which served as a basis for Sections 304, 305 and 306.

Terry Durkin and Sandy Lipovsky of the National Marine Fisheries Service provided helpful reviews and basic information for text and maps.

John McKern of the U.S. Army Corps of Engineers, Walla Walla District provided valuable material on shoreline vegetative habitats and wildlife.

Joe Welch of the U.S. Fish and Wildlife Service, Jim Lauman and Doug Taylor of the Oregon Department of Fish and Wildlife and Jack Howerton of the Washington Department of Game provided reviews of wildlife sections.

Cultural Characteristics

Bob Franklin of Ft. Stevens State Park in Oregon and Ralph Jones of Ft. Canby State Park in Washington provided assistance in the preparation of Section 402.

Don Mathison of the Cowlitz-Wahkiakum Governmental Conference provided information for all the sections on cultural characteristics.

Finally, special appreciation is due Judy Crosby, Magdalena Cristobal and Becky Nelson who typed the text and assisted in the preparation of many figures and tables, and to Walt Lindstrom who drafted nearly all the figures in the Inventory.

COLUMBIA RIVER ESTUARY INVENTORY

TABLE OF CONTENTS*

*Detailed tables of contents are provided at the beginning of each section.

100 INTRODUCTION

100 INTRODUCTION

100.1 PURPOSE AND USES OF THE INVENTORY

The purpose of the Columbia River Estuary Inventory of Physical, Biological and Cultural Characteristics is to collect published and unpublished information about the estuary into a single document. The Columbia River estuary and the surrounding region (Figure 100-1) have been the subjects of numerous scientific research and planning studies in the past. This information is published in various planning documents, books, technical reports and scientific journal articles. Although this material should be a basis for well-informed resource management decisions concerning the estuary and its shorelines, much of it has not been available in a form useful to decision-makers. This problem is particularly evident at the local level, where the highly-trained technical staff needed to conduct extensive literature reviews and interpret research results is not usually available. Further, some of the data collected in recent years have never been published, and subsequent studies have often begun without full knowledge of past efforts. The Inventory is a first step in attempting to solve these problems.

The Inventory has several uses. First, the information is designed to be a primary resource for development of the CREST Land and Water Use Plan. The citizen committees developing plans for sub-areas of the estuary use this information to help make objective, rational decisions to guide future growth. Second, the Inventory is designed to provide technically, trained individuals with summaries of information about the estuary relating to their own and other fields. Third, the Inventory is designed to help determine research needs and to guide future research efforts, such as the Columbia River Estuary Special Study being coordinated by the Pacific Northwest River Basins Commission. Fourth, current research projects should benefit from the Inventory information and from the reference materials collected during its compilation.

100.2 CREST PLANNING PROGRAM

The Columbia River Estuary Study Taskforce (CREST) is a bi-state organization of local governments that, in cooperation with state and federal agencies, is developing a plan for the future use and management of waters, wetlands and shorelands of the Columbia River estuary area.

The planning program is part of the Oregon and Washington Coastal Zone Management Programs. For Washington portions of the study area, the CREST planning program represents a first revision to Shoreline Management Programs. In Oregon, the plan provides components for each jurisdiction's local comprehensive plan; the components conform with state planning goals and guidelines for estuarine resources and shoreland areas.

At the outset of its program, CREST established five general goals to guide the development of a management program. These were:

GOAL 1: To improve and diversify the economy of the area;

GOAL 2: To reconcile conflicting uses of estuarine resources;

GOAL 3: To protect and enhance natural resource values of the estuary;

GOAL 4: To improve estuarine resource management through intergovernmental communication and coordination at local, state and federal levels; and

GOAL 5: To increase public understanding of the natural value of the estuary and its usefulness to man.

To accomplish these goals, the CREST work program was divided into three areas including (1) an estuary information system, (2) an estuary management program and (3) current project coordination.

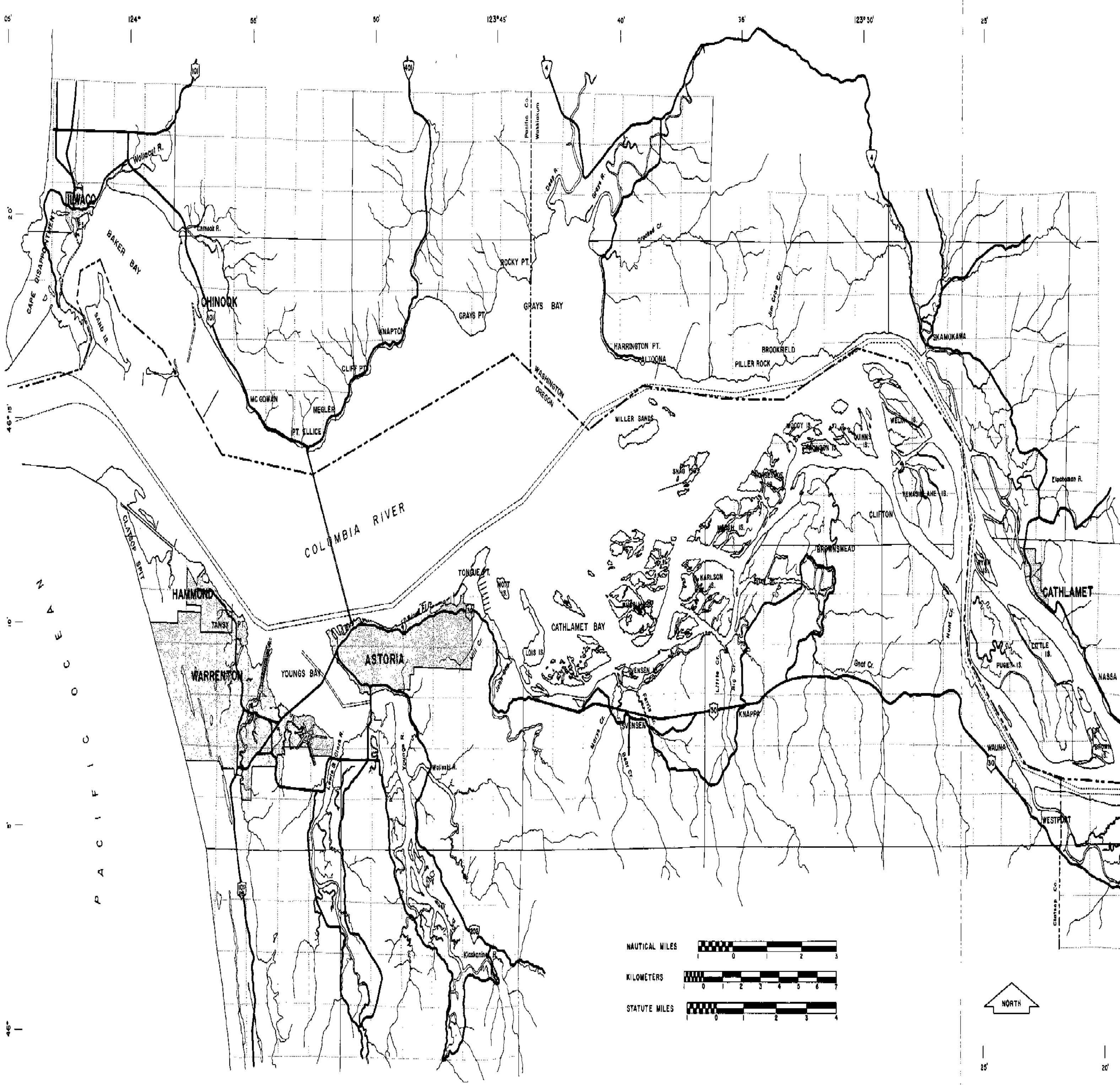
The information system is the foundation of the program and consists of a library of materials relating to the estuary, the Inventory, a research-needs proposal and various informational publications dealing with permit systems, estuary research and the natural environment.

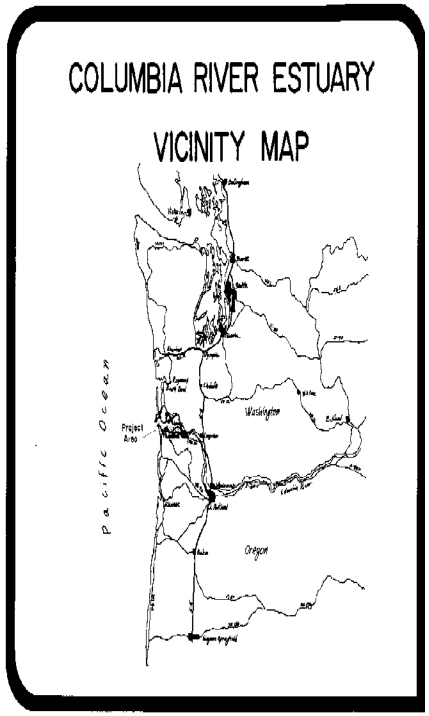
The CREST management program consists of an analysis of estuary conflicts and problems, a description of the existing management regime, regional policies, a land and water use plan and a process for future coordination and management. The estuary-wide policies and the land and water use plan are the heart of the program.

Current project coordination has involved CREST in what is essentially an interim estuary management role. Development projects and research activities essential to the planning program are evaluated for consistency with the goals and objectives of the organization.

A. CREST Regional Policies

CREST Regional Policies are defined as "specific courses or methods of action to guide present and future decisions toward established CREST goals." The goals are used to organize the policy subjects that relate





CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

100-1

to economic development, land and water use, intergovernmental cooperation and public education. The policies serve as guidelines for developing the land and water use plan and for decisions on specific projects proposed for the estuary area. Particularly important are the policies relating to dredging, filling, construction, diking and other activities in the waters and wetlands of the estuary. The Inventory provides some of the site-specific information necessary to carry out the policies.

B. Land and Water Use Plan

The land and water use plan provides for the specific allocation of water, wetland and shoreland areas to different broad use or activity categories. Development of such a plan involves the complex interaction of many interests at the local, state and federal level. Plan development requires a standardized classification system and a rational way to apply it. CREST has developed such a system and planning process, and the Inventory serves as the primary information resource for working through the process.

To provide for more local involvement in the planning, the estuary has been divided into seven distinct planning areas (Figure 100-2*). When completed, the combined plans will be evaluated for consistency and to ensure an estuary-wide balance of conservation and development.

100.3 INFORMATION GAPS AND RESEARCH NEEDS

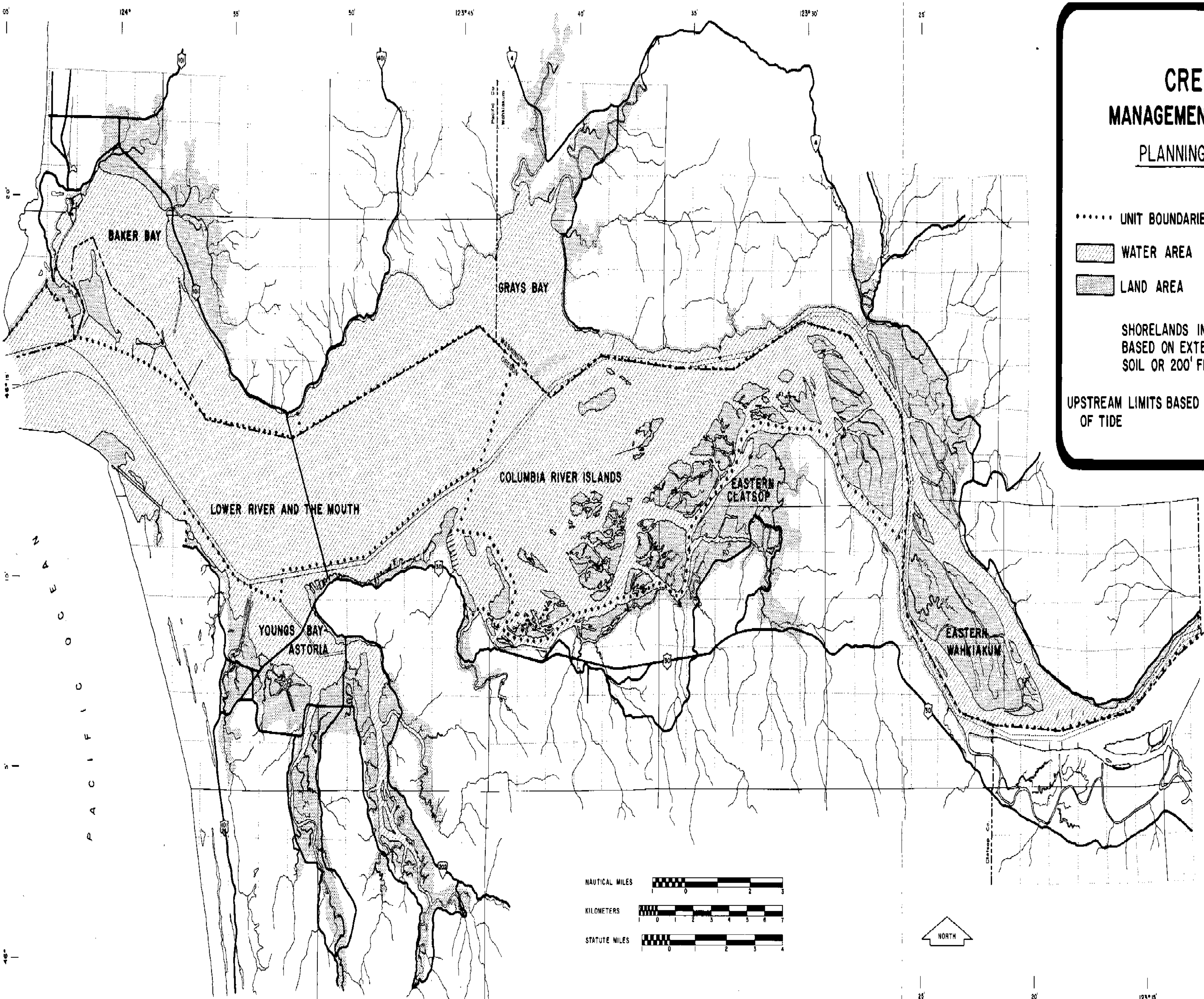
Although much research has been conducted in the Columbia River estuary by the National Marine Fisheries Service, the Corps of Engineers, the U.S. Geological Survey, Oregon State University and the University of Washington, there has never been a coordinated, comprehensive research effort. Many published reports are narrow in scope and not very useful for answering broad ecological questions about how the estuary functions and the impacts of proposed developments.

Analysis of the information in this document does provide tentative answers to some questions: there are however, other questions which can only be answered by thorough and integrated physical, chemical, geological and biological research. It is also extremely important that an integrated research program first determine what questions need answers.

---

*While at press, units were combined, and five planning areas remain. The units are: Youngs Bay-Astoria, Baker Bay, Lower River and Mouth/ Columbia River Islands, Wahkiakum County and Eastern Clatsop County.

The Columbia River Estuary Special Study is intended to fill the need for a comprehensive research program. Coordinated by the Pacific Northwest River Basins Commission, this study will commence in 1978 and is scheduled to last at least five years. The Special Study is expected to provide information on habitats, food chains, circulation, sediments, engineering problems and human use of the estuary. It is particularly important that information from this study be provided to local decision-makers in a form which is useful to them.



CREST MANAGEMENT UNITS

PLANNING AREAS

- UNIT BOUNDARIES
- WATER AREA
- LAND AREA

SHORELANDS INLAND BOUNDARY IS BASED ON EXTENT OF TIDELAND SOIL OR 200' FROM SHORELAND

UPSTREAM LIMITS BASED ON ESTIMATE OF HEAD OF TIDE

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 100-2

200 PHYSICAL CHARACTERISTICS

201

CLIMATE

COLUMBIA RIVER ESTUARY
CLIMATIC CHARACTERISTICS

David Jay
Robert E. Blanchard

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FIGURES

TABLES

201 CLIMATE

Most aspects of life along the coasts of Oregon and Washington are influenced by the North Pacific Ocean and its weather systems. The ocean, through its influence on climate, river flow, estuarine circulation and productivity and many other aspects of daily life in the Northwest, makes possible a culture in which economic, social and recreational activities are closely related to the natural resources of the area. The purpose of this section, then, is to examine the North Pacific weather, oceanic circulation, coastal current systems and upwelling and their interactions with the Columbia River estuary and the Coast.

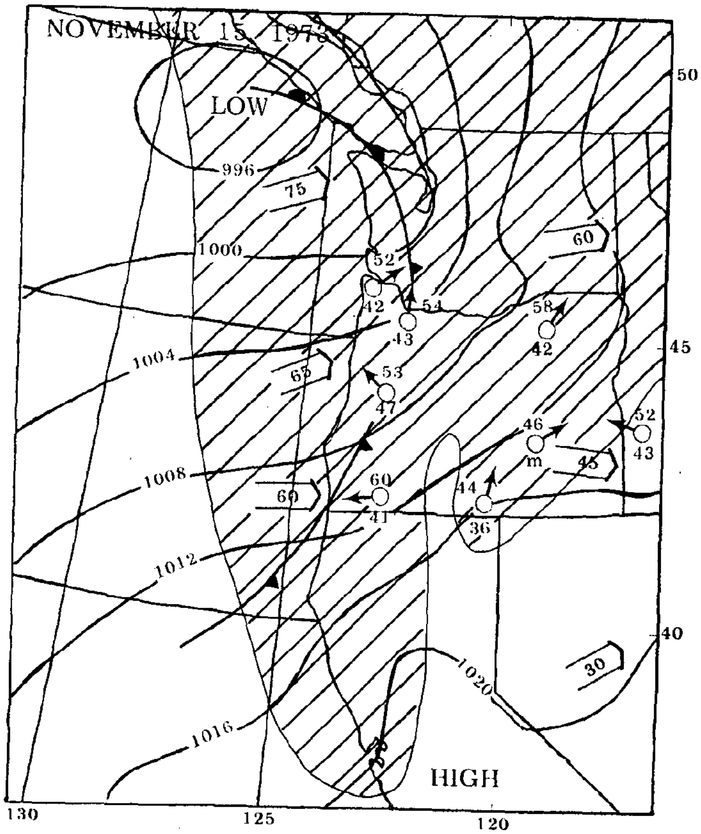
201.1 ATMOSPHERIC CIRCULATION

The oceanic and atmospheric circulations are so closely related that it is difficult to describe one in isolation from the other, but let us begin with the typical winter and summer weather patterns. Winter weather in the Northwest generally consists of a series of atmospheric low pressure cells coming in from the ocean. These storms bring moderate temperatures, abundant rain and strong winds from the south or west (Figure 201-1a). The average pressure distribution for February (Figure 201-2a) shows that these storm systems originate in the Gulf of Alaska, where a prominent low, known as the Aleutian Low, is found most of the winter. Note that winds around a low pressure cell move in a counter-clockwise direction. The high pressure cell off Baja California, known as the North Pacific High, is weak at this time of year.

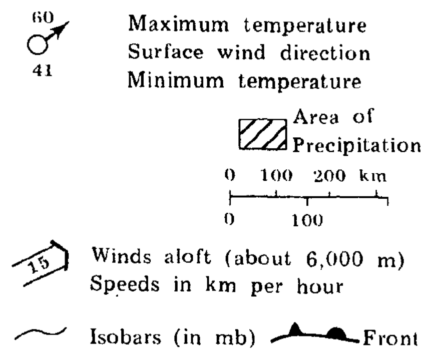
In contrast, the North Pacific High dominates the summer pressure distribution(Figure 201-2b), bringing winds from the north and west, moderate temperatures, little rain and frequent fog (Figure 201-1b). Note that winds around a high pressure cell are in a clockwise direction. Such weather predominates year round in Southern California, as can be seen from the winter pressure distribution (Figure 201-2a).

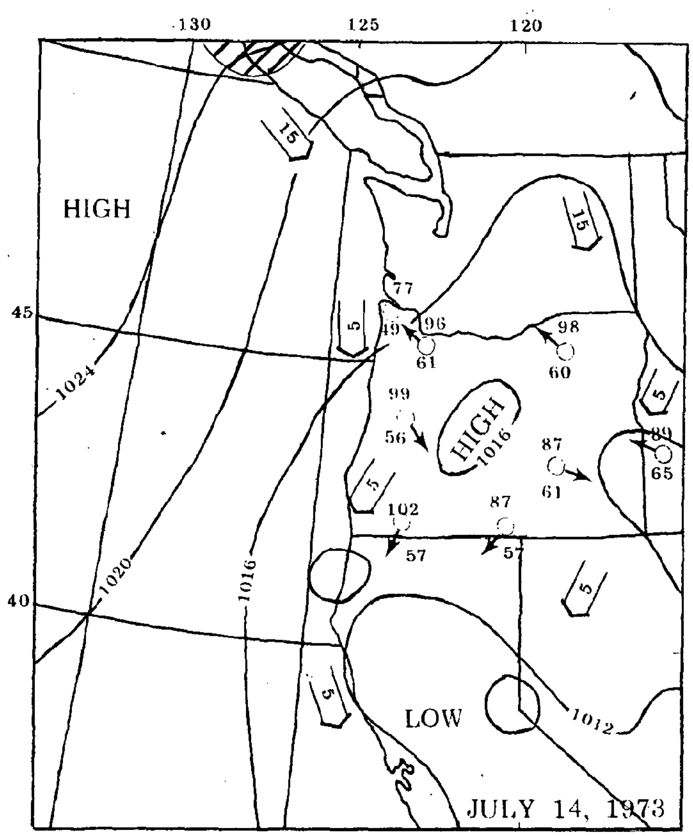
It is important to realize that winter and summer weather patterns may occur any time of year, and that the weather on any day may be very different from the average situation for that month.

Figure 201-1



(a) Winter



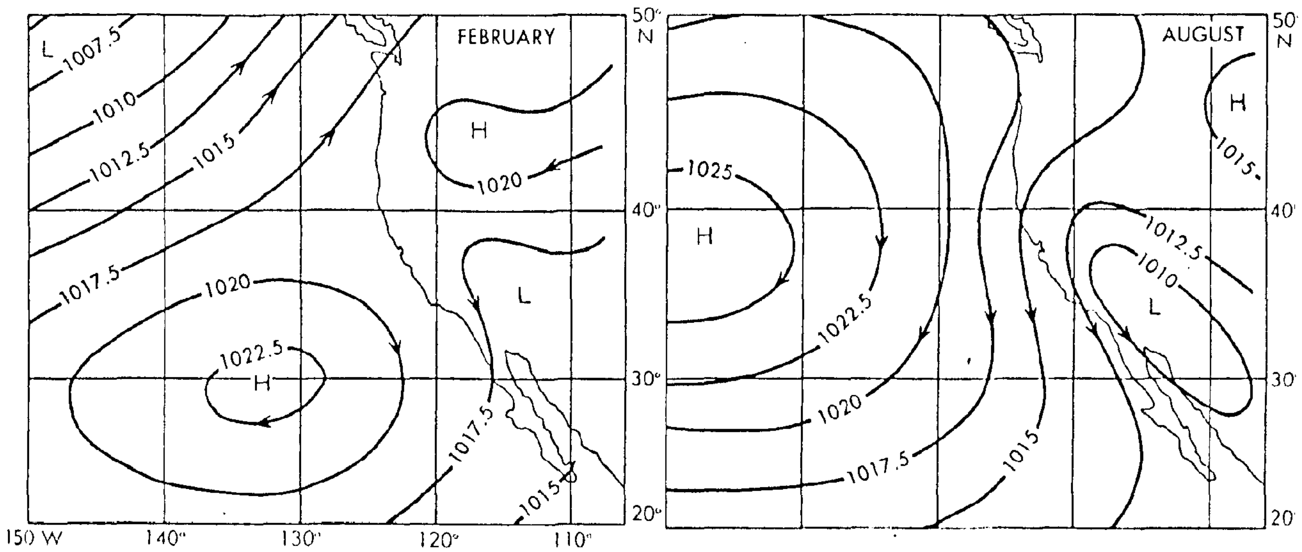


Typical winter (a) and summer (b) weather patterns in the Pacific Northwest. Winter weather is characterized by counter-clockwise circulation around a low pressure cell that brings southerly winds and storms. Summer weather is characterized by clockwise circulation around a high pressure cell, that brings fair weather and northerly winds.

From: Loy et al., 1976

(b) Summer

Figure 201-2



(a) (b)

Average monthly atmospheric sea level pressure (in millibars) over the eastern North Pacific Ocean and the western coast of North America during February (a) and August (b). Winds are clockwise around a high pressure cell and counter-clockwise around a low.

From: Reid *et al.*, 1958

While summer storms certainly do occur, they are less frequent and generally less violent than winter storms. Typical summer weather also occurs during the winter. In fact, the drought of 1976-1977 resulted from the persistence of a high pressure cell off the coast during most of the winter.

201.2 COASTAL CURRENTS, UPWELLING AND THE COLUMBIA RIVER PLUME

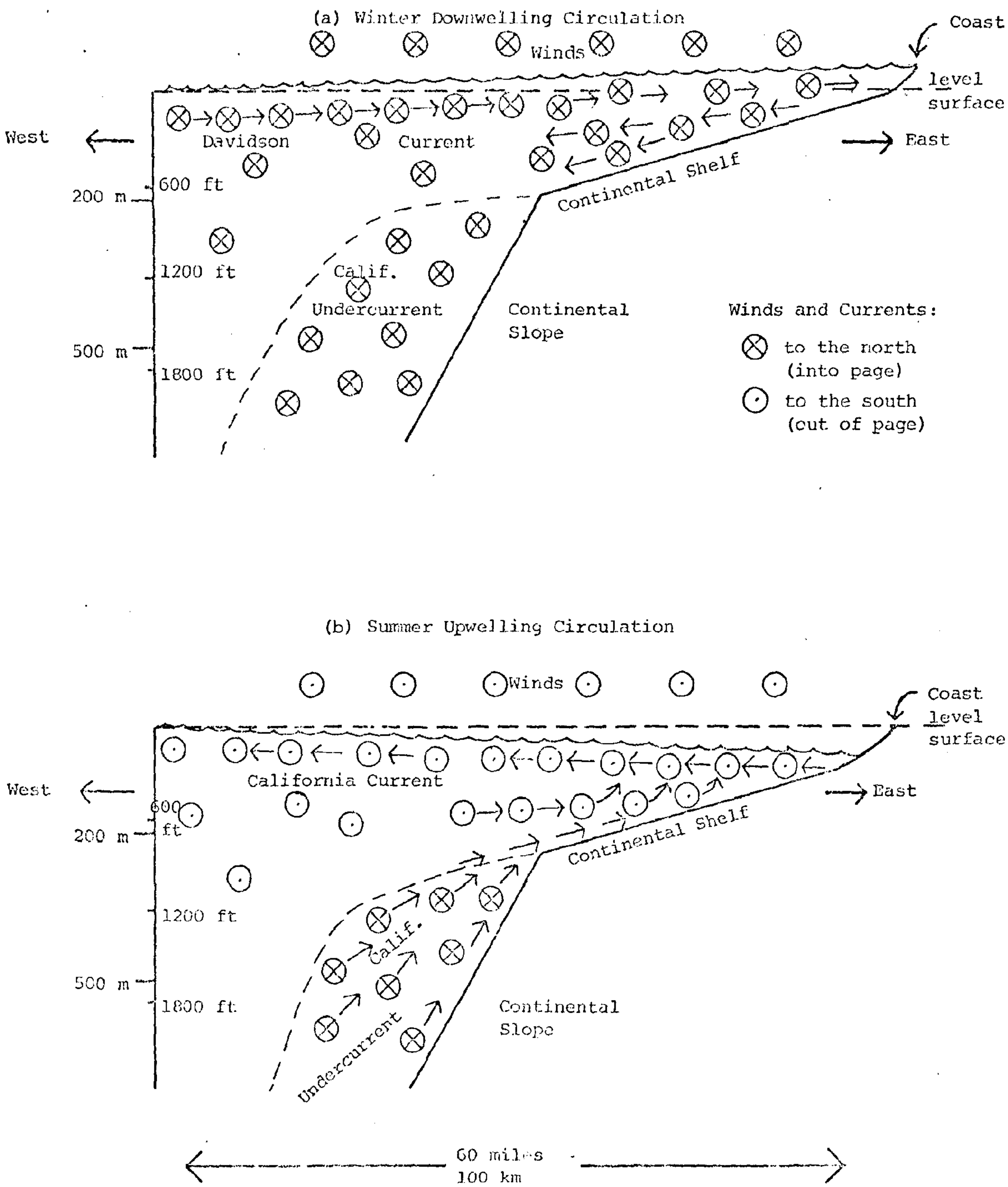
The coastal winds play an extremely important role in driving the coastal current system and the summer upwelling of cold, nutrient-rich water that makes the continental shelf off Oregon and Washington an important fishery zone.* Again, there are two basic patterns, summer and winter. During the winter (usually November to March), currents over the continental shelf off Oregon and Washington are predominantly to the north, slightly onshore at the surface and somewhat offshore at the bottom (the downwelling circulation, Figure 201-3a). The northerly wind-driven surface current is known as the Davidson Current. Its strength is greatest inshore and decreases in an offshore direction. Strong fluctuations in this current accompany storms; oceanic "weather" is just as variable as atmospheric weather. Surface current speeds typically range from 20 to 80 cm/sec (0.4 to 1.6 knots).

Northward flow also occurs near the bottom along the continental slope at the edge of the continental shelf at depths of 200 to 1000 m (650 to 3300 ft). This slow (5 to 20 cm/sec; 0.1 to 0.4 knots) deep flow persists throughout most of the year and is known as the California Undercurrent. It brings water with salinity and temperature characteristics of water of similar depths in the tropical Pacific Ocean to the Northwest. This water, rich in nutrients, helps to nourish the biological productivity as it is brought to the surface during the upwelling process.

Upwelling occurs primarily during the spring and summer (usually April to October), though it may occur any time during the year when

*The continental shelf is the broad, generally flat region extending from the coast to a depth of about 200 m (660 ft). The shelf is between 16 to 70 km (10 to 44 miles) wide off Oregon and Washington. At its seaward edge is the continental slope that descends to abyssal depths and is incised by numerous canyons.

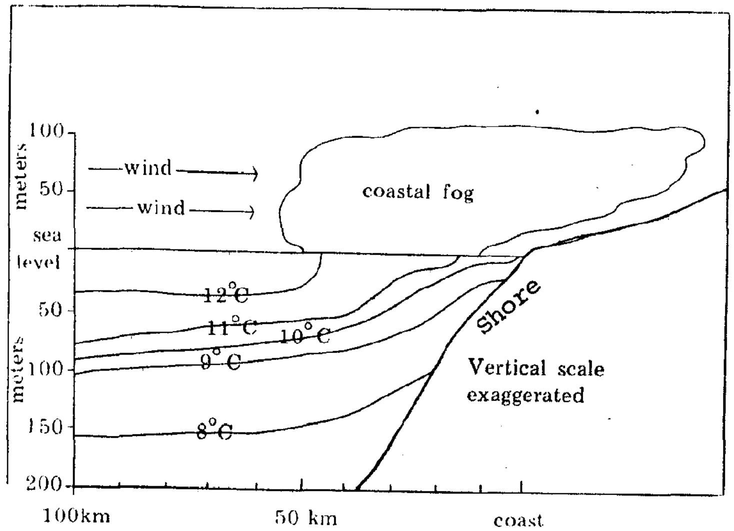
Figure 201-3 Continental Shelf Circulation off Oregon and Washington



typical summer wind and weather patterns occur. Upwelling (Figures 201-3b and 201-4) is the slow vertical movement (at speeds of perhaps 5 to 20 m/day; 16 to 65 ft/day) of nutrient rich water to the surface, from depths of 100 to 500 m (330 to 1650 ft). It occurs in an irregular and patchy manner from just outside the surf zone to about 15 miles offshore. Upwelling is strongest close to the coast and to the south of prominent capes. The appearance of a patch of cold upwelled water generally stimulates intense biological productivity and often causes coastal fog as warm, moisture-laden air is cooled. Upwelling is extremely important in supplying nutrients to the estuary, as discussed in Section 205. The upwelled water is cold (8 to 12°C; 46 to 54°F) despite its tropical origin, because of the cold temperatures below the surface layer in all the oceans of the world. While these cold waters are biologically very productive, they are definitely not conducive to swimming; water temperatures along the Oregon coast differ little summer to winter.

What causes upwelling? The detailed mechanisms are quite complex, but simply stated, upwelling is caused by the offshore movement of surface waters that accompanies the generally southward, wind-driven summer currents (Figure 201-3b). The offshore movement of surface waters results in a measurable lowering of sea level at the coast and a compensating onshore and upward flow in the lower layers. This compensating flow is the upwelling. The winds from the north and west result in flow to the south and offshore, because of influence of the earth's rotation. Because the earth rotates, any freely moving object in the Northern Hemisphere has a tendency to be deflected slightly to the right; this is known as the coriolis force. The coriolis force is one of the basic determining factors in oceanic and atmospheric circulation, accounting for the clockwise and counter-clockwise rotation of winds around high and low pressure cells, respectively. It also accounts for the slight onshore movement of surface currents during the winter (Figure 201-3b) and is important in estuarine circulation, air navigation and ballistics.

The southerly and westerly wind-driven surface currents observed on the continental shelf during the summer are a part of the



EFFECTS OF UPWELLING
(off Brookings, Oregon)

Figure 201-4

Upwelling occurs frequently along the coast during the summer and results from the interaction of northerly winds and the rotation of the earth.

From: Loy *et al.*, 1976

broad, southerly flow known as the California Current. Velocities are typically less than 20 cm/sec (0.4 knots), but greater velocities are often associated with the narrow band of upwelling near the coast. The California Current generally extends at least 500 miles offshore and is part of the large-scale circulation of the Pacific Ocean. In some offshore regions, the California Current may extend to depths of 1000 m (3300 ft). It is, however, underlain by the northward-flowing California Undercurrent along the continental slope (Figure 201-3b).

Another major influence on the circulation in the coastal region off Oregon and Washington is the plume of relatively fresh water from the Columbia River. The Columbia River is the second largest river in North America, having an average discharge of about 268,000 cfs (see Section 202 for more details). It provides an average of 77% of the freshwater flow into the Pacific Ocean between San Francisco Bay and the Straits of Juan De Fuca. Because of the low flow of other coastal streams during the late summer, the Columbia River normally provides about 90% of the freshwater inflow into the area during that period. The percentage is about 60% in the winter, when the coastal streams are in freshet.

The movement of the Columbia River effluent plume is influenced by the winds and the wind-driven surface currents. Thus, its position, as traced by the area of surface water with low salinity, is highly variable (Figure 201-5a and b). During the summer, the plume responds to the northerly winds and upwelling circulation and spreads widely to the south and offshore. It may cover hundreds of square miles (Figure 201-5a). Because of light winds, the effluent usually does not mix down to depths greater than 70 m (130 ft). During the winter, the downwelling circulation and strong southwesterly winds push the effluent to the north and confine it to a narrow zone along the Washington coast (Figure 201-5b).

201.3 REPRESENTATIVE CLIMATIC DATA

Climatic data covering the estuary area is important, because, among other things, it helps to establish a perspective on the natural setting and it provides an indication of conditions or combinations of conditions that are potentially hazardous, either directly or indirectly.

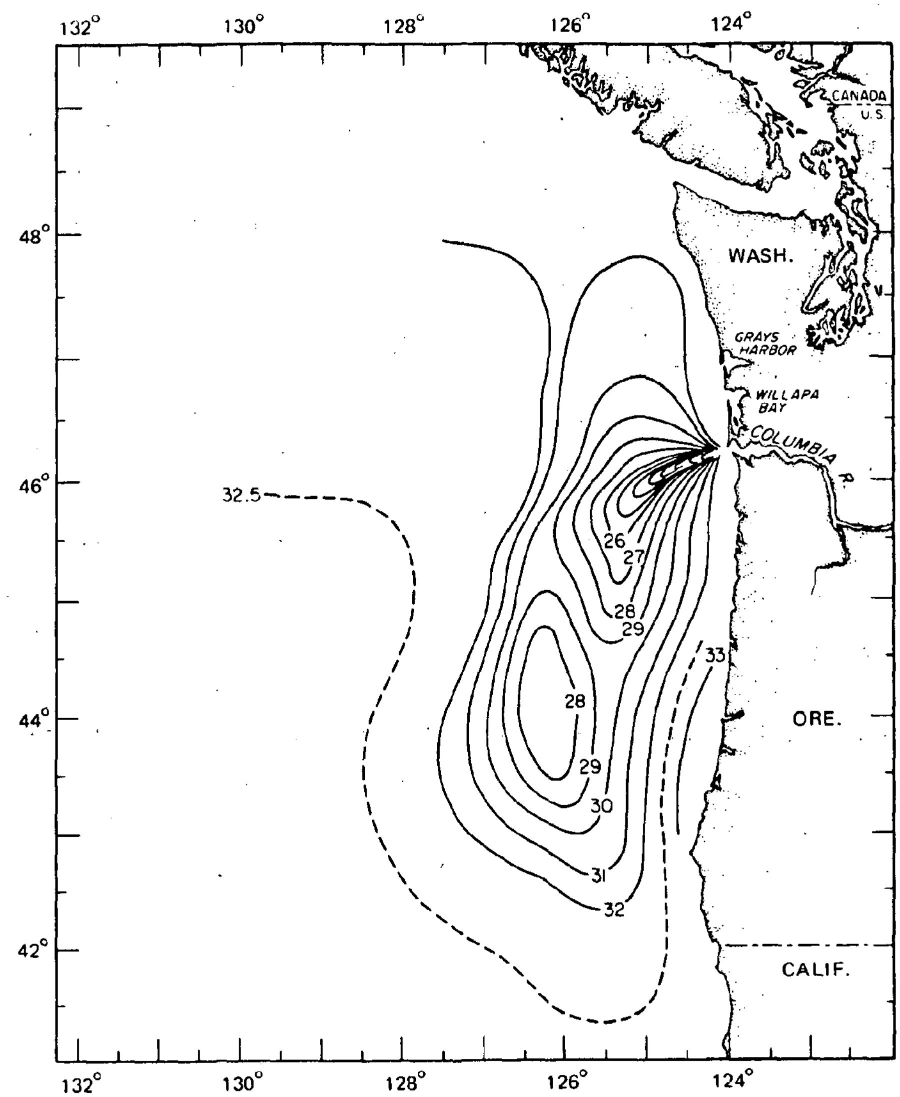
Typical of the Northwest Coastal Region, the Columbia River estuary climate is humid, temperate and characterized by cool and rainy winters. Temperatures seldom rise above 85° F or fall below 20° F. Table 201-1 summarizes Astoria's monthly climatic data from 1940 to 1970; it provides representative data for precipitation, temperature and cloud cover for the estuary area. Most precipitation occurs from October through April, with rainfall in excess of 0.10 inches an average of 200 days per year. Climatic conditions vary somewhat from the coastal area to the eastern part of the estuary, in that there is less precipitation and a somewhat greater temperature range to the east.

Prevailing summer winds are from the north and northwest. During the winter, prevailing coastal winds are from the southwest, south or southeast, with storms coming primarily from the southwest. These coastal winter winds are modified in the estuary, by heavier air that moves down the Columbia River Gorge from colder interior regions. Consequently, prevailing winds recorded at Astoria during the winter months are generally from the east and southeast; average monthly wind velocities and directions are shown in Figure 201-6.

Weather hazards may occasionally occur in the form of heavy rains, high winds, freezing temperatures, fog or combinations of these; problems related to these weather conditions should be kept in mind when evaluating all aspects of the estuary.

Figure 201-5

Movement of the Columbia River Effluent Plume

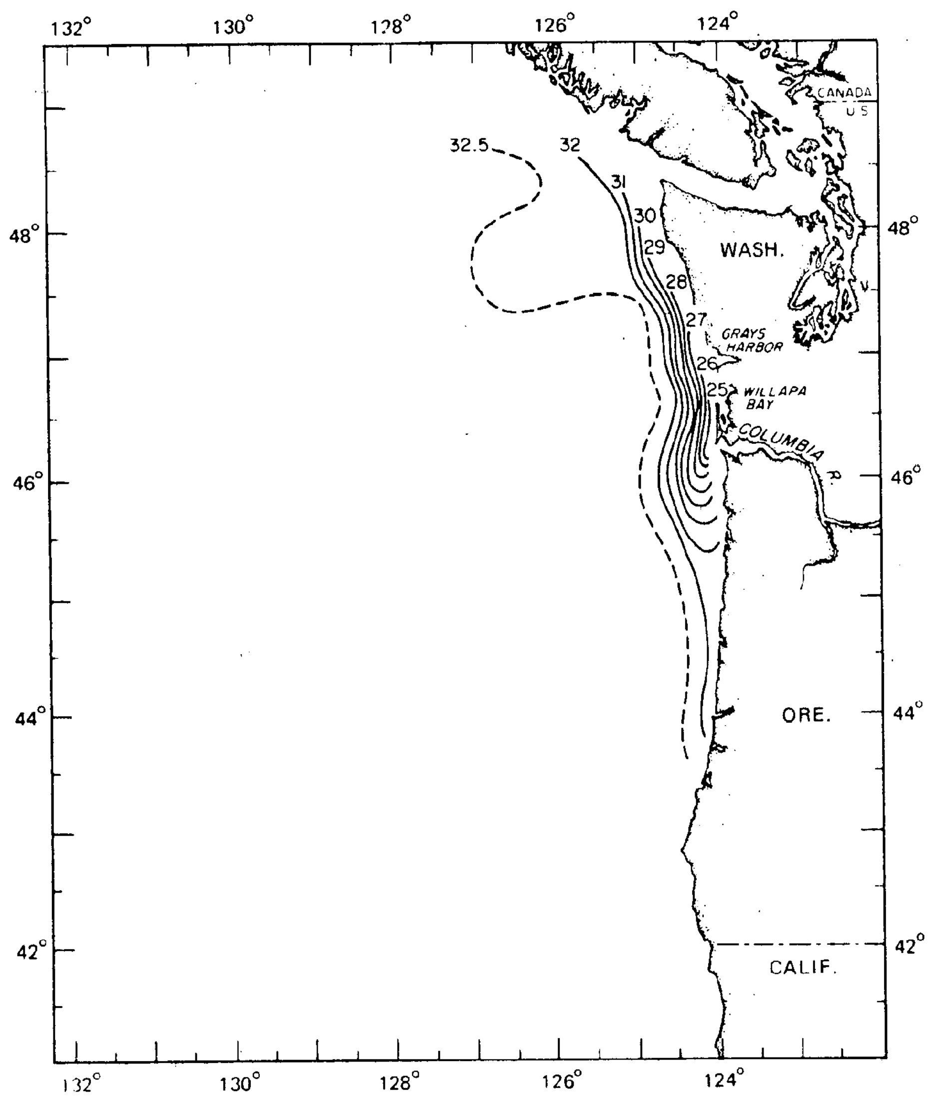


(a) Surface salinities in $^{o}/oo$ (parts per thousand) off Oregon and Washington during (a) summer and (b) winter. Salinities of less than $32.5^{o}/oo$ are indicative of the Columbia River effluent plume.
(a) Northerly summer winds push the plume offshore and to the south.

From: Barnes et al., 1972

Figure 201-5

Movement of the Columbia River Effluent Plume



(b) Winter - downwelling circulation and southerly winds push the plume onshore and to the north.

From: Barnes et al., 1972

TABLE 201-1

Monthly Average Climatic Data*
Astoria, Oregon

	Precipitation (Inches)	Temperature (°F.)	Number of Days	
			Cloudy	Heavy Fog
January	9.73	40.6	25	4
February	7.82	43.6	22	3
March	6.62	44.4	23	2
April	4.61	47.8	22	2
May	2.72	52.3	20	2
June	2.45	56.5	20	2
July	0.96	60.0	15	2
August	1.46	60.3	15	5
September	2.83	58.4	14	6
October	6.80	52.8	19	7
November	9.78	46.5	22	4
December	10.57	42.8	25	4
Annual	66.34	50.5	242	43

From: Department of Commerce, 1975

Note: Maximum 24 hour rainfall of 4.32 inches was measured in January, 1974.

*Based on data from 1940-1970.

Figure 201-6a

Surface Wind Rose (Annual)
Astoria
From: Richardson and Associates, 1975

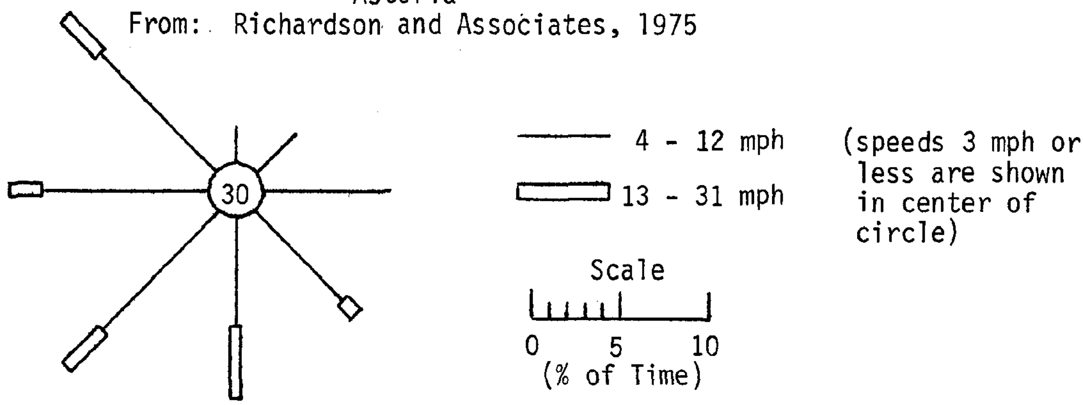
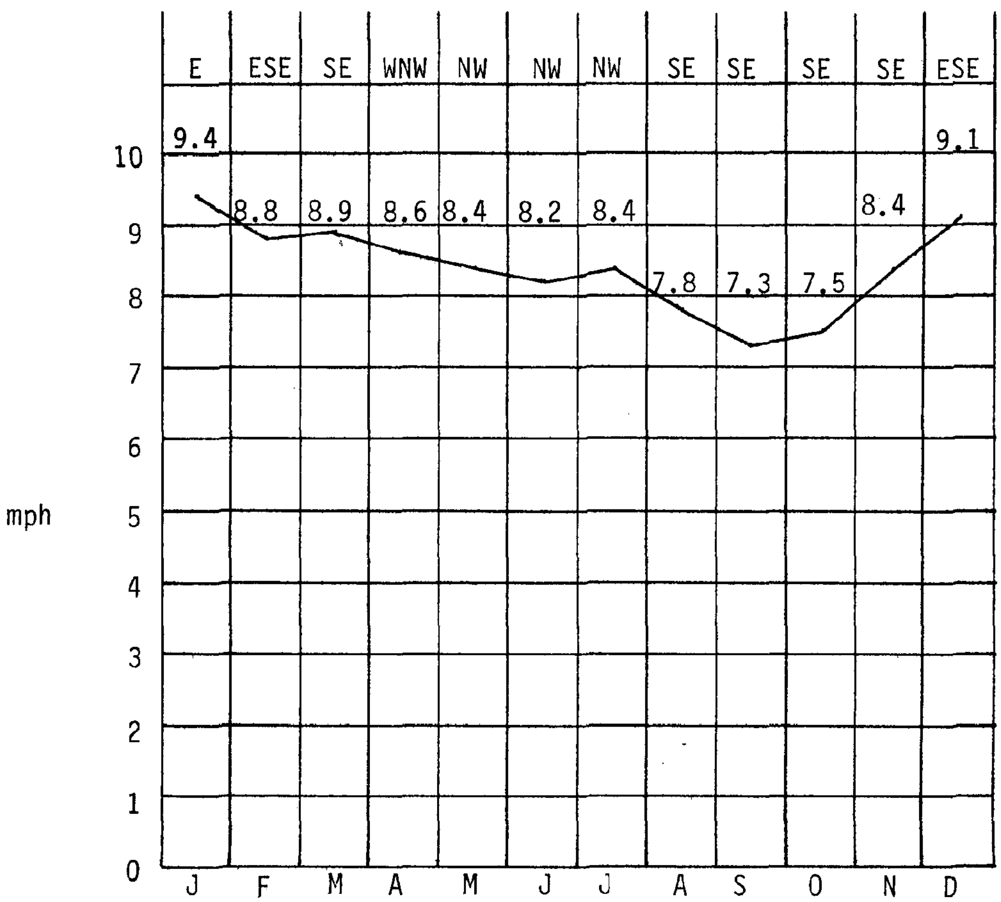


Figure 201-6b
Monthly Average Wind Velocity
and Prevailing Direction*
From: Department of Commerce, 1975



*Based on data from 1941 - 1976

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202

FRESHWATER RESOURCES

COLUMBIA RIVER ESTUARY

FRESHWATER RESOURCES

James W. Good
David Jay

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FIGURES

TABLES

202 FRESHWATER RESOURCES

The Columbia River estuary has a great and variable freshwater flow. Examination of the estuary's freshwater resources is important in that the physical, biological and chemical processes are dramatically affected by the flow level. River runoff at the mouth is characterized by low flow from August to October, variable winter flow, with occasional peaks due to winter storms, and a late spring runoff peak. There have been exceptions to these generalities such as in 1977 (the lowest flow year on record, when no spring freshet ever occurred because of a prolonged winter drought and reservoir storage changes).

The estuary receives its discharge from three primary sources: the mainstem of the Columbia River, the Willamette River Basin, and the Lower Columbia region, including the Lewis and Cowlitz Rivers in Washington. The tributaries which drain directly into the estuary provide a small, but regionally important fraction of total freshwater inflow.

202.1 THE COLUMBIA RIVER

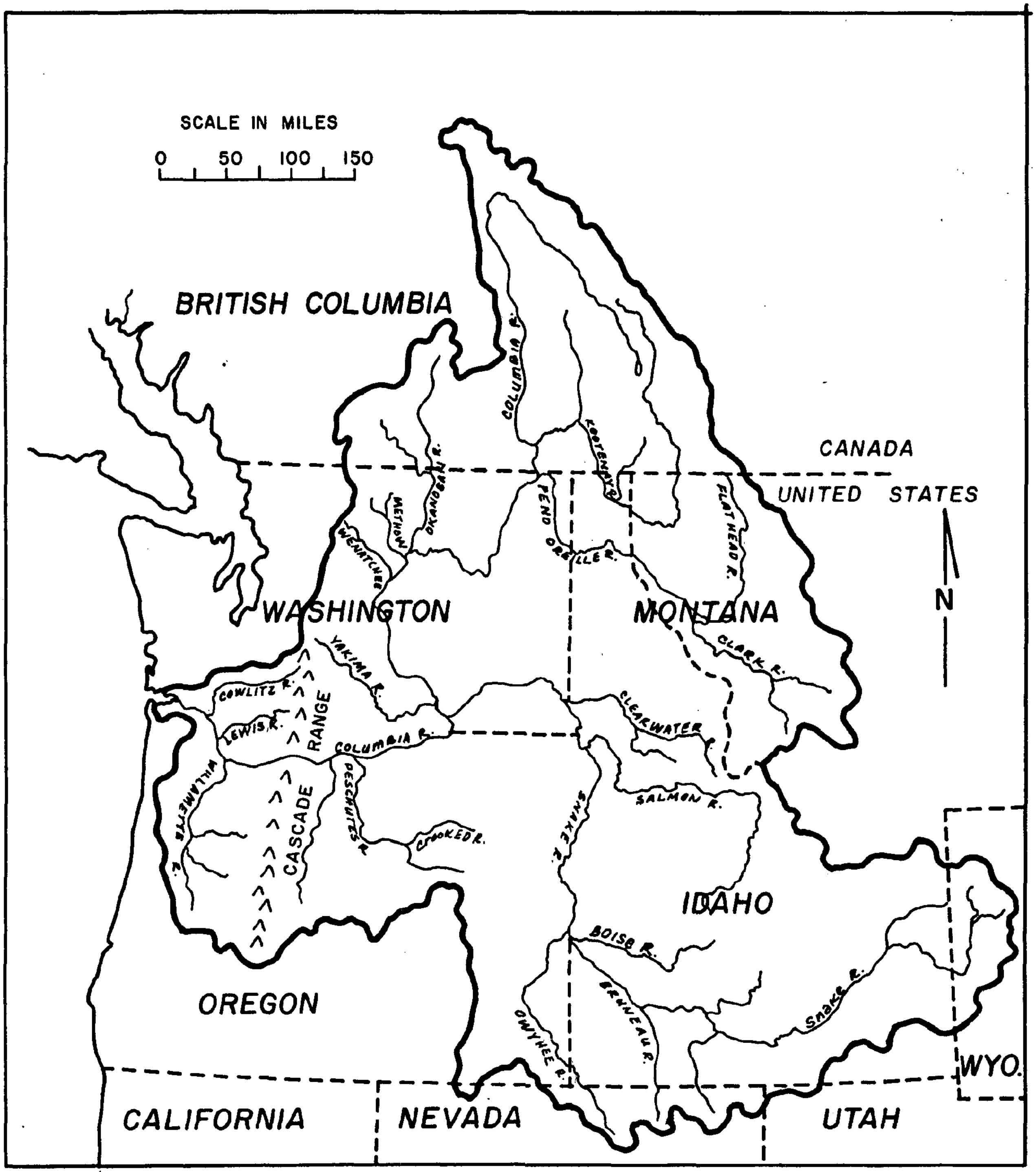
The Columbia River is the largest river in western North America (Figure 202-1). Climate, season and water storage behind dams greatly affect flow levels in the Columbia River. For purposes of discussion, the drainage basin can be divided by the Cascade Mountains into eastern and western sub-basins (Figure 202-1).

The western sub-basin, although it contains only about 8 percent (21,000 square miles) of the total area (258,000 square miles) of the Columbia River basin, accounts for about 24 percent of the total river flow or three times the runoff per square mile provided by the eastern sub-basin; this is primarily because of the mild, wet winters. The major western tributaries (Willamette, Lewis and Cowlitz Rivers) have a flow that is 5 to 10 times greater from December through March, than during other months. Summers are relatively dry in comparison.

The eastern portion of the drainage basin experiences cold winters and hot, dry summers. The flow from the region is relatively low during the fall and winter months; in late spring it increases significantly, due to melting winter snow.

FIGURE 202-1

COLUMBIA RIVER BASIN



Flows at various points of the Columbia River are shown in Table 201-1 a, b & c. The flows measured at Vancouver represent the discharge contributed by the eastern sub-basin (except for a few small drainages such as the Sandy River), those at Longview include the discharge from major western tributaries, and the flows at the mouth include the discharge from the estuary tributaries. The data for the eastern and western sub-basins are graphically displayed in Figure 202-2. Before completion of eleven dams on the main stem, average maximum flow at the mouth was about 660,000 cfs in late spring, while average low flow was about 70,000 cfs in late summer and fall. In the last ten years, eleven main stem dams and approximately 120 tributary dams have provided a controlled river flow ranging from 116,000 cfs (September, 1966) to 630,000 cfs (June 1972). In contrast, the flow during the flood of June 1894 was close to 2,000,000 cfs for several days.

Monthly mean flows at the mouth, averaged over the period 1961 to 1975, ranged from 132,000 cfs for September to 494,900 cfs for June. Averages and extremes are shown in Figure 202-3. Flow variability is greatest in June and smallest in August and September. The yearly average flow at the mouth was 268,500 cfs or about 194 million acre-feet per year. The yearly average flows varied from 220,800 cfs (160 million acre-feet per year; about 20% below average) to 348,300 cfs (250 million acre feet; about 30% above average) during this period (Table 202-1a). Water year 1977 has been an extremely unusual year, with a prolonged winter drought. Drought periods have struck the Pacific Northwest before, but 1977 seems to have been the driest year in the last century (Section 202.4).

202.2 ESTUARY TRIBUTARIES

Although estuary tributaries contribute a small fraction of total Columbia River runoff (approximately 3.5 percent or 9,000 cfs annual average), these streams are very important for fish habitat, as domestic water supply sources and for their scenic and recreational value.

Drainage basins of the streams tributary to the estuary are shown in Figure 202-4. Streams tributary to the estuary in Clatsop County include the Skipanon River, Lewis and Clark River, Youngs River, John Day River, Big Creek, Bear Creek, Hunt Creek, Gnat Creek-Blind Slough and Plympton Creek. In Wahkiakum County, tributaries include the Grays River, the Deep River, Skamokawa Creek, and Alder Creek. Pacific County tributaries include the Wallacut and Chinook Rivers.

TABLE 202-1a

Monthly and Annual Mean Flow
In Cubic Feet Per Second

Columbia River at Mouth, Near Astoria, Oregon

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August	Sept.	Annual
1961	112,000	236,000	164,000	175,000	410,000	323,000	260,000	488,000	673,000	255,000	146,000	110,000	279,000
1962	111,000	140,000	218,000	158,000	176,000	190,000	347,000	428,000	505,000	271,000	180,000	116,000	237,000
1963	143,000	224,000	229,000	136,000	278,000	184,000	298,000	409,000	471,000	284,000	160,000	121,000	244,000
1964	104,000	192,000	147,000	261,000	158,000	171,000	224,000	401,000	724,000	400,000	190,000	126,000	258,000
1965	134,000	159,000	441,000	345,000	321,000	210,000	330,000	492,000	601,000	326,000	189,000	131,000	306,000
1966	131,400	153,800	175,100	284,400	186,600	248,500	233,400	302,100	375,000	290,200	160,700	116,300	220,800
1967	125,400	175,300	264,800	286,600	250,200	214,800	206,700	284,200	610,600	398,200	173,900	127,400	259,000
1968	157,600	170,400	233,200	234,700	325,200	250,200	175,700	216,100	394,700	287,100	164,900	157,200	231,000
1969	184,200	268,600	312,800	337,500	269,800	254,600	416,800	478,100	397,800	281,600	148,200	123,300	290,500
1970	159,100	179,600	240,500	375,100	298,900	228,000	207,400	304,900	379,300	209,800	145,300	131,600	238,800
1971	152,200	200,700	271,700	381,100	320,900	351,400	361,800	546,400	562,500	340,100	190,100	145,400	318,400
1972	157,500	218,400	332,800	354,200	346,200	555,500	402,900	472,100	630,400	344,500	209,200	161,100	348,300
1973	145,800	184,400	292,300	271,200	189,600	213,900	180,900	177,400	172,000	148,500	144,900	128,000	187,500
1974	137,400	297,100	391,400	479,900	389,400	368,700	416,400	432,400	552,900	359,900	196,800	149,900	346,700
1975	156,400	190,800	268,100	344,400	300,200	326,000	271,500	365,100	373,800	241,100	152,700	135,400	261,900
AVG.	140,700	199,300	265,400	294,900	281,300	272,600	288,800	386,500	494,900	295,800	170,100	132,000	268,500

TABLE 202-1b

Monthly and Annual Mean Flow
In Cubic Feet Per Second

Columbia River
at Longview, Washington

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August	Sept.	Annual
1961	108,000	226,000	156,000	164,000	391,000	306,000	253,000	501,000	666,000	244,000	144,000	108,000	271,000
1962	109,000	133,000	203,000	152,000	168,000	185,000	346,000	428,000	500,000	264,000	176,000	113,000	232,000
1963	139,000	214,000	218,000	129,000	270,000	179,000	288,000	412,000	466,000	275,000	157,000	120,000	238,000
1964	101,000	180,000	149,000	243,000	150,000	161,000	221,000	410,000	725,000	368,000	186,000	125,000	252,000
1965	132,000	151,000	422,000	334,000	305,000	203,000	337,000	492,000	598,000	315,000	187,000	129,000	300,000
1966	129,000	148,700	168,000	266,000	179,300	235,700	225,200	307,000	369,500	283,800	154,500	114,300	214,600
1967	121,600	167,400	247,100	269,800	234,300	205,500	197,600	293,600	612,400	377,900	170,200	124,400	251,300
1968	150,700	166,100	220,500	221,800	307,100	240,200	169,100	223,200	391,500	278,100	162,000	151,700	223,100
1969	177,400	256,100	298,400	323,300	260,800	249,000	410,800	473,100	392,600	271,900	144,700	123,100	282,100
1970	154,100	173,800	230,400	355,200	284,600	219,200	202,200	312,400	371,800	204,100	144,400	129,800	232,200
1971	147,200	194,700	253,700	356,900	308,800	339,300	350,600	556,000	554,000	328,000	186,300	140,600	309,400
1972	154,000	208,900	311,800	337,600	331,100	534,500	389,100	475,500	627,200	331,000	205,400	156,900	338,800
1973	147,100	176,300	275,400	261,500	185,300	205,600	178,300	175,600	167,400	149,000	144,200	123,500	182,600
1974	136,300	277,200	370,700	460,700	370,200	354,400	410,600	424,500	553,100	343,100	191,500	151,300	336,500
1975	156,000	181,800	252,300	325,200	288,700	317,900	265,600	364,100	369,300	231,800	150,900	134,400	253,100
AVG.	137,500	190,300	251,700	280,000	268,900	262,300	282,900	389,900	490,900	285,600	166,900	129,700	261,100

TABLE 202-1c

Monthly and Annual Mean Flow
In Cubic Feet Per Second

Columbia River

at Vancouver, Washington

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August	Sept.	Annual
1961	93,300	120,000	86,200	88,500	194,000	168,000	191,000	440,000	635,000	231,000	136,000	98,800	205,000
1962	91,500	85,500	90,200	85,000	112,000	109,000	266,000	368,000	467,000	250,000	165,000	104,000	183,000
1963	110,000	127,000	137,000	93,600	169,000	128,000	187,000	338,000	444,000	260,000	148,000	111,000	188,000
1964	86,500	98,000	82,700	91,500	79,100	93,200	168,000	361,000	670,000	365,000	173,000	114,000	198,000
1965	119,000	109,000	201,000	168,000	202,000	163,000	290,000	454,000	575,000	304,000	178,000	122,000	240,000
1966	112,600	113,600	122,000	135,500	131,300	146,600	169,700	268,500	346,100	268,300	143,800	102,200	171,600
1967	101,600	109,600	134,600	150,300	149,800	147,600	157,300	254,700	583,900	364,300	160,500	112,900	202,000
1968	117,300	121,300	148,000	139,900	181,600	182,200	133,200	199,000	364,600	266,400	144,600	131,100	177,300
1969	126,600	149,100	158,700	193,900	182,800	198,400	362,800	419,700	352,400	248,500	129,500	103,200	219,000
1970	121,600	130,800	241,500	194,400	166,500	165,100	162,200	272,000	354,500	192,000	132,400	113,000	178,700
1971	120,000	129,800	145,000	188,300	217,200	234,700	273,200	502,200	506,000	300,200	169,300	115,600	241,600
1972	121,800	141,200	166,200	184,300	217,000	364,000	312,200	411,600	582,500	310,300	189,200	134,500	261,200
1973	122,700	138,100	178,400	168,000	148,000	163,100	147,400	155,300	151,700	135,200	131,300	108,000	145,600
1974	114,400	142,900	199,200	290,200	262,200	246,600	324,900	371,300	493,200	314,300	177,600	136,800	255,800
1975	133,000	142,000	157,000	189,800	198,100	233,500	222,000	320,600	340,200	211,400	136,300	114,400	199,900
AVG.	112,800	123,900	143,200	157,400	174,000	182,900	224,500	342,400	457,700	268,000	154,300	114,800	204,500

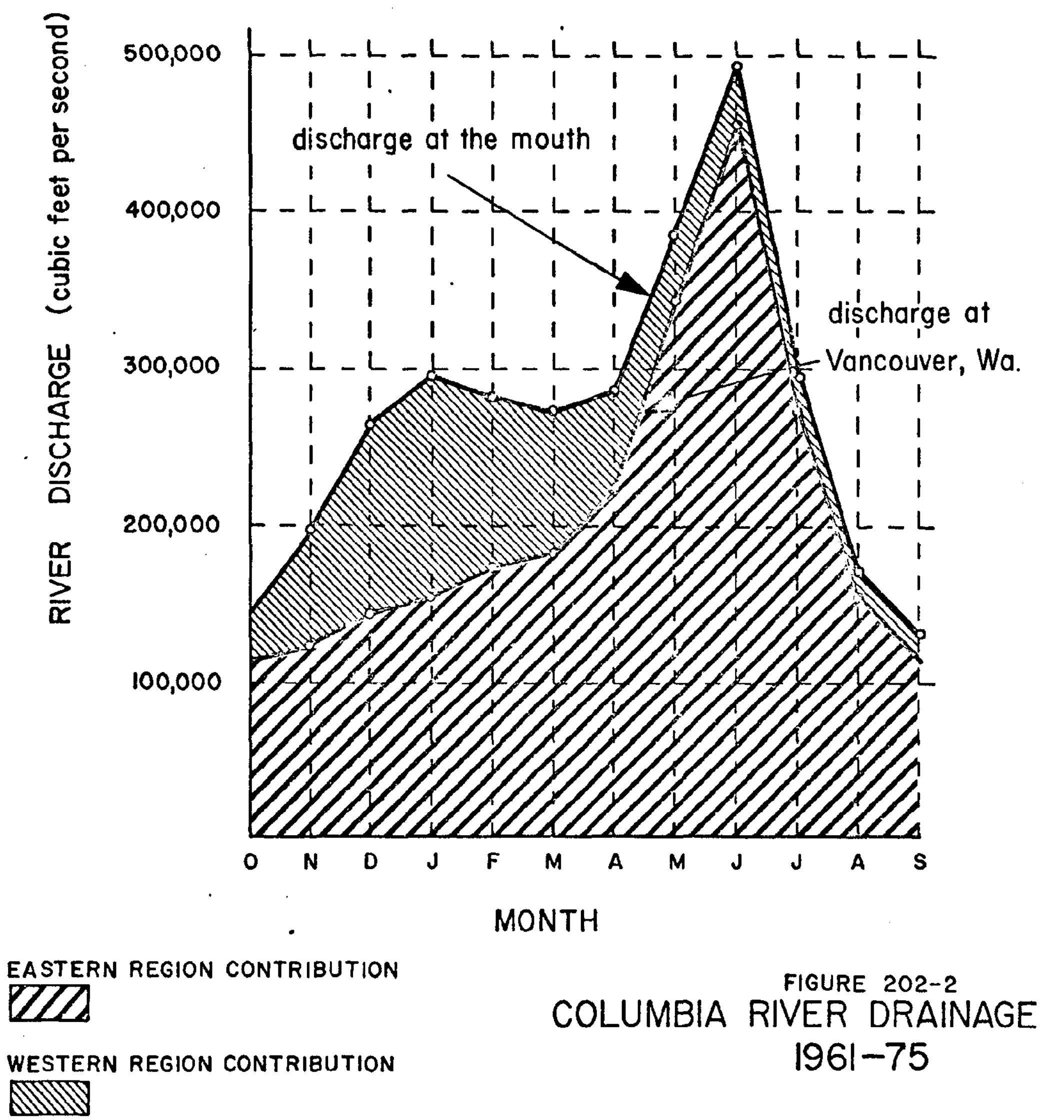


FIGURE 202-2

COLUMBIA RIVER DRAINAGE BASIN

1961–75

DISCHARGE OF EASTERLY AND WESTERLY SUB-REGIONS

(SOURCE U.S. GEOLOGICAL SURVEY DATA)

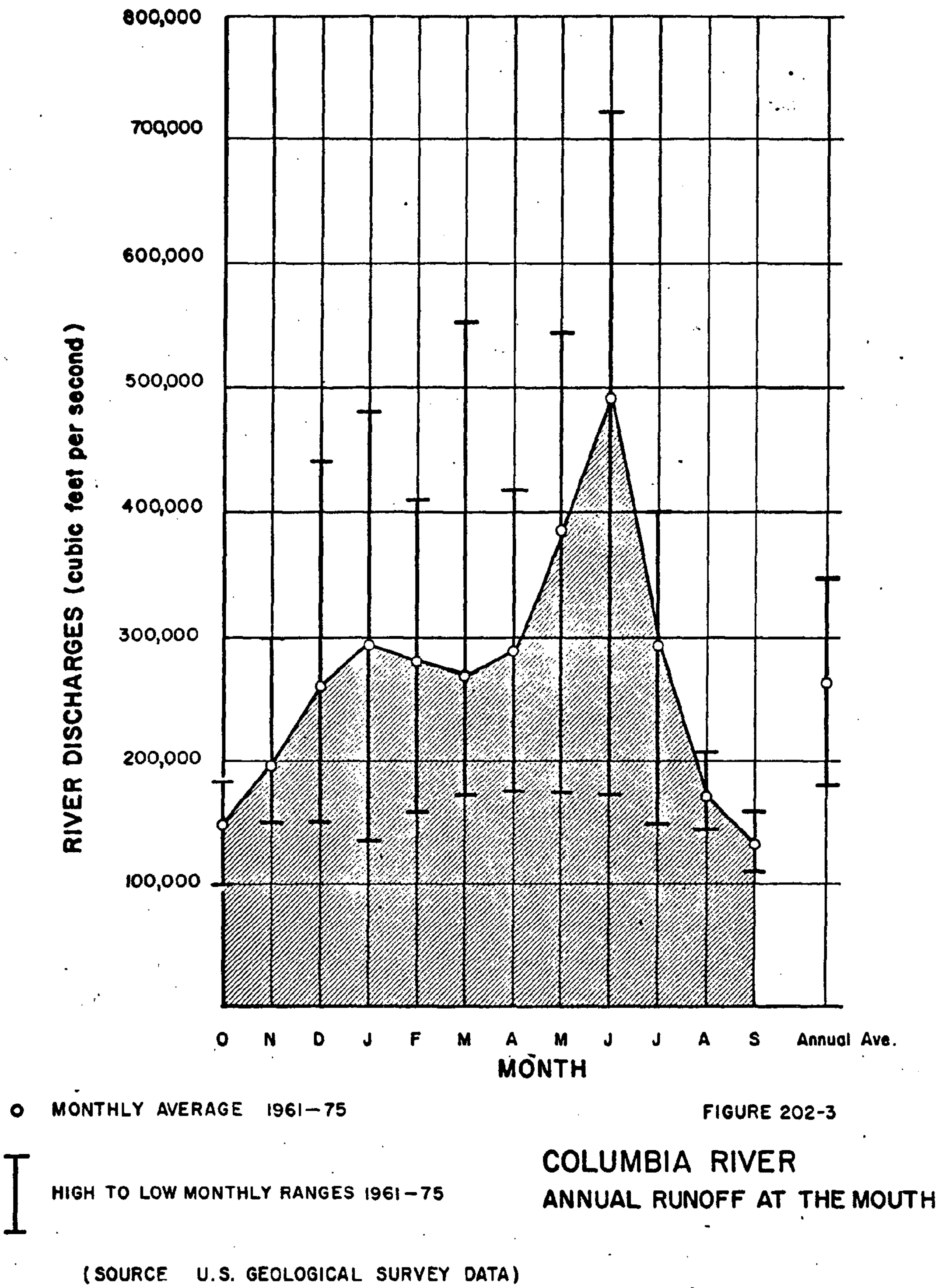
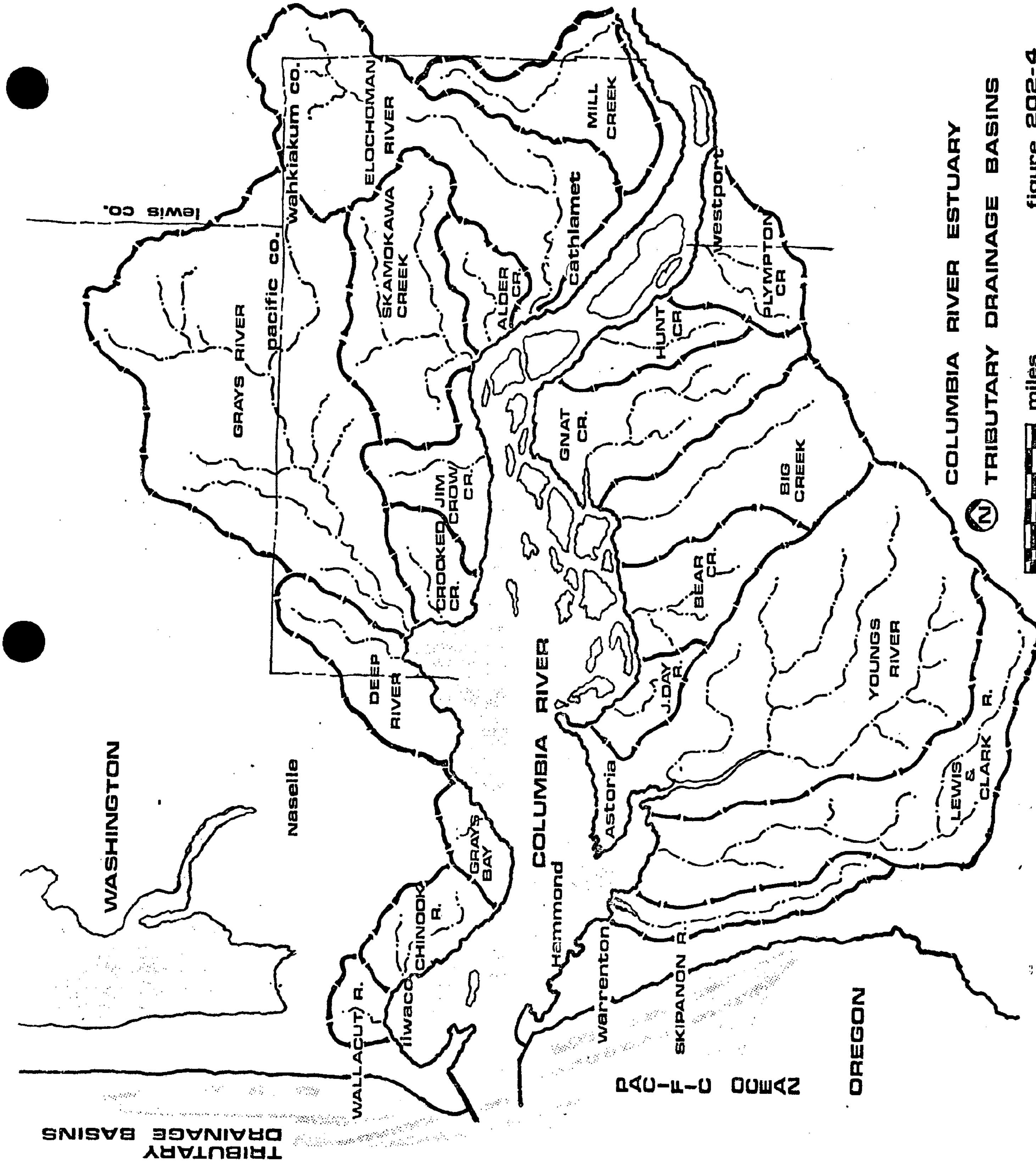


FIGURE 202-3

COLUMBIA RIVER
ANNUAL RUNOFF AT THE MOUTH



COLUMBIA RIVER ESTUARY
TRIBUTARY DRAINAGE BASINS
figure 202-4

Table 202-2 prevents the flow rates of major estuary tributary streams. While average flows appear sufficient for local needs, seasonal distribution creates severe problems. Occasional serious flooding occurs during winter storms, and the available flows in late summer and fall often fail to meet consumer demands and established minimum flows for aquatic life.

Water quality problems in estuary tributary streams result from direct solar heating of streamwaters and point and non-point pollutant sources. The chief water quality problems are high turbidity, coliform counts and temperature. Non-point sources include natural erosion, erosion resulting from removal of vegetative cover (chiefly caused by logging and road building activities), animal wastes, log storage, storm drainage from urban areas and runoff from agricultural lands during heavy rains. There are significant difficulties associated with regulation of non-point sources, and they are a major problem. Additional localized problems stem from point sources of pollution and include industrial wastes and raw sewage dumped directly into estuary tributary streams. The Oregon Department of Environmental Quality and the Washington Department of Ecology have established strict standards for point sources such as sewage and industrial outfalls. These standards are discussed in Water Quality Basin Plans and are discussed in Section 205.

202.3 SHORT-TERM VARIABILITY OF FRESHWATER FLOW

Seasonal variations in freshwater flow play a major role in determining seasonal patterns of other physical, chemical and biological aspects of the estuary. The monthly average flows shown in Tables 202-1a, b and c hide variations in flow on time scales of less than a month. The daily average flow is more variable than the monthly average flow, and the hourly flow is even more variable. Because plankton, some fish populations, conditions at the bar, and the salinity patterns in the estuary respond to the weekly, daily, and even hourly variability of freshwater flow, understanding of these facets of the estuary requires knowledge of short-term variations. For this reason, it is important to examine gaging methods used to measure the daily average flow.

Freshwater flow can be directly measured either by recording flow through the spillway of a dam or by use of current meters suspended in the water. However, there are no dams on the Columbia below Bonneville Dam at

TABLE 202-2

SELECTED DATA
COLUMBIA RIVER ESTUARY TRIBUTARY STREAMS

STREAM	DRAINAGE BASIN (Square Miles)	MEASUREMENT LOCATION	DISCHARGES, CFS Min.	Max.	Average	(For Fish) RECOMMENDED STREAMFLOWS CFS Summer Low Minimum	Summer Low Optimum	Winter High Minimum	Winter High Optimum	Notes/Remarks
Skipanon River	16	Mouth	1.6	585	49.5	None Established				1
Lewis and Clark River	62	Mouth	8.3	3,010	255	15	50	80	115	1
Youngs River	122	Mouth	18.4	6,600	588	15	82	138	190	1
Klaskanine River										
North Fork	NA	Stream Mile 4.7	3.0	245		8	31	70	86	2
South Fork	NA	Mouth	11.0	356	No data	10	44	80	100	3
Walluski River	NA	No data				None Established				
Bear Creek		No data				3	10	15	26	
Big Creek	39	Stream Mile 2.9	21.0	538	No data	20	52	90	130	2
Gnat Creek	26	No data								
Hunt Creek		No data								
Plympton Creek			4.85	No data	No data	4	13	20	34	
Wallacut River	5.7	No data								
Chinook River	12.9	No data								
Deep River		No data								
Grays River										
South Fork		above South Fork	17.0	8,900	341					4
West Fork		above Grays River	0.1	4,770	127					4
Jim Crow Creek		No data								
Skamokawa Creek		No data								
Elochoman River	65.8	Cathlamet	9.8	8,530	374					4
Mill Creek		No data								

1. OSU Ocean Engineering Program, 1975
2. OCC&DC, 1974
3. Oregon State Game Commission, 1972
4. Wahkiakum County Water and Sewer Study, 1970

river mile (RM) 145, and current meter measurements are too expensive to be made routinely.

Therefore, the estimates of average monthly Columbia River flow at Vancouver, Longview, and the mouth prepared by the U.S. Geological Survey (USGS), are based on measurements of the main stem at the Dalles Dam and of some 25 tributaries at other dams below the Dalles. In addition, some 20% of the Columbia River Basin below the Dalles Dam is ungaged. Estimates must be made for these areas based on precipitation records. Inflows of ground water are not measured or estimated. The monthly averages, computed in this way, are thought to be accurate within 2 or 3%.

Estimates of daily average flows in the tidal section of the river must be based on a more sophisticated method, because of the upstream flows during part of the tidal cycle. This method involves installation of two precision tide gages, some five to ten miles apart on a relatively straight section of river. A computer model calculates the flow from the slope of the water's surface and the cross-sectional area of the channel, as observed every 15 minutes. Current meter measurements must be used to calibrate this kind of model, and the elevation difference between the zero levels on the two tide gages must be known to an accuracy that is obtained only by careful surveying. Furthermore, the computer model used is not strictly applicable to the lower reaches of the river, where the freshwater is diluted by denser salt water. Nontheless, the USGS (Lutz, Hubbell, and Stevens, 1975) has estimated daily average flows for the Columbia River at Beaver Army Terminal (RM 53) and Astoria (RM 13).

The daily average flows at Astoria for March 1968 to June 1970 are shown in Table 202-3. Several important conclusions can be drawn from it and from the rest of the study:

First, the daily average flows are more variable than the monthly average flows; the range of the daily flows during this period was -7,400 to 630,000 cfs, while the range of monthly average flows for the same period was only 123,000 to 478,000 cfs. Instantaneous flows as high as 2,250,000 cfs were observed during peak ebb flows. Manipulations of the amount of water stored at main steam dams are an important source of daily variability.

Second, the variability of daily average flows at Astoria is greater than that at Beaver Army Terminal because of the greater influence of the tides and storm surges in the estuary. Negative average daily flows occur occasionally during storm tides (this point is discussed in detail in

TABLE 202-3

Daily Mean flow of the Columbia River at Astoria, Oregon

(in thousands of cubic feet per second)

	1968										1969												1970					
Day	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
1	---	222	---	324	320	135	118	64.9	161	234	1/292	1/245	193	293	416	499	457	216	150	114	137	143	190	388	168	114	172	381
2	---	260	---	340	312	90.7	58.0	66.3	172	236	1/283	1/255	177	359	439	510	460	187	116	126	116	106	160	302	132	105	172	408
3	---	236	---	357	292	85.0	58.7	108	227	244	1/258	1/253	190	369	444	493	421	136	112	164	70.9	71.5	147	327	185	161	152	513
4	---	206	---	346	273	53.8	105	205	246	276	1/266	1/260	220	422	449	485	390	117	95.8	124	23.0	164	206	329	1/185	226	217	518
5	---	249	---	316	261	56.6	150	193	250	340	1/296	1/285	229	504	421	479	352	137	91.8	68.5	82.9	130	217	330	1/211	95.4	1/265	455
6	---	195	---	305	235	113	222	250	244	379	1/336	304	278	424	386	444	323	99.7	70.2	29.8	183	136	246	310	168	193	1/266	480
7	---	182	---	297	242	210	250	239	232	318	1/414	258	262	309	351	408	316	101	56.3	1/91.0	186	156	228	346	268	224	248	445
8	---	159	---	315	265	262	242	205	195	362	422	228	284	337	318	402	311	70.3	57.1	1/154	286	177	205	288	250	251	276	446
9	224	151	---	353	337	285	223	165	262	288	398	275	293	374	349	400	281	99.1	121	201	284	197	223	252	210	254	257	446
10	207	150	112	419	380	257	226	164	275	276	387	220	268	383	396	390	263	105	156	273	259	178	234	228	191	269	270	458
11	195	190	149	480	402	216	217	143	272	313	451	228	211	352	410	415	308	137	182	238	219	159	205	221	217	286	234	417
12	214	224	187	467	428	157	168	189	332	343	378	261	197	345	445	440	325	152	180	236	234	244	169	202	209	238	236	387
13	242	204	246	498	384	162	131	182	316	278	326	323	168	437	471	448	300	234	223	186	210	243	140	222	1/208	188	219	353
14	274	198	272	504	378	160	149	138	262	260	287	357	175	441	528	474	308	232	208	164	161	262	276	160	1/178	177	199	314
15	269	235	234	490	359	133	142	199	255	225	330	342	173	460	534	501	322	230	154	135	164	226	279	92.9	1/127	114	153	284
16	273	224	173	462	330	114	90.2	151	227	286	356	346	146	432	579	470	1/309	223	125	157	170	194	286	1/186	1/181	159	216	232
17	273	177	179	449	299	75.9	67.2	98.0	239	272	413	232	247	450	549	472	1/286	186	82.5	139	168	174	259	1/297	1/198	196	216	256
18	264	85.7	153	422	270	37.7	65.6	104	267	350	369	211	280	473	558	437	1/263	181	67.5	118	114	170	298	1/364	1/241	174	228	319
19	252	96.7	119	417	246	40.6	82.1	122	302	366	325	222	260	426	555	391	1/240	167	68.3	126	78.5	160	331	355	238	213	292	381
20	231	96.2	139	432	202	84.3	160	204	332	322	322	268	277	437	558	391	1/260	144	59.7	66.2	99.8	194	361	349	242	188	326	416
21	212	92.2	134	390	188	91.3	211	229	278	312	311	278	332	456	540	339	1/237	109	-3.2	1/39.0	200	256	430	353	254	216	360	444
22	146	47.1	195	395	198	135	238	279	332	262	322	203	292	380	522	260	1/194	50.4	-7.4	1/115	230	309	431	333	238	243	422	429
23	132	127	257	425	208	185	221	269	333	214	278	183	362	408	516	233	1/167	23.3	95.9	1/163	220	374	506	252	248	253	437	419
24	146	150	276	431	216	251	226	248	313	199	268	189	309	442	516	220	1/160	47.5	158	1/237	231	375	601	204	278	238	428	383
25	165	166	338	442	266	254	1/186	270	302	215	229	170	261	417	466	220	1/149	93.3	220	1/214	217	381	630	240	226	245	435	317
26	238	---	312	446	278	225	1/186	220	221	203	226	183	230	400	463	220	82.0	165	228	1/186	202	397	569	188	241	249	418	279
27	257	---	330	443	254	215	1/181	154	248	224	172	149	242	388	479	254	124	228	212	163	194	319	608	157	208	252	430	264
28	292	---	379	411	243	243	147	69.2	202	259	205	149	221	395	446	310	184	263	171	211	172	294	621	182	214	221	393	247
29	326	---	397	394	204	214	74.9	60.4	164	274	183	---	212	399	450	386	258	224	150	167	151	281	508	-----	188	176	404	235
30	276	---	377	374	187	168	41.5	144	151	324	1/236	---	228	401	491	440	290	190	142	169	169	251	491	-----	168	158	401	247
31	215	---	318	---	151	149	-----	130	---	1/314	1/220	---	273	---	483	---	255	164	-----	165	-----	207	398	-----	129	-----	377	---
Mean:	---	---	---	405	278	157	155	170	254	283	308	246	242	404	469	394	277	152	125	153	175	224	337	266	206	203	294	372
Max:	326	260	397	504	428	285	250	279	333	379	451	357	362	504	579	510	460	263	228	273	286	397	630	388	278	286	435	518
Min:	132	47.1	112	297	151	37.7	41.5	60.4	151	199	172	149	146	293	318	220	82.0	23.3	-7.4	29.8	23.0	71.5	140	92.9	129	95.4	153	232

1/ Estimated.

From: Lutz, et al., 1975

Section 203.3B). Under these conditions there is a net movement of water from the ocean into the estuary for a day, or even two days, accompanying a storm surge. The extreme variability of flow in the estuary is one of the reasons that the Columbia River bar is so hazardous. Both wave conditions and the strength of ebb currents are only partially predictable.

Third, day-to-day flow variability of estuary tributary streams, while important for fish migration and local water supply, is too small to have a significant effect on flow at the mouth.

In summary, the monthly average flows routinely published by USGS do not indcate the full extent of flow variability in the lower river and estuary.

202.4 RIVER FLOW DURING THE WATER YEARS 1976 and 1977

Columbia River Flow data for the water years 1976 and 1977 (Septem- 1975 to September 1977) were not received in time to be incorporated into Table 202-1. This information has been appended here, because of the record low flow during water year 1977 (Table 202-4). The flow data for water year 1977 are as yet provisional, but major changes in the final figures are unlikely. The data were provided by M.E. Young of the U.S. Geological Survey, Northwest Water Resource Data Center (Young, personal communication).

The estimated monthly mean flow (Table 202-4a) at the mouth did not exceed 200,000 cfs for any month from September 1976 to September 1977. The highest monthly mean flow (about 180,000 cfs) occurring in January and March, the lowest monthly mean flow in July (104,600 cfs). The average flow for the year was 155,000 cfs. Comparison of 1977 flow data with historical flow data for the period 1928 to 1976 shows that record low monthly mean flows occurred in April, June, July and August. In fact, 1977 was considerably drier than any other year on record. The previous low flow year was 1931, when the mean and adjusted mean flow was 166,000 cfs.

The U.S. Geological Survey also calculates monthly average adjusted flows. This is the flow that would have occurred in the absence of changes in storage in dam reservoirs. These flows show the major influence exerted by the dams on Columbia River flows. The average adjusted flow for the year 1977 was 141,200 cfs (Table 202-4b). That is, the dam reservoirs

TABLE 202-4a

Monthly and Annual Mean Flow
In Cubic Feet Per Second

Columbia River at Mouth, Near Astoria

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August	Sept.	Annual
1976	168,200	251,800	409,700	309,600	313,900	318,400	346,300	411,300	337,100	267,600	241,200	192,100	303,800
1977	174,200	170,100	174,300	180,200	165,700	180,500	150,800	178,100	155,800	104,600	105,400	120,200	155,000

TABLE 202-4b

Monthly and Annual Adjusted Mean Flow
In Cubic Feet per Second

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August	Sept.	Annual
1977	102,500	95,620	99,370	85,870	101,100	128,700	183,900	273,700	284,900	133,900	110,300	94,590	141,200

Flow Data were provided by M.E. Young, US Geological Survey, (Young, personal communication)
Northwest Water Resources Data Center, Portland, Oregon
Data for 1976 are final; those for 1977 are provisional
Mean Flow are estimates of flows that would actually be observed at mouth, if a gage were in place.
Adjusted Mean Flows are those that would be observed in the absence of dams.

were depleted at an average rate of nearly 14,000 cfs for the entire year to meet the needs of irrigation projects, hydroelectric power and migrating fish. Additional storage losses also occurred from evaporation. Comparison of the monthly average and monthly average adjusted flows shows that dam storage exerted a strong leveling effect on the flows (Table 202-4b). Monthly average flows ranged from 104,600 cfs to 180,500 cfs, while the adjusted flows from 85,870 cfs to 284,900 cfs.

What were the consequences of the drought for river users? Fish passage conditions for both adults and juveniles were extremely poor. Unusually hot weather, together with the low flows, resulted in very high stream temperatures in the river. Few downstream migrant juveniles would have survived had some not been trucked or barged around the dams. It was also necessary to release water in excess of power needs so that downstream migrants could escape the turbines. Electrical power use by interruptible customers was cut. Some upstreams areas suffered severe lowering of water levels, decreasing water quality and interfering with navigation. Water levels in the lower river were not greatly affected, but dredging needs were unusually low, because bedload sediment transport was less than normal. Sufficient water reserves were available to avoid, for one year, many consequences of the drought. The consequences of a second year of drought would, however, be much more severe.

202.5 REFERENCES

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203

TIDES AND TIDAL CURRENTS

COLUMBIA RIVER ESTUARY
TIDES AND TIDAL CURRENTS

David Jay

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203 TIDES AND TIDAL CURRENTS

The tides are the source of much of the energy that drives the physical circulation of the Columbia River estuary. This energy results in the mixing of fresh and salt water, turbulence, and the regular up and down stream movement of estuarine waters known as the flood and ebb of the tide. The rise and fall of the tide, the causes and effects of these tidal fluctuations, and the associated tidal currents are discussed in this section.

203.1 THE ORIGIN OF TIDAL PHENOMENA

A. The Astronomical Tides

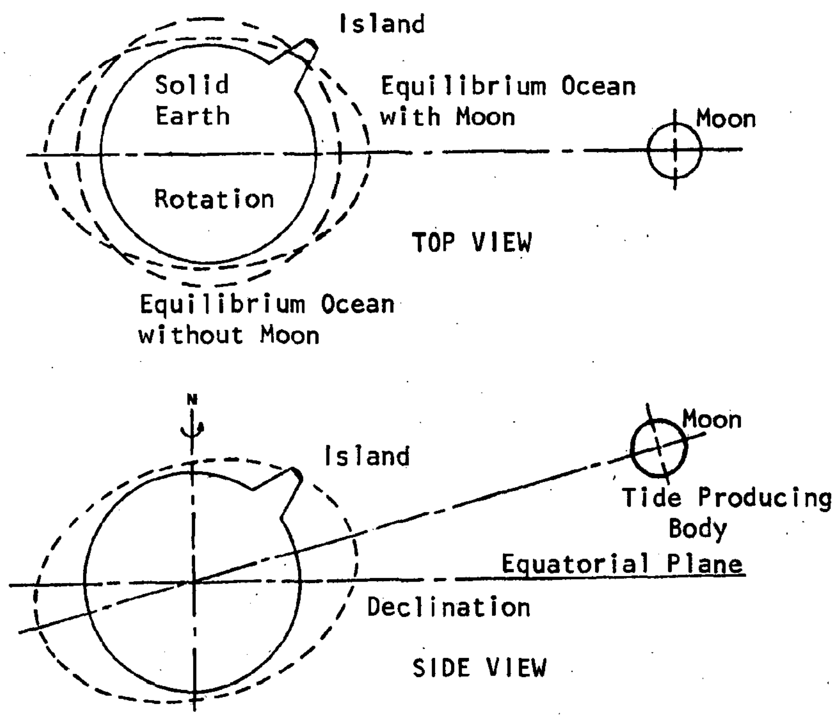
The tides result from complex gravitational interactions of the sun, the moon, and the earth. Although some 380 interactions occur (and each causes a different component of the tides), only about 20 are of practical importance. The simplest explanation of the tides is that the gravitational attraction of the moon (or sun), as it passes overhead, causes a bulge in the surface of the water (Figure 203-1).

This bulge, both at the point directly beneath the moon and on the opposite side of the earth, moves around the earth as the moon does and is experienced as a high tide. Since there are two bulges, one on each side of the earth, two high tides occur each lunar (or moon) day (about 24 hours 50 minutes). That is, the lunar semi-diurnal (twice daily) tidal component has a period of one half of a lunar day, or 12 hours and 25 minutes. There is also a diurnal tidal component having a period of one lunar day. In a similar way, the rotation of the earth around the sun results in diurnal and semi-diurnal tidal components, with periods of one, and one-half solar (sun) days (24 and 12 hours), respectively. There are a total of 10 semi-diurnal and 6 diurnal components to the tides, each having a slightly different period.

Components with periods of about 28 days result from the rotation of the moon around the earth (the phases of the moon) and the variation in distance of the moon from the earth. Spring tides, those of greatest range (distance between high and low water) occur when the moon is new or full and when the moon is closest to the earth (Figure 203-2a).

Figure 203-1

The Generation of the Tides



The gravitational force of the moon (and the sun, also) causes the distortion of the water's surface we know as the tides. A bulge (HW) appears directly underneath the moon and on the opposite side of the earth.

From: McLellan, 1965

During the spring tides, the sun and moon are in line and their gravitational forces act in the same direction. Neap tides, those of smallest range, occur when the sun and moon are acting at right angles to each other (Figure 203-2b). There is a solar yearly component related to the declination of the sun, the angle between the earth's axis and the earth's plane of rotation around the sun (Figure 203-1). The sun's declination also causes the seasons.

The tidal forces and their periods are known from astronomy with great precision. The response of any given part of the ocean to these forces is mysterious and can only be predicted on the basis of observations with a tide gage. Every year the National Ocean Survey of the Department of Commerce publishes "Tide Tables" and "Tidal Current Tables" for most of the world. Those for the West Coast of the U.S. are listed in the references in Section 203.5. The relative strengths and phases of the tidal components for various Oregon and Washington points are given by Callaway (1971).

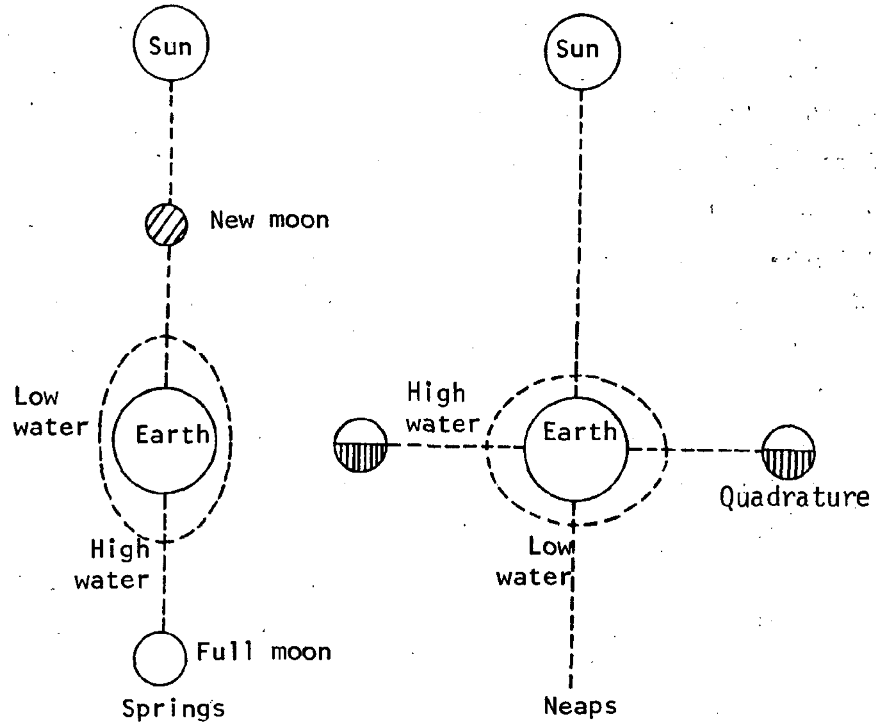
B. Tidal Datum Levels

In the Columbia River and on the open coast nearby, both diurnal and semi-diurnal tidal components are important. The result is a mixed tide. The rise and fall of a mixed tide as observed at a tide gage is shown in Figure 203-3. Most of the important tidal datum levels are defined in Figure 203-4 and Table 203-1, using Astoria Port Docks as an example. The elevation of Mean Lower Low Water (MLLW) is, by definition, 0.0 ft. The diurnal range is the difference between Mean Higher High Water (MHHW) and MLLW. The mean range is the difference between Mean High Water (MHW) and Mean Low Water (MLW). The Mean Tide Level (MTL) is the average of MHW and MLW, and Mean Sea Level (local MSL) is the average of all hourly observations at a given station. MSL, also known as the Sea Level Datum of 1929 and the National Geodetic Vertical Datum of 1929 (NGVD, 1929), is sea level at coastal stations not influenced by river flow, is part of the first order leveling network and is used by surveyors and engineers. The Columbia River Datum (CRD), the average of low waters during a low flow period in 1911, is also sometimes used for engineering purposes. Table 203-2 shows the mean and diurnal ranges, MTL, NGVD, and MLLW relative to MSL for all available stations

Spring and Neap Tides

Figure 203-2a

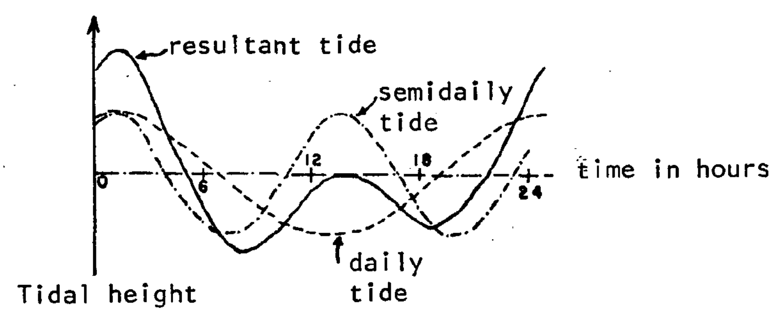
Figure 203-2b



When the moon and sun act in the same plane, the lunar and solar tidal bulges combine to produce large amplitude spring tides. When the lunar and solar tide bulges are 90° out of phase, their combined effect produces smaller amplitude neap tides.

From: Duxbury, 1971

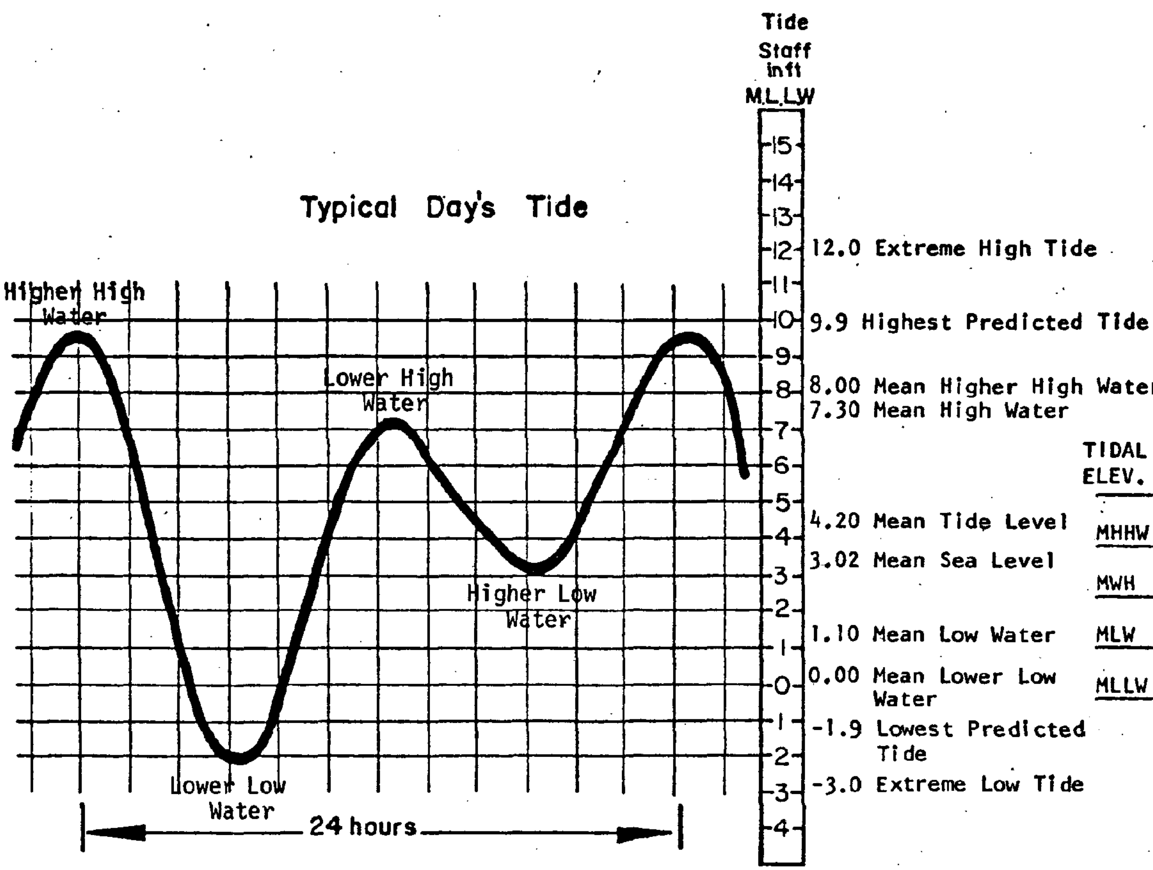
Figure 203-3 Rise and Fall of a Mixed Tide



A diurnal and a semi-diurnal tide when combined produce a mixed tide

From: Gross, 1972

TIDAL ELEVATIONS FOR ASTORIA PORT DOCKS



---LOCAL TIDE STATIONS---

TIDAL ELEV.	Ft. Stevens	Warrenton	Lewis & Clark River	Youngs River	Youngs Bay	Port Docks	Tongue Point
MHHW	8.3	8.3	8.7	8.6	8.6	8.0	8.3
MWH	7.6	7.7	8.0	8.0	7.9	7.3	7.6
MLW	1.2	1.2	1.1	1.1	1.2	1.1	1.1
MLLW	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 2Q3-4

A typical tidal height curve of the mixed type observed in the Columbia River, showing tidal datum levels. Adapted from: Division of State Lands, 1973

TABLE 203-1

Definitions of Important Tidal Datums

Extreme High Water (EHW) - The highest projected tide that can occur. It is the sum of the highest predicted tide and the highest recorded storm surge. Such an event would be expected to have a very long recurrence interval. In some locations, the effect of rain induced freshet must also be taken under consideration. The extreme high tide level is used by engineers for the design of harbor structures.

Highest Measured Tide - The highest tide actually observed on the tide staff.

Highest Predicted Tide - Highest tide predicted by the Tide Tables.

Mean Higher High Water (MHHW) - The average height of the higher high tides observed over a specific time interval. The intervals are related to the moon's many cycles which range from 28 days to 18.6 years. The time length chosen depends upon the refinement required. The datum plane of MHHW is used on National Ocean Survey charts to reference rocks awash and navigational clearances.

Mean High Water (MHW) - The average of all observed high tides. The average is of both higher high and of the lower high tide recorded each day over a specific time period. The datum of MHW is the boundary between upland and tideland. It is used on navigational charts to reference topographical features.

Mean Tide Land (MTL) - The average of MHW and MLW at a given station. MTL usually does not coincide with Local MSL because the tide curve at most stations is not perfectly symmetric.

Local Mean Sea Level (Local MSL) - The average height of the water surface for all stages of the tide at a particular observation point. The level is usually determined from hourly height readings.

Mean Sea Level (MSL) - A datum based upon observations taken over a number of years at various tide stations along the west coast of the United States and Canada. It is officially known as the Sea Level Datum of 1929, 1947 adj. and is the most common datum used by engineers. MSL is the reference for elevations on the U.S. Geological Survey Quandrangles. The difference between MSL and Local MSL reflects numerous factors ranging from the location of the tide staff within an estuary to global weather patterns.

Mean Low Water (MLW) - The average of all observed low tides. The average is of both the lower low and the higher low tides recorded each day over a specific time period. The datum of MLW is the boundary between tideland and submerged land in Oregon.

Mean Lower Low Water (MLLW) - The average height of the lower low tides observed over a specific time interval. The datum plane is used on Pacific coast nautical charts to reference soundings.

Columbia River Datum (CRD) - The average of low water during the low flow period in 1911, as defined by the Corps of Engineers. It is about 0.05 to 0.2 ft. below MLLW in the estuary.

Lowest Predicted Tide - The lowest tide predicted by the Tide Tables.

Lowest Measured Tide - The lowest tide actually observed on the tide staff.

Extreme Low Water (ELW) - The lowest estimated tide that can occur. Used by navigational and harbor interests. ELW is the boundary between tidelands and bedlands in Washington.

Data provided by Division of State Lands, 1973

Table 203-2. Times of Slack, High and Low Water, Tidal Ranges and Elevations*

Location	River Mile	Time of Slack Before Ebb	Time of Peak Ebb	Average Speed In Knots		Time of HW	Time of LW	Ranges		Elevations Relative to MLLW	
				Ebb	Flood			Mean	Diurnal	Local MTL	NGVD 1929
North Jetty	1.5					0.0	5.91	5.6	7.5	4.00	3.80
Main Channel	2.0	.89	4.16	4.3	2.6						
S. Channel off Clatsop Spit	5.0	1.23	4.0	3.5	1.8						
N. Channel off Clatsop Spit	5.0	1.81	4.58	4.2	3.6						
Pt. Adams, Ore	7.0					+.31	6.30	6.4	8.3	4.40	3.51
N. Channel off McGowan, Wa	9.0	.98	4.0	3.8	1.2						
S. Channel off Tansy Point	10.0	1.14	4.16	2.5	1.3						
Port of Astoria, Ore	13.0					+.60	6.88	6.2	8.0	4.20	3.02
Hungry Harbor, Wa	15.0					+.80	6.78				
S. Channel off Astoria	16.0	2.11	5.07								
Tongue Point	18.0					+.76	7.10	6.5	8.2	4.35	3.05
Harrington Point, Wa	23.0					+1.08	7.80	6.1	7.7	3.95	2.56

*All times are in hours from HW at North Jetty
From: U.S. Army Corps of Engineers, 1959 and U.S. Department of Commerce, 1975

Table 203-2 Times of Slack, High and Low Water, Tidal Ranges and Elevations (Cont.)

Location	River Mile	Time of Slack Before Ebb	Time of Peak Ebb	Average Speed In Knots: Ebb	Average Speed In Knots: Flood	Time of HW	Time of LW	Ranges: Mean	Ranges: Diurnal	Elevations Relative to MLLW: Local MTL	Elevations Relative to MLLW: MSL, 1947 at Jetties ≠
Channel off Harrington Pt.	23.5		5.5	1.7	1.0						
Skamokawa, Wa	33.3					1.67	8.68	5.6	6.9		2.15
Channel off Bradwood, Ore	39.0		7.08	2.4							
Cathlamet, Wa	40.0					1.98	9.18	5.2	6.4		
Wauna, Ore	42.0					2.01	9.25	5.2	6.3		1.76
Eagle Cliff, Wa	50.8					2.45	9.95	4.5	5.5		1.32
Beaver Army Terminal, Ore	53.3							4.3	5.2		
Stella, Wa	55.2					2.75	10.43	4.0	4.9		.79
Off Longview	66.0		9.5	1.0							
Longview, Wa	66.0					3.18	11.17	3.3	4.0		.34
Kalama, Ore	72.5					3.63	11.85	2.6	3.2		-.29
St. Helens, Ore	86.0					4.25	12.67	2.0	2.5		-.89
Knappa Landing, Wa.	--					5.18	13.4	1.5	2.0		
Mouth of Willamette	101.5					6.18	14.4	1.4	2.0		-1.40

≠ From: U.S. Army Corps of Engineers Map CL-03-116

Table 203-2 Times of Slack, High and Low Water, Tidal Ranges and Elevations (Cont.)

Location	River Mile	Time of Slack Before Ebb	Time of Peak Ebb	Average Speed In Knots		Time of HW	Time of LW	Ranges		Elevations Relative to MLLW	
				Ebb	Flood			Mean	Diurnal	Local MTL	MSL, 1947 at Jetties
Vancouver, Wa	105.5					6.48	14.57	1.3	1.8		-1.82
Ellsworth, Wa	112.0					6.92	14.98	1.0	1.4		-2.48
Washougal, Wa ≠	123.0							0.5	0.9		-3.83
Warrendale, Ore	141.0							0.4	0.6		-5.89
Youngs Bay:											NGVD, 1929
PP&L Pier						.52	6.70	6.7	8.6	4.55	3.60
Youngs River								6.9	8.6	4.55	
Lewis & Clark River								6.9	8.7	4.55	
Skipanon River at Bridge						.52	6.62	6.5	8.3	4.45	
Cathlamet Bay:											
Settlers Pt., Svensen, Ore	22.0					1.10	7.82	6.3	8.0	4.15	2.69
Baker Bay:											
Fort Canby, Wa								6.0	7.8	4.10	3.12
Ilwaco, Wa						.52	6.95	6.0	7.6	4.00	3.90
Chinook, Wa						.52	6.37	6.2	7.9	4.20	

≠ Times of HW and LW affected by runoff levels in the Lower Columbia River. A more detailed discussion of datum levels is given in OSU, Ocean Engineering Programs (1975). Datum levels for additional points can be found in the "Tide Tables."

C. Tidal Currents

Accompanying the rise and fall of the tide are tidal currents. On flood tide, water moves from the ocean into the estuary and from the estuary upstream into the river. On ebb tide, currents move in a downstream direction. The tidal currents as observed at any point then, are oscillatory, alternately ebbing and flooding. The strongest ebb currents occur at the time of peak ebb, and the strongest flood currents occur at the time of peak flood. Between ebb and flood, there is usually a brief period of no current, or in some locations, slight and irregular currents. This period is known as slack water. The relative strengths of flood and ebb vary with position in the channel, the salinity distribution, the winds, and the freshwater runoff level. In the river upstream of the estuary (high runoff season) or of RM 70 (low runoff season), the tidal currents are overwhelmed by the downstream river flow. Current speed varies with the tidal stage, but flood currents never occur. Tidal forces and river flow are two major factors governing currents in the estuary and river. These currents are further discussed in Section 204 (Estuarine Circulation).

D. Standing and Progressive Wave Tides

The rise and fall of the tides, as observed at any point, result from the movement of one or more tidal waves past the point of observation. In most estuaries, there is one wave propagating upstream from the ocean, while another reflected wave moves simultaneously downstream. Even the Columbia River estuary is not large enough to have measurable tides caused by the sun and the moon acting directly on the water of the estuary. We must distinguish between progressive and standing waves. In the case of the progressive wave, the reflected wave is so weak that it is unimportant; the crest and trough of the wave (HW and LW) move progressively upstream, so that HW and LW occur later at any point upstream from the mouth. The range of a progressive wave usually decreases upstream, because the effects of friction; a constriction of the channel may result in a local increase in range, however. For a purely progressive wave, peak flood corresponds with HW and peak ebb with LW (Figure 203-5a). Progressive waves are often found in long, narrow channels (such as rivers).

A standing wave results when the reflected wave is as strong as the wave moving upstream; that is, a standing wave results from the addition of two progressives of the same period and height, but moving in opposite directions. Standing waves are often found in bays. High tide and slack water occur at the same time throughout the bay, when the tidal prism of the bay is full. Low tide and slack water occur at the same time throughout the bay, when the tidal prism of the bay is empty (Figure 203-5b).

Normally, the smallest range is at the mouth of the bay, and the range increases toward the head of the bay (Figure 203-6). If the length of the bay is close to one-fourth of the wave length of the tidal wave, a phenomenon called resonance occurs, and the tidal range increases dramatically toward the head of the bay.

203.2 THE TIDES IN THE COLUMBIA RIVER

The head of the tide in the Columbia River is Bonneville Dam (RM 145), but current reversals caused by the tides are observed only to about RM 70, even under low river flow conditions. Under high river flow conditions, current reversals caused by the tides are limited to the estuary. Tables 203-2 and 203-3 show the important tidal datum levels along the Columbia River. Since any river, even a tidal one, runs downhill, the level of MLLW rises upstream relative to MSL (Table 203-3). Also shown in Table 203-3 is the 100-year flood level, relative to MSL and local MLLW. The 100-year flood level rises dramatically, upstream from the estuary. Tidal elevations in the estuary are less severely affected by floods than those upstream, because the estuary is much broader and has less resistance to flow. For any given change in stage, much larger flows may be conveyed through the estuary than through the upstream river sections. However, the estuary is much more vulnerable to flooding caused by storm surges than the upriver areas.

The response of the Columbia River and its estuary to tidal currents is determined by several factors, including the depth (bathymetry) of

IDEALIZED PROGRESSIVE WAVE

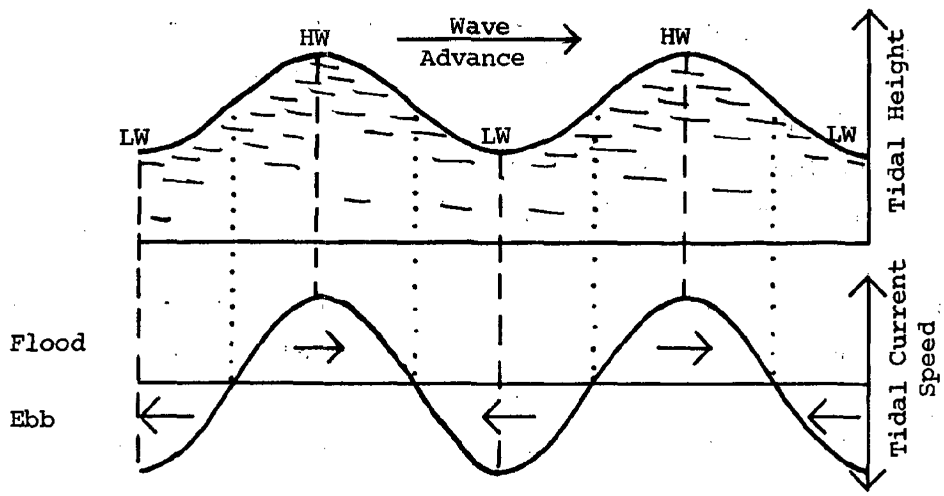


Figure 203-5a

An idealized progressive wave tide in which HW occurs at the time of peak flood and LW at peak ebb. Slack waters occur at mid-tide.

From: Gross, 1972

IDEALIZED STANDING WAVE

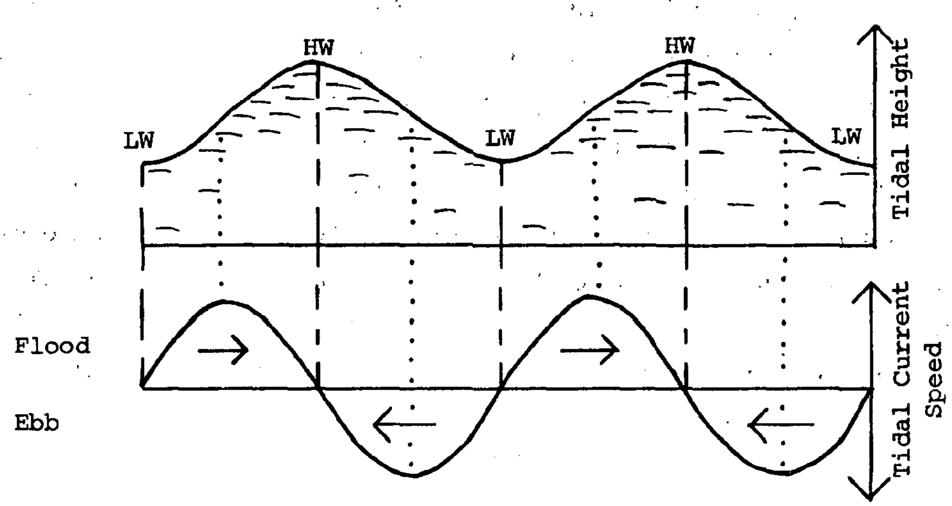


Figure 203-5b

An idealized standing wave in which HW occurs at the time of slack after flood and LW at slack after ebb. Peak flood and ebb occur at mid-tide.

A Standing Wave in an Open Basin

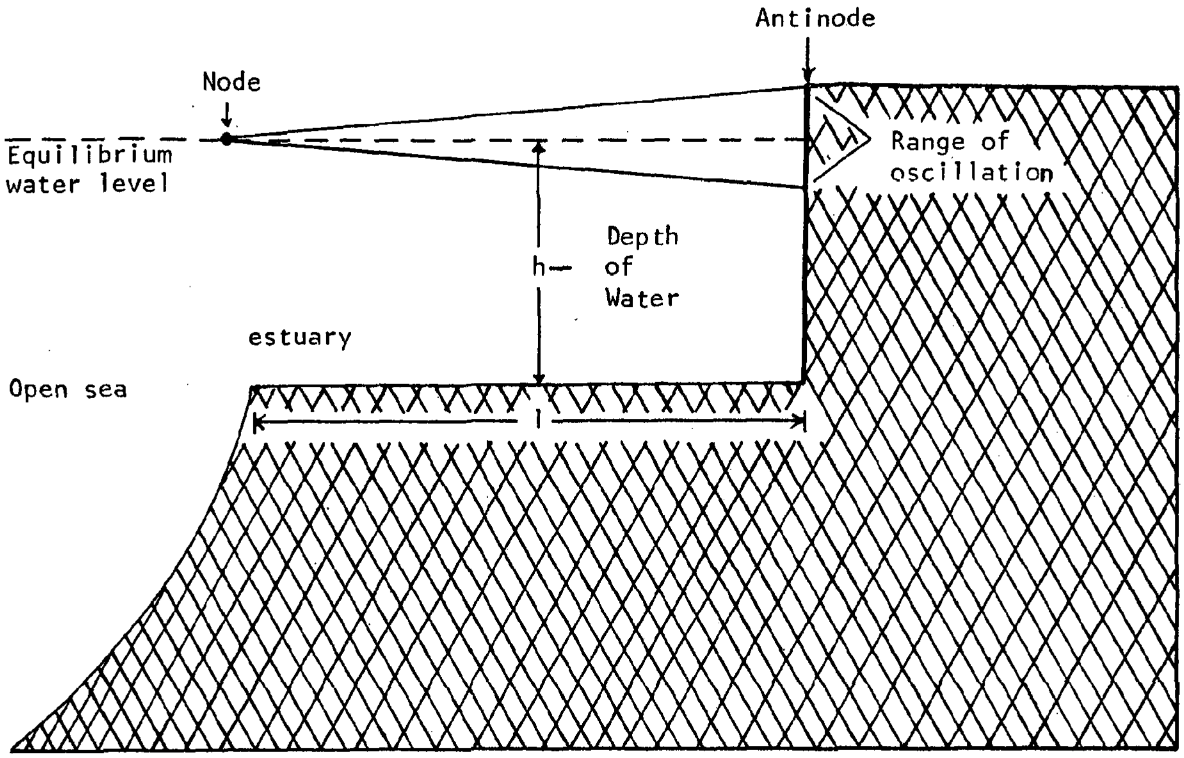


Figure 203-6

The fundamental standing wave in an open-ended basin has a node at the basin's mouth. Maximum change in water level occurs at the antinode at the head of the estuary. For resonance to occur, the basin's length (L) must be 1/4 of the wave length of the tide.

From: Duxbury, 1971

Table 203-3
Elevations in feet of MLLW and 100-year flood level for the Columbia River

Elev. of local MLLW Relative to MSL Datum at the Jetties	River Mile	Location	100-Yr. Flood Level Relative to MSL Datum at the Jetties 1947	100-Yr. Flood Level Relative to local MLLW
-3.80	0	South Jetty, Ore	--	--
-3.56	8.5	Fort Stevens, Ore	8.3	12.0
-3.07	14.0	Astoria, Ore	8.35	11.4
-3.03	17.0	Tongue Point, Ore	8.4	11.4
-2.61	24.0	Altoona, Wa	8.7	11.3
-2.43	26.0	Pillar Rock, Wa	9.1	11.4
-2.15	33.3	Skamokowa, Wa	9.5	11.7
-1.76	41.5	Wauna, Ore	10.6	12.4
-1.65	45.0	Westport, Ore	11.0	12.6
-1.32	51.0	Eagle Cliff, Wa	11.9	13.2
-0.79	56.0	Stella, Wa	13.2	14.0
-0.34	66.0	Longview, Wa	16.0	16.3
-0.17	67.5	Rainier, Ore	16.5	16.7
+0.29	76.0	Kalama, Wa	19.0	18.7
+0.89	86.0	St. Helens, Ore	21.7	20.8
+1.40	101.5	Mouth of Willamette River	25.5	24.1
+1.82	106.5	Vancouver, Wa	26.7	24.9
+2.84	113.0	Fishers Landing, Wa	29.2	26.4
+3.83	123.0	Washougal, Wa	31.8	28.0
+5.61	136.0	Multnomah Falls, Ore	34.0	28.4
+5.89	142.0	Warrendale, Ore	35.3	29.4
+8.45	143.3	Bonneville Dam	40.8	32.3

From: U.S. Army Corps of Engineers Map CL-03-116 the estuary and river and the freshwater flow. The most fundamental factor is the bathymetry (Figure 203-7). The bathymetry of the estuary is extremely complex, with multiple channels and sloughs, many islands and major bays. The riverine sections upstream from the estuary are simpler, but multiple islands and channels are still present. Generally speaking, the estuary below Harrington Point is broad. There is an abrupt narrowing between Harrington Point and Jim Crow Point, and the system is basically a tidal river above Jim Crow Point. This pattern determines the observed tidal features; both standing and progressive waves are important below Harrington Point, and the progressive wave predominates above Harrington Point.

A. Progressive Wave Characteristics

Table 203-2 shows the times of slack before ebb, peak ebb, and high and low water (all relative to the time of HW at the North Jetty), and the mean and diurnal ranges for locations from the North Jetty to near the Bonneville Dam. These data can be used to understand the nature of the tides in the Columbia River and estuary. The times of HW, LW, and peak ebb become progressively later upstream, as is to be expected from a progressive wave tide. The crest of the tidal wave (HW) takes 6.92 hours to travel from the North Jetty to Ellsworth, Wa. (RM 112). The trough of the tidal wave (LW) takes 9.07 hours to travel the same distance; this is a difference of more than 2 hours. The travel speed of a long wave in shallow water is controlled by the depth; the trough of the wave travels upstream more slowly, because it is moving in shallower water than the crest of the wave. Similar behavior can be seen as long waves shorten, peak up, and break on an ocean beach. It appears that the crest of a tidal wave takes about 9 hours to travel from the mouth to the dam (RM 145). Thus, there is about 3/4 of a whole tidal wave in the river at one time, since a new highwater appears at the mouth every 12 hours and 25 minutes. The decrease of the mean and diurnal tidal ranges upstream from Tongue Point is also characteristic of a progressive wave tide.

B. Standing Wave Characteristics

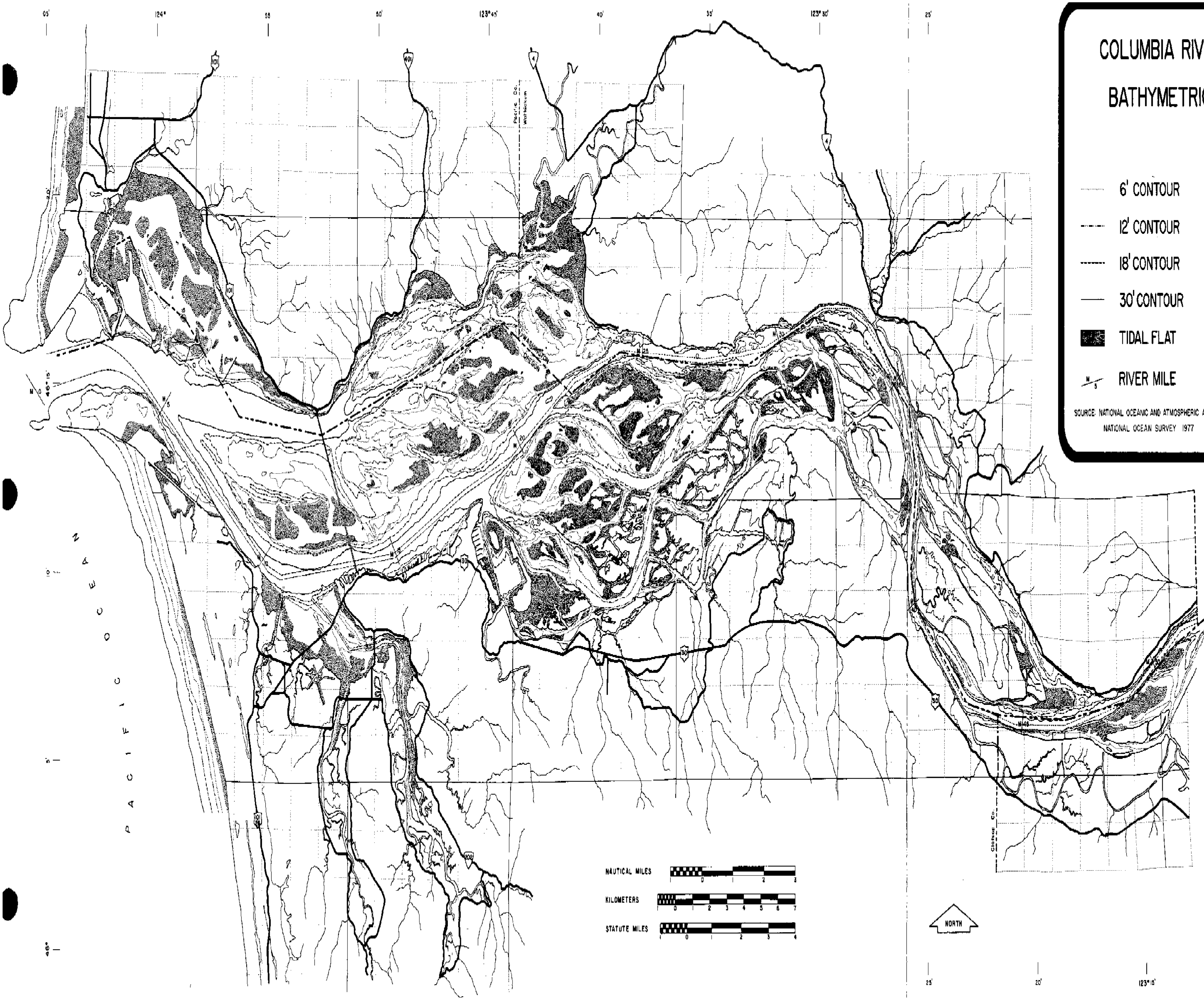
The tide in the Columbia River is not, however, a pure progressive wave; it also exhibits standing wave characteristics. For example, the diurnal range of the tide increases from 7.5 ft at the mouth to 8.3 ft at Point Adams and 8.2 ft at Tongue Point. A somewhat greater amplification takes place in Youngs Bay, where the range reaches 8.6 ft in the bay itself, and 8.7 in the Lewis and Clark River. This amplification is characteristic of a standing wave tide.

Also characteristic of a standing wave tide is the simultaneous occurrence of high tide and slack before ebb throughout the estuary. For a standing wave tide then, peak ebb and peak flood occur between the times of high and low water. In fact, slack before ebb occurs about .9 to 1.3 hours after HW at the North Jetty, in the reach between the mouth and Tongue Point. Were the tide a purely progressive wave, slack before ebb would occur about 3 hours and 12 minutes after HW at the North Jetty. The observed tide is thus, a combination of progressive and standing waves, as is seen in Figure 203-8. This is only the first of many instances where we will find that the Columbia River estuary is a complicated system.

The available current data are much less complete than the tidal height data. Furthermore, the current data listed in Table 203-3 are for surface currents, at low river stages only. Under these conditions, salinity intrusion in the estuary is maximized and the times of slack water vary considerably with depth. The times of slack and peak flows are much more affected by runoff levels than are the times of HW and LW. With these limitations in mind, interpretation of the current data suggests that the standing wave tide character is important up to about Harrington Point. The incoming tidal wave apparently undergoes partial reflection as it passes the abrupt narrowing of the river in the reach between Harrington and Jim Crow Points. Upstream of Jim Crow Point, the tidal wave is nearly a progressive wave.

C. Tidal Characteristics of Youngs Bay

Insufficient data are available to define the tides in the major bays, except in Youngs Bay. The greatest diurnal ranges in the entire estuary are observed in Youngs Bay: 8.6 feet at the Pacific Power and Light pier in Astoria and in the Youngs River, and 8.7 feet in the Lewis and Clark River. The time of HW in Youngs Bay is very nearly the same as in the adjacent river channels. Furthermore, HW occurs nearly



COLUMBIA RIVER ESTUARY BATHYMETRIC CHART

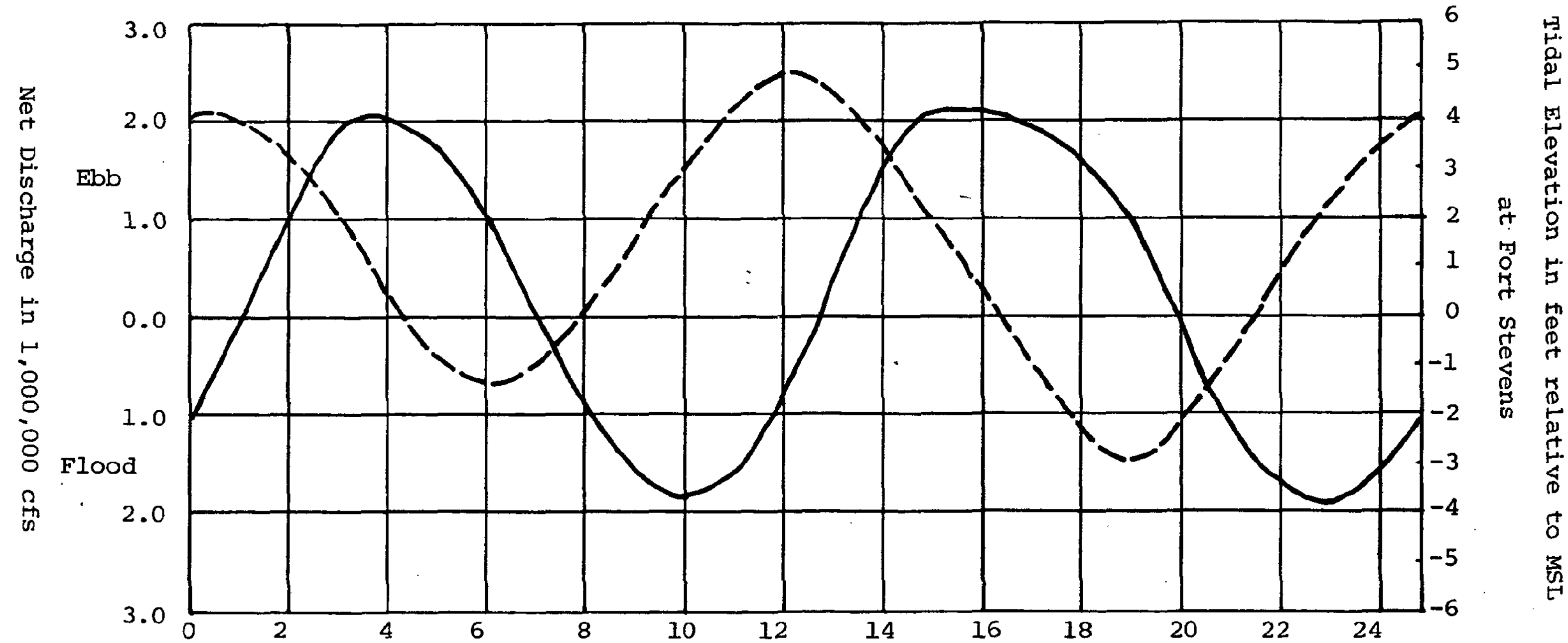
6' CONTOUR
12' CONTOUR
18' CONTOUR
30' CONTOUR
TIDAL FLAT
RIVER MILE

SOURCE: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SURVEY 1977

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
203-7

Tidal Height and River Discharge at the Mouth



Time in hours from moon's transit of 124th Meridian

——— River Discharge

– – – Tidal Elevation

Average Freshwater Flow = 200,000 cfs

Figure 203-8

River flow at the mouth and tidal height at Fort Stevens as a function of time over a diurnal tidal cycle. Note the mixed tide and the departure from a symmetrical sine curve.

From: Herrman, 1970

simultaneously through the Youngs Bay system, close to time of slack water. There is a delay of .06 to 1.5 hours in the time of LW; however, there is no evidence of a progression up river in Youngs River or the Lewis and Clark River of the times of HW or slack. The tide in Youngs Bay is almost a pure standing wave. Since the times of HW and LW are nearly the same in Youngs Bay as in the main river channel, the currents in Youngs Bay must be out of phase with those of the main channel, to produce the standing wave effect in the Bay. In fact, slack water occurs about two hours earlier in the Bay than in the main channel. This is only possible with a standing wave tide. A detailed discussion of the tides and circulation of Youngs Bay is found in the Alumax Report (OSU Ocean Engineering Programs, 1975).

D. Tidal Characteristics of the Other Bays

The tides in Baker Bay appear to be similar to those in the North Channel. A slight progressive effect is probably responsible for the small decrease in range and the short delay in HW and LW at Ilwaco, compared with Chinook and Fort Canby. A slight standing wave effect in Cathlamet Bay is suggested by the increase in range at Settlers Point (8.0 feet) over Harrington Point (7.7 feet). No tidal data are available for Grays Bay.

203.3 TIDAL CURRENTS AND CIRCULATION PATTERNS

The complex circulation in the Columbia River estuary is caused by a number of factors, the tides and the freshwater flow being the most important. The freshwater flow (Section 201) results from the downward slope of the river's surface and bed (water runs downhill), and it causes seaward currents to predominate in the estuary. Even under low river flow conditions, ebb lasts almost an hour longer than flood, at the surface in the estuary. The freshwater flow is the dominant influence in the river upstream of the estuary, overwhelming all others.

Figure 203-8 shows the variation of river flow and tidal height during a tidal cycle at the mouth under low runoff conditions (as reproduced by the Corps of Engineers Model), which is discussed in Section 207. While the influence of the tides causes the basic pattern of reversing currents, the freshwater flow causes the ebb flow to exceed the flood flow. Slack water does not occur at HW and LW as it should for a standing wave tide, nor do the peak ebb and flood flows occur at LW and HW as they should for a progressive wave tide. Thus, the tides in the Columbia River estuary have characteristics of both standing and progressive wave tides. The tides and the freshwater flow, then, are the basic factors controlling the estuarine circulation.

Figure 203-8 does not show vertical and lateral current variations. These variations result from the rotation of the earth, the shape of the channel, and the distribution of salt in estuarine waters. The mixing of relatively heavy salt water with relatively light river water causes currents related to the resultant density distribution (heavy water displaces light water). Wind driven currents, waves, and storm surges are also important in the Columbia River estuary. These phenomena are discussed in Section 204 on Estuarine Circulation.

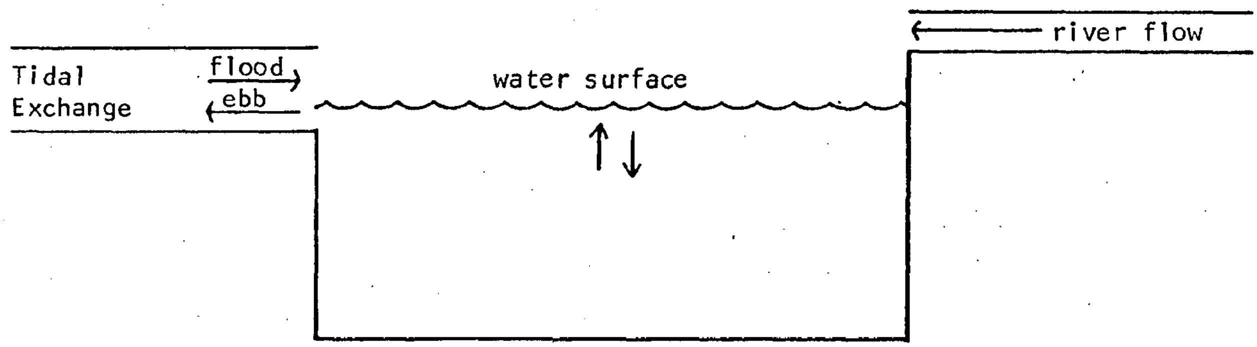
A. Mass Balance

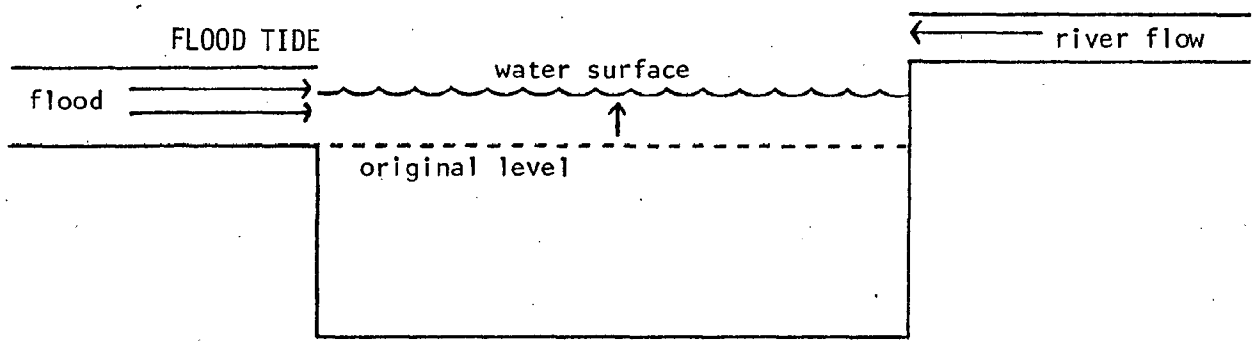
Figure 203-8 shows flood and ebb flows at the mouth of up to 1.8 and 2.2 million cfs respectively, during certain parts of the tidal cycle. Flows on a spring tide are considerably larger, up to 2.55 and 3.4 million cfs, respectively. We also know that upriver of the estuary, the flow is always downstream, toward the mouth. How far upstream current reversal occurs depends on the runoff level and the strength of the tide, but the exact river mile is unimportant here. For present purposes, we may think of the estuary as a box with two openings, one at the ocean end and one at some point in the river [RM 50 to RM 70, depending on the runoff level, where the current is always downstream (Figure 203-9)]. The object here is to relate the amount of water in the box to the rate of inflow and outflow at the two openings, that is, to establish the conservation of the mass of "principle of continuity" as the oceanographer calls it. We may state the principle as follows, "the change in volume of water in the box (estuary) is equal to the difference between the rate of flow into the box and the rate of flow out of the box," or in equation form:

Change in volume of water in box =
(rate of flow into the box) - (rate of flow out of box).

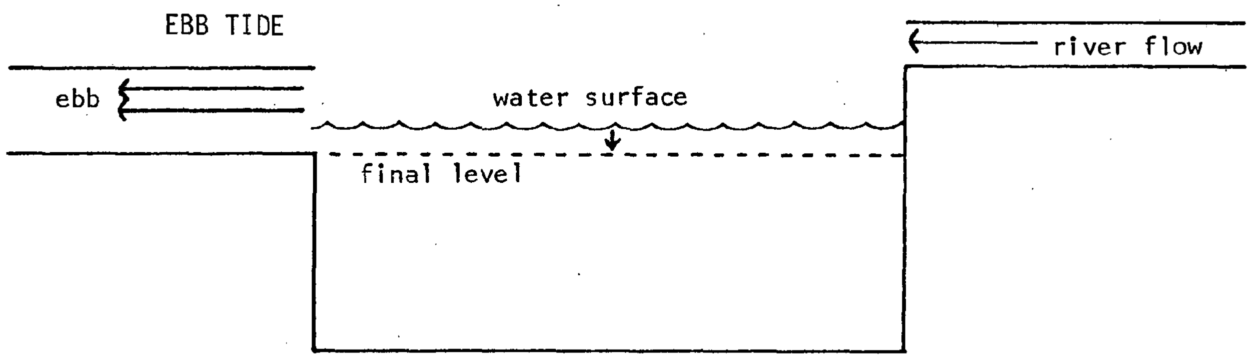
Figure 203-9

BOX MODEL OF AN ESTUARY





Increase in Volume of Box = Volume of River flow on flood + volume of flood tide.



Decrease in Volume of Box = Volume of ebb flow - volume of river flow on ebb

Total volume change = 0 = Volume of river flood during tidal cycle + flood flow volume - ebbflow volume

We have already chosen the box so that the flow at the river end is always into the box. The flow at the ocean end is alternately into (flood) and out of (ebb) the box (Figure 203-9). River water entering the estuary must, of course, eventually leave the estuary and flow into the ocean, as part of an outgoing (ebb) tide. The reason for the rise and fall of the tide in the estuary is obvious; as more water comes into estuary on flood tide, the average tide level of the estuary must rise. As the estuary empties on ebb tide, the average tide level of the estuary must fall.* This is simply conservation of mass. Furthermore, the total volume of the outgoing ebb tide must be equal to the sum of the volume of the incoming flood tide and the volume of the river flow during the tidal cycle, if the total amount of water in the estuary is to be the same at the end of the tidal cycle as it was at the beginning.

To give some idea of the relative importance of river flow and tidal exchange in the estuary, the tidal exchange at the mouth during an ebb or flood ranges from about 0.4 to 1.45 million cfs (Table 203-4), depending on the range of the tide, and averages about 0.64 million cfs. The average freshwater flow ranges from 0.12 to 0.63 million cfs, averaging about 0.27 million cfs. The average freshwater flow during a tidal cycle (12.4 hours) may vary from essentially zero to 2.25 million cfs, as a result of reservoir storage manipulations and other factors. Tidal flows are thus more than twice as strong, on the average, than the river flow, but the river flow is subject to wider variations and almost overwhelms the tidal influence during the spring freshet.

B. The Tidal Prism and Storage of Water in the Estuary

According to the simple box model of the estuary presented in the last portion, the volume change of the estuary during the tidal cycle results from the inflow of river water and the ebb and flood of the tidal currents at the mouth. The total inflow or outflow at the mouth on an ebb or flood tide is known as the tidal prism. The tidal prism is a fundamental concept in understanding the workings of any estuary.

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*There is one pitfall here. Tidal levels do not change simultaneously throughout the estuary (Table 203-3), thus the behavior of the tide at any given point is not the same as the behavior of the total volume of water in the estuary. Only for a standing wave tide are the two identical. Thus, we have spoken here of the "average tide level." The model used here is a very simple one. Other effects such as precipitation, evaporation, and tributaries flowing into the estuary have been ignored as insignificant.

TABLE 203-4

COLUMBIA RIVER TIDAL PRISM

FLOOD				EBB			
Tidal Range at Ft. Stevens in ft.	Total Flow 10^4 acre ft.	Total Flow 10^9 ft^3/tide	Average Flow Rate 10^5 ft^3/sec	Tidal Range at Ft. Stevens in ft.	Total Flow 10^4 acre ft/tide	Total Flow 10^9 ft^3/tide	Average Flow Rate 10^5 ft^3/sec
6.4	57.8	25.2	5.70	5.5	66.2	28.9	6.53
7.1	62.1	27.0	6.12	8.0	89.2	38.9	8.80
8.0	82.8	36.0	8.16	6.0	78.3	34.1	7.72
9.6	84.2	36.7	8.30	11.6	126.5	53.4	12.1
6.5*	61.6	26.85	6.01				
8.0*	75.8	33.02	7.38				

Except as otherwise noted, all values taken from measurements made on U.S. Army Corps of Engineers model, with 200,000 ft^3/sec freshwater flow.

From: Herrman, 1970

* Values computed from nautical charts, assuming listed tidal range at Astoria.

From: Neal, 1965

The size of the tidal prism depends on several factors, the most important being the range of the tide, the freshwater runoff level, the duration of the flood or ebb, and the elevation of the HW or LW at the end of the flood or ebb.

The tidal prism may be estimated by using nautical charts and data contained in the Tide Tables (as in Neal, 1965) or calculated from detailed observations of the ebb and flood currents at the mouth. Such measurements have not been made for the Columbia River, but the Corps of Engineers has calculated the tidal prism for flood and ebb tides and varying tidal ranges, from observations made on their estuary model (Table 203-4); the model is described in Section 207. As is evident in Table 203-4, ebb tide volumes or tidal prisms are larger than flood tide volumes for similar tidal ranges. The reason for this is explained in Figure 203-9; the ebb tidal prism must be equal to the flood tidal prism plus the river flow during the tidal cycle, if the volume of the estuary is to remain the same. The tidal prism volume must then depend on the level of freshwater runoff.

Another important source of tidal prism variation is the absolute level of the HW or LW at the end of a flood or ebb; the higher the absolute level, the greater the tidal prism for any given range. For example, a flood tide that begins at 1.0 feet and ends at 9.0 feet will have greater tidal prism than a flood tide beginning at 0.0 feet and ending at 8.0 feet, even though the ranges are the same (all elevations relative to MLLW). The reason for this phenomenon is the existence of the extensive tidal flats in the Columbia River estuary. A higher tide will inundate larger areas of the tidal flats, effectively increasing the water surface area of the estuary. It is important that estuarine tidal flats be preserved, not only for their intrinsic biological value, but also to preserve the flushing capacity of an estuary (see Section 206 for a detailed discussion). San Francisco Bay is the classic example of an estuary that has lost a substantial fraction of its tidal prism through the filling and diking of its tidelands. The ability of San Francisco Bay to cleanse itself of wastes has suffered as a result.

The tidal exchange in an estuary is at a maximum at the mouth and decreases upriver, to the point where flood tide is no longer observed.

That is, the tidal currents become progressively weaker in the upstream direction, until the riverine influence entirely dominates the tidal influence. The situation is illustrated in another box model, slightly more complicated than the first model (Figure 203-10a and b). Box 1 represents the ocean, boxes 2 and 3 represent the estuary, box 4 represents a section of river between approximately RM 50 and Bonneville Dam, where tidal height variations occur, but flood currents are never observed, and box 5 represents the upstream sections of the river.

On flood tide (Figure 203-10a), the tidal flow from the ocean into the estuary (F_1) in part, serves to raise the tide level in box 2 (the tidal prism P_2). Thus, the tidal flow into box 3 (F_2) is smaller than F_1 ($F_1 \approx F_2 + P_2$). Filling the tidal prism of box 3 (P_3) takes the entire tidal flow from 2. As a result, there is no tidal flow from box 3 into box 4 ($F_3 = 0$). Nonetheless, the surface level of box 4 rises; that is, the tidal wave propagates all the way to Bonneville Dam (RM 145), the head of the tide, even though upstream tidal currents extend only to about RM 50 (RM 70 under low flow conditions). The tides in this section of the river represent storage of inflowing river water (R_5), that will be discharged on the following ebb tide.

Figure 203-10b shows the situation on the following ebb tide. The downstream flow from each box into the next box downstream, is larger than the flow received from the box upstream, by the volume of the tidal prism. For example, the flow E_1 from box 2 into box 1 (the ocean) is bigger than the flow E_2 from box 3 into box 2, by the volume of the tidal prism P_2 of box 2 ($E_1 = E_2 + P_2$). The river flow R_5 over Bonneville Dam remains the same. The relationships among the various flood and ebb volumes are summarized in tabular form below each figure. Note that the ebb flow out of each section exceeds the flood flow into that section, by twice the river flow during a flood or ebb, which is the river flow during an entire tidal cycle. Detailed information on the tidal prism for Columbia River by nautical mile up to about RM 55, is found in Neal (1965).*

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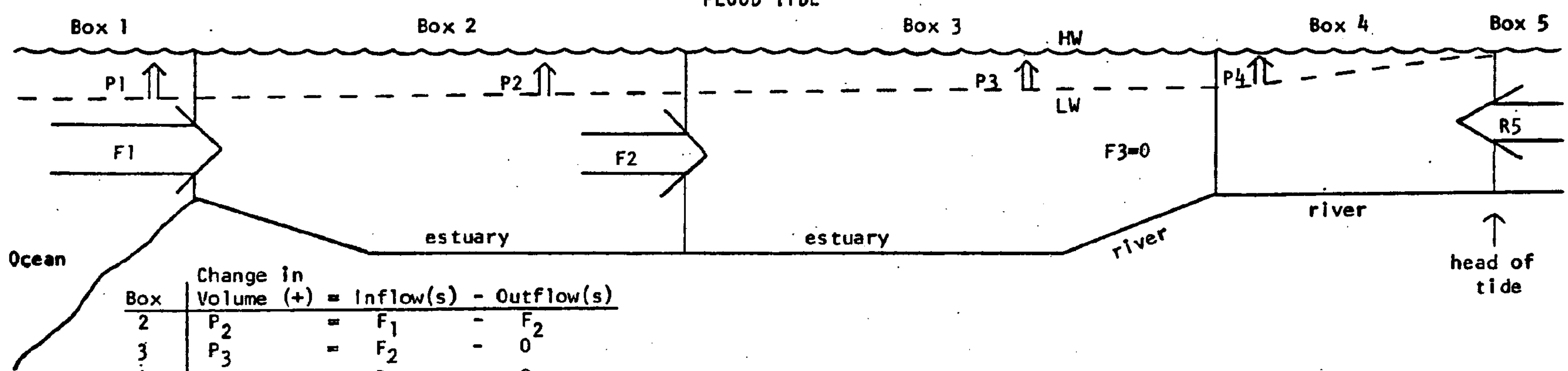
*The River Mile (RM) labels used here and by the Corps of Engineers are in statute miles (5280 ft). Nautical charts and some other sources use nautical miles (6000 ft).

FLOOD AND EBB TIDES IN AN ESTUARY - BOX MODEL

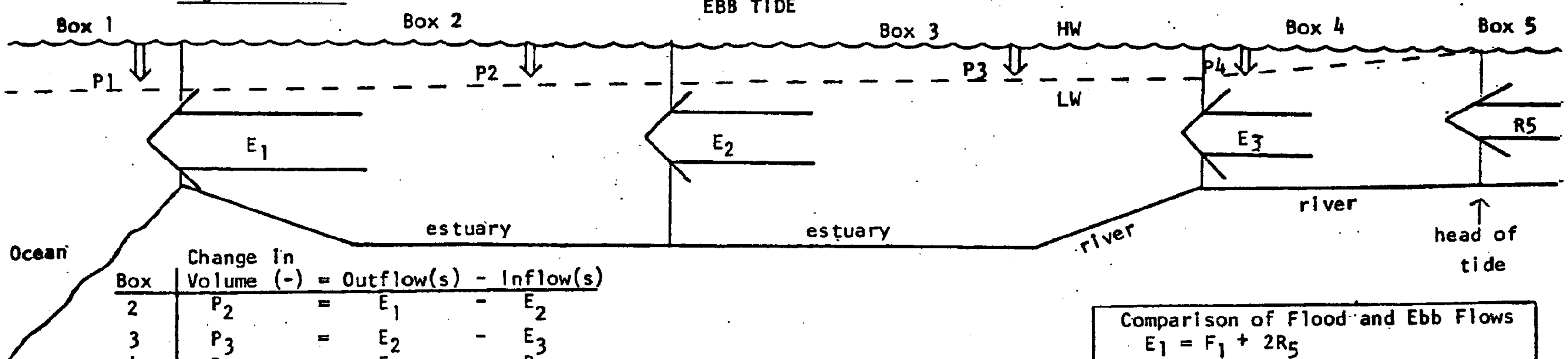
Figure 203-10a



Box	Change in Volume (+)	=	Inflow(s)	-	Outflow(s)
2	P_2	=	F_1	-	F_2
3	P_3	=	F_2	-	0
4	P_4	=	R_5	-	0
5	0				

$F_1 > F_2 > F_3$

Figure 203-10b



Box	Change in Volume (-)	=	Outflow(s)	-	Inflow(s)
2	P_2	=	E_1	-	E_2
3	P_3	=	E_2	-	E_3
4	P_4	=	E_3	-	R_5
5	0				

$E_1 > E_2 > E_3 > R_5$

Comparison of Flood and Ebb Flows

$E_1 = F_1 + 2R_5$

$E_2 = F_2 + 2R_5$

$E_3 = 2R_5$ ($F_3 = 0$)

Closely related to the concept of the tidal prism is that of storage of water in the estuary. The hypothetical tidal cycles with which we have been dealing have ended with the water level in the estuary at the same elevation at the end of the tidal cycle, as at the beginning of the cycle. A 12.4 or 24.8 hour tidal cycle, normally, however, ends with the water level higher or lower than at the beginning of the cycle (Figure 203-8). The result is temporary storage of sea and river water in the estuary or loss of water from the estuary to the ocean. This storage or loss, in turn, requires increased or decreased flow at the mouth.

How important is this effect? The surface area of the Columbia River and estuary to the Clatsop County border is about 150 square miles or 4.2 billion square feet. Thus, if the surface level of the estuary undergoes a net rise of one foot during a semi-diurnal (12.4 hour) tidal cycle, the storage of water in the estuary will be 4.2 billion cu ft. This compares with the runoff during the tidal cycle of 12.2 billion cu ft, assuming an average runoff of 269,000 cfs. If the estuary undergoes a net rise of 3 feet during a tidal cycle, then the net storage would be 12.6 billion ft greater than the runoff during this period. There would, under these circumstances, be no net runoff at the mouth of the river during the 12.4 hour period. A <u>diurnal inequality</u>, the height difference between successive highwaters or successive low waters, of three feet or more, is not at all uncommon during certain times of the month. Thus, successive ebb tides may vary greatly in strength. The tide level over a 24.8 hour diurnal tidal cycle generally results in a net change of no more than a foot.

There is an important exception to this rule however, and that concerns storm surges and other tidal height changes related to weather systems. A storm surge may result in a net upstream flow at the mouth for several days at a time (under low runoff condition), raising the water level in the estuary as much as four feet above normal levels. As the tide levels fall following such a surge, very strong ebb tides will be observed, contributing to dangerous conditions over the bar.

There is also a regular, bimonthly cycle of storage of water in the estuary, associated with spring and neap tides. Comparison (Figure

203-11) of daily mean discharges at Beaver Army Terminal (RM 53; representative of freshwater flow into the estuary) and Astoria (RM 14) shows clearly, this bimonthly storage pattern. When the flow at Astoria exceeds that at RM 53, the estuary empties. When the flow RM 53 exceeds that at Astoria, the estuary fills. Thus, freshwater flows through the estuary are far more variable than is indicated by examination of monthly average freshwater flow data (Section 202.3). This variability must be considered in interpreting field data collected in the estuary.

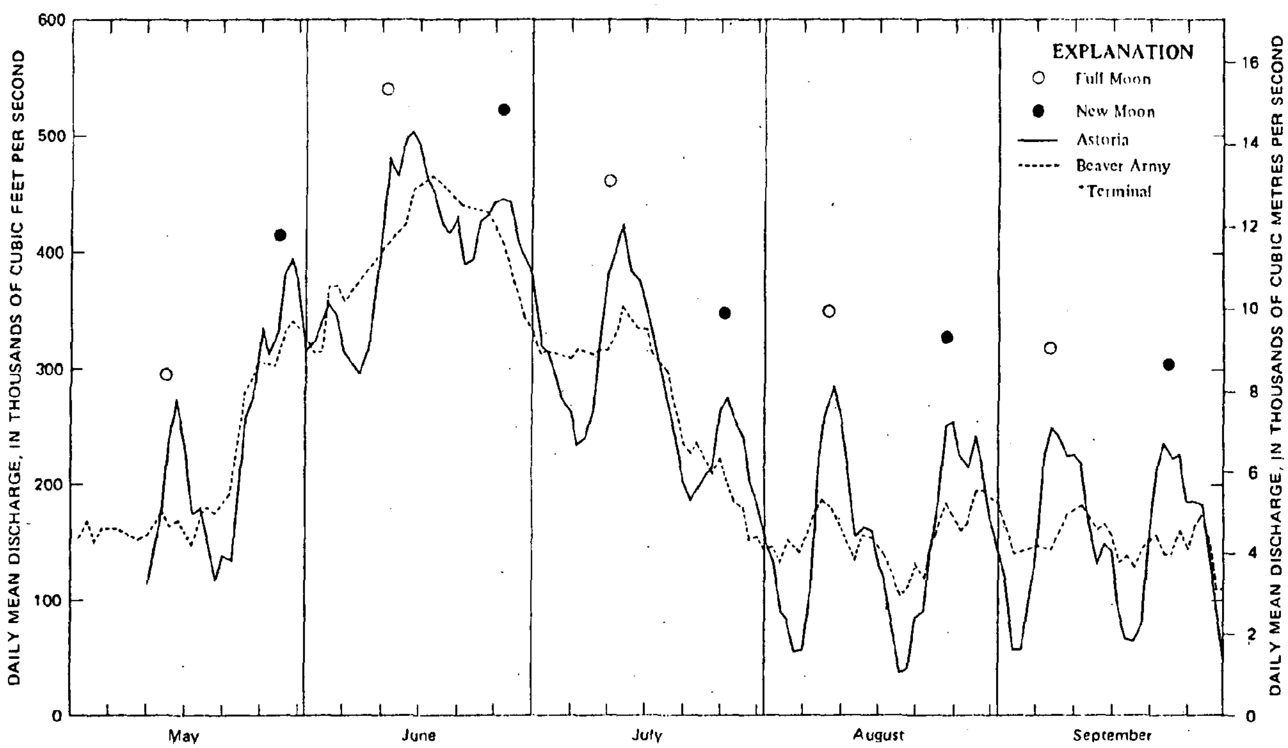
C. Observed Tidal Currents

The currents observed at any given point in the estuary are a product of a variety of influences. The effects of freshwater flow and the manifold influence of the tides have already been described. Other important influences are the irregular shape of the bottom of the channels, the curvature of the banks of the river, the rotation of the earth (the Coriolis effect), the winds, and the distribution of salt water in the estuary. Generally speaking, we can expect the strongest flows to follow the lines of the main channels. Irregularities in the bottom of the channels result in random changes in velocity, known as turbulence, and in a general decrease in flow speeds close to solid boundaries. Channel curvature also exerts an important effect. Flow is strongest to the outside of a curve. This is the familiar centrifugal force that one feels when going around a corner in an automobile. The channel from the entrance to Clatsop Spit is concave to the south. The strongest flow then, is on the outside (the north side), and there is a tendency for flood flows to be stronger in the North Channel than in the South Channel. The channel from Tongue Point to Clatsop Spit is concave to the north. Thus, ebb flows tend to be stronger, as a rule, in the south channel.

Another influence that must be considered is the rotation of the earth, the so-called "Coriolis force." There is a tendency for any moving object in the Northern Hemisphere to turn slightly to the right. This tendency must be considered in air navigation, weather forecasting, and oceanography. The Coriolis force is most important in large, slow flows, such as, weather systems and open-ocean currents. It is also

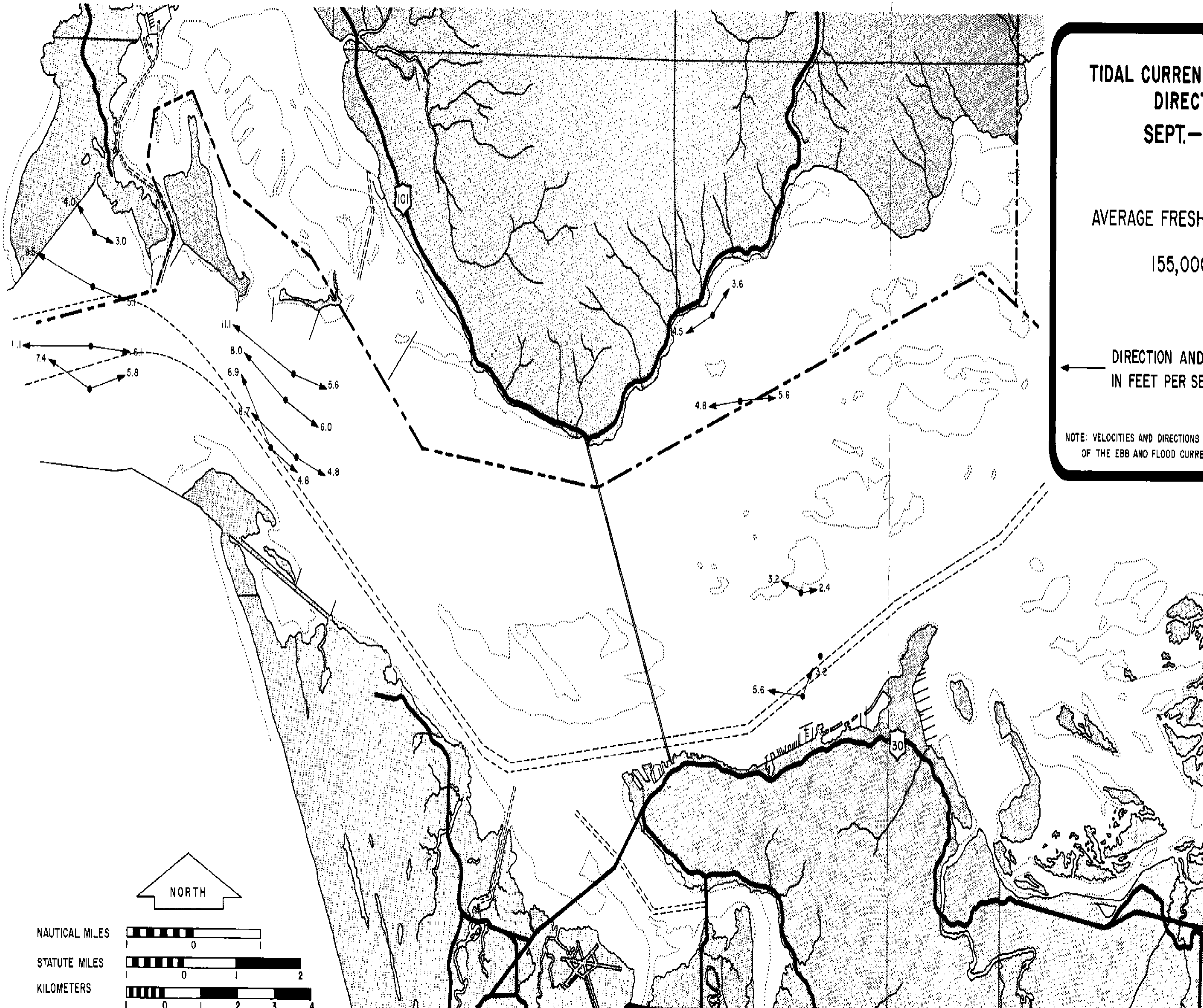
Figure 203-11

Daily Mean Discharges at Beaver Army Terminal and Astoria, May to September 1968



When the discharge is greater (less) at Astoria than at Beaver Army Terminal, the volume of water in the estuary decreases (increases). The cycle of emptying and filling is correlated with the cycle of neap and spring tides.

From: Lutz et al., 1975



TIDAL CURRENT SPEED AND DIRECTION SEPT.— 1959

AVERAGE FRESH WATER FLOW

155,000 c.f.s.

← DIRECTION AND SURFACE VELOCITY IN FEET PER SECOND

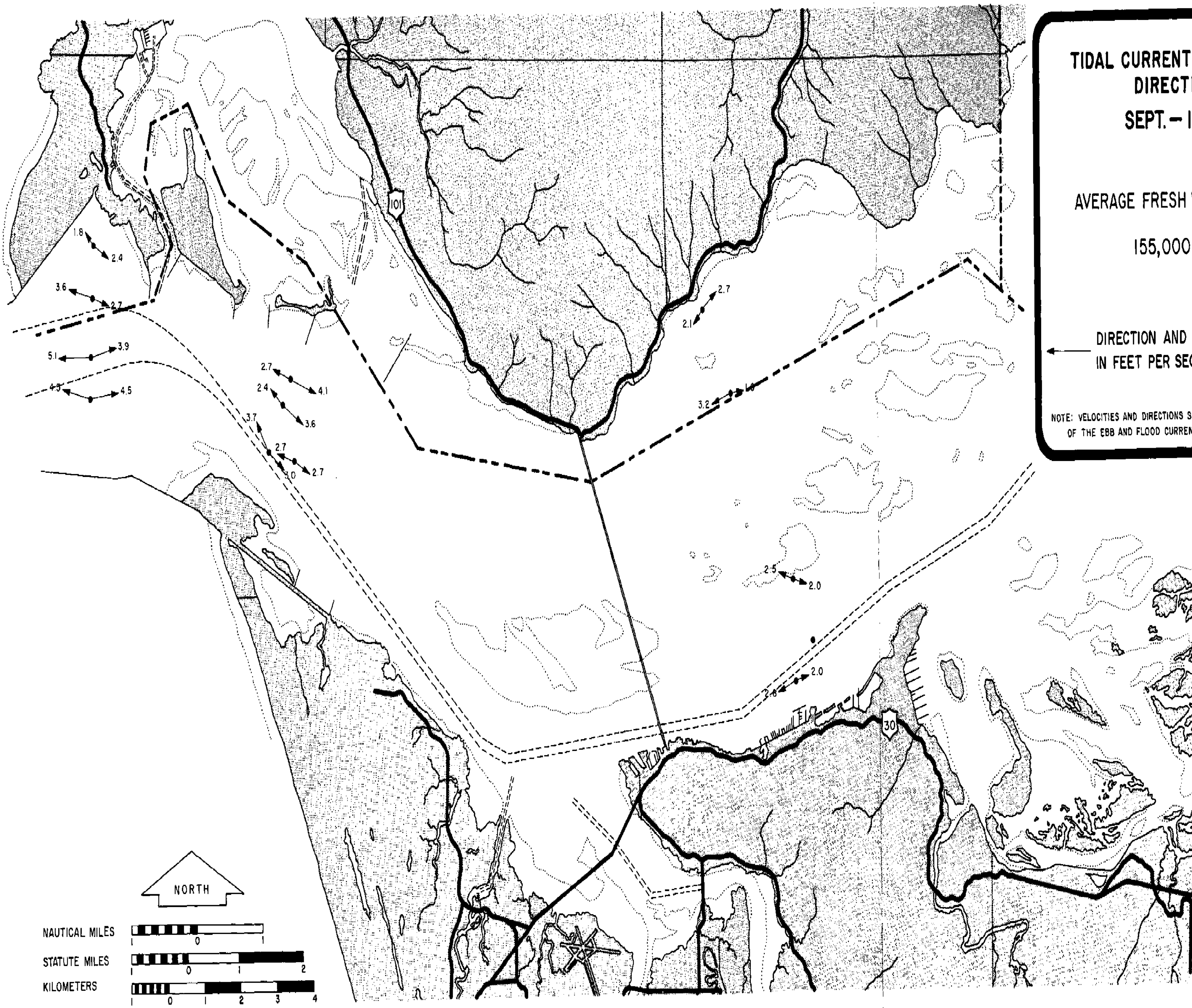
NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

203-12



TIDAL CURRENT SPEED AND DIRECTION
SEPT. — 1959

AVERAGE FRESH WATER FLOW

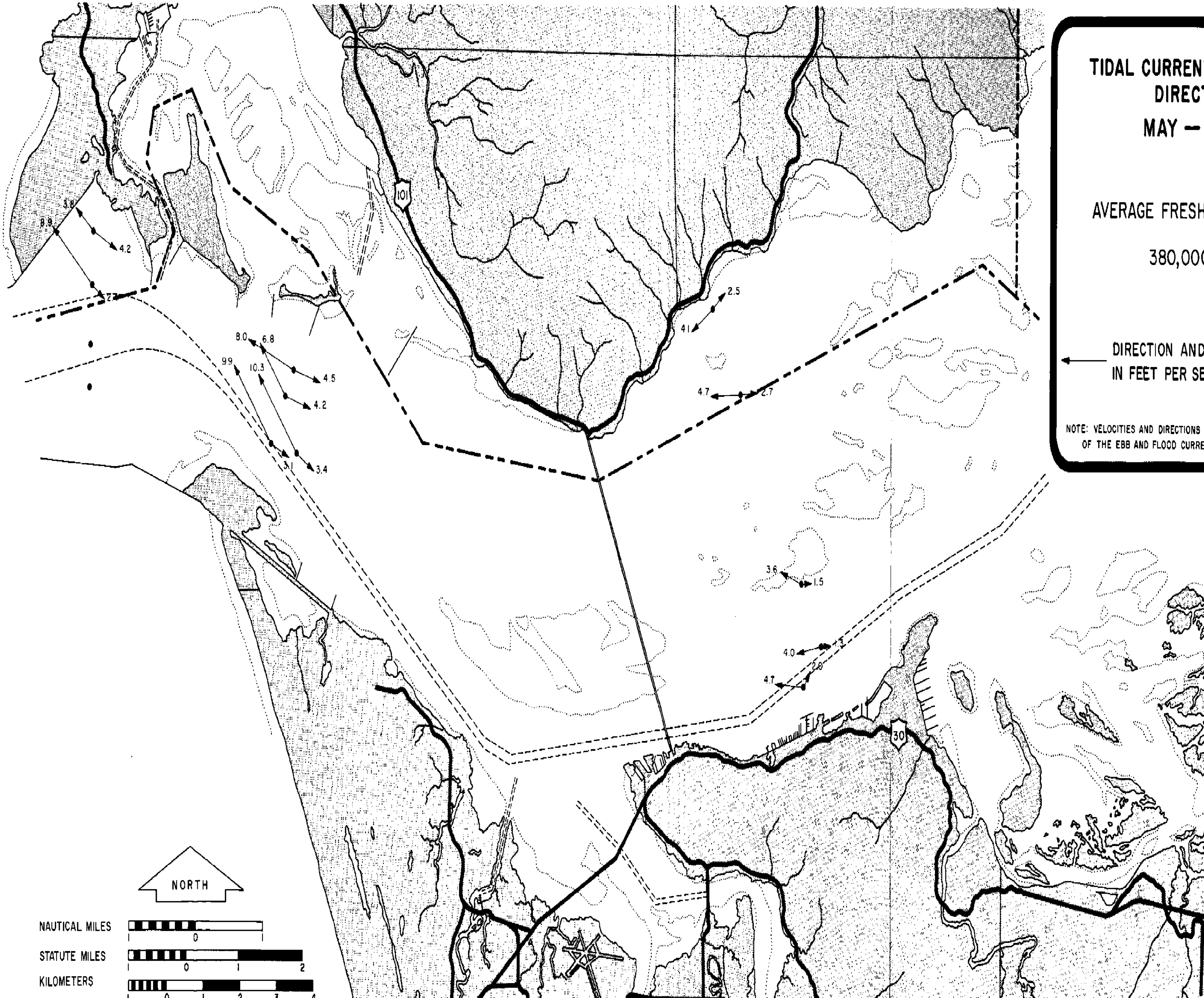
155,000 c.f.s.

← DIRECTION AND BOTTOM VELOCITY IN FEET PER SECOND

NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 203-13



TIDAL CURRENT SPEED AND DIRECTION
MAY — 1959

AVERAGE FRESH WATER FLOW

380,000 c.f.s.

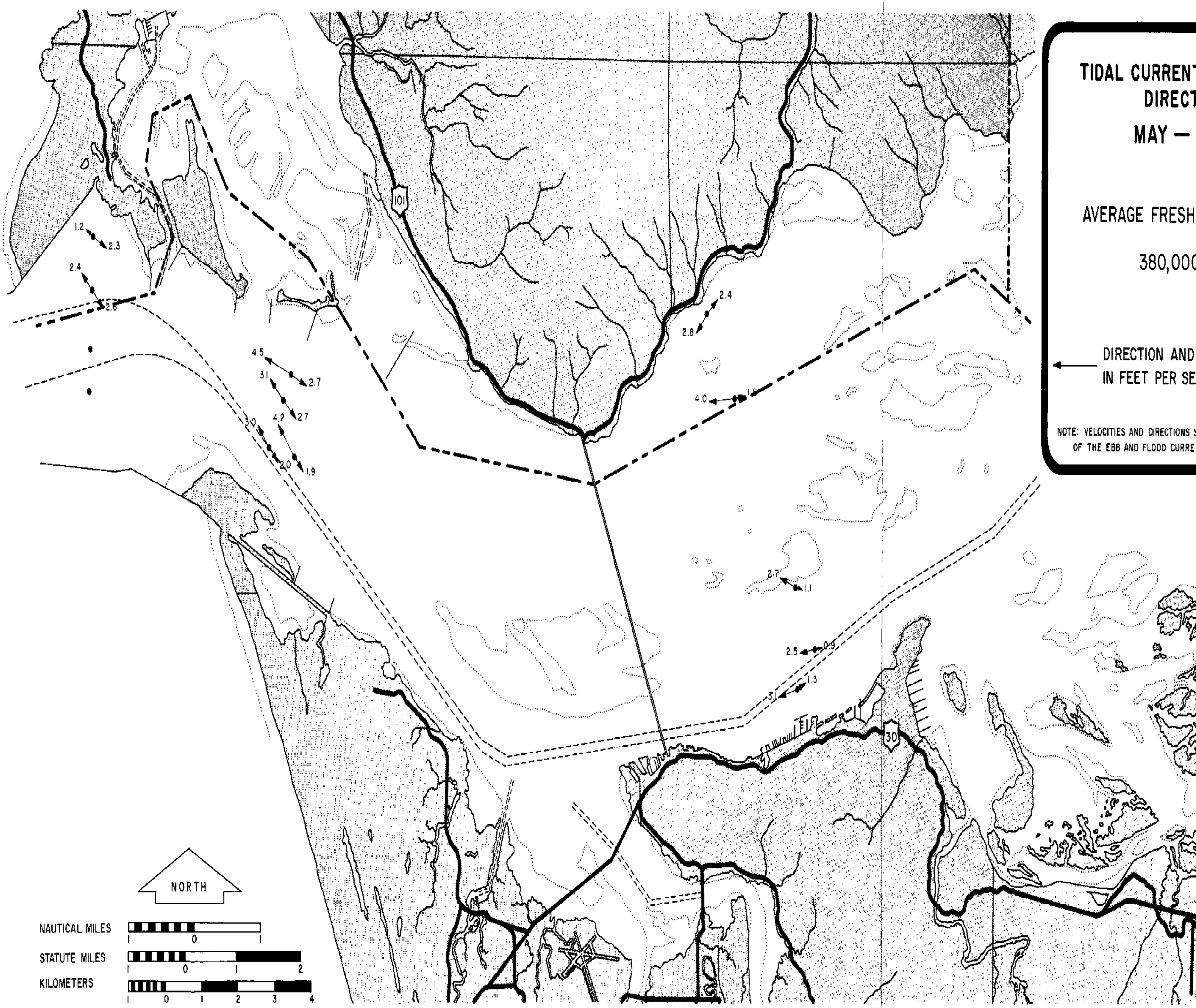
← DIRECTION AND SURFACE VELOCITY IN FEET PER SECOND

NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

203-14



TIDAL CURRENT SPEED AND DIRECTION

MAY — 1959

AVERAGE FRESH WATER FLOW

380,000 c.f.s.

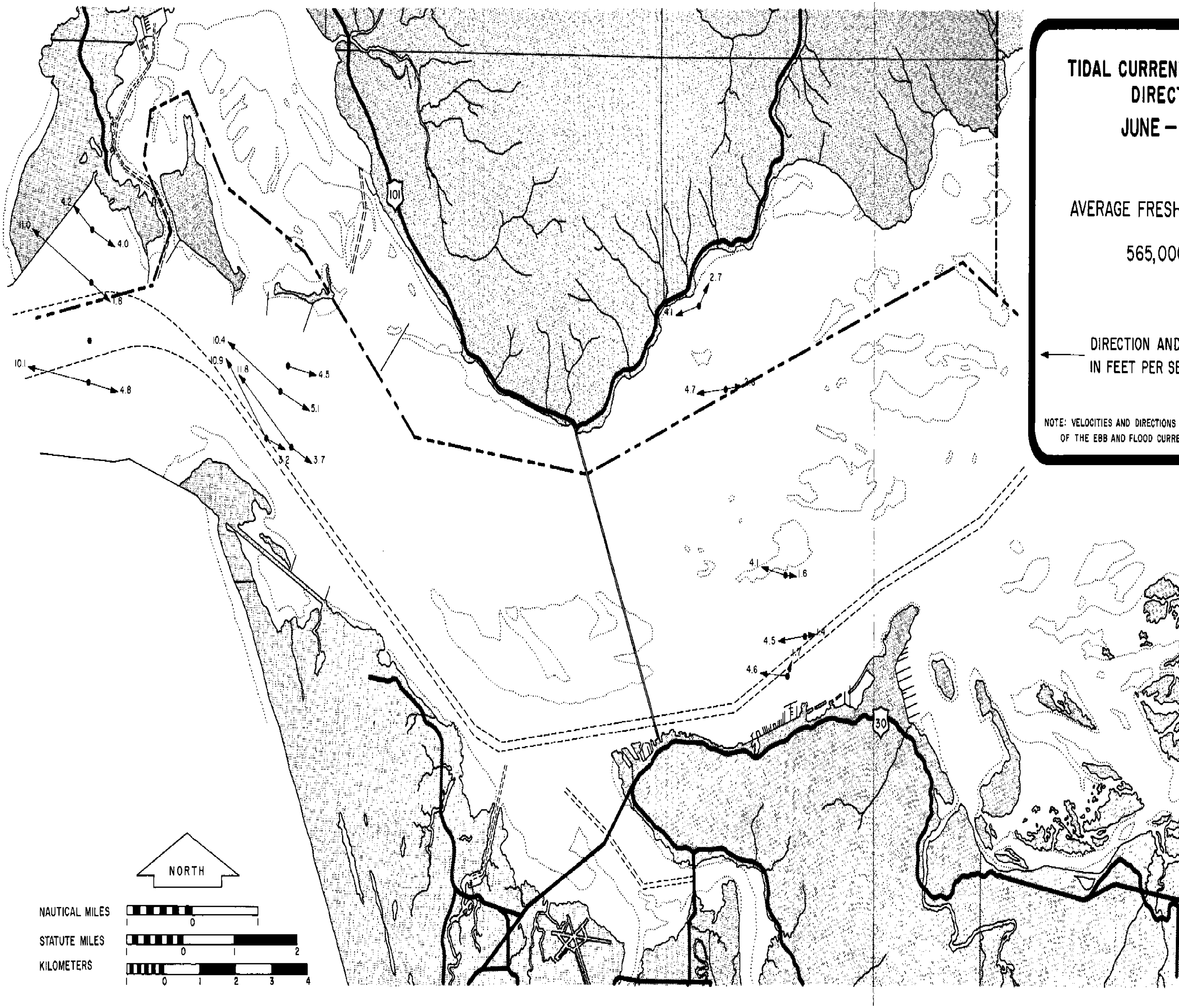
← DIRECTION AND BOTTOM VELOCITY IN FEET PER SECOND

NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

203-15



TIDAL CURRENT SPEED AND DIRECTION
JUNE – 1959

AVERAGE FRESH WATER FLOW

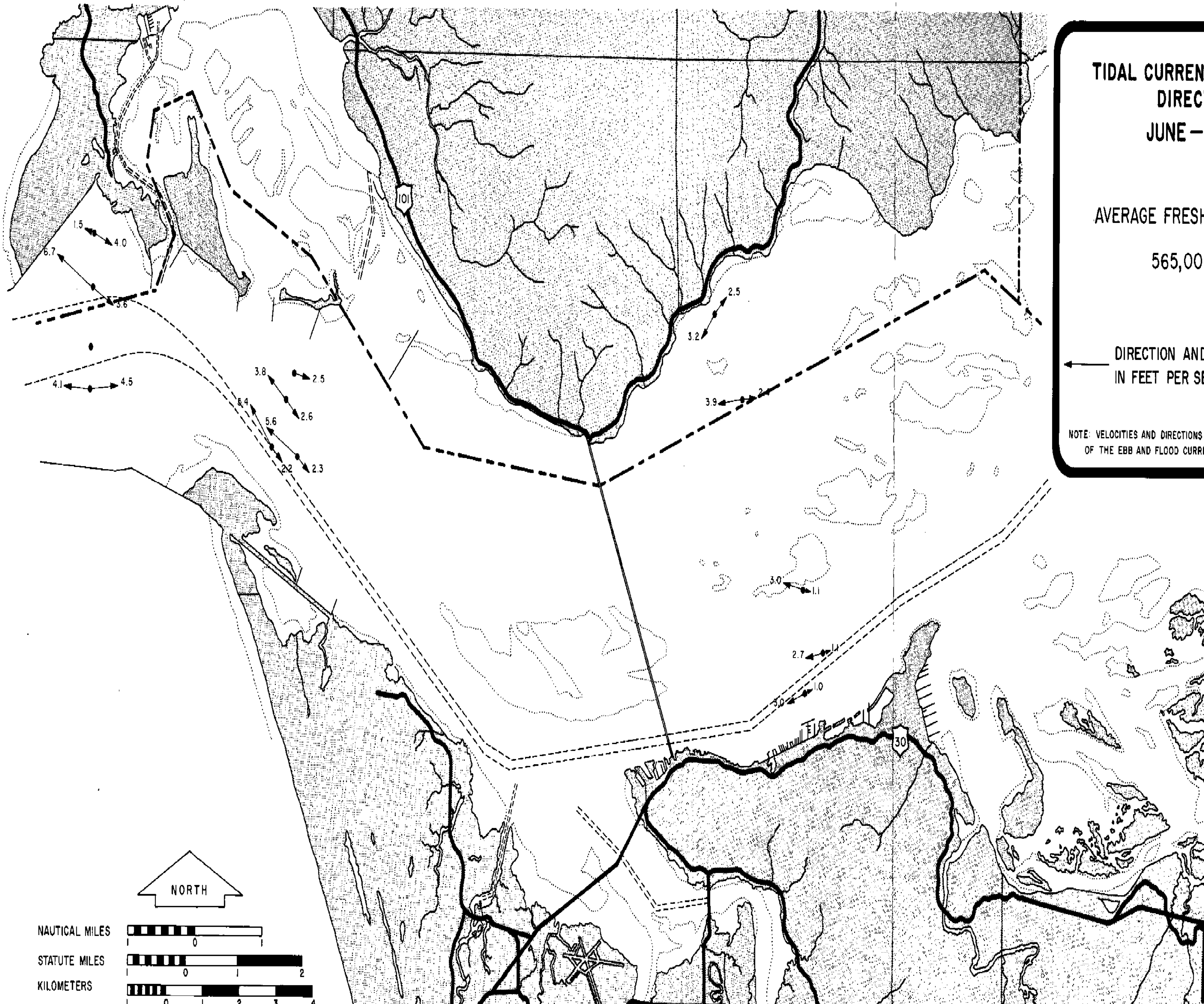
565,000 c.f.s.

← DIRECTION AND SURFACE VELOCITY IN FEET PER SECOND

NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
203-16



TIDAL CURRENT SPEED AND DIRECTION JUNE – 1959

AVERAGE FRESH WATER FLOW

565,000 c.f.s.

← DIRECTION AND BOTTOM VELOCITY IN FEET PER SECOND

NOTE: VELOCITIES AND DIRECTIONS SHOWN ARE AT THE STRENGTH OF THE EBB AND FLOOD CURRENTS.

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

203-17

important in many wide shallow estuaries. The currents in the Columbia River tend to be strong (up to 10 feet/sec), and the effects of the Coriolis force are somewhat weaker than those of the channel curvature in the reaches near the mouth. Winds and storm surges also produce strong currents, acting for brief periods of a few days or less, but no quantitative data are available on these effects.

There are no tidal current charts available for the Columbia River Estuary. The Corps of Engineers has published diagrams of surface and bottom peak flood and ebb currents under different river flow conditions, for 13 different locations in the estuary (Figures 203-12 to 203-17). These diagrams are based on short records and cannot be regarded as authoritative, but better data are not available. The 13 stations are located on three cross-sections, one between the jetties, one off Clatsop Spit, and one off Astoria. A detailed interpretation of these figures is only possible with an understanding of estuarine circulation, which is considered in Section 204.

A qualitative idea of the circulation in the estuary as a whole, or for any sub-area of the estuary, may be obtained from the Corps of Engineers scale model of the estuary. The flows in the model only approximate those in the estuary, and the model cannot be used to determine detailed circulation patterns until it is further verified. Furthermore, certain important processes such as winds, pollutant mixing and solar heating cannot be reproduced in the model. Particularly in shallow areas, the winds may be the dominant influence in determining the circulation.

The Oregon State University ALUMAX study team compiled from a series of photographs of the flows in the model charts showing the surface circulation at different stages of the tide in Youngs Bay for a freshwater flow of 215,000 cfs (Figure 203-18). A different pattern would result under different freshwater flow conditions, because the circulation patterns are dependent upon the degree of salinity intrusion. Youngs Bay is also subject to northwesterly and southwesterly winds that strongly influence circulation patterns. It would be extremely valuable to produce similar interpretive diagrams for surface and bottom currents in other areas of the estuary, particularly for the other bays.

CIRCULATION PATTERNS, YOUNGS BAY, OREGON

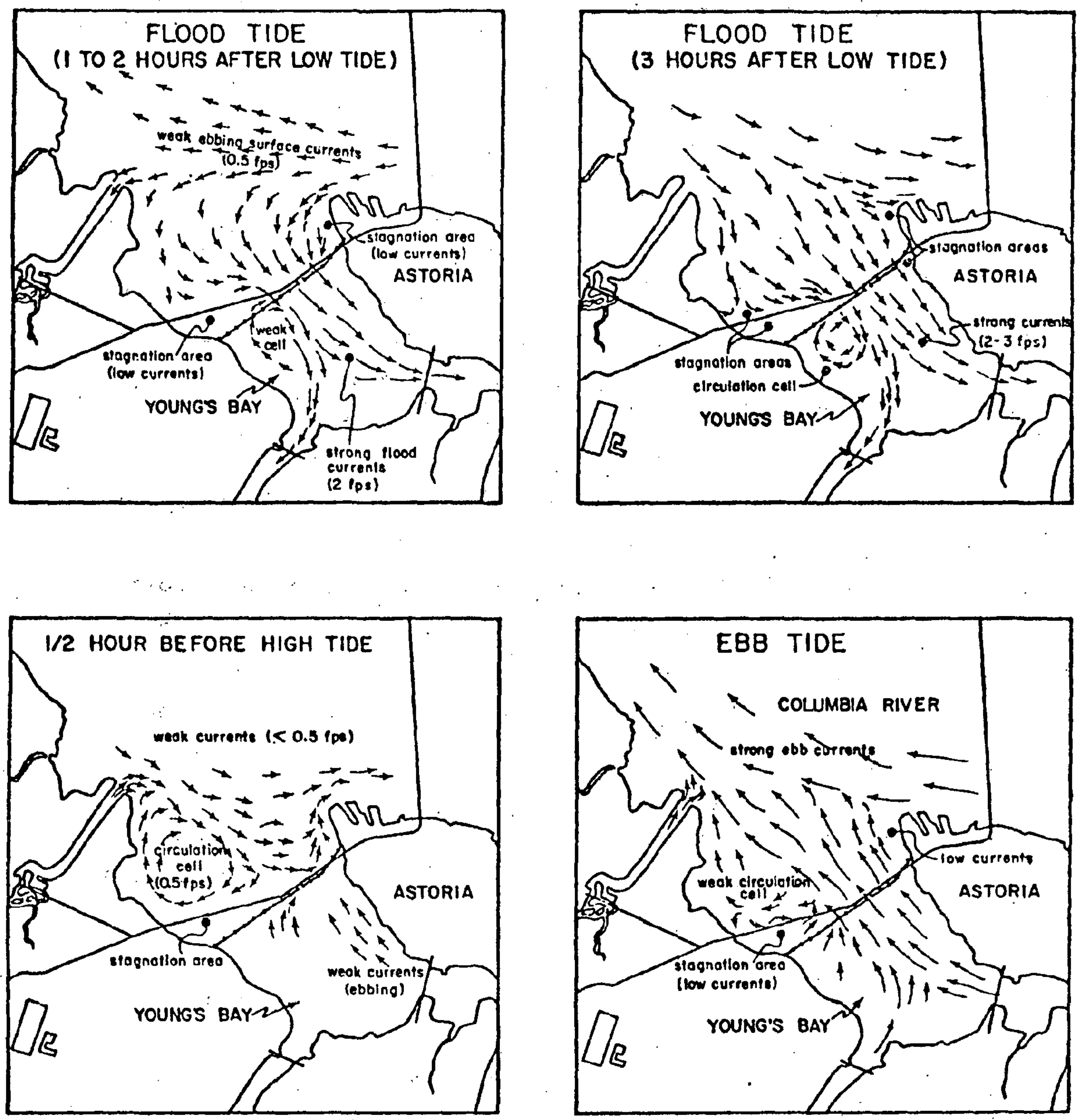


Figure 203-18

Tidal current patterns for Youngs Bay, as predicted by the Corps of Engineers model.

From: OSU Ocean Engineering Programs, 1975

203.4 TIDAL DATUM LEVELS AND MANAGEMENT OF AQUATIC LANDS

Certain tidal datum levels are used by both Oregon and Washington to define aquatic lands. Generally speaking, submerged lands (Oregon) and bedlands (Washington) are those lands below the level of tidal influence, and tidelands include the lands that are alternately covered and uncovered by the tide. Because of the differences in definitions, ownership, and management between the two states, it is necessary to discuss the situation in each state separately.

A. Oregon

In Oregon, tidelands and submerged lands that are owned by the state are managed by the Division of State Lands (DSL). Submerged lands are defined in Oregon as being those lands below MLW, and submersible lands or tidelands are defined as being those lands between MLW and MHW. DSL has the authority to buy, sell, and trade submerged and submersible lands, and extensive areas of Oregon's estuarine lands have been sold to private interests. The questions of ownership of, and regulatory power over these lands are quite complex and are currently disputed within the Columbia River. Generally speaking, ownership of submerged or submersible lands does not negate the public right of navigation in the overlying water, nor does land ownership imply ownership of the resources in the overlying waters. Ownership generally does imply the right of access, and with suitable permits, the right to construct piers, etc. Dredging and filling are subject to considerably stronger restraints. These matters are examined in more detail in Clark (1974). Advisory Committee to the State Land Board (1972) lists relevant ORS sections.

Other tidal datum elevations are important in Oregon because of the Land Conservation and Development Commission's (LCDC) Coastal Goals. In Oregon, <u>wetlands</u> are defined as extending from Extreme Low Water (ELW) to an upper limit defined by the extent of aquatic and semi-aquatic vegetation. This vegetation generally extends somewhat above Mean Higher High Water (MHHW). LCDC defines <u>intertidal areas</u> as being those areas between Mean Lower Low Water (MLLW) and MHHW. <u>Tidal Marsh</u> areas are vegetated wetlands above Lower High Water and below the line of non-aquatic vegetation. Shorelands are lands above MHHW.

B. Washington

In Washington, ownership and responsibility for management of bedlands and tidelands for the greatest long-term public benefit are vested in the Department of Natural Resources (DNR). Tidelands are those lands above ELW but below MHW, with the exceptions noted below. Upstream from Altoona, ELW is assumed to coincide with the Columbia River Datum (CRD). CRD was established by the Corps of Engineers for engineering purposes, as the average level of LW during a low-flow period in 1911. It does not, in actual fact, coincide with ELW. Below Altoona, ELW is assumed to be -3.0 feet on MLLW.

Washington distinguishes between first and second class tidelands. First class tidelands are those within or in front of the corporate limits of any city, and within one mile (along the shore) thereof on either side and between the line of MHW and the inner harbor line, where harbor lines have been established, and within two miles (along the shore) of the corporate limits on either side and between MHW and ELW, where harbor lines have not been established. First class tidelands may include areas below ELW, depending on the location of the inner harbor line. The inner harbor line is to be established in navigable waters. First class tidelands cannot be sold, but they may be leased for periods of up to 55 years. The harbor area is the area between the inner and outer harbor lines; it is to be reserved for landings, wharves, streets and other conveniences of navigation and commerce. The harbor area is to be between 50 and 2000 feet wide. The state may not sell any part of the harbor area, but it may lease areas for up to 30 years. The lands beyond the outer harbor line may not be sold or leased.

Second class tidelands are those lands between ELW and MHW beyond the harbor area, or more than two miles along the shore away from any city. They may not be sold, but they may be leased for periods of up to 55 years.

Although the Department of Natural Resources has sold some bedlands and tidelands in the Lower Columbia River, it is now prohibited from doing so. Almost all of Washington's bedlands in the Columbia River below the Astoria bridge have been leased to Washington Mineral Products, a black sands mining concern. The company has not yet attempted to do any mining in the estuary.

C. CREST

Since the CREST program must apply to both states, some compromise between the two aquatic land classification systems was needed. CREST defines waters as the water and submerged lands below ELW; wetlands, as those lands and waters between ELW and the line of non-aquatic vegetation (or MHHW, where a line of non-aquatic vegetation cannot be defined), and shorelands as those lands above MHHW or the line of non-aquatic vegetation and inside the CREST shoreland boundary. In non-tidal sloughs and lakes, wetlands extend from -6 feet on Ordinary Low Water to the line of non-aquatic vegetation. Ordinary Low Water is defined in non-tidal waters as the line to which the water normally recedes during the low-flow period of the year. The CREST shoreland area generally encompasses all tideland soils and extends 200 feet inland from MHHW, in areas where tidal soils are absent or less than 200 feet in horizontal extent.

203.5 REFERENCES

A. General Discussions of Tidal Phenomena

1. Duxbury, A.D. 1971. The Earth and its Oceans. Addison-Wesley, Reading, Ma. Chapter 17, pp.316-339.
2. Gross, M.G. 1972. Oceanography a View of the Earth. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. Chapter 10, pp.267-294.
3. McLellan, H.J. 1975. Elements of Physical Oceanography. Pergamon Press, New York, N.Y. Chapter 15, pp.107-116.

These three introductory oceanography textbooks contain general discussions of tidal phenomena and their causes, definitions of commonly used terms and some helpful illustrations. The most elementary discussion is contained in Gross, along with a section concerning estuarine tides. The best definitions and the most detailed discussion is contained in McLellan. Duxbury is intermediate in difficulty.

B. Tides and Currents in the Columbia River Estuary

1. Callaway, R.J. 1971. "Applications of Some Numerical Models to Pacific Northwest Estuaries." IN Proceedings: 1971 Technical Conference on Estuaries of the Pacific Northwest. Circ. #42, Engineering Experiment Station, Oregon State University, Corvallis, Oregon.

Contains harmonic analysis of tides for Tongue Point and other Northwest tide stations.

2. Herrmann, F.A. Jr. 1970. Tidal Prism Measurements at the Mouth of the Columbia River. U.S. Army Engineer Waterway Experiment Station, Vicksburg, Miss.

A study of current measurements made on the Corps of Engineers scale model of the estuary to calculate the tidal exchange into and out of the Columbia River under low runoff conditions. A lot of measurements with little interpretation.

3. Lutz, G.A., Hubbell, D.W., and Stevens, H.H. Jr. 1975. Discharge and Flow Distribution, Columbia River Estuary. Geological Survey Professional Paper. U.S. Government Printing Office, Washington, D.C. 433pp.

Tidal height observations and a limited number of current measurements were used to calibrate a mathematical model to calculate river flow on a daily basis at Beaver Army Terminal (RM53) and Astoria (RM15). The accuracy of the calculated flows is only fair, but the interpretation of the flow data and current measurements elucidates several important features of the water storage and circulation in the Columbia River Estuary. Flow predominance as a function of depth and lateral and longitudinal position in the channel is discussed. This is a very technical paper, not easily read by the layman.

4. Oregon State University, Ocean Engineering Programs. 1975. Physical Characteristics of the Youngs Bay Estuarine Environs. School of Engineering, Corvallis, Oregon.

Contains a readable discussion of tides and currents in the estuary and the various geodetic datum levels. Reports the results of research on the tides and tidal currents in Youngs Bay and River, and in the Skipanon and Lewis and Clark Rivers.

5. U.S. Army Corps of Engineers, Portland District. 1960. Current Measurement Program Columbia River at Mouth Washington and Oregon Interim Report. Volume I to IV.

Volume I contains the text explaining the field program and the plates in the other three volumes. Volume II contains the plates showing velocity. Volume III contains the plates showing direction. Volume IV contains plates showing salinity, tidal height, flow predominance, surface and bottom peak ebb and flood, currents, scour vs. shoal, and flow at the mouth. A large and valuable collection of data with no interpretation. Several theses and technical papers have been written using this data.

6. U.S. Department of Commerce, National Ocean Survey. 1975. Tide Tables 1976 West Coast of North and South America. 222pp.

7. U.S. Department of Commerce, National Ocean Survey. 1975. Tidal Current Tables, 1976, Pacific Coast of North America and Asia.

These are the official volumes upon which all published tidal predictions for the West Coast of the U.S. are based. Smaller unofficial volumes for the Oregon and Washington Coasts and the Columbia River are available locally. They contain daily predictions of tidal heights, times, current speeds and directions, and times of slacks for reference stations. The predictions for a large number of other stations may be calculated from those of the reference stations.

C. Tidelands and Submerged Lands

1. Advisory Committee to the State Land Board. 1972. Submerged and Submersible Lands of Oregon. State of Oregon, Salem, Oregon. 165pp.

A compilation of ORS Sections, court cases and State Attorney Generals' opinions relating to all aspects of state lands, including submerged and submersible lands. Index.

2. Clark, C.D. 1974. Survey of Oregon's Water Laws. Water Resources Institute, Oregon State University, Corvallis, Oregon. pp.1-65.

Contains a discussion of the laws and court decisions pertaining to submerged and submersible lands. The discussion is very legalistic, but clear and well-organized.

3. Division of State Lands. 1973. Oregon Estuaries. State of Oregon, Salem, Oregon. n.p.

An inventory of tidelands in Oregon estuaries. The section on the Columbia River is not detailed enough to be of any practical use but is good for general features. Contains excellent illustrations that define the significance of various tidal datum levels.

204 ESTUARINE CIRCULATION

COLUMBIA RIVER

ESTUARINE CIRCULATION

David Jay

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FIGURES

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TABLES

204 ESTUARINE CIRCULATION

204.1 GENERAL FEATURES OF ESTUARIES

A. Definitions

The classic definition of an estuary is provided by Cameron and Pritchard: "An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage." [IN The Sea, Vol II (M.N. Hill, ed)]. We have defined the estuary, for planning purposes, as extending to the east end of Puget Island at river mile (RM) 46. In fact, the upstream limit of salt intrusion at the end of flood tide, for the minimum regulated monthly average Columbia River flow of about 120,000 cfs, is near Harrington Point (RM 23). Much lower daily average flows occur (Section 202.3) and result in salinity intrusion at least as far as Pillar Rock. It is doubtful, however, that salinity intrusion ever reaches even the west end of Puget Island. In contrast, the maximum regulated river flow of 600,000 cfs results in salinity intrusion, at the end of flood tide, only in the lower 10 miles of the estuary. Salinity intrusion at the end of ebb tide during high river flow does not reach RM 3.

The Columbia River is the second largest river in North America and its estuary deviates from Pritchard's definition in that large sections of it do not contain any salt water during much of the year. Nonetheless, the sloughs and tidal marshes between Cathlamet Bay and Puget Island are an integral part of the physical and biological system thought of as the estuary. It is important to realize, however, that the salinity pattern of the Columbia River estuary is not typical of most coastal plain-drowned-river valley estuaries. Most such estuaries are more saline and have a less variable salinity pattern. Because of the very strong freshwater flow, much of the mixing that takes place inside most estuaries occurs outside the mouth of the Columbia River, in the coastal ocean.

B. Classification of Estuaries by Geomorphology

Estuaries are classified in different ways. The simplest and most intuitive system is based on geomorphology, that is, on geological form. Geologically speaking, estuaries are a transition region between land and sea. Sea level rises and falls relatively quickly over geological time.

Large quantities of sediment are brought down the river into the estuary and other sediments are eroded from the open coast by wave action. Sediments from both sources are deposited in the estuary. Thus, estuaries are relatively transient phenomena, with a lifetime of few thousand years or less.

The Columbia River estuary is of the drowned-river-valley type. During past ice ages, sea level was as much as 600 feet below its present level. This allowed the Columbia River to build a valley out across the continental shelf. The extension of this valley down the continental slope is known as the Astoria Canyon and was eroded during periods of lowered sea level by sediments carried to the edge of the shelf, moving down the continental slope. As sea level rose to its present level, the former river channel was flooded by seawater and began to fill with sediment. The present position of the estuary is a function of sea level. The river channel and estuary of glacial times are now covered by many feet of sediment. Other northwest estuaries such as Puget Sound are of the fjord type, and they were carved out by glacial action. San Francisco Bay, on the other hand, was caused by movements of the San Andreas fault system. Many Gulf and East Coast estuaries are of the bar-built type, and they have shallow lagoons behind large sand spits or barrier beaches. Many drowned-river-valley estuaries, including the Columbia River, also have sand spits at the entrance.

C. Classification of Estuaries by Salinity Structure.

The currents caused by the freshwater inflow and tidal action in the Columbia River have been discussed in Section 202 and 203. Currents in estuaries are also caused by the density distribution; that is, water of lesser density is displaced by water of greater density.

The density of sea water is determined by the salinity or the amount of dissolved salts in grams per kilogram of water (or parts per thousand, symbolized by $^{\circ}/_{\circ\circ}$), the temperature, the pressure, and the amount of suspended sediment. The amount of suspended sediment is generally important only near the bottom. The pressure can be ignored since the depth range is small (from 0 to about 200 feet). Thus, we may think of the density as determined by the salinity and temperature of the water (Figure 204-1).

Density increases as salinity increases and temperature decreases. As a practical rule, the salinity is the predominant factor in determining the density structure of most Pacific Northwest estuaries. In the Columbia River estuary, temperature plays only a secondary role during most seasons.

Therefore, the salinity structure is the primary concern in this section. In the freshwater reaches of the river, vertical temperature gradients are the main cause of density differences, but the density differences are small, compared to those caused by salinity intrusion in the lower part of the estuary. Temperature differences are most important during the summer; then, the sea water intruding into the estuary is cold because of upwelling, and the freshwater is at its warmest (Section 206). Temperature is also a very important determinant of biological activity. The strong wind, wave and tidal mixing tends to destroy vertical density stratification and has a strong influence over the circulation.

Because salinity is the major determinant of density, estuaries are also classified by salinity structure. Most estuaries belong to one of the following four types:

1. Salt-Wedge Estuaries

A river with a large freshwater discharge and relatively little tidal action, such as the Mississippi River, will form a "salt-wedge" estuary (Figure 204-2). Salt water intrudes along the bottom, and the freshwater flows out in the surface layer. The limited tidal action and the sharp difference in flow speed between the top and bottom layer cause a certain amount of mixing between the layers. Although salt water from the lower layer mixes into the upper layer, very little freshwater from the upper layer mixes down into the lower layer, as shown in Figure 204-3. This mixing, which is inhibited by the density difference between the layers, is essentially a one-way process.

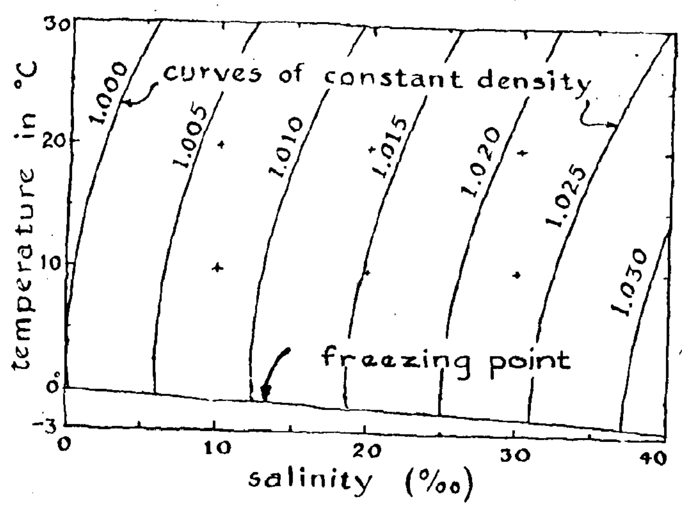
This vertical mixing pattern is known as entrainment, and is an extremely important feature of the circulation of salt-wedge and partially-mixed estuaries. The continual loss of water from the lower layer into the upper layer necessitates landward flow in the salt wedge, to satisfy the conservation of mass. The surface layer becomes increasingly brackish toward the ocean, but the salinity difference between the layers is usually at least 20 °/₀₀.

2. Fjords

Fjords have a salinity structure similar to that of the salt-wedge estuary. The major differences are topographic. Fjords tend to be long. narrow, and very deep; by definition, they have a sill at the mouth (Figure 204-4). If the sill protrudes into the fresh, surface layer, then renewal of the bottom salt water layer inside the sill is cut off almost completely.

Figure 204-1

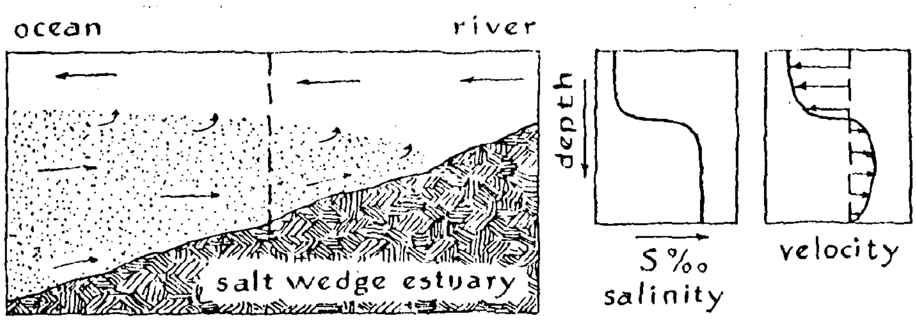
Seawater Density as Determined by Temperature and Salinity



From: Gross, 1972

Figure 204-2

Salinity and Current Speed In a Salt-Wedge Estuary

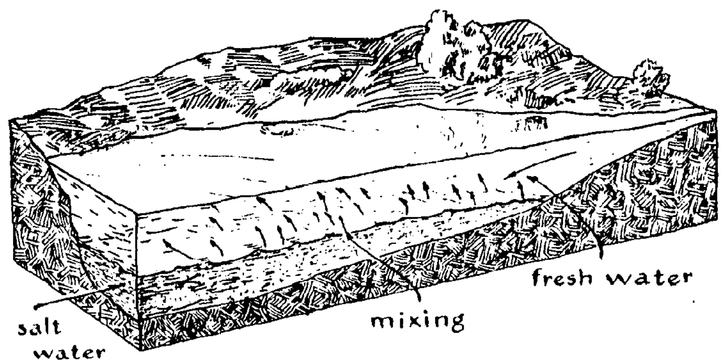


Variation in salinity and current speed with depth in a simple salt-wedge estuary. The two layers are sharply defined by the vertical gradients in temperature and salinity.

From: Gross, 1972

Figure 204-3

Mixing in a Salt-Wedge Estuary

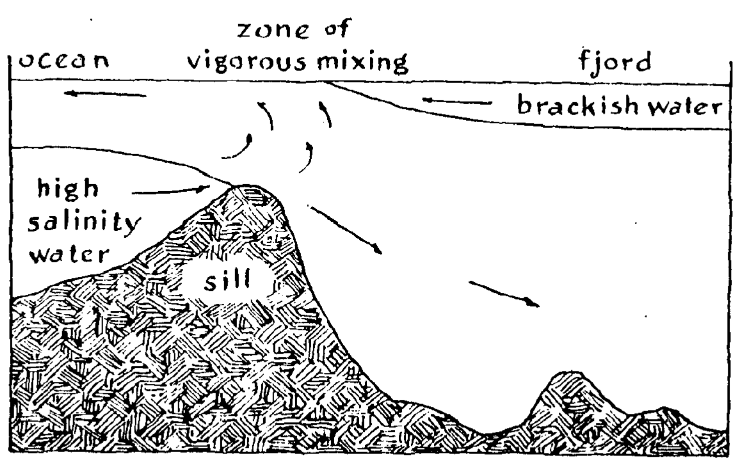


Schematic representation of a simple salt-wedge estuary showing the two-layered structure with a landward flow in the saline subsurface layer and a seaward flow in the less-saline surface layer.

From: Gross, 1972

Figure 204-4

Mixing in a Fjord



Schematic representation of circulation in a simple, fjord-like estuary. Note sill that restricts circulation of the bottom layer.

From: Gross, 1972

The oxygen in the bottom layer of such a fjord may be entirely used up by decaying organic matter, and toxic hydrogen sulfide (H_2S) may buildup over a period of years. On those rare occasions when the bottom water is displaced by heavier sea water (during a large storm or very high tide), the ensuing vertical mixing of the H_2S may result in fish kills. However, most fjords maintain enough bottom circulation to avoid such toxic conditions.

3. Partially-Mixed Estuaries

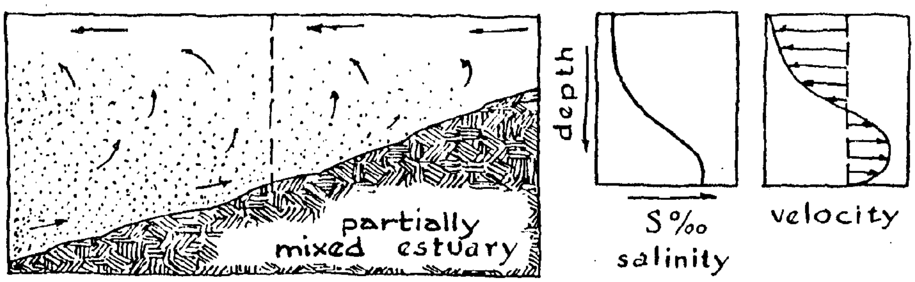
An estuary with a smaller ratio of freshwater flow to tidal flow than a salt-wedge estuary will usually fall into the partially-mixed or moderately-stratified category. Let us consider the circulation in such an estuary. A partially-mixed estuary still has a landward flow of relatively salty water at the bottom and seaward flow of relatively freshwater in the surface layer (the estuarine or gravitational circulation; see section 204.1D), but the layers are less sharply defined (Figure 204-5). The changes (with depth) of salinity and velocity, are more gradual than in the salt-wedge case, and the top to bottom salinity difference is generally less than 20°/oo. Vertical mixing, driven by tidal energy, is greatly enhanced over the salt-wedge case, and even the surface water will be noticeably saline.

Consider for an example, a case where the average salinity of the surface layer at cross-section A of an estuary is 17.5°/oo, the average salinity at cross section A of the bottom layer is 33°/oo and the average salinity of the ocean water is 35°/oo. Since the salinity of pure river water is nearly zero, the surface layer must consist on the average, of one part ocean water and one part river water (Figure 204-6). The bottom layer, is almost entirely (about 93%) ocean water. Ignoring the small amount of freshwater that has been mixed down into the lower layers, the volume of water flowing out to sea in the top layer at cross-section A is about twice the freshwater flow. The compensating inflow in the bottom layer that supplies the sea water in the surface layer must then be equal to river flow. The salinity of both layers must increase downstream (though the changes in the bottom layer are less than those in the top layer).

At cross-section B, closer to the ocean (Figure 204-6), the salinity of the top layer is 30°/oo and that of the bottom layer 34°/oo. The seaward flow in the top layer must then be about seven times the freshwater flow and the upstream flow in the bottom layer about six times the fresh-

Figure 204-5a

Salinity and Current Speed
in a Partially-Mixed Estuary

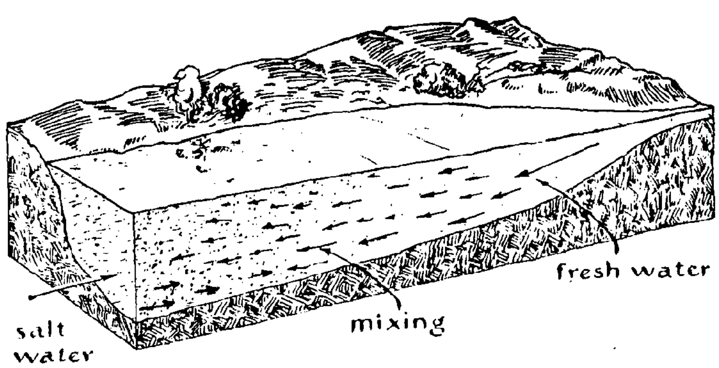


The variations in salinity and current speed in a partially-mixed estuary. Vertical gradients in salinity and current are not abrupt.

From: Gross, 1972

Figure 204-5b

Mixing in a Partially-Mixed Estuary



Schematic representation of water movements in a partially-mixed estuary. There is a net landward movement in the subsurface layers and a seaward flow in the surface layer, although the difference between the layers is not as pronounced as in the salt-wedge estuary.

From: Gross, 1972

water flow, since the surface layer is 6/7th sea water. The volume of both the upstream flow in the bottom layer and the downstream flow in the surface layer increases downstream toward the ocean. This is simply the result of conservation of mass. The flow in the bottom layer decreases in the upstream direction, as water from the bottom layer is entrained into the upper layer (with very little water from the upper layer being mixed down into the lower layer). The flow of the top layer increases as its salinity increases toward the ocean because of the entrainment of water from below.

4. Vertically Well-Mixed Estuaries

An estuary will aproach a vertically well-mixed condition when the ratio of tidal flow to river flow becomes large. Like the salt-wedge estuary, the well-mixed estuary is somewhat of an abstraction, and most real estuaries fall in between, in the partially-mixed category. Practically speaking, an estuary where the surface to bottom salinity difference is less than 1 or 2°/oo may be classified as vertically well-mixed.

In a well-mixed estuary (shown in Figure 204-7), the salinity does not vary with depth. The salinity does, however, increase toward the ocean. Because of the absence of vertical salinity differences, there is no vertical salt transport and no entrainment. The net flow (averaging out the tidal fluctuations) is not, as one might expect, the same at all depths. There are two reasons: first, the influence of bottom friction, and second, the horizontal differences in salinity (and thus density). There remains a tendency for a strong surface outflow, with a weaker outflow or no net flow at depth. In the absence of net upstream flow along the bottom, the question naturally arises as to why the salt penetration may be observed several tidal excursions from the mouth, even at the end of the ebb tide. The salt penetration is related to the interactions between tidal currents, tidal heights and salinity variations during a tidal cycle. Without tidal currents and the resultant turbulent mixing, salt penetration would not occur at all in an estuary with a net downstream flow at all depths.

Vertically well-mixed estuaries may be further subdivided into those that are uniform in the cross-channel direction (i.e laterally homogenous) and those that are not. Laterally-homogenous estuaries are generally narrow and without the uneven bottom, shoals, marsh islands and bends in the channel that are found in the Columbia River. In large bays, the coriolis force is often important because, as the earth rotates, flowing water tends to turn

Figure 204-6

Entrainment in a Partially-
Mixed Estuary

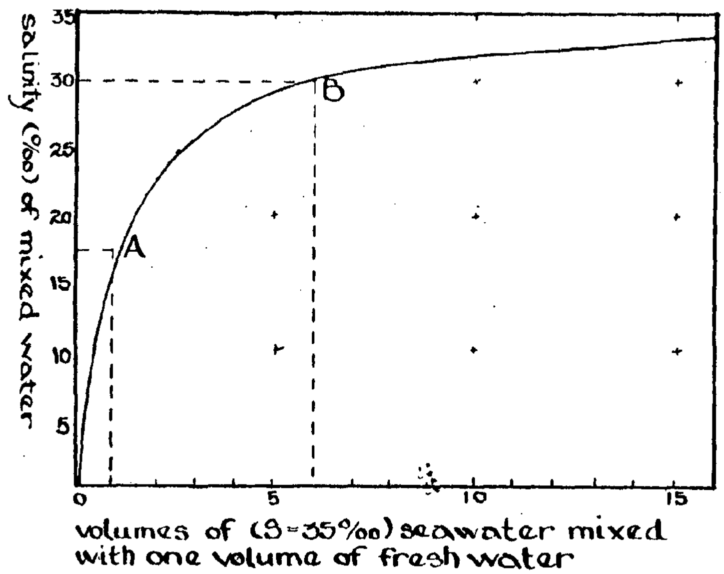
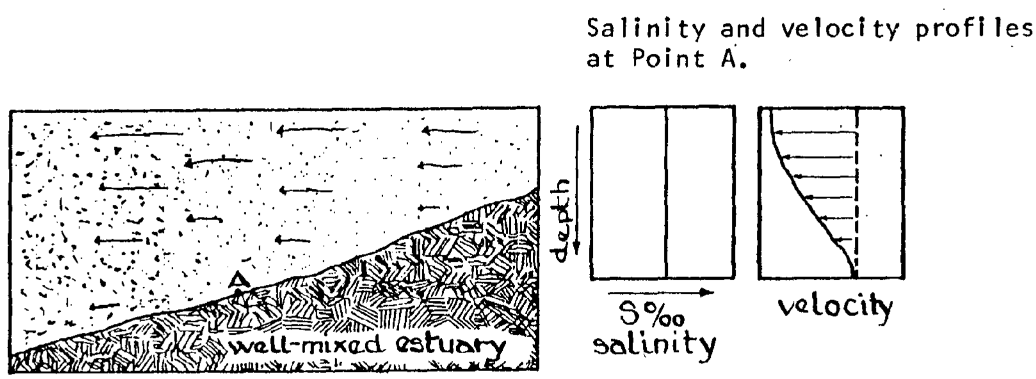


Figure 204-6 Relationship between surface salinity in an estuary and the relative amounts of seawater (salinity 35%) and fresh water (salinity 0%) involved in the mixture.

From: Gross, 1972

Figure 204-7

Mixing in a Well-Mixed Estuary



The variations in salinity and velocity in a well-mixed estuary.

From: Gross, 1972

slightly to the right. Thus, the flood flow is stronger on the right side of a tidal river, and the ebb flow stronger on the left side (looking upstream). Bends in the channel may reinforce or cancel the effect of the coriolis force.

5. Classification of the Columbia River Estuary

One problem with the classification of estuaries by salinity structure is that a given estuary may be partially-mixed during one season and vertically well-mixed or salt-wedge during another. It is also possible for different cross-sections of an estuary to belong to different classes. Again, nature is rarely simple. The Columbia River is a classic example of this complexity. Under high flow conditions, the Columbia River tends to be highly stratified, particularly upstream from the mouth, but it apparently does not become a salt-wedge because of the strong tidal mixing (Figure 204-8). The surface water at the mouth usually remains slightly saline. This suggests a partially-mixed state, except at the end of ebb during high flow conditions, when salt penetration is found only along the bottom in the lower 2 to 5 miles of the river. This is the closest approach to a true salt wedge. Under low flow conditions, the estuary is partially-mixed, but may approach a vertically-homogenous state near the mouth (Figure 204-9). The salinity structure classification of the Columbia River estuary is summarized in Table 204-1.

D. Gravitational Circulation

The question addressed here is the nature of the upstream bottom currents that are so important in the circulation of an estuary. Consider the time-averaged circulation, averaged over a period long enough to remove tidal fluctuations. As mentioned in Section 202, the currents generated by the freshwater flow result from the downward slope of the water's surface toward the ocean. Were no other forces at work in the estuary, aside from this down-slope toward the ocean, then the time-averaged currents in the estuary would be seaward at all depths, as they are in the river (ignoring channel irregularities). The presence of a bottom saline layer and the entrainment of the saline water into the surface layer requires upstream bottom currents. The force driving these upstream bottom currents results from the distribution of density (i.e salinity) in the estuary. The technical name for this force is the pressure gradient force, or pressure difference force.

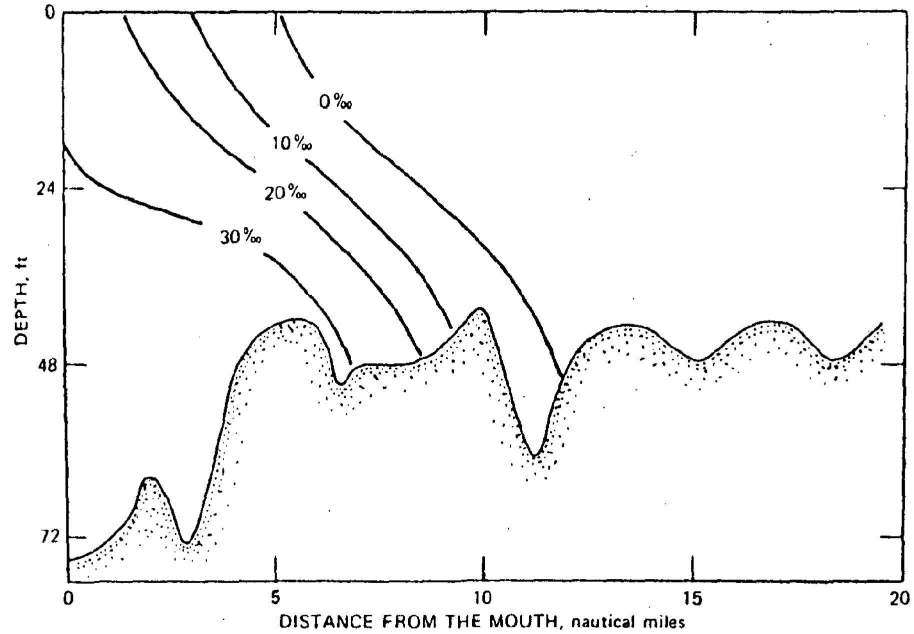


Figure 204-8 - Longitudinal salinity distribution during high tide and high river flow.

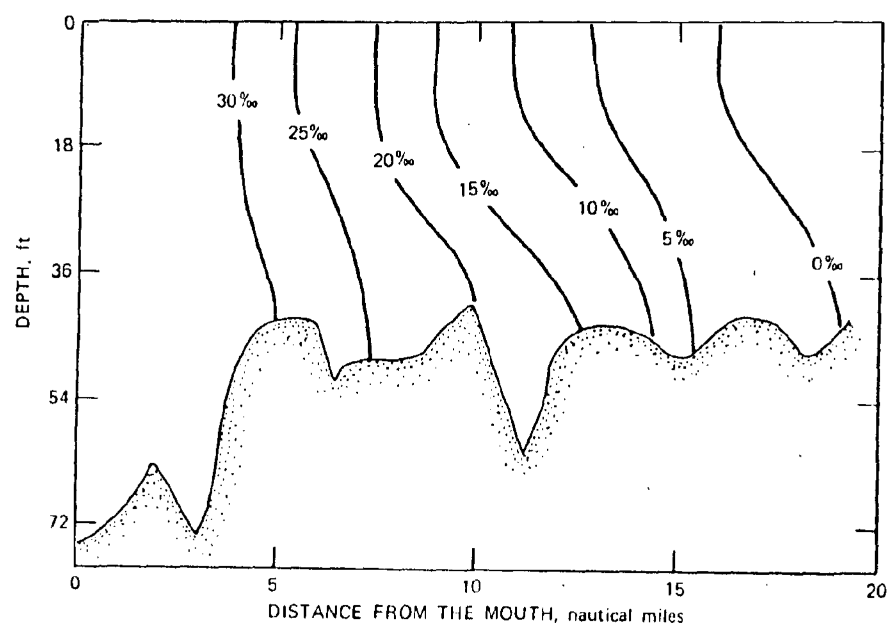


Figure 204-9 - Longitudinal salinity distribution during high tide and low river flow

From: Neal, 1972

Figure 204-1

Classification of the Salinity Structure of Columbia River Estuary

	Low River Flow		High River Flow	
	Minimum Salinity °/oo (Ebb)	Maximum Salinity °/oo (Flood)	Minimum Salinity °/oo (Ebb)	Maximum Salinity °/oo (Flood)
	Near the Mouth			
Surface Salinity	5.8	30.5	1.3	18.7
Bottom Salinity	20.0	32.5	5.9	30.3
Classification	B	D	B	B
	Near Tongue Point			
Surface Salinity	Insufficient data	6.3	0.0	0.0
Bottom Salinity		15.9	0.0	20.0
Classification		B		A

A = Salt-Wedge Estuary
B = Partially-Mixed Estuary
D = Well-Mixed Estuary (with cross-channel variations)

From: Neal, 1972

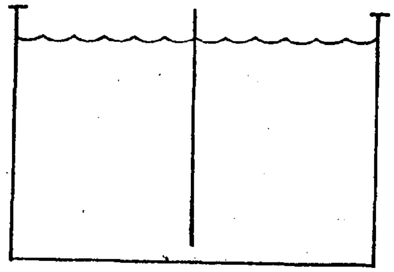
An intuitive understanding of the effects of surface slope and density can be obtained in the following way. Consider an aquarium full of water and divided down the middle by a partition with a hole at the bottom through which water is free to flow (Figure 204-10a). As long as the water level is the same on both sides, no water will flow through the hole. If more water is poured into one side, water will flow through the hole until the water level is again equal on both sides (Figures 204-10b). The water flows through the hole because the pressure is greater on the upstream side of the hole. The water will flow regardless of the depth of hole in the water. Thus, the pressure is greater at all depths on the upstream side. This example is analogous to the surface slope case, and it is evident that a downsloping surface causes downstream movement of water because, at any depth, the pressure is always greater on the upstream side of any water parcel.

The case where the water is denser on one side of the partition than the other is similar. Suppose that the fluid level is the same on both sides of the partition, but that one side is filled with an oil (heavier than water), that does not mix with water (Figure 204-10c). The oil will flow through the hole until the weight of fluid on each side of the partition is the same, that is, until the pressure is the same on both sides of the hole. The fluid level will actually stand higher on the water side. The result would be similar if the oil were replaced with salt water, but some mixing would take place between the salt and freshwater (Figure 204-10d). In this case, the pressure difference or pressure gradient between the two sides of the partition is generated by the difference in density of the two fluids. When the fluids come to rest, the pressure difference at the bottom caused by the difference in density of the fluids will be just balanced by the pressure difference at the bottom caused by the difference in height of the water surface across the partition. There are two important points to remember here. First, the fluid must be in motion so long as horizontal pressure differences or gradients exist at any depth in the fluid. Second, pressure differences or gradients may be generated either by the slope of the water's surface or by the distribution of density in the body of water.

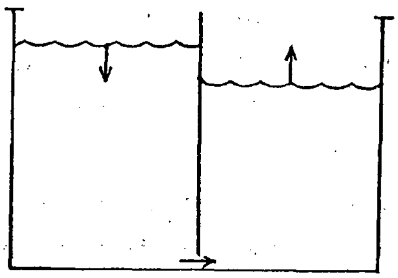
These pressure difference forces in part drive the circulation of an estuary. Upstream from the estuary, the river surface has a downward slope, which means the pressure is always greater on the upstream side of any parcel of water, at any depth. Thus, the water tends to move downstream.

FIGURE 204-10

WATER MOTIONS CAUSED BY PRESSURE DIFFERENCES
RELATED TO WATER LEVEL DIFFERENCES AND DENSITY DIFFERENCES

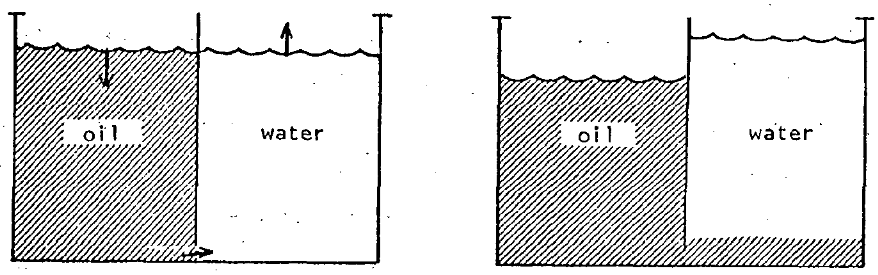


A. Water level and density same on both sides - no pressure difference, therefore no motion.



B. Water level higher on left side, density same on both sides - pressure greater on left side, therefore water flows from left to right until state (A) is reached.

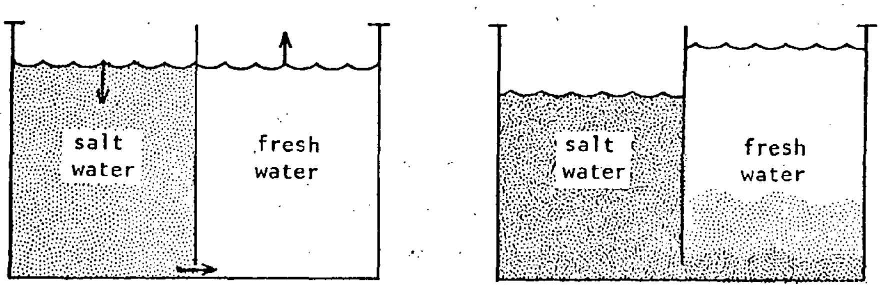
Initial State



Final State

C. Initial State: fluid level same on both sides, but oil is denser, therefore pressure is greater on the left side and oil flows to right side. In Final State right side is higher, but oil is denser, therefore the pressure is the same on both sides.

Initial State



Final State

D. The situation is the same as in (C) except that the salt and fresh water have mixed somewhat. (The difference in density of fresh and ocean water of same temperature usually does not exceed 3%. Thus, the elevation difference has been exaggerated for clarity.)

COLUMBIA RIVER ESTUARY

INVENTORY

OF

PHYSICAL, BIOLOGICAL AND CULTURAL CHARACTERISTICS

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most heavily during August and September between Tongue Point and the mouth. A few fall Chinook also enter the river in October and November. The majority of both upriver and lower river fall Chinook are caught by the ocean fishery (Chaney and Perry, 1976). The principal Chinook spawning areas in the lower river are the following hatcheries: Big Creek, Klaskanine River, Sea Resources (Chinook River), Grays River, and Elochoman River. The principal lower river natural spawning streams are the Lewis and Clark River, Bear Creek, South Fork Klaskanine River, and Plympton Creek (Kujala, 1976).

The overall outlook for the combined fall Chinook run is good (Chaney and Perry, 1976). There is extensive natural and hatchery production in tributaries below and immediately above Bonneville Dam. The outlook for fish produced above the Bonneville pool is not good. Adult fall Chinook counts at John Day, McNary, and Priest Rapids Dams were all below average in 1975, while the number counted going over Ice Harbor Dam into the Snake River was a record low. This reflects the virtual destruction of this once-productive run by main stem Columbia and Snake River dams. These dams have almost eliminated the once vast main stem river spawning habitat (Figure 306-2). Only about 50 miles of the Columbia River above Bonneville Dam has not been impounded by dams. Chronic passage mortalities at main stem dams threaten the remaining natural production in the upper basin. The rehabilitation of the upriver run currently has low priority due to their lack of freshwater sport fishing value (Chaney and Perry, 1976).

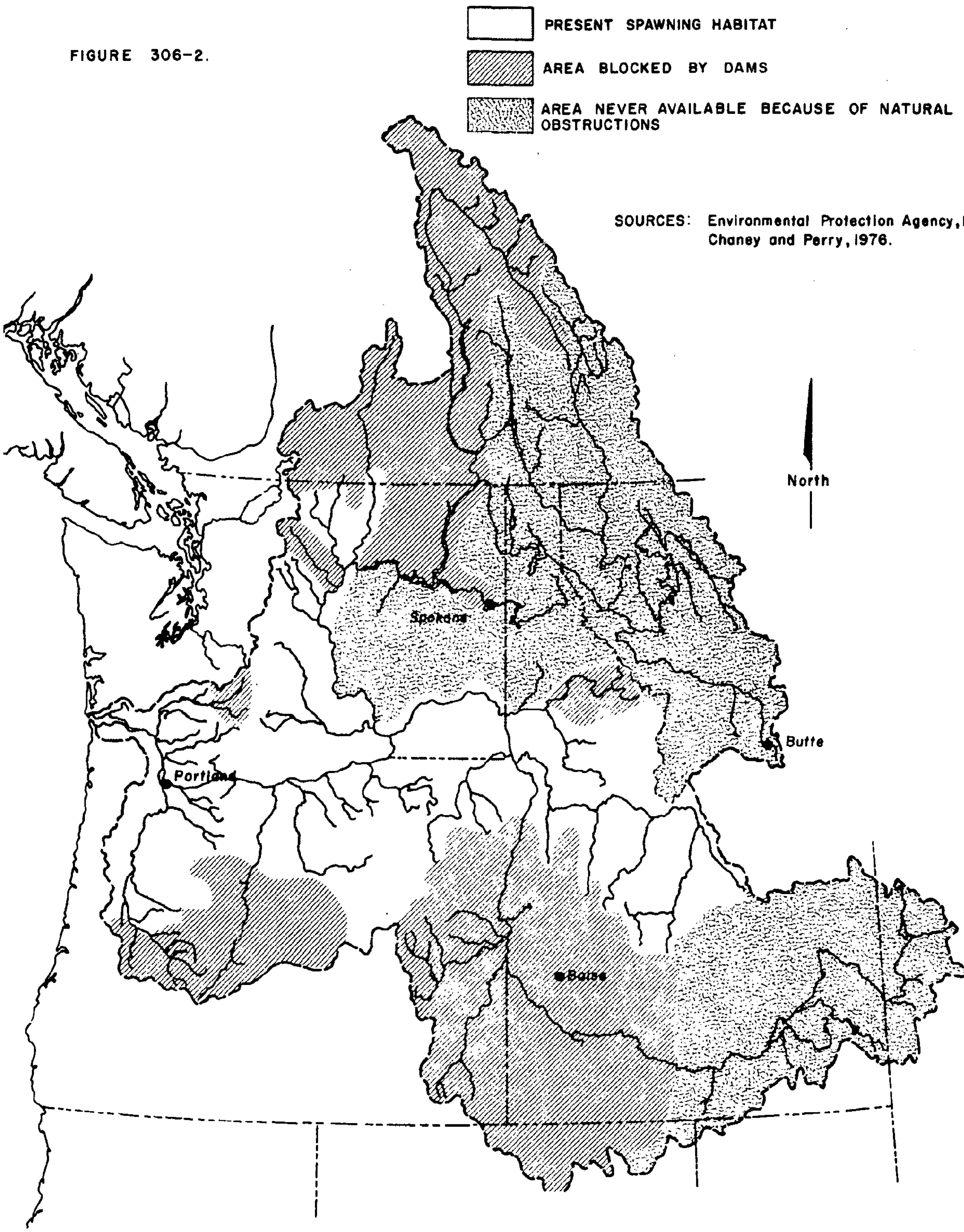
4. Juvenile Chinook Migration, Food ahd Habitat Preferences

As juvenile Chinook salmon migrate to the sea, their food and habitat requirements change. In the Hanford reach of the Columbia during spring and early summer, juvenile Chinook feed mainly on Chironomidae (the family name for midges) insects, caddisflies, and true bugs (Becker, 1973). In the Prescott-Kalama reach, salmon averaging 100 mm long (4 in) are at the peak of their migration in June and July; in addition, they feed largely on insects (adults and larvae) in spring and fall, and mainly on the zooplankter Daphnia during the summer (Craddock, Blahm, and Parente, 1976).

In an unpublished study by the U.S. National Marine Fisheries Service, C. Sims presents much of what is known on the migration and growth of juvenile Chinook in the estuary. Downstream migration of all juvenile Chinook at Jones Beach, Oregon (just upriver from Puget Island) occurs in two peaks, an early one in late May and a much larger one in late July and

COLUMBIA BASIN ANADROMOUS SALMON AND STEELHEAD SPAWNING HABITAT

FIGURE 306-2.



early August. Throughout Sims' 1966-1972 study period, the percentage of migrants that entered the estuary during May and June declined while the percentage that entered in August increased significantly. Subyearling fall Chinook, when migrating through the estuary, concentrate in shallow near-shore areas and avoid deeper channels; yearling Chinook, primarily spring and summer stock, are most abundant in offshore channel areas. These yearlings concentrate within 3 m (10 ft) of the water surface.

Fall Chinook usually stay in freshwater only 60-90 days after the yolk sac is absorbed, whereas spring and summer juveniles stay in freshwater for at least a year and consequently in the spring are usually 10-20 mm (3/4 in) larger. Some fall Chinook may hold up their migration until they are yearlings; they go out from February to May (Durkin, personal communication). As a result of tagging studies, Sims speculates that most fall Chinook juveniles pass quickly through the estuary. Their average length, 70-80 mm (3 in), shows that the majority become smolts (the stage when they are able to go to sea) before reaching the estuary. During the study, some fishes captured at Clatsop Spit, Oregon (RM 5) passed through the estuary from Jones Beach, Oregon (RM 72) in 6 days.

There is no published information on the migratory habits of juveniles produced in the rivers and hatcheries in the vicinity of the estuary. The U.S. National Marine Fisheries Service is continuing research on migratory habits of juvenile salmonids in the Columbia River estuary.

Research on food habits and distribution of juvenile Chinook in the lower estuary, almost exclusively in Youngs Bay, has been conducted mainly by Oregon State University, and the U.S. National Marine Fisheries Service. Juvenile Chinook are present in Youngs Bay during most of the year (Higley and Holton, 1975). From January to May, those from low salinity areas feed mainly on the bottom-dwelling amphipod Corophium sp. Those from higher salinity areas feed on Corophium, Neomysis sp. (a shrimp-like organism), and Chironomids (larvae and adults of midge insects) from January to May; they feed almost exclusively on Corophium from June through September. Durkin (unpublished data) reports the results of a brief study of the Port of Astoria proposed fill site in Youngs Bay. Large numbers of Chinook juveniles move through the area in April, May, and June, and he speculates that there may continue to be large numbers of them until September or October. Lipovsky (personal communication on unpublished or continuing work by the U.S. National

Marine Fisheries Service) states that most young salmon seem to feed on smaller items like zooplankton during the summer in the middle and upper estuary, then switch to insects and Corophium sp. in the fall and spring months. In the lower estuary, the diet is mainly Corophium, supplemented by insects and insect larvae in the fall.

B. Coho Salmon

Coho salmon, or silvers, are natives of the North Pacific Ocean and are found from Baja California around the Pacific rim to Korea and northern Japan. They are most abundant from Oregon to southeast Alaska (Hart, 1973). Adults are distinguished by a white gumline and black spots on the back and upper lobe of the tail. Coho produced in Columbia River hatcheries are major contributors to ocean fisheries from California to the central Washington coast (Oregon Department of Fish and Wildlife, 1976). The population of coho dwindled in the 1950's and increased tremendously in the 1960's, due to improved hatchery techniques and new fish food such as the Oregon Moist Pellet developed at the Oregon State Seafood Lab in Astoria (Kujala, 1976). This increased production boosted the ocean troll and sports catch and opened new gillnet areas such as Youngs Bay (which had been closed for over thirty years) and Grays Bay.

Coho adults, generally 3 years old and weighing 8-14 pounds, enter the estuary in August, reach peak numbers in September and run until November; the majority are destined for tributaries and hatcheries below Bonneville Dam (Chaney and Perry, 1976). In the estuary, they behave much like fall Chinook spending up to 30 days in brackish water before moving upstream, and are generally found in deeper channels of the river, Youngs Bay, and Grays Bay (Kujala, 1976). The principal coho spawning areas in the estuary region are the following hatcheries: Klaskanine River, Big Creek, Elochoman River, Grays River, and Sea Resources (Chinook River). Their primary natural spawning streams are Lewis and Clark River, Youngs River, Klaskanine River, Bear Creek, Big Creek, Gnat Creek, Elochoman River, Grays River, and Chinook River. Juveniles spend one year in freshwater feeding largely on terrestrial insects, and are territorial. Their survival and well being is very dependent on adequate summer stream flow and high water quality (Hart, 1973). On their downstream migration, Sims (personal communication) finds that yearling coho are most abundant in offshore river channel areas. At Jones

Beach, Oregon, these migrants average 110-130 mm (4-1/3 - 5 in). Durkin and Lipovsky of the U.S. National Marine Fisheries Service (personal communication) report that almost all wild coho smolts have spent one year in freshwater; the greatest number out-migrate during the first two weeks of May. Their diet in the lower estuary may be largely Corophium and insects. Little else is known of the migration and feeding habits of juvenile coho salmon in the Columbia River estuary.

C. Sockeye Salmon

Sockeye salmon, or blueback, are the smallest (average 4 lbs) of the Pacific salmon entering the Columbia River (Kujala, 1976). They are found from the Klamath River in California around the Pacific rim to Kamchatka in Asia. Adult coho are distinguished from other salmon by their forked tail and the fine black speckling on their blue back. Adults enter the estuary in June, are most abundant in late June, and have gone upriver by mid-July (Kujala, 1976). They are found throughout the estuary during the run, but most travel very close to shore and in shallow water near sandbars adjacent to the channel such as along the Sand Island jetties and along the piers on the Astoria waterfront. These adults are almost exclusively destined for Columbia River tributaries above Priest Rapids Dam (RM 395) and suffer drastic adult mortality at the main stem dams (Chaney and Perry, 1976). Much of the upriver spawning habitat, in Washington and Idaho, is eliminated or degraded due to these dams. Most juveniles spend one year in a lake, and migrate seaward when they are 60-95 mm (2-3/8 - 3-3/4 in) and lake temperature is 4-7°C (39-45°F) (Hart, 1973). Juveniles migrate in the spring (Johnsen and Sims, 1973). They are found during May in the estuary near the surface of deeper channels; the migration is nearly complete by the end of May (Durkin, personal communication).

Because of their small size and lack of sport fishing value, sockeye are not artificially propagated anywhere in the Columbia Basin, and the outlook for run recovery is poor (Chaney and Perry, 1976). Because of declining numbers, there has been no commercial season in the Columbia River since 1972 (Kujala, 1976).

D. Chum Salmon

Chum salmon, often called dog salmon because of the hooked snout and the canine-like front teeth of breeding males, are found from San Francisco around the Pacific rim to Kamchatka in Asia (Carl, Clemens, and Lindsey, 1967). They are the second most abundant salmon species throughout this range (Chaney and Perry, 1976). Adults entering the estuary average four years old and weigh 10-12 pounds. They are recognized by the absence of large black spots, and all fins (except the dorsal fin) are black-tipped. Spawning adults are brightly colored with red and yellow blotches along the sides (Kujala, 1976). Adults migrate during November and December, follow main river channels and are destined for lower river tributaries (Chaney and Perry, 1976).

Chum salmon were once an important fishery in the river, but runs have declined drastically (Kujala, 1976). The commercial catch is a few hundred per year and the commercial season usually closes just when chum are starting to enter the river. Their flesh is the lowest quality of the salmon, but it is marketable fresh, frozen, canned, or smoked. The decline in numbers of chum is thought to be largely the result of subtle environmental changes and degradation of spawning habitat by man's activities (Chaney and Perry, 1976). Competition with other juvenile salmonids may also be a factor.

There are now some chum enhancement programs in the lower river. Chum eggs from Japan were hatched, reared, and released at the Grays River Hatchery for the first time in 1976. As the result of work by the Clatsop Economic Development Committee salmon enhancement project, approximately 1.2 million chum salmon from the Hoodsport Hatchery, Washington, were reared at the Klaskanine Hatchery, Oregon, and released in April, 1977. This was made possible by a special Oregon Governor's Grant and local voluntary help (Kujala, personal communication).

Sea Resources, a non-profit organization in Chinook, Washington, artificially propagates chum salmon at its hatchery on the Chinook River. It is attempting to increase the run size and is having moderate success. Chum salmon egg incubation boxes have been planted in many lower river tributaries in an effort to establish or enhance chum salmon runs.

Little is known of the migration and food and habitat preferences of juvenile chum in the Columbia River mainly because there are so few fish. Chum fry from the Cowichan River of British Columbia feed heavily on chironomid insect larvae and cladoceran zooplankton and grow appreciably during their brief freshwater stay (Sparrow, 1968). Fry migrate to sea when they are about 37 mm (1-1/2 in) long their first spring, and none remain in freshwater after July (Carl et al., 1967). Chum fry in the Nanaimo River of British Columbia migrate to sea from March to the end of May (Siebert, Brown, Healy, Kask, and Naiman, 1977). In March, these fish stay in shallow mudflat areas in the estuary an average of 13-18 days, but only 1.5 days in May. From early March to late May the relative weight increase of these fish is 4% per day, and their principal food is epibenthic and interstitial harpacticoid copepods (in the Columbia River estuary this would probably be Canuella).

National Marine Fisheries Service research results provide the few facts known about Columbia River chum fry (Sims, unpublished). While still in freshwater, fry eat mostly chironomid insect larvae and pupae, and copepod and cladoceran zooplankton. Chum fry enter the estuary in early March, stay in near shore areas, and go to sea by June. Their average length is 40-50 mm (2 in). Their diet in the brackish water at Point Ellice is the two copepods Eurytemora and Canuella, the amphipod Corophium, varying amounts of the amphipod Paraphoxus, and the mysid Neomysis. Epibenthic invertebrates are the most important food of chum fry in the lower river. Chum fry in Youngs Bay and off Hammond eat Corophium and zooplankton (Lipovsky, personal communication of unpublished NMFS research).

E. Steelhead Trout

Steelhead are sea-run rainbow trout found from southern California to the Aleutian Islands (Hart, 1973). Adults average 6 to 12 pounds and are distinguished from other salmonids by the elongated body, short blunt head, many large black spots, white gumline, absence of red slash marks under the jaw, and red cheeks and lateral band during spawning. Returning adults have usually spent from 2 to 3 years as juveniles in freshwater and 2 to 3 years at sea (Hart, 1973), and some, mostly winter run, are able to spawn again another year. Columbia River steelhead are either summer run or winter run, and travel mainly in deep river channels or at times, near shorelines.

Summer run steelhead enter the estuary from April through October, with peak abundance from July to early September (Chaney and Perry, 1976). Some are destined for tributaries just below Bonneville Dam, but most go further upriver. The upriver run is composed of two segments; early smaller fish are headed for tributaries throughout the mid and upper Columbia and Snake River drainages; the larger, later fish are destined mainly for Idaho's Clearwater River drainage. Traditionally, these fish have been very important to both commercial and sports fishermen, but since 1974, summer steelhead have been illegal to harvest commercially. Sports, and Indian net fisheries still exist. Both segments of the upriver run are in serious trouble, mainly due to the cumulative effects of main stem Columbia and Snake River dams. Record low counts of summer steelhead in 1974 and 1975 entered both the Snake River over Ice Harbor Dam and over Priest Rapids Dam into the upper Columbia.

Winter run steelhead enter the estuary in November, are most abundant in January and February, and continue to run through March or April (Kujala, 1976). These fish are destined almost entirely for tributaries below Bonneville Dam. Only winter steelhead spawn in estuary tributaries; natural spawning occurs in the Lewis and Clark River, Youngs River, Klaskanine River, Bear Creek, Big Creek, Gnat Creek, Grays River, Jim Crow Creek, and Elochoman River. Winter steelhead are reared at the following hatcheries: Klaskanine River, Big Creek, Gnat Creek, and Beaver Creek (on the Elochoman River). Winter steelhead have been classified as game fish in Washington since 1933, but were a commercial species in Oregon until 1969 (Chaney and Perry, 1976). Sports fishermen are now the primary harvesters of winter steelhead. The winter runs are in good condition due to extensive natural reproduction and large hatchery releases in lower Columbia River tributaries.

Little is known of the migrations, or food and habitat requirements of juvenile steelhead in the Columbia River estuary. During their 1 to 4 year freshwater life, they are presumed to feed largely on stream-produced insects and invertebrates. Migrating juvenile steelhead are found in the upper estuary in April through June, near the surface in deeper channel areas (Johnsen and Sims, 1973). At Jones Beach, Oregon, these migrants average 170-200 mm (6-7/10 - 8 in), (Sims, personal communication). Their diet during passage through the estuary is unknown.

F. Cutthroat Trout

Coastal cutthroat trout are found from northern California to Prince William Sound in the Gulf of Alaska. Adults weigh from 1-1/2 to 4 pounds (Hart, 1973). Adults are distinguished from other salmonids by a fairly long sharp snout, presence of orange or red streak under each half of the lower jaw, many small dark spots, and absence of a broad red lateral band. They often stay within estuaries, move in and out with the tides and feed heavily on young coho, stickleback, rockfish, sculpin, and flatfish (Carl et al., 1967). In the Columbia River estuary region, cutthroat spawn in small streams as 3 or 4 year olds from December-February, and are artificially propagated at the Beaver Creek Hatchery (on the Elochoman River). Fry in British Columbia stay in the streams for varying lengths of time, feeding on crustaceans, aquatic and terrestrial insects, and sticklebacks. In spring, they out-migrate with coho on which they feed heavily (Carl et al., 1967). Juvenile cutthroat are found in the Columbia River estuary from April through June near the surface in deeper channel areas (Johnsen and Sims, 1973); juveniles are found throughout the estuary only in several spring months (Durkin, personal communication). The primary harvesting of adult cutthroat trout is by sports fishermen.

G. White Sturgeon

White sturgeon are found primarily in fresh and brackish waters from northern California to the Gulf of Alaska, and may live longer than 100 years and weigh over 1500 pounds (Hart, 1973). Adults in the Fraser River mature at about age 15 when they are 40 inches long. White sturgeon are gray above and lighter below, have a short, broad snout with four barbels closer to the tip of the snout than the mouth, and have rows of sharp bony plates instead of scales. They are harvested in both commercial and sports fisheries for their high quality flesh, and eggs from which caviar is made. Jordan and Evermann (1923) stated that until 1888 they brought only 4-5¢/pound dressed and caviar was 25-35¢/pound. At that time, salmon fishermen usually just knocked them in the head and threw them away. A major fishery later developed and the stocks were very depleted by 1902.

White sturgeon in the Fraser River, British Columbia, spawn in spring and early summer at intervals of 4 to 11 years; young fish are found in lower river sloughs (Hart, 1973). In the Sacramento River, large fish move upstream in winter and spring and downstream in summer. Some sturgeon migrations seem to be associated with the availability of spawning and spawned-out eulachon (Columbia River smelt). In the fall of some years, there are large numbers of sturgeon concurrent with large numbers of anchovy (Kujala, 1976). Although sometimes taken in the ocean, the lower limit in the river is usually from the Chinook Jetty to Hammond, Oregon. Upriver they are usually found in main channels and deep holes (Figure 306-3). White sturgeon may be taken throughout the year in the estuary, and measure from a few inches to several feet.

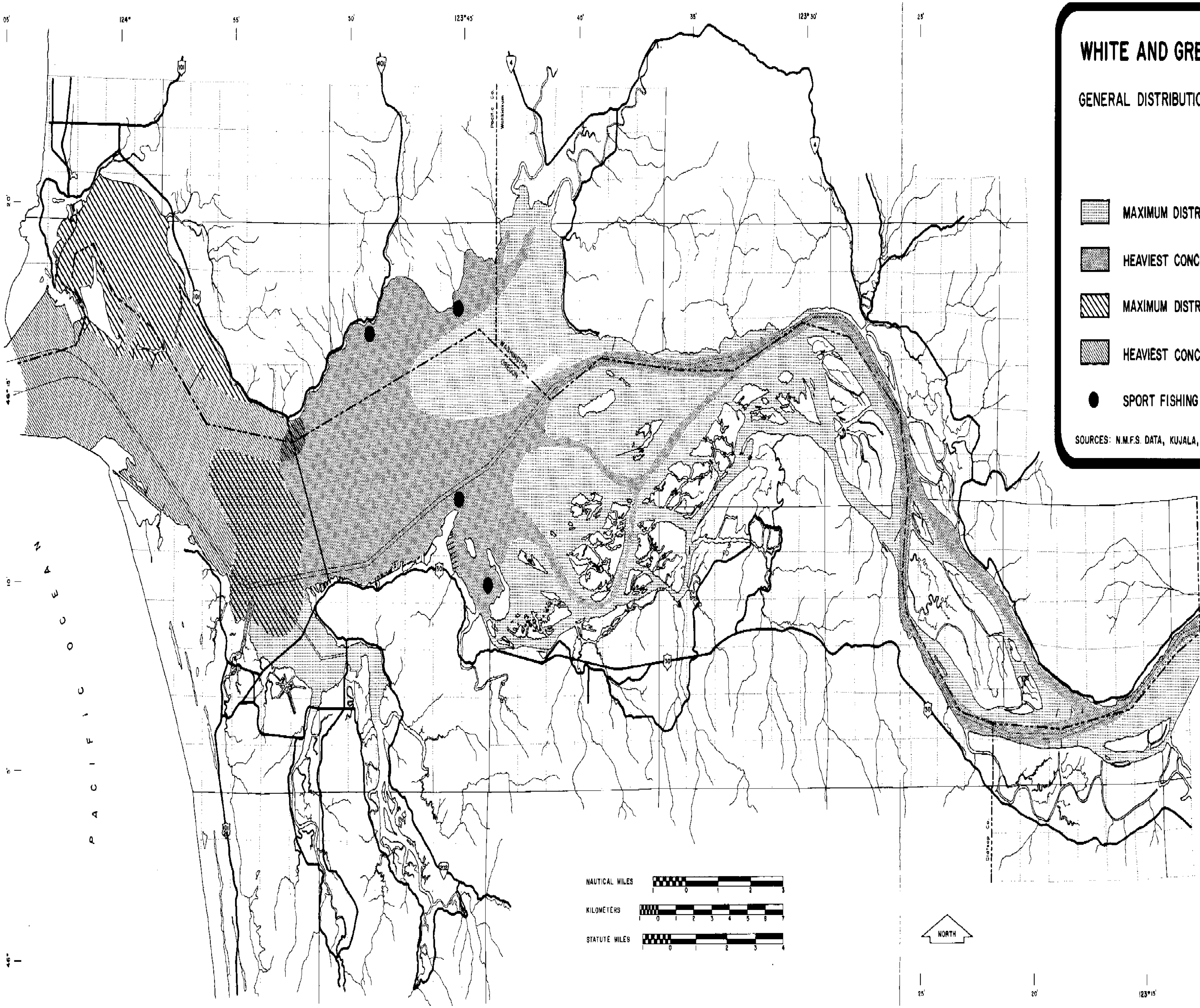
The food of juveniles is reported to be insect larvae and mysids. Two hundred mm (8 in.) juveniles from California eat amphipods and mysids (Hart, 1973). Juveniles from the Columbia River estuary eat mostly amphipods and polychaete worms (Haertel and Osterberg, 1967). The adult diet includes suckers, sculpin, stickleback, lamprey, young sturgeon, crayfish and molluscs.

H. Green Sturgeon

Green sturgeon are found in brackish and salt waters from southern California around the Pacific rim to Taiwan, and may reach seven feet in length and weigh 300 pounds. They are olive green on the back, have olive green stripes on the belly, four barbels in a line closer to the mouth than to the tip of the snout, a snout concave in profile, and rows of sharp bony plates instead of scales (Hart, 1973). In the Columbia River, the green sturgeon is usually found in deep brackish water downriver from the Astoria Bridge, although at times of low river flow, it may be found upriver as far as Tongue Point (Kujala, 1976), (Figure 306-3). They are present in the lower estuary year-round but are of little importance to either the commercial or sport fisherman. Green sturgeon flesh is of much lower quality than white sturgeon, but it is marketable smoked or kippered; there is no market for their caviar (Kujala, 1976).

I. Starry Flounder

This flatfish is found from southern California around the Pacific rim to Korea and is distinguished by rough skin and alternating dark and light bands on the unpaired fins; both eyes are usually on the right side but may be on the left side (Hart, 1973). They are found both in estuaries and the ocean. According to Kujala (1976), starry flounder have been used primarily as mink food, but they now are becoming more important as a human food fish. River and ocean starry flounder is filleted, and fishermen receive between 7 to 10 cents/pound. Flounder are an incidental part of a salmon gillnetter's catch. Daily catches of 500 to 1,000 pounds are not uncommon during the May fishing season. Fishes less than 2-1/2 years old and commonly 2 to 3 pounds, are most numerous in the shallow brackish water of the estuary such as Desdemona Sands, Middle Channel between Tongue Point and the Astoria Bridge, and north of Taylor Sands from the bridge to Grays Point (Figure 306-4). Ripe adults are taken in the estuary although actual spawning probably occurs in the ocean. No newly-hatched starry flounder larvae have been taken. Large numbers of juveniles (0-1 year) are present in shallow estuary bays such as



CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 306-3

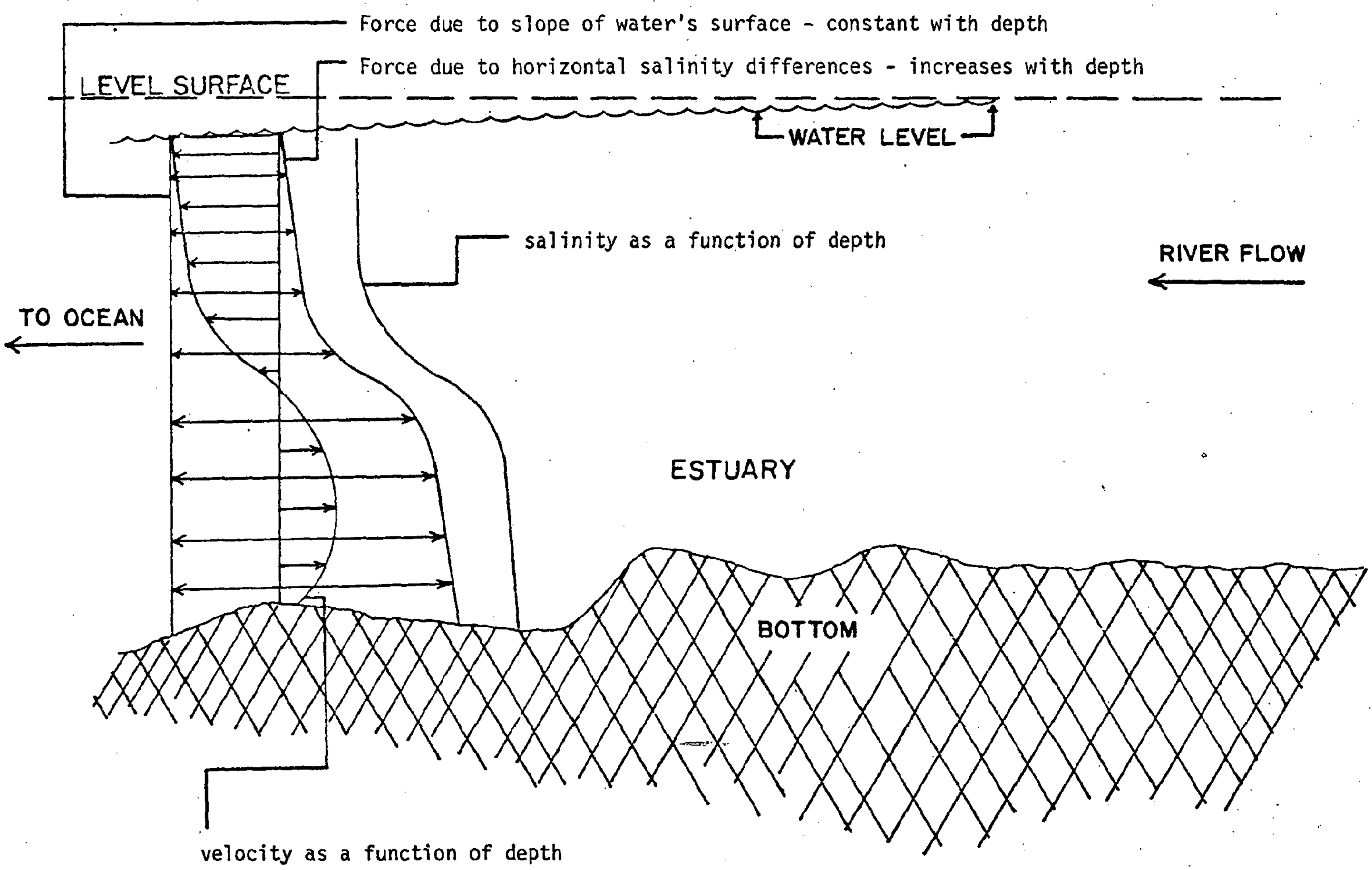
This is true in the estuary also, but an additional factor must be considered; that factor is the intrusion into the estuary of seawater, which has a density greater than that of river water. At any depth, the salinity (and thus density) is normally greater in the downstream direction. This is true whether the estuary is a salt-wedge type, partially-mixed, or even well-mixed (Figures 204-3, 5 or 7). Average bottom currents in estuaries are usually upstream, or they are at least not as strongly downstream as the surface currents. The upstream bottom currents result from the pressure difference force associated with the salt water intrusion. Since the density is greater on the downstream side of any water parcel, there is a pressure difference force pushing the water in an upstream direction (Figure 205-11). At the surface, the pressure difference force caused by the water surface slope is greater than that caused by the density difference. Thus, the surface currents (on the average) are downstream. At the bottom, the pressure difference force caused by the salinity intrusion (this force increases with depth), often is greater than that caused by the surface slope (this force is the same at all depths), and the average bottom currents will then be in an upstream direction (Figure 204-11). This pattern is known as the gravitational or estuarine circulation and is present in all estuaries. The effects of tidal currents, the winds and other forces must be superimposed upon this average picture to determine the actual currents at any time.

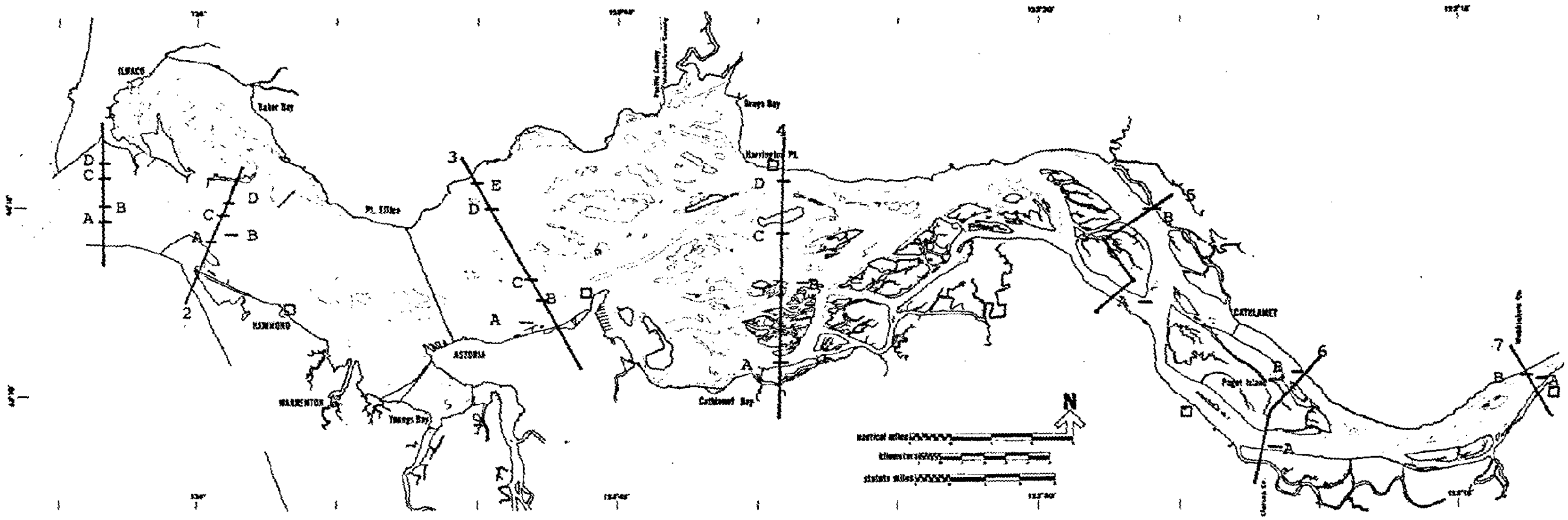
204.2 SALINITY AND CURRENT DISTRIBUTION

The data base for most of the physical oceanographic studies of the Columbia River estuary is the 1959 Corps of Engineers field study. Parameters measured include temperature, salinity, current speed and direction, and tidal height. Measurements were made over three nine-day periods in May, June, and September under intermediate (380,000 cfs) high (560,000 cfs) and low (160,000 cfs) flow conditions, respectively. These data and a small amount of sediment data were published in 1960 in a four-volume report by the Corps of Engineers called Interim Report on 1959 Current Measurement Program Columbia River at Mouth Oregon and Washington. Much of the material used in this section is taken either directly from the Interim Report or from papers and theses based on this report. The station locations are shown in Figure 204-12.

FIGURE 204-11

VERTICAL PROFILES OF PRESSURE FORCES, VELOCITY, AND SALINITY IN A PARTICALLY-MIXED ESTUARY





— = A Station Location

—— = 2 Range Location

☐ = Recording tide gage

Figure 204-12 Station Location for the 1959 Corps of Engineers Current and Salinity Study

From: U.S. Army Corps of Engineers, Portland District, 1960

Using the abstractions of the salt-wedge, partially-mixed, and well-mixed estuaries, and the circulation typical of such bodies, it is now possible to examine the complexities of the circulation in the Columbia River estuary.

A. Salinity and Current Distribution off Clatsop Spit

Figures 204-13 to 204-16 show the salinity distribution and current speed under high and low-runoff conditions, for the Clatsop Spit-Sand Island Range (Range 2 in Figure 204-12). Salinities are shown for HW, LW and mean over a tidal cycle, and currents are shown as means for flood and ebb tides, and as a tidal cycle mean.

Consider first the low-runoff, current and salinity distribution for flood tide (Figure 204-14a and 16a). The flood tide velocities at any depth are greatest on the north (right, looking downstream) side. Accordingly, the high tide salinity at any depth is greatest on the north side also. The stronger flood on the north side probably results from both the greater depth of the North Channel, and the fact that the North Channel is on the "outside of the curve." These factors evidently outweigh the coriolis force which tends to push the water toward the left (south) side.

The ebb tide velocity in the low-runoff case (Figure 204-16b) is greatest at the surface on the north side and in mid-stream at depth. The lowest ebb velocities are found at the bottom of both channels and along the north side, near the bottom. Accordingly, the salinity (Figure 204-14b) is lowest near the surface and in the middle. There is however, a small lens of relatively freshwater off Clatsop Spit. It appears that vertical mixing is weaker in the South Channel, where currents are slower. Highest salinities are found at the bottom of the two channels. In this case, the coriolis force and channel curvature work together to produce the strong surface ebb in the North Channel. The estuary is in a partially mixed state on both flood and ebb.

The non-tidal, low-runoff, current and salinity patterns (Figures 204-14c and 16c) are averaged over the entire tidal cycle. The average currents are downstream (especially at the surface), except at the bottom of the North Channel and along the north side. In a typical, partially-mixed estuary, the net upstream bottom flow is expected to be stronger on the right side (looking upstream), because of the coriolis force. Evidently, the channel curvature is more important here. The average salinity increases with depth, and the lowest salinities are on the south side,

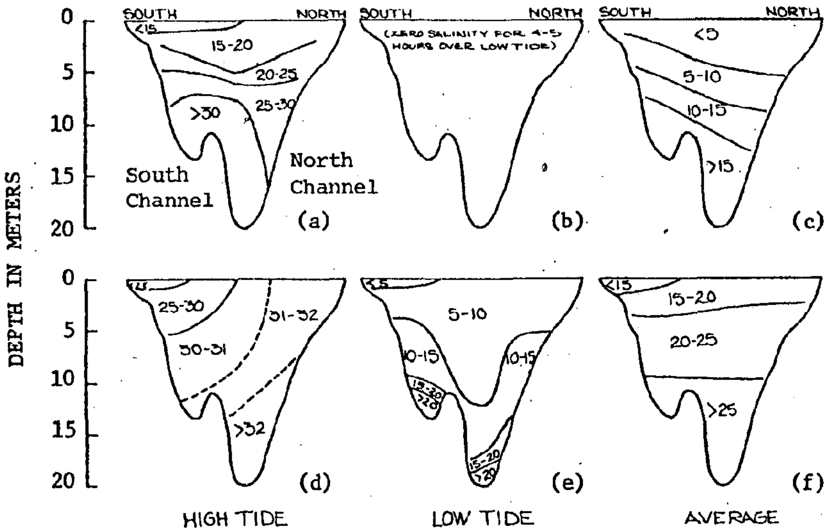


Fig. 204-13

High River Discharge 558,000 cfs

Fig. 204-14

Low River Discharge 169,000 cfs

Salinity in ‰, Clatsop Spit - Sand Island section under high and low discharge conditions.

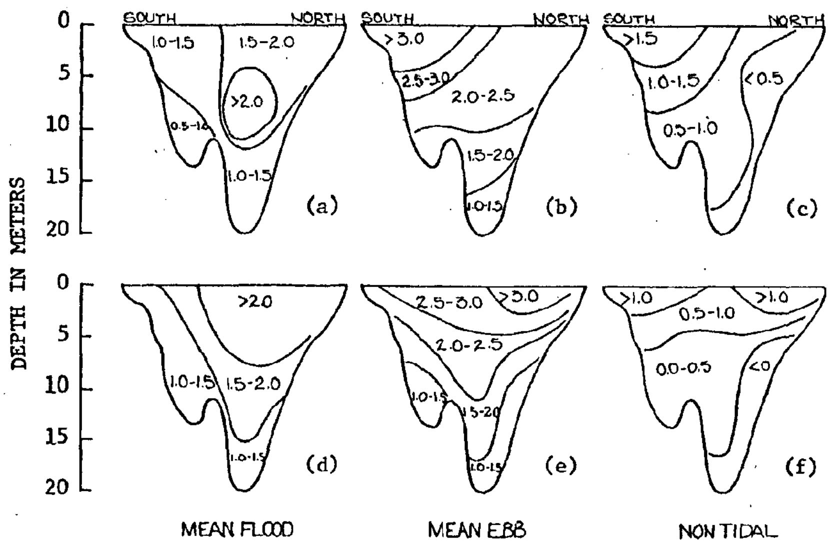


Fig. 204-15

High River Discharge 558,000 cfs

Fig. 204-16

Low River Discharge 169,000 cfs

Current speed in knots, Clatsop Spit - Sand Island section (positive nontidal current indicates seaward flow) under high and low freshwater flow conditions. The cross-section shown is seen from upstream looking downstream. The depth is exaggerated for clarity.

From: Hansen, 1965

a feature common to the HW and LW distributions. There is little cross-channel variation in the average distribution below the surface, however.

The high-runoff, salinity and current distributions (Figure 204-13 and 15) may now be compared to those for low-runoff conditions (Figures 204-14 and 16). Under high-runoff conditions, flood currents are much stronger in the North Channel, with the maximum flow at mid-depth (Figure 204-15a), but the cross-channel salinity differences are rather weak (Figure 204-13a). Near the bottom, the salinity is actually greater on the south side. The high and low-runoff flood current distributions are rather similar, and bottom salinities are not greatly different in the two cases. There is much greater vertical salinity stratification in the high-runoff case, however, and the estuary approaches a salt-wedge state, except that the boundary between top and bottom layers remains rather diffuse. Because of the strong tidal currents, the estuary never becomes a true salt-wedge.

The high-runoff, ebb current pattern (Figure 204-15b) differs greatly from that for low runoff (Figure 204-16b). The strongest ebb currents are in the South Channel for the high-runoff case, rather than in the North Channel; no salinity intrusion at all is observed during most of the ebb (Figure 204-13b). The governing factor in this case is probably the direct connection of the South Channel to the main channel, upriver of the estuary.

The non-tidal, high-runoff current and salinity patterns (Figure 204-13c and 15c) differ significantly from those for low-runoff (Figure 204-14c and 16c). The most important difference is the absence of net upstream bottom flow. The average flow is downstream everywhere, strongest at the surface in the South Channel, and weakest in the North Channel. The absence of net upstream bottom flow is unusual in partially-mixed estuaries, yet the strong vertical salinity gradients in the average distribution are clearly not those of a vertically well-mixed estuary. This suggests that the salt transport mechanisms in the Columbia River estuary are not those typical of a partially-mixed estuary (Section 204.4). It is likely that a cross-section closer to the mouth would show a net upstream bottom flow. The high-runoff, average salinity distribution (Figure 204-13c) appears somewhat unusual in that lowest salinities are observed in the North Channel, while the strongest ebb flow is found in the South Channel. The salinity at all depths is much less than for the low-runoff case (Figure 204-14c), and cross-channel salinity differences are prominent.

It has been suggested in several studies that the average flow in the Columbia River estuary can be described in terms of a clockwise eddy, with the inflow strongest in the North Channel and the outflow strongest in the South Channel. This is most clearly evident in the high-flow case in Figure 204-15. Other studies suggest that this pattern also varies with the winds and with the monthly cycle of spring and neap tides; and it cannot therefore be regarded as firmly established. If such a pattern does exist, it has important implications for siting of sewer outfalls and other waste discharges. These matters are discussed in Section 206 (Tidal Flushing).

B. The Longitudinal Current and Salinity Distributions

The current and salinity patterns for other cross-sections could be examined in detail, as were those for the Clatsop Spit section. Instead, let us examine the distribution of current and salinity along the channel. Two examples of the longitudinal salinity distribution at high tide are shown in Figures 204-8 and 204-9. Note the great vertical differences in salinity near the mouth in the high-runoff case (Figure 204-8). The estuary is approaching a salt-wedge state. In the low runoff case (Figure 204-9), the estuary is vertically well-mixed near the mouth, but it is partially mixed upstream.

Recent studies (Sternberg et al., at press) suggest that the salinity distribution outside the mouth is markedly assymetric. There is a natural, deep channel running north-northeast to south-southwest between buoys 4 and 6 and south of the navigational channel. Apparently, this channel is the major source of saltwater intrusion to the estuary. The outflow of freshwater is more evenly distributed and responds strongly to the winds. Currents off the end of the South Jetty follow the orientation of the natural channel, and during the period of measurement (June 1975), bottom currents were predominantly into the estuary. This was not true of currents off the North Jetty or near buoy #1. Unfortunately, these data have not been fully analyzed.

Variations in salinity during a tidal cycle are shown in (Figure 204-17). The greatest salinity intrusion near the mouth occurs within one-half hour of the end of the flood tide (about 1600 hours). Slack water occurs progressively later, upstream of the mouth. Thus, slack water and the maximum salinity intrusion between Tongue Point and Harrington Point (RM 18 to 23) occur between 1600 and 1800 hours. The greatest salinity

LONGITUDINAL SALINITY DISTRIBUTION IN THE FOURTH CHANNEL
UNDER LOW-FLOW CONDITIONS

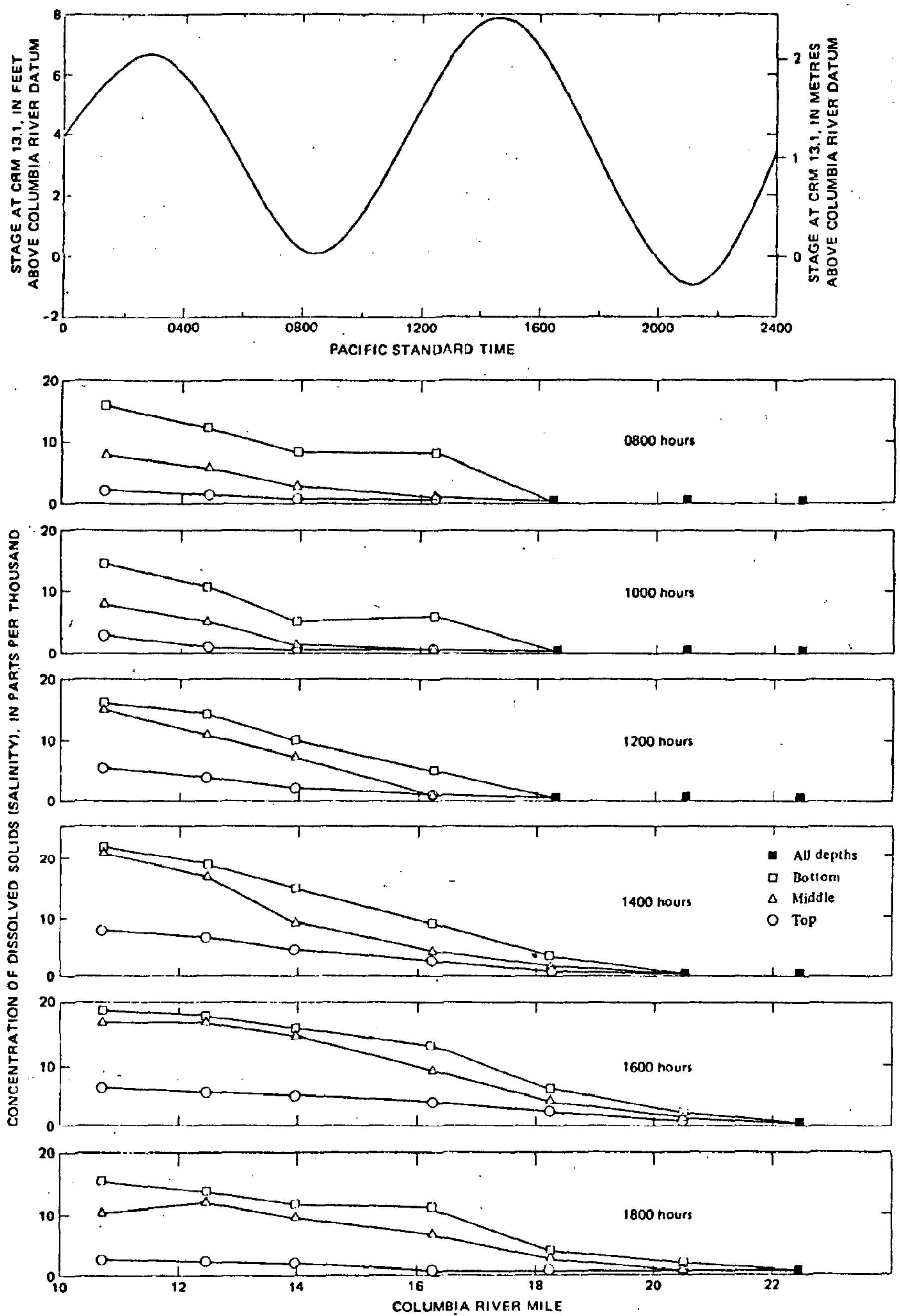


Figure 204-17 Salinity distribution along the longitudinal axis of the South Channel at various times in the tidal cycle on September 14, 1969.

From: Lutz et al., 1975

variation occurs at mid-depth, between River Miles 10 and 14. Top and bottom salinities are much less variable.

The salinity variations are intimately related to the variations in current during the tidal cycle. Figure 204-17 should be compared to Figure 204-18 that shows the flow predominance as a function of depth for the South Channel for the same period. Flow predominance is defined as the percentage of the total flow at any point that is downstream (toward the ocean) during a tidal cycle.* A flow predominance of 50% indicates that upstream and downstream currents are evenly balanced. The flow predominance at RM 22.4 is about 80% downstream at all depths. There is little vertical variation in flow predominance because salinity is zero at all depths throughout the tidal cycle. The fact that about 80% of the flow is in the downstream direction shows the importance of the freshwater flow; the ebb currents are stronger and of longer duration than the flood currents.

The flow predominance shows wide variation with depth at RM 10.7 and RM 12.4. The downstream flow predominance is 10% or less, near the bottom, and between 70 and 80% near the surface. The top-to-bottom salinity variation in this region is about $15°/_{oo}$ during part of the tidal cycle. Accordingly, bottom currents are upstream and surface currents downstream (on the average). The flow at all depths is more strongly downstream at RM 16.3 than at RM 13.9. The flow near RM 14 is complicated by the cross-river flow in the old Astoria Ferry Channel, and it is not surprising that the flow predominance profile shows anomalies here.

The flow at mid-depth and near the bottom is evenly balanced between flood and ebb (50% downstream flow predominance) near RM 17. This is an area of zero net flow during a tidal cycle, and it is an area of sedimentation. The location of this null zone varies about between RM 5 (very high runoff) and RM 21 (very low runoff). Because the null zone acts as a sediment trap, the lower estuary has been rapidly filling in for the last 100 years (Section 208 has a detailed discussion of sedimentation problems).

*For the mathematically inclined:

$$\text{Flow Predominance} = 100\% \times \frac{\Sigma\,(|V_{ebb}|\Delta t)}{\Sigma\,(|V_{ebb}|\Delta t + |V_{flood}|\Delta t)}$$

Where V_{Ebb} and V_{Flood} are the observed ebb and flood velocities and Δt the time interval between samples.

Flow Predominance Under Low-Flow Conditions

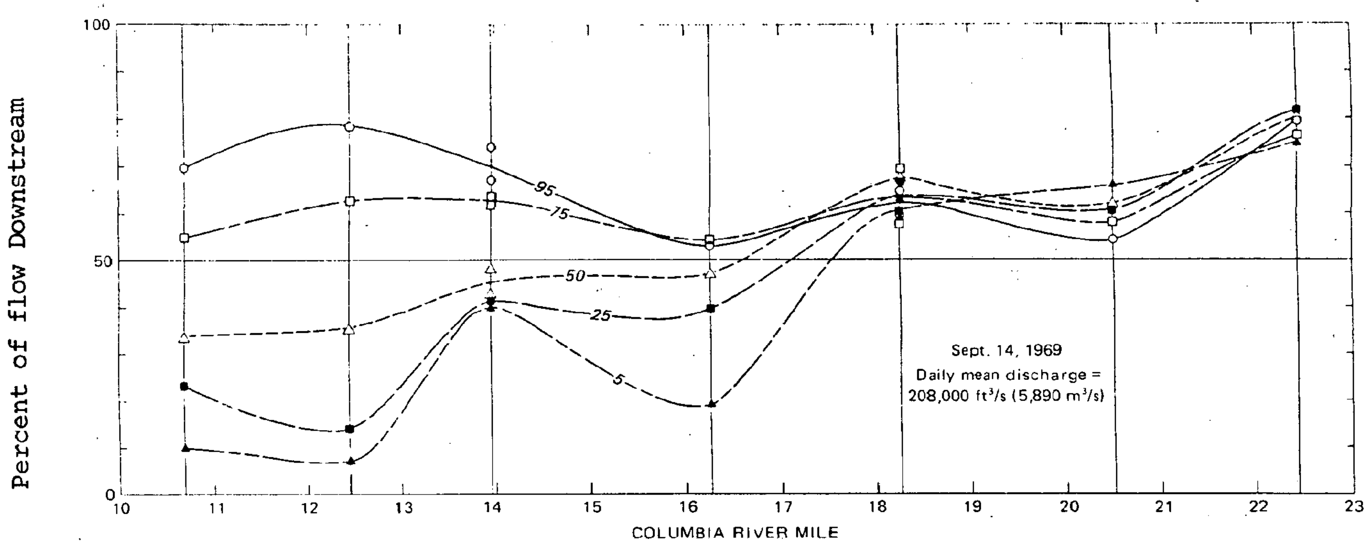


Figure 204-18

Flow predominance as a function of River Mile and percent of depth from bottom under low-flow conditions (5% of depth is near bottom, 95% depth is near surface).

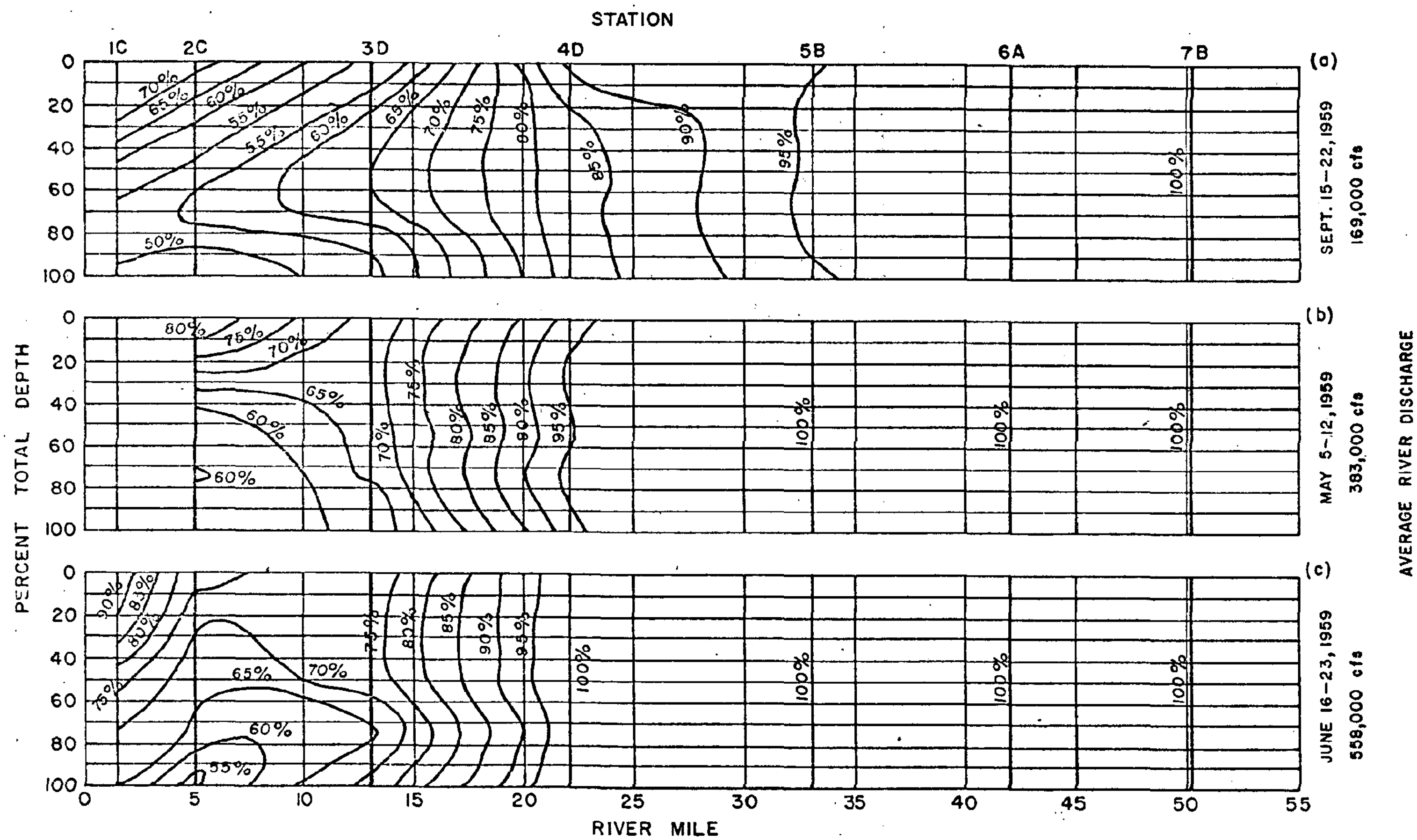
From: Lutz et al., 1975

Flow predominance may also be shown as a function of depth and distance along the channel, by contours of equal flow predominance. Figure 204-19 shows flow predominance in the North Channel for three flow levels, and Figure 204-20 provides the same information for the South Channel. The location of the stations used in constructing these figures is shown in Figure 204-12. The patterns are complex, but several major features are evident. First, the currents are nearly 100% downstream at, and above, Harrington Point, except under the lowest runoff conditions. Second, upstream flow predominance is evident only at RM 5, and then only under the lowest flow conditions. Third, the surface ebb flow predominance decreases in a downriver direction between lines 5 and 3, but then increases again between lines 3 and 1. Cross-channel flow in the old Astoria Ferry Channel may have some distorting effect on the flow predominance at the stations on line 3; however, most of the observed changes in flow predominance result from changes in salinity structure. The flow level has the greatest effect in the South Channel; the downstream flow predominance along the bottom of the North Channel increases only slightly with increasing runoff. Strong vertical differences in currents in the North Channel result from the tendency to form a salt-wedge. In contrast to conditions in the North Channel, the downstream flow predominance increases at all depths in the South Channel, with increasing runoff. Vertical salinity differences seem to have less effect on the currents here. Flow predominance patterns are not only a function of runoff, they are also related to tidal range and winds. For example, one possible reason for the low downstream flow predominance at station 3D in the North Channel under low flow conditions, would be a strong westerly wind. The causes of the differences in the low-runoff, flow predominance patterns for the South Channel shown in Figures 204-17 and 20 are unknown.

Temperature data were routinely collected during the Corps of Engineers 1959 field study; however, the data have not been published. Temperature data from other studies appears in Section 205.2

204.3 CIRCULATION AND SALINITY PATTERNS IN YOUNGS BAY AND ITS TRIBUTARIES

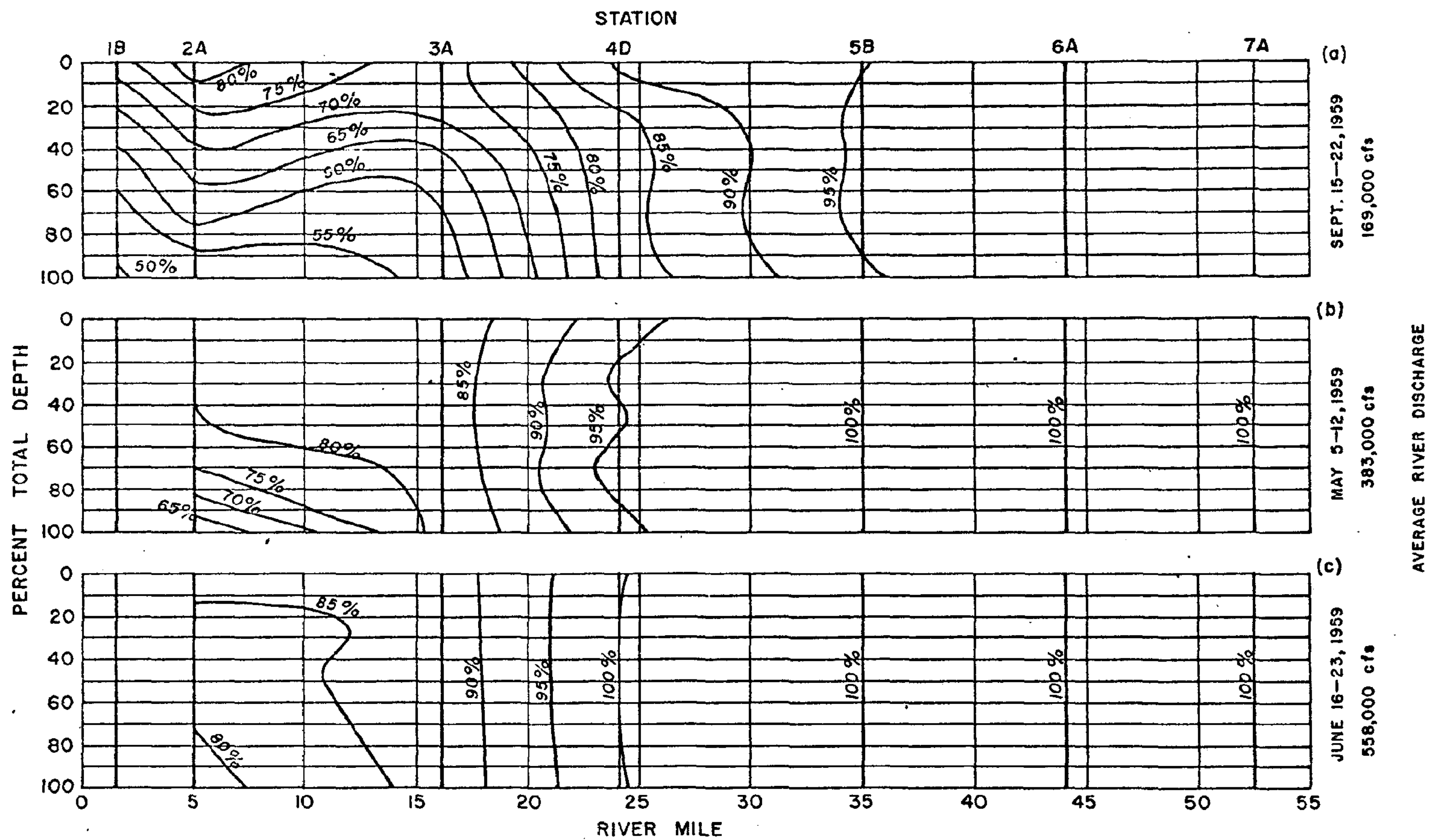
The available information on circulation and salinity patterns in Youngs Bay comes from the Alumax Report: Physical Characteristics of the Youngs Bay Estuarine Environs, Ocean Engineering Programs, OSU, 1975. Measurements of temperature, salinity, pH, dissolved oxygen, fluoride, and turbidity were taken at 23 stations in the bay and its tributaries (the



NORTH CHANNEL

FIGURE 204-19

From: U.S. Army Corps of Engineers, Portland District, 1960



SOUTH CHANNEL

FIGURE 204–20

From: U.S. Army Corps of Engineers, 1960

Youngs, Lewis and Clark, and Skipanon Rivers) four times between June 1976 and January 1976 (Figure 204-21). The following is a summary of the information in the Alumax report.

The tides and the Columbia River freshwater flow play a major role in the circulation in the Youngs Bay area, just as they do in the Columbia River. There is an additional controlling influence in Youngs Bay, however. That influence is the freshwater flow of the tributaries to the Bay. These tributaries are large enough to greatly influence the Bay, but they are not large enough to exert a major influence on the Columbia River. The salinity patterns in the Columbia River estuary are largely the result of the mixing of ocean water and freshwater coming down the main stem from above the estuary (Section 204.2). The temperature and salinity patterns in Youngs Bay result from the mixing of ocean water, main stem water and water from the Youngs Bay tributaries. In studying the circulation of Youngs Bay, consideration must not only be given to the seasonal variations in flow of the main stem but also to those of the Youngs Bay tributaries.

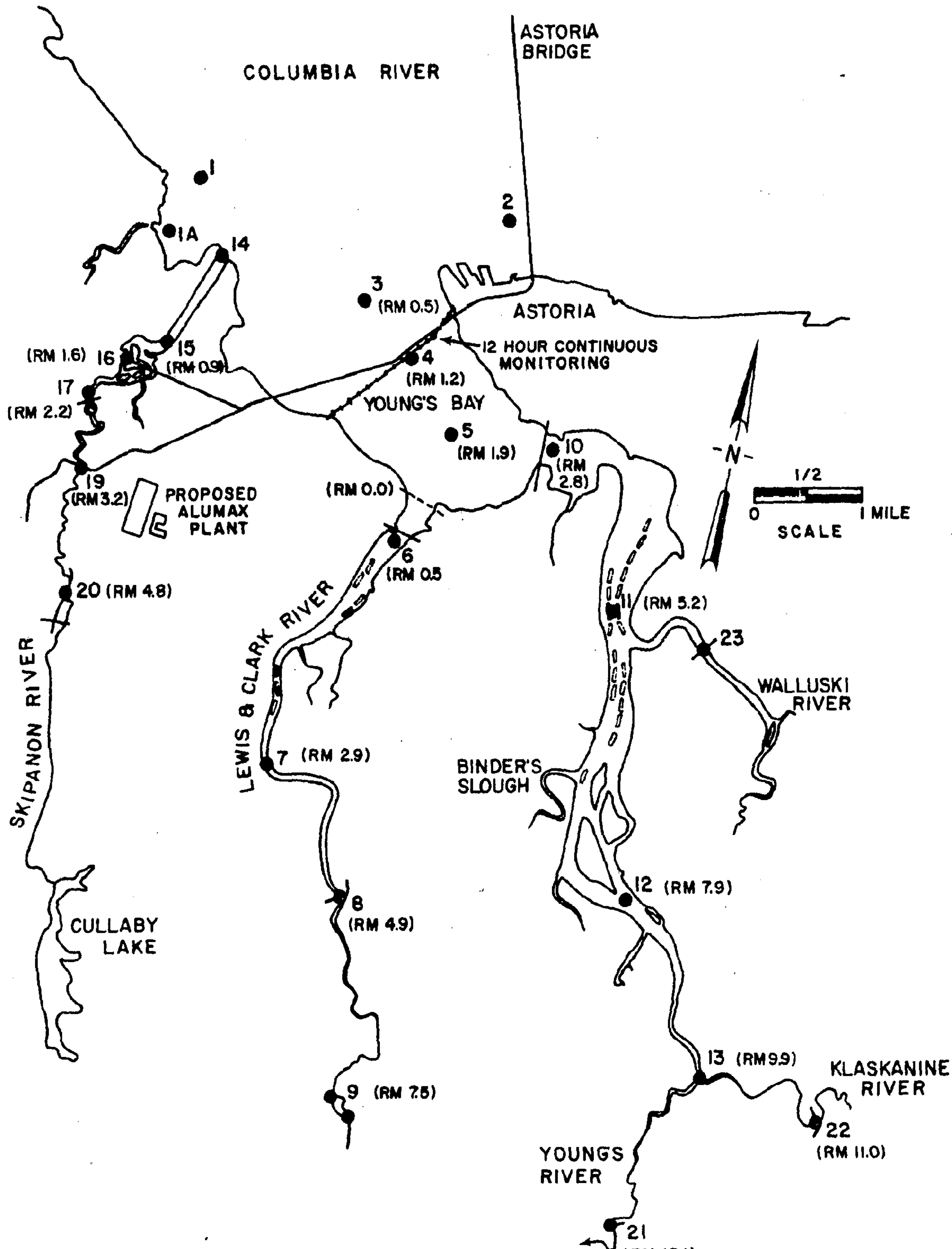
The seasonal river flow patterns of the main stem and the Youngs Bay tributaries are compared in Figure 204-22. The patterns are nearly inverse to one another. The main stem shows a very strong peak in the spring and early summer (April to July) that is fed by the melting snowpack and a weaker winter maximum. The Youngs Bay tributaries show, in contrast, very low runoff from June to September and a very strong winter maximum (November to April). The Alumax sampling program was designed to provide coverage of these seasonal flow variations. Samples were taken in June, August and October 1974 and in January 1975. No samples were taken during the spring, however. The geographic coverage of the data was good.

The June survey was taken during a period of very high Columbia River runoff and fairly low tributary runoff. Accordingly, Youngs Bay and River and the Lewis and Clark River contained only freshwater, mostly from the Columbia River. Water temperature is shown as a function of River Mile in Youngs Bay and River in Figure 204-23. The Columbia River water has a temperature of about 14°C (57°F) and the Youngs River water temperature is about 11°C (52°F). The water in the Youngs River was Columbia River water to RM 6, even at low tide. High levels of dissolved oxygen were found throughout the Bay.

The Skipanon River showed slight salinity intrusion (0 - 3°/∘∘) below the dam, even though the Columbia River outside the mouth of the Skipanon

Figure 204-21

Water Quality Stations for the Oregon State University Study of Youngs Bay



From: OSU, Ocean Engineering Programs, 1975

was entirely fresh. The circulation in the Skipanon is quite sluggish. Evidently, the salinity intrusion had occurred during some previous tidal cycle. Dissolved oxygen levels were not depressed, thus the water had not been trapped for long. Typical water quality values for the Bay and its tributaries in June are shown in Table 204-2a.

The August survey was taken during a period of moderate Columbia River flow (300,000 cfs) and low tributary flow. The water in Youngs Bay was found to be a mixture of Columbia River and sea water, with a little tributary water upstream in the tributaries. Vertical salinity stratification was found only at the mouth of the Bay, near the Columbia River. The rest of the Bay was found to be well-mixed. Figure 204-24a & b shows the pattern of salinity vs. River Mile for the Youngs and Lewis and Clark Rivers. The salinity decreases in the upstream direction in the Lewis and Clark River in the usual manner (Figure 204-24b). The Youngs River has a maximum in salinity between RM 3 and RM 5 at both HW and LW (Figure 204-24a) This maximum can only occur if Youngs Bay fills from two different water sources on flood tide. The most likely explanation of the upstream maximum relates to the difference in the time of the currents in Youngs Bay and the Columbia River. During the first two hours of flood in Youngs Bay, the Columbia River is ebbing, and increasingly freshwater pours into Youngs Bay from the east. During the last four hours of flood in Youngs Bay, the Columbia River is also flooding, and increasingly salty water pours into Youngs Bay from the west. A continuous recording of conductivity (i.e. salinity) and tidal height at the Youngs Bay Bridge supports this interpretation.

Considerable salinity stratification was observed in the Lower Skipanon River, and some salinity intrusion occurred upstream of the tide gate, indicating that the tide gate was not functioning properly. There was one rather alarming feature observed in this study. The dissolved oxygen level in the Lower Skipanon River was severely depressed (0.6 mg/liter), about 1/10th of the level observed in Youngs Bay and upstream in the Skipanon River. This value is not sufficient to sustain marine life. The Skipanon River evidently had reached its carrying capacity for organic wastes, during the critical summer season. Future development in this area will require careful consideration of the problem and possibly, reduction of present loads. The most likely sources of the existing problem are: the decay of organic material, non-point discharges (marinas and surface

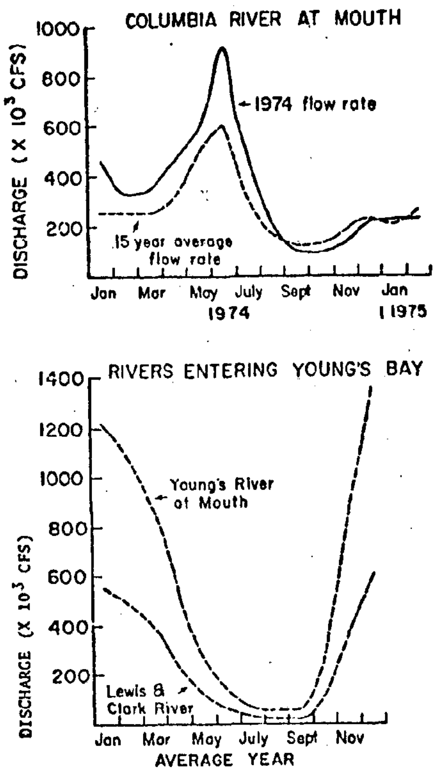


Fig. 204-22 Monthly average flow rates for Columbia River and Youngs Bay tributaries. The Columbia River has a very high flow peak in June, and the Youngs Bay tributaries peak in December.

From: OSU, Ocean Engineering Programs, 1975

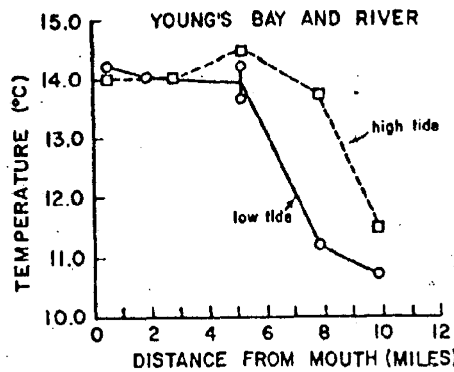


Fig. 204-23 Water Temperature vs. River Mile, Youngs Bay and River, June 5, 1974. Columbia River water has a temperature 14°C (57°F) and Youngs River water has a temperature of about 11°C (52°F).

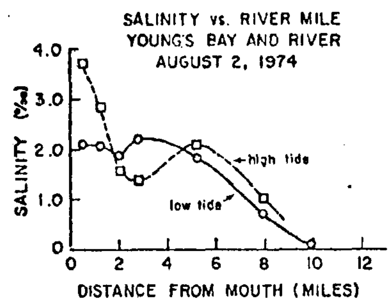


Fig. 204-24a Salinity vs. River Mile, Youngs Bay and River, August 2, 1974.

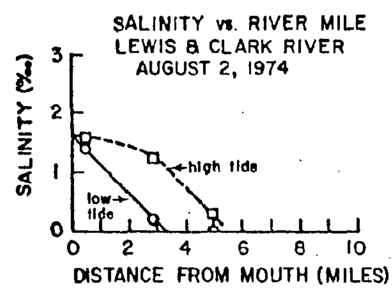


Fig. 204-24b Salinity vs. River Mile, Lewis & Clark River, August 2, 1974.

Note the upstream maximum in salinity that occurs in the Youngs River. This maximum results from circulation patterns in Youngs Bay. It is not apparent in the Lewis & Clark River.

runoff from industrial operations) and cannery wastes. Typical water quality values for the Youngs Bay area are shown in Table 204-2b.

The October survey was conducted during a period of minimum runoff in both the Columbia River (120,000 cfs) and its tributaries (Youngs River, about 12 cfs). Salt water intrusion was greatly increased over that observed in August. The increased salinity intrusion resulted in considerable stratification on flood tide in Youngs Bay and its tributaries (Figure 204-25a & b). The salinity structure in the Skipanon River approached a salt-wedge state, with top-to-bottom differences of about 20°/₀₀ (Figure 204-25c). Both the Skipanon and the Youngs Rivers showed upstream salinity maxima. The upstream maximum in the Youngs River was caused by phase differences between currents in the Bay and in the River, as explained above. The maximum in the Skipanon River may have a similar cause, or it may be due to storage of salt water in the Warrenton Boat Basin. Typical water quality values for the Youngs Bay area are shown in Table 204-2c.

The January survey was conducted during a period of moderate runoff in the Columbia River (220,000 cfs) and high winter runoff in the tributary streams. Youngs Bay and River were filled by a mixture of local freshwater, Columbia River freshwater, and sea water. Some vertical salinity differences were observed on flood tide, but the salinity never exceeded 5.4°/₀₀, even on the bottom. The Lewis and Clark River was entirely fresh at all stages of the tide. Local and Columbia River freshwater masses cannot be easily differentiated on the basis of temperature, since both are in the range of 4.5 to 5°C (40-41°F). They can, however, be distinguished on fluoride levels, which are much higher in the Columbia River.

Considerable stratification and salinity values up to 10°/₀₀ were observed in the Skipanon River. Dissolved oxygen values were high at all stations. Typical water quality values for the Youngs Bay area are shown in Table 204-2d.

204.4 SALT BALANCE AND SALT TRANSPORT MECHANISMS IN THE COLUMBIA RIVER ESTUARY

The amount of salt in an estuary will remain approximately the same from one tidal cycle to the next, so long as there are no dramatic changes in wind, freshwater runoff, or tidal range or height. Yet, the net flow (average velocity) at any cross-section of the estuary is in a downstream direction, as it must be, to allow the discharge of river water to the ocean. The river water is noticeably diluted by sea water before it reaches

Table 204-2a: Typical Water Quality Values, June 5, 1974, Youngs Bay area

Area	Station No. in Fig. 204-21	Temp. (°C)	pH	D.O. (mg/1)	Fluoride (ppm)	Turbidity (J.T.U.)	Salinity (°/oo)
Columbia River (near Youngs Bay)	3						
High Tide		14.2	7.4	10	-	17	0
Low Tide		14.2	7.2	10	-	15	0
Youngs Bay (RM2)	5						
High Tide		14.0	7.3	10	.16	4	0
Low Tide		14.2	7.0	9	.15	11	0
Youngs River (RM8)	12				(RM10)		
High Tide		13.7	6.6	9	.03	5	0
Low Tide		11.0	6.5	9	.03	3	0
Lewis & Clark R. (RM5)	8				(RM7)		
High Tide		12.0	6.5	10	.03	9	0
Low Tide		11.0	6.3	9	.03	8	0
Skipanon River (RM3)	19						
High Tide		-	6.2	7	-	6	0
Low Tide		-	6.3	8	-	10	0
Alder Slough	1a						
High Tide		14.1	7.3	10	-	10	0

From: OSU, Ocean Engineering Programs, 1975

Table 204-2b: Typical Water Quality Values, August 2, 1974, Youngs Bay

Area	Station No. in Fig. 204-21	Temp. (°C)	pH	D.O. (mg/l)	Fluoride (ppm)	Turbidity (J.T.U.)	Salinity (°/₀₀)
Columbia River							
(near Youngs Bay	3						
High Tide		15-20.2*	7.3	8	-	17	3.0-14.0*
Low Tide		20.5	7.2	9	-	22	1.2
Youngs Bay (RM2)	5						
High Tide		21.0	7.0	9	-	17	1.6
Low Tide		20.8	7.1	8	.21	22	2.1
Youngs River (RM8)	12				(RM11)		
High Tide		23.0	7.0	9	-	15	1.0
Low Tide		22.0	7.1	8	.06	60	0.6
Lewis & Clark R. (RM5)	8						
High Tide		(RM3)	6.5	7	-	16	0.3
Low Tide		20.6	6.6	7	.07	15	0
Skipanon River (RM3)	19						
High Tide		-	6.5	6	-	16	0.1
Low Tide		-	6.5	6	-	15	0.1

*Stratified

From: OSU, Ocean Engineering Programs, 1975

Table 204-2c: Typical Water Quality Values, October 16, 1974, Youngs Bay

Area	Station No. in Fig. 204-21	Temp (°C)	pH	D.O. (mg/1)	Fluoride (ppm)	Turbidity (J.T.U.)	Salinity (°/ₒₒ)
Columbia River (Near Youngs Bay)	3						
High Tide		13.0	7.7	5-8*	.27-.60*	2-12*	8-22*
Low Tide		15.0	7.4	8	.20	4	1-20*
Youngs Bay (RM2)	5						
High Tide		15.0	7.3	9	.22-.45*	4	4-10*
Low Tide		14.2	7.3	8	.27	20	5.3
Youngs River (RM8)	12						
High Tide		15.0	7.0	9	.19	28	4.1
Low Tide		14.5	7.2	8	.20	30	4.2
Lewis & Clark (RM5)	8	(RM3)					
High Tide		14.5	-	8	.11	-	3.4
Low Tide		14.0	7.5	8	.19	30	1.6
Skipanon River (RM3)+	19						(RM5)
High Tide		(RM1)=	-	10	.39	-	0.5
Low Tide		14.0	7.2	8	.34	7	0.14
Alder Slough	1a						
High Tide		11.5-13.5*	7.4	8	.55	2	15.7

*Stratified
=Surface
+Tide Gate at RM2.2 was not operating properly

From: OSU, Ocean Engineering Programs, 1975

Table 204-2d: Typical Water Quality Values, January 30, 1975, Youngs Bay area

Area	Station No. in Fig. 204-21	Temp. (°C)	pH	D.O. (mg/l)	Fluoride (ppm)	Turbidity (J.T.U.)	Salinity (°/₀₀)
Columbia River (near Youngs Bay)	3						
High Tide		5.0	7.5	7	.14	20	3.1-9.5*
Low Tide		4.5	7.3	7	.10	25	0
Youngs Bay RM2)	5						
High Tide		5.0	7.4	7	.10	24	1
Low Tide		4.5	7.5	8	.09	17	0
Youngs River (RM8)	12						
High Tide		4.5	6.8	8	.04	19	0
Low Tide		4.5	6.6	8	.04	10	0
Lewis & Clark R. (RM5)	8						
High Tide		4.5	6.6	8	.03	9	0
Low Tide		4.5	6.8	8	.03	7	0
Skipanon River (RM3)	19						
High Tide		4.5	6.8	10	.05	10	0.1
Low Tide		4.5	6.4	10	.04	10	0
Alder Slough	1a						
High Tide		4.5	7.6	8	.10	48	0.30

*Stratified

From: OSU, Ocean Engineering Programs, 1975

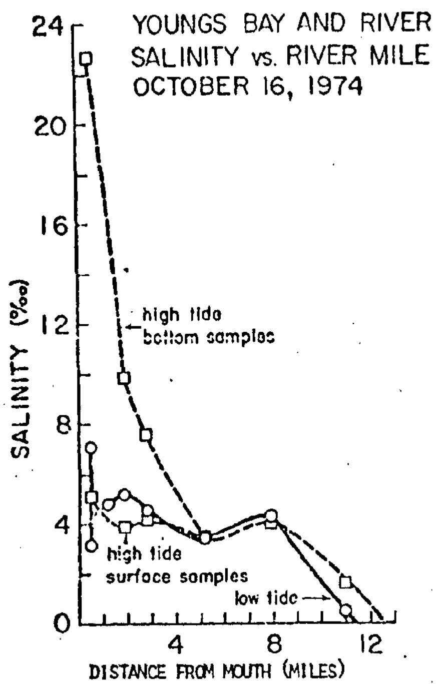


Fig. 204-25a Salinity vs. River Mile, Youngs Bay and River, October 16, 1974.

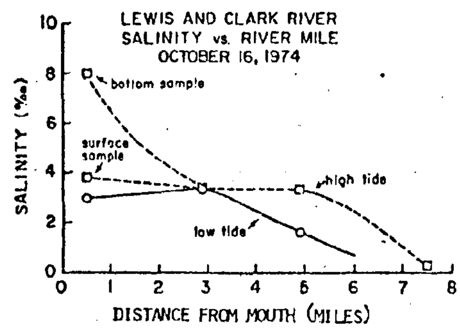


Fig. 204-25b Lewis & Clark River, Salinity vs. River Mile, October 16, 1974.

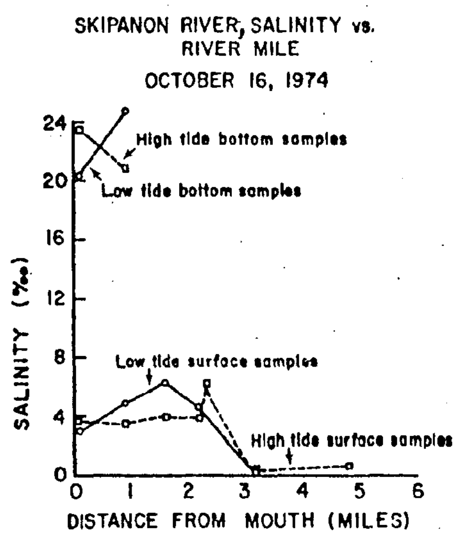


Fig. 204-25c Salinity vs. River Mile, Skipanon River, October 16, 1974.

Figure 204-25a, b, c

Salinity vs. River Mile in a)Youngs Bay and River, b) the Lewis & Clark River, and c) the Skipanon River. Note the strong salinity stratification in a) and c), approaching a saltwedge state, and the upstream salinity maximum in a) and c).

the sea, and salt is therefore discharged to the sea, along with the freshwater. This downstream movement of salt to the sea caused by the net freshwater flow must be balanced by one or more salt transport mechanisms that move salt in an upstream direction. The gravitational or estuarine circulation is just such a mechanism (Figure 204-26 and 27). In most estuaries, the usptream bottom flow of relatively saline water provides, through entrainment (Figure 204-2), most of the salt that is discharged along with the river water in the surface layer. The salt balance in such an estuary is simple.

Salt transported downstream = Salt transported upstream, or

Salt transport by net flow (downstream) = Salt transport by estuarine circulation + other small terms (upstream)

The balance in the Columbia River estuary is not so simple. Major variations in salt transport mechanisms are known to occur with different runoff levels and may occur with different tidal ranges and wind conditions. Recalling Figure 204-15c, the average currents during a tidal cycle under high runoff conditions are downstream at all depths off Clatsop Spit. The estuarine circulation still exists, in that bottom ebb currents are weaker and bottom salinities much greater, but the estuarine circulation is too weak to balance the downstream salt transport by the mean flow.

What are the other important salt transport mechanisms in the Columbia River estuary? The important mechanisms are related to the variations during a tidal cycle of tidal height, (cross-sectionally averaged) salinity and (cross-sectionally-averaged) velocity. At any cross-section of the estuary, high tide occurs during the later part of flood tide, and low tide occurs during the later part of ebb (Figure 204-26 and 27). Thus, the average tidal height and cross-sectional area at any cross-section is greater during flood than ebb. Similarly, the average salinity at any cross-section is greater on flood than ebb, and the salinity maximum occurs about half an hour before slack water (the time difference depnds on the runoff level). Thus, equal current speeds on flood and ebb would result in a net upstream movement of salt for two reasons: first, a greater volume of water flows through the larger cross-sectional area on flood, and second, the water flowing upstream on flood is saltier than that flowing downstream on ebb. We know, of course, that the ebb currents are much stronger than flood currents, so that the freshwater flow of the river may be discharged

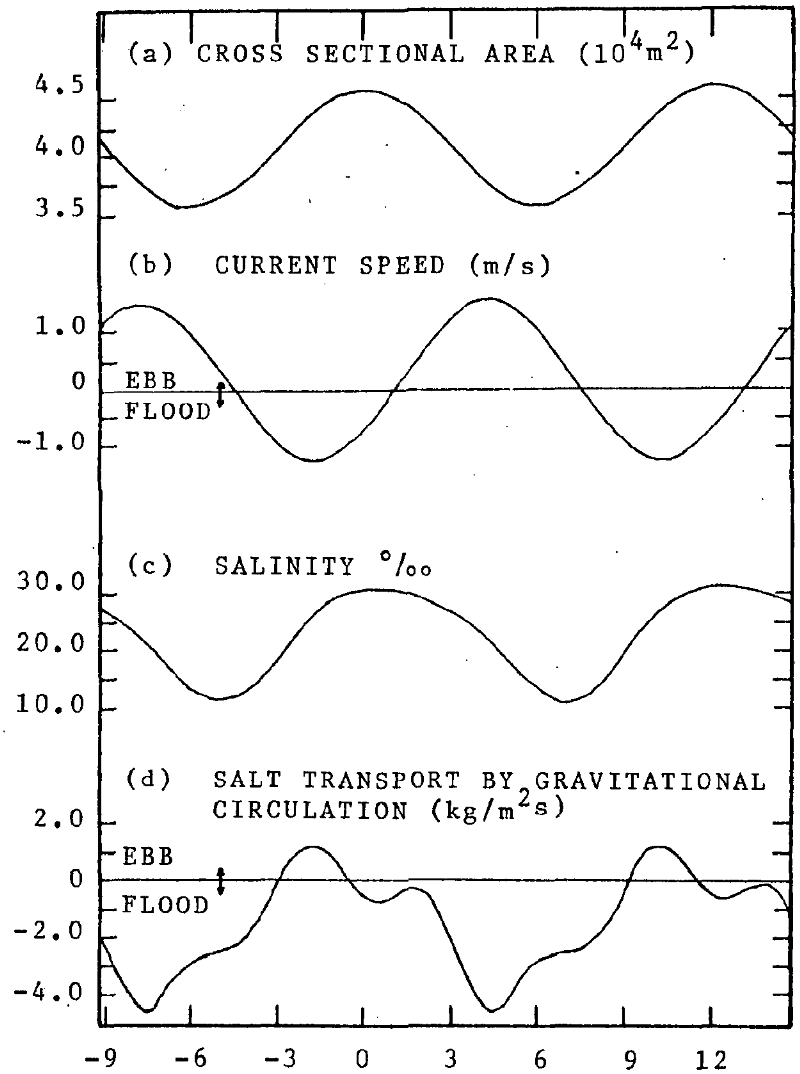


Figure 204-26 Tidal variation of mean conditions at low river stage, Clatsop Spit - Sand Island section.

The cross-sectional area of channel (a) the current speed (b) and salinity averaged over the cross-sectional area (c) all vary with tidal height. The salt transport by the gravitational circulation (d) is in the upstream direction on the average, and most strongly so under low flow conditions.

From: Hansen, 1965

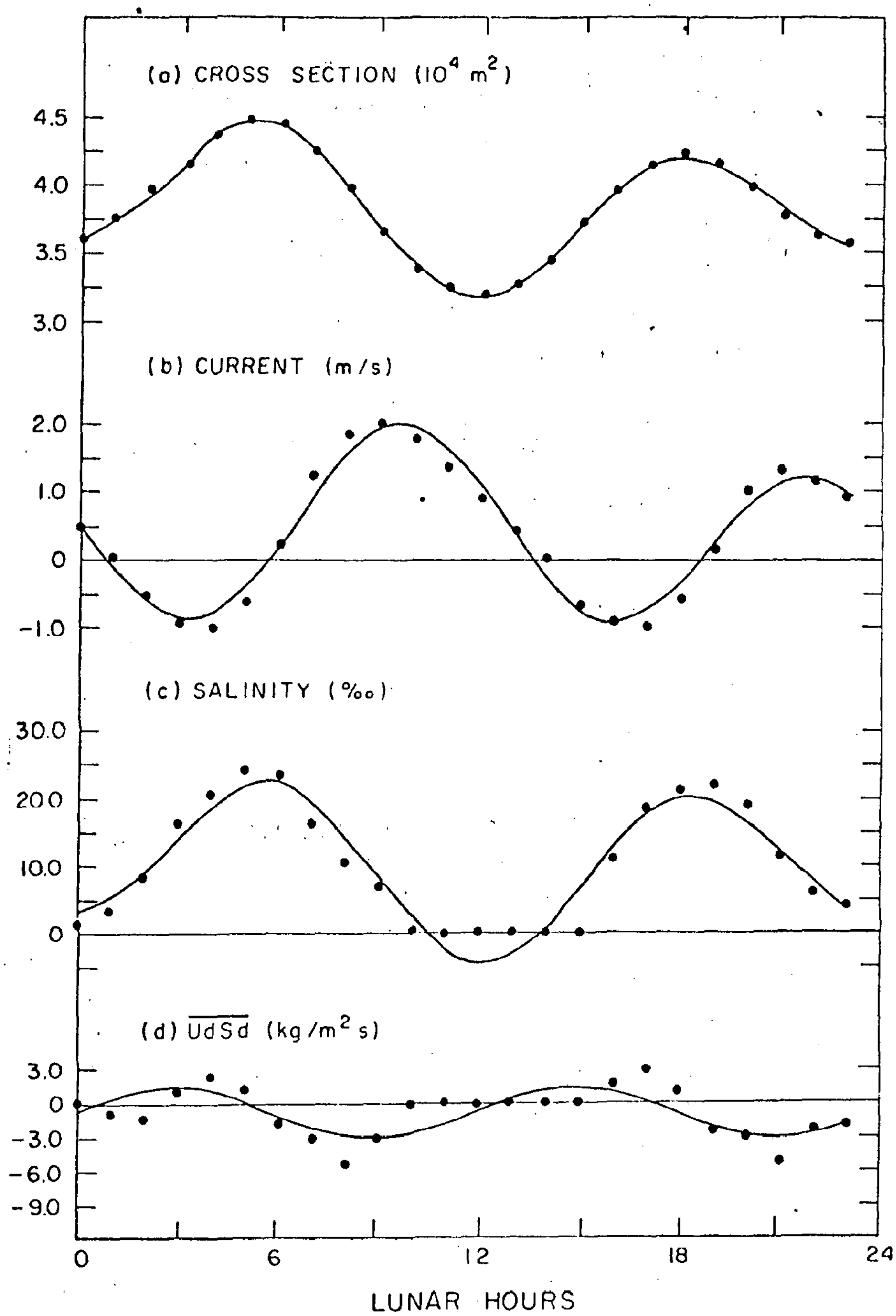


Figure 204-27: Tidal variation of mean conditions at high river flow, Clatsop-Sand Island section. (a) the cross sectional area of the channel, (b) the current speed and (c) the salinity all vary with tidal height. The salt transport by the gravitational circulation (d) is in the upstream direction on the average, but less so then in the low flow case.

From: Hughes, 1968

to the sea. Despite the stronger ebb currents, the above mechanisms, which we will combine under the name: "transport by tidal cycle variations," accounts for a significant amount of the upstream salt transport. The salt transport balance for the Columbia River estuary under high and low-runoff conditions is summarized in Table 204-3. These figures are based on data from only a few days and do not represent average conditions. Wide variations are possible.

More recent research on other estuaries has suggested that cross-channel variations in currents and salinity of the sort covered in Section 204.2 are also important in transporting salt. For example, net upstream flow in the estuary under low river-flow conditions is concentrated along the north side of the estuary, as well as the bottom of the North Channel (Figure 204-16c). Thus, there is transport by the lateral circulation, as well transport by gravitational (or vertical) circulation. And since cross-channel variations in salinity and current occur during flood and ebb that are not evident in the tidal cycle averages, lateral variations during the tidal cycle contribute another term. These lateral variations in the net flow and in the flow during a tidal cycle are not broken out of the gravitational circulation and tidal cycle variation terms in Table-204-3. Furthermore, different cross-sections of the estuary show differences in salinity structure along the length of the estuary (Section 204.2B). The salt transport is different from that in most estuaries that have been studies in detail, and further research is needed. This research is important because sedimentation in the estuary and its navigational channel is closely related to salinity intrusion.

Table 204-3

Percent Contribution to the Salt Transport Balance at the Clatsop Spit-Sand Island Cross-section Under Low and High Fresh-Water Flow Conditions

Transport Downstream Salt			Transport Upstream Salt						
Net Flow	+ Other*	=	Gravitational Circulation	+	Tidal Cycle Variations	+	Other*	Transport Mechanisms
96.8%	3.2%	=	16.5%	+	72.7%	+	10.8%	High Freshwater Flow
91.6%	8.4%	=	47.5%	+	40.8%	+	11.7%	Low Freshwater Flow

This table is compiled from calculations for Clatsop Spit cross-section by D.V. Hansen, 1965 and F.W. Hughes, 1968. Both papers are based on data collected on Range 2 during the Corps of Engineers 1959 field study (Figure 204-12)

*"Other" transport processes include turbulent transport and transport arising from vertical shear resulting from bottom friction. Also in the "other" category is the (unknown) change from one tidal cycle to the next in the amount of salt stored in the estuary.

204.5 REFERENCES

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An extremely technical discussion of the salt balance and mixing processes in the Columbia River under high discharge conditions. The data used are taken from the Corps of Engineers' 1959 field study. Not readable by the layman.

G. Lauff, G.H. (ed.). 1967. Estuaries. Publication No. 83. American Academy for the Advancement of Science, New York, New York.

The proceeding of a major conference on estuaries. All aspects are covered: geology, physics, biology, fisheries, chemistry, etc. Some papers are very readable, other obscure. An excellent general reference.

H. Lutz, G.A. and H.H. Stevens, Jr. 1975. Discharge and Flow Distribution, Columbia River Estuary. Geological Survey Professional Paper, U.S. Government Printing Office, Washington, D.C. 443pp.

Tidal height observations and a limited number of current measurements were used to calibrate a mathematical model that calculates river flow on a daily basis at Beaver Army Terminal (RM53) and Astoria (RM15). The accuracy of the calculated flows is only fair, but the interpretation of the flow data and current measurements elucidates several important features of the water storage and circulation in the Columbia River estuary. Flow predominance as a function of depth and lateral and longitudinal position in the channel is discussed. This is a very technical paper, not easily read by the layman.

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K. Oregon State University, Ocean Engineering Programs. 1975. Physical Characteristics of the Youngs Bay Estuarine Environs. School of Engineering, Corvallis, Oregon.

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A readable discussion of some results from the U.S. Army Corps of Engineers physical models of the Columbia River and other estuaries. Some of the figures are incorrectly labelled.

M. Sternberg, R.W., J.G. Creager, W. Glassley, J. Johnson. At press. Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon. Environmental Effects Laboratory. U.S. Army Engineers Waterways Experiment Station. Vicksburg, Mississippi.

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N. U.S. Army Corps of Engineers, Portland District. 1960. Current Measurement Program Columbia River at Mouth Washington and Oregon Interim Report. Volume I to IV.

Volume I contains the text explaining the field program and the plates in the other three volumes. Volume II contains the plates showing velocity. Volume III contains the plates showing direction. Volume IV contains plates showing salinity, tidal height, flow predominance, surface and bottom peak ebb and flood, currents, scour vs. shoal, and flow at the mouth. A large and valuable collection of data with no interpretation. Several theses and technical papers have been written using this data.

205

NUTRIENTS, MIXING AND WATER QUALITY

COLUMBIA RIVER

ESTUARINE NUTRIENTS, MIXING AND WATER QUALITY

David Jay

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205 ESTUARINE NUTRIENT, MIXING AND WATER QUALITY

The purpose of this chapter is to examine the physical, biological, chemical and cultural processes governing the concentrations of nutrients, dissolved oxygen, suspended particulate matter and pollutants in the Columbia River, its estuary and the adjacent ocean waters. As the largest river in western North America, the Columbia River is a major supplier of both water and nutrients to the North Pacific Ocean (Section 205.1). At the same time, the ocean is a major supplier of nutrients to the estuary through the mechanism of upwelling. The seasonal and spatial distribution of nutrients in the river and adjacent ocean areas is a complicated matter influenced by a number of physical, biological and chemical processes. The mixing of river and ocean water masses and the associated biological productivity and nutrients distributions are discussed in Section 205.2. The input of pollutants and their effects on water quality are considered in Section 205.3.

205.1 CHEMICAL BUDGETS OF THE COLUMBIA RIVER

The Columbia River supplies an average of about 269,000 cfs of water to the Pacific Ocean (Section 202). This is about 8,500,000,000,000 cf/year. This immense volume carries with it large quantities of such important dissolved nutrients as nitrate (and other nitrogen compounds), phosphate, silicate, and carbon dioxide, dissolved oxygen (DO), large quantities of organic, particulate matter that also enter the marine food chain and pollutants such as radioactive wastes, industrial wastes and sewage. As discussed in Section 201, the Columbia River effluent plume spreads out over a wide area of the North Pacific Ocean; it hugs the Coast of Washington (winter) or moves offshore and to the south (summer), depending on the prevailing winds. The Columbia River water also influences such properties as the temperature, salinity and pH (acid-base balance) of offshore waters.

To determine the amounts of dissolved nutrients and other dissolved substances supplied to estuarine and ocean waters, we must construct budgets; the budgets reflect the amount of each substance entering the estuary during each month of the year. These budgets suggest how much of each nutrient is available to support biological productivity. In addition to the material transported down the river into the estuary and then into the ocean, large quanitities of dissolved nutrients are supplied to the estuary from the ocean, particularly during upwelling periods (Section 201). The actual amount of nutrients contributed to the estuary by this mechanism is not known; it is probably as important biologically as the nutrient input from the river. Estimates in this section account only for the dissolved substances transported into the estuary from the river.

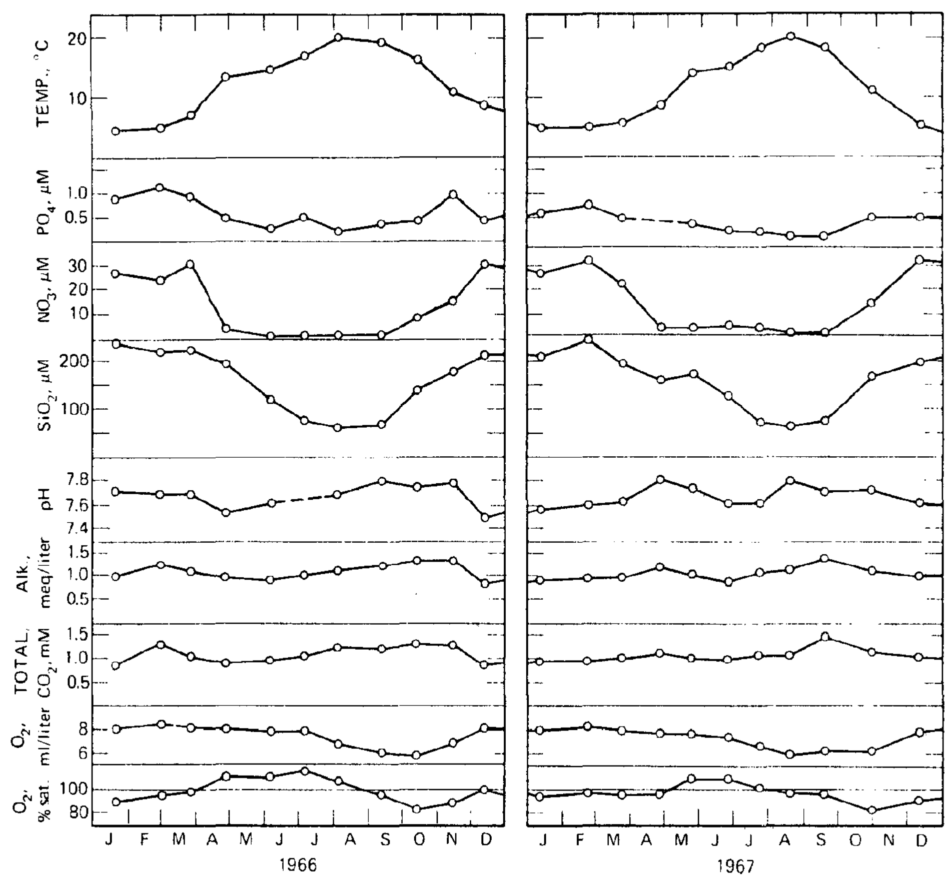
P. K. Park and other researchers from Oregon State University have calculated nutrient budgets for the years 1966 and 1967, based on data collected at Clatskanie (RM 55) and in the estuary. The results for the two locations are similar, so only the data from the estuary are presented here. Since many of the samples collected in the estuary consisted of a mixture of ocean and river water (as determined by salinity), it was necessary to extrapolate to zero salinity, to determine the concentration of the various substances in the river water (Figure 205-1). The transport of nutrients and other dissolved substances from the river to the ocean is shown in Table 205-1. The units used in Table 205-1 are standard chemical units (in most cases, the mole) to facilitate comparison of the uptake of various nutrients by phytoplankton. The right hand column gives an average yearly transport (in tons) for the two years.

A. Sources of Variability in the Chemical Budget

The transport of a dissolved substance is the product of the river flow rate and the concentration of the substance. The seasonal and year-to-year variations in freshwater flow are discussed in Section 202. High flows are usually observed during the spring snow melt and during an occasional winter storm. Low flows are normally observed during the late summer and fall. The concentration of a given substance in the Columbia River depends on at least five factors: 1) variation in river flow; 2) percentage of the river flow coming from each tributary; 3) variations in biological activity; 4) variations in pollutant loads (e.g. sewage, industrial wastes, agricultural runoff, runoff from forest lands) and 5) variations in air-sea interactions.

Figure 205-1

The Seasonal Variation of Chemical Parameters
in the Estuary



There is a strong seasonal variation of temperature and chemical parameters in the Columbia River estuary at zero salinity. Nutrients such as phosphate, nitrate and silicate are depleted during the summer, as it the dissolved oxygen.

From: Park *et al.*, 1972

TABLE 205-1

MONTHLY CHEMICAL INPUT FROM THE COLUMBIA RIVER INTO THE NORTHEASTERN PACIFIC OCEAN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual Budget	Average for two years in million tons/year
Phosphate, 10^6 moles														
1966	19.3	13.1	19.3	12.0	9.4	9.8	8.6	3.1	3.2	4.7	10.3	7.2	119	0.01
1967	11.7	12.2	9.5	6.9	8.0	11.4	4.6	1.3	0.9	3.7	6.3	7.2	84	
Nitrate, 10^6 moles														
1966	548	319	521	265	47	14	11	6	18	84	200	420	2450	0.18
1967	517	519	398	145	65	170	93	20	14	116	264	477	2800	
Silicate, 10^9 moles														
1966	5.32	3.19	4.56	3.51	3.88	3.07	1.51	0.74	0.70	1.36	2.19	3.15	33.2	3.60
1967	4.04	4.00	3.34	2.63	3.63	6.02	2.84	0.81	0.69	1.61	2.34	3.15	35.1	
Alkalinity, 10^9 eq*														
1966	21.3	14.4	21.6	17.4	21.9	26.5	21.9	12.9	11.0	12.8	15.0	12.8	210	11.30
1967	16.9	16.2	15.4	16.4	22.9	38.2	30.3	14.7	11.8	14.3	13.5	15.6	226	
Total CO_2, 10^9 moles														
1966	18.7	14.0	22.3	16.6	21.2	27.1	24.1	13.9	11.0	12.5	15.0	12.8	209	10.90
1967	17.9	16.2	15.9	16.5	22.0	41.1	30.9	14.4	12.2	15.3	14.5	16.4	233	
Oxygen, 10^9 liters														
1966	166	104	156	140	188	220	163	75	56	60	88	120	1540	2.80
1967	152	139	129	119	164	318	210	79	56	76	91	122	1660	

*Alkalinity is the net negative charge per unit mass of water that reacts with the H^+ ion. It is expressed in equivalents (moles of negative charge).

From: Park et al, 1972.

There are strong variations from tributary to tributary in the kind and quantity of dissolved materials introduced. These variations result from: natural differences (e.g. soil type, amount of suspended sediment carried); differences in the uses of land (agriculture, timber harvest, urban, etc.); and the introduction of pollutants.

The strongest, and for our purposes, the most significant source of seasonal variation in nutrients and DO is biological activity in the river and estuary. Phytoplankton (small algae growing in and moving with the water) and fixed plants such as marsh grasses, take up nitrogen, phosphate and carbon dioxide; some phytoplankton also take up silicate. DO is given off during the photosynthetic process. The phytoplankton are eaten by zooplankton (small animals growing in and usually moving with the water), or they decay in the water or on the bottom; decomposition consumes DO. The zooplankton excrete both particulate and dissolved organic matter. The flushing of the estuary is sufficiently rapid that much of the zooplankton, phytoplankton and other particulate organic matter is swept out to sea before it can be decomposed, oxidized to the form of nutrients and reutilized by the phytoplankton. These cycles exhibit strong seasonal variability (Section 304; Plankton).

The concentration of the dissolved gases, carbon dioxide and oxygen is also affected by air-water interactions and the temperature of the water. Higher salinities and temperatures decrease the solubility of both carbon dioxide and DO. Carbon dioxide is below saturation levels in the Columbia River, however, and the concentration varies only by about 20% during the year (Figure 205-1).

In contrast, DO shows a strong seasonal cycle (Figure 205-1). The water is supersaturated with DO during the spring, because of the intense primary productivity. DO levels fall during late summer, because of the reduced dilution of waste under low flow conditions, because of the large amount of organic matter in the river to be oxidized, because of the reduced solubility of DO in the warmer, saltier water, and because the warmer water increases the rate at which material is oxidized. Thus, the estuary and the river have much less capacity to assimilate man's wastes during the late-summer, low-flow period than during the rest of the year. Regulation of freshwater flow in the Columbia River by the many dams has served to increase the summer minimum flows. An increase in consumptive water use, however, would reduce summer minimum flows, at least in dry years. Water diversion from the river is therefore, a major water quality issue.

It is likely that the total year-to-year variability in the dissolved nutrient budget is somewhat larger than year-to-year variability in freshwater flow (Section 202), but smaller than the year-to-year variability in sediment transport (Section 208). Firm conclusions cannot be drawn from two years' data, however.

B. Limiting Factors in Primary Productivity

Biological productivity is one of the major causes of the variability of the nutrient and DO distributions. The use of nutrients and production of DO by phytoplankton during photosynthesis, and the consumption of DO and release of nutrients during decomposition are the most important processes. The rate of primary productivity (as the photosynthetic process is known) in the estuary is governed by a number of factors: available sunlight, turbidity (the amount of particulate, matter in the water), temperature, salinity, nutrient concentrations, the concentrations of phytoplankton in the estuary, the rate of river flow, and the tidal range.

To summarize material discussed in Section 304, primary production is low during the winter, and large quantities of nutrients flow out to sea without ever being incorporated into the estuary food chain. It is likely that the major limiting factor during this period is lack of light. The Columbia River is sufficiently turbid during most of the year to limit phytoplankton growth to the surface layer. The coming of spring, with longer days, more sun and higher water temperatures, is almost always accompanied by a dramatic increase in numbers of phytoplankton. During much of the summer, the vital nutrients, nitrate and phosphate, are reduced by primary productivity to almost undetectable levels in the river upstream from the estuary (Figure 205-1). During this period, the phytoplankton population in the estuary is essentially an extension of the upstream, riverine population. The major sources of nitrogen and phosphate in the estuary are the decomposition of organic matter in the water column and the transport of nutrients from the ocean. Freshwater species do not grow well in the brackish water containing nutrients from the ocean, and the salt water species are confined to the salt-wedge along the bottom, where light intensities are low. Therefore, primary productivity in most of the estuary is low. The water temperature exerts an important influence over the plankton species present.

The tidal currents and the freshwater flow through the estuary also exert a strong influence on primary productivity. The rate of primary productivity is proportional to the population of living phytoplankton cells. If the river flow or tidal action is too strong, the plankton will be carried out to sea so quickly that it will be impossible for a large population to establish itself in the estuary; primary production will remain low. This phenomenon is also observed in Puget Sound. A sudden decrease in river flow during the summer may result in a dramatic increase in populations and primary productivity.

In summary, most of the nitrogen and phosphorus in the estuary during the spring and summer is tied up in particulate organic matter (zoo - and phytoplankton). This particulate organic matter is not included in the chemical budget of dissolved substances (Table 205-1). Most of this organic material is, nonetheless, carried out to sea and enters the marine food chain just as surely as would the equivalent amount of dissolved nutrients.

C. Nutrient Ratios and Limiting Factors

It has been suggested that lack of nutrients is the major factor limiting primary production during the summer in the Columbia River estuary. Table 205-1 shows substantial depletion of silicate and phosphate, and almost total depletion of nitrate during the summer months. In contrast, carbon dioxide levels vary by only 20% during the year, and the levels do not appear to be depleted during the summer. To determine which nutrient or nutrients are limiting, it is necessary to know the relative amounts of nutrients used during primary production. Nutrient utilization ratios must be compared to the nutrient ratios observed in the water column, to determine which nutrient is actually in shortest supply.

All the important freshwater species and most of the important marine species of phytoplankton in the estuary are diatoms. These phytoplankton have a casing known as a "test" made of silicate. Thus, they use large quantities of silicate. Nutrient utilization ratios vary, depending on the species of phytoplankton, the health of the cells, and the nutrient ratios in the water column. That is, most phytoplankton compensate to some degree when a particular nutrient is in short supply. Therefore, exact nutrient utilization ratios cannot be given, but a reasonable range of values for the C:Si:N:P ratios for diatoms is:

C	: Si	: N	: P
40-125	11-42	12-18	1

That is, for each atom of phosphorous (P) incorporated in the form of phosphate, 12 to 18 atoms of nitrogen (N) in the form of nitrate, nitrite, ammonia or organic nitrogen, 11 to 42 atoms of silicon (Si) in the form of silicate, and 40 to 125 atoms of carbon (C) as carbon dioxide or organic carbon will be incorporated during primary production. Observed nutrient uptake ratios for plankton off the coast of Oregon and Washington fall within this range. Decay of the phytoplankton returns nutrients to the water in the same ratio, though different nutrients are regenerated at different rates. In particular, the decay of organic nitrogen is considerably slower than that of organic phosphate.

The nutrient utilization ratios must be compared to the observed nutrient ratios in the estuary. It is clear from Table 205-2 that carbon dioxide and silicate were always present in great excess over nitrate and phosphate. It also appears that nitrate was the limiting factor in the summer of 1966, while nitrate and phosphate were more closely in balance during the summer of 1967. These results must be interpreted with caution for two reasons. First, the actual nutrient utilization ratios are not definitely known. Second, recent research suggests that phytoplankton prefer to use sources of nitrogen (nitrite, ammonia, urea, other organic nitrogen compounds) other than nitrate. These other forms of nitrogen are available only as decay products of organic material in the water (or as pollutants introduced by man),

TABLE 205-2

Observed Nutrient Ratios of Columbia River Water
at Zero Salinity for the Years 1966 and 1967

	Carbon Dioxide		Silicate		Nitrate		Phosphate
	1966	1967	1966	1967	1966	1967	
Jan.	968	1532	280	350	28	44	1
Feb.	1067	1319	240	330	24	42	1
Mar.	1153	1687	240	350	27	42	1
Apr.	1385	2400	290	380	31	21	1
May	2250	2757	410	450	5	8	1
Jun.	2771	3592	310	530	1	15	1
Jul.	2800	6667	180	610	1	20	1
Aug.	4518	11000	240	620	2	15	1
Sep.	3486	13300	220	750	6	15	1
Oct.	2646	4167	290	440	18	32	1
Nov.	1460	2290	210	370	20	42	1
Dec.	1770	2290	440	440	58	67	1
Yearly Average	1760	2773	280	420	20	33	1

From: Park *et al.*, 1972

and nitrate is normally available in much higher concentrations, except under conditions of nutrient limitation.

It is also known that the regeneration of phosphate by decay of organic matter is faster than the regeneration of nitrogen compounds. It is probably safe to conclude, on the basis of the data in Table 205-2 and on experience in other coastal areas, that nitrogen is the limiting nutrient in the Columbia River estuary and the adjacent ocean waters.

Silicate and carbon dioxide are both available in excess in the river. As a result, the C:P and Si:P ratios increase during the summer, because only about 20% of the carbon dioxide and 60 to 75% of the silicate is utilized in primary production. In contrast, as much as 90% of the phosphate and 99% of the nitrate is used to support primary production in the transition zone, just outside of the mouth of the estuary. Carbon dioxide is present in excess throughout the surface layers of the world ocean. The carbon dioxide does, however, play an important role in governing the acid-base balance of both the river and the ocean.

205.2 MIXING OF WATER MASSES AND THE SPATIAL DISTRIBUTION OF NUTRIENTS AND PARTICULATE MATTER

Salinity is used as a tracer of the complex mixing processes that occur at the mouth of the estuary (Section 204). Salinity is a conservative property; that is, it changes only through the mixing of water masses. Below the surface, temperature is also a conservative property; however, solar heating and air-water exchange of heat make temperature a non-conservative property at the surface. Therefore, it must be used cautiously as a tracer of the mixing of water masses. The properties of major concern in this chapter, the nutrients, DO and particulate organic matter are all strongly non-conservative. Other factors besides mixing that affect these properties are discussed in Section 205.1. By comparing the distributions of the non-conservative properties with those of the conservative properties, it is possible to learn about the conservative mixing processes and the non-conservative biological processes.

Mixing processes that occur between river and ocean water during the summer have been studied in some detail by T. J. Conomos, M. G. Gross, and other oceanographers from the University of Washington.

A. Water Mass Analysis

The first step in such an analysis is to identify the water masses involved in the mixing processes. A water mass is simply water with certain rather narrowly defined salinity and temperature characteristics. If the water masses are properly defined, then the temperature and salinity characteristics of all the water in an area can be defined in terms of mixtures of a small number of parent water masses. It is, of course, necessary to explain the source of each water mass and the forces causing it to mix with the other masses.

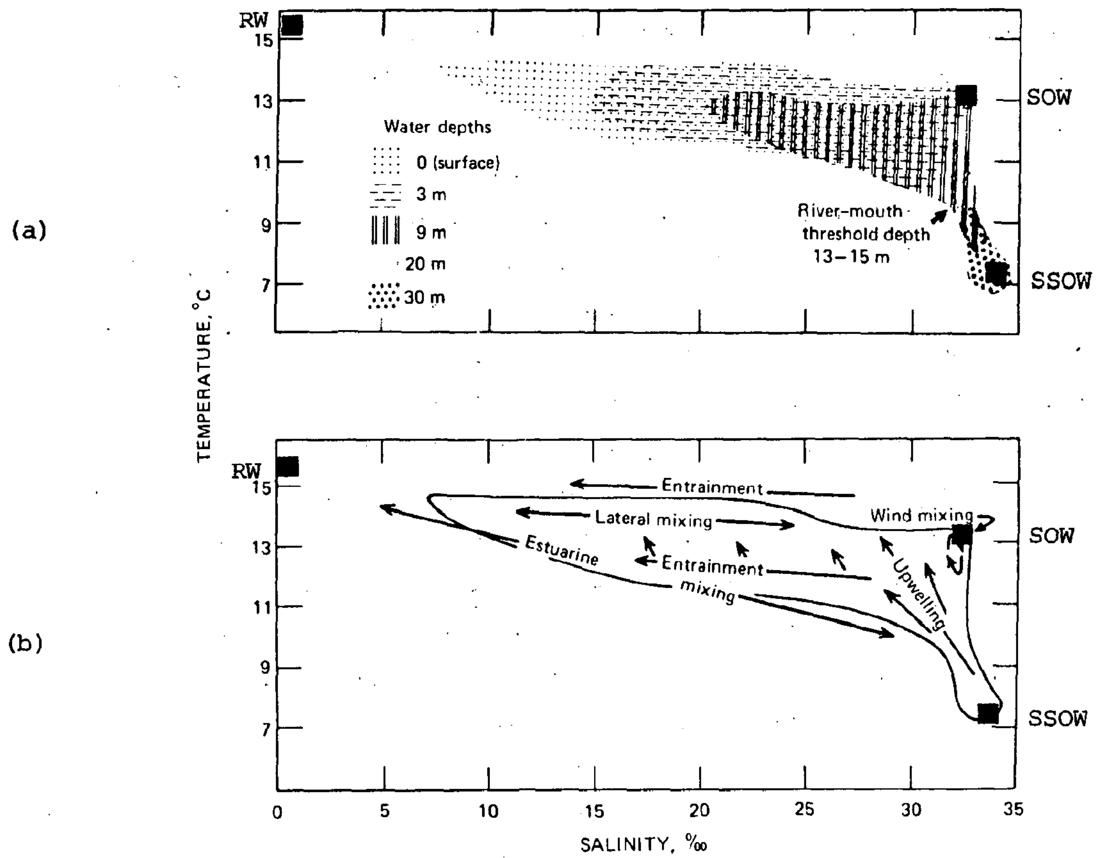
Water masses are usually identified using temperature-salinity (T-S) diagrams such as Figure 205-2a and b. Temperature is shown on the vertical axis and salinity on the horizontal axis. Any sample of water may be located on such a diagram, according to its temperature and salinity. Depths are also indicated in Figure 205-2a. As shown in Figures 205-2b and 205-3, the temperature and salinity properties of the waters at the mouth of the Columbia River can be explained in terms of three water masses: River Water (RW), Surface Ocean Water (SOW), and Sub-Surface Ocean Water (SSOW). The three water masses occupy the three extreme positions of the observed T-S distribution. All mixtures of the various water masses must have properties between these extremes. For example, the average values of the temperature and salinity in the SOW during June 1965 were about 31.8°/₀₀ and 13° C. The averages for the SSOW at that time were 33.6°/₀₀ and 7.6° C, respectively. A mixture of equal volumes of SOW and SSOW would have a salinity of about 32.7°/₀₀ and a temperature of 10.3° C; each property would be midway between the extremes. It is a general rule that mixing between water masses proceeds along a straight line on a T-S diagram. That is, as SOW is diluted by larger and larger amounts of SSOW, its properties will approach those of SSOW along a line drawn on the T-S diagram between the positions of SOW and SSOW.

The properties and locations of the three water masses during June, 1965 are in Figures 205-2, 205-3, 205-4. RW had a salinity of less than 1°/₀₀ and a temperature that varied during the summer from about 15 to 19° C. RW was low in phosphate and nitrate although it probably contained some available nitrogen in other forms (Figure 205-3).

Figure 205-2

Temperature Salinity Diagrams

June 1965

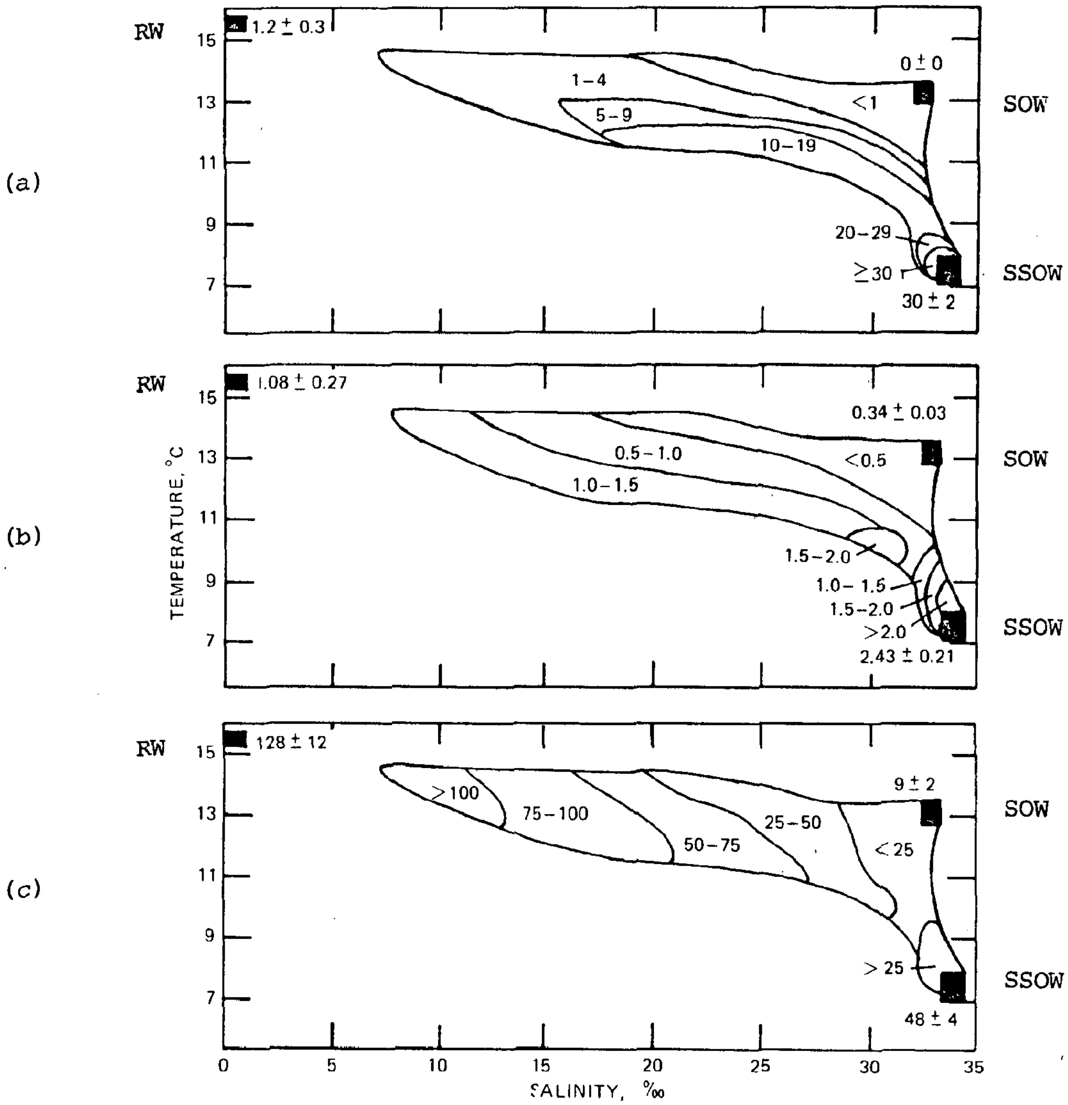


Spatial distributions of water types (a) and major physical processes affecting water parcels (b) as functions of temperature and salinity, June 1965 survey.

From: Conomos et al., 1972

Figure 205-3

Nutrient Concentrations as a Function of Temperature and Salinity



Nitrate (a), phosphate (b), and silicate (c) concentrations in microgram atoms per liter as functions of temperature and salinity, June 1965 survey. The concentration gradients coupled with the configurations of contour boundaries indicate the direction of nutrient supply.

From: Conomos et al., 1972

It was also the major source of silicate in the nearshore area off the Columbia River. Its DO content was high during high flow periods but declined during the late-summer, low-flow period.

SOW was also warm (12.7 to 13.7° C in June), and it had a salinity in the range of 31.7 and 31.85 °/oo (Figure 205-3). SOW was generally found more than 15 km (9 mi) offshore in a shallow surface layer (less than 15 m or 50 ft deep). It was very low in nutrients but supersaturated with DO, because of intense primary production. SOW is a mixture of river and ocean water that has been at the surface long enough to have its nutrients depleted. The study summarized here did not reach far enough to sea to obtain SOW entirely uncontaminated by RW. The rule of the thumb commonly used by oceanographers is that any water in this area with a salinity of less than 32.5 °/oo is part of the Columbia River plume. This plume may extend several hundred miles out to sea during the summer (Section 201). The sampling in this study was concentrated within 60 km (36 mi) of the coast.

SSOW was the coldest (less than 8° C) and saltiest (more than 33.4 °/oo) water in the study area. SSOW moved into the nearshore area from the deeper waters of the continental shelf and slope (perhaps as deep as 500 m or 1600 ft), because of the wind-driven coastal upwelling process (Section 201). This water had been below the surface for long periods of time (as long as several hundred years). Much organic matter had decomposed in the SSOW, and consequently, observed nutrient levels were high and DO levels low. Silicate values were not as high as in the river, however.

Underlying the SOW and above the SSOW, there was a transition layer with intermediate properties, which was a mixture of SSOW and SOW.

B. <u>Mixing Processes at the Mouth of the Columbia River</u>

The basic mixing processes occurring in the area are shown schematically in Figure 205-4. Mixing takes place in two stages. In the first stage, RW mixes with SSOW (and to some extent with SOW) in the estuary. The SSOW has reached its position along the bottom, close to the shore, because of the wind-driven coastal upwelling that prevails during most of the spring and summer, and because of entrainment of ocean waters into the Columbia River effluent plume. The entrainment* of SSOW into the surface RW is driven by the tidal and river currents. This form of upwelling is extremely important in providing nutrients to the lower estuary and mouth area during the summer. As pointed out in Section 205.1, almost all the phosphates and nitrates in the river are used up before the water reaches the estuary, thus, the SSOW is the major source of nutrients (except silicate) for the estuary during the summer.

The second-stage mixing takes place primarily within a transition zone between estuarine and oceanic conditions that extends about 20 km (12 mi) from the mouth of the river (Figure 205-5). The SSOW that has been brought near the surface by the wind and river induced upwelling is entrained into the surface layer formed by the first-stage mixing; this further increases the salinity, phosphate and nitrate content of the mixture. Lateral mixing with SOW also occurs during this stage.

Outside of the transition area, entrainment ceases to be a major factor in the vertical mixing. Wind-driven mixing is the dominant factor in the oceanic area. Winds are seldom strong enough during the summer to cause strong vertical mixing across the halocline (vertical salinity and density gradient) below the Columbia River plume. The plume, therefore, retains its identity as it spreads out to the south and west. The nutrients from first and second-stage mixing are quickly consumed, and they are not replaced because of the inhibited vertical mixing. The outer part of the plume is, therefore, an area of relatively low productivity.

During periods of high flow, the first and second stage mixing processes are displaced further out to the sea, and even the first stage mixing occurs mostly outside the estuary.

C. Nutrient Distribution, Transport and Utilization

Phosphate and nitrate are reduced to extremely low levels in the RW before it reaches the estuary. The silicate is depleted, but not exhausted. Silicate concentrations in the RW still considerably exceed those in the SOW and SSOW, though the SSOW acts as a secondary source of silicate. To a much lesser extent, the RW acts as a secondary source

*Entrainment has been discussed in detail in Section 204.1 C and D; it is the process whereby relatively-fresh river water flows over denser, more saline ocean water and is progressively diluted by saltwater from below. Very little freshwater mixes down into the salty, bottom layer.

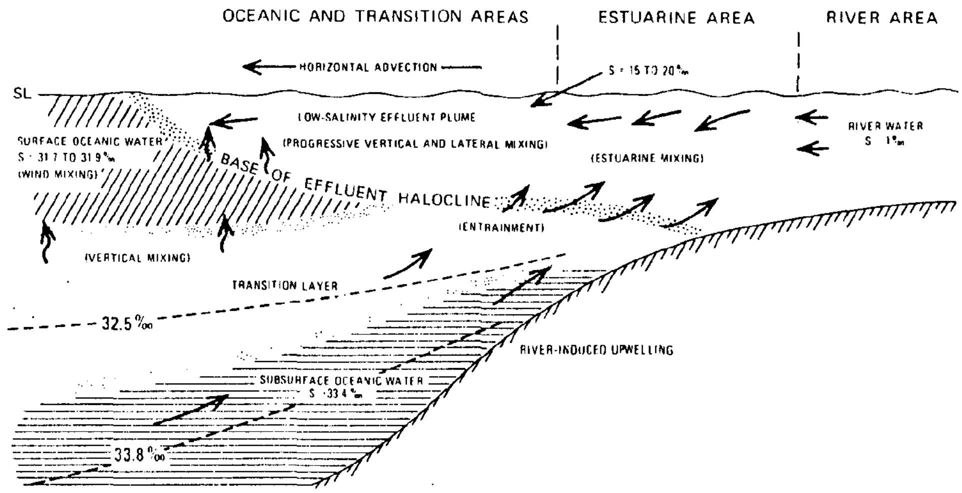


Figure 205-4

Physical processes, circulation, and salinity distribution during summer.

From: Conomos *et al.*, 1972

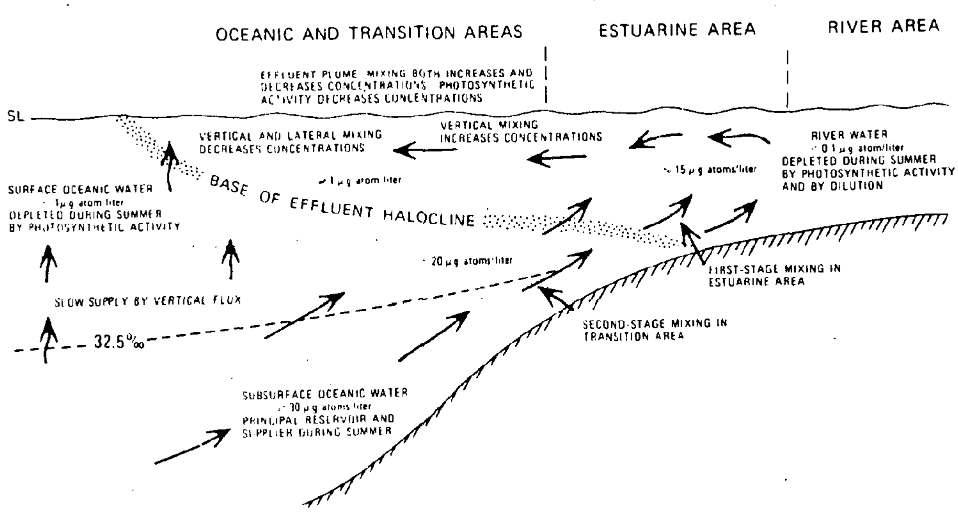


Figure 205-5

Nitrate distribution and supply mechanisms during summer. The primary source of nitrate is the Sub-Surface Ocean Water (SSOW). The River Water (RW) and the Surface Ocean Water (SOW) are both depleted in nitrate during the summer.

From: Conomos *et al.*, 1972

of phosphate. The behavior of silicate then, is somewhat different from that of the phosphate and nitrate. The behavior and distribution of nitrate is of concern, because nitrogen is the limiting nutrient. It must be remembered, however, that other forms of nitrogen are also utilized by phytoplankton (Section 205.1B). The seasonal variability and spatial distribution of phosphate is similar to that of nitrate.

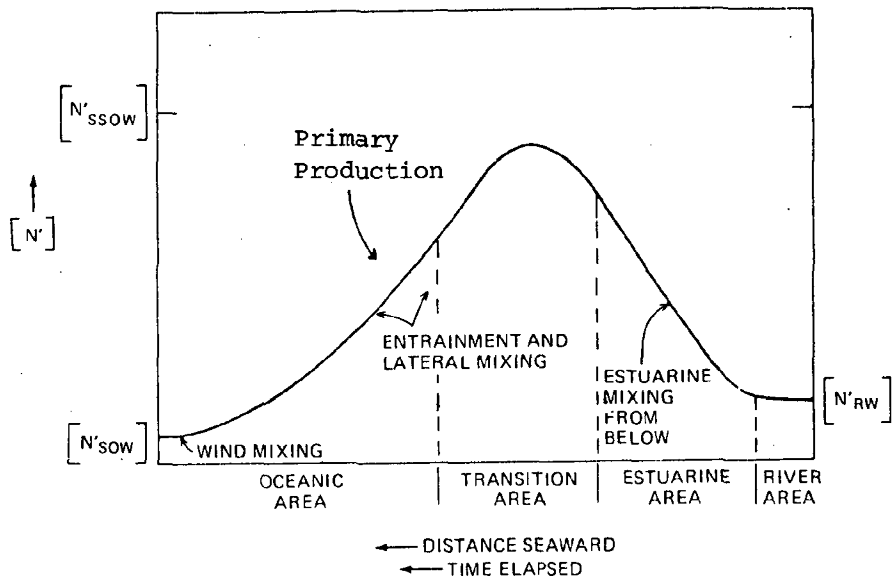
A simple model of the nitrate supply and transport near the mouth of the Columbia River is shown in Figure 205-5 and 205-6. The first-stage mixing between RW and SSOW in the estuarine area increases both the salinity and nitrate content. If this mixing is sufficiently rapid, and if there is any time delay between the appearance of nutrients in the surface layers and the onset of increased productivity, then the concentration of nitrate in the waters at the mouth of the estuary will be much larger than in the upper estuary and river.

The second-stage mixing will continue to increase salinity and nitrate values, so long as the mixed RW and SSOW in the plume overlay SSOW or transition water. Once the plume is sufficiently far out to sea that it overlays SOW depleted of all nutrients, the plume will continue to gain salinity but begin to lose nitrate by vertical mixing. During the second stage mixing process, the plume will be depleted by intense primary productivity until its nitrate content is no higher than that of the SOW. The rate of primary production in the nutrient-depleted areas of the plume will then be controlled by the rate of recycling of nitrogen compounds by decay. The nitrogen will be recycled before it is oxidized to nitrate. Thus, a parcel of water leaving the estuary will first be enriched in nitrate or phosphate by vertical mixing and then depleted by primary production and mixing (both vertical and horizontal).

The resulting nutrient distribution shows a sharp peak at the mouth of the estuary or within a distance of 20 km (12 mi) in the seaward direction (Figure 205-6). The area just outside the mouth then, is an area of especially high productivity. The highest concentration of chlorophyll *a* (the photosynthetic pigment found in algae) and the highest rate of plankton growth are found there (Figure 205-7a and 7b). It is no surprise that the Dungeness Crab fishery is also concentrated in this area. The mixing zone outside the mouth is one of the most

Figure 205-6

Processes Affecting the Concentration of Nitrate

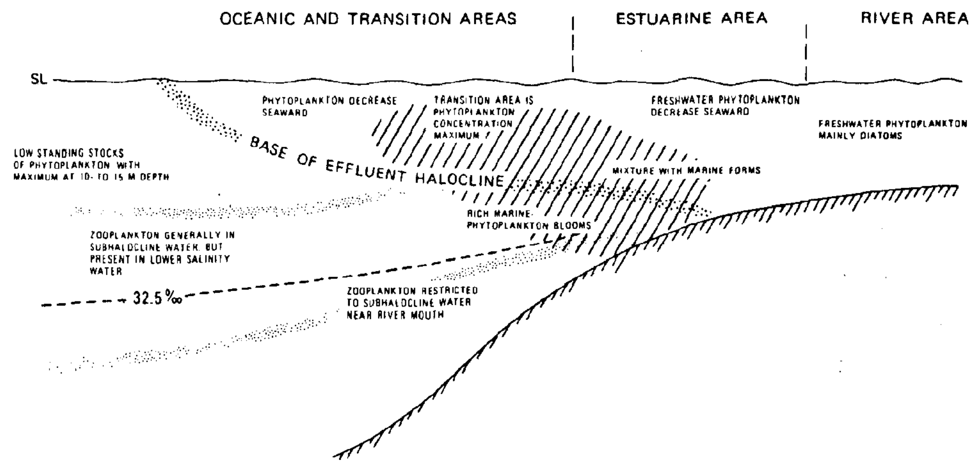


The concentration of nitrate in a parcel of water (indicated by [N]) first increases and then decreases as the parcel moves from the river (right) through the transition zone (center) and out to the open ocean (left). The physical and biological processes acting on the [N] are indicated.

From: Conomos et al., 1972

Figure 205-7 (a)

Phytoplankton and Zooplankton Distribution and Production

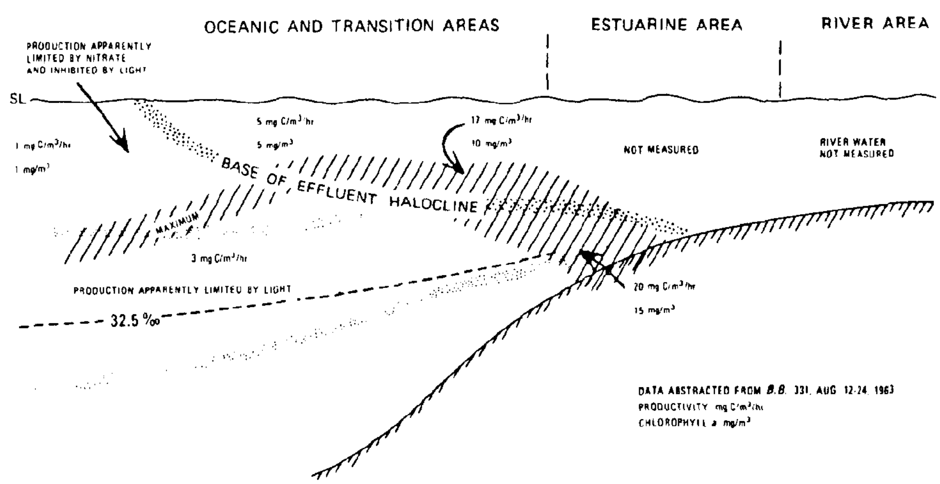


Note: The location of maximum population of phytoplankton seaward of the mouth of the estuary.

From: Conomos et al., 1972

Figure 205-7 (b)

The Rate of Primary Productivity (Production of Phytoplankton)



Note: The location of maximum productivity seaward of the mouth of the estuary.

From: Conomos et al., 1972

productive areas of the entire Oregon and Washington continental shelf. These factors must be taken into consideration in planning navigational improvements and dredged material disposal at sea.

The silicate distribution is somewhat different from the nitrate and phosphate distributions. The RW is the major silicate source and all mixing processes, as well as primary productivity, tend to deplete the silicate concentration. On the other hand, silicate is relatively abundant and is apparently never completely used up; it is not generally the limiting nutrient.

Some nutrient data collected by Haertel, Osterberg and others from Oregon State University show peak nutrient concentrations in the late summer inside the estuary, in association with the salt-wedge. The OSU data do not extend below about RM 5, and the U of W data discussed in the preceeding paragraphs did not always extend upstream of the mouth. In some instances, the U of W data did show a double nutrient maximum, with one peak at, or outside of the mouth, and another in the lower estuary. Haertel and Osterberg hypothesize that the nutrient peak inside the estuary is associated with the "null zone" (Section 208). This area of little net horizontal movement occurs near the upstream limit of salinity intrusion. Colloidal material tends to aggregate in the salt-wedge, and the resulting fine particulate matter tends to settle out in the null zone. The null zone moves up and down river between approximately RM 5 and RM 20, depending upon freshwater flow and tidal range. Dead and decaying phytoplankton and zooplankton make up part of the particulate matter concentrated in the null zone. The decay of this material results in a decrease in the concentration of DO. The null zone is probably also an area of enhanced productivity; such is the case in many other estuaries.

D. The Cycling of Particulate Organic Matter

Conomos and Gross of the U of W have also studied the composition, transport, production and decay of particulate matter in the area in and adjacent to the Columbia River estuary during the summer. The Columbia River transports large quantities of suspended material. About 85 to 95% of this material is inorganic sediment and is not of concern here (see Section 208). The remaining 5 to 15% of the material is particulate organic matter and consists mainly of phytoplankton and detritus; a small portion of it is zooplankton. The cycling of particulate organic matter is intimately related to the cycling of nutrients. Nitrogen, phosphorus and silicate that is not in dissolved form is tied up in particulate organic matter. This particulate material eventually oxidizes to the form of dissolved nutrients and again cycles through the system.

The processes affecting the concentration of particulate organic matter are shown in Figure 205-8a and 8b. The area of the most intense primary production is in the transition zone just outside of the estuary. Large quantities of organic particulates in the form of freshwater phytoplankton are carried into the area by the river flow. As a parcel of water moves out to sea, the particulate organic matter (as a percentage of the total particulate matter) increases. This results both from enhanced primary productivity in the transition zone and from the settling out of the inorganic particles. The absolute concentration of organic particulates decreases from the transition zone outward, and this decrease results from mixing with less turbid ocean water masses, zooplankton grazing and the settling out of detritus and phytoplankton.

205.3 WATER QUALITY

There are over 300 known municipal and industrial facilities that discharge wastes directly into the Columbia River and its tributaries below Bonneville Dam; few of these are in the estuary itself. A much larger number of industries discharge into sewer systems that eventually discharge into the Columbia River system. Most of the larger municipal systems listed below treat industrial wastes. Dischargers are concentrated along the Columbia River between Longview and Washougal and in the Willamette River Valley. It is not yet possible to determine the percentage of municipal and industrial wastes in the chemical budgets of Section 205.1. Furthermore, it is likely that non-point sources of pollution (wastes not entering the water through an outfall pipe or channel) such as agriculture and forestry runoff, are more important than the point source with regard to Biochemical Oxygen Demand (BOD), turbidity, biocides and some other pollutants. Nonetheless, management of point sources is extremely important for several reasons, including: (1) human wastes are a major source of dangerous bacteria and viruses; (2) point sources, because they discharge at a definite location, may cause severe localized overloading of the river; (3) certain industrial wastes may be the only source of some highly toxic substances, and (4)

Figure 205-8

The Cycling of Particulate Organic Matter

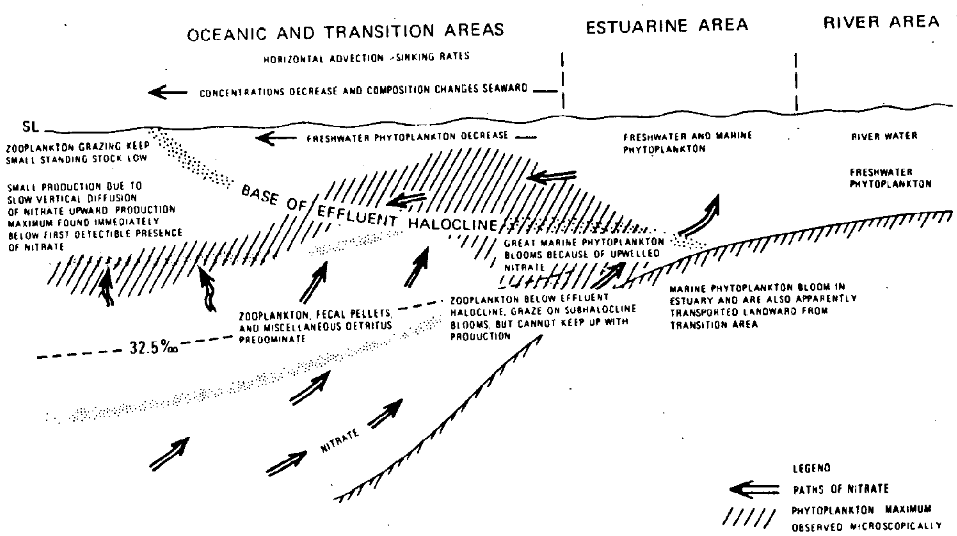


Figure 205-8 (a)

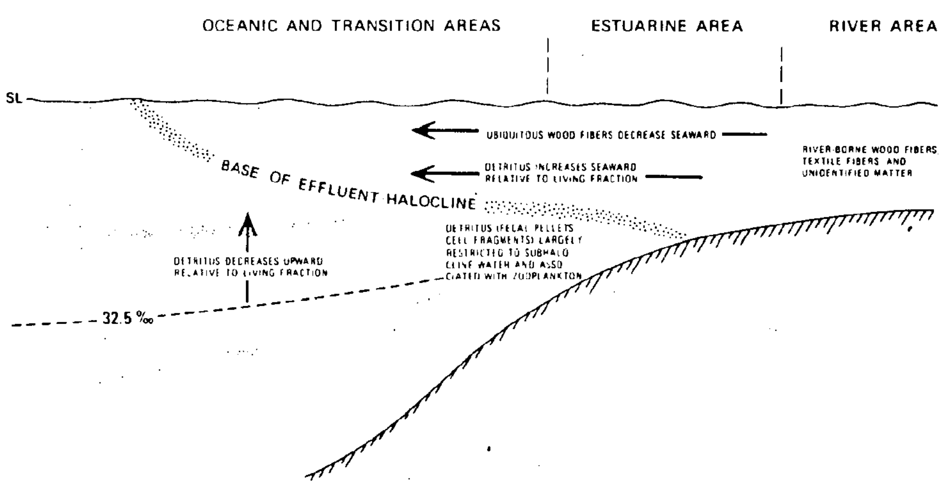


Figure 205-8 (b)

Concentrations, paths and processes of formation and dispersion of suspended organic material: a) living fraction, b) detritus.

From: Conomos and Gross, 1972

control of point sources may make the crucial difference between overloading the system with waste and not overloading the system. It should also be recognized that some discharges are actually beneficial to the living systems in the river.

Long-term water quality improvement requires a non-point source control program and is one of the five major water quality problems in the Lower Columbia River. The others are gas super-saturation caused by numerous main-stream dams, tributary stream siltation, high summer stream temperatures and over-allocation of flows in the tributaries and main stem. Gas super-saturation causes downstream migrant juvenile fish to die of "the bends." Gas super-saturation is not a problem in the estuary area, however. Tributary stream siltation results from some forestry and agricultural practices, urban run-off and natural erosion. It is primarily a non-point source problem. High stream temperatures result both from point source discharges and from the heating of water in dam storage pools.

Over-allocation of stream flow is neither a point nor a non-point source problem; it is caused by removal of water from the stream rather than addition of pollutants. Reduced stream flow reduces the amount of wastes that can be assimilated and usually increases stream temperatures. As mentioned in Section 202.2, the normal summer stream flow in some river and estuary tributaries is less than the water rights to the water, so that simultaneous exercise of existing water rights could completely dry up a stream. Over-allocation of main stem water was not a problem until the record low-flow year of 1977, when there was not enough water to meet the needs of agriculture, hydroelectric power and fisheries. Compromise was necessary on all sides. Over-allocation may be a problem again, if major increases in irrigation occur, or if any water is sold outside the basin.

A. Water Quality Management in Oregon and Washington

Disposal of wastes is one of the benefits provided to man by a large river system; it has also been greatly abused. It is a national goal to end the discharge of pollutants to the nation's waters by 1985, and to maintain the receiving water quality necessary to serve all other recognized beneficial uses. These and other basic requirements for water quality management are set forth in the Federal Water Pollution Control Act Amendments of 1972 (PL-92-500), administered by the Environmental Protection Agency (EPA). Washington and Oregon have both established water quality programs to comply with the EPA requirements. The Washington program is authorized by RCW 90.48.

and administered by the Department of Ecology (DOE). The Oregon program is authorized by ORS Chapter 468 and administered by the Department of Environmental Quality (DEQ). Under the requirements of PL 92-500, all point source dischargers must obtain a National Pollutant Discharge Elimination System (NPDES) permit that specifies the amounts and concentrations of pollutants that may be released by the industry in the interim period before 1985. These permits are granted and administered by DOE and DEQ; both Washington and Oregon administer most aspects of their water quality programs by agreement with EPA.

Section 303(e) of PL 92-500 requires that each state have a continuing planning process to meet the requirements of the act. Both states have prepared Water Quality Management Plans that list, basin by basin, water quality problems, facilities, needs and dischargers. The basins below Bonneville Dam that are of primary interest with regard to water quality in the estuary include the: Willapa; Cowlitz-Wahkiakum, Lewis and Middle Columbia River (in part) Basins (encompassing Water Resource Inventory Areas WRIA 24 to 28) in Washington and the North Coast-Lower Columbia River, Willamette River and Sandy River Basins in Oregon. Basins above Bonneville Dam and below the Hanford Nuclear Reservation are of somewhat lesser importance. Basin Management Plans and data provided by EPA (Siler, Unpublished) provide the basis for the summary of industrial and municipal dischargers below.

The water quality standards in both Oregon and Washington are set so that certain beneficial or characteristic uses may be maintained. Since the uses vary with the body of water, so do the standards. The Washington and Oregon uses for the Lower Columbia River and its tributaries are shown in Table 205-3. Washington classified its waters using a system ranging from Class AA (best) to class C (worst). The Columbia River and most of its tributaries are considered to be class A. The upper reaches of the Grays River are class AA. The uses to be protected are similar in the two states, with a few exceptions: log storage and rafting, and the spawning and rearing of warm water game fish are not protected in Oregon. The water quality standards are also generally similar, though there are many differences in details (Table 205-4). The most significant differences are the standards for dissolved chemical substances in Oregon. It should be realized, however, that additional effluent limits for individual industries are published by EPA. These limits are set according to the technology used in a plant, the

TABLE 205-3

WATER USES TO BE PROTECTED IN OREGON AND WASHINGTON

Oregon - North Coast/Lower Columbia River Basin

Beneficial Uses to be Protected	Estuary and Adjacent Marine Waters	Columbia River	All Other Streams and Tributaries Thereto
Public Domestic Water Supply			X
Private Domestic Water Supply		X	X
Industrial Water Supply	X	X	X
Irrigation		X	X
Livestock Watering		X	X
Anadromous Fish Passage	X	X	X
Salmonid Fish Rearing	X	X	X
Salmonid Fish Spawning	•X	X	X
Resident Fish & Aquatic Life	X	X	X
Wildlife and Hunting	X	X	X
Fishing	X	X	X
Boating	X	X	X
Water Contact Recreation	X	X	X
Aesthetic Quality	X	X	X
Hydro Power			
Commercial Navigation	X	X	

From: State of Oregon, Department of Environmental Quality, 1976

Washington

Characteristic Uses to be Protected	Watercourse Classification AA and A	
FISHERIES		
Salmonid		
Migration	F	M
Rearing	F	M
Spawning	F	
Warm Water Game Fish		
Rearing	F	
Spawning	F	
Other Food Fish	F	M
Shellfish		M
WILDLIFE	F	M
RECREATION		
Water Contact	F	M
Boating and Fishing	F	M
Environmental Aesthetics	F	M
WATER SUPPLY		
Domestic	F	
Industrial	F	M
Agricultural	F	
NAVIGATION	F	M
LOG STORAGE AND RAFTING	F	M
HYDRO-POWER	F	

F and M indicate that the particular use is to be protected in fresh or salt waters, respectively.

From: State of Washington, Department of Ecology, 1975

Table 205-4

Water Quality Standards for Oregon and Washington Portions of the Columbia River Estuary and Tributaries

Parameter	Oregon: Columbia River	Oregon: Estuarine Waters	Oregon: Freshwaters	Washington: Class A	Washington: Class AA
Dissolved oxygen	90% saturation	6 mg/l	90% saturation; 95% in spawning areas	8 mg/l fresh 6 mg/l marine	9.5 mg/l fresh 7.0 mg/l marine
Temperature	T>68°F: No increase T<68.5F: 0.5°F increase due to all discharges T<66°F: 2.0°F increase	No significant increase above natural.	Same as Col. Riv. except 58°, 57.5° and 56°, respectively	Water temperature shall not exceed 65°F (fresh) or 61°F (marine) due to measurable (0.5°F) effects of discharge Greater increases allowed at lower temperature	Water shall not exceed 60°F (fresh) or 55°F (marine) due to measureable (0.5°F) effect of discharge. Greater increases allowed at lower temperature.
Turbidity (Jackson) Turbidity Units, JTU)	10% increase over background conditions, exceptions may be granted			5 JTU over natural background	
pH (log of hydrogen ion concentration	6.5 to 8.5	7.0 to 8.5	6.5 to 8.5	6.5 to 8.5 (fresh)	7.0 to 8.5 (marine)
Fecal Caliform (MPN)	1000 per 100 ml (average), and no more than 20% of samples may exceed this value		240 per 100 ml, and no more than 20% of samples shall exceed this value	240 (average), no more than 20% samples exceeding 1000 per 100 ml in freshwater	50 (fresh) or 70 (salt) average, with no more than 20% exceeding 230 per 100 ml
Total dissolved gases	Liberation of dissolved gases in sufficient quantities to cause objectionable odors or to deleterious to fish life or or other uses is prohibited, Otherwise, 105% of saturation.			110% of saturation	
Radioactive material	Not to exceed maximum permissible concentrations for drinking water			Less than those that might affect public health, the natural aquatic environment, or any water use (same for other toxic materials)	
Aesthetic valves	Shall not be offensive to the human senses of sight, taste, smell or touch, be deleterious to fish or other aquatic life, affect the potability of drinking water or the palability of fish or shellfish			shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch or taste.	
Other prohibited conditions	Development of fungi or other growths having deleterious effects. Formation of deleterious bottom or sludge deposits. Discoloration, oily sleek, floating solids, or coating of aquatic life				
Dissolved chemical substances	Columbia River Substance / Concentration mg/l: As 0.01 Ba 1.0 Bo 0.5 Cd 0.003 Cr 0.02 Cu 0.005 CN 0.005 F 1.0	Substance / Concentration mg/l: Fe 0.1 Pb 0.05 Mn 0.05 Phenols 0.001 Total Dissolved solids 500. Zn 0.01 (applies only to freshwater)			
Dissolved chemical substances	Freshwater streams and tributaries: Same except total dissolved solids 100 mg/l				
	When the natural conditions exceed any of the above standards, the natural water quality is the standard.				

From: State of Oregon, Department of Environmental Quality, 1976
State of Washington, Department of Ecology, 1975

age of the plant, and the amount of production. Overall limits are also set, and the standards vary according to whether the discharges goes directly into the river or whether it is first treated by a sewage plant. It is not possible in this Inventory to set out the many standards for the different industries on the Lower Columbia River.

Oregon and Washington have also designated the Columbia River and its tributaries according to the factor or factors limiting water quality. Oregon has designated the Lower Columbia River and its Oregon tributaries as Water-Quality limited. This implies that water quality standards cannot be met, even if best practical treatment is achieved by all point sources, because of non-point source violations (turbidity, coliform bacteria counts and temperature). These violations result from natural variations in stream flow and temperature as well as human activity, primarily agriculture and logging. Washington, in contrast, classifies the Lower Columbia as Water-Quality--Point-Source Gas limited, suggesting that gas supersaturation caused by dams is the limiting factor in water quality. Gas supersaturation is not a problem in the estuary area.

B. <u>Municipal and Industrial Waste in the Columbia River</u>

The major dischargers to the estuary are municipal sewage treatment plants (STP's), seafood processors, fish hatcheries and other miscellaneous industries, including the Crown Zellerbach pulp and paper mill in Wauna and BioProducts in Warrenton (Table 205-5). While different industries and municipalities introduce into the water a wide variety of wastes ranging from sewage to exotic chemicals, it is customary to show the relative importance of different discharges according to the Suspended Solids and Biochemical Oxygen Demand (BOD) released (both measured in lbs/day). The BOD is the amount of oxygen that will be consumed in 5 days incubation of the waste at 20° C. These two measures were developed in the early days of sanitary engineering and are, in reality, very crude. They indicate the total amount of suspended material released and the potential for removal of oxygen from the water, respectively. They do not give any indication of the presence of such substances as heavy metals, pesticides and other organics that may be harmful in minute concentrations.

Table 205-5 suggests that the Crown Zellerbach Plant at Wauna is responsible for about 20% of the point source BOD and 35% of the point source Suspended Solids released into the estuary, while the fish processors

Table 205-5

Municipal and Industrial Waste Loadings for the Columbia River Estuary≁

Source	Flow MGD	BOD lbs/day	Suspended Solids lbs/day	Oil & Grease lbs/day
Municipal STP's:				
Astoria	3.3	(1000)	(2100)	
Tongue Pt. Job Corps Center	(0.5)	125	125	
Olney Elementary School	ND*	0.3	0.3	
Warrenton	(0.6)	250	300	
Shoreline Sanitation District	(0.05)	12	12	
Cathlamet	(0.05)	(2.4)	(7)	
Ilwaco	ND*	ND	ND	
Ft. Canby State Park	ND	ND	ND	
Sub-totals	≈ 6	≈2,000	≈3,000	
Fish Processing Plants**				
Bumble Bee Seafoods Hawthorne Plant	(0.975)	ND	(3898)	(2,956)
Ocean Foods	(0.3)	ND	(2620)	(1,774)
Astoria Seafoods	(0.45)	ND	(665)	(18)
Bumble Bee Seafoods Elmore Plant	(1.79)	(3,240)	(1,240)	(308)
Barbey Packing	(.92)	(5,153)	(1,162)	(274)
New England Fish Co.	(0.1)	ND	(941)	(659)
Pacific Shrimp	(0.4)	ND	4,330	3,363
Alaska Packers	(0.75)	(3210)	(3779)	(2540)
Chinook Packing Co.	(0.07)	ND	ND	ND
Ilwaco Fish Co.	ND	ND	8,000	5,146
Kasko, Inc.	ND	ND	ND	ND
Sub-totals	≈(6)	≈ 20,000	≈(32,000)	≈(20,000)
Fish Hatcheries:				
Grays River	8.3	417	ND ≠	
Big Creek	ND	ND	3,340	
Beaver Creek	11.0	642	2632	
Gnat Creek	ND	ND	2,500	
Elokomin	8.4	493	ND	
Klaskanine	ND	ND	2,200	
Sub-totals	-	≈ 4000	≈(18,000)	
Miscellaneous:				
Crown Zellerbach, Wauna Plant	74	5,995	21,816	
BioProducts, Inc.	(0.527)	-	-	
Sub-total	74.5	≈5,995	≈ 22,000	
TOTAL	≈100	≈32,000	≈65,000	

Data taken from State of Oregon, DEQ, 1975 and State of Washington, DOE, 1975 and Siler, D., Unpublished.

≁ parentheses indicate maximum quantities set by NPDES permit and not observed quantities

* ND indicates no data

** Standards to take effect in mid 1977 will reduce the BOD and Suspended Solids produced by the Fish Processing Industry.

≠ Summer loads only; winter loads are about 50% of figures listed.

are responsible for 50% of the Suspended Solids, about 60% of the BOD, and most of the Oil and Grease. The fish hatcheries contribute about 28% of the Suspended Solids load. The municipal wastes are not an important source of either BOD or Suspended Solids. These figures over-estimate the importance of the fish processors and fish hatcheries, in that the values used are upper limits set by the NPDES permits. Fish processing is seasonal and the actual discharges are probably less through much of the year; the fish hatcheries operate at less than 50% of the above levels 9 months per year. Flows are also much lower during the dry season in the municipal STP's, because of the absence of the storm flow. Only the figures for the Crown Zellerbach plant are based on actual year-around operations. It should be noted however, that this plant has reduced its output of BOD by nearly 90% (to reach the present level of 6000 lb/day) by installing new waste treatment facilities.

The estuary is affected not only by wastes released directly into the estuary, but also those released upstream. The major municipal and industrial discharges into the Columbia River below Hanford and into the entire Willamette River Basin are shown in Tables 205-6 and 7. Many small dischargers (e.g. fish hatcheries and small sewage treatment plants) have been omitted from both tables. These tables were prepared from computer outputs provided by the EPA (Siler, unpublished). It must be emphasized that the computer files on which Tables 205-5, 205-6, and 205-7 are based contain some erroneous material. Considerable editing and interpretation has been required; errors are possible. The estuary is primarily affected by dicharges released downstream from Bonneville Dam; however, major industrial facilities have been included up to and including the Hanford Nuclear Reservation. No municipal or canning waste discharges above Bonneville are included in Table 205-6 because these wastes probably have no effect on the river below Bonneville Dam.

Tables 205-6 and 205-7 present in considerable detail the BOD and Suspended Solids loadings for the Lower Columbia River and tributaries. This material is summarized in Table 205-8. The total BOD and Suspended Solids loadings are both about 373,000 lb/day. About 66% of the BOD Load (246,000 lb/day) and 43% of the Suspended Solids load (160,000 lb/day) are provided by the municipal and industrial dischargers between Longview and Camas.

Table 205-6

Percent Contribution to Waste Loadings for the Columbia River and Tributaries During the Period 1/1/76 to 8/31/77 (Major Dischargers Only) ≠

(a) Municipal Summary

FACILITY NAME	LOCATION	RIVER MILE	FLOW MGD	BOD * lb/Day	BOD * %M≠	BOD * %T≠	Suspended Solids LB/Day	Suspended Solids %M	Suspended Solids %T	Other Important Pollutant Released
Oregon:										
Astoria STP	Astoria	13.7	3.2	(1000)	3.0	0.4	(2100)	7.5	0.9	Bacteria; viruses; industrial wastes
Gresham STP	Gresham	117.5	4.7	896	2.7	0.3	886	3.2	0.4	Bacteria; viruses
Multnomah Cty-Inverness STP	Portland	113.5	1.2	(500)	1.5	0.2	(500)	1.8	0.2	Bacteria; viruses
Columbia Blvd STP	Portland	105.5	76.2	14,200	42.2	5.1	16,530	58.8	7.1	Bacteria; viruses; industrial wastes metals
St. Helens STP	St. Helens	Primarily Boise Cascade Pulp Mill effluent - See Industrial Waste Section								
Oregon Sub-totals				16,600	49.3	5.9	20,000	71.2	8.6	
Washington:										
Clark Co. STP	Vancouver	106.5	0.2	(500)	1.5	0.2	(500)	1.8	0.2	Bacteria; viruses
Cowlitz Co. DPW STP	Longview	66.0	4.5	1,109	3.3	0.4	957	3.4	0.4	Bacteria; viruses
Longview Primary STP	Longview	68.1	4.2	5,163	15.4	1.9	2,077	7.4	0.9	Bacteria; viruses
Columbia Slope STP	Vancouver	106.5	(4.0)	(1000)	3.0	0.4	(1000)	3.6	0.4	Bacteria; viruses
Westside STP	Vancouver	106.5	7.0	9,263	27.5	3.3	3,570	12.1	1.5	Bacteria; viruses; industrial wastes
Washington Sub-totals				17,000	50.7	6.1	8,100	28.8	3.5	
Municipal Subtotals				33,600	100.0	12.0	28,100	100.0	12.1	

≠ Numerous minor discharges have been omitted. All sewage plants above Bonneville dam have been omitted since thorough aeration is accomplished at each dam spillway. Subtotals and totals have been rounded off to three significant figures.

* BOD is the Biochemical Oxygen Demand after incubation at 20°C for 5 days.

≠ % M is the % of the total Municipal discharges
% I is the % of the total Industrial discharge
% T is the % of total discharges

All data provided by D. Siler, Environmental Protection Agency, Surveillance and Analysis Division, Seattle, Wa. (Siler, Unpublished), in the form of computer summaries of reports provided by dischargers. The accuracy of the reported data is highly variable.

Table 205-6 (Continued)

Percent Contribution to Waste Loadings for the Columbia River Below Richland
During the Period 1/1/76 to 8/31/77 (Major Dischargers Only)

(b) Municipal Summary

FACILITY NAME	LOCATION	RIVER MILE	FLOW MGD	BOD lb/Day	BOD %M	BOD %T	Suspended Solids lb/Day	Suspended Solids %M	Suspended Solids %T	Other Important Pollutant Released
Oregon:										
St. Helens STP (Boise Cascade)	St. Helens	86.0	32.1	10,330	4.2	3.7	20,607	10.0	8.8	Bacteria; viruses; heat; pH
Crown Zellerbach Pulp Mill	Wauna	41.2	42.7	5,995	2.4	2.1	21,816	10.6	9.4	Zn; pH
Kaiser Gypsum Co.	St. Helens	86.7	0.4	678	0.3	0.2	531	0.3	0.2	Heat
Martin Marietta Alum.	The Dalles	189.0	17.0	1	0.0	0.0	723	0.4	0.3	Flouride; heat; pH; oil & grease
PGE Trojan Plant	Rainier	72.8	41.4	0	0.0	0.0	8,950	4.4	3.8	Heat; pH; radioactive materials
Reichhold Chemicals, Inc.	St. Helens	82.0	14.2	-	-	-	-	-	-	Total N; NH_3; pH
Reynolds Metal, Co.	Troutdale	120.3	3.7	37	0.0	0.0	284	0.1	0.1	Flouride
Oregon Subtotals				17,000	6.9	6.1	52,900	25.8	22.7	
Washington:										
Alcoa, Inc.	Vancouver	103.0	4.8	-	-	-	579	0.3	0.3	Heat; flouride
Boise Cascade Corp	Vancouver	106.0	6.3	7,246	2.9	2.6	1,608	0.8	0.7	pH; heat
Boise Cascade Corp	Wallula	317.0		6,452	2.6	2.3	7,542	3.7	3.2	
Chevron Chem. Co.	Kennewick	323.0	9.0	-	-	-	511	0.2	0.2	pH; heat; NH_3; NO_3
Crown Zellerbach Pulp Mill	Camas	120.7	77.2	54,819	22.3	19.6	48,346	23.6	20.7	pH; heat
Longview Fibre Co.	Longview	68.1	54.9	63,850	25.9	22.8	48,690	23.7	20.9	pH; heat
Martin Marietta Alum.	Cliffs	215.7	18.6	-	-	-	1,937	0.9	0.8	Fluoride; heat; oil and grease
Reynolds Metal Co.	Longview	63.1	12.4	-	-	-	763	0.4	0.3	Cyanide; flouride; oil and grease
US ERDA Hanford	Richland	350.2	(464)	-	-	-	-	-	-	Heat; radioactive wastes
Wash. Pub.Power Supply-Hanford	Richland	380.0	730	-	-	-	-	-	-	Heat; radioactive wastes
Wash. Pub.Power Supply #1	Richland	351.8	(5.5)	-	-	-	-	-	-	Radioactive wastes; heavy metals
Weyerhauser-Chlorine Pit	Longview	63.7	3.2	-	-	-	(189)	0.1	0.1	pH; Ni; Zn; pH; lead; mercury
Weyerhauser Pulp Div.	Longview	63.5	72.0	87,500	35.5	31.3	34,000	16.6	14.6	pH; heat
Weyerhauser Wood Prod.	Longview	64.8	(12.8)	(9,300)	3.8	3.3	(8,000)	3.9	3.4	Oil and grease; phenols
Washington Sub-total				229,000	93.0	81.9	152,000	74.2	65.3	
Industrial Sub-totals				246,000	100.0	88.0	205,000	100.0	87.9	
TOTALS				280,000		100.0	233,000		100.0	

Table 205-7

Percent Contribution to Waste Loadings for the Willamette River and Tributaries During the Period 1/1/76 to 8/31/77 (Major Dischargers Only)†

(a) Municipal Summary

FACILITY NAME	LOCATION	RIVER MILE**	FLOW MGD	BOD* lb/Day	BOD* %M≠	BOD* %†	SUSPENDED SOLIDS lb/Day	SUSPENDED SOLIDS %M	SUSPENDED SOLIDS %†	OTHER IMPORTANT POLLUTANT RELEASED
Albany STP	Albany	119	5.3	512	2.2	0.7	402	1.8	0.4	Bacteria; viruses; canning wastes
Beaverton STP	Beaverton	28.4 / 38.1	1.9	437	1.9	0.6	342	1.5	0.3	Bacteria; viruses; canning wastes
Clackamas County S D # 1	Milwaukie	18.5	4.0	538	2.3	0.7	484	2.2	0.4	Bacteria; viruses; industrial wastes
Corvallis STP	Corvallis	131	5.4	562	2.4	0.8	976	4.5	.8	Bacteria; viruses; canning wastes
Cottage Grove STP	Cottage Grove	187 / 22	1.3	299	1.3	0.4	248	1.1	0.2	Bacteria; viruses; canning wastes
Eugene STP & WTP	Eugene	178	16.8	6587	29.1	9.7	4025	18.6	3.5	Bacteria; viruses; industrial wastes
Hillsboro (#1) West Side STP	Hillsboro	28.4 / 37	1.6	148	0.6	0.2	102	0.8	0.1	Bacteria; viruses; industrial wastes
Independence STP	Independence	95.3 / 1	0.5	481	2.1	0.7	437	2.0	0.4	Bacteria; viruses; industrial wastes
Lebanon STP	Lebanon	109 / 11.7	1.8	297	1.3	0.4	139	0.6	0.1	Bacteria; viruses; pH
McMinnville STP	McMinnville	54.9 / 11.2	2.6	221	0.9	0.3	172	0.7	0.1	Bacteria; viruses;
Oak Lodge Sanitary District	Milwauk	20.1	20.6	287	1.2	0.4	264	1.2	0.2	Bacteria; viruses; industrial wastes
Oregon City STP	Oregon City	25.2	2.7	368	1.6	0.5	488	2.2	0.5	Bacteria; viruses;
Portland - Tryon Creek STP	Portland	20.3	5.1	655	2.9	0.9	748	3.4	0.6	Bacteria; viruses; industrial wastes
Salem - Willow Lake STP	Salem	78.2	17.2	6001	26.5	8.8	5948	27.6	5.1	Bacteria; viruses; canning wastes
Springfield STP	Springfield	184.3	7.6	1651	7.3	2.4	1706	7.9	1.5	Bacteria; viruses
Aloha STP	Aloha	28.4 / 38.1	4.5	234	1.0	0.3	257	1.1	0.2	Bacteria; viruses
Durham STP	Durham	28.4 / 9.5	6.5	313	1.3	0.4	351	1.6	0.3	Bacteria; viruses; industrial wastes
Fanno Creek STP	Beaverton	28.4 / 9.4	3.9	688	3.0	1.0	1324	6.1	1.1	Bacteria; viruses
Metzger STP	Hillsboro	28.4 / 9.4	2.6	503	2.2	0.7	715	3.3	0.6	Bacteria; viruses
Tigard STP	Tigard	28.4 / 9.4	1.4	156	0.6	0.2	296	1.3	0.3	Bacteria; viruses
Woodburn STP	Woodburn	35.7 / .8	1.0	377	1.6	0.5	555	2.5	0.5	Bacteria; viruses; pH
Sub-totals				21,200	92.7	30.4	21,400	91.2	17.2	

† Percentages do not add to 100%, and BOD and Suspended Solids do not add to totals shown because numerous minor dischargers have been omitted.
* BOD is the Biochemical Oxygen Demand after incubation at 20°C for 5 days.
≠ %M is the % of total Municipal dischargers
%I is the % of total Industrial discharges
%T is the % of total dischargers
** 28.4/38.1 indicates that source enters at tributary River Mile (RM) 38.1 and that the tributary enters the Willamette River at RM 28.4

All data provided by D. Siler, Environmental Protection Agency, Surveillance & Analysis Division, Seattle, Wa. (Siler, Unpublished), in the form of summaries of reports provided by dischargers. The accuracy of the reported data is highly variable.

Table 205-7 (Continued)

Percent Contribution to Waste Loadings for the Willamette River and Tributaries
During the Period 1/1/76 to 8/31/77 (Major Dischargers Only)

(b) Industrial Summary

FACILITY NAME	LOCATION	RIVER MILE	FLOW MGD	BOD lb/Day	BOD % M#	BOD % +	SUSPENDED SOLIDS lb/Day	SUSPENDED SOLIDS % M	SUSPENDED SOLIDS % +	OTHER IMPORTANT POLLUTANT RELEASED
American Can Company	Halsey	147.2	12.8	1556	3.4	2.2	2761	3.6	2.4	
Boise Cascade Corporation	Salem	84.2	15.8	6478	14.2	9.5	8977	11.9	7.7	
Crown Zellerbach Corporation	West Linn	26.4	9.8	2478	5.4	3.6	4377	5.8	3.8	pH
Crown Zellerbach Corporation	Lebanon	109 / 11.7	3.3	2683	5.9	3.9	2485	3.3	2.1	Heat
Evans Products Company	Corvallis	132.2	0.9	2726	6.0	4.0	2689	3.6	2.3	pH; heat
Oregon Metallurgical Corp.	Albany	119.5 / 3.6	735	--	--	--	123	0.2	0.1	Fluoride; chloride; metals; Cd; oil and grease
Oregon Steel Mills - Rivergate	Portland	1.7	10.9	--	--	--	3100	4.1	2.7	pH; heat
Pennwalt Corporation	Portland	7.4	23.1	--	--	--	2080	2.8	1.8	Lead; chromium; zinc; ammonia; pH heat
Portland Willamette Company	Portland	101.5 / 9.7	0.01	--	--	--	0	0.0	0.0	Nickel; chromium; cyanide
Publishers Paper Company	Newberg	50	24.8	10493	23.1	15.4	13787	18.3	11.8	Zinc
Publishers Paper Company	Oregon City	27.5	12.0	7541	16.6	11.1	8822	11.7	7.6	Zinc
Rhodia, Incorporated	Portland	7	0.05	952	2.1	1.4	1016	1.4	0.9	Phenolics; herbicides; pH; heat
Tektronix Inc.	Beaverton	28.4 / 38.1	0.4	--	--	--	--	--	--	Chromium; ammonia; total metals; cyanide; pH
Teledyne Wah Chang	Albany	118.9 / 2	1.8	--	--	--	221	0.3	0.2	Metals; ammonia; organics; radioactive wastes
Western Kraft Corporation	Albany	116.5	8.2	2505	5.5	3.6	5365	7.1	4.6	Heat
Weyerhaeuser Co.	Springfield	174.8 / 14.7	36.8	7868	17.3	11.5	19213	25.5	16.4	Heat; pH
Sub-total				45,300	99.5	66.2	75,200	99.6	64.4	
TOTALS				70,200		96.6	117,000		81.5	

Table 205-8

Summary of Municipal and Industrial Loadings Based on Tables 205-5, 205-6, and 205-7

	Municipal Loadings						Total Industrial Loadings						Timber Products Industry Loadings					
	BOD			Suspended Solids			BOD			Suspended Solids			BOD			Suspended Solids		
	lb/day	%M	%T	lb/day	%M	%T	lb/day	%I	%T	lb/day	%I	%T	lb/day	%I	%T	lb/day	%I	%T
Lower Columbia River above Estuary																		
Oregon*	16,000	27.2	4.2	17,900	34.1	4.8	11,000	3.5	3.0	31,000	9.7	8.3	11,000	3.5	3.0	21,100	6.6	5.7
Washington	17,000	29.8	4.6	8,100	15.4	2.2	229,000	72.6	61.4	152,000	47.5	40.8	229,000	72.6	61.4	148,000	46.2	39.7
Estuary Area	≈1,700	3.0	0.5	≈3,000	5.7	0.8	≈30,000	9.5	8.0	≈62,000	19.3	16.6	6,000	1.9	1.6	21,800	6.8	5.8
Willamette River	22,900	39.9	6.1	23,500	44.7	6.3	45,300	14.4	12.2	75,200	23.5	20.2	44,400	14.1	11.9	69,600	21.7	18.7
Sub-totals	57,100	100.0	15.3	52,500	100.0	14.1	316,000	100.0	84.7	320,000	100.0	85.9	290,000	92.1	78.0	261,000	81.4	69.9

Total BOD: ≈ 373,000 lb/day

Total Suspended Solids: ≈ 373,000 lb/day

*Oregon Municipal and Industrial loadings from Table 205-6 adjusted to avoid duplication of loadings also included in Table 205-5.

The Willamette River is the next most important source; it provides about 15-1/2% of the BOD load (58,000 lb/day) and 26-1/2% of the Suspended Solids load (98,000 lb/day). The Willamette River is much smaller than the Columbia River; therefore, BOD has been more critical there, and better data are available. It is known, for example, that there is another 27,000 lb/day of BOD in Portland Harbor that cannot be attributed to any known point or non-point sources. Some of this load is probably attributable to bottom sediments, but it appears likely that there are some unregulated discharges into the Harbor. The Willamette River is still the best local example of how a river can be cleared up if discharges are carefully managed.

According to Table 205-8, the estuary area is the third greatest supplier of BOD (32,000 lb/day or 8.6%) and Suspended Solids (65,000 lb/day or 17.4%). However, estuary loadings (Table 205-5) are based on permitted values rather than actual discharges, and many minor facilities such as fish hatcheries are included in Table 205-5 that are not included in Tables 205-6 and 205-7. The net effect is to exaggerate the estuary loadings.

Basin wide, it is clear from Table 205-8 that the timber products industry is the major contributor of both BOD (290,000 lb/day or 78%) and Suspended Solids (260,000 lb/day or 81%). The timber products industry in Washington (between Camas and Longview) alone contributes about 60% of the point source BOD load (223,000 lb/day) for the entire basin. It should be emphasized again that the point source BOD and Suspended Solids problem are not the largest water quality problems in the Columbia River; they are however, the best documented and most easily regulated. Non-point sources of BOD are probably more important than the point sources, and the point source contribution to the total yearly suspended solids load of about 6 million tons (Section 208.3) is rather minor (about 68,000 tons/year or 1.1%).

The data provided by EPA (Siler, Unpublished), DOE (1975) and DEQ (1976) and summarized in Tables 205-6 and 205-7 suggest that the impact of point sources is greater in other areas: the heat budget, radioactive contaminants, heavy metals and miscellaneous organic chemicals (including herbicides and pesticides). The nuclear plants, the aluminum industry, and the timber products industry contribute to undesirably high stream temperatures, but solar heating of storage ponds behind dams provides even more heat.

The nuclear Industry (The Hanford Nuclear Reservation, the Washington Public Power Supply facilities, the Portland General Electric Trojan Plant and Teledyne Wah Chang) are the major sources of radioactive material. Hanford was the major source of radioactive material still found in Columbia River sediments, though the reactors responsible for the bulk of this material are no longer active. Present day discharges of radioactive material are much smaller than those during the period 1945-1970.

Toxic metals such as mercury (Hg), chromium (Cr), cadmium (Cd) and lead (Pb) are released by a number plants in the metal plating and fabrication industries (Oregon Metallurgical Corp, Oregon Steel Mills, Portland Willamette Co., and Teledyne Wah Chang) and chemical industry (Pennwatt Corp.). Teledyne Wah Chang merits special mention because of the large number of unusual, radioactive and/or toxic materials used, the classified nature of the processing and the controversy over its discharges. Urban storm runoff and other non-point discharges are also important sources of metals. Teledyne Wah Chang, and Tektronix, Inc. on the Willamette River and Reichold Chemicals Co. and Chevron Chemical Corp. on the Columbia River release large amounts of nitrates and ammonia (NO_3^- and NH_3). Rhodia, Inc. produces herbicides, Teledyne Wah Chang and probably several other firms release toxic organic compounds. In some instances at least, these industrial wastes are not adequately characterized, and with the possible exception of radioactive materials, the impacts of the numerous chemicals mentioned above on the Columbia River and estuary are simply not known. It is almost certain that non-point discharges are a far more important source of herbicides and pesticides than are the point sources. Furthermore, no comprehensive summary of the industrial discharges into municipal sewer systems exists. Thus, our knowledge of pollutants released in the Columbia River remains crude.

In summary, the Columbia River has not experienced the extremely severe water quality problems that have plagued other rivers in this country, both because of its large river flow and because of the relatively low population density in much of its drainage basin. Industrial and non-point source water quality problems are present and should not be ignored. These include tributary siltation, over-allocation of tributary and main stem flows, non-point source pollution, gas supersaturation, overheating, BOD loadings, and the introduction of toxic substances including: metals, biocides, radioactive materials, and miscellaneous organic chemicals.

205.4 REFERENCES

A. Conomos, T.J., M.G. Gross, C.A. Barnes and F.A. Richards. 1972. "River-Ocean Suspended Particulate Matter Relations in Summer." IN The Columbia River Estuary and Adjacent Ocean Waters Bioenvironmental Studies. (A.T. Pruter and D.L. Alverson, ed.) University of Washington Press, Seattle, Washington. pp.176-202.

The distribution, concentration, production, consumption and diffusion of inorganic and organic particulate matter originating in the Columbia River, the estuary and coastal ocean are described on the basis of field studies. Excellent illustration

B. Conomos, T.J., and M.G. Gross. 1972. "River-Ocean Nutrient Relations in Summer." IN The Columbia River Estuary and Adjacent Ocean Waters Bioenvironmental Studies. (A.T. Pruter and D.L. Alverson, ed.). University of Washington Press, Seattle, Washington. pp.151-175.

The physical processes governing the mixing of river and ocean water during the upwelling season are described using T-S diagrams. The distribution of nutrients is explained in terms of physical processes and biological activity. Excellent illustrations

C. Haertel, L., and C. Osterberg. 1967. "Ecology of Zooplankton, Benthos and Fishes in the Columbia River Estuary." Ecology 43:459-472.

Fauna of the Columbia River estuary were sampled over a 21 month period. The largest numbers of fish and benthic invertebrates occupy the slightly brackish water of the central part of the estuary; the major plankton blooms also occur in this area. Some species use the upper estuary as a nursery ground.

D. Haertel, L., C. Osterberg, H. Curl, P.K. Park. 1969. "Nutrient and Plankton Ecology of the Columbia River Estuary." Ecology 50(6):962-978.

Monthly samples of nutrients, phytoplankton and zooplankton were taken in the Columbia River estuary over a period of 16 months in order to determine distribution with season and salinity, and interrelationships between plankton and nutrients. The estuarine phytoplankton are composed primarily of freshwater species. The zooplankton are composed of estuarine, fresh and marine species.

E. Park, P.K., C.L. Osterberg, and W.L. Forster. 1972. "Chemical Budget of the Columbia River." IN The Columbia River Estuary and Adjacent Ocean Waters. University of Washington Press, Seattle, Washington. pp.123-134.

The input of nutrients, dissolved oxygen and other dissolved substances to the ocean from the Columbia River for the years 1966 and 1967 is calculated on the basis of data collected in the estuary. Readable.

F. Park, P.K., M. Catalfomo, G.R. Webster and B.H. Reid. 1970. "Nutrients and Carbon Dioxide in the Columbia River." Limnol. Oceanogr. 15:70-79.

Nitrate, phosphate, silicate, alkalinity and carbon dioxide budgets were calculated for the Columbia River on the basis of data collected at Clatskanie. Nutrient ratios and calcite saturation in the river are discussed.

G. Siler, D. Unpublished. Average Loadings: Intermediate Summary and Percent Contribution of Loadings for the Lower Columbia River and Willamette River Basin (computer printouts). Environmental Protection Agency, Surveillance and Analysis Division, Water Surveillance Branch, Seattle, Washington.

H. State of Oregon, Department of Environmental Quality. 1976. Proposed Water Quality Basin Plan. Salem, Oregon.

1. North Coast-Lower Columbia River Basin, text 46pp. appendices, various paginations.
2. Willamette River Basin, text 57pp., appendices, various paginations.
3. Sandy River Basin, text 49pp., appendices, various paginations.

The basin plans show the major industrial dischargers in each basin. Loadings allowed for each discharger are given. Water quality problems and needs are discussed for each basin.

I. State of Washington, Department of Ecology. 1975. 303(e) Water Quality Management Plan. Olympia, Washington.

1. Water Resource Inventory Area 24. Willapa Basin, 128pp.
2. Water Resource Inventory Area 25, 26. Cowlitz-Wahkiakum Basin, 149pp.
3. Water Resource Inventory Area 27,28,29,30,31. Lewis and Middle Columbia River Basins, 201pp.

The basin plans show the major municipal and industrial dischargers in each basin, and in some instances, the loadings allowed for each discharger. Water quality data for each river segment are given, along with a discussion of water quality problems.

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FLUSHING CHARACTERISTICS

COLUMBIA RIVER ESTUARY
FLUSHING CHARACTERISTICTS

David Jay
James W. Good

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206 FLUSHING CHARACTERISTICS

Tidal currents and river flow generate complex circulation patterns throughout the estuary and distribute natural substances (nutrients, drift debris, plants and animals), as well as introduced pollutants (sewage, industrial and fish processing waste, etc.). Because of its strong circulation and extensive wetlands, the Columbia River estuary has considerable ability to assimilate certain wastes. Some wastes are consumed by plants and algae in the primary production process, others are oxidized by bacteria or by contact with the air, and still others are diluted and washed out to sea. Waste disposal is thus one of the beneficial properties of estuaries.

Preservation of the rich biological resources of the estuary requires knowledge of how much and what type of waste material can be assimilated. Overloading the system can degrade or eliminate its ability to assimilate waste. This section then, focuses on the ability of the estuary to dilute wastes so that they will not reach harmful concentrations.

To determine the ability of an estuary to absorb reasonable levels of pollutants, it is first necessary to know the rate at which it flushes or exchanges water with the open sea. An estuary's flushing ability is measured in terms of flushing time. The flushing time is defined by Neal (1965) as "the average time required for the river water, with its contained pollution, to move through the surveyed area." Flushing time is normally estimated in tidal cycles (12 hours 25 minutes per cycle), since the ebb and flow of the tide partially govern the flushing process.

206.1 FACTORS GOVERNING ESTUARINE FLUSHING

Flushing is not a constant, simple process. It depends on the complex interaction of many factors operating in the estuary. The calculation of flushing time is based on certain definite assumptions. It is a physical property that can be predicted for the estuary, its bays and tributary streams. As such, flushing times are useful (in a general way) for comparing one estuary to another, or different parts of a single estuary. For example, one would not place a sewage outfall in a poorly flushed area of an estuary. The physical characteristics of an estuary, the source of a pollutant and its physical, chemical and biological properties are important when considering flushing and are discussed here.

A. Characteristics of the Estuary

Physical factors which control flushing of an estuary include (1) freshwater discharge (the primary controlling factor for flushing of the Columbia River estuary), (2) tidal range (measured in feet between High and Low Water marks) and average tidal level during each tidal cycle, (3) the vertical differences in salinity and currents and the resulting vertical mixing and (4) wind and wave action. When making flushing predictions, these factors are simplified. Though not discussed here, several methods may be used to make predictions. Each has its advantages and disadvantages.

B. Pollutant Source and Properties

The calculation of flushing time also requires assumptions about the character of the pollutant. To understand the significance of a flushing time calculation, it is necessary to know what assumptions were made with regard to:

1. Timing of Introduction--Pollutants are usually introduced in one of three ways:

- A one-time introduction, as in the case of an oil spill,
- An intermittent introduction, as in the case of pesticides, which run off of farmlands after heavy rainfall, and
- Continuous input, as from an industrial or municipal outfall;

2. Source--A pollutant source may be from a single location, called a "point-source," or from a dispersed area known as a "non-point-source." Introduction may be directly into the estuary or from an upriver or tributary source;

3. Physical Properties--Such properties as the density, solubility and size (if the material is suspension) of a pollutant are extremely important in determining its behavior; and

4. Biological and Chemical Properties--Pollutants are classified according to the interactions with a body of water and the biological and chemical processes occurring there. A substance whose concentration is

affected only by simple mixing of water masses is known as "conservative." Conservative substances include salt, some detergents and heat (ignoring air-sea interactions). Examples of non-conservative substances include dissolved oxygen (produced by photosynthesis, consumed by respiration) and nutrients (consumed by plants).

206.2 FLUSHING AND POLLUTANT DISTRIBUTION

While some information on flushing times and pollution distribution exists for the Columbia River estuary, it is important to realize that these values are only predictions, and that results differ, depending on the prediction technique used. Verification of flushing predictions through actual field study of the estuary has been impossible, due to cost and technical limitations. Because of recent advances in computer modeling of estuaries, better flushing predictions can be made. However, there are not enough data available for the Columbia River to merit any extensive computer modeling.

The Columbia River estuary, because of its great discharge of freshwater, is, in general, extremely well-flushed. Various combinations of tides and river flows may cause flushing times to vary from as low as two tidal cycles, to as high as ten (about 1-5 days). These are rather low flushing times, compared to other estuaries. For example, New York harbor takes from 6-10 days to flush. In some portions of the estuary, however, water is exchanged with the sea less rapidly than in others. For example, the poor flushing time exhibited by the lower Skipanon River would have led to a buildup of fluoride pollutant in that area during periods of low river flow, which would have been lethal for some aquatic life, had an aluminum reduction plant been constructed at Warrenton. The potential also exists for harmful pollutant buildup in other areas, such as backwater sloughs, low discharge tributaries and poorly circulating zones of the estuary.

Table 206-1 shows predicted flushing times for the main body of the estuary in tabular and graphic forms. During low river flow typical in September and October (120,000 cfs), flushing time is nearly five days (nine tidal cycles, Table 206-1). At moderate flows of about 380,000 cfs, the flushing time is about 4.4 tidal cycles (2 days 7 hours).

TABLE 206-1

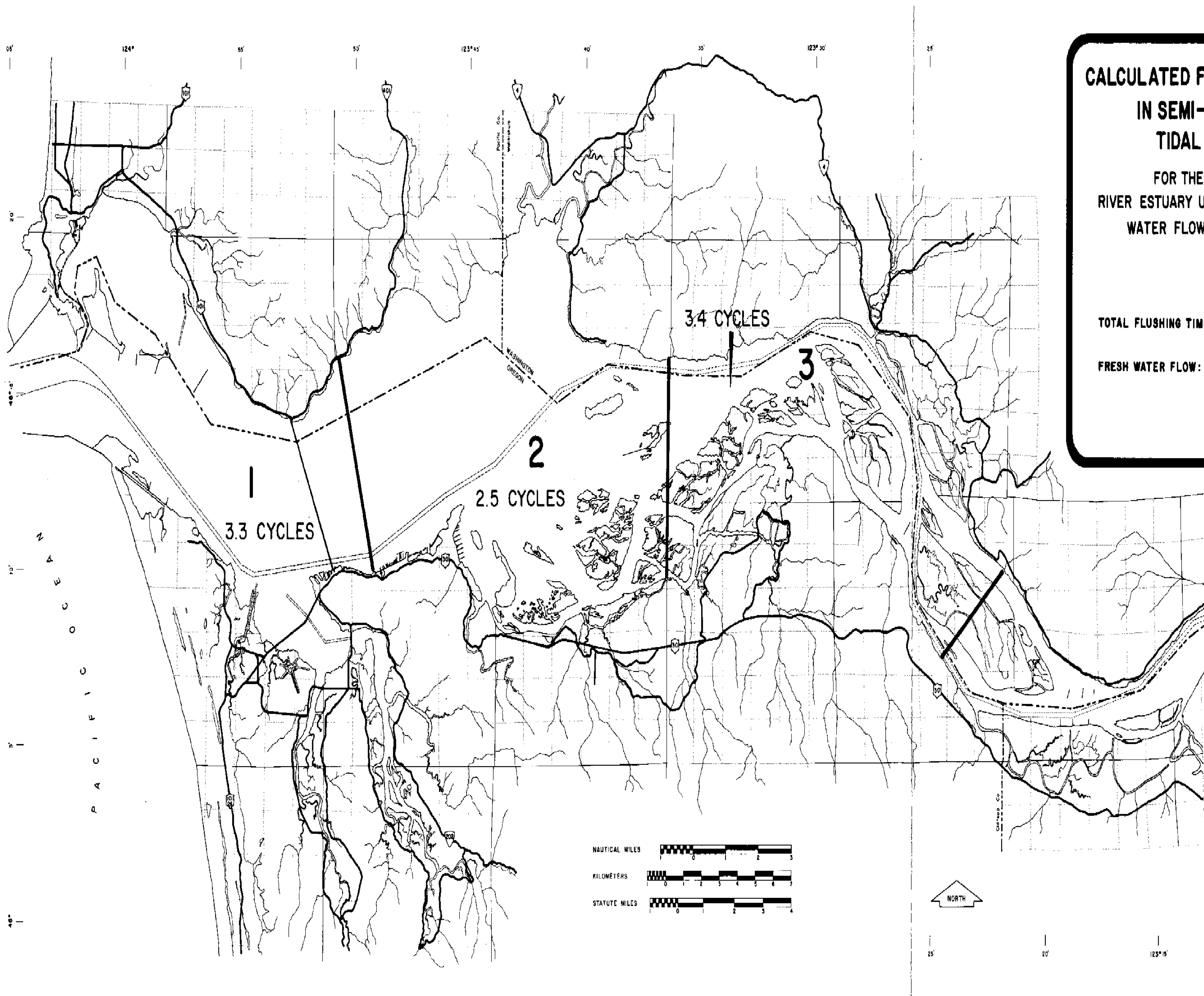
PREDICTED FLUSHING TIMES FOR COLUMBIA RIVER ESTUARY 1/

RIVER FLOW (cubic feet/second)	TIDAL RANGE (in feet)	FLUSHING TIME (in semi-diurnal tidal cycles)	POLLUTANT LOAD BUILDUP AFTER MANY TIDAL CYCLES 2/ (amount x load introduced per tidal cycle)
123,000	6.5	9.9	8.0
	8.0	9.1	
153,000	6.5	8.6	7.6
	8.0	8.7	
169,000	6.5	8.2	7.2
	8.0	7.8	
382,000	6.5	4.4	3.5
	8.0	4.3	

1/ Flushing times are averages, calculated by the modified-tidal prism method. Calculations are based on the indicated tidal range. One tidal cycle equals 12 hours, 25 minutes.

2/ After many tidal cycles and with a continuous, constant input of pollutants carried by river flow, the amount of pollutant in the estuary will be equal to some value (shown in Column 3) times the load introduced per tidal cycle. This does not refer to concentration at any location, but only the total amount in the entire estuary.

From: Neal, 1965



CALCULATED FLUSHING TIME IN SEMI—DIURNAL TIDAL CYCLES

FOR THE COLUMBIA RIVER ESTUARY UNDER LOW FRESH WATER FLOW CONDITIONS

TOTAL FLUSHING TIME: 9.1 TIDAL CYCLES

FRESH WATER FLOW: 123,000 C.F.S.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

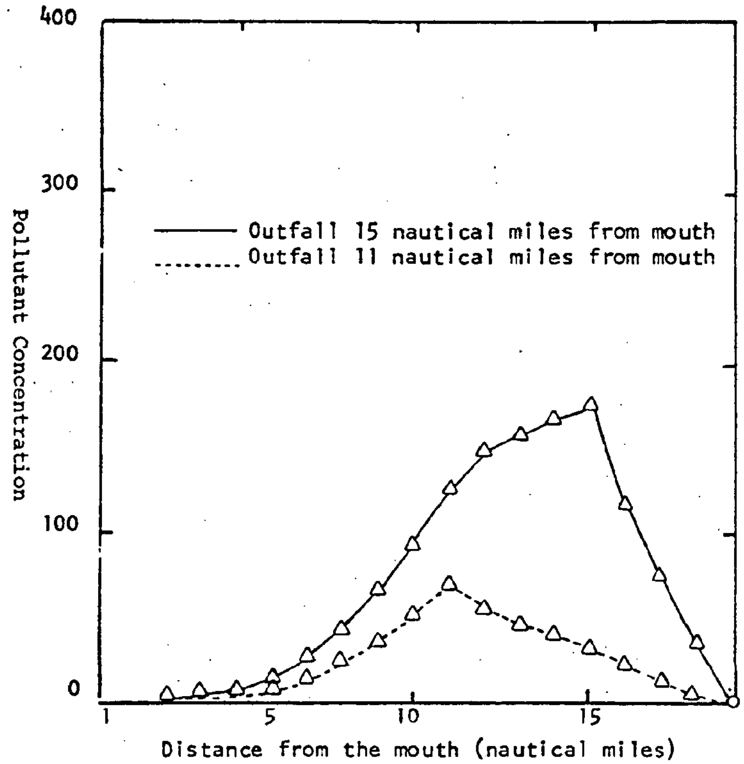
FIGURE 206-1

The calculation methods are not adaptable to the very high flows (600,000 cfs), typical of the spring freshet. At these high flow levels, the flushing time is probably less than two days (four tidal cycles). The third column in Table 206-1 shows the buildup of a continuously introduced pollutant after many tidal cycles. For example, if during each tidal cycle 1,000,000 gallons of a conservative pollutant were introduced to the estuary (with a river flow of 200,000 cubic feet per second), the constant amount of that pollutant present in the estuary would be approximately 7,000,000 gallons. Flushing would prevent greater buildup. The waste would be widely distributed by currents and mixing, and it would be more concentrated in some locations than others. Flushing times for three subsections of the estuary are shown in Figure 206-1. The flushing time for a pollutant released at any point is the sum of flushing time for segments downstreams from the release site.

Some very simple flushing tests have been run with the Corps of Engineers physical model of the estuary. These involved one-time-only releases of pollutant, rather than the continuous release that the above flushing time calculations assumed. The releases were made at RM 47 (above Puget Island), at peak ebb and peak flood for freshwater flows of 200,000 and 600,000 cfs. Concentrations were observed for the ebb tide case and then for the flood tide case. Between 4 and 8 semi-diurnal tidal cycles (about 2-4 days) were required to flush the pollutant out of the estuary under high runoff (600,000 cfs) conditions, while between 12 and 16 tidal cycles (about 6-8 days) were required under low flow conditions (200,000 cfs).

Figures 206-2, 206-3 and 206-4 show how a pollutant continuously introduced into the estuary at specific points is distributed under equilibrium conditions (after many tidal cycles). The relative concentration from one area to the next usually decreases, as you go up or downriver from the point of introduction. Such is not the case, however, with the hypothetical outfall located in the north channel at RM 9 (Figure 206-3), where upstream concentrations will be higher than those at the outfall or downstream. This is probably due to the strong flood and weaker ebb currents along the north channel in that area, but it may be an artifact of the model. On the other hand, the absolute

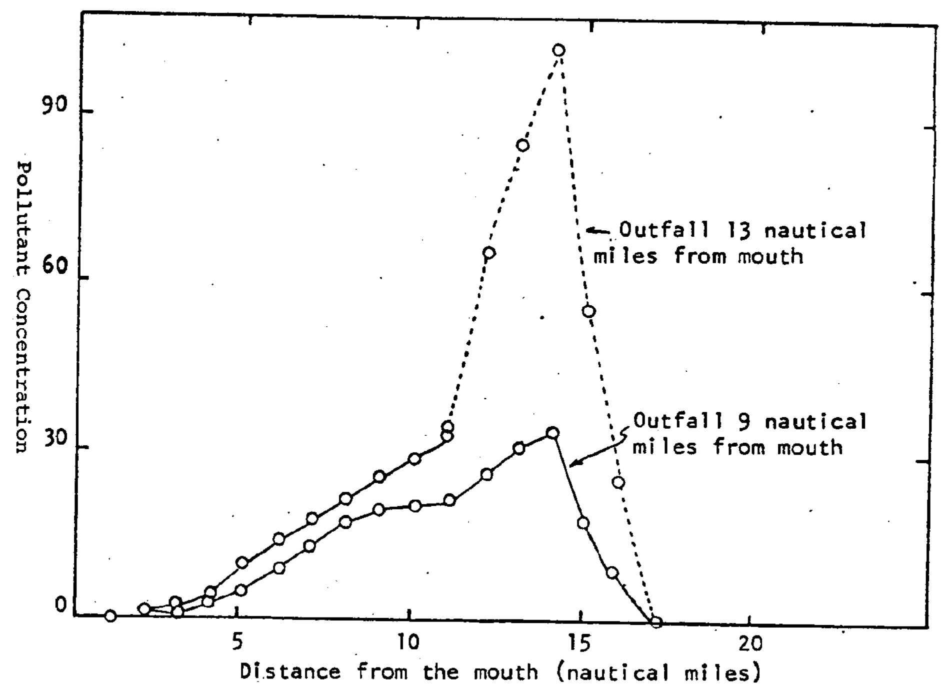
Figure 206-2 Predicted Pollutant Distribution - South Channel



Pollution distribution for the south channel calculated by a mathemetical model for fresh water flow of 123,000 cfs. Outfalls are located at RM 11 and 15.

From: Neal, 1965

Figure 206-3 Predicted Pollutant Distribution - North Channel



Distribution of a conservative pollutant calculated for the north channel using a mathematical model. Outfalls are located at 9 and 13 nautical miles from the mouth. Fresh water flow is 123,000 cfs.

Figure 206-4 Predicted Pollutant Distribution - Entire Estuary

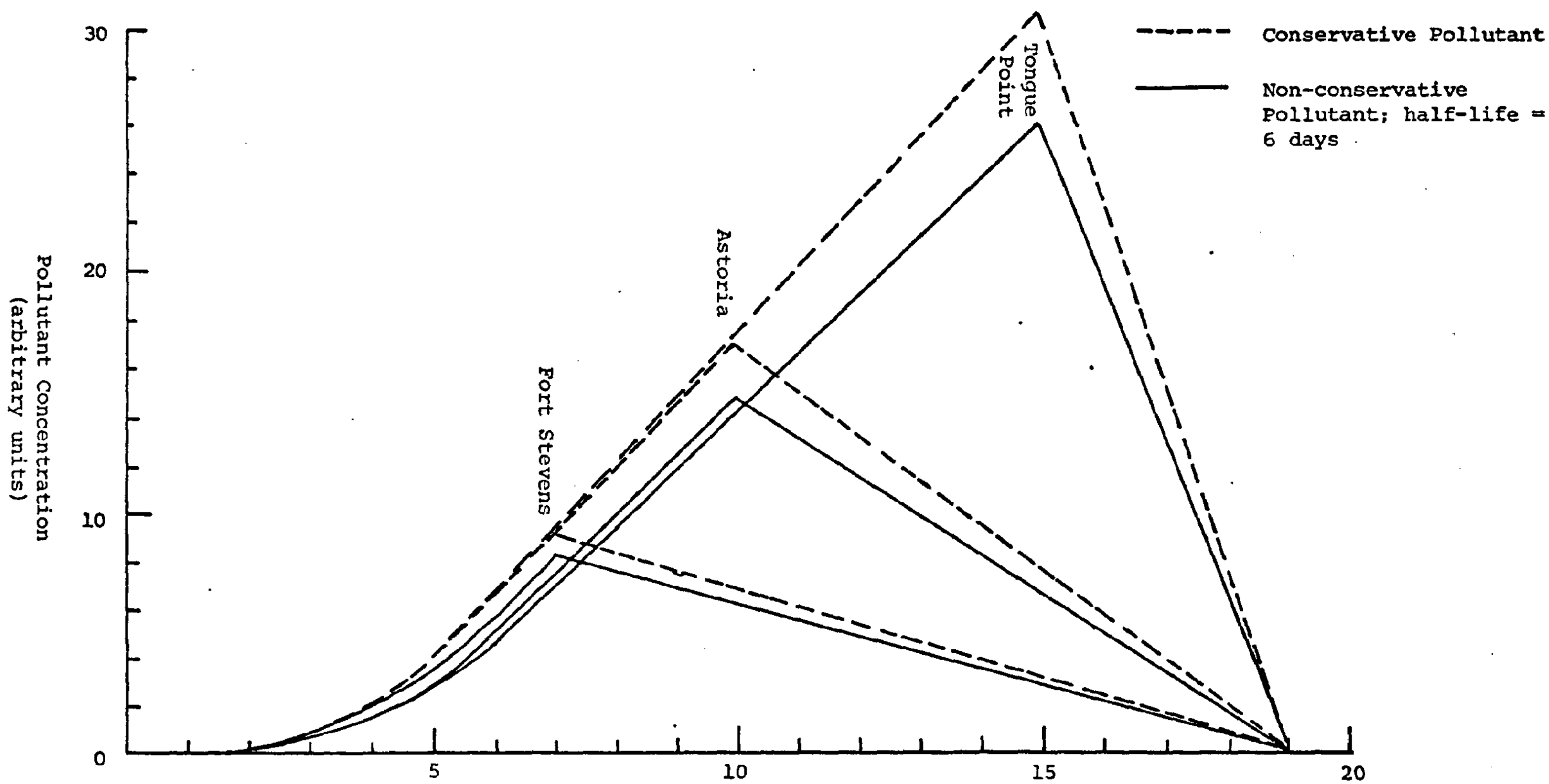


Figure 206-4

Distribution of pollutants predicted by a mathematical model for continuous release at each one of three outfalls of a conservative pollutant and a pollutant which decays with a half-life of about six days. The pollutant that decays might be a radioactive contaminent or it could be a nutrient used by plankton, for example. The freshwater flow is 123,000 cfs.

concentration of pollutant is higher in the south channel (Figure 206-2) by a factor of about two. These two factors represent a considerable dilemma, with important implications for the location of any major outfall in the estuary. Without further tests, it is unclear whether it is preferable to locate any major new outfalls on the north or south channel. Such knowledge is needed to determine the best sites for industry.

206.3 FLUSHING CHARACTERISTICS OF YOUNGS BAY AND ITS TRIBUTARIES

Thus far, flushing time has been discussed as a property of the main body of the estuary. Flushing times may also be calculated for estuary tributaries. In fact, this more detailed knowledge is often needed in the planning process. For example, outfalls should be located where river currents and ebb tidal flows are strong (areas that are well-flushed). Knowledge of flushing characteristics is also important in the siting and design of marinas, which often experience flushing problems. Furthermore, areas that are naturally poorly-flushed are often areas of high biological productivity, if they are not overwhelmed by pollutants. Finally, physical alterations such as dredging, filling and channelization of flow may strongly affect flushing characteristics of localized areas, even if the characteristics of the estuary as a whole are not affected. These localized effects should be evaluated.

Localized flushing data are available only for Youngs Bay and its tributaries. Table 206-2 and Figure 206-5 show predicted flushing times for several sub-areas of the Youngs Bay drainage system to the main channel of the river outside the bay, depending on the actual river flow and tidal range. Flushing time varies from about one day (Youngs Bay - 1.9 tidal cycles) to 18 days (lower Skipanon River - 37.6 tidal cycles). Flushing the pollutant out the Columbia River would then take another 1 to 4 tidal cycles, depending on the flow conditions. Flushing time predictions have not been made for other sub-areas of the estuary, including Baker Bay, Grays Bay or Cathlamet Bay. Baker Bay, however, is probably not so well-flushed as the Youngs Bay area, because it lacks freshwater inflow from tributaries; however, no supporting information is available.

TABLE 206-2

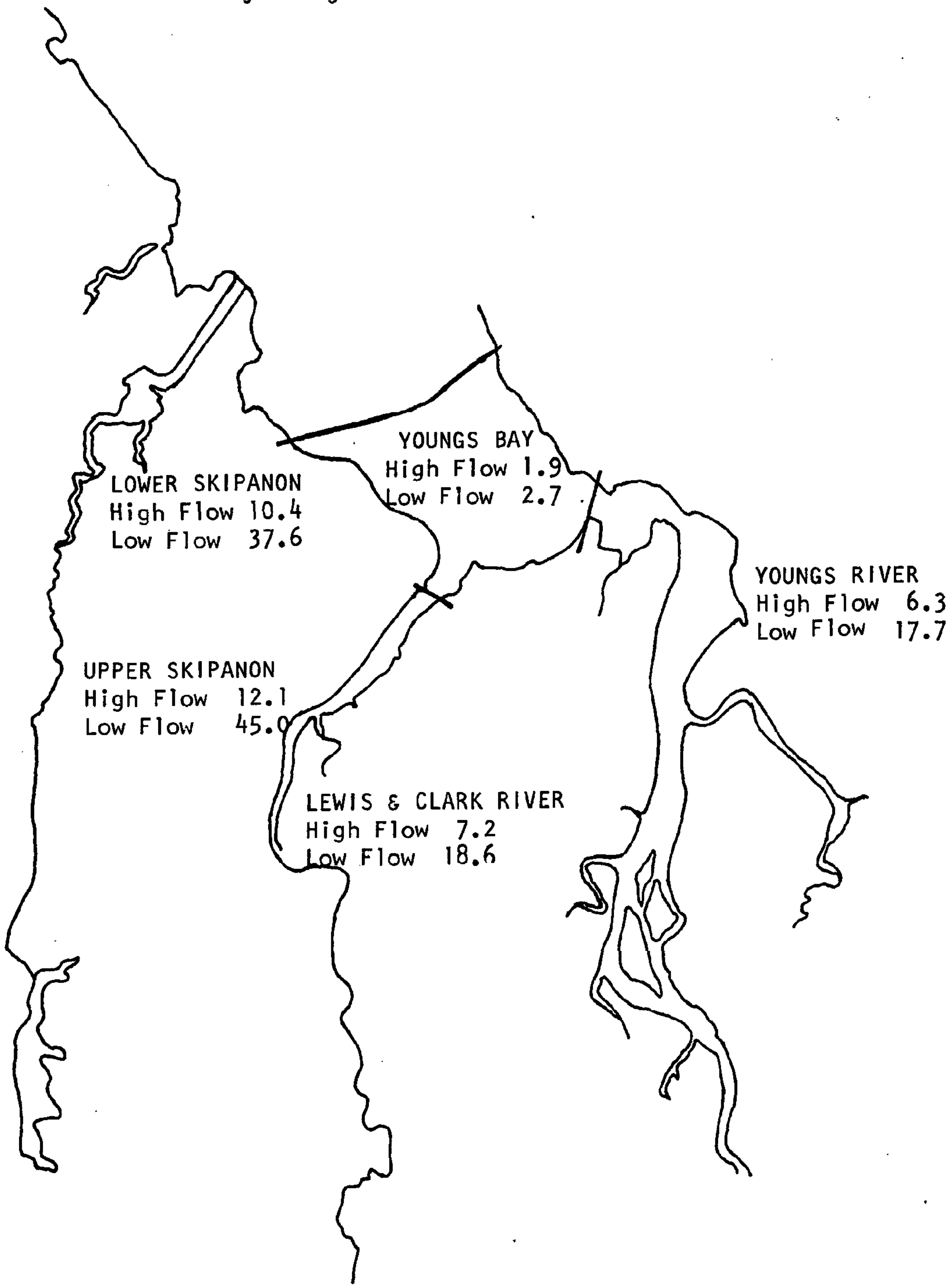
PREDICTED FLUSHING TIMES FOR YOUNGS BAY DRAINAGE SYSTEM 1/

AREA	RIVER FLOW (cubic feet per second)	TIDAL RANGE (in feet)	FLUSHING TIME (in semi-diurnal tidal cycles)
Youngs Bay (area between 3 bridges)	785	8.0	1.9
	24	6.0	2.7
Youngs River	560	8.0	6.3
	12	6.0	17.7
Lewis & Clark River	225	8.0	7.2
	12	6.0	18.6
Skipanon River (downstream of tidegate)	50	8.0	10.4
	1.6	4.0	37.6
Skipanon River 2/ (upstream of tidegate)	50	3.5	12.1
	5	3.5	45.0

1/ Predicted flushing times derived from Alumax study of physical characteristics of Youngs Bay (OSU Ocean Engineering Programs, 1975). One tidal cycle equals 12 hours and 25 minutes. All flushing times represent the average time required to flush a pollutant from the area indicated to the main channel of the Columbia River. A further 1 to 4 tidal cycles, depending on the fresh water flow, is required to flush the pollutant out of the river to the ocean.

2/ The tide range is governed by the tidegate and riverflow. The upper Skipanon River flushes much more rapidly when the tidegate is open during the winter.

FIGURE 206-5 Flushing Time in Tidal Cycles of Youngs Bay and Tributaries for high and low flows as calculated by a mathematical model. High and low freshwater flows for each tributary are given in Table 206-2.



From: O.S.U. Ocean Engineering Programs, 1975

206.4 REFERENCES

A. Neal, Victor T. 1965. A Calculation of Flushing Times and Pollution Distribution for the Columbia River Estuary. Ph.D. Dissertation. School of Oceanography, Oregon State University. 82pp.

This is the best general reference for flushing characteristics of the Columbia River estuary. It also has an excellent description of the other physical characteristics. Three different methods of predicting flushing times are compared.

B. Oregon State Ocean Engineering Program
teristics of the Youngs Bay Estuarine Environs. Final report to Alumax Pacific Aluminum Corporation. Ocean Engineering Programs, Oregon State University, Corvallis, Oregon. 310pp.

This publication describes the principles, methods used to calculate flushing times for Youngs Bay and its tributaries.

C. Simmons, Henry. 1971. "The Potential of Physical Model to Investigate Estuarine Water Quality Problems." IN Proceedings: 1971 Technical Conferences on Estuaries of the Pacific Northwest. Circular 42. Engineering Experiment Station, Oregon State University, Corvallis, Oregon. pp.4-28.

This article briefly discusses some flushing tests the Corps of Engineers conducted using the physical model of the Columbia River estuary.

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ESTUARY PHYSICAL CIRCULATION MODELS

COLUMBIA RIVER ESTUARY
PHYSICAL CIRCULATION MODELS

David Jay

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207 ESTUARY PHYSICAL CIRCULATION MODELS

A comprehensive study considering all aspects of the physical circulation of the Columbia River Estuary would be both nearly impossible and prohibitively expensive, because of the size and the many natural and man-influenced sources of variability in the estuary. For example, a detailed circulation study might require measurement of currents and salinity at 60 or more stations. Such measurements must reflect short-term, seasonal and year-to-year variability caused by factors such as the tides, winds and freshwater flow and be taken simultaneously at as many locations as possible. Such a study would still not exhaust the range of flow characteristics that actually occur in the river.

Consequently, scientists and planners use models. Estuarine modeling serves a number of purposes: first, it simplifies problems by limiting variables to a reasonable number; second, it allows systematic variation of important parameters over naturally occuring ranges without extensive field data collection; third, it reduces the time, manpower and money required to take measurements; and finally, it allows prediction (to a limited degree) of the results of natural and man-made changes in the estuary.

Before a model can be used to predict the effects of changes in the estuary, it must be verified; that is, the model must be adjusted or tuned, so that it reproduces a variety of existing conditions. The existence of an estuary model does not eliminate the need for field data collection, but the data needed is usually much less and the understanding achieved much greater than if analyses are made without such a model.

It must be realized that most models of an entire estuary are greatly simplified and are not intended to produce either highly accurate or detailed predictions for specific areas. They are best used to provide a general understanding of an estuary and the way it functions under different wind, tide and runoff conditions; this is precisely the kind of understanding that is most difficult to achieve through analysis of a field data. In some instances, models of a small part of an estuary may be constructed on a larger scale, to provide detailed information about a limited area.

207.1 TYPES OF MODELS

The kind of model selected is determined by what is to be modeled. A number of modeling approaches exist for physical circulation and sediment transport, and some modeling has been done on fish and plankton populations and water quality parameters such as nutrients, dissolved oxygen and bio-chemical oxygen demand, but none has been done in the Columbia River. Models of physical circulation and sediment transport are of primary interest here.

There are three basic kinds of physical circulation models: electrical, physical and mathematical. In an electrical model, electrical current flowing through a wire is used to model water flowing in a channel. Electrical models are useful in simulating tidal flows in a complicated network of channels, but they cannot easily be used to reproduce the effects of salinity intrusion, winds, and vertical and cross-channel variations in current speeds. Consequently, such models have not been used in the Columbia River estuary.

Physical models are simply small-scale versions of the real estuary or prototype. They can be used to model physical circulation, sediment transport, the handling of ships and the effects of physical alterations such as jetties or deeper channels. They do not usually reproduce temperature and wind effects, or the coriolis force (the effect of the earth's rotation about its axis). The most fundamental problem with physical models, however, is that the relationships among the forces driving the physical circulation become distorted. Some forces, such as those related to surface slope of the water, are reduced in proportion to the scale of the model. Others, such as the coriolis force and the viscous (frictional) properties of water are not. In a physical model, it is impossible to accurately model the mixing of salt and freshwater or the distribution of a pollutant, even if all the velocities are accurately scaled.

There is a bewildering variety of mathematical models available. While the usefulness of any mathematical model may be restricted to a few problems, the variety of available approaches makes this the most versatile type of modeling. Mathematical models may be used to examine physical circulation, populations, the effects of physical alterations, sediment transport, and many other aspects of estuaries.

Analytical and computer modeling are the two fundamental kinds of mathematical models. An analytical model has a set of mathematical equations that are solved exactly, using the standard methods of calculus and differential equations. This is a "pencil and paper" approach to modeling that is extremely useful to the scientist, in that it improves theoretical understanding of the forces working in an estuary. Generally speaking, analytical models cannot take into account the complexities of the geometry of a real estuary. For this, a computer model is necessary. It is common, however, to use a less-detailed analytical model to determine what computer modeling approach is best to get detailed answers. Computer models then, are the type of mathematical models normally encountered by planners.

A computer model is similar to an analytical model in that it begins with a set of equations that are to be solved by the computer. Because computers are so much faster than hand calculations, much larger and more complicated systems may be considered. It is necessary, however, to incorporate into the model all that is known of the fundamental forces at work in an area. The computer cannot do the thinking for us. What it can do is provide numerical solutions where analytical solutions cannot be found and carry out huge numbers of calculations in a short period of time.

Estuaries are extremely complex bodies and the equations of motion that govern physical circulation and pollutant transport are notoriously difficult to solve. Even the largest computers are too small and too slow to solve the full equations of motion and apply them to any real estuary (at a useful level of detail). Therefore, simplifications are necessary, and it is customary to classify models according to the simplifications used. Assumptions concerning time dependence and the number of physical dimensions modeled are usually made. Currents, salinity, pollutant concentrations, etc. vary in an estuary over time and in all three spatial dimensions: length, width and depth. A model may be simplified by ignoring one or more of these dimensions. The most common simplifications are: averaging out the tidal fluctuations or all the time variation (a steady-state model); ignoring the cross-channel variations (two-dimensional model); ignoring both the cross-channel and vertical variations (one-dimensional model); and/or keeping the density (and thus salinity) constant. It is almost always necessary to simplify the geometry of the estuary. The effects of wind, waves and runoff from smaller tributaries are also often ignored. The kind of information and level of detail needed, determine what model is appropriate for any given problem. Generally speaking, the Columbia River is highly variable in time and all three spatial directions; in addition, wind, waves, salinity variations and tributary flow are all important.

Computer models were first introduced so that the problems of physical models might be avoided. The advantage of computer modeling is in the variety of questions that can be answered, the level of detail that can be achieved, the small amount of space needed and, to some extent, the theoretical understanding that can be obtained. Such models do have a number of faults. The amount of data needed for verification is just as great with the physical models. Although the distortion of the driving forces that occurs with physical models is avoided, these same forces must be approximated by adjustable parameters; these parameters usually cannot be measured and their meaning is often unclear. A computer model must be "tuned" to duplicate observed conditions by adjustment of parameters; given enough parameters, the model can be made to duplicate any set of field observations, regardless of whether the physics of the model are similar to that of the prototype. Finally, a physical model must obey the laws of physics and behave in a "reasonable" manner; a mathematical model is under no such obligation. Results of a computer model may be unreasonable because of errors in the simplifying assumptions, errors in programming or the accumulated errors in the mathematical approximations used.

207.2 MODELS OF THE COLUMBIA RIVER ESTUARY

The two most important models of the Columbia River Estuary are the Corps of Engineers' hydraulic model and the mathematical model produced by Callaway, Byram and Ditsworth for the Federal Water Pollution Control Administration (now the U.S. Environmental Protection Agency).

A. The Corps of Engineers Hydraulic Model

The Corps' hydraulic model is located at the Waterways Experiment Station in Vicksburg, Mississippi, with most of the other Corps' models for harbors all over the United States. The model reproduces the area from about six miles offshore to River Mile 52 (Beaver Army Terminal). It covers an area of about 1.1 acres (Figure 207-1); the horizontal scale is 1:500, but the vertical scale is 1:100.

The vertical distortion is necessary because of the effects of surface tension. Surface tension is the same in model and prototype. If the horizontal and vertical scales were both 1:500, then the layer of water in the model would be so thin that its motion would be entirely dominated by surface tension, except in the deepest areas. It is impossible to make the model 1:100 horizontally because it would then cover an impractically large area of more than 25 acres. The time and velocity scales are 1:50 and 1:10, respectively. These are determined by the speed of propagation of a wave in the model, which is in turn, determined by the depth. The discharge and volume ratios are 1:500,000 and 1:25,000,000. The salinity is the same in model and prototype.

The model is equipped with tide and wave generators, a pump to simulate long-shore currents outside the mouth, and freshwater inflows to simulate tributaries. Because the depth distortion makes the flow too efficient, it is necessary to install metal strips sticking up from the bottom to increase the friction. The mixing of fresh and salt water and pollutant transport cannot be accurately modeled because of both the vertical distortion and the failure of frictional forces to scale properly. Tidal heights, currents and salinities are measured with miniature instruments.

Sediment transport can be simulated, to a limited degree, in the movable bed part of the model (Figure 207-1). However, there are problems in finding sediment fine enough to be of the correct scale, relative to the sands and silts in the river, and because bottom friction is not properly scaled in the model. Thus, sediment transport in the model cannot be anything more than qualitatively accurate. Nonetheless, the Corps relies on the results of model tests in designing channels and jetties, because it is the best method available. They are now, however, planning to use both mathematical sediment transport models and the hydraulic model in the feasibility study for a deeper channel at the Mouth of the Columbia River. The Columbia River Estuary Model is being repaired and will be re-verified, on the basis of results of field work conducted in 1977 and 1978.

B. Federal Water Pollution Control Administration Computer Model.

Callaway, Byram and Ditsworth have prepared a time-dependent, quasi-two-dimensional model of the Columbia River from Bonneville Dam to the ocean; it models the heat budget of the river in that reach. While provision is made for thermal effluents, the main emphasis is on meteorological effects, including solar heating and heat exchanges between the air and water. This model is part of a larger one which models the Columbia River to the Canadian border. Such a model can be used to determine, for example, the effects of various water storage schemes and water diversion projects on stream temperatures which, in turn, affect fish runs. The model can also be used to determine the distribution of pollutants, but it is a fairly large-scale model and is not intended to predict in detail, the concentration of

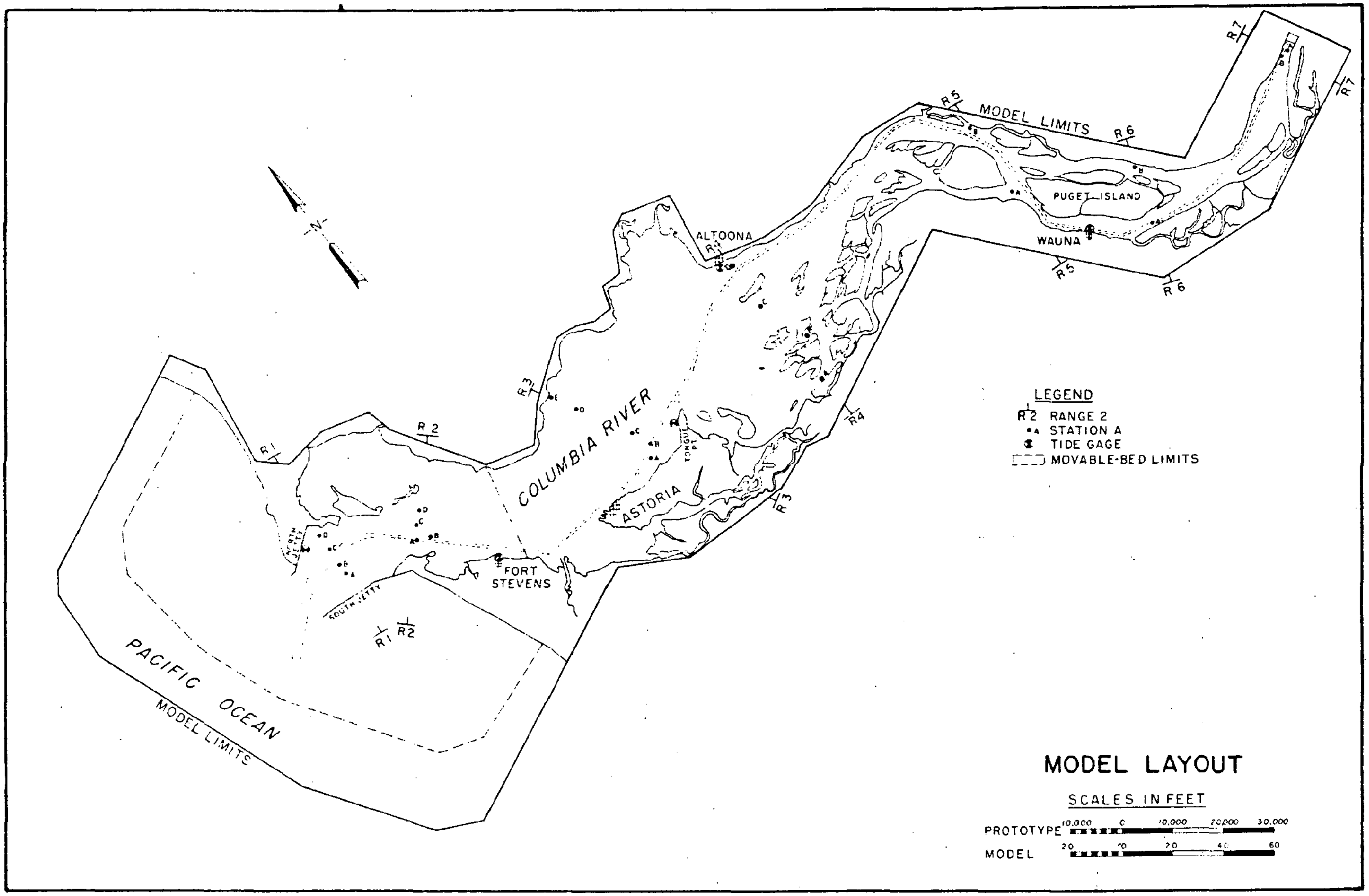

Figure 207-1. The layout of the Corps of Engineers Hydraulic Model at the Waterways Experiment Station. The horizontal scale is 1:500, the vertical scale 1:100. The movable bed section of the model is surrounded by the dashed line.

From: Herrmann, 1968

a pollutant around and immediately downstream from an outfall. A finer scale model would be required for that purpose.

The model does not consider depth variations in current or density; in this sense, it is oriented toward the riverine part of the system. It does, however, take into account the time variations and those along the length of the river channel; that is, it reflects tidal currents and fluctuations in runoff. It is quasi-two-dimensional in that cross-channel variations are considered indirectly. The wider sections of the river and areas where there are several channels separated by islands are simulated by a network of channels (Figure 207-2). Flows vary from one channel branch to another, and in this way, cross-channel variations are considered. The model works as if the entire estuary were a series of islands separated by the channel branches (Figure 207-2). Since shallow sand bars do separate many channel branches, the approximation is fairly accurate.

The model takes the freshwater inflow at Bonneville Dam and the tidal height and current speed at the mouth as the basic inputs. It calculates tidal heights and currents throughout the river. It then uses the calculated heights and velocities, meteorological data (temperature, wind speed, solar radiation, etc.) and thermal effluent volumes to calculate the temperature distribution. Pollutant distributions can also be calculated.

C. Other Mathematical Models

There are several other mathematical models that model specific aspects of the Columbia River Estuary. They are discussed in Section 204, because they are not general-purpose models and are more easily understood in conjunction with a discussion of estuarine circulation.

It is likely that a detailed (mathematical) physical circulation/sediment transport/pollutant distribution model of the estuary will be needed in the future. Such a model would be useful in evaluating the effects of potential channel alterations and water diversion schemes; it should also be coordinated with sediment transport models of such critical areas as the mouth.

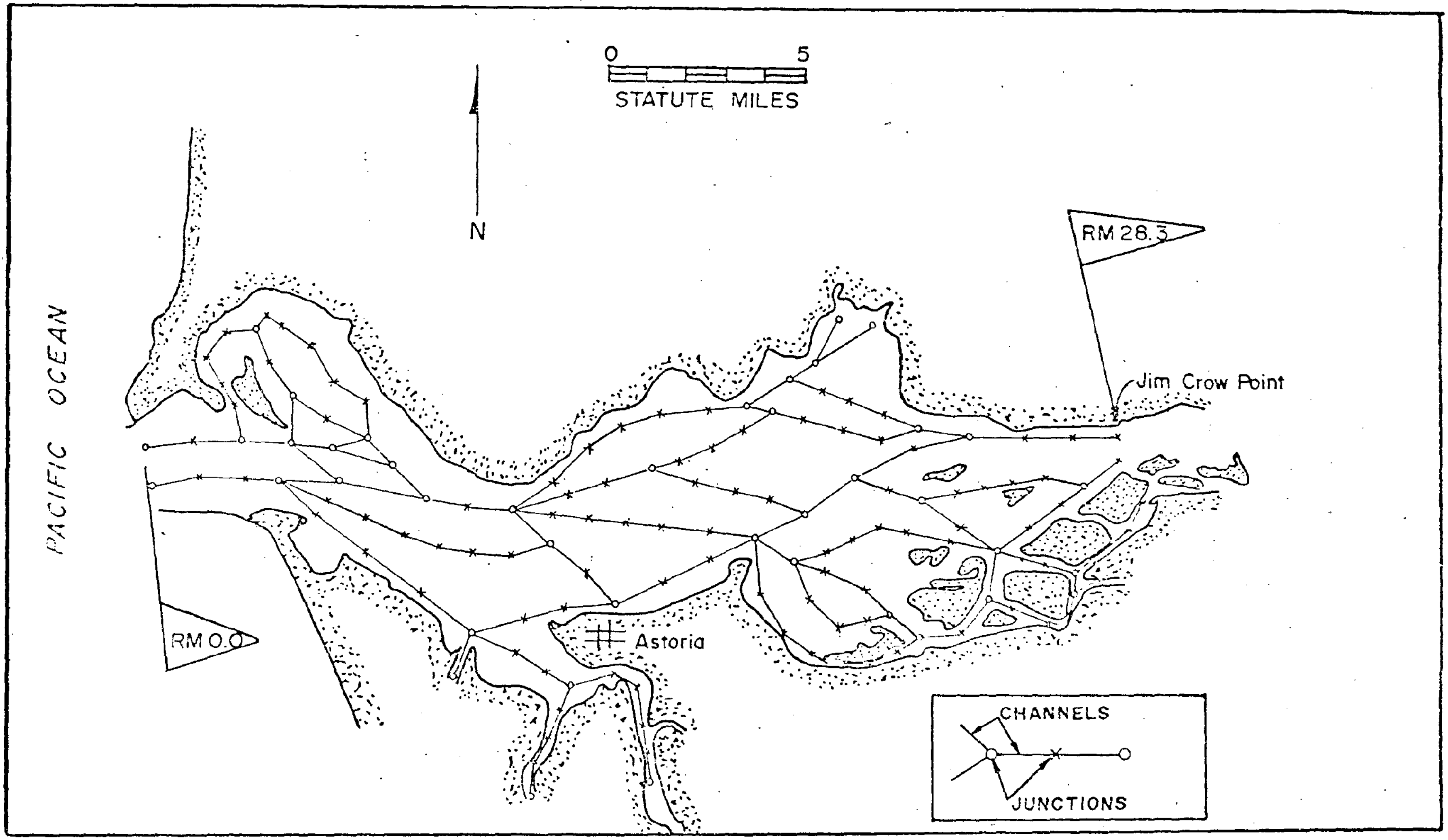

Figure 207-2 Columbia River Schematization
River Mile 0.0 (Pacific Ocean) to
River Mile 28.3 (Jim Crow Point)

From: Callaway <u>et al</u>., 1969

207.3 REFERENCES

A. Calloway, R.J., K.V. Byram, G.R. Ditsworth. 1969. Mathematical Model of the Columbia River from the Pacific Ocean to Bonneville Dam: Part I Theory, Program Notes and Programs. U.S. Department of Interior, Federal Water Pollution Control Administration, Northwest Region, Corvallis, Oregon. 155pp.

B. Calloway, R.J. and K.V. Byram. 1970. Mathematical Model of the Columbia River from the Pacific Ocean to Bonneville Dam: Part II Input and Initial Verification Procedures. U.S. Department of Interior, Federal Water Pollution Control Administration, Northwest Region, Corvallis, Oregon. 130pp.

This two-volume report presents in great detail the verification and use of the circulation and heat budget mathematical model prepared for the Columbia River. Computer programs included. Very technical.

C. Herrmann, F.A. 1968. Model Studies of Navigation Improvements, Columbia River Estuary Report, Hydraulic and Salinity Verification. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. 24pp. 218 plates, 15 photographs.

A Corps of Engineers report detailing the verification of the physical model of the estuary. Technical.

208

SEDIMENT AND SEDIMENT TRANSPORT

COLUMBIA RIVER ESTUARY

SEDIMENT AND SEDIMENT TRANSPORT

David Jay

James W. Good

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FIGURES

TABLES

*Figure follows the page indicated

208 SEDIMENT AND SEDIMENT TRANSPORT

208.1 ESTUARINE SEDIMENTS

Estuarine sediments are the organic and inorganic substances which carpet the estuary floor. They are an extremely important component of the total estuarine system, for they provide food and shelter for diverse plant and animal life. Sediments play an important role in the maintenance of estuarine water quality as they harbor bacteria; these bacteria decompose organic wastes, and decomposition releases nutrients to fuel the production of new plant material. Some inorganic sediments are a valuable resource to man, because they provide fill material to create new land and may contain potentially valuable minerals, such as iron. However, because of the movement of sediments within the estuary, the federal government spends millions of dollars annually for dredging and navigational improvements, designed to stabilize the estuarine system. Local ports also spend substantial sums each year to maintain access to ship berths. Dredged material disposal often creates environmental problems by causing turbidity in the water column, benthic (bottom) habitat disturbance and removal of area from the estuary. Consequently, knowledge of sediment characteristics and sediment transport (movement) is an important factor in deciding how to best utilize estuarine resources.

Estuarine sediments can be divided into two broad classes, inorganic and organic. Most sediments in the Columbia River are inorganic sands, silts, and clays; these sediments are introduced into the estuary from the ocean, the main stream of the Columbia River, and local tributaries. Organic material consisting of dead plant and animal matter, wood fibers and chips, chemical, industrial and human waste, and other matter, forms a small but important fraction of estuarine sediments. Some organic materials are beneficial, while others are harmful. Organics tend to behave like fine inorganic clays and silts, and they settle out from suspension over tidal flats and in estuary tributaries. Unlike the inorganic sediments, they contribute needed food material to support the rich tidal flat life system.

Inorganic clay, silt, sand, gravel and large particles are classified by size according to what is commonly called the Wentworth Scale. Clay and silt particles are also called "fines," while the larger particles are labeled "coarse" (Table 208-1).

Much can be learned about the origin and transport of sediments by studying the size distribution (percentage of material of each size) and mineralogy (types of minerals) of a sample. The "sorting" of the sediment is a parameter that describes the range of sediment sizes found in a sample and is an important indicator of the processes at work. A well-sorted sample with only a small range of particle sizes indicates either that a single, consistent process is operating, or that only one size of sediment is supplied to the area. More complicated size distributions, containing more than one prominent sediment size, are indicative of multiple sources of sediment and/or multiple processes at work. Another frequently used property of the sediment size distribution is "skewness." It measures the assymmetry of the size distribution; that is, does the size distribution have a tail of fine or coarse material or an unbalanced central peak? The skewness is also indicative of both the sources of sediment and the processes at work.

Millions of tons of sediment enter the Columbia River estuary each year, and much is deposited before it reaches the river mouth. More than 130 major dams in the Columbia River drainage basin have probably reduced sediment discharge upriver from the estuary, by physically blocking bottom-transported sediments and by replacing the free flowing river with slack water, where suspended sediment settles out. On the other hand, maximum flow levels are much lower (reducing the amount of sediment moving from the estuary out to sea during spring freshet), and estuary tributaries carry much more sediment because of logging and agricultural practices. Sediments are suspended and redistributed in the estuary in response to tidal wave and river forces; these vary significantly on daily, weekly, monthly, seasonal and annual time scales. Movement of sediment is greatest when water turbulence is highest, that is, when tidal or wave energy is great, river discharge very high or some combination of the three.

TABLE 208-1 GRAIN SIZE SCALES FOR SEDIMENTS

		GRADE SCALES: Phi = $-\log_2$(diameter in mm)	GRADE SCALES: millimeters
BOULDER			
		−8	256
COBBLE		−7	128
		−6	64
PEBBLE		−5	32
		−4	16
		−3	8
		−2	4
GRANULE			
		−1	2
SAND	VERY COARSE		
		0	1
SAND	COARSE		
		+1	$\frac{1}{2}$
SAND	MEDIUM		
		+2	$\frac{1}{4}$
SAND	FINE		
		+3	$\frac{1}{8}$
SAND	VERY FINE		
		+4	$\frac{1}{16}$
SILT	COARSE		
		+5	$\frac{1}{32}$
SILT	MEDIUM		
		+6	$\frac{1}{64}$
SILT	FINE		
		+7	$\frac{1}{128}$
SILT	VERY FINE		
		+8	$\frac{1}{256}$
CLAY	COARSE		
		+9	
CLAY	MEDIUM		
		+10	$\frac{1}{1024}$
CLAY	FINE		
		+11	
CLAY	VERY FINE		
		+12	$\frac{1}{4096}$
COLLOID			

FROM: SHEPARD, 1963

Waves, including both seas generated by local winds and swell generated by distant storms, are the most important causes of sediment transport near the mouth of the river and over the bar. Wave energy is also important in the lower estuary.

Material is transported by the river in one of three ways:

1) dissolved in solution,
2) as suspended sediment in the water,
3) bouncing along the bottom with the flow of the water as "bedload."

Particle size, particle density and current speed are the three most important factors that determine whether or how a particle will be transported. Silts and clays, because of their small size, generally stay suspended in river currents and account for most of the total river sediment input to the estuary. Sands move primarily along the bottom, as bedload. A fourth factor, cohesion of particles, is significant in the process of resuspension or erosion. After deposition, finer particles, such as silts and clays, tend to adhere tightly to one another; thus, resuspension through erosion becomes more difficult. Therefore, sands of about .18 mm in diameter (2.5Ø)* are more easily resuspended than either smaller or larger particles, if the smaller material is cohesive (Figure 208-1).

208.2 SEDIMENT DISTRIBUTION

A detailed map of the Columbia River estuary showing the distribution of sediments by dominant type (i.e. sand, silt, clay) cannot be constructed because the data are not available. It is possible, however, to map information on the general nature of sediments in various areas of the estuary. This is done by first dividing the estuary bottom along its length into marine, transition and riverine zones. These correspond to what have also been called the lower, middle and upper estuary. It is important to note that the boundaries of these zones represent an "average" low flow situation, and their position varies with daily, monthly, seasonal and annual fluctuations of tides, weather and river discharge.

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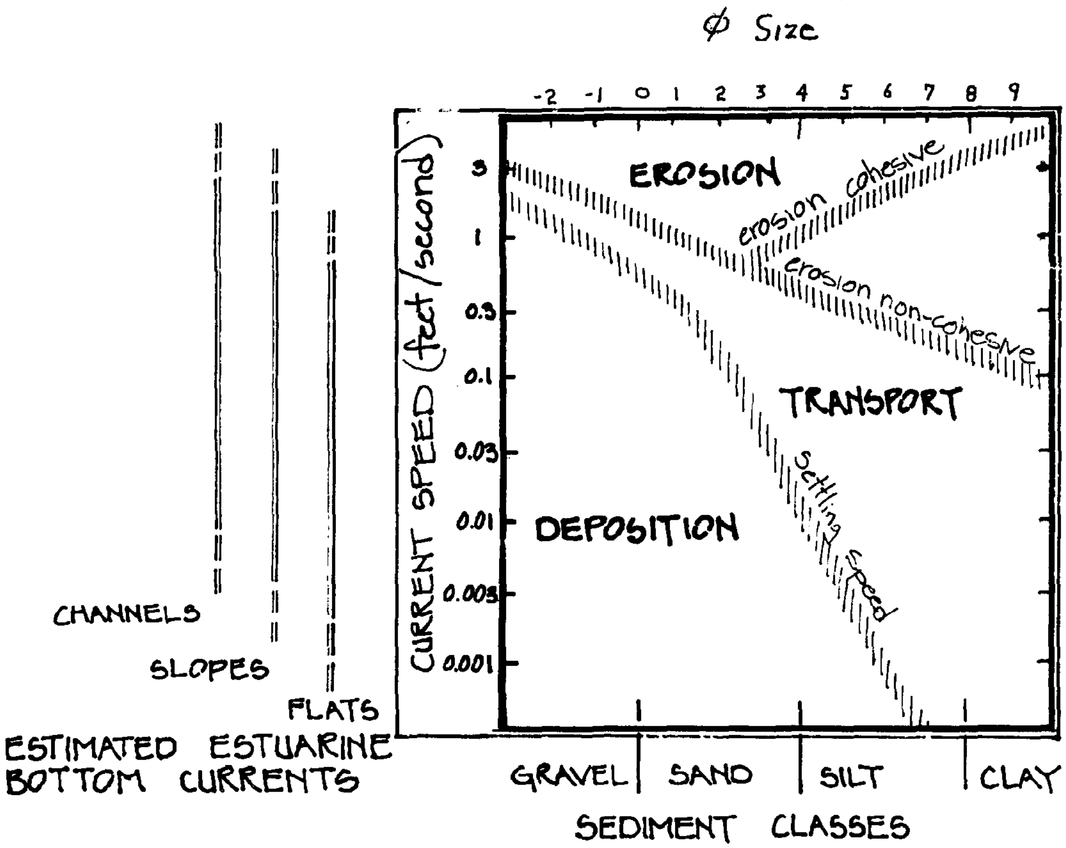
*Ø or "phi" is a Greek letter pronounced like "fee." The Ø scale is a system used to classify sediments by size, so that diameter in mm=$2^{-Ø}$. That is, Ø is the negative of the logarithm to the base 2 of the diameter.

FIGURE 208-1



CURRENT SPEEDS REQUIRED FOR EROSION AND TRANSPORT OF SEDIMENTS

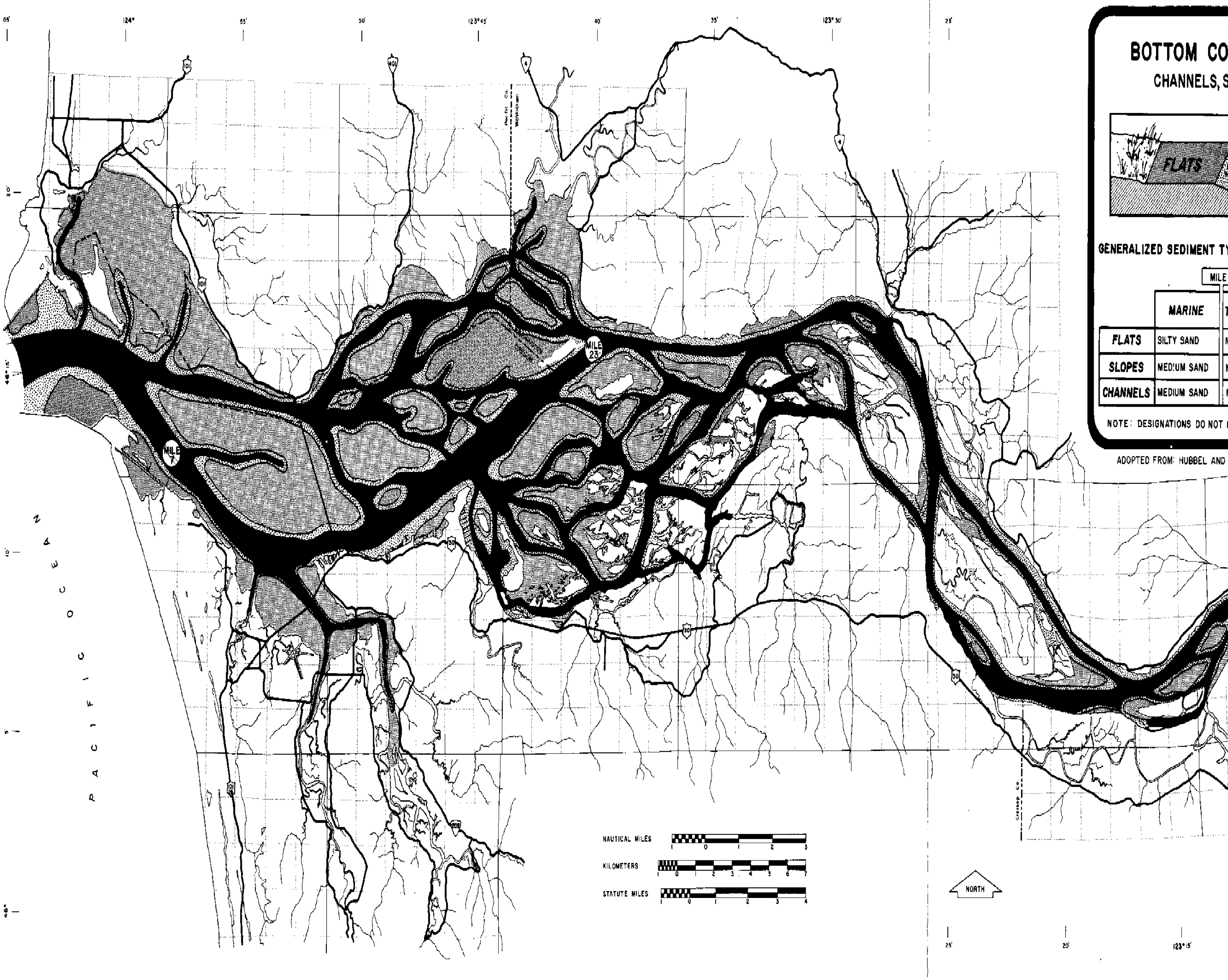
The next step is to divide the estuary into physical classes called channels, slopes and flats. Channels are areas where there are measurable currents, though these usually flow alternately downstream and upstream, because of tides. They form a continuous, interwoven network throughout the estuary, are bounded laterally by slope areas, are usually the deepest part of the estuary and have flat or gently sloping beds. Slopes are areas that are adjacent to channels on one side and are adjacent to a flat or the shore on the other side. They have a relatively steep bed slope. Flats are intertidal and shallow subtidal areas. They have low bed slopes and low current velocities over them. Many are bounded completely by slopes (i.e. Desdemona Sands), while others lie between slopes and the shore.

Data collected and analyzed by the U.S. Geological Survey (USGS) showed that generalizations can be made about sediment textural characteristics of channels, slopes and flats in marine, transitional, and river divisions of the estuary. These observations are summarized in Figure 208-2 and Table 208-2. Figure 208-2 shows the distribution of channels, slopes and flats throughout the estuary, as well as the associated sediment types. The map is based on degree of slope, rather than contours of equal depth, and so actual channel depths may vary significantly. General observations are as follows:

(1) Channels contain the coarsest sediments. Of the marine, transition and river divisions, river channel sediments are coarsest, marine channel sediments are intermediate, and the transition channel sediments are finest. The sediments are moderately well-sorted and tend to be skewed toward coarse material.

(2) Flats contain the finest sediments and those that are most poorly sorted (variable in size). Sediments on flats also tend to be skewed toward fine particles. Of the three longitudinal divisions, sediments are finer in the river and marine divisions than in the transition division, where extensive mid-estuary sand flats occur (i.e. Desdemona Sands).

(3) Slope sediments are relatively less variable in textural characteristics throughout the estuary, and are slightly more uniform in size near the mouth. The particle size, sorting and skewness on the slopes are between the values observed for the channels and flats.



BOTTOM CONFIGURATION

CHANNELS, SLOPES & FLATS

GENERALIZED SEDIMENT TYPE IN THREE ESTUARY ZONES

	MARINE	TRANSITION	RIVER
		MILE 7	MILE 23
FLATS	SILTY SAND	MEDIUM SAND	VERY FINE SAND
SLOPES	MEDIUM SAND	MEDIUM SAND	MEDIUM SAND
CHANNELS	MEDIUM SAND	MEDIUM SAND	COURSE SAND

NOTE: DESIGNATIONS DO NOT IMPLY EQUAL DEPTH.

ADOPTED FROM: HUBBEL AND GLENN, 1973

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

208-2

TABLE 208-2

SEDIMENT TEXTURAL CHARACTERISTICS

Summary of textural statistics of surficial sediment samples grouped according to geomorphic class and longitudinal division

Longitudinal division	Geomorphic class	Number of samples	Particle size statistic in phi notation								
			Mean grain diameter			Sorting			Skewness		
			Range	Average	Standard deviation	Range	Average	Standard deviation	Range	Average	Standard deviation
Riverine	Channels	37	-2.97 to 5.30	1.51	1.34	.22 to 2.72	.69	.53	- .77 to .35	- .07	.21
	Slopes	40	- .47 to 6.35	2.46	1.52	.30 to 2.56	.88	.62	- .52 to .63	.03	.23
	Flats	22	1.36 to 7.08	3.22	1.56	.31 to 2.67	.92	.74	- .14 to .70	.14	.21
	All	99	-2.97 to 7.08	2.27	1.59	.22 to 2.72	.82	.62	- .77 to .70	.02	.23
Transitional	Channels	14	.97 to 5.03	2.58	1.45	.25 to 2.13	.89	.66	- .30 to .55	.07	.24
	Slopes	18	1.04 to 5.17	2.59	1.12	.22 to 1.87	.68	.46	- .33 to .40	.02	.19
	Flats	10	1.07 to 5.23	2.44	1.11	.30 to 1.41	.54	.34	- .10 to .39	.09	.16
	All	42	.97 to 5.23	2.55	1.31	.22 to 2.13	.72	.52	- .33 to .55	.05	.20
Marine	Channels	7	1.55 to 5.60	2.33	1.46	.26 to 3.06	.77	1.02	- .13 to .42	.06	.18
	Slopes	5	1.90 to 3.81	2.42	.78	.26 to 1.85	.64	.68	- .07 to .81	.19	.36
	Flats	8	2.03 to 5.95	3.99	1.41	.21 to 2.10	1.31	.68	- .10 to .80	.34	.27
	All	20	1.55 to 5.95	3.02	1.48	.21 to 3.06	.96	.83	- .13 to .81	.20	.28

From: Hubbell and Glenn, 1973

In general, sand is the most common sediment size in the estuary. Many areas contain small, but significant quantities of silt, while clay material is generally sparse. Some gravel is also present. An "average" sediment sample from the estuary would contain 1 percent gravel, 84 percent sand, 13 percent silt and 2 percent clay. However, the actual textural characteristics at specific locations around the estuary vary widely, and many samples contain sand, almost exclusively.

During the 1974 study of Youngs Bay sponsored by Alumax Pacific Aluminum Corporation, some data on sediment texture were gathered. A complete analysis was not made, but the percentage of fine sediments (silt and clay fraction) was measured (Figure 208-3) and the average sediment size and sorting are shown in Figures 208-4 and 208-5.

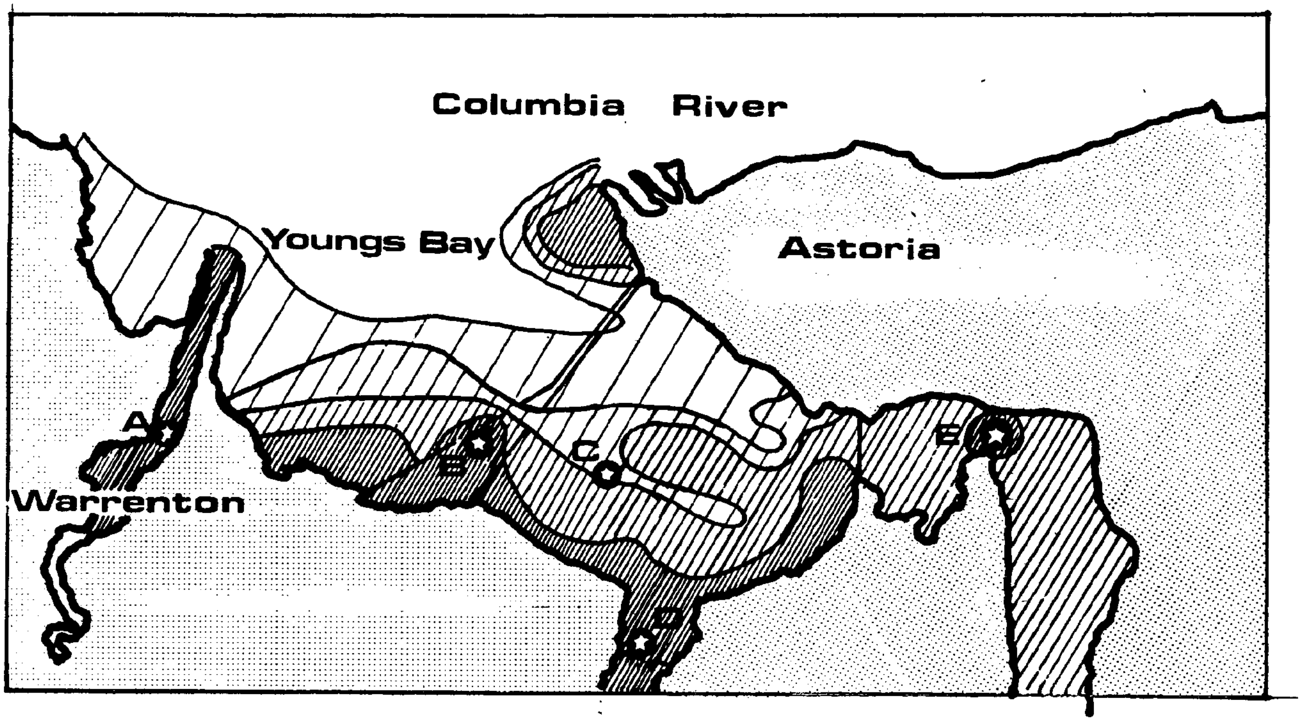
Very little fine sediment is found in the Youngs Bay main channel, where tidal and river current velocities are great enough to prevent fine sediment accummulation. The sediments in the channel are well-sorted; this indicates the relative consistency of the processes at work. In general, the shallow southwest side of the bay contains finer material than the north side. There are pockets of fine sediment in protected areas, such as behind the Highway 101 Causeway, in the Skipanon Waterway, in the Lewis and Clark River area and to the west of Pier 3.

The variation of textural characteristics with depth in the core samples supports the theory that alternating periods of erosion and deposition occur in Youngs Bay, particularly in the lower sections of the Youngs and Lewis and Clark Rivers. Textural variations are probably caused by natural seasonal cycles, by construction of piers, bridges, etc., as well as by the dredging maintenance of the navigation channel. For example, sediment texture was significantly coarser south of the Youngs Bay Bridge prior to the causeway construction.

Although the average deposition rate for the entire Youngs Bay area is about 1 cm/year, the deposition rates show considerable spatial and temporal variability. Recent deposition rates for selected sites (since 1964) are depicted in Figure 208-3.

FIGURE 208-3

YOUNGS BAY: Percentage of fine sediments (clay and silt)



Recent Deposition Rates (in centimeters)

SITE A-5.5 CM PER YR
B - 4 CM PER YR
C - 2 CM PER YR
D-1.5 CM PER YR
E-1.8 CM PER YR

Percent Clay and Silt

0 - 10%
10 - 30%
30 - 50%
50 - 70%
GREATER THAN 70%

(Source: Johnson and Cutshall, 1975)

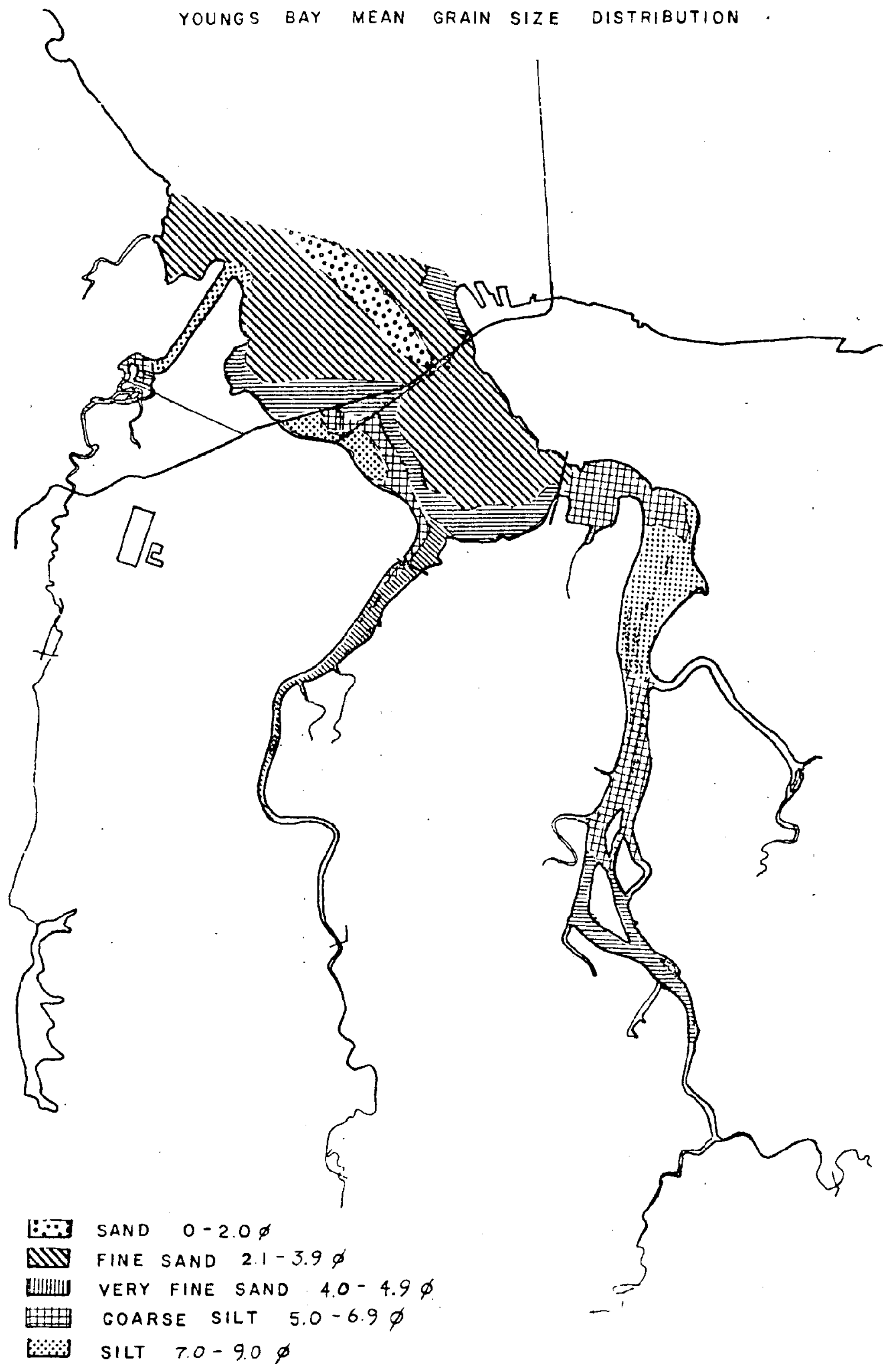


Figure 208-4

The coarsest material is seen in the areas where the currents are strongest. Fine materials are found in sheltered areas.

From: OSU Ocean Engineering Programs, 1975

Sediment Sorting in Youngs Bay

Figure 208-5

Sorting of sediments in the Youngs Bay area. Sediments in the main channel tend to be well-sorted. The rivers carry sediments of many different sizes, thus, the sorting in the tributaries is poor.

From: OSU Ocean Engineering Programs, 1975

208.3 SUSPENDED SEDIMENT TRANSPORT

In the tidal part of the river, flow is alternately upriver and downriver. In the part of the river subject to saltwater intrusion, the different densities of saline and freshwater cause a characteristic estuarine circulation pattern to develop under low flow conditions. An upriver flow of dense saltwater predominates in the lower layers.

The tidal flow also transports suspended sediments alternately upriver and downriver. Particularly during slack water, some of the particles in suspension in the upper layers, settle down into the lower layers; they are then transported back upstream. This process is accelerated by "flocculation." Flocculation occurs when tiny suspended clay particles, upon contact with saline water in the mixing zone of the estuary, are attracted to one another, form larger, heavier particles, and settle more rapidly than individual particles. Over many tidal cycles, this action causes suspended sediments to accumulate in the zone where the average flow near the bottom is zero. This zone is termed the "turbidity maximum" or null zone; it has physical and biological significance and harbors some of the densest populations of microscopic food animals in the estuary.

During the high river flow periods, the suspended sediment peak concentration in the null zone will oscillate with the tide, from about river mile (RM) 3 to RM 8 (Clatsop Spit to Hammond Mooring Basin). During periods of low river flow, the peak sediment concentrations generally occur between RM 14 and RM 23 (Astoria to Harrington Point). When river flow is moderate, the null zone is between the extremes.

Analysis of data collected by USGS shows that when river discharge is low, maximum resuspension of bottom sediments (mostly silts and clays) takes place with the flood tide. Silts and clays are carried upriver, and as high water slack occurs, the silt settles out. Relatively little silt and clay (about 20 percent) is resuspended on the succeeding ebb tide. It might be concluded that much of the near-shore shoaling of port slips that occurs during the late summer, low-river-flow periods results from this mechanism. The USGS measured a net upstream transport of suspended sediment of 7,400 tons in one day, for a moderately low river discharge of 231,000 cubic feet per second (cfs), (Figure 208-6); the bedload transport for the period was

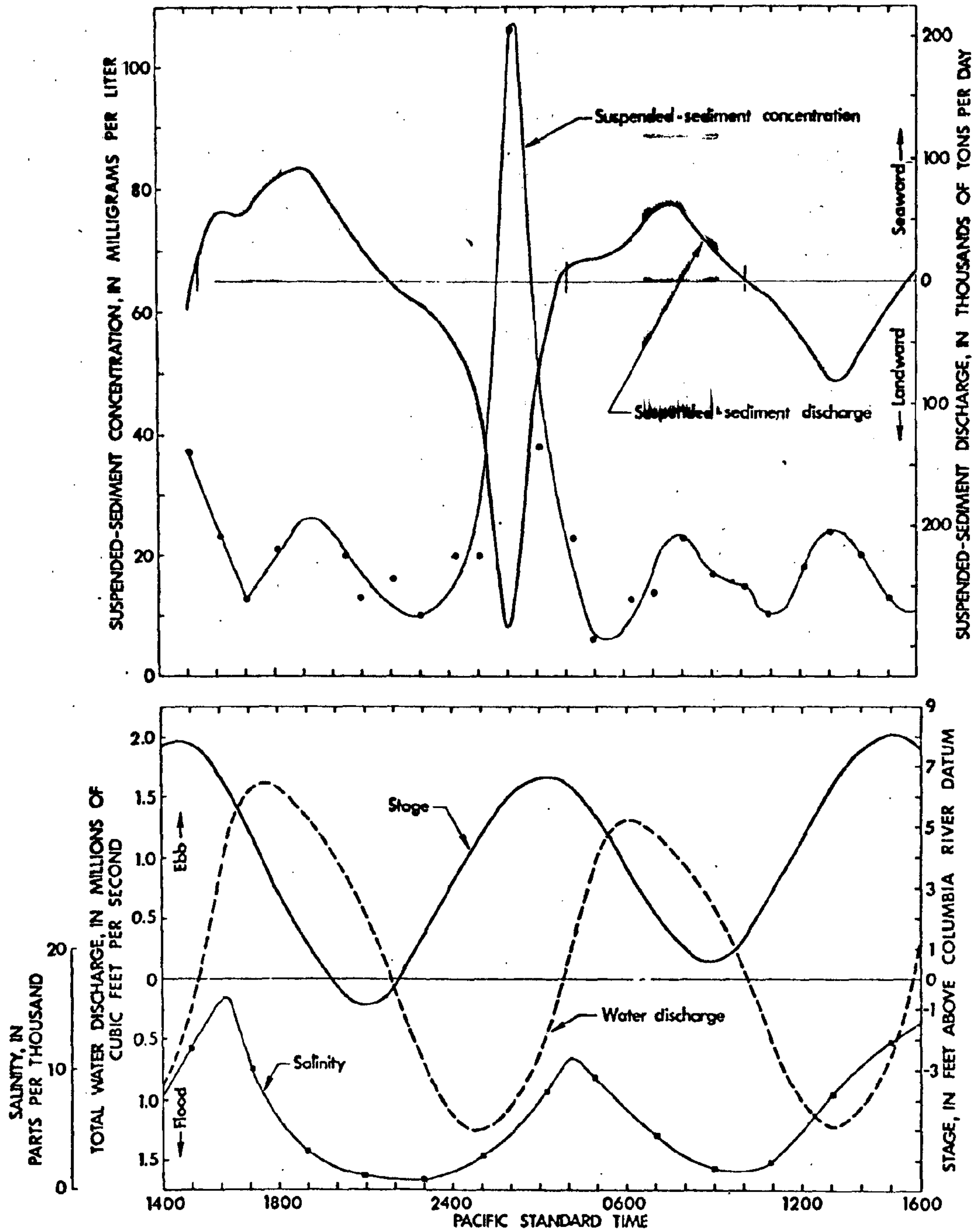


Figure 208-6

Temporal variations in total water discharge, water-surface elevation (stage), salinity, and the concentration and discharge of suspended sediment at CRM 13 on September 14-15, 1969. Suspended-sediment concentrations and salinities were determined from depth-integrated samples from the routine sampling site. Low freshwater flow conditions - 231,000 cfs.

From: Hubbell et al., 1971

not known and might add to the transport.

In contrast to this low flow situation, sediment resuspension at high river discharge (468,000 cfs) was greatest during ebb flows. Ebb currents were significantly stronger than flood currents at the point of measurement (RM 13, south side of navigation channel), primarily because of high river discharge and limited salinity intrusion. The concentration of suspended sediment was much higher during high river flow (approximately 5 times the low flow concentration in this case), and much of this suspended sediment probably moved through the estuary to the ocean. Even so, significant shoaling of estuarine areas may also occur during high river flows. The total downstream transport was 50,000 tons (Figure 208-7). It should be realized that the null zone was downstream of RM 13, at the time of these measurements. It is, therefore, expected that the sediment transport would be downstream at this location. Suspended sediment transport at the mouth, however, might still have been upstream, because of upstream movement in the salt wedge.

It has not been possible to routinely measure sediment transport (suspended or bedload) in the estuary. The USGS has estimated suspended sediment transport at Astoria (RM 13) and at Beaver Army Terminal (RM 53) for the period May 1968 to June 1970, on the basis of a mathematical model of Columbia River freshwater discharge (Section 202.3), and a limited number of suspended sediment transport measurements of the type shown in Figures 208-6 and 208-7. These results must be considered as only approximate. A two-year time span is too short to encompass the range of variability in sediment transport conditions or to accurately establish long-term trends resulting from dam construction. The results are best understood in light of the data on suspended sediment transport upstream from the estuary.

Measurement of suspended sediment transport is much easier in the upstream sections of the river, where current reversal rarely or never occurs. Suspended sediment concentrations were routinely observed at Vancouver (RM 105) during the water years 1963 to 1970. These data, combined with the calculated daily freshwater flow at Vancouver, can be used to calculate suspended sediment transport at

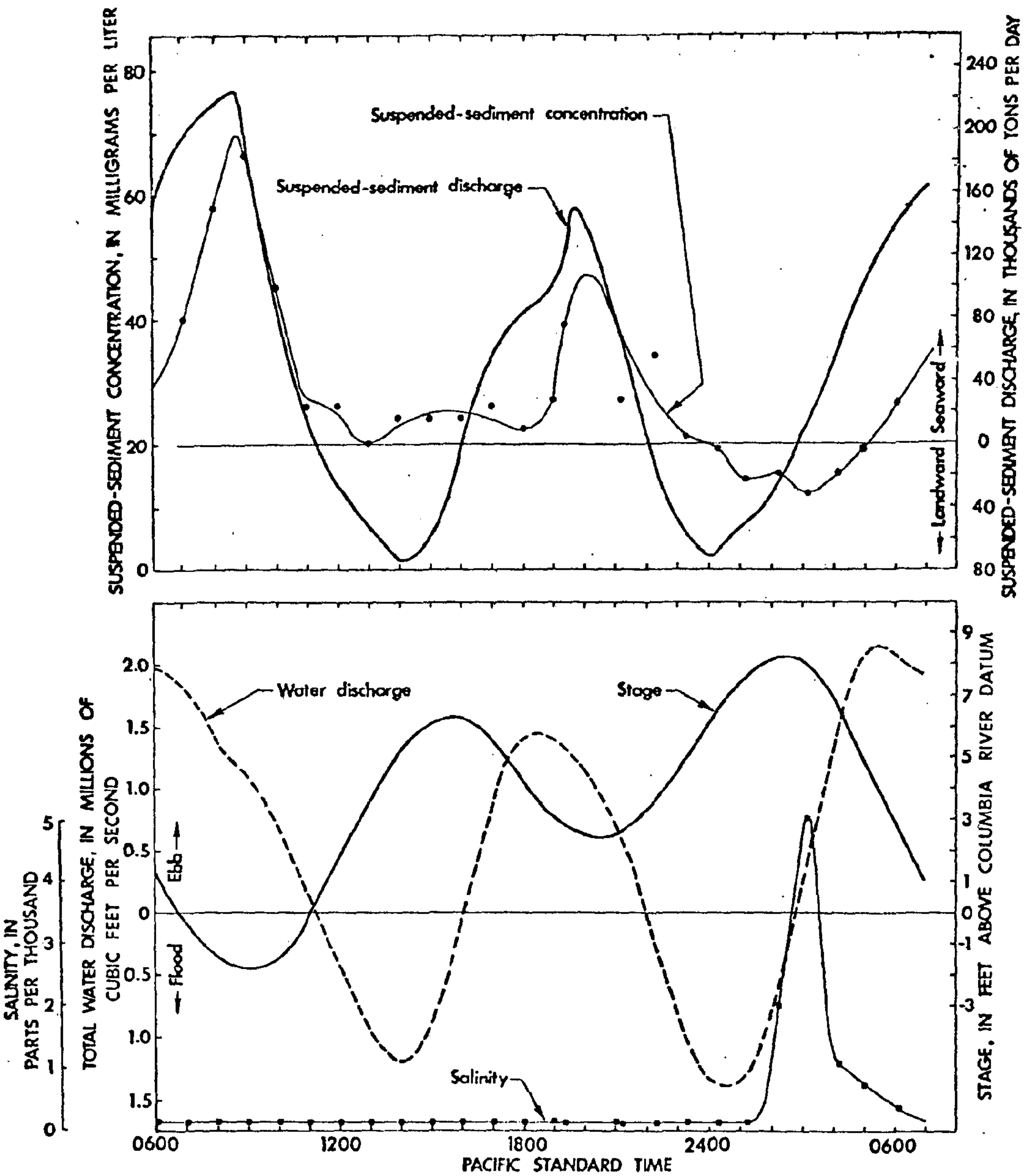


Figure 208-7

Temporal variations in total water discharge, water-surface elevation (stage), salinity, and the concentration and discharge of suspended sediment at CRM 13 on May 23-24, 1970. Suspended-sediment concentrations and salinities were determined from depth-integrated samples from the routine sampling site. High freshwater flow conditions - 468,000 cfs.

From: Hubbell et al., 1971

Vancouver (Table 208-3). It is apparent from Table 208-3 that the suspended sediment transport is even more variable than the freshwater flow. This extreme variability occurs because of the greatly increased ability of swifter currents to suspend sediment and the variable input of sediment to the river system. The average yearly suspended sediment transport at Vancouver between 1963 and 1970 was about 10 million tons (about 0.3 tons/sec) and ranged from 4.3 to 30.8 million tons. It is likely that a longer series of observations would reveal even more extreme variability, since no extreme freshets occurred during the period 1963 to 1970. Most of this transport (about 60% on the average) occurred during the spring freshet; in some years more than 10 million tons of sediment were transported in a 7 to 12 week period.

Major winter freshets are less frequent than spring freshets, but they may result in even greater suspended sediment transport. A winter flood west of the Cascades carried 10.2 million tons of sediment past Vancouver between 12/17/64 and 1/7/65. This included nearly 8.6 million tons in a single week, equivalent to 14.3 tons/sec.

It appears that winter floods carry much higher concentrations of sediment, but the suspended sediment is somewhat finer than sediment carried during most spring freshets. The high concentration of fine material probably results from the direct erosion of soil by heavy rains and the attendant runoff. The winter freshets usually do not result in runoff levels as high as during the typical spring freshet; consequently, winter freshets are not able to resuspend as much coarse material from the bottom.

Finally, it is necessary to evaluate the sediment transport in the tributaries above the estuary and below Vancouver (principally the Willamette River). Suspended sediment transport data are available for the Willamette River for water year 1963 only. The total suspended sediment transport for the water year was about one million tons, or one-sixth of that at Vancouver. There were four periods of high transport in the Willamette River during the year, but none of them corresponded to the spring freshet. In contrast, only one winter storm was large enough to strongly affect sediment transport in the Columbia River at Vancouver. Thus, the sediment transport patterns in the

Table 208-3
Freshwater Flow and
Suspended Sediment Transport
In the Columbia River at Vancouver

	Fresh Water Flow In 10^3 CFS				Suspended Sediment Transport In 10^6 Tons/Wk.		In 10^6 Tons	
Water Year	Yearly Average Flow	Average Flow During Freshet	Peak Weekly Average Flow During Freshet	Duration of Freshet In Weeks ‡	Average Transport During Freshet	Peak Transport During Freshet	Total Transport During Freshet	Total Transport For Year
1963*	188	434	459	6	0.3	0.35	1.8	6.1
1964	198	435	652	9	1.2	2.1	10.5	12.0 (9 Months Only)
1965	240	426	519	12	1.1	1.8	13.6	30.8‡‡
1966	172	322	391	7	0.4	0.6	3.0	5.5
1967	202	530	634	8	1.1	1.8	8.8	10.5
1968	177	332	397	9	0.3	0.5	2.6	4.3
1969	219	349	461	16	0.3	0.8	5.1	6.1
1970	179	335	403	7	0.3	0.5	2.0	4.5 (9 Months Only)
							(Av: 5.9)	(Av: 10.0)

Unless otherwise noted, data are unpublished. They were provided by D.W. Hubbell, USGS, Water Resources Division, Denver, Colorado. The water year extends from October 1 to September 30. Thus, water year 1970 ran from October 1, 1969 to September 30, 1970.

*From Progress Report Radionuclide Transport of the Columbia River Pasco to Vancouver, Washington Reach, July 1962 to Sept. 1963, USGS Open File Report. Portland, Oregon, 1966. Transport for 1963 were calculated on a different basis than for following years and the figures are not totally comparable.

‡Duration of freshet is simply the number of weeks in the spring during which elevated transports were observed.

‡‡Yearly total also includes a major winter storm centered west of the Cascades that contributed 10.2 million tons of sediment, 8.6 million tons during a single week.

Willamette River cannot be presumed to be similar to those in the Columbia River. Consistent with the importance of storms in the Willamette River drainage, almost all of the suspended sediment transport was clay and silt, rather than sand.

With this background information, we can better evaluate the suspended sediment transport data for Astoria (RM 13), Beaver Army Terminal (RM 53) and Vancouver (RM 105) shown in Table 208-4. The sediment transport at Vancouver for the periods 7/1/68 to 6/30/69 and 7/1/69 to 6/30/70 were 6.8 and 4.5 million tons per year, respectively (Table 208-4). This is rather low compared to the 8-year average of 10 million tons (Table 208-4). Nearly all the transport at Vancouver for the 68-69 period was during the prolonged, but not particularly intense, 1969 spring freshet. The 1970 freshet was short and with the exception of 1963, resulted in less sediment transport than any other spring freshet between 1963 and 1970.

The sediment transport at Beaver Army Terminal was larger both years (7.7 and 7.5 million tons) than at Vancouver. This does not mean there was a loss of sediment in the reach between, as the Sediment Accumulation Column in Table 208-4 might suggest. The Willamette River and several other tributaries enter the Columbia River in this reach. Since dredging is routinely required in this reach, it is safe to assume there is a net accumulation of sediment in most years. There was a dramatic accumulation (more than 5 million tons) of sediment in the Beaver Army Terminal - Astoria reach in both years. The total accumulation (10.5 million tons) was about two-thirds of the downstream suspended sediment transport at Beaver Army Terminal during this period and amounts to an average of about 1 cm/yr deposition over the entire area of the reach. It is also likely there was a considerable accumulation of sediment in the estuary below Astoria during this period. Estimates based on the distribution of radionuclides in the estuary suggest that about one-third of the fine sediment (instead of the two-thirds suggested by this study) passing through the estuary is retained in the sediment. This discrepancy remains to be resolved.

Comparison of the various transports and accumulations during high and low flow periods indicates that three of the four freshet periods shown in Table 208-4 resulted in significant accumulations of

Table 208-4

Suspended Sediment Transport at Vancouver,
Beaver Army Terminal (RM53) and Astoria (RM13)
May 1968 to June 1970

Year	Suspended Sediment Transport In 10^6 Tons			Sediment Accumulation In 10^6 Tons	
	Vancouver	Beaver Army Terminal	Astoria	Vancouver-Beaver* Army Terminal	Beaver Army Terminal-Astoria
7/1/68 to 6/30/69	6.80	7.69	2.30	-.89	+5.39
7/1/69 to 6/30/70	4.50	7.46	2.36	-2.96	+5.10
2 Year Total	11.30	15.15	4.66	-3.85	+10.49
Freshet Periods					
5/21/68 to 7/22/68	2.64	2.37	1.09	0.27	1.28
3/26/69 to 7/1/69	5.12	4.86	3.08	0.26	1.78
5/14/70 to 7/1/70	1.95	2.18	2.37	-.23	-.19
1/15/70 to 2/18/70	0.83	2.68	-0.35	-1.85	3.03
					5.90 Total
Low Flow Periods					
7/30/68 to 10/14/68	.30	.59	-1.90	-.29	2.49
7/23/69 to 9/30/69	.27	.43	-.87	-.16	1.30
					2.79 Total

Data is unpublished. It was provided by D.W. Hubbell of the USGS, Water Resources Division, Denver, Colorado.
*Sediment Transport at Beaver Army Terminal exceeds that at Vancouver in most cases, because of input from Willamette, Cowlitz, Kalama, and other rivers.

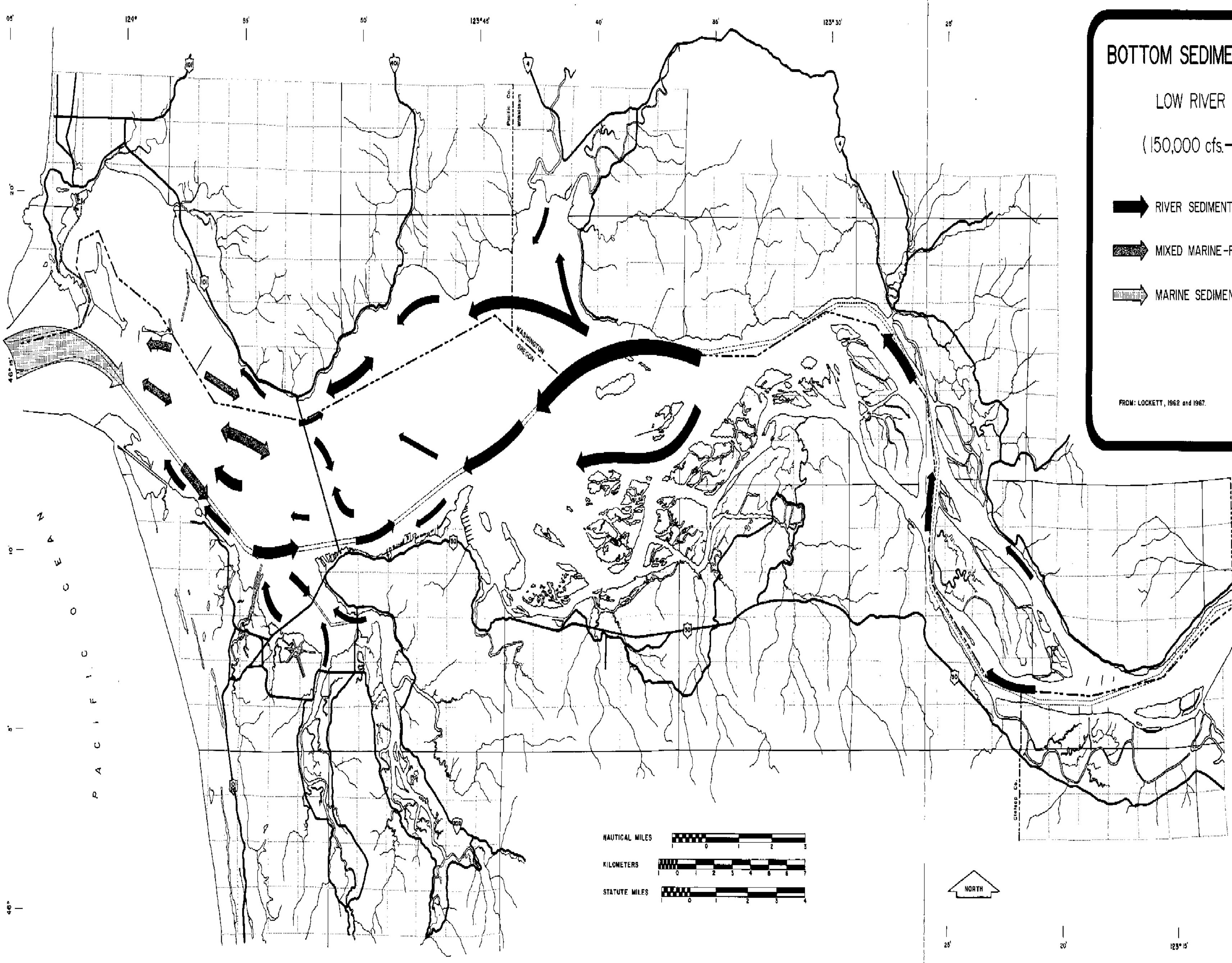
sediment in the estuary. The freshet accompanying the storm of early 1970 was particularly notable in that there was no increase in sediment transport in the estuary at all. The spring freshet of 1970 stands out because it did not result in any accumulation of sediment. It is believed that strong freshets do result in very large movements of suspended sediment to the ocean, but no such freshets occurred during the two-year study period. The many dams on the Columbia River have the effect of reducing the peak flows during freshets. It is likely that this has increased sediment accumulation in the estuary.

Significant sediment accumulation in the estuary also occurred during the late-summer low-flow periods in 1968 and 1969. Very little sediment moved down the river into the estuary during these periods. The major transport into the estuary was from the ocean; this sediment transport accompanied the increased salt intrusion.

It must be remembered that the above discussion concerns only the suspended sediment transport. The sands and gravels most often important with regard to dredging move primarily along the bottom as bedload. Sands, however, may move in suspension during freshets. Under most conditions, it is likely that the bedload constitutes an important part of the total sediment transport in the river below Vancouver.

208.4 BOTTOM SEDIMENT TRANSPORT

As noted earlier, the sediments transported along the bottom are predominantly the coarser sands and gravels. The effect of currents over the bottom causes the sand to form dunes, oriented in the direction of transport. Dune orientation has been used to develop a map (Figure 208-8) of bottom sediment transport (bedload) at a low river flow period (about 125,000 cubic feet per second). Between Harrington Point and Tongue Point (RM 18 to 23), sediment movement along the bottom was seaward and generally confined to the navigation channel. Below Tongue Point, transport in the channel was upstream, while along the slopes adjacent to the channel, transport was seaward, at least as far downstream as RM 5. On the north side of the estuary, sediment transport transport along the bottom was generally upstream in the deep channel, but it occurred in both directions on slopes. In the old ferry



BOTTOM SEDIMENT TRANSPORT

LOW RIVER DISCHARGE

(150,000 cfs.–EARLY FALL)

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 208–8

channel between Astoria and Ellice Point, transport was in a northerly direction at the south end of the channel, and it was in a southerly direction at the north end.

During the spring freshet in late May and June, and during occasional winter floods, bottom sediment transport increases and is probably seaward in channels all the way to the river mouth. Sediment transport along slopes is probably seaward through the entire length of the estuary, while cross-channel transport at Astoria is likely to be predominantly north to south. No measurements of transport at high flows have been made that confirm these suspected patterns.

Detailed information is not available for sediment movement in Baker Bay, Grays Bay or Cathlamet Bay, though all three areas and the entire estuary are gradually filling with sediment. Some sediment movement information is available for Youngs Bay and its tributaries. Bottom sediment transport is downstream in the Youngs River, almost to the mouth (Daggett Point). Bottom transport in the Lewis and Clark River generally does not extend to the mouth, due to the upstream movement of tidal currents. In Youngs Bay, sediment (predominantly river/ ocean derived coarse sand) moves up the channel along the bottom as far as the Youngs Bay Bridge; downstream (seaward) movement along slopes marginal to the channel is likely. These estimates are not based on direct measurements and need confirmation. Bottom transport in the Skipanon River is probably negligible. The area around the mouth of the Skipanon is dominated by sediments derived from the Columbia River.

It would be highly desirable to have estimates of bedload transport in the estuary; none are available. However, the USGS has estimated the transport of coarse sediment (sand) at Vancouver, for the water year 1963. Their method of calculation is highly empirical, and the results must be regarded as only an approximation of the bedload transport. For one thing, a part of the coarse material is carried in suspension, rather than as bedload. According to the method used by the USGS, the proportion of sand, as a percentage of the total sediment transport at Vancouver, varies from 0% for a freshwater flow of 100,000 cfs to about 65% for a flow of 700,000 cfs. Using this method, the

USGS estimated coarse sediment transports of 2.3 and 0.11 million tons for the Columbia River at Vancouver and the Willamette River, respectively. The suspended sediment transports were 6.1 and 1.03 million tons, respectively. The bedload transport of the Willamette River was, under the observed conditions, negligible. Crude estimates for the other years, 1964-70, may be made by assuming that bedload transport only occurs during freshet periods. Using this simplified approach, it appears that the bedload transport at Vancouver varied from about 1 to about 10 million tons per year, from 1963 to 1970. Thus, the total sediment transport at Vancouver during the years 1968 to 1970 varied from about 5.3 to 41 million tons. Greater transports are not impossible, but completion of the system of main stem dams has probably decreased bedload and suspended sediment transport.

208.5 SEDIMENTATION IN THE ESTUARY 1792 TO DATE

The immense power of the forces operating in the Columbia River estuary has been stressed repeatedly in this Inventory, as have the numerous efforts by man to control, or at least to limit, the effects of these natural forces. The evidence suggests that sedimentation patterns in the estuary have been greatly affected by the jetties at the mouth, other physical alterations within the estuary and the regulation of freshwater flow by the many dams constructed upriver from the estuary. This section examines then, the sedimentation patterns and their relationships to man's activities in the estuary during the last 185 years, as determined from bathymetric charts and other historical resources.

A. Columbia River at the Mouth

The single most important alteration of estuary circulation and sedimentation patterns was accomplished by the construction of the jetty system at the mouth. Before the jetties were constructed, the mouth of the river was between Point Adams and Cape Disappointment, and all land areas seaward of these points are the result of the jetty construction (Figure 208-9). The natural channel, before the construction of the jetties, was extremely variable; controlling depths at the outer bar, then located only slightly west of Cape Disappointment, were between 20 and 30 feet. The channel oscillated between two basic

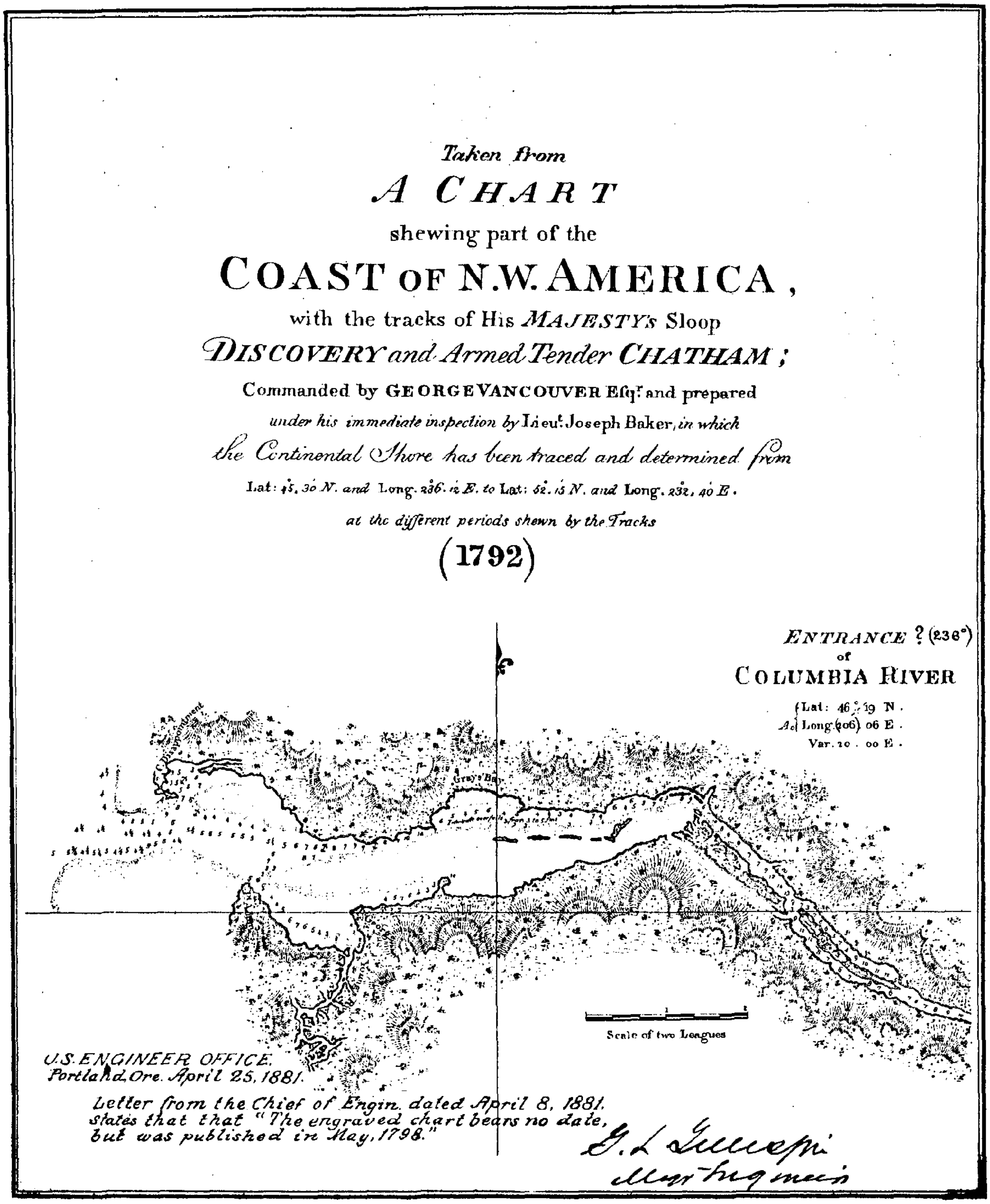


Figure 208-9

Entrance of the Columbia River as it was charted in 1792 by Captain George Vancouver.

From: Lockett, 1962

forms. In one form, there was a single channel off Point Adams (Figure 208-11). In the other form, there were two channels, one close to Point Adams and another just south of Cape Disappointment (Figure 208-10). Apparently, the growth of Clatsop Spit, a transient feature prior to construction of the jetty, pushed the single channel further and further to the north, lengthening the path the water had to take to discharge into the ocean. The difference in the phase of the tide across the Spit, and the large waves accompanying storms eventually breached the Spit, forming a second channel, with a shallow area between called Middle Sands. The south channel then became the most important channel, and Peacock Spit closed off the north channel. As Clatsop Spit grew, the cycle began again. The purpose of jetty construction was to stablize the channel and hopefully, to achieve greater depths, by narrowing the channel and increasing scour.

Major alterations began with authorization of a 30 foot channel in 1882 and the construction of the original South Jetty (4-1/2 miles long, out to the knuckle) between 1883 and 1895 (Figure 208-12); note the creation of Clatsop Spit as a permanent land area. The South Jetty was not a success. By 1902, the entrance had shoaled to a controlling depth of 22 feet. A 40 foot channel was authorized, and between 1903 and 1913, the South Jetty was extended two miles beyond the knuckle to a total length of 6-1/2 miles. Major repairs to the South Jetty were completed between 1931 and 1936 and again in the early 1960's.

The North Jetty was constructed between 1913 and 1917. The most favorable entrance conditions ever achieved occurred between 1925 and 1927 (Figure 208-13). These conditions have not recurred. The North Jetty was rehabilitated in 1938-39, at which time Jetty A was constructed, extending south from Cape Disappointment. At the same time, the pile dikes on Sand Island and the Chinook pile dike were constructed. Jetty A was designed to prevent undermining of the North Jetty and to improve the scour in the channel. Jetty B, parallel to Jetty A but further out to sea, has been authorized but not constructed.

Further important changes in the configuration of the entrance have been proposed. By resolution of Congress, adopted July 8, 1972, the Corps of Engineers has been directed to study the advisability of

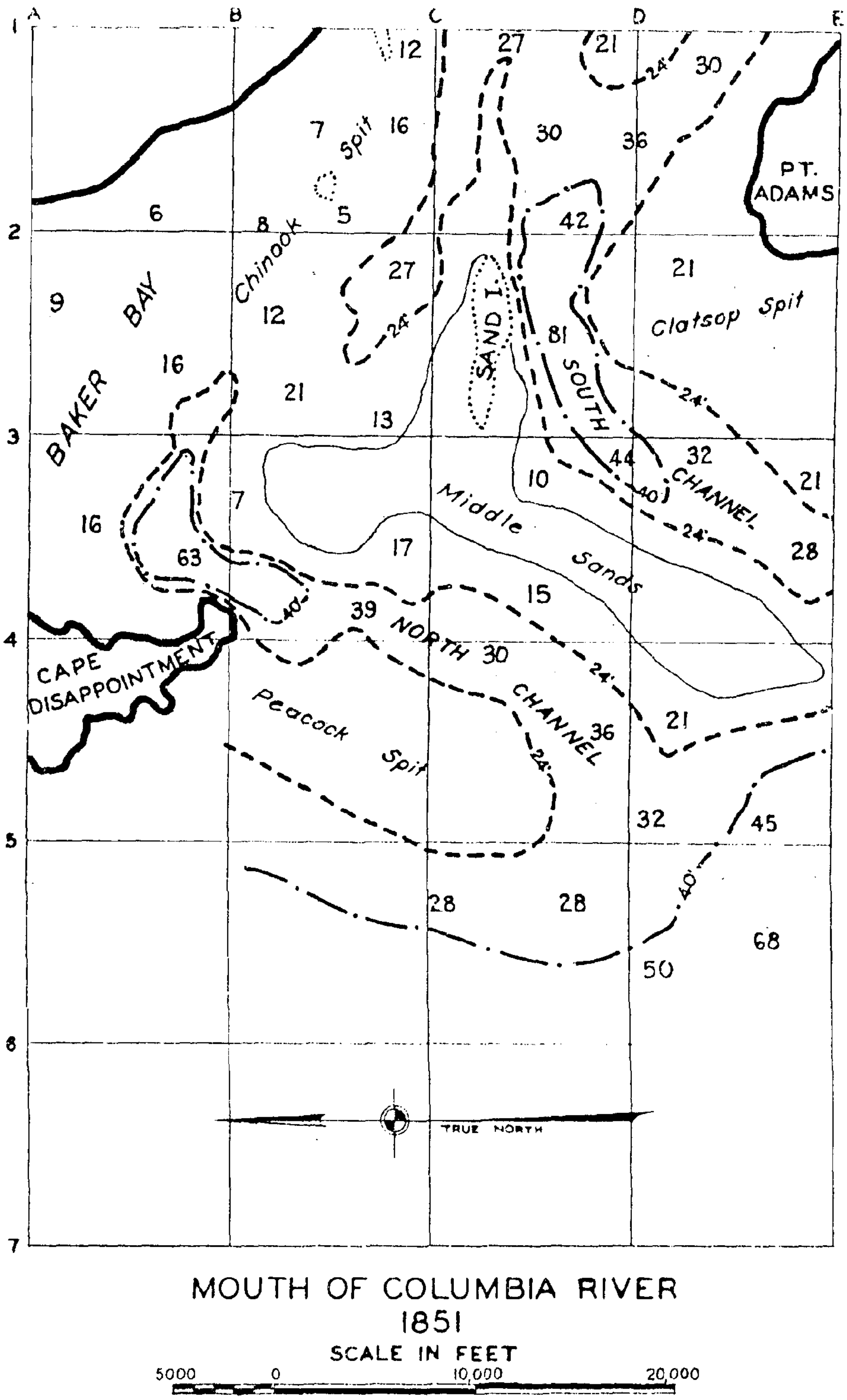


Figure 208-10

The entrance to the Columbia River as it appeared in 1851, with two entrance channels. The controlling depths were 28 to 30 feet. Charts from 1839 and 1841 show a similar configuration.

From: U.S. Army Corps of Engineers, Portland District, 1938

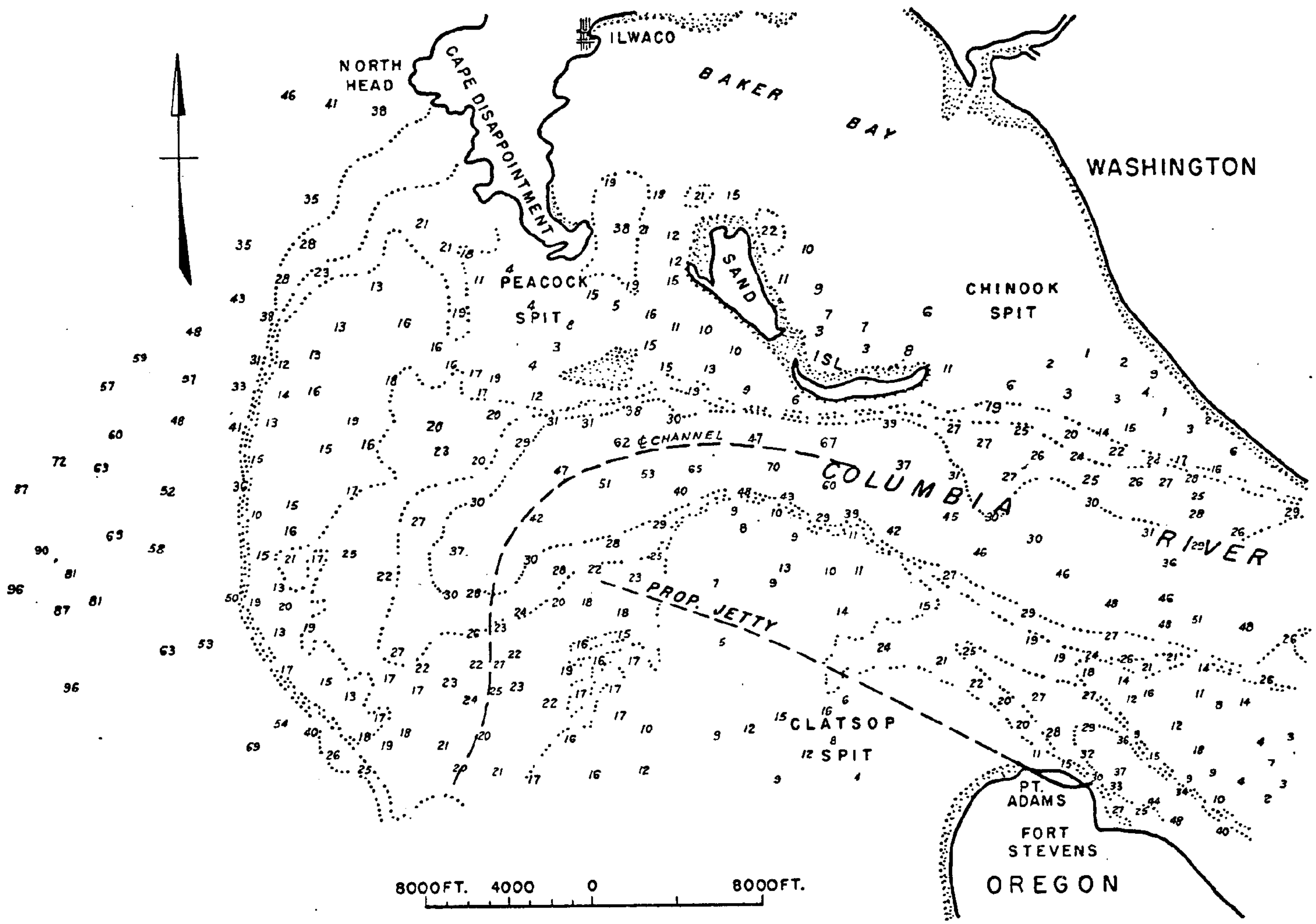


Figure 208-11
The mouth of the Columbia River as it appeared in 1885, just prior to construction of the jetty system. At this time there was a single channel with a controlling depth of about 20 feet.

From: Lockett, 1962

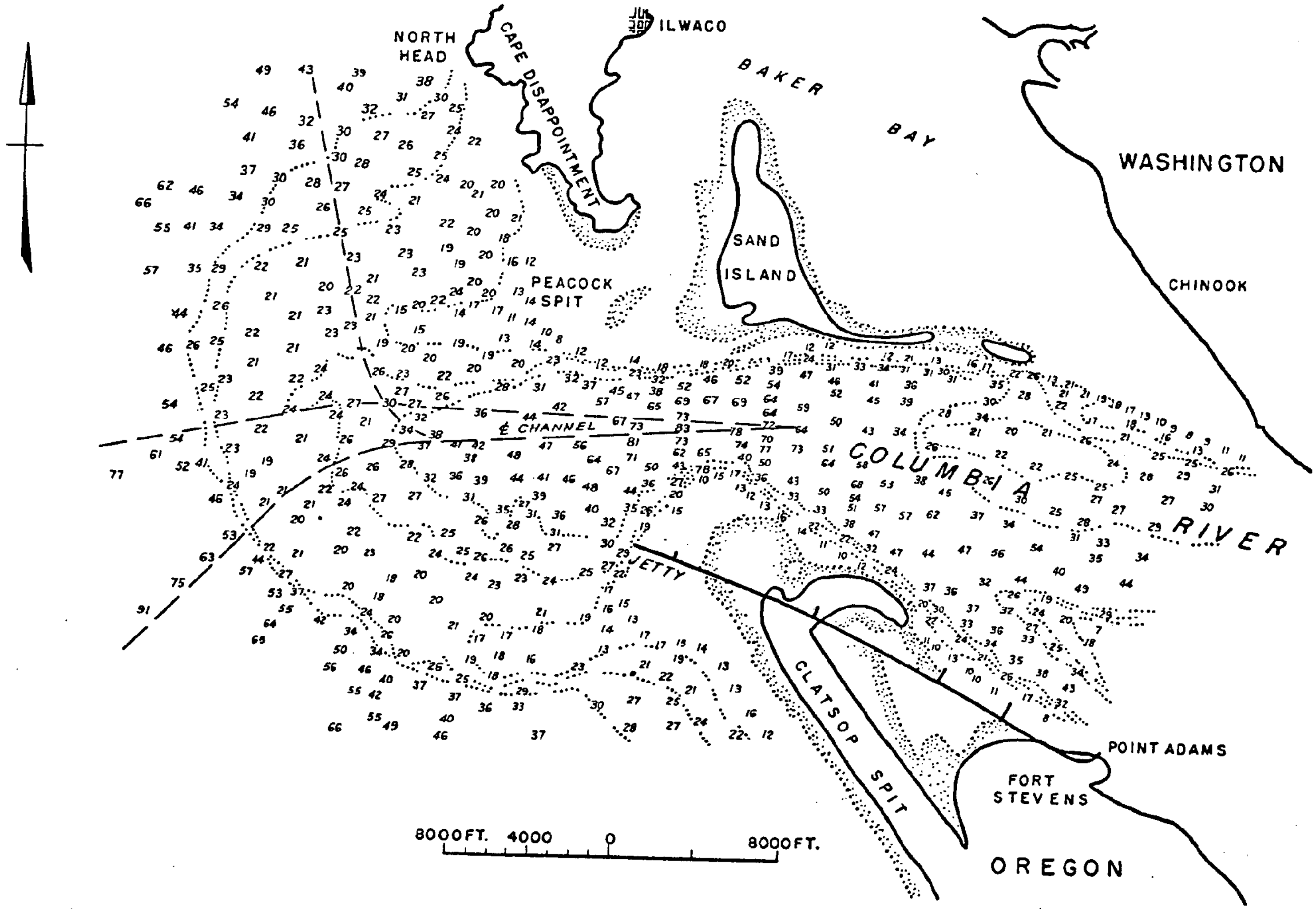


Figure 208-12

The Columbia River Entrance as it appeared in 1902 after the construction of the original South Jetty.

From: Lockett, 1962

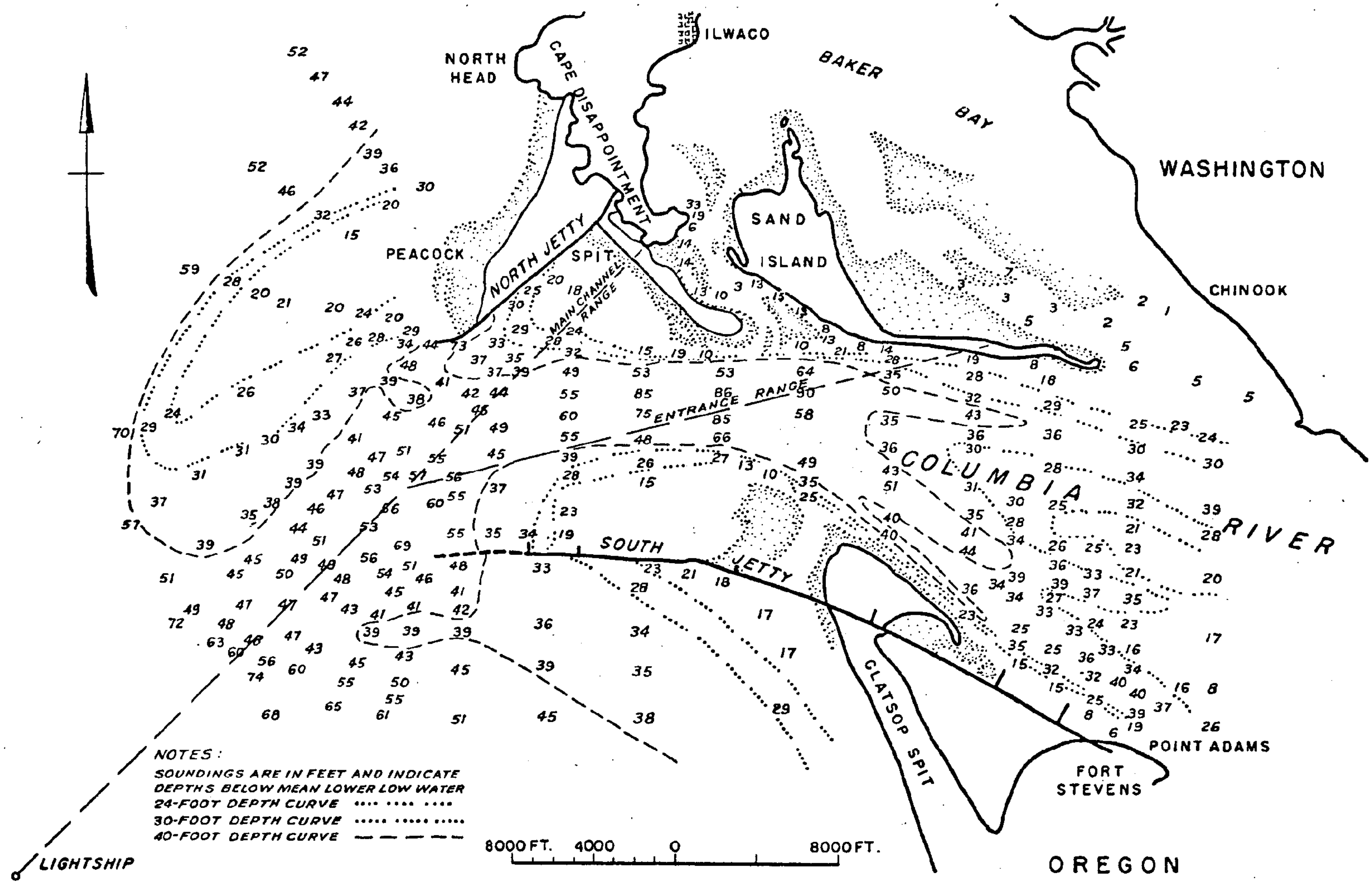


Figure 208-13

The Columbia River Entrance as it appeared in 1927, the best alignment ever attained.

From: Lockett, 1962

modifying the Columbia River at the Mouth Project (RM -2 to 3). The Corps has drawn up a Plan of Survey, including field measurements, reconstruction of the physical model and design studies to determine: the feasibility of constructing a deeper (55' or 60') and narrower (1600' rather than 2640') entrance channel, the possibility of different channel alignment, and the practicality of construction of Jetty B and repair of the existing jetties, including extension of the South Jetty to its original length. Maintenance of the project would probably also require a new dredge. The study is scheduled to be completed by 1981.

The major questions that will be addressed in this study are related to: the amount of maintenance dredging required, the effects of all parts of the project on sedimentation in the channel area, the changes in salinity regime that would result from the project, the fate of dredged materials deposited in various disposal sites, and the cost effectiveness of all parts of the project. Additional studies will be required to determine the environmental effects of the increased dredging on the channel area and the proposed dredged material disposal sites, and the effects of increased salinity intrusion on shoaling inside the estuary. Major modifications of the type proposed cannot be carried out without careful consideration of all the environmental effects.

Thus far, the net result of the construction of the jetty system has been the movement of the outer bar further to sea and migration of Middle Sands northward to its present position as Sand Island, the stabilization of Clatsop and Peacock Spits as permanent land areas, and the maintenance, through considerable dredging, of the 48 foot entrance channel (authorized in 1954). The changes in the configuration of the entrance have been quite obvious. The effects on the estuary of the deeper entrance channel have also been profound, though less obvious.

B. <u>The Lower Estuary</u>

There has been a persistent trend toward shoaling throughout the Lower Estuary from Tongue Point to Sand Island. This tendency has been particularly acute in Youngs and Baker Bays. A detailed study of Corps of Engineers bathymetric surveys over the past century would probably reveal a great deal about the causes of shoaling in the estuary. Such a study has not been done. Nonetheless, some conclusions are possible. As mentioned in Section 208.3, the turbidity maximum or null zone associated with salinity intrusion in the estuary results in an accumulation of sediment. The position of the null zone varies with runoff, tide and wind conditions (approximately between Sand Island and Tongue Point). The controlling depth at the bar has increased from about 20 to 25 feet in 1885, to the present 48 feet. This has necessarily increased the salinity penetration accompanying bottom upstream flow in the estuary. The increase in salinity penetration appears to have greatly increased the rate of shoaling in the estuary, though there have evidently been other contributing factors.

Lockett, in his paper "Sediment Transport and Diffusion: Columbia Estuary and Entrance," states that between 1868 and 1958, the net shoaling within the 11 mile reach between Upper Sand Island and Tongue Point has been about 77,000,000 cubic yards, and that the cause of this shoaling is the flocculation of fine material caused by the increased salinity intrusion. This quantity represents about 13 or 14% of the low tide volume of the estuary in the reach in question. There is a natural tendency for the estuary to fill in, but it cannot have been filling in at a rate of 15% per century, or it would have ceased to exist long ago. It cannot be determined without further research, what part of the observed shoaling can be attributed to increased salinity intrusion, since there are other possible causes. One possible cause is the system of dams that regulate the freshwater flow so that the maximum monthly average flow during the spring freshet is less than one third the maximum flow observed during the flood of 1893. It is known that freshets are responsible for moving very large quantities of sediment out to the ocean. Thus, it seems possible that the observed shoaling below Tongue Point is, in part, related to regulation of the freshwater flow. On the other hand, it can be argued that the dams also decrease the supply of sediment to the estuary and might, therefore, tend to decrease shoaling in the estuary. It should also be realized that much of the sedimentation in the estuary has been on the extensive mid-estuary flats, made up of material too coarse to be affected by flocculation. Lockett's proposed mechanism is most applicable to Baker and Youngs Bays, where extensive deposition of fine material has occurred.

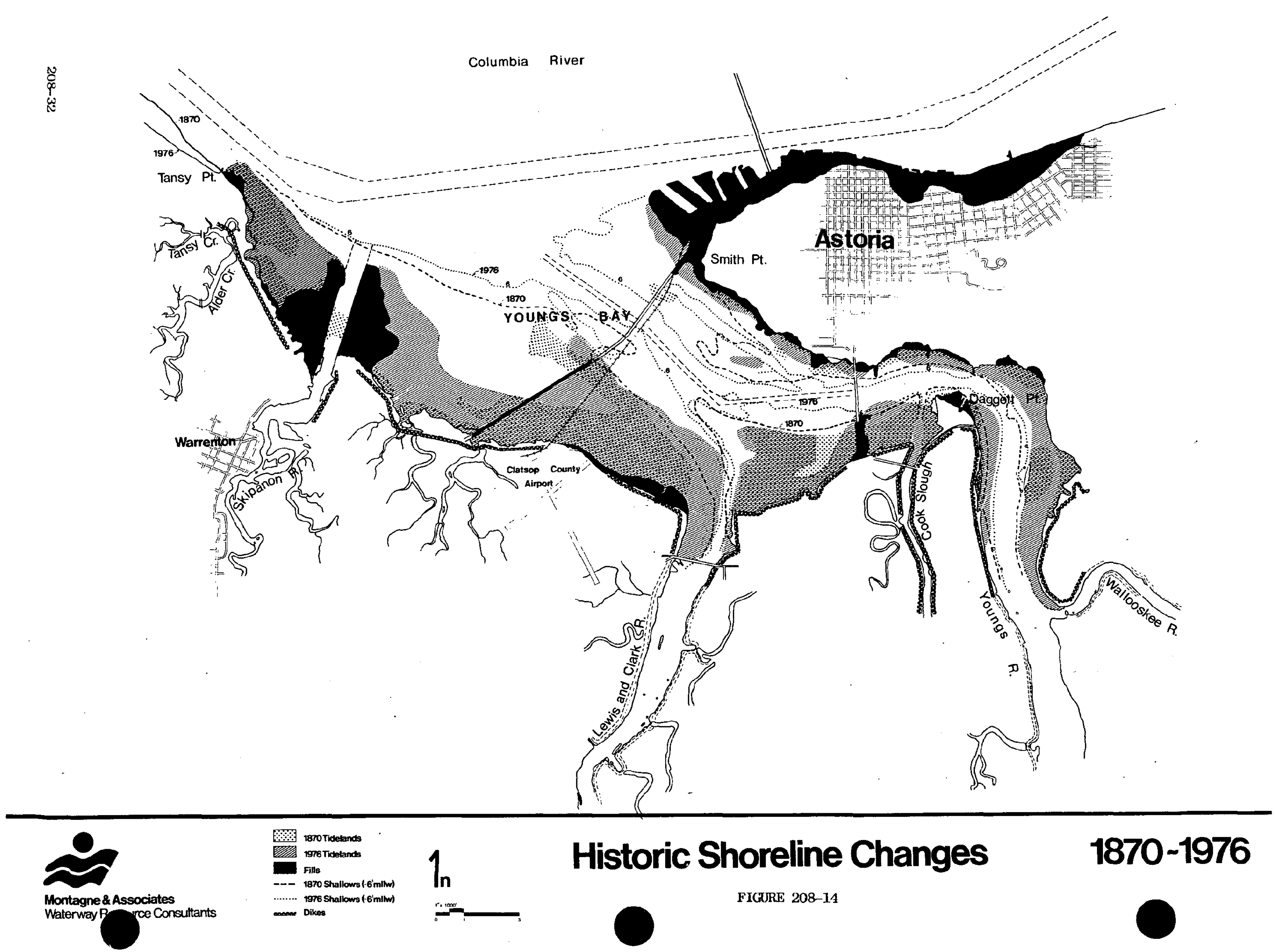
The relative importance of the dams and the increased channel depth with regard to the shoaling problem should be determined by sediment transport measurements in the river, under different flow conditions. It would also be possible to compare shoaling rates in the estuary below Harrington Point, with the rates in Cathlamet Bay (an area of minimal salinity intrusion), using old Corps of Engineers bathymetry data. Such a determination should be made before any further deepening of the channel in the estuary and entrance is attempted. That is to say, there is probably a maximum feasible for the channel entrance, and this depth should be determined.

There may also be limitations on channel depth from the point of view of fishery resources. These limits should also be determined. Our present state of knowledge is so poor that it cannot now be said with any degree of confidence, whether the observed shoaling over the last 100 years has had beneficial or deleterious biological effects. It seems reasonable, however, that a shoaling rate of 15% per century is unacceptable in the long run. It certainly is contrary to the intent of the Oregon Estuarine Resources Goal.

C. <u>Youngs Bay</u>

Extensive alteration of the shoreline has occurred in the Youngs Bay-Astoria area by filling, erosion and "natural" sedimentation processes (Figure 208-14). Major fills have taken place along the entire Astoria waterfront, at the mouth of the Skipanon River, and in Youngs Bay itself. Since the construction of the jetties, considerable erosion has occurred between Tansy Point and Point Adams. The area of intertidal and shallow submerged lands (less than 6 feet deep) has increased greatly in Alder Slough, along both sides of Youngs Bay, and in the Lewis and Clark and Youngs Rivers. The most important causes have probably been the fills at the mouth of the Skipanon River, the fill for the causeway bridge across Youngs Bay and the fills for the Port Piers. These fills have greatly reduced near-shore current speeds and have resulted in the settling out of fine material.

It is likely that increased salinity intrusion has played some role in the sedimentation in Youngs Bay. It is also possible that



Historic Shoreline Changes 1870-1976

FIGURE 208-14

extensive logging and log rafting have caused sedimentation. However, the open water sections of Youngs Bay (outside the causeway and in the channels) experience both sedimentation and erosion, with erosion predominating in some areas. Average sedimentation rates are shown in Figure 208-3. The sediments seaward of the causeway are predominantly of Columbia River origin, and Columbia River sediments are evident even in the slower flowing, lower reaches of the tributaries. It is likely therefore, that the influence of logging activities on sedimentation patterns is confined to the tributaries themselves. Sharp vertical differences in sediment properties in the cores suggest that periods of erosion may be associated with major freshets occurring perhaps once a decade.

D. Baker Bay

Baker Bay is a very complex area for which virtually no data are available. The long-term trend in Baker Bay is definitely one of filling, as Sand Island has migrated to the north. Considerable filling has occurred since the 1930's, after the stabilization of Sand Island; this indicates that other forces are at work. Baker Bay has no major tributary streams, and it is located close to the mouth. Currents in the area are quite variable and relatively unknown; they seem to respond strongly to the winds. Considerable salinity intrusion (up to 20°/₀₀ at Ilwaco Basin under low runoff conditions) is known to occur, and the condition is probably augmented by southwesterly winds. The accumulation of fine materials in most parts of the Bay suggests that a turbidity maximum and considerable sedimentation accompanies the salinity intrusion. The influence of a deeper channel over the bar may be important here. Other likely causes of the sedimentation problem in Baker Bay are the many fish traps constructed before 1920, the Chinook pile dike constructed in the late 1930's, the breach between the two Sand Islands and logging activity in the tributary streams. Unless the causes of the increased sedimentation are determined and remedial measures taken, further difficulties in maintaining the Chinook and Ilwaco channels will probably be experienced. It is not known whether the intertidal areas with fine sediments in Baker Bay are as valuable for salmon habitat as areas of similar elevation in Youngs Bay.

E. The Port of Astoria Slips

The Port of Astoria normally spends between $200,000 and $300,000 per year for maintenance dredging in Slips 1 and 2, located at Smith Point between Piers 1 and 2, and 2 and 3, respectively. This sedimentation is believed to be related to the turbidity maximum that accompanies salinity intrusion. If this hypothesis is correct, then most sedimentation occurs under moderate to low freshwater flows, because salinity intrusion does not reach Smith Point under high water freshwater flow conditions. It is believed that on the incoming tide, the pier slips fill predominantly along the bottom, when sediment-laden water flows in. The sediment settles out in the slip because of the low velocities prevailing there, relative to the channel outside the slips. The outflow from the slips on falling tide is more evenly distributed with depth and does not resuspend the material that has settled out. In support of this hypothesis, most of the material found in the pier slips is clay and silt that would be carried in suspension; it is not sand, that might be carried in as bedload.

As is shown in Figure 203-14, there is a part of the tidal cycle during which Youngs Bay is ebbing and the Columbia River flooding. Water then flows around Smith Point from Youngs Bay, into the pier slips. It has been suggested that the sediments in the pier slips are carried in from Youngs Bay. This might occur during high flow conditions in the Youngs Bay tributaries (winter) or during periods of strong southwesterly or northwesterly winds (resulting in the strongest wave action at Smith Point). A determination of the sedimentation mechanisms involved might save the Port of Astoria some costs in maintenance dredging, but it is unlikely that the problem can be entirely solved, because of the natural tendency for siltation in the quiet water in an estuary.

208.6 SEDIMENTS AND SEDIMENT TRANSPORT ON THE CONTINENTAL SHELF NEAR THE MOUTH

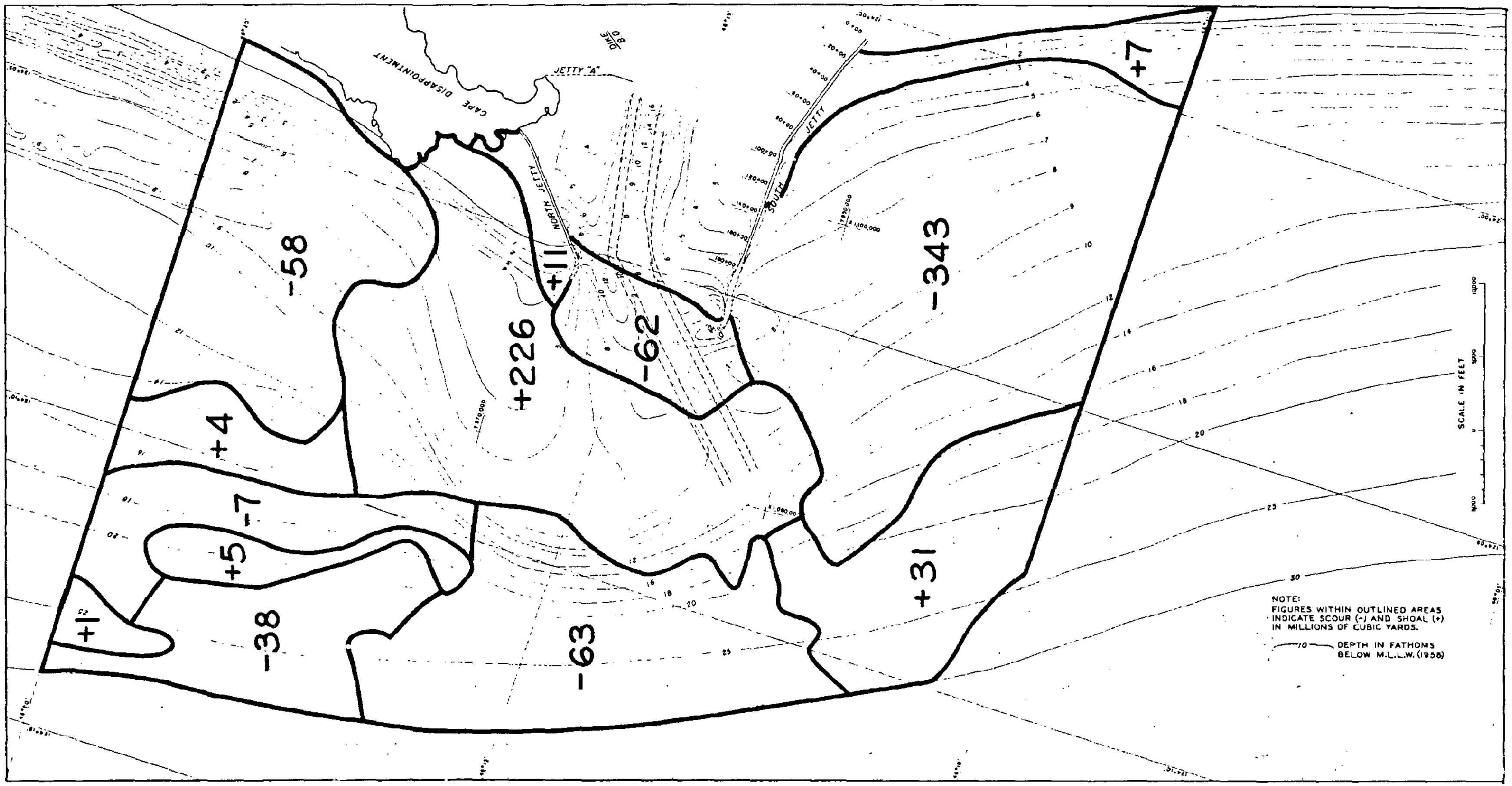
As part of the Dredged Material Research Program, the Corps of

Engineers is preparing a report on the sedimentary processes occurring outside the mouth of the Columbia River. The report, entitled: Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon Appendix A: Investigation of the Hydraulic Regime and Physical Nature of Bottom Sedimentation, was prepared by a research group from the University of Washington headed by Richard Sternberg and Joe Creager. The brief summary presented here is based on the working draft of the report, and therefore, the conclusions are tentative.

The sedimentary environment near the mouth of the Columbia River is dominated by modern sediments originating from the river, though older sediments probably deposited during glacial times are prominent on the middle and outer shelf. Sediments found in the study area are fine sands, silts and clays. The coarsest material (fine sand about .18 mm in diameter or 2.5 Ø) is found near the mouth of the river and away from the mouth of the river, where it has been carried during dredged material disposal. Slightly finer material (diameter about .15 mm or 2.75 Ø) occurs extensively on the inside and to the north of the outer bar (or "tidal delta" as the geologist calls it). Finer sand (diameter about 10 mm or 3.25 Ø), coarse silt (diameter about .044 mm or 4.5 Ø) and finer silts and clays, as small as .0002 mm or 12 Ø, are widely distributed to the south of the river.

The effects of man's activities are evident in other ways in addition to disposal of dredged material. The building of the jetty system has created Clatsop Spit as a permanent feature, as discussed in Section 208.5. Furthermore, the tidal delta (outer bar) has shifted seaward about 3,000 m (nearly 2 miles). The long-term trend since the jetty construction has generally been erosion south of the mouth (and offshore of Clatsop Spit) and deposition north of the mouth (Figure 208-15). These changes are evidently a response to altered sediment transport patterns, resulting from the building of the jetties. As the system seeks a new equilibrium, there has been some concern that erosion offshore from Clatsop Spit and at the point where the jetty intersects the spit would result in a breach of the spit and creation of a new channel at that point.

The building of the dams on the Columbia River and its tributaries has had the effect of greatly reducing the spring freshets and the



OFFSHORE SCOUR AND SHOAL VOLUMES, 1877-1926

Figure 208-15a

Construction of the South and North Jetties during this period resulted in creation of Clatsop and Peacock Spits, extensive erosion off Clatsop Spit, deposition off Peacock Spit, and seaward movement of the bar

From: Lockett, 1962

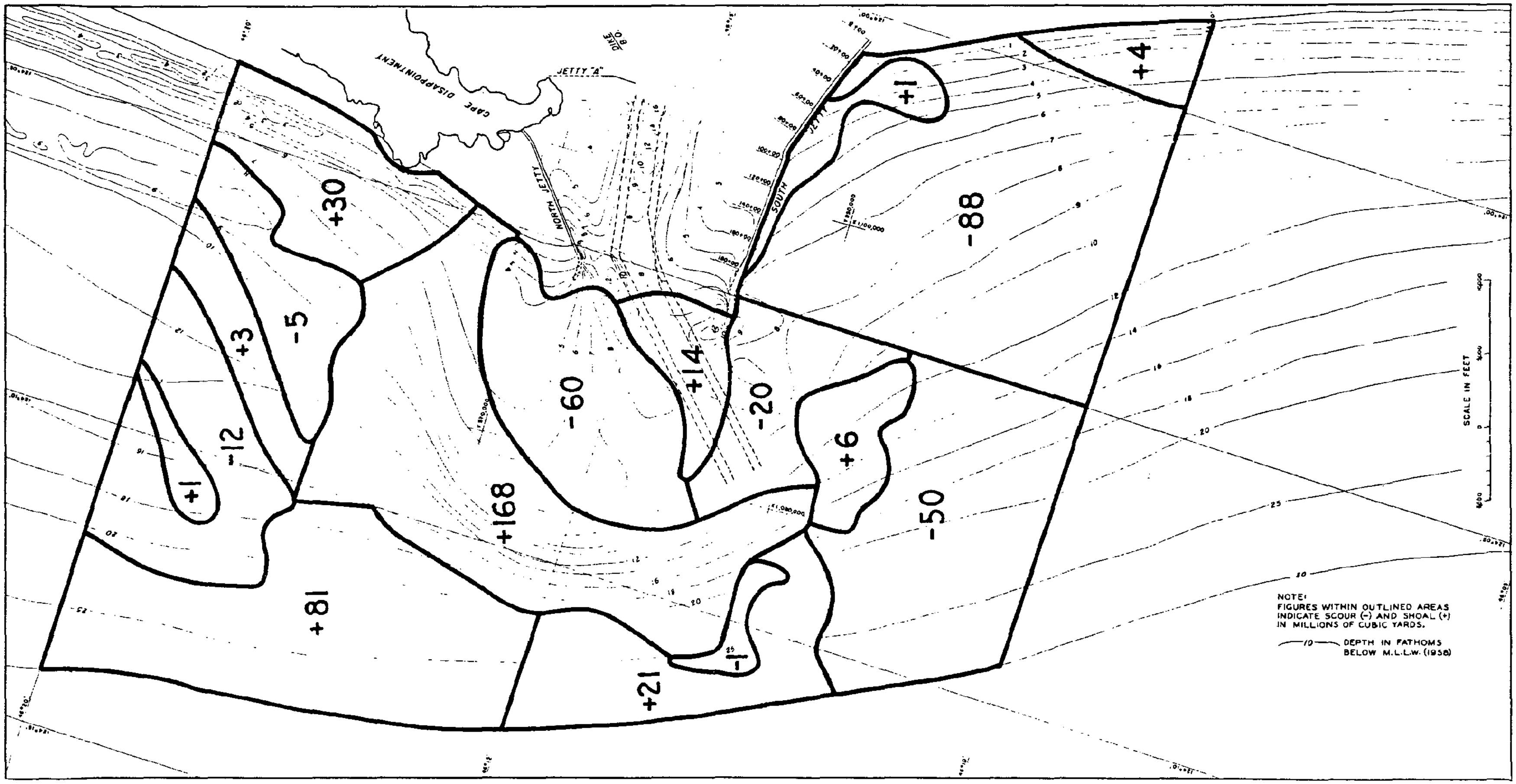


Figure 208-15b OFFSHORE SCOUR AND SHOAL VOLUMES, 1926-1958

The South Jetty cut off the sand supply to the area off Clatsop Spit; erosion has continued. The bar has continued to build outward and deposition continues north of the mouth, in most areas.

From: Lockett, 1962

amount of sediment flushed out of the estuary, as discussed in Section 202 and 208.3. Nonetheless, observations from this study indicate that the river pours large concentrations of sediment into the ocean during high flow periods, both as suspended load and as bedload. The other major source of sediment in transport over the inner shelf is the resuspension during storms of riverine material deposited on the shelf during calm periods.

The major forces acting to move the sediments are: the continental shelf circulation, tidal currents, river or estuarine currents, and wind and wave driven currents. Tidal currents outside the entrance and the large-scale continental shelf circulation are relatively weak, generally less than 20 cm/sec (less than 1/2 knot). The currents caused by the river flow are of similar strength. These currents are all too weak to move even fine sands, though they may transport the silt and clay fractions that are already in suspension. The really important movers of sediment are the currents driven by local winds (up to 80 cm/sec or about 1.6 knots) and the currents caused by locally-generated seas and swell generated elsewhere. Significant wave heights may range up to 33 ft, with a 13 second period, and the resultant currents may reach 80 cm/sec at the bottom. The threshold speed for transport of all the materials found in the study area is about 29 cm/sec (about 0.6 knots). Currents of this speed will carry silts and clays in suspension and sands as bedload. The coarsest material found on the shelf as a result of dredged material disposal (diamater larger than .18 mm or 2.5 Ø), cannot be resuspended by even the most violent storms and moves only as bedload. Finer sands can be carried as suspended loads by storms and as bedload during non-storm periods.

Bedload transport is a slow process; sediments move as sand waves, as individual grains bounce along the bottom. Even a major storm (of the sort that occurs only once in several years), will result in a bedload transport distance of perhaps 350 feet over a several day period. Suspended sediment, in contrast, moves with the water. Thus, virtually all movement of fine sands (.15 mm or 2.75 Ø to .09 mm or 3.5 Ø) occurs during the few storms every year that are strong enough to resuspend this material. The general direction of bedload transport is to the north and slightly offshore. This is the same direction as suspended sediment transport during most major storms. The same conclusion was reached by Ballard (1964) in his study of nearshore sediments. Lockett (1967) concluded incorrectly that the transport was primarily to the south. The conclusion that the longshore transport is mainly to the north is firmly established.

These facts allow a partial explanation of the seasonal movements of sediment on the continental shelf near the mouth. The most sediment is carried out of the river during high flow periods, generally in the spring, but occasionally in the winter. The coarser sediments are deposited on the tidal delta, as mentioned above. The silts and clays stay in suspension longer and move to the south and offshore during fair weather (winds and currents flow to the south). They move to the north and close to the coast during stormy periods (winds and currents flow to the north). It appears that large volumes of fine sediment are deposited to the south of the mouth of the river during the summer; they are then moved to the north (and somewhat offshore), during the winter. Some of the finest sediment, of course, does not settle out on the shelf and moves out to sea. The result is considerable seasonal variation of sediment characteristics near the mouth and the sorting of particles with different sizes and densities.

One of the more interesting features of the sediment patterns in the study area is the concentration of relatively fine, but dense magnetic minerals (known as black sands); they occur in the nearshore area, both north and south of the jetties. This material originates from the river, and the observed deposits result from the sorting out of the small percentage of magnetic material in the river sediments. The authors speculate that enough of this material has accumulated to trap further magnetic minerals in the magnetic field generated by the existing deposits.

Research efforts were concentrated in two dredged material disposal areas: B and G (Figure 208-16). Approximately 28,000,000 cubic yards of material have been dumped in/or near B since 1957, forming a distinctive bathymetric feature, somewhat inshore of the authorized area (Figure 208-16). This feature contains some 10,000,000 cubic yards of the material. Mineralogical analysis shows a plume

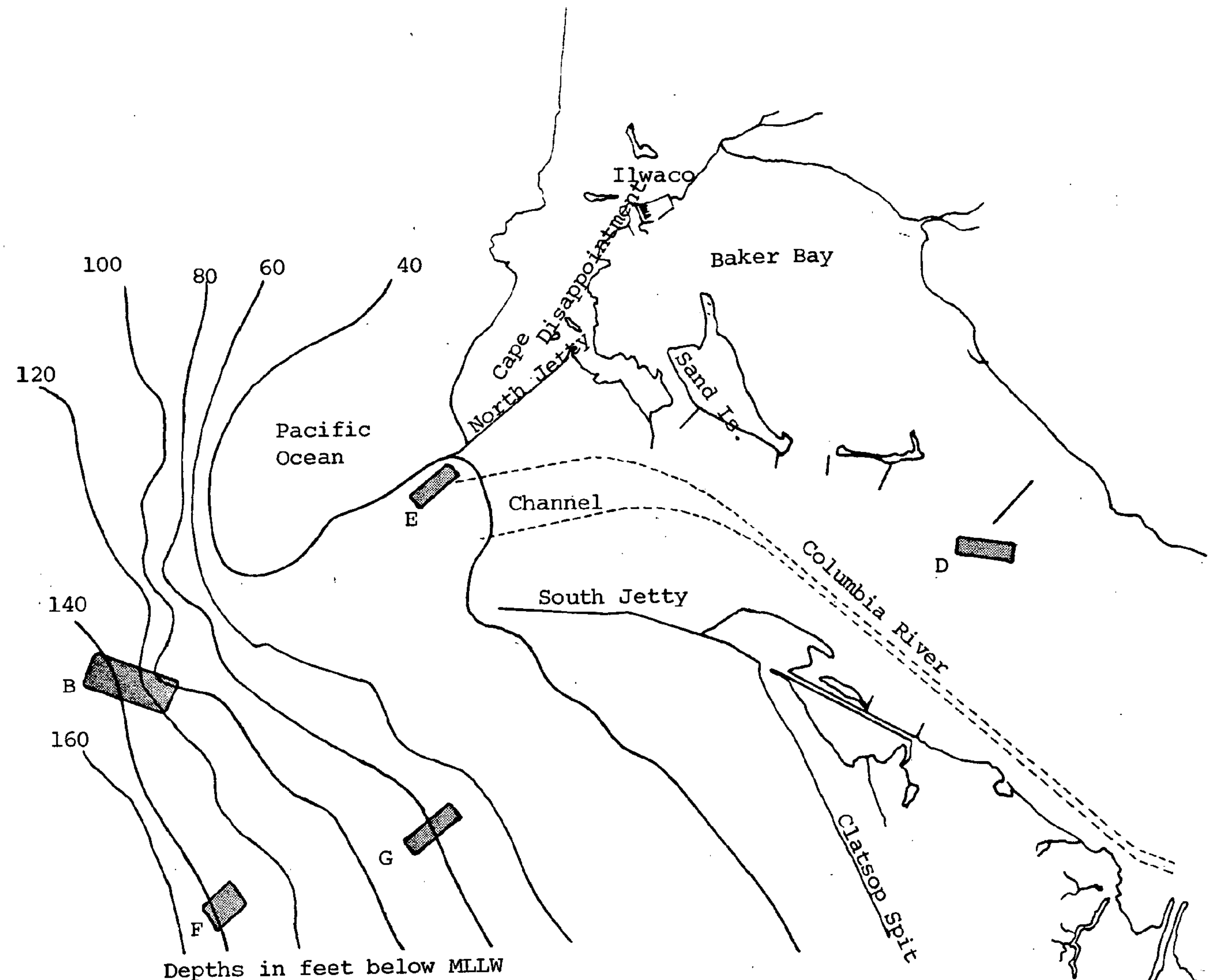


Figure 208-16

Corps of Engineers dredged material disposal site for the project at the mouth of the Columbia River.

From : U.S. Army Corps of Engineers, 1975 of material that has moved to the north away from site B. Since almost none of the dredged material deposited here was subject to resuspension, the balance of the material dumped at B must be in this plume. Records of the amounts of material disposed of are not sufficiently accurate to merit a detailed comparison, however.

Site G was an experimental area; 600,000 cubic yards of dredged material were dumped there, in an attempt to determine the effects of disposal on the marine environment. About 71% or 424,000 cubic yards of this material formed a recognizable bathymetric feature. Since more than 99% of the material deposited at Site G is too coarse to be resuspended, it appears that some 28% of the material was not deposited in the study area or could not be detected by the methods used. Deposition of material outside the authorized area remains a problem in most hopper dredging. Sediment transport data suggest that the material at both sites B and G is quite stable. After only four months, the dredged material at site G was already largely covered over by a thin layer of finer material from the normal seasonal migration of sediments in the area. Because of the lack of resuspension, increased turbidity is not a long-term environmental problem. Most of the environmental impacts of the disposal in site G were the immediate ones that occurred at the time of disposal. Problems included increased turbidity, smothering of organisms and disruption of fishing activities. Populations of fish and benthic animals do not recover for several months after disposal.

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C. Haushild, W.L. K.W. Perkins, H.H. Stevens, G.R. Dempster, Jr., and J.L. Glenn. 1966. Progress Report: Radionuclide Transport of the Columbia River, Pasco to Vancouver, Washington Reach, July 1962 to September 1963. U.S. Geological Survey. Open File Report, Portland, Oregon.

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D. Hickson, R.E., and F.W. Rodolf. 1950. "History of Columbia River Jetties." IN Proc. First Conference on Coastal Engineering, Chapter 32. Council on Wave Research, University of California, pp.283-298.

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E. Higley, D.L., R.L. Holton, and P.D. Komar. 1976. Analysis of Benthic Infauna Communities and Sedimentation Patterns of a Proposed Fill Site and Nearby Regions in the Columbia River Estuary: Part I and II.

Part I contains analysis of the effects of the proposed Port of Astoria fill west of Pier 3 on the benthic populations on the site. The amphipod *Corophium* was found in high concentrations at the site and elsewhere. Part II consists of a brief analysis of sedimentation patterns in the port pier slips and adjacent areas.

F. Hubbell, D.W. and J.L. Glenn. 1973. Distribution of Radionuclides in Bottom Sediments of the Columbia River Estuary. U.S. Geological Survey Professional Paper 433-L. U.S. Government Printing Office, Washington, D.C. (Stock No. 2401-00247). 63pp.

Data on 172 surficial sediment samples from the estuary are summarized. Specific data on 27 cores (geomorphic position, sediment description, remarks) are presented as well. The authors divide the estuary bottom into geomorphic areas of channels, slopes and flats and longitudinal divisions of marine, transition and fluvial based on sediment characteristics. Vertical profiles of sediments are summarized. Radiological techniques are used to estimate the per cent and absolute amounts of fine sediments (less than 62 microns) retained in the estuary annually. Net deposition rate at a site above Tongue Point is also presented. This publication gives the reader an appreciation for the complexity of sediment characteristics of the Columbia River Estuary and is part of the best work to date on Columbia River Estuary sediments.

G. Hubbell, D.W., J.L. Glenn and H.H. Stevens. 1971. "Studies of Sediment Transport in the Columbia River Estuary." IN Proceedings of the 1971 Technical Conference on Estuaries in the Pacific Northwest. Circular 42. Engineering Experiment Station, Oregon State University, Corvallis, Oregon. pp.190-226.

Information on sediment transport and deposition in the Columbia River Estuary was obtained by measuring and sampling flow, surveying the bed with acoustic techniques, and determining radionuclide levels. Flow measurements and water sediment samples show that temporal variations in suspended-sediment concentrations and in suspended-sediment discharges are large and significantly affected by a turbidity maximum that develops and migrates longitudinally in the estuary. Bottom sediment transport along the channels and marginal slopes for both the north and south channel is discussed. A generalized map of bottom sediment movement during low flow is presented. Information is given on retention of fine sediments within the estuary and net deposition rate at a site above Tongue Point.

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K. Lockett, John B. 1967. "Sediment Transport and Diffusion: Columbia Estuary and Entrance." Journal of Waterways and Harbors Division, Proceedings of American Society of Civil Engineers. Vol. 93, No. WW4, Proceedings Paper 5601. pp.167-175.

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N. Sternberg, R.W., J.G. Creager, W. Glassley, J. Johnson. At press. Aquatic Disposal Field Investigations Columbia River Disposal Site, Oregon. Environmental Effects Laboratory. U.S. Army Engineers Waterways Experiment Station. Vicksburg, Mississippi.

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Q. U.S. Army Corps of Engineers, Portland District. 1975. Columbia and Lower Willamette River Maintenance and Completion of the 40-foot Navigation Downstream of Vancouver, Washington and Portland, Oregon: Final Impact Statement.

Impact statement outlining possible impacts, both negative and positive, of completing and maintaining the navigation channel. Discusses actual projects, methods and disposal areas.

209 PHYSICAL ALTERATIONS

COLUMBIA RIVER ESTUARY

PHYSICAL ALTERATIONS

Robert E. Blanchard

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FIGURES

TABLES

*Figure follows the page indicated.

209 PHYSICAL ALTERATIONS

Since their arrival in the lower Columbia area, people have altered the natural environment to make more efficient use of resources. Although there have been natural changes, the human changes have probably had a greater impact on the area. As technology has advanced, more dramatic alterations to the natural estuary have occurred.

This section will discuss man-made alterations to the estuary area. It will examine both the reasons for and the problems associated with actions such as dredging, filling, and dike and jetty construction in the estuary area, and it will also provide general information about dredging methods available to the Portland District Corps of Engineers.

209.1 DREDGING AND DISPOSAL

A. Dredge Methods

Four major factors determine the type of dredge used for a project. The first is the location of the area to be dredged, second is the size of the area to be dredged, third is the availability of disposal sites, and wind and wave conditions in the area to be dredged constitute the fourth factor. Hopper dredges and other methods that require short set-up times are used to remove small shoals in the estuary and all shoals in open water, while pipeline dredges, which require a long set-up time, are used where extensive dredging is required.

1. Hopper Dredges

These dredges are self-propelled, ocean-going vessels that store the dredged material in hoppers (holding tanks), until reaching a disposal site. Because they can operate in rough and open water, hopper dredges are used to maintain the mouth of the Columbia River and channels where pipeline dredges cannot operate, or where there are no nearby disposal sites.

Hopper dredges are equipped with one or two large centrifugal pumps, with suction pipes hinged on each side of the ship. The intake is toward the stern of the ship and is raised and lowered by cables. The suction pipes are equipped with broad scrapers that feed a thin layer of bottom materials into the pipes as they are dragged along the bottom. As the material is pumped into the hopper, the sediments settle out and the liquid overflow is discharged into the water. When the hoppers are full, the dredge moves to the disposal site, large valves in the bottom of the hoppers are opened, and the material is flushed out. Hopper dredges often require many runs over the same course to attain the desired depth and width for the project.

The Portland District Corps of Engineers uses three hopper dredges: the Biddle, the Harding and the Pacific. The Biddle has a capacity of 3,060 cubic yards, a maximum dredging depth of 62 feet, and a minimum dredging depth of 17 feet 7 inches. Its cruising range is 4000 miles.

The dredge Harding has a capacity of 2,682 cubic yards, a maximum dredging depth of 62 feet, and a minimum depth of 20 feet. The cruising radius is 2,200 miles.

The Pacific has a 500 cubic yard capacity, can dredge to a maximum depth of 45 feet, and has a minimum dredging depth of 12 feet. The Pacific has a cruising range of 5000 miles. None of these dredges can keep up with the shoaling problem of the mouth of the Columbia.

In 1977, the dredge Essayons, the largest in the United States, worked at the mouth to deepen the channel to the authorized depth of forty-eight feet. The Essayons is from the Philadelphia District Corps of Engineers. If the channel across the Columbia bar is ever deepened, a new dredge would have to be built to maintain the authorized depth.

2. Pipeline Dredge

Pipeline dredges usually consist of a large centrifugal pump mounted on a nonpropelled, specially designed barge. Bottom materials are pumped up through a large diameter suction pipe to the barge, and then on to the disposal area through a pipeline network. The end of the suction pipe is equipped with a revolving cutter-head that breaks up the bottom material for easier transport. The suction pipe with cutter-head is lowered to the desired depth by a large hinged ladder controlled by cables, that extend forward from the bow of the barge. The cutter-head is turned by a shaft that extends down the ladder and is powered by a motor on the barge. The pipeline network is floated on pontoons, extending as far as 4,000 feet to the disposal site. Greater distances can be attained through the use of booster pumps.

Pipeline dredges are towed to the dredge site, and the pipeline is assembled. During operation, the dredge is held in position by anchors, swing lines, and spuds. Spuds are long, steel shafts that pass through openings in the barge and can be raised and lowered independently. They are dropped into and raised from the river bottom by a spud motor; they serve as a pivot for the dredge when positioned alternately.

When the barge is in position, the spuds are dropped and anchors are placed on each side. Swing lines attached to the anchors can then be tightened or loosened to swing the bow and cutter-head back and forth in a small arc. During dredging, only one spud is placed at a time, thus allowing the dredge to move forward, as it swings back and forth. Dredging can be almost continuous, except for changes in anchor positions and addition of pipeline sections.

The major limitation of the pipeline dredge is that disposal areas must be relatively close to the dredging operations. The main advantage is the large volume of material that can be dredged in a short period of time.

The Corps of Engineers currently operates only one pipeline dredge, the <u>Oregon</u>. This dredge can move 2,000 to 3,000 cubic yards of material an hour. It has a maximum dredging depth of 85 feet and a minimum dredging depth of 12 feet.

3. Clamshell Dredge

These dredges consist of a floating platform with a crane operation and an accompanying barge. The platform and barge are towed to the dredging location and are held by anchor lines. The dredging is done by a "clamshell" or shovel at the end of a cable. This cable is raised and lowered by a motor, so that the shovel drops to the bottom, gathers a load of bottom material and is raised to the surface. The crane then turns and deposits the material in the barge alongside. When the barge is filled to capacity, it is towed to the disposal site, where large valves on the bottom are opened and the material is flushed out.

4. "Sandwick"

The "Sandwick" is a specially modified landing craft, mechanized with a hinged, hydraulically operated deflection door installed on the stern of the vessel. Because the "Sandwick" does not remove material through the use of pumps or buckets, it is not considered a dredge, but it is termed a sand bypasser.

Normal procedure provides for the "Sandwick" to locate itself over the shoal to be removed and place four anchors opposite each quarter of the craft. With the anchors in place, the deflector door is lowered and the throttles are opened to about three-quarter speed. This causes large volumes of water, moving at a relatively high velocity, to be directed downward into the shoal. This agitates the material so that it can be carried by the currents to settle in locations up to several hundred feet away.

In silts, material can be agitated at depths of 20 feet and displaced 400 to 600 feet or more, without the "Sandwick" changing positions. As the size of material to be displaced increases, the working depth and the distance the material is displaced decreases.

B. Disposal Methods

Methods of disposal vary with the type of dredge, dredge site, and disposal sites. Hopper dredges deposit their material at sites which are to form the base for new islands, at sites where pipeline dredges later will deposit the material on land, and at ocean disposal sites.

For pipeline dredges, two methods are normally used. The first is a method called "end dumping." In this process, the end of the discharge pipe is placed in the disposal area, with no retaining dikes. Bottom sediments and water are pumped through the pipeline to the disposal area. The mixture is then allowed to flow over the disposal area; most of the sediments settle out before the water finds its way back to the main river course.

A second disposal method for pipeline dredged material is formation of an open ended, linear dike that runs parallel to the river. The discharge pipe is aimed in a direction which forces the exhaust water to flow around the end of the dike; this provides the greatest amount of settling time before, the excess water returns to the main channel. As disposal continues, the dike is lengthened to continue to allow adequate settling time.

C. Disposal Sites and Additional Filled Lands

There are numerous sites where dredge materials are deposited within the estuary region. Disposal sites are in the estuary waters, on the estuary shorelands, and in the open ocean. Figure 209-1 shows the active and potential disposal sites for channel maintenance projects within the estuary region.

The amount of material that can be deposited at a water disposal site is difficult to determine. The deposited material is continually transported to other areas by existing currents. Material in adjacent areas is being transported into and through the disposal area. In addition, it should be noted that a disposal site is a target area. When the hoppers are flushed, it is projected that the material will be deposited within the boundaries of the designated disposal sites. However, because of currents that may exist, the material does not always land on target.

The criteria used by the U.S. Army, Corps of Engineers for determining when a land disposal site is exhausted include the depth of the fill (the amount the fill exceeds twenty feet Columbia River Datum), the distance from the height of the surrounding dike, and the cost of continuing disposal at the site.

Disposal area B is located in the Pacific Ocean. This site is used for material dredged from both the mouth of the Columbia River and the Columbia River channel. The disposal area is 230 and is at a water depth of 130 feet.

Area D is located south of Chinook, Washington in the Columbia River. The source of the disposed material is the mouth of the Columbia River and the Columbia River channel. The disposal site is 92 acres, at a depth of 50 feet.

Area E is an ocean disposal site. It is used to deposit dredged material from both the mouth of the Columbia River and the

Columbia River channel. The site has 92 acres and a depth of 70 feet.

Area F, in the Pacific Ocean, is used solely for disposal of material dredged from the channel at the mouth of the Columbia River. This area is 74 acres, at a depth of 125 feet.

Area G is an experimental site, used on a one time only basis, to determine the effects and movement of disposed material.

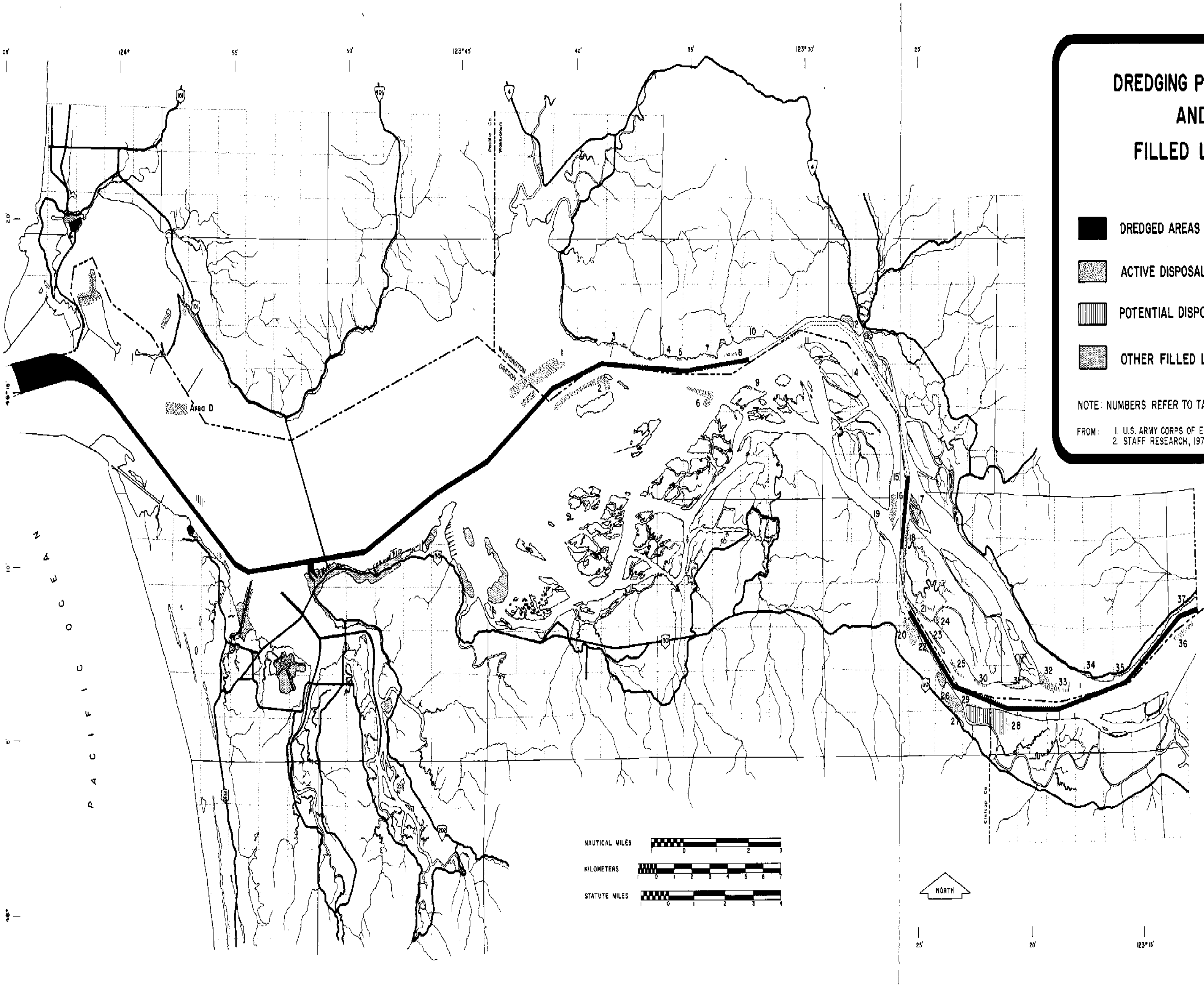
Additional estuary disposal sites are at Tansy Point (6 acres at 50 feet), Point Adams (6 acres at 25 feet), and Sand Island (6 acres at 40 feet). The Tansy Point and Point Adams sites are used for material dredged from the Columbia and Lower Willamette Rivers. The Sand Island disposal site is used for dredged materials from Baker Bay.

The land disposal sites listed in Table 209-1 are listed according to the numbers assigned them in Figure 209-1. The table includes the site location, habitats on the site (when percentage is given, it is an estimate), wildlife value, and the acreage, according to the U.S. Army Corps of Engineers.

Areas noted as additional filled lands in Figure 209-1 are primarily old disposal areas. Based on calculations made from this figure, there are over 700 acres of fill in the estuary. Of this total, approximately 250 acres are active disposal sites. As shown on the map, areas previously filled by man are concentrated in the Youngs Bay/ Astoria area. Besides old disposal areas, filled lands include industrial and commercial sites that have been leveled and raised above the floodplain with fill. Downtown Astoria was filled after a fire destroyed virtually the entire downtown area; this fill raised the land above water and flood level.

D. Projects

Figure 209-1 also provides information on the projects currently being carried out in the Columbia River estuary and the tributaries that flow into it. The term "project" not only refers to the completion and maintenance of the main navigation channel but also includes a number of side projects that are related to the main channel. Table 209-2 lists all projects that have been authorized in the Columbia River estuary, whether they have been completed or not.



DREDGING PROJECTS AND FILLED LANDS

- DREDGED AREAS
- ACTIVE DISPOSAL SITES
- POTENTIAL DISPOSAL SITES
- OTHER FILLED LANDS

NOTE: NUMBERS REFER TO TABLE 209-1

FROM: 1. U.S. ARMY CORPS OF ENGINEERS, 1975
2. STAFF RESEARCH, 1977

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 209-1

TABLE 209-1

LAND DISPOSAL SITES

Site	Location (Approx River Mile)	Habitat	Wildlife	Size*
1.	Rice Island (RM 21.0)	fill/sand, grass	occassional waterfowl, shorebird and aquatic mammal use	130
2.	Miller Sands Island (RM 23.5)	fill/sand, grass	waterfowl, shorebirds, aquatic mammals (within wildlife reserve)	240
3.	Altoona, Wa. (RM 24.3)	sand beach		10
4.	(RM 24.8)	fill/sand, grass	shorebirds	10
5.	Pillar Rock (RM 27.1)	fill/sand, grass	little use	10
6.	Jim Crow Sands (RM 27.2)	fill/sand, grass, pines	waterfowl, shorebirds	70
7.	Jim Crow Point (RM 28.2)	fill/sand	waterfowl resting area	10
8.	Pile dikes off channel (RM 29.1)	open water/pile dikes	possibly some fish use	20
9.	Woody Island (RM 29.1)	75%- fill/sand 25%- tideland/willow	waterfowl & shorebird resting	20
10.	Upstream of Brookfield, Wa. (RM 29.5)	80%- fill/sand 20%- tideland/alder, willow	some waterfowl & mammal use use	10
11.	Fitzpatrick Island (RM 31.2)	90%- fill/sand 10%- tideland/marsh	important waterfowl & shore-bird resting & feeding	30
12.	Downstream of Skamokawa, Wa. (RM 33.4)	fill/sand, snags, spruce, willow, grass	within wildlife reserve songbirds, small mammals	60

TABLE 209-1 CONT.

LAND DISPOSAL SITES

Site	Location (Approx River Mile)	Habitat	Wildlife	Size*
13.	Between Brooks Slough and Skamokawa Slough (33.7)	tideland/spruce, alder willow, sedge, grass	important wetland habitat for deer, invertebrates, birds	20
14.	Welch Island No. Bank (RM 34.0)	fill/sand	little use	20
15.	N. tip of Tenasillahe Island (RM 36.8)	80%- beach/sand 20%- tideland/willow, alder	little use	10
16.	Upstream end of Tenasillahe Island (RM 38.3)	fill/sand, willow, grass	little use, within wild-life reserve	60
17.	Nigger Island (RM 38.0)	75%- tideland/marsh 25%- tideland, willow, cottonwood, sedge	important deer, waterfowl shorebird, small mammal habitat	
18.	Duncan Slough, Puget Island (RM 38.7)	fill/sand	fishermen access	30
19.	Along Clifton Channel (RM 38.7)	fill/sand, debris	little use, fishing access	20
20.	Wauna, Or. (RM 40.5)	riparian, small trees	mammals	20
21.	W. of Welcome Slough Puget Island (RM 40.9)	fill/sand, willow	fishing access	30
22.	Wauna, Or. (RM 40.8)	fill/sand, water	little use	20
23.	NW end Coffee Pot Island (RM 41.3)	fill/sand, willow	shorebirds	20
24.	Puget Island, SE of Welcome Slough (RM 41.2)	diked marsh, pasture	waterfowl use	10
25.	SE end Coffee Pot Island (RM 42.5)	fill/sand, grass, willow	little use, some waterfowl	50

TABLE 209-1 CONT.

LAND DISPOSAL SITES

Site	Location (Approx River Mile)	Habitat	Wildlife	Size*
26.	Driscoll Slough (RM 42.9)	fill/sand	little use	50
27.	Driscoll Slough (RM 43.0)	riparian/Douglas fir, alder, Big leaf maple	deer, small mammals, songbirds	100
28.	Westport Slough (RM 43.6)	riparian/cottonwood, alder, grass, willow, Douglas fir	deer, small mammals, furbearers, songbirds	140
29.	Westport Slough (RM 44.0)	fill/sand	little use	50
30.	Pancake Point (RM 43.8)	fill/sand	little use, fishing access	20
31.	White Island (RM 45.0)	fill/sand	none	40
32.	E. end Puget Island (RM 46.3)	fill/sand	waterfowl resting	220
33.	Off E. end Puget Island (RM 47.1)	water		30
34.	Cape Horn, Wa. (RM 47.6)	fill/sand	fishing access	20
35.	Old Waterford Cannery (RM 48.7)	fill/sand	little use	10
36.	Eureka Island, Bar (RM 50.9)	fill/sand, grass, willow cottonwood	some songbird use	70
37.	Riverbank E. edge of Eagle Cliff (RM 51.3)	fill/sand, cottonwood	fishing access, some songbird use	30

* acres

TABLE 209-2

DREDGING PROJECTS
COLUMBIA RIVER ESTUARY

Project	Authorized Depth (ft) and Width (ft)	River Mile	Dredging Frequency	Dredge Type	Disposal Sites*	Amount**
Columbia River at the mouth	48 x 2640		Annual	Hopper	Ocean and Estuary	4,000,000 C.Y.
Columbia River						
- Astoria Area	40 x 600	3-21		Hopper	Harrington Point Sump, Area D	
- Miller Sands	40 x 600	22-25	4 out of every 5 years	Hopper	1, 2	850,000 C.Y.
- Pillar Rock Bar	40 x 600	25-28	Annual	Hopper, Pipeline	6, assorted WA beaches	310,000 C.Y.
- Brookfield - Welch Island Beach	40 x 600	29-33	Annual	Hopper, Pipeline	9, 11	250,000 C.Y.
- Skamokawa Bar	40 x 600	33-36	1 out of every 5 years		12	180,000 C.Y.
- Puget Island Bar	40 x 600	36-40.5	3 out of every 5 years		15, 18	230,000 C.Y.
- Wauna - Lower Westport Bar	40 x 600	40.5-45	4 out of every 5 years		21, 22, 23, 25 26, 27, 30	510,000 C.Y.
- Upper Westport Bar	40 x 600	45-42	3 out of every 5 years		31, 32, 34	420,000 C.Y.
- Eureka Bar	40 x 600	49-53	2 out of every 5 years		35, 37	150,000 C.Y.
- Columbia River at Baker Bay	10 x 150 (from mooring for 2.5 Miles)	3	Annual	Hopper, Pipeline, "Sandwick"	Sand Island	30,000 C.Y.

TABLE 209-2 CONT.

DREDGING PROJECTS
COLUMBIA RIVER ESTUARY

Project	Authorized Depth (ft) and Width (ft)	River Mile	Dredging Frequency	Dredge Type	Disposal Sites*	Amount**
Columbia River - Chinook, WA to Sand Island	10 x 150 10 x 275-500 (turning Basin)	7	Annual	Pipeline, Hopper	Chinook, Breakwater, Area D	20,000 C.Y.
Skipanon Channel, OR	30 x 200 (1.8 miles long) 30 (turning Basin) 12 (mooring basin) 6 x 40 (4500 ft. up-stream from railroad bridge)	10	as needed	Pipeline, Hopper	Tansy Point, along Channel	
Youngs Bay & Youngs River, OR	10 x 150	12	as needed	Pipeline	along shoreline	
Deep River, WA	8 x 100 (at entrance) 8 x 60 (to Deep River, Wash)	22	as needed	Pipeline	along shoreline	
Grays River, WA		23	No maintenance has been done since project completed in 1909.			
Skamokawa Creek, WA	6.5 x 75	33.5	as needed	Pipeline "Sandwick"	along shoreline	
Skamokawa Slough, WA	24 x 150	34	No work has ever been done			
Elochoman Slough, WA	10 x 100	39	Every 5 to 10 years	Pipeline "Sandwick"	along shoreline	
Lewis & Clark Connecting Channel	10 x 150 (1.5 miles) 10 x 100 (2.9 miles)	13	Every 10 years	Pipeline	along shoreline	50,000 C.Y.
Astoria Harbor and Turning Basin	40 deep	13	Annual	Clamshell	ocean, Area D	120,000 C.Y.

*See Figure 209-1.
**Average Annual Amount

There are two new major projects currently being considered that would affect the Columbia River estuary. The first consists of a proposed fill just west of pier three at the Port of Astoria. The fill site, according to the Port's permit application, would provide a long-term disposal site for dredged materials from the two slips and the turning basin. This would amount to approximately 200,000 cubic yards annually. It is proposed that this filled area would eventually have a commercial value for port development. At present, status of this project is undecided, due to the refusal of the Oregon State Division of State Lands to agree to a permit. Their decision is based on the biological productivity of the area.

The second proposed project entails the deepening of the main navigation channel to 55 or 60 feet across the bar. The current depth over the bar is 48 feet. This project is still in the development stage. A feasibility study is currently under consideration by the Portland District, U.S. Army Corps of Engineers. The channel would be narrowed from 2,600 feet to 1,600 feet, and repair of the South Jetty and building of Jetty B are contemplated. The navigation channel might also be realigned.

209.2 DIKES AND LEVEES

A. Diking, Drainage, and Improvement Districts

Of the 170,000 acres of floodplain bordering the lower Columbia River (mouth to RM 125), approximately 110,500 acres, or 65% are protected by dikes and levees. Diking, drainage, and improvement districts have been formed to take responsibility for maintaining these structures. The administrative positions within these districts are elected. The districts are considered political entities, and as such, have taxation power and, in Washington, the power of emminent domain.

There are 21 flood control districts located in the Columbia River estuary area. Table 209-3 shows the floodplain elevation and levee height within each flood control district. This data is currently being reviewed and updated by the Portland District, U.S. Army Corps of Engineers. As noted in the table, the flood control

TABLE 209-3

FLOOD CONTROL DISTRICTS

Local Name	Legal Name	Floodplain and Elevation	Elevations, Top of Levee	Freeboard	Datum
CLATSOP COUNTY, OREGON					
Blind Slough Area	Clatsop County Diking District #7	1933 H.W. 8.6	11.6	3.0	M.S.L.
City of Warrenton Diking District #1	Formed one district effective 2/12/73	1933 H.W. 7.6	11.6	4.0	M.S.L.
City of Warrenton Diking District #2		1933 H.W. 7.6	11.6	4.0	M.S.L.
City of Warrenton Diking District #3		1933 H.W. 7.6	11.6	4.0	M.S.L.
Clatsop County Drainage District #1		1933 H.W. 8.8	11.8	3.0	M.S.L.
Clatsop County Diking District #2		1933 H.W. 7.6	11.6	4.0	M.S.L.
Clatsop County Diking District #5		1933 H.W. 7.6	10.6	3.0	M.S.L.
John Day River Area	Clatsop County Diking District #14	1933 H.W. 7.8	8.8	1.0	M.S.L.
Karlson Island	Clatsop County Diking District #10	1933 H.W. 8.5	10.5	2.0	M.S.L.
Knappa Area	Clatsop County Diking District #12	1933 H.W. 8.6	10.6	2.0	M.S.L.
Lewis & Clark River Area	Clatsop County Diking District #11 & 8	1933 H.W. 7.7	10.7 to 8.7	3.0 to 1.0	M.S.L.
Tenasillahe Island	Clatsop County Diking District #6	1933 H.W. 11.9	14.9	3.0	U.S.E.:2.56 Below M.S.L.

TABLE 209-3 CONT.

FLOOD CONTROL DISTRICTS

Local Name	Legal Name	Floodplain and Elevation	Elevations, Top of Levee	Freeboard	Datum
Walluski River Area*	Clatsop County Diking District #13	1933 H.W. 7.7	7.7 to 6.0	None	M.S.L.
Westport District	Clatsop & Columbia Counties, Diking District #15	1876 H.W. 11.0	13.0	2.0	M.S.L.
Youngs River Area	Clatsop County Diking District #9	1933 H.W. 7.7	8.7	1.0	M.S.L.
PACIFIC COUNTY, WASHINGTON					
Pacific County Diking District #1		Revetment Work Only			
WAHKIAKUM COUNTY, WASHINGTON					
Deep River Area		1933 H.W. 8.2	9.2	1.0	M.S.L.
Diking District #4	Wahkiakum County Diking District #4	1933 H.W. 9.1	11.1	2.0	M.S.L.
Puget and Little Island	Wahkiakum County Con-Consolidated Diking District #1	1876 H.W. 12.6	14.1	1.5	U.S.E.:2.62 Below M.S.L.
Skamokawa Creek Area	Wahkiakum County Diking District #5	1933 H.W. 9.5 to 25.0	10.5 to 26.0	1.0	M.S.L.
Upper Grays River Area		1933 H.W. 8.5	10.5	2.0	M.S.L.

*No longer active

From: U.S. Army Corps of Engineers, 1970 structures are sufficient in height to withstand the previous high water. However, the Corps of Engineers has estimated that many of the dikes in the estuary area are not sufficient to withstand a 100-year, unregulated flood event. In addition, many of the dikes are in serious states of disrepair and could possibly be breached during flood stages.

B. Flood Control Structures

The alluvial land forming the floodplain has been used for raising crops and grazing for many years. As early as 1899, residents of the lower Columbia area realized that use of the floodplain for any agricultural activity, other than intermittent grazing, would require levees to protect the land from the annual floods. Most of the existing flood protection facilities in the area were constructed prior to 1925.

As noted before, approximately 65% of the floodplain in the lower Columbia area is protected by dikes and levees. Of approximately 36,604 acres of tideland soils in the estuary area, nearly 26,021 acres, or 71% are removed from the floodplain by flood control structures. Figure 209-2 shows the location of dikes and the protected floodplain.

Land uses in these diked areas range from conservation to industry. By far, the largest land use of diked lands is agriculture. This is evident in the Youngs Bay area and in eastern Clatsop County around Brownsmead, and in Wahkiakum County. Conservation areas occur in the Columbian White-Tailed Deer and Lewis and Clark Wildlife Refuges. Many forested areas are also protected by dikes, especially in the Deep River area. In almost all the protected areas, low density residential districts occur, often in connection with the land use in that region.

C. Estuarine Restoration

In an estuary area that is ripe for development, potentially productive areas should be considered for restoration to the estuary. The recently adopted planning goals and guidelines that relate to Oregon's coastal zone, address this issue in the Estuarine Resources Goal.

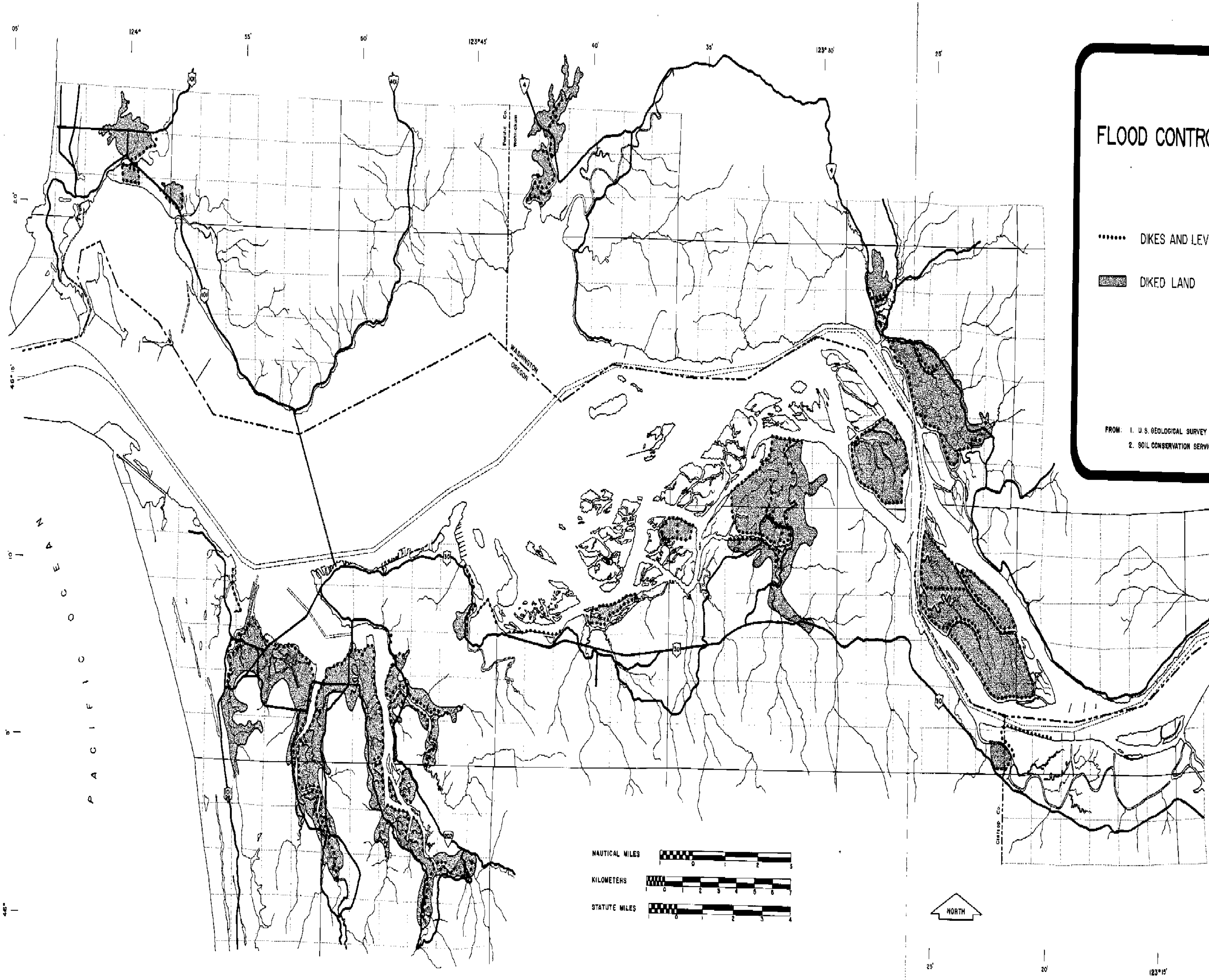
The goal specifically states that "when dredge or fill activities are permitted in inter-tidal or tidal marsh areas, their effects shall be mitigated by creation or restoration of another area of similar biological potential..." In speculating which areas of the estuary region could possibly undergo a change in land use to be returned to estuarine activity, the following criteria might be considered:

1. The area should be of suitable elevation.
2. It should currently have a low intensity land use.
3. The land should be publicly owned, or public purchase should be possible.
4. The land should not be artificially filled, or it must be possible to remove the fill and restore the area to intertidal or subtidal elevation.
5. There should be no adjacent land use that conflicts with restoration.
6. There should be a greater benefit accrued by restoring the area to an estuarine condition than some other land use or leaving it in its present condition.

In considering mitigation sites for dredge and fill activities that provide areas of similar biological potential, the areas should have similar ecological characteristics. This requires consideration of the salinity regime, tidal exposure and elevation, substrate type, current velocity and patterns, orientation to solar radiation, and the slope.

While estuarine restoration is a valid concept, it should be noted that additional lands have been formed both naturally and artificially. Under the direction of the U.S. Army Corps of Engineers, the Miller Sands project at RM 24 has created habitat by planting on dredge disposal material.

The estuary has also been filling naturally. In Oregon, Sand Island and the area east of Clatsop Spit have been accreting. Baker Bay has also been filling. Based on information provided by John Lockett in his article "Sediment Transport and Diffusion: Columbia River Estuary and Entrance," it is estimated that approximately 12% of the volume of the estuary below mean lower low water (MLLW) from upper Sand Island to Tongue Point filled in, between 1868 and 1958. Although precise information regarding all sites does not exist, areas in the estuary known to have been filled by man are shown in Figure 208-1.



FLOOD CONTROL STRUCTURES

DIKES AND LEVEES

DIKED LAND

FROM: 1. U.S. GEOLOGICAL SURVEY
2. SOIL CONSERVATION SERVICE

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 209-2

209.3 JETTIES AND PILE DIKES

A. Jetties

Prior to the construction of the South Jetty in 1885, the channel across the bar at the mouth of the Columbia River was unstable. A natural cycle occurred in which Clatsop Spit grew and continually encroached on the channel, pushing it to the north. Eventually, the spit was breached and a swash channel across the spit was formed. The swash channel eventually became the main channel, leaving the northern portion of the spit as an island. Thus, there were at various times, one or two channels at the mouth. The natural channel depth rarely exceeded 25 feet. Investigation of old charts shows that Sand Island was probably cut off from Clatsop Spit and gradually shifted north and east to its present position.

Construction of the South Jetty, which was to run from Point Adams, seaward for four and one-half miles, began in 1885. The channel was not affected until 1889 when rapid construction began, and the channel depth increased from 20 feet to 30 feet. However, the channel continued to swing north and began to shoal, so additional improvements were authorized to maintain a 40-foot channel across the bar.

In 1903, extension of the South Jetty for two and one-half miles was begun. This work was completed in 1913, and then work began on the North Jetty. This jetty, running from Cape Disappointment to the southwest approximately two and one-half miles, was completed in 1917.

Today, the two jetties are impressive structures. The South Jetty has a top width that varies from 45 to 70 feet, with an elevation of 26 feet above MLLW in some areas. The base width of the outer portions is approximately 350 feet, and the total height from the bottom is up to 76 feet. Wave action has lowered the outer one and one-half miles of the South Jetty to about MLLW. The dimensions of the North Jetty are 25 feet wide on top, with an elevation of 28 to 32 feet above mean lower low water. Nearly 3 million tons of stone were used in constructing the North Jetty.

While the construction of these two jetties improved the entrance conditions to the Columbia River, the main channel still shifted to the north, resulting in the erosion of Sand Island and Peacock Spit. In the early 1930's , to prevent further shifting of the channel, Jetty A was built southward from Cape Disappointment, and four pile dikes were constructed on the south side of Sand Island. Today the channel is relatively stable, and the natural scouring is supplemented by annual dredging to keep the average depth across the bar close to 48 feet. However, it has not been possible to maintain the authorized channel width of 1/2 mile for the channel at the mouth.

B. Pile Dikes

Pile dikes are permeable structures built of a double row of timber piles bolted together by a horizontal spreader beam to give them stability. The piles are driven into the river bottom. They are usually aligned perpendicular to the shoreline and reach toward the channel.

Pile dikes are generally constructed in a series of several dikes and control the river flow by directing and constricting flows. The same volume of water is confined to a narrower channel and has a greater velocity, thereby providing a tendency toward self-maintenance of the channel. This was the purpose for the construction of the three pile dikes built on the south side of Sand Island, and the Chinook Jetty built south of the town of Chinook, Washington across the state boundary.

Pile dikes also serve to reduce bank erosion. While breaking the effect of the current and directing it toward the channel, pile dikes encourage the deposition of material along the dikes. Three pile dikes were constructed near Tansy Point, where swift currents previously eroded the bank.

Pile dikes may also have undesirable effects such as increased erosion in other areas and increased sedimentation in channel areas in the lee of a dike. Increased sedimentation in the Cathlamet and Chinook channels is probably due in part, to the construction of pile dikes designed to increase scour in the adjacent Columbia River channel.

209.4 ROADWAYS AND CAUSEWAYS

There are four primary highways in the estuary area, U.S. 101, U.S. 401, U.S. 30, and Washington State Road (SR) 4, plus numerous minor roads. These roadways are vital links for both intracommunity and intercommunity travel. The residents count on an efficient road system for both their own travel and for the shipment and receipt of goods.

The four major roads mentioned above account for the majority of traffic in the region. U.S. 30 runs east-west through Clatsop County along the Columbia River. U.S. 101 runs north-south through Clatsop and Pacific Counties, crossing Youngs Bay as a causeway and bridge, and crossing the Columbia River at the Astoria-Megler Bridge. The north-south route divides at the Washington side of the bridge, with U.S. 101 going west to Ilwaco and the Long Beach Peninsula and U.S. 401 going north to Naselle and State Highway 4. SR 4 is the east-west route along the estuary in Washington. This road provides a direct link from Longview and Kelso to the Washington coast.

Table 209-4 shows data on the traffic volume at various recorder points on the highway system in the estuary. These figures indicate average daily traffic totals (ADT), which is a year-round average number of vehicles which pass the recording point in either direction, in one day. They can be misleading in the analysis of road adequacy, since they are average annual figures. What they don't demonstrate is the high volumes of traffic during the tourist and fishing seasons, when these highways experience peak loads. Such information should be considered for road design and maintenance. The traffic records show the monthly averages only at the permanent recorders, which are located outside the CREST study area.

Permanent recorders are located on the highways that bring traffic into the area, and they can be used to indicate possible peak volumes. An example of the peak flows that occur are indicated by the Gearhart recorder. Fluctuations are also shown by comparing the August and January averages; these figures indicate that on an average day in August, there was over three times as much traffic, as on an average day in January.

TABLE 209-4

TRAFFIC VOLUME OF MAJOR ROADS

Highway	Location of Recorder	Average Daily Traffic Count					
		1971	1972	1973	1974	1975	1976
OREGON							
U.S. 30	Westport Road	3100	3250	3300	3300		
U.S. 30	Big Creek Bridge	3100	3250	3300	3300		
U.S. 30	East City Limits, Astoria	5400	5600	5600	5600		
U.S. 30	West of Rainer Recorder #05-006*	4000	4264	4567	4606		
U.S. 101	Astoria Megler Bridge	1430	1500	1560	1570		
U.S. 101	South City Limits of Astoria, Youngs Bay Bridge	8200	8700	8700	9000		
U.S. 101	North of Gearhart, Recorder #04-001*	5317	5751	5661	5464		
WASHINGTON							
S.R. 4	Junction of S.R. 401		1460	1750	1650	1900	2050
S.R. 4	Wahkiakum County Line		1700	1800	1700	2100	2250
S.R. 4	Cathlamet Western City Limits		3150	3000	2850	2900	3150
U.S. 101	Chinook Unincorporated Sign				2000	2250	2600
U.S. 101	Ilwaco Eastern City Limits		1650	1650	1650	1850	2000
S.R. 401	Junction of U.S. 101		1360	1280	1220	1380	1500

*Permanent Recorder

From: Washington State Department of Highways, 1972-1976; Oregon State Highway Division, 1971-1974

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210

TOPOGRAPHY SOILS AND ASSOCIATED HAZARDS

COLUMBIA RIVER ESTUARY

TOPOGRAPHY, SOILS AND ASSOCIATED HAZARDS

Robert E. Blanchard
David Jay

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FIGURES

TABLES

*Figures follows the page indicated.

210 TOPOGRAPHY, SOILS AND ASSOCIATED HAZARDS

People use various landforms for everything from aesthetics to provision for their basic existence. Although the human relationship with the land is basically of a positive nature, natural phenomena also pose physical hazards to society.

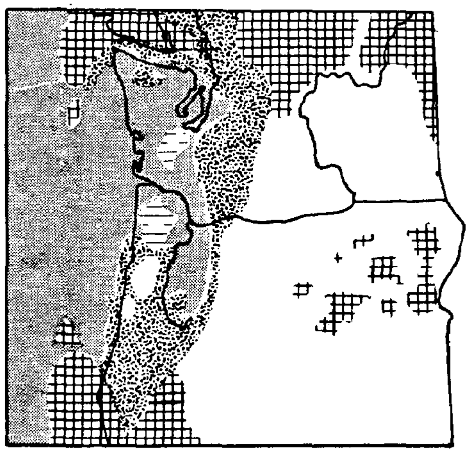
This section will explore the geology and soils of the Columbia River estuary area and describe their history, uses and limitations. Hazard areas will also be discussed, in an attempt to make people more aware of the tenuous relationship between people and nature.

210.1 GEOLOGICAL HISTORY

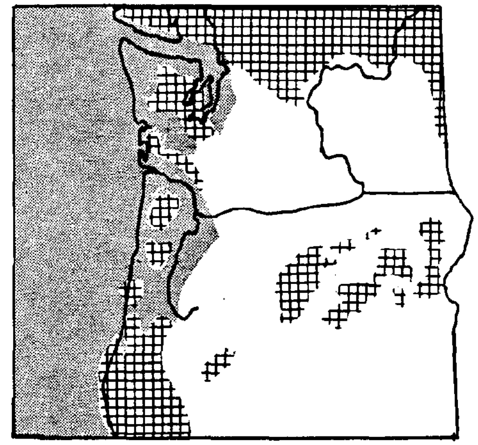
The geological history of the Oregon and Washington coasts is one of alternating periods of uplift and of submersion under the sea. Beds of undersea and terrestrial volcanic basalts and andesites alternate with marine sediments, such as sandstones and siltstones.

Some 50 million years of geological history are summarized in Figure 210-1. Most of the coastal area was under the sea during the period from 58 to 36 million years Before Present (B.P.), (Figure 210-1a). Intense undersea volcanic activity flooded the floor of this basin with many thousands of feet of submarine basalts, probably resulting in an island arc. The southern part of the basin was filled with several thousand feet of sedimentary debris derived from the land. These sedimentary and volcanic deposits make up large parts of the present Coast Range. Inland, large lava flows covered much of both states, and the base of the Cascades Range was laid down.

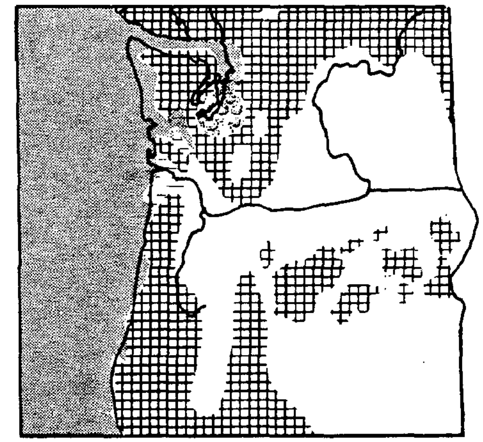
The period from 36 to 25 million years B.P. (Figure 210-1b) was characterized by uplift of the southern part and expansion of the northern part of the coastal sea and extensive volcanic activity inland. Sills of basaltic material up to 1000 ft thick were intruded into the sediments laid down in the previous period. These sills form the base of some of the higher peaks in the present Coast Range. More marine sediments were laid down on the west side of the Coast Range; these extensive estuarine and river-delta sediments consist mostly of volcanic debris carried from inland.



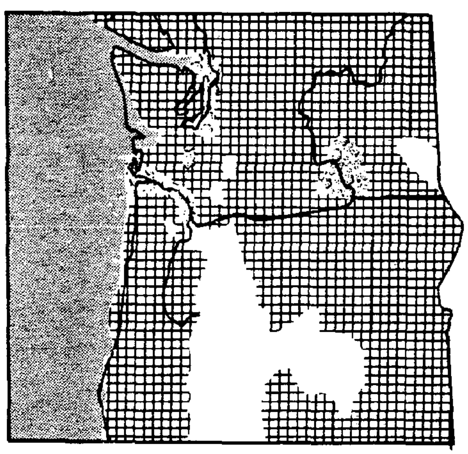
EOCENE - 50 MILLION YEARS B.P.
(a)



OLIGOCENE - 30 MILLION YEARS B.P.
(b)



MIOCENE - 15 MILLION YEARS B.P.
(c)



PLIOCENE - 5 MILLION YEARS B.P.
(d)

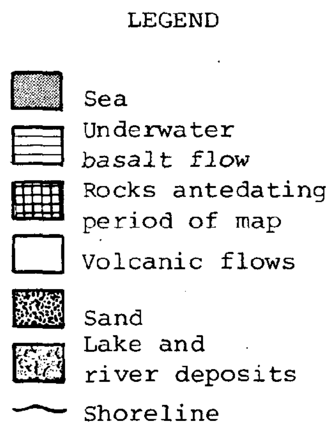


Figure 210-1. Important Geological Events in the last 50 million years B.P.

From: Loy et al., 1976

The period from 25 to 12 million years B.P. (Figure 210-1c) was characterized by uplift and, therefore, by retreat of the coastal sea to a small area around the mouth of the Columbia River. This basin gradually filled with sand and silt, alternating with layers of lava from undersea volcanic activity. Extensive folding and faulting occurred as a result of the uplift.

The most important feature during this period was the deposition of the Columbia River basalts that are prominently displayed in the Columbia River Gorge and form some of Oregon's more prominent, rocky headlands. These flows built up the Cascade Range and covered some 200,000 square miles in Oregon and Washington. Subsidence in the Willamette Valley area late in this period allowed deposition of lake sediments, as volcanic material blocked streams. Continued uplift eliminated the marine basin near the mouth of the Columbia River.

The period from 12 to 1 million years B.P. (Figure 210-1d) was one of further deposition of lake and river sediments in the Willamette and Columbia River Valleys. Volcanic activity continued to build up the Cascades.

The last million years have been characterized by repeated periods of glacial advance and retreat, with corresponding fluctuations in sea level. The entire Lower Columbia and Willamette River Valleys have been submerged during interglacial periods when sea level was as much as 350 ft above present levels (resulting in the deposition of much fine silt). Wave terraces were cut into the hills of the present coast during these periods, and submerged terraces were formed and ancient beach sands deposited on the present continental shelf during glacial periods of lower sea level. During periods of glacial retreat, several enormous floods came down the Columbia River, reworking sediments up to 700 ft above the Willamette Valley floor, as in the case of the Spokane flood of 20,000 years B.P. These floods and great flow in the Columbia River during the periods glacial retreat, eroded a river channel across the continental shelf. An undersea Astoria Canyon remains as a remnant of erosion by submarine movement of river sediment down the continental slope. The Columbia River estuary must have been near the edge of the continental shelf during this period. The last rise in sea level, some 18,000 years B.P., drowned the river valleys of glacial times and created the estuaries near their present locations. These estuaries have continued to fill and change position.

210.2 TOPOGRAPHY (SLOPE)

The shorelands adjacent to the Columbia River estuary have a diverse topography; the region includes the lowlands of the Clatsop Plains and Youngs Bay area, the numerous islands of the river, and the mountainous areas between Chinook Point and Point Ellice in Washington. Such diversity has resulted in a variety of management techniques to make best use of the land. For example, timber owners use harvesting techniques to control soil loss when ground cover is removed; many low-land areas have extensive diking systems to prevent inundation by high tides and stream freshets.

Consideration of the potential hazards in areas adjacent to shorelands is essential to human safety. A slope map (Figure 210-2) is a special kind of topographic map designed especially for planning purposes. Slopes have been categorized differently in the three counties in the estuary area; these reflect the different agencies that have done geologic and soil investigations. Slopes in Wahkiakum County are broken into 0-10%, 10-20%, and 20%+ categories. Clatsop County's slope categories are 0-9%, 10-24%, 25-49%, and 50%+. Slope categories in Pacific County vary, depending on the soil phase. The inventory map is prepared on such a scale that the slope information has been generalized into low, moderate, and steep slopes. For each classification, there are probably some local areas with slopes that do not fall within the assigned category. Table 210-1 shows the slope categories and their descriptions for Clatsop County. These can also be used to generally describe the topography of Pacific and Wahkiakum Counties, since the categories do overlap slightly.

The slope map shows, in general, the areas both where development should be considered carefully or possibly precluded because of slope. It also provides a tool for helping to determine geologic hazard areas susceptible to landslides. These hazards are further discussed in Section 210.3.

GENERALIZED SLOPE MAP

LOW

MODERATE

STEEP

	CLATSOP CO.	PACIFIC CO.	WAHKIAKUM CO.
LOW	0-9 %	0-8 %	0-10 %
MODERATE	10-24%	9-29%	11-19 %
STEEP	25%-	30%-	20%-

FROM: SOIL CONSERVATION SERVICE

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
210-2

Table 210-1

Slope Description

Slope Category	Description
0-9% (Low) Good suitability for development	Nearly flat ground to moderately gentle slope. Alluvial surfaces throughout lowlands. These slopes generally present few problems to development
10-24% (Moderate) Moderate suitability for development	Smooth slopes on steeper parts of isolated hills, gently inclined areas within mountains. Slopes should be considered carefully in design of any construction. These slopes include some that have good suitability for development and some that are poorly suited.
25+% (Steep) Poor suitability for development	Steep to precipitous slopes, cliffs, bluffs, and steep mountain slopes. Erosion is often active and landslide potential is high. Slopes pose significant problems to most types of land development and even preclude development along precipitous slopes.

210.3 SOILS

Soils are mixtures in varying proportions of partly or completely decomposed rocks, minerals, and organic material. Soil development is characterized by distinct horizontal layers, or horizons, which are influenced by their environments.

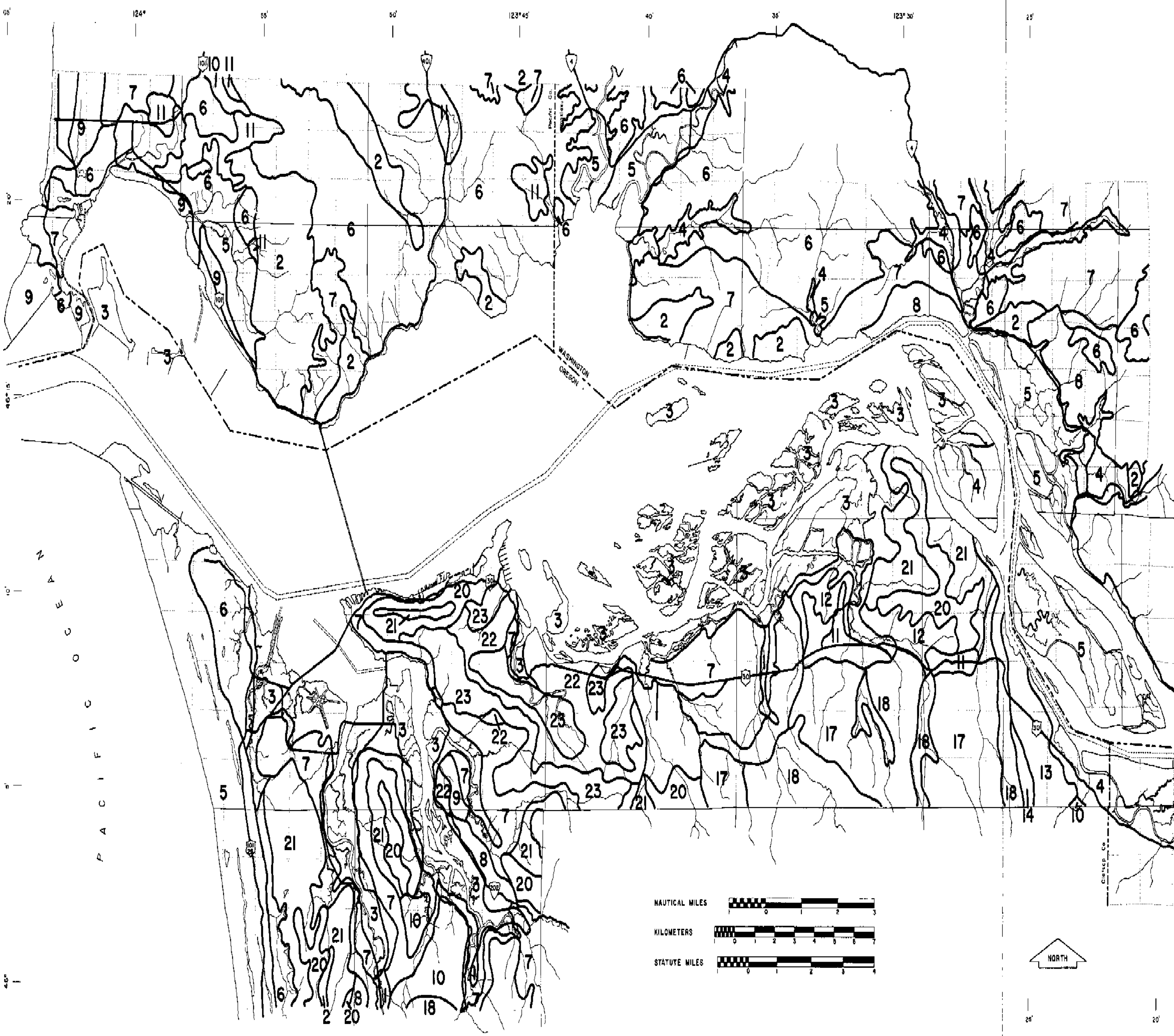
The basic features that influence the soil are:

1. Topographic relief
2. Parent material
3. Biological activity
4. Climate, and
5. Time

These factors combine to give a soil a distinctive color, texture, structure, organic content, and consistency, and each soil type can be identified by different combinations of these factors.

Soils of similar characteristics are grouped homogeneously (into a soil series) by the U.S. Soil Conservation Service (SCS). Each series is named after a community, town, river, or other geographical feature near the area where the soil was first mapped. A soil type is an individual soil; its name consists of the series name, plus the name of the texture of the surface horizon. Soil associations are groupings of soils that are geographically associated in a repeating pattern. An association consists of one or more major soils for which it is named, and usually one or more minor soils. The soils in one association may occur in another; they do differ in pattern and proportion.

General soil maps are useful for determining an approximate idea of the soils in a region, for comparing different parts of an area, or for finding large tracts that are suitable for a certain kind of land use. A generalized soil map is too broad to be suitable for specific site planning such as farm management plans, park plans, or designs for roadways or septic tank fields. These types of activities require use of detailed soil survey maps and information, and on-site investigations. A soil association map for the Columbia River estuary region is shown in Figure 210-3. Tables 210-2, 210-3, and 210-4 indicate the soil associations present and their component soil types for each of the three counties.



GENERALIZED SOIL ASSOCIATIONS

CLATSOP COUNTY

1. NEHALEM ASSOCIATION
2. BRENNER-NESTUCCA ASSOC.
3. COQUILLE-TIDAL MARSH (FRESH)-CLATSOP ASSOC.
4. SAUVIE-PEAT ASSOC.
5. WESTPORT-GEARHART-DUNELAND ASSOC.
6. GRAILLER-WARRENTON ASSOC.
7. WALLUSKI-KNAPPA ASSOC.
8. CHITWOOD-HEBO ASSOC.
9.
10. ASTORIA-WINEMA ASSOC.,30-60%
11. SVENSEN ASSOC.,0-30% SLOPE
12. SVENSEN ASSOC.,30-60% SLOPE
13 ASTORIA-HEMBRE-KLICKITAT ASSOC. 3-30% SLOPE
18. HEMBRE-KLICKITAT ASSOC.,30-60% SLOPE
20. TOLOVANA ASSOC., 3-30 SLOPE
21. TOLOVANA ASSOC., 30-60 SLOPE
22. TOLOVANA ASSOC., SANDSTONE SUBSTRATUM, 3-30% SLOPE
23. TOLOVANA ASSOC., SANDSTONE SUBSTRATUM, 30-60% SLOPE

WAHKIAKUM COUNTY

1. GERMANY-CATHLAMET ASSOC.
2 WAHKIAKUM-BUNKER ASSOC.
3. ZYZYL-LUTES ASSOC.
4. GREHALEM-NUBY ASSOC.
5. OCOSTA-SAUVIE ASSOC.
6. LYTELL-ASTORIA ASSOC.
7. ZENKER-ELOCHOMAN ASSOC.
8. ELOCHOMAN-HEMBRE ASSOC.

PACIFIC COUNTY

2. WAHKIAKUM-HEMBRE ASSOC.
3. GREHALEM-NUBY ASSOC.
4 GREHALEM-NUBY ASSOC
5. OCOSTA-SAUVIE ASSOC.
6. LYTELL-ASTORIA ASSOC.
7. ZENKER-ELOCHOMAN ASSOC
9 YAQUINA-NETARTS ASSOC.
10. OCOSTA ASSOC.
11. WILLAPA ASSOC.

FROM: SOIL CONSERVATION SERVICE

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
210-3

Table 210-2

Clatsop County Soil Associations and Components[1]

(1) Nehalem Association
  *Nehalem silt loam
  Nehalem silt loam, non-overflow
  Minor soils:
    Gardiner fine sandy loam
    Riverwash
    Brenner silty clay loam

(2) Brenner - Nestucca Association
  *Brenner silty clay loam
  Nestucca silty clay loam
  Minor soils
    Nehalem silt loam
    Hebo silty clay loam
    Brallier peat

(3) Coquille -- Tidal Marsh (fresh) -- Clatsop Association
  *Coquille silty clay loam
  Tidal marsh (fresh)
  Clatsop silty clay loam
  Clatsop silty clay loam, sand substratum
  Minor soils:
    Brallier peat
    Fill land, sandy
    31 silty clay loam

(4) Sauvie -- Peat Association
  *Sauvie silty clay loam
  Peat
  Minor soils:
    Tidal marsh (fresh)

(5) Westport-Gearhart-Dune Land Association
  *Westport fine sand
  Gearhart fine sandy loam
  Dune land
  Minor soils:
    Warrenton loamy fine sand
    Brallier muck

(6) Brallier-Warrenton Association
  *Brallier muck
  Warrenton loamy fine sand
  Minor soils:
    Gearhart fine sandy loam

*Soil type covering the largest area within the association.

1. The number in parenthesis corresponds to the association numbers in Figure 210-3.

(7) Walluski-Knappa Association
*Walluski silt loam, 0 to 7% slope
Walluski silt loam, 7 to 12% slope
Walluski silt loam, 12 to 20% slope
Knappa silt loam, 0 to 3% slope
Knappa silt loam, 3 to 7% slope
Knappa silt loam, 7 to 12% slope
Knappa silt loam, 12 to 20% slope
Minor soils:
Terrace escarpments
Meda gravelly loam, 3 to 12% slope
35 silty clay loam, 3 to 12% slope

(8) Chitwood - Hebo Association
*Chitwood silty clay loam, 0 to 7% slope
Chitwood silty clay loam, 7 to 12% slope
Hebo silty clay loam
Minor soils:
Walluski silt loam, 0 to 7% slope
Walluski silt loam, 7 to 12% slope

(10) Astoria-Winema Association, 30-60% slope
*Astoria silt loam, 30 to 60% slope
Astoria silt loam, 3 to 30% slope
Astoria silt loam, landslide, 30 to 60% slope
Winema silty clay loam, 30 to 60¢ slope
Winema silty clay loam, 3 to 30% slope
Minor soils:
33 silt loam, 30 to 60% slope
Hembre silt loam, 30 to 60% slope
13 silt loam 20 to 60% slope
Trask gravelly loam, 5 to 50% slope
Alluvial land
Freshwater marsh

(11) Svensen Association, 0 to 30% slope
*Svensen loam, 12 to 20% slope
Svensen loam, 0 to 7% slope
Svensen loam, 7 to 12% slope
Svensen loam, 20 to 30% slope
Svensen loam, 30 to 60% slope
Minor soils:
Tolovana silt loam, sandstone substratum, 3-30% slope

(12) Svensen Association, 30 to 60% slope
*Svensen loam, 30 to 60% slope
Svensen loam, 20 to 30% slope
Minor soils:
Tolovana silt loam, sandstone substratum, 30 to 60% slope

(13) Astoria-Hembre-Klickitat Association, 3 to 30% slope
*Astoria silt loam, 3 to 30% slope
Astoria silt loam, 30 to 60$ slope
Hembre silt loam, sedimentary rock substratum, 3 to 30% slope
Hembre silt loam, sedimentary rock substratum, 3 to 60% slope
Klickitat stony loam, 5 to 30% slope
Minor soils:
Rock outcrop
Alluvial land

(14) Astoria-Hembre-Klickitat Association, 30 to 60% slope
*Astoria silt loam, 30 to 60% slope
Astoria silt loam, 3 to 30% slope
Hembre silt loam, sedimentary rock substratum, 30 to 60% slope
Klickitat stony loam, 30 to 60% slope
Minor soils:
Alluvial land
Rock outcrop

(18) Hembre-Klickitat Association, 30 to 60% slope
*Hembre silt loam, 30 to 60% slope
Hembre silt loam, 3 to 30% slope
Hembre silt loam, 60 to 90% slope
Klickitat stony loam, 30 to 60% slope
Klickitat stony loam, 5 to 30% slope
Minor soils:
Kilchir-Klickitat soils, 60 to 90% slope
Rock outcrop
Alluvial land

(20) Tolovana Association, 3 to 30% slope
*Tolovana silt loam, 3 to 30% slope
Tolovana silt loam, 3 to 12% slope
Tolovana silt loam, 12 to 20% slope
Tolovana silt loam, 20 to 30% slope
Tolovana silt loam, 30 to 60% slope
Minor soils:
Alluvial land
Freshwater marsh

(21) Tolovana Association, 30 to 60% slope
*Tolovana silt loam, 30 to 60% slope
Tolovana silt loam, 3 to 30% slope
Minor soils:
Alluvial land
Freshwater marsh

(22) Tolovana Association, Sandstone Substratum, 3 to 30% slope
*Tolovana silt loam, sandstone substratum, 3 to 30% slope
Tolovana silt loam, sandstone substratum, 30 to 60% slope
Minor soils:
Alluvial land

Table 210-3

Southern Pacific County Soil Associations and Components[1]

(2) Wahkiakum-Hembre Association
*Wahkiakum silt loam, 8 to 30% slope
*Wahkiakum silt loam, 30 to 65% slope
*Wahkiakum silt loam, 65 to 90% slope
Hembre silt loam, 1 to 8% slope
Hembre silt loam, 8 to 30% slope
Hembre silt loam, 30 to 65% slope
Hembre silt loam, 65 to 90% slope
Minor soils:
Squally gravelly silt loam, 5 to 30% slope
Squally gravelly silt loam, 30 to 65% slope

(4) Grehalem-Nuby Association
*Grehalem loam
Nuby silt loam
Minor soils:
Humptulips silt loam
Skamo silt loam
Riverwash

(5) Ocosta-Sauvie Association
*Ocosta silty clay loam
Sauvie silt loam
Minor soils :
Tital marsh (fresh)
Udipraments, level
Riverwash

(6) Lytell-Astoria Association
*Lytell silt loam, 8 to 30% slope
*Lytell silt loam, 30 to 65% slope
*Lytell silt loam, 65 to 90% slope
Astoria silt loam, 1 to 8% slope
Astoria silt loam, 8 to 30% slope
Astoria silt loam, 30 to 65% slope

(7) Zenker-Elochoman Association
*Zenker silt loam, 8 to 30% slope
*Zenker silt loam, 30 to 65% slope
*Zenker silt loam, 65 to 90% slope
Elochoman silt loam, o to 8% slope
Elochoman silt loam, 30 to 65% slope
Elochoman silt loam, 65 to 90% slope
Minor soils:
Skamo silt loam

*Soil series covering the largest area within the association.

1. The number in parenthesis corresponds to the association numbers in Figure 210-3.

(9) Yaquina-Netarts Association
*Yaquina loamy sand
*Netarts fine sand
Duneland
Seattle muck
Westport sand
Shalcar much
Orcus peat

(10) Ocosta Association
*Ocosta silt loam
Tidal flats
Rennie silty clay loam
Made land

(11) Willapa Association
*Willapa silt loam, 1 to 8% slope
*Willapa silt loam, 8 to 30% slope
*Willapa silt loam, 30 to 65% slope
*Nemah silty clay loam

From: Pacific County, Soil Conservation Service

Table 210-4

Wahkiakum County Soil Associations and Components[1]

(1) Germany-Cathlamet Association
- *Germany silt loam, 1 to 8% slope
- *Germany silt loam, 8 to 30% slope
- *Germany silt loam, 30 to 65% slope
- Cathlamet silt loam, 1 to 8% slope
- Cathlamet silt loam, 8 to 30% slope
- Cathlamet silt loam, 30 to 65% slope
- Cathlamet silt loam, 65 to 90% slope
- Minor soils:
  - Stimson silt loam
  - Raught silt loam, 8 to 30% slope
  - Raught silt loam, 30 to 65% slope

(2) Wahkiakum-Hembre Association
- *Wahkiakum silt loam, 8 to 30% slope
- *Wahkiakum silt loam, 30 to 65% slope
- *Wahkiakum silt loam, 65 to 90% slope
- Hembre silt loam, 1 to 8% slope
- Hembre silt loam, 8 to 30% slope
- Hembre silt loam, 30 to 65% slope
- Hembre silt loam, 65 to 90% slope
- Minor soils:
  - Squally gravelly silt loam, 5 to 30% slope
  - Squally gravelly silt loam, 30 to 65% slope

(3) Murnen-Lutes Association
- *Murnen silt loam, 5 to 30% slope
- Murnen silt loam, 30 to 65% slope
- Lutes silt loam, 8 to 30% slope
- Lutes silt loam, 30 to 65% slope
- Lutes silt loam, 65 to 90% slope

(4) Grehalem-Nuby Association
- *Grehalem loam
- Nuby silt loam
- Minor soils:
  - Humptulips silt loam
  - Skamo silt loam
  - Riverwash

(5) Ocosta-Sauvie Association
- *Ocosta silty clay loam
- Sauvie silt loam
- Minor soils:
  - Tidal marsh (fresh)
  - Udipsament, level
  - Riverwash

[1]The number in parenthesis corresponds to the association numbers in Figure 210-3.

*Soil series covering the largest area within the association.

(6) Lytell-Astoria Association
*Lytell silt loam, 8 to 30% slope
*Lytell silt loam, 30 to 65% slope
*Lytell silt loam, 65 to 90% slope
Astoria silt loam, 1 to 8% slope
Astoria silt loam, 8 to 30% slope
Astoria silt loam, 30 to 65% slope

(7) Zenker-Elochoman Association
*Zenker silt loam, 8 to 30% slope
*Zenker silt loam, 30 to 65% slope
*Zenker silt loam, 65 to 90% slope
Elochoman silt loam, 1 to 8% slope
Elochoman silt loam, 8 to 30% slope
Elochoman silt loam, 30 to 65% slope
Elochoman silt loam, 65 to 90% slope
Minor soils:
Skamo silt loam

(8) Elochoman-Hembre Association
*Elochoman silt loam, 1 to 8% slope
*Elochoman silt loam, 8 to 30% slope
*Elochoman silt loam, 30 to 65% slope
*Elochoman silt loam, 65 to 90% slope
Hembre silt loam, 1 to 8% slope
Hembre silt loam, 8 to 30% slope
Hembre silt loam, 30 to 65% slope
Hembre silt loam, 65 to 90% slope
Minor soils:
Skamo silt loam

From: Wahkiakum County, Soil Conservation Service

A. Soil Characteristics

Nine soil characteristics were evaluated in an attempt to give a generalized picture of basic soil properties for the individual soils. These characteristics are those most commonly investigated to determine limitations to many of the activities related to development. The soil matrices in Tables 210-5, 210-6, and 210-7 indicate these characteristics.

The following paragraphs provide a definition of each of the soil characteristics.

1. Depth of Seasonally High Water Table

This category refers to the depth, in feet, of the seasonally high water table below the surface of the soil. A high water table may indicate a ponding problem or an impermeable layer of soil. Either condition affects the proper functioning of a septic tank filter field.

2. Permeability

This quality refers to the ability of a soil to allow water or air to travel through the different soil horizons. For our purposes, we only considered the permeability of the upper layer of soil, as noted on the SCS interpretation sheets. Low permeability means that the water is able to flow through the soil horizons very slowly or not at all, and it will tend to move laterally. High permeability means that water can flow to deeper levels rapidly and may eventually reach a layer of deep ground water, commonly called an aquifer.

3. Percent of Slope

Best described as the steepness of an area, precent of slope is determined by dividing vertical increase by horizontal distance. Slope is determined by the geologic characteristics of a region and in turn, influences other factors such as drainage, climate, and vegetation. In addition, the slope of the land surface partially determines the suitability of an area for development.

4. Susceptibility to Flooding

The susceptibility to flooding is determined by many factors. Included among these are water discharge from the drainage basin, soil slope, the elevation of that soil above the normal height of the water surface, and the occurrence and variability of tidal fluctuations.

TABLE 210-5

CREST

COLUMBIA RIVER ESTUARY STUDY TASKFORCE

SOIL CHARACTERISTICS MATRIX

CLATSOP COUNTY

subst	substratum	ld	landslide	c	clay
sy	sand	s	silt	f	fine
		sed	sedimentary	g	gravelly
		st	stony	l	loam

SOILS	map sym	% SLOPE	DEPTH TO BEDROCK	EROSION POTENTIAL	FLOOD POTENTIAL	WATER TABLE	PERMEABILITY	SHRINK / SWELL		AGRICULTURE CLASS	HYDROLOGIC GROUP		
Alluvial land	1A	●	○	●	○	●	◐			VIe	B		
Astoria s l ld	2-IE	◐	●	◐	●	●	◐	●		VIe	B		
Astoria s l ld	2-IF	○	●	○	●	●	◐	●		VIe	B		
Brallier muck	3A	●	○	●	○	○	◐	◐		IVw	D		
Brallier peat		●	○	●	○	○	◐	◐		IVw	D		
Brenner s c l	4A	●	○	●	○	○	◐	●		IIIw	C D		
Clatsop s c l	5A	●	○	●	○	○	◐	◐		IIIw	D		
Clatsop s c l sand subst	26A												
Coquille s c l	7A	●	○	●	○	○	○	◐		IVw	D		
Dune land	8A	●	○	○	●	●	●	●		VIIIe	A		
Fill land sy	17A	●		◐			◐						
Freshwater Marsh	15A	●	○	●	○	○	○			VIIw	D		
Gardiner fsl	25A	●	○	●	○	●	●	●		IIw	A		
Gearhart fsl	9A		○	○	●	●	●	●		VIe	A		
Hembre sl	12F	◐	●	◐	●	●	◐	●		VIe	B		
Hembre sl	12G	○	●	○	●	●	◐	●		VIe	B		
Hembre sl	12H	○	●	○	●	●	◐	●		VIIe	B		
Hembre sl sed rock subst	12-IE	◐											
Hembre sl sed rock subst	12-IF	○											
Kilchis - Klickitat soils		○	●	○	●	●	●	●		VIIs	C		
Klickitat st l	20E	◐	●		●	●	◐	●			B		
Klickitat st l	20F	○	●		●	●	◐	●			B		
Knappa s l	14A	●	○	●		●	◐	●		IIc	B		
Knappa s l	14B	●	○	●		●	◐	●		IIe	B		
Knappa s l	14C	◐	○	●		●	◐	●		IIIe	B		
Knappa s l	14D	◐	○	●		●	◐	●		IIIe	B		
Meda g l	32C	●	○	●	●	●	◐	●		IIIe	B		
Nehalem s l	16A	●	○	●	○	○	◐	●		IIc	B		
Nehalem s l non-overflow	16-A1	●	○	●	○	○	◐	●					
Peat	21A	●	○	●	○	○	◐	◐		IVw	D		
Riverwash	18A	●	●	○	○	○	●	●		VIIIs	A		
Rock outcrop	30A			●	●	●	●	●		VIII	D		
Sauvie s c l	19A												
Svenson l	37B	●	○	◐	●	●	●	●		IIe	B		
Svenson l	37C	◐	○	◐	●	●	●	●		IIIe	B		
Svenson l	37D	◐	○	○	●	●	●	●		IVe	B		
Svenson l	37E	○	○	○	●	●	●	●		VIe	B		
Svenson l	37F	○	○	○	●	●	●	●		VIIe	B		
Terrace escarpments	28E	○	●	○		●				VIe			
Tidal marsh (fresh)	22A	●	○							VIIIw			
Tolovana s l	38F	◐	○	◐	●	●	◐	●		VIe	B		
Tolovana s l	38G	○	○	◐	●	●	◐	●		VIe	B		
Tolovana s l sandstone subs	38-E1	◐	○	◐	●	●	◐	●		VIe	B		
Tolovana s l sandstone subs	38-F1	○	○	◐	●	●	◐	●		VIe	B		
Walluski s l	6B	●	○	◐	●	○	◐	●		IIe	B		
Walluski s l	6C	◐	○	◐	●	○	◐	●		IIe	B		
Walluski s l	6D	◐	○	◐	●	○	◐	●		IIIe	B		
Warrenton l f sy	23A	●	○	●	●	○	●	●		IVw	B/D		
Westport f sy	24E		○	○	●	●	●	●			A		
31 s c l	31B												
35 s c l	35B	●											

RATING (constraints)	LOW	MED	HIGH
	●	◐	○
% SLOPE	0-9 %	10-24%	25+
DEPTH TO BEDROCK	<60		+60
EROSION POTENTIAL	LOW	MED	HI
FLOOD POTENTIAL	NO		YES
WATER TABLE	+6ft		<6ft
PERMEABILITY	+2 in/hr	6-2 in/hr	<6 in/hr
SHRINK / SWELL	LOW	MED	HI

TABLE 210-6

CREST

COLUMBIA RIVER ESTUARY STUDY TASKFORCE

SOIL CHARACTERISTICS MATRIX

PACIFIC COUNTY

s	silt	c	clay
sy	sand	f	fine
		g	gravelly
		l	loam

SOILS	map sym	% SLOPE	DEPTH TO BEDROCK	EROSION POTENTIAL	FLOOD POTENTIAL	WATER TABLE	PERMEABILITY	SHRINK / SWELL	AGRICULTURE CLASS	HYDROLOGIC GROUP
Astoria s l	100	●	●	●	●	●	◐	●	VIe	B
Astoria s l	101	◐	●	◐	●	●	◐	●	VIe	B
Astoria s l	102	○	●	○	●	●	◐	●	VIIe	B
Blaney	351	◐	○	◐	●	○	○	●	IVe	B
Blaney	352	○	○	◐	●	○	○	●	VIe	B
Boistfort	360	●	○	◐	●	●	◐	●	IIIe	B
Boistfort	361	◐	○	◐	●	●	◐	●	IVe	B
Boistfort	362	○	○	◐	●	●	◐	●	VIe	B
Bunker s l	600	●	●	◐	●	●	◐	●	IIIe	B
Bunker s l	601	◐	●	◐	●	●	◐	●	IVe	B
Bunker s l	602	○	●	◐	●	●	◐	●	VIe	B
Bunker s l	603	○	●	◐	●	●	◐	●	VIIe	B
Coastal Beaches	7	●		○	○	○	●	●	VIII	
Crim	380	●	○	●	○	○	○	●	IIIw	C
Dune land	9	●		○	●	●	●	●	VIII	
Elochoman s l	290	●	○	◐	●	●	◐	●	IIIe	B
Elochoman s l	291	◐	○	◐	●	●	◐	●	IVe	B
Elochoman s l	292	○	○	◐	●	●	◐	●	VIe	B
Elochoman s l	293	○	○	◐	●	●	◐	●	VIIe	B
Fill land	5	●				○			IVw	
Grehalem s l	210	●	●	●	○	○	◐	●	IIIw	B
Katula	411	◐	●	◐	●	●	◐	●	VIe	B
Katula	412	○	●	◐	●	●	◐	●	VIIe	B
Katula	413	○	●	◐	●	●	◐	●	VIIe	B
Knappa s l	330	●	●	●	●	●	◐	●	IIe	B
Lytell s l	281	◐	●	◐	●	●	●	●	IVe	B
Lytell s l	282	○	●	◐	●	●	●	●	VIe	B
Lytell s l	283	○	●	◐	●	●	●	●	VIIe	B
Nemah s c l	430	●		●	●	○	○	○	VIw	D
Netarts f sy	440	●		○	●	○	●	●	VIe	A
Nuby s l	320	●	○	●	○	○	◐	●	IVw	C
Ocosta s c l (fresh)	130	●	○	●	○	○	○	○	IVw	D
Ocosta s c l (salt)	131	●	○	●	○	○	○	○	VIIIw	D
Orcas peat	460	●		●	○	○	●	○	VIIIw	A
Rennie s c l	470	●		●	○	○	◐	○	IIIw	C
Salzer s c	480	●		●	○	○	○	○		D
Satsop s l	160	○	○	●	●	○	◐	◐	IVw	B
Seattle muck	490	●		●	○	○	◐	○	IIw	A
Shalcar muck	500	●		●	○	○	◐	○	IIw	A
Skamo s l	590	○	○	●	●	○	◐	◐	IVw	B
Squally g s l	621	◐	○	◐	●	●	●	●	IVe	B
Squally g s l	622	○	○	◐	●	●	●	●	VIe	B
Sylvia	520	●	○	●	●	○	○	●	IIIw	C
Udipsamments (level)	3	●	○		●	●			VIIs	A
Umbric Dystrochrepts	4	○	○	○	●	●			VIIIe	
Westport sy	540	●		○	●	○	●	●	VIIe	A
Willapa s l	560	●			●	○	◐	◐	Vs	C
Willapa s l	561	◐			●	○	◐	◐	VIe	C
Willapa s l	562	○			●	○	◐	◐	VIe	C
Yaquina l sy	580	●			○	○	●	●	VIIe	C
Zenker s l	631	◐		○	●	●	●	●	IVe	B
Zenker s l	632	○		○	●	●	●	●	VIe	B
Zenker s l	633	○		○	●	●	●	●	VIIe	B

RATING (constraints)	LOW	MED	HIGH
	●	◐	○
% SLOPE	0-9 %	10-24%	25+
DEPTH TO BEDROCK	<60		+60
EROSION POTENTIAL	LOW	MED	HI
FLOOD POTENTIAL	NO		YES
WATER TABLE	+6ft		<6ft
PERMEABILITY	-2 in/hr	.6-2 in/hr	<.6 in/hr
SHRINK / SWELL	LOW	MED	HI

TABLE 210-7

CREST
COLUMBIA RIVER ESTUARY STUDY TASKFORCE

SOIL CHARACTERISTICS MATRIX

WAHKIAKUM COUNTY

c clay
l loam
g gravelly
s silt

SOILS	map sym	% SLOPE	DEPTH TO BEDROCK	EROSION POTENTIAL	FLOOD POTENTIAL	WATER TABLE	PERMEABILITY	SHRINK / SWELL		AGRICULTURE CLASS	HYDROLOGIC GROUP
Arta s l	170	●		●			◐			IIc	B
Astoria s l	100	●	●	●	●	●	◐	●		VIe	B
Astoria s l	102	◐	●	◐	●	●	◐	●		VIe	B
Astoria s l	103	○	●	○	●	●	◐	●		VIIe	B
Bunker s l	120	●	●	◐	●	●	◐	●		IIIe	B
Bunker s l	122	◐	●	◐	●	●	◐	●		IVe	B
Bunker s l	123	○	●	◐	●	●	◐	●		VIe	B
Bunker s l	124	○	●	◐	●	●	◐	●		VIIe	B
Cathlamet s l	110	●	○	◐	●	●	◐	●		IIe	B
Cathlamet s l	112	◐	○	○	●	●	◐	●		IVe	B
Cathlamet s l	113	○	○	○	●	●	◐	●		VIe	B
Cathlamet s l	114	○	○		●	●	◐	●		VIe	B
Elochoman s l	290	●	○	◐	●	●	◐	●		IIIe	B
Elochoman s l	291	◐	○	◐	●	●	◐	●		IVe	B
Elochoman s l	292	○	○	◐	●	●	◐	●		VIe	B
Elochoman s l	293	○	○	◐	●	●	◐	●		VIIe	B
Germany s l	150	●	○	●	●	●	●	●		IIe	B
Germany s l	151	◐	○		●	●	●	●		IIIe	B
Germany s l	153	○	○	○	●	●	●	●		IVe	B
Grehalem l	210	●	●	●	○	○	◐	●		IIc	B
Humptulips s l	140	●	○		○	●	◐	●		IIIw	B
Knappa s l	330		●	●	●	●	◐	●			B
Lutes s l	241	◐	●	●	●	●	●	●		VIe	B
Lutes s l	242	○	●		●	●	●	●		VIIe	B
Lutes s l	243	○	●		●	●	●	●		VIIe	B
Lytell s l	281	◐	●	◐	●	●	●	●		IVe	B
Lytell s l	282	○	●	◐	●	●	●	●		VIe	B
Lytell s l	283	○	●	◐	●	●	●	●		VIIe	B
Nuby s l	320	●	○	●	○	○	◐	●		IVw	C
Ocosta s c l	130	●	○	●	○	○	○	○		IVw	C
Raught s l	191	◐	●	◐	●	●	●	●		IIIe	B
Raught s l	193	○	●	○	●	●	●	●		VIe	B
Riverwash	2	●	●	●	○	○	●	●			
Sauvie s l	230	○		●						IVw	C D
Skamo s l	160	○	○	●	●	○	◐	◐		IVw	B
Squally g s l	310	○	○	◐	●	●	●	●		IVe	B
Squally g s l	311	○	○	◐	●	●	●	●		VIe	B
Stimson s l	180	●	○		●	○	○	●		IVw	C
Tidal Marsh (fresh)	6	●	○		○						
Udipsamments (level)	3	●	○		●	●				VIIs	A
Umbric Dystrochrepts	4	○	○	○	●	●				VIIIe	
Wahkiakum s l	221	◐	○	◐	●	●	●	●		Ve	B
Wahkiakum s l	222	○	○		●	●	●	●		VIe	B
Wahkiakum s l	223	○	○		●	●	●	●		VIIe	B
Zenker s l	136	◐		○	●	●	●	●		IVe	B
Zenker s l	138	○		○	●	●	●	●		VIe	B
Zenker s l	139	○		○	●	●	●	●		VIIe	B
(Murnen) Zyzyl s l	300	◐								VIe	B
(Murnen) Zyzyl s l	301	○								VIIe	B

RATING (constraints)	LOW ●	MED ◐	HIGH ○
% SLOPE	0-9 %	10-24%	25+
DEPTH TO BEDROCK	<60		+60
EROSION POTENTIAL	LOW	MED	HI
FLOOD POTENTIAL	NO		YES
WATER TABLE	+6ft		<6ft
PERMEABILITY	+2 in/hr	.6-2 in/hr	<6 in/hr
SHRINK / SWELL	LOW	MED	HI

Areas most susceptible to flooding are along valley bottoms, stream and river beds, and at the mouths of rivers and streams. With proper planning, flood-prone areas can be and are used for many beneficial purposes, without posing a serious hazard. Certain recreational and agricultural uses are examples. Periodic flooding is sometimes beneficial, as it may renew soil nutrients on croplands.

5. Erosion Potential

Erosion Potential refers to the likelihood of the soil being washed away by rainfall and subsequent runoff, if suitable ground cover is not maintained. Factors influencing erosion potential are rainfall, degree of the slope, length of the slope, and type of ground cover.

6. Shrink-Swell Potential

Shrink-swell potential is the extent to which the soil swells increases volume) when it gets wet and shrinks (decreases volume) when it dries out. It refers to the relative change in soil material volume to be expected with changes in moisture content. Shrinking and swelling of certain soils causes serious damage to building foundations, roads, and other structures. A high shrink-swell potential indicates a maintenance hazard for structures built in, on, or with such soil material.

7. Depth to Bedrock

This characteristic refers to the depth, in feet, from the soil surface to bedrock. Bedrock prevents or restricts root and water penetration and represents the lower boundary of the soil horizon. For agricultural uses, deep bedrock is generally favorable, whereas for development, shallow bedrock is desirable for good foundations.

8. Hydrologic Group

Hydrologic soil groups are used to characterize surface runoff from thoroughly wetted, bare soil, after rainfall. The influence of ground cover is treated independently from hydrologic soil groups. Soils are grouped from A to D, with group A having the lowest surface runoff potential and D having the highest runoff potential.

a. GROUP A

Group A soils have low surface runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravel. These soils have a high rate of water transmission.

b. GROUP B

Group B soils have moderately low surface runoff potential and moderate infiltration rates when thoroughly wetted. They consist chiefly of moderately deep to deep, moderately to well drained soils, with moderately rapid permeability. These soils have a moderate rate of water transmission.

c. GROUP C

Group C soils have moderately high surface runoff potential and slow infiltration rates when thoroughly wetted. They consist chiefly of soils with a layer that impedes downward movement of water, soils with moderately fine to fine texture, soils with slow infiltration, or soils with moderate seasonal water tables. These soils may be somewhat poorly drained. They include well and moderately well drained soils, with slow to very slow permeability at twenty to forty inches. Thus, these soils have a slow rate of water transmission.

d. GROUP D

Group D soils have high runoff potential and very slow infiltration rates when thoroughly wetted. They are chiefly shallow clay soils with a high swelling potential, a permanent high water table, very slow infiltration, and nearly impervious claypan or layer at, or near, the surface.

9. Agricultural Suitability

Agricultural capability classes show, in a general way, the suitability of soils for most kinds of field crops. The classes are determined by soil limitations, potential hazards and risks of damages when used for field crops. The grouping does not consider major land reshaping that would change some characteristics of the soils. Nor does it take into consideration, possible major reclamation projects. In grouping the soils in the Columbia River Estuary, two levels were used, the capability class and the subclass.

The capability classes are designated by Roman numerals I through VIII. The numerals indicate progressively greater limitations and narrower choices for practical use.

a. Class I soils have few limitations that restrict their use. They may be used safely for cultivated crops, pasture, range, woodland, or wildlife.

b. Class II soils have moderate limitations that reduce the choice of plants or require moderate conservation practices. They are suited for cultivated crops, pasture, range, woodland, or wildlife.

c. Class III soils have severe limitations that reduce the choice of plants, require special conservation practices, or both. They are best suited for cultivated crops, pasture, range, woodland, or wildlife.

d. Class IV soils have very severe limitations that reduce the choice of plants, require very careful management, or both. Their soils are best suited for cultivated crops, pasture, range, woodland, or wildlife.

e. Class V soils are not likely to erode but have other limitations, impractical to remove, that limit their use largely to pasture, range, woodland, or wildlife.

f. Class VI soils have severe limitations that make them generally unsuited for cultivation. They are largely limited to less intensive pasture, range, recreation, woodland, or wildlife uses.

g. Class VII soils and landforms have limitations that preclude their use for commercial plants, and restrict their use to recreation, wildlife, or water supply.

h. Class VIII soils and landforms have limitations that preclude their use for commercial plants, and restrict their use to recreation, wildlife, or water supply.

10. Capability Subclasses

Capability subclasses are soil groups within one class. By adding a small letter e, w, s, or c to the class numeral, the primary limiting factor is designated. The letter "e" indicates that the main limitation is risk of erosion, unless close-growing plant cover is maintained. The letter "w" indicates that water in or on the soil interferes with plant growth or cultivation (in some soils the wetness can be partly corrected by artificial drainage). The letter "s" indicates that the soil is limited, due to its shallow dry or stony nature. The letter "c", used in only some parts of the United States, shows that the chief limitation is climate that is too cold, too dry, or too cloudy for production of many crops.

B. Use of Map, Table, and Matrix

The soil association map, tables, and soil matrices can be used together to determine the general characteristics for an area. After locating the area in question on the map, consult the table for the appropriate county. The association numbers on the map correspond to the numbers on the tables. After determining the major soil in the association, the soil matrix can be consulted to determine the soil characteristics. It should be emphasized that this method provides a general indication of the characteristics of an area. To determine specific features, a detailed map of soil types should be consulted or an on-site investigation should be performed, before consulting the matrix. It should also be noted that the soils were rated on the majority characteristic. Thus, a characteristic may occasionally include a range larger than the rating.

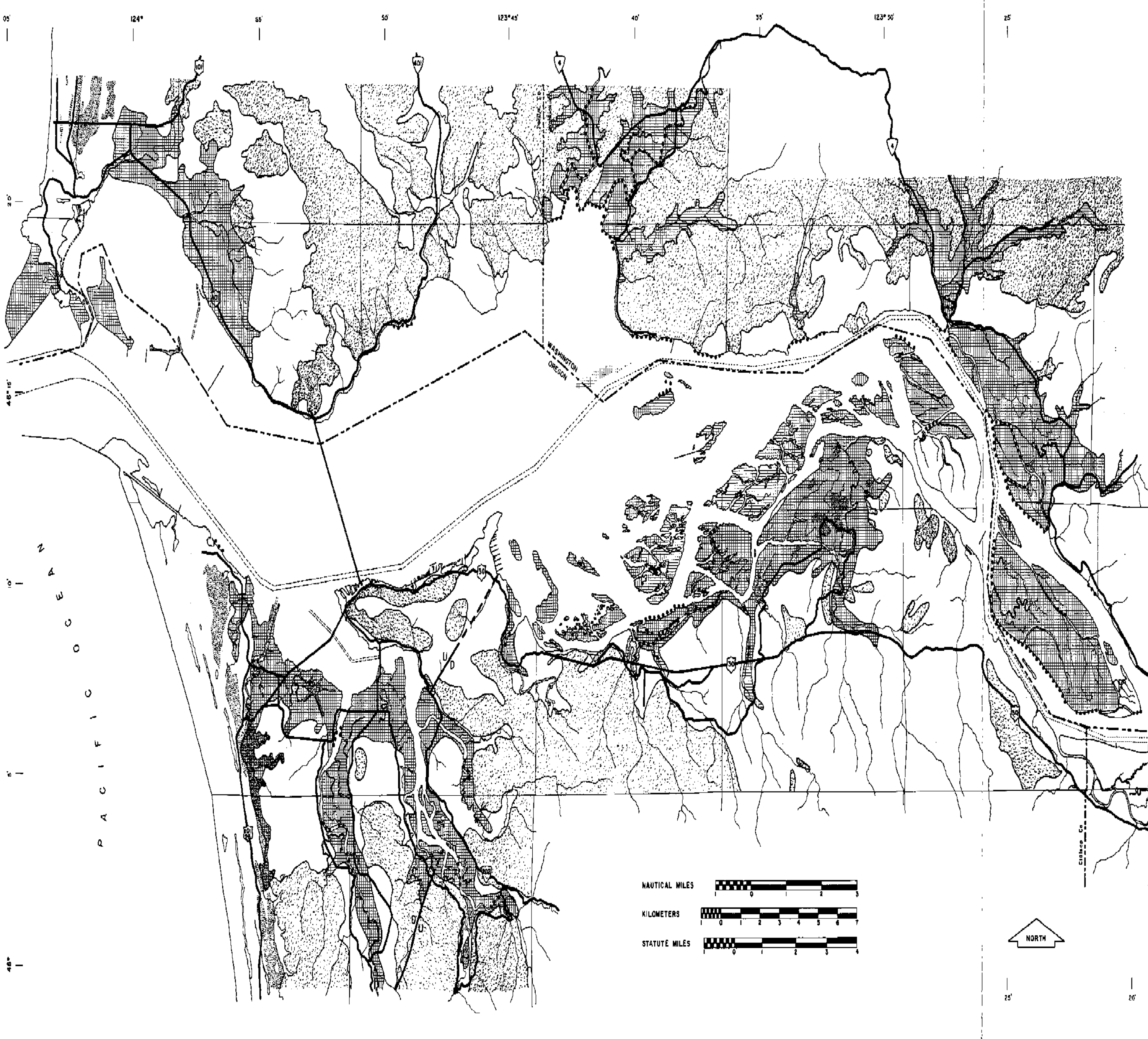
210.3 HAZARDS

The hazards section and map (Figure 210-4) show areas where, under certain conditions, there could be risk to human life or serious property loss. In the three county areas adjacent to the Columbia River estuary, such risks could result from landslides, floods, earthquakes, and the presence of compressible soils. Much of the information mapped in Figure 210-4 is generalized. Exact boundaries of the hazards can be established only by future detailed studies of specific localities.

A. Landslides

The erosion of slopes through any of a variety of processes results in slope retreat or "landsliding". One of the major forms of slope retreat is soil creep, the slow downslope movement of earth and rock under the influence of gravity. Variations of temperature and water content, and the influence of plant and animal activity are important factors in the rate of soil creep. A more rapid downslope movement similar to soil creep is called a debris slide or landslide.

The term "slump" is used when a more or less continuous mass of earth slips downhill. On nearly vertical slopes, masses of bedrock or earth may become detached and fall. This type of activity is termed "rockfall."



HAZARDS

- FLOODING
- LANDSLIDE TOPOGRAPHY
- COMPRESSIBLE SOILS
- STREAMBANK EROSION
- FAULT LINE
  - DASHED WHERE APPROXIMATE
  - U UPTHROWN SIDE
  - D DOWNTHROWN SIDE

FROM 1. STATE OF OREGON DEPT. OF GEOLOGY AND MINERAL INDUSTRIES, 1972 & 1973.
2. SOIL CONSERVATION SERVICE.

CREST
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FIGURE 210-4

The various forms of landslides are directly related to the topography of an area. Massive land failure is caused primarily by the high winter rainfall, which saturates the weathered and soft marine sedimentary rocks underlying a good portion of the study area. The areas noted as having landslide topography are obvious hazard areas. However, stable areas could also be endangered when located below the landslide topography.

Landslide topography is a major feature of the uplands surrounding the estuary. Much of Wahkiakum County's uplands would be prone to mass movement, should the vegetative cover be removed. The shoreline area between the eastern boundary and the town of Cathlamet is also subject to downslope movement, if there is vegetation removal or an increase in the intensity of activity along the shoreline.

Clatsop County also has large areas subject to landslides. The major area is noted as being south of Astoria. This area is mostly in timber production and with proper management, it won't experience massive slope failure. Astoria has several locations of active slope movement. Much of this has been caused by urban activities and has resulted in damage to public and private property. Eastern Clatsop County has little area that is subject to slope failure. The two areas that would affect the study area are on the shoreline between Aldrich Point and Bradwood and the upland area south of Wauna and Westport.

B. Floods

A flood is defined as a condition that prevails when the waters of a stream or river exceed the capacity of the normal channel and overflow the adjacent flood plains. Unfortunately, detailed flood studies have not been completed for the lower Columbia region. The 100-year floodplain determinations exist for Wahkiakum County, parts of Clatsop County, and the Chinook area of Pacific County. Flood potential for the rest of the area must be evaluated from a combination of general studies including: Flood frequency profiles, prepared by the U.S. Army Corps of Engineers; flood area delineation in Clatsop County, Oregon, by the Oregon Department of Geology and Mineral Industries; 100-year flood event approximation by diking and drainage districts; and soils information on soils with flooding potential.

The reach of the Columbia River in the estuary undergoes no significant seasonal fluctuations in depth and areal extent. In fact, the fluctuations that do occur in the estuary are on a daily basis, in response to tidal action.

The small streams draining into the estuary are subject to only moderate variations in streamflow and generally pose no threatening hazards to most of man's activities. However, the Big Creek drainage area, in the eastern section of the estuary in Clatsop County, is subject to torrential flooding and related erosion. The steep slopes and low permeability of this drainage area account, in large part, for the high runoff.

Flooding in the estuary area is caused by heavy rainfall, high tides, and strong winds. Construction of dikes, levees, or landfills can protect lands from flooding. However, such construction can also shift the water that would fill the floodplain downstream, to flood some other area. This type of activity could occur in the diked areas of Youngs Bay and Grays Bay and the sloughs around Skamokawa and Brownsmead. Also unique to the estuary is the factor that water may be unable to drain because of high tides or winds, and it will "back up" into other areas and may result in a flood condition.

Flood frequency profiles completed by the U.S. Army Corps of Engineers provide an estimated height of a 100-year, unregulated flood event. Table 210-8 shows these heights at selected points throughout the estuary. The 100 and 500-year floodplains have also been mapped for parts of the estuary area by the Federal Insurance Administration of the U.S. Department of Housing and Urban Development. These are used in the administration of the Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

While flooding in the Columbia River is largely regulated, except for tidal fluctuations, flooding does occur in the tributaries within the study area. This flooding may subsequently affect the area at the mouth of the tributary where it joins the estuary, but is will have little effect on the overall river height. As shown on the hazards map, flooding potential exists on almost all estuary area lowlands.

Another type of flooding, a tsunami (seismic wave), should also

Table 210-8

100-Year Flood Event Unregulated[1]

Location	Height[2]
Fort Stevens, Oregon	8.5
Astoria, Oregon	8.8
Tongue Point, Oregon	9.0
Harrington Point, Washington	9.1
Jim Crow Point, Washington	9.6
Skamokawa Creek, Washington	10.2
Lower End of Puget Island, Washington	11.0
Wauna, Oregon	11.9
Upper End of Puget Island, Washington	13.0

[1] United States Army Engineer District, Portland, Columbia River Flood Frequency Profiles, Fall and Winter Freshets, Drawing #CL-03-133/1, 1972.

[2] Height is the approximate height above mean sea level in feet.

be mentioned. These waves are sea waves caused by submarine earthquakes or volcanic eruptions. While the coastline is the area most affected by this type of wave activity, it can also cause damage within the estuary. The tsunami generated by Alaska's Good Friday earthquake in March, 1964, caused $20,000 worth of damage to the dock and log raft areas in Warrenton. Tide level reached an unexpected high of about 11.5 feet above mean sea level.

The extent of damage caused by a tsunami in an estuary dependent on several factors: the source of the disturbance, the level of the tide (tidal height) and the strength of the tide (spring or neap). The most dangerous conditions would occur when a tsunami struck at high tide during spring tides from a source that enabled the energy to travel directly through the mouth of the river.

C. Earthquakes

The west coast of North America is situated along an active earthquake belt which encircles the Pacific Ocean Basin. Although the coastal parts of California and Washington experience more seismic activity than coastal Oregon, earthquake potential is still a significant hazard.

In July, 1938, an earthquake of approximate intensity 3.5 on the Richter Scale originated at an epicenter near Astoria. Recorded damage was minimal, and the tremor was significant only in that it showed the potential for earthquakes in the estuary area.

Vibrating ground motion during earthquakes can affect not only buildings, bridges, and other structures, but also areas of potential land subsidence and landslides. Areas of peat and organic soils and thick sections of sand and gravel may consolidate and subside as a result of seismic shaking. Since subsidence is usually uneven, buildings on this type of ground will be tipped or destroyed. In regions of moderate to high relief and unstable slopes with saturated ground conditions, such as often occur in the estuary region during winter and spring months, seismic shaking could produce massive landslides.

Large earthquakes with epicenters outside the estuary region also have significance with regard to seismic shaking hazards. In

November, 1962, an earthquake occurred in the Portland area and was felt over a total area of 20,000 square miles. An earthquake centered at Olympia, Washington occurred in April, 1949, and was felt as far south as Cape Blanco on the southern Oregon coast.

D. Streambank Erosion

Erosion of streambanks, while not a severe hazard in the estuary, often poses hazards to activities that may be present along the shoreline. It subsequently serves as a constraint to development. Within the estuary, erosion occurs along the islands where the river flow is constricted (therefore faster) and along many tributary streams, where the meandering course of the waterway results in erosion. Figure 210-4 shows areas of streambank erosion based upon observations of the Counties' Soil Conservation Office staff.

Most of the eroding areas within the estuary and the tributaries are adjacent to low intensity land uses such as agriculture and forest uses. Because of this, there is no widespread danger to human life, but rather, it constitutes a continuing loss of property, unless measures are taken to slow the process. The primary hazard exists where erosion is affecting dikes that protect low lying areas from flooding. This consists of eroding areas such as Puget Island, Deep River, Grays River, Elochoman River, and the Lewis and Clark River.

E. Compressible Soils

Compressible soils include peat and organic soils. In the estuary, they occur in the tidal flats of the Columbia, Skipanon, Lewis and Clark, and John Day Rivers and in the Clatsop Spit area. In addition, some terraces are underlain by layers of peat and organic soils.

While compressible soils do not constitute a hazard to the degree of earthquakes, landslides and floods, they certainly are a limitation to development. Peat and organic soils are poor foundation materials for many types of construction. They contain a high proportion of void space to solids and do not consolidate readily under natural conditions. Structural loads on peat, however, will cause consolidation, as water is forced out of the voids. Settlement, which is usually irregular, can amount to more than 50 percent of the thickness of the original layer.

Peat can also occur in the subsurface without any indications of its presence at the ground surface, particularly in tidal flats or other low lying areas of high ground water. Compressible soils situated as far as 50 feet below the surface, can compress significantly under heavy loads.

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300 BIOLOGICAL CHARACTERISTICS

301

ECOLOGICAL CONCEPTS AND TERMINOLOGY

COLUMBIA RIVER ESTUARY

ECOLOGICAL CONCEPTS AND TERMINOLOGY

James W. Good

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301 ECOLOGICAL TERMS AND CONCEPTS

An estuary must be viewed as a concept rather than a physical entity that can be easily defined and geographically mapped. The Columbia River estuary provides an excellent example of the difficulty involved in defining the limits of a particular estuary. Great and variable freshwater discharge, significant tidal and wave energy, markedly variable salt water intrusion, morphology and other factors combine to make it an unusually dynamic estuary. The response of plant and animal life to these dynamics is extremely complex and not well understood. Subsequent sections describing biological resources often make note of this fact. Nevertheless, there have been many useful research studies that provide facts and insight into the ecological complexities of the estuary. This section defines the concepts and terminology used when discussing these complexities.

301.1 ESTUARINE ECOSYSTEM DEFINED

An estuary is defined by Odum in Fundamentals of Ecology (1971) as "a semi-enclosed coastal body of water which has a free connection with the open sea; it is thus strongly affected by tidal action, and within it, sea-water is mixed (and usually measurably diluted) with freshwater from land drainage."

The word ecology is derived from the Greek word *oikos* which means "house" or "place to live." Ecology, then, is the study of the place where organisms live.

A system is defined by Webster as "regularly interacting and inter-dependent components forming a unified whole."

An ecological system, or ecosystem, is a unified whole consisting of all organisms in a given area interacting with the abiotic (non-living environment) in such a way that the energy flow leads to a clearly defined structure of food relationships, biologic diversity, and cycling of minerals and nutrients.

An estuarine ecosystem is a transition zone between adjacent marine and freshwater environments. However, many of its most important physical and biological characteristics are not transitional, but different from both the river and the ocean. Variability is a key characteristic, and while stressful conditions often limit the number of species present, the food conditions are so favorable that estuaries are packed with an abundance of life.

301.2 ECOSYSTEM COMPONENTS

Although ecosystems are often very complex and difficult to fully understand, they are made of basic components which are easily defined. The first three components listed below make up the non-living or abiotic environment, while the last three make up the living or biotic environment and constitute biomass (living weight). These basic components of ecosystems include the following: (1) the physical regime which includes temperature, solar radiation, wind, tidal forces, pollution, and other physical factors; (2) inorganic substances such as carbon dioxide, nitrogen, phosphate, and water that are involved in mineral cycling; (3) organic compounds such as proteins, carbohydrates, fats, and humic substances that link living and non-living components; (4) producers such as green marsh plants and microscopic plants called phytoplankton that are able to manufacture food from simple inorganic substances and sunlight by the process of photosynthesis; (5) consumers, chiefly invertebrate animals, fish, birds, and man which ingest producers and/or other consumers; (6) decomposers, primarily bacteria and fungi that break down particulate organic matter, and release nutrients to fuel new production by plants. This organic matter may be living organisms or the remains of plants and animals, collectively called detritus. When the abiotic components of the ecosystem are suitable for plant production, the consumers may flourish and contribute detritus to the decomposers, which in turn release nutrients to plant production, and so the cycle goes.

301.3 ECOLOGICAL TERMINOLOGY

Analysis of functional relationships in the estuarine ecosystem makes the above descriptive information more useful. For the understanding and best possible ecosystem management, it is important to know how energy flows through the system, how food chains or webs are constructed, how diversity and abundance vary, how nutrients cycle, and how the system is controlled. Some of these functional relationships will be examined as they apply to the Columbia River estuary in subsequent sections of the Inventory. But first, some terms and concepts used in ecology must be defined and discussed.

A. Productivity and Standing Crop

Primary productivity is defined as the rate at which producers (primarily green plants, algae, and phytoplankton) convert nutrients, carbon dioxide and light energy from the sun into food material (new plant tissue).

The key word in the definition is rate, because productivity refers to the energy fixed per unit of time. Secondary productivity refers to the rate at which consumers, such as zooplankton, fish and man, store energy at higher levels on the food chain.

In general terms, productivity refers to biological "richness." However, productivity should not be confused with standing crop, which is the number or weight of individuals present at any one given time. While this measure is often directly related to productivity, it is not necessarily so. Standing crop or biomass, is more a measure of the production that is stored or held in reserve. This storage is a key factor in stabilizing the estuarine ecosystem in that it provides a food and energy reserve for times of the year when productivity is low. Major storage components in estuaries include tidal marshes and mudflats.

B. Ecosystem Organization

Ecosystems are studied and discussed on different organizational levels, each increasingly complex. These levels are:

1. Individual Level

Individual organisms of a single species are the lowest level of organization in ecology. However, even individual organisms are very complex.

2. Population Level

Populations are groups of individuals of the same species, such as total number of a particular estuary fish. A population interacts with the living and non-living environs and fluctuates in numbers.

3. Community Level

Ecological communities are assemblages of different populations that occur in a given defined area and which affect one another in a significant way. There are communities, for instance, in mud flats, marshes and open water.

4. Ecosystem Level

The ecosystem level embraces the several communities that make up, for example, the estuarine ecosystem. The present assemblages of species, populations, communities and ecosystems are the result of long-term evolutionary and shorter-term successional processes.

C. Ecological Succession

Ecological succession in a given area is the gradual replacement of less mature communities with more mature communities. This replacement results from interactions of species with the environment. In an estuary marsh, for example, the plant communities which colonize the flat at the outer edge continue to move outward, being replaced by more mature communities.

D. Chemical Cycling

Chemicals such as carbon, oxygen, hydrogen, nitrogen, sulfur and others are the materials of which living organisms are made. Non-living chemical nutrients are taken up by green plants, organized, passed on in the food chain and eventually broken down by decomposers, once again available for uptake and new plant production (Figure 301-1). In the Columbia and other estuaries, the physical availability of nutrients is strongly controlled by river flow. Nutrients flowing downstream are continually being flushed out of the estuary to the sea.

E. Energy Flow

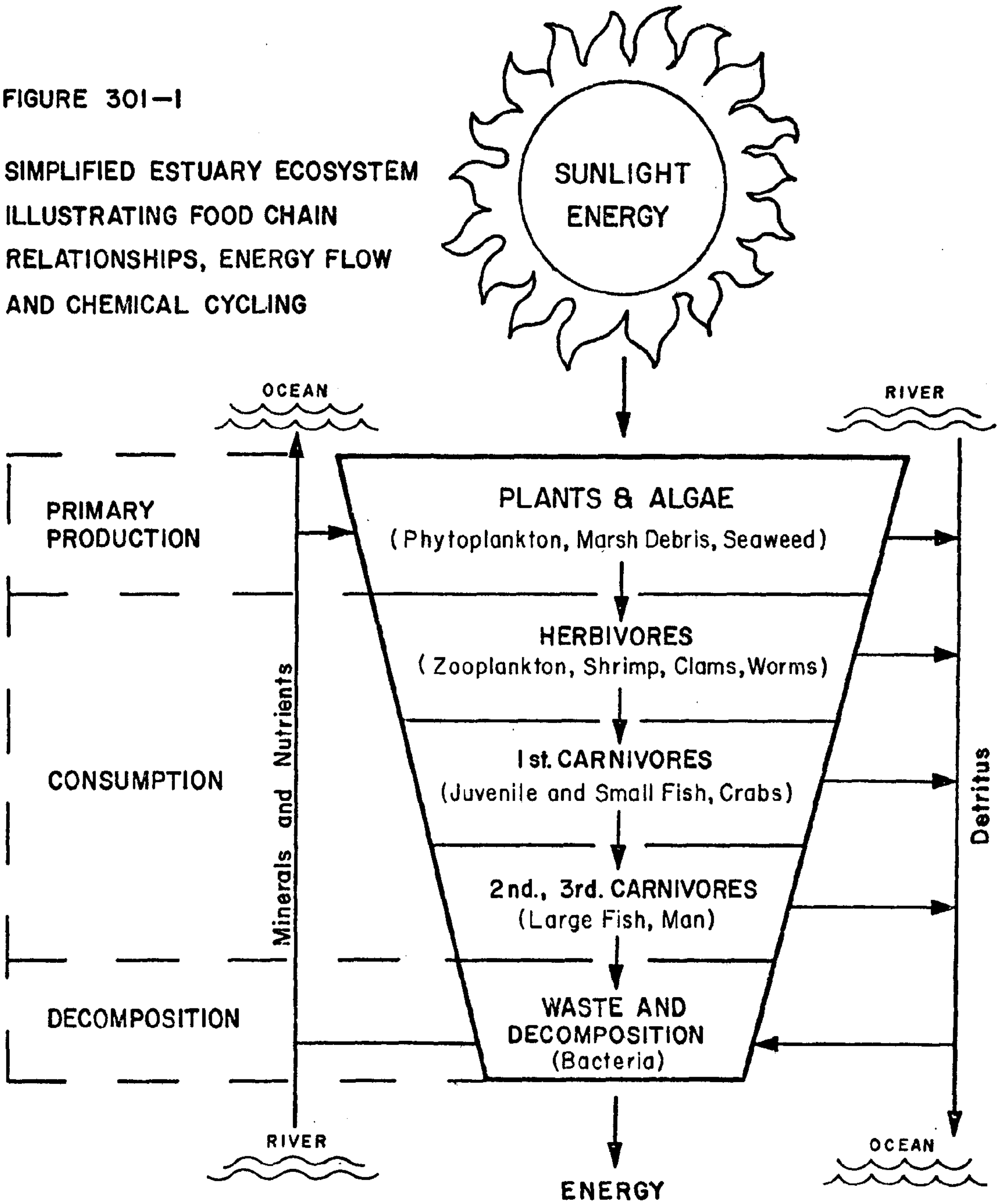
The ultimate source of energy for life in our world is the sun. Flowing through ecosystems, this energy is the essential driving force behind the cycling of chemical nutrients. Light energy from the sun is captured, converted and stored by green plants and subsequently passed on to higher levels in the food chain. The energy thus diverted into the living world is used to maintain and further organize the living world. Eventually, however, the energy which has been temporarily diverted and stored must be lost as organisms die and are decomposed (Figure 301-1).

F. Food Webs

The term food web implies complex producer-consumer interrelationships. While feeding relationships can be complex and variable, the concept is simple and can be described as a "food chain" (Figure 301-1). A primary producer converts sun energy to plant material. This material is eaten by animal herbivores, which in turn, are preyed upon by carnivores and/or omnivores, which also feed on plants directly. Each transfer along the chain is about 10% efficient; that is, for every 10 pounds of biomass consumed, only one pound is used to produce biomass in the consumer. The rest is lost to body function maintenance and waste. Decomposers or microconsumers form an essential link in the food chain, breaking down

FIGURE 301—I

SIMPLIFIED ESTUARY ECOSYSTEM ILLUSTRATING FOOD CHAIN RELATIONSHIPS, ENERGY FLOW AND CHEMICAL CYCLING



1. ENERGY FLOWS THROUGH THE SYSTEM AND IS LOST.
2. MINERALS, NUTRIENTS, AND DETRITUS ARE BROUGHT DOWNSTREAM WITH THE RIVER, RECYCLED AND EVENTUALLY LOST TO THE OCEAN.

complex organic matter into its inorganic, non-living chemical constituents, which again become available for primary production. Each step in the food chain is termed a trophic (or feeding) level. The interrelationship between these levels is the food web and varies with season and location in the estuary.

G. Carrying Capacity

Carrying capacity is the ability of an ecosystem to support organisms, usually expressed in biomass or numbers. This concept has significant implications in man-managed systems, where changes in carrying capacity often result from physical or biological alterations.

H. Limiting Factors

Limiting factors are the ecosystem characteristics which limit diversity or abundance of species. Availability of light, nutrients, food, habitat and space are examples of factors which limit populations.

I. Species Abundance and Diversity

Species abundance refers to the number of organisms of the same species in a given area. Species diversity refers to the number of different species in a given area. In estuaries, species diversity is often low, but the abundance of those species present is often very great.

J. Habitat and Ecological Niche

The habitat of an organism is the place where it lives, or the place where one would look for it. Habitat may also refer to the place occupied by an entire community, such as a tidal marsh community. The ecological niche, on the other hand, is a more inclusive term that includes not only the physical space occupied, but also the functional role (such as feeding relationships), its position with respect to environmental gradients including salinity, temperature, sediments, moisture, and other conditions of existence. By analogy, it may be said that the habitat of an organism is its "address" and niche is its "profession," biologically speaking.

301.4 BIOLOGICAL CLASSIFICATION BY SALINITY

Variable salt content in estuarine waters is one of the most biologically significant differences between it and adjacent marine and freshwater environments. All forms of life in an estuary must respond to these changes and their response is used as a basis for differentiating between groups of plants and animals. The distinction is most clearly illustrated with aquatic animal life in estuaries. While species, size, form, feeding habits and other characteristics are used to group or classify various animals, their distribution, abundance and behavior in response to different salinities is a major consideration for all. Table 301-1 describes the major groupings of estuarine animals according to their response to salinity differences. Plankton, benthic invertebrates and fishes are discussed in subsequent sections using the terminology in this table. Salinity ranges in the table are those commonly used in the literature.

Table 301-1 ESTUARINE ANIMAL COMPONENTS ACCORDING TO SALINITY

I. THE FRESHWATER COMPONENT

A. The stenohaline* freshwater component, not penetrating salinities greater than 0.5°/oo.

B. The euryhaline* freshwater component

1. First grade - penetrate downstream through oligohaline salinities (0.5-5°/oo)

2. Second grade - penetrate downstream through mesohaline salinities (5-18°/oo)

3. Third grade - penetrate downstream through polyhaline salinities (18-30°/oo).

II. THE MARINE COMPONENT

A. The stenohaline component, not penetrating a salinity below 30°/oo.

B. The euryhaline component, extending from the sea over the middle reaches of the estuary wherever conditions are suitable.

1. First grade - penetrate upstream through polyhaline salinities 30-18°/oo)

2. Second grade - penetrate upstream through mesohaline salinities (18-5°/oo)

3. Third grade - penetrate upstream through oligohaline salinities (5-0.5°/oo).

III. THE ESTUARINE COMPONENT

Comprising the few species which are restricted to estuaries, and penetrate neither fresh or fully saline waters.

IV. THE MIGRATORY COMPONENT

Which spends only a part of its life in the estuary

A. Marine species which enter the estuary for a part of their life cycle either to feed, e.g. flounder, or to spawn, e.g. herring.

B. Species which migrate through estuaries from the sea to freshwater.

1. Anadromous species, ascending the rivers to spawn, e.g. salmon.

*Stenohaline refers to organisms with a very narrow range of tolerance to salinity
*Euryhaline refers to organisms with a wider and variable range of tolerance to salinity

Adapted From: Perkins, 1974

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302 TIDAL MARSHES

COLUMBIA RIVER ESTUARY

TIDAL MARSHES

James W. Good

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*Figure follows the page indicated.

302 TIDAL MARSHES

Tidal marshes are communities of vascular aquatic or semi-aquatic vegetation, rooted in poorly drained, poorly aerated soil, with varying quantities of salt. Tidal marshes are generally found between lower high water (LHW) and approximately extreme high water (line where non-aquatic vegetation begins).

From the mouth to about river mile (RM) 50, the Columbia River estuary has approximately 11,457 acres (4,629 hectares) of tidal marsh (Table 302-1 and Figure 302-1). The largest part of this acreage (7,173 acres) is preserved in the Lewis and Clark and Columbian White-Tailed Deer National Wildlife Refuges. The next largest marsh areas are in Grays and Youngs Bays. Many tidal marshes diked in the early part of this century are not included in these acreage totals, and no information is available on their original size.

The values and functions of tidal marshes are examined later in this section. Common and scientific names of predominant tidal marsh plants (Table 302-2) have been included for purposes of clarification. Figure 302-2 graphically shows some common Columbia River estuary tidal marsh plants.

302.1 ENVIRONMENTAL FACTORS

Environmental factors such as the duration of tidal exposure and submergence, tidal water salinity, water quality, and soil nutrients largely determine the location of tidal marshes and plant species distribution.

Generally, the predominant influence on the Columbia River tidal marshes is the very high flow of freshwater, which dilutes and limits salt water intrusion. This is particularly important in the spring, when river runoff is often more than double that of normal, and new marsh plants are germinating or spreading roots after winter dormancy. Because the river waters are less dense than intruding salt water from the ocean, the river freshwater tends to float on the surface and spread over newly-sprouting marsh plants as the tides rise. Local winter and spring rains reinforce the freshwater effects, causing high estuary tributary water flows, high water tables, and relatively low soil and soil water salinities.

Table 302-1

TIDAL MARSHES OF THE COLUMBIA RIVER ESTUARY[1]

Area[2]	Acres	Hectares[3]
Baker Bay	816	331
Lower River and Mouth	293	119
Youngs Bay-Astoria	1,136	449
Grays Bay	1,449	587
Eastern Clatsop	569	230
Eastern Wahkiakum	464	188
Columbia River Islands[4]	6,730	2,725
Columbia River Estuary	11,457	4,629

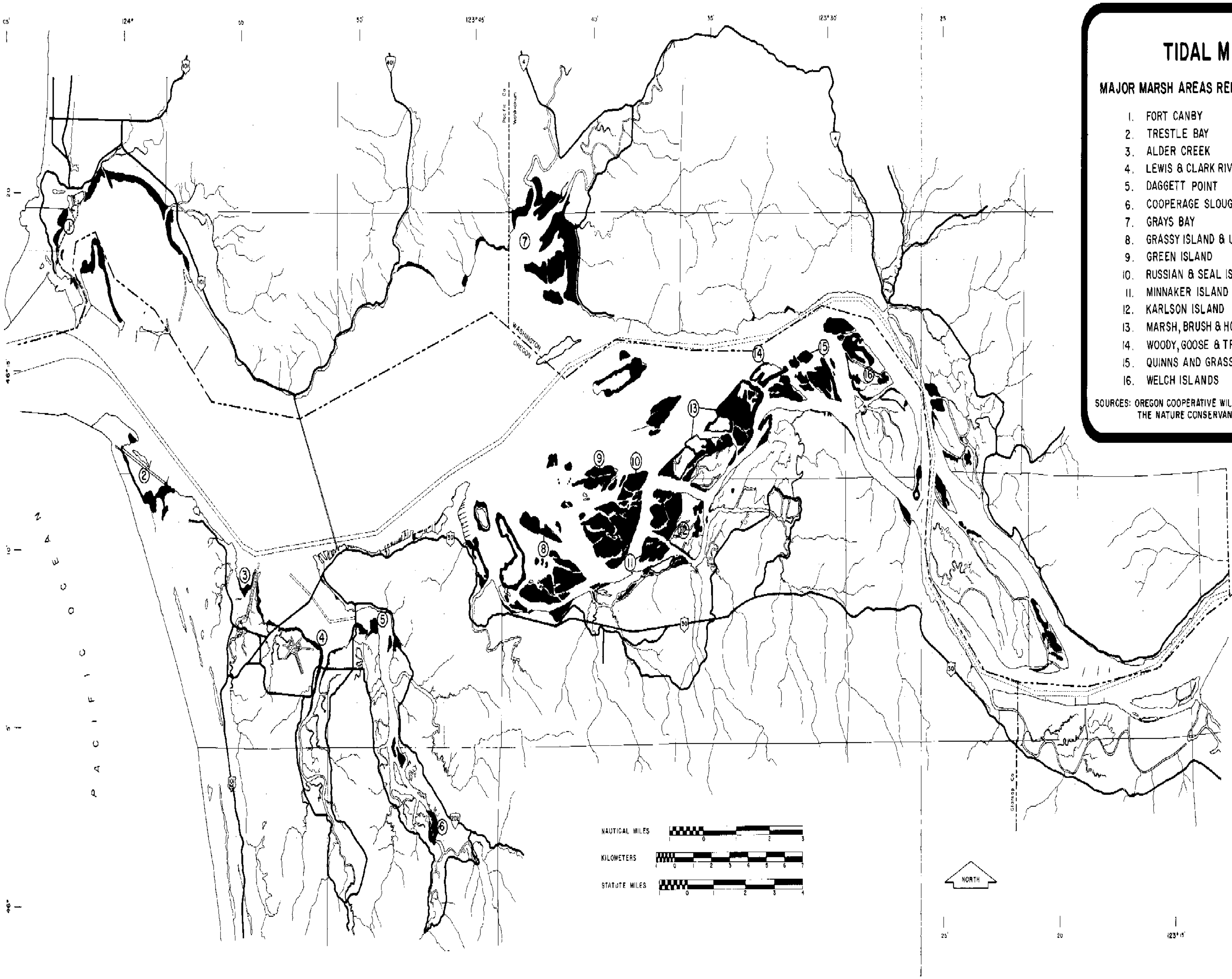
1) For purposes of this inventory, the Columbia River Estuary includes lower river areas which are part of Clatsop, Pacific, and Wahkiakum Counties.

2) Areas correspond to the subareas of the estuary used in CREST planning (Figure 100-2).

3) There are 0.405 hectares per acre.

4) The Lewis and Clark and Columbian White-Tailed Deer National Wildlife Refuge includes this area and small portions of two other areas. Tidal marshes within refuge boundaries total 7,173 acres (2,095 hectares).

From: 1. Oregon Cooperative Wildlife Research Unit, 1976
2. Other aerial photo interpretation



TIDAL MARSHES

MAJOR MARSH AREAS REFERED TO IN THE TEXT

1. FORT CANBY
2. TRESTLE BAY
3. ALDER CREEK
4. LEWIS & CLARK RIVER
5. DAGGETT POINT
6. COOPERAGE SLOUGH
7. GRAYS BAY
8. GRASSY ISLAND & UNAMED ISLANDS
9. GREEN ISLAND
10. RUSSIAN & SEAL ISLANDS
11. MINNAKER ISLAND
12. KARLSON ISLAND
13. MARSH, BRUSH & HORSESHOE ISLANDS
14. WOODY, GOOSE & TRONSON ISLANDS
15. QUINNS AND GRASSY ISLANDS
16. WELCH ISLANDS

SOURCES: OREGON COOPERATIVE WILDLIFE RESEARCH UNIT, 1976
THE NATURE CONSERVANCY, 1977.

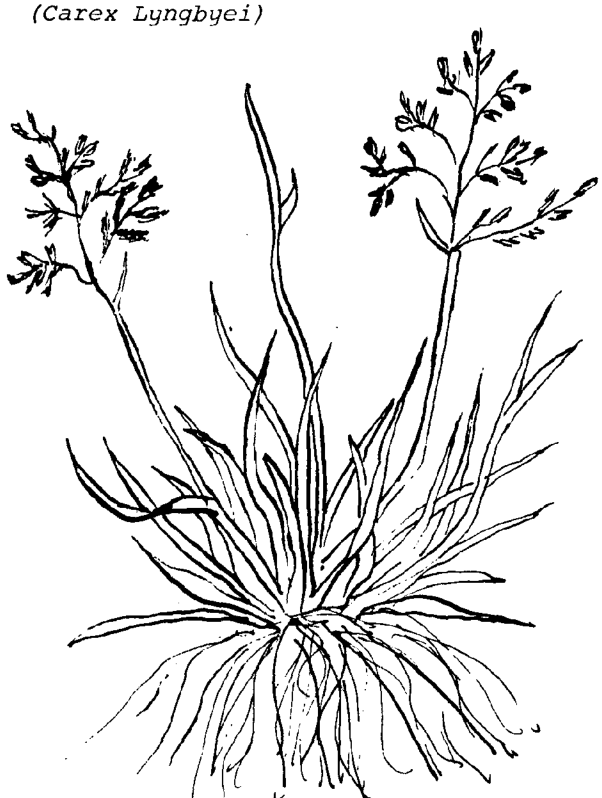
CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
302—1

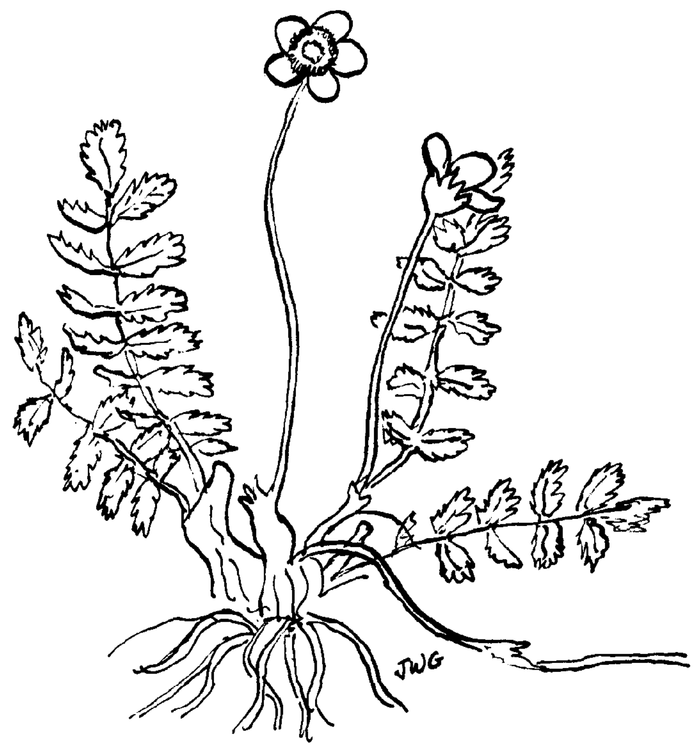
Figure 302-2. SOME COMMON COLUMBIA RIVER ESTUARY TIDAL MARSH PLANTS

Lyngby's sedge
(Carex Lyngbyei)

Three-square bulrush
(Scirpus americanus)



Tufted hairgrass
(Deschampsia caespitosa)



Pacific silverweed
(Potentilla pacifica)

TABLE 302-2

COMMON AND SCIENTIFIC NAMES OF THE MORE ABUNDANT PLANTS IN THE COLUMBIA RIVER ESTUARY TIDAL MARSHES

Common name	Scientific name
Beaked spike-rush	*Eleocharis rostellata*
Birds-foot trefoil	*Lotus corniculatus*
Common cattail	*Typha latifolia*
Common reed	*Phragmites communis*
Creeping bentgrass	*Agrostis alba*
Lesser cattail	*Typha angustifolia*
Lyngby's sedge	*Carex lyngbyei*
Marsh horsetail	*Equisetum palustre*
Pacific silverweed	*Potentilla pacifica*
Pacific water-parsley	*Oeneanthe sarmentosa*
Pointed rush	*Juncus oxymeris*
Reed canarygrass	*Phalaris arundinacea*
Seacoast bulrush	*Scirpus maritimus*
Seaside arrow-grass	*Triglochin maritimum*
Softstem bulrush	*Scirpus validus*
Spreading rush	*Juncus supiniformis*
Thread rush	*Juncus filiformis*
Three-square bulrush	*Scirpus americanus*
Toad rush	*Juncus bufonius*
Tufted hairgrass	*Deschampsia caepitosa*
Wapato	*Sagitaria latifolia*

The tidal wave (height variation) is relatively unaffected by the river flow, and it progresses upstream, well past what is thought of as the estuary.

The freshwater influence in tidal reaches of the Columbia results in marsh areas being dominated by freshwater or marginally salt-tolerant species such as Lyngby's sedge, softstem bulrush and common reed. The conspicuous absence of more salt-tolerant species, such as saltgrass and alkali grass, is further evidence of freshwater predominance, even in marshes close to the river mouth. Pickleweed is also absent, but this is typical of Northern Oregon salt marshes.

302.2 PLANT COLONIZATION, SUCCESSION AND MARSH TYPES

Succession is defined as the orderly replacement of one natural community by another and is a basic phenomenon in tidal marshes. The tidal marshes of the Columbia River estuary exhibit successional zones from lower high water (LHW) tide level, inland, to the juncture with terrestrial vegetation. Each of these zones has specific tolerance to the environmental factors of scour, saltwater, degree of exposure or submergence, nutrient supply and biological activities.

The first stage in succession, colonization of the tideflats by pioneer plants, is largely determined by the type of tideflat sediment; but it is also influenced by freshwater predominance in the Columbia estuary. A typical mudflat colonizer, seaside arrow-grass, is present only in lower and mid-estuary marshes and then in very low numbers. Three-square bulrush, beaked spike-rush, softstem bulrush and seacoast bulrush are more common colonizing species in various areas of the estuary.

After initial colonization, an area is usually invaded by Lyngby's sedge, by far the most dominant marsh species in the entire estuary. After die-back of some original colonizers, an area is invaded by a third stage of plants including tufted hairgrass, Pacific silverweed, creeping bentgrass and more sedge. In upper estuary marshes, a sedge/pointed rush/tufted hair-grass association is almost always the dominant high marsh community.

The tidal marsh is a transition area between the estuarine and terrestrial environments. Each stage of the succession process brings about an increase in the height of the marsh which results in a new set of environmental factors. The lower marsh, the area submerged twice daily by high tides, is predominantly estuarine habitat and provides food and shelter for animal communities of the estuary. The high marshes generally exhibit more freshwater and upland characteristics.

This successional feature of tidal marshes resulting in their expansion is termed progradation, meaning an increase in land area due to accretion along the shore. Since the Columbia estuary has filled substantially over the past century, it can probably be assumed that its marshes are prograding. This is suspected when one compares old navigation charts with maps of the present extent of tidal marshes. However, there are some areas where the reverse process, retrogradation, is probably taking place.

Marsh vegetation types and various dominant plant communities found in each were described in 1975 by C.A. Jefferson in "Plant Communities and Succession in Oregon Coastal Salt Marshes." The vegetation types of saline-brackish water tidal marshes included (1) low sand, (2) low silt, (3) sedge, (4) immature high, (5) mature high and (6) bulrush and sedge. Freshwater tidal marshes mentioned, but not discussed in detail, included (1) bulrush, (2) intertidal gravel marsh, (3) diked salt marsh and (4) high, freshwater intertidal marsh. Because of the absence of many of the common salt-tolerant marsh plants in the Columbia estuary, application of these described vegetative type-plant community associations must be done somewhat loosely. Probably all vegetative types (both estuarine and freshwater) are present in the Columbia estuary, with some modification of communities, due to the very low salinities present. The next section describes the vegetative type-plant communities in general, based on available information. The areas described correspond to the seven CREST planning areas.

302.3 COLUMBIA RIVER ESTUARY MARSH TYPES AND COMMUNITIES

A. Youngs Bay

The marshes of Youngs Bay, its tributaries and the Tongue Point area total approximately 1,136 acres (Figure 302-1). These marshes have not been studied in detail, but descriptions of some areas are available.

Marshes fringe the southwest edge of Youngs Bay, and continue up the west bank of the Lewis and Clark River for several miles. There are scattered marsh areas along the rest of the bay and up the Walluski and Youngs River. Undoubtedly, a significant proportion of the diked land in the lower Youngs and Lewis and Clark River areas were tidal wetlands, prior to diking in the 1920's and 1930's. This contention is supported by the presence of thousands of acres of tideland soils (compresssible, organic, peat-like). At the time of diking, aquatic vegetation probably inhabited only the outer fringes of the area, with the remainder of the land having built up gradually over the past several thousand years.

The tidal marsh located in the small cove between Tansy Point and the peninsula which forms the west bank of the Skipanon River (known as Alder Creek), is approximately 75 acres, and species composition reflects the predominant influence of freshwater. The outer sandy portion of the marsh is dominated by softstem bulrush, a common colonizing species in other areas of the estuary. Cattail is also present in isolated stands. These species grade into sedge marsh and through a mixed sedge (mature high marsh) area where upland species begin to invade. A bark fill on the east side of this area is encroaching on a portion of the marsh area.

Cooperage Slough is an 100 acre tidal marsh located about nine miles up the Youngs River on the east shore and has been surveyed and described by The Nature Conservancy. The daily mean tidal range is approximately 8.5 feet, and there is an intricate network of tidal channels draining the marsh and adjacent forest, which is second growth red alder and Sitka spruce. The marsh is essentially an undisturbed freshwater marsh and is similar to many on the islands in Cathlamet Bay. On low muddy areas adjacent to tidal channels, softstem bulrush dominates along with other scattered vegetation including wapato. On slightly higher areas, an association of Lyngby's sedge, Pacific water-parsley and Pacific silverweed dominates. This grades into a higher area with scattered bulrush and upland species, including dense clumps of lady-fern. Wetland shrub species occupy the highest portion of the marsh and include Hooker's willow, crabapple, young alder and others.

Daggett Point (Russian Point) is another area surveyed by The Nature Conservancy. This marsh area is very similar to Cooperage Slough in species composition and distribution. There is significant stand of common reed growing up to 10 feet tall, and a portion of the mature high marsh is dominated by tufted hairgrass along with seaside arrowgrass, sedge and silverweed.

Other areas of Youngs Bay marshes have been described only generally, but as elsewhere in the estuary, they are dominated by species characteristic of freshwater tidal marshes. Cattail, bulrush, and sedge are probably dominant, with distribution of these species a function of substrate type and degree of tidal submergence and exposure.

B. Baker Bay

Tidal marshes totaling nearly 816 acres fringe almost the entire shore of Baker Bay, except where shorelines are intensively developed. Tidal marshes also fringe the north and east side of Sand Island. These marshes have not been characterized in detail, except for one intensively sampled area adjacent to Fort Canby State Park (Figure 302-1).

Vegetation in this area grades sharply from upland older forest to immature high marsh, through sedge and three-square bulrush communities. The area shows complete vegetative coverage except for tidal channels. The upper marsh has rich species diversity dominated by sedge. Between this area and relatively pure stands of sedge is an area co-dominated by Pacific silverweed and sedge. Creeping bentgrass is also an important species here. The zone dominated by sedge contains few other species. The pure stand of three-square bulrush represents the initial colonization of the low sandy portion of the marsh. This marsh area is probably representative for Baker Bay, though verification would be useful.

C. Grays Bay

The Grays Bay area has the second largest concentration of tidal marsh in the estuary, with some 1,449 acres. The substrate of the higher marsh area sampled in Grays Bay is generally sandy, with sparse vegetation dominated in three different areas by a toad rush/spreading rush association, an introduced species called birds-foot trefoil and marsh horsetail. Lyngby's sedge dominates the next band of vegetation in each area. The lower end of this zone grades into vegetation dominated by beaked spike-rush and softstem bulrush. The bulrush forms large circular rings on the outer edges of the marsh, which are clearly visable on aerial photographs. Beaked spike-rush forms less uniform, more solid patches. Areas occupied by both species extend far out into the bay and are accessible only at very low tides. The marsh area thus grades from an immature high marsh to sedge marsh to bulrush marsh.

D. Lower River and Mouth

The northeast edge of Fort Stevens State Park borders on the Columbia River and is fringed with about 300 acres of tidal marsh. These are in a protected area sometimes known as Trestle Bay, located southeast of Clatsop Spit. The spit and embayment were formed in the last part of the 19th century, after construction of the south jetty. The marsh is bounded on the upland side by dunes and scotchbroom and on the river side by a sand-mud flat.

The transition area between upland mature high marsh is very diverse, with a mixture of species from both groups. The mature high marsh is dominated by Pacific silverweed and creeping bentgrass. Thread rush and common reed are also found here in patches. The area grades into an area dominated by creeping bentgrass and sedge. Sedge then becomes dominant to the outer edge of the marsh, covering more than 50% of the entire marsh area. At the edge of the marsh, a few colonizing species such as seaside arrowgrass and three-square bulrush are found. The marsh area thus grades from a mature high marsh to an immature high marsh to a low sandy marsh. Some low-salinity-tolerant species are found in this lower estuary marsh, but the distinct absence of saltgrass and pickleweed are indicative of the predominance of freshwater, even close to the river mouth.

E. Eastern Clatsop

The Eastern Clatsop planning area contains some 569 acres of tidal marsh, much of it is in embayments along the shoreline. Small marshes are also present at the mouths of streams draining into the Columbia. A thorough survey of these marshes is needed, particularly in the eastern part of the area. Gnat Creek marsh and Big and Little Creek marshes are areas surveyed by the Nature Conservancy.

One other marsh area, approximately two miles east of the outlet of the John Day River into Cathlamet Bay, has been intensively sampled. The marsh is bounded on the east, south, and west by a stand of Sitka spruce and willow and on the north, by the south channel of the Columbia River. Eskeline Creek drains into the marsh from the southwest, and a railroad divides the marsh into the north and south parts. The marsh has no elevational gradient and no obvious zonation of vegetation. The south area of the marsh is dominated by Lyngby's sedge, common cattail and marsh horsetail, with many other species in lesser numbers. The patchy distribution of these species is attributed to differences in time of colonization, the freshwater influence of the creek and selective feeding habits of nutria (an introduced rodent). North of the railroad, the marsh exhibits much less diversity than on the south side, and it is dominated by sedge, marsh horsetail, Pacific water parsley and softstem bulrush.

F. Eastern Wahkiakum

Eastern Wahkiakum County has a few significant stands of marsh vegetation totaling 188 acres. These marshes are located at the juncture of Elochoman Slough with the Columbia river, Nigger Island, and the upriver and end of Puget Island. These marshes are probably somewhat different from each other; they tend to be dominated by sedge, softstem bulrush, and seacoast bulrush and possibly common cattail. Pointed rush and tufted hair-grass are also likely to be present, particularly in the higher marsh areas. These marshes need further study and description.

G. Columbia River Islands

Approximately 20 major islands within the Lewis and Clark National Wildlife Refuge contain some 6,730 acres of tidal marsh. Each of these islands was surveyed by the Oregon Cooperative Wildlife Research Unit (Oregon State University), as part of a Corps of Engineers study of riparian habitat. Their descriptions are briefly summarized here.

1. Grassy Island (River Mile 22)

The deposits forming this tidal marsh island have a northwest orientation. The older deposits are along the southern edge, extending into younger sand deposits to the northwest and northeast. The older deposits are dominated by Lyngby's sedge and the younger deposits by softstem bulrush and seacoast bulrush. Sedge grows under the two species of bulrush, but it is abundant only along the more elevated southern edge. Pointed rush is moderately abundant in the area dominated by Lyngby's sedge. Softstem bulrush is somewhat less abundant than seacoast bulrush. The two species each dominate some sections of the island; they co-dominate a fairly large area, as well.

2. Unnamed Island (near Oregon Shore) Between River Miles 21 and 23

These islands are entirely tidal marsh. Lyngby's sedge, in association with smaller amounts of pointed rush and tufted hairgrass, dominates the southern edges of these islands. The lower sand flats to the west and north are dominated by softstem bulrush and seacoast bulrush; the latter is more clearly prevalent along the northeast extension of the eastern-most island, which appears to be a new area of deposition.

3. Green Island

The northeast section of this island has the highest elevation and is dominated by Lyngby's sedge. Several extensive sand deposits of low elevation occur on the north and southwest part of the island. These sand flats are covered by patches of softstem bulrush, seacoast bulrush, and beaked spike-rush. Softstem bulrush is the most abundant and seemingly, the most suited to deep water.

4. Russian and Seal Islands

Russian and Seal Islands are areas of deposition similar to, but older than, that of the unnamed islands between RM 21-23. Vegetation is entirely tidal marsh. The proportion of the islands dominated by the more mature Lyngby's sedge /pointed rush /tufted hairgrass association, in relation to that dominated by the younger softstem bulrush or seacoast bulrush associations, is about nine to one for Russian and Seal Islands.

The areas of most recent deposition for Russian and Seal Islands are along the northwest and southwest sides. Softstem bulrush and seacoast bulrush dominate these sandflats. Lesser cattail and beaked spike-rush dominate some patches of vegetation. The latter occurs most frequently in tidal channels. Patches of softstem bulrush and, less frequently, seacoast bulrush, are found along the northwest tip of Russian Island, softstem and seacoast bulrush occur in pure stands, as well as in association with each other and sedge. Marsh horsetail also forms patches in which it is the dominant species. Wapato is the most abundant species on the tidal flat that extends from the southwest corner of Russian Island.

5. Minnaker Island

Most of Minnaker Island is dominated by Lyngby's sedge. Pointed rush and tufted hairgrass are important vegetation, although they are not as prevalent as on some of the other islands. Pacific willows are becoming established in a few places. Patches of softstem bulrush and beaked spike-rush dominate the younger shorelines.

6. Karlson Island

Only the western end of Karlson Island is undisturbed tidal marsh. Much of the island has been diked (no longer functional, however) or is forested by Sitka spruce and Pacific willow. Most of the tidal marsh is the Lyngby's sedge/pointed rush/tufted hairgrass association. This association covers the southern half of the marsh, except for the extreme western edge. The western edge is a low marsh, dominated by softstem bulrush. A large stand of common reed forms the northern edge of the marsh. A stand of marsh horsetail is adjacent to the southern edge of the reed stand.

7. Snag Island

The older northeast section of this island, dominated by Lyngby's sedge, slopes into extensive sand flats dominated by stands of softstem bulrush, seacoast bulrush, and beaked spike-rush. Generally, the Lyngby's sedge growing on Snag Island is shorter and has less vegetative growth than that on most other islands; the density of beaked spike-rush is also lower. The stands of seacoast bulrush are very tall and thick; other than Douglas' aster, they are the only species to appear healthy and robust at the time of the OSU survey. Lesser cat-tail is also present in patches.

8. Marsh, Brush and Horseshoe Islands

Approximately 75 percent of the acreage of Brush and Horseshoe Islands is tidal marsh. Only about 20 percent of Marsh Island is tidal marsh. The marsh vegetation of these islands is another example of intertidal freshwater marsh dominated by Lyngby's sedge, in association with tufted hairgrass and pointed rush. The hairgrass has a higher percent cover value (30%) on these islands than on the islands previously described.

9. Woody Island

A dense stand composed of Sitka spruce, western red cedar, creek dogwood, and Pacific willow covers approximately 60 percent of Woody Island. A narrow band of marsh extends around the island, and it is more extensive on the southern shore adjacent to Horseshoe and Tronson Islands. The dominant marsh type is the Lyngby's sedge/pointed rush/tufted hairgrass association. There are patches also dominated by marsh horsetail, reed canarygrass and softstem bulrush.

10. Tronson Island

Apprxominately 10-15 percent of this island is covered by Pacific willow shrubs; the remainder is tidal marsh composed mainly of Lyngby's sedge/ pointed rush/tufted hairgrass association. Marsh horsetail is dominant in depressions.

11. Goose Island

This small island, adjacent to the north side of Tronson Island, is covered by tidal marsh. The Lyngby's sedge/pointed rush/tufted hairgrass association dominates the high ground. On the sandy, low deposit on the southwest side, beaked spike-rush and spreading rush are the dominant species.

12. Grassy (RM 31) and Quinns Islands

These two islands have similar vegetation. A narrow stand of Pacific willow occurs on the older eastern shore of Quinn Island. The Lyngby's sedge/pointed rush/tufted hairgrass association extends from the trees into sandflats, which are dominated by patches of softstem bulrush and beaked spike-rush.

13. Fitzpatrick Island

This island has a concave surface. The southwest shore, elevated a meter or more above the river bottom, is edged with willows. Adjacent to the northern section of the willow band is a sizeable patch of lesser cattail. The number of species associated with the dominant Lyngby's sedge found at the edge of the willows, decreases toward the center and increases on the elevated northeastern and southern edges of the island. Scattered Pacific willows are growing in these higher areas. Lyngby's sedge, (approximately 12 inches tall), is the main component of the vegetation of the rest of the island. Beaked spike-rush dominates the tide channels.

14. Welch Island

Welch Island is of intermediate age. The north end, where sand has most recently accreted, is covered with beaked spike-rush; it also grows in the outlets of the tidal channels. This changes rapidly into a marsh dominated by Lyngby's sedge. Shallow roots of the sedge fill the substrate completely, and the plant sheds an abundance of leafy material which rapidly decomposes. These factors, and sedge's propensity for trapping debris and sediment have resulted in an elevation about a foot above the tide flat. Most high tides inundate the island, and the marsh is crisscrossed by an intricate network of moderately deep drainage channels. A large number of species characteristic of mature sedge marsh have colonized the island, but only the sedge has become well established.

302.4 FUNCTIONS AND VALUES OF TIDAL MARSHES

A great deal of research has been conducted concerning the functions and values of tidal marshes. Most of this research has been on the Atlantic Coast, and some recent work has been done in Nehalem Bay. While the value of the Columbia estuary marshes has not been studied, much of the information from other areas applies. Analysis of this information clearly shows that marshes fulfill certain functions which are directly or indirectly beneficial to man.

A. Biological Productivity and Detrital Export

Tidal marsh plants, like all other green plants, use the sun's energy to convert inorganic substances (water and carbon dioxide) into organic materials (simple sugars), through the process of photosynthesis. Because all living things are ultimately dependent on organic material produced by green plants, the productivity of a group of plants is an important factor in determining how many and what kind of organisms will live in an area. In comparison with other producers of both the land and the sea, tidal marshes have environmental conditions that are conducive to a high productivity rate.

Production of high yield agricultural crops by man requires a significant input of petroleum energy in the form of nutrient fertilizers (i.e. phosphates and nitrates) and petroleum fuel to run farm machinery. In the tidal marsh, the high yield is produced with no input of energy or nutrients by humans. The nutrients, phosphates and nitrates are available in the seawater which floods the marsh, and the energy subsidy is provided by tidal action.

Table 302-3 summarizes some of the available data on relative primary productivity of some agricultural crops and marshes common to the Columbia estuary.

The major importance of the high productivity of estuarine marshes is its contribution to secondary production of estuarine water and bottom-dwelling populations. Tidal action transports a large proportion of fixed organic marsh material into estuary waters, as dissolved or particulate organic material. This export of marsh production is the primary means of organic enrichment of estuaries. The marsh detritus serves as food for amphipods, clams, crabs, insects, polychaetes and oligochaetes (worms), as well as other species. These animals, in turn, become food for larger animals including fish, birds and ultimately man. Table 302-4 lists the percentage export of net production from marshes in Nehalem Bay, Oregon; these are similar marshes to Columbia River tidal marshes.

B. Fish and Wildlife Habitat

The significance of the marsh as fish and wildlife habitat relates to both its high biological productivity, assuring an abundance of food for animals, and its position in the land-sea interface, providing a diversity of habitat types within a small area.

At different times of the year, many species of waterbirds and shorebirds utilize the marsh for feeding and nesting. The lower Columbia area in general, and its tidal marshes in particular, support large populations of waterfowl in the fall and winter. Several tidal marshes are popular duck hunting areas.

The expanses of marsh and adjacent flats uncovered at low tide attract raccoon, skunk and muskrat for feeding, while the higher marshes provide habitat for small burrowing rodents. One of these rodents, nutria, is a harmful introduced species, which has destroyed many cattail marshes in upper estuary areas. Blacktail and the endangered Columbian white-tailed deer are also common visitors to the marsh.

TABLE 302-3

NET PRODUCTION OF DRY MATTER

	Grams/square meter/year
Wheat field (world average)	288[1]
Rice field (world average)	511[1]
Sugar Cane (Hawaii)	2711[1]
Low Sandy Marsh (Jefferson Co., Wa.)	738[2]
Immature High Marsh (Jefferson Co., Wa.)	1041[2]
Mature High Marsh (Jefferson Co., Wa.)	283[2]
Sedge (Carex Sp.) Marsh (Jefferson Co., Wa.)	2000[2]
Sedge (Carex lyngbyei) Marsh (Nehalem Bay, Or.)	1746[3]
Bulrush (Scirpus maritimus) Marsh (Nehalem Bay, Or.)	609[3]
Rush/Bentgrass (Juncus/Agrostis) Marsh (Nehalem Bay, Or.)	1479[3]

From: 1. Odum, 1971
2. Northwest Environmental Consultants, 1975
3. Eilers, 1975

TABLE 302-4

ORGANIC EXPORT FROM NEHALEM BAY SALT MARSHES

Marsh Type	Percent Export	Tidal range above MLLW
Bulrush (Scirprus)	80%	4.3 - 6.0 ft.
Sedge (Carex)	100%	5.5 - 7.4 ft.
Rush bentgrass (Juncus/Agrostis)	49%	7.4 - 9.2 ft.

From: Eilers, 1975

At high tide, when tidal creeks are filled with water, fish come in from subtidal areas. Juvenile salmon, starry flounder, three-spine sculpin and other species utilize these areas. The importance of the marshes to juvenile salmon deserves special mention. The edges of marsh areas provide sheltered habitats for juvenile salmon, where food in the form of amphipods and other small invertebrates (which feed directly on marsh detritus), is plentiful and larger predatory species of fish are avoided.

C. Erosion Buffer

Eroding streambanks present significant problems in many areas of the estuary and tributary streams, particularly where dikes come down to the water's edge. Cost for dike repair, rip-rap and other shoreline protection is extremely high. Tidal marshes act as natural bulkhead in protecting the shoreline from erosion; when preserved, they can save considerable cost to the upland owner.

D. Water Quality Maintenance

Columbia River waters often have high turbidity (cloudiness), particularly during high runoff periods. The turbidity can have the effect of reducing light penetration, and can therefore reduce the productivity of the phytoplankton. When the water containing suspended sediments covers a tidal marsh, the vegetation of the marsh slows the water movement and causes the sediment to be deposited in the marsh. Thus, the marsh helps to reduce the turbidity in the surrounding water and increases the total production of phytoplankton.

The tidal marsh also maintains water quality by its removal of inorganic nutrients from the water. These nutrients include phosphates and nitrates which may have their source in sewage effluent or septic tank leachates. The tidal marshes, particularly the lower marshes which are covered daily by the tides remove the nutrients from the estuary waters.

New wastewater treatment facilities are now being constructed in many parts of the United States; some are able to remove the nutrients from sewage effluent. This form of treatment, tertiary treatment, is very costly. A recent study values the work of the East Coast marshes in removing just phosphorus, at between $480 and $1420 per acre per year. The report states that the marshes appear to be uniquely adapted to removal of nitrogren from the water, as well. This treatment of the water is expensive when done technically, but it is performed by the marsh for free.

It should be emphasized, however, that secondary treatment, or removal of organic solids of sewage (a relatively inexpensive process), cannot be done efficiently by a tidal marsh, since it is already naturally high in organic detritus. Raw sewage would put an additional burden on the functioning of the marsh.

E. Recreation Use

Another important function of the tidal marsh is that of providing an area for a wide range of recreational uses. These uses range from hunting and fishing to photography and nature study. While the social value of these activities and the intrinsic aesthetic qualities possessed by tidal marshes cannot be easily quantified, they cannot be overlooked in assessing their overall importance.

Marshes form a highly interrelated ecosystem, with little capability to resist or recover from the effect of intensive human activity within marsh. Recreational use of the marsh must then be examined in terms of suitability. Such ecological suitability would be measured by how well a site could meet a need of the particular recreational use, without incurring long-term, detrimental, and/or irreversible impacts (changes) to the natural system. Uses which are best suited to a marsh are of low intensity, and cause little disruption to the sensitive environment.

302.5 REFERENCES

A. Aikens, Glen J. and C.A. Jefferson. 1973. Coastal Wetlands of Oregon, prepared for the Oregon Coastal Conservation and Development Commission.

This publication gives only limited information about Columbia River estuary marshes, some of which is inaccurate. Vegetation types and community associations found in Oregon coastal salt marshes is described and tideland communities discussed.

B. Bierly, Kenneth. 1973. Warrenton Lumber Company Bank Fill, unpublished.

Describes the tidal marsh communities in the Alder Creek area of Youngs Bay.

C. Eilers, Hio Peter. 1974. Plants, Plant Communities, Net Production and Tide Levels: The Ecological Biogeography of Nehalem Salt Marshes, Tillamook County, Oregon, unpublished. Ph.D Dissertation. Oregon State University.

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D. Gosselink, James G., D.P. Odum and R.M. Pope. 1974. The Value of Tidal Marsh, publication No. LSU-SG-74-03. Center for Wetland Resources, Louisiana State University, Baton Rouge.

Natural tidal marshes are evaluated in monetary terms based on their values to fisheries and waste assimilation. The analysis computes the estimated total social value of tidal marshes at $50,000-$80,000 per acre.

E. Jefferson, Carol A. 1975. Plant Communities and Succession in Oregon Coast Salt Marshes, unpublished. Ph.D. Dissertation. Oregon State University.

The salt marshes of Oregon are described by vegetation type and community associations. Successional patterns and the significance of environmental factors are discussed. Several of the communities described are present in Columbia River tidal marshes.

F. Montagne and Associates. 1976. Natural Resource Base and Physical Characteristics of the Proposed Offshore Oil Platform Fabrication Site, Warrenton, Oregon: (Technical Reports, Data Base and Appendix), prepared for Pacific Fabricators, Inc.

This report analyzes data collected in Spring 1976 and compares it with recent, more comprehensive studies of the Youngs Bay area. Included are physical data, tidal marsh and habitat information, vertebrate wildlife information, and fish and benthic data.

G. The Nature Conservancy (Oregon Chapter). 1977. Oregon Natural Areas: Clatsop County Data Summary.

A detailed description of several potential natural areas in the CREST study area, including Dagget Point, Tansy Point, Cooperage Slough and Gnat Creek Marsh.

H. Northwest Environmental Consultants. 1975. The Tidal Marshes of Jefferson County, Washington, prepared for the Jefferson County Planning Department, Port Townsend, Washington.

An excellent resource on all aspects of tidal marshes of the Pacific Northwest, with particular reference to Jefferson County.

I. Odum, Eugene P. 1971. Fundamentals of Ecology, 3rd Edition. W. B. Sanders Co.

A basic textbook and reference for the study of ecological systems. Includes sections on marine, estuarine and freshwater ecosystems.

J. Oregon Cooperative Wildlife Research Unit. 1976. Inventory of Riparian Habitats and Associated Wildlife Along the Columbia River, prepared for the U.S. Army Corps of Engineers, Walla Walla District.

Photointerpretive analysis of land forms and vegetation is provided along with intensive vegetative analysis of tidal marsh and other riparian communities. No production or detrital export data were developed. Associated wildlife including waterfowl, other birds, mammals amphibians and reptiles were studies in relation to their habitats. This study was the primary information source for tidal marsh mapping and description in this section.

303 SHORELINE HABITAT AND WILDLIFE RESOURCES

COLUMBIA RIVER ESTUARY

SHORELINE HABITAT AND WILDLIFE RESOURCES

James W. Good
George D. Potter

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*Figure follows the page indicated.

303 SHORELINE HABITAT AND WILDLIFE RESOURCES

Tidal marshes and riparian grass, shrub and forest lands along the edges of the Columbia River estuary provide valuable habitat for many species of aquatic and terrestrial birds, mammals, amphibians, reptiles, and invertebrates. These areas are also a valuable recreational and aesthetic resource. However, much of the shoreline, particularly in flat areas, has been altered for urban development and shoreline roadways, or diked and drained for agriculture. Many of the steeper forested areas along the shoreline are managed for timber production. Thus, while the estuary area is not heavily urbanized, the natural character of riparian vegetation and habitat has been substantially altered.

The dependence of each species upon particular habitats is the key concept when considering estuary wildlife. The various species of animals associated with the estuary are most easily categorized by the type of habitat they occupy. Tidal marshes, freshwater wetlands, islands, sloughs and riparian fringes are all extremely valuable habitat for wildlife. The most current source of information on Columbia River estuary habitats and their wildlife is the recent study prepared for the U.S. Army Corps of Engineers [Oregon Cooperative Wildlife Research Unit (OCWRU), 1976. Inventory of Riparian Habitats and Associated Wildlife along the Columbia River]. This publication was a primary source document for the following discussion of wildlife habitat and resources.

Vegetative habitats along the shorelines of the estuary are mapped in Figure 303-1. The relative amount of shoreline area in the various habitat categories is given in Table 303-1, but this excludes the shoreland of Youngs Bay, and estuary tributary streams.

Of special importance with regard to habitat and wildlife management in the lower Columbia area are the two national wildlife refuges located between river miles 20 and 39. Established in 1972 and managed by the U.S. Fish and Wildlife Service (Department of Interior), the Columbian White-Tailed Deer and Lewis and Clark National Wildlife Refuges serve to protect some of the most important

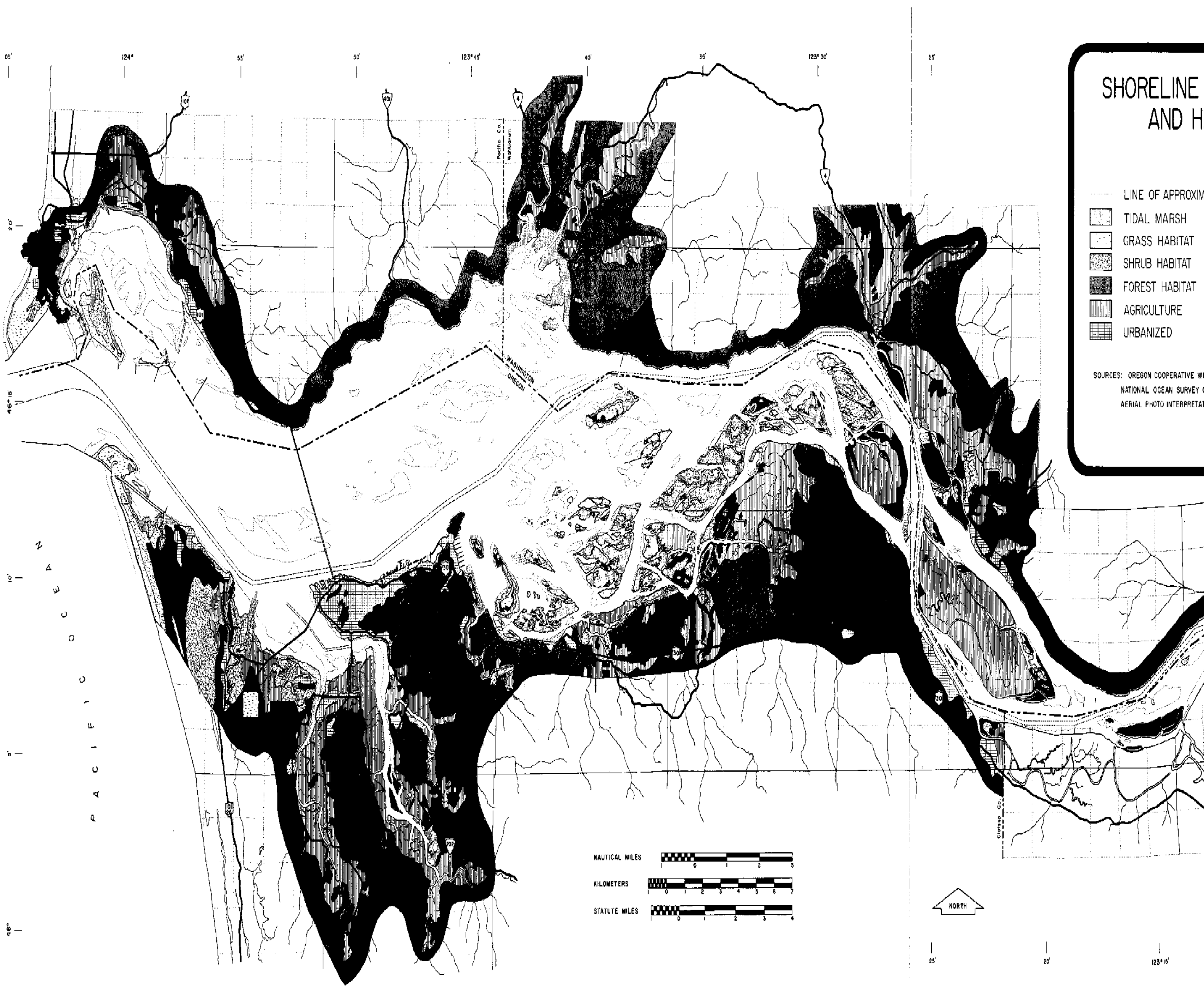
TABLE 303-1

SHORELINE HABITAT TYPES IN THE COLUMBIA RIVER ESTUARY
(in decreasing order of shoreline area occupied)*

Tidal marsh
Shrub willow
Grassland
Willow/cottonwood, large trees
Cottonwood, large trees
Willow, large trees
Sitka spruce/western red cedar/cottonwood/alder
Beachgrass
Alder
Sand
Willow, small trees
Residential/urban
Pasture
Sitka spruce/cottonwood/willow
Willow/ash
Cottonwood/ash
Industrial
Willow/alder
Sitka spruce
Douglas fir/alder/maple
Douglas fir/Sitka spruce/alder
Alder/Sitka spruce
Maple/Douglas fir
Alder/Douglas fir
Cottonwood/Sitka spruce
Shrub willow
Herbaceous types
Beachgrass/sedge meadow
Willow/cottonwood/ash
Airport
Cottonwood/willow/alder
Blackberry
Douglas fir/western red cedar/alder
Douglas fir
Developed parks or campgrounds
Ash
Shrubs/beachgrass
Douglas fir/oak/maple
Marsh
Shrub types
Ponds, lakes, and reservoirs
Willow/cottonwood
Cottonwood
Oak/Douglas fir
Douglas fir/western red cedar/maple
Rock rip-rap
Sitka spruce/western red cedar/alder
Oak/maple

*Order of habitats is based on a narrow shoreline strip of variable width and does not include Youngs Bay or estuary tributary streams.

From: Oregon Cooperative Wildlife Research Unit, 1976



SHORELINE VEGETATION AND HABITAT

- LINE OF APPROXIMATE MEAN LOWER LOW WATER
- TIDAL MARSH
- GRASS HABITAT
- SHRUB HABITAT
- FOREST HABITAT
- AGRICULTURE
- URBANIZED

SOURCES: OREGON COOPERATIVE WILDLIFE RESEARCH UNIT, 1976.
NATIONAL OCEAN SURVEY CHARTS 6151, 6152.
AERIAL PHOTO INTERPRETATION.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
303-1

wildlife areas of the estuary. The 5,200 acre deer refuge encompasses Tenasillahe, Hunting and Price Islands, as well as part of the mainland near Cathlamet, Washington. Most of this land is diked, moist floodplain pasture with numerous sloughs, channels and blocks of shrub and forest. The Lewis and Clark Refuge encompasses 35,000 acres, two-thirds of which are open water. Some 20 named islands and numerous unnamed bars, flats and tidal marshes total about 9,400 acres, making it the largest natural marsh in Western Oregon. The marsh vegetation is also a major food and nutrient supplier to plant and animals low on the estuarine food chain. Uses in these refuge areas are limited to game management, recreation, hunting and scientific research.

Wildlife discussed in this section includes waterfowl, birds other than waterfowl, big game, small mammals, reptiles, amphibians and marine mammals. These wildlife are extremely valuable because of the roles they play in the natural functioning of estuary and upland ecosystems and because of the recreational opportunities they provide for hunters, trappers, photographers, and bird and nature observers. The future of wildlife species in the lower Columbia River region depends largely on the decisions made by man regarding shoreland development, logging and navigational practices, and the management of hydroelectric dams upriver from the estuary.

303.1 OREGON SHORELINE HABITAT

Wet beach sand and stablized foredunes characterize the Oregon side of the mouth of the Columbia River which is part of Fort Stevens State Park. The dunes run transversely from southwest to northeast and provide a rolling landscape. On the foredunes, coast pine and scotchbroom range from dense inland stands to scattered individuals near the shoreline.

Tidal marshes and mudflats occur on the shoreline southeast of Clatsop Spit in the area known as Trestle Bay. There are deep tidal channels, and marsh vegetation occupies distinct vegetative bands between upland dry areas and mud flats. Lyngby's sedge, common reed, creeping bentgrass, and Pacific silverweed are locally dominant species in these marshes.

From Fort Stevens east to Tongue Point, the Columbia River shoreline is distinctly urban. Youngs Bay, however, is characterized by fringing tidal marshes along dikes or rip-rapped shorelines. Much of the diked land in Warrenton and up the Youngs River and Lewis and Clark River is used as pasture. Upland from these areas, the slopes are forested with Sitka spruce, Douglas fir, western red cedar, western hemlock and red alder (in clearcut areas).

Between Tongue Point and Westport, the estuary has many tidal marsh islands in various stages of succession to upland vegetation. Marshes are dominated by Lyngby's sedge, slough sedge, bulrushes and creeping bentgrass. Pacific willow and Hooker's willow form dense stands on islands, and forested swamps on these islands are dominated by Sikta spruce. These areas are all part of the Lewis and Clark and Columbian White-Tailed Deer National Wildlife Refuges and constitute one of the largest natural marshes on the West Coast.

Much of the low-lying shoreland in the upper estuary is used for agriculture, though in several areas, steep forested slopes come down to the water's edge. The Westport/Wauna area is more heavily urbanized and dominated by the Wauna Paper Mill. Areas along the shoreline in the upper estuary are utilized as dredged material disposal sites for maintenance of the Columbia River 40 foot channel. Pile dikes along the shore have the effect of lessening shoreline erosion by trapping sediments, but at the same time removing natural shoreline habitat.

303.2 WASHINGTON SHORELINE HABITAT

Wet beach sand and the stabilized dunes of Peacock Spit are met abruptly by the basalt rock outcroppings of Cape Disappointment on the Washington side of the Columbia River mouth.

Baker Bay, a large, extremely shallow embayment, is fringed by narrow tidal marshes, that grade into red alder and Sikta spruce forests. Parts of the bay shoreline are urbanized, and low-lying alluvial soil areas up tributary streams are diked and used for pasture.

Steep mountain slopes, forested predominantly with Sitka spruce, western hemlock and Douglas fir come down to the river's edge upstream from Baker Bay, except where the roadway runs along the shoreline for about 10 miles, where Grays Bay and River interrupts the topography, and where Skamokawa Creek and the Elochoman River drain into the Columbia.

The tidal marshes in Grays Bay are extensive, with bulrushes and sedges dominating. Up the tributary streams, lowlands are diked and used for agriculture. The diked lands up Skamokawa Creek and the Elochoman River are also used for agriculture, though a large portion near the Elochoman is part of the White-Tailed Deer Refuge. In well-drained but frequently flooded sites along this stretch of shoreline, black cottonwood, Sitka spruce and western red cedar are prevalent. Salal, salmonberry, wild blackberry and dogwood form dense understories, and there are small areas of tidal marsh.

Puget Island is almost entirely diked and used for agricultural crops and pasture. Swamp forest and marsh areas are present on the upriver and downriver ends of the island. Many shoreline areas along this portion of the river are used as dredged material disposal areas.

Upstream from the urbanized Cathlamet area, the Columbia cuts through the Coast Range. Steep cliffs and forested, undeveloped areas predominate through the remainder of Wahkiakum County.

303.3 WATERFOWL

Many species of waterfowl utilize the Columbia River estuary for resting, feeding and breeding (Table 303-2 and Figure 303-2) throughout the year. Though it produces only a limited number of waterfowl, it receives intensive use by migrant waterfowl in fall and winter, and serves as a staging area for early spring migrations north.

A. Migrant Waterfowl

The lower estuary is not rich in waterfowl habitat. While limited tidal marshes and urbanization cause concentrations to be low, Baker Bay, Trestle Bay and Youngs Bay afford some waterfowl refuge. Baker Bay has the heaviest migrant waterfowl use in the lower estuary (Table 303-3). Coots, pintail and widgeons use the area in October, with increased use by canvasbacks, scaup and white-winged and surf

TABLE 303-2

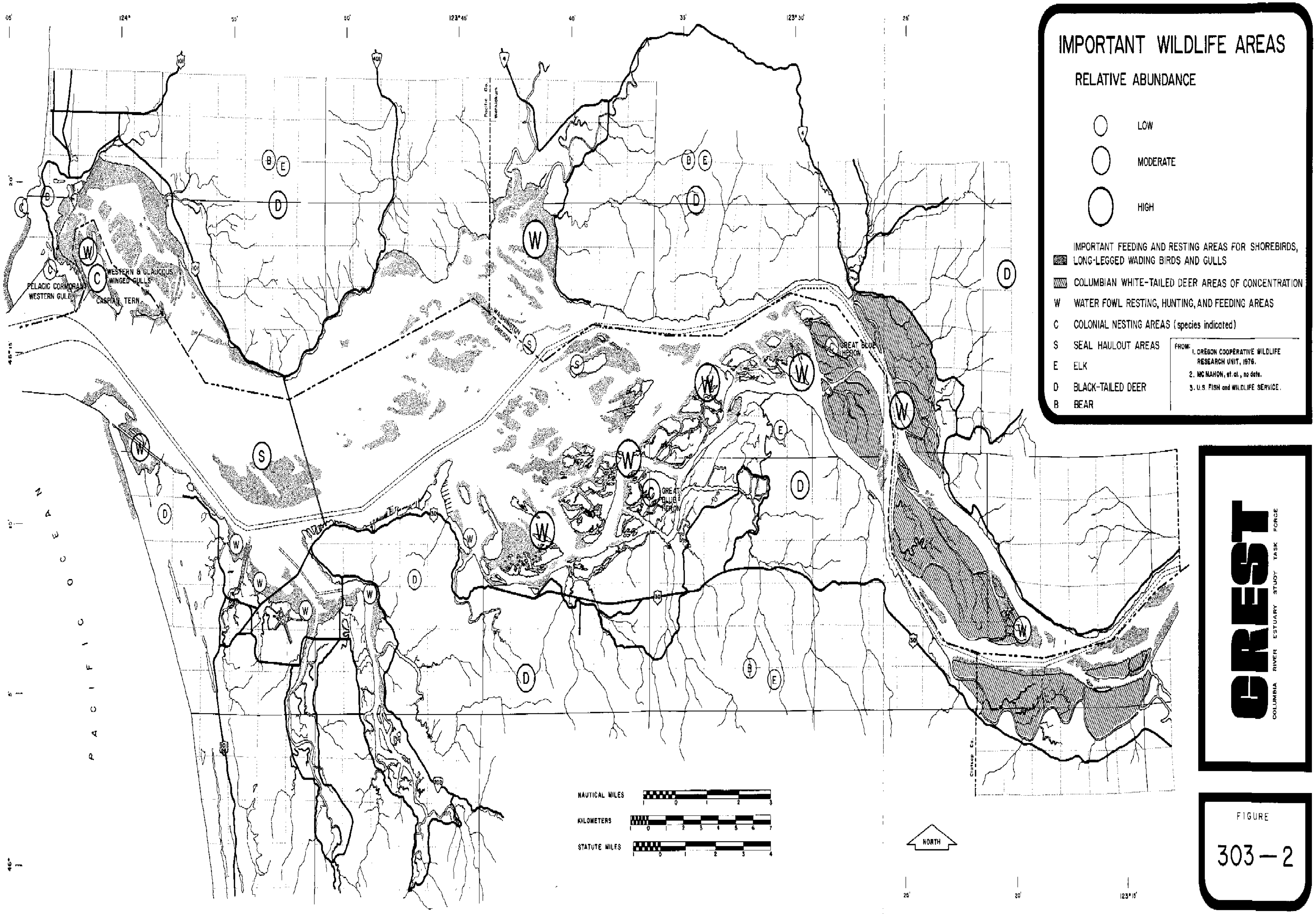
SPECIES OF WATERFOWL OBSERVED IN THE
COLUMBIA RIVER ESTUARY

Species	Lower Estuary[1] RM 0-12	Upper Estuary[1] RM 12-79*	Lower River and Estuary[2] RM 0 - 140
Whistling Swan	x	x	x
Canada Goose	x	x	x
White-fronted goose		x	x
Snow goose		x	x
Mallard	x	x	x
Gadwall		x	x
Pintail	x	x	x
Green-winged Teal	x	x	x
Blue-winged Teal			x
Cinnamon Teal		x	x
European Widgeon		x	x
American Widgeon	x	x	x
Shoveler		x	x
Wood Duck		x	x
Ring-necked duck			
Canvasback	x	x	x
Greater Scaup			x
Lesser Scaup	x	x	x
Redhead			
Common Goldeneye			x
Barrow's Goldeneye	x	x	x
Bufflehead	x	x	x
White-winged Scoter		x	x
Surf Scoter	x	x	x
Ruddy Duck		x	x
Common Merganser	x	x	x
Hooded Merganser		x	x
Western Grebe	x	x	x
American Coot	x	x	x
Harlequin			x
Old Squaw			x

*most species in upper unit were in National Wildlife Refuges (RM 18-39)

From: 1. Oregon Cooperative Wildlife Research Unit, 1976 (species were actually observed in the area).

2. Ives and Saltzman, 1970 (include species present from the mouth to Bonneville Dam).



IMPORTANT WILDLIFE AREAS
RELATIVE ABUNDANCE
LOW
MODERATE
HIGH
IMPORTANT FEEDING AND RESTING AREAS FOR SHOREBIRDS, LONG-LEGGED WADING BIRDS AND GULLS
COLUMBIAN WHITE-TAILED DEER AREAS OF CONCENTRATION
W WATER FOWL RESTING, HUNTING, AND FEEDING AREAS
C COLONIAL NESTING AREAS (species indicated)
S SEAL HAULOUT AREAS
E ELK
D BLACK-TAILED DEER
B BEAR
FROM: 1. OREGON COOPERATIVE WILDLIFE RESEARCH UNIT, 1976.
2. MC MAHON, et. al., no date.
3. U.S. FISH and WILDLIFE SERVICE.
PACIFIC OCEAN
WESTERN & GLAUCOUS WINGED GULLS
PELAGIC CORMORANT
WESTERN GULL
CASPIAN TERN
GREAT BLUE HERON
WASHINGTON
OREGON
Pacific Co.
Wahkiakum
Clatsop Co.
NAUTICAL MILES
KILOMETERS
STATUTE MILES
NORTH
CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 303—2

TABLE 303-3

Migrant Waterflow Concentrations in the Lower Columbia River Estuary

(River Mile 1-12)

Concentration	Species	Geographical Location	Vegetation Habitat	Seasonal Occurrence
High	American widgeon	Baker Bay	Tidal Marsh/ Open Water	Fall
Low	Coots	Baker Bay	Tidal Marsh/ Open Water	Fall
Moderate	Canvasback duck	Baker Bay	Tidal Marsh/ Open Water	Winter
Low	Surf & White-winged scoters	Baker Bay	Tidal Marsh/ Open Water	Winter
Moderate	Western Grebes	Baker Bay	Tidal Marsh/ Open Water	Winter
High	Pintail	Baker Bay	Tidal Marsh/ Open Water	Fall

From: 1. Oregon Cooperative Wildlife Research Unit, 1976
2. U.S. Fish and Wildlife Service (Personal Communication), 1977

scoters in December and February. Western grebes are present throughout the winter. Tidal marshes and shorelines along the bay and its islands are used for resting and feeding.

Trestle Bay on the Oregon shore is used by dabbling ducks and coots in early winter and by diving ducks, primarily canvasbacks, during the remainder of winter. Areas opposite Alder Creek and in Youngs Bay and its tributary streams also have some tidal marsh and shoreline habitat important to migrant waterfowl (Table 303-4).

The upper estuary, particularly Grays Bay and the Lewis and Clark/ Columbian White-Tailed Deer National Wildlife Refuges (River Mile 20-39), receives intensive use by migrant waterfowl. Tidal marshes provide resting and feeding areas for widgeon, pintail, mallards, whistling swans, Canadian and white-fronted geese, coot, green-winged teal, common merganser, western grebe, gadwall, scaup and other species. Diversity and abundance vary throughout the winter season, but a distinct buildup of mallard, Canadian goose, pintail and widgeon occurs in February as a precursor to spring migration north in March. This is illustrated in Figure 303-3, where the estimated number of waterfowl-use-days for the lower and upper estuary are compared. While all refuge areas are used by most species, areas of particular concentration are shown in Table 303-5 and Figure 303-2. Waterfowl concentrate in the area of Karlson Island (a protected sanctuary during hunting season). Grassy, Russian and Seal Islands (RM 23-25) are concentration areas for whistling swans, and Canadian geese/widgeon are concentrated on Tensillahe (RM 35-38).

B. Resident Waterfowl

The estuary area is not a major production area for waterfowl. Estimates of annual waterfowl production for the national wildlife refuges in the estuary area are shown in Table 303-6. Monthly waterfowl populations for the same areas during spring and summer months are shown in Table 303-7. Ideal habitat for nesting and breeding are areas of non-tidal marsh/shrub-marsh vegetation. The low production of waterfowl in the estuary area is attributed to the limited amount of such habitat. Nevertheless, several areas of the lower estuary where tidal marshes are associated with upland habitat, are used for nesting and breeding (including Sand Island in Baker Bay, Trestle Bay, and Youngs Bay). Mallards are the predominant resident

TABLE 303-4

YOUNGS BAY AND RIVER, WINTERING AREA
ESTIMATED WATERFOWL POPULATIONS

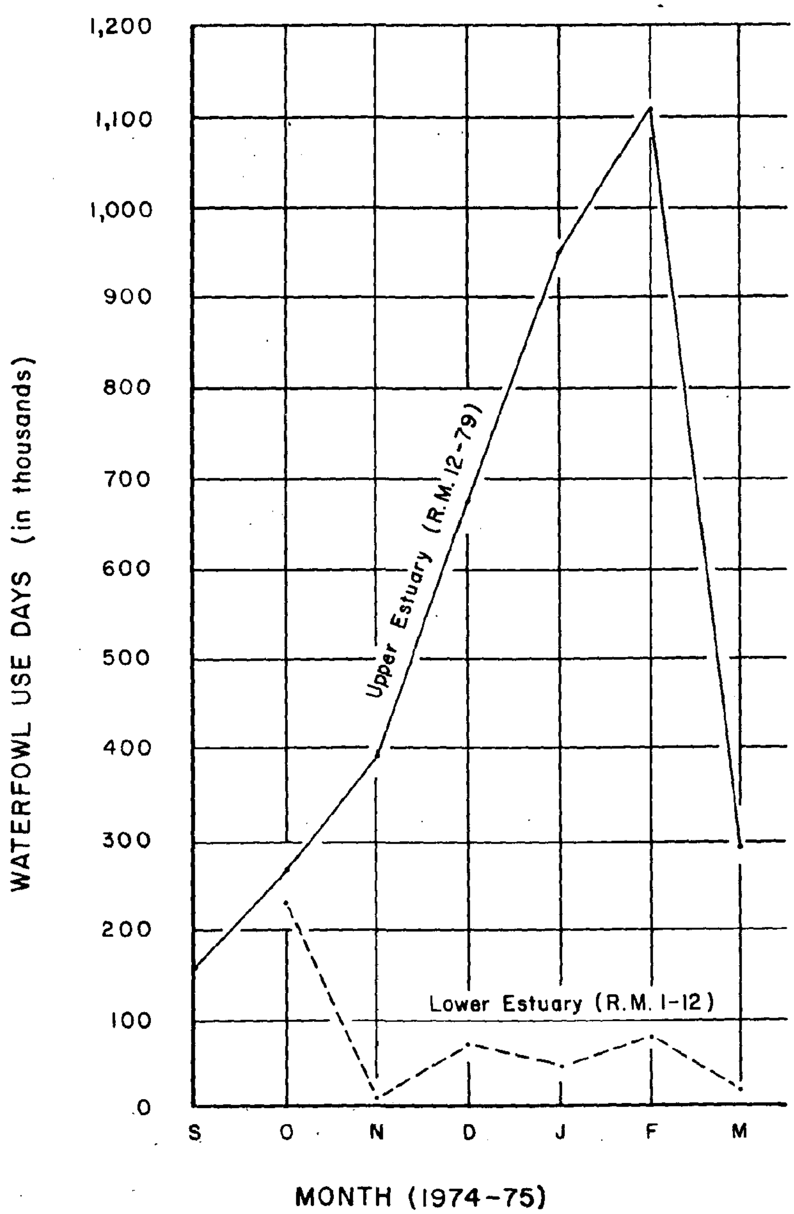
Species	December 1975	January 1976	February 1976	March 1976.
Coot	50	50	60	40
Swan	10	20	30	2
Canada geese	50	150	50	10
Mallard	150	350	150	50
Pintail	50	110	75	10
Green-winged teal	110	-	-	-
Widgeon	300	600	400	100
Shoveler	-	5	5	-
Scaup	-	50	50	300
Bufflehead	10	50	50	50
Common merganser	35	40	40	30
Unidentified	200	150	250	100

NOTE: Gull use heavy during all months

*Based on one flight per month and occasional observations. Restricted to Youngs River from mouth to approximately RM 5 (above Haven Island).

From: Dave Fisher, Manager Columbian White-Tailed Deer National Wildlife Refuge

ESTIMATED WATERFOWL USE OF THE UPPER AND LOWER COLUMBIA RIVER ESTUARY DURING FALL AND WINTER, 1974-75.



FROM: OREGON COOPERATIVE WILDLIFE RESEARCH UNIT, 1976.

FIGURE 303-3

TABLE 303-5

MIGRANT WATERFOWL CONCENTRATION
IN THE
UPPER COLUMBIA RIVER ESTUARY (River Mile 12-50)*

Concentration	Species	Geographical Location	Vegetation Habitat	Seasonal Occurrence
Moderate	Canada Geese	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
Low	White-fronted Geese	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Fall/spring
High	Mallards	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
High	Widgeons	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
High	Pintail Ducks	National Wildlife Refuge RM 18-38	Tidal Marsh and Islands	Winter
High	Whistling Swans	Grassy, Russian & Seal Islands	Intertidal Marsh and Flats	Winter

*Areas further upriver receive greater habitat use by migrant waterfowl.

From: Oregon Cooperative Wildlife Research Unit, 1976

TABLE 303-6

ANNUAL WATERFOWL PRODUCTION ESTIMATES REPORTED BY REFUGE PERSONNEL FOR LEWIS AND CLARK/COLUMBIAN WHITE-TAILED DEER NATIONAL WILDLIFE REFUGES

Species	Birds/YEAR			
	Lewis & Clark Refuge		Columbian White-Tailed Deer Refuge	
	1974	1975	1974	1975
Canada goose	5	8	6	6
Mallard	150	125	40	60
Gadwall				
Pintail	15			
Green-winged teal	75	85	50	50
Blue-winged/Cinnamon teal	45	20	40	40
American widgeon				
Shoveler				
Wood duck	35	35	60	45
Redhead				
Ring-necked duck				
Canvasback				
Lesser/greater scaup				
Ruddy duck				
Common merganser	50	50	75	60
Hooded merganser	10	15	15	12
Pied-billed grebe				
American coot				
Total	385	338	286	273

From: Oregon Cooperative Wildlife Research Unit, 1976 (Production estimates obtained from NWR managers).

TABLE 303-7

MONTHLY WATERFOWL POPULATION ESTIMATES (APRIL-AUGUST 1974)
PREPARED BY REFUGE PERSONNEL FOR LEWIS AND CLARK
AND COLUMBIAN WHITE-TAILED DEER NWR's

Species	April	May	June	July	August
Whistling swan					
Canada goose	225	50	20	27	30
White-fronted goose					100
Mallard	925	425	300	230	800
Gadwall					
Pintail	325	100	45	35	200
Green-winged teal	400	135	135	155	180
Blue-winged/Cinnamon teal	75	55	75	50	70
American widgeon	1600	600	100	90	350
Shoveler	2	2	18	10	
Wood duck	55	55	70	75	85
Redhead					
Ring-necked duck					
Canvasback					
Lesser/greater scaup	350	220	15		
Common/Barrow's goldeneye					
Bufflehead	20				
Ruddy duck					
Common merganser	350	250	120	100	100
Hooded merganser	7	15	30	23	25
American coot	10				
Unidentified ducks	300	250	135	150	250
Total	4634	2173	1063	945	2190

From: Oregon Cooperation Wildlife Research Unit, 1976 population in the wildlife refuge areas and Grays Bay, but wood ducks, green-winged teal, blue-winged/cinnamon teal and common merganser also nest and breed in these areas.

303.4 BIRDS OTHER THAN WATERFOWL

According to the recent study of habitat and wildlife along the lower Columbia conducted by the Oregon Cooperative Wildlife Research Unit (OCWRU), some 149 species of birds are found near the mouth and along the shorelines of the estuary (Table 303-8). This does not include the 26 species of waterfowl discussed in the previous section, indicating that a least 175 species of birds can be found in the estuary area. These include waterfowl and marine birds, wading birds, shorebirds, game birds, raptors and others. Some are migrants (present or passing through only at certain seasons), while others are permanent residents. Many nest along the shorelines, several in colonies such as the large herony on Karlson Island.

Many of the non-waterfowl birds play an important role in the functioning of the estuarine ecosystem, feeding on organic matter, small fish, crustaceans and mollusks. This is particularly true for the long-legged wading birds and shorebirds which utilize sand and mud flats extensively.

Some of the riparian habitat sampled by OCWRU researchers had very high densities for bird communities. The richness of riparian habitat was attributed to several factors including (1) the linear dimensions of the riparian habitat areas, providing large areas of "edge" which are known to be productive (2) the nutrient rich, productive flats and marshes which provide food for many species, (3) the tall and multilayered vegetation such as cottonwood/willow habitat and (4) the isolation of riparian vegetative strips which create "islands" that may be attractive to birds.

A. Wading Birds, Shorebirds and Gulls

The several species of wading birds and the many shorebirds and gulls play an important role in the natural functioning of the estuary. While gulls are some of the most common birds seen on the shorelines, sandpipers, plovers, great blue heron and other waders provide

Table 303-8

Species of Birds (Other than Waterfowl), Their Preferred Habitat and Estimated Abundance[1] Along Estuary Shorelines

[1] Abundance Rating

AB = abundant--100 or more birds observed/day/observer
Vc = very common--50-99 birds/day/observer
C = common--10-49 birds/day/observer
U = uncommon--5-9 birds/day/observer
R = rare--0-4 birds/day/observer
Vr = very rare--fewer than 5 birds/season/observer
A = accidental--10 or fewer records/season

Seasons are abbreviated as follows:

F = Fall
W = Winter
Sp= Spring
S = Summer

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
WATERFOWL MARINE BIRDS									
Common Loon	Open water	U	C	U					
Artic Loon	Open water	U	R	U		R			
Red-throated Loon	Open water	U	R	U					
Red-necked Grebe	Open water			R					
Western Grebe	Open water	Vc	Vc						
Pied-billed Grebe	Open water					R			
Double-crested Cormorant	Open water	U	U				C		
Brandt's Cormorant	Bays and estuaries	U	U	U	U				
Pelagic Cormorant	Bays and estuaries	U	U	U	U				
White-winged Scoter	Coastal waters	U	U	U	U				
Surf Scoter	Coastal waters	U	C	Ab	U				
Black Scoter	Coastal waters	R	R	R					
Common Merganser	Open water					U	R	R	R
Red-breasted Merganser	Coastal area			R	Vr			R	
Caspian Tern	Open water	C		C	C	C		U	U
Common Murre	Open water	U		U					
Pigeon Guillemot	Open water			U	U				
Cassin's Auklet	Open water					Ac			

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
LONG-LEGGED WADING BIRDS									
Great Blue Heron	Shoreline	U	U	U	U	U	U	R	R
Green Heron	Shoreline							Vr	Vr
Great Egret	Marsh, mud flats	Vr							
Black-crowned Night Heron	Marsh	Ac		Ac					
American Bittern	Marsh, grassland	Vr		Vr	Vr				
Sandhill Crane	Fields, marshes					Vr	C	U	
American Coot	Marshes, open water	C	C						
RAPTORS									
Turkey vulture	Open country							R	R
Sharp-skinned Hawk		R		R				R	
Cooper's Hawk	Cottonwood	U							
Red-tailed Hawk	Woodlands	U	U	U	U	R	R	R	R
Rough-legged Hawk	Open country	U	U						
Bald Eagle	River's edge	R	R	R	R	R	R		
Marsh Hawk	Marsh, fields	U	U	U	U				
Osprey	Lakes, rivers, Cliff faces					Vr	Vr		
Barn Owl	Ash-willow, cottonwood					R		R	
Screech Owl	Tree-willow, cottonwood			R	R	R	R	R	R
Great Horned Owl	Cottonwood, oak-pine			R	R			R	R
Snowy Owl	Beachgrass, beaches		R						
Saw-whet Owl	Tree-willow, cottonwood	U		R		R			R
Peregrine Falcon	Tidal flats, open country	R	R			R	R		
American Kestrel	Open country	U	U	U	U			R	R
Northern Shrike	Open country, grassland	U	U			R			

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
GAME BIRDS									
Ruffed Grouse	Forest	U	R		R	R	R		R
California Quail	Open forest and agricultural land					R	R	R	R
Ring-necked Pheasant	Shrubland, agricultural land	R	R	R	R	R	R	R	R
Common Snipe	Marshes	U	U	U		C	U	C	
Band-tailed Pigeon	Forest			R				R	R
Mourning Dove	Cottonwood, tree willow			R	R			U	R
SHOREBIRDS AND GULLS									
Semipalmated Plover	Mud flats	C		C	U				
Snowy Plover	Sandy beaches	R	R	R	R				
Killdeer	Mud flats, beaches		U		U	R		R	R
Golden Plover		Vr							
Black-bellied Plover	Mud flats, beaches	U	U	U					
Surfbird	Rip-rap		U						
Ruddy Turnstone	Mud flats	R	U						
Black Turnstone	Rip-rap		U	U					
Whimbrel	Mud flats	U		U					
Spotted Sandpiper	Sandy beaches					R	R		R
Solitary Sandpiper	Mud flats	R		R					
Wandering Tattler	Rip-rap	U		U					
Greater Yellowlegs	Mud flats	R				R			
Knot	Tidal flats			U					
Pectoral Sandpiper	Marshes	R							
Least Sandpiper	Mud flats	C		C				R	
Dunlin	Mud flats	Vc	Ab	Ab		Ab			
Western Sandpiper	Mud flats, marsh	Vc	C	Vc	U	C		Vc	
Sanderling	Sand beaches		U			C		R	
Northern Phalarope	Open water	C		C					
Parasitic Jaeger	Tidal marshes	R							

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
SHOREBIRDS AND GULLS (Cont.)									
Glaucuous-winged Gull	Bay and estuaries	Vc	Vc	Vc	Vc	U	C	U	U
Western Gull	Bays, estuaries, river	C	C	C	Ab	R	R		
Herring Gull	Bays, rivers edge	U	U	U		U	U	U	
Thayer's Gull		U	U	U		U	U		
California Gull	Bays, river	Ab	C	C	Ab	Ab			U
Ring-billed Gull	Bays, river	U			Ab		Vc		
Mew Gull	Bays, estuaries	C		C		R	C	U	
Bonaparte's Gull	Bays, estuaries	U				C			R
Heerman's Gull	Open water	U			U				
Black-legged Kittiwake		U			U				
OTHER BIRDS									
Vaux's Swift	Sitka spruce, tidal marsh	C		U		C		R	R
Rufous Hummingbird	Conifers, edges			U	U			R	U
Belted Kingfisher	Rivers, streams, ponds	R	R	R	R	U	U	U	U
Common Flicker	Open forests	U	U			R	R	R	R
Yellow-bellied Sapsucker	Cottonwood, tree willow								R
Hairy Woodpecker	Cottonwood		U			R	R	R	R
Downy Woodpecker	Tree willow, cottonwood	U		U		R	U	U	R
Willow Flycatcher	Cottonwood							R	R
Western Flycatcher	Alder				C			Vr	
Western Wood Peewee	Cottonwood								U
Olive-sided Fly-catcher	Sitka spruce							R	R
Horned Lark	Grasslands	U		U					
Violet-green Swallow		C		U	C	Vc		C	C

Species	Preferred Habitat	Lower Estuary (RM 0-12) F	W	Sp	S	Upper Estuary (RM 12-79) F	W	Sp	S
OTHER BIRDS (Cont.)									
Tree Swallow	Tree willow, cottonwood	C		C	U	Vc		C	U
Rough-winged Swallow	Near water					C		U	U
Barn Swallows		C		C	C	Vc		U	U
Cliff Swallow	Rock scarps, buildings			U	C	Vc		R	R
Purple Martin	Rivers edge, sandy beaches					R		R	R
Steller's Jay	Conifers, tree willow					U	R	R	R
Scrub Jay	Tree willow								Vr
Common Raven	Cliffs, grasslands, rabbitbrush	R	R	R	R				
Common Crow	Beachgrass, tree willow, open country	U	U	C	C	C	C	U	U
Black-capped Chickadee	Woodlands	C	U	U	U	Vc	C	C	C
Chestnut-backed Chickadee	Conifers			R		U	U	U	
Bushtit	Deciduous woods			R		R		R	
Red-breasted Nuthatch	Tree willow, conifers	R				R	R		
Brown Creeper	Cottonwood		U			R	R	R	
Wrentit	Alder	R							
Winter Wren	Tree willow, cottonwood	C	C	C	C	C	C	U	R
Bewick's Wren	Tree willow, cottonwood	U	U	U	C	U	U	U	U
Long-billed Marsh Wren	Cat-tail marsh, sedge marsh	R	R			R	R	R	R
Rock Wren	Cliff faces, rocky area	Vr							
Sage Thrasher					Ab				
American Robin	Cottonwoods	C	U	U	C	Vr	R	C	C
Varied Thrush	Conifers	U	U			C	R		

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
<u>OTHER BIRDS</u> (Cont.)									
Hermit Thrush	Conifers	R					R	R	
Swainson's Thrush	Cottonwood, tree willow				C		R	C	
Golden-crowned Kinglet	Tree willow, cottonwood	Vc	C	U		Vc	C	U	
Ruby-crowned Kinglet	Conifers, cotton-wood	R	R	R		U	R	R	U
Cedar waxwing	Conifers, cotton-wood								U
Starling	Cottonwood, urban areas	C	C	C	Vc	Vc	R	C	C
Hutton's Vireo	Alder				R	R			R
Red-eyed Vireo	Cottonwood								R
Warbling Vireo	Tree willow, cottonwood								R
Orange-crowned Warbler	Tree willow			U	R	U		U	
Yellow Warbler	Shrub willow, cottonwood								C
Yellow-rumped Warbler	Woodlands							U	
Black-throated Gray Warbler	Woodlands				R	R		R	
Yellowthroat	Marsh edges, tree willow			U	U		R	R	
Wilson's Warbler	Shrub willow			U	U		C	R	
House Sparrow	Urban areas, farms	C	C	C	C				
Western Meadowlark	Grasslands, rabbitbrush	C	U	U	U			U	
Red-winged Blackbird	Shrub willow, cotton marsh			U	U	Vc	R	U	R
Northern Oriole	Cottonwood							R	U
Brewer's Blackbird	Fields, farmlands				U		R		
Brown-headed Cowbird	Fields, farmlands, tree willow, cottonwood		U		U		C		C

Table 303-8(Cont.)

Species	Preferred Habitat	Lower Estuary (RM 0-12)				Upper Estuary (RM 12-79)			
		F	W	Sp	S	F	W	Sp	S
OTHER BIRDS (Cont.)									
Western Tanager	Conifers					R			
Black-headed Grosbeak	Cottonwood				R				
Lazuli Bunting	Russian olive								
Evening Grosbeak	Woodlands	C	C					R	
Purple Finch	Cottonwood					R	R	U	U
House Finch	Cottonwood urban areas					R	R	R	
Pine Siskin	Conifers			C	U	Vc	R	U	R
American Goldfinch	Tree willow, brushy areas	R			U	Vc		R	C
Red Crossbill	Conifers			Vc		Vc	U	C	
Rufous-sided Towhee	Cottonwood		R			R	R	R	R
Savannah Sparrow	Grasslands	U		C	C	C		R	
Dark-eyed Junco	Woodlands					R	U	R	R
White-crowned Sparrow	Russian olive					U		U	
Fox Sparrow	Sitka spruce, cottonwood					R	R		
Song Sparrow	Tree willow, cottonwood	U	C	C	C	C	C	C	C

From: Oregon Cooperative Wildlife Research Unit, 1976
(List compiled from actual observations and references which cite birds occurring in the area.)

aesthetic pleasure for nature-watchers. These birds feed on diets of small fish, crustaceans, insects, frogs and other small animals. Several of the shorebird species noted in Table 303-8 are migratory and present only during certain seasons. Among the shorebirds, the common snipe provides some recreational use as game.

B. Raptors

Raptors found in the estuary area include the sharp-shinned hawk, the Cooper's hawk, the red-tailed hawk, the rough-legged hawk, the bald eagle, the marsh hawk, the osprey, the peregrine falcon, the American kestrel, the saw-whet owl, the barn owl, the screech owl, the great horned owl, the snowy owl, the Northern shrike and the turkey vulture. Found at various times of the year, raptors utilize most types of shoreline habitat from beachgrass to cottonwood (Table 303-8). Many of these birds play an important role in rodent and insect control, and all are protected by law. Most raptors are classified as rare or uncommon in the estuary area. The peregrine falcon, a rare visitor to the estuary area, is the only species considered endangered nationally.

C. Colonial Nesting Birds

Colonial nesting birds which nest in the estuary area include the great blue heron, the pelagic cormorant, the glaucuous-winged gull, the western gull and the Caspian tern. Table 303-9 shows breeding sites and population statistics for colonial nesting birds in the estuary area, excluding Youngs Bay. Colonial nesting birds generally utilize the same area from year to year. These nesting sites should be preserved.

Of particular interest are the known heronies in the estuary area; two of these are in the National Wildlife Refuges and protected. The herony on Karlson Island, according to a recent study sponsored by the National Science Foundation, is the largest known on the Oregon coast; it consists of 175 nests in 48 Sitka spruce trees and covers almost an acre. An estimated 442 young birds were produced in the herony during the year of the study. The Karlson Island herony and another on Welch Island are the only ones reported, although others may exist.

D. Gamebirds

Gamebirds present along the estuary shoreline include the ruffed grouse, the California quail, the ring-necked pheasant, the band-

TABLE 303-9

BREEDING SITES AND POPULATION STATISTICS FOR COLONIAL NESTING BIRDS IN THE COLUMBIA RIVER ESTUARY AREA[1]

Species	Geographical Location	Numbers of Pairs	Type of Habitat
Pelagic Cormorant	Cape Disappointment CRM-2	Undetermined	Cliff Face
Great Blue Heron	Karlson Island CRM-26	175 pairs[2]	Tidal Spruce
Great Blue Heron	Welch Island CRM-34	28 active nests	Cottonwood
Glaucuous-winged Gull	Sand Island CRM-5	360-520 pairs estimated	Rock, rip-rap, sand, grass, drift
Western Gull	Cape Disappointment CRM-2	Undetermined	Cliff Face
Western Gull	Sand Island CRM-5	540-780 pairs	Rock, rip-rap, sand, grass, drift
Caspian Tern	Sand Island CRM-5	100+ pairs[3]	Rock, rip-rap, sand, grass, drift

From:
1. Oregon Cooperative Wildlife Research Unit, 1976
2. McMahon, undated
3. Joe Welch, 1977 (Personal communication)

tailed pigeon, the mourning dove and the common snipe. Their preferred habitat and estimated abundance are included in Table 303-8. In general, the OCWRU found that gamebirds are not abundant in the estuary except for common snipe in tidal marsh areas. The upper estuary, however, has more species and higher densities of gamebirds than the lower estuary.

Other gamebirds which the Oregon Department of Fish and Wildlife report are present in the estuary area include mountain quail, blue grouse, valley quail, and bobwhite quail.

303.5 BIG GAME

Four species of big game are known to live in the Columbia River estuary area; included are elk, black bear, black-tailed deer and the endangered Columbian white-tailed deer (Figure 303-2). Cougar, which might be expected to occur in the area, have not been reported in recent studies.

Near the Columbia River mouth, black-tailed deer are the only big game species that commonly utilize immediate shoreline habitat. Beach grass, open fields or brushy clearcut areas are used for grazing, with alder and coniferous habitat used extensively for cover. Black bear and elk occur in upland areas, especially along the Washington shore.

All four species inhabit the estuary areas above Baker Bay on the Washington shore and east of Astoria on the Oregon shore. Black-tailed deer, which are numerous in both Washington and Oregon areas of the estuary, utilize many habitat types; they seem to prefer upland forested areas, however, where the cover affords maximum protection. Elk are also found on both shores, sometimes in herds feeding in pasture areas. Forested habitats such as Sitka spruce, Douglas fir and alder are likewise utilized. Occasionally, black bear are found along mid to upper estuary shorelines, though they much prefer the more isolated upland forest areas.

The Columbian white-tailed deer is listed as an "endangered" species by the U.S. Department of Interior. To preserve and protect this species in its riverbottom land natural habitat, the 5,230 acre Columbian White-Tailed Deer National Wildlife Refuge was established in 1972. The refuge lands which encompass Price Island, Hunting Island, Tenasillahe Island and part of the mainland northwest of Cathlamet, are mostly diked.

In a 1975 study of habitat use and activity patterns, L. H. Suring reported that preferred habitat of the deer in summer and spring is grazing vegetation, such as natural or cattle-maintained pasture. Woody cover and forage is necessary for fall feeding, to permit fat storage for overwintering, for breeding and for protection from severe weather and possible predators. Where either too much open area (pasture) or heavily wooded cover occurs without interspersion, deer use and densities are reduced.

There are numerous estimates of white-tailed deer populations. Presently, there are thought to be about 200-300 on the Washington shore of the Columbia between Skamokawa and Cathlamet, about 50 on Tenasillahe Island, about 50-75 on Puget Island, 25-30 on the Oregon shore between Westport and Clatskanie, for a minimum total of about 325 deer. There are also reports of sightings near Grays Bay, Welch Island, Wallace Island and farther upriver at Deer Island. Former distributions included Columbia River islands and shorelands from the Dalles to Astoria, and the Cowlitz and Willamette River valleys. A larger, healthy and unprotected population of white-tailed deer is still active in Douglas County, Oregon. Alteration or loss of habitat appears responsible for the decline in original distribution and population. Continued management and research is needed if this species is to be preserved.

303.6 AQUATIC AND TERRESTRIAL FURBEARERS

Aquatic furbearers in the estuary area include beaver, river otter, mink, muskrat and nutria. Terrestrial furbearers include raccoons, opossums, coyotes, striped and spotted skunk, porcupines and gray fox.

Aquatic furbearers, particularly beaver, nutria and muskrat, are much more abundant in the upper estuary wildlife refuge areas than in the lower estuary, or any other areas farther up the Columbia. Muskrats and nutria are very common in tidal marsh, willow and

Sitka spruce habitat. Otter are not common along estuary shorelines, but utilize small tributary streams and sloughs. Only low densities of mink occur along estuary shorelines. Beaver are very common, utilizing many vegetative habitats. Beaver use of sloughs, ponds and other areas protected from wave action and from extreme tidal fluctuations is extensive. However, tidal willow and spruce habitat between river miles 26 and 38 reportedly have intensive beaver use as well. According to unpublished reports by the Washington Department of Game, the Oregon Department of Fish and Wildlife, and observations by the OCWRU, some 409 beaver and estimated 6,000 nutria were harvested by trappers in the estuary area during the 1974-75 seasons. This gives a minimum estimate of abundance.

Of terrestrial furbearers in the estuary area, raccoons are most common; they utilize alder and beachgrass, but prefer intertidal habitats. Opossums prefer non-tidal habitats and are more common in reaches of the estuary area and farther upriver. Of particular interest are reports of gray fox by the OCWRU, since this animal has not been previously reported along Washington or Oregon shores of the estuary.

303.7 SMALL MAMMALS, REPTILES AND AMPHIBIANS

In the OCRWU study of wildlife associated with riparian habitat, nineteen species of small mammals, including shrews, mice, rabbits, voles, moles, weasels, squirrels, chipmunks and mountain beaver were trapped or observed. Deer mice and species which feed on insects were most common. Habitats where different species were observed or trapped are shown in Table 303-10.

Reptiles and amphibians found in the estuary area include frogs, snakes, salamanders, lizards and newts; they are listed by habitat type occupied in Table 303-11. The highest number of species and greatest abundance of reptiles and amphibians are found along the immediate shoreline "edge" habitats. Upland habitat and tidal marshes, are not as extensively used.

Bats are found in low densities in the estuary area. They utilize most habitat types.

TABLE 303-10

SPECIES OF SMALL MAMMALS IDENTIFIED IN VARIOUS COLUMBIA RIVER ESTUARY HABITATS (RIVER MILE 0-79)

TIDAL MARSH

Vagrant shrew
Dusky shrew
Pacific Water shrew
Shrew-mole
Deer mouse
Townsend's vole
Creeping vole
Pacific jumping mouse
Short-tailed weasel
Long-tailed weasel
Norway rat

TIDAL SHRUB WILLOW

Vagrant shrew
California ground squirrel
Deer mouse

TIDAL SITKA SPRUCE

Vagrant shrew
Dusky shrew
Pacific water shrew
Trowbridge's shrew
Brush rabbit
Eastern cottontail
Townsend's chipmunk
Northern flying squirrel
Deer mouse
Pacific jumping mouse
Long-tailed weasel

COTTONWOOD/WILLOW

Vagrant shrew
Townsend's mole
Eastern cottontail
Deer mouse
Townsend's vole
Pacific jumping mouse

ALDER

Vagrant shrew
Dusky shrew
Pacific Water shrew
Trowbridge's shrew
Shrew-mole
Coast mole
Snowshoe hare
Townsend's chipmunk
Douglas' squirrel
Deer mouse
Townsend's vole
Long-tailed vole
Pacific jumping mouse
Long-tailed weasel
California ground squirrel

COTTONWOOD

Vagrant shrew
Townsend's mole
Brush rabbit
Eastern cottontail
Townsend's chipmunk
California ground squirrel
Deer mouse
Townsend's vole
Long-tailed vole
Creeping vole

WILLOW

Vagrant shrew
Brush rabbit
Deer mouse
Townsend's vole

REED CANARYGRASS

Vagrant shrew
Deer mouse
Townsend's vole

Table 303-10 (cont'd)

MAPLE/DOUGLAS FIR	BEACHGRASS
Snowshoe hare	Vagrant shrew
Mountaine beaver	Dusky shrew
California ground squirrel	Shrew-mole
Norway rat	Coast mole
Pacific jumping mouse	Brush rabbit
Long-tailed weasel	California ground squirrel
	Deer Mouse
	Creeping vole

From: Oregon Cooperative Wildlife Research Unit, 1976

TABLE 303-11

Species of Reptiles and Amphibians Identified in Various Columbia River Estuary Habitat (River Mile 0-79)

TIDAL SHRUB WILLOW

Pacific treefrog
Northern red-legged frog
Northwestern salamander
Rough-skinned newt
Northwestern garter snake

SITKA SPRUCE

Pacific treefrog
Northern red-legged frog
Northwestern salamander
Red-spotted garter snake
Northwestern garter snake

COTTONWOOD

Pacific treefrog
Northern red-legged frog
Bullfrog
Red-spotted garter snake
Northwestern garter snake

REED CANARYGRASS

Pacific treefrog
Northern red-legged frog
Long-toed salamander
Red-spotted garter snake
Northwestern garter snake

TIDAL MARSH

Pacific treefrog
Northern red-legged frog
Red-spotted garter snake
Northwestern garter snake
Rough-skinned newt
Western red-backed salamander
Eschscholtz's salamander

BEACHGRASS

Pacific treefrog
Red-spotted garter snake

COTTONWOOD/WILLOW

Long-toed salamander
Red-spotted garter snake
Northwestern garter snake

DOUGLAS FIR/MAPLE

Pacific giant salamander
Western red-backed salamander
Rough-skinned newt
Olympic salamander
Northern alligator lizard
Red-spotted garter snake

DOUGLAS FIR/HEMLOCK

Eschscholtz's salamander
Western red-backed salamander

PASTURE

Pacific treefrog
Northwestern salamander
Long-toed salamander
Rough-skinned newt

ALDER

Pacific treefrog
Northern red-legged frog
Bullfrog
Red-spotted garter snake
Rough-skinned newt

CAT-TAIL/BLACKBERRY LINED POND

Bullfrog

WILLOW/REED CANARYGRASS

Northwestern garter snake

From: Oregon Cooperative Wildlife Research Unit, 1976

303.8 MARINE MAMMALS

Harbor seals are the most common marine mammal in the estuary, although California sea lions are increasingly using the lower Columbia River.

Sand bars and islands, such as Desdemona Sands (RM 9), Miller Sands (RM 25), and Rice Island (RM 22) are haulout areas for harbor seals and can be considered vital habitat (Figure 303-2). A December, 1976 count of harbor seals in the estuary numbered them at nearly 1,000. They extend far upriver and have been sighted at Oregon Falls in the Willamette River.

In the last few years, the California sea lion has been using the Columbia estuary more frequently. One confirmed sighting at Bonneville Dam extends the known range of this species. The increased estuary and river use by sea lions and seals stems largely from a decreased level of harrassment resulting from enforcement of the 1972 Marine Mammal Protection Act. This increased range of marine mammals and their effect on the fish harvest, as well as their interferences with river fishermen, has resulted in a growing controversy.

303.9 REFERENCES

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D. Montagne and Associates. 1976. Natural Resource Base and Physical Characteristics of the Proposed Offshore Oil Platform Fabrication Site, Warrenton, Oregon (Technical Reports, Data Base and Appendix). Prepared for Pacific Fabricators, Inc.

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E. Skidmore, Owings and Merrill. 1973. A Plan for Land and Water Use, Clatsop County: Phase I, prepared for Clatsop County. Portland, Oregon.

Contains limited information on estuary habitats, but is very general and applies to Clatsop County only.

F. Suring, L.H. 1975. Habitat Use and Activity Patterns of the Columbian White-tailed Deer along the Lower Columbia River. M.S. Thesis, Oregon State University.

A detailed study of the activity and utilization of different vegetative habitats is given.

G. State of Oregon, Coastal Conservation and Development Commission. 1974. Fish and Wildlife Resources of the Oregon Coastal Zone. Prepared by Ken Thompson, Oregon Department of Game and Dale Snow, Fish Commission of Oregon.

This report discusses fish and wildlife in the coastal zone including offshore, estuaries, freshwater, and uplands. The estuarine area includes submerged lands, coastal tideland, submersible lands and coastal saltmarsh.

H. State of Oregon, Cooperative Wildlife Research Unit. 1976. Inventory of Riparian Habitats and Associated Wildlife Along the Columbia River: Final Report, prepared for U.S. Army Corps of Engineers.

Recently completed study classifying riparian habitat and associated wildlife of the greater portion of the estuary and its shorelands. Includes qualitative and quantitative sampling of vegetation and wildlife, habitat classification maps, etc. A vast amount of data and valuable resource. This study was the primary source document for this inventory of wildlife.

I. State of Oregon, Department of Fish and Wildlife. 1976. Fish and Wildlife Habitat Protection Plan for Clatsop County, prepared by Doug Taylor and Warren Knispel for Clatsop County Department of Planning and Development.

Information on fish and wildlife resources and specific recommendations for habitat protection are provided. Data on recreational use of fish and wildlife is also given.

J. State of Oregon, Game Commission. 1972. Outdoor Almanac: Wildlife Conservation. Portland, Oregon.

Individual leaflets on wildlife such as birds, fish, game, etc. are provided with specific information on individual species.

K. State of Oregon, Department of Transportation. 1975. Lower Columbia River Ports Region Study. Prepared by Planning Section, Salem, Oregon.

This publication contains natural resource data, wildlife distribution maps, etc. for the lower Columbia area in support of proposed port development areas.

L. State of Washington, Department of Game. 1975. A Baseline Survey of Significant Marine Birds in Washington State. Coastal Zone Environmental Studies Report No. 1.

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M. State of Washington, Department of Game. 1975. Marine Shoreline Fauna of Washington: A Status Survey. Coastal Zone Environmental Studies Report No. 2.

Fact sheets on many species of birds and mammals inhabiting the shoreline of Washington including the lower Columbia River.

N. U.S. Army Corps of Engineers. 1976. Final Environmental Impact Statement: Lower Columbia Bank Protection Project (Washington and Oregon). Portland, Oregon.

Riparian biology is discussed and tables of species of birds, mammals, etc. found in the lower Columbia area are presented.

O. U.S. Army Corps of Engineers. 1975. Final Environmental Impact Statement: Columbia and Lower Willamette River Maintenance and Completion of the 40-foot Navigation Channel Downstream of Vancouver, Washington and Portland, Oregon.

Descriptive information on riparian biology and tables of data on birds and mammals are provided.

P. U.S. Department of Interior, Bureau of Sports Fisheries and Wildlife. 1973. Final Environmental Impact Statement: Proposed Additions to and Operation of the Columbian White-Tailed Deer National Wildlife Refuge.

Describes the acquisition of over 5,000 acres in the Columbia River estuary area as refuge land to preserve habitat of the endangered Columbian white-tailed deer.

304 PLANKTON

COLUMBIA RIVER ESTUARY

PLANKTON

James W. Good

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304 PLANKTON

All swimming and floating organisms belong to the "pelagic" division. Active swimmers, such as salmon and herring constitute the "nekton," whereas, weak swimmers and the floating, drifting life, form the "plankton." This group includes bacterioplankton (bacteria), phytoplankton (plants) and zooplankton (animals).

One of the most useful groupings for plankton is size classification. The largest plankton (macroplankton) range from 0.2 millimeters (mm) to more than a meter and include animals such as copepods, fish larvae and jellyfish. The next smaller group (microplankton) ranges from 0.02-0.2 mm and includes most phytoplankton and protozoans. Plankton in the smallest size grouping (nannoplankton), less than 0.02 mm, include bacteria and the smallest phytoplankton. To understand plankton and their relationship to physical factors and to each other, it is necessary to understand their growth and reproductive processes.

Bacterioplankton may regenerate within a few hours by asexually reproducing a copy of their genes and then dividing into two. Phytoplankton, which may reproduce sexually or asexually, generally require a day or more to double in size, even under favorable environmental conditions.

Zooplankton growth rates vary enormously from less than a week for some protozoa to more than a year for some larger macroplankton. As an example, the dominant estuarine copepod in the Columbia, *Eurytemora hirundoides*, has a generation time of about three months (with favorable summer conditions).

This section examines what is known about the plankton of the Columbia River estuary. Phytoplankton production and nutrient relationships and other limiting factors are considered and zooplankton distribution, abundance and relationships to physical and biological variables are also discussed.

304.1 PHYTOPLANKTON

Phytoplankton, one of the primary producers in the estuarine ecosystem, utilize nitrogen, phosphate, silicate, carbon dioxide and other minor constituents in the photosynthetic process to produce organic matter. Phytoplankton require sunlight for photosynthesis and therefore are confined to surface waters where light penetrates. A 1967-68 survey of Columbia River estuary phytoplankton by Lois Haertel and other Oregon State University researchers represents the only available data on the subject; it is the basis of this discussion.

A. Oxygen and Nutrients

Nutrients in the estuary are derived from three sources: (1) freshwater entering the estuary, (2) marine waters, and (3) regeneration within the estuary by zooplankton excretion and decomposition processes. Nutrient budgets are examined in detail in Section 205 (Estuarine Water Quality, Nutrients, Mixing and Pollutants), with monthly oxygen and nutrient inputs shown in Table 205-1.

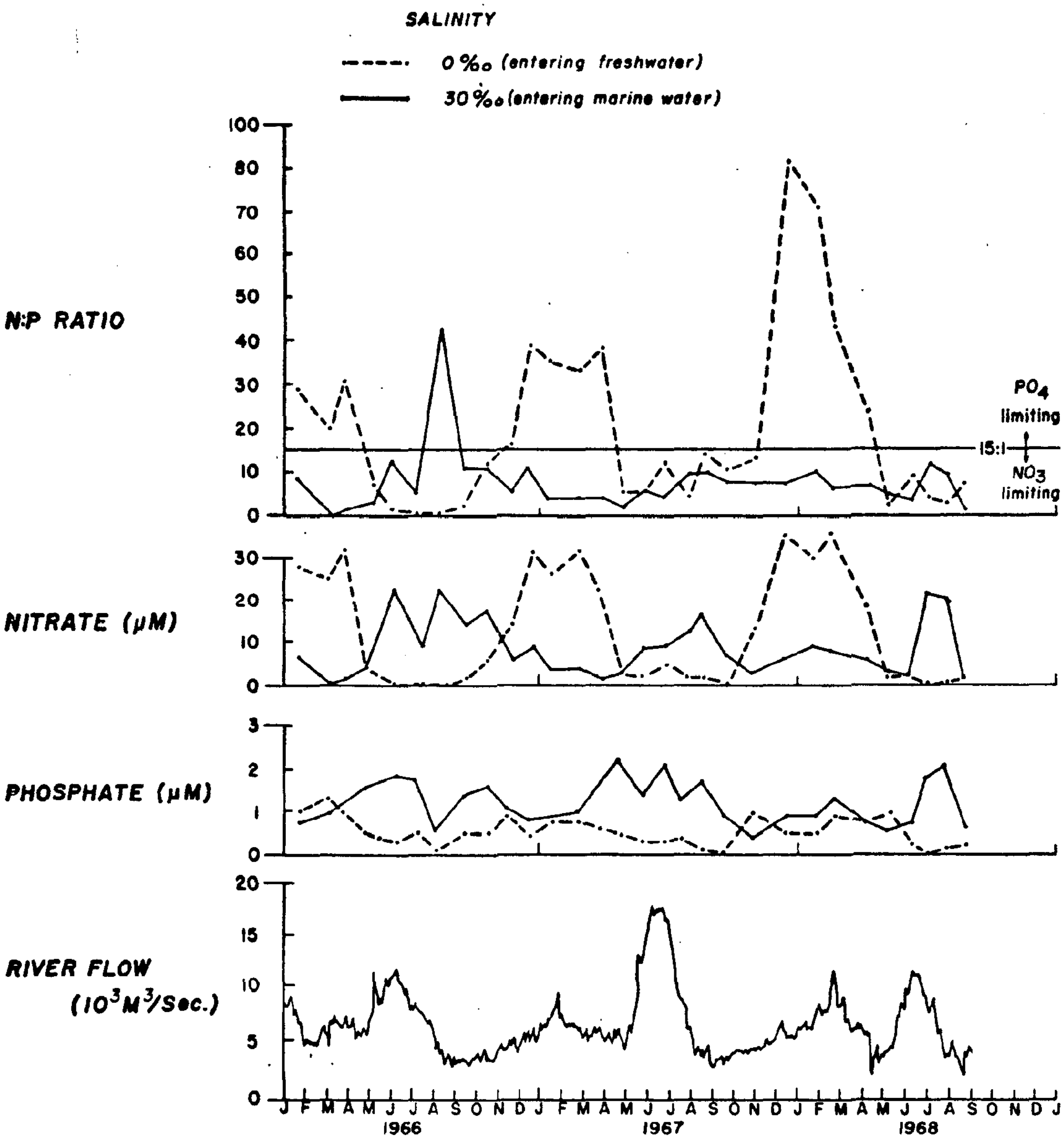
Oxygen values are generally high in the estuary, owing to high values (5-8 ml/liter) from incoming freshwater. Oxygen in the salt wedge is generally lower (2-3 ml/liter) during summer, when offshore upwelling occurs. Silicate values are always high in river water and probably are never limiting, even though river phytoplankton (diatoms) utilize large quantities of silicate to manufacture their delicate encasements. Silicate values in the salt wedge are much lower. Phosphate levels (Figure 304-1) are about equal in entering fresh and marine waters in winter, depleted in late summer freshwaters (probably due to upriver phytoplankton growth and uptake) and enriched in entering marine waters during upwelling season. Nitrate levels in entering freshwater vary from near zero in summer to high levels (Figure 304-1) during winter, while nitrate levels in entering marine waters behave in the opposite manner. The depression in summer nitrate values to very low levels is probably due to upriver phytoplankton growth and uptake, and would seem to indicate that nitrate is limiting for summer phytoplankton production in the estuary. However, other forms of nitrogen such as ammonia, may be available and utilized by the freshwater phytoplankton which extend into the estuary. Plankton/nutrient relationships are also discussed in Section 205.

B. Phytoplankton Distribution and Abundance

Haertel and other Oregon State University researchers found that the Columbia River estuary has no unique flora, but rather is a mixture of marine and more dominant freshwater species.

The most abundant phytoplankton are freshwater diatoms including *Melosira* spp., *Fragilaria crotonensis*, *Asterionella formosa*, *Stephanodiscus astrea* and *Syndra ulna*. These species, which are characteristic of eutrophic lakes, indicate that the estuarine phytoplankton represent a downstream

CHANGES IN NITRATE, PHOSPHATE, N:P RATIO, AND RIVER FLOW WITH SEASON, 1966–1968.



FROM HAERTEL, ET. AL., 1969

FIGURE 304-1

extension of the river plankton. Phytoplankton are most abundant in the entering freshwater, with chlorophyll *a* and the number of cells decreasing downstream, with increasing salinity. Green and red algaes are also present in entering river water, though they are not nearly so abundant as the diatom species. Marine phytoplankton present in the intruding salt wedge but never more than 10% of the total estuarine flora, include such species as Asterionella japonica, Fragilaria oceania and Anabaena sp.

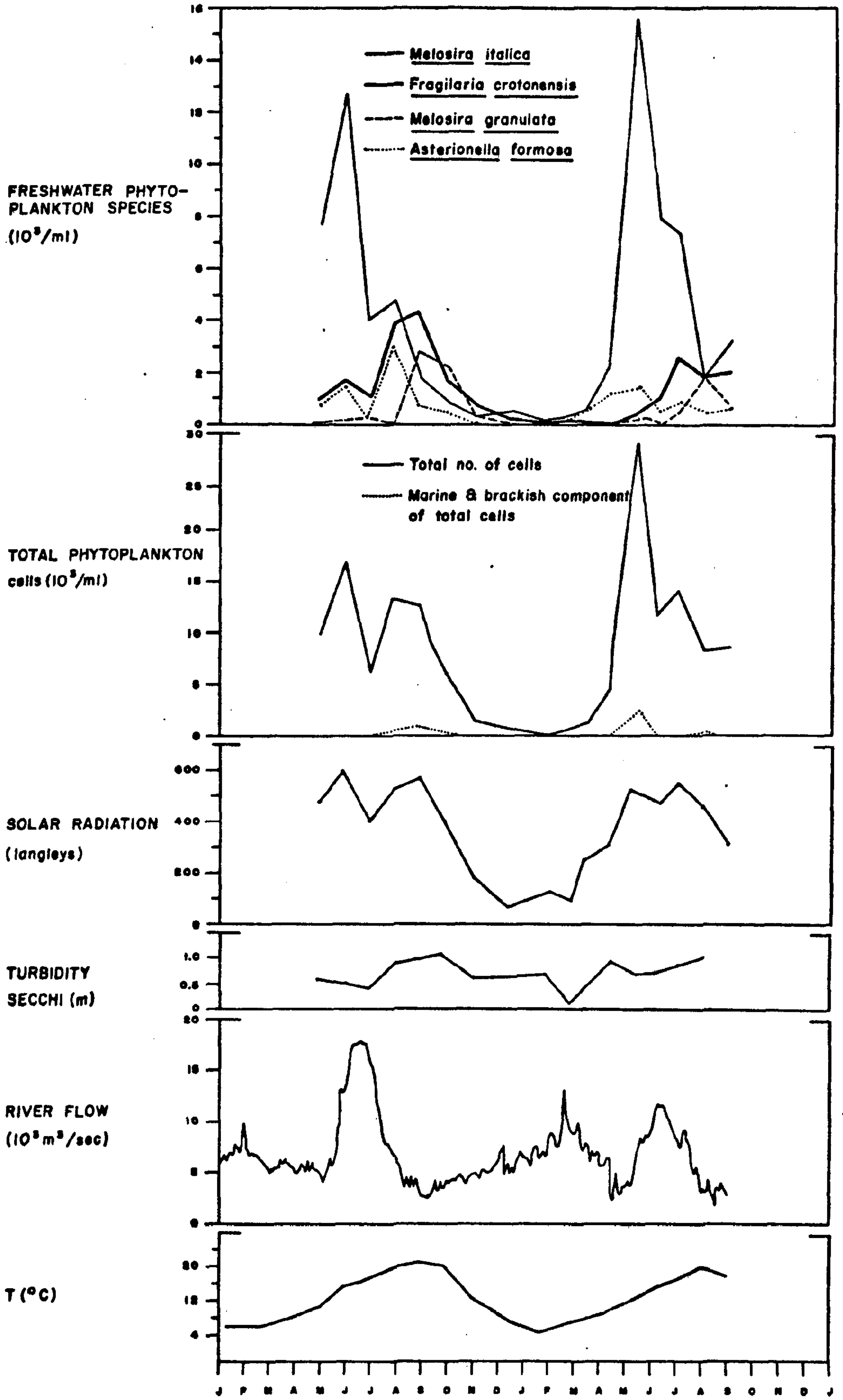
Freshwater phytoplankton are most abundant between April and September (Figure 304-2), with maximum peaks of 17,000 and 26,000 cells/milliliter (ml) in May of 1967 and 1968 respectively. Populations are low to non-existent in winter. Marine phytoplankton populations reached a maximum of 600 to 1,600 cells/ml in late summer of 1967 and 1968.

C. Factors Limiting Phytoplankton Productivity

Factors affecting productivity in the estuary may include (1) the availability of light, (2) the depth of the photic layer which is a function of river water turbidity, (3) concentration and resupply rate of nutrients, (4) water temperature, (5) river flow and amount of vertical mixing, (6) the rate of grazing by herbivores (primarily zooplankton) and (7) the presence or absence of micro-constitutents (e.g. vitamins) or growth-inhibiting substances in water. Several of these variables are illustrated in Figure 304-2 as compared to the standing crop of total phytoplankton and major freshwater phytoplankton species which extend into the estuary. No actual measurements of production (rate/unit of time) have been made.

In winter, nutrient levels are high (Figure 304-1) and would not be limiting. River flow has high and low periods during winter without apparent effect on phytoplankton numbers. Also, high year-round turbidty (secchi disc readings) with a variable photic layer (0.1 to 1.1 meters in depth) does not correlate significantly with changes in phytoplankton abundance, though it must certainly keep overall productivity relatively low. Of the remaining variables studied, only the amount of solar radiation shows a strong correlation with the spring increase and fall decrease in phytoplankton abundance. This indicates that light must limit phytoplankton production in winter.

Either nitrate or phosphate levels might be limiting during the summer, though the depleted nutrients in entering freshwater are substantially enriched in the lower estuary through mixing with entering upwelled marine waters (Section 205.2). Regeneration of phosphate and ammonia by animal excretion and other sources may also serve to keep sufficient nutrients



PHYTOPLANKTON CELLS (AVERAGED BY DATA FROM ALL STATIONS SAMPLED) COMPARED WITH LIGHT, TEMPERATURE, RIVER FLOW AND SECCHI DISC READINGS. FROM HAERTEL, et. al., 1969.

FIGURE 304-2

available. Nonetheless, research in the adjacent continental shelf waters and in other estuaries suggests that nitrogen is the limiting factor, because of its slow regeneration and other factors. The Columbia River might be an exception to this general rule, but no evidence suggests that this is so.

Seasonal succession of the four major freshwater diatom species (Figure 304-1) showed that Melosira italica was definitely a spring species, M. granulata and Fragilaria crotonensis were more abundant in summer and Asterionella formosa was abundant during both seasons. Increase in temperature over the summer was shown to be the controlling factor in this succession of species.

In summary, overall phytoplankton abundance (and presumably productivity) is probably limited on a year-round basis by the high turbidity (and shallow photic zone) in the Columbia River estuary, owing to great and variable river flow, high suspended sediment loads and strong tidal mixing forces. Within the resultant shallow productive surface layer, available light appears to limit phytoplankton during the winter. Low nutrient levels, particularly nitrate, have the potential to limit growth in summer.

304.2 ZOOPLANKTON

In contrast to the phytoplankton, which consist of only a few principal groups, the zooplankton include animals from many animal phyla. Some of the groups represented in the Columbia River estuary zooplankton are protozoans, coelenerates (cnidarians), ctenophores, polychaetes, rotifers, copepods, mysids, chaetognaths, mollusks, tunicates and vertebrates.

Many zooplankton organisms, such as calanoid copepods, live their life-cycle as plankton, while others, such as some fish and benthic invertebrates, are planktonic only in larval stages. In spring and early summer, these temporary plankton may be quite abundant as they seek dispersal and food. Some benthic animals, such as amphipods and harpacticoid copepods, live both in the sediments and water column with equal ease. Accordingly, the division between plankton, free-swimming animals and bottom dwellers is not precise, but varies depending on individual life cycles, feeding and other behavioral habits. For this reason, benthic invertebrates and fish which spend part of their life cycle as plankton will be discussed in subsequent sections of this Inventory.

While several investigators have compiled species lists of zooplankton in the Columbia River estuary, the only ecological studies of zooplankton are those performed by Haertel and other Oregon State University researchers from 1964 through 1968. These studies are the basis for much of the following discussion.

A. Distribution and Abundance

High and variable river flows, large tidal range and relatively short flushing time combine to make the Columbia River estuary an unstable environment as compared to many other smaller estuaries. However, what stability does exist, allows the formation of three distinct zooplankton groups including (1) freshwater species which are carried by river flow and remain associated with the freshwater areas of the estuary, eventually to be flushed out to sea; (2) an indigenous estuarine group which maintains itself within fairly defined salinity ranges; and (3) a marine group which generally remains associated with the intruding salt wedge. At times during the tidal cycle, stratification in the estuary is such that all three groups might be found in one location, each predominant at different water depths. Table 304-1 is a checklist of common zooplankton found in the estuary by different investigators.

1. Freshwater Group

Dominated by the copepod, Cyclops vernalis and two cladocerans, Bosminia longirostris and Daphnia longispina, the freshwater zooplankton are abundant throughout the estuary at low tide. At high tide, when salinities are above 5°/oo, they are much depleted in the estuary and are found further upstream. They are most abundant in late summer [2,000-5,000/cubic meter (m^3)], with a lesser peak in spring. A population minimum of 20-50/m^3 occurs in February and March. The major factors causing lower winter populations are decreased temperature and continual loss to the ocean, though phytoplankton are undoubtedly an important food source for zooplankton in summer, there is little statistical correlation with phytoplankton abundance. This is probably because phytoplankton abundance is highest in early summer when light levels are highest, and zooplankton are most abundant in late summer when temperatures are highest.

2. Estuarine Group

Of particular interest are the indigenous species, which maintain their populations in the center of the estuary despite the unstable environment. These are dominated by the Eurytemora hirundoides and Canuella canadensis, which show obvious depletion both upstream and downstream as

TABLE 304-1. CHECKLIST OF COMMON ZOOPLANKTON IN THE COLUMBIA RIVER ESTUARY

FRESHWATER GROUP

Cladocerans

Bosmina longirostris
Ceriodaphnia pulchella
Daphnia longispina
Daphnia pulex
Diaphanosoma brachyrum
Leptodora kindtii
Moina brachiata
Sida crystallina
Simoncephalis serrulatus
Alona costata
Alona quadrangularis
Chydorus globosus
Eurycercus lamellatus
Ilyocryptus sordidus
Leydigia acanthocercoides
Pleuroxis denticulatus
Camptocercus rectirostris
Macrothrix sp.
Alona affinis
Pleuroxis striatus
Chydorus sphaericus

Copepods

Paracyclops finbratus
Bryocamptus niemalis
Cyclops vernalis
Diaptomus spp.
Epischura nevadensis

Rotifers

Brachionus spp.
Asplanchna sp.
Kerattella sp.

ESTUARINE (OLIGOHALINE) GROUP

Copepods

Eurytemora hirundoides
Canuella canadensis (predominantly benthic)

MARINE GROUP

Cladocerans

Evadne nordmanni
Podon sp.

Tunicates

Oikopleura sp.

Coelenerates

Aurelia sp.
Aequoria sp.

Ctenophores

Pleurobrachia sp.

Copepods

Acartia clausi
Acartia longiremus
Pseudocalanus minutus
Calanus finmarchicus
Epilabidocera amphitrites
Oithona spinirostis
Oithona similis

From: Haertel and Osterberg, 1967
Haertel and others, 1969
Higley and Holton, 1975
Snyder *et al.*, 1973

illustrated in Figure 304-3. Eurytemora, by far the most abundant zooplankter in the water column, has populations reaching 10,000-100,000/m^3 in late April and May. Eurytemora populations reach a second, lesser peak in late July and a third peak in early winter. These variations in abundance are associated with the generation time of Eurytemora, which is approximately 3 months at warmer summer temperatures. The long period between the early winter and late spring peaks is probably due to colder water temperatures.

Haertel tested several variables for correlation with Eurytemora abundance including water temperature, phytoplankton abundance, transparency and river flow, with no conclusive results. Along with life cycle patterns noted above, river flow also definitely affects Eurytemora abundance, as was shown by the January 1967 floods, from which seriously depleted Eurytemora populations did not recover for 18 months. In contrast, upstream freshwater plankton recovered rapidly from the flood and downstream marine species were unaffected.

Canuella, a harpacticoid copepod, is generally much less abundant in the water column than Eurytemora, but this is because it is primarily a benthic dweller and not sampled adequately by plankton tows.

Both Eurytemora and Canuella are more abundant at 10 meters than closer to the surface. This may be the key behavioral mechanism which maintains these species in the central part of the estuary. Other species which concentrate near the surface are swept out to sea.

3. Marine Groups

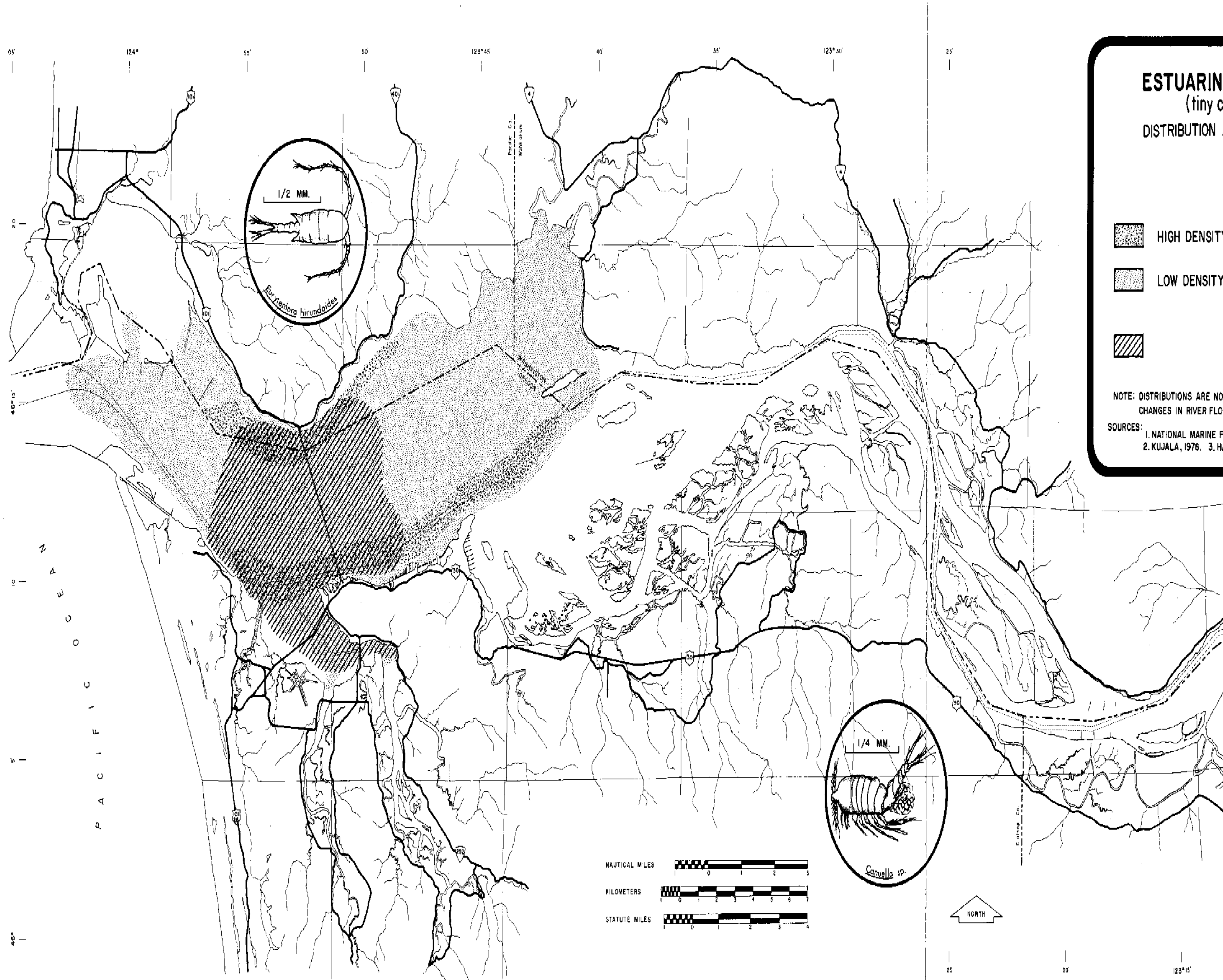
The Marine group of zooplankton associated with the salt wedge shows increasing abundance with increasing salinities. Peak populations ranging from 1,000 to 10,000/m^3 occur throughout the year, but are depleted somewhat during the winter. Predominant species include Acartia clausi, Acartia longiremus, and Pseudocalanus minutus. Variations in seasonal distribution of these species can be attributed to the strong variability of river flow and resultant salinities.

B. Zooplankton - Nutrient - Phytoplankton Relations

It was noted earlier in this section that nitrate and phosphate are seriously depleted in river waters entering the estuary in summer. For phytoplankton species able to reproduce in the slightly brackish estuarine waters, phosphate and particularly nitrate would seem to be the limiting factors. However, zooplankton are known to excrete phosphate and ammonia (which is a more favorable source of nitrogen than nitrate). With populations ranging from 10,000-100,000/m^3, Eurytemora may plan an important role in the regeneration of nutrients which then become available for maintaining estuarine phytoplankton production. No data have even been collected on ammonia to test this hypothesis, and it is not known whether the freshwater phytoplankton extending into the estuary have the ability to reproduce in brackish water.

C. Zooplankton Food Web Relationships

Zooplankton that have been discussed in this section are among the smaller macroplankton which feed on phytoplankton and other particulate organic matter in the estuary. As such, they are classified as herbivores and are food for the first carnivores, including larger invertebrates and juvenile fish. There have been several studies of feeding habits of fishes, which will be discussed in detail in a subsequent section of this inventory. To summarize, zooplankton are important food items in the estuary, particularly the more abundant species such as Eurytemora.



ESTUARINE COPEPODS
(tiny crustaceans)
DISTRIBUTION AND ABUNDANCE

HIGH DENSITY — *Eurytemora* sp.
LOW DENSITY — *Eurytemora* sp.

Canuella sp. (PREDOMINANTLY BENTHIC IN HABITAT)

NOTE: DISTRIBUTIONS ARE NOT STATIC BUT VARY MARKEDLY WITH CHANGES IN RIVER FLOW AND TIDAL CYCLES

SOURCES:
1. NATIONAL MARINE FISHERIES SERVICE DISTRIBUTION CHART.
2. KUJALA, 1976. 3. HAERTEL, 1969. 4. MISITANO, 1974.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
304–3

304.3 REFERENCES

A. Haertel, L. 1969. Plankton and Nutrient Ecology of the Columbia River Estuary. Unpublished Ph.D. Thesis. School of Oceanography, Oregon State University. 71pp.

B. Haertel, L., and C. Osterberg. 1967. "Ecology of Zooplankton, Benthos and Fishes in the Columbia River Estuary." Ecology 48:459-472.

Fauna of the Columbia River estuary were sampled over a 21-month period. The largest numbers of fish and benthic invertebrates occupy the slightly brackish water of the central part of the estuary; the major plankton blooms also occur in this area. Some species use the upper estuary as a nursery ground.

C. Haertel, L., C. Osterberg, H. Curl, P.K. Park. 1969. "Nutrient and Plankton Ecology of the Columbia River Estuary." Ecology 50(6):962-978.

Monthly samples of nutrients, phytoplankton and zooplankton were taken in the Columbia River estuary over a period of 16 months in order to determine distribution with season and salinity, and interrelationships between plankton and nutrients. The estuarine phytoplankton is composed primarily of freshwater species. The zooplankton are composed of estuarine, fresh and marine species.

D. Higley, D.L. and R.L. Holton. 1975. Biological Baseline Data, Youngs Bay, Oregon, 1974, prepared for Alumax Pacific Aluminum Corp. School of Oceanography, Oregon State University.

Presents 1974 baseline data collected as part of "Physical, Chemical and Biological Studies on Youngs Bay." Information includes animals present, distribution and seasonal abundance. Feeding habits of selected fish species are presented along with information on the life history and behavioral characteristics of the most abundant amphipod, *Corophium salmonis*.

E. Kujala, Norman. 1976. Columbia River Estuary Fishes and Invertebrates. Unpublished background report prepared for the Columbia River Estuary Study Taskforce.

An inventory of commercially and ecologically important fish and invertebrate plankton and benthos, with distribution and abundance maps on various species, and information on reproduction and nursery areas. A primary information source for inventory sections on estuary plankton, benthic invertebrates and fishes.

F. Misitano, David A. 1974. Zooplankton, Water Temperature and Salinities in the Columbia River Estuary, December 1971 through December 1972. Data Report 92, National Marine Fisheries Service, NOAA, Seattle, Washington. 31pp.

Excellent data on plankton organisms present from the mouth to Harrington Point along with associated temperature and salinity is presented. However, it does not include a discussion of results or draw any conclusions.

G. Parsons, T. and M. Takahashi. 1973. Biological Oceanographic Processes. Pergammon Press, New York. 186pp.

A technical review of plankton and the chemical and ecological processes in which they are involved. Difficult but useful background reading.

H. Perkins, E.J. 1975. The Biology of Estuaries and Coastal Waters. Academic Press. 678pp.

A comprehensive, well-documented and readable book on the subject, with useful information on plankton ecology and numerous other subjects.

I. Snyder, George R., R.J. McConnell, J.T. Durkin, D.A. Misitano, and H.R. Sankorn. 1973. Checklist of Aquatic Organisms in the Lower Columbia and Willamette Rivers, completion report to U.S. Army Corps of Engineers, Portland District. National Marine Fisheries Service. 41pp.

This checklist includes information on zooplankton in the estuary and upriver to Portland. It was compiled from a review of the literature and from a 1973 survey by the National Marine Fisheries Service. Information on finfish, shellfish, benthic organisms and larval fishes is also given.

305

BENTHIC INVERTEBRATES

COLUMBIA RIVER ESTUARY
BENTHIC INVERTEBRATES

James W. Good

NOTE: Much of the descriptive and distribution information in this section was derived from the background report on estuary fishes and invertebrates prepared for CREST by Mr. Norman Kujala, Oregon Ocean Services, Warrenton, Oregon, (reference K., pg. 305-15).

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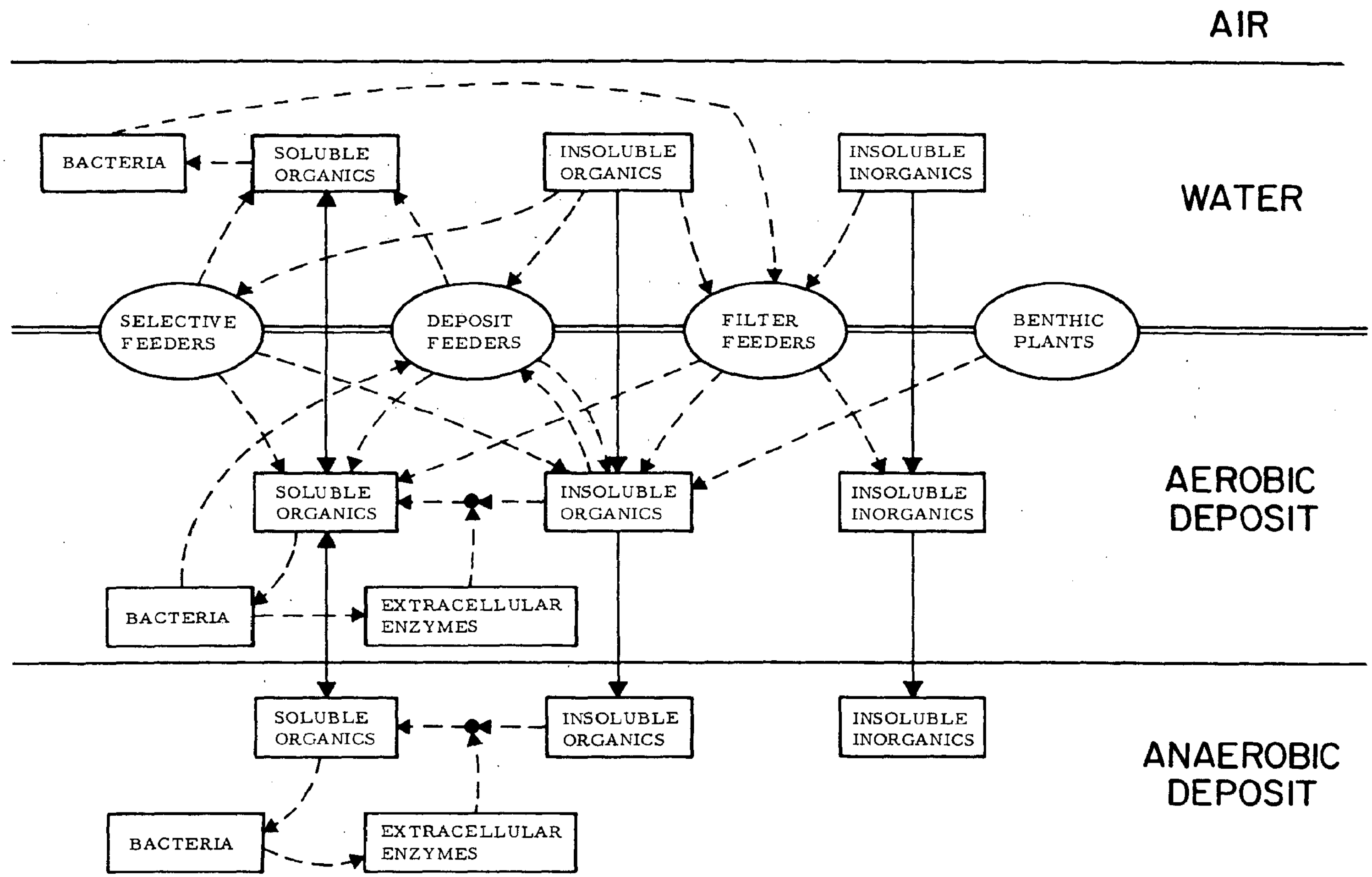
*Figure follows the page indicated.

305 BENTHIC INVERTEBRATES

All organisms, plant or animal, which live within, on, or closely associated with the bottom sediments belong to a group known as benthos. Benthic animals that live within the sediments are called infauna while those that live on or just above the sediment surface are epifauna. Much of the infauna is microscopic, living among the particles of sediment. Infauna may be sedentary or mobile, burrowing through the sediments. Epifauna are usually larger mobile animals, but some are also sessile, attaching themselves to available firm substrates, such as rock or wooden piling.

Another convenient way to classify benthic organisms is by size. The smallest group, microbenthos, includes all animals 0.04 millimeters (mm) or less. Bacteria, small protozoa, fungi, algae, diatoms and other microscopic organisms fall into this category. Many of these organisms live adhered to sand particles or particulate organic matter while others, such as some diatoms, form filamentous colonies on the surface of plants, rocks or sediment. The bacteria in the sediments are an extremely important component of the estuarine ecosystem, recycling nutrients to fuel new production of plant matter. Meiobenthos include organisms which are larger than 0.04 mm but smaller than 1 mm in size. Predominant meiobenthos include nematodes and harpacticoid copepods. They are generally confined to the top few centimeters (cm) of sediment. Macrobenthos include organisms which are larger than 1 mm in size and visable with the naked eye. Most epifauna (crab, shrimp, etc.) and some infauna (clams, polychaetes, etc.) are included in this group. The larger macrofauna can be divided into three feeding types: selective particle feeders, deposit feeders and filter feeders (Figure 305-1).

Selective particle feeders may be scavengers, predators or herbivores, feeding either on whole organisms they capture or fragments of plants or animals. Fishes, crabs, some worms and other mobile species fall into this category. The food is primarily organic material and broken down by mechanical and chemical processes. Wastes are combined with mucous and often form distinctive fecal pellets, which may make up a significant percentage of the bottom sediments.



INSOLUBLE ORGANICS WITHIN WATER INCLUDE PHYTOPLANKTON, ZOOPLANKTON, DETRITUS, ETC.
SOLID LINES REPRESENT PHYSICAL TRANSFER
● DENOTES CHEMICAL REACTION

FIGURE 305-1. CONCEPTUAL MODEL OF LARGER ANIMALS WITHIN BENTHIC SYSTEM

From: Bella, 1975

Deposit feeders include two general types. Some are worms that move through the sediment, ingesting and utilizing what organic material is contained therein, and discarding the remains as feces. Other deposit feeders bury themselves in the sediment. Using siphons or other extensions, they suck up detritus that has recently fallen to the bottom. These animals are unselective in what they feed upon, but they often have efficient sorting mechanisms. Nevertheless, the feces of these deposit feeders may contain a high percentage of inorganic material.

Filter feeders draw in water and particulate matter. Most clams, for example, use tiny hair-like cilia to create currents of water over a mucous network which traps particles. Others, such as tube-dwelling worms, may force water through their burrows by body movements. Some have efficient sorting mechanisms, much the same as deposit feeders. Feces of filter feeders is primarily organic.

The feeding habits of benthic animals can have a significant effect on the sediments and overlying waters. Deposit feeders turn over huge quantities of sediment particles and bring oxygen to deeper layers. Filter feeders and some deposit feeders remove detrital and particulate material from the water and sediment surface, sometimes with a marked local effect on turbidity. These animals play an important role in partially breaking down organic matter for the microorganisms which complete the mineralization process.

305.1 FACTORS AFFECTING BENTHOS DISTRIBUTION AND ABUNDANCE

The distribution and abundance of estuarine benthos are affected by many physical and biological factors which vary in both spatial and temporal dimensions. These include (1) substrate type, (2) salinity and other chemical and physical conditions of the water, (3) river flow, (4) tidal forces and degree tidal exposure, (5) exposure to wave and current action and (6) effects of grazing, predation and harvesting. All of these factors are important in the Columbia River estuary and two of the most important are discussed in detail.

A. Substrate

Most of the intertidal and subtidal areas of the Columbia River esutary are covered with a layer of unconsolidated substrate composed of fine mineral sediments (silt and clay), coarse mineral sediments (sand, gravel, and cobbles) and organic matter. While all areas have a mixture of these materials, the component which predominates is determined by a variety of factors including (1) the rate and type of sediment supply, (2) organic detrital input, (3) biological activity and (4) the energy environment (river flow, currents, waves, tides, wind). The latter physical forces are dominant factors in the Columbia.

The general distribution of sediment types in Columbia River estuary channels, slopes and flats is discussed in Section 208 of this Inventory (Sediment and Sediment Transport). To summarize, sand is the predominant sediment type for the entire estuary, with an "average" sediment sample containing 1% gravel, 84% sand, 13% silt and 2% clay. However, the actual textural characteristics at specific locations in the estuary vary widely. Sand is the dominant sediment type in channels, which form a continuous, interwoven network throughout the estuary (Figure 208-2). Upper and lower estuary channels, however, have coarser sand than those in the middle estuary. On the steeper slopes, which separate the channels from flats, sediments are predominantly sand, but are often less coarse than adjacent channels. Flats contain the finest sediments and are the most variable. Flats in the central part of the estuary (e.g. Desdemona Sands) are predominantly sand, while the flats in Baker Bay, Youngs Bay and Cathlamet Bay have significant quantities of silt, clay and organic material, along with fine sand. Because of the more sheltered nature of the latter areas and the higher organic content of the sediments, the benthos is richer in both diversity and abundance of species. The fine sand in these areas is suitable for filter feeders and the organic detritus present is necessary for deposit feeders.

B. Salinity

The gradual changes in salinity from the mouth to the upper part of the estuary is the primary factor to which all forms of estuarine life must respond. As with plankton and fishes, benthic invertebrates can be divided into freshwater, estuarine and marine components. In the Columbia, salinity penetration depends on tidal cycles, river flow variations and complex mixing processes. These are discussed in detail in Section 204 (Estuarine Circulation). Maximum salinity penetration during low flow and high tide is about River Mile (RM) 23, opposite Harrington Point. During average flow conditions on high tide, saline waters will intrude to about Tongue Point (RM 18), while during high flow, only to about Youngs Bay (RM 12).

On the ebb tide during high river flow, salt water may be pushed nearly out of the estuary (RM 2-5). The strong ebb and flood currents and high and variable river flow create a very unstable environment for benthic animals. Mobile epifauna may migrate back and forth with the ebb and flood of the tide, but infauna may be subjected to overlying waters with marked daily salinity changes.

The salinity of water within the sediment (interstitial water) is extremely important to infauna distribution. While no information is available on the subject with regard to the Columbia River estuary, two opposing factors may be at work. First, overlying saline waters tend to percolate downward, raising interstitial water salinity. Some studies have shown that interstitial water remains more saline than fresh overflowing ebb tide water. However, the influence of ground water pressure, may be significant in keeping interstitial salinities slow, particularly during winter when the water table on adjacent shorelands is high. This subject needs further study to determine its relationship to infauna distribution.

Salinity seems to be an extremely important variable relative to abundance of benthic organisms in the estuary. Species which are found upriver from the estuary (e.g. certain copepods, mysids and amphipods) greatly increase in numbers in the low salinity of the waters of the mid-estuary.

305.2 DOMINANT GROUPS OF BENTHIC INVERTEBRATES

Each group and each species of benthic invertebrates contributes to the healthy functioning of the estuary ecosystem. To date, research emphasis has been on the abundant and presumably more important species, both from an economic and ecologic perspective. Decapod shellfish, mysids, amphipods, polychaetes, oligochaetes, mollusks, nematodes and insect larvae are discussed in some detail in this section. Groups such as benthic copepods, isopods, nemerteans, bacteria and other micro and meiofauna are not discussed, though they may be extremely important.

In general, the shallow, fine sediment areas of the middle estuary harbor the greatest concentrations of benthic invertebrates, particularly infauna. Benthic populations in Baker Bay and Youngs Bay are extremely rich. Grays Bay and Cathlamet Bay have not been as extensively studied as other areas, but because of greater freshwater influence, it might be expected to be less rich. The central area of the estuary, where sediments are generally coarser, is less important for infauna, but has large populations of epifauna which move about the bottom. There are few studies which have examined complex ecological relationships. Distribution relative to salinity and sediment texture is discussed for some groups, and limited data on feeding relationships are presented. However, a comprehensive ecologically-oriented study of benthic invertebrates and their relationship to each other and other groups of organisms would be extremely useful.

A. Decapod Shellfish

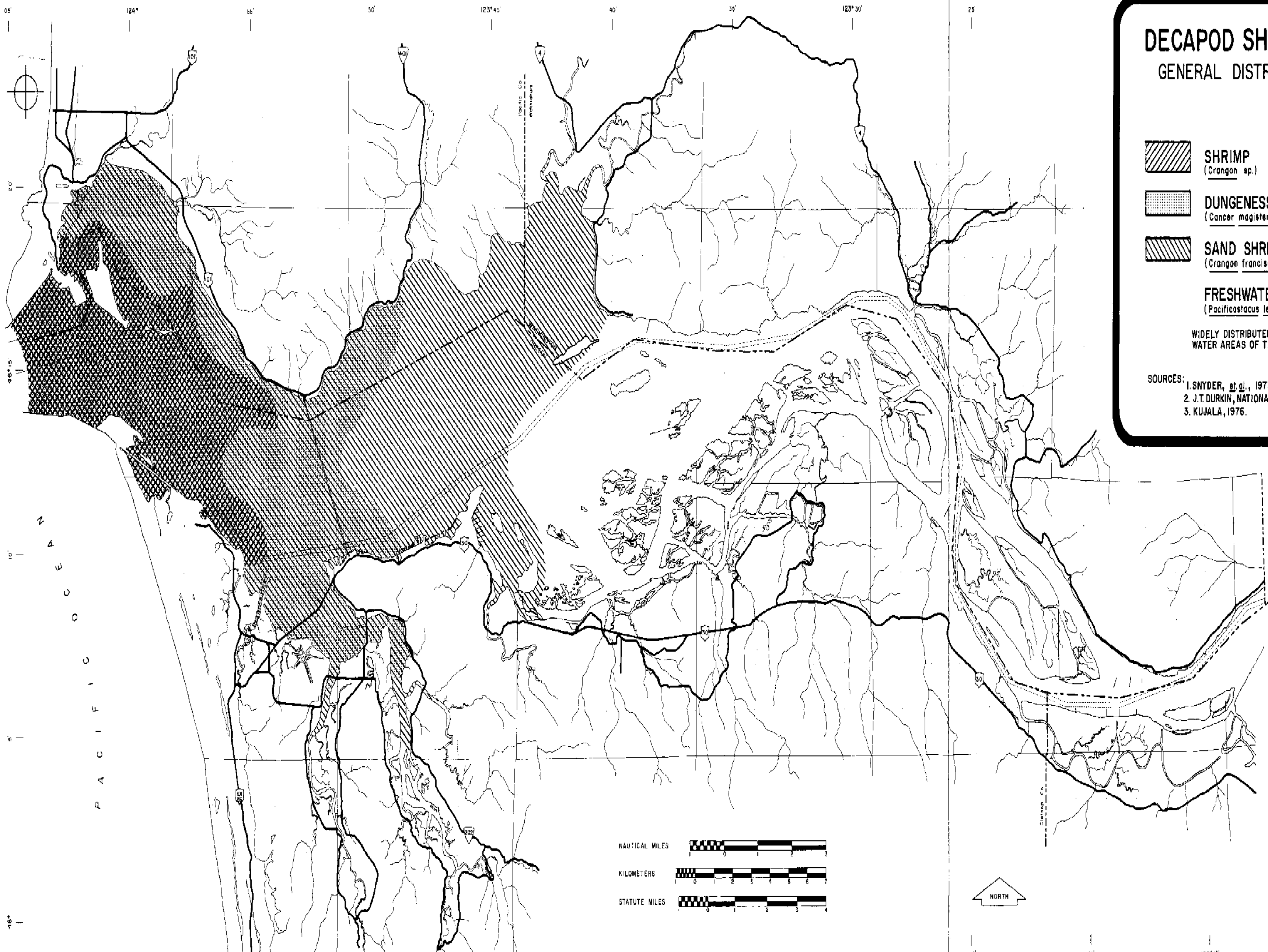
There are four decapod shellfish found in the estuary. These species are listed (Table 305-1) and discussed below as to their distribution and use of the estuary. Figure 305-2 illustrates their distribution in the estuary.

Table 305-1 DECAPODS FOUND IN THE COLUMBIA RIVER ESTUARY

Common Name	Scientific Name	Salinity Preference
Dungeness Crab	*Cancer magister*	Marine to mesohaline
Sand Shrimp	*Crangon franciscorum*	Marine to Oligohaline
Shrimp	*Crangon* sp.	Marine to polyhaline
Freshwater Crayfish	*Pacifastacus leniusculus*	Freshwater to Oligohaline

From: Snyder *et al.*, 1973

Dungeness crab (*Cancer magister*) are epifauna found in salt water along the Pacific Coast from Southern California to Alaska. In the Columbia River estuary, they are found associated with intruding salt water throughout the year. During low river flow (when saline water penetration is greatest), juveniles may be found as far as 15 miles upstream to Astoria. Adults are generally limited to the deep channels of the lower estuary from Hammond and Chinook jetty out to the mouth. An important winter fishery exists for crab in the ocean just off the mouth and some commercial and sport fishing is done in the deep channels of the lower estuary off Sand Island. Crab (male only) may be taken only with pots (traps) and must be 5-3/4 inches or wider across the shell.



DECAPOD SHELLFISH

GENERAL DISTRIBUTION

SHRIMP (*Crangon sp.*)

DUNGENESS CRAB (*Cancer magister*)

SAND SHRIMP (*Crangon franciscorum*)

FRESHWATER CRAWFISH (*Pacificastacus leniusculus*)

WIDELY DISTRIBUTED IN SLOUGHS AND FRESH-WATER AREAS OF THE ESTUARY.

SOURCES:
1. SNYDER, et al., 1973.
2. J.T. DURKIN, NATIONAL MARINE FISHERIES SERVICE.
3. KUJALA, 1976.

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

305-2

Though spawning takes place in the adjacent ocean, the estuary appears to be an important nursery area for immature Dungeness crab. For example, hundreds of small crab (three to four inches across the shell) have been caught during a ten minute otter trawl tow in the Desdemona Sands area. Smaller numbers can be taken in a similar manner at the entrance to Youngs Bay and off Chinook Point. Large numbers of adults and juveniles can also be found in Baker Bay during the fall. Dungeness crab are scavengers, making use of both plant and animal material available to them on the bottom.

Sand shrimp (Crangon franciscorum) are classified as epifauna and adults are about three inches long and have a gray speckled sandy color. The first pair of walking legs are chelate (have pincers). Of the marine decapods found in the estuary, sand shrimp are most tolerant of low salinities, with young shrimp found as far upstream as Harrington Point (RM 22), as well as in Grays Bay and Cathlamet Bay. As spawning season approaches, adult sand shrimp, which are confined to the more saline lower estuary areas, move toward the ocean. Eggs hatch in water of high salinity. In early summer, the newly hatched shrimp migrate into waters of reduced salinity in the mid to upper estuary. They are abundant through fall, but are found in more saline waters in winter. Large populations of adult and immature sand shrimp are also found in Baker Bay. Sand shrimp are not taken commercially but may have some potential. Sand shrimp are primarily scavengers but may prey upon animals, such as worms. They are important as a food item for many fishes including white sturgeon, starry flounder, sculpin, sand sole, tomcod, hake, longfin smelt and the shellfish, Dungeness crab.

The other species of Crangon found in the estuary was originally classified by Haertel as Crangon nigracauda, the blacktail shrimp. Subsequent work by Richardson, Colgate and Carey of Oregon State University and the National Marine Fisheries Service researchers, show that this shrimp may actually be Crangon stylirostris or Crangon alaskensis elongata; it is an epibenthic animal found only in waters of higher salinity below RM 6 to 7.

Western freshwater crayfish (Pacifastacus leniusculus) are found in tributary streams and sloughs throughout the mid to upper estuary as well as farther upriver where salinities are low. In appearance somewhat like a small lobster, these animals are considered a delicacy locally and are harvested in the fall when adults are migrating into freshwater streams to spawn. They are caught commercially and for personal use by using traps or by hand-collecting in streams or flats of the estuary. The migration peak is in October, but no data are available on the size of the population.

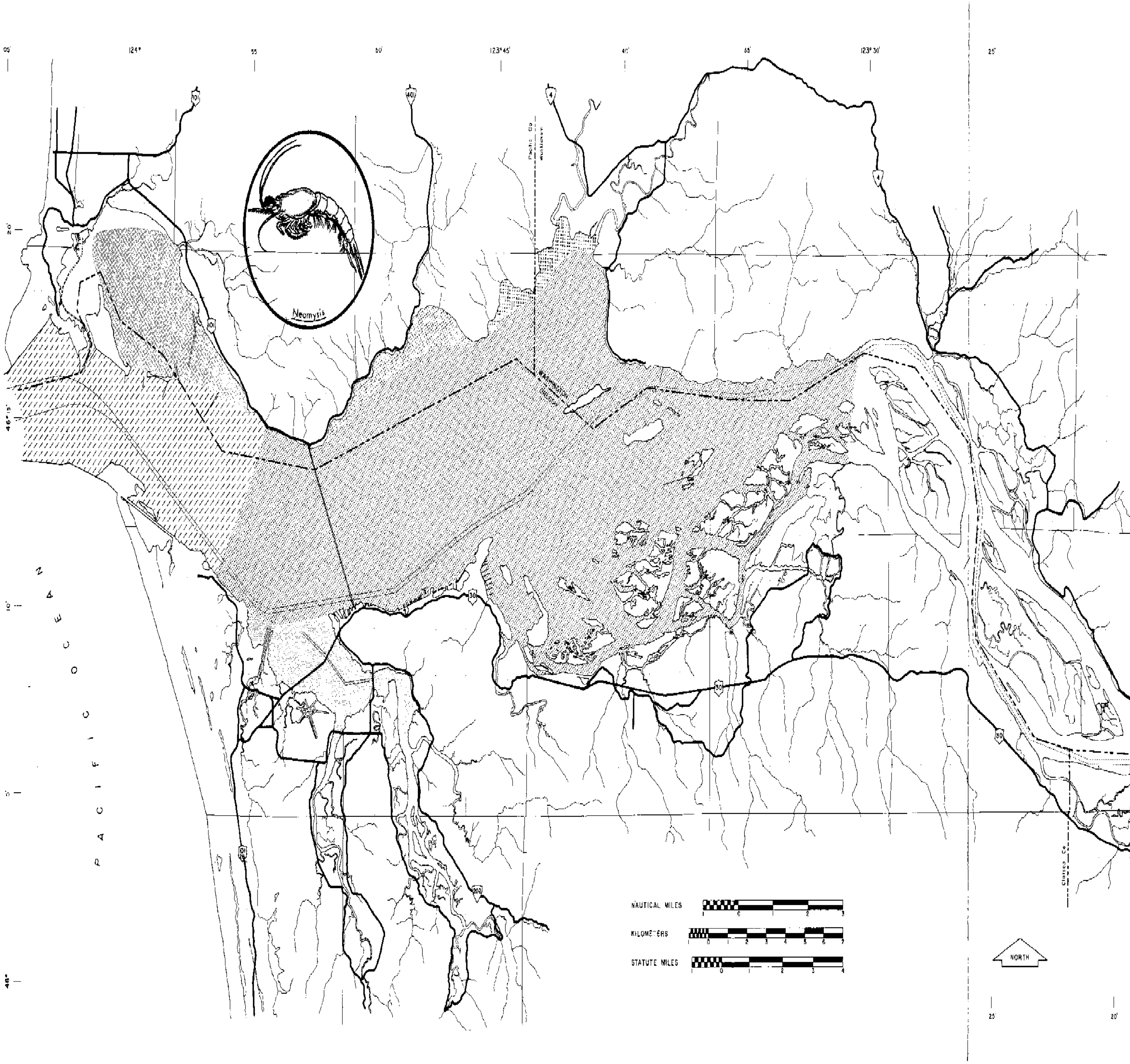
B. Mysids

Mysids are small shrimp-like crustaceans. Species associated with estuaries are difficult to group as either plankton or benthos, since most spend daylight hours on or near the bottom sediments and then enter the plankton during darkness, probably to feed. The predominant feeding mechanism is filter feeding, with detritus and diatoms common in the diet. They also may prey on small animals, such as copepods. Their variety in diet and medium size, relative to other estuarine invertebrates, makes them an important link in the estuarine food web.

Estuarine mysids vary in their ability to penetrate freshwater. Marine mysids associated with the Columbia River estuary include: *Neomysis kadiakensis* (which is very abundant in the ocean off the mouth), *Neomysis rayii*, *Acanthomysis macropsis* and *Archaeomysis grebnitzkii*. These periodically abundant species remain in waters of relatively high salinity; their collective distribution is shown on Figure 305-3 as "other mysids." The most abundant mysid in the Columbia River estuary is *Neomysis mercedis*, brackish to freshwater species whose distribution is also shown in Figure 305-3. This species is found throughout the year, but is most abundant in spring and summer. The size of mysids (2-4 cm) makes them an important food item for many estuarine fish. Large numbers of *Neomysis mercedis* have been found in the stomachs of white sturgeon, chinook salmon fingerlings, starry flounder, longfin smelt, staghorn sculpin, tomcod, shiner perch and prickly sculpin.

C. Amphipods

Amphipods are small (up to 1 cm) crustaceans which occur in great numbers in certain areas of the Columbia River estuary. Some are epifauna, some build tube-like burrows and some migrate out of the sediments into the water column under certain conditions, particularly at night. The feeding mechanisms of amphipods are varied, and include filter-feeding, deposit-feeding and scavenging.



MYSIDS

GENERAL DISTRIBUTION AND ABUNDANCE

- HIGH DENSITY — *Neomysis mercedis*
- LOW DENSITY — *Neomysis mercedis*
- OTHER MYSIDS

NOTE: DISTRIBUTION SHOWN IS GENERALIZED AND BASED ON LIMITED SAMPLING.

SOURCES:
1. NATIONAL MARINE FISHERIES SERVICE DISTRIBUTION CHART.
2. KUJULA, 1976.
3. HAERTEL AND OSTERBERG, 1976.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
305-3

Common amphipods found in brackish water areas of the Columbia River estuary include Anisogammarus confervicolous, Eohaustorius washingtonianus, Paraphoxus milleri and two species of the genus Corophium. Other species of lesser numerical importance are also found, mostly in the intruding salt water of the lower estuary. The abundance of amphipods at selected sites sampled by Higley and Holton are shown in Figure 305-4.

Two species, Corophium salmonis and Corophium spinicorne are the most dominant amphipods in the estuary. C. salmonis is found in mudflats where it builds tubes in the mud, whereas C. spinicorne is more abundant along the shoreline where it builds its tubes on vegetation, piling, rocks and other surfaces. Anisogammarus is also abundant in these vegetated areas, but can also be found in the central sandy flats of the Columbia River (e.g. Desdemona Sands). Other species are locally dominant in certain areas.

According to Higley and Holton, the brackish water areas of the central estuary where fine sand predominates harbors the highest density of the amphipod Corophium, with up to 57,000/square meter found in certain areas of Youngs Bay. Salinity and substrate texture appear to be ideally combined in this area. On the other hand, they found that coarse sand areas generally have low densities, probably because the substrate is too loosely compacted to support a burrow tube. Densities of up to 6,400/square meter were found in the Skipanon River and 29,000/square meter in the Lewis and Clark River. Based on Higley and Holton's limited sampling in areas of the estuary other than Youngs Bay, amphipods appear to be both widespread and abundant. Grays Bay shows densities of nearly 10,000/square meter, Cathlamet Bay up to 21,000/square meter, and the MARAD Basin near Tongue Point had nearly 10,000/square meter. In Baker Bay densities are generally well below 1,000/square meter, probably because of the more saline water present. At Miller Sands (RM 23), National Marine Fisheries Service studies indicate Corophium densities of up to 4,000/square meter. Corophium salmonis, the most abundant of all amphipod species, is predominantly a low salinity to freshwater species and is found in lesser number all the way up the river to Portland.

Amphipods, particularly Corophium, are an ecologically important estuarine group in that they are very abundant, consume large amounts of detrital and other material, and serve as an important food source for many species of fish which use the estuary including starry flounder, longfin smelt, staghorn and prickly sculpin, shiner perch, tomcod, white sturgeon and downstream migrant Chinook, coho and other salmon fingerlings. The large quantities of amphipods consumed by juvenile salmon may indicate a critical interrelationship, but there are no definitive data available.

Several of the benthic amphipods appear to make a nightly migration into surface waters, and some researchers believe they find their way back to the bottom area they left. However, there must undoubtedly be some colonization of new areas as individuals are swept away by tidal currents.

D. Polychaetes

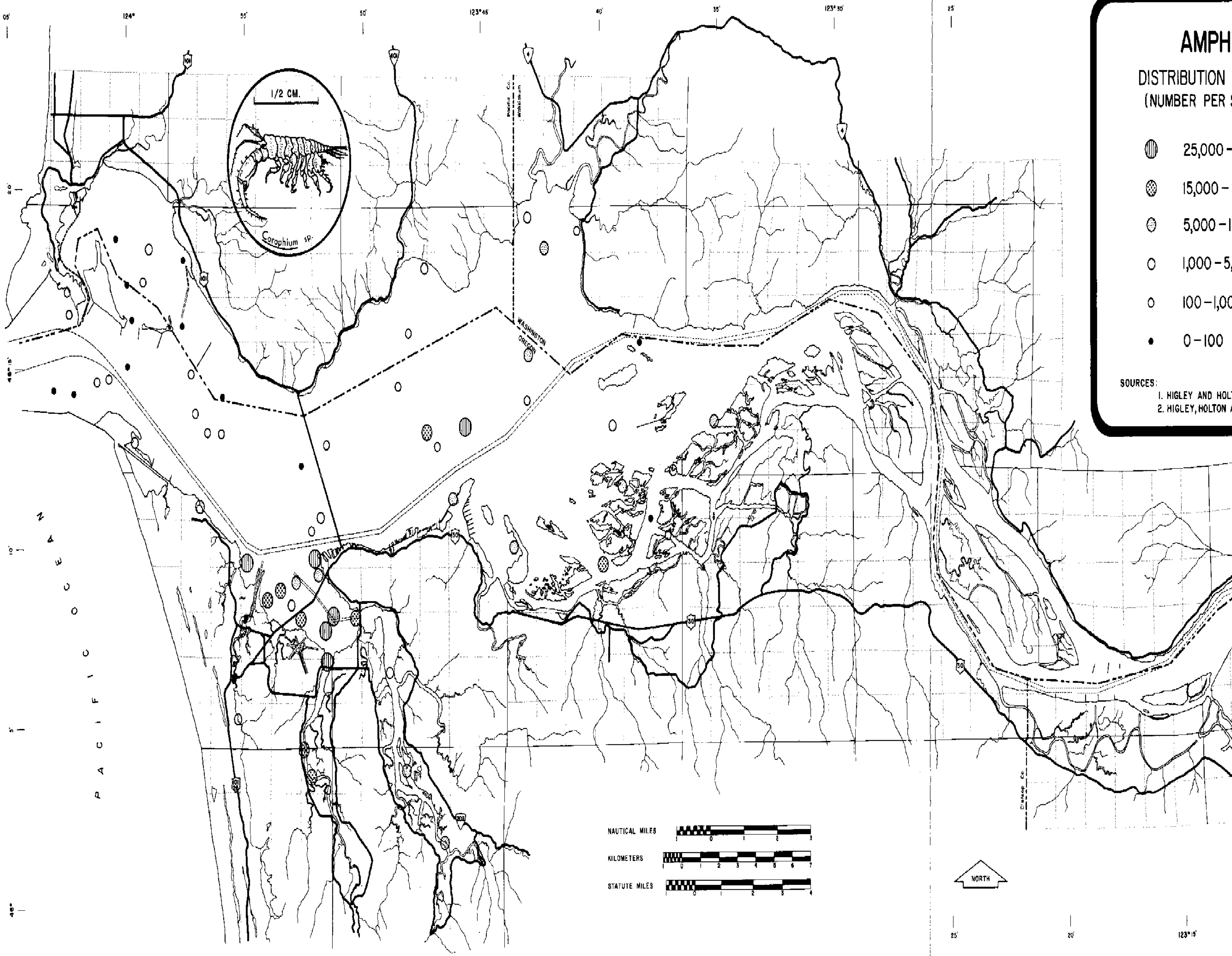
Polychaetes are a group of predominantly marine Annelid worms and are found in bottom sediments of the Columbia River estuary. Their distribution and abundance, according to Higley and Holton, is illustrated in Figure 305-5. These patterns are best understood when they are compared to sediment texture and salinity information. Polychaete densities are low upstream from Tongue Point because of little or no salinity there and the predominant marine nature of this animal group. Even Neanthes (Nereis) limnicola, an estuarine species tolerant of freshwater, is not abundant upstream from Tongue Point. Below Tongue Point, densities are low in coarse sand areas and highest in shallow protected areas such as Baker Bay, Youngs Bay and smaller embayments, indicating a preference for fine sand and smaller size sediment.

Polychaetes range in size from less than 1 cm to 10 or more. The estuarine species, Neanthes limnicola may grow to 10 cm. It and other polychaetes are an important food source in the estuary for starry flounder, white sturgeon, prickly sculpin, staghorn sculpin, tomcod, lemon sole, shiner perch, and Dungeness crab. Polychaetes also play an important ecological role in the estuary by irrigating and turning over the sediments.

Though present throughout the year in estuarine sediments, polychaetes probably exhibit seasonal population fluctuations. Their life cycles in the Columbia have not been studied, but information from similar estuaries probably applies. For example, Neanthes limnicola has been found to be self-fertilizing with a benthic larvae, while other species have planktonic larval forms.

E. Oligochaetes

The Oligochaeta class of Annelid worms contains familiar terrestrial species, such as the earthworm, and about ten families of predominantly freshwater aquatic worms. Some species have penetrated downstream into



AMPHIPODS

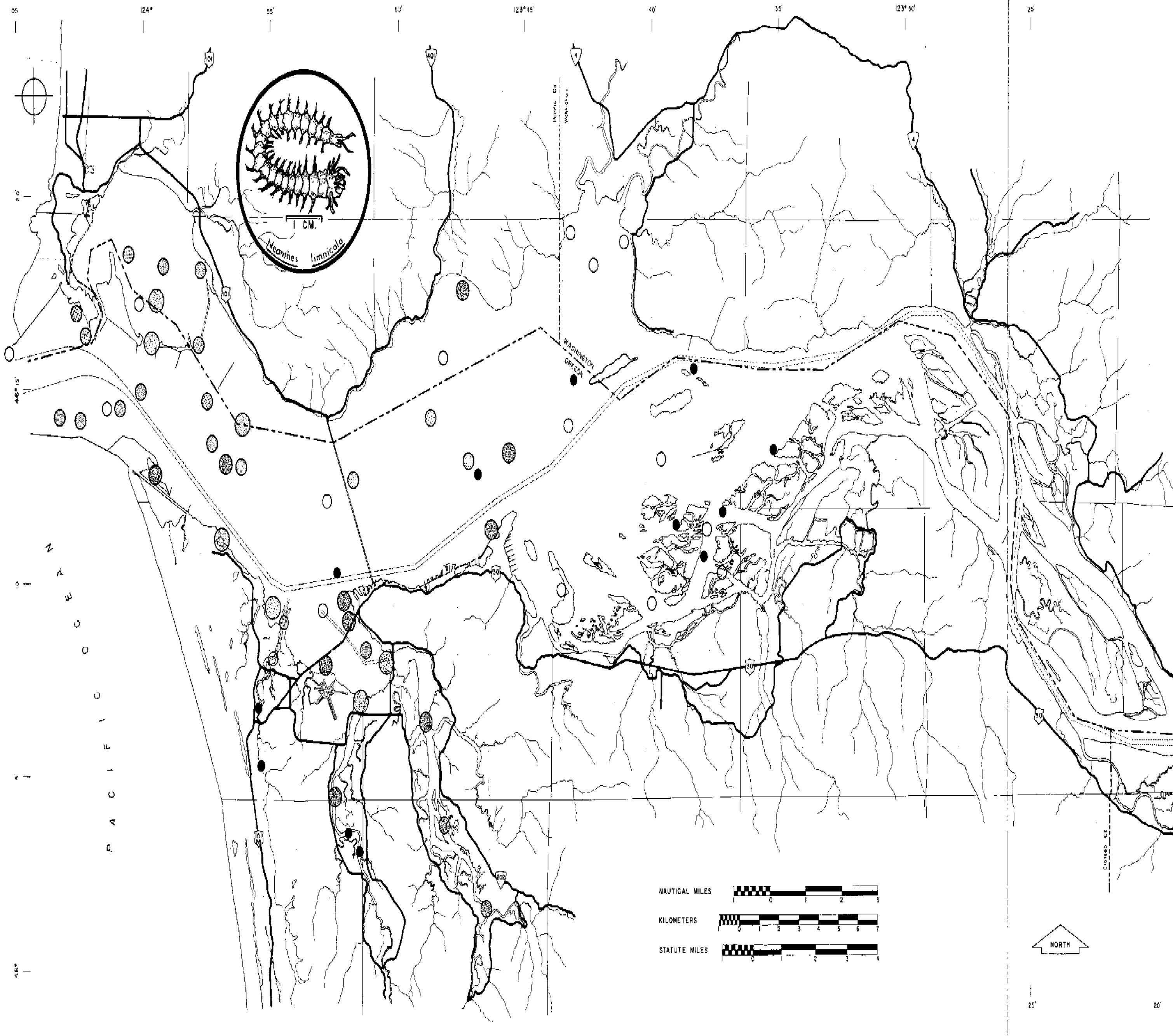
DISTRIBUTION AND ABUNDANCE
(NUMBER PER SQUARE METER)

- 25,000 - UP
- 15,000 - 25,000
- 5,000 - 15,000
- 1,000 - 5,000
- 100 - 1,000
- 0 - 100

SOURCES:
1. HIGLEY AND HOLTON, 1975.
2. HIGLEY, HOLTON AND KOMAR, 1976.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
305-4



POLYCHAETES
(MARINE WORMS)
ABUNDANCE AT SELECTED SITES
(number per square meter)

- 1,000-UP
- 500-1,000
- 100-500
- 1-100
- 0

FROM: 1. HIGLEY AND HOLTON, 1975.
2. HIGLEY, HOLTON AND KOMAR, 1976.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
305-5

estuarine waters and there are also a few marine species. These tiny worms are found in the estuary sediments and range from 1 to 5 cm in length. They look like a common earthworm, slightly pink to red color, with a clitellum or band around the body near the front end. The worms are generally on the surface or buried in the first few centimeters of bottom sediment. Many species are associated with decaying organic matter such as leaves and seaweed.

Oligochaetes are a dominant group of organisms in bottom sediments of the Columbia River estuary. They are most abundant in fine sediment areas, as illustrated by the distribution and abundance data from Higley and Holton in Figure 305-6. Youngs Bay and Baker Bay are the most productive areas studied to date, with concentrations of up to 50,000 and 75,000/square meter respectively. Oligochaetes are permanent residents of the estuary. A decline in density might be expected during the winter months, but seasonal patterns were not that apparent in studies to date.

As a numerically important bottom dweller, oligochaetes play an important role in estuary ecosystem functioning. They aerate the top layers of sediment and may be important as food for estuary fishes, though it is difficult to determine to what extent because they are quickly digested. Crustaceans, such as amphipods, mysids, and shrimp, are more frequently noted in fish stomach analysis because the chitinous shell slows down digestion.

F. Mollusks

The Columbia River estuary does not have the common bay clams (cockel, gaper, softshell, etc.) and oysters found in nearly every other Pacific Coast estuary. This is probably due to the high freshwater discharge and resulting low salinities present in the Columbia. Of mollusks present in the estuary, two bivalve clams, *Macoma inconspicua* and *Corbicula fluminea* (a freshwater species) are the most common and abundant. The distribution of these species is shown in Figure 305-7. The patterns shown are generalized and based on limited sampling.

Macoma inconspicua is a small, white clam about 1 to 2 cm in length, found in brackish waters of the lower estuary. Highest densities have been recorded in Baker Bay with 28,421 and 3,757/square meter at two different locations in Higley and Holton's 1975 study. Densities are generally under 1,000/square meter in most other areas where *Macoma* is present. *Macoma* has been found to be an important food item for starry flounder, sculpin and Dungeness crab.

Corbicula fluminea is a small freshwater species found in the Columbia River estuary, in some estuary tributary streams and upstream in freshwater areas. They range up to 3.5 cm in length, are round, brown and ridged. There seems to be some overlap with Macoma habitat, as illustrated by Higley and Holton's sample in the Lewis and Clark River, where 168 Macoma and 56 Corbicula/square meter were present. Corbicula were found by the National Marine Fisheries Service to be the second most dominant benthic animal (next to the amphipod, Corophium) upstream of the estuary to Vancouver, Washington. Corbicula are likewise found in many estuary areas, including Grays Bay, Cathlamet Bay and Youngs Bay.

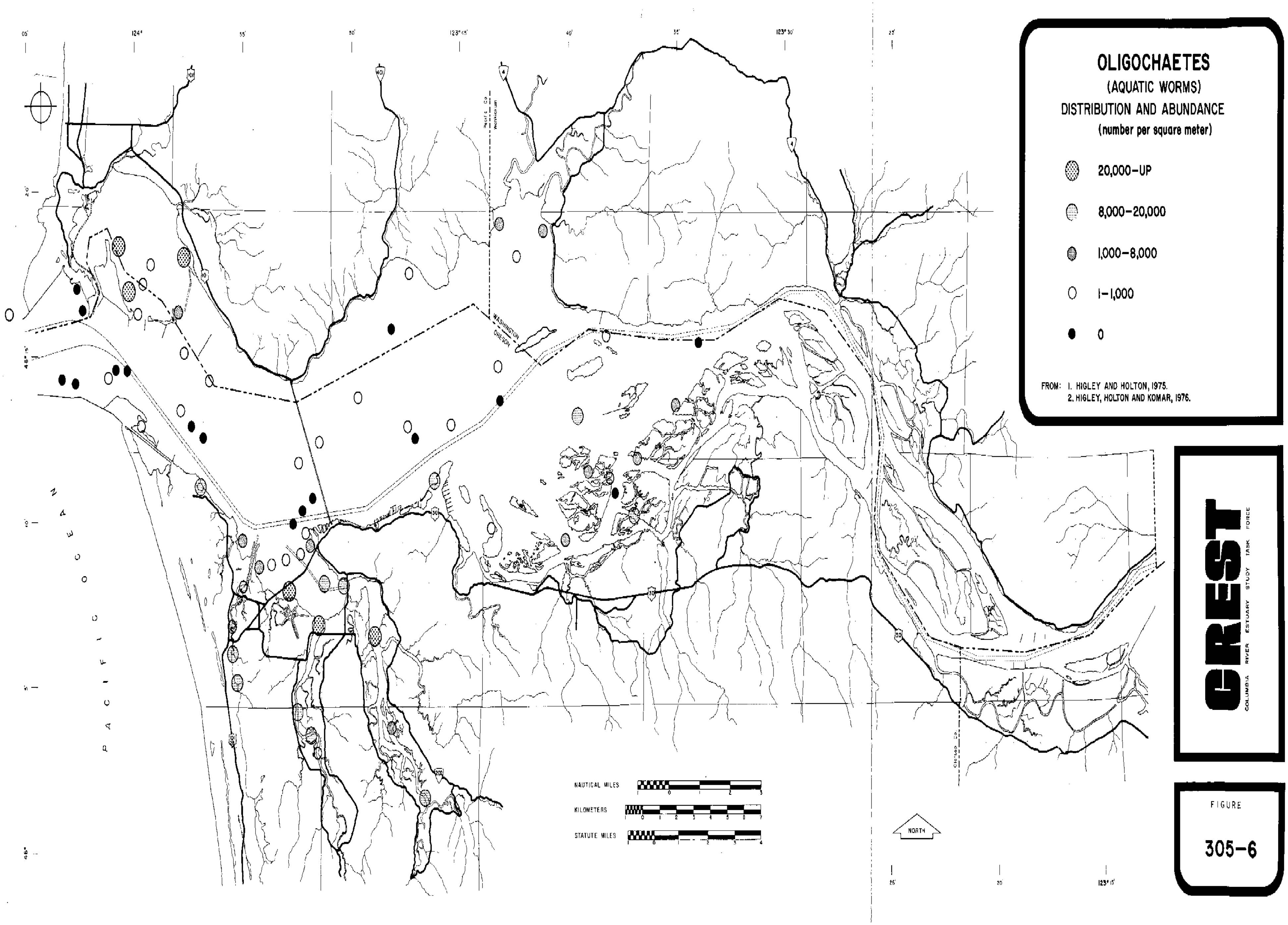
Another freshwater clam, Anodonta, is present in upper estuary areas, though no studies of its distribution or abundance are available. Several species of this clam may be present. These dark-colored clams are the largest ones in the estuary, ranging up to 12 cm in length.

G. Nematodes

Nematodes are small, unsegmented benthic worms which are found in large numbers in certain estuary areas. Higley and Holton found over 44,000/square meter at one Baker Bay site, though most areas sampled had considerably fewer nematodes. In Youngs Bay west of Pier 3, about 1,000 to 2,000/square meter were present in an average sample. High densities were also present in other estuary areas where fine sediments predominated; in Grays Bay, up to 7,290/square meter were found, and in Cathlamet Bay, up to 4,467/square meter. Up to 8,299/square meter were found opposite Alder Slough in Warrenton. While no studies of species composition of Columbia River estuary nematodes has been attempted, up to 37 separate species have been identified in other estuaries, indicating that they are a diverse as well as abundant group. Ecologically, these meiofauna organisms contribute to aeration of bottom sediments and probably serve as food for larger benthic organisms.

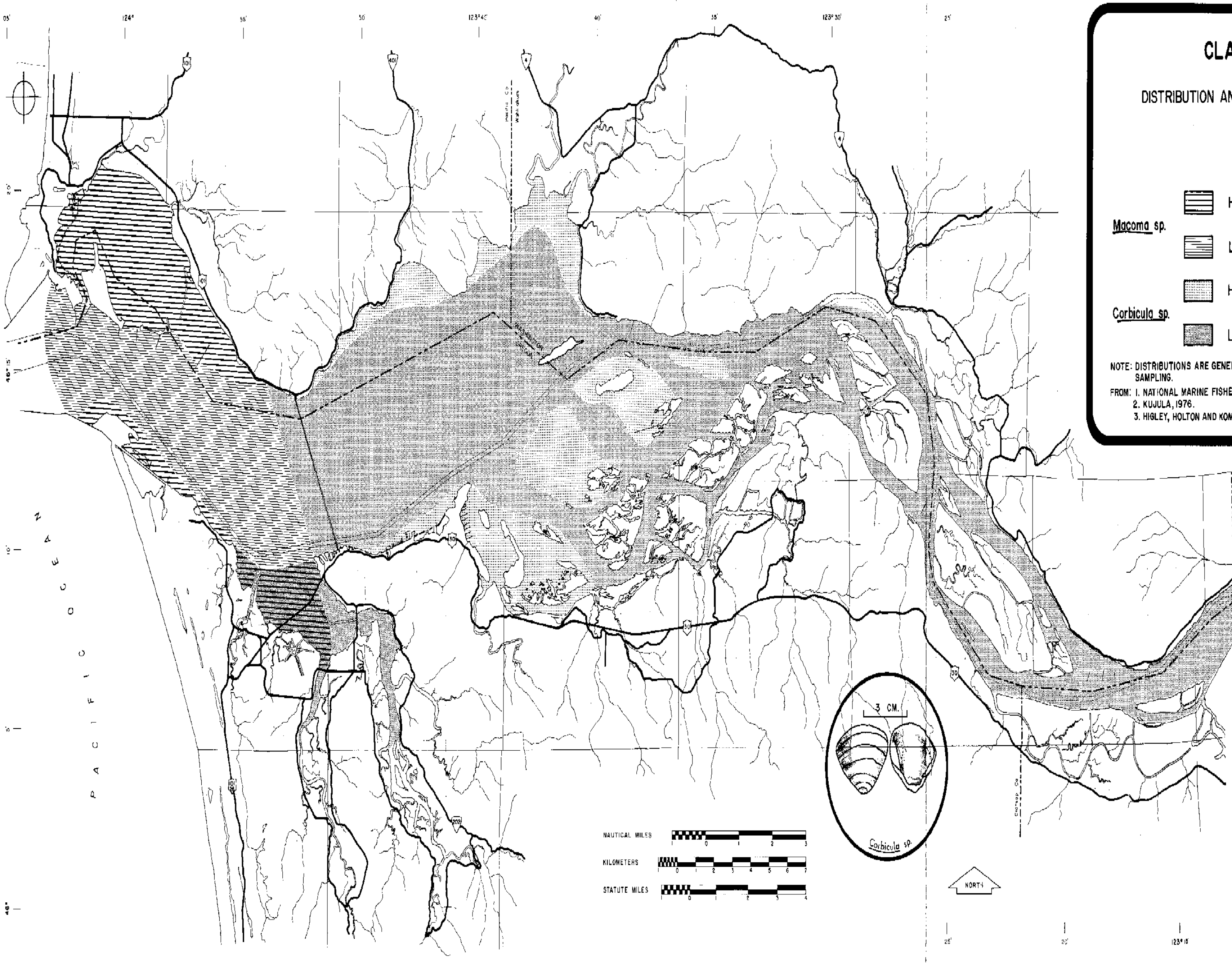
H. Chiromonids (midges)

Midges or chironomids are mosquito-like aquatic insects whose larvae live in the bottom sediments. In some freshwater parts of the estuary, chironomids are an important component of the benthic fauna. In Higley and Holton's work, chironomids were found in Youngs Bay and its tributary streams. Highest concentrations were in the upper Skipanon River where up to 2,472/square meter were found. Similar concentrations probably exist



CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 305–6



CLAMS

DISTRIBUTION AND ABUNDANCE

Macoma sp.
- HIGH DENSITY
- LOW DENSITY

Corbicula sp.
- HIGH DENSITY
- LOW DENSITY

NOTE: DISTRIBUTIONS ARE GENERALIZED AND BASED ON LIMITED SAMPLING.

FROM: 1. NATIONAL MARINE FISHERIES SERVICE.
2. KUJULA, 1976.
3. HIGLEY, HOLTON AND KOMAR, 1976.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
305-7

in freshwater portions of many estuary tributaries and sloughs. Juvenile salmon captured at many estuary sites including Youngs Bay and Miller Sands use chironomids as food. Other diptera insects are likewise utilized by juvenile salmon. Chironomid larvae emerge as flying adults and later lay eggs in water weeds to repeat their life cycle.

305.3 REFERENCES

A. Bella, David A. 1975. Tidal Flats in Estuarine Water Quality Analysis, prepared for U.S. Environmental Protection Agency. pp.10-20.

A description of the general chemical benthic system and benthic system for larger benthic animals is presented. Feeding mechanisms of macrobenthos are described.

B. Durkin, J.T. and S.J. Lipovsky. 1975. Baseline Fish and Shellfish Investigations Offshore of the Columbia River Conducted from October 1974 through June 1975. Interim report to the Dredged Material Research Program, U.S. Army Corps of Engineers. National Marine Fisheries Service, NOAA. 49pp.

Preliminary results of this study are presented including information on demersal fish and their food habits. This information is to be correlated with other research being conducted to determine the effects of dredge material disposal off the mouth of the Columbia River.

C. Durkin, J.T. 1975. An Investigation of Fish and Decapod Shellfish Found at Four Dredge Material Disposal Sites and Two Dredge Sites Adjacent to the Mouth of the Columbia River. Completion Report to U.S. Army Corps of Engineers. National Marine Fisheries Service, NOAA. 29pp.

Results of sampling conducted at two lower estuary dredge sites and disposal sites B, D, E and F are presented including fish and shellfish present, and effects of dredging and disposal on their distribution and abundance.

D. Green, J. 1968. The Biology of Estuarine Animals. University of Washington Press, Seattle. 401pp.

An extremely useful background text for estuarine biology, with information on vegetation, plankton, benthic organisms and freshwater species. Specific sections on benthic organisms such as amphipods, crab, etc. are presented.

E. Haertel, Lois. 1965. Biological Studies in the Columbia River Estuary: Progress Report Ecological Studies of Radioactivity in the Columbia River and Adjacent Pacific Ocean. (C. Osterberg, ed.). Department of Oceanography, Oregon State University. pp. 3-50.

A good list of the aquatic organisms in the estuary with distributions, seasonal occurrence, and food habits of many species. The best information in one report.

F. Haertel, L., and C. Osterberg. 1967. "Ecology of Zooplankton, Benthos and Fishes in the Columbia River Estuary." Ecology 48:459-472.

Fauna of the Columbia River estuary were sampled over a 21-month period. The largest numbers of fish and benthic invertebrates occupy the slightly brackish water of the central part of the estuary; the major plankton blooms also occur in this area. Some species use the upper estuary as a nursery ground.

G. Higley, D.L., and R.L. Holton. 1975. Biological Baseline Data, Youngs Bay, Oregon, 1974, prepared for Alumax Pacific Aluminum Corporation. School of Oceanography, Oregon State University. 91pp.

Presents 1974 baseline data collected as part of "Physical, Chemical, and Biological Studies on Youngs Bay." Information includes animals present, distribution and seasonal abundance. Feeding habits of selected fish species are presented along with information on the life history and behavioral characteristics of the most abundant amphipod, Corophium salmonis. Numerous sample stations in Youngs Bay, Youngs River, Lewis and Clark River and the Skipanon River provides the best available data on benthic organisms in this area.

H. Higley, D.L., R.L. Holton and P.D. Komar. 1976. Analysis of Benthic Infauna Communities and Sedimentation Patterns of a Proposed Fill Site and Nearby Regions in the Columbia River Estuary, prepared for the Port of Astoria. Oregon State University, School of Oceanography, Corvallis, Oregon. Reference 76-3. 78pp.

Distribution and abundance data on benthic communities is presented for stations ranging from the mouth to Pillar Rock including each of the major embayments of the estuary. This study was a major data source for distribution maps and discussion of benthic communities. Discussion centers on two important groups, polychaetes and amphipods.

I. Higley, D.L., V.G. Johnson and K.J. McMechan. 1975. Annotated Bibliography of Aquatic Environmental Conditions at Miller Sands Island, Columbia River, Oregon, prepared for the U.S. Army Corps of Engineers, Portland District. Oregon State University, School of Oceanography, Corvallis, Oregon. 34pp.

Useful summary of literature on estuarine benthic ecology, particularly amphipod biology. Sections on general estuary studies, Pacific Coast estuaries, fish ecology, etc. are provided.

J. Kujala, Norman F. 1966. Columbia River Sampling Program. Progress Report. Ecological Studies of Radioactivity in the Columbia River Estuary and Adjacent Pacific Ocean. (J.E. McCauley, ed.). Department of Oceanography, Oregon State University, Corvallis, Oregon. pp.15-20.

K. Kujala, Norman F. 1976. Columbia River Estuary Fishes and Invertebrates. Unpublished background report prepared for the Columbia River Estuary Study Taskforce.

An inventory of commercially and ecologically important fish and invertebrate plankton and benthos, with distribution and abundance maps on various species, and information on reproduction and nursery areas. A primary information source for CREST Inventory sections on estuary plankton, benthic invertebrates and fishes.

L. Montagne and Associates. 1976. Natural Resources Base and Physical Characteristics of the Proposed Offshore Oil Platform Fabrication Site Warrenton, Oregon (Technical Reports, Data Base and Appendix). Prepared for Pacific Fabricators, Inc.

A report of benthic sampling of intertidal and submerged lands immediately adjacent to the Skipanon River-Youngs Bay construction site. The amphipod Corophium was a dominant organism.

M. Perkins, E.J. 1975. The Biology of Estuaries and Coastal Waters. Academic Press, 678pp.

A comprehensive, well-documented and readable book on the subject, with useful information on benthic ecology and numerous other subjects.

N. Richardson, M.D., W.A. Colgate and A.G. Carey. 1976. A Study of Benthic Baseline Assemblages in the MCR Disposal Site Area, Annual Interim Report, 1 October 1974 - 31 August 1975. Oregon State University, School of Oceanography, Corvallis, Oregon.

Contains preliminary results of baseline information on benthic community structure and classification at several disposal sites off the mouth of the Columbia River. Study is being conducted as part of the Corps of Engineers Dredged Material Research Program. Five different species distribution patterns and at least eight different macrobenthic assemblages were defined for the area. Both abundance and biomass increased with depth.

O. Snyder, G.R., R.J. McConnell, J.T. Durkin, D.A. Misitano, and H.R. Sanborn. 1973. Checklist of Aquatic Organisms in the Lower Columbia and Willamette Rivers, completion report to U.S. Army Corps of Engineers, Portland District, National Marine Fisheries Service. 41pp.

This checklist includes information on benthos in the estuary and upriver to Portland. It was compiled from a review of the literature and from a 1973 survey by the National Marine Fisheries Service. Information on finfish, shellfish, plankton and larval fishes is also given.

306

FISHES

COLUMBIA RIVER ESTUARY

FISHES

Kurt Buchanan

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FIGURES .

*Figure follows the page indicated.

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TABLES

306 COLUMBIA RIVER ESTUARY FISHES

Fishes of commercial importance and fishes which affect them are discussed in this section. In addition, life history information and the ways the Columbia River estuary affects these fishes are presented. Information used is from research reports of the National Marine Fisheries Service, Oregon State University, Oregon Department of Fish and Wildlife, Washington State Department of Fisheries, an interim report on Columbia River estuary fishes and fisheries written for CREST by Mr. N. Kujala, and various other publications and communications.

Available information emphasizes only certain fishes and/or areas in the estuary. Many areas of the estuary have never been sampled.

306.1 FISHES FOUND IN THE ESTUARY

Numerous researchers list fishes found in the Columbia River estuary, and their findings are summarized in Table 306-1. The fishes are classified as marine, migratory, and/or freshwater according to the system described in Table 301-1 (Estuarine Animal Components). For fishes which use estuaries, this system of classification is somewhat arbitrary because the constantly changing physical characteristics of the estuary make the distribution and occurrence difficult to place within boundaries.

No fishes are known to be restricted to the Columbia River estuary, that is, unable to penetrate either fresh or fully saline waters. Those classified as migratory either enter the estuary to feed or spawn, or pass through the estuary from saltwater to spawn in freshwater.

306.2 LIFE HISTORIES OF SELECTED FISHES

Aspects of the life history of the following fishes are discussed in this section: all salmon and trout except mountain whitefish, white and green sturgeon, starry flounder, English sole, Columbia River smelt, longfin smelt, American shad, Pacific herring, northern anchovy, Pacific lamprey, Pacific staghorn sculpin, northern squawfish, largemouth bass, yellow perch, and freshwater catfishes. These fishes are discussed either because of their economic importance or their relationship to economically important fishes.

Table 306-1

Fishes of the Columbia River Estuary

FAMILY & COMMON NAME	SCIENTIFIC NAME	Marine	Freshwater	Migratory
Salmonidae				
Chinook salmon	Oncorhynchus tshawytscha	x		x
Coho salmon	Oncorhynchus kisutch	x		x
Chum salmon	Oncorhynchus keta	x		x
Sockeye salmon	Oncorhynchus nerka	x		x
Steelhead trout	Salmo gairdneri	x		x
Cutthroat trout	Salmo clarki	x	x	x
Mountain whitefish	Prosopium williamsoni		x	
Osmeridae				
Eulachon (Columbia River smelt)	Thaleichthys pacificus	x		x
Whitebait smelt	Allosmerus elongatus	x		
Rainbow smelt	Osmerus mordax	x		
Longfin smelt	Spirinchus thaleichthys	x		x
Surf smelt	Hypomesus pretiosus	x		
Petromyzontidae				
Pacific lamprey	Entosphenus tridentatus	x		x
River lamprey	Lampetra ayresi	x		x
Acipenseridae				
Green sturgeon	Acipenser medirostris	x		x
White sturgeon	Acipenser transmontanus		x	x
Pleuronectidae				
Starry flounder	Platichthys stellatus	x		
English sole	Parophrys vetulus	x		
Sand sole	Psettichthys melanostictus	x		
Butter sole	Isopsetta isolepis	x		
Bothidae				
Speckled sanddab	Citharichthys stigmaeus	x		
Percichthyidae				
Striped bass	Morone saxatilis	x		x
Agonidae				
Pricklebreast poacher	Stellerina xyosterna	x		
Blacktip poacher	Xeneretmus latifrons	x		

Table 306-1 (Cont.)

FAMILY & COMMON NAME	SCIENTIFIC NAME	Marine	Freshwater	Migratory
Ammodytidae				
Pacific sandlance	Ammodytes hexapterus	x		
Chimaeridae				
Ratfish	Hydrolagus colliei	x		
Clupeidae				
American shad	Alosa sapidissima	x		x
Pacific herring	Clupea harengus pallasi	x		x
Cottidae				
Pacific staghorn sculpin	Leptocottus armatus	x		
Buffalo sculpin	Enophrys bison	x		
Brown Irish lord	Hemilepidotus spinosus	x		
Prickly sculpin	Cottus asper		x	
Riffle sculpin	Cottus gulosus		x	
Tidepool sculpin	Oligocottus maculosus	x		
Cyclopteridae				
Showy snailfish	Liparis pulchellus	x		
Ringtail snailfish	Liparis rutteri	x		
Embiotocidae				
Shiner perch	Cymatogaster aggregata	x		
Redtail surfperch	Amphistichus rhodoterus	x		
Engraulidae				
Northern anchovy	Engraulis mordax	x		
Gadidae				
Pacific hake	Merluccius productus	x		
Pacific tomcod	Microgadus proximus	x		
Hexagrammidae				
Lingcod	Ophiodon elongatus	x		
Greenling	Hexagrammos sp.	x		
Pholidae				
Saddleback gunnel	Pholis ornata	x		
Rajidae				
Longnose skate	Raja rhina	x		

Table 306-1 (Cont.)

FAMILY & COMMON NAME	SCIENTIFIC NAME	Marine	Freshwater	Migratory
Scorpaenidae				
Darkblotched rockfish	Sebastes crameri	x		
Black rockfish	Sebastes melanops	x		
Squalidae				
Spiny dogfish	Squalus acanthias	x		
Stichaeidae				
Pacific snake prickleback	Lumpenus sagitta	x		
Trichodontidae				
Pacific sandfish	Trichodon trichodon	x		
Catostomidae				
Largescale sucker	Catostomus macrocheilus		x	
Centrarchidae				
Largemouth bass	Micropterus salmoides		x	
Warmouth	Lepomis gulosus		x	
Bluegill	Lepomis macrochirus		x	
Pumpkinseed	Lepomis gibbosus		x	
White crappie	Pomoxis annularis		x	
Black crappie	Pomoxis nigromaculatus		x	
Cyprinidae				
Squawfish	Ptychocheilus oregonensis		x	
Peamouth	Mylocheilus caurinus		x	
Carp	Cyprinus carpio		x	
Chiselmouth	Acrocheilus alutaceus		x	
Dace	Clinostomus sp.		x	
Gasterosteidae				
Threespine stickleback	Gasterosteus aculeatus		x	
Ictaluridae				
Channel catfish	Ictalurus punctatus		x	
Yellow bullhead	Ictalurus natalis		x	
Brown bullhead	Ictalurus nebulosus		x	
Percidae				
Yellow perch	Perca flavescens		x	

Sources: Durkin, T.J., and D.A. Misitano (1974)
Durkin, T.J., and R.J. McConnell (1973)
Fies, T.T. (1971)
Gaumer, T., D. Demory, and L. Osis (1973)
Haertel, L., and C. Osterberg (1967)
Higley, D.L., and R. L. Holton (1975)
Misitano, D.A. (1977)

A. Chinook Salmon

Of all the Pacific salmon, adult Chinook salmon, or kings, are the largest; they average between 12 and 30 lbs. and on rare occasion, they may weigh over 100 lbs. They are found in larger rivers from southern California around the Pacific rim to Hokkaido, Japan and northern China (Hart, 1973). They are the most important commercial fish in the area. Adults are silver with black spots on the back, dorsal fin, and both lobes of the tail fin, and black coloring on the inside of the jaws. Juveniles spend from a few months to over a year in freshwater before migrating to the sea, and most return to spawn when they are 4 or 5 years old. The greatest numbers of migrating adults follow the deeper channels such as the main ship channel and the old ship channel on the Washington side of the river (Kujala, 1976), (Figure 306-1). Spawning generally occurs in larger tributaries and hatcheries. In the Columbia River, there are spring, summer and fall Chinook; these divisions refer to the timing of adult migration.

1. Spring Chinook

Spring Chinook enter the estuary as two major runs. The first run is from February to April, with peak numbers coming in late March (Kujala, 1976). It is composed of two segments of about equal size that head for the Cowlitz and Willamette Rivers. The second major spring run passes through the lower river in April and May and heads for tributaries above Bonneville Dam. The outlook for the lower river segment of spring Chinook is good because of large, increasingly successful hatchery programs on lower river tributaries (Chaney and Perry, 1976).

The spring Chinook runs above Bonneville Dam are primarily fish produced in the Snake River, with additional production by Columbia River tributaries above McNary Dam and mid-river tributaries between McNary and Bonneville Dams. The once-productive upriver spring Chinook run is in precarious condition mainly as the result of great dam-related mortality of adults and juveniles. In 1975, the entire main stem Columbia was closed to upriver spring Chinook fishing for the first time in history, and fishing was prohibited in Snake River tributaries in Idaho for the second consecutive year. This closure was continued in 1976. The record low river flow in 1977 created conditions that were as good as currently possible for adult passage at main stem dams (Chaney and Perry, 1976). There were sufficient numbers to allow a commercial and sport fishery.

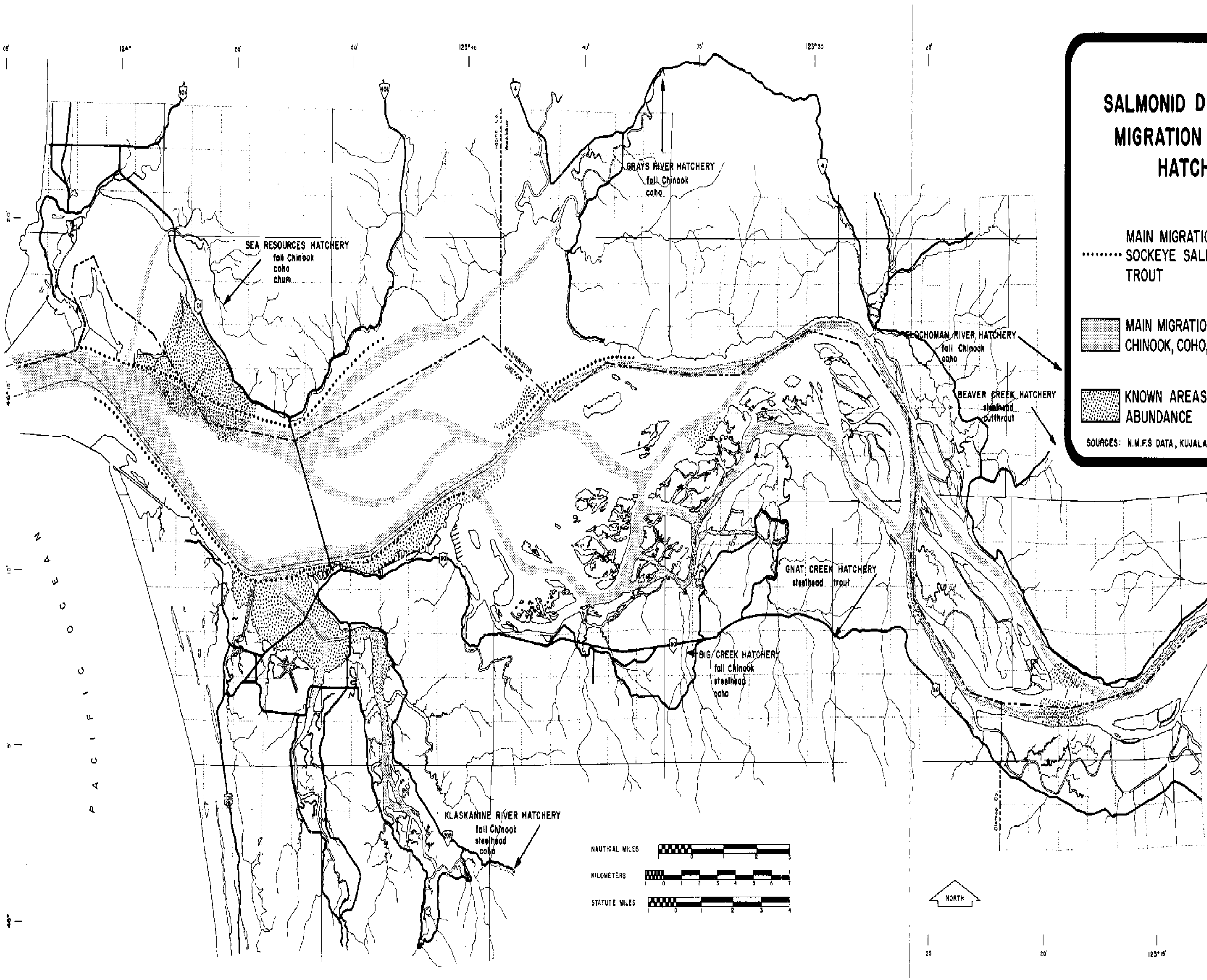
In a high flow year, those fish would have been "caught" by dams instead of fishermen. There is a good potential for substantial run recovery and rehabilitation of sports and commercial fisheries when passage problems are resolved at main stem dams.

2. Summer Chinook

Summer Chinook enter the estuary in late May, reach peak numbers in June, and are gone upriver by July (Chaney and Perry, 1976). The run is composed of two distinct segments. One is destined primarily for the Salmon River drainage in Idaho, and the other for tributaries of the Columbia River above its confluence with the Snake. Because of their high quality and size, summer Chinook have been seriously overfished in the lower Columbia. The stocks have been further reduced by loss of spawning habitat due to construction of Grand Coulee Dam in 1941. Fishing restrictions allowed a slow recovery to an all time high in 1957. Since then, however, there has been a drastic decline in the stocks. This parallels the increase in main stem Columbia and Snake River dams. Summer Chinook salmon suffer heavy adult and juvenile mortalities at main stem dams. The condition of the Snake River runs is particularly bad, with very few adults returning over the dams. The lower Columbia commercial, summer Chinook season was closed in 1965 for the first time and has not been reopened. Main stem and tributary sports fisheries were closed throughout the Columbia Basin in 1974. The ocean commercial and sports fisheries still take numbers of these fishes. Since summer Chinook salmon have been almost totally ignored in salmon research and artificial propagation efforts, and they suffer high, chronic dam-related mortalities, it is doubtful that they will soon contribute significantly to commercial and sport catches.

3. Fall Chinook

The fall Chinook run is the largest and the most economically important run to the lower river and offshore fishery. The run is composed of two major divisions (Kujala, 1976). The early, upriver run is destined primarily for mid-river tributaries and hatcheries between Bonneville and McNary Dams; it enters the estuary in late July, peaks in the estuary in late August, and peaks at Bonneville Dam by mid-September. The lower river fall Chinook run enters the river in late August, peaks in early September, and runs until late September. These fish are headed primarily for tributaries below Bonneville Dam. The two runs overlap and are harvested



SALMONID DISTRIBUTION, MIGRATION ROUTES AND HATCHERIES

•••••••• MAIN MIGRATION ROUTES FOR ADULT SOCKEYE SALMON AND STEELHEAD TROUT

MAIN MIGRATION ROUTES FOR ADULT CHINOOK, COHO, AND CHUM SALMON

KNOWN AREAS OF SMOLT ABUNDANCE

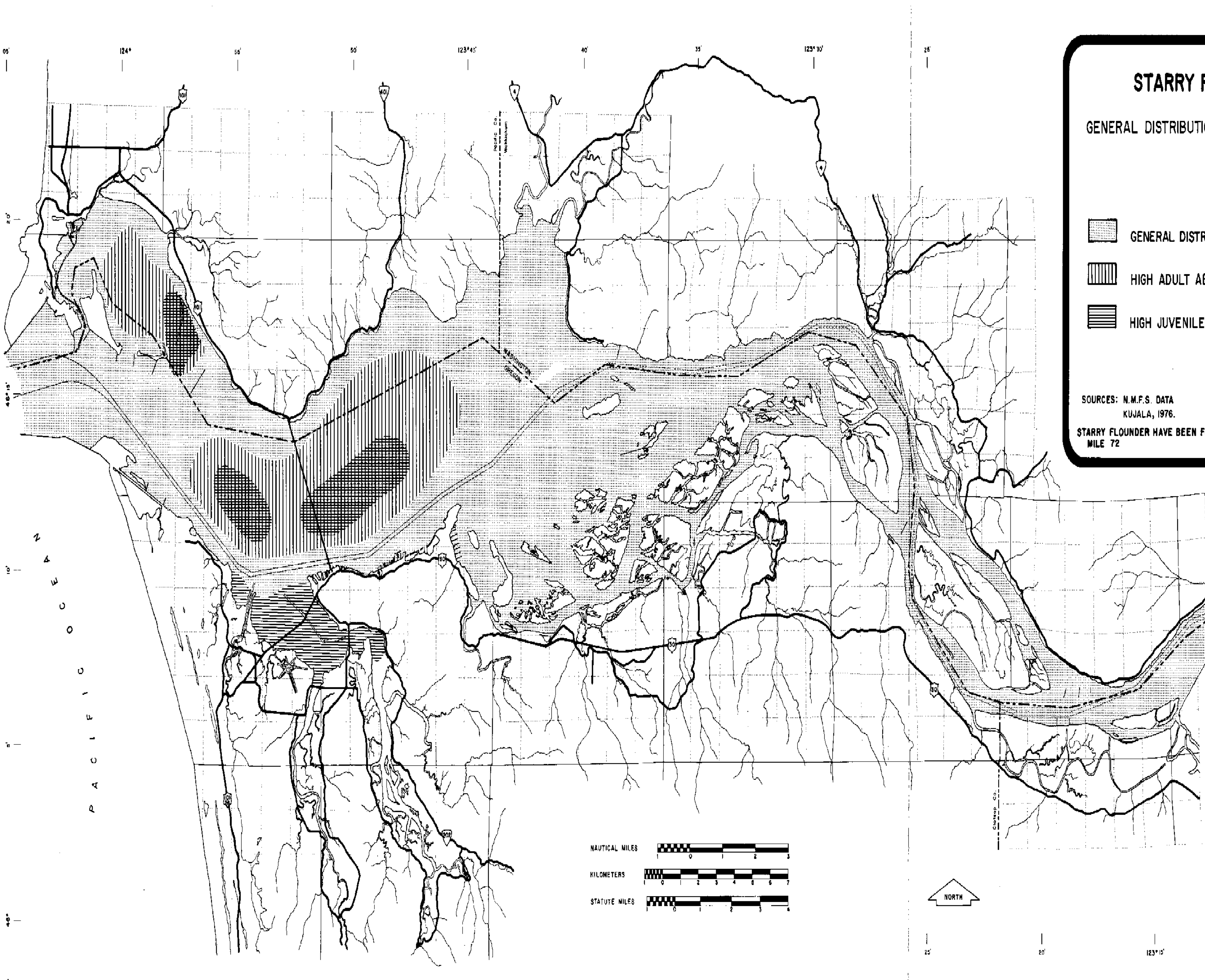
SOURCES: N.M.F.S DATA, KUJALA, 1976.

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

306—I



STARRY FLOUNDER

GENERAL DISTRIBUTION AND ABUNDANCE

- GENERAL DISTRIBUTION
- HIGH ADULT ABUNDANCE
- HIGH JUVENILE ABUNDANCE

SOURCES: N.M.F.S. DATA
KUJALA, 1976.

STARRY FLOUNDER HAVE BEEN FOUND UPSTREAM AS FAR AS MILE 72

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
306-4

Youngs Bay, Baker Bay, Grays Bay, Alder Slough, and west of Miller Sands; they are also found upriver in freshwater.

Starry flounder spawn in December and January in California, and in February and April in Puget Sound (Hart, 1973). The juveniles are symmetrical and planktonic until they become 10 mm long (3/8 in), and then the left eye migrates to the right side and the fish settles to the bottom. Age 1+ fish, about 90 mm (3-1/3 in), are found in Youngs Bay during most of the year; 0+ age fish 30-40 mm (1-1/2 in) are found in higher salinity stations by the end of May and in lower salinity stations by mid-June (Higley and Holton, 1975). These 0+ age fish grow to about 80 mm (3-1/8 in) by September. In general, the lower salinity stations have smaller fishes. At the higher salinity stations, the fish diet (listed in decreasing importance), from January to May was Corophium, harpacticoid copepods, bivalves, and Neomysis (small shrimp-like crustaceans); from June to September was Corophium, polychaete worms, harpacticoid copepods, Neomysis, and bivalves; and from October to November was bivalves and polychaete worms. The diet in shallower, lower salinity stations from January to May was polychaete worms, Corophium, and harpacticoid copepods; from June to September almost entirely Corophium, and some Neomysis; and from October to December again almost entirely Corophium.

The most detailed published information concerning starry flounder in the Columbia River estuary is that of Haertel and Osterberg (1967). Starry flounder is one of the most common fishes in the estuary and the upper estuary is probably used as a nursery area. Flounder older than 2-1/2 years are seldom caught in the estuary. Many more starry flounder are caught at Harrington Point (freshwater) than at Chinook Point (brackish to salt water). Fishes at Harrington Point are generally 0+ or 1+ years old, and the 0+ age fish appear during June. These 0+ age fish, after reaching a length of 50-60 mm (2-1/4 in), shift their diet from copepod plankton to amphipods, and polychaete worms. Over 50% of the older fish's diet is Corophium. At Harrington Point in the summer, young flounder also eat the small clam Corbicula. During the winter, starry flounder quit feeding.

J. English Sole

Adult English sole are an important part of the commercial trawl catch in the ocean and are partly distinguished from other flatfishes by their quite pointed snout. Larval English sole are found upriver to Youngs Bay in two size ranges, 4-6 mm (1/5 in) and 20-21 mm (3/4 in) (Misitano, 1977). Large numbers of juveniles up to 75-100 mm (3-4 in) are present below the Astoria Bridge and are caught at the mouth of Youngs Bay ship channel, off Chinook Point, and in Chinook Channel (Kujala, 1976). Zero to two year old fish eat mostly copepods, amphipods, and polychaetes, and also eat some mysids and small fish (Haertel and Osterberg, 1967). English sole juveniles appear to use the estuary as a nursery area.

K. Columbia River Smelt, or Eulachon

Eulachon are found in salt water from the Russian River in California north to the eastern Bering Sea and Pribilof Islands (Hart, 1973). They are 175-225 mm (7 - 9 in) long, slender, blue or blue-brown on upper parts and silver-white on sides and belly, and have an adipose fin (a small fleshy fin) between the dorsal fin and tail, like a salmon. Smelt are commercially fished from December until April in the Clatskanie to Longview reach, with little fishing done below Tongue Point (Kujala, 1976). Smelt are highly valued as a food fish. The size of runs has increased in recent years, and smelt have returned to the Sandy River in Oregon after being absent for many years. In 1973, 2.3 million pounds were harvested. Adults enter the estuary from the sea in December, peak in February, and the run is finished by April. They are found throughout the estuary during migration but travel mainly along the deeper channels and adjacent banks (Figure 306-5). According to the Washington Department of Fisheries (1967), most are destined for the Cowlitz River, the rest spawn along the Eaglecliff-Stella reach of the Columbia River and the Grays River, Kalama River, Lewis River, and Sandy River. These adults spawn over fine pea sized gravel to which the eggs stick. Adults usually die after spawning. The young hatch in about 30 days, and they feed only on their yolk sacs as the river currents carry them to sea. These yolk sac juveniles, 6-8 mm (1/4 in) are found in the estuary only from February to May (Misitano, 1977). They are not seen again in the estuary until they return as adults to spawn.

L. Longfin Smelt

Longfin smelt are found from San Francisco Bay to central Alaska. They are distinguished by having an adipose fin, and long pectoral fins (fins near the gills) that reach nearly to the pelvic fins (middle belly fins), and being pale olive brown on the back and silver-white on sides and belly (Hart, 1973). Adults reach 100-125 mm (4 - 5 in) at maturity and are generally considered marine. Information on British Columbia populations

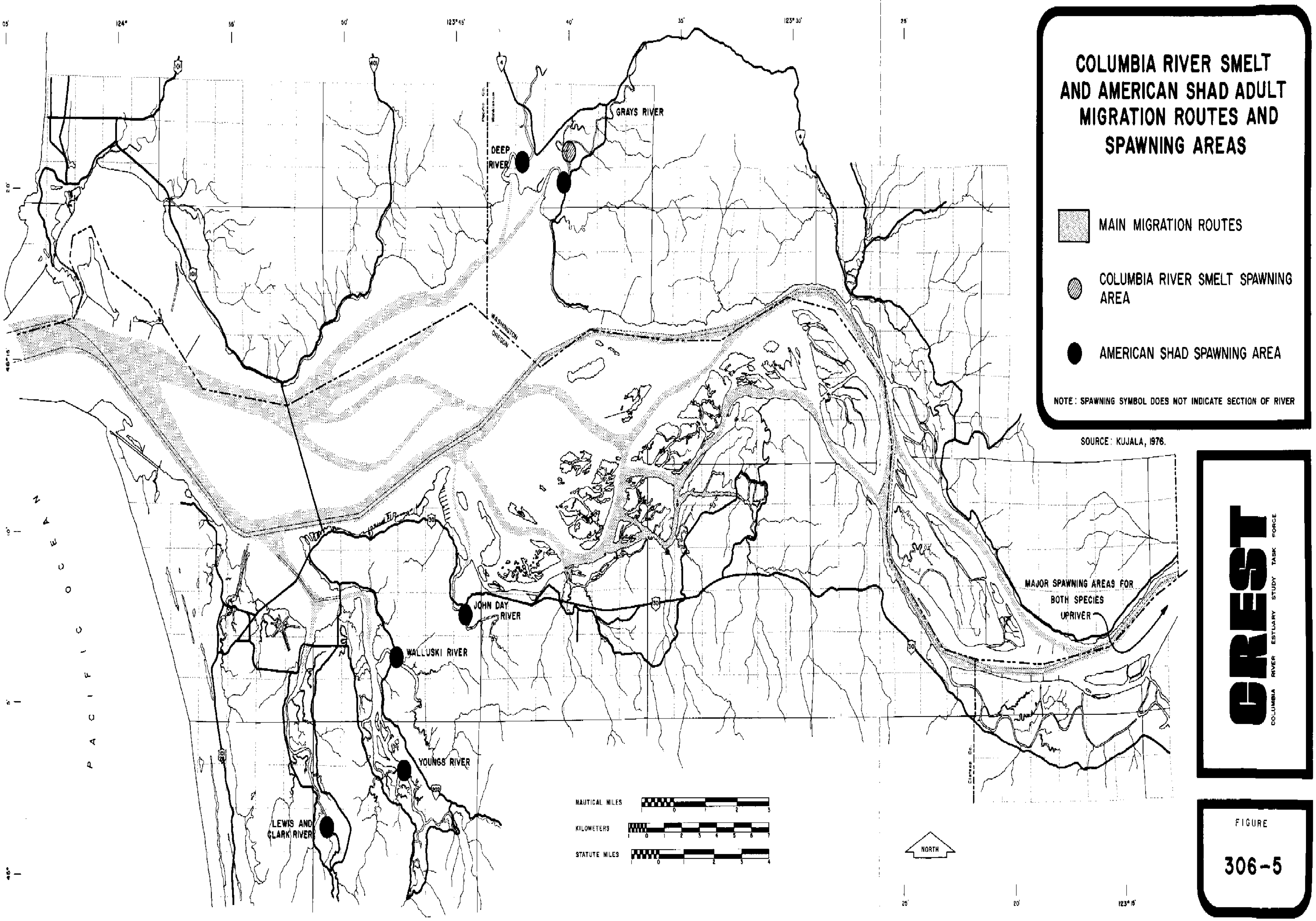

PACIFIC OCEAN
GRAYS RIVER
DEEP RIVER
WASHINGTON
OREGON
JOHN DAY RIVER
WALLUSKI RIVER
YOUNGS RIVER
LEWIS AND CLARK RIVER
MAJOR SPAWNING AREAS FOR BOTH SPECIES UPRIVER
NAUTICAL MILES
KILOMETERS
STATUTE MILES
NORTH
COLUMBIA RIVER SMELT AND AMERICAN SHAD ADULT MIGRATION ROUTES AND SPAWNING AREAS
MAIN MIGRATION ROUTES
COLUMBIA RIVER SMELT SPAWNING AREA
AMERICAN SHAD SPAWNING AREA
NOTE: SPAWNING SYMBOL DOES NOT INDICATE SECTION OF RIVER
SOURCE: KUJALA, 1976.
CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 306-5

indicates that spawning takes place at the end of their second year, from October to December in streams near the sea. Adults usually die after spawning.

Little is known about longfin smelt in the Columbia River estuary. Juveniles and adults are found throughout the year from Harrington Point to the mouth, primarily in the main river channels along sandbars and in Youngs Bay (Kujala, 1976). Larval longfin smelt comprise 67% of the total catch of larval fishes throughout the year (Misitano, 1977). Many newly hatched smelt are found during the early months of the year. Thus, it is quite possible that the estuary area is used for spawning by longfin smelt (Higley and Holton, 1975). Older juveniles in Youngs Bay eat Corophium, Neomysis, and zooplankton. Smelt from larval stages to 130 mm (5 in) are also found in Youngs Bay.

Longfin smelt are a very important source of food for other fishes in the Columbia River estuary. Longfin smelt are the most common fish consumed throughout the estuary (Haertel and Osterberg, 1967).

M. American Shad

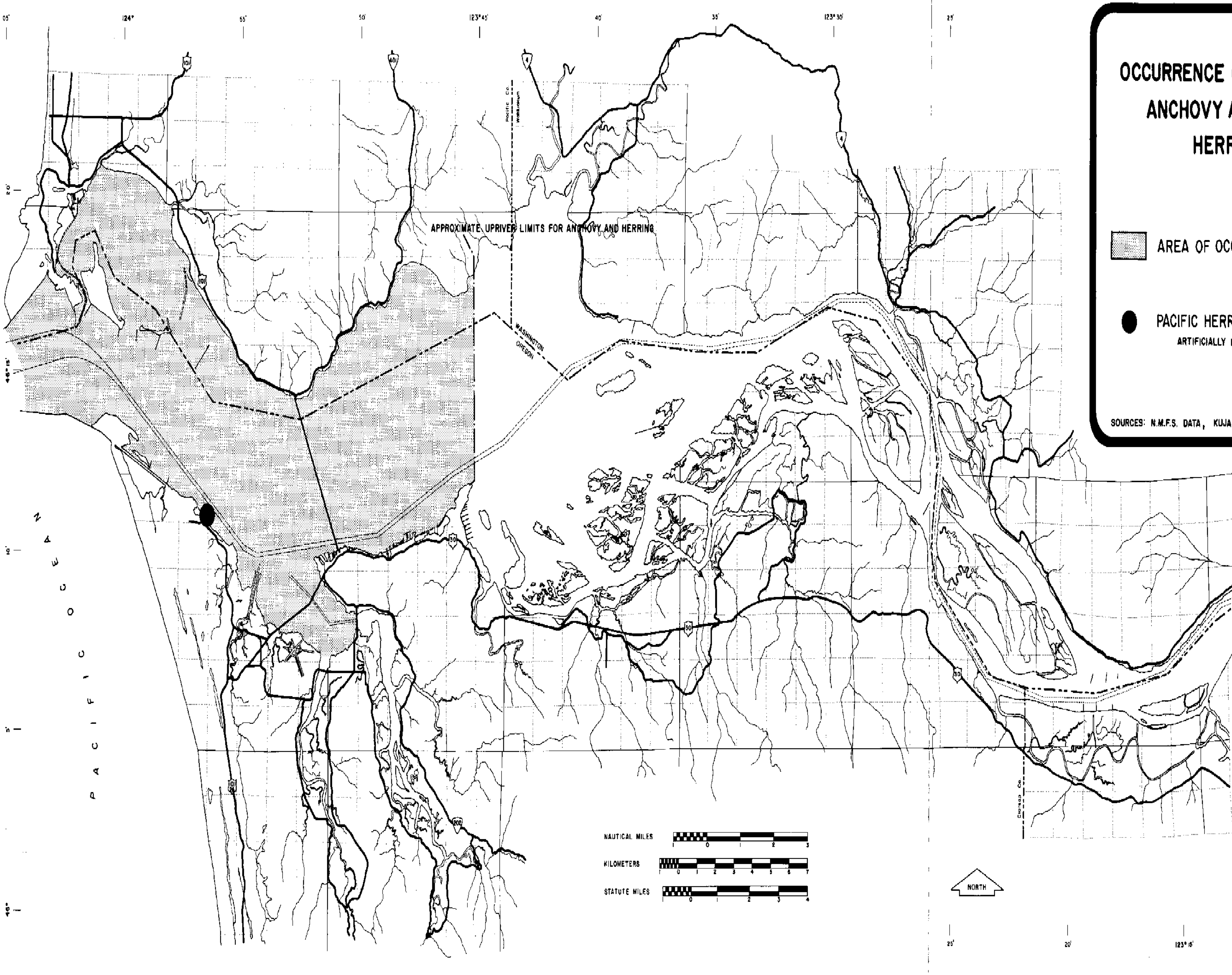
American shad are native to the Atlantic coast of North America. They were introduced to the Pacific coast and may now be found from Baja California, around the Pacific rim to Kamchatka in Asia. They were introduced into the Sacramento River in 1871, and from 1885 to 1886, 910,000 were introduced into the Columbia River (Jordan and Evermann, 1923). They are recognized by their large scales, deeply forked tail, compressed body, keeled scales along the belly, metallic blue-back shading to silver-white below, and a variable row of 4 round dark spots on the shoulders (Hart, 1973). In the Columbia River, spawning females average 4 pounds in weight; males weigh about 1 pound (Kujala, 1976). There is a commercial season for shad in Youngs Bay, John Day River, and Grays Bay between mid-May and mid-June (Kujala, 1976). They are principally taken for the females' roe, which when fried, is a delicacy. Shad are also taken by sports fishermen and are considered prized fighting fish to catch on artificial flies and lures. In 1902, of all the economically important fishes in the U.S., only cod and Chinook salmon exceeded American shad in value (Jordan and Evermann, 1923).

Adults enter the Columbia River estuary from the sea in late April, run through June and travel mainly in the main river channels (Figure 306-5). Although they spawn mainly in the upriver tributaries, shad also spawn in the Youngs River, Walluski River, Lewis and Clark River, Deep River, Grays River, and in slow moving sloughs near the head of tidewater. Males migrate upriver first, and most are five years old; most females are six years old (Washington State Department of Fisheries, 1967). Shad prefer shallow flats near the mouths of creeks for spawning and feed little before and during spawning (Jordan and Evermann, 1923). They spawn near the surface at night and the fertilized semi-bouyant eggs hatch 3-6 days later (Wash. State Dept. of Fish., 1967). Adults may return to sea and spawn again another year. Most juveniles migrate seaward in late fall or winter. However, some lower river juveniles may migrate in May and June (F. Young - Oregon Fish and Wildlife Comm. in Kujala, 1976). Adults and juveniles may be found throughout the year in the lower estuary (Kujala, 1976). Juvenile American shad from 50-170 mm (2 - 7 in) are found in Youngs Bay throughout the year (Higley and Holton, 1975). The diet and habitat preferences are not known for these juveniles.

N. Pacific Herring

Pacific herring are marine fish found from Baja California to the Beaufort Sea (off northern Alaska), and are distinguished by their large, easily removed scales, blue-green to olive colored back and silver sides and belly. Adults may be 250-300 mm (10 - 12 in) long (Hart, 1973). Herring are an important commercial fish used for human consumption, fish meal, and bait. Their diet is normally larger zooplankton and larval fishes.

Herring spawn yearly in schools in salt water from the high tide line out to a depth of 30 feet (Wash. State Dept. of Fish., 1967). This occurs during winter and spring months. The eggs adhere to vegetation, pilings, etc., and hatch in 10-14 days. The juveniles mature in 2 or 3 years. Mature adults enter the river in the greatest numbers during winter, spring, and early summer primarily during spring tides (Kujala, 1976). There is only one known spawning area in the Columbia River estuary, and it is artificial. Misitano (1977) states that evergreen boughs placed in the water at the National Marine Fisheries Service boat house in Hammond, Oregon, were used for spawning by 33 adult herring, 163 mm (6-1/2 in) average length, from 10-17 April. Moderate spawning also took place 1-3 July (Figure 306-6). Juvenile herring from 10-40 mm (1-1/2 in) long were found during March, May and June from the mouth upriver to Astoria, although they were relatively scarce.



OCCURRENCE OF NORTHERN ANCHOVY AND PACIFIC HERRING

AREA OF OCCURRENCE

PACIFIC HERRING SPAWNING
ARTIFICIALLY INDUCED

SOURCES: N.M.F.S. DATA, KUJALA, 1976.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
306-6

Herring of all age classes can be found throughout the year in the estuary (Kujala, 1976). Their distribution is associated with the salt-wedge. Their maximum penetration upriver is in the vicinity of Tongue Point, and occurs during high tides and low runoff.

Little is known of the food and habitat requirements of herring in the estuary. A few herring 40-120 mm (1-1/2 - 4-3/4 in) long are present in Youngs Bay in August and November (Higley and Holton, 1975). One herring 70 mm (2-3/4 in) long and captured in Youngs Bay in October by Higley, Holton and Komar (1976) had eaten calanoid and cyclopoid copepod zooplankton.

O. Northern Anchovy

Anchovy are marine fishes found from Baja California to the Queen Charlotte Islands off the coast of British Columbia (Hart, 1973). Adults are 150-180 mm (6 - 7 in) long, feed on plankton, and are recognized by their large scales, large mouth, and metallic blue or green color above and silver on the sides and belly. Anchovy are an important food for other fishes such as salmon and tuna. In the Columbia River estuary, white sturgeon and hake feed on them (Kujala, 1976). No commercial fishery for them exists in the estuary, although in some years tuna fishermen use them for bait in the late summer and early fall.

Large schools of anchovy enter the Columbia River periodically from May through December (Kujala, 1976), and are associated with the salt or brackish waters. They may be found from Tongue Point to the mouth during low river flow in late summer and fall, from the Chinook Jetty to the mouth during high river flow, and in Youngs Bay at the highway bridge in September and October (Figure 306-6). At times, the changing tides and freshwater runoff seem to trap anchovy at the water surface where they are seen in distress. It is not likely that anchovy spawn in the estuary, although this is not definitely known. The food and habitat requirements of the juveniles are also not known. A few juvenile anchovy 22-68 mm (1-2-3/4 in) long are present from Hammond, Oregon, to the mouth during January, March, October and November (Misitano, 1977).

P. Pacific Lamprey

Lamprey are marine fish found from Baja California, around the Pacific rim to Hokkaido, Japan. These primitive fish are elongated and may reach 68 cm (27 in) in length; they are recognized by a jawless mouth and seven gill pores (Hart, 1973). In British Columbia, adult lamprey enter spawning streams from the sea from July to October but do not spawn until the following spring. Pacific lamprey enter Big Creek, Oregon, in great numbers from summer through fall (R. Sheldon - Big Creek Hatchery Manager, personal communication). Approximately 200,000 Pacific lamprey transit the Columbia River annually (Corps of Engineers, 1976). In the spring, both sexes dig the nest, the eggs hatch in 2-4 weeks, and the larval lamprey drift downstream and bury themselves in mud at the bottom of pools. The adults die after spawning. After five years of feeding in the stream on algae and zooplankton, the 110 mm (6 in) juveniles metamorphose into adult form, migrate downstream in spring, and soon start a parasitic life on fishes. In turn, white sturgeon feed on them.

Commercial species of marine fishes are frequently found with lamprey scars (Hart, 1973). The lamprey attaches itself to a fish and feeds on the fish's blood and tissue. The prey is greatly weakened but may survive. Damage to the growth of the fish and the quality of its flesh must be significant but is unassessed. There is no known estimate of the numbers of fish that are attacked and do not survive. These fish are a direct loss, but the effect on the commercial fisheries resource is uncertain.

There are also river lamprey present in the Columbia River but, unlike Pacific lamprey, adults only reach 30 cm (12 in) in length. Their life history is similar to the Pacific lamprey, and they also prey on juvenile and adult salmon (Carl _et al._, 1967).

Q. Pacific Staghorn Sculpin

Pacific staghorn sculpin are found from northern Baja California to the Gulf of Alaska. It is a marine species tolerant of very low salinities and is often found as a bottom-dweller in estuaries. Adults may reach 46 cm (18 in), and their distinguishing characteristics include eyes placed high on the large flattened head, antler-like spines on the gill plates, and strongly marked fins (Hart, 1973). Locally, these fish are often called bullheads. They are voracious feeders and larger individuals feed on fishes if given the opportunity.

Large numbers of adults and juveniles are found from the mouth of the Columbia River upriver to at least Tongue Point. Staghorn sculpin, mostly juveniles, are present in Youngs Bay throughout the year in both high and low salinity water (Higley and Holton, 1975). Their diet at a high salinity station is mostly Corophium, and Neomysis from January to May; mostly Crangon shrimp, fish and Neomysis from June to September, and Corophium and Cragon from October to December. At a lower salinity site, the diet from January to September is mostly Corophium and Neomysis. Staghorn sculpin are quite numerous at Chinook Point, Astoria, and Harrington Point (Haertel and Osterberg, 1967). Their diet gradually changes with increasing age. Juveniles up to one year consumed small prey items such as amphipods, copepods and small fishes, while older individuals consume larger fish and very young crabs. Ripe adult staghorn sculpin appear during February and March, and although spawning has not been observed, there is probably a spawning population in the estuary (Misitano, 1977). A few very young fish, 6-13 mm (1/2 in) long, have been captured upriver to Astoria from January to March, and May to September.

The freshwater prickly sculpin are numerous in the estuary and may migrate to the estuary for spawning. Their diet, from studies by Higley and Holton (1976), and Haertel and Osterberg (1967), is largely amphipods, small shrimp, and some lampreys.

R. Northern Squawfish

Northern squawfish are a predaceous minnow found from British Columbia to central California, and are distinguished by their large size, (up to 4 feet), strong scales, large mouth and pointed head, and deeply forked tail (Jordan and Evermann, 1923). Although they are primarily a lake fish, they are found both in slower moving sections and sloughs of rivers, and in fish ladders at dams where they carry diseases which seriously affect migrating salmonids.

Squawfish spawn from May to early July in British Columbia, and their small adhesive eggs hatch in about a week (Carl et al., 1967). They reach sexual maturity at about 30 cm (12 in) in their sixth year, and may live 15 or 20 years. Terrestrial insects and plankton form the bulk of the juvenile diet, whereas the diet of adults is mostly fish. They are primarily bottom dwelling fishes and eat many bottom-dwelling sculpins, although at times they consume large numbers of salmon fry.

S. Largemouth Bass

The largemouth bass is one of America's favorite game fish. They attain a large size, have an aggressive nature, and are hard fighters. To hook and land a big one in most waters requires patience, knowledge, and skill (California Department of Fish and Game, 1966). These fish are natives of the east coast of North America and were introduced into the Columbia River in the late 1800's. They are distinguished by their large mouth, green-brown color, wide dark band down the length of the side, and an almost completely divided dorsal fin. Bass prefer lakes and sluggish oxbow areas with many weeds and clear water of 80°F. In water below 50°F they become inactive.

Individuals mature at age 2 or 3, and may live to 16 years in cold water. They build nests and spawn when the water temperature reaches or exceeds 60°F. Eggs usually hatch in a week, and the fry eat zooplankton and crustaceans. Larger juveniles eat insects and adults eat mainly fish.

There is little sports fishing pressure on largemouth bass in the estuary although Fies (1971) finds that there are populations in many of the lower river sloughs. The effect of bass feeding on the populations of migrating juvenile salmonids in the estuary and upriver areas is not known.

T. Yellow Perch

Yellow perch are a highly edible game fish and were introduced into the Columbia River from eastern North American in 1890. They are distinguished by their yellow color, orange lower fins, and 6 to 8 dark vertical bars. Yellow perch mature at about two years and spawn when water temperature reaches 7-13°C (45-55°F). They weave their long strings of eggs, up to 8 feet, in aquatic plants and tree roots. They are a schooling fish, avoid strong currents, and compete with and may eat young salmon and trout. The diet also includes small crustaceans, snails, aquatic insects, and other fishes (California Department of Fish and Game, 1966).

There is little sports fishing pressure on yellow perch in the estuary, although Fies (1971) finds that there are populations in many of the lower river sloughs. The effect of yellow perch feeding on populations of migrating juvenile salmonids in the estuary and upriver areas is not known.

U. Freshwater Catfishes

Although Fies (1971) finds that there are populations of yellow and brown bullheads and channel catfish in many of the lower river sloughs, there is little sports fishing pressure.

There are no freshwater catfishes native to the Pacific coast of North America; these were introduced into the Columbia River in the late 1800's. As adults, they are omnivorous and occasionally become heavy fish eaters. The effect of these catfishes feeding on populations of migrating juvenile salmonids in the estuary and upriver areas is not known.

306.3 TIMING OF ANADROMOUS FISH MIGRATIONS

The Columbia River estuary is part of the migration routes of a number of anadromous fishes, both adults and juveniles. The adults have matured in the ocean, and are returning to freshwater to spawn. The resulting juveniles stay in freshwater for varying lengths of time before migrating to the sea. Knowledge of the adult migration times, as seen in Table 306-2, has been gained largely through the commercial fisheries. Juvenile migration times are not as well known. Research, largely by the U.S. National Marine Fisheries Service, provides the information found in Table 306-3.

More detailed information about migration is provided in the previous section on life histories of fishes.

306.4 ECOLOGY OF FISHES IN THE COLUMBIA RIVER ESTUARY

A. Fish Distribution

The distribution of fishes throughout the estuary is quite variable, being affected by many physical and biological factors. Time of year, stage of tide, water quality, food availability, adequate habitat, and physiological needs all affect where certain fishes may be found at any particular time. However, the gradual change in salinity from the mouth to the upper part of the estuary is probably the primary factor which determines the distribution of fishes. In the Columbia, salinity penetration depends on tidal cycles, river flow variations and complex mixing processes. These are discussed in detail in Section 204 (Estuarine Circulation). Maximum salinity penetration during low flow and high tide is about to river mile (RM) 23, opposite Harrington Point. During average flow conditions on high tide, saline waters intrude to about Tongue Point (RM 18) while during high flow, only to about Clatsop Spit (RM 5). On the ebb tide during high river flow, salt water may be pushed nearly out of the estuary (RM 2-5).

Freshwater fishes are commonly found in the sloughs and slow moving areas of the upper estuary, although they may also be found in the freshwater areas of the rest of the estuary. According to Fies (1971), sufficient populations of freshwater game fishes are present in upriver sloughs,

Table 306-2
Timing by Month of Adult Fish Runs in the
Columbia River Estuary

COMMON NAME	J	F	M	A	M	J	J	A	S	O	N	D
Spring Chinook Salmon		x	x	x	x							
Summer Chinook Salmon					x	x	x					
Fall Chinook Salmon							x	x	x	x	x	
Coho Salmon								x	x	x	x	x
Sockeye Salmon						x	x					
Chum Salmon											x	x
Summer Steelhead Trout				x	x	x	x	x	x	x		
Winter Steelhead Trout	x	x	x	x							x	x
Cutthroat Trout	x	x					x	x	x	x	x	x
Columbia River Smelt, or Eulachon	x	x	x	x								x
American Shad				x	x	x						
Pacific Lamprey							x	x	x	x	x	

Sources: Chaney and Perry (1976)
Hager, personal communication
Kujala (1976)
Sheldon, personal communication

Table 306-3

Timing by Month of Major Juvenile Outmigration in the Columbia River Estuary

COMMON NAME	J	F	M	A	M	J	J	A	S	O	N	D
Spring Chinook Salmon (a)			x	x	x	x	x	x	x			
Fall Chinook Salmon (b)			x	x	x	x	x	x	x			
Coho Salmon				x	x	x						
Sockeye Salmon				x	x	x						
Chum Salmon			x	x	x	x						
Steelhead Trout			x	x	x	x						
Cutthroat Trout				x	x	x						
Columbia River Smelt, or Eulachon		x	x	x	x							
American Shad	x	x			x	x					x	x
Pacific Lamprey			x	x	x							

a = yearlings
b = subyearlings

Sources: Durkin, personal communication
Hart (1973)
Misitano (1977)
Sims, unpublished NMFS Research
F. Young, Oregon Fish and Wildlife Comm. in Kujala, 1976

particularly Blind Slough, to support moderate sport fishing pressure although there is little use presently. The effect of predation by these fishes on migrating juvenile salmonids is unknown. These sloughs surely provide rest and food to migrating juvenile salmonids, and food, rearing and spawning habitat to freshwater gamefish. Also found here are white sturgeon, juvenile starry flounder, and seasonally, adult American shad. The sloughs and freshwater marshes represent a great nutrient pool and must significantly contribute to the productivity of the entire estuary, although, no measurements of this contribution are available.

Throughout the lower river below Harrington Point, Washington, euryhaline fishes (those found over a wide range of salinities) provide the bulk of species present. These fishes include starry flounder, prickly and Pacific staghorn sculpin, longfin smelt, Pacific tomcod, and Pacific snakeblenny (Haertel and Osterberg, 1967). Throughout this area, the greatest variety and number of fishes are taken consistently in water of oligohaline to mesohaline salinities (0.5 to 18 $^{o}/_{oo}$). This was true whether these waters were found at Astoria, in the fall, or at Chinook Point, as in other seasons. These sites usually had large blooms of the copepod Eurytemora at those times of year (Figure 304-3).

A different distribution pattern is seen for larval and juvenile fishes by Misitano (1977). The greatest variety of species are captured closer to the mouth of the river where salinities are highest. Many of these species are marine. The reduction of salinity upriver is reflected by a corresponding decrease in the variety of species. Although the area from Youngs Bay to Tongue Point has the fewest species and lowest salinities, the area accounts for almost 50% of all larval fishes found during the year. This high percentage is due to the influx of larval longfin and Columbia River smelt to the estuary from upstream, during the first part of the year. Throughout the estuary, larval and post-larval fishes are most abundant from January to May.

When juvenile salmonids are found in the estuary, they frequent primarily two kinds of areas: shallow, slow moving areas and deeper channels. As a rule, migrating subyearling salmonids, (i.e., fall chinook and chum), prefer mudflats and beaches. Tidal flats and adjacent shallow water areas, as shown in Figure 203-7 (Columbia River Estuary Bathymetric Chart), are important areas to these fall Chinook and chum juveniles. Older migrating juveniles, i.e., spring and summer Chinook, coho, sockeye, steelhead and cutthroat trout prefer the deeper channel areas. Downstream migrant salmon undergo physiological changes that enable them to enter salt water. After these changes occur, the juveniles are called smolts. The smoltification process is largely a function of fish size, water temperature, and daylength. As smoltification occurs, the fish lose their juvenile markings and assume their silver ocean coloration. In the Columbia River, juvenile salmonids usually became smolts before entering the estuary. It is felt that smolts are physically able to enter salt water as soon as it is encountered and do not require a period of adaptation to salt water while they are in the estuary. Youngs Bay seems to be a very important area in the estuary, where migrating smolts make their change to a salt water life. The sheltered waters are also a rich food source for these fishes.

The distribution of fishes throughout the rest of the estuary is very poorly known with many of the pertinent research results not yet available in the open literature. Fishes use lower river sands such as Desdemona Sands as feeding areas. The main river channels are used for migrations of adult salmonids, smelt, and shad, and are also frequented by sturgeon, starry flounder, and occasionally herring and anchovy.

B. Spawning and Nursery Areas

The estuary supports runs of many fishes migrating to spawning grounds at different times of the year, but actual spawning within the estuary seems to be limited to Pacific herring, Pacific staghorn sculpin, prickly sculpin, and a new species of snailfish (Misitano, 1977). The spawning sites of the very numerous longfin smelt are not known but seem to be either in the estuary or in freshwater streams emptying into the estuary.

The Columbia River estuary is used as a nursery or rearing area for at least the following species: juvenile salmonids (for varying lengths of time), white and green sturgeon, starry flounder, English sole, butter sole, Pacific tomcod, longfin smelt, and prickly and Pacific staghorn sculpin. Numbers of minnows, sunfishes, and various freshwater gamefish spend their lives and reproduce in the freshwater parts of the estuary.

The relative importance of various estuary areas as nurseries for these fishes is not well understood. The contributions of estuary wetlands, marshes, and shallow water areas to fish production is probably quite high, although the extent of the contribution is not yet known. These areas provide a source of nutrients and detritus which helps support plant and animal production throughout the estuary, and also provide suitable habitat for various invertebrate animals, such as the amphipod Corophium and the mysid Neomysis. There is much evidence to show that these animals are an important part of the diet of fishes, such as juvenile salmonids that use the estuary for a nursery. It is likely that all those shallow water food rich areas, as shown in Figure 304-3, and Figures 305-3, 4, 5, 6 and 7, (General Distribution and Abundance of Canuella and Eurytemora, Mysids, Amphipods, Polychaetes, Oligochaetes, and Molluscs), are extremely important to the further production of many kinds of fishes in the estuary.

C. Estuary Contributions to Offshore Fish Production

There is a large commercial fishery off the mouth of the Columbia River for both salmonids and bottom-dwelling fishes. English sole and butter sole are known to use the estuary as a nursery, and large numbers of the adults are caught in this fishery. Juveniles of many species including salmonids may stay and feed in salt water off the mouth of the Columbia River. The contribution of estuary and Columbia River produced nutrients, plankton, larval and juvenile fishes, and invertebrates to the offshore fish production is not clearly understood, but it is probably substantial.

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400 CULTURAL CHARACTERISTICS

401

LAND AND WATER USES

COLUMBIA RIVER ESTUARY

LAND AND WATER USE

Robert E. Blanchard

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FIGURES

*Figures follows the page indicated.

401 LAND AND WATER USE

The analysis of current land use patterns is basic to the planning process. Existing land use in the estuary area is a direct reflection of the geography and natural resources of the region. Water uses have developed over time and in response to industrial, commercial, recreational and natural resource use patterns. Land and water uses also reflect the area's social and economic development.

This section details current land and water uses in the estuary area, land ownership of the adjacent shorelands, and zoning. It is important to examine land and water uses because they have a direct relationship to many of the physical and biological processes operating in the estuary. Existing uses also influence the type or direction of future plans and development.

401.1 EXISTING LAND USE

Land use patterns show the type of development that exists in an area. Figure 401-1 indicates generalized land use patterns in the Columbia River estuary area. U.S. 30 is the major arterial on the Oregon side of the Columbia River and connects Astoria with Portland. Beginning at the eastern boundary of Clatsop County and heading west, a variety of land uses are found. In the communities of Westport and Wauna, forest product industries and some agriculture predominate. Also, construction and operation of the Crown Zellerbach pulp and paper mill has resulted in new residential development near there.

To the west, the diked lands along the Columbia River provide excellent land for agricultural uses, while the land further away from the river is generally devoted to forest use.

Near the towns of Knappa and Svensen, the uses are a combination of forest, agricultural, and residential. Residential uses are prevalent near both Astoria and the industrial complex in the Wauna-Westport area. There are a variety of uses that are unique to a riverfront environment; examples of such uses include log storage in the sloughs and moorage for numerous houseboats. The area is also near the western boundary of the Lewis and Clark National Wildlife

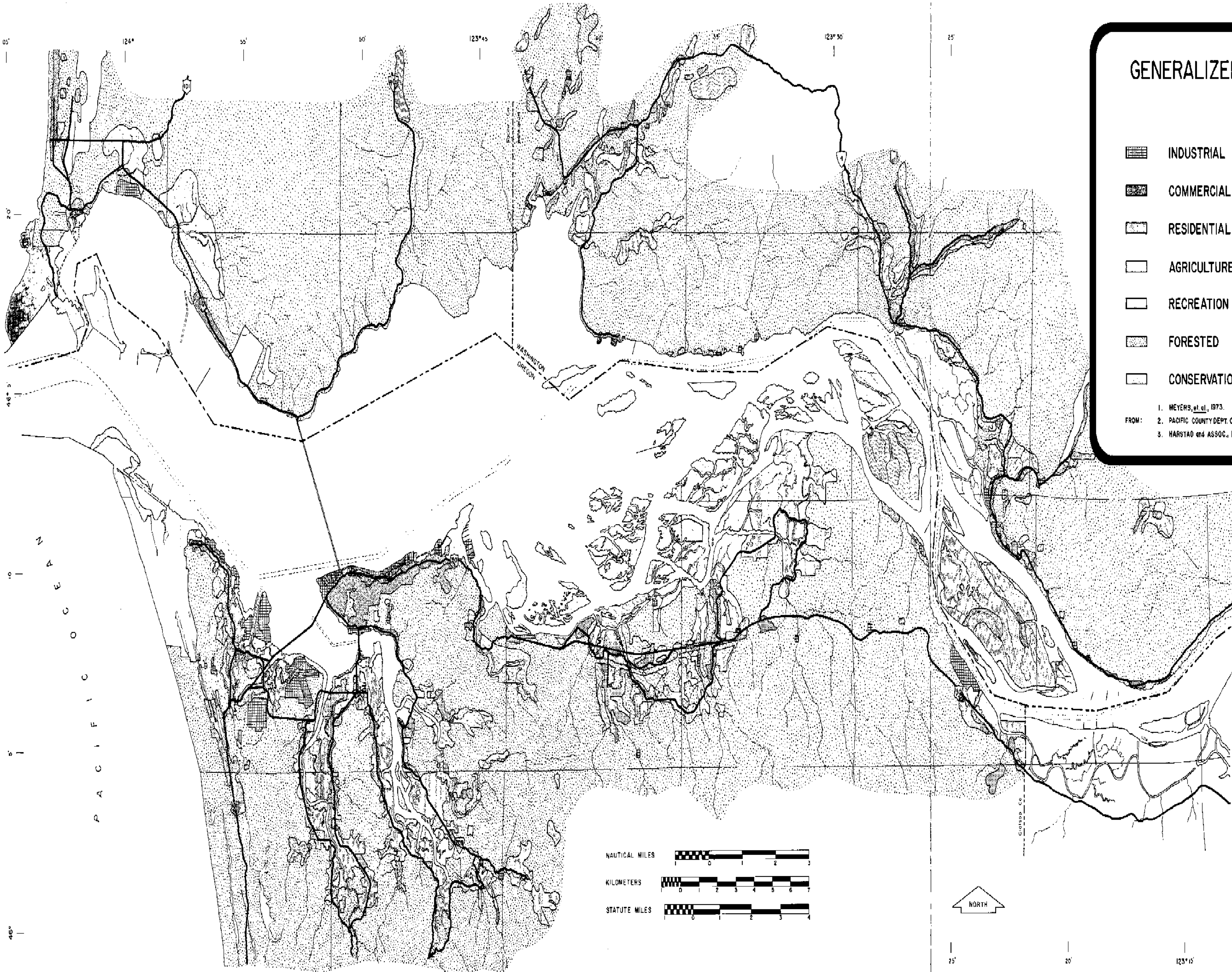
Refuge, which includes most of the islands in the Columbia River from Puget Island to Tongue Point.

Land use in the Astoria area is the most intensive in the entire estuary region. Its location near the mouth of the Columbia River has resulted in development of an intensive industrial-commercial waterfront; the Port of Astoria and the fish processing industries are particularly dependent on this location. The City of Astoria is the financial and shopping center for the region, including those Washington communities in the lower estuary area. This area supports industrial, commercial, residential, institutional, cultural, and recreational land uses. At Tongue Point, northeast of Astoria, a Federal Job Corps Center and Coast Guard unit occupy the former Naval base. South of Astoria, land use reverts to agriculture and forestry, where diked estuarine lands provide valuable agricultural land for pasture.

Across Youngs Bay from Astoria is the Clatsop County Airport, owned and operated by the Port of Astoria. The Coast Guard also maintains a unit at the airport to support their rescue operations.

Toward the Pacific Ocean, industry in support of the commercial fishing fleet is present along much of the waterfront. Although there are limited agricultural and forest uses, the focus of the land use in the Warrenton-Hammond area is toward commercial and sport fishing and toward the services that support recreational activities at nearby Fort Stevens State Park and the coastal beaches. The proposed Brown and Root offshore platform fabrication yard along the Skipanon Waterway may increase the residential demand for this area.

In Washington, land adjacent to the estuary is predominately in forest use from the eastern boundary of Wahkiakum County to the Ilwaco area, in Pacific County. In Wahkiakum County, according to the Wahkiakum County Water and Sewer Study prepared in 1970, over 83 percent of the entire county is forested land. The next most intensive land use is agriculture; it occupies only about seven percent of the total land area. The shoreland area in Wahkiakum County consists almost exclusively of forested land, with some agricultural land use north of



GENERALIZED LAND USE

- INDUSTRIAL
- COMMERCIAL
- RESIDENTIAL
- AGRICULTURE
- RECREATION
- FORESTED
- CONSERVATION

FROM:
1. MEYERS, et al., 1973.
2. PACIFIC COUNTY DEPT. OF PUBLIC WORKS, 1974.
3. HARSTAD and ASSOC., 1970

CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

401—1

Cathlamet and Skamokawa and in the Grays Bay area. The two exceptions to this general pattern are Puget Island, an agricultural and rural residential area, and the conservation oriented Columbian White-Tailed Deer National Wildlife Refuge, located southeast of Skamokawa and east of the Lewis and Clark National Wildlife Refuge.

In Wahkiakum County, the City of Cathlamet is the only incorporated community, with other residential concentrations occurring in the estuary area at Skamokawa, Roseburg, Eden, Altoona, Pillar Rock, Eagle Cliff, and on Puget Island.

With the exception of Cape Disappointment and the Ilwaco areas, Pacific County is very similar to Wahkiakum County in its land use patterns. The eastern portion of the county is exclusively in forest use. West of the Astoria bridge, the predominant uses are rural in nature. There is a population center at Chinook and recreational activity at Fort Canby State Park. The U.S. Coast Guard maintains a unit on the eastern side of Fort Canby.

401.2 WATER USE

Water uses in the Columbia River estuary range from recreation to industry, and include many activities that directly support the economy of the region. Marinas, mooring basins, and launching ramps provide access to the water throughout the estuary. These areas support both commercial and recreational use of the river in the eastern portions of the estuary. Many people enjoy pleasure boating and fishing both on the river itself, and on the sloughs and channels throughout the lowland areas. As the river widens to the west, recreational boating decreases, and the main water uses are commercial fishing and navigation. Commercial fishing is conducted throughout the estuary, but it is more intensive west of Tongue Point. Figure 401-2 shows commercial water uses throughout the estuary. Recreational uses are discussed in Section 402 (Recreation).

Industrial uses and other activities supporting industry are widespread. Many of the sloughs in the eastern portions of the estuary and the lower reaches of the Youngs, Lewis and Clark, and Elochoman Rivers serve as log storage sites. Logs are often stored adjacent to where they will be used, until they can be processed or loaded aboard a ship for export.

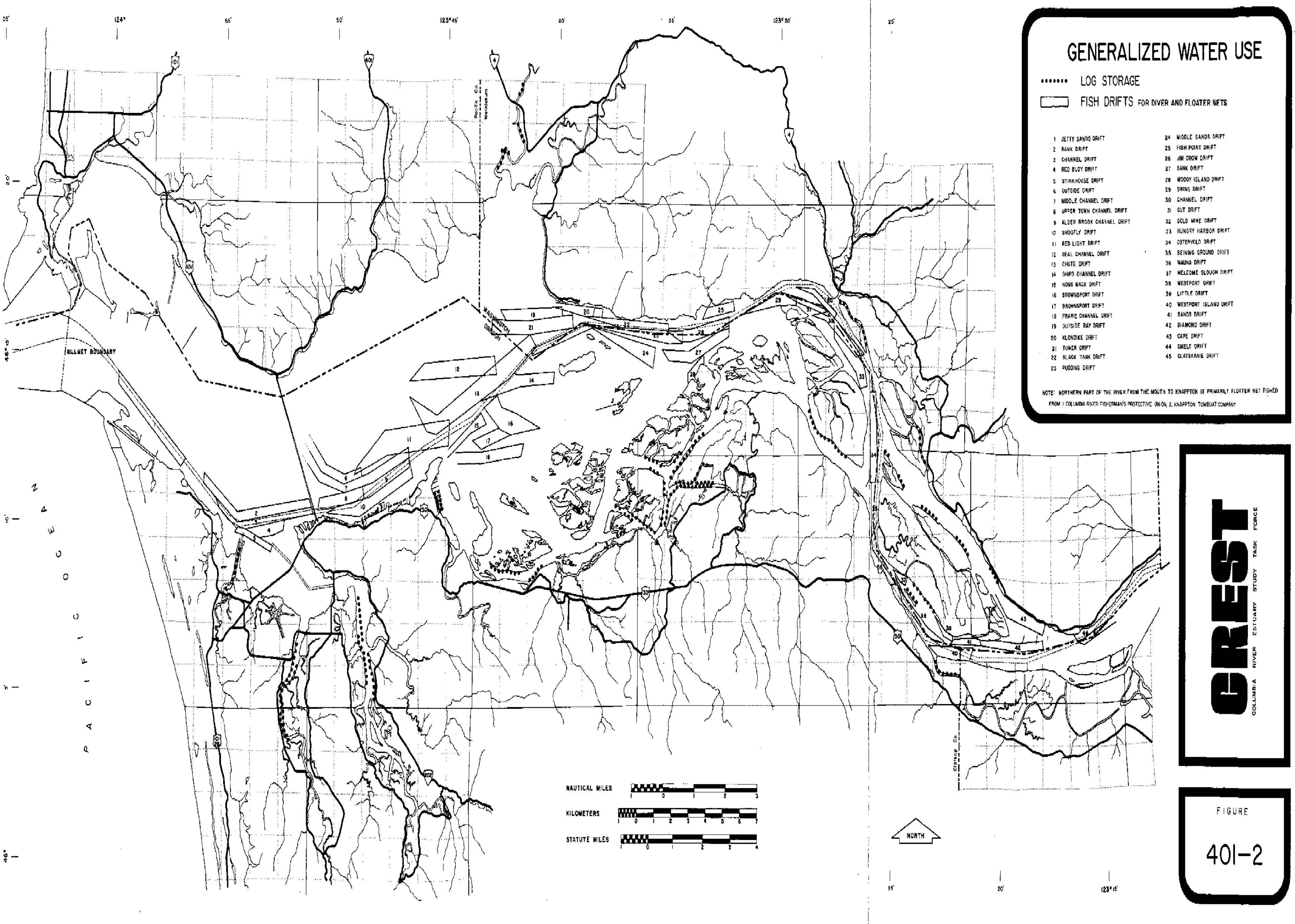
Dredging of the navigation channel is a continuous project in the Columbia River. The disposal of dredge materials takes place at many sites along the river, both in the water and on the land. This activity is discussed in Section 209 (Physical Alterations).

Commercial fishing is probably the main use of the Columbia River estuary; it is also the industry that is most dependent on maintaining the productivity of the estuary. Fish drifts are located throughout the estuary, from the mouth to the eastern boundary, including the mouths at Youngs Bay and Grays Bay. Fish drifts are the recognized areas that gillnetters are allowed to fish. The areas mapped in Figure 401-2 are those areas used by gillnetters with both "diver" nets and "floater" nets. A "diver" net is one that is weighted so it moves along the bottom. As the name implies, a "floater" net is one that hangs down from floats on the surface.

The Columbia River is also used as a water highway for ocean-going ships and barges. Any ship crossing the Columbia River bar must pass through the estuary. Because of the large number of vessels crossing at the Columbia mouth, no official count has been made. In 1973, however, deep draft ships that crossed the bar numbered 4080. Related to this figure are the maritime activities of the ports. While the Port of Astoria is the site of industrial activities such as loading of logs, grain, and barges, the other ports in Ilwaco, Chinook, and Wahkiakum County are primarily mooring areas where commercial and charter fishing concerns are based, and where individual boat owners moor their boats.

401.3 LAND OWNERSHIP

Land ownership patterns are a valuable tool for indicating where future development is most likely to occur. Urban-type development usually occurs first on the small, private holdings, although larger private holdings offer the possibility for large-scale developments (including recreational or industrial complexes). Figure 401-3 depicts the pattern of public and private ownership in the estuary area.



CREST

COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

401-2

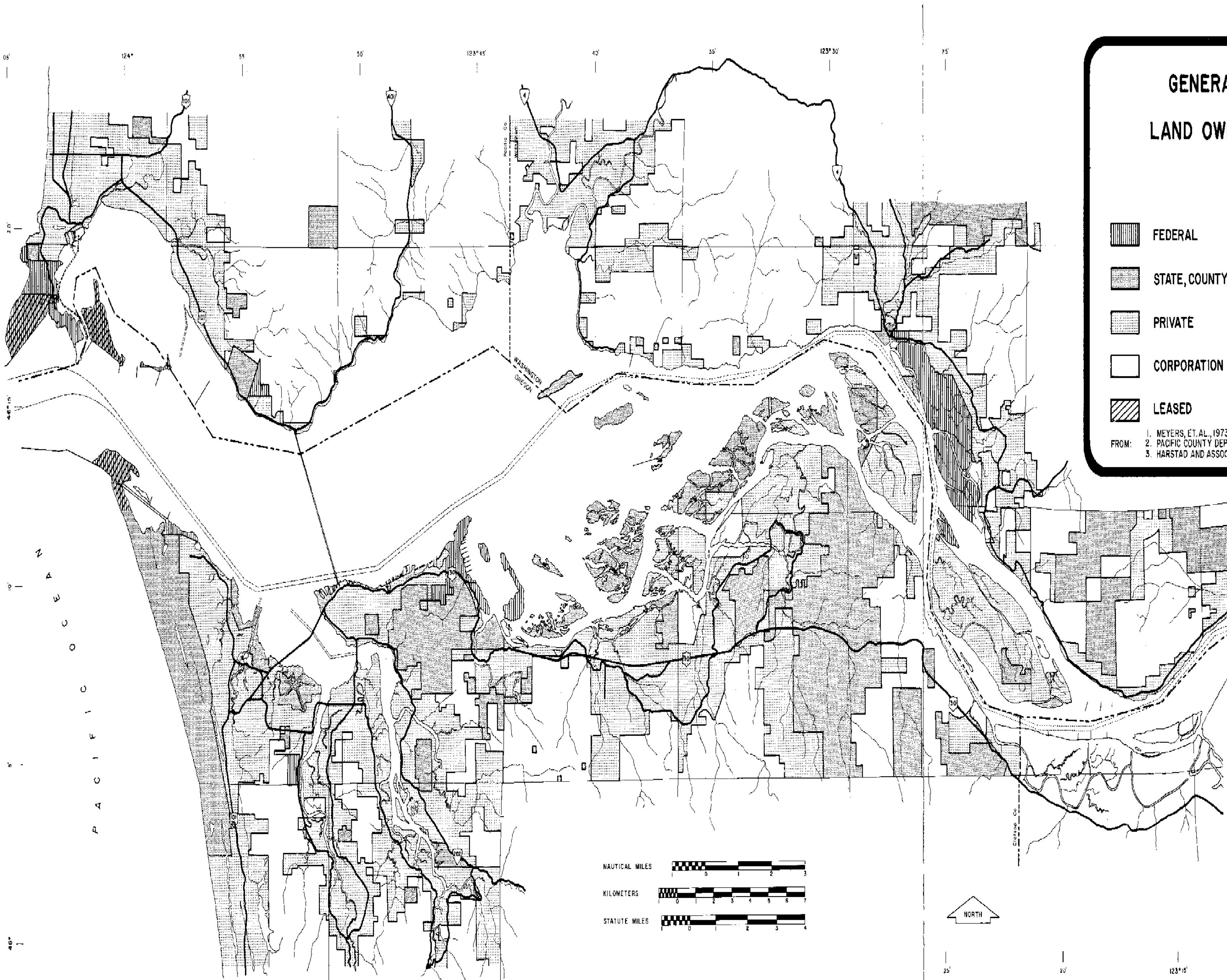

GENERALIZED
LAND OWNERSHIP
FEDERAL
STATE, COUNTY, MUNICIPAL, PORT
PRIVATE
CORPORATION
LEASED
FROM: 1. MEYERS, ET. AL., 1973
2. PACIFIC COUNTY DEPT. OF PUBLIC WORKS, 1974
3. HARSTAD AND ASSOC., 1970
PACIFIC OCEAN
WASHINGTON
OREGON
Pacific Co.
Clatsop Co.
NAUTICAL MILES
KILOMETERS
STATUTE MILES
NORTH
CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE 401—3

Land ownership patterns within the estuary region indicate the influence of the forest products industry in the area. Crown Zellerbach is the largest property owner in Clatsop County. Boise Cascade is the next largest. Although most of their holdings are in the upland areas beyond the estuary shorelands, a large portion of the shoreland area is also held in corporate ownership. As shown on the land ownership map, the majority of lands in Pacific and Wahkiakum Counties shorelands are held by private corporations. This is in contrast to the statewide pattern, where the federal government controls the majority of the land.

Federal lands include all holdings by an agency of the United States government. Most of the federal lands located in the estuary, a very limited area compared to other holdings (with the exception of the wildlife refuges), are administered by the Corps of Engineers. A large portion of federal land at the mouth of the Columbia River is leased to the States of Washington and Oregon for Fort Canby and Fort Stevens State Parks.

Ownership by other government entities is negligible in Washington. In Oregon, although state lands include parks, highways, and riparian lands, the majority of the state's holdings are forest lands in the eastern portion of the estuary shorelands.

Smaller parcels of private lands account for the remainder of the ownership. These include owners of small forest tracts, farm and rural residential tracts, and urban and suburban lots.

401.4 ZONING

The zoning of an area provides an overview of existing land use and an indication of the areas where future development is expected to occur. Zoning is the most common way of implementing comprehensive plans. Implementation of zoning ordinances allows local jurisdictions to guide development into suitable areas.

Zoning within the estuary region is indicative of the basically rural nature of the area. Large areas of agriculture, forest use, and general development zones are used to maintain the agriculture and timber resources of the area. It should be noted that the large residential zones in Clatsop County do not indicate large developments in the Youngs Bay and Tongue Point to Knappa areas, but show rural residential areas of low density, that cover a large area.

Zoning in the estuary area is in a state of flux, because local jurisdictions are currently compiling comprehensive land use plans. Because the planning processes in the various jurisdictions of the CREST planning area are at different stages of development, the generalized zoning map does not necessarily reflect the existing situation in the estuary area.

401.5 REFERENCES

A. Harstad Associates, Inc. 1970. Wahkiakum County Water and Sewer Study, prepared for the Wahkiakum County Commissioners.

General examination of existing physical and social conditions and water and sewer systems in Wahkiakum County. Development of a comprehensive water and sewer plan. Land use information on existing land use patterns.

B. Meyers, Joseph D., Richard T. Leonard, and Oscar R. Granger. 1973. A Plan for Land and Water Use, Clatsop County, Oregon: Phase I, prepared for the Clatsop County Planning Commission and Board of County Commissioners by Skidmore, Owings, and Merrill.

Survey and analysis of natural environment and existing development and survey of public attitudes and goals. Land use information on land use patterns and ownership.

C. Pacific County Department of Public Works. 1974. Water Quality Management Plan, Willapa Basin, prepared for the Pacific County Regional Planning Council.

Examination of natural, economic, and cultural conditions in Pacific County. Development of a comprehensive plan for the management of water and sewage collection and disposal. Land use information consists of land use patterns and determinents, development trends.

D. Pacific County Zoning Ordinance No. 41 and Zoning Map.

Map: Graphic representation of official zone boundaries.
Ordinance: Definition of zone giving permitted, conditional, and prohibited uses within each zone.

E. The Richardson Associates. 1975. Master Plan for the Columbia River at the Mouth, Final Review Draft, prepared for the U.S. Army Corps of Engineers, Portland District.

Analysis of physical features at study area to determine the best recreational and fish and wildlife uses of the project area. Land use information consists of existing land use and land ownership.

F. Robert E. Meyer Engineers, Inc. 1971. Preliminary Land Use Plan, Pacific County, Washington, prepared for the Pacific County Regional Planning Council.

Inventory of natural, economic and cultural conditions, examination of areas where further studies are needed, showing priority areas for planning. Land use data shows land use patterns, ownership, and criteria considered in land use policy decision.

402

RECREATION

COLUMBIA RIVER ESTUARY

RECREATION

Robert E. Blanchard

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FIGURES

TABLES

*Figure follows the page indicated.

402 RECREATION

The demand for recreational activities and facilities has been expanding rapidly during the last few years both nationally and in the Pacific Northwest.

For the Pacific Northwest as a whole, tourism is the fourth largest industry in terms of employment. Tourism also ranks as the fastest growing industry in the Northwest. The Bonneville Power Administration predicts that tourism will be the area's largest industry by the year 2000.

It is difficult to assign economic value to recreation. Its benefits are essentially aesthetic and subjective, and to assign a monetary value to recreational experiences involves both arbitrary assumptions and the priorities of the individual doing the analysis. There are often expenditures that aren't considered in analysis of the money spent by participants. For instance, surveys of campers do not take into account their purchases of food and other items from area businesses.

402.1 RECREATION AREAS

A. Fort Stevens State Park

Located in Oregon at the mouth of the Columbia River, Fort Stevens State Park is an historic site. Construction by the U.S. Army began in 1863, with the objective of defending the mouth of the Columbia River from a Confederate invasion. During World War II, Battery Russell, the Fort's seventh battery, had the distinction of being the only fortification in the continental United States to be fired upon by an enemy since the War of 1812.

Recreation attractions at the park are varied. There is access to fifteen miles of ocean beach for clam digging, surf bathing, and beachcombing. Saltwater fishing is available at the South Jetty and Jetty Sands, and freshwater fishing, swimming, and boating are available at Coffenbury Lake. In addition, hiking trails, biking trails, and camping areas are provided.

One unique attraction at Fort Stevens is the rusting skeleton of the Peter Iredale. A four-masted British Bark which went aground in 1906, its remains are one of the most photographed sights in the Pacific Northwest.

There are currently 603 campsites in the 3,762 acre park. Of these, 223 are trailer sites with full hookups, 120 are improved sites with water and electricity, and 260 are tent sites. As one of the most popular recreation areas in the state of Oregon, Fort Stevens recorded a day visitor attendance (car count) of 781,084 during fiscal year 1975-1976. Overnight camping totaled 187,174 camper nights.

B. Fort Canby State Park

Fort Canby State Park is located in Washington, across the Columbia River from Fort Stevens. During the Civil War, in 1862, Fort Cape Disappointment was established there as part of the coastal defense system. In 1875, the name was changed to Fort Canby.

Two primary attractions at Fort Canby are the Coast Guard station and the Cape Disappointment lighthouse. The lighthouse, activated in 1856, was the first in the Pacific Northwest. The Coast Guard station is one of the most active in the United States, with the responsibility for operations at the mouth of the Columbia River.

The 1,666 acre park offers a variety of recreational activities including picnicking, hiking, swimming, boating, fishing, clamming, beachcombing, and camping. There are 250 campsites available, with 60 of these providing full hook-up services for trailers. In keeping with the activities available and services provided at the park, 670,014 people participated in day use activities during 1976. Overnight campers numbered 39,257.

C. Fort Columbia State Park

Like Fort Canby and Fort Stevens, Fort Columbia was built to guard the mouth of the Columbia River. After World War II, the site was declared obsolete, and it was soon established as a state park. Picnicking, hiking, and exploring the gun emplacements and old buildings are the primary activities. Camping is not allowed on park grounds. Located on U.S. Highway 101 between Chinook, Washington and the Astoria-Megler bridge, the park grounds are located at Chinook Point, a Registered Historic Landmark.

D. River Park

A day use park, the River Park is located along the Columbia River at the boundary of Wahkiakum and Cowlitz Counties. Comprised of six acres, with 3,000 feet of shoreline, activities available include picnic sites and shoreline access.

E. Lewis and Clark National Wildlife Refuge

In the Columbia River estuary, the river begins to widen, and the flow slows. The slowing water deposits its silt load to form low, marshy islands and sandbars. These islands form the Lewis and Clark National Wildlife Refuge. Established in 1972, the refuge is situated along the Oregon side of the main channel of the river, beginning at approximately RM 20 and extending upriver fifteen miles.

The refuge encompasses approximately 35,000 acres, but tidelands or open water comprise nearly two-thirds of this area. Some twenty named islands, as well as unnamed bars, mudflats, and tidal marshes total 9,400 acres. Most of the islands, particularly those in the lower stretches, become flooded twice daily at high tide. On the upstream islands, marsh vegetation gradually changes to trees and shrubs.

Wildlife abounds throughout the refuge. Water areas serve as feeding grounds and migratory routes for many kinds of fish. Bald eagles are frequently seen during the winter months. Beaver, muskrat, raccoon, mink, weasel, and an occasional deer frequent the upper islands. The islands also serve as both a wintering area and a migrational stopover for Pacific Flyway waterfowl originating in Alaska.

Recreational opportunities at the refuge include hunting, fishing, and wildlife observation. The islands of the lower Columbia River are accessible only by boat. Deep channels separate most of the islands, allowing small boat navigation, at least at high tides. Hunting for waterfowl is considered excellent at the refuge. Certain parts may be closed to hunting, however, so it is necessary to check with the refuge officer. Sport fishing for salmon, trout, sturgeon, and warm water game fish occurs throughout the refuge. Most fishing is done by boat, although sandy beaches on many islands present bank fishing opportunities. Wildlife observation and photography are also popular activities there. The refuge is managed by the U.S. Fish and Wildlife Service of the Department of the Interior.

F. Columbian White-Tailed Deer National Wildlife Refuge

Located east of the Lewis and Clark National Wildlife Refuge, the Columbian White-Tailed Deer National Wildlife Refuge covers approximately 5,200 acres of Tenasillahe, Hunting, and Price Islands, and part of the mainland near Cathlamet, Washington. Most of this area is floodplain land, which is devoted to cattle grazing and is divided into small, poorly drained pastures.

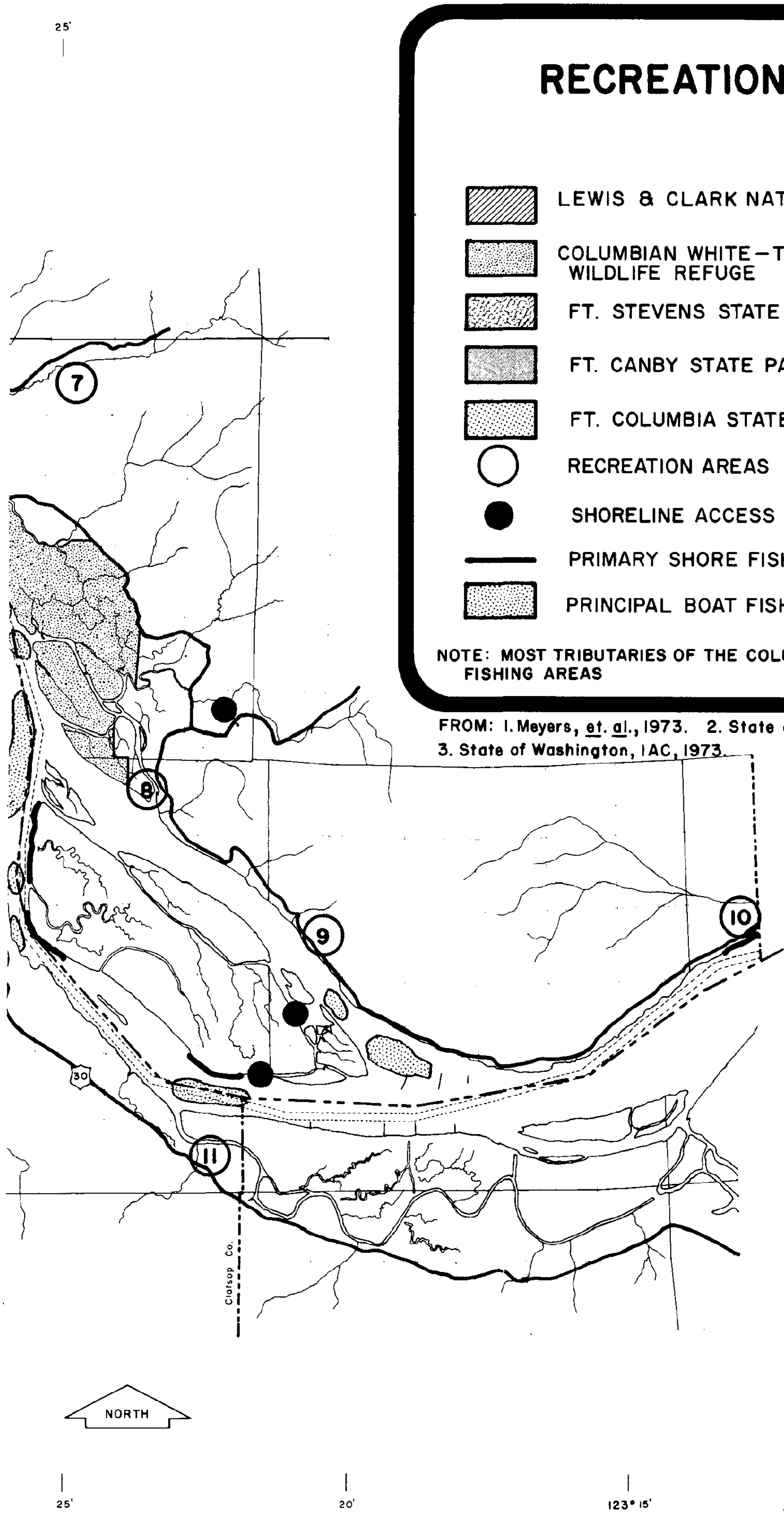
In addition to protecting the Columbian white-tailed deer, which is an endangered species, the refuge is also part of the overall Columbia River wintering area for waterfowl of the Pacific Flyway. Whistling Swan, Canadian Geese, mallards, and other waterfowl are often found in the refuge. Other shore and marsh birds, such as the great blue heron, sandpipers, bald eagles, and red-tailed hawks also frequent the area. Mammals that inhabit the area include mink, beaver, raccoons, and river otters.

Recreational values of the refuge include wildlife observation, hunting, hiking, and fishing. The deer are easily observed from the county road that encircles the mainland portions of the refuge. Automobiles, which the deer have grown used to, act as blinds for observation. Tenasillahe Island, accessible only by boat, retains its semi-wilderness character for hiking. Occasionally, a portion of the refuge may be open to waterfowl hunting. Warm water fishing for salmon, steelhead, and trout is available on Brooks Slough, Steamboat Slough, Elochoman Slough, and the interior sloughs and canals of the refuge. Boats are prohibited from the interior waters of the refuge.

The refuge is under the management of the U.S. Department of Interior, Fish and Wildlife Service.

G. Other

Additional recreation areas, including camping areas, water access points, fishing areas, and fairgrounds have been noted on Figure 402-1. Table 402-1 presents a matrix of recreational sites denoting available facilities and activities.



RECREATION AREAS

- LEWIS & CLARK NATIONAL WILDLIFE REFUGE
- COLUMBIAN WHITE-TAILED DEER NATIONAL WILDLIFE REFUGE
- FT. STEVENS STATE PARK
- FT. CANBY STATE PARK
- FT. COLUMBIA STATE PARK
- RECREATION AREAS (see table 402-1)
- SHORELINE ACCESS ONLY
- PRIMARY SHORE FISHING AREAS (Columbia River)
- PRINCIPAL BOAT FISHING AREAS (Sport Fishing)

NOTE: MOST TRIBUTARIES OF THE COLUMBIA RIVER ARE SHORE FISHING AREAS

FROM: 1. Meyers, et. al., 1973. 2. State of Oregon, Fish Commission, 1971 3. State of Washington, IAC, 1973.

CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE

402-1

TABLE 402-1

Recreation Areas

Site Number		Day	Overnight	Camping	Picnicking	Boating	Swimming	Hunting	Fishing	Hiking	Sightseeing	Bicycling	Historic
1	Ilwaco Boat Basin	X				X			X				
2	Chinook Boat Basin	X				X			X				
3	Chinook Park	X	X		X				X		X		
4	K-M Wayside	X			X								
5	Wahkiakum County Fairgrounds	X											
6	Skamokowa Park	X	X	X	X	X	X		X				
7	Wilson Creek	X			X								
8	Cathlamet Marina	X				X			X				
9	Abe Creek	X			X								
10	River Park	X			X								
11	Westport	X				X		X	X				
12	Bradley Wayside	X			X					X	X		
13	Aldrich Point Boat Ramp	X				X		X	X				
14	Knappa	X				X							X
15	Big Creek Park	X			X				X				
16	John Day Boat Ramp Park	X											
17	East Boat Basin	X				X			X				
18	West Mooring Basin	X	X			X			X				
19	Youngs Bay Boat Ramp	X				X			X				
20	Youngs River Falls	X			X	X	X		X	X	X		
21	Fort Clatsop National Monument	X			X					X	X		X
22	Warrenton Boat Basin	X	X	X	X	X			X		X		
23	Hammond Boat Basin	X				X			X				
	Fort Canby State Park	X	X	X	X	X			X	X	X	X	X
	Fort Columbia State Park	X			X					X	X		X
	Fort Stevens State Park	X	X	X	X	X	X		X	X	X	X	X
	Lewis and Clark National Wildlife Refuge	X						X	X	X			
	Columbian White-Tailed Deer National Wildlife Refuge	X						X	X	X			

From: Meyers *et al.*, 1973

402.2 STATEWIDE COMPREHENSIVE OUTDOOR RECREATION PLANS

Statewide Comprehensive Outdoor Recreation Plans are prepared by states to comply with, and receive funds under, the Land and Water Conservation Fund Act (Public Law 88-578), administered by the Bureau of Outdoor Recreation. The purpose of these plans is to provide guidelines to meet the recreational goals of the states. In establishing these guidelines, the states conduct surveys to determine the availability of recreational sites. The states then examine the demand for both use of existing sites and for additional opportunities. Analysis of these studies shows the need for providing the opportunity for additional recreational activities, sites for pursuing these activities, and maintenance of existing facilities.

A. Activity Categories

Table 402-2 lists the activities that are polled by the states and by several federal agencies related to outdoor recreation. The Washington State agency that administers outdoor recreation programs is the Interagency Committee for Outdoor Recreation. In Oregon, this agency is the Oregon State Highway Division. Federal agencies that conduct recreation studies include the Outdoor Recreation Resources Review Commission, the U.S. Forest Service, the Bureau of Land Management, and the Bureau of Outdoor Recreation.

In analyzing these activities, a ranking can be determined to show the relative number of participants. This helps administrators and planners to establish priorities at a statewide level, for certain types of facilities and activities. The ranking of activities reflects the relative availability of areas to support certain activities and the socio-economic characteristics which influence demand.

For recreational studies, states are divided into districts, for the purposes of inventory and analysis. The components of these districts make conversion of figures to a specific area extremely difficult. The Columbia River Estuary region is in District 1 in Oregon (all of Clatsop and Tillamook Counties). In Washington, the estuary area falls in two districts: District 2, South Coast (Pacific and Grays Harbor Counties) and District 6, Lower Columbia (Wahkiakum, Cowlitz, Clark and Klickitat Counties). Because of the size of these

TABLE 402-2

OUTDOOR RECREATION ACTIVITIES

- Driving
- Sightseeing
- Picnicking
- Water Sports
  - Sailing
  - Power Boating
  - Other Boating
  - Water Skiing
  - Outdoor Swimming Pool
  - Other Outdoor Swimming
- Camping
- Beach Use
  - Visiting the Beach
  - Clamming
  - Crabbing
- Outdoor Events
- Sports and Games
- Walking
- Hiking
- Fishing
- Hunting
- Golf
- Winter Sports
- Resorts
- Horseback Riding
- Visiting Local Parks
- Bicycling
- Mountain Climbing
- Rock Hounding
- Others

From: State of Oregon, 1972
State of Washington, 1973

districts, no attempt was made to extrapolate the information for the estuary area.

B. Supply

The supply of recreational lands and facilities is determined by an actual inventory of areas operated by governmental agencies and private interests. To identify such areas, each state uses a similar system.

The state of Oregon classifies recreational lands into six classes:

1. High Density Recreation areas
   - Urban
   - Non-Urban
2. Generally developed recreation areas.
   - Areas within 25 miles of a city
   - Areas between 26 - 60 miles from a city
   - Areas over 60 miles from a city
3. Large single purpose recreational or multi-purpose areas with no development except for trails
4. Recreation areas in outstanding natural areas, usually with little recreational development
5. Designated wilderness areas
6. Historic and cultural areas.

District 1 in Oregon has a supply of 17,610 acres of recreational land, with 2,050 sites at 90 areas. These statistics do not include wilderness areas or historic and cultural areas. The figures compare to statewide totals of 117,130 acres (15%) at 1,860 areas (5%) with 32,970 sites (6%).

Washington identified and inventoried eighteen area types. An area type is defined as "an environment suitable and desirable for certain varied and related outdoor recreational purposes." Area types are based on major environmental features and use capabilities of an area.

The eighteen area types are:

-Small urban recreation areas
-Large urban recreation areas
-Regional recreation areas
-Winter sports areas
-Golf course areas
-Outstanding natural areas
-Historical/Cultural areas
-Wildlife habitat

-Scenic roads
-Urban shoping areas
-Urban malls and squares
-Saltwater shorelands
-Freshwater shorelands
-Forest areas
-Wilderness
-Trails - Urban
-Trails - Non-urban
-Wetlands

Table 402-3 shows the supply of recreational lands, by area types, for the South Coast and Lower Columbia Districts. The supply figures that have been noted omit private recreational developments. While there are a few of these in the estuary area, the Statewide Comprehensive Outdoor Recreation Plans only inventory them on a statewide basis. Therefore, no figures are provided for the specific areas.

C. Demand

Demand for outdoor recreation is defined as "the desire for outdoor recreation resources, facilities, and opportunities and the intentions and ability to utilize same." The term "participation" is often substituted for demand, in recreational studies. This substitution eliminates any difference between use and demand, by making them equal. Because actual demand is difficult to evaluate and qualify, most studies focus on satisfied demand, rather than unfulfilled demand that might result from constraints such as time, distance, and the lack of facilities.

Demand studies are usually conducted by surveys. Resident households are asked about activity and area preferences, and park visitors are questioned as day users and campers. Also included in any demand survey is the out-of-state tourist. The figures are often shown as "activity days." An activity day is generally defined as one person taking part in an activity for all, or any part of a day. The use of this measurement shows the relative popularity for activities (as analyzed in Oregon) and types of areas (as in Washington). In this way, activity priorities can be analyzed for future needs.

Demand analysis for the development of priorities, projection of needs, and establishment of implementation programs must consider other factors in addition to the statistics provided by participation. Consideration must be given to possible changes that will affect the

TABLE 402-3

Supply of Public Recreation Lands
District 2 and 6 [1]

AREA TYPE	SOUTH COAST	LOWER COLUMBIA	STATE
	No./Acres	No./Acre	No./Acre
Small Urban	36/117	96/446	1,511/7,671
Large Urban	6/138	16/1,251	192/14,080
Regional	13/3,429	13/2,400	172/46,374
Forest	12/187,382	52/1,019,88	357/8,831,125
Wildlife Habitat	6/4,557	6/37,688	160/1,100,302
Freshwater Shoreland	47/680	102/3,546	808/153,855
Saltwater Shoreland	15/496	-	152/6,380
Historical/Cultural	9/748	22/2,016	152/12,454
Outstanding Natural	1/12,344	1/31,694	19/2,070,604
Wilderness	-	8,482	4/1,095,361

[1] A percentage of the statewide total was not figured due to the amount of the Lower Columbia District that is outside our study area.

From: State of Washington, 1973

demand. For instance, public awareness and concern for the natural environment has resulted in more people desiring and participating in outdoor activities. In addition, such things as liberalized vacation rules, improvement of transportation routes, increased discretionary income to spend on recreation, and other socio-economic factors, all contribute to the demand for recreation.

Activity participation for the districts which include the Columbia River estuary have a ranking similar to the states. The rankings of the states also are similar to nationwide preferences. The activities most preferred are driving for pleasure and sightseeing.

D. Need

Needs result from subtracting the supply from the demand. To determine the need, it is necessary to apply standards to each activity. Table 402-4 shows Use Standards that were applied in the needs analysis for the Oregon Statewide Comprehensive Outdoor Recreation Program. Then, these standards are applied to user activities, to determine the total area needed. Subtracting the supply (miles, boat launch lanes, etc.) shows the actual needs of an area.

Needs analysis is used to justify and prioritize expenditures for acquisition and development. Statewide analysis in Washington alone, estimated that over $1.5 billion dollars were needed at the time of the plan preparation to merely meet current needs. Priorities are necessary to guide the implementation of fund expenditures, to ensure that the public benefit is maximized.

402.3 SCORP ANALYSIS FOR ESTUARY AREA

As stated before, it is difficult to scale down the Outdoor Recreation Plans for the states to reflect the conditions and needs of the Columbia River estuary region. However, it is possible to note activities that occur in the area and some of its apparent needs.

Important to the estuary are water related activities. Boating and fishing are the two most popular. During 1971, the Fish Commission of Oregon conducted a study that determined principal recreational fishing areas and type of fish caught. Figure 402-1 shows these areas, and Table 402-5 indicates the fish species caught during this survey. Additional activities within the area include those discussed in the

TABLE 402-4

USER STANDARDS
(Oregon)

ACTIVITY	STANDARD	COMMENTS
Hunting	1 acre per 0.0133 user	Equal to 75 acres per hunter
Boating	1 lane per 175 users	Recognize that not all boaters require launch lanes
Swimming	1 acre beach per 400 users	
Swimming	1 pool per 300 users	
Camping	1 site per 8 users	
Picnicking	1 site per 7 users	
Walking (urban)	1 mile per 20 users	
Hiking	1 mile per 10 users	Includes nature walks & hiking
Horseback Riding	1 mile per 4 users	On recognized trail
Horseback Riding		Requires no special facility riding along county roads, etc.
Snow Activities	1 acre per 9 users	Includes skiers & snow players who use developed facilities
Fishing	1 mile major stream per 12 users	The boating standard serves the lake fishing people
Golf	1 hole per 25 users	
Outdoor Games	1 acre per 8 users	
Bicycle	1 mile per 20 users	
Pleasure Driving	1 mile per 100 users	A scenic driving standard
Sporting Events	1 acre per 500 users	Includes stadium & Parking
Cultural Events	1 acre per 400 users	Includes building & parking
Beach	1 mile per 500 users	
RESOURCE STANDARDS:		
Streams	1 mile major stream per 12 users	At this time the fishing needs are the only needs we have considered
Lakes	240 acres per 1 lane 0.5 acres per 1 acre beach	

From: State of Oregon, 1972

TABLE 402-5

SPECIES HARVESTED

Columbia River Estuary

COMMON NAME	LOCAL NAMES
Black rockfish	Black sea bass, black snapper
Cabezon	Rock cod, bullhead
Chinook salmon	King salmon, salmon
Coho salmon	Silver salmon
Columbia River Chub	Peamouth
Spiny dogfish	
Lingcod	
Pacific staghorn sculpin	Bullhead
Pacific tomcod	
Red Irish lord	Bullhead
Redtail surfperch	
Sand sole	
Shiner perch	Shiners
Starry flounder	
Striped seaperch	Rainbow perch
Whitespotted greenling	Seatrout
Dungeness crab	Market crab

From: Fish Commission of Oregon, 1971

Statewide Comprehensive Outdoor Recreation Plans, except for winter sports and mountain climbing.

Assuming that the needs analysis done for District 1 in Oregon is representative for the estuary, the primary needs are for hunting (acres), camping (sites), picnicking (sites), and fishing (mile). This analysis did not take into consideration the private sector, which provides lodging and some activities.

402.4 REFERENCES

A. Meyers, Joseph D., Richard T. Leonard, and Oscar R. Granger. 1973. A Plan for Land and Water Use, Clatsop County, Oregon: Phase I, prepared for the Clatsop County Planning Commission and Board of County Commissioners by Skidmore, Owings, and Merrill.

Survey and analysis of natural environment and existing development and survey of public attitudes and goals. Recreation information includes current recreation land use and the effect of recreation and tourism on the county's economy.

B. The Richardson Associates. 1975. Master Plan for the Columbia River at the Mouth, Final Review Draft, prepared for the U.S. Army Corps of Engineers, Portland District.

Analysis of physical features at study area to determine the best recreational and fish and wildlife user of the project data.

C. State of Oregon, Fish Commission. 1971. Columbia River Estuary Resource Use Study.

Summary of a study conducted of the recreational use of marine food fish, shellfish, and other miscellaneous invertebrates. Information on boat and shore fishery, tideflat fishery, angler origin, commercial fishery, and the food production areas, fish feeding areas, and fish migration routes.

D. State of Oregon, Highway Division. Oregon Outdoor Recreation, third edition supplement.

Oregon's Statewide Comprehensive Outdoor Recreation Plan Study and analysis of the supply of recreation activities and facilities, the demand for specific activities and the needs reflected. Also discussed are the standards that apply to activities and how to furnish recreational sites and opportunities.

E. State of Washington, Interagency Committee for Outdoor Inventory. 1973. Washington Statewide Comprehensive Outdoor Recreation and Open Space Plan; Volume I.

Washington's Statewide Comprehensive Outdoors Recreation Plan Study and analysis of the supply of recreation activities and facilities, the demand for specific activities and the needs reflects. Also discussed in how to implement and plan and meet the needs.

F. Miscellaneous information concerning Fort Canby and Fort Stevens State Parks.

403 SIGNIFICANT AREAS

COLUMBIA RIVER ESTUARY

SIGNIFICANT AREAS

Robert E. Blanchard

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FIGURES

TABLES

*Figure follows the page indicated.

403 SIGNIFICANT AREAS

Significant areas are discussed in this section of the Inventory because such areas must be considered in the planning process. Areas already designated as significant are examined, together with areas with potential for such designation; they require special management considerations to guarantee their retention as unique areas.

403.1 WASHINGTON STATE SHORELINE OF STATEWIDE SIGNIFICANCE

The Washington State Shoreline Management Act of 1971, identified specific shorelines throughout the state as Shorelines of Statewide Significance. The Columbia River shoreline, from the mouth to the eastern boundary of Wahkiakum County is classified as such, based on section 90.58.030 of the legislation. This section, as it applies to the Columbia River and its tributaries, defines shorelines of statewide significance as "....those natural rivers...west of the crest of the Cascade Range downstream of a point where the mean annual flow is measured at one thousand cubic feet per second or more..." The mean annual flow of the Columbia River, as measured at the mouth, is 259,000 cubic feet per second. For planning purposes, shorelines are identified in the act as all the waters of the state and their associated wetlands, including as a minimum, all upland areas 200 feet landward (measured horizontally from ordinary high water).

In accordance with the above sections of the act, the following streams and rivers in the Columbia River estuary area and their associated wetlands are classified as shorelines of statewide significance:

- Columbia River (plus all unnamed tributaries within 200 feet)
- Deep River
- Elochoman River
- Grays River
- Skamokawa Creek

The extent of these areas is shown in Figure 403-1.

403.2 OREGON AREAS OF CRITICAL CONCERN

A. Identification Process

Although the process exists for designating areas of particular concern in the State of Oregon, no areas have been designated. This process was established by Senate Bill 100 in 1973. It begins with the nomination of an area by citizens, city and county governments or state agencies. A technical and legal evaluation and inventory of the area is then done. The Land Conservation and Development Commission (LCDC) recommends areas of statewide concern, together with management actions, to the Joint Legislative Committee on Land Use. That committee then recommends approval or disapproval to the state legislature.

B. Candidate Areas

Based on inventories and public input, the Oregon Coastal Conservation and Development Commission (OCC&DC), before disbanding in 1975, identified several specific sites as potential areas of critical state concern. The criteria used by OCC&DC included:

1. Areas of significant natural value or importance (relating to the preservation of resources), and
2. Areas of significance for development of activities, uses, or facilities of more than local significance.

These criteria were then applied to the resource areas where public concern had been documented. These resources were:

1. Natural Resources of the Oregon Coastal Zone
    a. Estuaries
    b. Wetlands
    c. Freshwater and shorelands
    d. Uplands (forest, agricultural, urban and recreational lands)
    e. The continental shelf
    f. Beaches and dunes
2. Coastal values
    a. Visual resources
    b. Fish and wildlife habitat areas
    c. Historical and archaeological sites
    d. Scientific natural areas
3. Constraints on Coastal Zone Management
    a. Geological hazards (including floodplains)
    b. Development pressures and conflicts.

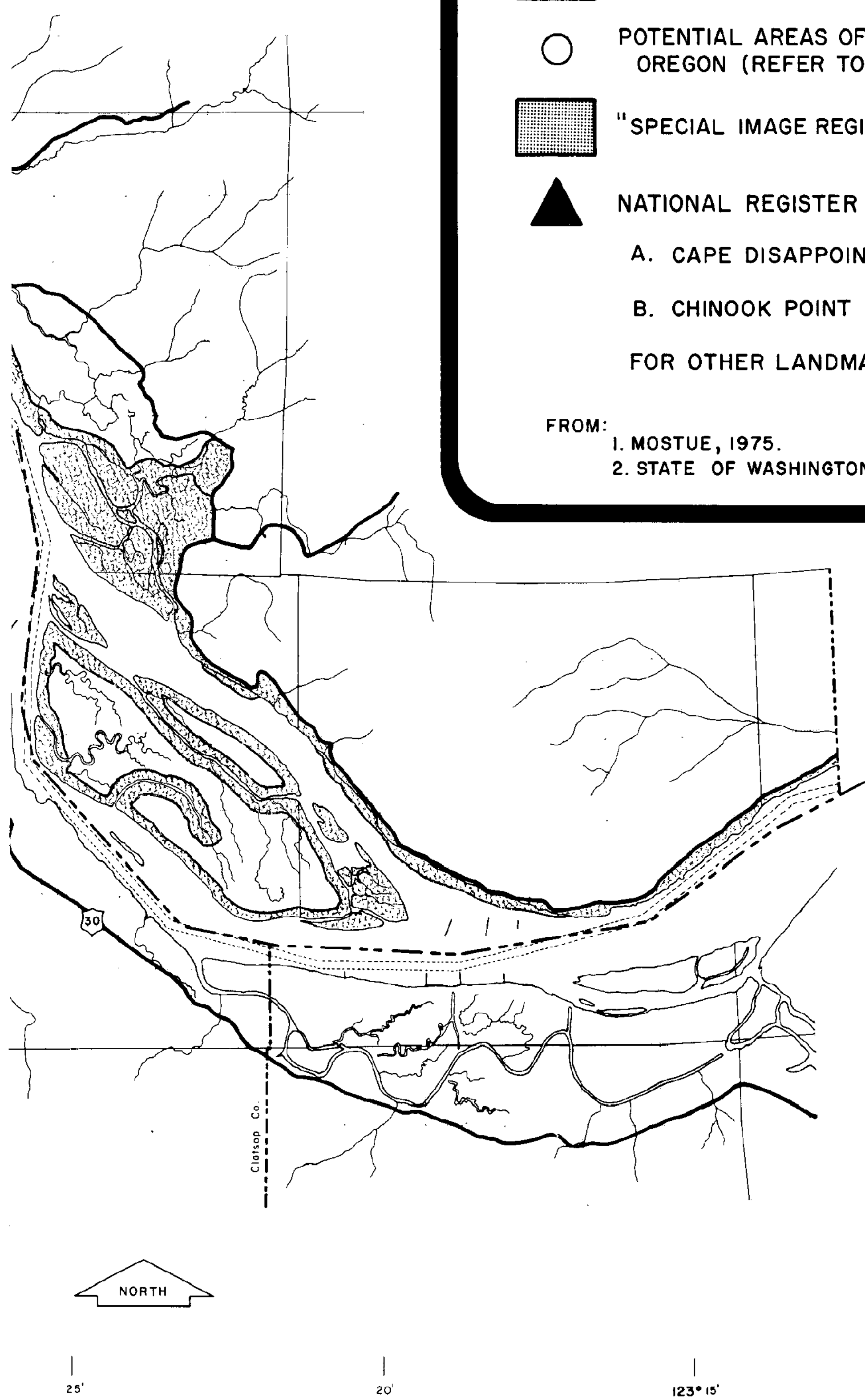
25'

AREAS OF STATEWIDE CONCERN

- WASHINGTON STATE SHORELINES OF STATEWIDE SIGNIFICANCE
- POTENTIAL AREAS OF CRITICAL CONCERN IN OREGON (REFER TO TABLE 404-1)
- "SPECIAL IMAGE REGION"
- NATIONAL REGISTER OF HISTORIC LANDMARKS
  - A. CAPE DISAPPOINTMENT
  - B. CHINOOK POINT

FOR OTHER LANDMARKS SEE TABLE 403-1

FROM:
1. MOSTUE, 1975.
2. STATE OF WASHINGTON, DEPT. OF ECOLOGY, 1976.



CREST
COLUMBIA RIVER ESTUARY STUDY TASK FORCE

FIGURE
403—1

By applying the criteria to the identified resource areas, OCC&DC identified 80 areas of potential concern. Table 403-1 shows those areas that fall within the Columbia River estuary region. In addition, OCC&DC recommended that areas of critical state concern also include: "Special Image Regions" (as identified in Visual Resource Analysis of the Oregon Coastal Zone); those sites designated in the National Register of Historic Landmarks; and those sites listed in the OCC&DC Historical and Archaeological Inventory, as being of national and statewide concern. A special image region was identified as existing in the area west of Highway 101 to the Pacific Ocean, from the Columbia River south to just south of Tillamook Head.

The National Register of Historic Landmarks lists four sites in Oregon that are in the estuary area. Included are Fort Astoria, Elmore Cannery (Bumble Bee), Fort Stevens, and Fort Clatsop National Memorial.

403.3 HISTORICAL AREAS

The Columbia River estuary region is rich in historical lore. Indian encampments lined the river in the days before white settlers came. The Clatsop, Chinook, Cathlamet, and Wahkiakum tribes all lived in the estuary area.

The first white men to live in the area were probably slaves. About 1725, two shipwrecked sailors were found by Indians on the beach near the present site of Gearhart, and they were taken prisoner to serve as slaves.

One of the sailors, referred to as Konapee, was skilled in making knives and hatchets from iron and soon won the Indians' respect. Eventually, both men were released from captivity and settled near the present town of Hammond. This site, called Konapee by the Indians, was probably the first place a white man lived on the north coast.

The mouth of the Columbia River was an area of several explorations by fur trading nations. The estuary was first described in 1775 by the Spanish Captain Bruno Heceta, but he thought it was land locked, and the rough bar discouraged him from closer inspection. Seventeen years later, Captain Robert Gray successfully crossed the bar and spent over a week inspecting the area and trading with the Indians. Gray changed

Table 403-1

Areas of Potential State Concern[1]
Columbia River Estuary Area

1. City of Astoria
2. Big Creek and Little Creek Estuary
3. Clatsop Plains
4. Cullaby Lake
5. Elmore Cannery (Astoria)
6. Fort Astoria
7. Fort Clatsop National Monument
8. Fort Stevens
9. Lewis and Clark River Marsh
10. Lower Columbia River (areas to be determined)
11. Swash Lake
12. Tansy Point

From: OCC&DC, 1975

the name of the river from "Wauna" as the Indians called it, to "Columbia." A short time later, Lt. John Broughton, a member of an expedition led by Captain George Vancouver, sailed approximately 100 miles upriver exploring and mapping.

Although previous settlements had been attempted, and Lewis and Clark had established several encampments, including their winter headquarters at Fort Clatsop, it wasn't until 1810 that the first permanent settlement, Astoria, was begun. Named after John Jacob Astor, owner of the Pacific Fur Company, Astoria was founded as a center for the trade market in the lower Columbia area.

The estuary region continued its colorful history to the present. Following the pattern of the Pacific Northwest as a whole, the area played an important role in the developing trade, lumber, and fishing industries.

Many historical sites have been inventoried and marked throughout the area. The National Register of Historic Landmarks lists eight sites in the three counties. These areas are shown on Figure 403-1 and listed on Table 403-2. There are numerous additional historical sites surrounding the estuary that have county and statewide significance. These were not listed but include Indian villages, exploration sites, settlements and shipwrecks. The Cities of Astoria and Cathlamet each contain concentrations of historical sites.

403.4 SCIENTIFIC AREAS

Several different kinds of scientific study have been and are being carried out in the estuary. Compared to other estuaries on the Oregon coast, the Columbia River has been studied extensively. However, compared to other large estuaries, like Puget Sound, there has been relatively little research conducted. Current scientific projects include planting and habitat studies in Marsh Islands, and fisheries research throughout the lower estuary.

A. Columbia River Marsh Islands

The Marsh Islands of the lower Columbia River provide a valuable research area for wildlife and habitat study. The islands are an important link in the chain of marsh habitat that provides the life needs of migratory birds that live along the Pacific Coast. The islands

TABLE 403-2

National Register of Historic Landmarks
Columbia River Estuary Region

- Clatsop County
  - Elmore Cannery (Astoria)
  - Fort Astoria (Astoria)
  - Fort Clatsop National Memorial
  - Fort Stevens
- Pacific County
  - Cape Disappointment
  - Chinook Point
- Wahkiakum County
  - Deep River Pioneer Lutheran Church
  - Grays River Covered Bridge

are both a wintering area and a migrational stopover for Pacific Flyway waterfowl. Being subject to tidal action, they are rich in marine nutrients that are food for the island residents.

B. Miller Sands

A manmade island of dredge material at approximately river mile twenty-three, Miller Sands is currently being used by the U.S. Army Corps of Engineers Waterways Experiment Station. It is being planted to stabilize it against wind erosion and is being used as an experimental test site for marsh habitat creations.

C. Alder Slough

Alder Slough, located between Tansy Point and the Skipanon Waterway, is the location of a monitoring station used by Oregon State University. The slough is sporadically used to measure the collection of radionuclides in the water, as a result of the operations of Hanford and Trojan nuclear power plants.

D. Archaeological

Archaeological investigations in the lower Columbia valley have been limited in scope and generally unsystematic. Little is known about the archaeological resources of the project area. Extensive sightings of villages throughout the region were recorded in the original journals of the Lewis and Clark Expedition and in the ships' logs of explorers. Much of the research and analysis which has been done on archaeological sites has been done by amateurs. Professional archeologists have conducted investigations on the lower reaches of the Columbia River for the Corps of Engineers in conjunction with dredge disposal/bank protection projects and research for master plans.

The villages of the early inhabitants of the lower Columbia River Basin were concentrated along the rivers and streams of the region. The dense forest environment hindered land travel, but the rivers offered easy travel and an abundant food supply (primarily salmon and the plant wapato).

Of the villages identified by the early explorers, many have been eroded away by Columbia River floods and the wash of ships. Other locations have been lost when the Columbia River changed its course and the sites were left far from the river banks. Still others have been buried by the silts of floods.

403.5 AESTHETIC/SCENIC AREAS

The environment throughout the Columbia River estuary has many unique qualities. While several areas encourage active participation, there are also areas that are appropriate for passive activities and have an aesthetic value. Scenic areas within the estuary vary, often dramatically, from site to site. Frequently, it's the site itself that has a particular value such as a large stand of trees or a waterfall. In other areas, it's the view available from a site that makes it significant.

A. Columbia River at the Mouth

The mouth of the Columbia River and the adjacent shorelands offer a particularly unique experience. Fort Canby and Fort Stevens both have scenic shorelands within the park boundaries. But their real appeal is their beach and the ocean environment. Beach activities, including clamming, shell collecting, and walking, draw people from a wide area.

Both parks also offer a river experience. Fort Stevens, in Oregon, and Fort Canby, in Washington, have access to the Columbia River. One of the most impressive sights in the entire estuary area, is from the northern end of Clatsop Spit, where, on a clear day, the view extends from the Columbia River Bar on the west to Mt. St. Helens to the east.

B. Fort Columbia

The aesthetics at Fort Columbia are based primarily on its view. From the area around the old gun emplacements, the view to the southeast includes the City of Astoria, and to the southwest consists of Sand Island, Cape Disappointment, and the Columbia River to the bar.

C. Catscomb Hill

Catscomb Hill is a hilltop park within the City of Astoria. The location of the Astoria Column enables one to view the Pacific Ocean, the Columbia River, and the bar to the west, Saddleback Mountain and the Youngs and Lewis and Clark Rivers to the south, and the State of Washington, from Cape Disappointment to Point Ellice, to the north.

D. Highways

While not particularly pleasing in themselves, roads and highways often provide a series of diverse scenic views and experiences. The coastal highways are noted for their views, and within the estuary region, those along the river provide a similar experience. Aesthetic resources are often considered in designing a road. As a result, driving for pleasure is ranked as one of the most pursued recreational activities.

Highways 101 and 30 in Oregon and Highways 401 and S.R. 4 in Washington offer several areas with views related to the estuary. Highway 101 provides a sweeping panorama of the Columbia River as you cross Youngs Bay. To the south, the view is more estuarine in nature, with smaller rivers, tidal flats, and riparian vegetation. Highway 401 in Washington also offers a river view, with Oregon in the background. Highway 30 and S.R. 4 have occasional views of the Columbia River that reflect the estuarine environment. Highway 30, especially near Astoria, gives excellent opportunities to view the Marsh Islands of the Columbia River. S.R. 4, as it winds along the shoreline in eastern Wahkiakum County, offers many pleasing views of the river.

E. Other

There are numerous other areas within the estuary that provide pleasant aesthetic experiences. They differ from those described above in that they aren't accompanied by an extensive view of the water, but this does not lessen their value. The region has numerous forested areas, meadows and panoramic hill views.

403.6 NATURAL/CONSERVATION AREAS

The two conservation areas within the estuary are the Lewis and Clark National Wildlife Refuge and the Columbian White-Tailed Deer National Wildlife Refuge. These two areas were discussed extensively in the recreation section (see Section 402 and Figure 402-1).

Both refuges have limited development within their boundaries, primarily for grazing and haying, and they concentrate on maintaining natural habitats for wildlife. Studies are underway to better define habitat requirements, especially for the deer.

Natural areas have been identified for Clatsop County by the Oregon Nature Conservancy. Their study identifies potentially significant natural areas and endangered species. Table 403-3 lists those areas within the estuary area. Most of these areas have been

TABLE 403-3

IDENTIFIED NATURAL AREAS

Bradwood Cliffs

Knappa Slough

Big and Little Creek Estuary

Tansy Point

Lewis and Clark River Marsh

Aldrich Point

Youngs River Falls

Tongue Point

Cooperage Slough

Bradley Park

Clatsop Spit and Tressle Bay

Dagget Point

Sand Island

Tenasillahee Island

Calender Slough

Gnat Creek Marsh

Walluski River Wetlands

Youngs Bay

(Plus Eagle Nests at John Day and various areas identified geographical names: Walluski River Site, Mill Creek Old Growth, Astoria Old Growth, West of Lewis and Clark River).

From: The Nature Conservancy, 1974

mapped either in Figure 403-1 or in the recreation section. Designed to help local governments comply with Oregon's land use planning goals, the study recommends that each of the identified areas be investigated thoroughly for special management considerations.

403.7 REFERENCES

A. Beckham, Stephen D. 1974. Historical and Archaeological Resources of the Oregon Coastal Zone, prepared for the Oregon Coastal Conservation and Development Commission.

A resource inventory of historical and archaeological areas on the Oregon coast. Sites are classified as to their importance to the local area, county, state, or the nation.

B. Cowlitz-Wahkiakum Governmental Conference. 1975. Wahkiakum County Inventory of Historic Places.

Compilation of inventory worksheets completed during historic inventory of Wahkiakum County. Sites included those of local and greater than local significance.

C. Meyers, Joseph D., Richard T. Leonard, and Oscar T. Granger. 1973. A Plan for Land and Water Use, Clatsop County, Oregon: Phase I, prepared for the Clatsop County Planning Commission and Board of County Commissioners, by Skidmore, Owings, and Merrill.

Survey and analysis of natural environment and existing development and survey of public attitudes and goals. Listing and locations of areas with historic and cultural significance.

D. Mostue, Ariel Brian. 1975. Potential Areas of Critical State Concern In the Oregon Coastal Zone, Masters thesis. Department of Landscape Architecture, School of Architecture and Allied Arts, University of Oregon.

Description of concept of areas of critical state concern, potential criteria for their selection, and a case study of Tansy Point.

E. The Nature Conservancy, Oregon Chapter. 1974. Clatsop County Inventory of Natural Areas on Private Lands.

Inventory and documentation of significant natural areas in Clatsop County. This served as a pilot project for developing a methodology for continuing a statewide inventory.

F. The Nature Conservancy, Oregon Chapter. 1977. Oregon Natural Areas, Data Summary.

Identification of significant natural areas in Clatsop County and recommended protection programs.

G. State of Oregon, Coastal Conservation and Development Commission. 1975. Final Report.

The final report of the OCC&DC, presenting policies and management recommendations for the management of the Oregon coastal zone.

H. State of Oregon, Land Conservation and Development Commission. 1976. Draft: Oregon Coastal Management Program.

The draft program for Oregon's coastal zone in accordance with the Coastal Zone Management Act of 1972. This document provides a recommended method and selection criteria for areas of particular concern.

I. State of Washington, Department of Ecology. 1976. Washington State Coastal Zone Management Program.

The adopted coastal zone management program for the State of Washington. Describes existing legislation to deal with the management of shorelines of statewide significance and geographic areas of particular concern.

J. Walker, Havens, and Erickson. 1974. Visual Resource Analysis of the Oregon Coastal Zone, prepared for the Oregon Coastal Conservation and Development Commission.

A study that identifies and evaluates coastal environments and provides criteria which can be applied to the aesthetic analysis of developments.

404

ECONOMIC CHARACTERISTICS

COLUMBIA RIVER ESTUARY

ECONOMIC CHARACTERISTICS

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404 ECONOMIC CHARACTERISTICS

Information about the level of employment, economic structure and its potential for change is important to the planning process. Economic activities such as, factories, stores, tree farms, etc. all occupy land, and in turn, influence the location and viability of other activities. In addition, the level of economic activity is directly related to the size of the population, which affects the need for housing, and public services. For example, if a piece of land is developed as a shopping center, it usually attracts more retail business and medium density residential development, thus resulting in a large complex of mixed retail, commercial, and residential uses. If the same piece of land is developed as an industrial complex, it usually attracts supporting industrial activities, such as warehouses, and wholesale suppliers. Because either of the original choices preempts the probability of the other occurring in the same place, long-range trends must be considered. Both types of activity are needed, but each must be located in a suitable place so that they do not conflict with each other.

As local government carries out its responsibilities for land and water resource management, it must consider fluctuations of the local economy. Land and water requirements of the various facets of the economy must be understood to make decisions which support all sectors of the economy, take best advantage of scarce resources, and avoid use conflicts.

404.1 ECONOMIC SECTORS

The economy of the three counties in the estuary area is currently very dependent upon local natural resources. Forest products, commercial fishing, agriculture, and tourism constitute roughly half of the dollar value of the local economies in the region. These facets of the economy, together with port activities, are discussed in the following section.

A. Fishing and Fish Processing

The fishing industry employment includes both commercial fishermen, and employees of seafood processing plants. Statistics on fisheries employment do not accurately reflect the number of people engaged in fishing and fishery related activities. The Clatsop County Plan, Phase I (1973) estimates the number of fishermen for the Astoria area at nearly 3,000. However, estimates are difficult to calculate because of the many independent and part-time operations. According to a representative of the Columbia River Fisherman's

Protective Union, the number of people involved in fishing, based on gill-netting and offshore fishing licenses, has been steadily increasing over the last several years. Employment figures for 1974 showed that Clatsop County employed by far, the largest number of people in seafood processing on the entire Oregon Coast, this was nearly two thirds of the total Oregon coastal zone employment for seafood processing.

Silver, Chinook, and Chum salmon are the principle marine species landed at Hammond, Warrenton and Astoria, Oregon and Ilwaco and Chinook, Washington. Other varieties include Albacore Tuna, Rockfish, Sturgeon, and shellfish. Shellfish production in Pacific County is over half of the entire shellfish production in Washington State. The relative value of the five major fisheries of the Columbia River Estuary is ranked in the following order: 1) salmon, 2) crab, 3) tuna, 4) shrimp, and 5) groundfish. Commercial fish landings and their estimated values for 1971 through 1975 are shown in Tables 404-1 and 404-2.

B. Forest Products

Although forest lands cover an average of 87% of the acreage of each county in the estuary area, commercial forest land in the CREST study area is minimal.

Forest products data include those who work in the forests as well as those who work in the mills. Historically, the forest products industry has been the biggest employer in both Pacific and Wahkiakum Counties. In Clatsop County, it ranks behind the government, wholesale and retail trade, and food processing sectors. While the lumber products industry provides a fairly stable year-long employment situation, the number employed has experienced a net decrease since 1970.

Forest economists expect employment in the forest industries of the Pacific Northwest to continue to decline in the future, as productivity increases and the timber resource base remains static or declines. For the estuary area, this would have the largest impact on Wahkiakum County. The least impact would occur in Pacific County, since wood product processing occurs outside the estuary area, primarily in Raymond and South Bend.

While forest-related employment is slowly decreasing, continued growth is expected in foreign and domestic demand of forest products. Therefore, it appears that the local supply of raw materials may limit growth, rather than market demand.

Table 404-1

Commercial Food Fish Landings
1971 - 1975 (in pounds)

	1971	1972	1973	1974	1975
Oregon:					
Columbia River:[1] (Zones 1,2,7)[1]					
Salmon	3,882,172	3,043,176	4,716,051	2,968,748	3,709,998
Sturgeon	134,076	119,721	180,091	276,220	231,442
Tuna	-	-	-	-	-
Groundfish	-	-	121,174	200,508	73,700
Other[2]	237,162	347,554	235,577	281,232	33,002
Total:	4,253,410	3,510,451	5,252,893	3,726,708	4,048,142
Astoria:					
Salmon	951,250	491,515	309,588	483,794	399,380
Sturgeon	4,517	1,267	1,860	484	1,582
Tuna	11,293,939	22,377,175	19,102,041	26,723,583	16,599,703
Groundfish	10,524,609	10,618,335	9,450,108	9,907,149	9,372,829
Other[2]	6,976,395	6,245,345	3,786,801	8,115,627	6,206,555
Total	29,750,710	39,733,637	32,650,398	45,230,637	32,580,049
Washington:					
Cathlamet:					
Salmon	514,401	381,265	645,664	183,133	355,161
Sturgeon	14,309	20,105	23,011	8,993	41,590
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Other[2]	57,122	102,775	63,552	6,277	52,827
Total	585,832	504,145	732,207	198,403	449,578
Chinook:					
Salmon	605,868	573,084	475,836	489,653	451,857
Sturgeon	6,927	38,291	10,907	13,170	10,209
Tuna	2,100	3,065	60,784	27,112	83,110
Groundfish	13,678	10,503	34,287	22,843	10,037
Other[2]	1,630,588	559,430	1,205,671	542,074	617,739
Total	2,259,161	1,184,373	1,787,485	1,094,852	1,172,952
Ilwaco:					
Salmon	2,771,436	1,622,530	939,831	1,539,425	1,426,251
Sturgeon	7,300	15,876	8,112	28,046	32,349
Tuna	1,796,514	5,695,937	6,602,236	11,333,827	9,226,048
Groundfish	8,593	10,062	20,198	410,338	202,533
Other[2]	1,406,151	1,819,579	711,114	1,448,667	439,039
Total	5,989,994	9,163,984	8,281,491	14,760,303	11,326,220
Puget Island					
Salmon	12,042	18,398	20,963	4,388	-
Sturgeon	260	94	434	51	
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Other[2]	2	-	235	79,087	-
	12,304	18,492	21,632	83,526	-
Skamokawa:					
Salmon	61,699	5,500	84,750	233,973	800
Sturgeon	258	707	866	12,265	-
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Other[2]	25	1,511	-	2,013	-
Total	61,982	7,718	85,616	248,251	800

1 Zones 1 and 2 include the Columbia River to the Eastern Boundary of Wahkiakum County, Zone 7 is Youngs Bay

2 Includes Steelhead, Shad, Smelt, and Shellfish

From: Oregon Department of Fish and Wildlife
Washington Department of Fisheries

Table 404-2

Estimated Value at Fisherman's Level of
Commercial Food Fish Landings
1971-1974*

Oregon:	1971	1972	1973	1974	1975*
Columbia River (Zones 1,2,7)[1]					
Salmon	$ 1,310,000	$ 1,589,000	$ 4,246,000	$ 1,855,000	
Sturgeon	28,000	22,000	42,000	52,000	
Tuna	-	-	-	-	
Groundfish	-	-	5,000	8,000	
Other[2]	61,000	139,000	100,000	45,000	
Total	$ 1,399,000	$ 1,750,000	$ 4,393,000	$ 1,960,000	
Astoria:					
Salmon	$ 322,000	$ 242,000	$ 206,000	$ 340,000	
Sturgeon	-	-	-	-	
Tuna	3,086,000	6,805,000	6,490,000	9,982,000	
Groundfish	865,000	1,009,000	1,134,000	1,475,000	
Other[2]	1,410,000	1,934,000	1,189,000	2,207,000	
Total	$ 5,683,000	$ 9,990,000	$ 9,019,000	$14,004,000	
Washington					
Cathlamet:					
Salmon	$ 152,734	$ 206,134	$ 566,108	$ 168,091	$ 344,443
Sturgeon	3,595	4,933	5,800	2,370	13,481
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Other[2]	7,563	16,257	25,437	1,966	5,995
Total	$ 163,892	$ 227,324	$ 597,345	$ 172,427	$ 363,919
Chinook:					
Salmon	$ 220,992	$ 314,848	$ 467,957	$ 340,581	$ 379,358
Sturgeon	731	7,171	2,931	1,564	2,342
Tuna	641	1,070	24,494	9,539	27,425
Groundfish	183	162	3,719	1,287	840
Other[2]	348,326	212,490	286,359	277,162	197,669
Total	$ 570,883	$ 535,741	$ 785,450	$ 630,133	$ 607,634
Ilwaco:					
Salmon	$ 1,049,595	$ 929,856	$ 832,199	$ 1,220,958	$ 1,157,519
Sturgeon	969	3,990	1,978	6,065	9,307
Tuna	556,938	1,936,643	2,707,433	4,155,339	3,110,426
Groundfish	1,193	1,131	2,395	71,067	38,828
Others[2]	272,012	621,132	182,886	543,991	230,742
Total	$ 1,880,707	$ 3,492,752	$ 3,726,891	$ 5,997,420	$ 4,546,822
Puget Island:					
Salmon	$ 4,485	$ 10,598	$ 19,727	$ 2,362	-
Sturgeon	64	24	146	12	
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Others[2]	1	-	76	7,007	-
Total	$ 4,550	$ 10,622	$ 19,949	$ 9,381	$ -
Skamokawa:					
Salmon	$ 19,137	$ 4,357	$ 80,529	$ 141,374	707
Sturgeon	49	172	300	3,202	-
Tuna	-	-	-	-	-
Groundfish	-	-	-	-	-
Other[2]	6	526	-	510	-
Total	$ 19,192	$ 5,055	$ 80,829	$ 145,086	$ 707

*Figures for Washington include data for 1975.

1 Zones 1 and 2 include the Columbia River to the Eastern Boundary of Wahkiakum County, Zone 7 is Youngs Bay.

2 Includes Steelhead, Shad, Smelt, and Shellfish

From: Oregon Department of Fish and Wildlife
Washington Department of Fisheries

With regard to local supply, it is important to note that most companies attempt to operate on a sustained yield basis. However, the sustained yield harvesting patterns are based on company holdings, rather than county boundaries. Therefore, while these companies may manage their total timber reserves on a sustained yield basis, there is no assurance they operate on such a basis in a specific county. Without sustained yield operations, it may become necessary to import timber from outside the county to maintain employment levels in local mills.

Another factor involves the export of logs. Currently, there is a large foreign demand, particularly from Japan. Forest owners and harvesters generally favor export because the value of the timber tends to be higher when foreign buyers are involved. However, other wood product users generally favor fewer exports; they feel that the local area would benefit more from the expansion of local manufacturing and construction industries.

C. Tourism

While tourism grows, it continues to be diffcult to study and measure. It is a diffuse activity and has many participants. Motel operators sell services to tourists on a full time basis, while grocers and service station operators may provide goods and services to tourists without even knowing it. Because tourism overlaps the service and retail trade, statistics related to it are not easily identified. The majority of the tourist trade in the estuary occurs in Clatsop and Pacific Counties. Wahkiakum County enjoys a moderate tourist industry, based upon an abundance of natural hunting and fishing areas. Wahkiakum County is primarily a stop-over place for tourists on the way to other Washington coastal county destinations.

The tourist industry in Pacific and Clatsop Counties is concentrated on the Pacific Ocean. Major tourist attractions in the estuary area include activities associated with charter fishing and Fort Stevens and Fort Canby State Parks. Figures for the two parks indicate a combined total of 226,174 camper nights for 1976. Assuming an average expenditure of about $5.00 per person per day results in a total value of $1,132,155 (Fort Canby: 39,257 camper nights, $196,285; Fort Stevens: 187,174 camper nights, $935,870). Figures on average expenditures for sport fishermen are not available.

In 1973, information for Clatsop County indicated that the tourist industry had an annual value of about $26,000,000. Table 404-3 provides more detailed information on the annual value of the industry. This type of information has not been compiled for the other two counties.

TABLE 404-3

Clatsop County Tourism

	Visitors	Visitor Days	Value	Percent of value
Commercial Lodging Visitors	335,000	670,000	$ 17,575,000	67%
Day Visitors	1,765,000	1,765,000	7,000,000	27%
State Park Overnight Visitors	105,000	210,000	1,050,000	4%
Second Home Visitors	56,000	135,000	675,000	2%
Total	2,260,000	2,780,000	$ 26,300,000	100%

From: Meyers et al., 1973

For the Pacific Northwest as a whole, tourism is the fourth largest industry (in terms of employment), and it is also one of the fastest growing.

Beneficial economic impacts resulting from increased tourist activity include increased tax base, with consequent increase in tax revenue to local government and increased property values in the estuary area, with consequent returns to local owners.

There are several less desirable results expected to accompany tourist development including:

- jobs in the tourism industry tend to be low paying;
- employment in tourism is subject to greater seasonal fluctuation than the rest of the Clatsop County economy and tends to raise the off-season unemployment rate;
- increased property tax revenue may be offset by increased demand for public facilities and services to accomodate the volume of tourists, particularly sewers, water and roads;
- much of the financial return from tourist development will go to investment centers outside of the county;
- there are likely to be conflicts with other land uses such as local industry and residential areas;
- rapid or excessive development of tourist facilities could adversely affect the environmental attractiveness of the area and ultimately cause a decline in volume and dollar value of the tourist industry.

D. Agriculture

The estuary area has limited agricultural resources. Production has been concentrated in the bottom lands and tidal areas, where soil and moisture conditions have been most favorable. Agricultural activity is limited even in those areas, since much of the land requires the construction and maintenance of dikes to maintain productivity.

Table 404-4 summarizes the agricultural characteristics for Clatsop, Pacific and Wahkiakum Counties. As noted, the three counties are following the national trends of fewer farms. Each county experienced a decrease in

TABLE 404-4

Agricultural Characteristics

	CLATSOP COUNTY			PACIFIC COUNTY			WAHKIAKUM COUNTY		
	1969	1974	% Change	1969	1974	% Change	1969	1974	% Change
Number of Farms	258	254	-2%	298	290	-3%	198	163	-17%
Land in Farms (acres)	23,745	26,706	13%	38,945	34,570	-11%	20,849	16,848	-19%
Percentage of County Land Area		5%			6%			10%	
Value of									
Agricultural Products (total)	$ 2,136,000	$ 2,523,000	18%	$3,230,000	$3,473,000	8%	$2,145,000	$2,940,000	37%
All Crops	$ 189,000	$ 204,000	8%	$1,500,000	$1,297,000	14%	$ 21,000	$ 36,000	71%
Forest Products	$ 44,000	$ 227,000	416%	$ 133,000	$ 227,000	71%	$ 82,000	$ 185,000	126%
Livestock, Poultry and their products	$ 1,902,000	$ 2,093,000	10%	$1,597,000	$1,949,000	22%	$2,042,000	$2,719,000	33%
Farm Operators	258	254	-1%	298	290	3%	198	163	-18%

From: 1974 Census of Agriculture, Clatsop County
1974 Census of Agriculture, Pacific County
1974 Census of Agriculture, Wahkiakum County

the number of farms, especially Wahkiakum County. The largest decrease, however, occurred in Clatsop County between 1959 and 1969. During this period, there was a decrease of 43.5% in the number of farms and 56.9% in the amount of land in farms. As can be seen from the percentage of county lands that are in agricultural production, agriculture is not a large part of the local economy; of thirty-six counties in the State of Oregon, Clatsop County ranks last.

Agricultural employment, as with employment in the tourist industry, is difficult to assess since it is combined with other sectors. The accompanying table uses the number of farm operators as an indicator of employment.

Several factors contribute to the relatively low economic importance of agriculture in the estuary. To begin with, there is relatively little land suitable for farming. Most of the small amount of agricultural land is also highly desirable for residential and roadside commercial development. Non-agricultural uses can afford to pay more for the land, and have forced some out of farming. Outside employment of farm operators is another factor which has contributed to the decline of farming in the area. Many farmers work part of the year at other jobs, and as the financial returns of the outside job increase, less effort is expended in farming.

Although Clatsop County appears to be losing land in agricultural use, there is a pattern of small farms, producing a low income stream, with the operator working in other employment for part of the year that continues. This complements the seasonal employment cycles of some of the county's industries.

E. Port Activities

There are five port districts in the Columbia River estuary: the Port of Astoria, the Port of Ilwaco, the Port of Chinook, and Port Districts One and Two in Wahkiakum County. While they are all ports by legal definition, the port activities commonly associated with maritime shipping are limited to the Port of Astoria. The other ports are primarily concerned with boat moorage and commercial and sport fishing.

The Port of Astoria satisfies a demand for water transportation services in the estuary and beyond. The demand for this service comes from economic activities such as industrial and commercial operations with final products which are exported beyond the estuary region. These operations use port services for receiving raw materials or intermediate products and for the shipment of their products. The majority of the port's transportation services are related to such activities. Additional water transportation demand comes from transshipment activities. These include demands generated from outside the area for transportation services which require a shift in the mode of transportation being used to move a given commodity; for example, grain is moved to the port by railroad and transferred to an outgoing vessel.

Benefits generated by the port's activities include: employment; income produced by the transportation activities; and those savings (compared with the use of the next most efficient mode of transportation or alternative port system) by the county business sector to which service is provided. A recent study done for the Port of Astoria estimated that each dollar of payroll expenditures by the Port of Astoria generated approximately $1.60 of income in the county.

The recently completed plan for the Port of Astoria suggests that the next five year period will be critical in determining whether the port grows or not. Expansion of port facilities and shipping activity offers a potential for future economic development; its location at the mouth of the Columbia River offers a natural passageway inland to a large market area.

Most of the shipments which cross the Columbia River Bar continue upriver to Portland. However, with the trend toward larger, less maneuverable, and deeper draft vessels, the Astoria area becomes more attractive as a point for cargo transfer (to barges for shipping to a distribution point further upriver). If an upcoming study shows that it is feasible to deepen the channel across the bar and upriver for a few miles, such transshipment activity may occur in the near future.

The development of more shipping activity will have significant economic benefits by itself, but it will also tend to attract certain processing and manufacturing activities which advantageously locate away from large population centers. The wood products industry at Longview, Washington is an example of this; logs are trucked into the port complex and either loaded as they are or processed into lumber and distributed to world or national markets by ship, rail, or truck.

404.2 LABOR FORCE AND EMPLOYMENT

Employment is a most important aspect of the total economic picture because of the direct involvement of all segments of the population. Tables 404-5, 404-6, and 404-7 show employment (by economic activity) for the three counties in the study area, from 1970 to 1975. Table 404-8 shows the

TABLE 404-5

CLATSOP COUNTY RESIDENT LABOR FORCE, UNEMPLOYMENT AND EMPLOYMENT

	1970	1971	1972	1973	1974	1975	1976
Civilian Labor Force	12,080	12,540	12,730	13,170	13,070	13,350	13,460
Unemployment	960	1,150	1,000	930	990	1,430	1,260
Percent of Labor Force	7.9	9.2	7.9	7.1	7.6	10.7	9.3
Total Employment	11,120	11,390	11,730	12,240	12,080	11,920	12,200

CLATSOP COUNTY NONAGRICULTURAL WAGE AND SALARY EMPLOYMENT
(By Place of Work)

	1970	1971	1972	1973	1974	1975	1976
Total Wage and Salary	9,540	9,640	9,850	10,270	10,400	10,230	10,710
Manufacturing, Total	3,200	3,250	3,250	3,250	3,370	3,030	3,310
Food Products	1,360	1,370	1,450	1,330	1,440	1,080	1,370
Lumber & Wood Products	980	1,020	940	1,010	1,000	970	950
Other Manufacturing	860	860	860	910	930	980	990
Nonmanufacturing, Total	6,340	6,390	6,600	7,020	7,030	7,200	7,400
Contract Construction	350	310	300	340	240	260	340
Transportation-Comm-Utilities	560	490	600	630	650	660	630
Wholesale & Retail Trade	1,770	1,870	1,920	1,980	2,050	2,020	2,120
Finance, Ins. & Real Estate	280	260	270	300	320	340	330
Services & Miscellaneous	1,430	1,440	1,480	1,600	1,610	1,660	1,730
Government	1,950	2,020	2,030	2,170	2,160	2,260	2,250

From: Clatsop Economic Development Committee

TABLE 404-6

Pacific County Resident Labor Force, Unemployment and Employment

	1970	1971	1972	1973	1974	1975
Civilian Labor Force	6400	6490	6470	6480	6330	6210
Unemployment	560	550	530	520	500	690
Percentage of Labor Force	8.8	8.5	8.2	8.0	7.9	11.1
Total Employment	5840	5940	5940	5960	5830	5520

Pacific County Non-agricultural Wage and Salary Employment (By Place of Work)

	1970	1971	1972	1973	1974	1975
Total Wage & Salary	4650	4650	4730	4740	4720	4600
Manufacturing, total	1810	1790	1880	1860	1790	1680
Food Products	470	520	470	480	470	470
Lumber & Wood Products	1300	1230	1360	1330	1260	1150
Other Manufacturing	40	40	50	50	60	60
Non-manufacturing, total	2840	2860	2850	2880	2930	2920
Mining & Miscellaneous	140	140	130	150	190	190
Construction	100	110	120	130	110	110
Transportation-Comm-Utilities	220	220	220	210	220	190
Trade	740	760	760	730	720	730
Finance, Ins., & Real Estate	70	80	90	110	110	130
Service	450	430	430	460	500	510
Government	1120	1120	1100	1090	1080	1060

From: State of Washington, Employment Securities

TABLE 404-7

WAHKIAKUM COUNTY RESIDENT LABOR FORCE , UNEMPLOYMENT AND EMPLOYMENT

	1970	1971	1972	1973	1974	1975
Civilian Labor Force	1330	1270	1310	1390	1350	1320
Unemployment	60	60	70	50	60	100
Percentage of Labor Force	4.5	4.7	5.3	3.6	4.4	7.6
Total Employment	1270	1210	1240	1340	1290	1220

WAHKIAKUM COUNTY NONAGRICULTURAL WAGE AND SALARY EMPLOYMENT

(By Place of Work)

	1970	1971	1972	1973	1974	1975
Total Wage and Salary	880	810	860	920	900	890
Manufacturing, Total	480	450	470	510	490	480
Lumber & Wood Products	470	440	440	490	480	470
Other Manufacturing	10	10	30	20	10	10
Nonmanufacturing, Total	400	360	390	410	410	410
Transportation-Comm-Utilities	90	90	90	100	100	80
Trade	80	70	80	80	70	90
Finance, Ins., & Real Estate	20	20	20	20	10	10
Service	50	40	50	60	70	70
Government	160	140	150	150	160	160

From: State of Washington, Employment Securities Department

TABLE 404-8

Employment Distribution, 1975

	Clatsop	Pacific	Wahkiakum
Food Products Manufacturing	11%	10%	-
Lumber & Wood Products Manufacturing	10%	25%	53%
Other Manufacturing	10%	1%	1%
Construction	3%	2%	-
Transportation-Comm-Utilities	5%	4%	9%
Trade	20%	16%	10%
Finance, Insurance, and Real Estate	3%	3%	1%
Service and Miscellaneous	16%	11%	8%
Government	22%	23%	18%
Other	-	5%	-

From: Clatsop Economic Development Committee distribution of employment among the various categories for 1975.

The "Civilian Labor Force" has shown little fluctuation for several years. The unemployment rate has also shown little change until 1975, when there was a uniform increase of approximately three percent. The annual average for unemployment does not demonstrate the changes during the year resulting from the seasonal nature of many of the jobs. This is usually represented by significantly higher unemployment rates during the period from November to February, when the construction business, wood products industry, and tourism have slowed.

Lumber and wood products have figured prominantly in the employment history of the estuary area and will probably continue to do so. In Wahkiakum County, the forest products industry employs over fifty percent of those employed. There has been a slight decline in employment in recent years, probably due to increased mechanization and more efficient harvesting methods.

Overall, employment in each sector of the labor force remained fairly constant. The greatest change is in employment in the service sector. The service sector includes activities such as nursery schools, recreational facilities and security police.

The basic economy of Clatsop County relies on employment in the three major activities: fish processing, lumbering and wood products, and tourism. Each of these is important enough to exert a strong influence on the overall economy. Each is fairly sensitive to changes in market conditions and subject to unpredictable natural events such as unusually large or small runs of fish for fish processing, periods of drought, storm, or fire for forestry, extremely cold and wet summers for tourism. Consequently, overall employment fluctuates considerably from year to year. A more diversified economic base, including more stable employment sources, would tend to reduce the yearly fluctuations.

404.3 ECONOMIC ANALYSIS METHODOLOGY

Each economic sector is linked to several others by purchases and sales. These relationships can be analyzed by the use of an "input-output model." Table 404-9 is a transaction matrix compiled for Clatsop County during 1968, when the impact of a large aluminum plant which was considering relocation in Clatsop County was being investigated. No attempt was made to update this matrix. This matrix is included to show the kind of tools used to analyze local economies. This type of study has not been completed for Pacific or Wahkiakum Counties.

The transaction matrix shows the dollar amounts of actual sales or purchases (transactions) made by the various sectors of the Clatsop County economy. Included are the business sectors, sectors consisting of local government and the sectors that make up final demand. Final demand consists of the households of the community, business and government outside of the county, and those expeditures related to maintaining or expanding the capital stock of the local economy (depreciation and investment). When reading the matrix, it should be noted that all sectors are recorded twice, once across the top and again down the side. By reading down a column from a sector listed across the top, one can see where that sector made its purchases and how much was spent for goods and services. In summary, one is able to identify the magnitude and distribution of purchases by various sectors by reading down the columns in Table 404-9. To discover the pattern of sales in the community one engages in a similar exercise by reading across the row

Interpretation of the transactions in the public sectors of local government (sectors 17-28) requires some additional explanation. Local government purchases goods and services from local businesses (columns 17-28 with rows 1-16). However, the reverse is only partially true. Taxes may be viewed as payments by the private sectors for the purchase of goods and services from local government. But the purchase-sale analogy is not perfect in this case of public transaction. To some extent, the tax goes into a common coffer and the funds collected are disbursed through various services provided by local government. Some of these services are quite general, in that they benefit equally broad segments of the local community. Others directed at some very specific groups. For a variety of reasons it may be impossible or undesirable for local government (or any level of government) to collect its revenue from various groups of the public, only on the basis of the benefits which these groups may derive from the local government's services. However, to interpret the numbers in the intersections of columns 1-15 and rows 16-28 of the matrix would require such an assumption. It would have to be assumed that goods and services provided by the local government to the various sectors of the economy would be exactly equal to the tax payments. Of course, a much simpler explanation is called for: these numbers simply represent tax payments.

Table 404-9

Direct and indirect effects of one dollar change in business within Clatsop County, Oregon, 1968

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]
[1] Lumber	1.0830	0.0007	0.0008	0.0040	0.0021	0.0014	0.0008	0.0005	0.0005	0.0141	0.0004	0.0004	0.0074	0.0002	0.0002	0.0051
[2] Commercial fishing	*	1.0029	.0660	*	.0001	*	*	*	*	*	*	*	*	.0001	*	.0002
[3] Fish processing	.0001	.0001	1.0007	.0002	.0009	.0001	.0001	.0002	.0001	*	*	.0004	*	.0012	*	.0023
[4] Agriculture	*	.0001	.0121	1.0121	.1293	.0001	*	*	*	*	*	*	*	*	.0001	.0002
[5] Manufacturing	.0001	.0004	.0934	.0003	1.0002	.0005	.0003	.0001	.0001	*	.0002	.0001	*	.0002	.0043	.0018
[6] Lodging	.0001	.0005	.0001	.0003	.0002	1.0008	.0003	.0002	.0002	*	.0002	.0008	.0001	.0002	.0054	.0001
[7] Cafes & taverns	*	*	*	*	*	*	1.0000	*	*	*	*	*	*	*	*	.0012
[8] Service stations	.0085	.0577	.0060	.0373	.0193	.0016	.0006	1.0116	.0022	.0069	.0027	.0003	.0020	.0010	.0020	.0094
[9] Automotive sales and service	.0026	.0250	.0060	.0067	.0165	.0050	.0014	.0074	1.0038	.0064	.0108	.0024	.0074	.0014	.0031	.0065
[10] Communication & transportation	.0359	.0473	.0590	.2894	.1458	.0971	.0277	.0328	.0334	1.0172	.0195	.0210	.0109	.0148	.0139	.0051
[11] Professional services	.0216	.0371	.0031	.0029	.0015	.0029	.0050	.0016	.0012	.0017	1.0055	.0038	.0011	.0012	.0018	.0181
[12] Financial services	.0121	.0058	.0144	.0383	.0292	.0036	.0024	.0021	.0605	.0007	.0021	1.0048	.0115	.0027	.0108	.0088
[13] Construction	.0024	.0030	.0045	.0075	.0107	.0089	.0558	.0033	.0058	.0045	.0148	.0112	1.0470	.0030	.0040	.1056
[14] Retail & whole-sale trade	.0466	.0653	.0317	.1941	.0814	.0990	.1175	.1796	.0323	.0201	.0325	.0254	.0219	1.0333	.0138	.0457
[15] Retail services & organizations	.0108	.0950	.0142	.0539	.0158	.1206	.0581	.0275	.0191	.0035	.0367	.0102	.0089	.0269	1.0173	.0063
[16] Port authority	.0007	.0002	.0002	.0010	.0004	.0009	.0002	.0001	.0002	.0017	.0001	.0013	.0001	.0003	.0002	1.0000
[17] Education	.0251	.0075	.0045	.0264	.0103	.0319	.0071	.0041	.0032	.0247	.0031	.0040	.0029	.0096	.0080	.0010
[18] County roads	.0011	.0003	.0002	.0011	.0004	.0013	.0003	.0002	.0001	.0010	.0001	.0002	.0001	.0004	.0003	*
[19] Law enforcement	.0014	.0004	.0002	.0014	.0005	.0016	.0004	.0002	.0002	.0013	.0002	.0002	.0001	.0005	.0004	.0001
[20] Health department	.0005	.0001	.0001	.0005	.0002	.0006	.0001	.0001	.0001	.0005	.0001	.0001	.0001	.0002	.0002	*
[21] Welfare	.0035	.0010	.0006	.0034	.0013	.0041	.0009	.0005	.0004	.0032	.0004	.0005	.0004	.0012	.0010	.0001
[22] General fund	.0032	.0009	.0005	.0031	.0012	.0037	.0008	.0005	.0004	.0029	.0004	.0017	.0004	.0011	.0009	.0070
[23] City of Astoria	.0005	.0006	.0011	.0012	.0027	.0091	.0014	.0030	.0010	.0013	.0012	.0006	.0003	.0036	.0019	.0030
[24] City of Warrenton	*	.0001	.0002	.0003	.0001	.0003	.0006	.0003	*	.0002	*	.0001	*	.0008	.0004	.0030
[25] Town of Hammond	*	*	.0001	*	*	*	*	*	*	*	*	*	*	*	*	*
[26] City of Gearhart	*	*	*	*	*	.0014	*	.0001	*	*	*	*	*	.0001	*	*
[27] City of Seaside	.0001	.0003	.0001	.0005	.0003	.0082	.0018	.0012	.0004	.0005	.0005	.0005	.0001	.0016	.0008	.0001
[28] City of Cannon Beach	*	*	*	*	*	.0024	*	.0001	*	*	*	*	*	.0002	*	*
[29] Aluminum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	1.2599	1.3523	1.3198	1.6859	1.4704	1.4071	1.2836	1.2773	1.1652	1.1124	1.1315	1.0900	1.1227	1.1058	1.0918	1.2307

* Indicates a number too small to round up to 0.0001.

From: Collin et al., 1969

Table 404-9 (cont.)

Direct and indirect effects of one dollar change
in business within Clatsop County, Oregon, 1968

	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	
[1] Lumber	0.0004	0.0019	0.0003	0.0003	0.0002	0.0008	0.0007	0.0038	0.0034	0.0027	0.0006	0.0040	0.0002	[1]
[2] Commercial fishing	*	*	*	*	*	*	*	*	*	*	*	*	*	[2]
[3] Fish processing	.0001	.0001	.0001	.0001	*	.0001	.0005	.0001	.0002	.0002	.0001	.0001	.0002	[3]
[4] Agriculture	*	*	*	*	*	*	.0001	.0032	.0001	.0003	*	*	*	[4]
[5] Manufacturing	.0001	.0001	.0001	*	.0003	.0001	.0010	.0250	.0004	.0022	.0002	.0001	.0001	[5]
[6] Lodging	.0001	.0001	.0001	*	.0003	.0002	.0186	.0003	.0002	.0002	.0002	.0016	*	[6]
[7] Cafes & taverns	*	*	.0010	*	*	.0001	.0025	*	.0007	*	.0007	.0002	*	[7]
[8] Service stations	.0116	.0408	.0049	.0166	.0009	.0074	.0092	.0127	.0012	.0195	.0101	.0063	.0023	[8]
[9] Automotive sales and service	.0136	.1142	.0006	.0003	.0032	.0014	.0077	.0366	.0040	.0266	.0252	.0264	.0016	[9]
[10] Communication & transportation	.0106	.0097	.0197	.0198	.0094	.0516	.0132	.0202	.0073	.0197	.0109	.0102	.0022	[10]
[11] Professional services	.0044	.0435	.0246	.0001	.2753	.0219	.0116	.0260	.0047	.0262	.0792	.0336	.0022	[11]
[12] Financial services	.0016	.0100	.0005	.0002	.0012	.0007	.0020	.0073	.0058	.0059	.0029	.0195	.0006	[12]
[13] Construction	.0297	.2483	.0015	.0012	.0043	.0124	.0573	.3436	.4695	.2466	.0712	.5619	.0044	[13]
[14] Retail & whole-sale trade	.0920	.0922	.0529	.0531	.0323	.0745	.0831	.1062	.1359	.1357	.0986	.0719	.1166	[14]
[15] Retail services & organizations	.0260	.0236	.0254	.0018	.0617	.0241	.0668	.0479	.0354	.0421	.0343	.0095	.0039	[15]
[16] Port authority	*	.0001	.0001	*	*	.0001	.0002	.0001	.0001	.0001	.0001	.0001	.0254	[16]
[17] Education	1.0156	.0021	.0012	.0010	.0015	.0022	.0041	.0072	.0027	.0030	.0018	.0024	.0173	[17]
[18] County roads	.0001	1.0001	.0001	*	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0007	[18]
[19] Law enforcement	.0001	.0001	1.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0004	.0001	.0009	[19]
[20] Health department	*	*	*	1.0000	*	*	.0001	.0001	.0001	.0001	*	*	.0003	[20]
[21] Welfare	.0002	.0003	.0002	.0001	1.0002	.0003	.0003	.0004	.0003	.0003	.0002	.0003	.0022	[21]
[22] General fund	.0002	.0003	.0001	.0001	.0002	1.0037	.0003	.0004	.0003	.0009	.0011	.0024	.0022	[22]
[23] City of Astoria	.0004	.0006	.0003	.0002	.0005	.0004	1.0460	.0007	.0006	.0007	.0005	.0005	.0005	[23]
[24] City of Warrenton	.0001	.0001	.0001	*	*	.0001	.0004	1.0001	.0103	.0814	.0001	.0001	.0022	[24]
[25] Town of Hammond	*	*	*	*	*	*	*	*	1.0000	*	*	*	*	[25]
[26] City of Gearhart	*	*	*	*	*	*	*	*	*	1.0000	*	*	*	[26]
[27] City of Seaside	.0002	.0003	.0001	.0001	.0002	.0002	.0004	.0003	.0003	.0003	1.0002	.0002	.0002	[27]
[28] City of Cannon Beach	*	*	*	*	*	*	.0001	*	*	*	*	1.0189	*	[28]
[29] Aluminum	0	0	0	0	0	0	0	0	0	0	0	0	1.0000	[29]
Total	1.0271	1.5885	1.1340	1.0951	1.3919	1.2025	1.3264	1.6424	1.6837	1.6149	1.3387	1.7704	1.1862	Total

* Indicates a number too small to round up to 0.0001.

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405 DEVELOPMENT TRENDS

COLUMBIA RIVER ESTUARY

DEVELOPMENT TRENDS

Robert E. Blanchard

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FIGURES

TABLES

405 DEVELOPMENT TRENDS

An inventory of the number of people in an area, their ages, where they live, and future population projections is a basic requirement for planning. These figures are used to determine future land use needs and patterns. Together with the current utility and service figures, population statistics provide a basis for prediction of potential needs for schools, recreation, housing and other public facilities.

405.1 POPULATION

A. Historical Overview

Although county-wide figures and projections suggest a trend toward a probable growth in population for the three counties bordering the Columbia River estuary, there have been periods when the population decreased. Such decreases accompanied a change in the economic climate. The historical trends are shown in Table 405-1.

Pacific County's population has experienced several periods of fluctuation which have followed trends in the timber industry. The county's growth reached it zenith in the 1900-1910 decade, when the first major logging and saw-milling operations began. After this, population growth was slow. In the 1950's the war-caused building boom and related lumber boom ended, and the population in Pacific County declined. By the mid-1960's, the population stablized and began to increase.

Population growth in Wahkiakum County decreased at a rate of one percent per year over the twenty year period from 1940 to 1960. Since 1960, the county has slowly been regaining its population. The relatively small population in Wahkiakum County results from a combination of geographic, topographic, and economic conditions within the county. Poor agricultural soils and steep terrain have limited a major portion of the county's land to tree farming. As a result, there are few incentives for new industry to move to the region and there is little to attract new people.

Growth of the lumber and fishing industries during the first two decades of this century led to a rapid increase in population in Clatsop County and Astoria. The minor decrease in population during the 1920's was largely the result of the Astoria Fire of 1922 and the general economic depression. Wartime activity and the postwar boom resulted in an increase in

TABLE 405-1

Population Trends and Projections

	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990
Clatsop County	12765	16106	23030	21124	24697	30776	27380	28473	32600	36100
Astoria	8381	9599	14027	10349	10389	12331	11239	10244		
Pacific County	5983	12532	14891	14970	15844	16558	14674	15796	18555	22100
Ilwaco	584	664	787	750	656	628	518	506	1515*	2000*
Wahkiakum County			3472	3862	4286	3835	3426	3592	4369	5082
Cathlamet					621	501	615	647		1128

From: Harstad Associates, 1970
Meyers et.al., 1973

*This figure is for the Ilwaco-Chinook census division. This division showed an historical population as follows: 1950 - 1172, 1960 - 1023, 1970 - 1187.

population during the 1940's and 1950's. Although a net increase is shown from 1960 to 1970, the county's population actually fluctuated dramatically. The closing of the Tongue Point Naval Station in 1962 caused a sharp decrease in population. Construction work on the Astoria-Megler Bridge and the pulp mill at Wauna brought an influx of people to the county that continued to 1970, when the population returned to the 1950 level; since then, the population has remained approximately the same.

Focusing on the portions of the counties adjacent to the estuary, population figures are available for three incorporated areas. Cathlamet, Wahkiakum County's only incorporated community, has had a fairly constant population level since 1940. Ilwaco, Washington, after increases during the first part of the decade, has been steadily losing population since 1920. Astoria, since being ranked as Oregon's third largest city in 1920, has had a fluctuating population, following the overall trend of Clatsop County.

B. Population Characteristics

The characteristics of the three counties are very similar. Figures 405-1, 405-2, and 405-3 show the population composition by age group and sex. The date for these figures is county wide, and as such, take in far more people than actually reside in the estuary area. Pacific and Clatsop Counties' population pyramids indicate a higher proportion of people over 55 than Wahkiakum County. This is probably due to the attractive retirement atmosphere on the Long Beach Peninsula and the Oregon Coast. These figures also show a lower overall proportion of people in the 25 to 45 year age group. Such figures suggest an outmigration of people, when they reach an age to enter the labor market.

C. Projections

Population projections, in general, are very uncertain exercises. What will actually happen in the future is impossible to predict. For planning purposes, the future is based on previous trends and anticipated futures. Population projections are less reliable, as times further into the future are considered. Major changes in the economic base could alter the population greatly, as might many other changes.

Population projections to the year 1990 indicate continued growth for all three counties and their incorporated communities. At present, growth potential in the Hammond-Warrenton area is high, because of proposed industrial development. Astoria is likely to be affected by this development also, but

Figure 405-1.

POPULATION PYRAMID
1970
CLATSOP COUNTY

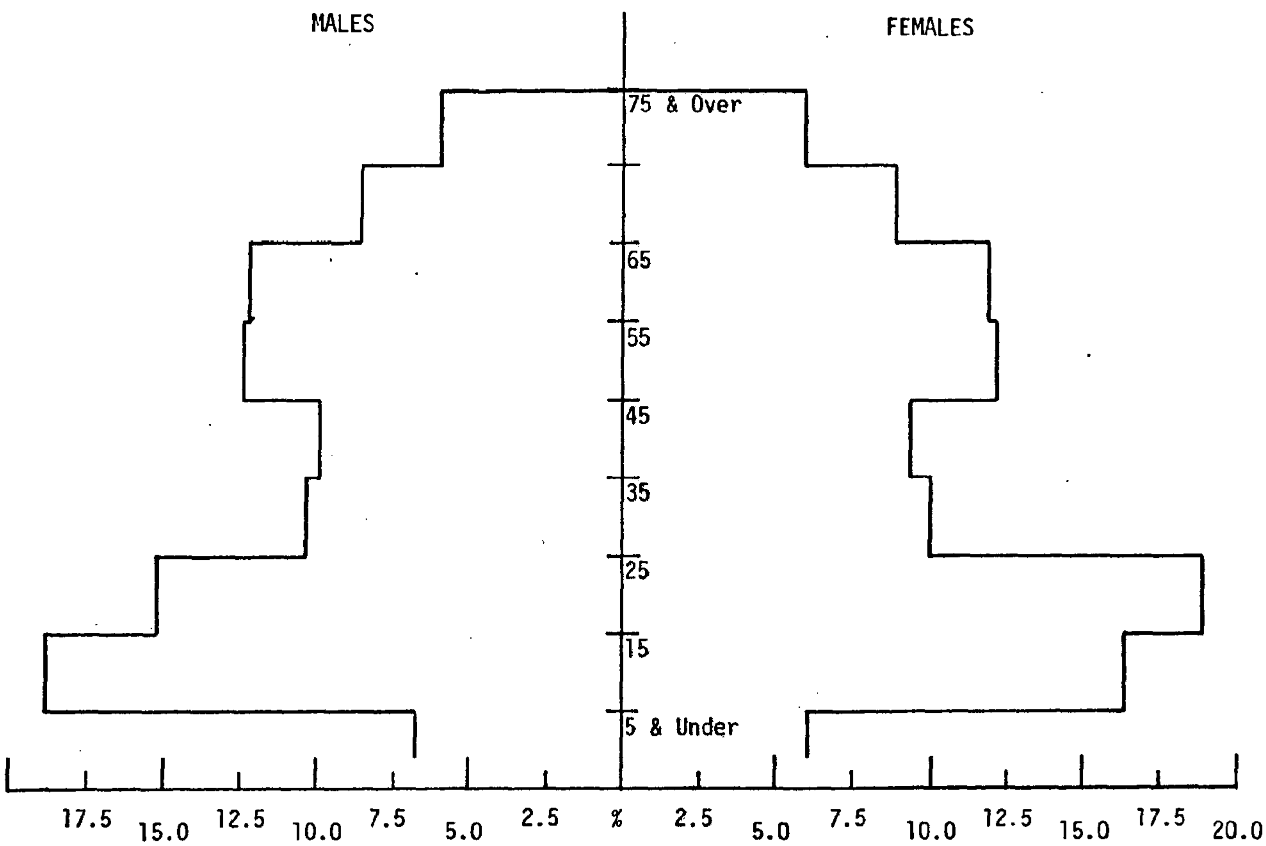


Figure 405-2.

POPULATION PYRAMID
1970

PACIFIC COUNTY

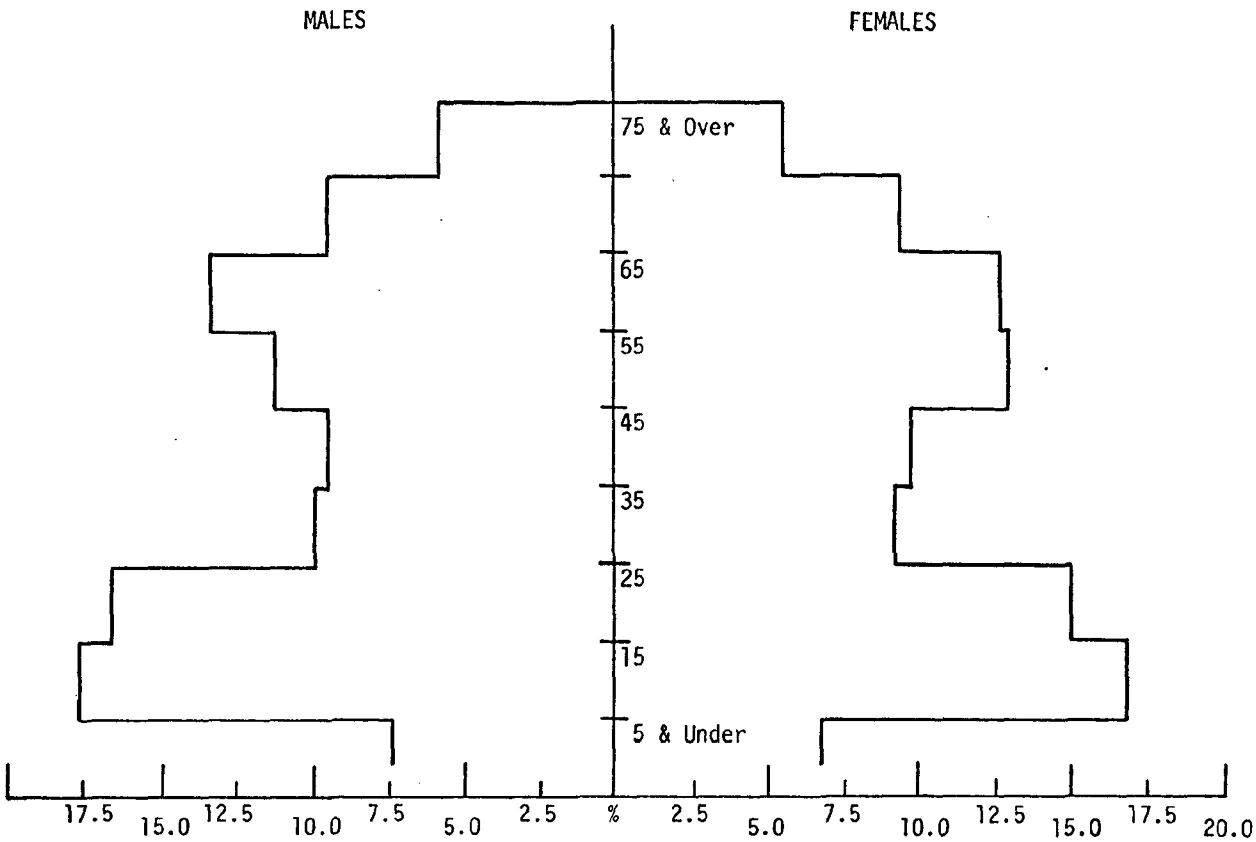
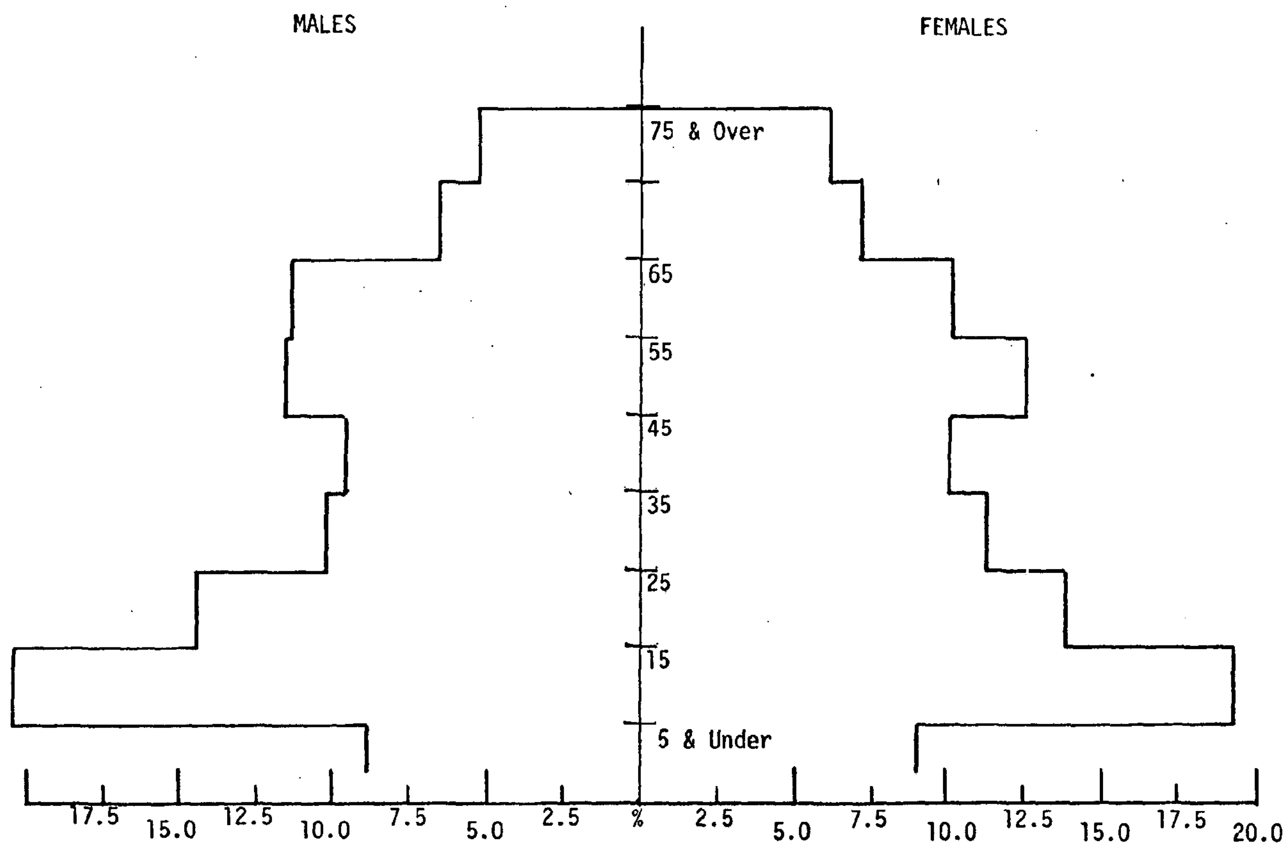


Figure 405-3.

POPULATION PYRAMID
1970
WAHKIAKUM COUNTY



to a lesser degree. Ilwaco could possibly expect small increases in population, as development pressures increase on the Long Beach Peninsula.

405.2 HOUSING

According to the last census, there were 12,240 housing units in Clatsop County, 8,014 in Pacific County, and 1,267 units in Wahkiakum County. Table 405-2 shows how these units were broken down by single family dwellings, seasonal homes, multi-family units, and mobile homes. As noted in the table, not all counties determined the total seasonal and mobile homes.

There is a high demand for housing in the estuary region at this time. This is primarily because of an unstable economy in the last few years which has resulted in slowed construction. As new industry locates in the region, the demand for housing is expected to increase in Clatsop County.

Along the shoreline of the estuary, the single family unit is the most common housing. This type of housing, generally in a rural setting, predominates in the upper estuary. Except near Astoria and Warrenton, there are few subdivisions in the area.

New building projects are limited to the shoreland area in Clatsop County west of Tongue Point. Subdivisions are proposed for the Hammond-Warrenton area. Condominium projects are also in the planning stages for Warrenton and Astoria.

405.3 TRANSPORTATION

The Columbia River Estuary region is served by a full range of transportation systems: highway, rail, water, and air. All of these systems have been influenced by the natural features of the area, especially the Columbia River. From the times of the earliest settlers, the river has been the major access route to the inland areas. The railroad follows the Columbia's south bank. The busiest access road on a year-round basis is U.S. 30, the Columbia River Highway. Highways in portions of the Washington counties also follow the river; ocean shipping and inland barge traffic utilize the Columbia and the major airport is located on estuarine lands near its mouth.

A. Highways

Three roads constitute the basic framework for the highway network. Highway 101 is the main north-south corridor, linking the estuary with other coastal points. It also provides the only highway link between Washington and Oregon, west of Longview.

TABLE 405-2

Housing Census

	Single Family	Multi-Family	Seasonal	Mobile Homes	Total
Clatsop County	9282	2541		417	12240
Pacific County	5825	525	1764		8014
Wahkiakum County	1122	82		63	1267

From: Harstad Associates, 1970
Howard *et al.*, 1972
Meyers *et al.*, 1973
Pacific County, Dept. of Public Works, 1974

U.S. 30 provides the major connection between Astoria and the manufacturing towns up the river, including Portland. S.R. 4 is the main access route between the Washington beaches and Interstate 5 and the Longview-Kelso area.

Land transportation services include cargo and passenger service. Both Washington and Oregon portions of the estuary region are served by several freight services. Passenger service is available in Clatsop County only.

B. Railroads

The estuary is served by the Burlington Northern Railroad. There are approximately fifty miles of single line track located along the south bank of the river, within the estuary area; branches extend beyond Astoria to Warrenton, Hammond, and Seaside. At this time, there is freight service only. There has been no passenger service to the estuary area since 1949. There is no rail service in either Wahkiakum or Pacific Counties.

C. Air

The Clatsop County Airport, located on the shores of Youngs Bay, is the major airport for the estuary area. It provides regularly scheduled passenger and freight service to Portland, and it has facilities for small, private aircraft. Charter service is also available. There is a small airport east of Ilwaco, with facilities for small planes, but it has no commercial service. There is no airport in Wahkiakum County.

D. Water Transportation

Water transportation activities are dominated by the Columbia River. However, federal waterway projects, as discussed in the physical alterations section, include most major tributaries throughout the estuary, as well as the Columbia River ship channel. Waterborne commerce includes dry cargo ships and tankers, barges, log rafts, commercial fishing vessels and pleasure craft.

405.4 UTILITIES

A. Water Systems

Under normal conditions, the existing water systems in the estuary area are adequate. There are situations that may occur from either natural or cultural influence, in which the water supply for some of the systems may become dangerously low. Nature can cause the water supply to dry up, to be rendered unusable, or to flow at such a low rate that domestic consumption would be restricted. Cultural problems include higher than normal consumption (because of the influx of summer residents and tourists) or an unexpected increased use of water by industry.

One potential source of water is the Columbia River. Although it has large quantities of water, there are problems associated with its use as a water supply. First, considerable effluent, some raw, some with only primary treatment, is discharged into the river upstream; second, salt water intrusion could dictate a water treatment plant no further downstream than the Wauna area; third, should there be a significant diversion of water from upstream, it could be more expensive to the consumer to process Columbia River water.

There are twenty-three water systems that are serving people in the estuary region. Water for these systems is taken from streams, rivers, lakes, springs,and groundwater. Specific data regarding major systems are summarized in Table 405-3.

B. Public Utilities

1. Electrical Power

Currently, all electrical power in the estuary area is supplied by the Bonneville Power Administration (B.P.A). In Clatsop County, it is distributed by Pacific Power and Light (P.P. & L.); Pacific County Public Utility District No. 2 is the distributor for Pacific County; and Public Utility District No. 1 of Wahkiakum County distributes electrical power in Wahkiakum County. Electrical power can be purchased directly from B.P.A, as Crown Zellerbach does at its Wauna mill.

The Lower Columbia River has been studied for possible nuclear power plant sites. While no sites have been designated for actual construction, there are two that have been proposed. One site is in Wahkiakum County on the Elochoman River, about four miles from Cathlamet. The other is in Clatsop County near Brownsmead.

2. Natural Gas

Natural gas is supplied to the three county area by two different companies. The Cascade Natural Gas Corporation serves Pacific and Wahkiakum Counties, and the Northwest Natural Gas Company serves Clatsop County.

TABLE 405-3

Clatsop Count

Westport Water Association
Existing Source: West Creek
Potential Source: Gnat Creek Artesian Aquifer
Plympton Creek
Capacity: estimated 187,000 g.d. (gallons per day)
Treatment: Chlorination

Wauna Water District
Source: Unnamed springs and streams
Capacity: No data
Treatment: None

Brownsmead Water District
Source: Mack Creek, Rock Creek
Potential Source: Gnat Creek Artesian Aquifer
Capacity: No data
Treatment: Hypo-Chlorination

Knappa Co-op Water Company
Source: Mill Creek
Potential Source: Big Creek/Astoria System
Capacity: No data
Treatment: Chlorination

Carmen Creek Water Association
Source: Carmen Creek
Capacity: At capacity 12,926 g.d.
Treatment: No data

Wickiup Water District
Source: Little Creek
Potential Source: Astoria System
Capacity: No data
Treatment: Chlorination

City of Astoria
Source: Bear Creek, Big Creek, Young's River
Capacity: No data
Treatment: Chlorination and Flouridation

Young's River-Lewis and Clark Water District
Source: Barney Creek
Capacity: Near Capacity
Treatment: Chlorination

Warrenton
Source: Lewis and Clark River
Potential Source: Seaside water system for emergencies
Capacity: No data
Treatment: Chlorination/flouridation and lime

Pacific County

Chinook Water Department
Source: Freshwater Creek
Capacity: 200,000 g.d.
Treatment: Chlorination and filtration

Ilwaco Water Department
Source: Black Lake
Capacity: 1,200,000 g.d.
Treatment: Filtration and Chlorination

Wahkiakum County

Cathlamet Water Department
Source: Elochoman River
Capacity: 504,000 g.d.
Treatment: Filtration and Chlorination

Gray's River Valley School
Source: Spring
Capacity: 86,400 g.d.
Treatment: None

Skamokawa-Silverman System
Source: Spring
Capacity: No data
Treatment: None

Sleepy Hollow Water Company
Source: Spring
Capacity: No data
Treatment: None

Westside Water Company
Source: Spring
Capacity: No data
Treatment: None

Wahkiakum County PUD Number 1
Source: Elochoman River (Cathlamet Water Department)
Capacity: 216,000 g.d.
Treatment: Filtration and Chlorination

3. Sewage Systems

Sewage systems include the collection, treatment, and disposal of sewage. The widely varying natural conditions and population densities found in the area preclude a simple solution for sewage disposal. Where population densities are high, an area-wide sewer system is a necessary solution to the problem. In low density areas, individual, on-site disposal systems often may be used. While on-site systems are often satisfactory, there are a number of physical constraints that affect the proper functioning of a septic tank system. These constraints include shallow soil depth to an impermeable layer, a seasonally high water table, low soil permeability, periodic flooding, and very steep slopes.

Sewered areas in the estuary include Astoria, Warrenton, Ilwaco, Cathlamet, the Crown Zellerbach mill at Wauna and the Tongue Point Job Corps Center. The existing sewage systems and their discharge points are summarized here.

Crown Zellerbach Corporation
Treatment: Secondary
Discharge Point: Columbia River

City of Astoria
Treatment: Secondary
Discharge Point: Columbia River, Youngs Bay

City of Warrenton
Treatment: Secondary
Discharge Point: Columbia River

Tongue Point Job Corps Center
Treatment: Primary
Discharge Point: Columbia River

City of Ilwaco
Treatment: Secondary
Discharge Point: Baker Bay

City of Cathlamet
Treatment: Secondary
Discharge Point: Columbia River

Other parts of the estuary area rely on septic tank systems for sewage disposal.

405.5 SCHOOLS

Within the boundaries of the estuary area are all or parts of eight school districts. Included are five in Clatsop County, two in Pacific County, and one in Wahkiakum County.

In addition to the public schools, there is one private school in Astoria, Star of the Sea. Clatsop Community College is also located in Astoria; several Associate Degrees are offered, as well as preparatory courses for four-year institutions.

405.6 INSTITUTIONAL AND LEGAL FRAMEWORK

Clatsop, Pacific, and Wahkiakum counties are all operated under a commissioner system of government. All of the municipalities have a mayor and city council, and Astoria and Warrenton have city managers for administrative tasks.

All of the individual governments have some form of regulation over the use of land. All but Wahkiakum County have zoning ordinances. Each, except Pacific County and Ilwaco, has an existing comprehensive plan as the framework for managing natural and cultural resources. Wahkiakum and Pacific Counties also have Shoreline Management Programs, as required by the Shoreline Management Act of 1972, which serve as regulatory tools for control of shoreline development. The governmental characteristics are summarized in Table 405-4.

TABLE 405-4

Governmental Characteristics

	Date of Incorporation	Population 1970 Census	Government	Comprehensive Plan	Zoning Ordinance
Clatsop County	Estab. 1844	28,473	3 Commissioners	Yes, 1968	Yes
Pacific County	Estab. 1851	15,796	3 Commissioners	No	Yes
Wahkiakum County	Estab. 1845	3,592	3 Commissioners	No	No
Astoria	1876	10,244	Mayor, City Council, City Manager	Yes, 1971	Yes
Cathlamet	1907	631	Mayor, City Council	Yes	No
Hammond	1918	500	Mayor, Town Council	Yes, 1976	Yes
Ilwaco	1891	506	Mayor, Town Council	Yes	Yes
Warrenton	1898	1,825	Mayor, City Council, City Manager	Yes	Yes

From: Meyers *et al.*, 1973

405.7 REFERENCES

A. Columbia-Pacific Resource Conservation and Development Project. 1972. Resource Action Program.

General description of physical and social characteristics of Grays Harbor, Pacific, and Wahkiakum Counties. Emphasis is on resources, both natural and cultural. Discussion of problems and needs relating to each of the resources. Specific development trend information includes housing, education, and transportation.

B. Harstad Associates, Inc. 1970. Wahkiakum County Water and Sewer Study, prepared for the Wahkiakum County Commissioners.

General examination of existing physical and social conditions and water and sewer systems in Wahkiakum County. Information includes population, water systems, and sewage disposal systems.

C. Howard, Paul and Michael Nicholson. 1972. Interim Housing Report, District One, prepared by the Clatsop-Tillamook Intergovernmental Council.

Discussion of existing housing, populations, and market conditions in Clatsop and Tillamook Counties. Attempt to project housing needs to 1985. Includes census data, employment data, and housing inventory.

D. Meyers, Joseph D., Richard T. Leonard, and Oscar T. Granger. 1973. A Plan for Land and Water Use, Clatsop County, Oregon: Phase I, prepared for the Clatsop County Planning Commission and Board of County Commissioners, prepared by Skidmore, Owings, and Merrill.

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E. Pacific County Department of Public Works. 1974. Water Quality Management Plan, Willapa Basin, prepared for the Pacific County Regional Planning Council.

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F. Robert E. Meyer Engineers, Inc. 1971. Preliminary Land Use Plan, Pacific County, Washington, prepared for the Pacific County Regional Planning Council.

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