Adult Fish Delay at John Day Dam

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COASTAL ZONE AND ESTUARINE STUDIES

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BACKGROUND

Migrating adult salmonids have been found to delay for an inordinate time before passing John Day Dam. The fishways and flows there are not substantially different from those at other large dams, in particular those at the downstream Bonneville and The Dalles Dams, where apparently there are no such passage delays. Recent cooperative studies between the National Marine Fisheries Service (NMFS) and the U.S. Army Corps of Engineers (CofE) have suggested that these migratory delays are related to and may be caused by industrial pollutants in the forebay of John Day Dam (Damkaer 1983). In FY83, we have continued to observe the distributions and concentrations of some inorganic pollutants, especially fluoride, and have begun bioassay experiments to determine the effects on salmonids of low fluoride levels.

APPROACH

Distribution of Potential Pollutants

The most obvious and tractable pollutants appeared to be fluoride and the free-states of certain heavy metals (cadmium, copper, lead, and zinc), and the 1983 work focused on these factors (Figure 1). This investigation compared daily fish counts at John Day Dam with "daily" fluoride concentrations in each fishway. Also, pollutant concentrations were observed at various points to several hundred meters below the dam.

Evaluation of the Behavior of Salmonids in Fluoride and Other Pollutant Gradients

The principal bioassay tests were conducted at Big Beef Creek, the University of Washington's experimental station on Hood Canal (Figure 2).

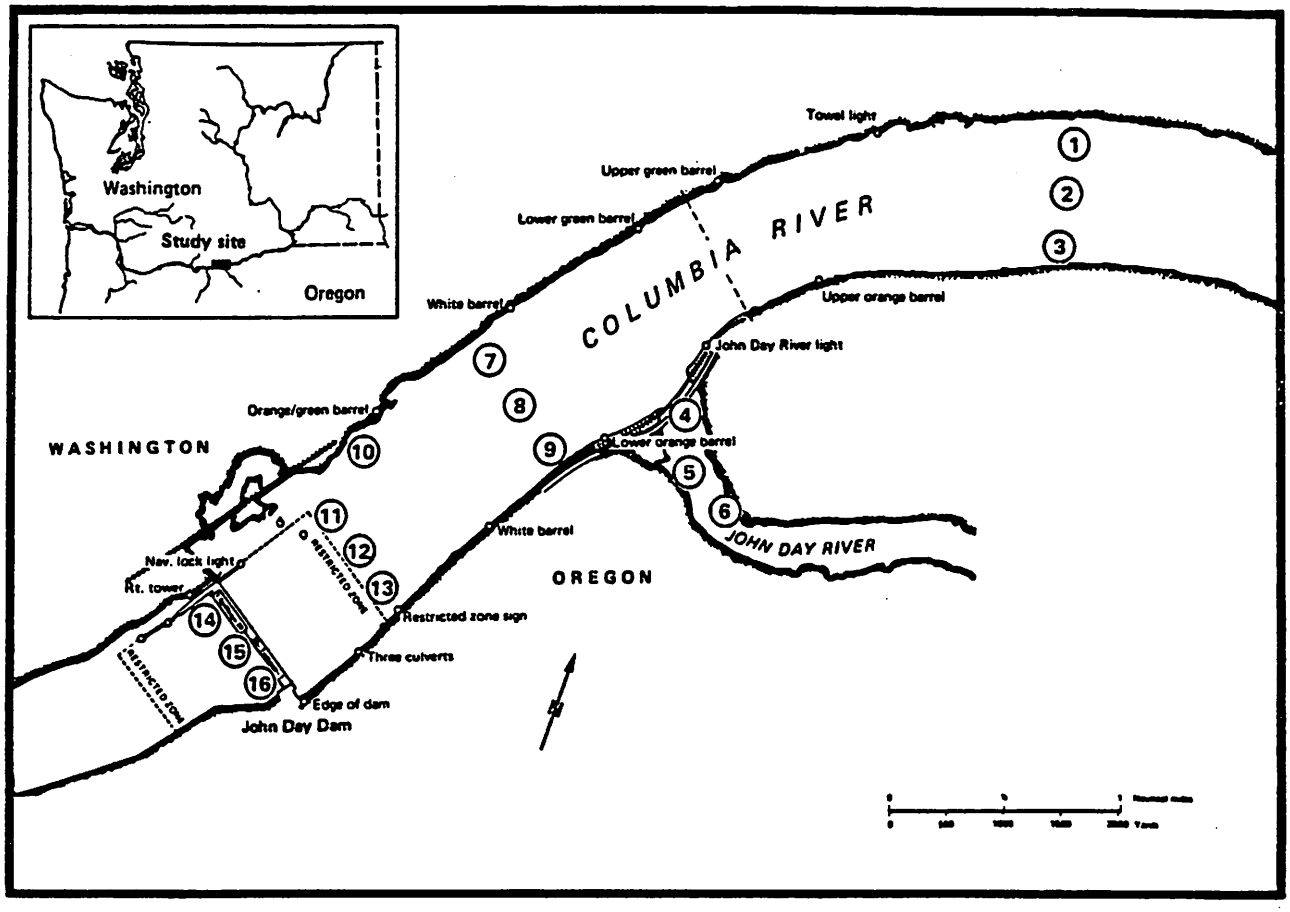

Figure 1.--Study area for adult salmonid passage delay program, John Day Dam region, Columbia River. Circled numbers indicate sampling sites (three sites on downstream side of The Dalles Dam not shown).

Preliminary tests with adult chum salmon, Oncorhynchus keta, were done in late fall 1982. From September through December 1983, over 400 tests were conducted using returning chinook, O. tshawytscha; coho, O. kisutch; and chum salmon.

One of two branches of Big Beef Creek was furnished with a two-choice flume (Figure 3). An 8-m partition longitudinally divides this flume. Upstream migrants can choose to proceed into the left or right arms, which are otherwise equivalent. Once a few meters into either side, fish are kept there by a funnel-trap. At the head of this two-choice flume, about 15 m from the starting point (fish acclimating area), a 55-liter carboy empties into the flowing creek water at each of the two arms of the flume. The flow-rates are identical from each carboy, adjusted to empty in about 1 h. Control tests were conducted using no fluoride in either carboy. Most of the other tests were conducted using sodium fluoride in only one carboy (randomly chosen each day). The fluoride concentration was established to result in approximately 0.5 ppm fluoride in the treatment arm of the flume. This concentration is equivalent to the highest fluoride level we observed in the Columbia River at John Day Dam.

Fish were tested one at a time, and were allowed to acclimate about 10 min in the holding area downstream from the two-choice flume. A gate was then carefully raised, from behind a concealed observation area, and each fish allowed 1 h to move upstream or not.

Small-scale experiments, using juvenile salmonids (chinook and coho salmon and steelhead/rainbow trout hybrids, Salmo gairdneri), were

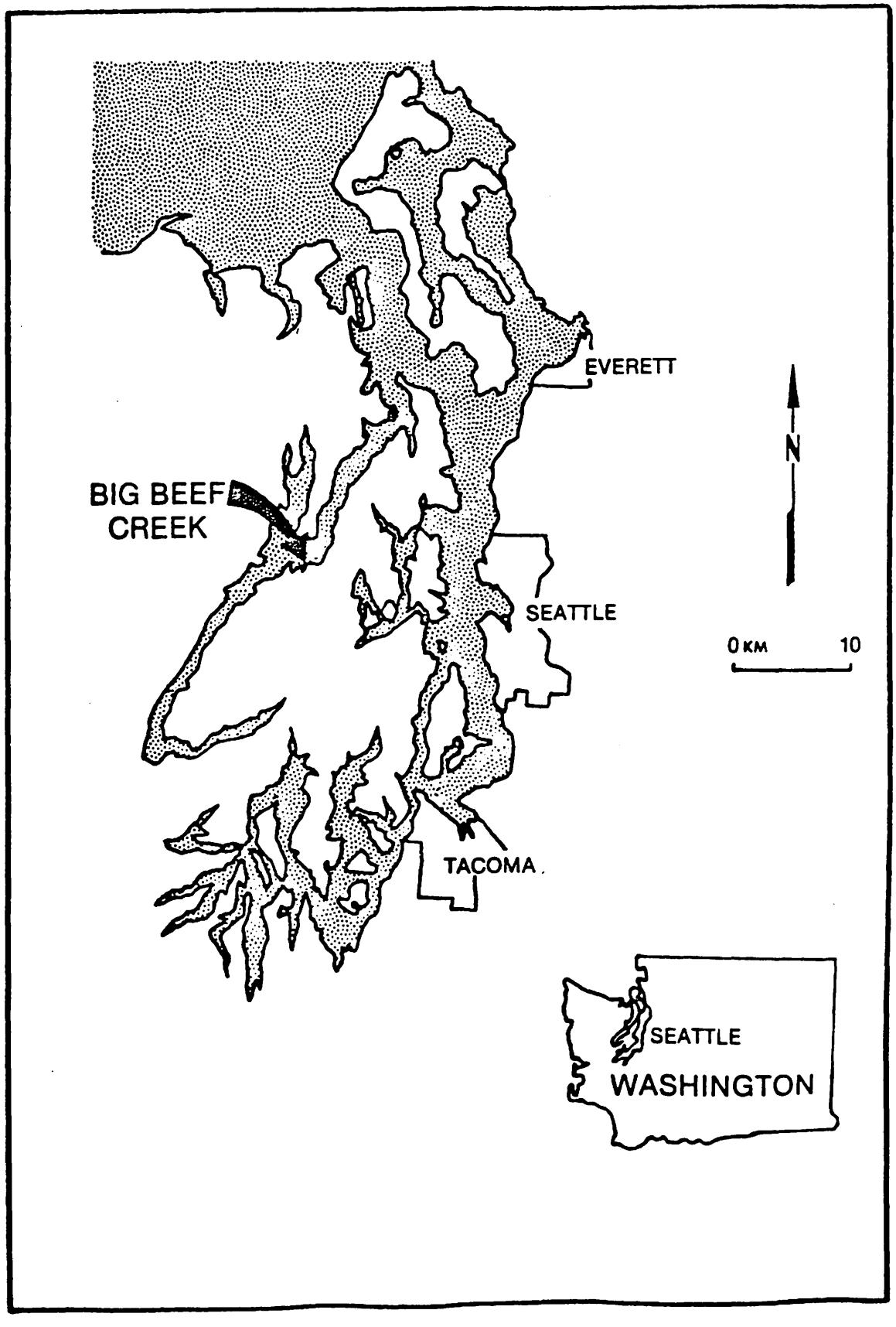

Figure 2.--Big Beef Creek study site for fluoride bioassays with returning salmon.

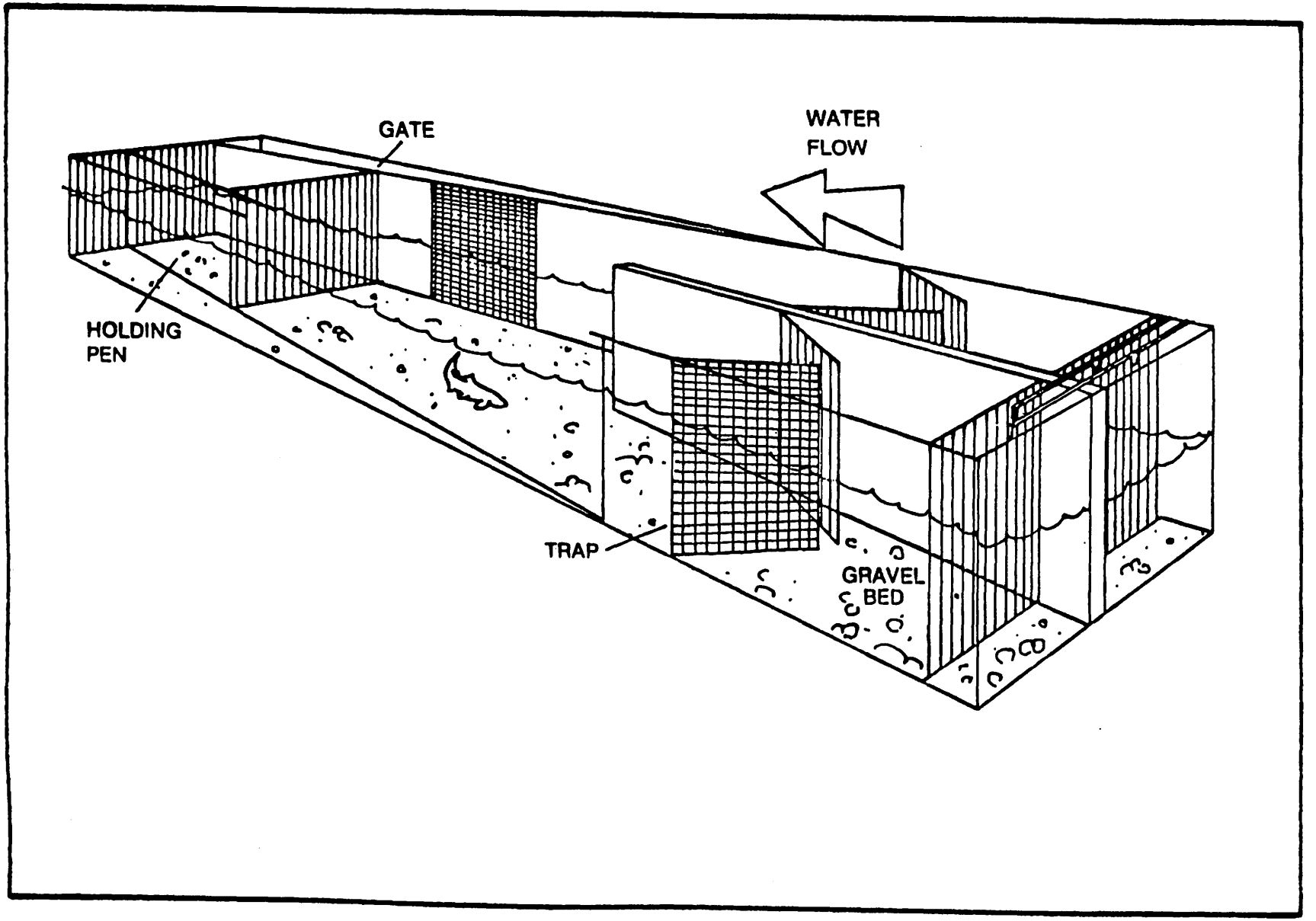

Figure 3.--Two-choice flume for fluoride-gradient salmon-behavior tests, diagrammatic view.

conducted when adult salmonids were not available. These laboratory bioassays were conducted at NMFS Montlake or Manchester laboratories. Several tests were carried out to determine effects of fluoride and industrial effluent gradients on the behavior (avoidance) of these juveniles in 5-ft long troughs. The treated water flowed into one end of the trough at the same rate as untreated water at the other end. The two water types mixed and left the trough at the center. Fish were introduced singly into the center of the trough and observed for about 0.5 h. Tests were conducted with 0, 0.3, 0.5, and 1.0 ppm fluoride, and with an aluminum-plant industrial effluent diluted to contain 0.5 ppm fluoride.

Groups of juveniles were also held for several weeks in fluoride concentrations of 0, 0.3, 0.5, and 1.0 ppm. Then swimming performance (stamina) was observed for each fish, tested in an adjustable-flow chamber. At the beginning of the bioassay and at the conclusion of the swimming test, blood was taken from each fish for thyroxine hormone (T_4) analyses.

In addition, mature chinook and coho salmon were held for up to 4 weeks in fluoride concentrations ranging from 0-1.0 ppm. Blood was drawn at 24 h and at 1-week intervals for T_4 analyses.

RESULTS

1. There was less fluoride in the John Day Dam forebay March-October 1983 than for the same period in 1982 (Figures 4-8). This was probably due to lesser fluoride discharge by the primary aluminum plant on the Washington shore just upstream from the dam. This plant has been modifying its pollution-discharge system, and since January 1983 has operated under stricter State requirements. The aluminum plant's discharge records have

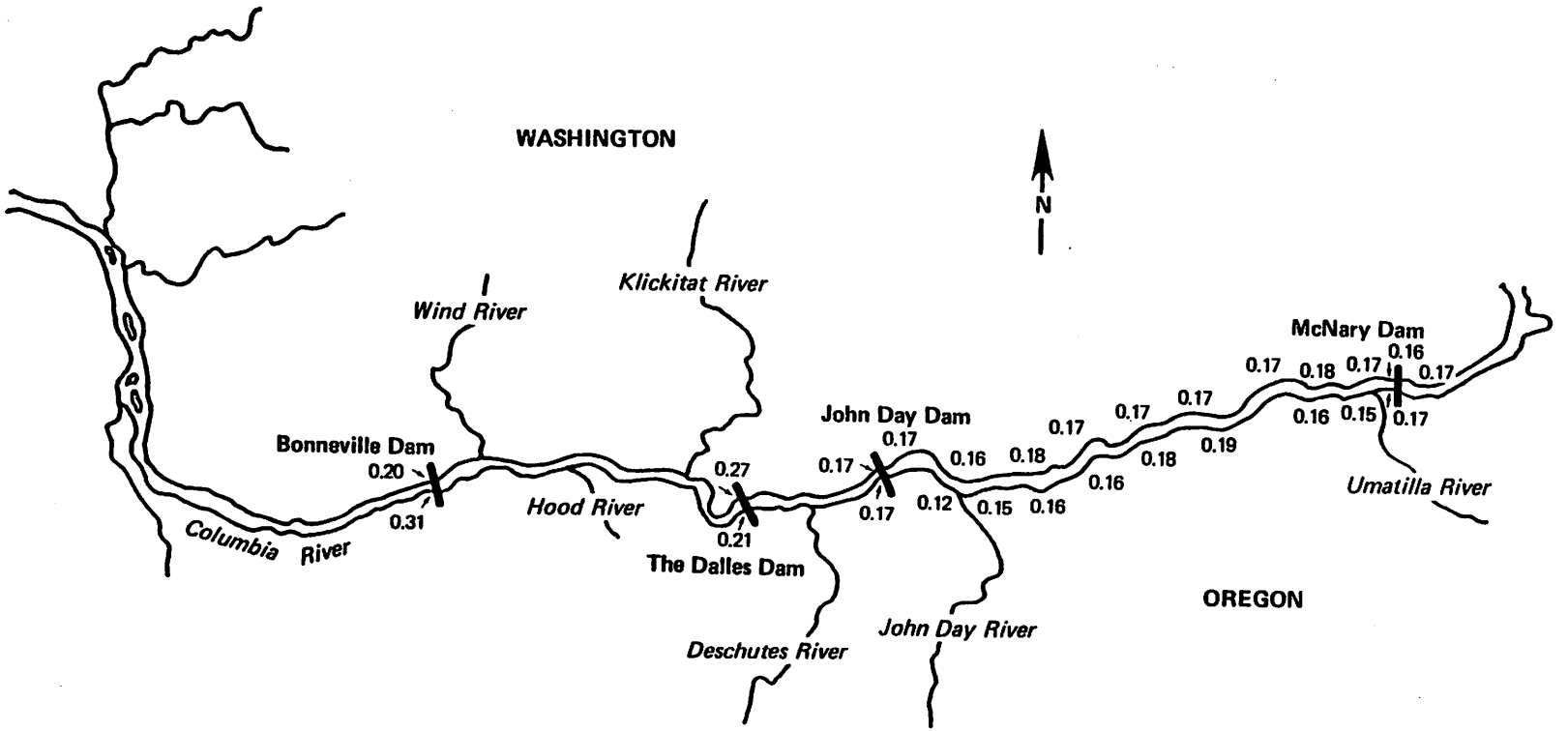

Figure 4.--Surface fluoride distribution (ppm) in the Columbia River from Bonneville Dam to McNary Dam, May 1983.

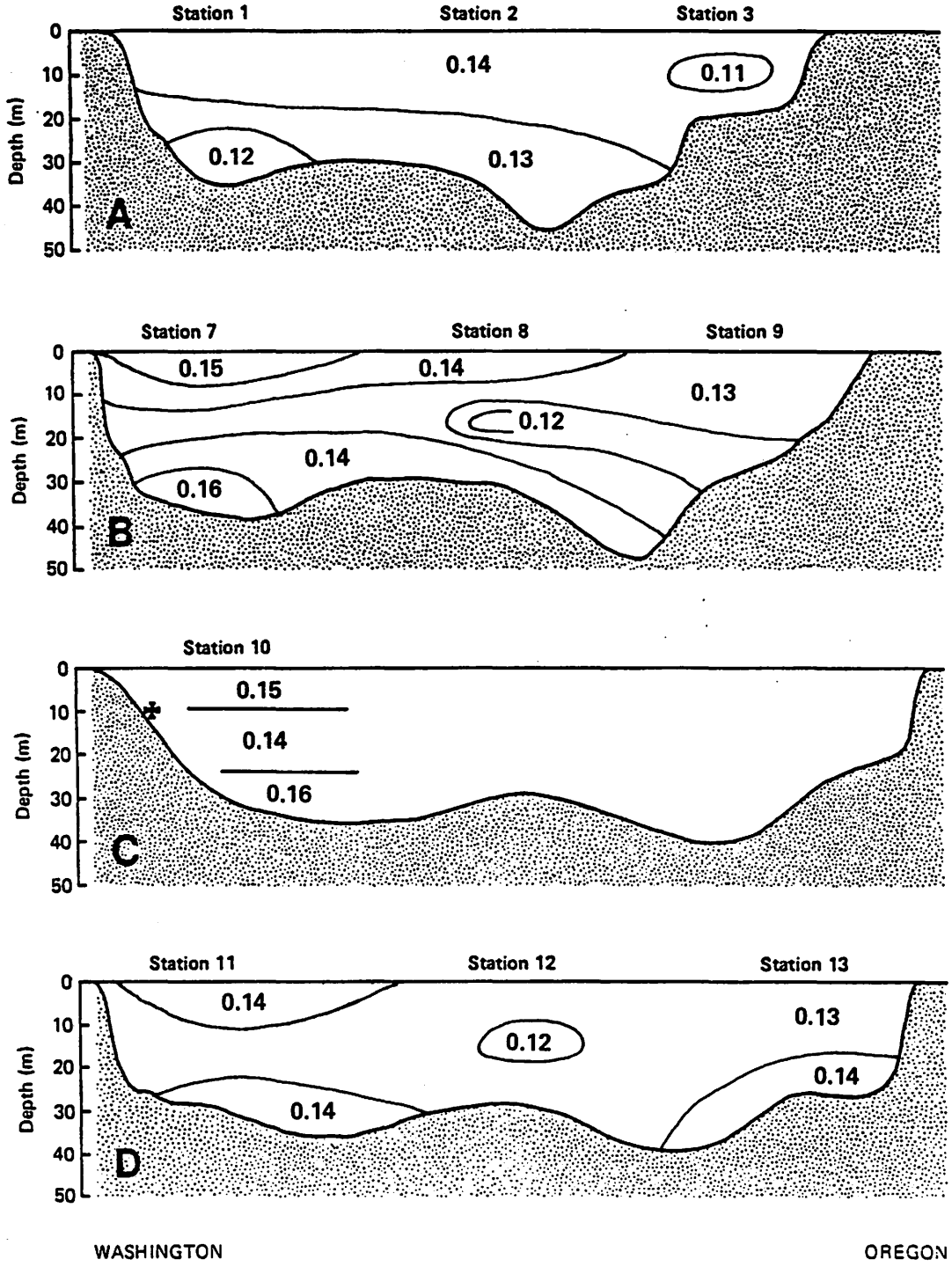

Figure 5.--Fluoride contours (ppm), 20-21 July 1983, John Day Dam region, Columbia River (see Figure 1 for station locations). Maltese cross indicates location of aluminum plant outfall.

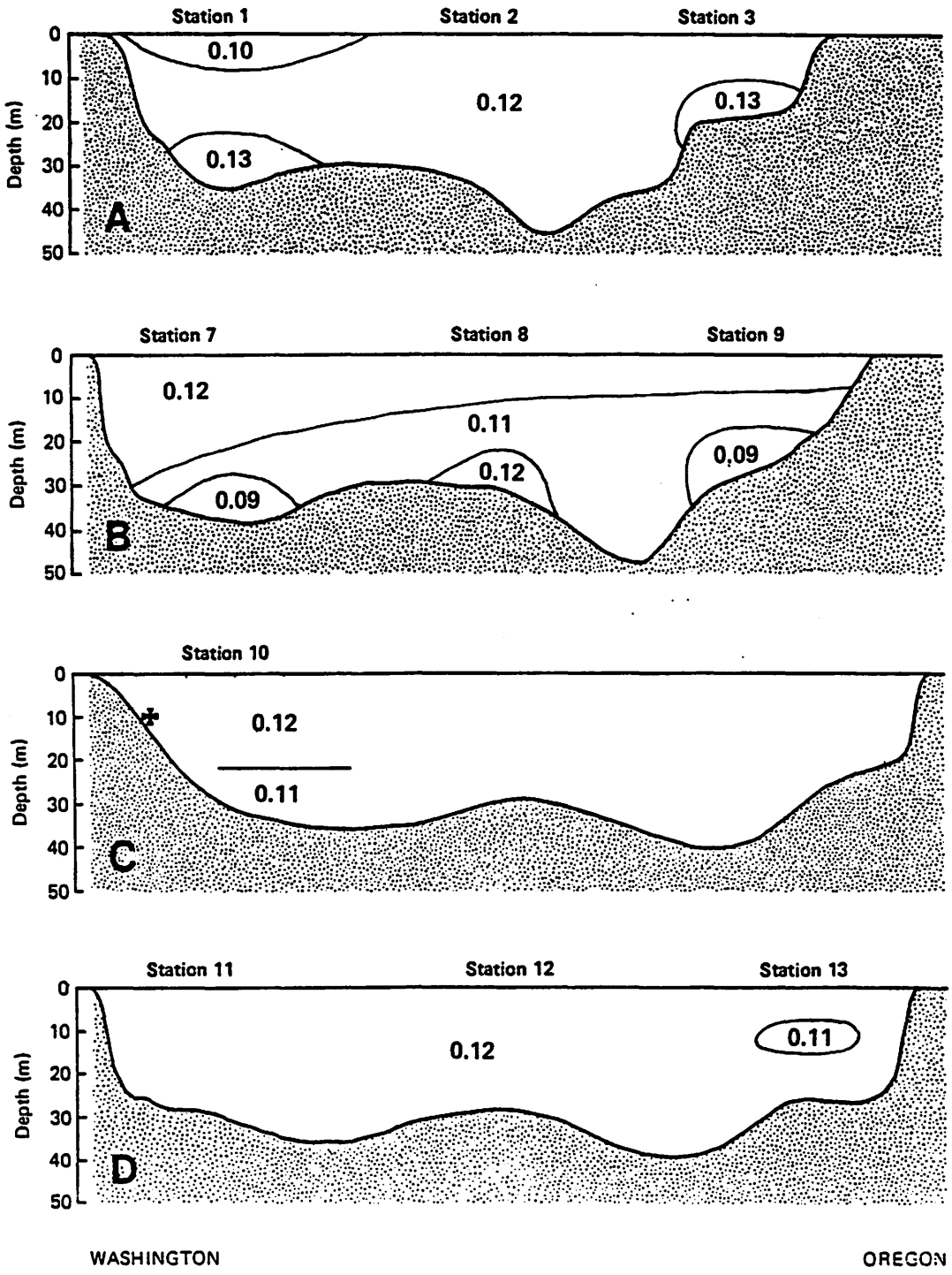

Figure 6.--Fluoride contours (ppm), 17-18 August 1983, John Day Dam region, Columbia River (see Figure 1 for station locations). Maltese cross indicates location of aluminum plant outfall.

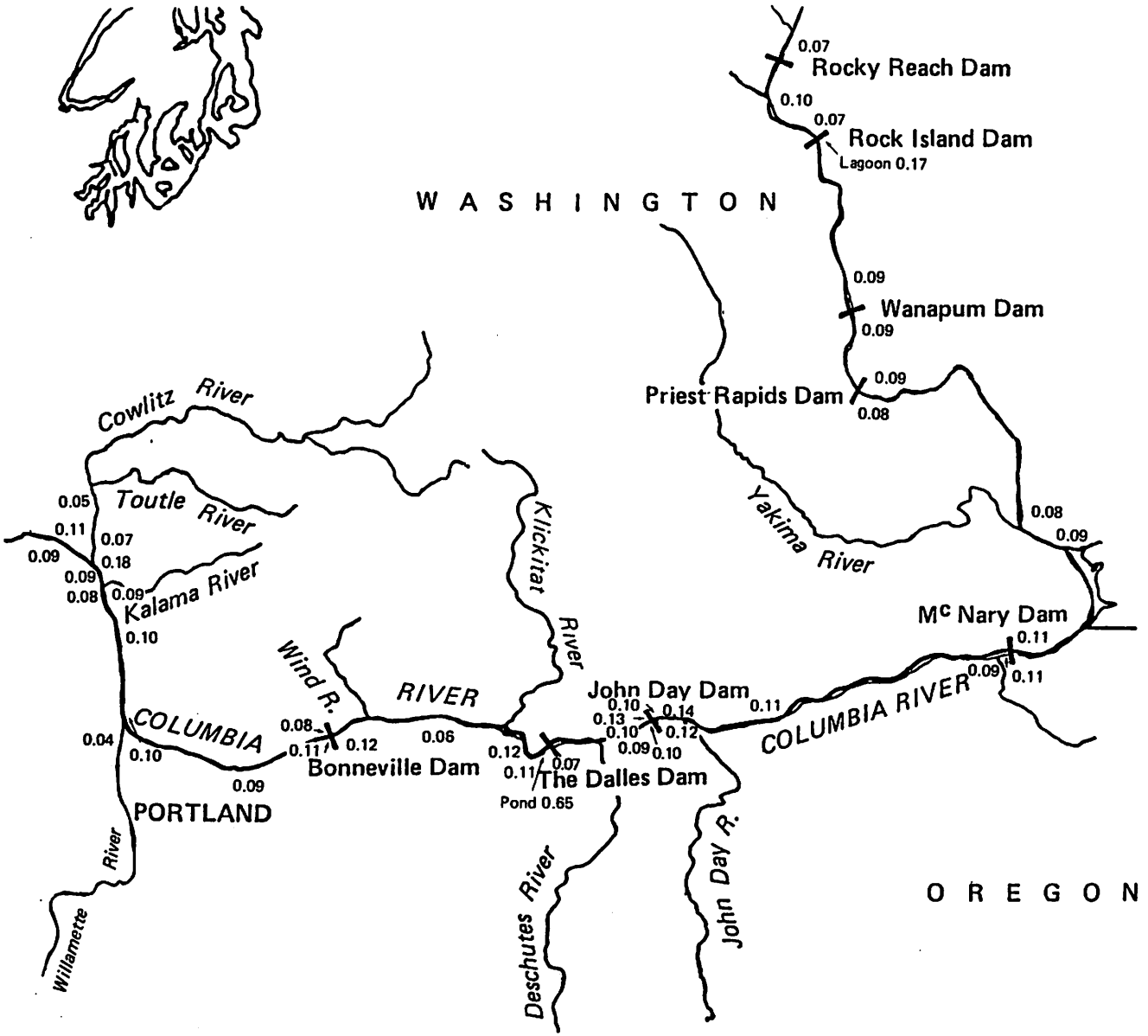

Figure 7.--Surface fluoride distribution (ppm) in the Columbia River from Longview, Washington, to Rocky Reach Dam, September 1983.

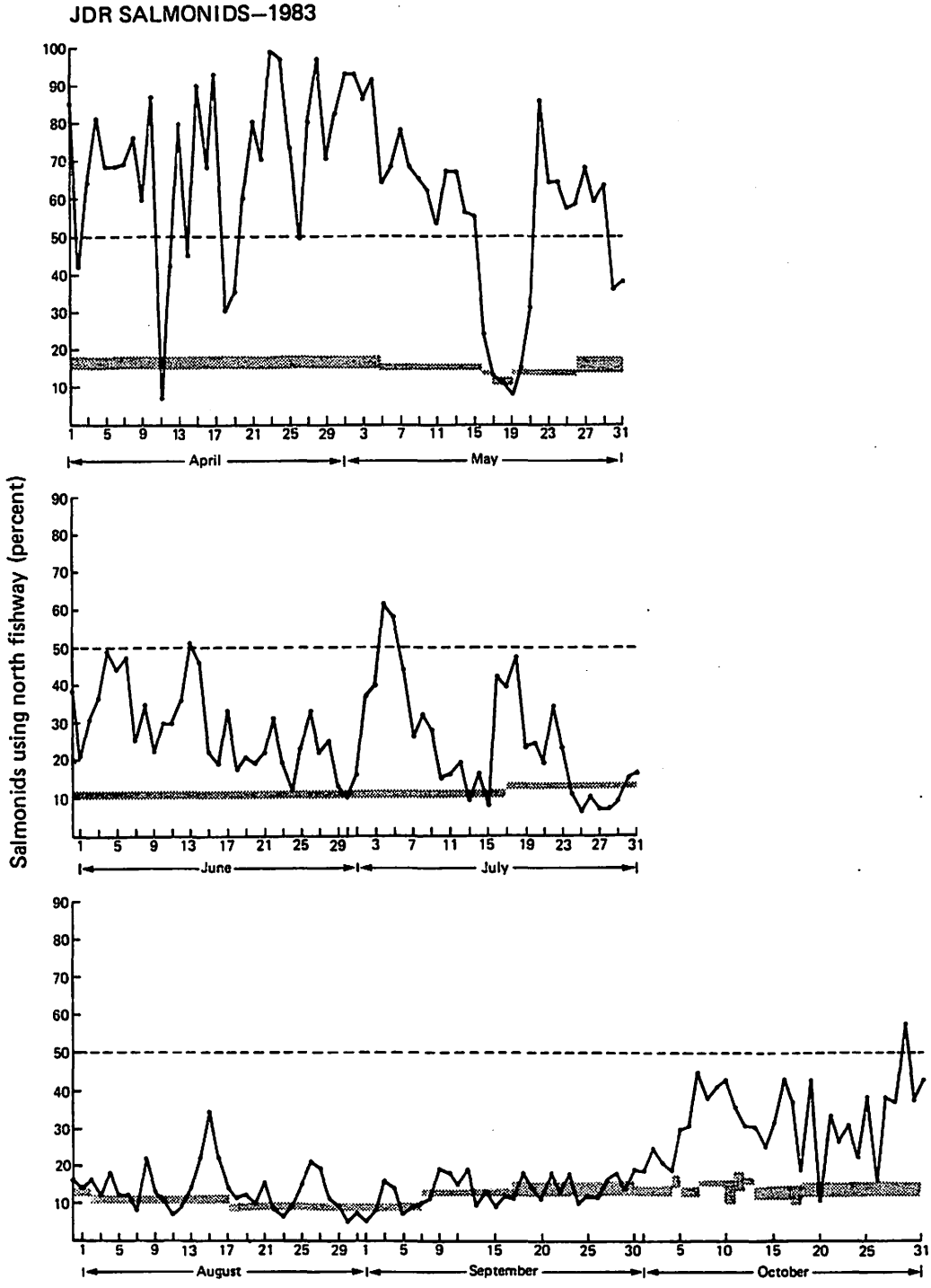

Figure 8.--Returning adult salmonids using north fishway at John Day Dam, Columbia River, 1983; horizontal bars are ranges of fluoride ion in the north and south fishways (X 10^{-2} ppm).

been obtained from the Washington State Department of Ecology (DOE), and we have adjusted the record below to account for a Columbia River background of 10 lbs/d fluoride:

1982 (DOE permit limits: average 680 lbs/d, maximum 1360 lbs/d)

	Discharge to river (lbs/d)	
	Average	Maximum
Jan	1145	2137
Feb	1185	1935
Mar	1031	1925
Apr	1451	2702
May	792	2185
Jun	853	1641
Jul	580	1542
Aug	703	1154
Sep	721	3088
Oct	811	1434
Nov	625	1003
Dec	474	756

Since 1 January 1983, the reporting method has also changed, and fluorides are now monitored at the discharge of the water treatment plant rather than at the outfall pond as before. Apparently some untreated water was still discharged to the river.

1983 (DOE new permit limits:* average 25 lbs/d, maximum 50 lbs/d)

	At treatment plant* (lbs/d)		Discharge to river (lbs/d)	
	Average	Maximum	Average	Maximum
Jan	0	10	121	372
Feb	0	5	163	395
Mar	0	4	144	257
Apr	0	16	156	235
May	0	0	167	440
Jun	0	1.2	150	297
Jul	0	4.1	204	1226
Aug	0	1.1	125	208
Sep	0	5.2	1490	6628
Oct	-	-	2867	9396
Nov	0	0	831	2313
Dec	1.7	63.3	291	624

Therefore, the reported 1983 fluoride discharge to the river before 19 September, by this plant, was about one-fifth that in 1982. The water-treatment system required repairs between 19 September-11 November, and during that time a large amount of fluoride was discharged.

John DeVore (Washington Department of Fisheries; personal communication) reported that of the upriver-bright fall chinook salmon passing Bonneville Dam, a significantly lower proportion reached McNary Dam after about 1979. The 1980-82 3-year average was 45%. However, in 1983 this proportion was 89%, the highest since 1972. DeVore also observed substantially fewer salmonid carcasses just below John Day Dam in 1983 than in 1982. It is interesting that these observations coincided with the significant 1983 fluoride-discharge reductions above John Day Dam.

There is no doubt that <u>on the average</u> the returning adult salmonids continue to "prefer" the south fishway (Oregon side) (Figure 9). However, on particular days more fish may pass the north fishway. Usually the day-to-day preference has been stable for 2-4 d, until late May. It was believed that this striking and consistent pattern may be a result of pollutant distributions in the forebay. However, in 1983, the daily percentage of fish using the north fishway appeared unrelated to the daily fluoride concentrations in either fishway (Figure 8). Possible relationships could be obscured by scale-effects, since our samples are only 250 ml/d, yet the salmonids receive continuous signals.

The 1983 daily pattern of fishway-preference did not seem to be related either to total Columbia River flow, to total spill at John Day Dam, or to the spill-to-flow ratio. However, there did appear to be a fairly close <u>negative</u> correlation between the daily south fishway passage

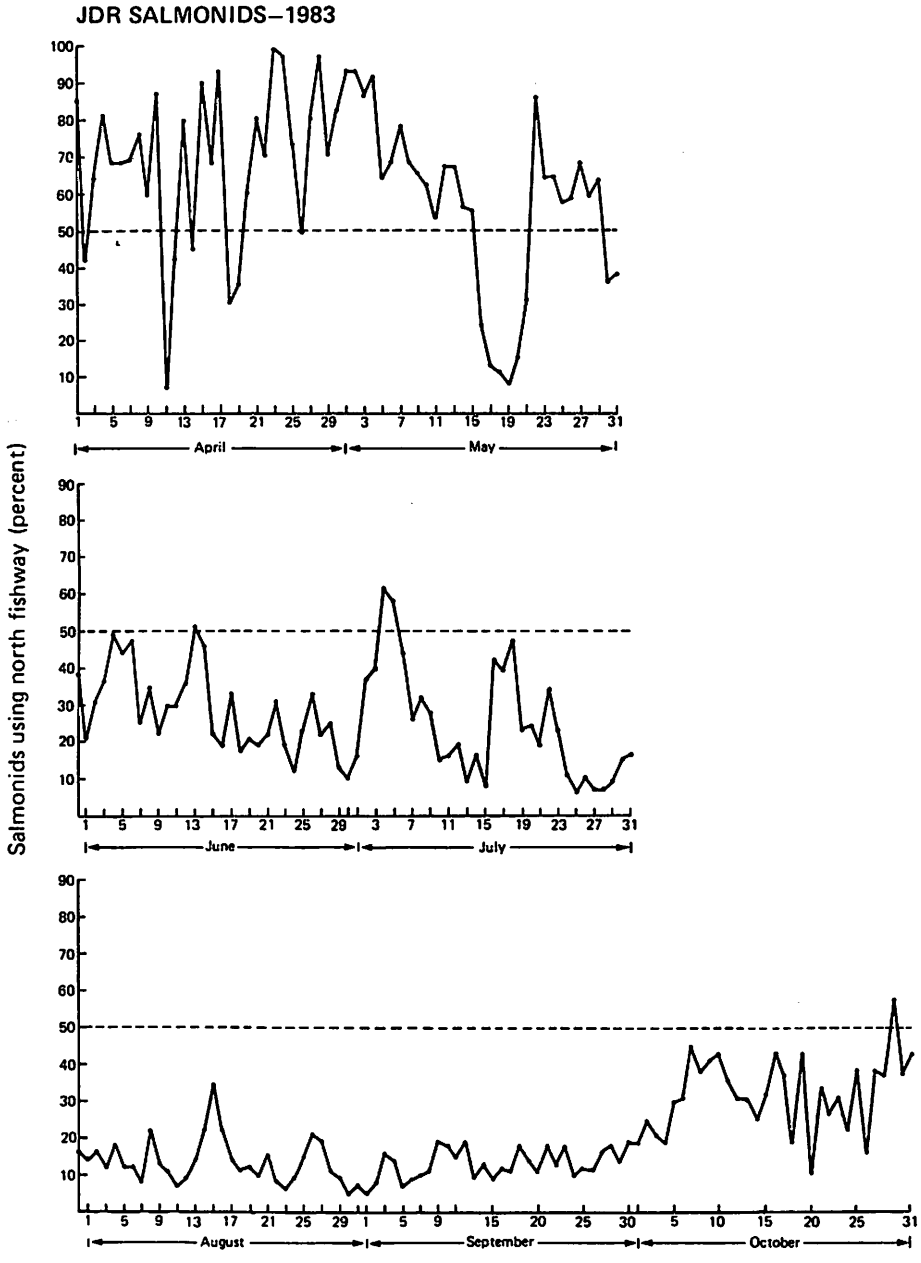

Figure 9.--Returning adult salmonids using north fishway at John Day Dam, Columbia River, 1983; through 31 October 28% passed the north fishway and 72% passed the south fishway.

and the daily John Day River flow-at-Service-Creek-plus 5 d. It is reasonable that high John Day River flow, with higher temperature and higher turbidity than the main Columbia River, and which would usually have a greater effect on the Oregon shore, may influence the salmonids' choice of fishway. Superimposed on this apparent effect of John Day River flow is a suggestion of a secondary positive correlation of north fishway passage with spill at Spillbay 1.

Temperatures in the John Day Dam region in July and August 1983 (Figures 10-11; Appendix Tables 1-2) were similar to the few summer-temperature observations of 1982. At these same times, dissolved oxygen and turbidity distributions indicated general decreasing values at all depths through the summer (Figures 12-15; Appendix Tables 1-2).

In 1983, the distributions of free heavy metals were slightly different from the 1982 patterns. Copper ion was of much lower concentration (ca. 10 ppb) and did not persist downstream from the fishways. Cadmium ion was about the same concentration as last year (ca. 2.3 ppb), but, like copper ion, it was not detected in the tailrace area. Both lead (ca. 8 ppb) and zinc (ca. 10 ppb) ions were in similar concentrations as in 1982, and this free, and toxic, state persisted at least a few 100 m downstream of the fishways.

2. The experiments with adult salmon at Big Beef Creek have shown that they react rather quickly to low concentrations of fluoride (0.5 ppm). To indicate that our observations reflect behavior due to fluoride alone, we have allowed many fish to react to the two-choice flume without fluoride in either carboy's effluent. In 30 to 50 tests with each species there was no significant channel preference (Appendix Tables 3-5). Only one of the

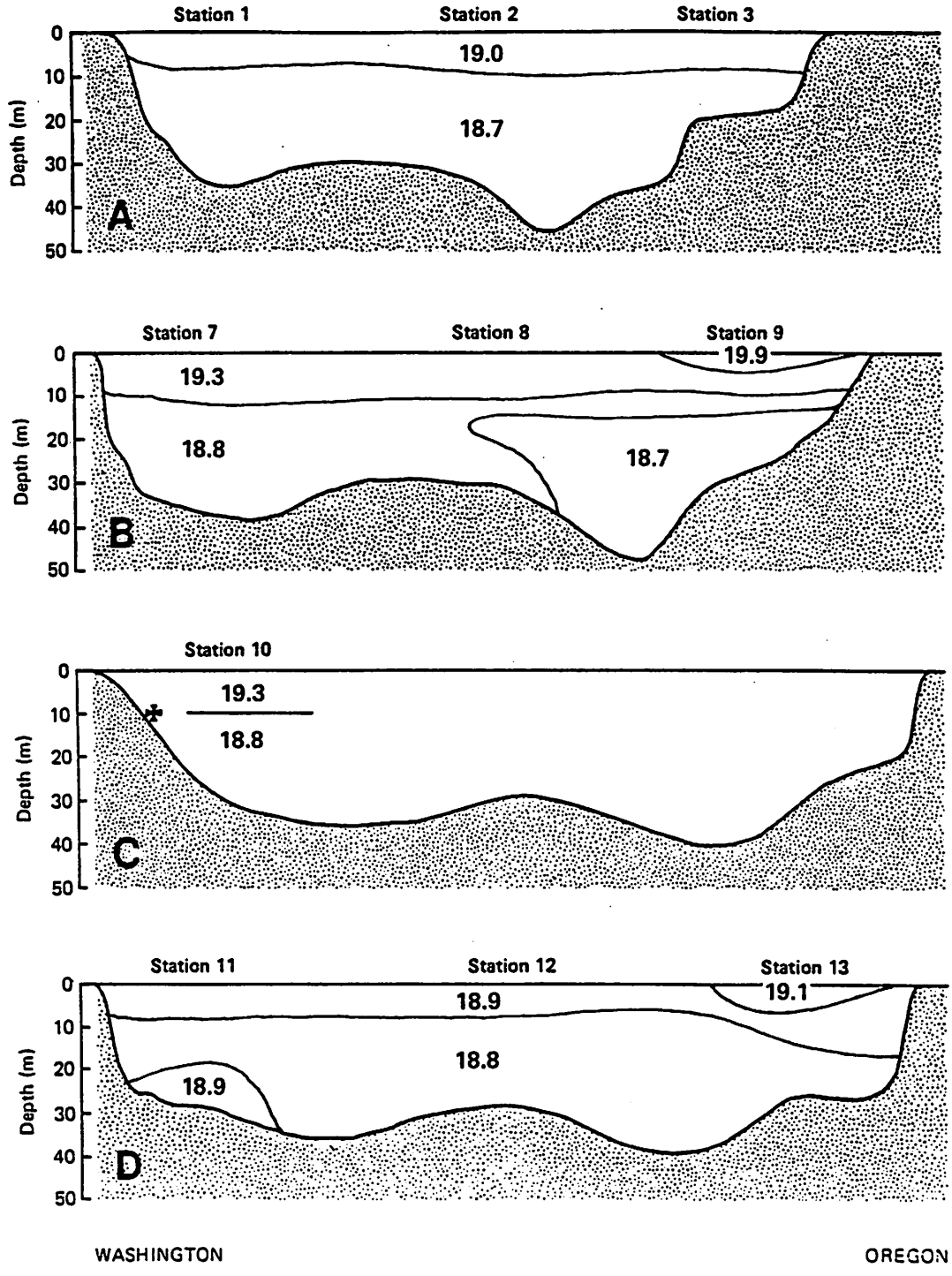

Figure 10.--Temperature contours (°C), 20-21 July 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

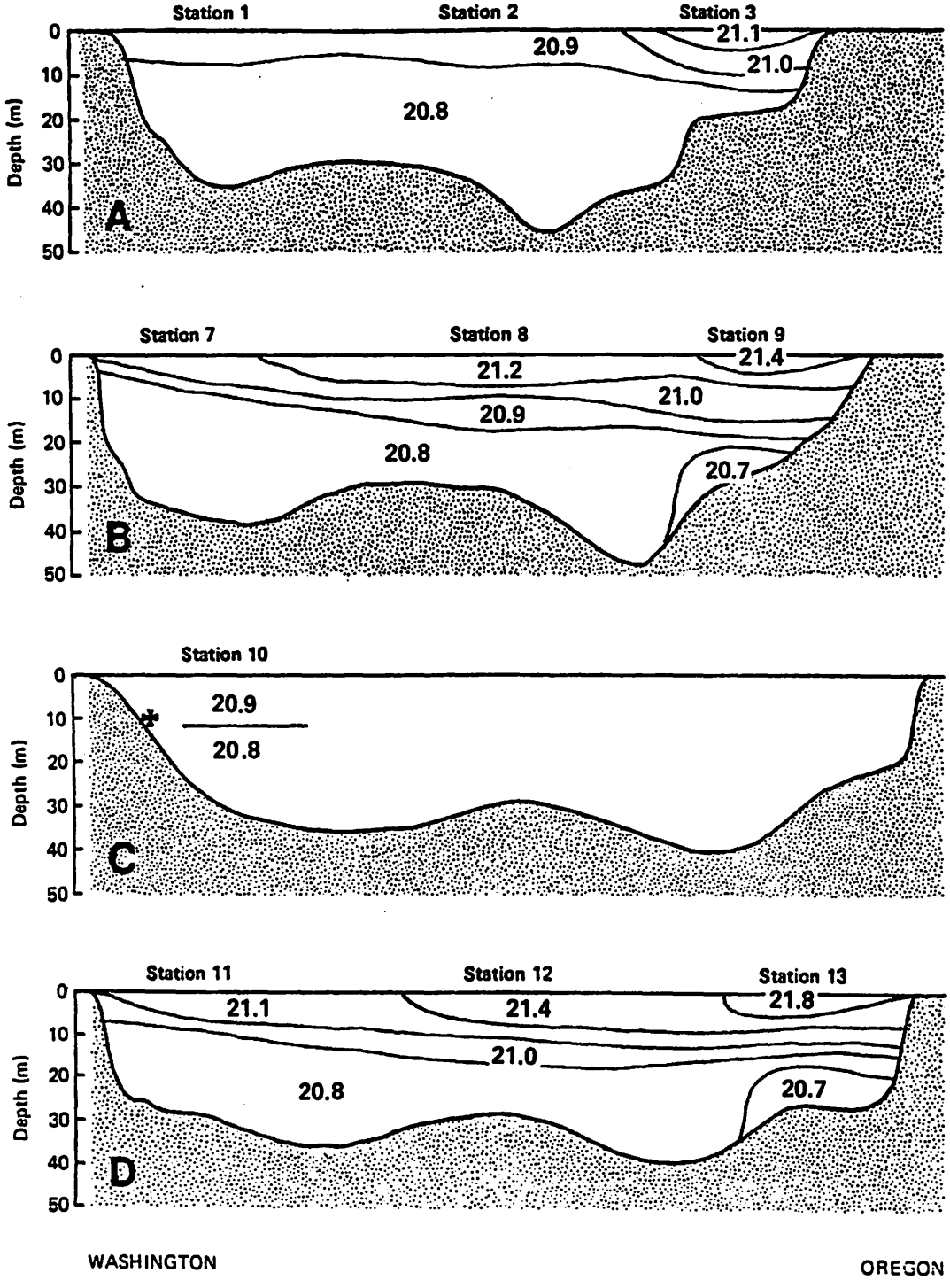

Figure 11.--Temperature contours (°C), 17-18 August 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

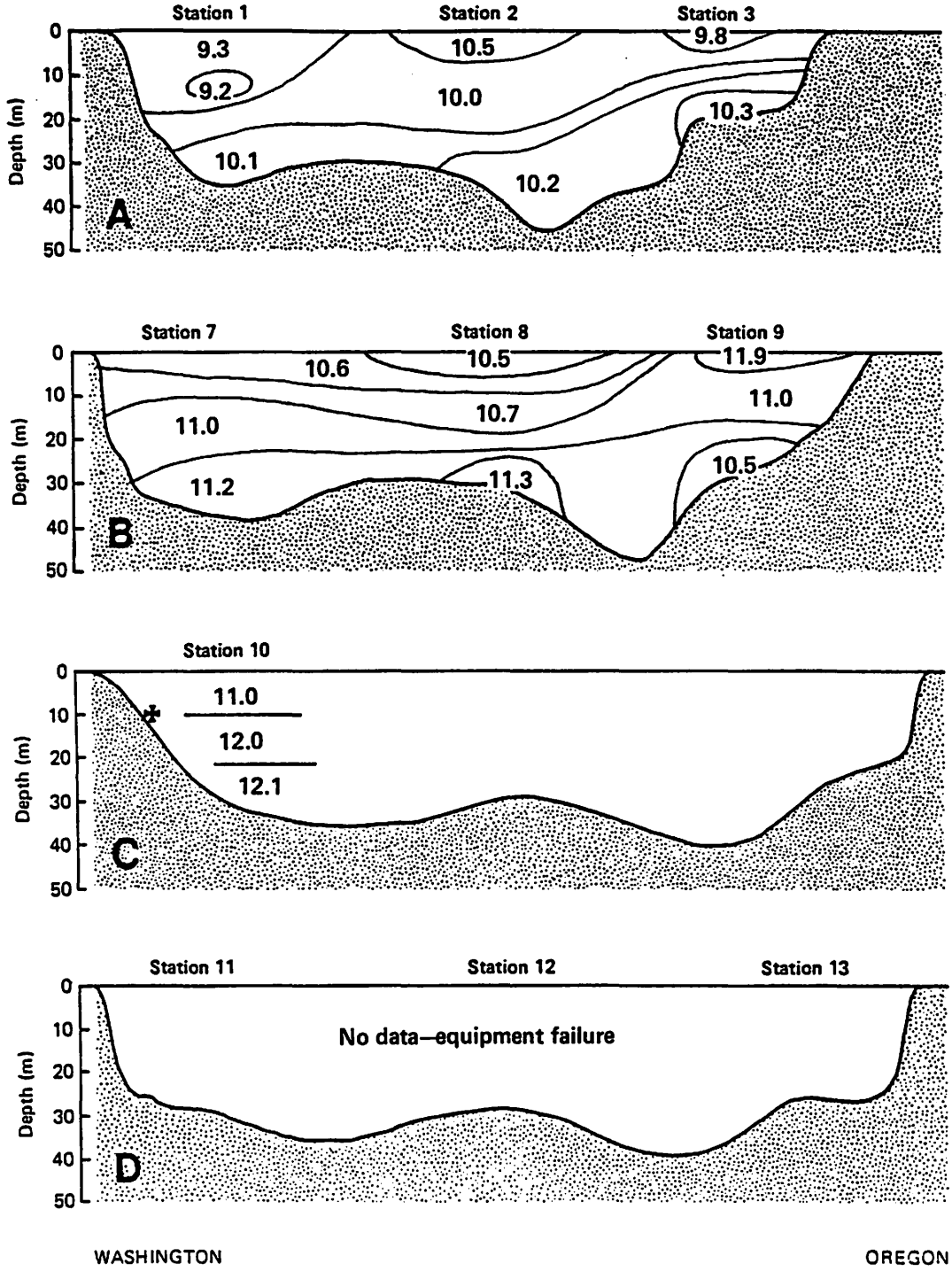

Figure 12.--Dissolved oxygen contours (ppm), 20-21 July 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

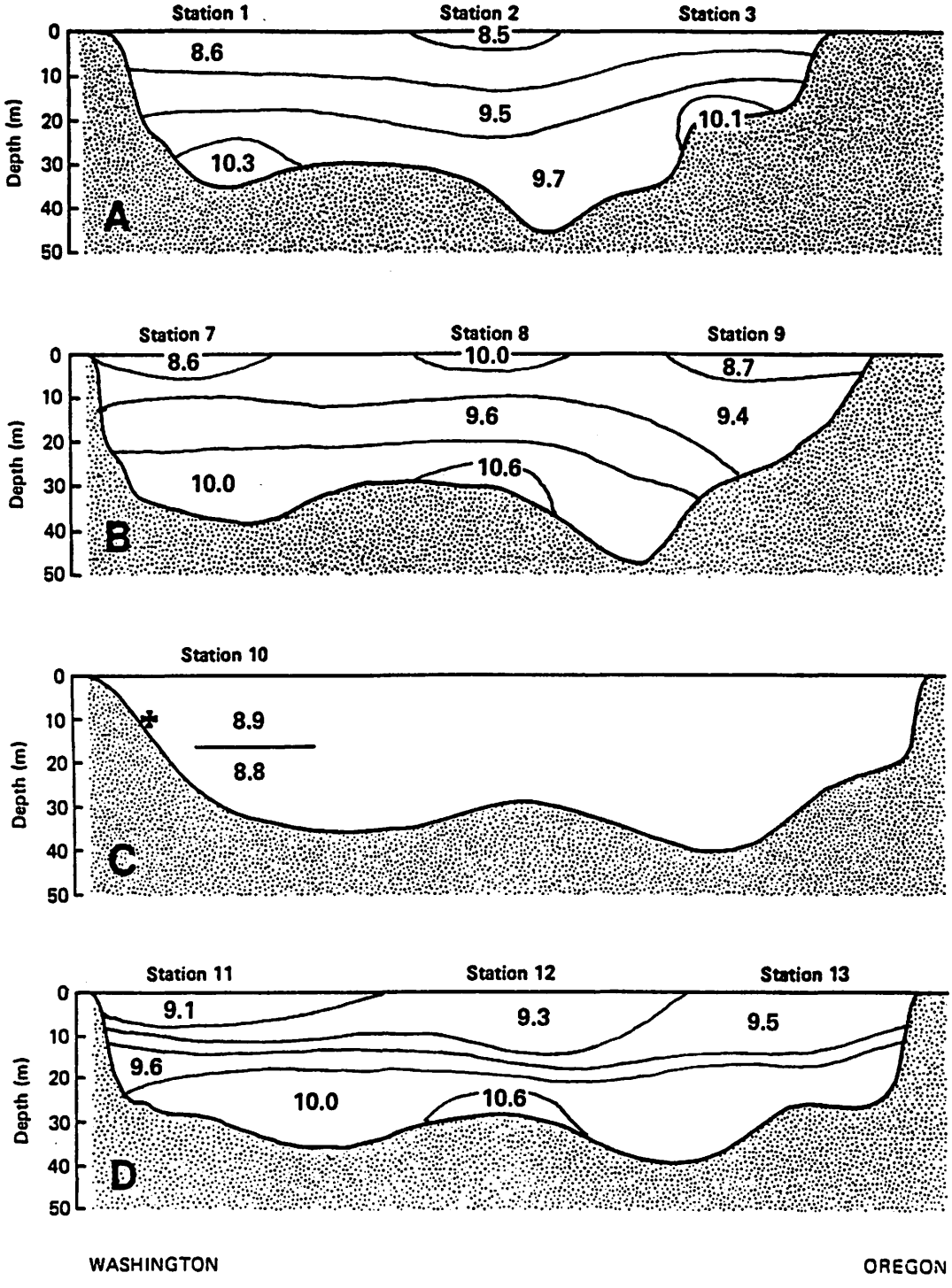

Figure 13.--Dissolved oxygen contours (ppm), 17-18 August 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

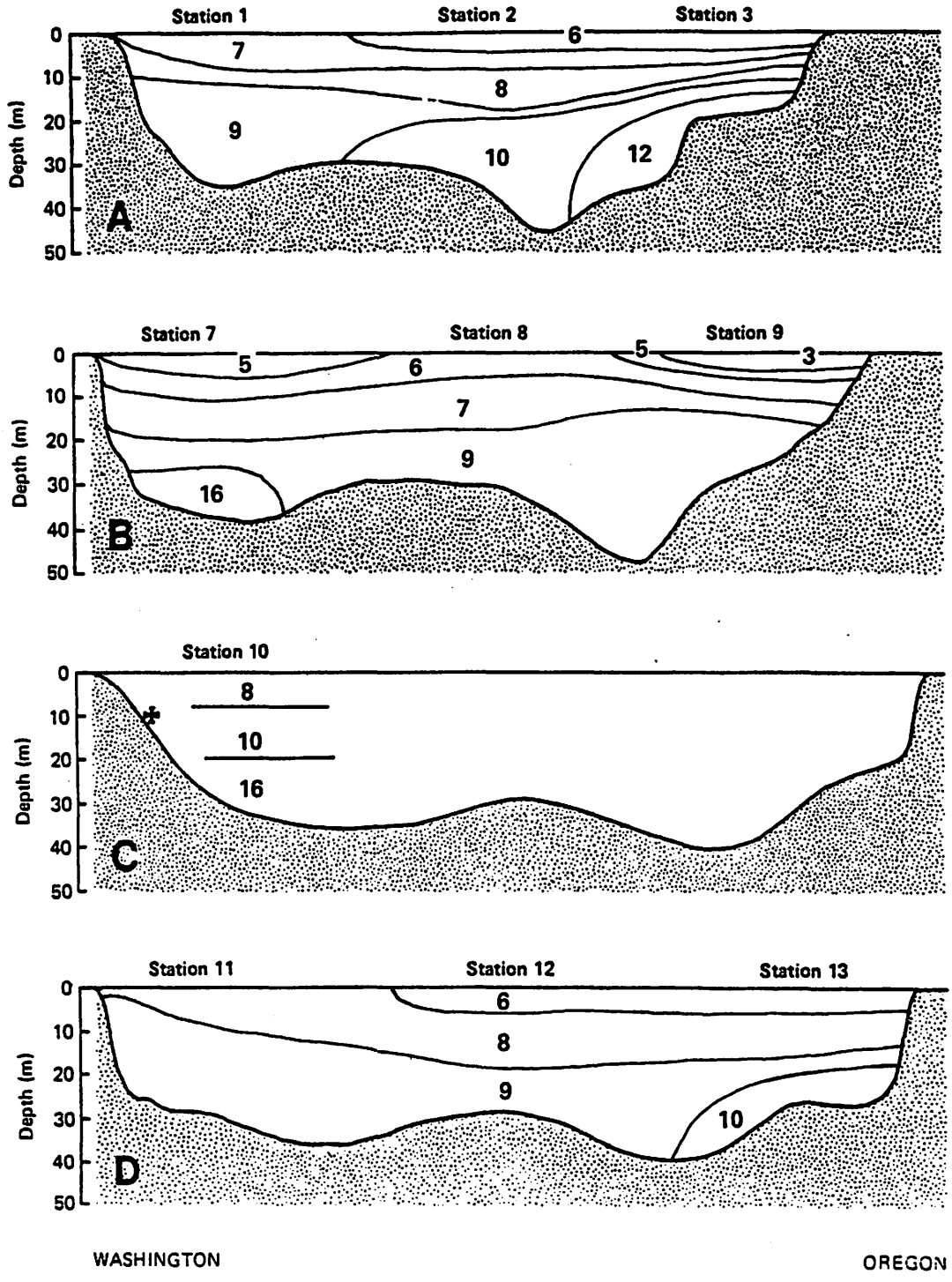

Figure 14.--Turbidity contours (NTU), 20-21 July 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

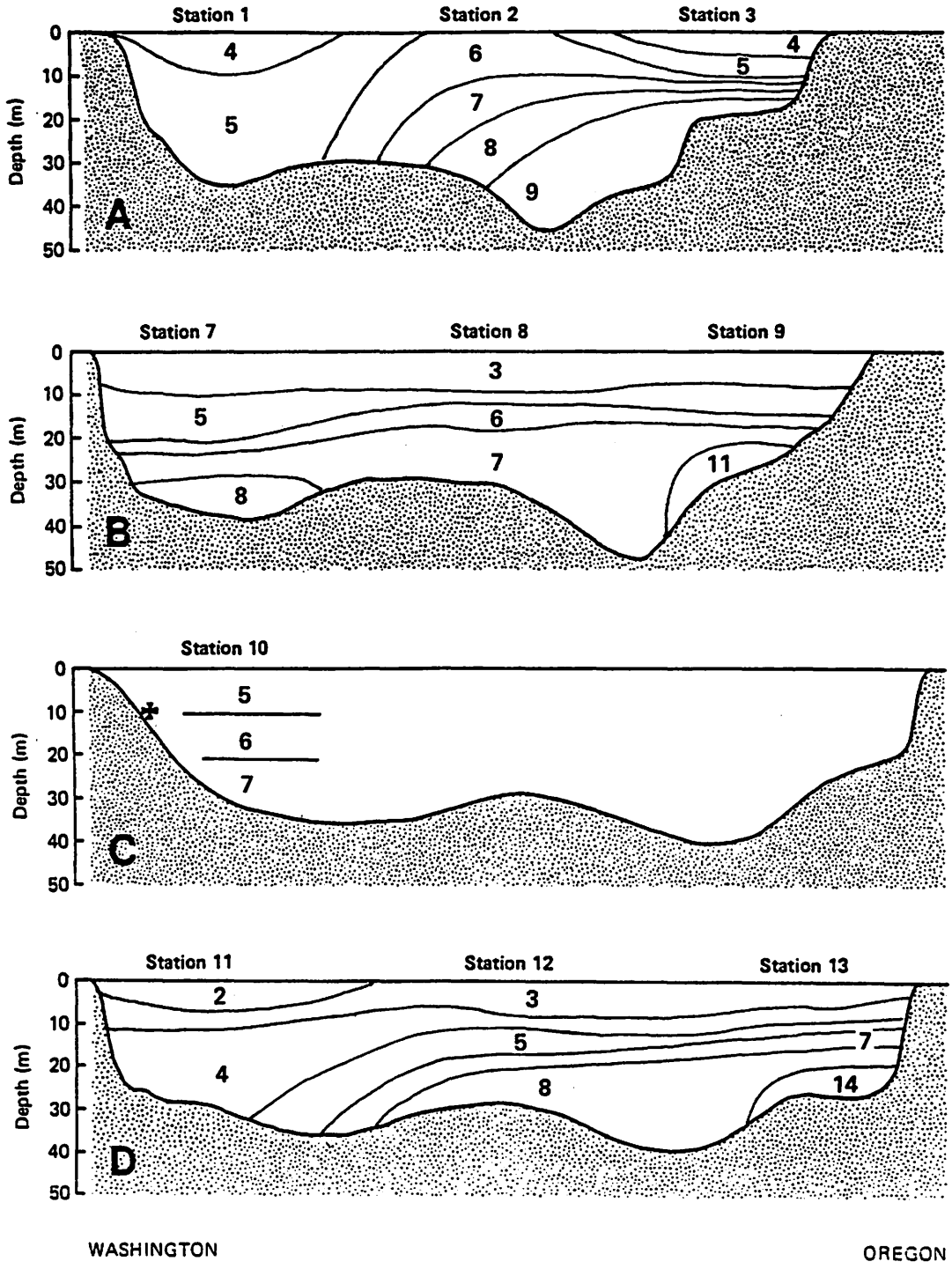

Figure 15.--Turbidity contours (NTU), 17-18 August 1983, John Day Dam region, Columbia River (see Figure 1 for station locations).

test fish failed to choose a passage and move upstream, although at the end of the test this fish was still active.

In over 100 experiments with returning male chinook salmon with fluoride entering one channel or the other, about half of the fish failed to make a choice. Their behavior was subdued, and very different from that of fish not exposed to fluoride. Of the chinook salmon moving upstream into one arm or the other, nearly 75% chose the non-fluoride side (Appendix Table 3).

In 97 fluoride tests with returning adult coho salmon, 64% moved upstream; of those, 66% chose the non-fluoride side. The experimental coho salmon generally appeared to be in better physical condition and were more active and decisive than the earlier-returning chinook salmon. However, while coho salmon seemed less subdued by the presence of fluoride in the water, they chose to avoid fluoride at nearly the same frequency as did the chinook salmon (Appendix Table 4).

During December, the last 77 fluoride tests were conducted with returning adult chum salmon. Of the 78% entering the two-choice flume, nearly 60% chose the non-fluoride side. The results with chum salmon did not indicate as strong an avoidance response as with chinook or coho salmon, but the variability of experimental conditions in December, in particular the large fluctuations in water temperature and the periods of extremely cold water (1° C), may have had some influence on the sensitivity of chum salmon (Appendix Table 5).

Bioassay tests on juvenile salmonids have shown that there is no preference for either end of the test apparatus when no pollutant is present. Strong statistically significant avoidance (chi-square test) was observed when 1.0 ppm fluoride was introduced to one end of the test

chamber. A lesser avoidance, but still significant, was recorded with 0.5 ppm fluoride stress. Though there was a tendency for the juveniles to avoid 0.3 ppm fluoride, we have not yet completed enough tests to note statistical significance. However, we have observed that the juveniles' general behavior (other than choice, no-choice) suggests a significant response even to this lowest test level of fluoride.

With dillution indexed on fluoride to give 0.5 ppm fluoride, the juveniles avoided the aluminum-plant industrial effluent in every case.

The swimming-performance tests suggested that increasing, but low, fluoride concentrations will decrease the stamina of juvenile salmonids. These tests will be improved and expanded in FY84. There were also significant alterations in levels of blood-T_4 in smolting juveniles kept in fluoride concentrations of 0, 0.3. 0.5, and 1.0 ppm. These bioassays will also be expanded. We have not yet obtained the blood analyses for the mature chinook and coho salmon kept in various fluoride concentrations.

SUMMARY AND CONCLUSIONS

1. It may be that in 1983, at least, the fluoride concentrations in the fishways did not determine the salmonids' choice of fishway. However, it is not the choice of fishway that has been the problem at John Day Dam; it is the serious delays of passage that have been observed in previous years. It is still possible that fluorides, even at the reduced 1983 levels, could cause these delays. Radio-tracking and position-logging of spring chinook salmon (and perhaps also of fall chinook salmon) are planned for 1984. These observations, combined with continued monitoring of pollutants, should reveal the extent of delays.

2. The observations of salmon behavior in the two-choice flume at Big Beef Creek are statistically significant (chi-square tests): (1) fluoride near 0.5 ppm affects the behavior of returning salmon; (2) in this concentration of fluoride, 20-50% of the salmon failed to continue upstream movements; and (3) those that continued upstream preferred the non-fluoride channel. Experiments in FY84 will be directed toward lower fluoride concentrations, to determine the threshold levels of fluoride for altered salmonid behavior. We will also begin observation on adult salmonids faced with diluted aluminum-plant industrial effluent.

The behavior of juvenile salmonids in the laboratory choice-apparatus is analogous to that of adults in the two-choice channels in the field. It may be argued that the observations on juveniles in fluoride gradients may not be applicable to the John Day Dam problem. However, it is believed that fluoride fundamentally interacts with cellular biochemical processes, and that the general responses of juveniles, including swimming performance, may be universal in this regard. The tests with adult salmonids are the principal efforts, and are given the highest priority when adults are available.

The mechanism of the fluoride effect on T_4 is not known. Low fluoride levels may increase secretion and/or decrease clearance of T_4. T_4 has been implicated in migratory behavior of juvenile salmonids, but the influence in adults is not known. T_4 has been shown to activate or depress various neural elements in the olfactory system of goldfish; similar effects of T_4 on this system in adult salmonids may interfere with homing migration.

Continuing laboratory bioassays with juveniles will enable us to

obtain preliminary observations on salmonids' responses to low levels of free lead and zinc ions. Tests with these materials on adult salmonids in the field are probably not possible at this time.

The greatly reduced fluoride discharges near John Day Dam provide a remarkable opportunity to test the early hypothesis that industrial fluorides (on the order of 0.3 ppm) may be implicated in the passage delay of adult salmonids. Field observations of delays, if any, in 1984, coupled with surveys of the continuing low-level pollutants, will give the best evaluation of this research to date. One must note that while apparent fluoride discharges have decreased markedly near John Day Dam, the possible heavy-metal activations may be unchanged. There is also the possibility that immediate reductions in direct discharge of fluorides will be followed shortly by substantially increased <u>indirect</u> additions from the newly constructed ("10-year life") pollutant holding-pond above the John Day Dam fishways. Future work, therefore, should continue to have both pollutant-monitoring and bioassay/behavior components aimed at the specific problem of Columbia River adult salmonid passage-delay.

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1983. Effects of water-borne pollutants on fish passage at John Day Dam, Columbia River. NOAA, NMFS, Northwest and Alaska Fisheries Center, Seattle, Washington. Report to the U.S. Army Corps of Engineers, Contract DACW57-82-F-0373. 77 p. (Processed).

APPENDIX

Tables 1-5

Appendix Table 1.--Physical characteristics of river water in the John Day Dam region, Columbia River, 20-21 July 1983 (see Figure 1 for station locations).

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
1	21 Jul	0840	35.0	0	18.99	9.9	0.12	9.3	7.0
				5	18.74	9.8	0.12	9.2	-
				10	18.73	9.9	0.12	9.2	-
				15	18.73	9.9	0.12	9.2	9.0
				20	18.74	10.0	0.12	9.4	-
				25	18.75	10.1	0.12	9.9	-
				30	18.76	10.2	0.12	10.1	9.0
2	21 Jul	0910	35.0	0	19.03	10.0	0.12	10.5	6.0
				5	18.72	9.8	0.12	9.6	-
				10	18.71	9.9	0.12	9.8	-
				15	18.71	10.0	0.12	10.0	8.0
				20	18.71	10.1	0.12	9.9	-
				25	18.73	10.1	0.12	10.1	-
				30	18.73	10.4	0.12	10.2	10.0
3	21 Jul	0940	25.0	0	19.04	9.7	0.12	9.8	6.0
				5	18.69	9.6	0.12	9.8	-
				10	18.68	9.7	0.12	9.9	-
				15	18.68	9.8	0.12	10.0	10.0
				20	18.69	9.8	0.12	10.2	-
				25	18.69	9.8	0.12	10.3	12.0
4	20 Jul	1700	17.0	0	20.48	10.2	0.14	-	7.0
				5	19.29	10.1	0.14	-	7.0
				10	19.25	10.1	0.14	-	-
				15	19.24	10.1	0.13	-	7.0
7	21 Jul	1010	28.0	0	19.30	10.2	0.12	10.6	5.0
				5	18.81	10.0	0.12	11.0	-
				10	18.74	10.1	0.12	10.9	-
				15	18.75	10.1	0.12	11.0	7.0
				20	18.76	10.1	0.12	11.1	-
				25	18.79	10.2	0.12	11.2	16.0

Appendix Table 1.--(cont.)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
8	21 Jul	1035	35.0	0	19.26	10.3	0.14	10.5	6.0
				5	18.85	10.2	0.13	10.5	-
				10	18.72	10.2	0.12	10.6	-
				15	18.73	10.3	0.12	10.7	7.0
				20	18.74	10.3	0.12	10.8	-
				25	18.74	10.4	0.12	11.0	-
				30	18.75	10.5	0.12	11.3	9.0
9	21 Jul	1105	35.0	0	19.86	10.2	0.14	11.9	3.0
				5	18.79	10.0	0.13	11.4	-
				10	18.71	10.1	0.12	11.2	-
				15	18.69	10.1	0.12	11.0	9.0
				20	18.71	10.1	0.13	10.9	-
				25	18.72	10.1	0.13	10.6	-
				30	18.74	10.2	0.13	10.5	9.0
10	20 Jul	1445	32.0	0	18.87	-	0.12	-	8.0
				5	18.82	9.4	0.12	-	-
				10	18.77	9.3	0.12	-	-
				15	18.76	9.3	0.12	-	10.0
				20	18.76	9.4	0.12	-	-
				25	18.76	9.4	0.12	-	-
				30	18.76	9.4	0.12	-	16.0
10	21 Jul	1230	32.0	0	19.31	10.1	0.12	11.0	5.0
				5	18.80	10.0	0.12	11.8	-
				10	18.77	10.0	0.12	12.1	-
				15	18.76	10.0	0.12	12.0	6.0
				20	18.76	10.1	0.12	12.1	-
				25	18.77	10.2	0.12	12.1	-
				30	18.78	10.2	0.12	12.1	8.0
L-1	21 Jul	1140	10.0	0	20.65	10.0	0.13	11.5	2.0
				5	19.13	9.8	0.13	10.8	-
				8	18.97	9.8	0.13	11.0	3.0

Appendix Table 1. (cont.)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
L-2	21 Jul	1200	7.3	0	21.08	10.0	0.13	10.8	2.0
				5	19.30	10.1	0.13	11.5	3.0
11	20 Jul	1510	28.0	0	18.93	8.9	0.12	-	8.0
				5	18.89	9.3	0.12	-	-
				10	18.84	9.3	0.12	-	-
				15	18.79	9.4	0.12	-	9.0
				20	18.81	9.4	0.12	-	-
				25	18.88	9.5	0.12	-	9.0
12	20 Jul	1530	35.0	0	18.91	9.5	0.12	-	6.0
				5	18.85	9.5	0.12	-	-
				10	18.85	9.5	0.12	-	-
				15	18.78	9.6	0.12	-	8.0
				20	18.78	9.6	0.12	-	-
				25	18.79	9.6	0.12	-	-
				30	18.81	9.7	0.12	-	9.0
13	20 Jul	1600	35.0	0	19.13	10.1	0.12	-	6.0
				5	18.97	10.0	0.12	-	-
				10	18.96	10.0	0.12	-	-
				15	18.92	10.1	0.12	-	8.0
				20	18.81	10.1	0.12	-	-
				25	18.76	10.2	0.14	-	-
				30	18.78	10.1	0.12	-	10.0
14	21 Jul	1330	-	0	-	-	-	-	8.0
16	21 Jul	1350	-	0	-	-	-	-	9.0

Appendix Table 2.--Physical characteristics of river water in the John Day Dam region, Columbia River, 17-18 August 1983 (see Figure 1 for station locations)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
1	18 Aug	0745	35.0	0	20.86	10.3	0.13	8.6	4.0
				5	20.84	10.3	0.13	9.3	-
				10	20.84	10.4	0.13	9.3	-
				15	20.84	10.4	0.13	9.5	5.0
				20	20.84	10.3	0.13	9.7	-
				25	20.84	10.3	0.13	10.1	-
				30	20.83	10.2	0.13	10.3	5.0
2	18 Aug	0812	35.0	0	20.90	10.2	0.13	8.5	6.0
				5	20.83	10.2	0.13	9.2	-
				10	20.83	10.2	0.13	9.3	-
				15	20.81	10.2	0.13	9.3	7.0
				20	20.82	10.2	0.13	9.3	-
				25	20.82	10.2	0.13	9.5	-
				30	20.81	10.1	0.13	9.7	8.0
3	18 Aug	0840	35.0	0	21.10	10.2	0.13	8.6	4.0
				5	21.01	10.2	0.13	9.4	-
				10	21.00	10.2	0.13	9.5	-
				15	20.96	10.1	0.13	9.6	7.0
				20	20.89	10.0	0.13	9.7	-
				25	20.77	9.7	0.13	10.0	-
				30	20.76	10.4	0.13	10.1	9.0
4	17 Aug	1720	28.0	0	22.52	10.4	0.19	8.9	3.0
				5	21.72	10.4	0.18	8.7	-
				10	21.37	10.3	0.17	8.6	-
				15	21.14	10.2	0.14	8.8	4.0
				20	20.81	10.1	0.13	8.8	-
				25	20.72	10.0	0.13	8.7	6.0
6	17 Aug	1830	22.0	0	22.23	10.6	0.19	8.8	4.0
				5	21.57	10.4	0.18	8.6	-
				10	21.20	10.3	0.16	8.7	5.0
				15	21.01	10.2	0.14	8.9	-
				20	20.87	10.0	0.16	8.9	8.0

Appendix Table 2. (cont.)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
7	18 Aug	0910	35.0	0	21.05	10.7	0.13	8.5	3.0
				5	20.90	10.7	0.13	9.5	-
				10	20.85	10.8	0.13	9.5	-
				15	20.82	10.9	0.13	9.6	5.0
				20	20.82	10.9	0.13	9.8	-
				25	20.81	10.9	0.13	10.0	-
				30	20.83	10.9	0.13	10.0	8.0
8	18 Aug	0935	35.0	0	21.22	10.8	0.14	10.0	3.0
				5	21.01	10.9	0.13	9.6	-
				10	20.99	10.9	0.13	9.6	-
				15	20.94	10.9	0.13	9.7	6.0
				20	20.90	10.8	0.13	9.7	-
				25	20.80	10.7	0.13	10.0	-
				30	20.83	10.7	0.13	10.6	7.0
9	18 Aug	1000	35.0	0	21.41	10.6	0.14	8.7	3.0
				5	21.03	10.5	0.13	9.4	-
				10	20.98	10.6	0.13	9.4	-
				15	20.97	10.3	0.14	9.4	5.0
				20	20.86	10.8	0.13	9.5	-
				25	20.71	10.7	0.13	9.3	-
				30	20.69	10.9	0.13	9.4	11.0
10	17 Aug	1620	35.0	0	20.87	10.6	0.13	8.9	5.0
				5	20.85	10.6	0.13	8.7	-
				10	20.85	10.5	0.13	8.8	-
				15	20.81	10.5	0.13	8.9	6.0
				20	20.72	10.6	0.13	8.8	-
				25	-	-	-	-	-
				30	-	-	-	-	7.0
L-1	18 Aug	1345	11.0	0	-	-	-	-	2.0
				10	-	-	-	-	4.0
L-2	18 Aug	1415	15.0	0	-	-	-	-	2.0
				15	-	-	-	-	3.0

Appendix Table 2.--(cont.)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
11	18 Aug	1040	35.0	0	21.06	10.4	0.13	9.1	2.0
				5	20.89	10.7	0.13	9.5	-
				10	20.83	9.7	0.13	9.5	-
				15	20.84	10.2	0.13	9.6	4.0
				20	20.84	9.8	0.13	9.7	-
				25	20.81	10.7	0.13	9.8	-
				30	20.83	10.9	0.13	10.0	4.0
12	18 Aug	1120	35.0	0	21.42	10.9	0.13	9.3	3.0
				5	20.96	10.9	0.13	9.3	-
				10	20.90	10.9	0.13	9.4	-
				15	20.83	10.8	0.13	9.3	5.0
				20	20.79	10.8	0.13	9.5	-
				25	20.80	10.7	0.13	9.8	-
				30	20.81	10.6	0.13	10.6	8.0
13	18 Aug	1150	35.0	0	21.76	-	0.14	9.5	3.0
				5	20.87	-	0.13	9.5	-
				10	20.81	-	0.13	9.5	-
				15	20.77	-	0.13	9.5	7.0
				20	20.72	-	0.13	9.4	-
				25	20.73	-	0.13	9.5	-
				30	20.72	-	0.13	10.0	14.0
14	18 Aug	1550	-	0	23.25	-	-	-	5.0
16	18 Aug	1610	-	0	21.40	-	-	-	6.0
Downstream (100m) from J.D. Dam									
North side	18 Aug	1530	-	0	-	-	-	-	6.0
South side	18 Aug	1630	-	0	-	-	-	-	5.0
17	17 Aug	1405	-	0	21.10	9.6	0.13	-	5.0
19	17 Aug	1435	-	0	21.09	9.6	0.13	-	5.0

Appendix Table 2.--(cont.)

Station	Date 1983	Time (PST)	Total depth (m)	Sample depth (m)	Temperature °C	pH	Conductivity (mmhos)	Dissolved oxygen (ppm)	Turbidity (NTU)
Bonneville Dam									
New powerhouse									
North fishway	17 Aug	1240	-	0	20.80	9.6	0.13	-	6.0
South fishway	17 Aug	1220	-	0	20.72	9.6	0.13	-	5.0
Old powerhouse									
Near south fishway	17 Aug	1145	-	0	20.72	9.6	0.13	-	5.0
South fishway	17 Aug	1115	-	0	20.72	9.6	0.13	-	6.0

Appendix Table 3.--Choices made by chinook salmon when exposed to fluoride in a two-choice flume.

Experimental conditions	Total tests	Results: Fluoride side	Results: Non-Fluoride side	Results: No choice
Fluoride right side	53	7	21	25
Fluoride left side	59	9	21	29
TOTALS	112	16	42	54
No fluoride either side (control)	43	19 (right side)	13 (left side)	11

χ^2 analysis

1. To test for fluoride avoidance among chinook making a choice,

$$\chi^2 = \frac{(16-29)^2}{29} + \frac{(42-29)^2}{29} = 11.7;\ P < 0.001;\ H_0 \text{ rejected.}$$

Conclusion: Chinook salmon avoided fluoride side.

2. To test preference for one side or the other among chinook salmon making a choice (no fluoride either side).

$$\chi^2 = \frac{(19-16)^2}{16} + \frac{(13-16)^2}{16} = 1.1;\ P \cong 0.30;\ H_0 \text{ accepted.}$$

Conclusion: No preference.

3. To test effects of fluoride on proportion of "No choices" (delays), [with no fluoride on either side (control), 74% (32 of 43) of the chinook salmon made a choice. It would therefore be expected that 83 chinook salmon of the 112 tested with fluoride present would also make a choice, if fluoride had no delaying effect, and 29 would not].

$$\chi^2 = \frac{(58-83)^2}{83} + \frac{(54-29)^2}{29} = 29.1;\ P < 0.001;\ H_0 \text{ rejected.}$$

Conclusion: Significantly more "No choices" (delays) occurred when fluoride was present.

Appendix Table 4.--Choices made by coho salmon when exposed to fluoride in a two-choice flume.

Experimental conditions	Total tests	Results: Fluoride side	Results: Non-Fluoride side	Results: No choice
Fluoride right side	44	14	17	13
Fluoride left side	53	7	24	22
TOTALS	97	21	41	35
No fluoride either side (control)	42	13 (right side)	17 (left side)	12

χ^2 analysis

1. To test for fluoride among coho salmon making a choice,

$$\chi^2 = \frac{(21-31)^2}{31} + \frac{(41-31)^2}{31} = 6.5;\ P \cong 0.01;\ H_0 \text{ rejected.}$$

Conclusion: Coho salmon avoided fluoride side.

2. To test preference for one side or the other among coho salmon making a choice (no fluoride either side),

$$\chi^2 = \frac{(13-15)^2}{15} + \frac{(17-15)^2}{15} = 0.5;\ P > 0.30;\ H_0 \text{ accepted.}$$

Conclusion: No preference.

3. To test effects of fluoride on proportion of "No choices" (delays), [with no fluoride on either side (control), 71% (30 of 42) of the coho salmon made a choice. It would therefore be expected that 69 coho salmon of the 97 tested with fluoride present would also make a choice, if fluoride had no delaying effect, and 28 would not].

$$\chi^2 = \frac{(62-69)^2}{69} + \frac{(35-28)^2}{28} = 2.5;\ 0.20 > P > 0.10;\ H_0 \text{ accepted.}$$

Conclusion: Significantly more "No choices" (delays) did not occur when fluoride was present.

Appendix Table 5.--Choices made by chum salmon when exposed to fluoride in a two-choice flume.

Experimental conditions	Total tests	Results: Fluoride side	Results: Non-Fluoride side	Results: No choice
Fluoride right side	40	17	13	10
Fluoride left side	37	8	22	7
TOTALS	77	25	35	17
No fluoride either side (control)	34	16	14	4

χ^2 analysis

1. To test for fluoride avoidance among chum salmon making a choice,

$$\chi^2 = \frac{(25-30)^2}{30} + \frac{(35-30)^2}{30} = 1.7;\ P \cong 0.20;\ H_0 \text{ accepted.}$$

Conclusion: Chum salmon did not avoid fluoride side.

2. To test preference for one side or the other among chum salmon making a choice (no fluoride either side),

$$\chi^2 = \frac{(16-15)^2}{15} + \frac{(14-15)^2}{15} = 0.1;\ P \gg 0.30;\ H_0 \text{ accepted.}$$

Conclusion: No "natural" preference.

3. To test effects of fluoride on proportion of "No choices" (delays), [with no fluoride on either side (control), 88% (30 of 34) of the chum salmon made a choice. It would therefore be expected that 68 chum salmon of the 77 tested with fluoride present would also make a choice, if fluoride had no delaying effect, and 9 would not].

$$\chi^2 = \frac{(60-68)^2}{68} + \frac{(17-9)^2}{9} = 8.1;\ .01 > P > 0.001;\ H_0 \text{ rejected.}$$

Conclusion: Significantly more "No choices" (delays) occurred when fluoride was present.