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Coastal Zone and Estuarine Studies

**CONCENTRATION, EXTENT,
AND DURATION OF SALINITY
INTRUSION INTO THE
COLUMBIA RIVER ESTUARY
SEPTEMBER—OCTOBER 1977-1978**

by
**Robert J. McConnell
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ABSTRACT

Eight 24-h surveys were conducted during September and October 1977 and 1978 to record the extent, concentration, and duration of salinity intrusions into the Columbia River estuary. Monitoring stations were established at Tongue Point, Harrington Point, Grays Point, and in the north channel of Cathlamet Bay. The objective was to simultaneously measure salinity during maximum (spring)^{1/} and minimum (neap)^{2/} tidal cycles.

Monthly neap tides produced the highest concentrations with the longest durations and farthest upstream intrusions of saline waters. Salinities reached 30 parts per thousand (o/oo) at Tongue Point and 17 o/oo at Harrington Point. Concentrations of salt water exceeding 11 o/oo were measured continually throughout one 24-h survey (7-8 September 1977) at Tongue and Grays Points. The farthest upstream intrusion of salt water \geq 2.0 o/oo was recorded between Buoy 14 and 14A at Columbia River Mile (RM) 26.5.^{3/}

- 1/ Tides of increased range occurring during the times of a new and full moon; these tides rise higher and fall lower than during the rest of the month.
- 2/ Tides of decreased range occurring during time of the first and last quaters; these tides do not rise as high or fall as low as tides during the rest of the month.
- 3/ River distances are presented in statute miles and tide elevations in feet to correspond to common usage on navigation and tide charts.

CONTENTS

| | Page |
|--|------|
| INTRODUCTION | 1 |
| STUDY PLAN AND METHODOLOGY | 2 |
| Site Locations | 2 |
| Methods and Materials | 4 |
| RESULTS AND DISCUSSION | 5 |
| Twenty-Four-Hour Surveys--1977 | 5 |
| Seven-Eight September | 5 |
| Tongue Point | 7 |
| Grays Point | 7 |
| Cathlamet Bay | 7 |
| Harrington Point | 7 |
| Rover Boat | 7 |
| Seventeen-Eighteen September | 8 |
| Tongue Point | 8 |
| Grays Point | 8 |
| Cathlamet Bay | 8 |
| Harrington Point | 8 |
| Rover Boat | 8 |
| Five-Six October | 10 |
| Tongue Point | 10 |
| Grays Point | 10 |
| Cathlamet Bay | 10 |
| Harrington Point | 10 |
| Rover Boat | 12 |

| | Page |
|---|------|
| Thirteen-Fourteen October | 12 |
| Tongue Point | 12 |
| Grays Point | 12 |
| Cathlamet Bay | 14 |
| Harrington Point | 14 |
| Rover Boat | 14 |
| Twenty-Four-Hour Surveys--1978. | 14 |
| Eighteen-Nineteen September | 14 |
| Tongue Point | 16 |
| Grays Point | 16 |
| Cathlamet Bay | 16 |
| Harrington Point | 16 |
| Rover Boat | 16 |
| Twenty-Five--Twenty-Six September | 16 |
| Tongue Point | 17 |
| Grays Point | 17 |
| Cathlamet Bay | 17 |
| Harrington Point | 17 |
| Rover Boat | 19 |
| Sixteen-Seventeen October | 19 |
| Tongue Point | 19 |
| Grays Point | 22 |
| Cathlamet Bay | 22 |
| Harrington Point | 22 |
| Rover Boat | 22 |

| | Page |
|--|------|
| Twenty-Four--Twenty-Five October | 22 |
| Tongue Point | 22 |
| Grays Point | 23 |
| Cathlamet Bay | 23 |
| Harrington Point | 23 |
| River Boat | 23 |
| SUMMARY AND CONCLUSIONS | 24 |
| RECOMMENDATIONS | 35 |
| ACKNOWLEDGEMENTS | 36 |
| LITERATURE CITED | 37 |
| APPENDIXES | |
| A. PILOT STUDIES* | |
| B. 1977 SALINITY SURVEYS (1-4)* | |
| C. 1978 SALINITY SURVEYS (5-8)* | |

*Available upon request from the authors C/O: Prescott Field Station (NMFS), Post Office Box 1051, Longview, WA 98632, Telephone (503) 556-0461.

INTRODUCTION

The Columbia River estuary is classed as Type B (partly mixed) most of the year, Type A (two-layered) at high river flow, and Type D (well-mixed) during low flow periods (Pritchard 1955, Burt and McAlister 1959).

Salinity levels have been reported in the Columbia River estuary by the U.S. Army Corps of Engineers (1960); Haertel (1965, 1969); Neal (1965); Haertel and Osterberg (1967); Misitano (1974); and Lutz et al. (1975). During the spring of 1977, the U.S. Army Corps of Engineers (CofE) conducted a survey to provide modeling data for their Waterways Experiment Station (WES), Vicksburg, Mississippi in relation to jetty design, etc. in the lower Columbia River.

Early in 1977 three events occurred which necessitated the gathering of additional up-to-date information on the intrusion of salinity into the Columbia River estuary: (1) near record low flows for the Columbia River were predicted for the summer/fall of 1977; (2) the CofE used their hopper dredges ESSAYONS and BIDDLE during the spring and summer of 1977 to remove approximately 6.9 million m³ of sediment from the Columbia River bar (this increased the depth of the bar from 14.6 to 16 m); and (3) on-site salinity studies were needed to verify the Columbia River physical model which was recently renovated for studies at the WES.

This study was authorized and funded by the Portland District CofE and was conducted by the National Marine Fisheries Service (NMFS), Coastal Zone and Estuarine Studies Division (CZES), Northwest and Alaska Fisheries Center. The initial objective was to determine the concentration, extent, and duration of salinity intrusion into the Columbia River estuary during low river flow periods, September and October (Contract DACW57-77-F-0715).

In August 1978, the CofE authorized (Contract DACW57-78-F-0778) NMFS to conduct a similar study in September and October of 1978 to obtain data to compare with data from the 1977 low-flow year.

STUDY PLAN AND METHODOLOGY

On 18 and 31 August 1977, preliminary studies were conducted during maximum tide elevation changes of 8.0 and 8.2 feet, respectively, to locate appropriate stations close to or on the main ship channel where vessels could anchor and not obstruct river traffic. In addition, sampling was conducted at various depths at locations north and south of the main ship channel to determine if salinity intrusions reached levels justifying documentation during the 24-h surveys to follow. Boats were anchored at pre-determined points until high tide or peak salinities occurred, then moved upriver following the 2 ‰ salinity level or downstream if salinities did not reach 2 ‰. We found that: vessels could anchor adjacent to the ship canal without interfering with river traffic, we could follow the salt wedge, and salinities varied with depth but not necessarily in a uniform pattern.

Site Locations

Stations selected for the 24-h salinity surveys are shown in Figure 1. Station 1 (Tongue Point) and Station 4 (Harrington Point) were located near the main ship channel. Station 2 was located near Grays Point on the Washington side of the river; whereas, Station 3 was on the Oregon side in Cathlamet Bay. River miles and the position of navigation buoys referred to in the text are also shown in Figure 1.

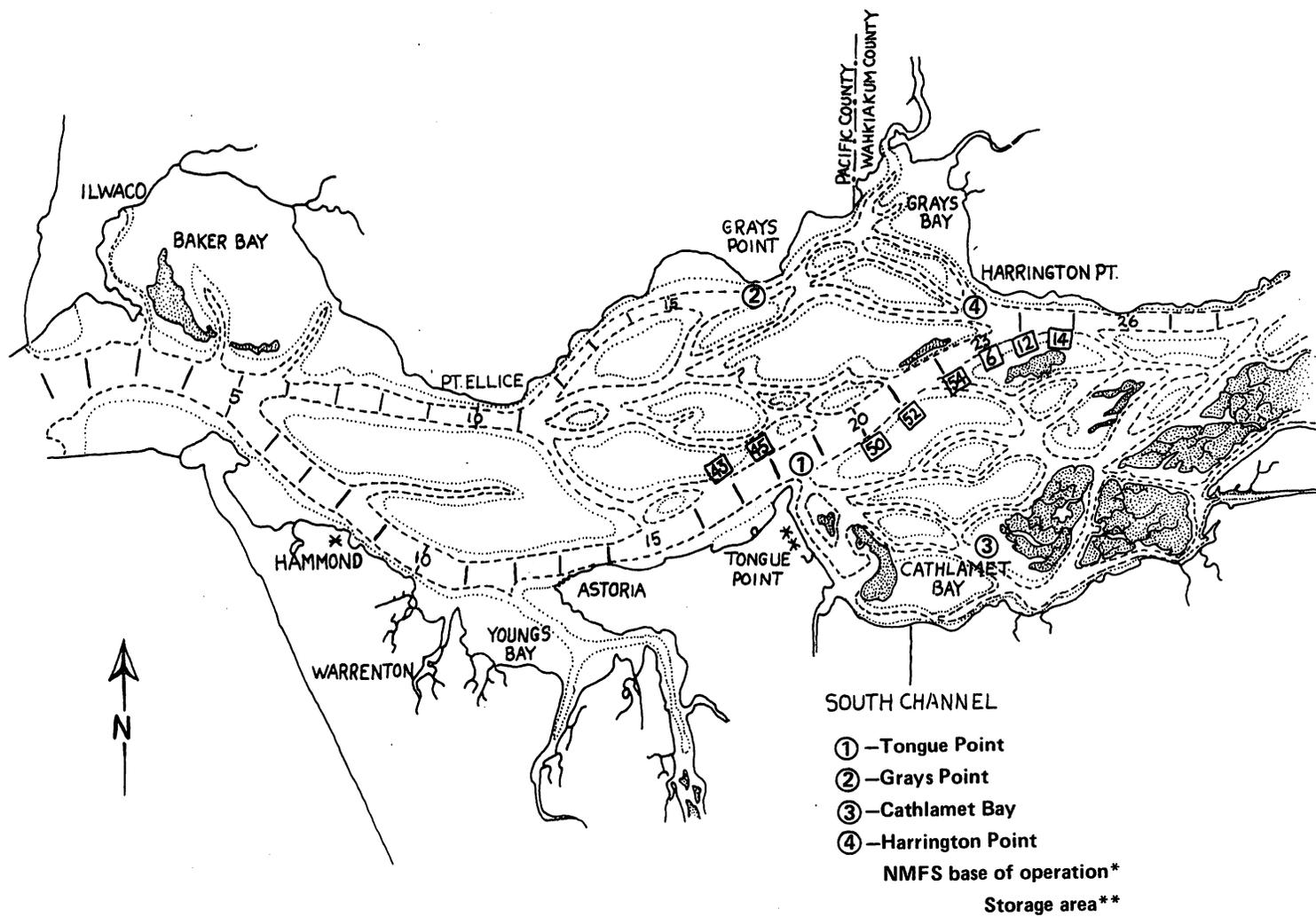


Figure 1.--Sampling stations in the Columbia River estuary for the 1977-1978 salinity surveys. Distance (in river miles) are located in the center of the channels. Pertinent navigation markers are indicated by numbered squares.

Methods and Materials

Salinity, conductivity, and temperature were measured hourly at each meter of depth during the eight 24-h survey periods at the following four locations in the estuary:

| Station name | River mile | Latitude | Longitude |
|------------------|------------|------------|-------------|
| Tongue Point | 18.2 | 46°12'56"N | 123°43'24"W |
| Grays Point | 19.3 | 46°12'25"N | 123°45'33"W |
| Cathlamet Bay | 21.3 | 46°12'13"N | 123°39'20"W |
| Harrington Point | 23.4 | 46°15'13"N | 123°40'03"W |

Raw data are tabulated in the Appendixes by survey and station. (See Table of Contents).

The four vessels were anchored on station and remained there for approximately a 24-h period. Some surveys were shortened because saline water had receded and the tide was ebbing. Salinity, conductivity, and temperature were measured and recorded at least once per hour (on the hour) during each survey. In addition, a roving boat was used to locate the furthest extent of saltwater intrusion >2.0 o/oo during each survey. Because of safety and the difficulty in locating position markers at night, the roving boat operated only during daylight. Radio communication was used to coordinate sampling periods and to check significant changes in salinity levels.

Measurements were taken with Beckman (Model #RS5-3) salinometers ^{4/} (calibrated with resistors) and all values were recorded to the nearest tenth.

Sampling periods were selected to correspond to the monthly spring and neap tidal cycles in September and October of 1977 and 1978.

^{4/} Reference to trade names does not imply endorsement by the National Fisheries Service, NOAA.

River flows were determined using the daily mean flow at Bonneville Dam, the Willamette River at Portland, and the Cowlitz River at Castle Rock. River flows presented for the 24-h survey periods were calculated by taking the average flow during a 7-day period (the first day of the sampling period plus the six previous days). Tide data were obtained from the National Ocean Survey NOAA and are for the Tongue Point tide station. Columbia River tide data are presented in relation to mean lower low water.

RESULTS AND DISCUSSION

Twenty-Four-Hour Surveys--1977

Seven-Eight September

The first 24-h survey started during an ebb tide at approximately 1410 h 7 September. This was during a neap tide cycle with a maximum tidal range of 6.8 feet. Average river flow was 3,114 m³/s (110,000 cfs) or 88% of the 15-yr average for this period. These conditions produced a substantial saline intrusion into the estuary not only in the navigation channel but also in the side channels. Maximum upstream intrusion (3.1 o/oo) was found at Buoy 12, which is approximately RM 25. Salinities exceeding 15 o/oo remained throughout the 24-h period at Tongue Point. Measurements were taken from the roving boat off Woody Island Channel and from Harrington Point to Grays Point; salinity was found in both areas. Water temperatures ranged from 20°C (river) to 14°C (brackish). Hourly salinity concentrations measured at our sampling stations are shown in Figure 2.

SALINITY ‰

■ 0 - .9

□ 1.0 - 10.9

▨ 11.0 - 20.9

▤ 21.0 - 30.9

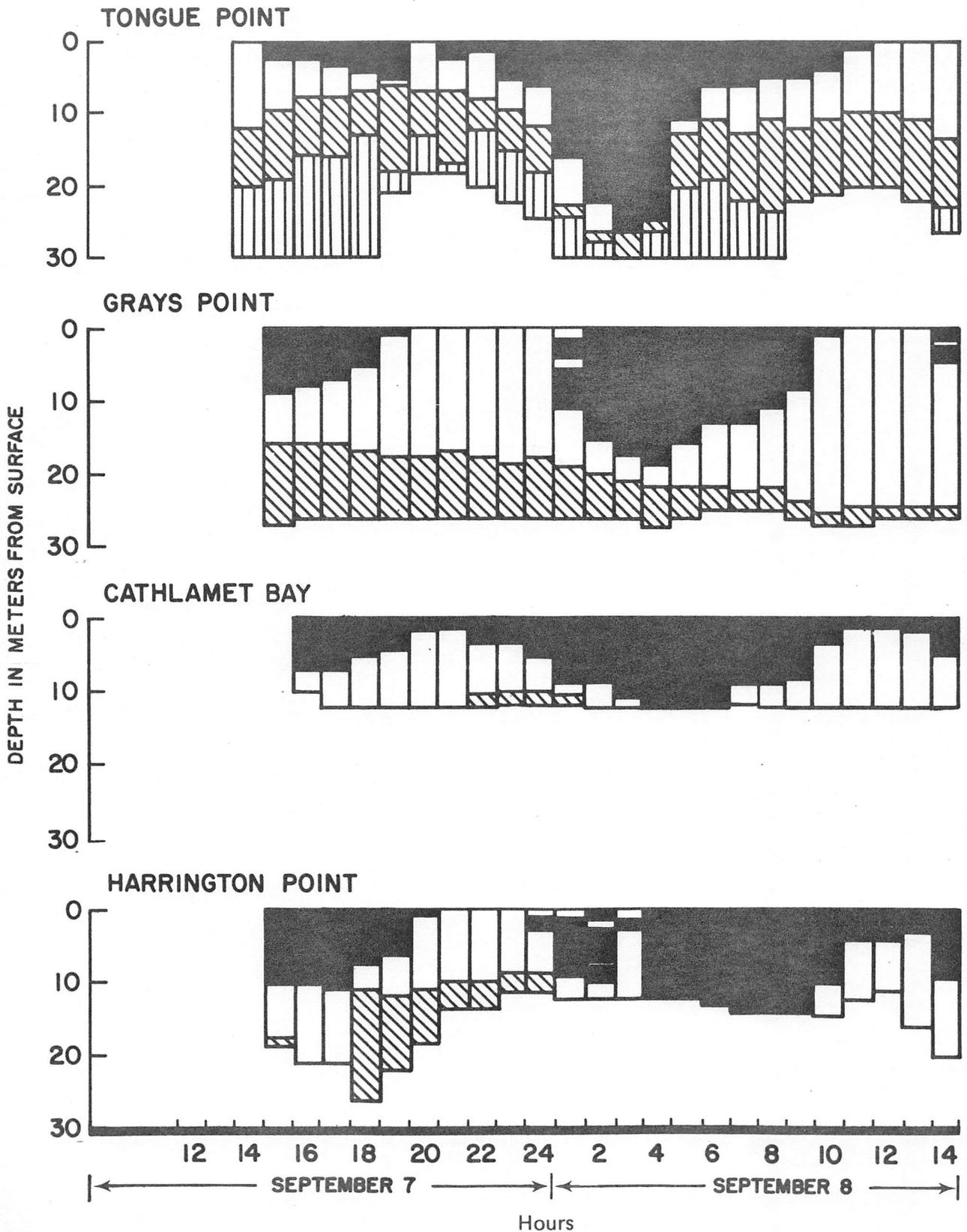


Figure 2.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 1 was on a neap tide cycle (7-8 September 1977) with a maximum tide differential of 6.8 feet. River flow $3114 \text{ m}^3/\text{s}$ (110,000 cfs).

Tongue Point--Beginning with the first measurements at 1400 h, salinities increased from surface to bottom. The initial salt content at the bottom was 21.0 o/oo, which increased to 23.0 o/oo salinity and remained above 20.0 o/oo until 0800 h the following morning. The salinity profile changed markedly during ebb tide between midnight and 0400 h on 8 September. Freshwater outflow caused increased temperatures in the upper water column with high salinity occurring only below 26 m. The salinity regime was typical of a layered system.

Grays Point--First measurement was taken at 1500 h and revealed a level of 13.7 o/oo at 27 m. Salinities remained above 10 o/oo in the lower water column throughout the survey. A strong freshwater layer was observed between 0100 and 0900 h.

Cathlamet Bay--Samples were first taken at 1630 h and were 9.5 o/oo at 10 m. The crew re-anchored the vessel in 12 m of water and found 9.9 o/oo on the bottom. Salt content peaked at 2400 h at 13.2 o/oo; by 0400 h salinities had dropped to <0.1 o/oo.

Harrington Point--Salinity at 18 m was 13.1 o/oo on the first reading (1440 h) decreased to 1.0 o/oo at 1540 h and then increased to 15.0 o/oo by 1715 h. Salinity remained above 10 o/oo until 0045 h (8 September) when it dropped to 3.5 o/oo.

Rover Boat--The objective was to determine the furthest extension of salinity exceeding the 2.0 o/oo level. At 1805 h 7 September, the furthest extension of 2.0 o/oo was measured in the navigation channel between Buoys 10 and 12 (approximately RM 24.6). The next day at 1309 h an intrusion of 3.1 o/oo salinity was measured in the navigation channel near RM 25.

Seventeen-Eighteen September

The second survey was conducted on 17-18 September at a tidal difference of 9.5 feet [Tongue Point--high-high (9.1 ft) tide occurred at 1548 h and low (-0.4) at 2242 h.] The high-high tide intrusion did not result in salinities that exceed 10.6 o/oo at any of the four monitoring stations (Figure 3); layering did occur. River flows averaged 3,270 m³/s (115,500 cfs) and were approximately normal for this time of year. Water temperatures ranged from 19°C (fresh) to 16°C (brackish).

Tongue Point--Salinity levels reached their maximum, 10.6 o/oo, at 1800 h but were zero from 2200 until 0300 h. Tide changes resulted in lightly brackish water followed by fresh water. Water temperatures ranged from 17° to 18°C.

Grays Point--Measurements indicated low brackish intrusions occurred during each of the two high tide cycles. Moderate or heavy salt intrusion did not occur. Salinities peaked at 6.9 o/oo at 1800 h and were low or zero during the 8 h between high tides. Water temperatures ranged from 17° to 18°C.

Cathlamet Bay--Minor salinity concentrations were recorded during the two high tides, and peaked at 3.9 and 1.3 o/oo, respectively. Water temperatures ranged from 17° to 18°C, reflecting the freshwater influence of these extreme tidal cycles.

Harrington Point--Salinities did not exceed 0.4 o/oo during this survey. Water temperature was 19°C.

Rover Boat--Measurements were taken 17 September from 1100 until 1800 h. A peak intrusion of 2.6 o/oo was measured at Buoy 54, (RM22) at 1740 h. Only main channel measurements were taken during this survey.

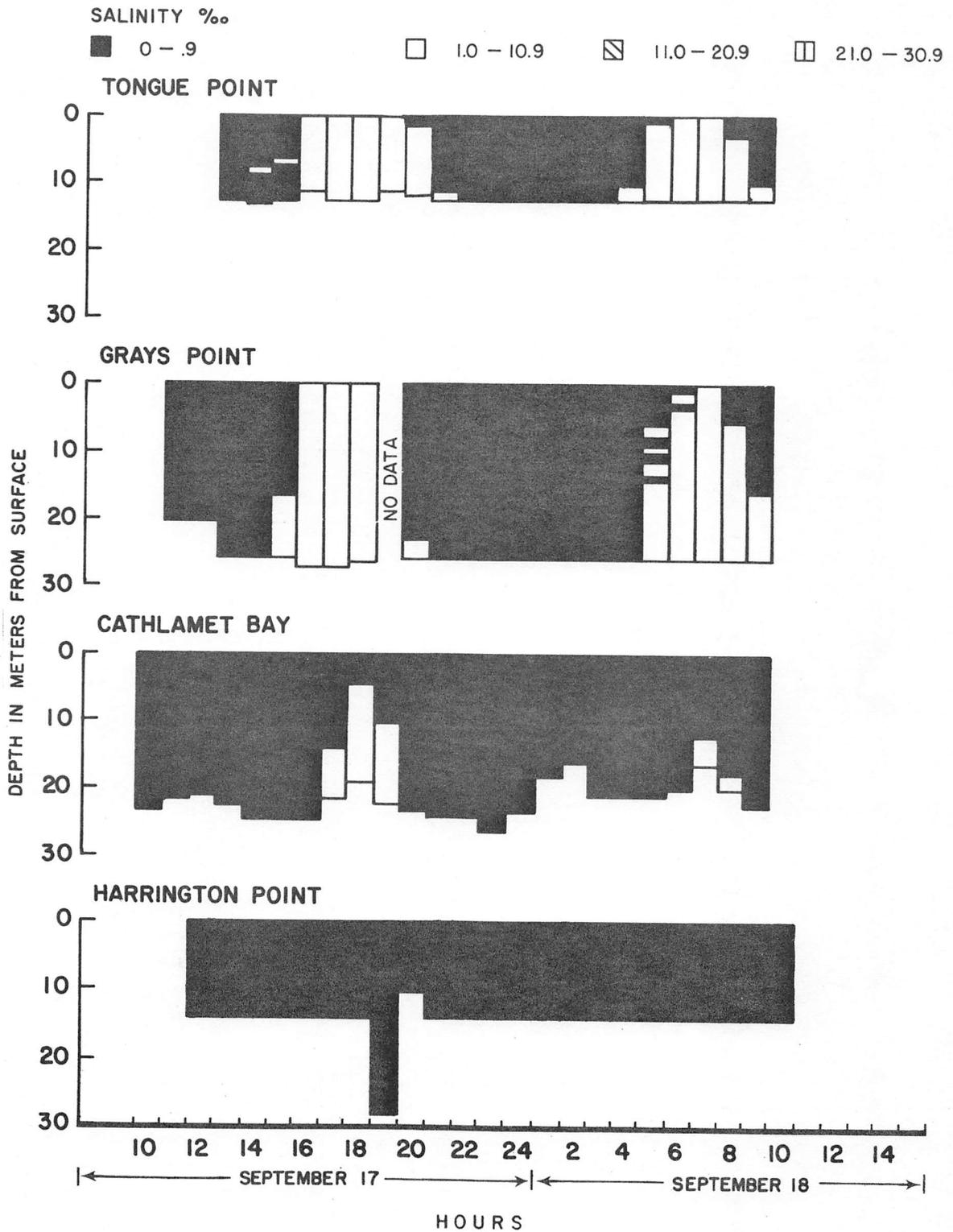


Figure 3.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 2 was on a spring tide cycle (17-18 September 1977) with a maximum tide differential of 9.5 feet. River flow 3,270 m³/s (115,500 cfs).

Five-Six October

The third survey was conducted between 1200 h 5 October through 1300 h 6 October. The neap tide had a maximum range of 5.8 feet; river flows averaged $3,665 \text{ m}^3/\text{s}$ (129,500 cfs). Water temperatures ranged from 11° to 16°C . Intruding salt water of varying concentration was found at all stations (Figure 4). The peak salinity (34.2 o/oo) found during the total study was measured at Tongue Point at 2130 h 5 October. Salinity was present at all stations but Harrington Point throughout this survey.

Tongue Point--Salinity near the bottom (12-13 m) remained above 20 o/oo during the first 11 h of the survey (1200-2300 h). Fresh water appeared in the top meter of water prior to low slack (0330 h) on 6 October. Erratic readings occurred during flood tide (0500-1000 h) on 6 October and may be due to river hydraulics.

Grays Point--Salinities near the bottom remained above 14 o/oo but did not exceed 17.1 o/oo (2030 h). Salinities less than 1.0 o/oo appeared in the top 4 m of water between 0200 and 0400 h on 6 October. Water temperatures ranged from 13° to 15°C .

Cathlamet Bay--Salinity was present at this station throughout the survey. Peak salinity (19.7 o/oo) occurred at 0500 h during the flood tide of 6 October. Water temperatures varied from 11° to 16°C .

Harrington Point--Initial salinity at 1200 h ranged from 0.2 o/oo at the surface to 5.6 o/oo at 10 m. These levels increased until 1800 h, at which time the sampling vessel moved upstream to replace the roving boat near Buoy 4 (RM 26). The vessel remained in this area until 2200 h, at which time it returned to the Harrington Point site. Peak salinity measured at the Harrington Point station (RM 23.4) was 16.6 o/oo near the bottom (18 m) at 2330 h on 5 October. During the low-high tide cycle on 6 October, the salinity peaked at 15.9 o/oo at 1130 h. A period of

freshwater outflow occurred during ebb flow. Water temperatures ranged from 13° to 15°C.

Rover Boat--Salinities were measured in the main ship channel during both high-high and high-low tide cycles. Measurements were also taken on the high-low tide in the north and south channels of Cathlamet Bay. Salinities of 8.7 o/oo were measured at 2100 h on 5 October between Buoy 14 and 14A (RM 26.5) in the main ship channel. This was the highest concentration of salt water to intrude this distance during any of the surveys.

Thirteen-Fourteen October

The fourth survey (13-14 October) was selected to monitor a 10-foot tidal change. On 13 October a high-high tide of 8.8 feet occurred at 1318 h, and a low-low tide of -1.3 feet occurred at 2012 h. Severe tidal currents occurred during ebb flow. River flows during this survey averaged 3420 m³/s (120,800 cfs). Salinity intrusions corresponding with the high-high tide (8.8 feet) were recorded at Tongue Point, Grays Point, and in Cathlamet Bay (Figure 5). Salinity was recorded only at Tongue Point and Grays Point during the (7.5-foot) low-high tide on 14 October. Salinities did not exceed 10.0 o/oo at any station during this survey. Water temperatures ranged from 12° to 15°C.

Tongue Point--For this survey, ship traffic, commercial gill net fishing, and severe currents caused us to deviate slightly from our regular sampling station and anchor the vessel in 14 m of water. Salinities reached a peak of 6.7 o/oo at 1500 h (high-high tide) and 3.8 o/oo at 0400 h (low-high tide). Fresh water was present from the surface to the bottom on ebb tide. Water temperatures ranged from 13° to 15°C.

Grays Point--Salinity data showed two mixed saline intrusions during the survey. Peak salinities recorded were 9.2 o/oo at 1530 h and 6.6 o/oo

SALINITY ‰

■ 0 - .9

□ 1.0 - 10.9

▨ 11.0 - 20.9

▤ 21.0 - 30.9

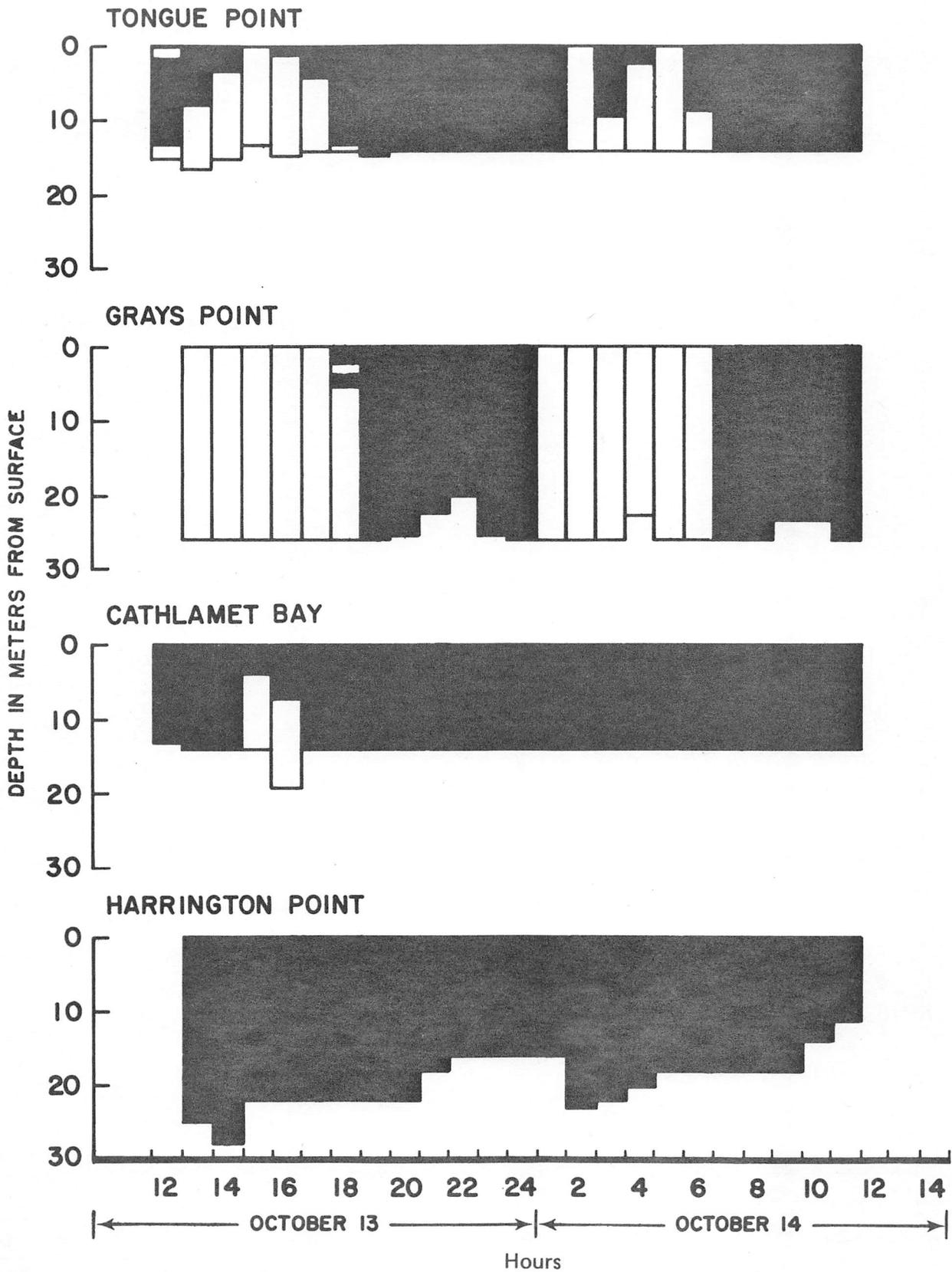


Figure 5.--Hourly salinity concentration taken at 1-m depth increments in the Columbia River estuary. Survey 4 was on a spring tide cycle (13-14 October 1978) with a maximum tide differential of 10.1 feet. River flow 3,420 m³/s (120,800 cfs).

at 0430 h. Tidal flows produced rapid changes in salinity. Water temperatures were 13° to 14°C.

Cathlamet Bay--Salinity peaked at 2.2 o/oo at 1600 h on 13 October. A low-high tide intrusion did not occur at this site. Water temperatures ranged from 12° to 15°C.

Harrington Point--Salinity did not reach 1.0 o/oo during the 24-h survey. Water temperatures remained relatively constant at 14° to 15°C.

Rover Boat--Temperature, conductivity, and salinity measurements were taken only on 13 October. A salinity intrusion of 2.1 o/oo reached Buoy 54 (RM 21.8) at 1600 h.

Twenty-Four Hour Surveys--1978

The objective of the 1978 salinity surveys was to obtain salinity information during a normal flow year for comparison with the data collected in the low flow year of 1977. Mean daily flow into the Columbia River estuary in September 1977 was approximately 3,318 m³/s (117,000 cfs) as compared to 4,780 m³/s (169,000 cfs) in September 1978. October 1977 flows averaged 3,362 m³/s (119,000 cfs) as compared to 4,379 m³/s (155,000 cfs) in October 1978.

Eighteen-Nineteen September

The fifth survey (first of 1978) was conducted on 18 and 19 September during a spring tidal cycle. Maximum tidal range was 9.2 feet with a high-high tide of 8.4 feet at 1430 h and the low-low tide (-0.8 feet) at 2100 h. Average river flow during this period was 5,159 m³/s (182,200 cfs). The highest concentration of salinity measured at the four monitoring stations (4.9 o/oo) occurred off Grays Point at 1630 h. Salinity concentrations did not exceed 0.9 o/oo in Cathlamet Channel or at Harrington Point (Figure 6). Water temperatures ranged from 18°C (fresh) to 16°C (brackish).

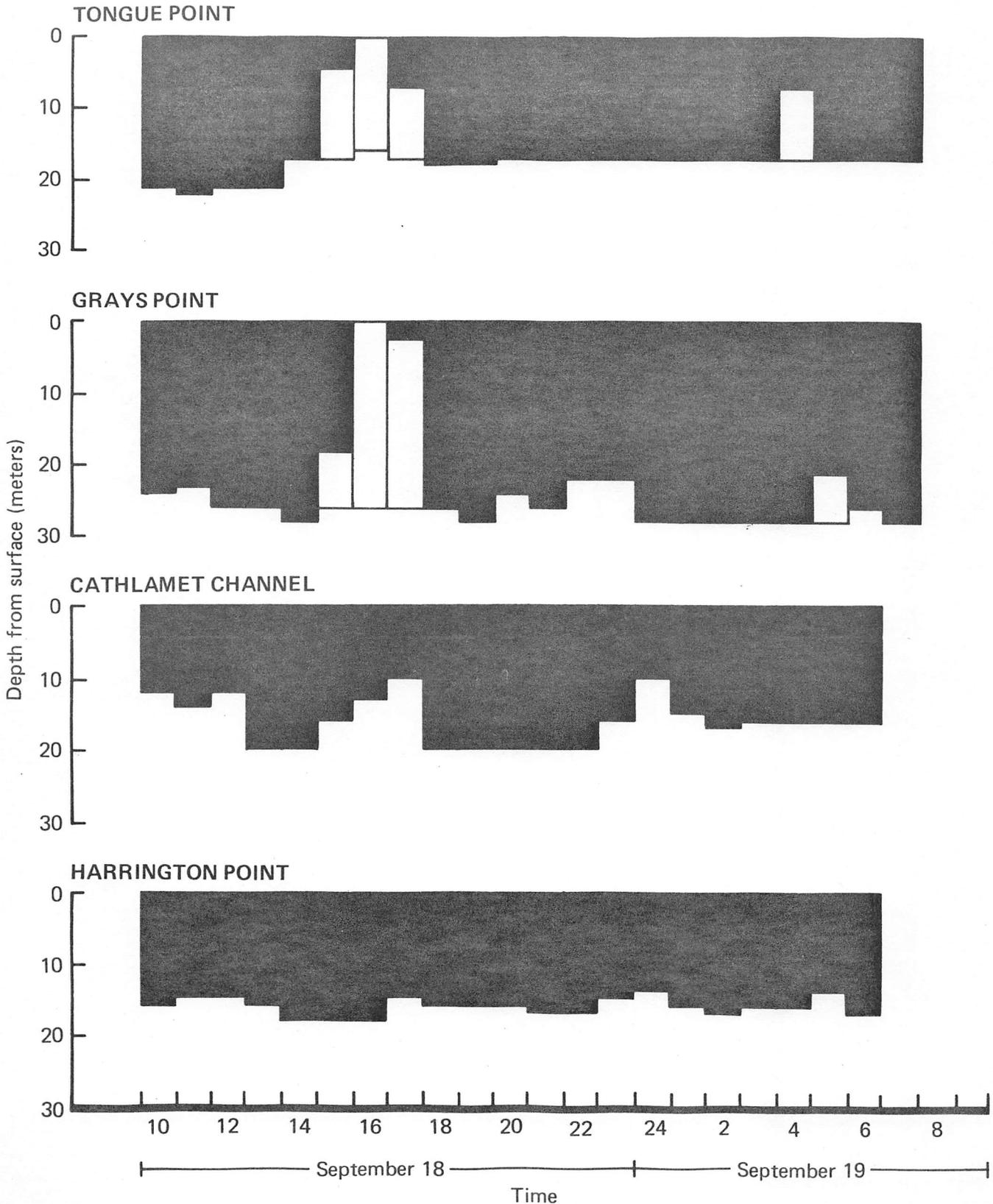


Figure 6.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 5 was on a spring tide cycle (18-19 September 1978) with a maximum tide differential of 10.1 feet. River flow $5,159 \text{ m}^3/\text{s}$ (182,200 cfs).

Tongue Point--Salinities 2.0 o/oo or greater were present at the Tongue Point station from 1500 to 1700 h; maximum salinity (3.4 o/oo) occurred at 1600 h during the high-high slack tide on 18 September. The highest salinity level recorded during the low-high cycle on 19 September was 1.4 o/oo at 0430 h. Water temperatures ranged from 16.3° to 17.4°C.

Grays Point--Salinities greater than 2.0 o/oo were first recorded near the bottom (12 to 26 m) at 1600 h on 18 September. This intrusion peaked at 4.9 o/oo 30 min later (1630 h) and then decreased to less than 1.0 o/oo by 1800 h. During the low-high tide cycle on 19 September, salinities did not reach 2.0 o/oo. Water temperatures ranged from 16.7° to 17.5°C.

Cathlamet Bay--Water in Cathlamet Bay remained fresh throughout the survey. Water temperatures varied between 16.7° and 17.5°C.

Harrington Point--Salinity at this station did not exceed 0.4 o/oo during the survey. Water temperatures ranged from 17.3° to 18.0°C.

Rover Boat--On 18 September salinity measurements were taken in the main ship channel from Buoy 27 (RM 9.9) to Tongue Point (RM 18.2) and also in the area north of the channel between the Astoria-Megler Bridge (RM 13.6) and Rice Island (RM 22.0). During this survey, salinities were generally higher in the area north of the ship channel. The furthest point of salt intrusion (2.8 o/oo) recorded was southwest of Rice Island (RM 20.4) at 1520 h.

Twenty-Five--Twenty-Six September

The sixth survey took place during the September neap tide cycle--with a maximum tidal range of 6.1 feet. The high-high tide at Tongue Point was 6.8 feet at 2000 h followed 7 h later with a low-low tide of 0.7 feet. Average daily river flow for the period was 5,005 m³/s (176,800 cfs). Salinities greater than 2.0 o/oo were present near the bottom at Tongue

Point, Grays Point, and in Cathlamet Bay throughout the 24-h survey (Figure 7). Measurements were taken from the roving boat throughout the upper estuary. A maximum upstream intrusion (3.7 o/oo) was recorded at 1300 h on 26 September at Buoy 12 (RM 24.9). Water temperatures ranged from 15.3°C (brackish) to 17.4°C (fresh).

Tongue Point--Sampling began at 1230 h 25 September. Salinity ranged from 0.9 o/oo at the surface to 16.9 o/oo at 17 m. Salinity within the water column steadily increased until 2000 h, when a maximum salinity of 21.9 o/oo was recorded at 17 m. The salt concentrations near the bottom (13-17 m) remained greater than 20.0 o/oo until 2300 h, then decreased to 4.9 o/oo by 0400 h, and increased again to 18.0 o/oo (1300 h) during the low-high tide cycle on 26 September. Water temperatures at this station ranged from 15.3°C (brackish) to 17.1°C (fresh).

Grays Point--Salinities near the bottom remained above 3.4 o/oo throughout the survey with a peak concentration of 12.8 o/oo occurring at midnight. Surface salinities during the 6.8-foot tide on 24 September remained below 1.0 o/oo (one exception 1.5 o/oo at 2230 h); however, during the low-high cycle on 25 September surface salinities greater than 1.0 o/oo were recorded over a 4-h period. A layering effect occurred during the ebb tide periods.

Cathlamet Bay--The bottom of Cathlamet Bay remained brackish throughout this survey. A peak salinity intrusion of 11.8 o/oo at 16 m occurred at 2400 h. A concentration of 9.0 o/oo was recorded at 1330 h on 26 September. A freshwater overflow occurred during the ebb tide period 2300 to 0900 h. Water temperatures ranged from 16.2°C (brackish) to 17.5°C (fresh).

Harrington Point--The first indication of a salinity intrusion at the Harrington Point site (RM 23.4) occurred at 2000 h, when a 1.9 o/oo

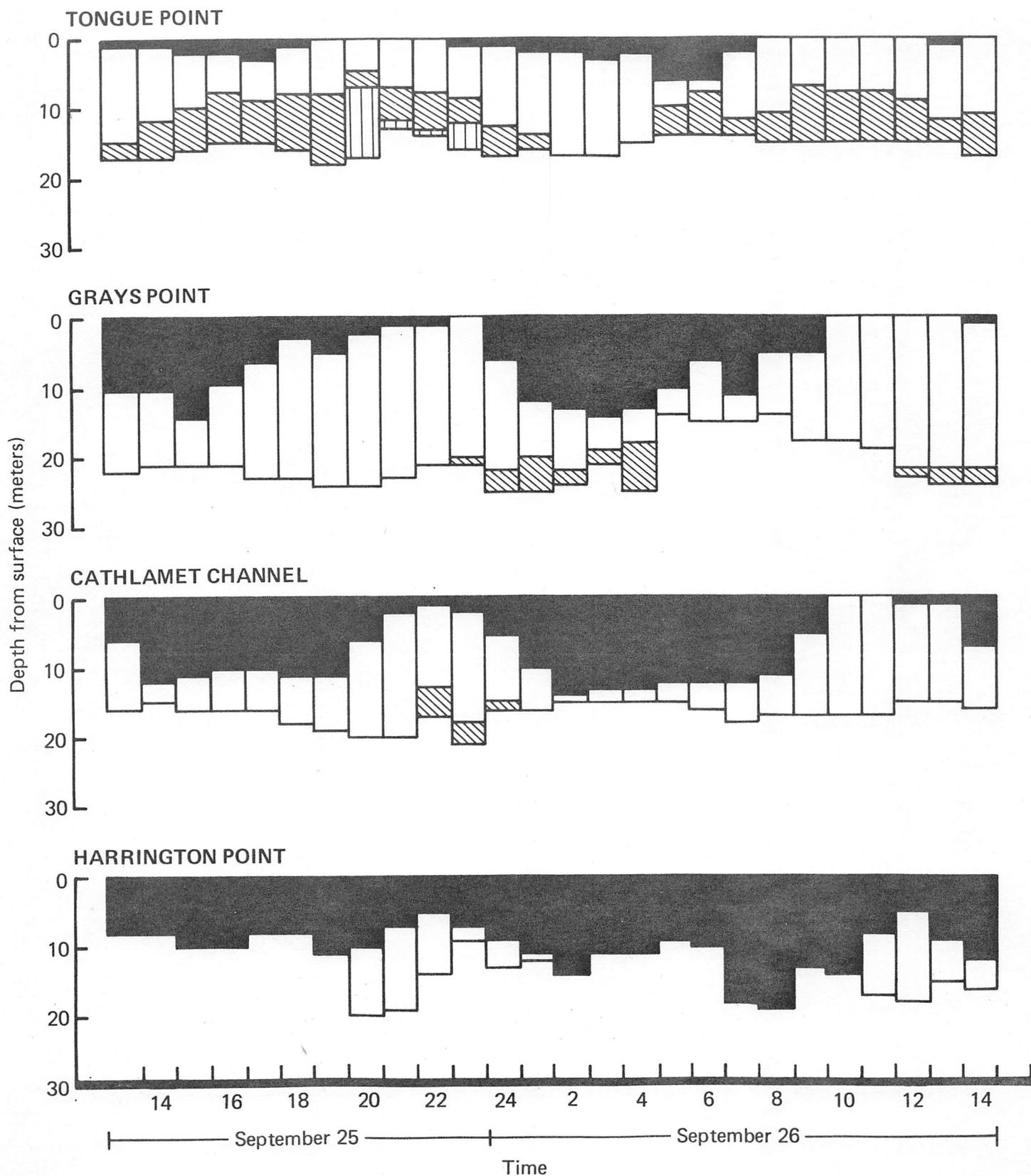


Figure 7.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 6 was a neap tide cycle (25-26 September 1978) with a maximum tide differential of 6.1 feet. River flow 5,005 m³/s (176,800 cfs).

salinity was recorded near the bottom. Maximum concentration (8.1 o/oo) did not occur until 0030 h; however, by 0200 h the concentration top to bottom was 0.2 o/oo. A level of 5.7 o/oo was recorded during the low-high tide on 26 September. The surface water layer (0-5 m) did not exceed 0.8 o/oo during the 24-h survey (Figure 7). Water temperatures at this site ranged from 16.6° to 17.2°C.

Rover-Boat--Measurements were taken in the main ship channel from 1230 to 1830 h on 25 September. On 26 September, the rover boat worked in Grays Bay and the main ship channel from 0800 to 1400 h. Maximum salinity intrusion (3.6 o/oo) was recorded at Buoy 12 (RM 24.9) at 1300 h during the low-high tidal cycle on 26 September.

Sixteen-Seventeen October

Survey Seven was conducted on 16 and 17 October during the spring tidal cycle. Highest tide of the month was recorded at Tongue Point on 16 October at 1312 h. The high-high tide (8.8 feet) was followed by a low-low tide of -1.1 feet; a differential of 9.9 feet. River flows averaged 4,346 m³/s (153,500 cfs).

The first salinity samples were taken at 0900 h on 16 October during a flood tide; monitoring continued until 0730 h on 17 October. Salinities did not exceed 9.2 o/oo at any of the four monitoring stations (Figure 8). Water temperatures ranged from 16.2°C (brackish) to 14.6°C (fresh).

Tongue Point--Highest surface salinity recorded at this station during the survey was 3.5 o/oo at 1430 h; however, maximum salinity did not occur until 1530 h when 8.6 o/oo was recorded at the bottom (13 m). A layering effect occurred during the flood tides but progressed rapidly to a fresh-water outflow. Water temperatures ranged from 14.6° to 15.8°C.

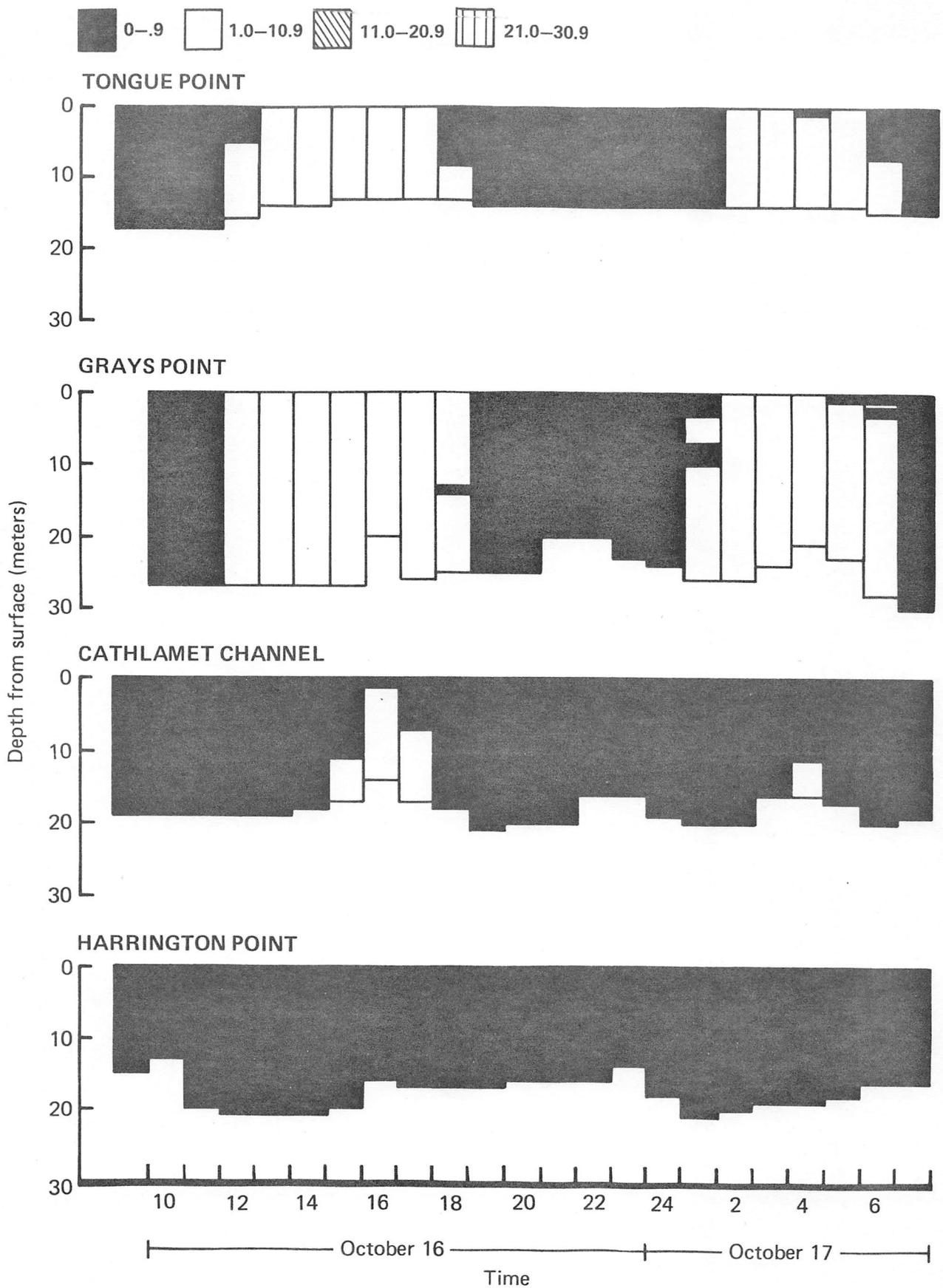


Figure 8.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 7 was on a spring tide cycle (16-17 October 1978) with a maximum tide differential of 9.9 feet. River low 4,346 m³/s (153,500 cfs).

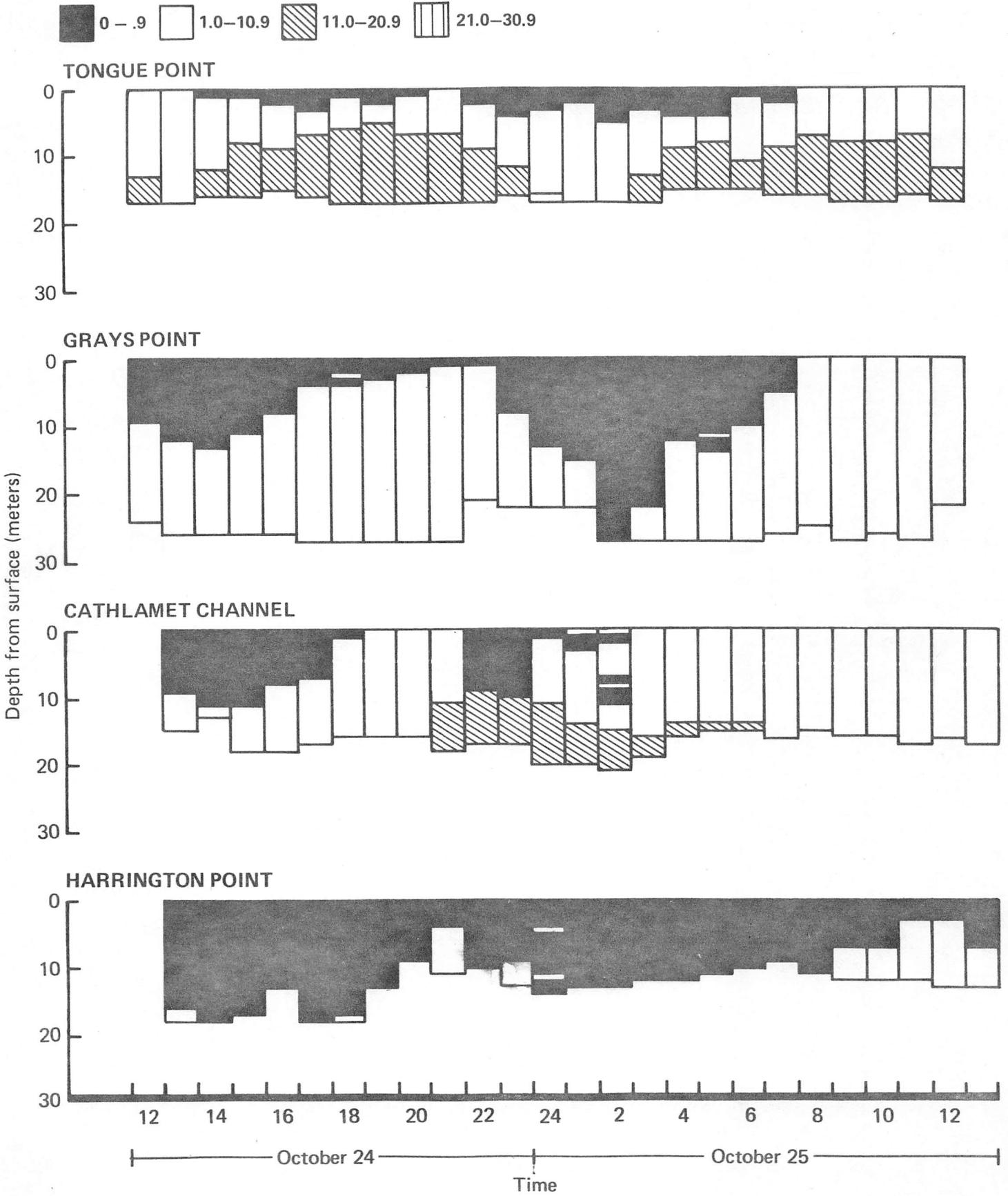


Figure 9.--Hourly salinity concentrations taken at 1-m depth increments in the Columbia River estuary. Survey 8 was on a neap tide cycle (24-25 October 1978) with a maximum tide differential of 9.9 feet. River flow 4,480 m³/s (158,200 cfs).

Grays Point--Highest salinity value recorded (9.2 o/oo) at any of the four monitoring sites occurred on the bottom (20 m) at 1600 h. Concentrations greater than 1.0 o/oo were present top to bottom between 1200 and 1800 h on 16 October and from 0130 to 0530 h on 17 October. A freshwater outflow was recorded during the ebb tide. Water temperatures ranged from 14.7° to 16.2°C.

Cathlamet Bay--A peak salinity of 2.0 o/oo occurred at 1500 h during high slack water on 16 October. Fresh water predominated at this station during most of the survey, with salinity levels in excess of 1.0 o/oo occurring between 1430 and 1630 h on the 16th and at 0400 h on the 17th. Water temperatures ranged from 15.7° to 16.2°C.

Harrington Point--Salinities at this site did not exceed 0.2 o/oo during this survey. Water temperatures ranged from 15.7° to 16.2°C.

Rover Boat--The rover boat operated between 0830 and 1615 h on 16 October taking samples in the main ship channel, Grays Bay, and Cathlamet Bay. A peak salinity intrusion of 3.7 o/oo was recorded at 1500 h in the main ship channel near Buoy 54 (RM 21.8).

Twenty-Four--Twenty-Five October

The eighth 24-h survey took place during a neap tide cycle on 24-25 October. Maximum tidal range during this survey was 5.6 feet. Average river flow was 4,480 m³/s (158,200 cfs). A substantial saline intrusion occurred throughout the estuary (Figure 9), with a maximum upstream intrusion of 4.2 o/oo recorded at Buoy 13 (RM 25.9) at 2230 h on 24 October. Water temperatures ranged from 11.5° to 15.1°C.

Tongue Point--Sampling began at 1200 h with an initial salinity of 1.4 o/oo at the surface and 19.0 o/oo at the bottom (17 m). One hour later at low tide, surface salinity was still 1.3 o/oo; however, the concentration at 17 m had decreased to 10.4 o/oo. A freshwater overflow at

the surface was recorded during the next 4 h; however, salinity below 10 m steadily increased during the flood tide reaching a peak of 22.9 o/oo on the bottom at 1900 h. During the low-high tide cycle a salinity of 20.4 o/oo was recorded at 0300 h. Water temperatures ranged from 11.5° (brackish) to 14.3°C (fresh).

Grays Point--Salinity at this site reached a maximum concentration of 10.1 o/oo at 1330 h on 25 September. A freshwater overflow varying from the top meter to a depth of 26 m was present during the first 20 h of the survey. At 0200 h the entire water column consisted of fresh water (<1.0 o/oo); however, from 0900 to 1330 h on 25 October salinities >1.0 o/oo were present top to bottom--peaking at 20.1 o/oo near the bottom at 1330 h (Figure 9). Water temperatures ranged from 13.3° to 15.1°C.

Cathlamet Bay--Salinity near the bottom exceeded 3.4 o/oo throughout the survey and reached a maximum concentration of 15.2 o/oo at 2130 h on 24 October. Concentrations >11.0 were present near the bottom of Cathlamet Bay over a 9-h period (2100 to 0600 h), and the entire water column contained salinities >1.0 o/oo during 14 of the 24 h surveyed. A freshwater overflow did occur during the late ebb tide (Figure 9).

Harrington Point--A peak salinity intrusion of 8.8 o/oo was recorded at 13 m at 2330 h on 24 October. A freshwater overflow was present throughout the survey, with salinities >1.0 o/oo occurring only at the peak of the flood tides. Water temperatures ranged from 13.8 to 14.7°C.

Rover Boat--On 24 October the rover boat operated in the main ship channel and in the south channel of Cathlamet Bay (Figure 1) from 1430 to 2300 h. At 1615 h a salinity reading of 4.7 o/oo was taken in the south channel at the mouth of the John Day River (RM 20.6). A maximum saltwater

intrusion of 4.2 o/oo was measured in the main ship channel at RM 25.4 at 2230 h.

On 25 October the rover boat operated in the main ship channel and Grays Bay from 0800 to 1230 h. At 1000 h a salinity of 2 o/oo was recorded off Rocky Point (RM 21.5). From 1230 to 1330 h the rover boat operated in the south channel of Cathlamet Bay. At 1330 h a salinity reading of 13.6 o/oo was recorded at the mouth of the John Day River (RM 20.6).

SUMMARY AND CONCLUSIONS

Salinity, conductivity, and temperature were measured hourly at each meter of depth at four locations in the Columbia River estuary during eight 24-h surveys. The extent of the saltwater intrusion was determined for each survey by following the saltwater wedge as it moved upstream.

The 1977 salinity studies took place during a near record low-flow for the Columbia River. Mean monthly flows into the estuary during September and October of 1977 were 77 and 70 % of the 15-yr average. River flows during September and October 1978 were near normal at 117 and 100 % of the 15-yr average, thus providing data for comparison.

Based on previous records, the concentration, extent, and duration of saltwater intrusion into the middle and upper Columbia River estuary (RM 18.2 to 26.5) were greater than expected. Haertel and Oserberg (1967) state maximum salinity in the Columbia River occurs with high tide and low river flow and probably intrudes less than 20 nautical miles (RM 23). Their salinity measurements in the upper estuary were taken at low tide and therefore represent minimum salinity. Lutz et al. (1975) measured salinity throughout the estuary during a September 1969 spring tide cycle (range 7.2 feet). Their records show salinities of less than 10 o/oo at Tongue Point (RM 18.2) and less than 2 o/oo near RM 20. These concentrations correspond

to our salinity data collected during the September 1977-1978 spring tide cycles. In October 1972, Misitano (1974) recorded salinities to 22 o/oo at Tongue Point (RM 18.2) and salinities to 6.6 o/oo at Harrington Point (RM 23.4). These data were collected during a neap tide cycle (tidal range 6.5 feet) at a monthly mean river flow of 4,460 m³/s (157,500 cfs).

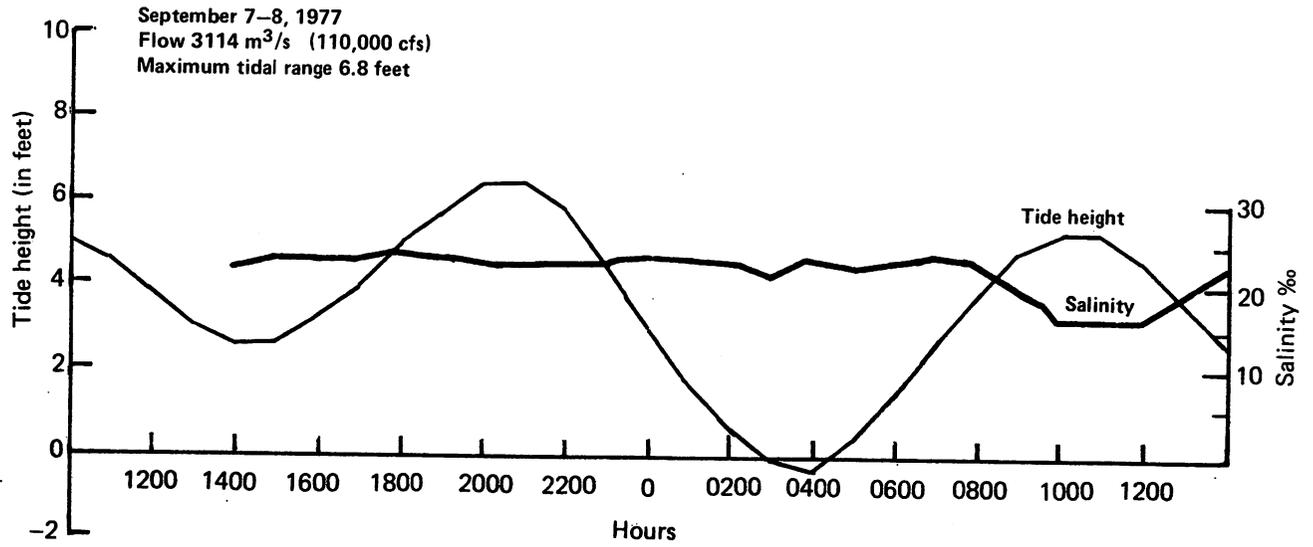
Our sampling periods for the 1977 and 1978 surveys were selected to correspond to the September and October monthly spring and neap tide cycles. Average river flow during the four 24-h salinity surveys in 1977 ranged from 3,114 m³/s (110,000 cfs) to 3,665 m³/s (129,500 cfs). Salinity data were collected over tidal ranges which varied from a minimum of 3.4 feet to a maximum of 10.1 feet. Figure 10 shows the 24-h tide cycles and corresponding salinities at Tongue Point for the 1977 surveys.

River flows during the 1978 salinity surveys ranged from 4,346 m³/s (153,500 cfs) to 5,159 m³/s (182,200 cfs). Maximum tidal range during the 1978 surveys was 9.9 feet on 16 October; a minimum tidal range of 2.9 feet was monitored on 24 October 1978. The tide cycles and corresponding salinities at Tongue Point are presented in Figure 11.

Monthly neap tides produced the highest salinity concentrations with the longest duration and the farthest upstream intrusion of saline water during each of the 4 months (Table 1). The higher river flows during the 1978 surveys did restrict the concentration and extent of intruding salt water; however, during the 25 October 1978 survey, saline water (4.2 o/oo) was measured at RM 25.4 during a mean flow period of 4,480 m³/s (158,220 cfs).

Extent of upstream intrusion of salinity was recorded for each survey; the criteria established was the farthest intrusion of salinity \geq 2.0 o/oo. Salinity intrusion in the main ship channel extended at least 20 miles upstream during all eight surveys (Figure 12).

TONGUE POINT Survey No. 1



TONGUE POINT Survey No. 2

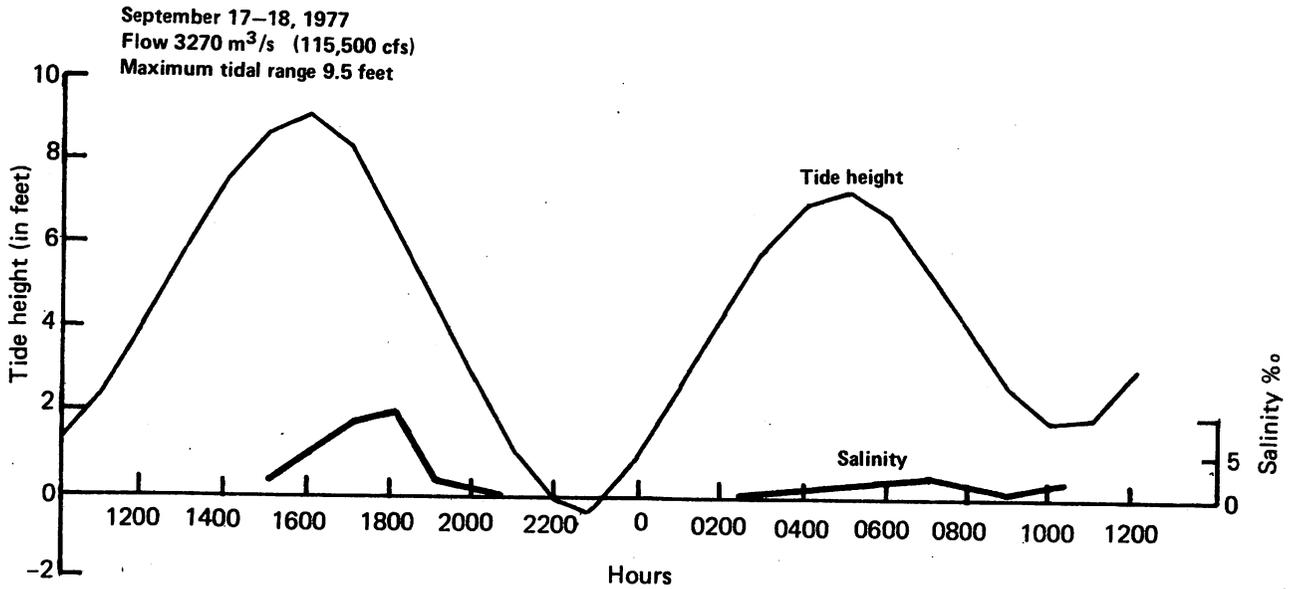
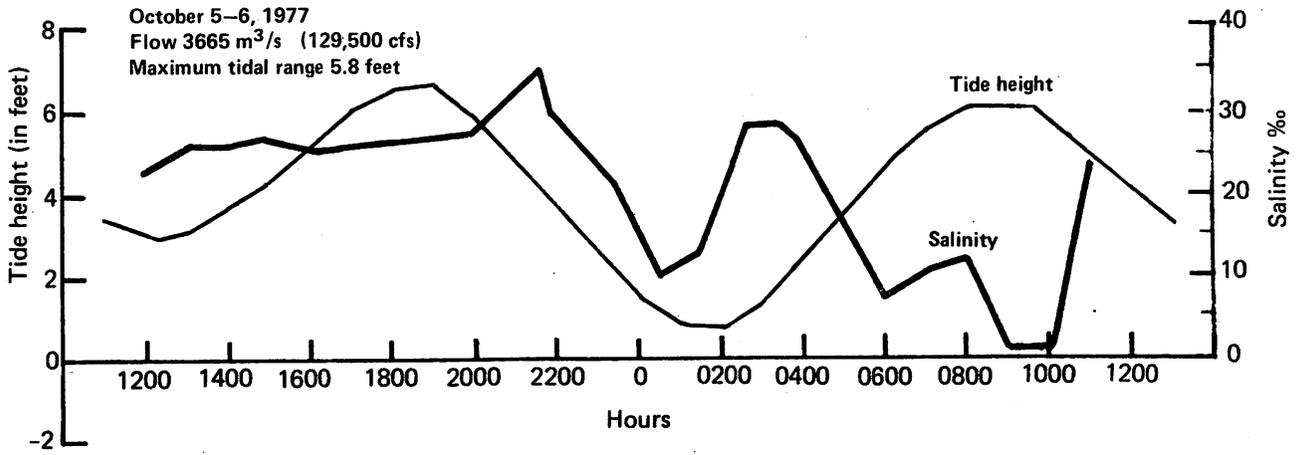


Figure 10.--The 24-h tide cycles and corresponding salinities at Tongue Point (RM 18.3) during the 1977 salinity survey.

TONGUE POINT Survey No. 3



TONGUE POINT Survey No. 4

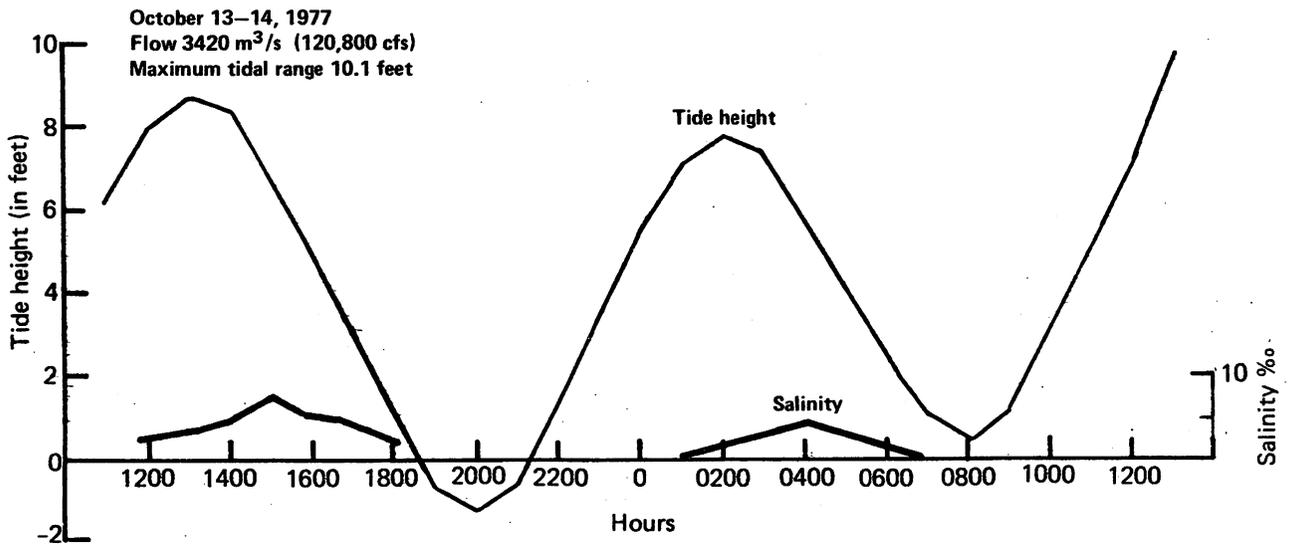
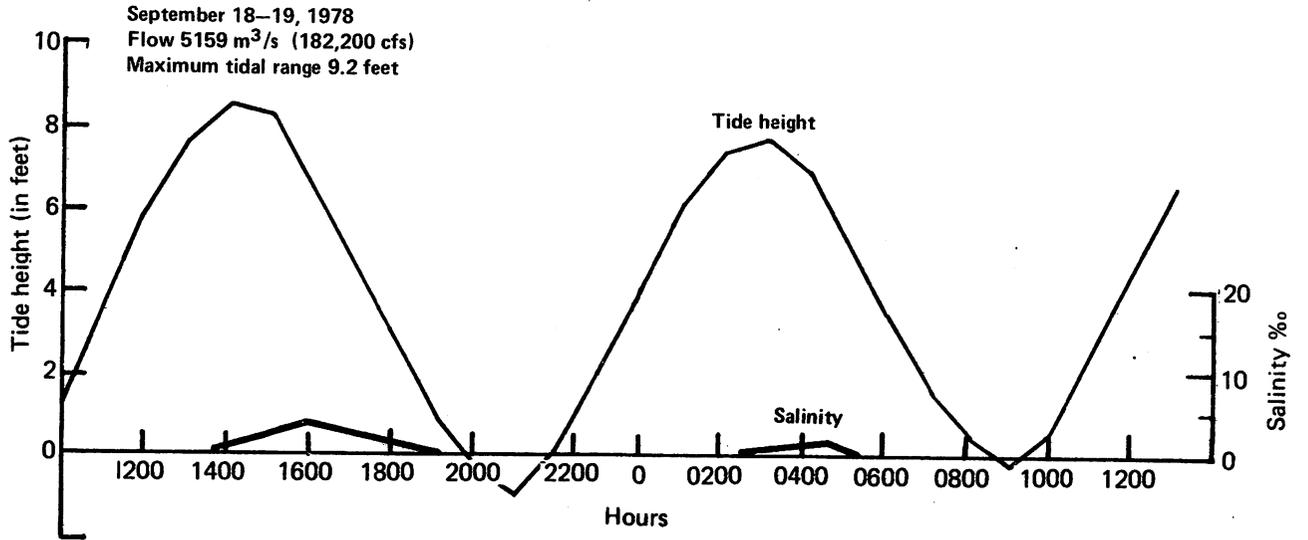


Figure 10.--Continued.

TONGUE POINT Survey No. 5



TONGUE POINT Survey No. 6

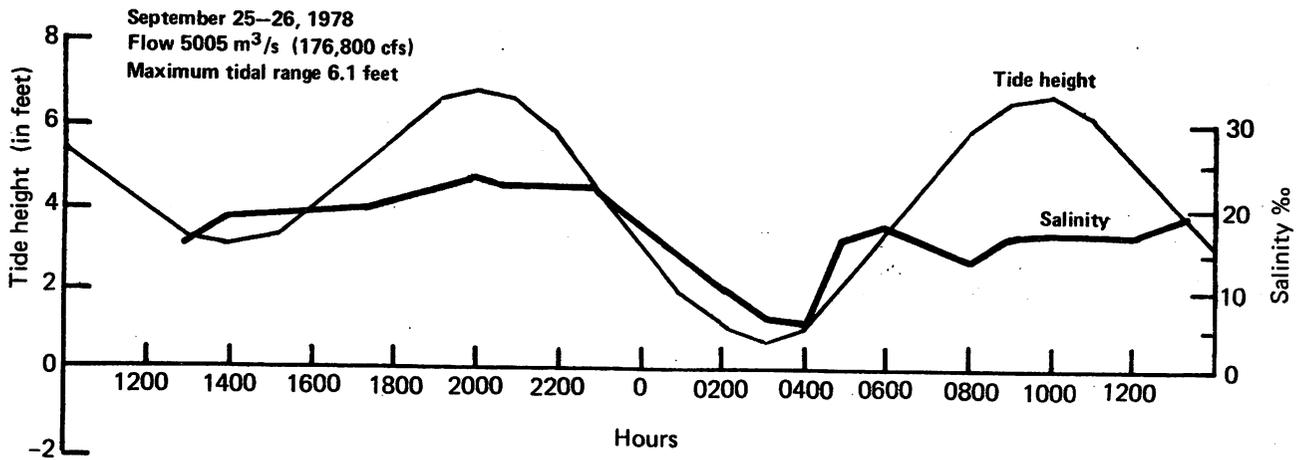
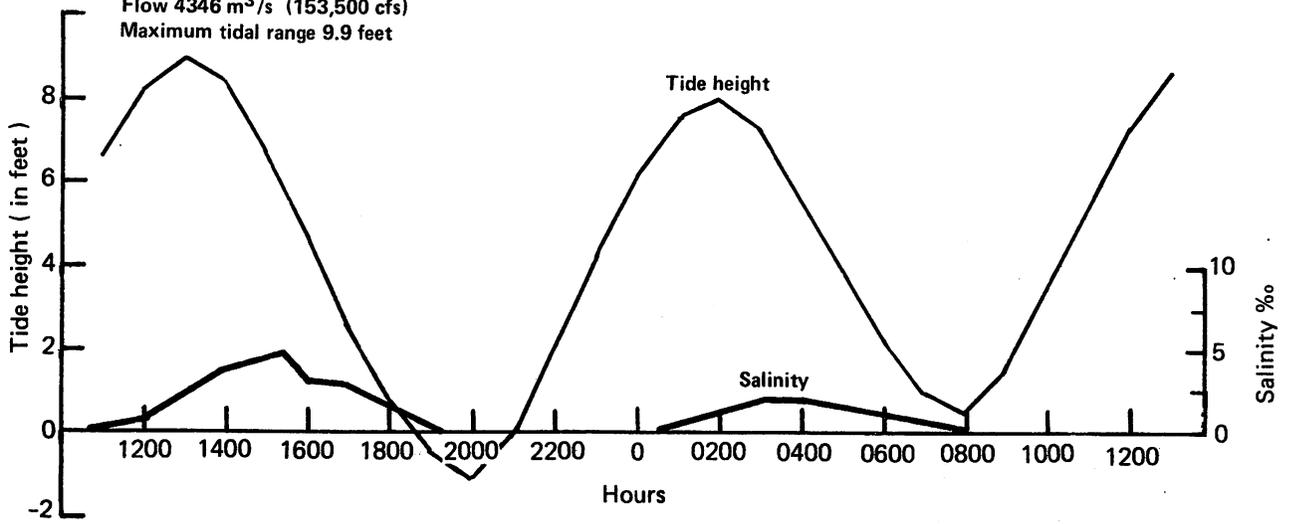


Figure 11.--The 24-h tide cycles and corresponding salinities at Tongue Point (RM 18.3) during the 1978 salinity survey.

Tongue Point Survey No. 7

October 16-17, 1978
Flow 4346 m³/s (153,500 cfs)
Maximum tidal range 9.9 feet



TONGUE POINT Survey No. 8

October 24-25, 1978
Flow 4480 m³/s (158,200 cfs)
Maximum tidal range 5.6 feet

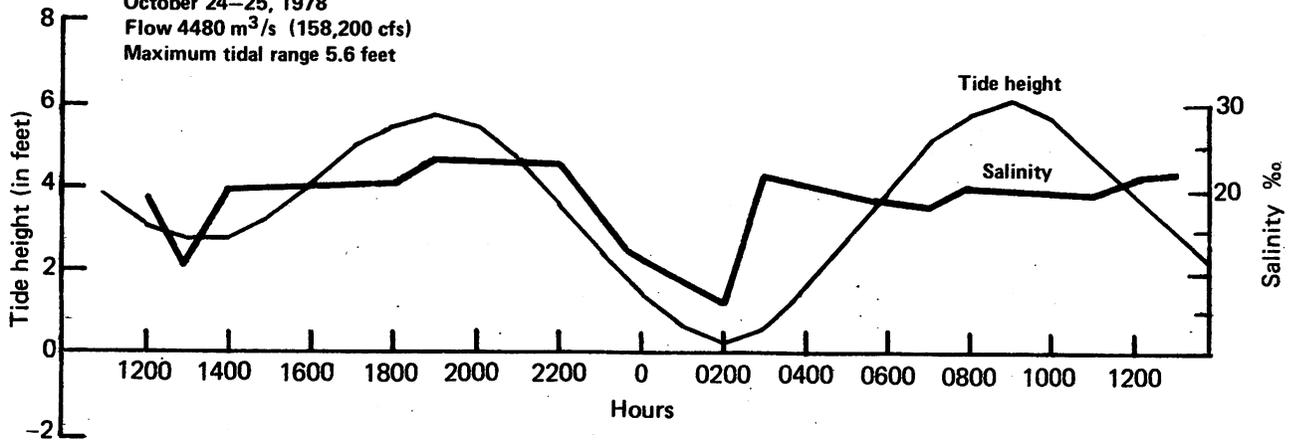


Figure 11.--Continued.

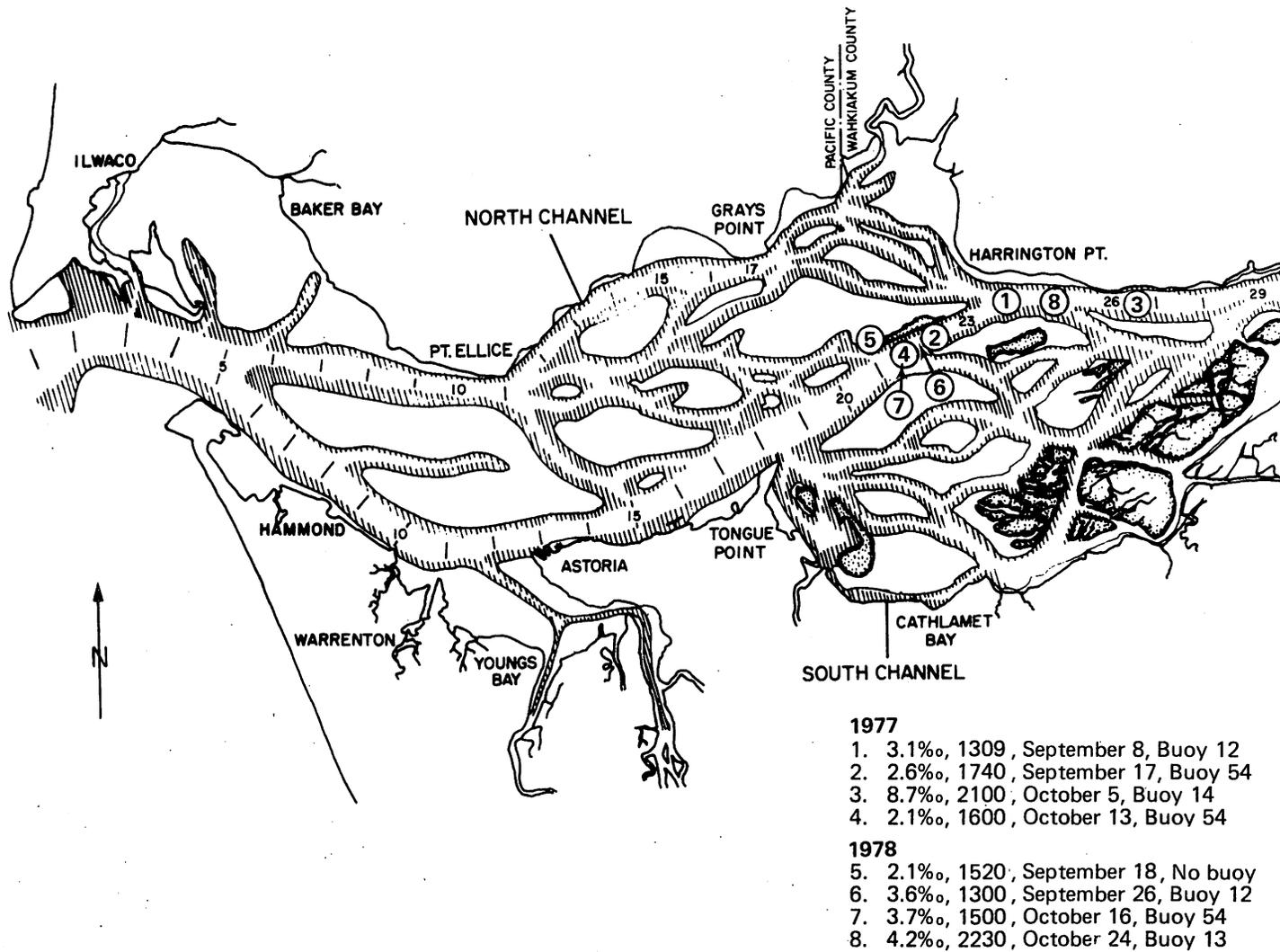


Figure 12.--Maximum upstream extent of salinity intrusion (>2.0 o/oo) in the Columbia River estuary during eight surveys September and October 1977, 1978.

Table 1...Maximum extent of saltwater intrusion of >2.0 o/oo during eight 24-h surveys in the Columbia River estuary September and October 1977-1978.

| Date | Flow | | Maximum tidal range (feet) | Distance of intrusion (miles) | Salinity recorded (o/oo) |
|----------|-------------------|---------|----------------------------|-------------------------------|--------------------------|
| | m ³ /s | (cfs) | | | |
| 1977 | | | | | |
| 7 Sept. | 3,114 | 109,983 | 6.9 | 25.0 | 3.1 |
| 17 Sept. | 3,270 | 115,484 | 9.5 | 22.0 | 2.6 |
| 5 Oct. | 3,665 | 129,454 | 5.8 | 26.5 | 8.7 |
| 13 Oct. | 3,420 | 120,774 | 10.1 | 21.8 | 2.1 |
| 1978 | | | | | |
| 18 Sept. | 5,159 | 182,194 | 9.2 | 20.4 | 2.1 |
| 26 Sept. | 5,005 | 176,758 | 6.1 | 24.9 | 3.6 |
| 16 Oct. | 4,346 | 153,478 | 9.9 | 21.8 | 3.7 |
| 24 Oct. | 4,480 | 158,220 | 5.6 | 25.4 | 4.2 |

The maximum concentration of salt water (34.2 o/oo) measured was at Tongue Point on 5 October 1977. This concentration surpassed all known documented records. In addition, salinity near the bottom (12-13 m) remained above 20 o/oo during the first 11 h of the survey.

Salinity concentrations near the bottom remained around 15 o/oo throughout the third survey (Figure 13). Maximum concentration of salinity at this site was 17.1 o/oo during the third survey. A saltwater intrusion >1.0 o/oo occurred in Grays Bay on all high-high and low-high tides during each of the eight surveys.

Maximum concentration of salinity at the Cathlamet Bay site was 19.7 o/oo on the third survey. A saltwater intrusion occurred at this site during all but the fifth survey.

Salinity data collected at Harrington Point (RM 23.4) shows a saltwater intrusion for all surveys taken during the neap tide cycles [Surveys 1, 3, 6, and 8 (Table 2)]. Salt water did not reach Harrington Point during the four surveys taken on spring tide cycles (Surveys 2, 4, 5, and 7). Maximum concentration at this site was 16.6 o/oo.

Studies by Haertel (1965) and Neal (1965) indicate that salinities were higher on the northern side of the river (North Channel) than in the main ship channel. This may be true for the lower estuary downstream from the Astoria Bridge (RM 13.6); however, a comparison between salinity data taken on the north side of the river at Grays Point (RM 19.3) and data taken in the main channel at Tongue Point (RM 18.2) shows much higher salinity concentrations at Tongue Point during seven of our eight surveys. The exception was Survey 7 (16-17 October 1978) conducted during the highest tide of the month. Data from this survey indicate slightly higher salinities at Grays Point (Grays Point, 9.2 o/oo; Tongue Point, 8.5 o/oo).

GRAYS POINT
October 5-6, 1977

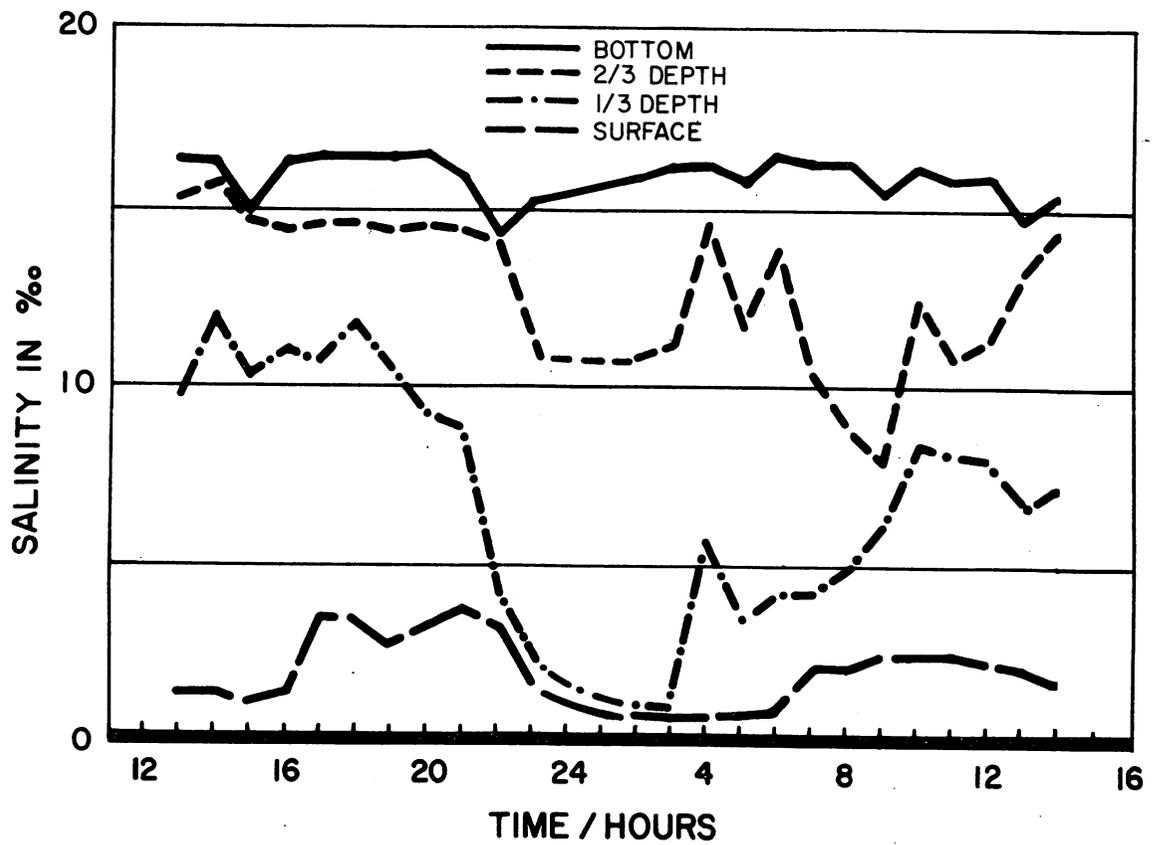


Figure 13.--Salinity concentration (o/oo) from four depths at Grays Point (RM 19.3) on the north (Washington) side of the Columbia River. This 24-h survey was during a neap tide cycle.

Table 2...Peak concentration and duration of salinity at Harrington Point (RM 23.4) during eight 24-h surveys. September-October 1977-1978.

| Survey | Flow | | Maximum tidal range (feet) | Peak concentration (o/oo) | Duration (h) |
|--------|---------------------|---------|----------------------------|---------------------------|--------------|
| | [m ³ /s) | (cfs) | | | |
| 1 | 3,114 | 109,983 | 6.8 | 15.0 | 18 |
| 2 | 3,270 | 115,484 | 9.5 | 0.0 | -- |
| 3 | 3,665 | 129,484 | 5.8 | 16.6 | 22 |
| 4 | 3,420 | 120,774 | 10.1 | 0.0 | -- |
| 5 | 5,159 | 182,194 | 9.2 | 0.0 | -- |
| 6 | 5,005 | 176,758 | 6.1 | 8.1 | 10 |
| 7 | 4,346 | 153,478 | 9.9 | 0.0 | -- |
| 8 | 4,480 | 158,220 | 5.6 | 8.8 | 10 |

Misitano's (1974) data and our data taken on the monthly neap tide cycles show higher concentrations of salinity, extending farther upstream, and remaining over a longer duration than previous studies. The earlier salinity studies in the upper estuary documented salinities at low tide (Haertel 1965; Haertel and Osterberg 1967) or during the monthly spring tide cycle (Lutz et al. 1975). Deepening of the Columbia River bar during the spring and summer of 1977 and the creation of a 40-foot by 600-foot channel through the estuary could also have contributed to the increased intrusion of salt water into the estuary.

RECOMMENDATIONS

If salinity patterns in the Columbia River estuary are changing then major ecological changes may occur. These changes could affect the distribution of benthic and pelagic fish and shellfish. Invertebrates that are beneficial to the food chain or that could be detrimental to the environment (wood borers or fouling organisms) could be changing in abundance and distribution within the estuary in such a way to affect major fisheries or impose major impacts at the fishing ports of Ilwaco and Chinook, Washington and Warrenton and Astoria, Oregon. Therefore, salinity intrusion into the Columbia River estuary should be more thoroughly examined and documented in greater temporal and spatial detail.

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