

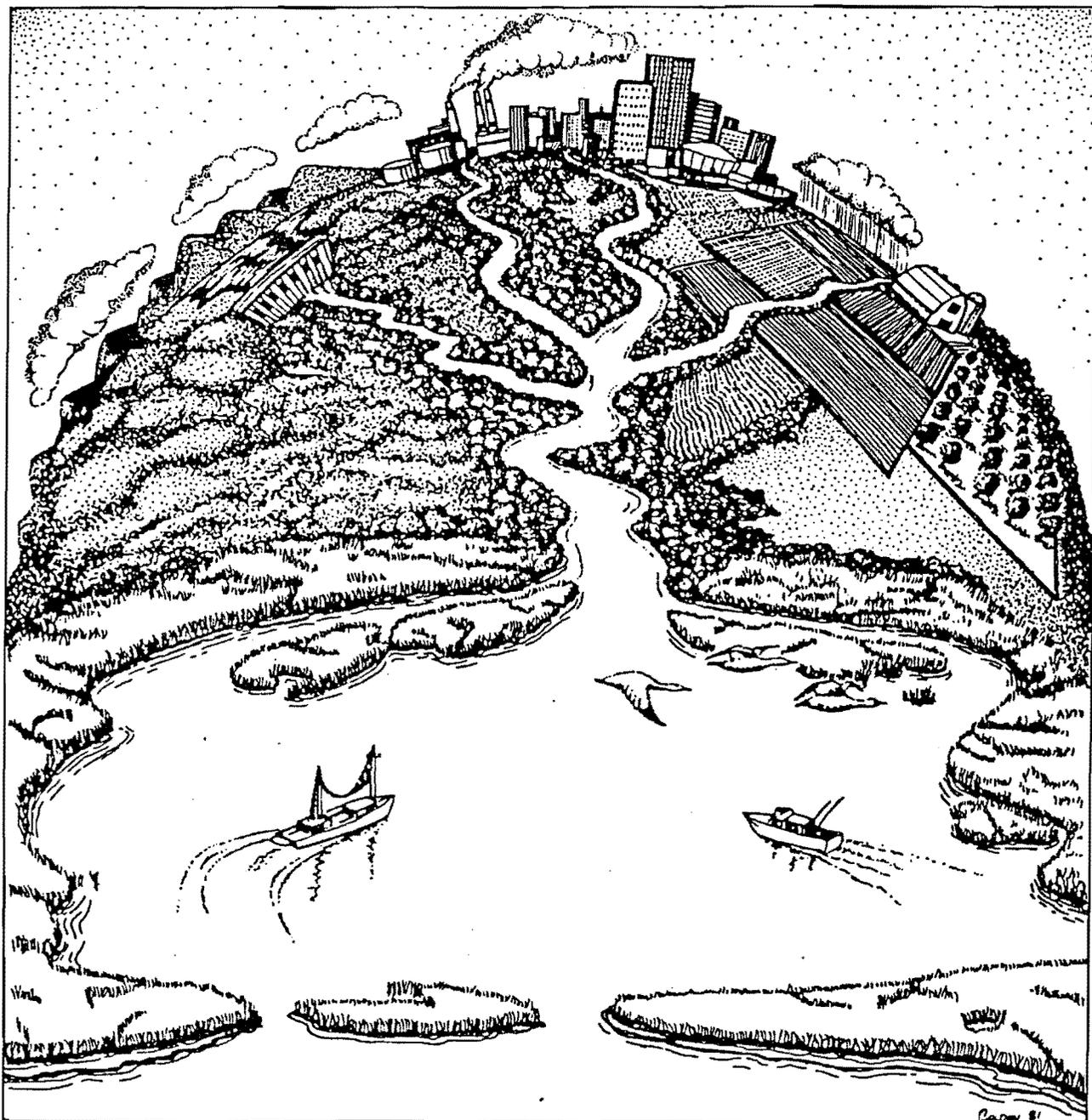
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CONCENTRATION, EXTENT, AND DURATION OF SALINITY

INTRUSION INTO THE COLUMBIA RIVER ESTUARY

SEPTEMBER-OCTOBER, 1977-1978

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ABSTRACT

Eight 24-hour (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) and minimum (neap) 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 (ppt) at Tongue Point and 17 ppt at Harrington Point. Concentrations of salt water exceeding 11 ppt were measured continually throughout one 24-h survey (7 to 8 September 1977) at Tongue and Grays Points. The farthest upstream intrusion of salt water 2 ppt was recorded between Buoy 14 and 14A at Columbia River Mile (RM) 26.5.

INTRODUCTION

In 1977 three events occurred which necessitated the gathering of 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 Corps of Engineers (COE) dredged approximately 6.9 million m³ of sediment from the Columbia River bar during the spring and summer of 1977 (this increased the depth of the bar from 14.6 to 16m); and (3) on-site salinity studies were needed to verify the Columbia River physical model which was recently renovated for studies at the COE Waterways Experiment Station (WES).

This study was partially funded by the Portland District COE and was conducted by the National Marine Fisheries Service (NMFS), Coastal Zone and Estuarine Studies Division (CZES), Northwest and Alaska Fisheries Center. The objective was to determine the concentration, extent, and duration of salinity intrusion

into the Columbia River estuary during a period of low river flow, September and October, 1977. In addition, NMFS conducted a similar study in September and October of 1978 to obtain data for comparison with the data from the 1977 low-flow year.

STUDY PLAN AND METHODOLOGY (METHODS AND MATERIALS)

In August 1977 preliminary studies were conducted to locate appropriate stations close to or on the main ship channel where vessels could anchor and not obstruct river traffic. Also, samples were taken 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 predetermined points until high tide or peak salinities occurred, then moved upriver following the 2 ppt salinity level or downstream if salinities did not reach 2 ppt.

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.

Salinity, conductivity, and temperature were measured at least once per hour (on the hour) at each meter of depth during eight 24-h survey periods at the four locations.

Measurements were taken with Beckman (Model #RS5-3) salinometers (reference to trade names does not imply endorsement by NMFS) values were recorded to the nearest tenth. River distances are presented in statute miles and tide elevations in feet to correspond to common usage on navigation and tide charts.

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. A roving boat was used to locate the furthest extent of salt-water intrusion (2.0) ppt during each survey. Because of safety and the difficulty in locating position markers at night, the roving boat operated only during daylight.

Sampling periods were selected to correspond to the monthly spring and neap tidal cycles in September and October of 1977 and 1978. Spring tides are tides of increased range occurring during the times of a new and full moon; these rise higher and fall lower than during the rest of the month. Neap tides are tides of decreased range occurring during times of the first and last quarters; these tides do not rise as high or fall as low as tides during the rest of the month.

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

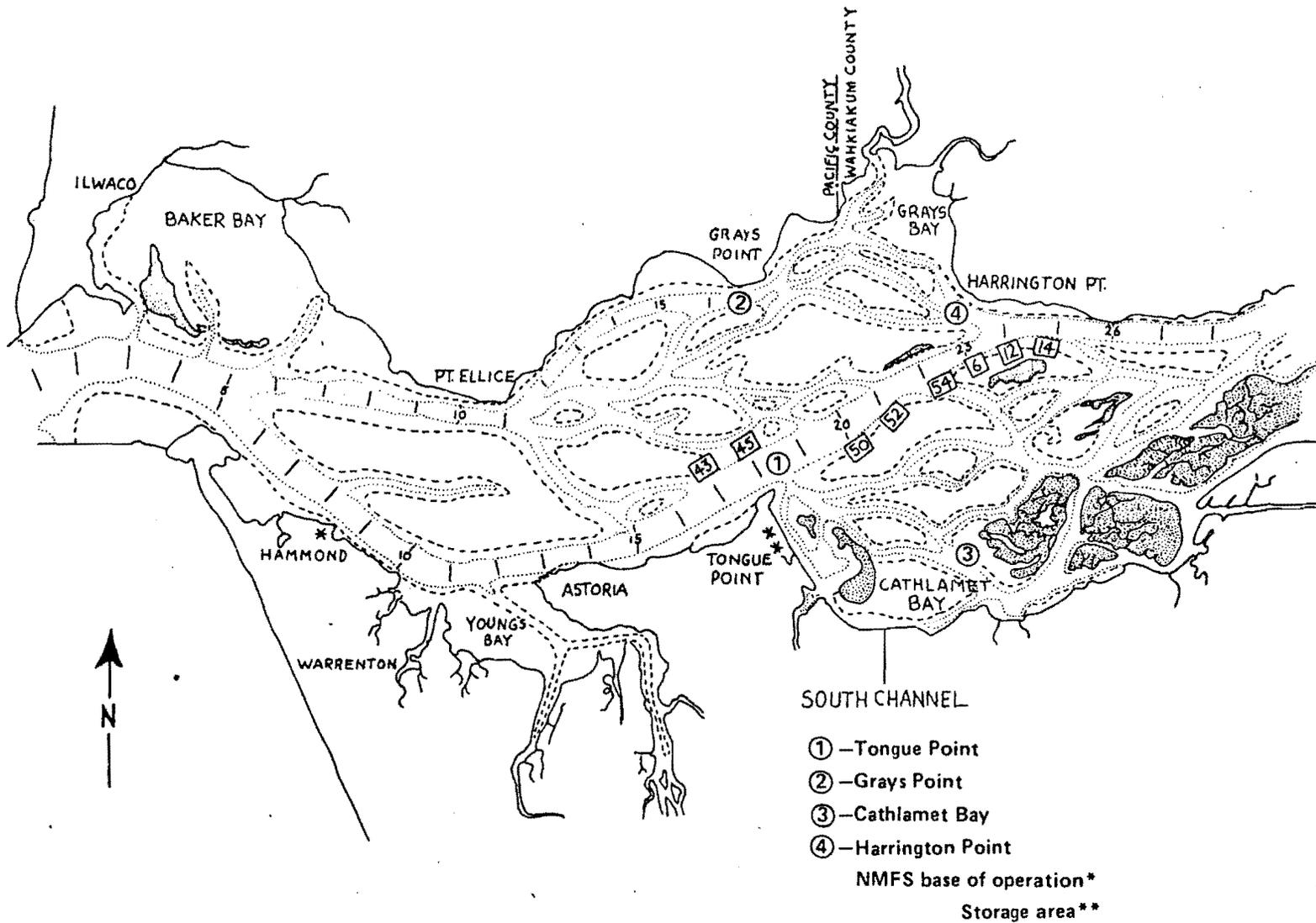


Figure 1. Sampling stations in the Columbia River estuary for the 1977-1978 salinity surveys. Distances (in river miles) are located in the center of the channels. Pertinent navigation markers are indicated by numbered squares.

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

24-HOUR SURVEYS, 1977

7 and 8 September

The first 24-h survey was during a neap tide cycle with a maximum tidal range of 6.8 feet. Average river flow was $3,114 \text{ m}^3/\text{s}$ (111,000 cfs) or 88 percent 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 ppt was found at Buoy 12, which is approximately RM 25. Salinities exceeding 15 ppt 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.

17 and 18 September

The second survey was during a spring tide cycle with a tidal range of 9.5 feet. The high-high tide intrusion did not result in salinities that exceed 10.6 ppt at any of the four monitoring stations (Figure 2). River flows averaged $3,270 \text{ m}^3/\text{s}$ (115,500 cfs) and were approximately

normal for this time of year. Water temperatures ranged from 19°C (fresh) to 16°C (brackish). A peak salinity intrusion of 2.6 ppt was measured at Buoy 54 (RM 22) at 1740 H.

5 and 6 October

The third survey was conducted on a neap tide cycle with a maximum range of 5.8 feet; river flows averaged $3,665 \text{ m}^3/\text{s}$ (129,500 cfs). Peak concentrations of salt water recorded during the study occurred at all four stations during this survey. Salinity was present at all but the Harrington Point site throughout this survey (Figure 2). Water temperatures ranged from 11° to 16°C . Salinities of 8.7 ppt 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 eight surveys.

13 and 14 October

The fourth survey (13 to 14 October) was selected to monitor a 10-ft 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 flow during this survey averaged $3,420 \text{ m}^3/\text{s}$ (120,000 cfs). Salinity intrusions corresponding with the high-high tide (8.8 feet) were recorded at Tongue Point, and in Cathlamet Bay (Figure 2). 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 ppt at any

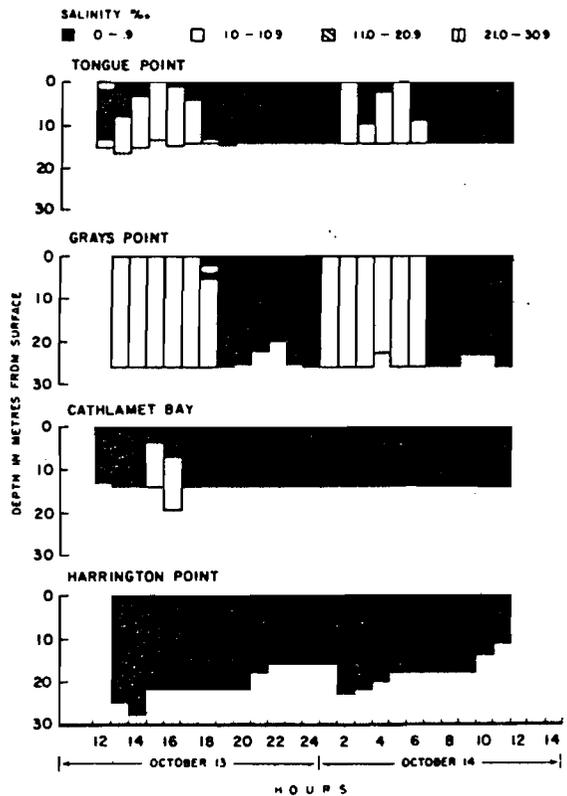
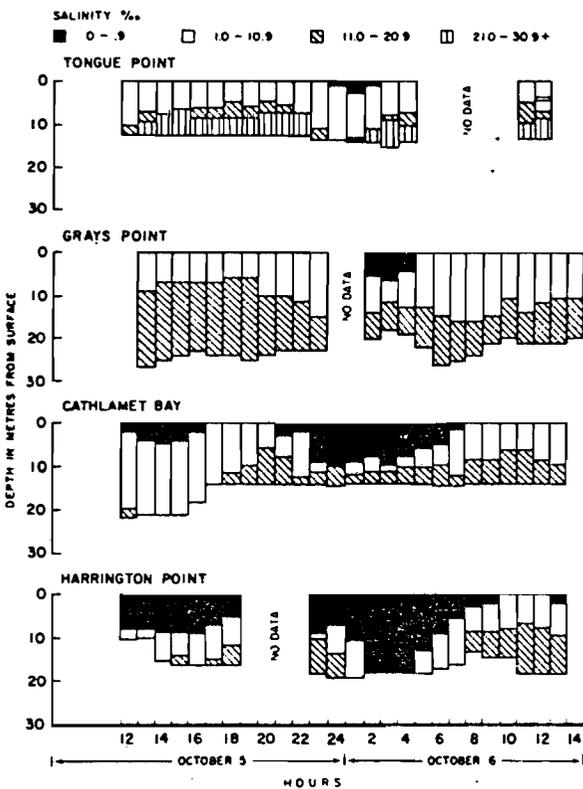
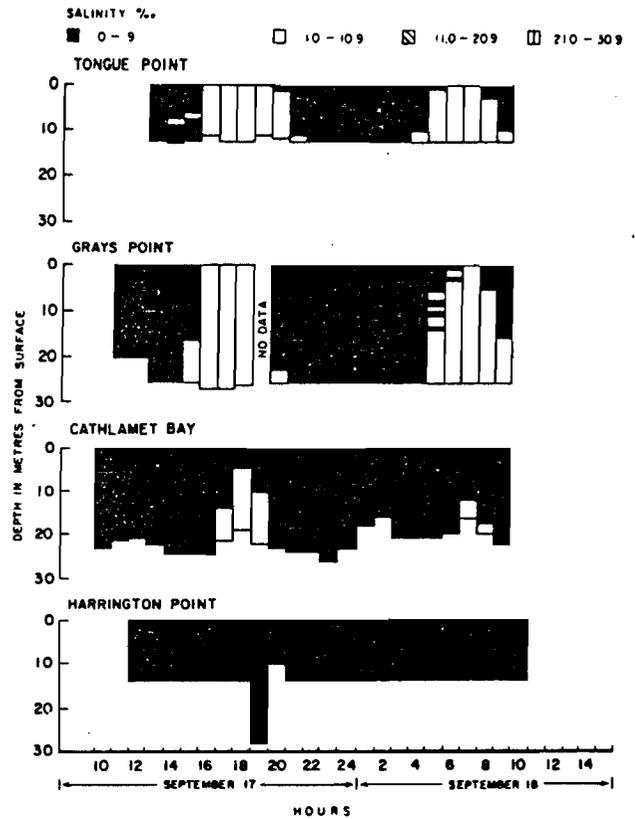
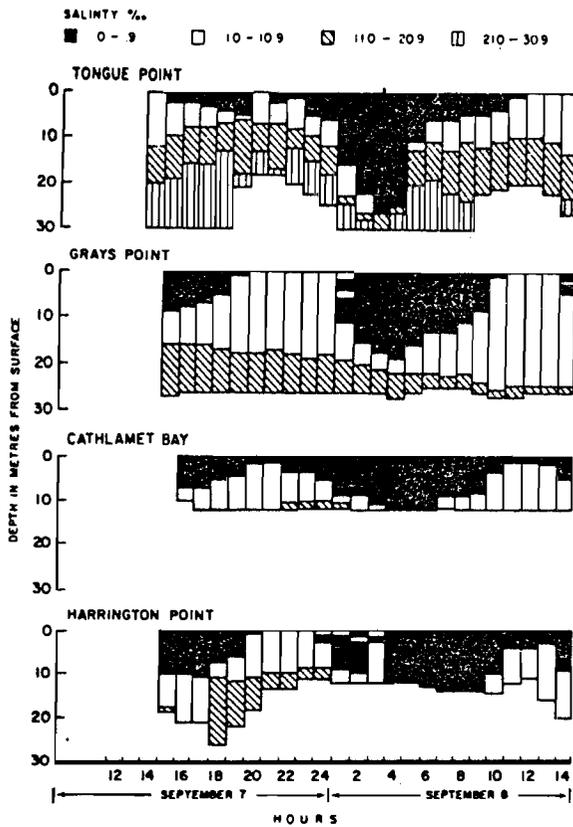


Figure 2. Salinity recorded during 1977 surveys at four locations in the Columbia River estuary.

station during this survey. Water temperatures ranged from 12° to 15°C. A salinity intrusion of 2.1 ppt reached Buoy 54 (RM 21.8) at 1600 h.

24-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.

18 and 19 September

The fifth survey 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 ppt) occurred off Grays Point at 1630 h. Salinity concentrations did not exceed 0.9 ppt in Cathlamet Bay or at Harrington Point (Figure 3). Water temperatures ranged from 18°C (fresh) to 16°C (brackish). The furthest point of salt water intrusion (2.8 ppt) recorded was southwest of Rice Island (RM 20.4 at 1520 h.

25 and 26 September

The sixth survey took place during the September neap tide cycle, with a maximum tide 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 (176,000 cfs). Salinities greater than 2.9 ppt were present near the bottom at Tongue Point, Grays Point, and in Cathlamet Bay throughout the 24-h survey (Figure 3). Measurements were taken from the roving boat throughout the upper estuary. A maximum upstream intrusion (3.7 ppt) 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).

16 and 17 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 (153,000 cfs). Salinities did not exceed 9.2 ppt at any of the four monitoring stations (Figure 3). Water temperatures ranged from 16.2°C to 14.6°C. A peak salinity intrusion of 3.7 ppt was recorded at 1500 h in the main ship channel near Buoy 54 (RM 21.8).

24 and 25 October

The eighth 24-h survey took place during a neap tide cycle on 24 and 25 October. Maximum tidal range during this survey was 5.6 feet. Average river flow was 4,480 m³/s

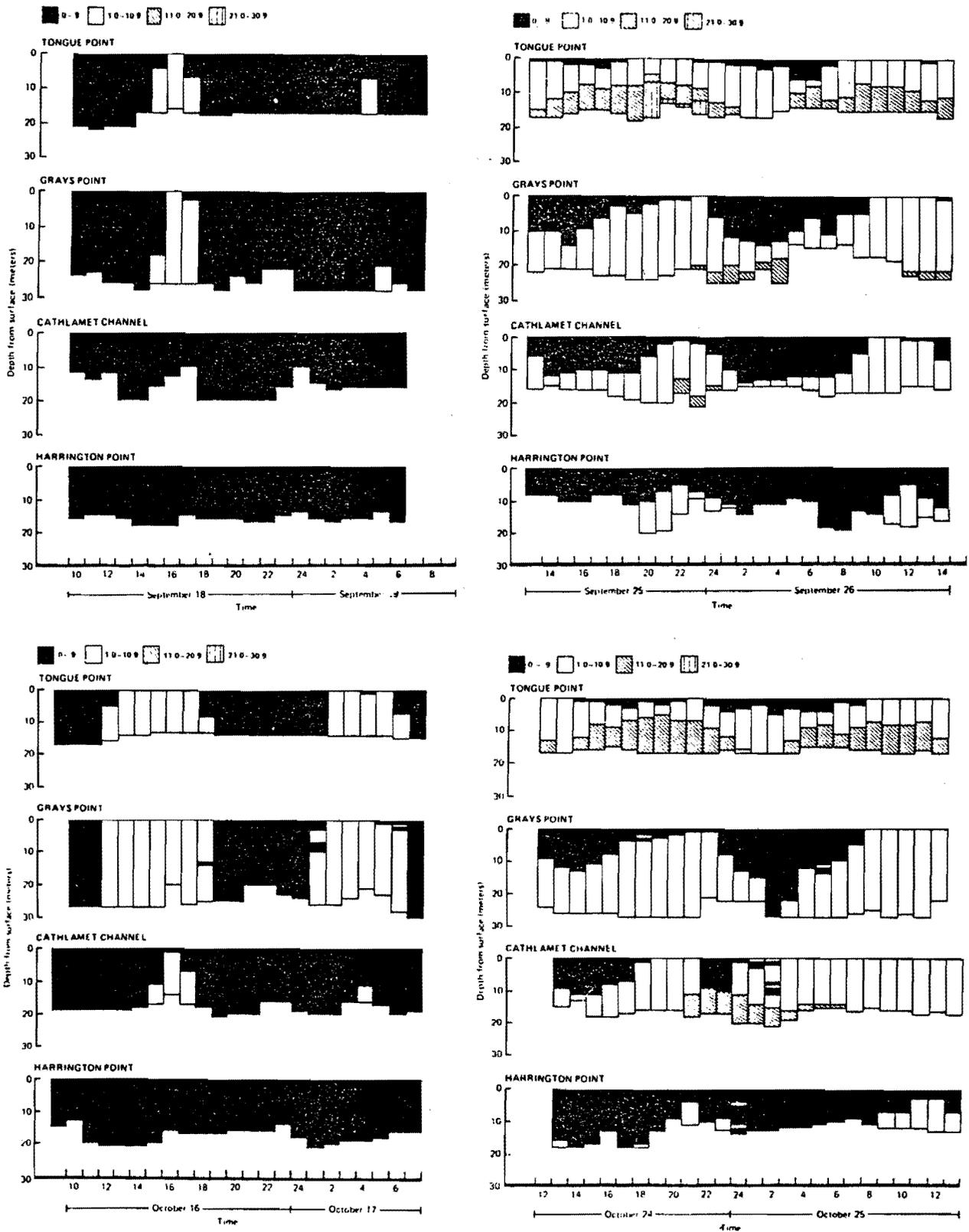


Figure 3. Salinity recorded during 1978 surveys at four locations in the Columbia River estuary.

(158,000 cfs). A substantial salinity intrusion occurred throughout the estuary (Figure 3), with a maximum upstream intrusion of 4.2 ppt recorded at Buoy 13 (RM 25.9) at 2230 h on 24 October. Water temperatures ranged from 11.5° to 15.1°C.

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 lowflow period for the Columbia River. Mean monthly flows into the estuary during September and October of 1977 were 77 and 70 percent of the 15-yr average. River flows during September and October 1978 were near normal at 117 and 100 percent of the 15-yr average, thus providing data for comparison.

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 (129,000 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 4 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 4,149 m³/s (182,000 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 5.

Extent of upstream intrusion of salinity was recorded for each survey; the criterion established was the farthest intrusion of salinity 2.0 ppt. Salinity intrusion in the main ship channel extended at least 20 miles upstream during all eight surveys (Table 1).

Monthly neap tides produced the highest salinity concentrations with the longest duration and the farthest upstream intrusion of saline water. The higher river flow during the 1978 surveys did restrict the concentration and extent of intruding salt water; however, during the 24 October 1978 survey, saline water (4.2 ppt) was measured at RM 25.4 during a mean flow period of 4,480 m³/s (158,220 cfs).

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

Maximum concentration of salinity recorded at the Gray Point site (RM 19.3) was 17.1 ppt during the

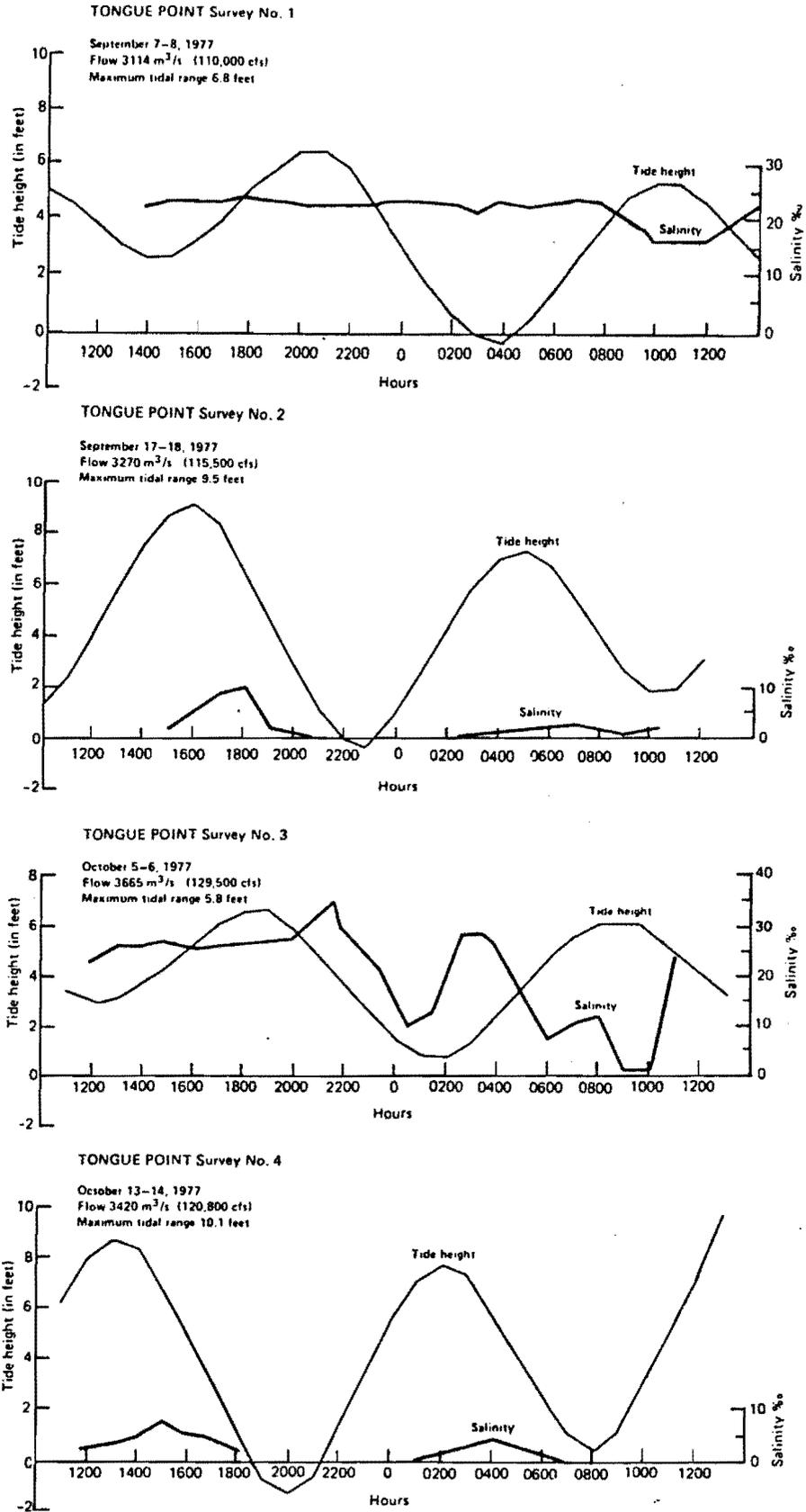


Figure 4. Twenty-four hour tide cycles and corresponding salinities at Tongue Point (RM 18.3) during the four 1977 surveys.

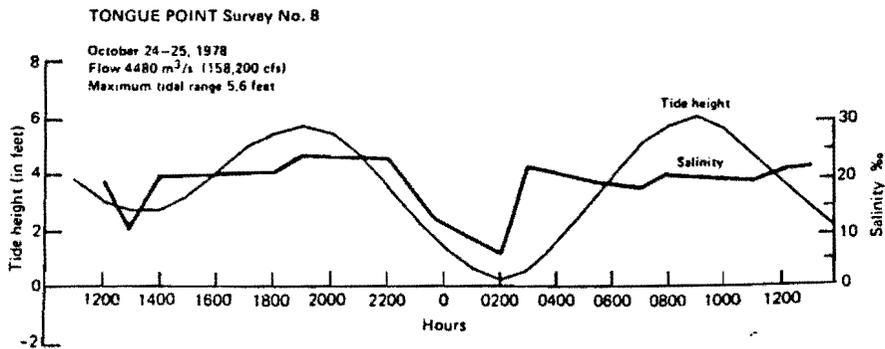
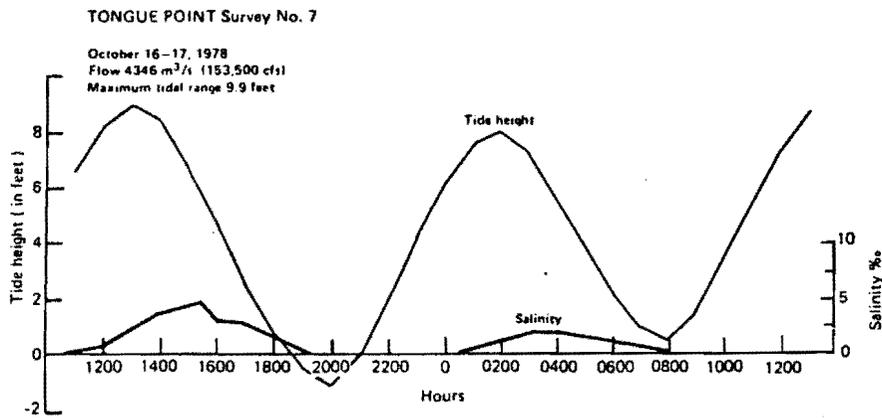
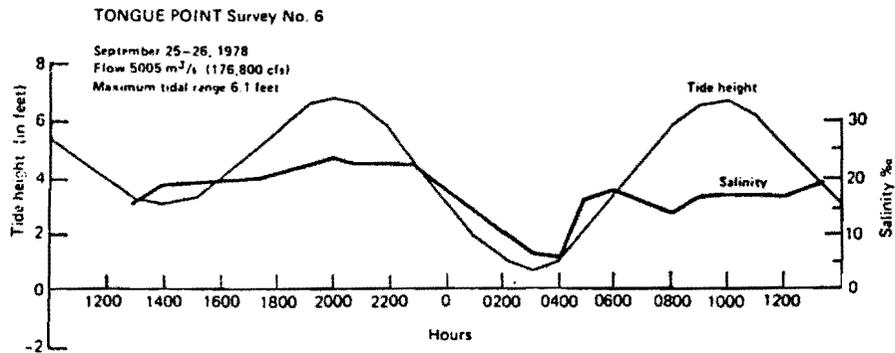
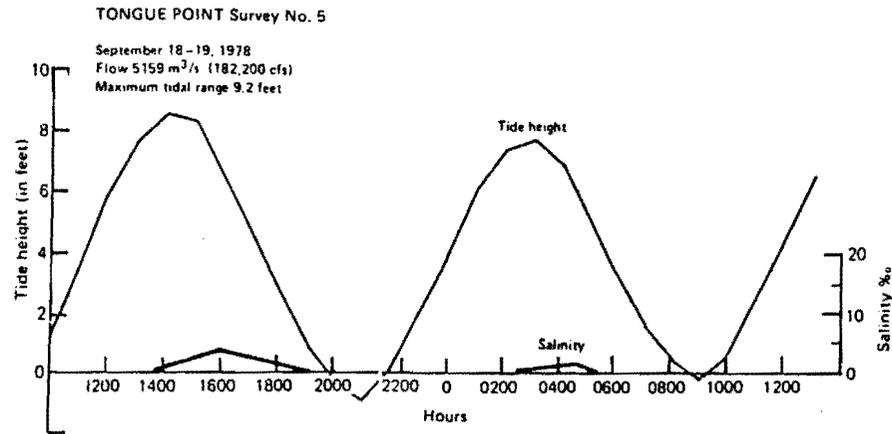


Figure 5. Twenty-four hour tide cycles and corresponding salinities at Tongue Point (RM 18.3) during the four 1978 surveys.

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	6.8	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

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	129,454	5.8	16.0	22
4	3,420	120,774	10.1	0.0	--
5	5,149	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

third survey. Salinity concentrations near the bottom remained around 15 ppt throughout this survey. A saltwater intrusion of 1.0 ppt occurred at Grays Point on all high-high and low-low tides during each of the eight surveys.

Maximum concentration of salinity at the Cathlamet Bay site was 19.7 ppt on the third survey. A salt water intrusion occurred at this site during all but the fifth survey.

Salinity data collected at Harrington Point (RM 24.5) 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). The highest salinity concentration measured at this site was 16.6 ppt.

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) was greater than expected. Haertel and Osterberg (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 ppt at Tongue Point (RM 18.2) and less than 2 ppt near RM 20. These concentrations correspond to our salinity data collected during the September 1977 and 1978 spring tide cycles. In October 1972, Misitano (1974) recorded salinities to 22 ppt at Tongue Point (RM 18.2) and salini-

ties to 6.6 ppt 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).

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 and 17 October 1978) conducted during the highest tide of the month. Data from this survey shows slightly higher salinities at Grays Point (Grays Point, 9.2 ppt, Tongue Point, 8.5 ppt).

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 or during the monthly spring tide cycle. 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 as to affect major fisheries or impose major impacts at the fishing ports of Ilwaco and Chinook, Washington 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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