CZES Coastal Zone and Estuarine Studies

PORTLAND HARBOR: PRELIMINARY BIOASSAYS AND SEDIMENT BIOASSAYS

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December 1979

PORTLAND HARBOR: PRELIMINARY DREDGING STUDY

AND

SEDIMENT BIOASSAYS

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INTRODUCTION

The U.S. Army Corps of Engineers (CofE) is reviewing alternatives for the disposal of dredged material from the Willamette River (Portland Harbor, Figure 1). One alternative is the flow-lane disposal of this material into the Columbia River. Flow-lane disposal of bottom material by hopper dredge or barge (Blahm and McConnell 1979; Durkin et al. 1979) results in unknown dilutions (dependent on river flow) of sediment with Columbia River water; and during periods of high river flow, fine grained material is rapidly dispersed downstream from the disposal site.

To determine if bottom material from Portland Harbor would be detrimental or beneficial to the biota of the Columbia River, the National Marine Fisheries Service (NMFS), the U.S. Geological Survey (USGS), and the Portland District CofE entered into a four-part cooperative study: (1) comprehensive chemical analyses of the bottom material, (2) elutriation studies, (3) dredging studies, and (4) bioassay tests. Part 1 is discussed by McKenzie (1977), Part 2 is reported upon in Rinella and McKenzie (1977), and Parts 3 and 4 are covered in this report.

On 16 December 1977, three round trips with the hopper dredge BIDDLE were made between Portland Harbor in the Willamette River (WRM 9.2)[1/] to a disposal site in the Columbia River at mile 100.5 (Figure 1). The NMFS, USGS, and CofE monitored the operation to explore and improve monitoring techniques for future studies. In addition, information was collected to provide information on test concentrations for use in the long and costly flow-through bioassay tests. However, due to the high river flows and rapid dispersion of sediment, this initial dredge study provided only limited information for the design of bioassay tests.

[1/] English units are used for distances and flows associated with navigation and dredging; metric units are used for other measurements.

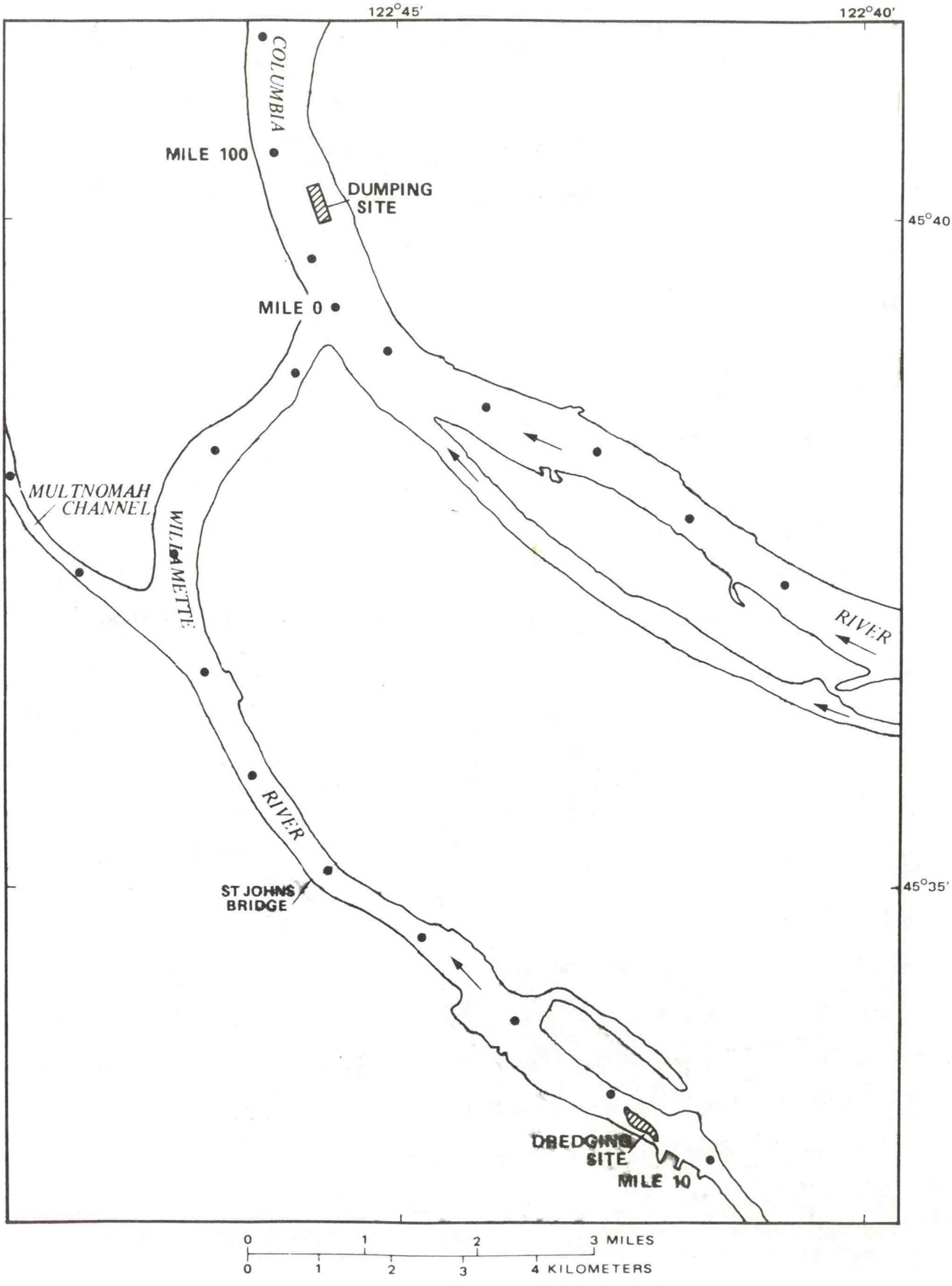

Figure 1...Dredging and dumping sites on 16 December 1977.

Static and flow-through bioassay tests were subsequently conducted at the NMFS Environmental Field Facility at Prescott, Oregon. Finfish were exposed to various concentrations of Portland Harbor sediment (Willamette River) to determine the potential effects of dredge material disposal in the Columbia River.

DREDGING STUDY

On 16 December 1977, the BIDDLE moved three loads of material (approximately 3,000 cubic yards total) taken from the bottom of the Willamette River (WRM 9.2) and deposited it in the Columbia River at Mile 100.5 (Figure 1). The USGS and NMFS in cooperation with the CofE monitored this operation.

On 16 December, the estimated mean daily water flow in the Columbia River at Bonneville Dam was 240,000 cubic feet per second (cfs); the Willamette River at Portland Harbor also had an estimated mean discharge of 240,000 cfs (Rinella and McKenzie, 1978). The 15-year average water flows in the Columbia and Willamette Rivers during this period are approximately 112,000 and 41,000 cfs.

The USGS and NMFS independently conducted surveys by bringing their boats near the stern of the dredge and then drifting downstream with the current while monitoring the water quality. Schedule of events are summarized in Table 1.

Temperature, dissolved oxygen, pH, turbidity, settleable matter, nonfilterable residue, and conductivity were generally measured at the water surface, mid-depth, and near bottom; NMFS did not monitor the first dredge loading operation at 0840 hours. One NMFS survey boat was used to monitor the first disposal in the Columbia River at 1024 hours, the second loading in the Willamette River at 1200 hours, and the last disposal at 1703 hours. Two NMFS survey boats were used to obtain maximum coverage during the second disposal and third loading sequence.

Techniques used for the determination of chemical and physical water quality parameters during the 16 December dredging study are the same as those described

Table 1...Time schedule of events for the Dredging Study, 16 December 1977.

Time	River	Mile	Remarks
0840	Willamette	9.2	Begin dredging: USGS monitoring
0845	Willamette	9.2	Dredging interrupted: clogged pipe
0900	Willamette	9.2	Dredging resumed
0915	Willamette	9.2	Dredging ended: 5-10% of hopper volume overflowed into Willamette
0920	Willamette	9.2	CofE transported dredge material to Columbia
1024	Columbia	100.5	Begin dumping: USGS-NMFS monitoring
1032	Columbia	100.5	Dumping completed: dredge doors closed
1200	Willamette	9.2	Begin dredging 2nd load: USGS-NMFS monitoring
1206	Willamette	9.2	Overflow from hopper began
1227	Willamette	9.2	Dredging ended, dredge material transported
1345	Columbia	100.4	NMFS (2 boats) and USGS collecting background data
1353	Columbia	100.5	Begin dumping
1358	Columbia	100.5	Dumping completed: USGS-NMFS sampling
1415	Columbia	99.2	downstream in an attempt to locate plume
1425	Columbia	99.2	Discontinued monitoring
1510	Willamette	9.5	NMFS (2 boats) and USGS collecting background data above dredge site
1522	Willamette	9.2	Dredging in progress
1527	Willamette	9.2	Overflow commenced
1550	Willamette	9.2	Dredging completed
1645	Columbia	101.5	NMFS (1 boat) monitoring above confluence of Columbia and Willamette Rivers
1705	Columbia	100.5	Begin dumping
1712	Columbia	100.5	Dumping completed
1730	Columbia	100.5	NMFS discontinued sampling

for monitoring the bioassay tests. Results of USGS findings are in their open file report 78-554 (Rinella and McKenzie 1978).

WILLAMETTE RIVER DREDGE SITE (WRM 9.2)

The first dredging operation was conducted with a minimal 5 to 10% of hopper load, by volume, overflow into the Willamette River. USGS reported little change in water quality during this first operation (Rinella and McKenzie 1978). The second dredge load was accomplished with what is considered a normal overflow period of approximately 20 minutes. Water quality parameters remained near background levels at the dredge sites. However, 46 meters downstream of the dredge (Table 2), a turbidity of 630.0 Jackson Turbidity Units (JTU) was recorded near the bottom. A reduction of dissolved oxygen (D.O.) from 12.0 mg/l background to 8.4 mg/l was associated with the above turbidity.

During the third loading operation, overflow was continued for 42 minutes to obtain maximum concentration in the Willamette River. The highest turbidity recorded was 595 JTU near the bottom, approximately 180 meters downstream of the dredge (Table 2); the D.O. associated with this sample was 11.9 mg/l.

Changes in temperature, conductivity, and pH were minimal at the dredge site when compared to background concentrations. Ranges in values for the 30 samples collected by NMFS were: water temperature, 8.4° to $9.0^{\circ}C$; conductivity, 0.05 to 0.15 millimhos/cm; pH, 6.7 to 7.0; D.O., 8.5 to 12.3 mg/l; and turbidity, 77.0 to 630.0 JTU (Table 2).

COLUMBIA RIVER DISPOSAL SITE (CRM 100.5)

Background data were collected upstream and/or downstream of the dump site for comparison with information obtained during and after the disposal operation. Water temperatures in the Willamette River ranged from 8.4° to $9.0^{\circ}C$ while water

Table 2...*In situ* water quality measurements at a Hopper dredge site at Willamette River mile 9.2, 16 December 1977. Some measurements were taken simultaneously with two survey boats.

Location	Time	Depth (m)	Temperature (°C)	Dissolved oxygen (mg/1)	pH	Turbidity (JTU)	Settleable matter (ml/1)	Nonfilterable residue (mg/1)
	Second loading: dredging commenced 1200 hours; overflow at 1206 hours continuing 21 minutes							
30 meters downstream of dredge (no overflow)								
	1159	18	9.0	12.0	6.9	90.0	0.40	259
	1206	0	8.9	12.3	7.0	77.0	0.26	181
46 meters downstream with overflow								
	1213	0	8.9	--	--	79.0	0.31	189
	1215	20	8.9	11.2	6.8	220.0	2.20	1170
	1220	9	8.9	12.4	6.9	84.0	0.30	179
	1225	15	9.0	8.5	6.7	630.0	12.70	1840
	Third loading: dredging commenced 1523 hours; overflow at 1527 hours continuing 21 minutes							
Control upstream of dredge site (WRM 9.5)								
	1510	0	8.5	11.9	7.0	78.0	0.28	190
		7	8.5	12.2	6.9	82.0	0.29	195
		13	8.5	12.2	6.9	88.0	0.31	205
30-4- meters downstream of dredge, no overflow								
	1522	0	8.4	11.8	6.9	78.0	0.28	190
		7	8.4	12.1	6.9	80.0	0.28	190
	1527	16	8.5	12.1	6.9	86.0	0.30	200
91-137 meters downstream								
	1523	0	8.9	11.8	6.9	80.0	0.28	190
		7	9.0	12.1	6.9	80.0	0.28	190
	1528	17	9.0	12.1	6.9	92.0	0.33	215
30-4- meters downstream, overflow commenced 1527								
	1530	0	8.5	11.8	6.9	82.0	0.29	195
		5	8.5	12.1	6.9	80.0	0.28	190
	1535	10	8.5	12.1	7.0	120.0	0.44	280

Table 2...Continued

Location	Time	Depth (m)	Temperature (°C)	Dissolved oxygen (mg/1)	pH	Turbidity (JTU)	Settleable matter (ml/1)	Nonfilterable residue (mg/1)
	Third loading continued, overflow							
90-100 meters	1535	0	8.6	12.1	6.9	86.0	0.30	200
		5	8.5	12.2	6.9	120.0	0.44	280
		10	8.5	12.2	7.0	200.0	0.79	500
100-180 meters	1543	0	8.5	12.0	7.0	86.0	0.30	200
		5	8.6	12.0	6.9	90.0	0.31	210
		10	8.5	11.9	6.7	595.0	11.40	1650
30 meters	1545	0	9.0	12.1	7.0	90.0	0.31	210
		6	9.0	12.1	6.9	78.0	0.27	185
		14	9.0	12.0	6.7	485.0	10.00	1310
914 meters	1550	0	8.6	12.1	7.0	90.0	0.31	210
		5	8.5	12.1	6.9	120.0	0.46	290
		13	8.6	12.1	6.9	335.0	1.50	884

temperatures in the Columbia River upstream from the confluence of the Willamette and Columbia Rivers ranged from 6.9° to 7.2°C. Water temperatures downstream from the mouth of the Willamette River ranged from 6.9° to 9.0°C, indicating a Willamette River influence at the disposal site.

It required approximately 3.25 hours for the Hopper Dredge BIDDLE to load and transport the material 10 miles to the disposal site, dump, and return to the dredge site (Figure 1). Data collected during the disposal operations are presented in Table 3.

A turbid surface plume was not apparent during the first disposal, and turbidities did not exceed river background by more that 10% surface to bottom. On the third dump (1703 to 1708 hours), a slight boil of turbid water was detected approximately 30 meters downstream of the dredge; associated turbidities surface to bottom were: surface, 100 JTU; 7 m, 120 JTU; and at 14 m, 160 JTU. Twenty minutes later turbidities at these same depths were 80, 82, and 82 JTU. Ranges for the 30 samples collected at the dredge disposal site were: temperature, 6.9° to 9.0°C; conductivity, 0.08 to 0.24 millimhos/cm; pH, 7.5 to 8.0; turbidity, 72.0 to 160.0 JTU; and dissolved oxygen, 11.4 to 12.0 mg/l. With the exception of turbidity during the third disposal, water quality parameters measured by NMFS did not exceed background levels at or downstream of the disposal area.

Due to the 240,000 cfs flow in the Columbia River on 16 December, rapid dilution of the disposed dredged material made it impossible to follow a plume downstream. The natural plume entering the Columbia River from the Willamette River was more visible than that which was observed during dredge disposal.

Table 3...*In situ* water quality measurements at a dredge disposal site at Columbia River mile 100.5, 16 December 1977.

Location	Time	Depth (m)	Temperature (°C)	Dissolved oxygen (mg/l)	pH	Turbidity (JTU)	Settleable matter (ml/l)	Nonfilterable residue (mg/l)
	First dump: dredge doors open 1024 hours - closed 1032 hours							
90-180 meters downstream of dredge*								
CRM 100.5	1024	0	9.0	11.9	7.6	62.0	0.15	108
		9	8.8	11.8	7.5	74.0	0.25	180
	1035	18	8.8	11.7	7.6	77.0	0.26	184
	Control: above dump site							
CRM 100.7	1055	0	7.5	12.0	7.8	90.0	0.31	210
		6	7.5	11.9	7.7	82.0	0.29	191
	1105	11	7.6	11.9	7.8	87.0	0.31	205
	Second dump: dredge doors open 1353 hours - closed 1358 hours							
	Control: at dump site							
CRM 100.4	1345	0	7.2	12.0	7.8	82.0	0.28	190
		5	7.1	11.9	7.7	84.0	0.29	195
	1350	11	6.9	11.9	7.7	96.0	0.34	225
30 meters downstream of dredge*(Boat #1)								
CRM 100.5	1345	0	7.2	11.4	7.6	74.0	0.26	175
		7	7.1	11.7	7.7	83.0	0.29	195
	1400	14	7.0	11.8	7.7	92.0	0.33	215
30 meters downstream of dredge*(Boat #2)								
	1358	0	7.2	11.7	7.7	84.0	0.29	195
		7	7.1	11.7	7.7	85.0	0.30	200
	1403	13	7.0	11.8	7.8	86.0	0.31	204
180 meters downstream of dredge*(Boat #1)								
	1400	0	7.8	11.9	7.5	72.0	0.24	165
		8	8.4	11.9	7.7	80.0	0.28	190
	1410	18	8.4	11.8	7.8	86.0	0.30	200
2250 meters downstream of disposal site								
CRM 99.2	1415	0	7.8	11.6	7.7	84.0	0.29	195
		6	7.8	11.8	7.7	76.0	0.27	185
	1425	15	8.0	11.7	7.7	84.0	0.29	195

Table 3...Continued

Location	Time	Depth (m)	Temperature (°C)	Dissolved oxygen (mg/1)	pH	Turbidity (JTU)	Settleable matter (ml/1)	Nonfilterable residue (mg/1)
	Third dump: dredge doors open 1703 hours - closed 1708 hours							
	Control: above confluence of Willamette River							
CRM 101.5	1645	0	6.7	11.4	7.8	78.0	--	--
		5	6.7	11.8	7.8	87.0	--	--
	1650	11	6.9	11.8	8.0	90.0	--	--
30 meters downstream of dredge*								
CRM 100.5	1705	0	7.0	11.4	--	100.0	0.36	235
		7	6.9	11.8	--	120.0	0.44	285
	1712	14	6.9	11.8	7.9	160.0	0.61	390
30 meters downstream of disposal site								
	1725	0	6.9	11.8	--	80.0	0.28	190
		7	6.9	11.9	--	82.0	0.28	191
	1730	12	6.9	12.0	7.9	82.0	0.28	191

*While dredge was dumping

BIOASSAYS

The bioassay tests were designed to biologically assess the information from sediment analysis, elutriate tests, and water quality. Sediment concentrations and water temperatures in the tests encompass or exceed those encountered during the initial dredge study (16 December 1977) or those expected during a full scale dredge/disposal operation.

TEST FACILITY

The NMFS Environmental Field Facility where tests were conducted was described in detail by Snyder et al. (1971). The facility is housed on two 33.5 by 10.5 m covered lighters moored on the Columbia River (Figure 2). The location is approximately 20 Columbia River miles downstream from the proposed dredge disposal site. The facility was originally designed and equipped to investigate effects of changing environmental parameters on aquatic biota.

All measurements, water samples, and analyses were completed using standard methods for the examination of water and wastewater (American Public Health Association 1975).

METHODS AND MATERIALS

Test Fish

Juvenile fall chinook salmon were obtained from the Little White Salmon Hatchery at Carson, Washington, and threespine stickleback were captured with beach seines in the Columbia River near the test facility. The fall chinook salmon ranged in fork length from 97 to 160 mm with an average of 113 mm; the adult stickleback ranged from 47 to 64 mm and averaged 57 mm. These species were selected for testing because of their abundance in the area, their suitability as bioassay animals, and

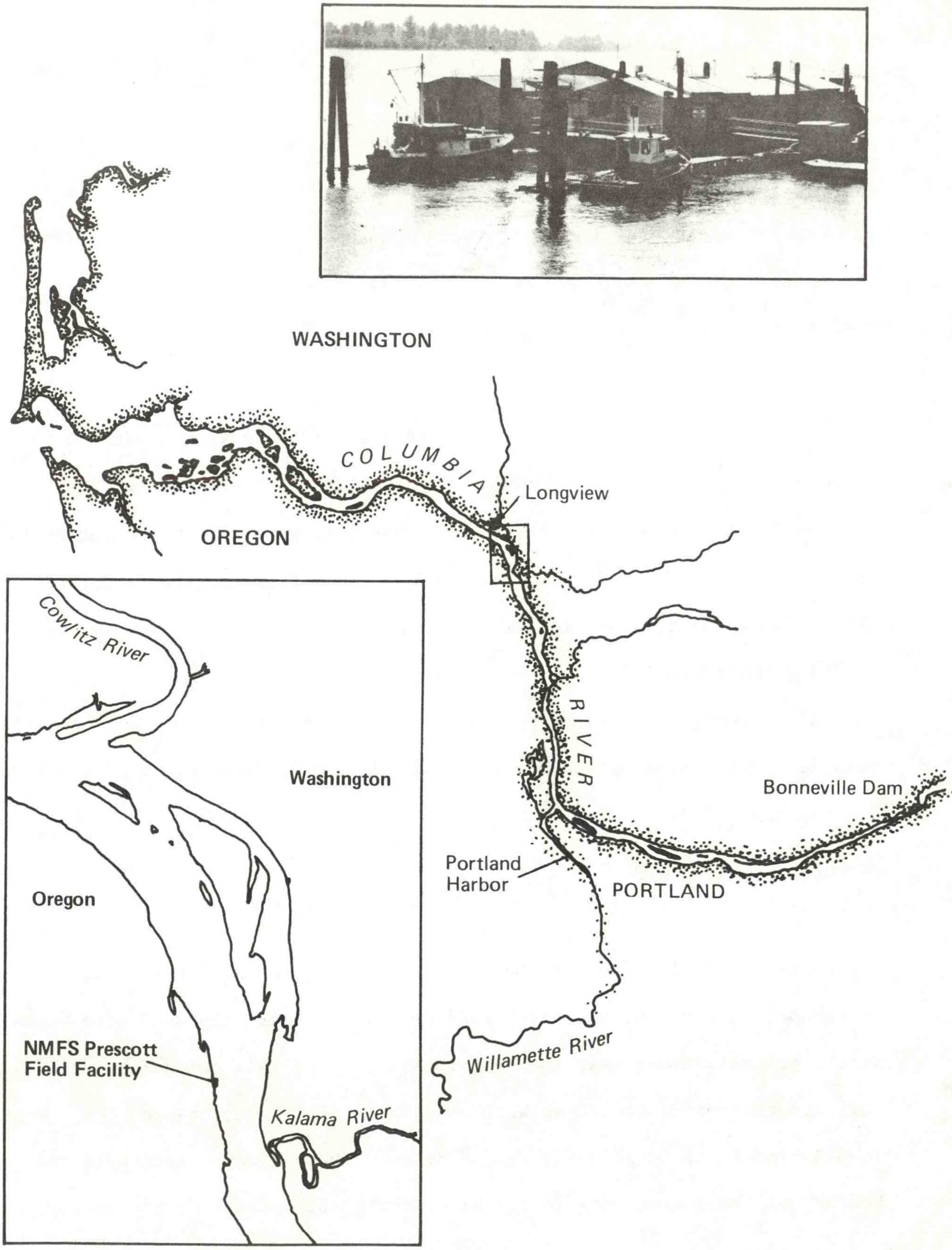

Figure 2...Lower Columbia River and locale (inset) of Prescott Field Facility.

the economic importance of chinook salmon. All test fish were held in Columbia River water and were temperature acclimated according to procedures outlined by Brett (1952). Test fish were not fed 1 day prior to, nor during the bioassay tests.

Sediments and Test Water

Sediment used in the bioassay was obtained from the bottom of Portland Harbor at the proposed dredging site, WRM 9.2. Material from the site of a clamshell dredging operation (WRM 11.2) was used for an additional 20°C 96-hour flow-through test. A tenth-meter Petersen dredge was used to collect sediment which was transported by boat to the Environmental Field Facility.

Water pumped directly from the Columbia River (RM 72) was heated and cooled to test temperatures, then mixed with sediment from Portland Harbor.

Bioassay Techniques

Two bioassay methods were used: static and flow-through (Weber 1973; EPA/CofE 1977; Rosenberger et al. 1978). Test tanks were 80 by 60 cm (Figure 3) filled to 170 liters. The tanks are made of wood, plexiglass, and stainless steel; the wooden surface is covered with chemical resistant epoxy coating.

Static tests were used to establish sediment concentrations for the 96-hour flow-through bioassays. Sediment to water concentrations in the static tests were 1:16, 1:24, 1:32, and 1:48. These concentrations were obtained by mixing sediment from the proposed dredge site with Columbia River water to a volume of 170 liters; e.g., 10 liters sediment mixed with 160 liters of water produces a volume to volume ratio of 1:16. Sediment to water concentrations used for the static bioassays were mixed in individual test tanks 16 hours prior to the introduction of fish to allow chemical constituents in the bottom sediment to be dissolved into the water column.

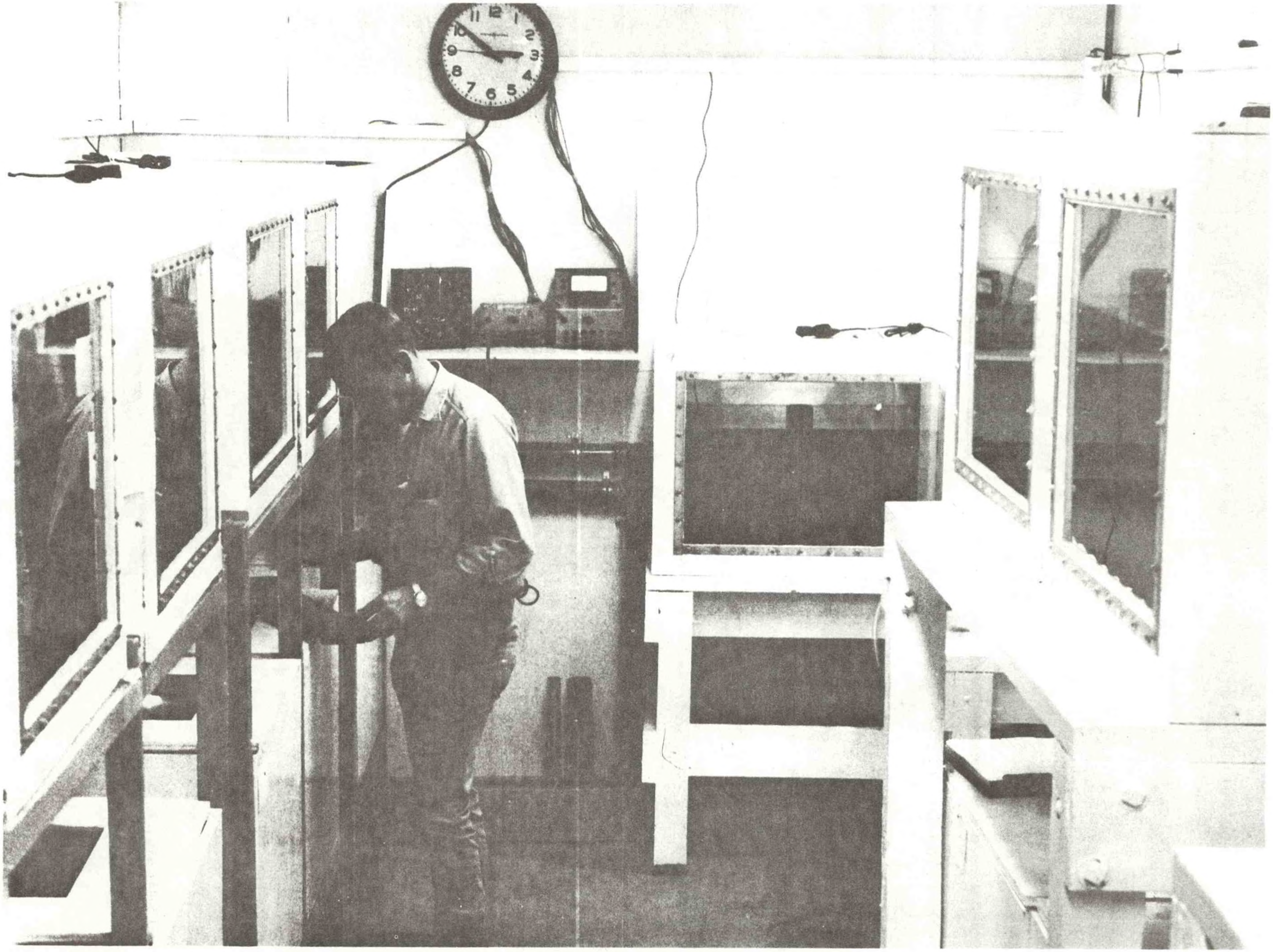

Figure 3—Flow-through bioassay tank; 175 l capacity, temperature controlled.

The sediment concentrations in the 96-hour flow-through bioassay tests were based on the results of the static tests and from background data gathered by NMFS during actual dredge and disposal studies. A base concentration of 1:32 sediment to water was used in tests with juvenile chinook salmon; 1:24 was used in tests with adult threespine stickleback.

The base concentration of Portland Harbor sediment and Columbia River water was premixed and poured into a 3,000 liter supply reservoir (Figure 4); freshly mixed material was added twice daily. Stirring paddles kept the sediment in suspension. The water supply to the reservoir was heated or cooled to the test temperature of 10^{o}, 15^{o}, or $20^{o}C$. The slurry from the reservoir was gravity fed to a stirred supply tank (Figure 4) which was equipped with a float switch and solenoid valve to maintain its volume level. Premixed, thermally adjusted, water and sediment from the supply tank was dispensed to a proportional diluter by a metering pump.

The diluter (Figure 5) described by Mount and Brungs (1967) is used to maintain a series of constant concentrations in flowing water. The functioning of the diluter depends on water flow, metering tubes, and venturi action to proportion water and sediment at a pre-determined concentration to individual test tanks.

Test concentrations in the flow-through bioassays were 100, 75, 50, 25, and 0 (control) % of the 1:32 or 1:24 base slurry. Test concentrations exceeded and/or encompassed turbidity levels found in the Columbia River by NMFS during the monitoring of four separate dredging and disposal operations.

Water flow to individual test tanks was adjusted to 1 liter/minute, providing a complete interchange in approximately 3 hours. To avoid overcrowding, 10 juvenile chinook salmon were used in each bioassay tank; twenty threespine stickleback were used because of their smaller size.

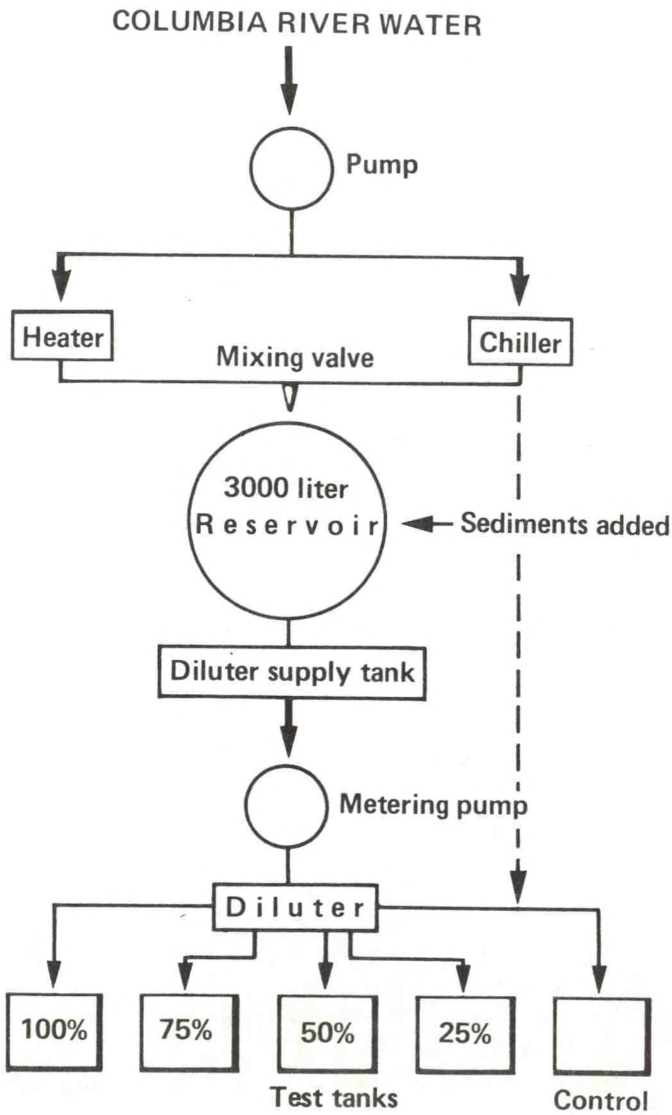

Figure 4...Flow diagram of water supply processing for bioassay of Willamette River sediment.

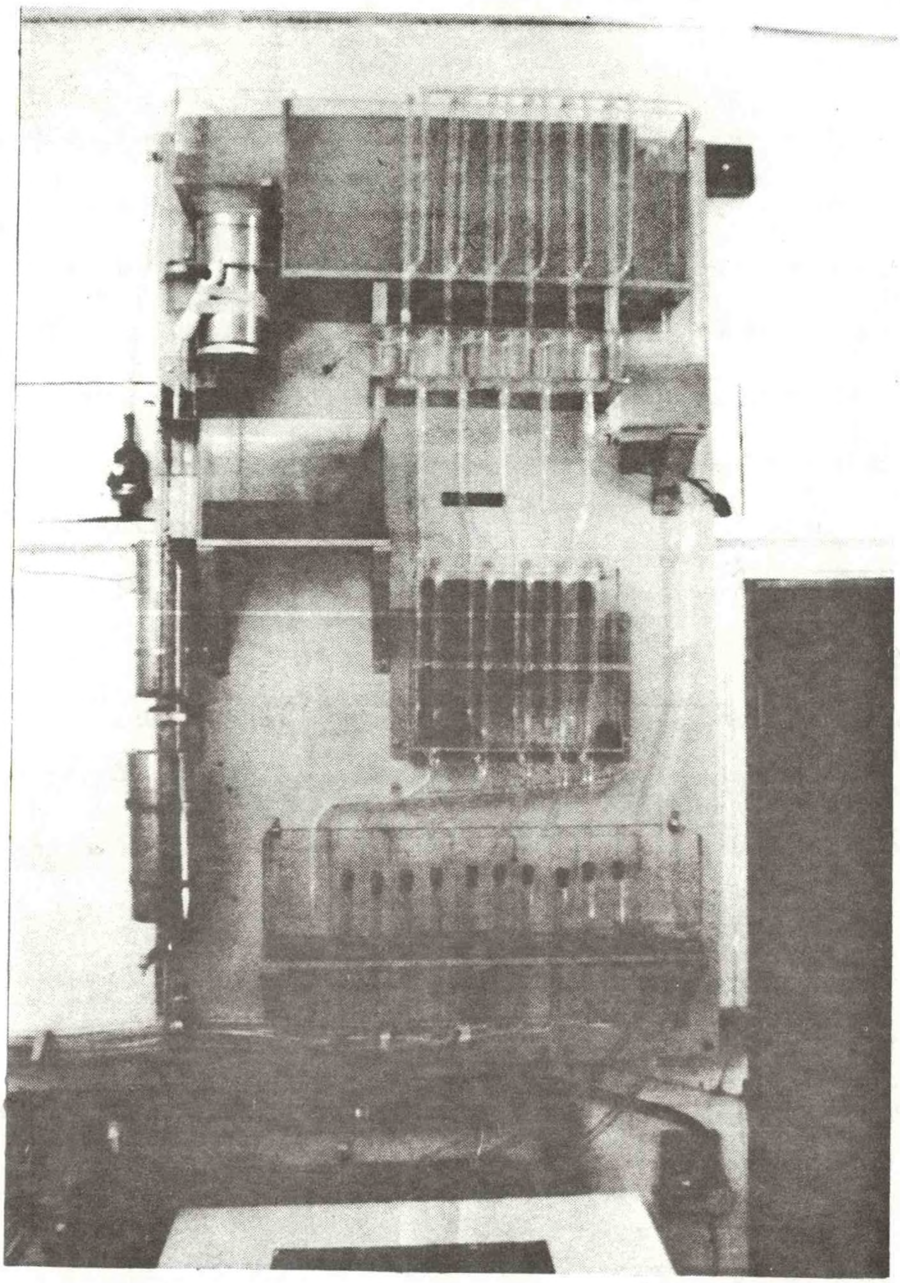

Figure 5. Diluter as used at Prescott Field Station to bioassay chemical fire retardants.

Test tanks were checked for dead fish each morning and afternoon by carefully running a dip net through the tank. Dead fish were weighed to the nearest 0.01 g and measured to the nearest mm; surviving fish were weighed and measured at the end of the test period. Visual inspections were made hourly, 0800 to 1630 hours, and any abnormal behavior was noted.

Water Quality Monitoring

Chemical and physical water quality was monitored daily in each test tank. Water temperature and D.O. measurements were taken directly from each tank. Water samples for pH, conductivity, ammonia, turbidity, settleable matter, and total nonfilterable residue were siphoned from 10 cm below the surface in each tank.

Water temperature was measured with a certified lab thermometer and recorded to the nearest tenth of a degree celsius (^{o}C). A YSI model 57 oxygen meter[2/] was used for D.O. determination. D.O. is recorded as milligrams per liter (mg/l). A Leeds and Northrup model 7404 meter was used to measure pH; conductivity was taken with a portable meter and recorded as millimhos/cm.

Ammonia levels were not taken during the static bioassays, nor in the 10^{o}C, nor the first 20^{o}C flow-through bioassays. Thereafter, ammonia-nitrogen (NH_3-N, mg/l) was measured daily with an Orion (Model 707) specific "ion" meter using the known addition method (Orion 1971).

Turbidity recorded as JTU was determined using an H.F. DRT 100 nephelometric turbidity meter with a full scale of 100 units. Values for those samples requiring dilution were calculated as outlined in Standard Methods for the Examination of Water and Wastewater (American Public Health Association 1975).

[2/] Reference to trade names does not imply endorsement by NMFS, NOAA.

Settleable material (mg/l) and total nonfilterable residue (TNFR, mg/l) were also determined using the methods described in Standard Methods for the Examination of Water and Wastewater.

The USGS provided NMFS with a partial chemical analysis of the bioassay sediment from the dredge site, and the material which settled on the bottom of the 100% bioassay tank. They also analysed the supernatant from the 100%, 20°C bioassay tank.

RESULTS

Static Bioassays

Ten each juvenile chinook salmon were subjected to various concentrations of Portland Harbor bottom sediment and Columbia River water for 24 hours at 10°C. Initial tests were conducted at four concentrations: 1:16, 1:24, 1:32, and 1:48 (Table 4). At the 1:16 concentration, 100% mortality occurred within 15 minutes; at 1:24, 100% mortality took place in 366 minutes; whereas, at the 1:32 ratio, 50% died in 378 minutes with 100% mortality at 403 minutes. No mortality occurred at the 1:48 concentration during the 24-hour exposure.

D.O. was the limiting factor in the static bioassay tests. The D.O. in the Columbia River was 9.8 mg/l at the time of mixing the test concentrations. Sixteen hours later (immediately prior to introducing the test fish), the D.O. in the 1:16 test tank had dropped to 2.2 mg/l and reached a low of 0.6 mg/l 7 hours later. D.O. in the 1:32 test tank was 3.8 mg/l when fish were introduced; 6 hours later, at the time of 100% mortality, D.O. was 1.4 mg/l.

Two additional static tests were simultaneously conducted at the 1:32 concentration; in one test, air stones added supplemental oxygen. In the tank without the additional air, 50% mortality occurred in 265 minutes and 100% in 443

Table 4...Time in minutes to mortality for juvenile chinook salmon and adult threespine stickleback tested at 10°and 12.9°C respectively with various ratios of Portland Harbor bottom sediment (WRM 9.2) and Columbia River water.

Juvenile Chinook Salmon 24-Hour Bioassay

Test concentration Mixing ratio	TNFR[1/] mg/l	Turbidity[2/] (JTU)	Time to mortality (min) 50%	100%
1:16	40,700	6,600	11	15
1:24	28,750	4,733	94	366
1:32	17,950	2,300	378	403
1:48	13,520	2,106	0	0

Adult Threespine Stickleback 96-Hour Bioassay

Test concentration Mixing ratio	TNFR	Turbidity (JTU)	Time to mortality (min)	
1:24	23,800	2,680	(15% mortality)	1300
1:32	15,400	2,040	0	
1:48	10,620	1,740	0	

1/ Total nonfilterable residue.

2/ Turbidity level after stirring and just prior to introduction of fish.

minutes; the lowest D.O. was 1.0 mg/l. In the test tank with supplemental air, only 20% mortality occurred; D.O. was 4.0 mg/l at the time fish were introduced but had returned to 9.0 mg/l after 24 hours.

Adult threespine stickleback were tested at 1:24, 1:32, and 1:48 ratios (Table 4). Twenty fish were used in each test concentration. Average test temperature was 12.9°C (ambient river).

No mortality occurred in the 1:32 or 1:48 concentrations, 15% mortality occurred in the 1:24 ratio after 1300 minutes. These tests continued for 96 hours at which time no additional mortality had occurred. D.O. in the 1:24 test tank ranged from 0.5 to 1.8 mg/l during the 96 hours. Turbidity in the 1:24 test tank ranged from 2,680 JTU at the time of mixing to 760 JTU after 96 hours.

A 48-hour static test at 20°C was conducted with threespine stickleback using bottom material from the Willamette River at mile 11.2 (site of a clamshell dredge operation). This test was at the 1:24 concentration. Twenty percent mortality occurred during the first 1,260 minutes (21 hours); no additional mortality was recorded. D.O. reached a low of 2.7 mg/l and remained near this level throughout the test.

96-Hour Flow-Through Bioassays

Ten juvenile chinook salmon were exposed to various concentrations of a 1:32 ratio of sediment to diluent. Twenty threespine stickleback were tested at various dilutions of a 1:16 base concentration.

Juvenile Chinook Salmon 10°C

Two flow-through bioassay tests were conducted at 10°C using juvenile chinook salmon. No mortalities occurred during the 96 hours of exposure to 100, 75, 50, 25, and 0 (control) % of the 1:32 base concentration (Table 5). Fish in 100% of the 1:32 ratio appeared stressed at the conclusion of the test and were swimming near the water surface.

Table 5...Average chemical and physical conditions during each 96-hour flow-through bioassay using dredge material from the Willamette River at mile 9.2 (1:32 base concentration). Included is percent mortality of juvenile chinook salmon.

Percent of concentration	Temperature (°C)	pH	NH_3-N (mg/1)	D.O. (mg/1)	Turbidity (JTU)	Settleable (ml/1)	TNFR (mg/1)	Percent (mortality)
					10°C			
0 (control)	9.9	7.50		10.9	10.1		12.0	0
25	10.1	7.30		9.7	268.0	0.39	361.0	0
50	10.1	7.20		8.5	585.0	1.29	587.0	0
75	10.3	7.07		7.7	777.0	2.32	748.0	0
100	10.5	7.03		7.6	910.0	3.25	873.0	0
					10°C			
0 (c)	10.1	7.79		10.7	4.6		8.0	0
25	10.6	7.35		9.3	246.0	0.23	236.0	0
50	10.9	7.19		8.4	522.0	1.09	501.0	0
75	11.2	7.16		7.5	695.0	1.92	669.0	0
100	11.6	7.12		7.3	806.0	2.51	775.0	0
					15°C			
0 (c)	14.7	7.75	0.32	9.5	6.7		8.0	0
25	14.7	7.37	0.85	8.5	314.0	0.33	303.0	0
50	14.8	7.19	1.58	7.5	628.0	1.48	646.0	0
75	14.8	7.05	1.54	6.8	791.0	2.38	724.0	0
100	14.9	6.98	2.19	6.8	888.0	3.00	857.0	0
					15°C			
0 (c)	14.8	7.57	0.13	8.8	8.2	0.19	14.0	0
25	14.8	7.25	0.98	7.6	250.0	0.19	240.0	0
50	14.6	7.03	0.88	6.6	510.0	0.92	441.0	0
75	14.6	6.90	1.08	5.8	676.0	1.66	631.0	0
100	14.6	6.81	1.40	5.9	792.0	2.35	766.0	0

Table 5...(Continued)

Percent of concentration	Temperature (°C)	pH	NH_3-N (mg/1)	D.O. (mg/1)	Turbidity (JTU)	Settleable (ml/1)	TNFR (mg/1)	Percent mortality
				20°C				
0 (c)	20.1	7.49		9.0	8.7	0.39	12.5	0
25	19.9	7.28		6.9	356.0	0.39	341.0	0
50	19.7	7.07		5.9	647.0	1.47	624.0	0
75	19.5	6.98		4.8	876.0	2.30	845.0	0
100	19.4	6.90		4.3	938.0	3.34	903.0	70 1/
				20°C				
0 (c)	19.8	7.72	0.16	8.6	9.9		10.3	0
25	19.7	7.28	1.25	7.5	596.0	1.25	572.0	0
50	19.6	7.09	1.50	6.1	892.0	3.07	860.0	0
75	19.5	7.02	2.38	5.1	985.0	3.82	898.0	0
100	19.4	6.94	2.90	3.5	1013.0	4.08	977.0	100 2/
				20°C 3/				
0 (c)	19.7	7.70	0.36	8.2	7.2		13.1	0
25	19.7	7.30	0.94	7.1	156.0	0.16	149.0	0
50	19.8	7.10	1.32	6.0	327.0	0.42	314.0	0
75	19.9	6.81	1.50	5.2	590.0	0.90	568.0	0
100	20.0	6.83	2.40	5.4	680.0	1.50	653.0	0

1/ LC_{50} 60 hours

2/ LC_{50} 90 hours

3/ Sediment from Willamette River mile 11.2

Turbidities at the 1:32 base concentration averaged 910 JTU and ranged from 690 to 985 JTU. D.O. decreased with increasing concentration of sediment ranging from an average 10.9 mg/1 in the control (0%) to 7.6 mg/1 in 100% of the 1:32 base concentration (Table 5). As concentration of sediment increased from control (0%) to 100%, the pH in the test tanks ranged from 7.4 to 7.03.

Turbidities during the second 10°C test series were generally lower. Values in the 100% tank ranged from 520 to 990 JTU and averaged 806 JTU. The mean daily chemical and physical conditions during each test are presented in Table 5.

Juvenile Chinook Salmon 15°C

No mortalities were recorded during the two 15°C bioassay tests. Fish at the higher concentrations (75 and 100% tanks) appeared stressed and were observed near the water surface during these tests.

Turbidities in the test tank containing 100% of the 1:32 base concentration averaged 888 JTU during the first 15°C test series, ranging from 730 to 980 JTU. Average turbidity during the second series was 792 JTU, ranging from 590 to 930 JTU. Levels of D.O. at 15°C were consistently lower than the D.O. levels during the 10°C tests (Table 5). At 15°C, D.O. ranged from 9.5 mg/1 in the control to 6.8 mg/1 in the 100% tank during the first series. In the second series, D.O. ranged from 8.8 mg/1 control to 5.9 mg/1 in the 100% tank. The pH ranged from 7.75 to 6.98 and from 7.57 to 6.81 during the two 15°C tests. The lower pH readings were found in the tanks with the highest concentrations of sediment. Ammonia nitrogen levels (NH_3-N) increased as the concentrations of sediment to water increased. Values ranged from 0.1 mg/1 in the control to 2.87 mg/1 in the 100% tank.

Juvenile Chinook Salmon 20°C

Three flow-through bioassay tests were conducted at 20°C. The first two were with Willamette River bottom material collected at WRM 9.2. The third was with sediment from WRM 11.2, the site of a clamshell barge dredging operation.

During the first 20^{o}C bioassay, 70% of the test fish in the 1:32 base concentration died within 69 hours. A 20% mortality occurred during the first 24 hours; whereas, 50% died between 52 and 68 hours. One mortality did occur at the 75% concentration although time to death is not known; this fish was found in the sediment at the conclusion of the test.

No mortalities occurred during the first 87 hours of the second 20^{o}C bioassay; however, all fish at the 1:32 base concentration died during the next 2 hours and 40 minutes. A 50% mortality occurred at 88 hours and 22 minutes, and 100% were dead at approximately 90 hours.

Turbidity during the second 20^{o}C tests was higher than during previous tests, averaging 1,013 JTU in the 100% test tank, ranging from 965 to 1,210 JTU. Oxygen in the 100% tank averaged 3.4 mg/1, ranging from 4.8 to 2.7 mg/1. Ammonia nitrogen (NH_3-N) in the 100% tank averaged 2.4 mg/1 and reached a high of 3.0 mg/1 (Table 5).

The USGS chemically analyzed the supernatant from the 100% test tank at 48 and 96 hours. Results of these analyses are presented in Table 6. Dissolved copper (6.0 μg/1), dissolved lead (13.0 μg/1), dissolved manganese (920.0 μg/1), and dissolved cadmium (2.50 μg/1) exceeded the water quality criteria for salmon and/or marine mollusks (EPA 1976).

Primary cause of mortality was suffocation due to the inability of the fish to clear sediment from their gills. Added to this were synergistic effects of temperature (20^{o}C), low oxygen (3.5 mg/1), and exposure to low levels of toxic material.

The third 20^{o}C bioassay series used bottom material from the site of a clamshell barge-dredging operation at WRM 11.2. Turbidity levels were lower than those measured when using material from WRM 9.2, since the sediment at WRM 11.2 was

Table 6...Analyses of the supernatant water U.S. Geological Survey collected during a 96-hour flow-through sediment bioassay at 20^{o}C with juvenile chinook salmon, using a 1:32 base concentration of Portland Harbor bottom sediment and Columbia River water.

Parameter	48 hours	96 hours
Temperature (°C)	19.40	19.50
pH	6.98	7.05
Conductivity (mmhos/cm)	148.00	155.00
Dissolved oxygen (mg/l)	3.20	2.70
Turbidity (JTU)	790.00	990.0
Suspended sediment (mg/l)	1540.00	1760.00
Residue loss on ignition (%)	12.00	13.00
Total organic carbon (mg/l)	61.00	83.00
Dissolved ammonia -N (mg/l)	1.70	1.80
Total ammonia -N (mg/l)	1.80	2.00
Dissolved copper (µg/l)	1.00	6.00
Total copper (µg/l)	300.00	260.00
Dissolved lead (µg/l)	6.00	13.00
Total lead (µg/l)	400.00	300.00
Dissolved manganese (µg/l)	920.00	840.00
Total manganese (µg/l)	4600.00	4200.00
Dissolved zinc (µg/l)	10.00	10.00
Total zinc (µg/l)	750.00	660.00
Dissolved cadmium (µg/l)	1.80	2.50
Total cadmium (µg/l)	2.00	2.60

coarser. Seventy-two percent of the bottom material at WRM 9.2 was <0.062 mm; whereas, only 28% of the sediment at WRM 11.2 was <0.062 mm. D.O. ranged from 4.0 to 6.0 mg/l in the (1:32) test tank which was higher than the D.O. in the other two 20°C tests.

Threespine Stickleback

A 96-hour flow-through bioassay was conducted using 20 adult threespine stickleback in a 1:24 base concentration of Willamette River bottom material (from WRM 9.2) mixed with Columbia River water (Table 7). Test water reflected the ambient Columbia River temperature during the test period (12.9°C).

No mortalities occurred during this test series. Turbidities in the 100% (1:24) test tank ranged from 950 to 1,600 JTU and averaged 1,182 JTU. D.O. of the mixing water (control) during this test series averaged 10.24 mg/l. D.O. levels in the 100% test tank averaged 6.66 mg/l and ranged from 4.6 to 7.3 mg/l. Daily chemical and physical parameters for this series are summarized in Table 7.

DISCUSSION

When in-water disposal of dredged material is being considered, it is generally desirable that the deposited material be structurally similar to the material at the disposal site; i.e., silt on silt, sand on sand, etc. A CofE report (Maki 1979) summarizes the results of water quality investigations relating to Portland Harbor dredge and dredge disposal studies. Material from the bottom of the Willamette River in the Portland Harbor area had been described as silty or fine grained, odorless, with no structural integrity, containing numerous diatoms, and having a high oxygen demand. Material in the Columbia River at the disposal site is generally medium to fine grained sand. It has been estimated (Maki 1979) that approximately 3.8 million cubic meters (5 million cubic yards) of suspended

Table 7...Mean daily chemical and physical conditions during a 96-hour flow-through bioassay test of dredged material from the Willamette River (WRM 9.2). Adult threespine stickleback were tested at ambient river temperature (12.9°C) at various dilutions of a 1:24 base concentration of sediment and Columbia River water.

Percent Concentration	Temperature (°C)	pH	NH_3-N (mg/1)	D.O. (mg/1)	Turbidity (JTU)	Settleable (mg/1)	TNFR (mg/1)	Mortality (%)
0	12.2	7.34	.14	10.23	9.2		14.5	0
25	12.4	7.33	.64	8.96	467.5	0.72	428.3	0
50	12.9	7.16	1.36	7.86	845.0	2.37	785.7	0
75	13.3	6.99	1.83	6.72	1020.0	4.47	1020.0	0
100	13.8	6.93	2.16	6.66	1182.0	6.20	1168.3	0

material flows from the Willamette River into the Columbia River during a normal flow year; therefore, material from the Willamette River is not foreign to the proposed disposal site at the confluence of the two rivers.

The 16 December 1977 study showed that the 1:32 slurry of Portland Harbor bottom material and Columbia River water used during the flow-through bioassay tests exceeded sediment concentrations during the 16 December dredge and disposal study. Highest sediment concentrations and turbidities were found near the bottom at both the dredge and disposal sites. The highest turbidity (630.0 JTU) was at the dredge site during the second loading operation; associated with this turbidity was a decrease in D.O. of 3.5 mg/l (12.0 to 8.5 mg/l). Maximum turbidity at the disposal site (160 JTU) occurred during the third disposal. Background turbidities in the Willamette River (WRM 9.2) on 16 December 1977 ranged from 78 to 90 JTU; at the Columbia River disposal site background turbidity ranged from 82 to 96 JTU. Rapid dilution was found at both locations due to the above average river flows.

A series of static bioassay tests helped establish a sediment to water concentration for the flow-through bioassay tests. Twenty-four-hour static tests were conducted at 10^{o}C using juvenile chinook salmon at four sediment concentrations: 1:16, 1:24, 1:32, and 1:48. At the 1:32 sediment to water concentration, half of the fish died in 378 minutes and all died by 403 minutes. No mortality occurred at the 1:48 concentration. D.O. was the limiting factor; at 403 minutes (100% mortality), D.O. in the 1:32 test tank was 1.4 mg/l. In a 1:32 static test where supplemental air was introduced, a 20% mortality occurred during 24 hours. A 15% mortality was recorded after 96 hours when adult threespine stickleback were tested in a 1:16 concentration of Willamette River bottom sediment and Columbia River water.

Replicate 96-hour flow-through bioassay tests using a concentration of 1:32 sediment (WRM 9.2) to water were conducted with juvenile chinook salmon at three temperatures: 10, 15, and 20^{o}C. An additional test at 20^{o}C used dredge material from WRM 11.2.

There were no mortalities at the 10^{o} or $15^{o}C$ test temperatures; however, fish did appear stressed and were observed swimming at or near the surface of the 1:32 supernatant test tank during the last 24 hours of the 96-hour exposure. No mortality occurred when adult threespine stickleback were tested at a 1:24 sediment to water base at ambient river temperature ($12.9^{o}C$).

During the first $20^{o}C$ flow-through bioassay, a 70% mortality occurred; half of the fish died between 52 and 68 hours of exposure to the 1:32 concentration. Average turbidity in this test tank over the 96 hours was 938.8 JTU.

There were no mortalities recorded during the first 87 hours of the second $20^{o}C$ test; however, all fish died in the 1:32 concentration during the next 3 hours. Average turbidity (1,013 JTU) was higher than during the first $20^{o}C$ test series. A chemical analysis (Table 6) of the supernatant water from the 1:32 test tank after 48 hours and 96 hours showed that dissolved copper, lead, manganese, zinc, and cadmium exceeded the EPA criteria for salmon and/or marine mollusks. Following is a comparison between the highest test concentration for each of the five metals and the EPA 1976 quality criteria for water:

Constituents	Test concentration (μg/l)	EPA quality criteria (μg/l)	Water use
Dissolved lead	13.0	5.0	Coho salmon
Total lead	400.0		
Dissolved zinc	10.0	1.0	Chinook salmon
Total zinc	750.0		
Dissolved manganese	920.0	100.0	Marine mollusks
Dissolved copper	6.0	1.8	Chinook salmon
Dissolved cadmium	2.5	0.4	Salmonid fishes

Lead: The American Fisheries Society (AFS) Water Quality Section, in a review (Thurston et al. 1978) of the EPA Red Book Quality Criteria for Water recommends that this criterion be established for total lead (not dissolved lead) in fresh water and that the criterion be based on a sliding scale of water hardness ($CaCO_3$). Hardness of the Columbia River near Prescott (CRM 72.0) ranges from 21 mg/l in January to 71 mg/l $CaCO_3$ in July/August, and therefore would be considered soft water. Applying the AFS recommendation for the protection of freshwater organisms at a hardness of 30 to 100 mg/l $CaCO_3$, the limit would be 25.0 μg/l total lead which is considerably lower than the 400.0 μg/l total lead measured in the supernatant water from the 1:32 test tank.

Zinc: AFS recommendation for zinc is similar to that for lead. With a water hardness between 0 and 75 mg/l $CaCO_3$, AFS suggested criterion is 50.0 μg/l total zinc. Highest total zinc concentration during the tests was 750.0 μg/l.

Dissolved copper: AFS suggests a dissolved copper standard between 5 to 15 μg/l for the protection of the entire ecosystem. The highest value (6.0 μg/l dissolved copper) at 96 hours may or may not exceed the dissolved copper standard.

Dissolved cadmium: The AFS proposed cadmium standards are also linked to water hardness. The suggested cadmium concentration in a hardness range of 35 to 75 mg/l $CaCO_3$ is 1.00 μg/l, which is below the 2.50 μg/l level at the completion of the second bioassay.

Dissolved manganese: AFS recommends an upper limit of 1,000 μg/l manganese as necessary to protect freshwater life. The highest concentration at 20°C in the 1:32 test tank was 920.0 μg/l at 48 hours.

Possible synergistic and/or antagonistic effects of zinc, cadmium and other trace metals are not taken into account when a singular criterion is considered.

Suspended sediments and turbidity levels obtained by mixing 1 part Willamette River bottom sediment with 32 parts Columbia River water exceed all turbidity and suspended sediment values recorded by NMFS during the monitoring of four separate dredge and dredge disposal operations in the lower Columbia River. These studies were: (1) Chinook Channel (Blahm et al. 1979); (2) Pillar Rock (Durkin et al. 1979); (3) Dobelbower Bar (Blahm and McConnell 1979); and (4) the present Portland Harbor hopper dredge disposal study. Changes in water quality from any of the four dredging operations were less and existed for far shorter times than the levels in the 96-hour bioassay tests.

General chemical and physical trends during the 96-hour flow-through bioassay test show that as the sediment to water concentrations increase, D.O. and pH decrease. The relationship of turbidity to D.O. at the three temperatures 10, 15, and 20^{o}C for each of the concentrations of Willamette River sediment is shown in Figure 6. As temperature increases D.O. decreases. The average value for D.O. in the 1:32 test tanks at 10^{o}C was 7.45 mg/l which is 68% of oxygen saturation. At 20^{o}C, the mean oxygen value in the 1:32 tanks was 3.9 mg/l at an average temperature of 19.4^{o}C; these tanks were 42% oxygen saturated. EPA D.O. criteria for freshwater life is a minimum concentration of 5.0 mg/l. In the two 20^{o}C 96-hour bioassay tests where mortality did occur, the D.O. concentrations averaged 4.3 and 3.5 mg/l, respectively.

The toxicity of an ammonia solution depends on the pH of the water since only the un-ionized molecule NH_3 is toxic to fish. The more basic the water, the higher un-ionized portion of ammonia (Thurston et al. 1974). As sediment to water ratio increased, so did the ammonia nitrogen levels, but pH went from basic toward acidic. For example, in the 1:32 test tank at 15^{o}C, a high of 2.87 mg/l NH_3-N was recorded at a pH of 6.85. The un-ionized portion of the NH_3 molecule is 0.005 mg/l, while the Red Book criterion for freshwater life is 0.018 mg/l NH_3.

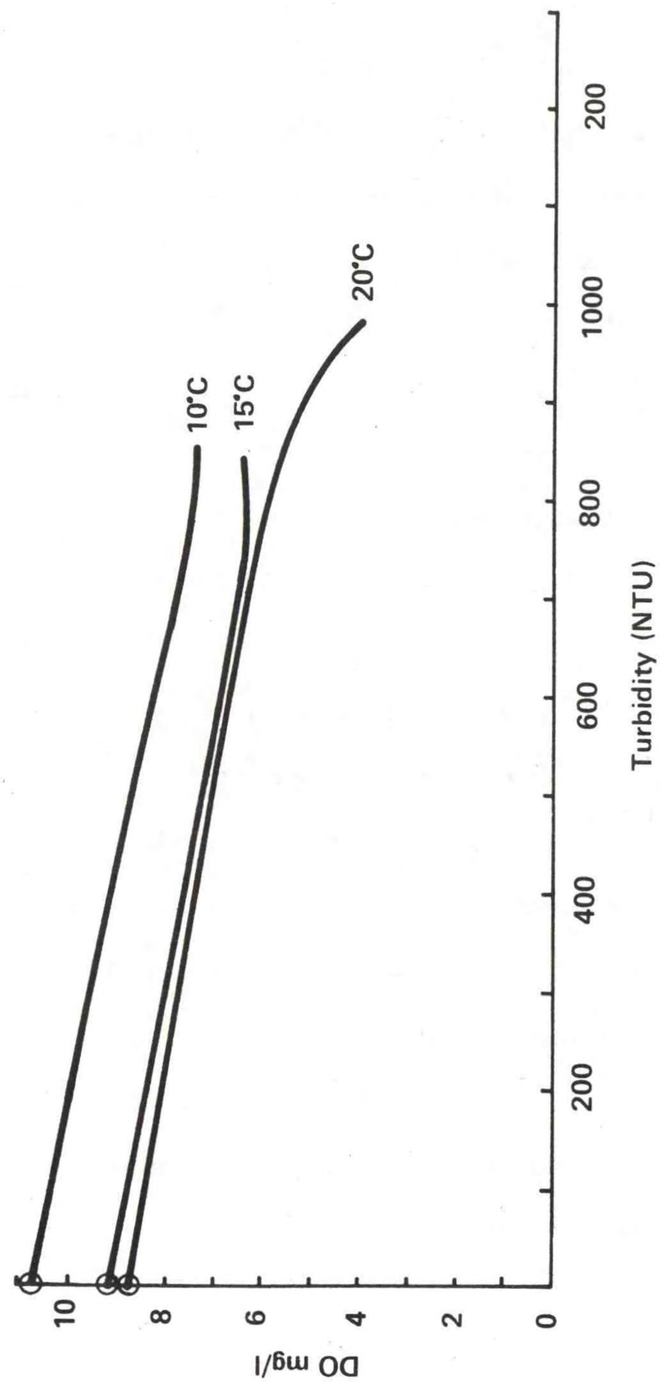

Figure 6.--Relationship of dissolved oxygen and turbidity for three water temperatures in 96-hour bioassays tests. Sediment ranged from 1:32 Willamette River sediment (WRM 9.2) to Columbia River water with no sediment.

Turbidity during the 96-hour flow-through tests fluctuated between test series and also during the 96 hours of the test. Although care was taken to collect and process the samples uniformly, sand and heavy material settled out so fast that material accumulated in the reservoir, the diluter supply tank, and in the 1:32 test tanks. Differences between samples with respect to fine and course material resulted in variations in turbidity and settleable and total nonfilterable residue. Another source of variability, especially in the TNFR, came from the necessarily small samples (20 to 50 ml). Larger samples could not be filtered in a reasonable time.

Studies with Lake Washington sediment and juvenile coho salmon tested at $8^{O}C$ (Craddock et al. 1978) did not establish a 50% lethal concentration at turbidities as high as 9,700 JTU's.

Patten (1976) tested coho salmon fingerlings in Lake Washington sediment and found no mortality at sediment concentrations up to 37,000 ppm after 96 hours at $16.6^{O}C$. Wallen (1951) in a study of warm water fish states that most individuals of all species tested endured exposures to sediment concentrations greater than 100,000 ppm for a week or longer; however, these same fish finally died at concentrations of 175,000 to 225,000 ppm.

Other studies by Patten (1976) demonstrated that given a choice, coho salmon fingerlings choose clear over turbid water and, therefore, would not be exposed to high turbidities for periods approaching the length of our exposures (96 hours).

We have no knowledge of the long-term effect these exposures might have on individual fish. It has been established that prolonged exposure to excessive turbidity is harmful to aquatic life in general by reducing productivity (Cordone and Kelley 1961). However, because test concentrations, water temperature, and duration of exposure during the 96-hour flow-through bioassay tests encompass and/or far exceed those expected during actual dredge disposal operation, it is felt that the direct impact on finfish in the area would be minimal. A logical extension of the present research would be to monitor a dredge and disposal operation of greater magnitude (70,000 to 100,000 yd^3) to determine conclusively if this alternative method of dredge disposal would have any effect on the aquatic ecosystems of the lower Columbia River.

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