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AN ASSESSMENT OF METALS CONTAMINATION IN LAKE ROOSEVELT

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NOTE TO READER: The original version of this report, published in June 1988, showed sediment concentrations of mercury to be on a dry weight basis when, in fact, the data were based on wet weight. In the present revised report, the mercury data have been corrected and are expressed in terms of dry weight. This correction results in an increase in the mercury concentrations reported in the sediments; for example, peak concentrations in Lake Roosevelt are in the range of 1.0 - 2.7 ug/g dry weight, not 0.30 - 0.74 ug/g dry weight as originally reported. The revision also afforded an opportunity to include an independent assessment of the health risks due to mercury levels in Lake Roosevelt sport fish, completed by the Washington Department of Social and Health Services in February 1989.

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SUMMARY

Lake Roosevelt, the upper Columbia River reservoir created by completion of Grand Coulee Dam in 1941, is the largest lake in Washington and sixth largest reservoir in the United States. Cominco Limited, the world's largest lead-zinc smelter and refinery, is located upstream of the lake at Trail, British Columbia, about 10 miles above the Canadian border. The Canadian government considers this to be the major source of metals to the Columbia River in British Columbia.

In response to reports of elevated metals concentrations in fish and other environmental samples from Lake Roosevelt, Ecology conducted a series of field surveys between May and September 1986 to determine the extent and significance of contamination. Metals--primarily zinc, copper, lead, arsenic, cadmium, and mercury--were analyzed in sediment and water samples from the lake and its tributaries, and in a variety of the lake's fish species. A core of the lake sediments was analyzed to determine the history of metals contamination. Selected sediment samples were also bioassayed to assess their potential toxicity.

Sediments in the upper reaches of the lake (i.e., above Kettle Falls) were found to contain high concentrations of iron, manganese, zinc, copper, and arsenic relative to tributary sediments. This was attributed to the presence of slag which is discharged from Cominco in the form of coarse-grained sand. Elevated concentrations of lead, cadmium, and mercury occurred farther downstream in association with finer grained materials. Analysis of a core of the lake bottom indicated the level of sediment contamination had not changed appreciably since the 1950s.

Bioassays with two invertebrate species, *Hyalella* and *Daphnia*, suggested no significant toxicity was associated with the metals concentrations in the sediments, but these results were somewhat compromised by technical problems experienced during the tests. Other investigators report laboratory experiments with Cominco and ASARCO, Tacoma, slag which suggest slag may have low toxicity to fish and invertebrates.

Metals concentrations in water samples from the lake and its tributaries were generally low and within EPA water quality criteria. However, long-term monitoring by the U.S. Geological Survey shows metals concentrations in the Columbia River 12 miles below the Canadian border to be highly variable, sometimes exceeding EPA criteria. Environment Canada has also observed this phenomena in the Columbia and attributed this to Cominco discharges.

Whole fish (largescale suckers) analyzed from the upper part of the lake had significantly more zinc, copper, lead, and cadmium than those from the lower lake. Analyses of Lake Roosevelt largescale suckers by the U.S. Fish and Wildlife Service (USFWS) as part of the National Contaminant Biomonitoring Program are in close agreement with findings of the present study and show that lead and cadmium concentrations in these fish are among the highest found nation-wide. This may be due, at least in part, to sediments in the gut contents of this bottom-feeding fish.

There is qualitative evidence that significant adverse biological effects are not occurring in the lake. A 1980-1983 study by USFWS found good recruitment, rapid growth, and low mortality of walleye, the lake's major sport fish. The Washington Department of Wildlife considers the lake typical of other reservoirs in its ability to support sport fisheries. Also, private organizations have had good success pen-rearing rainbow trout in the lake to enhance the local sport catch.

Metals concentrations in the edible tissue of Lake Roosevelt walleye, rainbow trout, and other sport fish were low. The maximum concentrations observed were well within limits set by FDA and other countries for fish marketed commercially.

FDA's action level for mercury is 1 part per million (ppm). Canada and several states within the U.S. (California and Wisconsin are two examples discussed) have adopted a 0.5 ppm limit for sport-caught fish because of the narrow margin between safe and toxic levels of mercury and concern for health risk to pregnant women, the fetus, and young children. Although analysis of Lake Roosevelt fish showed all samples contained less than 0.5 ppm, the B.C. Ministry of Environment has found concentrations between 0.5 - 1 ppm in a few Columbia River walleye above the border. As a result, they released an "information bulletin" in September 1987 suggesting meals of Columbia River walleye weighing over two pounds be eaten no more than once a week. The Washington Department of Social and Health Services, Office of Environmental Health Programs conducted an independent review of the Lake Roosevelt and upper Columbia data on mercury in fish and concluded that there does not appear to be a threat to public health from eating fish caught in Lake Roosevelt.

Cominco began reducing metals discharges to the Columbia River in the 1970s. The Ministry of Environment reports zinc, lead, cadmium, and mercury loads in liquid effluents have been reduced by 85 percent, 74 percent, 69 percent, and 80 percent, respectively, since 1977. The mercury load may be reduced further once construction of a new lead smelter is completed.

Cominco will continue to discharge slag to the Columbia River. Current discharges are in the range of 250 - 400 metric tons/day; the present permit allows up to 900 metric tons/day to be discharged. Lake Roosevelt is the ultimate sink for this material.

While results of Ecology's 1986 surveys did not find evidence that there is a serious threat to aquatic life or human health due to metals levels in Lake Roosevelt, additional study is recommended. This should include long-term monitoring of metals concentrations in fish and sediments and a more thorough evaluation of sediment toxicity.

INTRODUCTION

Between May and September of 1986, the Washington Department of Ecology conducted surveys of metals concentrations in bottom sediments, water, and fish from Franklin D. Roosevelt Lake, the dammed portion of the upper Columbia River in the reach between the international border (river mile [r.m.] 745.0) and Grand Coulee Dam (r.m. 596.6). The impetus for these surveys was reports of metals contamination in fish and other environmental samples, coupled with the presence of a potentially significant source--the Cominco Limited lead-zinc smelter and refinery in British Columbia.

The initial report of elevated metals concentrations in fish came out of analysis of samples collected in 1984 as part of Ecology's Basic Water Monitoring Program (Hopkins, *et al.*, 1985). Tissue samples from bridgelip suckers collected in the upper reaches of Lake Roosevelt at Northport had substantially higher zinc, copper, lead, and cadmium concentrations than fish from the nine other Washington rivers sampled that year. Sediment samples collected in conjunction with the fish also showed Northport to have higher metals concentrations than the other nine sites.

A second report of metals contamination in Lake Roosevelt fish came from the U.S. Fish and Wildlife Service (USFWS) National Contaminant Biomonitoring Program. As part of this program, metals have been analyzed in fish collected at Grand Coulee since 1970. Lowe, *et al.* (1985) reported that the cadmium and lead concentrations in Grand Coulee fish (analyzed whole) collected in 1978 and 1980 were among the highest in the nation.

A third indication of metals contamination was sporadic water quality alerts issued by the U.S. Geological Survey (USGS) for zinc, copper, lead, cadmium, and mercury in water samples from the Columbia River at Northport. Alerts are issued when water quality criteria of the U.S. Environmental Protection Agency (EPA, 1986) are exceeded.

In response to these reports, Ecology conducted a series of field surveys, shown in Table 1, to assess the extent and significance of contamination.

Table 1. Ecology surveys of metals concentrations in Lake Roosevelt during 1986.

Survey Description	Date
Tributary water quality during spring runoff	May 13-15
Sediment transect from border to Coulee Dam	August 4-8
Tributary water quality during summer low-flow	August 25-29
Sediment core near Kettle Falls	September 23
Fish collections at Northport, Gifford, Seven Bays	September 23-26
Lake water column samples	September 23-26

Specific survey objectives were as follows:

1. Determine the extent of metals contamination of the lake sediments as a function of distance from the border.

2. Obtain a core of the sediments and analyze the history of metals accumulation.

3. Screen selected sediment samples for toxicity to aquatic organisms.

4. Survey metals concentrations in water from the lake and its tributaries and assess potential impacts on aquatic organisms.

5. Determine the extent to which metals are being accumulated by fish and evaluate the potential for adverse effects.

6. Determine if metals concentrations in sport fish meet generally accepted criteria for human consumption.

STUDY AREA DESCRIPTION

Figures 1 through 3 show the study area. Lake Roosevelt is the largest of the 11 Columbia River reservoirs in Washington and the largest lake in the state. It is the sixth largest reservoir in the United States. Created by completion of Grand Coulee Dam in 1941, the lake has a full-pool length of 151 miles, average depth of 118 feet, and storage capacity of 9,562,000 acre/ft. Maximum depth is 400 feet. The Columbia River accounts for 89 percent of the annual average inflow to the lake. The Spokane and Kettle Rivers represent 7 percent and 3 percent of the inflow respectively, with the Colville and Sanpoil Rivers and numerous small tributaries making up the remaining 1 percent. (Stober, *et al.*, 1981; Beckman, *et al.*, 1985)

The U.S. Bureau of Reclamation (USBR) controls the level of Lake Roosevelt to provide water for irrigation, hydroelectric power, and flood control. From January through June the reservoir is reduced in volume by approximately 55 percent in preparation for spring runoff and peak power demand. Surface elevations are at a minimum in April, while full pool is usually attained between July and December. At full pool, the Columbia remains a free-flowing river above Northport. Mean annual water retention time of the lake was about 40 days during the period 1975-83. Monthly rates between 15 and 76 days have been reported. (Stober, *et al.*, 1981; Beckman, *et al.*, 1985)

The lake shore is sparsely populated. Grand Coulee (population 1,195), Kettle Falls (population 1,245), and Northport (population 342) are the largest communities. Much of the lower lake is bordered by the Colville and Spokane Indian Reservations. The lake and shoreline constitute the Coulee Dam National Recreation Area, which is managed by the National Park Service.

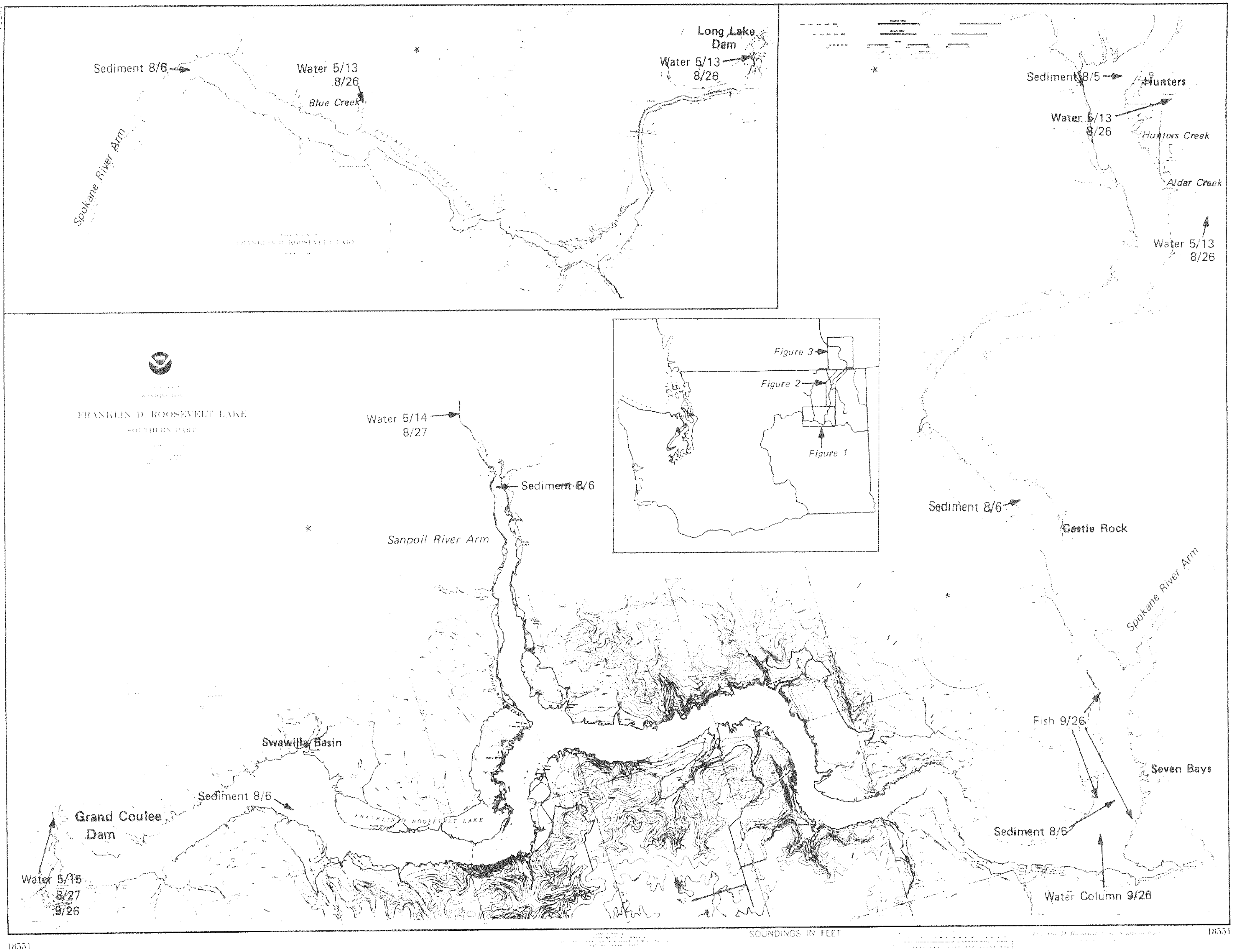


Figure 1. Locations of samples collected during Ecology's surveys of metals in Lake Roosevelt, May-September 1986 (lower lake).

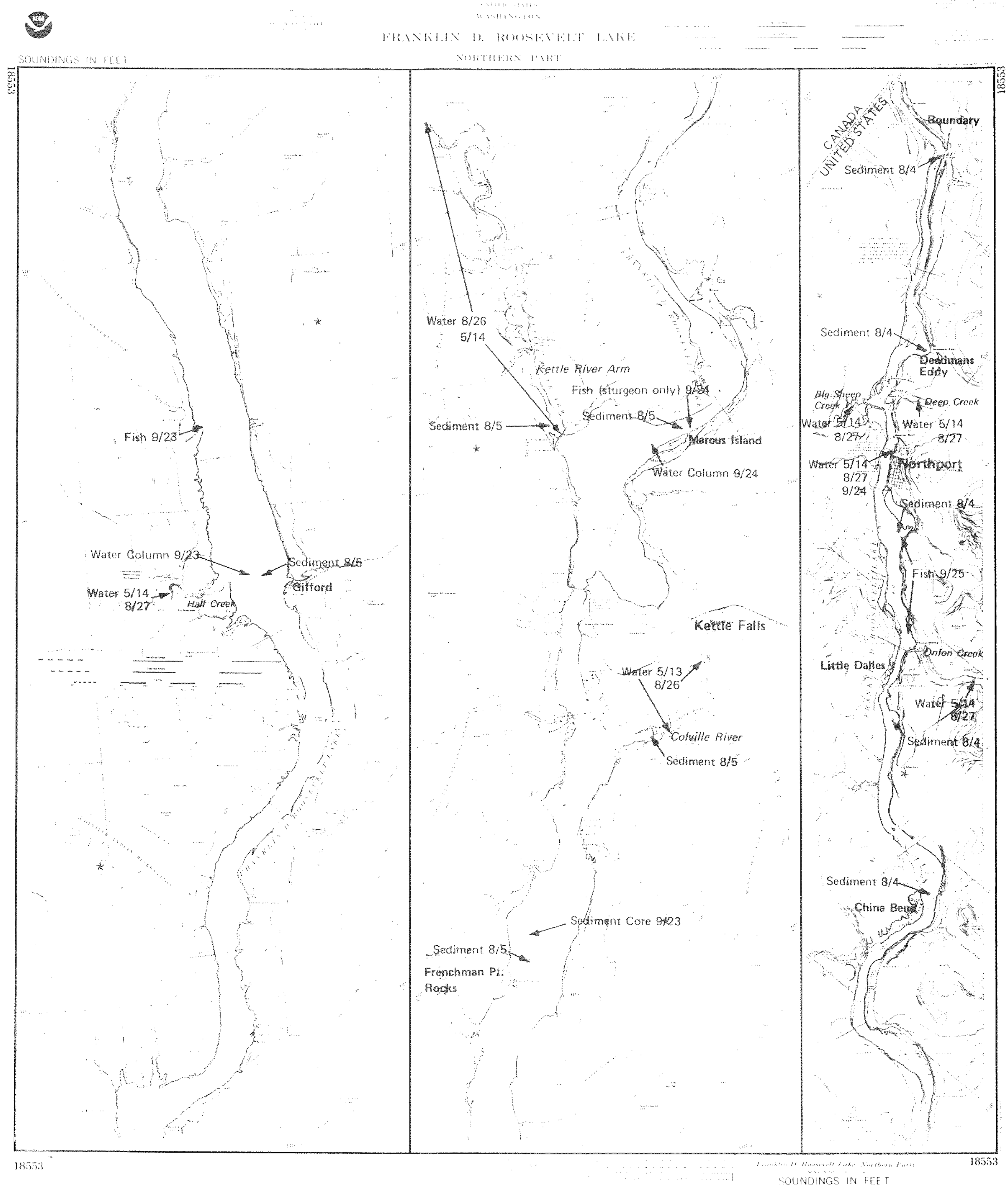


Figure 2. Locations of samples collected during Ecology's surveys of metals in Lake Roosevelt, May-September 1986 (upper lake).

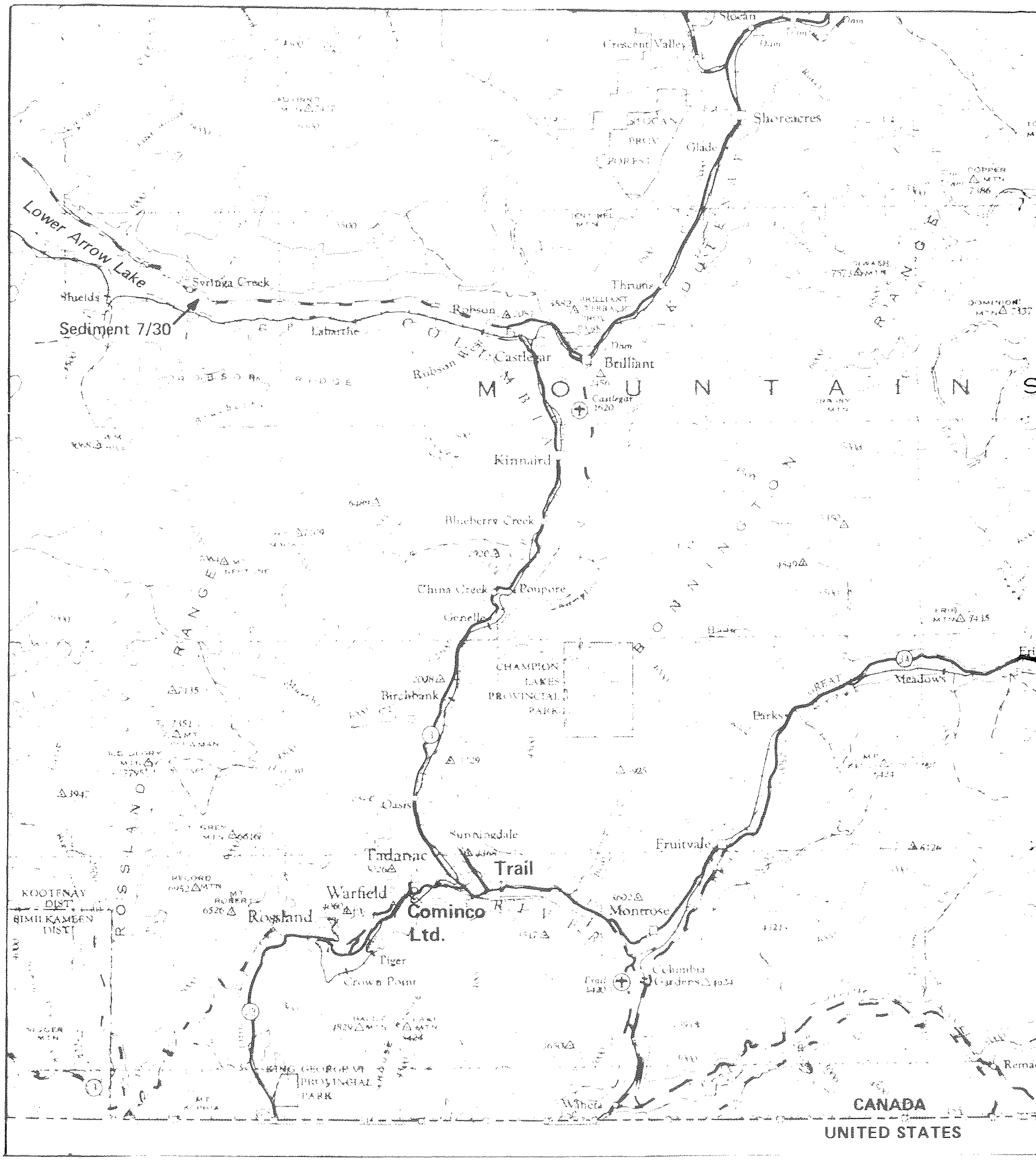


Figure 3. Columbia River between Lower Arrow Lake and international border, showing location of Lower Arrow Lake sediment sample collected for Ecology's surveys of metals in Lake Roosevelt, May-September 1986.

Cominco Limited is located on the right bank of the Columbia River at Trail, British Columbia, approximately 10 miles above the international border. It has been in existence since the turn of the century, and is the world's largest lead-zinc smelter and refinery. Extensive monitoring by the B.C. Ministry of Environment, and Environment Canada has documented the facility to be a source of iron, manganese, zinc, copper, lead, arsenic, cadmium, and mercury via liquid effluents and slag. They have concluded Cominco is the primary source of metals inputs to the Columbia River in British Columbia. (Ministry of Environment, 1979; Smith, 1987; Scheehan and Lamb, 1987)

A major spill of a sludge-acid mixture with a high mercury content occurred at Cominco in 1980. Samples of the mixture analyzed after the incident contained up to 540 parts per million of mercury (Ferguson, 1980). Six thousand pounds of mercury may have been discharged to the Columbia River (Arnquist, 1980).

Local sources of metals to Lake Roosevelt include historical mining and milling operations along the east shore of the lake between Northport and Kettle Falls, and in the Pend Oreille drainage (Orlob and Saxton, 1950). Mining and related activities along the Coeur d'Alene River in northern Idaho have resulted in zinc contamination of the Spokane River. The Coeur d'Alene discharges were largely curtailed in the late 1970s (Yake 1979; Mink 1971; and Patmont, *et al.*, 1987).

METHODS

Sediment Sampling

A series of sediment grabs were collected in Lake Roosevelt between August 4 and 8 in a longitudinal transect from the international border to Grand Coulee Dam. Sediments were also collected at the mouths of the Colville, Kettle, Spokane, and Sanpoil Rivers. On September 23, a core of the lake sediments was obtained off Frenchman Point Rocks, approximately seven miles below Kettle Falls (r.m. 703). This is the most upstream site in the lake where deposits of fine-grained sediments were found; bed material above Kettle Falls consisted primarily of sand, gravel, and cobble. The Ministry of Environment provided a sediment sample from Lower Arrow Lake (the Columbia River reservoir above Trail) which served as a reference for Lake Roosevelt sediments. Appendix I describes the location of each sediment sample.

Surface sediments in Lake Roosevelt were collected with a van Veen grab or Emery pipe dredge. The pipe dredge was used only for the sample collected just below the international boundary (Boundary, r.m. 742.8) where strong currents made the grab unstable. Sediments from China Bend (r.m. 723.8) and above were collected in back eddies and embayments in an effort to obtain fine material rather than the cobble and gravel characteristic of the upper main channel. Sediments below China Bend were collected as near mid-channel as length of sampling cable allowed (maximum sampling depth 135 feet). The Ministry of Environment used an Ekman grab in Lower Arrow Lake. Only the top 2 cm surface layer from the van Veen and Ekman grabs were taken for analysis. Depth of penetration of the pipe dredge ranged up to approximately 4 cm, based on observations in shallow water.

Each sediment sample was transferred to a stainless steel beaker and homogenized by stirring with a stainless steel spoon. The spoons and beakers were washed with LiquiNox detergent, 10 percent nitric acid, and de-ionized water between samples. Subsamples were taken for analysis of metals, grain size, and total organic carbon (TOC). At selected sites, additional material was retained for bioassay. Sample containers were glass jars with teflon-lined lids (I-Chem, Hayward, CA; see Appendix II for cleaning procedures). All sediment samples were transported on ice to the Ecology/EPA Environmental Laboratory in Manchester, Washington.

The core sample was taken with a two-inch gravity corer. On retrieval, the plexiglass liner containing the core was removed, overlying water decanted, and the ends of the liner capped. The core was kept vertical and transported to the Manchester laboratory on ice. There the core was frozen and later extruded from the liner and cut into 5 cm increments. The outer surface of each core segment was parred away with a stainless steel spatula and discarded. The remainder was placed in glass jars (I-Chem) for subsequent metals and radionuclide (core dating by cesium-137) analysis.

Water Sampling

Water was collected from Lake Roosevelt tributaries during spring runoff (May 13 through 15) and summer low flow (August 25 through 29). These two periods were considered to represent the range of metals concentrations and flows likely to be encountered in the lake's tributaries. Sampling sites were the Columbia River at Northport, Columbia River below Grand Coulee Dam, and the mouths[1] of the Colville, Kettle, Spokane, and Sanpoil Rivers. The Pend Oreille River, which enters the Columbia just above the border, was not sampled as it has been found not to have a significant impact on metals concentrations in the Columbia River (Sheehan and Lamb, 1987; Sheehan, 1988 personal communication). Based on metals analysis of stream sediments by the Washington Department of Natural Resources (Moen, 1969), seven creeks with potential metals contamination were also sampled.

Lake Roosevelt water column samples were collected September 23 through 26. Surface- and bottom waters were sampled at Marcus Island (r.m. 708.1), Gifford (r.m. 677.2), and Seven Bays (r.m. 634.3). The survey was originally to be conducted while the lake was stratified, but was delayed until September when it was learned that Cominco shut down from July 27 to August 25 for routine maintenance.

All water samples were single grabs. Surface samples were collected by hand. Bottom samples were collected with a ten-liter, teflon-lined, Go-Flo bottle using Kevlar/polyester line and teflon-coated messenger. Containers for metals samples were one-quart polyethylene cubitainers (I-Chem) with 2 mL of nitric acid (Ultrex) added as preservative. Mercury samples were taken in 250 mL glass bottles with nitric acid preservative. One-liter

1 Sampling sites at river mouths varied with lake elevation; see Table 9.

polyethylene bottles were used for samples analyzed for ancillary water quality variables (suspended solids, hardness, etc.).

Samples for determination of dissolved metals concentrations were transferred in the field to a fiberglass reservoir (Amicon), pressurized with nitrogen, and filtered through 0.45 micron polycarbonate membrane filters (Nucleopore). The components of the system, including the filters, were washed with nitric acid and rinsed with de-ionized water before use. All water samples were placed on ice immediately on collection and transported to the Manchester laboratory.

Temperature (ASTM precision thermometer) and pH (Orion 399A Ionalyzer) were measured in the field. Prior to water column sampling, a bathythermograph cast was made to assess stratification. Flow in creeks was gaged with a Marsh-McBirney magnetic flow meter and top-setting rod. Flow data for rivers were obtained from USGS.

Fish Tissue Collection

Fish were collected September 23 through 26 at three locations in the lake: r.m. 732 below Northport; r.m. 680 above Gifford; and r.m. 635 at Seven Bays. The primary target species were walleye (*Stizostedion vitreum*), the major sport fish in Lake Roosevelt, and largescale sucker (*Catostomus macrocheilus*), an abundant bottom-living species. Four to five individuals of each species and a few other sport fish as available--lake whitefish (*Coregonus clupeaformis*), yellow perch (*Perca flavescens*), and rainbow trout (*Salmo gairdneri*)--were collected at each site. A single white sturgeon (*Acipenser transmontanus*) was also obtained at Marcus Island (r.m. 708). Fish were caught with a gill net, except rainbow trout and sturgeon which were taken on hook and line. Fish selected for analysis were put in polyethylene bags and stored on ice for transport to the Manchester laboratory where they were frozen.

The fish were thawed and dissected at Manchester the week following collection. Fork length and weight of each specimen were recorded. Muscle tissue was analyzed from walleye and other sport fish, while suckers were analyzed whole for comparison with the data base of the previously mentioned USFWS national monitoring program. Muscle tissue samples were skinless fillets removed with stainless steel knives and homogenized in Waring blenders. Whole fish were homogenized in a Hobart grinder. Sample containers were glass jars with teflon-lined lids (I-Chem).

Analysis and Quality Assurance

Table 2 summarizes the analytical methods employed. Sediment samples were bioassays using the amphipod *Hyalella azteca* and the cladoceran (water flea) *Daphnia pulex*. Bioassay procedures are described in detail in Appendix III.

The accuracy and precision of the metals data were assessed by analysis of standard reference materials, laboratory duplicates, field replicates, and field blanks. Results on reference materials (Table 3), which provide an estimate of accuracy, were in good agreement with

Table 2. Analytical methods for Lake Roosevelt/upper Columbia River samples collected in 1986.

Analysis	Method	Method Number	Reference	Laboratory
-Sediment-				
percent moisture	dry at 105°C	209F	APHA (1985)	Ecology/EPA
total organic carbon	combustion/CO_2 measurement	--	in-house	Laucks Testing Labs
grain size	seive and pipet	--	Holme (1971)	Parametrix, Inc.
Fe	AA/flame	236.1	EPA (1983)	Ecology/EPA
Al	" "	202.1	" "	"
Mn	" "	243.1	" "	"
Zn	AA/furance	289.2	" "	"
Cu	" "	220.2	" "	"
Pb	" "	239.2	" "	"
As	" "	206.2	" "	"
Cd	" "	213.2	" "	"
Hg	AA/cold vapor	245.5	" "	"
Cs-137	gamma spectroscopy	HASL300	DOE (1983)	Univ. of Wash.
Hyalella bioassay	10-day static	--	Nebeker (1984)	Ecology/EPA
Daphnia bioassay	48-hour static	--	EPA (1985)	"
-Water-				
specific conductivity	Beckman RC20 meter	205	APHA (1985)	Ecology/EPA
total hardness (as $CaCO_3$)	EDTA titrimetric	314B	" "	"
total suspended solids	gravimetric	205C	" "	"
Zn (total recoverable)	AA/furance	289.2	EPA (1983)	"
Cu " "	" "	220.2	" "	"
Pb " "	" "	239.2	" "	"
As " "	" "	206.2	" "	"
Cd " "	" "	213.2	" "	"
Hg " "	AA/cold vapor	245.1	" "	"
-Tissue-				
percent moisture	dry at 105°C	209F	APHA (1985)	Ecology/EPA
Zn	AA/furance	289.2	EPA (1983)	"
Cu	" "	220.2	" "	"
Pb	" "	239.2	" "	Univ. of Wash.
As	" "	206.2	" "	Ecology/EPA
Cd	" "	213.2	" "	Univ. of Wash.
Hg	AA/cold vapor	--	in-house	Battelle

Table 3. Analysis of reference materials for surveys in Lake Roosevelt/upper Columbia River in 1986.

Reference Material	Metal	Analysis for Present Study[a]	Certified Value
NBS River Sediment	Fe	73960±110	113000±12000
SRM-1645 (ug/g)	Mn	716±4	785±97
	Zn	1640±10	1720±169
	Cu	110.4±1.7	109±19
	Pb	694±12	714±28
	As	52.9±0.1	66[b]
	Cd	7.6±0.2	10.2±1.5
	Hg	0.82±0.06	1.1±0.5
NBS Trace Elements in	Zn	54±13	66±2
Water SRM-1643b	Cu	20.2±0.4(SD,n=4)	21.9±0.4
(ug/L)	Pb	16.3±3.3(SD,n=4)	23.7±0.7
	Cd	24.2±8.9(SD,n=4)	20±1
	As	54±7(SD,n=4)	49[b]
NBS Oyster Tissue	Pb	0.52±0	0.48±0.04
SRM-1566a (ug/g)	Cd	3.46±0.23	3.50±0.4
NBS Albacore Tuna	Zn	14.0±0.2	13.6±1[b]
RM-50 (ug/g)	As	2.3 (n=1)	3.3±0.4[b]
NRCC Dogfish Muscle (ug/g)	Hg	0.747±0.005	0.798±0.047
EPA Trace Metals	Pb	0.20±0.02	0.26±0.18
in Fish (ug/g)	Cd	0.18±0.01	0.16±0.08

[a]mean ± range of duplicates, except as indicated

[b]not certified

certified values except for iron and cadmium in sediment and lead in water. The sediment and water data reported for these metals may underestimate actual concentrations.

The variability associated with analyses of individual field samples (precision) is indicated in Table 4 which gives results of duplicate analyses. Measurements of metals concentrations in sediment were generally more precise than for tissue or water.

Replicate field samples and field blanks (water samples only) were analyzed for each sample collection; these data are reported with the results. Metals data are reported in terms of parts per million for sediment (ug/g, dry-weight basis) and tissue (ug/g, wet-weight basis), and parts per billion for water (ug/L).

RESULTS AND DISCUSSION

Metals Analysis of the Surface Sediments

The concentrations of metals measured in the sediments of Lake Roosevelt and major tributaries are shown in Table 5. Analysis of replicate field samples at selected sites indicated single grab samples were generally representative of the physical/chemical characteristics of the sediments.

Lake sediments collected between the border and Kettle Falls (i.e., Marcus Island station) consisted primarily of brownish-black sand (81 to 99 percent). Below Kettle Falls, sediments were primarily silt and clay (80 to 97 percent), with the clay and sand content gradually increasing with distance downstream. Tributary sediments were mostly silt. Sandy sediments tended to have more organic carbon than silty/clayey sediments.

Lake Roosevelt sediments were elevated in concentrations of all metals except aluminum. Peak concentrations of zinc, copper, and mercury (26,840, 4,870, and 2.7 ug/g, dry, respectively) were two orders of magnitude higher in the lake than in its tributaries or in Lower Arrow Lake. Similarly, iron (326,200 ug/g), manganese (5,900 ug/g), lead (550 ug/g), arsenic (31.2 ug/g), and cadmium (5.7 ug/g) concentrations were elevated by one order of magnitude. As previously mentioned, samples above Marcus Island were taken outside the main channel in order to obtain fine material. Therefore, the metals concentrations reported for this reach (Boundary to China Bend) may not be representative of the bulk of the bed material which appeared to be gravel and cobble.

Metals concentrations in sediment from Lake Roosevelt tributaries were within a factor of two of those in Lower Arrow Lake, except for the Spokane River Arm which was relatively high in all metals, especially manganese, zinc, lead, arsenic, and cadmium. However, compared to Lake Roosevelt sediments above the Spokane confluence (i.e. Castle Rock and Hunters stations), the Spokane sediments were elevated only for zinc (1,540 ug/g vs. 954 and 610 ug/g).

Strong longitudinal gradients in metals concentrations were observed in the lake sediments. These are depicted in Figure 4 which plots metal concentration against river mile (average

Table 4. Analysis of duplicate samples for Lake Roosevelt/upper Columbia River surveys in 1986.

Matrix	Sediment (ug/g, dry)			Sediment (ug/g, dry)		
Sample No.	8612	8613	RR[a]	8624A	8624B	RR
Fe	145,880	159,900	9%	24,120	24,220	0.4%
Al	19,900	19,000	5%	20,800	20,300	2%
Mn	3,030	3,350	10%	370	370	0%
Zn	14,300	14,580	2%	98	97	1%
Cu	1,130	1,270	12%	35	36	3%
Pb	578	523	10%	9	9	0%
As	8.9	8.4	6%	4.3	4.2	2%
Cd	3.1	3.2	3%	0.7	0.6	15%
Hg	0.05	0.03	50%	0.19	0.16	17%

Matrix	Water (ug/L)								
Sample No.	8309A	8309B	RR	8310A	8310B	RR	8320A	8320B	RR
Zn	<1	<1	ND[b]	<1	<1	ND	2	<1	>70%
Cu	<1	<1	ND	<1	<1	ND	<1	<1	ND
Pb	<1	<1	ND	<1	<1	ND	<1	<1	ND
As	<1	4	>120%	<1	<1	ND	4	3	30%
Cd	0.2	0.3	40%	0.2	0.3	40%	0.8	0.6	30%
Hg	0.09	0.09	0%	NA	NA	--	NA	NA	--

Matrix	Whole Fish (ug/g, wet)			Fish Muscle (ug/g, wet)		
Sample No.	8582	8583	RR	8576	8577	RR
Fe	NA[c]	NA	--	NA	NA	NA
Al	NA	NA	--	NA	NA	NA
Mn	NA	NA	--	NA	NA	NA
Zn	31.7	31.8	0.3%	3.7	3.9	5%
Cu	0.73	0.66	10%	0.08	0.10	22%
Pb	1.90	2.35	21%	0.02	0.01	50%
As	0.04	0.06	36%	0.06	0.04	40%
Cd	0.34	0.43	24%	0.01	0.01	0%
Hg	0.23	0.26	12%	0.34	0.36	6%

[a] relative range of duplicates (range as percent of mean)

[b] not detected

[c] not analyzed

Table 5. Analysis of sediment samples[a] collected in Lake Roosevelt/upper Columbia River, August 4-6, 1986.

Location	River Mile	Sample Number	% Dry Weight	Grain Size (percent) Gravel (>2mm)	Sand (2mm-62um)	Silt (62um-4um)	Clay (<4um)	% TOC	Metals Concentrations (ug/g, dry) Fe	Al	Mn	Zn	Cu	Pb	As	Cd	Hg
-Lake Roosevelt/Upper Columbia River-																	
Lower Arrow Lk BC	790	8622	64.6	1.50	65.61	26.91	3.82	1.7	10,400	8,420	190	51	17	19	3.0	0.6	0.02
		8623	66.3	1.42	61.36	31.04	4.44	1.5	10,780	8,600	190	45	13	19	2.5	0.6	0.01
Boundary	742.8	8621	76.1	0.14	99.74	0.06	0.54	7.1	326,200	25,300	5,900	26,840	4,870	365	27.9	0.6	0.01
Deadman's Eddy	738.3	8619	76.4	0.08	99.18	0.58	0.60	3.7	257,600	24,000	4,340	22,920	3,390	389	19.7	2.1	0.08
Northport	733.0	8617	79.9	0.01	98.77	0.94	0.65	4.1	272,400	25,900	4,860	23,580	3,870	350	25.6	1.4	0.02
		8618	76.3	0.00	98.51	1.06	0.61	3.7	273,800	23,000	4,910	25,380	3,960	406	31.2	1.4	0.03
Little Dalles	728.1	8620	78.8	0.04	98.66	2.46	0.42	6.0	247,600	25,900	4,370	21,420	3,420	294	27.8	1.4	0.02
China Bend	723.8	8615	61.9	0.09	81.39	17.19	2.62	4.4	56,760	9,400	1,000	3,840	600	431	15.1	4.8	0.58
Marcus Island	708.9	8612[b]	81.4	1.01	96.79	2.36	0.78	2.9	152,890	19,400	3,190	14,440	1,200	550	8.6	3.2	0.05
		8614	77.5	0.06	97.02	2.30	0.90	2.0	59,380	10,300	1,050	3,940	630	425	12.7	4.7	0.04
Frenchman Pt. Rks	692.2	8609	37.3	0.00	2.83	79.88	14.84	3.5	32,580	16,700	550	1,090	165	434	8.7	5.7	2.0
Gifford	676.4	8608	27.9	0.00	0.63	68.95	27.73	2.8	34,840	21,600	850	1,060	111	467	11.6	5.7	2.7
Hunters	661.0	8607	31.7	0.00	6.44	67.30	27.25	2.3	35,080	20,800	1,070	610	80	277	7.5	5.0	1.3
Castle Rock	644.8	8606	44.9	0.04	5.87	60.02	29.30	2.7	34,900	21,200	790	954	67	349	10.4	5.5	1.0
Seven Bays	635.4	8602	28.5	0.00	13.32	48.70	34.34	2.5	36,620	26,500	1,750	976	66	296	13.1	5.6	1.3
		8603	28.9	0.00	35.08	55.94	30.72	2.9	36,680	22,500	1,750	981	68	289	15.3	5.4	1.3
Swawilla Basin	604.9	8600	29.9	0.83	24.05	45.62	34.36	1.5	33,480	27,000	1,320	757	65	206	7.6	5.2	1.0
-Tributaries to Lake Roosevelt-																	
Kettle R. Arm	706.4[c]	8611	58.7	0.03	22.25	73.67	2.58	2.4	20,520	11,500	420	60	29	5	2.8	0.3	0.02
Colville R. Mouth	699.5	8610	50.0	0.14	38.84	54.20	4.94	3.2	20,140	16,400	410	112	27	21	3.0	1.4	0.05
Spokane R. Arm	638.9	8605	33.2	0.00	5.39	50.58	39.27	3.8	36,960	31,600	1,040	1,540	53	128	11.5	5.6	0.16
Sanpoil R. Arm	615.0	8601	56.7	0.00	9.72	77.34	8.99	2.9	21,920	19,010	370	101	33	12	4.0	0.8	0.05
		8624[b]	57.6	0.00	14.92	77.86	8.33	3.7	24,170	20,600	370	98	36	9	4.2	0.6	0.03

[a] top 2 cm surface layer

[b] average of duplicates

[c] river mile on Lake Roosevelt at tributary confluence

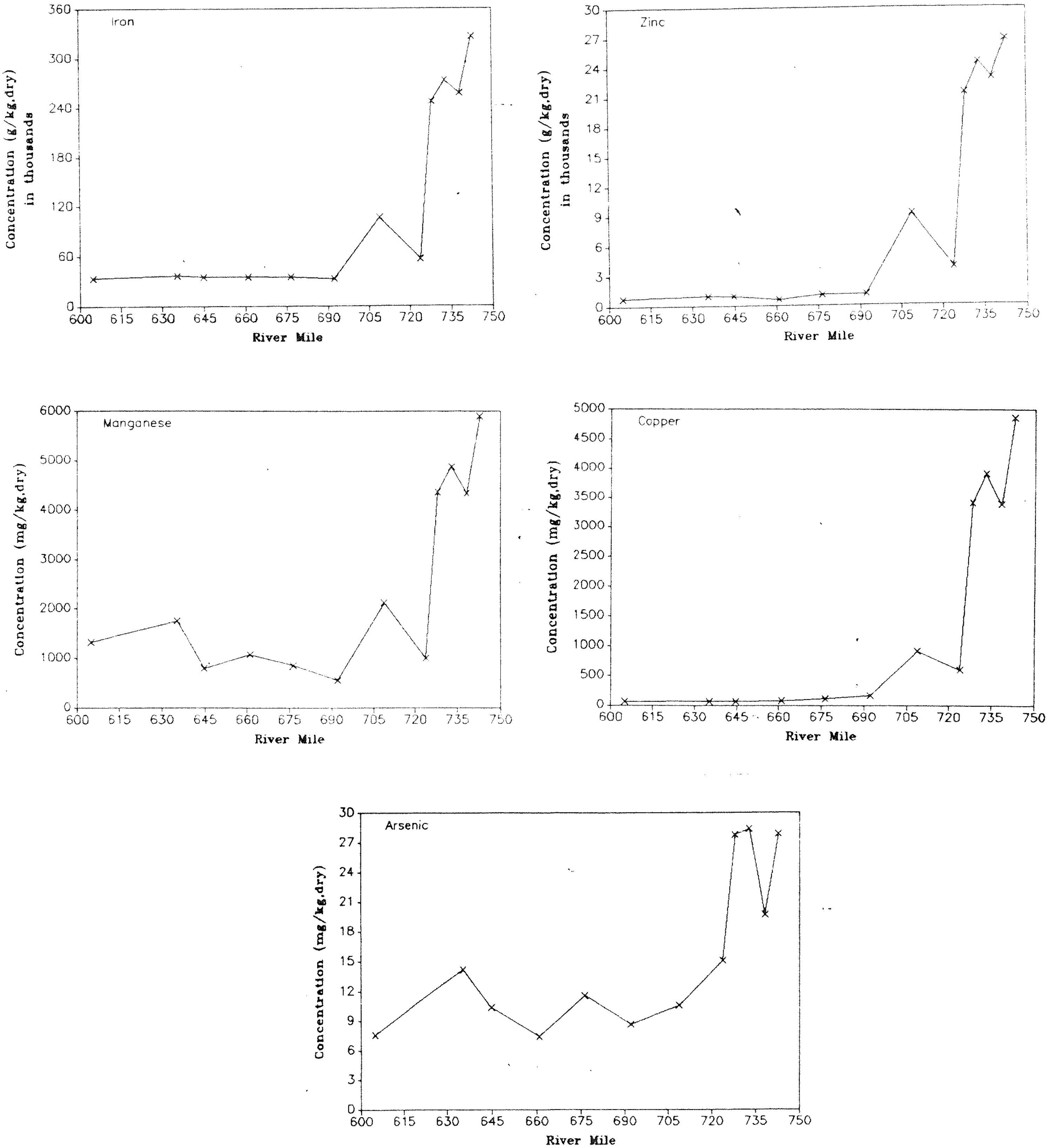


Figure 4. Metals concentration gradients in Lake Roosevelt sediments, 1986 (Kettle Falls is river mile 703).

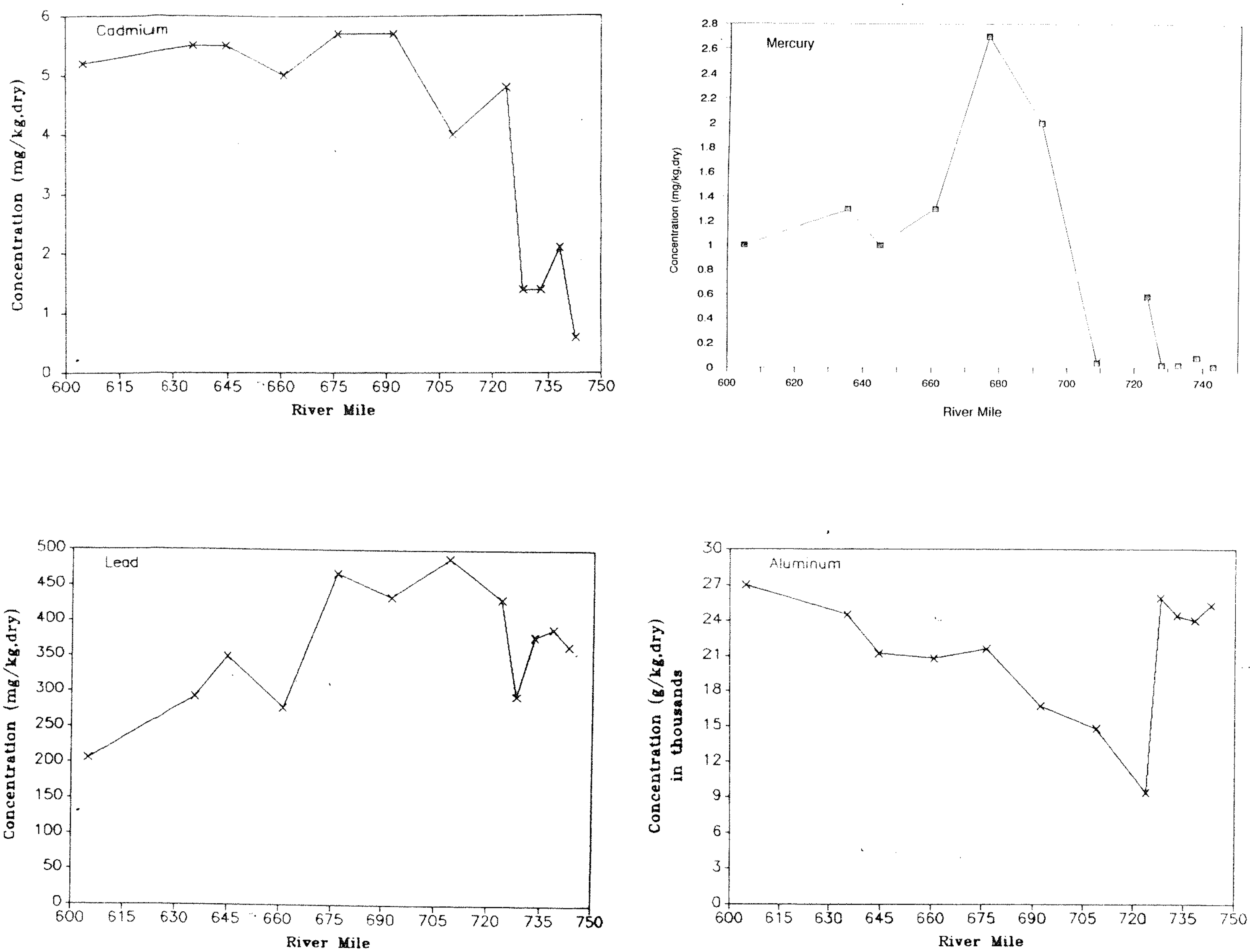


Figure 4 - continued.

concentrations were plotted for those sites where replicate samples were collected). Four patterns were evident, inferring different transport mechanisms and/or source materials:

1. Iron, manganese, zinc, copper, and arsenic. The highest concentrations of these metals occurred at the border. Concentrations decreased rapidly from the border downstream to Kettle Falls, below which they remained relatively constant. The high concentrations in the upper reaches of the lake are almost certainly due to slag particles originating from Cominco. Slag is discharged from Cominco in the form of a "coarse-grained sand;" an average of 460 metric tons/day was reported to have been discharged to the Columbia River in 1977 (Ministry of Environment, 1979). A matrix of correlation coefficients calculated using the data for Lake Roosevelt sediments showed significant intercorrelations among these five metals and the sand content of the sediments (Table 6).

2. Cadmium and mercury. Concentration gradients for cadmium and mercury varied inversely with the above metals in that concentrations increased with distance downstream of the border and reached maximum levels below Kettle Falls. There appeared to be evidence of a trend toward decreasing mercury concentrations from Kettle Falls to Grand Coulee Dam. While the distribution of these metals could be construed as indicating a local source, it is more likely the result of increasing silt and clay content of the sediments. Cadmium, mercury, silt, and clay were significantly intercorrelated (Table 6).

3. Lead. Lead concentrations in the sediments followed a pattern generally similar to mercury, but with a broader region of high concentrations extending from China Bend to Gifford. The reason for the observed distribution of lead in the sediments is not clear. Lead was not correlated with other metals, grain size, or organic carbon.

4. Aluminum. Metals derived from weathering of rocks are generally transported in rivers bound to aluminosilicates. Aluminum concentrations should therefore explain most of the natural variation in concentrations of other metals (Schropp and Windom, 1987; Horowitz, 1984). Aluminum concentrations in Lake Roosevelt sediments, however, were poorly correlated with other physical/chemical variables; concentration gradients were unlike those of other metals. Aluminum:metals ratios in tributary and lower Arrow Lake sediments were also very high relative to Lake Roosevelt sediments. This suggests artificial enrichment of other metals in the lake.

History of Sediment Contamination

Results from analysis of the sediment core taken off Frenchman Point Rocks below Kettle Falls are in Table 7. This site coincides with the location of maximum lead, cadmium, and mercury concentrations found in the surface sediments. Note that metals concentrations in the surface layer of this core are in good agreement with the nearby grab sample (Table 5).

The fallout radionuclide cesium-137 (half-life = 30 years) was analyzed in an attempt to date the core. This analysis gives two dates: (1) 1963, the peak of nuclear weapons testing,

Table 6. Correlation coefficient (r) matrix for selected variables measured in Lake Roosevelt/upper Columbia River sediment samples collected August 4-6, 1986.

	TOC	% Gravel	% Sand	% Silt	% Clay	Fe	Al	Mn	Zn	Cu	Pb	As	Cd	Hg
TOC	1.000													
% Gravel	-0.246	1.000												
% Sand	0.545*	0.135	1.000											
% Silt	-0.496	-0.182	-0.981	1.000										
% Clay	-0.606	-0.009	-0.909	0.851*	1.000									
Fe	0.740*	-0.037	0.798*	-0.795	-0.751	1.000								
Al	0.173	0.086	-0.073	-0.009	0.266	0.400	1.000							
Mn	0.706*	0.014	0.762*	-0.770	-0.655	0.981*	0.508	1.000						
Zn	0.709*	-0.006	0.821*	-0.817	-0.778	0.996*	0.369	0.974*	1.000					
Cu	0.766*	-0.121	0.779*	-0.774	-0.742	0.992*	0.380	0.966*	0.983*	1.000				
Pb	0.090	0.140	0.297	-0.242	-0.521	0.115	-0.543	0.027	0.164	0.070	1.000			
As	0.753*	-0.355	0.694*	-0.682	-0.620	0.876*	0.345	0.867*	0.865*	0.910*	-0.043	1.000		
Cd	-0.737	-0.005	-0.831	0.828*	0.773*	-0.990	-0.366	-0.972	-0.988	-0.982	-0.085	-0.869	1.000	
Hg	-0.425	-0.206	-0.906	0.927*	0.758*	-0.727	-0.032	-0.715	-0.750	-0.710	-0.050	-0.599	0.769*	1.000

Note: Analysis for Lake Roosevelt samples only; tributary and Lower Arrow Lake samples excluded (n=15)

*significant positive correlation ($p<0.05$)

Table 7. Analysis of a sediment core collected in Lake Roosevelt near Kettle Falls (Frenchman Point Rocks) on September 23, 1986.

Depth Increment (cm)	Metals Concentrations (ug/g, dry)									Cs-137 (pCi/g, dry[a] ± % error[b])
	Fe	Al	Mn	Zn	Cu	Pb	As	Cd	Hg	
0- 5	29,900	17,190	523	2,110	128	499	8.9	5.1	2.1	1.00 ± 6.6%
5-10	30,300	10.860	535	1,470	64	545	11.4	5.1	1.3	1.05 ± 4.7%
10-15	27,600	10,300	625	2,810	81	1,190	33.0	4.7	1.7	1.94 ± 2.1%
15-20	27,800	8,070	621	2,730	85	1,140	27.6	5.2	1.6	0.13 ± 12.4%
20-25	26,000	14,570	625	2,720	88	1,040	16.4	5.1	3.1	0
25-30	18,300	12,680	431	660	49	439	10.6	4.7	0.34	0
30-35	18,200	10,030	260	65	13	6	2.1	0.22	<0.01	0
35-40	18,000	10,410	255	53	13	4	1.0	0.12	<0.01	0
40-45	18,400	11,890	288	57	16	5	2.9	0.14	<0.01	0
45-50	19,000	10,740	288	53	17	3	0.6	0.10	<0.01	0

[a] picoCuries (10^{-12} Curies) = 2.22 disintegrations per minute

[b] precision based on counting statistics

and (2) 1954, the first major injection of bomb debris into the atmosphere (Schell and Nevissi, 1980). In the Lake Roosevelt core, cesium-137 activity peaked at 10 to 15 cm and could not be detected below 20 cm. On this basis, the increments 10 to 15 cm and 15 to 20 cm were considered to contain material laid down in 1963 and 1954, respectively.

The core data are plotted in Figure 5. Metals contamination in this part of the lake appears to have begun before 1954. The contaminated layer is now about 30 cm thick. Mercury concentrations in the recent sediments are at least two orders of magnitude above historical background levels (i.e. below 30 cm) while zinc, copper, lead, arsenic, and cadmium are one to two orders of magnitude above historical background. Except for lead, the level of contamination has apparently not changed appreciably since the 1950s. There is no evidence of the previously mentioned mercury spill at Cominco in 1980, but this may be due to the relatively thick increments analyzed.

The interpretation of the sediment record prior to 1954 is uncertain. Analysis of the deepest core layers suggests that, except for cadmium and mercury, present-day background concentrations (i.e., Lower Arrow Lake, Kettle and Sanpoil Rivers) are not greatly different from historical background. The steep gradient in increasing metals concentrations between the 30 to 35 cm and 20 to 25 cm increments may represent early impacts of Cominco discharges. Because sediment deposition probably didn't occur until closure of Grand Coulee Dam in 1941, the deepest core layers would be expected to correspond to the 1940's, suggesting relatively rapid sedimentation early in the lake's history.

Sediment Toxicity

Table 8 shows the results from bioassays of selected Lake Roosevelt sediment samples. Interpretation of these data is confounded by the fact that organisms exposed to the Lower Arrow Lake sample, intended as a reference sediment for purposes of this study, experienced relatively poor survival in both tests. An additional problem in evaluating the *Daphnia* results is that the aeration method used caused turbulence which may have stressed the organisms (see analyst's comments in Appendix III). This was considered to be the cause of high mortality in the laboratory control. In light of the above, the bioassay results should not be considered conclusive.

The lake sediments did not appear to be toxic to *Hyalella*. Extremely poor survival of *Daphnia* in Seven Bays sediments suggests a toxic effect, control mortality notwithstanding. Neither bioassay, however, had a pattern of response that was clearly related to metals concentrations or physical characteristics of the sediments.

The bioassays suggest an absence of toxicity in the upper reaches of the lake where the sediments are apparently contaminated by slag. Limited experimental data indicate slag may be relatively inert. Twenty-four-hour leaching experiments with ground Cominco slag and Columbia River water were performed in 1976 (Ministry of Environment, 1979). Zinc, lead, cadmium, and mercury were monitored. At a pH of 6.8 (lowest recorded for the river), negligible amounts of metals were leached. Greater leaching of zinc, lead and cadmium

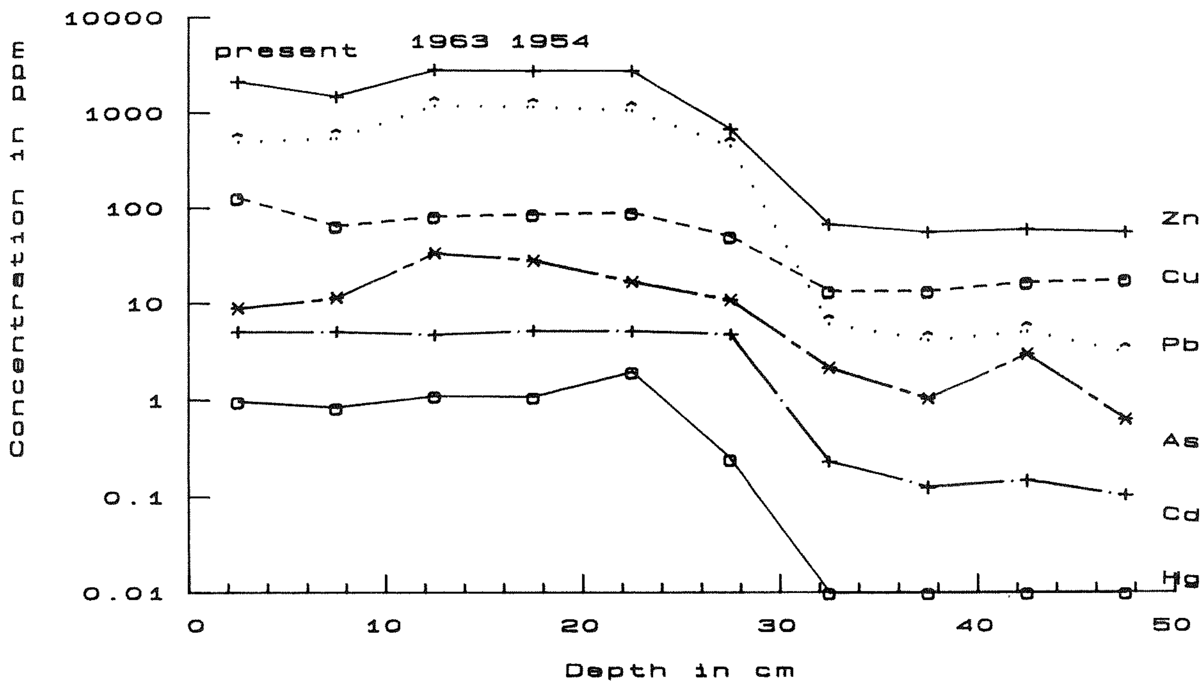


Figure 5. Profile of metals concentrations in a Lake Roosevelt sediment core collected near Kettle Falls, September 23, 1986 (ug/g, dry; log scale). Dates are estimates based on cesium-137 activity.

Table 8 Bioassays of sediment samples collected in Lake Roosevelt/upper Columbia River, August 4-6, 1986 (mean percent survival ± s.d.).

Location	Sample Number	Hyalella Bioassay (n=5)	Daphnia Bioassay (n=4)
Laboratory control	--	92 ± 11	70 ± 38
Lower Arrow Lake, B.C.	8622	78 ± 4	45 ± 19
Lake Roosevelt:			
Deadman's Eddy	8619	90 ± 7	55 ± 19
Marcus Island	8612	74 ± 20	75 ± 10
Gifford	8608	80 ± 14	65 ± 19
Seven Bays	8602	74 ± 18	35 ± 25

occurred at pH 2.0 suggesting possible enhance availability of these metals from slag ingested by fish.

Laboratory studies with slag from the ASARCO copper smelter in Tacoma, Washington, have shown that toxicity to fish and invertebrates decreases markedly after slag is aged in flowing seawater for three to four months. Freshwater and seawater leaching experiments with this slag measuring zinc, copper, lead, arsenic, cadmium, and mercury, have shown that only copper exceeded EPA water quality criteria after three to four months (Crecelius, 1986).

Metals Analysis of Tributary and Lake Water

Table 9 summarizes analyses of water collected from Lake Roosevelt tributaries during spring runoff and summer low flow. The primary seasonal differences observed in water quality were higher conductivity and hardness, and lower suspended solids during low-flow conditions, reflecting relative greater ground water contribution to tributary flows and less scouring. Metals concentrations were generally low under both flow regimes.

Low levels of some metals were detected in field blanks. Cadmium and arsenic concentrations in transport and/or transfer blanks[2] for both tributary surveys were similar to field samples. This also occurred for copper, but in the low-flow survey only. Although filter blanks were at or below detection limits, the occurrence of detectable levels of these metals in the other blanks casts doubt on the accuracy of the dissolved data. The data have been flagged where sample containers or sample handling may have contributed to concentrations measured in field samples. Also note that in some instances, particularly copper, the metal concentration measured in a filtered sample (dissolved) exceeded that in the unfiltered sample (total recoverable).

There was evidence of moderately elevated zinc concentrations during spring runoff conditions in the Columbia River at Northport (2 - 24 ug/L), Columbia River below Grand Coulee Dam (11 ug/L), Spokane River (52 ug/L), and in Onion, Hunters, Alder, and Blue Creeks (6 - 35 ug/L). As previously mentioned, the source of zinc in the Spokane River is historical mining activities in the Coeur d'Alene drainage. Yake (1979) has demonstrated a significant trend toward decreasing zinc concentrations in the Spokane for the period 1973 - 1978. Elevated zinc and other metals in Blue Creek is the result of runoff from the abandoned Midnight Mine (Sumioka, 1988, personal communication).

Based on the few samples analyzed, half or more of the zinc in the Spokane River (73 percent), Columbia River below Grand Coulee Dam (55 percent), and Blue Creek (53 to

2 Sample bottles filled with de-ionized water and carried unopended throughout the survey (transport blank) or de-ionized water transferred between sample bottles while in the field (transfer blank).

Table 9. Metals concentrations in surface water samples collected from the upper Columbia River and other tributaries to Lake Roosevelt in May and August of 1986.

Location	River Mile	Date	Sample Number	Flow (cfs)	Temperature (°C)	pH (S.U.)	Specific Cond. (umhos/cm)	Total Hardness as $CaCO_3$ (mg/L)	Total Suspended Solids (mg/L)	Metals Concentrations (ug/L)										
										Zinc		Copper		Lead		Cadmium		Arsenic		Mercury
										tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec
-Spring Runoff Survey-																				
Columbia R. @ Northport	753.1	5/14	8018	90,100	8.3	7.2	156	76	2	24	4	<0.5	1.3	<0.5	<0.5	0.3[a]	0.1	<1[a]	2	<0.05
" " " " (repl)			8020	--	--	--	160	80	2	2	4	1.9	1.0	<0.5	<0.5	0.3[a]	0.2	5[a]	4	<0.05
Deep Creek @ Mouth	737.0L	5/14	8016	(b)	6.4	8.1	289	150	13	2	<1	<0.5	<0.5	<0.5	<0.5	0.2[a]	<0.1	2[a]	1	<0.05
Big Sheep Creek @ Mouth	736.7R	5/14	8022	(b)	6.1	6.6	98	52	2	<1	<1	<0.5	<0.5	<0.5	<0.5	0.2[a]	0.2	5[a]	<1	<0.05
Onion Creek @ Mouth	730.1L	5/14	8014	17.3	3.9	7.8	297	160	8	13	4	<0.5	4.3	<0.5	<0.5	0.3[a]	0.4	6[a]	2	<0.05
Kettle R. @ Hedlund Bridge	706.4R	5/14	8024	8,390	7.6	6.7	84	36	10	<1	<1	<0.5	<0.5	<0.5	<0.5	0.1[a]	0.2	1[a]	5	<0.05
Colville R. @ Hwy. 25 Br.	699.5L	5/13	8012	407	9.8	7.6	272	140	18	<1	<1	0.8	<0.5	<0.5	<0.5	0.3[a]	0.2	<1[a]	1	<0.05
Hall Creek @ Mouth	677.5R	5/14	8026	157	8.4	7.1	98	44	8	<1	<1	0.8	1.6	<0.5	<0.5	<0.1[a]	<0.1	2[a]	<1	<0.05
Hunters Creek @ Hunters	659.0L	5/13	8010	11.9	12.0	8.1	277	140	11	8	<1	<0.5	2.8	<0.5	<0.5	0.4[a]	0.5	2[a]	5	<0.05
Alder Creek @ Hwy. 25 Br.	657.0L	5/13	8008	3.3	10.9	8.8	381	200	28	6	<1	1.5	<0.5	<0.5	<0.5	0.2[a]	0.3	3[a]	<1	<0.05
Spokane R. @ Long Lake Dam	638.9L	5/13	8002	11,590	10.3	6.8	101	46	7	52	38	<0.5	<0.5	<0.5	<0.5	0.4[a]	0.4	3[a]	3	<0.05
Blue Creek @ Mouth	(c)	5/13	8004	1.5	10.2	6.6	479	220	7	32	17	5.2	1.8	<0.5	<0.5	1.2[a]	0.6	<1[a]	2	<0.05
" " " " (repl)	(c)		8006	--	--	--	477	230	7	35	20	1.0	2.3	<0.5	<0.5	<0.5[a]	1.0	1[a]	2	<0.05
Sanpoil R. @ Mouth	615.0R	5/14	8028	370 est.	10.4	7.4	148	63	10	<1	<1	<0.5	<0.5	<0.5	<0.5	0.1[a]	0.2	3[a]	5	<0.05
Columbia R. blw Gr.Coulee Dam	596.3	5/15	8030	146,300	8.8	6.9	148	72	3	11	6	1.0	<0.5	<0.5	<0.5	0.2[a]	0.1	5[a]	1	<0.05
Transport Blank	--	--	8000	--	--	--	--	--	--	<1	--	<0.5	--	<0.5	--	0.4	--	2	--	<0.05
Transfer Blank	--	5/13	8001	--	--	--	--	--	--	<1	--	<0.5	--	<0.5	--	0.3	--	4	--	<0.05
Filter Blank	--	5/13	8032	--	--	--	--	--	--	--	<1	--	<0.5	--	<0.5	--	<0.1	--	<1	--
-Summer Low-Flow Survey-																				
Columbia R. @ Northport	753.1	8/27	8043	72,100	16.5	6.8	122	80	<1	<1	<1	<1[a]	1	<1	<1	0.7[a]	0.3	<1[a]	<1	<0.05
" " " " (repl)			8045	--	--	--	121	63	1	<1	<1	<1[a]	<1	<1	<1	0.7[a]	0.8	<1[a]	<1	<0.05
Deep Creek @ Mouth	737.0L	8/27	8041	4.4	13.4	7.0	367	200	2	<1	<1	<1[a]	<1	<1	<1	0.4[a]	0.9	2[a]	<1	<0.05
Big Sheep Creek	736.7R	8/27	8047	(b)	--	6.6	182	100	<1	<1	<1	<1[a]	1	<1	<1	0.5[a]	0.2	<1[a]	3	<0.05
Onion Creek	730.1L	8/27	8039	1.3	12.1	8.1	490	260	2	<1	<1	4[a]	1	<1	<1	0.8[a]	0.2	<1[a]	<1	<0.05
Kettle R. 1.3 mi abv Barstow	706.4R	8/26	8049	464	20.0	7.0	187	89	1	<1	<1	<1[a]	1	<1	<1	0.6[a]	0.4	<1[a]	<1	<0.05
Colville R. @ r.m. 5.0	699.5L	8/26	8037	33	19.3	7.7	386	190	18	<1	<1	1[a]	9	<1	<1	0.4[a]	0.5	<1[a]	<1	<0.05
Hall Creek @ Mouth	677.5R	8/27	8051	9.2	17.4	7.6	281	140	1	<1	<1	1[a]	<1	<1	<1	1.1[a]	0.3	2[a]	<1	<0.05
Hunters Creek @ Hunters	659.0L	8/26	8035	0.3	15.5	7.6	440	210	4	<1	<1	2[a]	3	<1	<1	1.0[a]	1.0	7[a]	<1	<0.05
Alder Creek @ Hwy. 25 Br.	657.0L	8/26	8033	dry																
Spokane R. @ Long Lake Dam	638.9L	8/26	8027	3,880	19.1	6.9	194	91	2	<1	<1	2[a]	4	<1	<1	0.3[a]	0.3	<1[a]	<1	<0.05
" " " " " (repl)			8031	--	--	--	194	92	<1	<1	<1	2[a]	<1	<1	<1	0.8[a]	0.4	<1[a]	<1	<0.05
Blue Creek @ Mouth	(c)	8/26	8029	dry																
Sanpoil R. @ Mouth	615.0R	8/27	8053	90 est.	22.3	8.7	210	96	1	<1	<1	<1[a]	1	<1	<1	0.9[a]	0.6	<1[a]	<1	<0.05
Columbia R. blw Gr.Coulee Dam	596.3	8/27	8055	100,200	18.5	6.5	126	62	1	<1	<1	<1[a]	<1	<1	<1	0.3[a]	0.4	<1[a]	<1	<0.05
Transport Blank	--	--	8024	--	--	--	--	--	--	<1	--	3	--	<1	--	1.3	--	<1[a]	--	<0.05
Transfer Blank	--	8/26	8025	--	--	--	--	--	--	<1	--	2	--	<1	--	0.2	--	3	--	<0.05
Filter Blank	--	8/26	8026	--	--	--	--	--	--	--	<1	--	1	--	<1	--	<0.2	--	<1	--

a = Also detected in blank(s)
b = Too large to gage flow
c = Tributary to Spokane River at r.m. 12.6R.

57 percent) was dissolved (i.e., < 0.45 micron); zinc was primarily in particulate form in the other tributaries. Zinc concentrations were near or below detection limits in all tributaries during low flow. Note that Blue and Alder Creeks were dry at that time.

Lead and mercury concentrations were consistently below detection limits (0.05 - 1 ug/L and 0.05 ug/L, respectively). While there was trace contamination of some field blanks with copper, cadmium, and arsenic, the maximum concentrations measured in tributaries were only a few ug/L or less.

Table 10 shows the concentrations of metals in water samples collected from the lake in September. The water column was not stratified. Metals concentrations were low in both surface- and bottom waters, consistent with the findings for most tributaries. Zinc, copper, and lead were near or below detection limits (1 ug/L). With the exception of an anomalous high mercury concentration (0.26 ug/L) in the surface sample at Marcus Island, water column concentrations of cadmium, arsenic, and mercury were similar to or less than the maximum concentrations measured in blanks (0.6, 7, and 0.09 ug/L, respectively).

EPA Water Quality Criteria

The significance of the metals concentrations measured in water from Lake Roosevelt and its tributaries can be assessed by comparison with EPA water quality criteria for protection of freshwater aquatic life (Table 11). EPA criteria for zinc, copper, lead, and cadmium vary with hardness, a property chiefly due to calcium and magnesium cations in freshwaters. The harder the water, the greater its capacity to complex metals thereby rendering them less toxic. The average hardness measured in the lake during the present study (74 mg/L as $CaCO_3$) was used to calculate the appropriate criteria.

As shown in Table 11, metals concentrations measured in Lake Roosevelt and its tributaries rarely approached the maximum concentrations EPA considers to be protective of aquatic life. The method detection limit for mercury was not low enough, however, to evaluate compliance with EPA's extremely low acute exposure criteria for this metal.

The EPA water quality criteria were developed for use with measurements of "acid-soluble" metals which EPA considered to most accurately represent the amount of metal biologically available. Since protocols for sample collection and analysis of acid-soluble metals have not yet been established, EPA recommends comparing criteria to total recoverable metals, which is the analysis done for the present study. EPA cautions that their criteria "may be overly protective when based on the total recoverable method" (EPA, 1986).

USGS Historical Water Quality Data

As part of the National Stream-Quality Accounting Network (NASQAN), USGS has monitored metals concentrations and other water quality variables in the Columbia River at Northport and the Spokane River at Long Lake. The data on zinc, copper, lead, cadmium, arsenic, and mercury at these two stations are summarized in Table 12. Similar data are included from a special USGS study of Blue Creek. Northport and Spokane River data older

Table 10. Analysis of water column samples collected from Lake Roosevelt in September, 1986.

Location	River Mile	Date	Sample Number	Sampling Depth[a] (ft.)	Dissolved Oxygen (mg/L)	Temperature (°C)	pH (S.U.)	Specific Cond. (umhos/cm)	Total Hardness (mg/L)	Total Suspended Solids (mg/L)	Metals Concentrations (ug/L) Zinc tot rec	Zinc diss	Copper tot rec	Copper diss	Lead tot rec	Lead diss	Cadmium tot rec	Cadmium diss	Arsenic tot rec	Arsenic diss	Mercury tot rec
Columbia R. @ Northport	753.1	24	8319	0.5	9.5	14.6	7.4	137	88	<1	<1	2	<1	<1	<1	<1	0.6^b	0.8^b	13	4^b	0.09^b
" (replicate)		24	8321	0.5	9.6	14.6	7.5	139	79	3	<1	<1	<1	<1	<1	<1	0.9^b	0.3^b	6	4^b	0.09^b
Lake Roosevelt @ Marcus Island	708.1	24	8315	0.5	9.6	15.1	7.9	144	87	<1	<1	<1	<1	<1	<1	<1	0.5^b	0.3^b	7	2^b	0.26^b
		24	8317	90	9.5	--	7.5	146	84	<1	<1	5	8	<1	<1	<1	0.2^b	0.4^b	3	2^b	<0.09^b
Lake Roosevelt @ Gifford	677.2	23	8309	0.5	9.2	15.8	7.9	116	67	<1	<1	<1	<1	<1	<1	<1	0.2^b	0.2^b	<1	<1^b	0.09^b
		23	8313	180	9.2	--	7.9	119	71	<1	<1	<1	<1	2	<1	<1	<0.2^b	0.2^b	4	3^b	0.09^b
Lake Roosevelt @ Seven Bays	634.3	26	8302	0.5	8.4	17.1	7.6	109	65	3	<1	<1	1	2	<1	<1	0.4^b	0.7^b	<1	<1^b	<0.09^b
		26	8307	140	8.5	--	7.1	109	65	<1	<1	<1	3	<1	<1	<1	0.7^b	<0.2^b	<1	<1^b	<0.09^b
Col. R. blw Grand Coulee Dam	596.3	26	8300	0.5	8.3	17.6	6.8	107	72	2	<1	<1	2	<1	<1	<1	0.5^b	0.5^b	--	--^{b}	0.09^b
" (replicate)		26	8311	0.5	--	--	--	110	65	<1	<1	<1	<1	<1	<1	<1	<0.2^b	<0.2^b	<1	<1^b	0.09^b
Transport blank	--	--	8304	--	--	--	--	--	--	--	<1	--	<1	--	<1	--	0.5	--	<1	--	<0.09
Transfer blank	--	26	8305	--	--	--	--	--	--	--	<1	--	<1	--	<1	--	0.6	--	<1	--	0.09
Filter blank	--	26	8323	--	--	--	--	--	--	--	--	<1	--	<1	--	<1	--	0.2	--	7	--

NOTE: Columbia R. @ Northport flow = 54,800 cfs; Columbia R. blw Grand Coulee Dam flow = 86,900 cfs

a = Total water depths were 100 feet (Marcus Island), 190 feet (Gifford), and 150 feet (Seven Bays)
b = Also detected in blank(s)

Table 11. EPA water quality criteria for metals compared to concentrations (total recoverable) observed in Lake Roosevelt and tributaries in 1986 (ug/L).

Metal	Chronic Criteria: 4-day average concentration not to be exceeded more than once every three years	Acute Criteria: 1-hour average concentration not to be exceeded more than once every three years	Concentration Range in Lake Roosevelt (n = 8)	Concentration Range in Tributaries	
				Spring Runoff Survey (n = 15)	Low-flow Survey (n = 15)
Zn	82[a]	90[a]	<1 (all)	<1 - 52	<1 (all)
Cu	9.2[a]	13.4[a]	<1 - 8	<0.5 - 5.2	<1 - 4[b]
Pb	2.2[a]	56[a]	<1 (all)	<0.5 (all)	<1 (all)
Cd	0.90[a]	2.8	<0.2 - 0.9[b]	<0.1 - 1.2[b]	0.3 - 1.1[b]
As (trivalent inorganic)	190	360	<1 - 13[b]	<1 - 6[b]	<1 - 7[b]
Hg	0.012	2.4	<0.09 - 0.26[b]	<0.5 (all)	<0.5 (all)

Source: EPA (1986 and 1987)

a = calculated for a total hardness (as $CaCO_3$) of 74 mg/L; arsenic and mercury criteria are independent of hardness (e.g., copper 4-day average = exp (0.8548[ln(hardness)] - 1.465)
b = Also detected in blank(s)

Table 12. Summary of USGS data on metals concentrations in tributaries to Lake Roosevelt.

	Flow (cfs)	Susp. Solids (mg/L)	Hardness (mg/L as $CaCO_3$)	Metals Concentrations (ug/L) Zinc tot rec	Zinc diss	Copper tot rec	Copper diss	Lead tot rec	Lead diss	Cadmium tot rec	Cadmium diss	Arsenic tot rec	Arsenic diss	Mercury tot rec	Mercury diss
Columbia River at Northport (NASQAN Station 12400520)															
Period of Record	78-87	77-86	78-87	78-82	78-87	78-82	78-87	78-82	78-87	78-82	78-87	78-82	78-87	78-82	78-87
No. of Observations	37	32	37	19	37	19	37	18	36	18	35	19	37	19	37
mean	96,900	9	70	78	37	25	5	27	7	1	3	1	1	0.2	0.3
standard deviation	36,200	7	7	32	29	25	3	22	6	0.5	5	0.7	0.4	0.3	1.2
median	95,000	6	70	70	26	18	5	20	5	1	1	1	<1	0.1	<0.1
maximum	219,000	18	83	160	160	100	14	73	18	2	21	3	2	1.3	7.0
Spokane River at Long Lake (NASQAN Station 12433000)															
Period of Record	78-86	78-86	78-86	78-82	78-86	78-82	78-86	78-82	78-86	78-82	78-86	78-82	78-86	78-82	78-86
No. of Observations	31	29	31	16	30	16	31	16	30	16	31	16	31	16	31
mean	6,950	7	55	91	49	12	3	16	5	1	<1	2	2	0.3	<0.1
standard deviation	4,710	8	27	50	35	8	2	13	6	0.5	0.6	1	2	0.5	0.1
median	4,900	4	56	90	50	8	3	10	3	1	<1	2	1	0.1	<0.1
maximum	20,100	28	97	190	130	33	8	43	20	2	2	5	3	2	0.5
Blue Creek at Mouth (Sumioka, 1988, preliminary data)															
Period of Record	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85	84-85
No. of Observations	12	12	13	13	13	13	13	13	13	13	13	13	13	12	12
mean	1.62	16	411	74	28	5	2	7	3	1	<1	1	1	0.1	<0.1
standard deviation	2.45	22	139	77	14	4	0.8	7	4	1	0.4	2	0.9	0.2	0
median	0.69	9	415	50	26	4	2	5	3	1	<1	<1	<1	<0.1	<0.1
maximum	7.49	80	614	300	59	16	3	20	17	3	2	5	3	0.6	<0.1

Note: 1/2 detection limit used in calculations than 1978 were not used because of poor detection limits. Note that USGS stopped measuring total recoverable metals in 1983 and that metals analyses were discontinued at the Spokane station after 1986. (The complete data set is in Appendix IV.)

USGS measurements of arsenic, cadmium, and mercury concentrations in the Columbia and Spokane Rivers and in Blue Creek are in agreement with those of the present study, allowing for differences in detection limits. On occasion, however, USGS has detected cadmium (up to 21 ug/L) and mercury (up to 7.0 ug/L) in the Columbia River at concentrations many times above EPA water quality criteria. Figure 6 shows the cadmium and mercury concentrations recorded at Northport by USGS since 1978. The Ecology and USGS data sets are also in reasonable agreement on zinc concentrations in Blue Creek. USGS, however, reports generally higher levels of zinc, copper, and lead in the Columbia River than found during the present study. Similar discrepancies are evident for copper and lead in the Spokane River and lead in Blue Creek.

One factor that may have contributed to these disparate results is sampling frequency. The water quality data from the present study are based on a small number of samples. The Columbia River at Northport was sampled on three occasions, the Spokane River twice, and Blue Creek once. The large standard deviations relative to the means for zinc, copper, and lead in the USGS data suggest metals concentrations are highly variable at these stations. This conclusion is consistent with the sporadic nature of the earlier-mentioned water quality alerts issued by USGS for metals at Northport. Smith (1987) evaluated water quality data collected by the Ministry of Environment between 1975 and 1977. He suggested the "episodic occurrence" of high metals concentrations in the Columbia River below Trail was related to discharges from Cominco.

Metals Analysis of Whole Fish

The metals concentrations measured in whole largescale suckers from Lake Roosevelt are shown in Table 13. Analysis of variance (ANOVA) showed the concentrations of zinc, copper, lead, and cadmium in fish from Northport, Gifford, and Seven Bays were significantly different ($p < 0.05$). There was a strong trend toward decreasing concentrations of zinc, copper, and lead moving downstream from Northport to Seven Bays.

Largescale suckers from Northport had about 15 times more lead (mean 6.09 ug/g, wet) than those at the lower end of the lake (mean 0.39 ug/g). Zinc and copper concentrations were higher by factors of about 2 and 7, respectively, at Northport relative to Seven Bay (means of 59.5 versus 23.1 ug/g and 4.82 versus 0.72 ug/g, respectively). Cadmium concentrations were highest at Gifford, but the range in mean concentrations for the lake as a whole was small (0.26 - 0.38 ug/g). Arsenic and mercury concentrations were not appreciably different between stations (overall mean of 0.14 ug/g for both metals).

It is not known if the high zinc, copper, lead, and cadmium concentrations in Lake Roosevelt whole suckers are due to accumulations in tissues--internal organs, skin, and bone usually contain the highest concentrations of these metals--or if this reflects the presence of

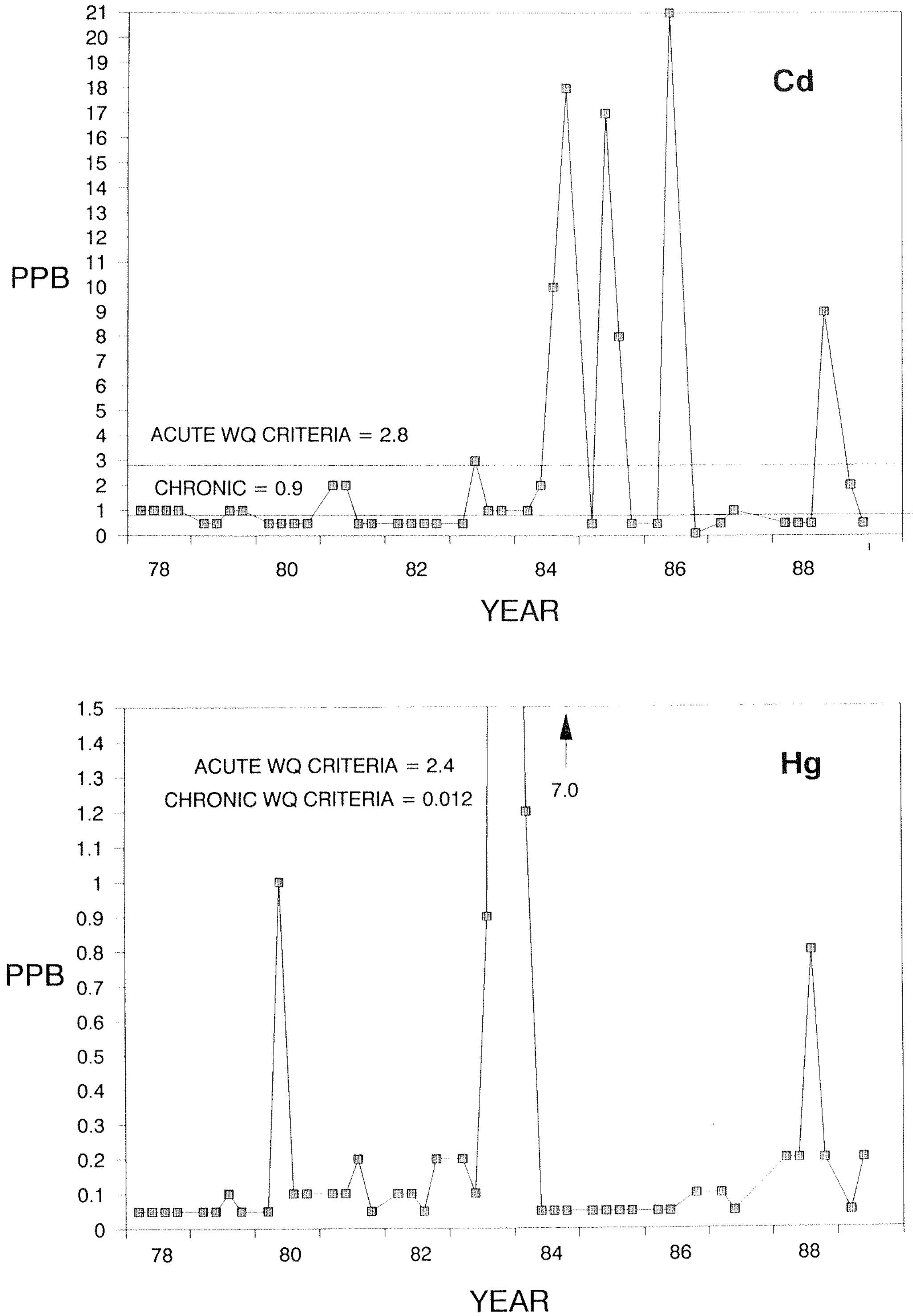


Figure 6. USGS historical data on cadmium and mercury concentrations in the Columbia River at Northport (dissolved metal in ug/L)

Table 13. Analysis of whole largescale suckers collected in Lake Roosevelt, September 23-26, 1986.

Location	River Mile	Sample Number	Fork Length (mm)	Weight (g)	Metals Concentrations (ug/g, wet) Zn	Cu	Pb	As	Cd	Hg
Northport	732	8592	503	1954	40.0	2.82	6.99	0.08	0.29	0.11
		8593	442	1344	64.9	5.20	7.34	<0.02	0.26	0.12
		8594	455	1287	46.5	4.88	4.61	0.20	0.34	0.14
		8595	473	1338	86.7	6.40	5.43	0.20	0.43	0.08
				mean =	59.5*	4.82*	6.09*	0.12	0.33*	0.11
Gifford	680	8582[a]	470	1376	31.8	0.70	2.12	0.05	0.39	0.25
		8584	459	1386	21.7	1.74	1.54	0.14	0.43	0.15
		8585	438	1120	28.5	0.90	2.33	0.30	0.37	0.16
		8597	441	1001	42.0	1.86	1.84	0.14	0.33	0.13
				mean =	31.0*	1.30*	2.00*	0.16	0.38*	0.17
Seven Bays	635	8572	414	1103	24.5	0.68	0.24	0.10	0.25	0.10
		8573	415	1070	21.9	0.62	0.55	0.16	0.22	0.17
		8574	410	1073	25.2	0.68	0.47	0.12	0.30	0.14
		8575	460	1164	20.9	0.90	0.31	0.14	0.25	0.10
				mean =	23.1*	0.72*	0.39*	0.13	0.26*	0.13

*significant difference between stations (ANOVA, $p<0.05$)

[a] average of duplicates

contaminated sediments in the gut contents of this bottom-feeding species. Between-station differences in metals concentrations in Lake Roosevelt suckers analyzed for the present study appeared to follow the longitudinal gradients observed in the sediments. The relative abundance of metals in these fish (zinc > copper, lead > cadmium > arsenic, mercury) also corresponds approximately to relative abundance in the sediments. Based on the data in Table 5, the amount of sediment in the gut need only have been between 1 - 0.1 percent of the total weight of the fish to account for the zinc, copper, and lead concentrations measured. Gut contents would have less potential influence on cadmium concentrations since the relative difference in the two media is only about a factor of 10.

USFWS National Contaminant Biomonitoring Program

Table 14 compares the metals concentrations measured in Lake Roosevelt largescale suckers with the most recent data on Washington State fish from the USFWS National Contaminant Biomonitoring Program (Lowe, *et al.*, 1985; May 1988 preliminary data). The concentrations measured independently at Grand Coulee (USFWS) and nearby Seven Bays (Ecology) agree closely. Fish in upper Lake Roosevelt clearly have very high whole-body concentrations of lead and cadmium, and zinc and copper (Northport specimens only), relative to fish in the lower Columbia, Snake, and Yakima Rivers. Carp collected by USFWS from the Columbia River at Pasco had zinc concentrations equivalent to those at Northport, but this is apparently a peculiarity of the species (Lowe, *et al.*, 1985). Arsenic and mercury concentrations do not appear elevated in Lake Roosevelt fish.

As described at the beginning of this report, USFWS reported finding cadmium and lead concentrations in Lake Roosevelt whole fish to be among the highest in the nation. Table 15 summarizes USFWS data from 1978-1981. Lowe, *et al.*, (1985) compared mean metals concentrations for the 112 stations sampled nation-wide and concluded the mean cadmium concentrations in fish collected at Grand Coulee in 1978 and 1980 were the highest in the nation. Mean lead concentrations ranked third and fourth highest in 1978 and 1980, respectively.

Significance of Metals Accumulation by Fish

The significance of the metals concentrations measured in Lake Roosevelt whole fish samples is difficult to determine. Zinc, copper, and arsenic are required by fish as essential trace elements (Mertz, 1981). Recognition of the fact that fish regulate levels of these metals in their tissues over a wide range of ambient water concentrations has raised questions about their use as monitors for zinc, copper, and arsenic in the aquatic environment (Phillips, 1980). Fish have no biological requirement for lead, cadmium, or mercury; elevations in these metals may represent a greater concern.

Criteria analogous to the EPA water quality criteria have not been established for metals in fish tissue. USFWS, however, has made recommendations for cadmium and mercury. Eisler (1985, 1987) recently reviewed the hazard these two metals pose to fish and wildlife. A cadmium concentration of 2.0 ug/g in whole body wet weight was concluded to be "evidence of probable cadmium contamination" while 5.0 ug/g "should be considered

Table 14. Summary of metals data on whole fish from Lake Roosevelt and other Washington State waters.

Location	Species Analyzed	Number of Samples	Metals Concentrations (mean, ug/g, wet)					
			Zinc	Copper	Lead	Arsenic	Cadmium	Mercury
Ecology (present study)								
Lake Roosevelt @ Northport	Largescale sucker	4	59.5	4.82	6.09	0.12	0.33	0.11
Lake Roosevelt @ Gifford	Largescale sucker	4	31.0	1.30	2.00	0.16	0.38	0.17
Lake Roosevelt @ Seven Bays	Largescale sucker	4	23.1	0.72	0.39	0.13	0.26	0.13
USFWS 1984 Collection[a] (preliminary data)								
Lake Roosevelt @ Grand Coulee	Largescale sucker and peamouth	4[b]	29.4	1.3	0.22	0.17	0.09	0.08
USFWS 1980 Collection (Lowe, *et al.*, 1985)								
Lake Roosevelt @ Grand Coulee	Largescale sucker and walleye	3[b]	19.8	0.67	0.50	0.22	0.17	0.12
Columbia River @ Pasco	Common carp and yellow perch	3	60.0[c]	1.1	0.23	0.06	0.04	0.04
Columbia River @ Cascade Locks	Largescale sucker and northern squawfish	3	17.0	0.9	0.10	0.32	0.03	0.17
Snake River @ Clarkston	Largescale sucker and white crappie	3	16.6	0.5	0.12	0.12	0.01	0.12
Snake River @ Ice Harbor Dam	Largescale sucker and northern squawfish	3	20.7	0.7	0.10	0.09	0.01	0.11
Yakima River @ Granger	Largescale sucker and black crappie	3	26.3	0.7	0.10	0.28	0.01	0.15

[a]Data provided by T.W. May

[b]USFWS samples are composites of five individuals each

[c]Individual zinc concentrations were 82.4 ug/g (carp composite 1), 75.4 (carp composite 2), and 22.1 ug/g (perch composite)

Table 15. Summary of data from the USFWS National Contaminant Biomonitoring Program on metals concentrations in whole fish.

Location	Year		Metals Concentration (ug/g, wet)					
			Zinc	Copper	Lead	Arsenic	Cadmium	Mercury
------------------- USFW (Lowe, *et al.*, 1985) ---------------								
U.S. Freshwaters	1978-79	mean	25.6	0.86	0.19	0.16	0.04	0.11
(112 stations	"	85th percentile	46.3	1.1	0.32	0.23	0.09	0.18
nation-wide)	"	maximum	168	38.8	6.73	2.0	0.41	1.10
Lake Roosevelt	1978	mean	46.5	0.67	0.78	0.15	0.26	0.06
@ Grand Coulee	"	maximum	60.1	1.0	1.13	0.20	0.41	0.09
U.S. Freshwaters	1980-81	mean	23.8	0.68	0.17	0.14	0.03	0.11
(112 stations	"	85th percentile	40.1	0.90	0.25	0.22	0.06	0.18
nation-wide)	"	maximum	109	24.1	1.94	1.7	0.35	0.77
Lake Roosevelt	1980	mean	19.8	0.67	0.50	0.22	0.17	0.12
@ Grand Coulee	"	maximum	28.7	1.0	0.97	0.33	0.26	0.13

life-threatening." Cadmium levels of 13.0 to 15.0 ug/g, wet in tissue "probably represents a significant hazard (to) higher trophic levels." Concentrations approaching these levels were not observed in Lake Roosevelt whole fish (or fillets, see below).

For protection of sensitive birds and small mammals, Eisler recommended mercury concentrations in food items not exceed 0.1 and 1.1 ug/g, wet, respectively. The former concentration is representative of mercury levels in whole fish analyzed from Lake Roosevelt (0.08 - 0.25 ug/g). The National Academy of Sciences, however, concluded mercury concentrations in fish could reach 0.5 ug/g and remain protective of fish-eating birds (NAS, 1973). This value was derived by considering that fish killed by mercury poisoning have contained 5 to 10 ug/g and that 0.1 to 0.2 ug/g is "apparently a usual background level for freshwater fish." Because data on safe mercury levels were not available, the U.S. Food and Drug Administration (FDA) criteria in effect at that time for human consumption was used, as it fell conveniently near background but well below toxic levels.

There is qualitative evidence that significant adverse biological effects are not occurring in the lake. USFWS assessed the fisheries resources in Lake Roosevelt during 1980-1983 (Beckman, *et al.*, 1985). They found "good recruitment, rapid growth (and) low natural mortality" of walleye, the lake's primary sport fish. Extensive reservoir drawdown in the spring, which flushes nutrients and plankton through the system and reduces bottom habitat, was identified as an important factor in reducing potential productivity.

Observations by the Department of Wildlife indicate that the lake's zooplankton populations have improved as the reservoir ages and that the lake appears typical of other reservoirs in its ability to support sport fisheries. Also, private organizations have had good success in pen-rearing rainbow trout at Seven Bays and, recently, Kettle Falls to enhance the local trout fishery. (Hisata, 1988, personal communication)

Finally, more than adequate numbers of specimens of all target species, except sturgeon, were easily obtained at all sites during the present survey. The sturgeon population in Lake Roosevelt is apparently not large. Catch-per-unit effort in 1987 averaged 83 hours per fish caught (National Park Service, 1987). This may be the result of overfishing--the present limit is two fish per day--or perhaps competition by walleye for prey items. While the possibility for metals toxicity cannot be ruled out, the sturgeon fishery in the Columbia River above the border is doing well with a one-fish-per- season limit (Setter, 1988, personal communication).

Metals Analysis of Sport Fish Muscle

Except for mercury, metals concentrations in the muscle tissue of walleye and other sport fish (Table 16) were much lower than in whole fish. There were no significant between-station differences in the metals concentrations in walleye muscle. Mean concentrations in walleye (overall) were 4.0 ug zinc/g, 0.24 ug copper/g, 0.19 ug mercury/g, 0.08 ug arsenic/g, 0.04 ug lead/g, and 0.01 ug cadmium/g. Walleye tended to have higher mercury and lower copper concentrations than the other species analyzed, while zinc, lead, arsenic, and cadmium concentrations were similar among species.

Table 16. Analysis of muscle tissue samples from sport fish collected in Lake Roosevelt, September 23-26, 1986.

Location	River Mile	Species	Sample Number	Fork Length (mm)	Weight (g)	Metals Concentrations (ug/g, wet) Zn	Cu	Pb	As	Cd	Hg
Northport	732	Walleye	8587	402	716	4.3	0.18	0.05	0.14	<0.01	0.11
			8588	373	534	4.0	0.12	0.03	0.16	0.01	0.29
			8589	330	399	3.9	0.18	0.02	0.10	<0.01	0.10
			8590	340	420	3.7	0.22	0.02	0.10	<0.01	0.17
					mean =	4.0	0.18	0.03	0.12	<0.01	0.17
		Lake whitefish	8591	404	1087	4.1	0.60	0.03	0.02	<0.01	0.10
Marcus Island	708	White sturgeon	8586	1240[a]	--	3.4	0.32	0.04	0.24	0.01	0.12
Gifford	680	Walleye	8576[b]	450	861	3.8	0.09	0.02	0.05	0.08	0.35
			8578	358	468	3.8	0.46	0.03	0.10	<0.01	0.22
			8579	355	464	3.5	0.12	0.08	<0.02	<0.01	0.09
					mean =	3.7	0.22	0.04	0.06	0.03	0.22
		Lake whitefish	8580	426	1451	4.5	0.56	0.03	0.28	0.01	0.12
		Yellow perch	8581	295	492	9.4	1.32	0.11	<0.02	0.01	0.40
Seven Bays	635	Walleye	8565	368	552	4.4	0.28	0.02	<0.02	<0.01	0.07
			8566	362	473	4.4	0.48	0.11	0.04	0.02	0.31
			8567	360	463	4.5	0.28	0.06	0.06	0.01	0.08
			8568	415	704	3.8	0.24	0.05	0.06	0.01	0.27
					mean =	4.3	0.32	0.06	0.05	0.01	0.18
		Lake whitefish	8571	389	935	3.4	0.44	0.04	<0.02	0.01	0.07
		Rainbow trout	8569	291	391	5.5	0.44	0.05	<0.02	0.04	0.04
			8570	337	611	4.6	0.40	0.07	0.12	0.01	0.04

[a] total length

[b] average of duplicates

Mercury Accumulation by Fish

Of the six metals analyzed, only mercury appears to be accumulating significantly in the muscle tissue of Lake Roosevelt fish. This is consistent with results of other studies that show that potentially toxic trace metals other than mercury, selenium, and arsenic are generally not found to accumulate in the axial muscle of fish (Schmitt and Finger, 1987 and references therein).

Mercury is unique among metals in being biomagnified between trophic levels in freshwater and marine food webs. As a result, the highest concentrations usually occur in long-lived carnivorous species. For example, muscle tissue concentrations in largemouth bass, lake trout, northern pike, tunas, swordfish, and black marlin have been reported to reach 1.0 to 16.5 ug/g in the presence of normal background concentrations (Eisler 1987 and references therein).

Mercury concentration is generally correlated with age and size in a given fish species; this relationship has been documented for walleye in other bodies of water (Phillips, 1980). The walleye collected for the present study, however, represent too narrow a size range to test this relationship for Lake Roosevelt.

The small size of the Lake Roosevelt walleye population and intense sport fishery has resulted in a decline in the age and size of the fish harvested (Beckman, *et al.*, 1985). As a result, there is presently limited availability of large fish; the size limit has been reduced accordingly to 16 inches total length. In the opinion of the Department of Wildlife, the size range (330-450 mm [13 - 18 inches] fork length) of the walleye analyzed for the present study are representative of 95 percent of the sport catch in the lake (Hisata, 1988, personal communication).

Construction of impoundments in and of itself can result in increased accumulation of mercury in fish due to enhanced bacterial activity in the sediments. Pre-impoundment and post-impoundment concentrations of mercury in walleye muscle at one Manitoba reservoir, for example, were 0.2 - 0.3 and 0.6 - 0.8 ug/g, respectively (Bodaly, *et al.*, 1984). Mercury levels usually decline as a reservoir ages (Abernathy and Cumble, 1977; Lodenius, *et al.*, 1983). There are insufficient data to determine historical trends of mercury in Lake Roosevelt sport fish.

Consumption of Lake Roosevelt Fish

Table 17 gives legal limits for metals concentrations in commercially marketed fish established by FDA and other countries compared to the concentration ranges found in Lake Roosevelt sport fish. Mercury is the only metal FDA regulates in fish. The median international limits shown for zinc, copper, lead, arsenic, cadmium, and mercury are from regulatory statutes of other countries as reported by Nauen (1983).

Table 17. Legal limits for metals concentrations in fish sold commercially for human consumption compared to concentrations measured in Lake Roosevelt sportfish in 1986 (ug/g, wet).

	Zinc	Copper	Lead	Arsenic	Cadmium	Mercury
FDA "Action Level"	--	--	--	--	--	1.0
Median International Legal Limits:	45	20	2.0	1.5	0.3	0.5
Lake Roosevelt Fish[a] (present study n=18)	3.4-5.5	0.09-1.32	0.02-0.11	<0.02-0.28	<0.01-0.08	0.04-0.40

Sources: FDA (1985) and Nauen (1983)

[a]Muscle tissue, all species.

The FDA limit is for methylmercury, this being the most toxic form due to its lipid solubility and ability to penetrate biological membranes (Beijer and Jernelov, 1979). Methylmercury is the predominant form of mercury in fish tissues (Eisler, 1987 and references therein). The FDA "action level" of 1.0 ug/g (parts per million) represents a judgment by FDA balancing potential for adverse health effects against economic impacts. When a product exceeds the action level, FDA can legally remove it from the marketplace.

As shown in Table 17, metals concentrations in Lake Roosevelt sport fish are well within limits set by FDA and other countries. For most metals, maximum tissue concentrations were an order of magnitude lower than the limit. Although the highest mercury concentration measured in muscle tissue of a Lake Roosevelt fish (0.40 ug/g in yellow perch) was less than half the FDA action level, this concentration does approach the median international limit of 0.5 ug/g.

Several states within the U.S. have adopted 0.5 ug/g as a guideline for health advisories on mercury in sport-caught fish. Wisconsin and California, for example, have made independent assessments of the hazard associated with mercury intake from fish because of concern for potential adverse effects on pregnant women and their fetuses, children, and people consuming fish at a higher rate than assumed by FDA. The rationale for departing from the FDA limit has been described by Anderson and Olsen (1986) for Wisconsin and Stratton, *et al.* (1987) for California. All other Wisconsin and California guidelines for contaminants in fish follow FDA action levels.

Wisconsin's guidelines (Appendix V) are designed to keep the total body burden of mercury below 15 mg which, based on a review of the literature, was considered to be the toxicity threshold. The guidelines allow 1.5 mg from sport-caught fish, 1.5 mg from all other dietary sources, and reserve 12 mg of mercury as an unallocated safety margin. Additional safety factors of two to four were incorporated in the guidelines for women of reproductive age, the fetus, and young children.

The California assessment uses mercury concentrations in blood rather than body burden. The lowest observed effect (LOE) level for methylmercury in adults was determined to be 200 parts per billion (ppb). The guidelines (Appendix VI) recommend an allowable daily intake (ADI) of 0.03 mg for a 70 kg adult which incorporates a safety factor of 10. An additional four-fold safety factor is used in the guidelines to protect women of reproductive age, the fetus, and young children.

FDA recently reviewed the validity of their 1.0 ug/g limit for mercury (Tollefson and Cordle, 1986). Using the LOE of 200 ppb and a safety factor of 10, an allowable daily intake of 0.03 mg was also derived. Based on the available data on fish consumption rates and mercury concentrations in various species of fish, FDA concluded that "the majority of fish consumers in the United States could easily double their intake and still remain below the mercury ADI" and that the action level of 1.0 ug/g provides "adequate protection" for most fish consumers including young children. FDA is supporting additional studies to "ensure that safe levels of prenatal exposure to mercury residues in fish are maintained." (As alluded to earlier, FDA formerly had an action level of 0.5 ug/g, but revised it to 1.0 ug/g in 1979 [FDA, 1979]. FDA faces a substantial regulatory problem with a 0.5 ug/g limit because of the common occurrence of mercury concentrations greater than 0.5 ug/g in some commercial species.)

In summary, the Wisconsin and California assessments depart from FDA in the need to protect women of reproductive age, the fetus, and young children when mercury concentrations in fish are in the range of 0.5 - 1.0 ug/g. The above-mentioned reports should be consulted for assumptions and methodologies used in assessing the health risks associated with mercury.

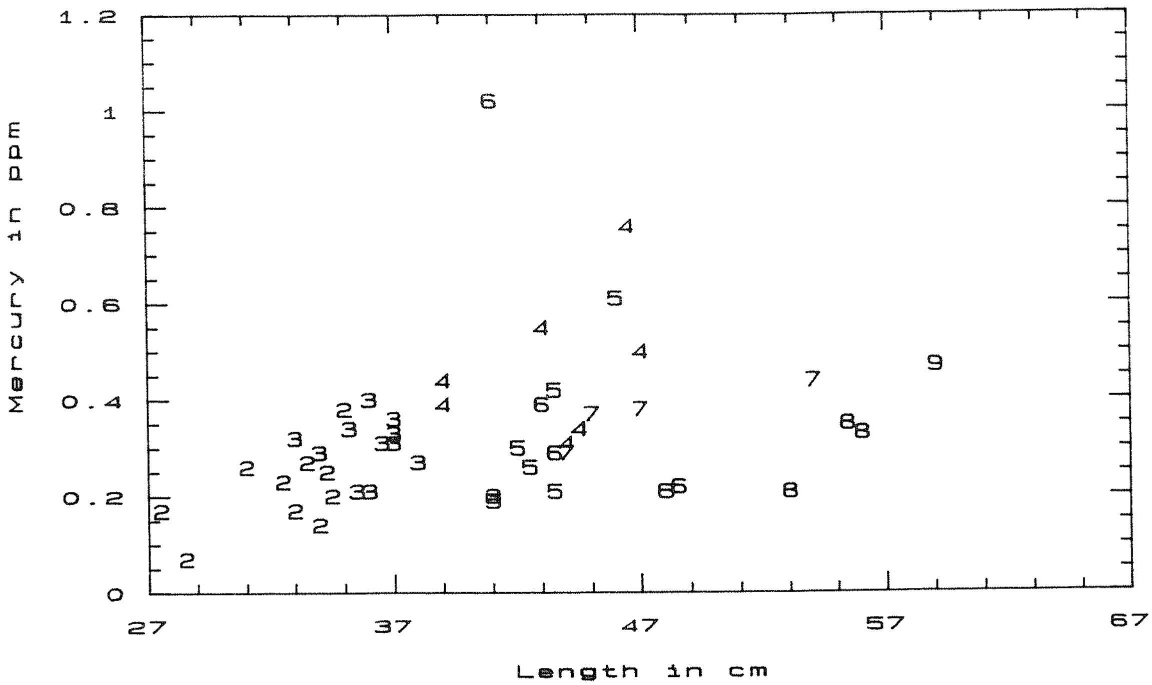
The Washington Department of Social and Health Services (DSHS) Office of Environmental Health Programs was provided the data on mercury in Lake Roosevelt fish and conducted an independent review of toxicological and epidemiological information relating to health effects from mercury contamination of food. Their assessment concluded that mercury levels below 0.5 ug/g "do not present a public health threat" and, since fish sampled by Ecology were below 0.5 ug/g, "no health advisory is required . . .." They further concluded that "at the present time, the public can consume fish as desired." Appendix VII contains the complete text of the DSHS review.

Metals Concentrations in British Columbia Fish near Comino

Canada has adopted a 0.5 ug/g tolerance level for mercury in sport fish (Sherbin, 1979). On September 3, 1987, the Ministry of Environment released an "information bulletin" (Appendix VIII) suggesting Columbia River walleye over two pounds be restricted to one meal per week. The data which precipitated this advisory were from a collection of walleye (and other species) between the international border and Lower Arrow Lake in July and August of 1986. These data, along with recently received data on mercury in walleye collected during July through September 1987, are plotted in Figure 7 (Appendix IX has the complete data set).

Although most of the mercury concentrations in the British Columbia walleye are within the range observed in Lake Roosevelt, six of the 50 specimens analyzed had concentrations in the range of 0.5 - 1.02 ug/g. An intercomparison exercise between the Canadian laboratories and the laboratory doing the Lake Roosevelt analyses for the present study (Table 18) has indicated close agreement on mercury measurements in fish tissue.

As shown in the figure, mercury concentrations in these walleye are not closely related to age or size of the fish. The best correlation obtained was for mercury concentration vs. length ($r = 0.339$; $p < 0.05$). The extent to which movements of fish in the upper Columbia drainage may have affected mercury concentrations is not known. Close inspection of the figure suggests two-to-four-year old fish were distinct from five-to-nine-year old fish with respect to mercury accumulation. Mercury concentration was well correlated with length in the two-to-four-year age classes ($r = 0.724$; $p < 0.05$).



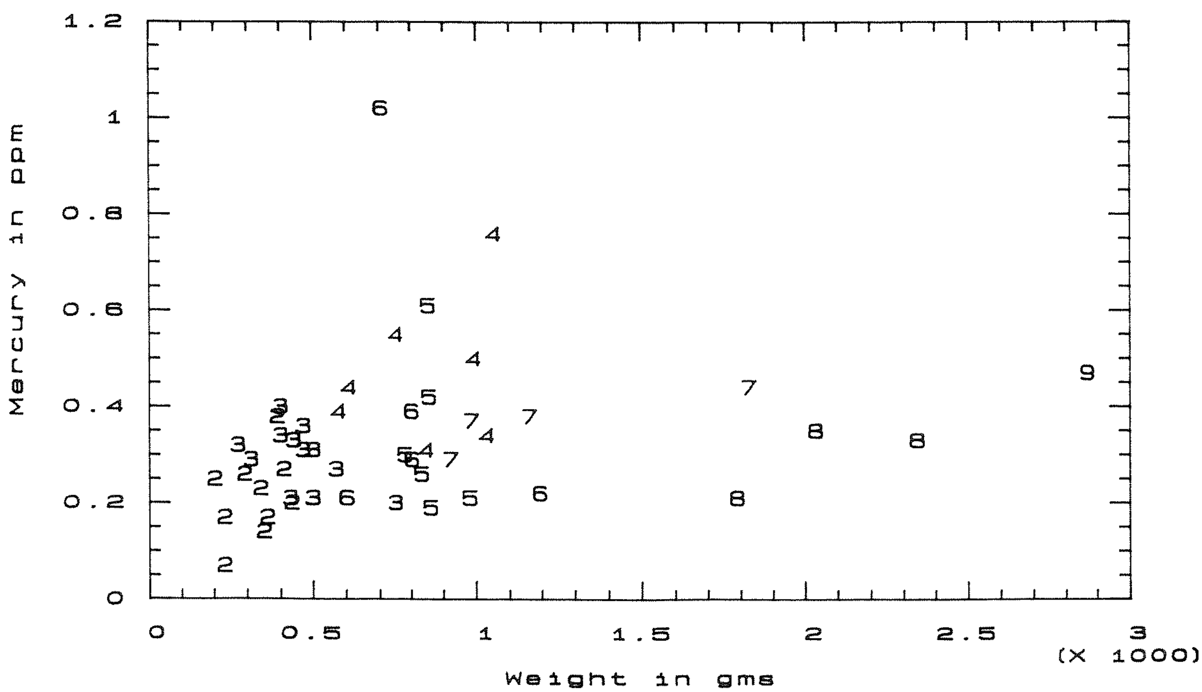


Figure 7. Mercury concentrations in muscle tissue versus length and weight of walleye collected in the upper Columbia River in 1986 and 1987 by B.C. Ministry of Environment (data points coded to fish age in years). Data supplied by R. Crozier.

Table 18. Laboratory intercomparison on mercury analysis of Lake Roosevelt fish tissue samples collected September 23 - 25, 1986 (ug/g, wet).

			Analysis By:		
Sample Type	Collection Site	Sample Number	Battelle Marine[a] Research Lab., Sequim, WA	B.C. Environmental Lab., Vancouver	Nat'l Water Quality Lab., Burlington, Ontario
Walleye muscle	Northport	8587	0.11	(Canadian laboratories analyzed a composite sample, see below)	
		8588	0.29		
		8589	0.10		
		8590	0.17		
		mean =	0.17		
Walleye muscle comp.	Northport	8587-90	NA[b]	0.22	0.24
		(dupl.)	NA[b]	0.22	0.17
Whole largescale sucker	Gifford	8584	0.15	0.15	0.16
		(dupl.)	0.16	0.13	0.15
NBS albacore tuna	--	--	NA[b]	1.01	0.90
RM-50	--	--	NA[b]	1.04	0.93
certified value = 0.95 ± 0.1 ug/g, dry					

[a]Did analysis for present study

[b]Not analyzed; see Table 3 for Battelle reference material analysis

Table 19 summarizes Ministry of Environment data for all species collected in 1986 and compares them to present study results for Lake Roosevelt. Except for largescale suckers, the zinc, copper, lead, cadmium, and mercury concentrations in muscle tissue of the British Columbia fish are similar to those in Lake Roosevelt. Canada did not analyze for arsenic.

British Columbia largescale suckers contained much more lead than any of the five sport fish species analyzed from Lake Roosevelt. While the maximum lead concentrations in sucker muscle approached the median international limit of 2.0 ug/g, there was also extreme variation among the specimens analyzed ($<$ 0.10 - 1.65 ug/g), which raises questions about the source of variation.

The effect of sample preparation on measurements of lead and other metals in fish from streams contaminated by mining has been investigated in detail by USFWS (Schmitt and Finger, 1987). They found the amount of lead in edible tissue was related to the calcium content of the sample because of inclusion of bone and scales. Catostomids (suckers) were singled out as being especially vulnerable to this effect because of numerous small intermuscular bones. This may explain the British Columbia data.

Samples of largescale suckers from Ecology's collection at Gifford were provided to the Ministry of Environment which analyzed muscle tissue rather than whole fish. The muscle tissues of these fish (Table 19) had substantially higher mercury concentrations than in the same species collected above the border (0.28-0.49 vs. 0.08-0.24 ug/g). These data suggest that, in contrast to sport fish analyzed for the present study, suckers, and perhaps other benthic species in Lake Roosevelt, may be accumulating higher levels of mercury in muscle tissue than expected.

Pollution Reduction by Cominco

In the late 1970s, Cominco embarked on a program to reduce metals discharges to the Columbia River. The effectiveness of the control measures implemented is indicated in Table 20 which summarizes metals loads in liquid effluents for the period 1977 through 1985 (Smith, 1987). No loads were reported for copper, which is monitored less frequently and considered one of the "less important components" of the effluents (Smith, 1987).

Based on these data, zinc, lead, cadmium, and mercury loads have been reduced by 85 percent, 74 percent, 69 percent, and 80 percent respectively, since 1977. (There is the suggestion of a trend toward decreasing zinc and lead in the surface layers of the Lake Roosevelt sediment core analyzed for the present study [Table 7], but this may not be significant.) With completion of a new lead smelter currently under construction, the mercury load is expected to be further reduced to less than half the 1985 level (Crozier, 1988, personal communication).

Cominco will continue to discharge slag. The present permit allows discharge of up to 900 metric tons/day, although current discharges are in the range of 250 - 400 metric tons/day. Lake Roosevelt is the ultimate sink for this material. The Ministry of Environment is of the opinion that it is not feasible to curtail slag discharge and considers it to represent little

Table 19. Summary of metals concentrations measured in muscle samples from Lake Roosevelt/upper Columbia fish by the Ministry of Environment, and Ecology in 1986.

Location	Species	Number of Samples	Metals Concentrations (mean and range, ug/g, wet)					
			Zinc	Copper	Lead	Arsenic	Cadmium	Mercury[a]
			Ministry of Environment (Crozier, 1987 preliminary data)					
Columbia River between Lower Arrow Lake and the International Border	Walleye	13	4.6	0.26	<0.10	NA[b]	<0.02	0.36
			(3.8-6.2)	(<0.02-0.41)	(<0.10 all)		(<0.02 all)	(0.02-0.76
	Mountain whitefish	14	5.6	0.79	<0.10	NA	<0.02	0.11
			(3.3-7.2)	(0.39-2.5)	(<0.10-0.29)		(<0.02-0.05)	(<0.05-0.18
	White sturgeon	1	NA	NA	NA	NA	NA	0.16
	Largescale sucker	16	8.7	0.62	0.60	NA	<0.02	0.15
			(6.0-13.2)	(0.47-0.97)	(<0.10-1.65)	NA	(<0.02-0.03)	(0.08-0.24
Lake Roosevelt @ Gifford	Largescale sucker	7	NA	NA	NA	NA	NA	0.41
								(0.28-0.49
			Ecology (present study)					
Lake Roosevelt between Northport and Seven Bays	Walleye	11	4.0	0.24	0.04	0.08	0.01	0.19
			(3.5-4.5)	(0.09-0.48)	(0.02-0.11)	(<0.02-0.16)	(<0.01-0.08)	(0.08-0.35
	Lake whitefish	3	3.9	0.53	0.03	0.10	0.01	0.10
			(3.4-4.5)	(0.44-0.60)	(0.03-0.04)	(<0.02-0.28)	(<0.01-0.01)	(0.07-0.12
	White sturgeon	1	3.4	0.32	0.04	0.24	0.01	0.12
	Yellow perch	1	9.4	1.32	0.11	<0.02	0.01	0.40
	Rainbow trout	2	5.0	0.42	0.06	0.07	0.02	0.04
			(4.6-5.5)	(0.40-0.44)	(0.05-0.07)	(<0.02-0.12)	(0.01-0.04)	(0.04 all)

[a]Canada data from provincial laboratory only.

[b]Not analyzed

Table 20. "Average annual loss (kg/day) from Trail Metallurgical Sewers. Values are for total metals. Data supplied by Cominco, Ltd." (from Smith, 1987)

Year	Zinc	Lead	Cadmium	Arsenic	Mercury
1977	8,444	254	95	10	7
1978	7,534	221	122	12	7
1979	7,173	210	77	10	5
1980	7,400	204	35	17	5
1981	5,211	159	28	13	2
1982	4,107	163	64	14	2.5
1983	2,100	105	41	14	2.5
1984	1,800	64	19	18	1.9
1985 (9 months)	1,200	65	29	18	1.2

hazard to the environment in light of previously mentioned studies showing slag is relatively inert (Crozier, 1988, personal communication). Results of their leaching experiments indicated slag's contribution to metals concentrations in the water column would be less than one percent of other Cominco discharges (Ministry of Environment, 1979).

CONCLUSIONS AND RECOMMENDATIONS

Ecology's 1986 surveys in Lake Roosevelt did not find evidence that the current levels of metals in this system pose a serious threat to aquatic life or human health. However, given the level of contamination of sediment and whole fish in some parts of the lake, narrow margin between natural background and potentially toxic concentrations of mercury in edible tissues of fish, continued operation of Cominco and discharge of slag (with attendant possibility of spills and unpermitted discharges), and value of the resources, some additional study and monitoring of the lake is recommended:

1. Ecology should establish a station on Lake Roosevelt for long-term monitoring of metals in fish tissues and sediments. This site should be located in the vicinity of Frenchman Point Rocks where the highest sediment concentrations of lead, cadmium, and mercury occur.

2. A program should be established to periodically monitor the edible tissue of Lake Roosevelt sport fish for mercury. This could be a cooperative effort between the National Park Service, Bureau of Reclamation, and Ecology.

3. Ecology should do additional analyses to better assess the bioavailability and toxicity of metals in Lake Roosevelt sediments. Four sites are recommended for study: Dead Man's Eddy (presence of slag); Frenchman Point Rocks (elevated lead, cadmium, and mercury); Seven Bays (inconclusive evidence of sediment toxicity in present study); and Spokane River Arm (elevated zinc in sediment and water).

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APPENDICES

Appendix I. Locations of sediment samples collected from Lake Roosevelt/upper Columbia River and tributaries in 1986 (surficial sediment except as noted).

Location	Date	River Mile	Depth (ft)	Description	Latitude	Longitude
-Lake Roosevelt/Upper Columbia River-						
Lower Arrow Lake, B.C.	7/30	790.0	36	50 yards off left bank, at Syringa Creek Park	--	--
Boundary	8/04	742.8	55	100 yards off left bank, at tower	48°58'20"	117°38'50"
Deadman's Eddy	8/04	738.3	40	150 yards off left bank, in Deadman's Eddy	48°56'05"	117°43'30"
Northport	8/04	733.0	27	0.2 mile off left bank, between Northport and Squaw Creek	48°54'10"	117°48'20"
Little Dalles	8/04	728.1	82	0.1 mile off left bank, just below Little Dalles	48°51'45"	117°52'50"
China Bend	8/04	723.8	36	0.2 mile off right bank, just below China Bar dike	48°48'35"	118°56'10"
Marcus Island	8/05	708.9	84	Mid-channel off NW end of Marcus Island	48°40'20"	118°03'05"
Frenchman Point Rocks	8/05	692.2	92	0.5 mile off right bank, between Frenchman Pt. Rocks & Martin Creek	48°30'20"	118°10'30"
" (core)	9/23	692.7	90	same as above	48°30'47"	118°10'10"
Gifford	8/05	676.4	105	0.6 mile off left bank, opposite Hall Creek	48°18'35"	118°09'40"
Hunters	8/05	661.0	110	0.4 mile off left bank, opposite Nez Perce Creek	48°07'50"	118°13'55"
Castle Rock	8/06	644.8	125	0.2 mile off right bank, just above Six-Mile Creek	47°58'40"	118°21'55"
Seven Bays	8/06	635.4	88	0.5 mile off right bank, between George Creek and Rattlesnake Draw	47°50'55"	118°21'50"
Swawilla Basin	8/06	604.9	135	0.3 mile off left bank, between Plum Point and Cayuse Bay	47°56'35"	118°50'30"
-Tributaries to Lake Roosevelt-						
Kettle River Arm	8/05	706.4[a]	22	Midchannel, 0.3 mile upstream from Kamloops Island bridge	48°41'00"	118°07'00"
Colville R. Mouth	8/05	699.5	41	Midchannel, 0.4 mile below highway 22 bridge	48°34'20	118°05'35"
Spokane River Arm	8/06	638.9	110	0.2 mile off left bank, at light "3", 7.5 miles upstream fm FDR Lk.	47°06'45"	118°12'55"
Sanpoil River Arm	8/06	615.0	40	Midchannel at Silvercreek, 7.3 miles upstream from FDR Lake	48°02'45"	118°39'55"

a = River mile on Lake Roosevelt at tributary confluence

Appendix II. Cleaning protocols for metals samples containers (I-Chem, Hayward, CA) used in 1986 Lake Roosevelt surveys.

Wide-mouth glass jars with teflon lid liners (sediment and fish tissue samples):

1. Wash containers, closures, and teflon liners in hot tap water with non-phosphate detergent.

2. Rinse three times with tap water.

3. Rinse with 1:1 nitric acid.

4. Rinse three times with de-ionized water.

5. Rinse with pesticide-grade methylene chloride.

6. Oven dry.

7. Remove containers, closures, and teflon liners from oven.

8. Place teflon liners in closures and place closures on containers. Attendant to wear gloves and containers not to be removed from preparation room until sealed.

9. QC checked by I-Chem.

Polyethylene cubitainers with teflon lid liners (water samples):

1. Wash bottles, closures, and teflon liners in hot tap water with non-phosphate detergent.

2. Rinse three times with tap water.

3. Rinse with 1:1 nitric acid.

4. Rinse three times with de-ionized water.

5. Air dry in contaminant-free environment.

6. Place teflon liners in closures and place closures on bottles. Attendant to wear gloves and bottles not to be removed from preparation room until sealed.

7. QC checked by Ecology/EPA Environmental Laboratory, Manchester, WA.

Appendix III. Summary of 1986 Lake Roosevelt sediment bioassays.

Hyalella azteca

Testing was done following the method of Nebeker, *et al*. (1984). This method involves exposing amphipods to sediment overlain with water, for ten days. Mortality is the recorded end-point. Test organisms used were from a culture maintained at Manchester Environmental Laboratory.

The day prior to the test, each sample was thoroughly homogenized and approximately 200 grams was weighed and placed into each of five one-liter beakers. Five control beakers using West Beach sand were prepared at the same time. Dechlorinated Manchester city water was then carefully added to bring the total volume of each beaker to 1,000 mL. Test beakers were incubated overnight to allow samples to settle and equilibrate.

To begin the test, ten *Hyalella azteca* were added to four of the five test beakers for each sample. Beakers were then randomly placed in a 20^{o}C incubator and aerated for ten days. Temperature was recorded each day of the test. Food was added the first day and as needed throughout the test period.

The fifth beaker prepared for each sample was used as a "dummy," to provide samples for pH and dissolved oxygen analyses at the beginning of the test.

Testing began August 15, 1986, and ended August 25, 1986. To terminate the tests, material from each beaker was poured through a Nalgene sieve from which live amphipods were recovered and counted. The liquid fraction from each sample was analyzed for pH and dissolved oxygen on termination of the test.

Daphnia pulex

Daphnid tests were conducted following a modification of the method described in U.S. EPA (1985) "Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms." To adapt the method for use with sediments, the freshwater amphipod test (Nebeker, *et al*., 1986) was used as a model. Test organisms used were from a culture maintained at Manchester Environmental Laboratory. Testing began August 13, 1986.

Approximately 40 grams of well-homogenized sample was weighed and added to each of five 250-mL beakers. Five control beakers using West Beach sand were also prepared. 150 mL of *Daphnia pulex* culture medium (moderately hard [about 85 mg/L $CaCO_3$] reconstituted distilled/deionized water) was carefully added to each beaker. Beakers were incubated overnight to allow samples to settle and equilibrate.

The following day, samples were aerated for at least 30 minutes. Five *Daphnia pulex* neonates (less than 24 hours old) were added to each of four of the five replicates for each sample. Beakers were placed in a 20°C incubator and aerated for 48 hours. Test organisms were not fed during the test. The fifth beaker was used as a "dummy" to provide samples for pH and dissolved oxygen at the beginning of the test.

After 48 hours the daphnids in each replicate were counted and percent survival was recorded. The liquid fraction from each sample was then measured for pH and dissolved oxygen.

Counting survivors at the end of the test was hampered by the presence of particulate matter in liquid fractions, and the difficulty encountered in locating test organisms on the surface of the sediment.

Control survival was 70 percent. Aeration of samples may have been responsible for the relatively low survival. Considerable "rolling" of animals was observed in the control beakers during the test, possibly causing stress or damage to the organisms.

M. Stinson, Ecology/EPA Environmental Laboratory, Manchester, WA.
September 24, 1987

Appendix IV. USGS data on metals concentrations in the Columbia River at Northport, 1978-1987 (NASQAN station 12400520).

				Metals Concentrations (ug/L)											
				Zinc		Copper		Lead		Cadmium		Arsenic		Mercury	
Date	Flow (cfs)	Suspended Sediment (mg/L)	Hardness (mg/L as $CaCO_3$)	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss
*05/20/87	130,000	--	63	--	14	--	7	--	<5	--	1	--	<1	--	<0.1
*01/21/87	95,000	--	72	--	27	--	7	--	<5	--	<1	--	<1	--	0.1
*11/18/86	64,000	--	75	--	32	--	8	--	13	--	<1	--	<1	--	0.1
*05/20/86	110,000	6	66	--	20	--	10	--	16	--	21	--	<1	--	<0.1
*02/29/86	57,500	4	83	--	26	--	1	--	3	--	<1	--	<1	--	<0.1
*12/18/85	97,600	6	72	--	29	--	4	--	4	--	<1	--	<1	--	<0.1
09/18/85	60,800	2	69	--	12	--	5	--	2	--	8	--	<1	--	<0.1
05/22/85	107,000	10	64	--	24	--	9	--	3	--	17	--	<1	--	<0.1
02/12/85	110,000	6	80	--	24	--	7	--	1	--	<1	--	<1	--	<0.1
11/13/84	81,700	2	75	--	25	--	8	--	6	--	18	--	<1	--	<0.1
09/12/84	88,400	2	63	--	18	--	5	--	14	--	10	--	<1	--	<0.1
05/08/84	108,000	6	77	--	42	--	4	--	11	--	2	--	<1	--	<0.1
01/11/84	91,200	1	75	--	26	--	6	--	14	--	1	--	<1	--	1.2
11/16/83	73,900	--	65	--	32	--	8	--	14	--	1	--	<1	--	7.0
09/28/83	63,000	2	66	--	13	--	7	--	5	--	1	--	<1	--	0.9
05/27/83	171,000	18	62	--	21	--	6	--	8	--	3	--	1	--	0.1
01/06/83	130,000	17	72	--	14	--	4	--	9	--	<1	--	1	--	0.2
11/09/82	64,000	6	69	--	19	--	6	--	11	--	<1	--	1	--	0.2
07/15/82	147,000	15	54	60	17	21	4	9	2	<1	<1	1	1	0.2	<0.1
05/13/82	144,000	17	72	60	26	20	11	24	9	1	<1	1	1	0.1	0.1
01/13/82	114,000	4	71	50	49	12	3	73	3	1	<1	1	1	0.3	0.1
10/02/81	94,000	2	64	120	32	16	3	65	6	2	<1	1	1	0.1	<0.1
07/08/81	219,000	13	60	90	20	15	4	13	1	1	<1	1	1	0.1	0.2
04/14/81	47,200	9	78	120	70	18	4	20	2	1	2	<1	1	0.1	0.1
01/08/81	129,000	6	70	70	50	20	5	10	3	1	2	1	1	0.1	0.1
10/09/80	62,800	3	72	60	50	11	2	8	<1	1	<1	2	2	<0.1	0.1
08/06/80	105,000	7	56	60	20	26	4	12	2	1	--	1	1	0.1	0.1
04/13/80	37,000	6	80	110	100	13	4	22	5	1	<1	1	1	1.3	1.0
01/16/80	85,400	6	71	80	60	42	<1	27	5	1	<1	2	<1	0.1	<0.1
10/17/79	86,200	9	67	80	60	100	14	71	18	2	1	1	1	0.1	<0.1
07/25/79	101,000	5	59	50	30	3	2	12	4	<1	1	3	1	0.1	0.1
04/24/79	60,100	6	77	80	70	9	4	19	<1	1	<1	3	2	0.2	<0.1
01/25/79	101,000	--	68	100	20	23	2	25	6	2	<1	1	1	<0.1	<0.1
10/30/78	104,000	3	67	50	30	83	1	50	<1	2	1	1	1	<0.1	<0.1
07/27/78	110,000	4	67	60	60	31	12	--	--	--	--	1	<1	0.1	<0.1
04/14/78	76,200	6	80	30	10	4	<1	10	3	1	1	1	<1	<0.1	<0.1
01/04/78	59,200	2	82	160	160	10	5	17	6	1	1	1	<1	0.2	<0.1

Source: USGS "Water Data Reports" for water years 1978-1985
*Provisional data, subject to revision

Appendix IV - (continued). USGS data on metals concentrations in the Spokane River at Long Lake, 1978-1987 (NASQAN station 12433000).

				Metals Concentrations (ug/L)											
				Zinc		Copper		Lead		Cadmium		Arsenic		Mercury	
Date	Flow (cfs)	Suspended Sediment (mg/L)	Hardness (mg/L as $CaCO_3$)	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss
*05/13/86	11,600	--	44	--	42	--	8	--	5	--	<1	--	1	--	<0.1
*01/13/86	4,900	1	69	--	59	--	3	--	1	--	1	--	1	--	0.4
*11/21/85	6,200	--	66	--	36	--	3	--	4	--	1	--	1	--	0.2
09/04/85	3,880	2	93	--	35	--	5	--	2	--	1	--	2	--	<0.1
05/28/85	20,100	6	30	--	53	--	3	--	<1	--	<1	--	<1	--	<0.1
01/16/85	5,250	4	71	--	54	--	5	--	20	--	<1	--	<1	--	<0.1
11/15/84	4,100	5	88	--	23	--	4	--	3	--	2	--	2	--	<0.1
09/13/84	3,600	5	97	--	13	--	7	--	3	--	<1	--	1	--	<0.1
05/15/84	13,000	6	42	--	100	--	5	--	7	--	<1	--	<1	--	<0.1
01/10/84	6,800	28	56	--	--	--	6	--	--	--	2	--	1	--	<0.1
11/17/83	4,720	3	85	--	16	--	5	--	16	--	2	--	1	--	<0.1
09/21/83	2,510	3	87	--	7	--	3	--	12	--	<1	--	2	--	0.5
05/19/83	13,000	6	36	--	61	--	2	--	12	--	2	--	1	--	<0.1
01/21/83	6,400	23	36	--	70	--	3	--	21	--	2	--	1	--	0.5
10/27/82	3,850	9	80	--	26	--	5	--	6	--	<1	--	2	--	0.3
07/21/82	5,250	5	<1	50	34	16	4	19	4	2	<1	2	1	0.3	0.1
05/19/82	20,300	24	3	110	70	5	3	34	8	1	<1	1	1	0.1	0.1
01/19/82	5,050	1	3	110	95	8	2	7	3	1	<1	5	1	0.1	0.1
10/20/81	3,160	2	8	90	<4	16	1	9	3	<1	<1	2	2	0.1	<0.1
07/21/81	3,920	2	46	50	50	4	2	1	3	1	<1	1	1	0.1	0.1
04/21/81	10,500	7	45	150	90	2	3	10	1	<1	1	1	1	0.2	0.1
01/20/81	7,070	4	37	190	130	19	2	21	1	1	<1	1	1	0.1	<0.1
10/21/80	3,830	5	76	30	6	8	2	19	0	0	<1	1	2	<0.1	0.1
07/09/80	4,170	4	45	140	30	33	2	39	2	1	<1	2	2	0.1	<0.1
04/18/80	6,330	6	47	120	90	8	2	4	0	1	<1	2	3	0.9	<0.1
01/23/80	6,360	3	66	70	80	8	<1	43	<1	1	<1	2	2	0.1	<0.1
10/10/79	3,950	3	74	40	<3	8	1	3	2	1	<1	4	3	<0.1	<0.1
07/30/79	3,860	4	66	40	10	4	2	8	<1	1	<1	3	1	0.1	0.1
04/23/79	14,000	5	38	150	110	10	2	17	1	1	<1	1	1	2	<0.1
01/18/79	3,950	4	87	90	60	22	4	16	5	1	<1	2	2	<0.1	<0.1
10/17/78	3,950	2	77	30	8	16	5	2	<1	<1	<1	1	2	<0.1	<0.1

Source: USGS "Water Data Reports" for water years 1978-1985
*Provisional data, subject to revision

Appendix IV - (continued) USGS data on metals concentrations in Blue Creek (Sumioka, 1988 in prep.).

Date	Flow (cfs)	Suspended Sediment (mg/L)	Hardness (mg/L as $CaCO_3$)	Metals Concentrations (ug/L) Zinc		Copper		Lead		Cadmium		Arsenic		Mercury	
				tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss	tot rec	diss
07/22/85	0.15	5	494	80	11	3	2	2	2	<1	<1	5	3	--	--
06/24/85	0.67	27	415	300	14	6	2	2	3	1	<1	4	2	<0.1	<0.1
05/20/85	2.39	13	263	60	16	8	1	2	4	1	<1	1	2	<0.1	<0.1
04/29/85	5.82	25	168	70	59	5	3	5	<1	<1	<1	2	2	<0.1	<0.1
03/21/85	7.49	80	202	160	40	10	2	1	2	3	<1	<1	2	<0.1	<0.1
02/25/85	0.83	6	370	30	31	4	<1	14	3	<1	<1	<1	<1	<0.1	<0.1
01/28/85	--	6	402	40	37	3	<1	<1	<1	<1	<1	<1	<1	<0.1	<0.1
12/19/84	0.55	5	452	40	44	<1	2	<1	<1	<1	1	<1	<1	<0.1	<0.1
11/26/84	1.02	9	387	20	28	2	2	15	<1	1	2	<1	<1	<0.1	<0.1
10/22/84	0.40	1	569	50	26	3	2	16	4	1	<1	<1	<1	<0.1	<0.1
09/24/84	0.23	--	614	20	16	16	2	17	4	1	1	<1	<1	0.1	<0.1
08/27/84	0.26	9	581	20	20	4	2	15	17	1	<1	<1	<1	0.6	<0.1
07/29/84	0.69	14	423	70	22	5	<1	20	3	2	1	<1	<1	0.1	<0.1

Appendix V. Wisconsin mercury/fish consumption guidelines (from Anderson and Olsen, 1986).

Group	Mercury Concentration in Fish (ug/g, wet)	Health Advice
1	<0.5	Anyone but pregnant women may eat unlimited quantities of these fish. Pregnant women should limit themselves to one meal per month of sport-caught fish from advisory-listed waters.
2	0.5	Pregnant women, nursing mothers, women of child-bearing age, and children under age 18 should not eat Group 2 fish. All other individuals may eat up to 26 meals per year of Group 2 fish but not more than one meal per day. These meals may be up to the rate of no more than 13 meals spread over 30 days and no more than 13 more meals during the following 11 months. Eating at this maximum rate for Group 2 fish excludes eating any Group 3 fish.
3	1.0	Pregnant women, nursing mothers, women of child-bearing age, and children under age 18 should not eat Group 3 fish. All other individuals may eat up to 13 meals per year with no more than 7 in a single month but only one meal per month after that until the remaining 6 meals are eaten. No more than 2 meals per week should be eaten. Eating at this maximum rate for Group 3 fish excludes eating any Group 2 fish.
4	>1.0	NO ONE SHOULD EAT GROUP 4 FISH.

Appendix VI. California mercury/fish consumption guidelines (from Stratton, *et al.*, 1987).

Mercury concentration in fish (ug/g, wet)	Exposure (dose) per meal[1] (ug Hg/kg)	Number of meals which would not exceed 12 ug/kg monthly intake[2]	Number of meals which would not exceed 3 ug/kg monthly intake[3]
2.0	6.0	2	0
1.5	4.5	2	0
1.3	3.9	3	0
1.0	3.0	4	1
0.9	2.7	4	1
0.8	2.4	5	1
0.7	2.1	5	1
0.6	1.8	6	1
0.5	1.5	8	2
0.4	1.2	10	2
0.3	0.9	13	3
0.2	0.6	20	5
0.1	0.3	40	10

[1]Consumption per meal is assumed to be 3 grams of fish/kg body weight for all ages (equivalent to an 8-oz. meal for a 70-kg man).

Example calculation: 1 ug/g = 1 ug Hg/gm fish
3 gm fish/kg body weight x 1 ug Hg/gm fish = 3 ug Hg/kg body weight

A meal that contained a dose of 3 ug Hg/kg body weight would represent 25% of the adult acceptable monthly intake of 12 ug/kg and 75% of the acceptable monthly intake during pregnancy. See footnotes 2 and 3 below.

[2]Based on the ADI of 0.4 ug/kg for age six and older, the acceptable monthly intake for this group would be 3.0 x 0.4 ug/kg or 12 ug/kg.

[3]Based on the ADI of 0.1 ug/kg for pregnant and lactating women and children under age 6, the acceptable monthly intake for this group would be 30 x 0.1 ug/kg or 3 ug/kg.

ichard J. Thompson
cting Secretary

STATE OF WASHINGTON

DEPARTMENT OF SOCIAL AND HEALTH SERVICES

Olympia, Washington 98504-0095

LD-11

February 6, 1989

TO: Bill Yake, Section Head
Toxics Investigation/Ground Water Monitoring
Department of Ecology
Mail Stop LH-14

FROM: J.S. Klingensmith, Ph.D.
Toxicologist
Toxic Substances Section

SUBJECT: POTENTIAL HEALTH CONCERNS ASSOCIATED WITH METHYLMERCURY LEVELS IN LAKE ROOSEVELT FISH

SUMMARY

* There is insufficient information available at this time to establish a statewide health advisory level for methylmercury in freshwater fish, and until additional data is available, each fishery should be evaluated on a case-by-case basis.

* The Department of Social and Health Services (DSHS) has concluded that methylmercury levels in fish below 0.5 ppm do not present a public health threat.

* Since methylmercury levels in fish sampled by Ecology from Lake Roosevelt were below 0.5 ppm, no health advisory is required at this time. However, DSHS recommends that additional data for methylmercury levels in fish be obtained to verify and extend previous sampling information.

The Washington State Department of Ecology has recently published a report entitled "An Assessment of Metals Contamination in Lake Roosevelt" (1988). This report revealed levels of mercury in fish which were within Food and Drug Administration (FDA) limits, but in one instance, close to advisory levels established by several states, Canadian provinces, and the National Academy of Sciences.

Because the State of Washington has not previously established a health advisory level for mercury contamination in freshwater fish, Ecology has requested a recommendation from DSHS.

Implementation of a statewide health advisory level or series of levels for methylmercury is a complex issue which will require the cooperative efforts of several state agencies. Mercury exposure levels from fish will depend upon species and age of fish, level of contamination, and frequency of consumption. A statewide advisory would require an extensive monitoring program to establish methylmercury levels in freshwater fish, catch and consumption data, and an effective communication process to inform the public of contamination levels in specific bodies of water.

There is also an additional public health issue to be resolved regarding the total amount of methylmercury to which the public is exposed from the consumption of seafood. Shrimp, lobster, crab, and commercial fish can contain significant methylmercury residues. Additional research to quantitatively evaluate total methylmercury exposures from different consumption patterns and sources could identify effective preventative measures. Ideally, a statewide advisory for mercury in freshwater fish would account for these additional exposures.

DSHS has evaluated this situation and believes that there is insufficient data at this time to develop a statewide health advisory for methylmercury levels in freshwater fish. Until a statewide advisory can be developed, health recommendations for Washington freshwater fisheries can only be proposed for specific bodies of water, based on information available at the time.

Based on a review of the toxicology literature and the activities of several regulatory authorities (principally FDA, Wisconsin, Michigan, and California), it appears that methylmercury exposure from fish consumption becomes a potential health concern at approximately 0.5 ppm. In the specific case of Lake Roosevelt, methylmercury levels measured by Ecology were generally comparable to the average levels found in the U.S. fish diet (0.3 ppm); no samples exceeded 0.4 ppm. Therefore, at the present time, the public can consume fish as desired.

However, DSHS does recommend that additional sampling of Lake Roosevelt fish for methylmercury levels be undertaken periodically. This recommendation is based on reports of methylmercury levels fish in excess of 0.5 ppm on the Canadian side of the lake and on limited sampling size of the most recent Ecology study.

JSK:mj

British Columbia — Ministry of Environment and Parks

Information Bulletin

Information Services Branch
Telephone: 387-9422
September 3, 1987

WALLEYE SITUATION CLARIFIED

The Ministry of Environment and Parks has provided additional information concerning recent reports of metal concentrations in Columbia River walleye.

While available information indicates that walleye are safe to eat, further studies are necessary to determine accurately the relationship of fish size to mercury concentration. In the meantime, it is suggested that walleye over two pounds be restricted to one meal per week.

Studies elsewhere have shown that large fish contain more metals than small fish of the same species, and that predator species such as walleye have the highest levels because their diet consists of other fish which have already concentrated metals in their tissues.

The Washington State Fish and Game Department has denied reports that it has posted walleye as unsafe for consumption. State enforcement staff have investigated these reports and have advised that the only known posting was an unauthorized handwritten notice.

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For further information, please contact: Rick Crozier, Environmental Section, Waste Management Branch, Ministry of Environment and Parks, Nelson, 354-6355.

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Appendix IX. Preliminary data provided by R. Crozier B.C. Ministry of Environment on metals concentrations in muscle tissue of upper Columbia River fish (ug/g, wet).

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
860707	BC/W	LSS	50.0	400		.13	.14	-.02	-.20	.54	.84	9.67	0011
860707	BC/W	LSS	46.5	1135	6	.14	.16	-.02	-.20	.52	.18	9.15	0015
860707	BC/W	LSS	48.5	1250	8	.10	.10	-.02	-.20	.57	.85	7.04	0012
860707	BC/W	LSS	54.0	1800	9	.15	.20	-.02	-.20	.59	.44	6.83	0014
860707	BC/W	LSS	48.0	050	6	.19	.18	.03	-.20	.51	.90	11.71	0013
870714	BC/W	LSS	51.0	1650		0.17							1513
870714	BC/W	LSS	51.0	1425		0.39							1504
870714	BC/W	LSS	47.0	1003		0.23							1505
870714	BC/W	LSS	51.0	1480		0.16							1514
870714	BC/W	LSS	47.0	1180		0.18							1508
870714	BC/W	LSS	49.0	1160		0.11							1500
870714	BC/W	LSS	48.0	1430		0.16							1509
870714	BC/W	LSS	49.0	1240		0.16							1501
870714	BC/W	LSS	49.0	1432		0.24							1511
870714	BC/W	LSS	49.5	1362		0.15							1503
870714	BC/W	LSS	45.0	1080		0.12							1510
870714	BC/W	LSS	50.5	1360		0.18							1512
870714	BC/W	LSS	50.5	1480		0.14							1507
870714	BC/W	LSS	47.5	1030		0.20							1502
870714	BC/W	LSS	47.0	1210		0.16							1506
860923	GIFF	LSS	495			.39							0001
860923	GIFF	LSS	470			.28							0005
860923	GIFF	LSS	445			.31							0006
860923	GIFF	LSS	453			.49							0003
860923	GIFF	LSS	472			.49							0004
860923	GIFF	LSS	473			.41							0007
860923	GIFF	LSS	491			.47							0002

LCN:BC/W=BEAVER CR TO WANETA;T/RI=TRAIL TO ROCK ISL;GIFF=GIFFORD POINT
USA;HKD=H KEENLEYSIDE DAM;CAST=CASTLEGAR;GEN=GENELLE;minus=less than
LENGTH=cm; Weight=gm; Age=yrs;

Appendix IX (continued)

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
860707	BC/W	MW	35.0	490	5	.10	.10	.03	-.20	.89	.14	5.12	0601
860707	BC/W	MW	32.5	450	5	.06	.06	-.02	-.20	.52	-.10	5.30	0606
860707	BC/W	MW	36.5	750	5	.18	.16	-.02	-.20	.49	-.10	5.88	0605
860707	BC/W	MW	35.0	450	5	.14	.13	.04	-.20	.55	.11	5.98	0020
860707	BC/W	MW	48.5	2300	7	.09	.08	-.02	-.20	.76	-.10	3.79	0609
860707	BC/W	MW	37.0	470	4	.10	.11	.05	-.20	.39	-.10	3.28	0018
870713	BC/W	MW	34.0	300		0.12							6846
870713	BC/W	MW	34.5	500		0.05							6844
870713	BC/W	MW	40.0	770		0.19							6832
870713	BC/W	MW	25.4	150		-.05							6841
870713	BC/W	MW	30.8	300		-.05							6840
870713	BC/W	MW	38.5	630		0.20							6830
870713	BC/W	MW	48.5	1080		0.20							6831
870713	BC/W	MW	37.5	612		0.13							6834
870713	BC/W	MW	38.0	540		0.19							6829
870713	BC/W	MW	34.0	622		0.07							6828
870713	BC/W	MW	39.5	710		0.22							6827
870713	BC/W	MW	36.6	400		0.21							6845
870713	BC/W	MW	36.5	400		0.13							6838
870713	BC/W	MW	27.0	200		-.05							6843
870713	BC/W	MW	37.0	540		0.19							6833
860708	T/RI	MW	35.0	500	5	.15	.15	.03	-.20	.47	-.10	6.02	0656
870713	BC/W	RBW	39.4	1000		0.05							6835
870713	BC/W	RBW	41.5	1000		0.06							6836
870713	BC/W	RBW	26.5	260		-.05							6826
870713	BC/W	RBW	50.0	1500		0.05							6847
870713	BC/W	RBW	53.0	1200		0.05							6848
870713	BC/W	RBW	42.0	900		0.05							6849

LCN:BC/W=BEAVER CR TO WANETA;T/RI=TRAIL TO ROCK ISL;GIFF=GIFFORD POINT USA;HKD=H KEENLEYSIDE DAM;CAST=CASTLEGAR;GEN=GENELLE;minus=less than
LENGTH=cm; Weight=gm; Age=yrs;

Appendix IX (continued)

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
860708	T/RI	LSS	50.0	1790	6	.15	.18	.02	-.20	.64	.73	10.73	0016
860708	T/RI	LSS	51.0	1420	5								
860708	T/RI	LSS	43.0	1150	4								
860708	T/RI	LSS	44.5	900	5	.15	.15	-.02	-.20	.97	1.65	13.24	0654
860708	T/RI	LSS	42.5	1010		.24	.21	-.02	-.20	.74	.37	8.00	0653
860708	T/RI	LSS	46.5	1110	6								
860708	T/RI	LSS	44.0	1010	10	.14	.18	-.02	-.20	.48	.79	8.68	0610
860708	T/RI	LSS	45.5	1060	5	.14	.15	-.02	-.20	.71	.17	8.81	0017
860708	T/RI	LSS	47.0	1240	7	.10	.11	-.02	-.20	.62	.34	8.05	0625
860708	T/RI	LSS	47.5	1240	7								
860708	T/RI	LSS	50.5	1450	8								
860708	T/RI	LSS	42.5	1000	5								
860708	T/RI	LSS	43.5	940	6	.16	.14	-.02	-.20	.47	.81	9.39	0624
860708	T/RI	LSS	41.0	950	5	.14	.15	.02	-.20	.81	.75	6.85	0623
860708	T/RI	LSS	49.0	1300									
860708	T/RI	LSS	49.5	1690	8								
860708	T/RI	LSS	44.0	1250	8								
860708	T/RI	LSS	47.0	1440	6	.15	.15	-.02	-.20	.52	.35	7.58	0621
860708	T/RI	LSS	50.5	1650	7	.17	.17	-.02	-.20	.57	-.10	6.01	0611
860708	T/RI	LSS	47.5	1290									
860708	T/RI	LSS	42.5	1040	6	.08	.08	-.02	-.20	.67	.33	8.52	0655
860707	BC/W	MW	35.5	680	5	.10	.11	-.02	-.20	.96	-.10	5.51	0602
860707	BC/W	MW	34.0	400	6	.14	.16	.03	.27	2.53	.29	37.32	0608
860707	BC/W	MW	38.0	560	6	.18	.16	.02	-.20	.63	-.10	5.67	0603
860707	BC/W	MW	30.0	500	4	-.05	.04	-.02	-.20	.53	-.10	6.56	0604
860707	BC/W	MW	37.0	690	5	.12	.09	-.02	-.20	.52	-.10	6.38	0600
860707	BC/W	MW	40.0	650	7	.11	.13	-.02	-.20	1.34	.12	6.42	0607
860707	BC/W	MW	35.5	710	5	.10	.10	.02	-.20	.41	-.10	7.21	0019

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USA;HKD=H KEENLEYSIDE DAM;CAST=CASTLEGAR;GEN=GENELLE;minus=less than
LENGTH=cm; Weight=gm; Age=yrs;

Appendix IX (continued)

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
860707	BC/W	LSS	50.0	400		.13	.14	-.02	-.20	.54	.84	9.67	0011
860707	BC/W	LSS	46.5	1135	6	.14	.16	-.02	-.20	.52	.18	9.15	0015
860707	BC/W	LSS	48.5	1250	8	.10	.10	-.02	-.20	.57	.85	7.04	0012
860707	BC/W	LSS	54.0	1800	9	.15	.20	-.02	-.20	.59	.44	6.83	0014
860707	BC/W	LSS	48.0	050	6	.19	.18	.03	-.20	.51	.90	11.71	0013
870714	BC/W	LSS	51.0	1650		0.17							1513
870714	BC/W	LSS	51.0	1425		0.39							1504
870714	BC/W	LSS	47.0	1003		0.23							1505
870714	BC/W	LSS	51.0	1480		0.16							1514
870714	BC/W	LSS	47.0	1180		0.18							1508
870714	BC/W	LSS	49.0	1160		0.11							1500
870714	BC/W	LSS	48.0	1430		0.16							1509
870714	BC/W	LSS	49.0	1240		0.16							1501
870714	BC/W	LSS	49.0	1432		0.24							1511
870714	BC/W	LSS	49.5	1362		0.15							1503
870714	BC/W	LSS	45.0	1080		0.12							1510
870714	BC/W	LSS	50.5	1360		0.18							1512
870714	BC/W	LSS	50.5	1480		0.14							1507
870714	BC/W	LSS	47.5	1030		0.20							1502
870714	BC/W	LSS	47.0	1210		0.16							1506
860923	GIFF	LSS	495			.39							0001
860923	GIFF	LSS	470			.28							0005
860923	GIFF	LSS	445			.31							0006
860923	GIFF	LSS	453			.49							0003
860923	GIFF	LSS	472			.49							0004
860923	GIFF	LSS	473			.41							0007
860923	GIFF	LSS	491			.47							0002

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LENGTH=cm; Weight=gm; Age=yrs;

Appendix IX (continued)

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
870713	BC/W	RBW	43.5	1200		-.05							6837
860713	BC/W	STR				.16							
870411	BC/W	STR	178	36200		0.69							
860707	BC/W	WAL	36.5	500	3	.31	.30	-.02	-.20	.28	-.10	5.19	0001
860707	BC/W	WAL	36.0	400	3	.40	.34	-.02	-.20	.21	-.10	4.79	0009
860707	BC/W	WAL	41.0	750	3	.20	.20	-.02	-.20	.40	-.10	4.84	0003
860707	BC/W	WAL	34.5	435	2	.20	.20	-.02	-.20	.25	-.10	3.96	0010
860707	BC/W	WAL	36.0	430	3	.21	.26	-.02	-.20	.29	-.10	4.01	0002
860707	BC/W	WAL	43.0	750	4	.55	.60	-.02	-.20	-.20	-.10	3.79	0006
860707	BC/W	WAL	43.5	980	5	.21	.25	-.02	-.20	.41	-.10	6.17	0004
860707	BC/W	WAL	46.5	1050	4	.76	.71	-.02	-.20	.35	-.10	4.63	0000
860707	BC/W	WAL	47.0	990	4	.50	.41	-.02	-.20	.22	-.10	5.53	0005
860707	BC/W	WAL	38.0	570	3	.27	.27	-.02	-.20	.24	-.10	3.93	0004
860707	BC/W	WAL	44.5	1030	4	.34	.33	-.02	-.20	-.20	-.10	4.08	0008
870713	BC/W	WAL	37.0	470	3	0.31							6628
870713	BC/W	WAL	28.5	230	2	0.07							6638
870713	BC/W	WAL	33.5	410	2	0.27							6627
870713	BC/W	WAL	34.3	200	2	0.25							6842
870713	BC/W	WAL	32.5	340	2	0.23							6636
870713	BC/W	WAL	37.0	440	3	0.33							6633
870713	BC/W	WAL	34.0	350	2	0.14							6632
870713	BC/W	WAL	35.0	390	2	0.38							6634
870713	BC/W	WAL	37.0	470	3	0.36							6631
870713	BC/W	WAL	31.0	290	2	0.26							6639
870713	BC/W	WAL	34.0	310	3	0.29							6626
870713	BC/W	WAL	33.0	270	3	0.32							6629
870713	BC/W	WAL	35.5	500	3	0.21							6635
870713	BC/W	WAL	35.2	400	3	0.34							6839

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LENGTH=cm; Weight=gm; Age=yrs;

Appendix IX (continued)

COLUMBIA RIVER NEAR TRAIL/CASTLEGAR 1986-87 FISH TISSUE ANALYSIS

Date	Loc	Spc	Length	Weight	Age	Hg-Prov	Hg-Fed	Cd	Cr	Cu	Pb	Zn	Fish#
870713	BC/W	WAL	33.0	360	2	0.17							6630
870713	BC/W	WAL	27.5	230	2	0.17							6637
870826	BC/W	WAL	43.0	800	6	0.39							
870827	BC/W	WAL	39.0	576	4	0.39							
870910	BC/W	WAL	53.0	1788	8	0.21							
870913	BC/W	WAL	48.0	602	6	0.21							
870824	CAST	WAL	39.0	607	4	0.44							
870824	CAST	WAL	41.0	859	5	0.19							
870824	CAST	WAL	43.5	854	5	0.42							
870915	CAST	WAL	46.0	851	5	0.61							
870924	CAST	WAL	55.4	2031	8	0.35							
870929	CAST	WAL	59.0	2867	9	0.47							
871008	CAST	WAL	56.0	2341	8	0.33							
871004	GEN	WAL	42.5	831	5	0.26							
860812	HKD	WAL				.24							0001
860812	HKD	WAL				.54							0002
870726	HKD	WAL	45.0	985	7	0.37							
870820	HKD	WAL	43.5	801	6	0.29							
870821	HKD	WAL	440	921	7	0.29							
870910	HKD	WAL	47.0	1160	7	0.38							
870911	HKD	WAL	44.0	845	4	0.31							
870913	HKD	WAL	48.5	1192	6	0.22							
870913	HKD	WAL	54.0	1825	7	0.44							
870920	HKD	WAL	41.0	706	6	1.02							
870920	HKD	WAL	42.0	779	5	0.30							

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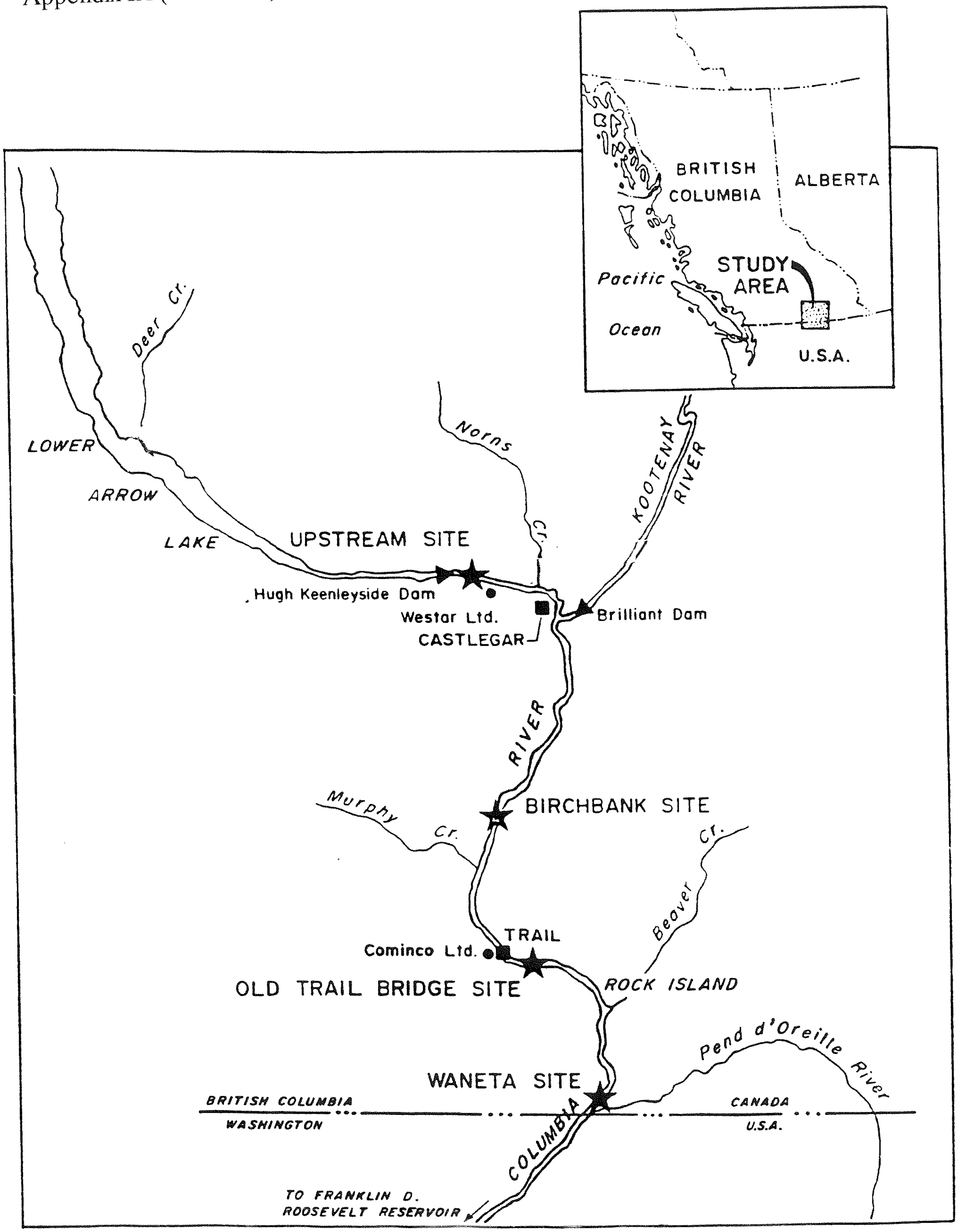
Appendix IX (continued)



Ministry of Environment fish collection locations in the Columbia River Basin, Columbia (from Smith, 1987). (★)