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TO: Carl Nuechterlein

FROM: Art Johnson A.J.

SUBJECT: Review of Metals, Bioassay, and Macroinvertebrate Data from Lake Roosevelt Benthic Samples Collected in 1989

BACKGROUND

The Department of Ecology's initial survey of metals in Lake Roosevelt was conducted in 1986. As described in the survey reports (Johnson *et al.*, 1988, 1990), discharges by the Cominco lead-zinc smelter in Trail, B.C., and to a lesser extent, historical mining and smelting in the Northport - Kettle Falls area and in the Coeur d'Alene drainage have resulted in contamination of the lake.

During August 14-17, 1989, six of the sites sampled in 1986 were re-sampled to better assess the potential for metals-induced toxicity. Dioxin and furan contamination of the lake had not been verified at the time. Approximate locations of the 1986 and 1989 sampling sites are shown in Figure 1.

Table 1 shows the type of samples collected and analyses performed. Measurements were expanded from those conducted in 1986 to include three additional bioassays (*Daphnia magna* elutriate, Microtox® and *Chironomus tetans*), analysis of metals in sediment pore water, ammonia and total sulfides in sediment, and benthic macroinvertebrate abundance and diversity. Because the Ecology Manchester Laboratory ultimately found it impossible to maintain healthy populations of *Chironomus*, this bioassay could not be completed. Different analytical methods were also employed in 1989 to achieve lower detection limits in water and measure total metals concentrations in water and sediment. Previously collected data were from a total recoverable analysis of water and a strong acid (partial) digestion of sediment, methods commonly employed in environmental surveys of this type.

Due to limited funding, sample size for this survey was small. In spite of the expanded analytical scheme, the data obtained provide limited insight as to whether or not adverse

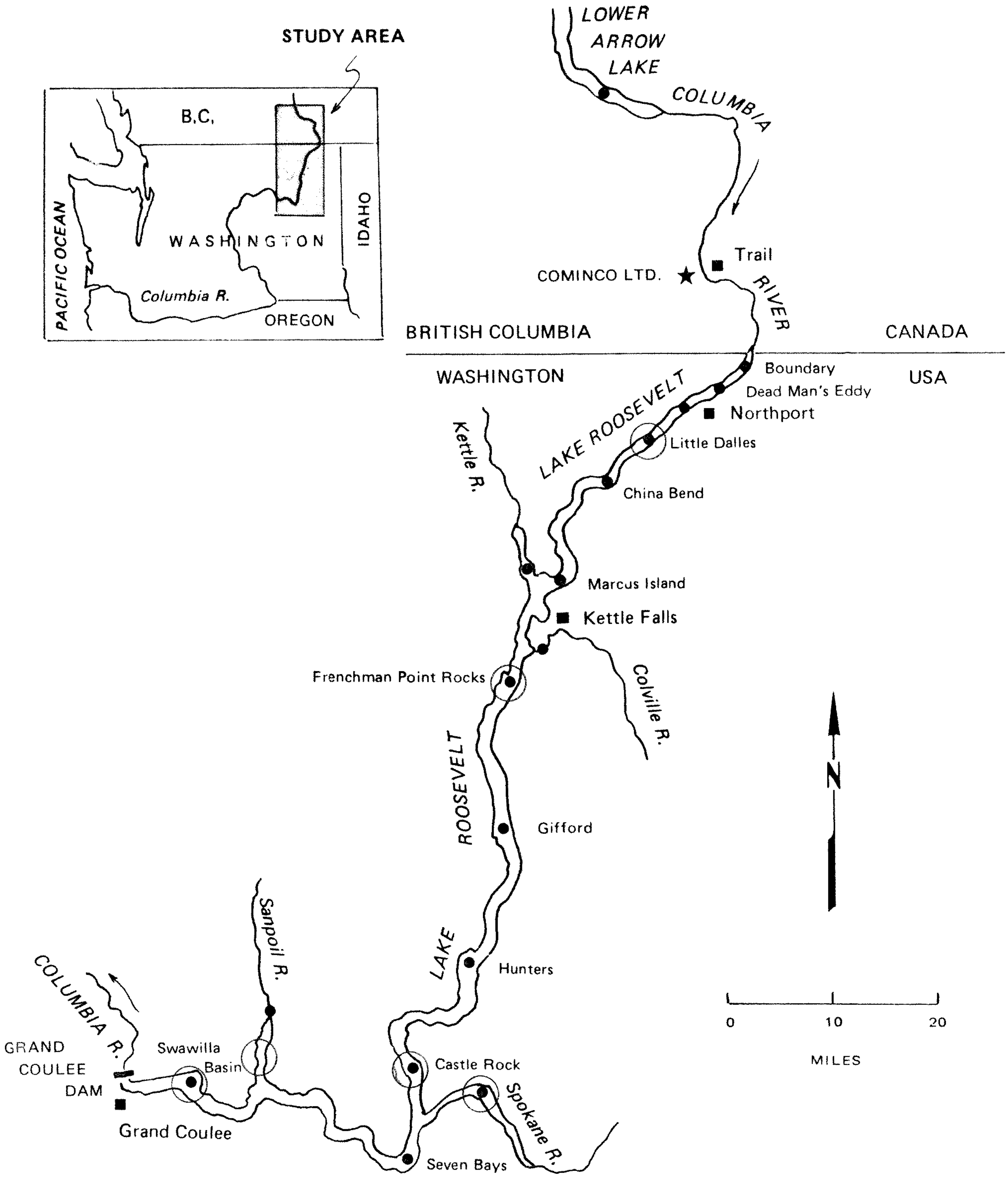

Figure 1. Lake Roosevelt showing sampling sites in 1986 (●) and 1989 (○).

Table 1. Plan of Analysis.

Analysis	No. Replicates per Site	Sample Type: Sediment	Pore Water	Bottom Water
Grain size	1	X		
TOC	1	X		
T. sulfides	1	X		
Ammonia	1	X		
Al	1*	X		
Fe	1	X		
Mn	1	X		
Zn	1	X	X	X
Cu	1	X	X	X
Pb	1	X	X	X
As	1	X	X	X
Cd	1	X	X	X
Hg	1	X	X	X
Hyalella bioassay	5	X		
Daphnia " (solids)	5	X		
Daphnia " (elutriate)	5	X		
Chironomus bioassay	5	X		
Microtox "	3	X		
Macroinvertebrate enumeration	5	X		
Temperature	1			X
pH	1			X
D.O.	1			X
Specific conductivity	1			X
Hardness	1		X	X
TSS	1			X

* All metals in sediment samples analyzed by both a total and a strong acid (partial) digestion.

biological effects are occurring in the lake. Obtaining answers to these questions will be one of the objectives of the Phase I workplan currently being developed for Lake Roosevelt by USGS.

A summary of findings and recommendations from review of the 1989 data are given below. A more detailed discussion of the data is provided in the remainder of the report.

SUMMARY OF FINDINGS

1. Metals concentrations measured in 1989 sediment samples were similar to those of the 1986 survey (strong acid digestion method).

2. A total metals analysis of the sediments showed data based on a strong acid digestion underestimate concentrations of Al, Fe, Mn, Zn, and Hg.

3. Based on recently published Canadian guidelines, the level of metals contamination in Lake Roosevelt sediments would be expected to be detrimental to benthic organisms. Bioavailibility of metals in Lake Roosevelt sediments may differ from that on which these guidelines are based.

4. Sediment pore water may contain toxic concentrations of several metals.

5. Analysis of metals in bottom water samples showed concentrations to be low, consistent with results of the 1986 survey.

6. Sediment bioassays showed some evidence of toxicity at several sites, but there were few correlations with metals concentrations. The results suggest Microtox® may be an indicator of Cd toxicity.

7. Diversity and abundance of benthic macroinvertebrates did not appear unusually low in the few samples analyzed.

RECOMMENDATIONS FOR PHASE I

1. Because several equally valid methods exist for obtaining data on metal concentrations in sediment and water, sampling and analytical methods for metals should be specified and a rationale provided for their selection.

2. Sediment pore water should be analyzed for metals and hardness. Pore water extraction should use currently accepted protocols.

3. Pore water bioassays should be considered for evaluating sediment toxicity.

4. *Hyalella* and *Daphnia* appear relatively tolerant of Lake Roosevelt sediments. A wider range of sensitive freshwater sediment bioassays are currently available than when Ecology's 1986 and 1989 surveys were conducted and should be considered in lieu of, or in addition to, *Hyalella* and *Daphnia* (see Blaise, 1991).

5. Microtox® should be included among the bioassays conducted.

6. The data so far obtained suggest metals concentrations in the lake water column are generally low. Therefore, efforts to quantify metals concentrations in water should focus on adequate monitoring to detect water quality violations at Northport and obtaining data needed to assess potential for release of metals from sediments to overlying waters.

7. The health of the benthic macroinvertebrate community needs to adequately assessed.

METHODS

Sampling

Sediment sampling sites were selected to be of comparable depth (approximately 80 feet) in an attempt to improve comparability of results for benthic macroinvertebrates. In the upper river, fine sediments could not be located in water this deep. After trying several different sites, upriver sediments were ultimately collected in 40 feet of water at Little Dalles.

Sediment samples were collected with a 0.1 m^2 van Veen grab (chemical analysis and bioassays) or 0.05 m^2 Ponar grab (benthic macroinvertebrate samples). At each sampling site, the surface 2-cm layer from five separate grabs was composited for analysis of grain size, total organic carbon, ammonia, metals, and bioassays. A subsample of the initial grab from this series was analyzed for total sulfides. Samples of the 2-cm surface layer from a separate set of four grabs were removed for extraction of pore water. Five benthic macroinvertebrate samples were obtained at each site by screening (0.5 μm) the total contents of five grabs made with the Ponar.

To minimize exposure to air, sediment for pore water extraction and total sulfides samples were collected immediately after surface water was drained from the grab, by quickly filling sample containers and leaving no headspace; containers were glass with teflon lid liners (I-Chem series 300). Compositing and subsampling techniques for other chemical analyses are described in Johnson *et al.*, (1988).

Water samples were collected approximately 1 meter off the bottom with a 10 liter, teflon-coated Go-Flo bottle using Kevlar/polyester line and a teflon-coated messenger. Sample containers were one liter teflon bottles previously cleaned with reagent grade HNO_3 and rinsed with deionized water. High purity HCl was added in the field as preservative.

All sediment and water samples were kept on ice in the field. Benthic invertebrate samples were preserved in ethyl alcohol.

Analysis

Analytical methods are given in Table 2. Pore water was extracted by centrifuging the sediment, filtering the supernatant (1 μm glass fiber), and fixing as other water samples. Elutriates for *Daphnia* bioassay were prepared by mixing a 1:4 ratio of sediment and water for 30 minutes, letting settle overnight, and decanting the elutriate for bioassay. Details of other analyses are provided in the method references.

DATA QUALITY

The accuracy of metals analyses on sediment and water samples was evaluated using standard reference materials (Table 3). Good agreement was achieved with certified values except for results obtained using the strong acid digestion of sediment. Because this method does not completely dissolve crustal materials, it underestimates the total concentrations of less soluble metals such as Al, Fe, Mn, and Zn.

The precision of the data reported here can be gauged by results on field-prepared splits of a composite sediment sample (Table 4) and replicate grabs of water samples (Table 5). Most sediment analyses agreed within 20%. The erratic results reported for total sulfides preclude further use of this data.

Results on replicate water samples also agreed well except for Hg. In addition to poor precision, analysis of a field blank showed some Hg contamination. The blank, consisting of a rinsate of the Go-Flo bottle with blank water, contained 0.009 μg/L of Hg. Hg concentrations lower than the field blank were measured in Lake Roosevelt bottom water samples (<0.001 to 0.006 μg/L). In light of these problems, all Hg concentrations in bottom water are reported as <0.01 μg/L.

Detailed descriptions of the procedures used for the bioassays were prepared by the Manchester Laboratory (Stinson, 1989a,b; Wade, 1989a,b). These include all pertinent information supporting the quality of the data.

RESULTS AND DISCUSSION

Comparison with 1986 Sediment Data

Table 6 compares the concentrations of metals and ancillary variables measured in sediment samples collected in 1986 and 1989 (strong acid digestion). The 1989 samples were collected

Table 2. Analytical Methods.

Analysis	Method	Reference	Laboratory
	Sediment Samples		
Grain size	Seive & pipette	Plumb (1981)	AmTest, Inc., Seattle, WA
TOC	Dorhman DC80 furnace	Tetra Tech, Inc. (1986)	Analytical Resources, Inc., Seattle, WA
T. Sulfides	Spectrophotometer	Tetra Tech, Inc. (1986)	Analytical Resources, Inc., Seattle, WA
Ammonia	KCl extraction	Plumb (1981)	Analytical Resources, Inc., Seattle, WA
Al,Fe,Mn,Zu,Cu Pb,As (total)	X-ray fluorescence	Nielsen & Sanders (1983)	Battelle Marine Research Laboratory, Sequim, WA
Cd (total)	GFAA	Rantala & Loring (1975)	Battelle Marine Research Laboratory, Sequim, WA
Hg (total)	CVAA	Bloom & Crecelius (1987)	Battelle Marine Research Laboratory, Sequim, WA
Al,Fe,Mn,Zn,Cu,Pb, As,Cd (strong acid digestion)	FAA or GFAA	EPA Method 3050	Battelle Marine Research Laboratory, Sequim, WA
Hg (strong acid digestion)	CVAA	EPA Method 3050	Battelle Marine Research Laboratory, Sequim, WA
Bioassays:			
Hyalella azteca	10-day survival	Nebeker et al., (1984)	Ecology/EPA Laboratory, Manchester, WA
Daphnia magna	2-day survival	Nebeker et al., (1984)	Ecology/EPA Laboratory, Manchester, WA
Microtox	light output @ 15 min.	Tetra Tech, Inc. (1986)	Ecology/EPA Laboratory, Manchester, WA
Macroinvertebrate enumeration	0.5 μm sieve	-----	EVS Consultants, Seattle, WA
	Water Samples		
Zn (total)	GFAA	EPA Method 200.9	Battelle Marine Research Laboratory, Sequim, WA
Pb,Cu,Cd (total)	GFAA	Bloom & Crecelius (1984)	Battelle Marine Research Laboratory, Sequim, WA
Hg (total)	CVAA	Bloom & Crecelius (1983)	Battelle Marine Research Laboratory, Sequim, WA
Temperature	precision thermometer	-----	field measurement
D.O.	Iodometric-azide	Standard Methods 4500-0	field measurement
pH	meter	EPA Method 150.1	Ecology/EPA Laboratory, Manchester, WA
Specific conductivity	meter	EPA Method 120.1	Ecology/EPA Laboratory, Manchester, WA
Hardness	titration	EPA Method 130.2	Ecology/EPA Laboratory, Manchester, WA
TSS	gravimetric	EPA Method 160.2	Ecology/EPA Laboratory, Manchester, WA

Table 3. Analysis of Standard Reference Materials.

Standard Reference Material	Replicate No.	Al (%)	Fe (%)	Mn	Zn	Cu	Pb	As	Cd	Hg
				SEDIMENT (mg/kg, total metal)						
NBS Buffalo	1	6.9	4.22	562	453	101	159	22.5	3.58	1.40
River Sediment	2	6.6	4.19	603	451	98	153	27.0	3.51	1.40
(SRM-2704)	3	-	-	-	-	-	-	-	3.44	1.37
Certified value =		6.1	4.11	555	438	98.6	161	23.4	3.45	1.44
NBS Estuarine	1	6.4	4.82	448	746	401	402	171	-	-
Sediment	2	5.8	4.76	490	722	400	408	158	-	-
(SRM-1645)										
Certified value =		6.4	4.87	490	824	452	404	211	2.38	4.57
NRCC Marine	1	6.4	3.46	395	125	20.5	26	14.1	0.32	-
Harbour Sediment	2	6.9	3.46	361	127	20.5	24	14.8	0.33	-
(PACS-1)										
Certified value =		6.2	3.35	375	138	18	28	11.6	0.36	0.063
				SEDIMENT (mg/kg, strong acid (partial) digestion)						
NRCC Estuarine	1	0.91	0.69	303	105	24.9	29	9.0	0.69	0.161
Sediment	2	0.91	0.71	324	100	25.7	30	8.5	0.66	0.183
(MESS-1)										
Certified value =		5.83	3.05	513	191	25.1	34	10.6	0.59	0.171
				WATER (μg/L, total metal)						
NBS Trace	1	-	-	-	69	18.0	27	71	10.2	33*
Elements in Water	2	-	-	-	66	17.7	28	77	10.5	-
(SRM-1643)	3	-	-	-	66	17.7	28	79	10.5	-
Certified value =		-	-	-	72	18	27	76	10	30*
NRCC River	1	-	-	-	-	-	-	-	<0.042	-
Water	2	-	-	-	-	-	-	-	<0.042	-
(SLRS-1)										
Certified value =		-	-	-	-	-	-	-	0.015	-

* NBS SRM - 1641b, mercury in water (ng/L)

Table 4. Precision of Sediment Data.

Location:	French Pt. Rocks			Coefficient of Variation*
Split No.:	1	2	3	(%)
Fines (% ≤ 63μm)	88.9	88.6	90.3	0.8
TOC (%)	20.9	21.0	20.5	1.2
T. Sulfides (mg/kg)	44.9	123.5	86.6	46
Ammonia (NH3-N, mg/kg)	258.7	298.9	254.8	9.0
Al (%, total metal)	6.6	6.3	7.9	12
Fe " " "	4.24	4.17	4.30	1.6
Mn (mg/kg, total metal)	820	781	787	2.6
Zn " " " "	1173	1145	1209	2.7
Cu " " " "	154	141	162	7.0
Pb " " " "	539	526	557	2.9
As " " " "	15.1	16.7	21.2	18
Cd " " " "	13	13	13	0
Hg " " " "	2.12	2.01	2.08	2.9
Al (%, strong acid digestion)	1.5	1.4	1.4	4.2
Fe " " " "	1.0	1.1	0.98	5.8
Mn (mg/kg, strong acid digestion)	592	585	529	6.1
Zn " " " " "	470	564	510	9.2
Cu " " " " "	150	155	149	2.1
Pb " " " " "	528	528	528	0
As " " " " "	12.2	12.2	11.6	2.9
Cd " " " " "	12	13	12	4.7
Hg " " " " "	1.80	1.48	1.70	9.6

* standard deviation as percent of mean

Table 5. Precision of Bottom Water Data.

Location:	French Pt. Rocks			Little Dalles		
Grab No.:	1	2	RPD	1	2	RPD
Temperature (°C)	18.3	18.3	0	18.8	18.8	0
pH (S.U.)	7.8	7.8	0	7.8	7.8	0
Spec. Cond. (μmhos/cm)	136	136	0	163	140	15
D.O. (mg/L)	9.2	9.1	1.1	9.6	9.4	2.1
TSS "	2	3	40	5	4	22
Hardness (mg/L as CaCO3)	69	66	4.4	84	67	22
Zn (μg/L)	1.6	1.4	13	2.4	1.8	2.9
Cu "	1.3	1.3	0	1.8	1.6	12
Pb "	1.6	1.4	13	2.8	3.5	22
As "	<0.95	<0.95	ND	<0.95	<0.95	ND
Cd "	0.048	0.072	40	0.17	0.17	0
Hg "	0.0004	0.005	170	0.009	0.003	100

RPD = Relative Percent Difference; range as percent of duplicate mean
ND = not detected.

in shallower water in order to compare benthic invertebrate communities. Differences in sampling depth may be the reason for the large discrepancy in results for Little Dalles where sample depth was considerably different between the two years. Both years data, however, are consistent in indicating that (due to the presence of slag) much higher Zn and Cu concentrations exist at Little Dalles than the other sites. With few significant exceptions, the remaining sites show reasonable-to-good agreement between the two data sets, considering differences in sampling location, time period, and laboratory doing the analyses.

Total Metal Concentrations in Sediments

The 1989 metals data from the strong acid digestion of sediment samples are compared in Table 7 to results of a total metals analysis. As already demonstrated for standard reference materials, the strong acid digestion underestimates concentrations of Al, Fe, Mn, and Zn. Analysis of Lake Roosevelt sediment samples by both methods additionally shows a strong acid digestion can substantially underestimate the amount of Hg present.

Sediment Guidelines for Metals

Ecology does not have freshwater sediment criteria, but is in the process of developing them (Bennett and Cubbage, 1991). EPA Region V and, more recently, the Ontario Ministry of Environment have advanced guidelines for chemical contaminants in freshwater sediments (EPA, 1977; Persaud *et al.*, 1991). The purpose of the EPA guidelines was to classify Great Lakes harbor sediments for open water dredge disposal. The Canadian criteria are intended to provide guidance on sediment issues ranging from prevention to remedial action.

The EPA guidelines class sediments as non-polluted, moderately polluted, or heavily polluted, based on EPA's assessment of natural background. The Canadian guidelines consist of a no-effect level (organic compounds only), a lowest effect level, and a severe effect level. These were derived from field data on chemical concentrations in sediment and associated benthic invertebrate communities. Sediment contaminated at the lowest effect level was found to be tolerated by 95% of benthic organisms; contamination at the severe effect level was found to be detrimental to 95% of benthic species.

The guidelines for metals are compared in Table 8 to the range of concentrations measured in Lake Roosevelt sediments collected in 1989 (strong acid data). These ranges generally encompass findings of the larger 1986 survey. Data for the Sanpoil River Arm, an uncontaminated region of the lake, were excluded. As can be seen from the table, by EPA guidelines Lake Roosevelt sediments are moderately to heavily polluted -- generally the latter -- by Fe, Mn, Zn, Cu, Pb, As, Cd, and Hg. Adverse effects of benthic organisms due to Mn, Zn, Cu, Pb, Cd, and Hg would be predicted to occur at one or more of the 1989 sampling sites, based on Canadian guidelines. The latter characterization of Lake Roosevelt sediments should be used with the understanding that the bioavailability of metals from Lake Roosevelt sediments may be less than sites used to develop the guidelines.

Table 6. Comparison of 1989/1986 Sediment Analyses (strong acid digestion).

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm
River Mile:	728.1/728.1	692.2/692.2	644.8/644.8	604.9/604.9	7.8/7.8	3.9/10.7
Depth (ft.):	40/82	87/92	80/125	80/135	80/110	80/40
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.
Fines (% ≤ 63μm)	5.8/2.9	89.3/94.7	95.8/89.3	84.2/79.98	86.4/89.85	96.4/86.26
TOC (%)	0.29/6.0	2.08/3.5	0.81/2.7	1.04/1.5	1.84/3.8	1.15/3.3
Ammonia (NH_3-N, mg/kg)	27.8/NA	271/NA	114/NA	188/NA	250/NA	78.1/NA
Al (%)	0.8/2.6	1.4/1.7	1.6/2.1	2.1/2.7	2.2/3.2	1.7/2.0
Fe (%)	2.7/24.8	1.0/3.3	1.1/3.5	1.0/3.3	1.1/3.6	0.9/2.3
Mn (mg/kg)	1610/4370	569/550	1800/790	2000/1320	1300/1040	613/370
Zn "	4870/21,420	515/1090	188/954	242/757	671/1540	142/100
Cu "	964/3420	151/165	61/67	49/65	45/53	38/34
Pb "	452/294	528/434	236/349	165/206	125/128	32/10
As "	16.4/27.8	12.0/8.7	16.7/10.4	12.6/7.6	14.8/11.5	6.2/4.1
Cd "	5.3/1.4	12/5.7	5.7/5.5	6.9/5.2	11/5.6	2.7/0.7
Hg "	0.46/0.02	1.66/2.0	0.56/1.0	0.13/1.0	0.11/0.16	0.05/0.04

NA = not analyzed

Table 7. Comparison of Total and Strong Acid Digestion of Sediment.

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9
Depth (ft.):	40	87	80	80	80	80
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.
Al (%)	7.8/0.8*	6.9/1.4	7.9/1.6	7.9/2.1	8.8/2.2	7.1/1.7
Fe (%)	11.2/2.7	4.2/1.0	4.3/1.1	4.3/1.0	4.4/1.1	4.0/0.9
Mn (mg/kg)	2160/1610	796/569	2100/1800	2280/2000	1460/1300	746/613
Zn "	7000/4870	1180/515	539/188	702/242	1480/671	263/142
Cu "	1040/964	152/151	62/61	57/49	42/45	39/38
Pb "	335/452	541/528	251/236	195/165	139/125	43/32
As "	19.6/16.4	17.7/12.0	14.3/16.7	13.8/12.6	19.0/14.8	7.9/6.2
Cd "	4.3/5.3	13/12	6.4/5.7	7.2/6.9	13/11	2.2/2.7
Hg "	0.62/0.46	2.07/1.66	1.05/0.56	0.78/0.13	0.16/0.11	0.11/0.05

* Total/Strong Acid

Table 8. Sediment Quality Guidelines Compared to Metals Concentrations in Lake Roosevelt (mg/kg, dry).

	EPA Sediment Guidelines		Lake Roosevelt Sediments	
Metal	Moderately Polluted	Heavily Polluted	Range of 1989 Samples*	Characterization as per Guidelines
Al (%)	-	-	0.8 - 2.2	-
Fe (%)	1.7 - 2.5	>2.5	1.0 - 2.7	moderately to heavily polluted
Mn	300 - 500	>500	569 - 2000	heavily polluted
Zn	90 - 200	>200	188 - 4870	" "
Cu	25 - 50	>50	45 - 964	" "
Pb	40 - 60	>60	125 - 452	" "
As	3 - 8	>8	12.0 - 16.7	" "
Cd	-	>6	5.3 - 12	" "
Hg	-	>1	0.11 - 1.66	heavily polluted at maximum value

	Canadian Sediment Guidelines		Lake Roosevelt Sediments	
Metal	Lowest Effect Level	Severe Effect Level	Range of 1989 Samples	No. Sites Approaching or Exceeding Severe Effect Level
Al (%)	-	-	0.8 - 2.1	-
Fe (%)	2	4	1.0 - 2.7	0 of 5
Mn	460	1100	569 - 2000	4 of 5
Zn	120	820	188 - 4870	3 of 5
Cu	16	110	49 - 964	2 of 5
Pb	31	250	125 - 452	4 of 5
As	6	33	12.0 - 16.7	0 of 5
Cd	0.6	10	5.3 - 12	5 of 5
Hg	0.2	2	0.11 - 1.66	1 of 5

* Strong acid (partial) digestion; Sanpoil River Arm (background area) data excluded

Metals in Pore Water

Moderately- to highly-elevated concentrations of several metals were measured in sediment pore water. As shown in Table 9, EPA water quality criteria for protection of aquatic life under conditions of chronic exposure were consistently exceeded for Pb (all sites) and Hg (all sites except Spokane Arm). Pore water from Little Dalles and French Point Rocks tended to have the higher metals concentrations, with EPA chronic water quality criteria also being exceeded for Cd and Zn (Little Dalles only).

The procedures for obtaining sediment and extracting pore water did not preclude changes occurring in the equilibrium between metals associated with sediment particles and in solution. Therefore, these results should not be taken as conclusive evidence that toxic conditions exist *in situ*. It should further be noted that the EPA chronic criteria for Hg is not based on aquatic toxicity but, rather, is designed to protect human health by theoretically preventing levels of Hg in edible fish tissue from exceeding the FDA action level of 1 ppm. Its application to pore water is questionable.

Metals in Bottom Water

Table 10 shows the metal concentrations measured in bottom water samples. The higher concentrations tended to occur in the upper lake. All concentrations, however, were well within EPA water quality criteria. Similar results were obtained for bottom water samples analyzed from other parts of Lake Roosevelt during 1986.

Violations of EPA water quality criteria for metals (primarily Cd and Hg) in Lake Roosevelt have so far only been documented in the upper reaches at the USGS/NASQAN station at Northport (Johnson *et al.*, 1988). Because limited numbers of water samples have been analyzed below Northport, the downstream extent and frequency of water quality violations are not known.

Sediment Bioassays

Results of the sediment bioassays conducted in 1989 are summarized in Table 11. None of the samples appeared to be extremely toxic, and where some toxicity was indicated, there were inconsistencies in patterns within and between sites. Lack of agreement among bioassays employing different species and end points, as in this survey, is not uncommon.

At four of the six sampling sites, survival of *Hyalella* and *Daphnia* exposed to bulk sediment was high. Both bioassays showed significantly reduced survival on exposure to Castle Rock and Swawilla Basin sediments. *Daphnia* maintained in elutriates prepared from the Castle Rock and Swawilla Basin sediments, as well as other sites, had uniformly high survival relative to the control, suggesting the amounts of metals (or other toxic constituents) released from the sediments during elutriate preparation were low.

Table 9. Sediment Pore Water Data.

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9
Depth (ft.):	40	87	80	80	80	80
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.
Hardness (mg/L as CaC03)	224	343	234	213	157	177
Zn (μg/L)	645(232)**	116	38	59	90	24
Cu "	22	16	6.0	3.1	3.7	4.5
Pb "	490(228)**	294(15)*	41(9.4)*	34(8.3)*	18(5.6)*	15(6.6)*
As "	7.6	19	20	13	53	25
Cd "	3.6(2.1)*	3.4(3.0)*	1.7	1.4	1.4	0.65
Hg "	0.51(.012)*	0.036(.012)*	0.063(.012)*	0.038(.012)*	0.004	0.023(.012)*

* > EPA chronic criteria (criteria shown in parenthesis, adjusted for hardness)

** > EPA acute criteria (criteria shown in parenthesis, adjusted for hardness)

Table 10. Bottom Water Data.

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm	
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9	
Depth (ft.):	40	87	80	80	80	80	Field
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.	Blank
Temperature (°C)	18.8	18.3	19.8	20.1	18.1	21.1	-
pH (S.U.)	7.8	7.8	7.5	7.4	7.2	7.6	-
Spec. conduct. (μmhos/cm)	152	136	137	132	118	182	-
D.O. (mg/L)	9.5	9.2	7.7	8.8	6.0	6.4	-
TSS "	4	2	1	2	1	<1	-
Hardness (mg/L as CaC03)	76	68	71	73	59	90	-
Zn (μg/L)	2.1	1.5	1.9	0.6	4.2	0.7	0.03
Cu "	1.7	1.3	<0.9	<0.9	<0.9	1.3	<0.9
Pb "	3.2	1.5	<0.6	<0.6	<0.6	0.7	<0.6
As "	<1.0	<1.0	<1.0	<1.0	<1.0	<0.1	<1.0
Cd "	0.17	0.03	<0.04	<0.04	<0.04	<0.04	<0.04
Hg "	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.009

Sediment from French Point Rocks and the Spokane Arm elicited a toxic response in the Microtox® bioassay. Other sites were not toxic by this test.

Hyalella and *Daphnia* bioassays were also conducted on Lake Roosevelt sediments in 1986 but at different sites. The results, however, are of questionable value due to technical problems encountered in conducting the tests.

Benthic Macroinvertebrates

The results of identification and enumeration of benthic macroinvertebrates are summarized in terms of abundance (mean number of organisms per grab) and diversity in Table 12. Diversity is expressed as Shannon's H; the term H'/H'max is a normalized Shannon, with a value of 1 being the most diversity possible. Table 13 contains the detailed data for individual taxa.

Interpretation of the data is complicated by the very different habitat conditions that exist at these sites with respect to temperature, currents, substrate, and in other ways. In general, the abundance and diversity of macroinvertebrates in these samples appeared typical of a lake. Large numbers of chironomids (midge larvae) were found in Little Dalles sediments compared to sites further downstream. This may be due to the course grain size of the Little Dalles sediments which would maintain high oxygen concentrations (Plotnikoff, personal communication).

Relation of Sediment Chemistry to Bioassays & Macroinvertebrates

The results of sediment bioassays and the abundance and diversity of macroinvertebrates were examined for correlations with sediment and pore water chemistry (Spearman's rank-correlation coefficient). For the most part little correlation was found. Among the four bioassays conducted, only Microtox® showed a correlation with metals concentrations. Microtox® light output was inversely correlated with Cd concentrations in bulk sediment and As concentrations in pore water (correlation coefficient of -0.83 in both cases). Judging by the relatively low As concentrations in pore water, the relationship between Microtox® and Cd is the more plausible correlation.

A number of strong positive correlations (0.81 to 0.98) were found between abundance of macroinvertebrates and Fe, Zn, Cu, Pb, and Hg in bulk sediment and/or pore water. This, however, can be largely attributed to the overriding influence of a single site, Little Dalles, because of the large numbers of midge larvae. No strong correlations were evident between diversity of macroinvertebrates and sediment or pore water chemistry.

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Table 11. Sediment Bioassays.

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm	Lab Control
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9	-
Depth (ft.):	40	87	80	80	80	80	-
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.	-
Hyalella (mean % survival, n = 5 replicates @ 20 animals each)	88	90	80*	70*	86	90	96
Daphnia (mean % survival, n = 5 replicates @ 20 animals each)							
Solid phase:	100	100	73*	92*	99	96	99
Elutriate:	84	86	88	90	98	78	96
Microtox (EC-50, n = 3)	>100	77	>100	>100	57	>100	-

* Significantly different from control

Table 12. Summary of Benthic Macroinvertebrate Data.

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9
Depth (ft.):	40	87	80	80	80	80
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.
Abundance (mean no. organisms per grab)	780.0	64.8	48.0	94.6	87.8	154.6
Diversity						
Shannons H'	1.42	3.11	2.88	1.92	2.74	2.15
H'/H' max	0.37	0.84	0.80	0.61	0.74	0.62
Total Taxa	14	13	12	9	13	11
% Chironomids	96.6	61.4	25.8	18.0	39.2	16.7

Table 13. Benthic Macroinvertebrate Community (mean of five grabs).

Location:	Little Dalles	French Pt. Rocks	Castle Rock	Swawilla Basin	Spokane River Arm	Sanpoil River Arm
River Mile:	728.1	692.2	644.8	604.9	7.8	3.9
Depth (ft.):	40	87	80	80	80	80
Sampling Date (1989):	16 Aug.	16 Aug.	15 Aug.	17 Aug.	15 Aug.	14 Aug.
Phylum Cnidaria						
Class Hydrozoa						
Hydra	9.3	1.8	2.2	1.4	0.6	0
Phylum Nematoda	2.3	1.4	11.6	57.4	1.4	3.8
Phylum Mollusca						
Class Pelecypoda						
Family Sphaeridae	0.3	0.2	3.4	3.6	18	71.2
Phylum Annelidae						
Class Oligochaeta	0.3	11.2	14.4	11.6	23.6	41.2
Class Hirudinea						
Helobdella (elongata?)	0	0	0	0	2.2	0
Phylum Arthropoda						
Class Crustacea						
Order Ostracoda	7.3	0	0	0	0	0
Order Eubranchiopoda	0.3	5.2	0	0	0	0.2
Order Copepoda	5.0	1.6	2	3	6.2	9.2
Order Isopoda						
Asellus occidentalis	0	0	0	0	0.6	0
Class Insecta						
Order Ephemoptera						
Ephemerella inermis	0	0	0	0	0	0.2
Order Diptera						
Family Ceratopogonidae	0.3	0.2	0.6	0	0	1
Family Chiromidae						
Chironomus	478.0	2.2	4.8	4.2	8.2	3.2
Cryptochironomus	3.0	0	0	0	0	0
Micropsectra	243.3	20.6	0.6	0.8	2.2	1.8
Potthastia gaedii group	0	3.8	0.4	0	1.2	0
Trissopelopia	28.3	9.4	5.6	12	22	20.4
Family Empididae						
Hemerodromia	0	0	0	0	0.2	0
Order Trichoptera						
Family Leptoceridae						
Oecetis	0	3	1	0	0	0.8
Family Hydropsychidae						
Hydropsyche	0.3	0	0	0	0	0
Class Arachnida						
Acari	0.7	0.4	0.4	0.6	0.6	1.4

REFERENCES

Bennett, J. and J. Cubbage. 1991. Summary of Criteria and Guidelines for Contaminated Freshwater Sediments. Washington State Department Ecology, Olympia.

Blaise, C. 1991. Microbiotests in Aquatic Ecotoxicology: Characteristics, Utility, and Prospects. Environ. Toxicol. Water Qual. 6, 145-155.

Bloom, N.S. and E.A. Crecelius. 1983. Determination of Mercury in Seawater at Sub-nanogram per Liter Levels. Marine Chem. 14:49-59.

------, and E.A. Crecelius. 1984. Determination of Silver in Seawater by Co-precipitation with Cobalt Pyrrolidine dithiocarbamate and Zeeman Graphite-furnace Atomic Absorption Spectrometry. Acta Chimica Acta 156:139-145.

------, and E.A. Crecelius. 1987. Distribution of Silver, Mercury, Lead, Copper, and Cadmium in Central Puget Sound Sediments. Marine Chem. 21:377-390.

EPA. 1977. Guidelines for the Pollutional Classification of Great Lake Harbor Sediments. EPA Region V.

Johnson, A., D. Norton, and B. Yake. 1988. An Assessment of Metals Contamination in Lake Roosevelt. Washington State Department of Ecology, Olympia.

Johnson, A., D. Norton, B. Yake, and S. Twiss. 1990. Transboundary Metals Pollution of the Columbia River (Franklin D. Roosevelt Lake). Bull. Environ. Contam. Toxicol. 45:703-710.

Nebeker, A.V., M.A. Cairns, J.H. Gakstatter, K.W. Maleug, G.S. Schuytema and D.F. Krawczyk. 1984. Biological Methods for Determining Toxicity of Contaminated Freshwater Sediments to Invertebrates. Environ. Toxicol. Chem. 3:617-630.

Nielson, K.K. and R.W. Sanders. 1983. Multi-element Analysis of Unweighed Biological and Geological Samples using Backscatter and Fundamental Parameters. Adv. X-Ray Anal. 26:385-390.

Persaud, D. *et al.* 1991. The Provincial Sediment Quality Guidelines. Water Res. Branch, Ontario Ministry of Environment.

Plum, R.H. 1981. Procedures for Handling and Chemical Analysis of Sediment and Water Samples. Tech. Rept. EPA/CE-81.1. U.S. Army Corps of Engineers, Vicksburg, MS.

Rantala, R.T. and D.H. Loring. 1975. Multi-element Analysis of Silicate Rocks and Marine Sediments by Atomic Absorption Spectrometry. At. Absorpt. Newslet. 14(5):1-4

Stinson, M. 1989a. Lake Roosevelt Sediment Study: Results of *Hyalella azteca* Bioassay. Memorandum to A. Johnson, Washington State Department of Ecology, Manchester Laboratory.

-----. 1989b. Lake Roosevelt Sediment Study: Results of Microtox® Bioassay. Memorandum to A. Johnson, Washington State Department of Ecology, Manchester Laboratory.

Tetra Tech, Inc. 1986. Recommended Protocols for Measuring Selected Environmental Variables in Puget Sound. *for* U.S. EPA Region 10 and the U.S. Army Corps of Engineers.

Wade, B. 1989a. Lake Roosevelt Sediment Study: Results of Solid Phase Bioassay Using *Daphnia magna.* Memorandum to A. Johnson, Washington State Department of Ecology, Manchester Laboratory.

-----. 1989b. Lake Roosevelt Sediment Study: Results of Elutriate Bioassay Using *Daphnia magna.* Memorandum to A. Johnson, Washington State Department of Ecology, Manchester Laboratory.

AJ:kd

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