94-e24

Attachment

DEPARTMENT OF ECOLOGY

July 11, 1994

To: Carl Nuechterlein
Eastern Regional Office

From: Dale Davis and Dave Serdar
EILS Program

Subject: Corrections to Spokane River PCB Data

With the release of our study report entitled **Results of 1993 Screening Survey on PCBs and Metals in the Spokane River** we began preparing for follow-up investigations on PCB contamination in the Spokane River. As part of this preparation we reviewed PCB data collected from the river and potential sources during earlier studies and monitoring efforts. During this review we found an apparent anomaly. The results of the 1993 study reported Arochlors 1242, 1254 and 1260; while earlier reports showed 1248, 1254, and 1260.

To investigate this discrepancy, we requested a review of the 1993 data by analysts at the Manchester Environmental Laboratory (MEL). On June 24 we received a memorandum ("Correction to Analytical Results for the Spokane River PCB Fish and Sediment Study") and revised data sheets from Dick Huntamer. A copy of Huntamer's memorandum is attached.

Tables 1 and 2 summarize the corrected data. While contamination previously identified as Arochlor 1242 has been changed to Arochlor 1248, the "total PCB" concentrations of each sample remain largely unchanged. Other general changes reflected in the latest data report are:

- Most of the reported concentrations of PCB 1248 and 1254 are now "J" qualified. This means that these concentrations are estimated.
- Some quantitation limits have been increased.
- For a few samples, reported concentrations of specific PCBs changed slightly.

These changes do not affect either the overall spatial pattern of PCB contamination previously reported or the health implications of the data. The corrections should help in the identification of potential historical or continuing sources.

DD:DS:gd
Attachments

cc: Lynn Singleton
Bill Yake
Larry Goldstein
Dick Huntamer
Pat Hallinan
Ron Langley

Ecology Data on PCBs in Spokane River Fish Collected July - August 1993 (ug/Kg (ppb) wet weight)

Location	Species	Sample Type	PCB-1242	PCB-1248	PCB-1254	PCB-1260	Total PCBs
Spokane Arm (FDR Lake)	Walleye	Fillet	8.8 U	8.8 U	15	8.8 U	15
	Smallmouth Bass	Fillet	7.1 U	20 U	28 J	7.1 U	28 J
	Kokanee	Fillet	50 U	50 U	70 J	22	92 J
	Largescale Sucker	Whole	31 U	200 J	250 J	190	640 J
Long Lake	Crayfish	Fillet	17 U	17 U	17 U	17 U	ND
	Yellow Perch	Fillet	7.1 U	10 U	9.2 J	7.1 U	9.2 J
	(duplicate analysis)	Fillet	6.8 U	10 U	9.6 J	6.8 U	9.6 J
	Largemouth Bass	Fillet	15 U	45 U	74 J	23	97 J
	Mountain Whitefish	Fillet	34 U	200 J	410 J	170	780 J
	Largescale Sucker	Whole	33 U	100 J	180 J	130	410 J
Above Nine Mile Falls Dam	Rainbow trout (sm)	Fillet	36 U	200 J	210 J	64	474 J
	Rainbow Trout (lg)	Fillet	31 U	200 J	240 J	65	505 J
	Mountain Whitefish	Fillet	40 U	200 J	280 J	42	522 J
	Largescale Sucker	Whole	35 U	400 J	600 J	210	1210 J
Above Upriver Dam	Rainbow trout (sm)	Fillet	78 U	400 J	550 J	78 U	950 J
	Rainbow Trout (lg)	Fillet	44 U	400 J	610 J	74	1084 J
	Largescale Sucker	Whole	37 U	800 J	1800 J	180	2780 J
	(duplicate analysis)	Whole	35 U	800 J	1800 J	170	2770 J
Above Post Falls Dam (Idaho)	Largescale Sucker	Whole	28 U	28 U	55	41	96

U = not detected at or above reported value
J = estmated concentration

MANCHESTER ENVIRONMENTAL LABORATORY

7411 Beach Drive E , Port Orchard Washington 98366

June 23, 1994

To: Lynn Singleton
Art Johnson

From: Dickey D. Huntamer

Subject: Corrections to analytical results for the Spokane River PCB fish and sediment study.

The attached are corrections to the previous data reported for the Spokane River Screening Survey. Due to the nature of PCB analysis the presence of more than one PCB mixture can present problems in identification and subsequent quantitation. There were a number of Arochlor's commercially produced. These were usually identified by a number such as 1242, 1254, 1260, etc. where the last two digits refer to the average percent chlorination. The mixtures are composed of numerous congeners which overlap with the next Arochlor mixture. When a sample contains only one Arochlor, there is usually no problem in identification and quantitation unless the sample is highly weathered. When two or more Arochlors are present, the situation becomes more complicated, but if the ranges of the two Arochlors do not overlap, then the two components can usually be calculated.

When the two ranges overlap, that is the back end of the first Arochlor overlaps with the front end of the second Arochlor, then interpretation becomes more difficult. The presence of a third Arochlor adds even more complexity to the problem. It is under these circumstances that mis-identification can occur and calculations become difficult.

The sediment and fish samples from the Spokane project were initially interpreted as having two components, Arochlors 1242 and 1254. This interpretation was carried through the rest of the samples and the results were calculated based on the presence of two components. Additional information indicated that Arochlor 1248 was also present, which can in reality be an average of Arochlor 1242 and 1254. This triggered a reexamination of the data to determine which samples have Arochlor 1248 and to determine how much.

The review established that Arochlor 1248 was indeed present in some of the tissue and sediment samples. The results for those samples in which Arochlor 1248 was found were estimated. This resulted in changes to the quantitations reported for the following samples.

Data Corrections to Spokane River Fish Tissue Samples

Sample ID	AROCHLOR 1242	1248	1254	1260
93-318240	nd	detected	J added	nc
93-318241	nd	detected	J added	nc
93-318242	nd	detected	J added	nc
93-318243	nd	detected	J added	nc
93-318243D	nd	detected	J added	nc
93-318244	nc	nc	nc	nc
93-318245	nc	nc	nc	nc
93-318246	U raised	U raised	J added	nc
93-318247	U raised	U raised	J added	nc
93-318248	nc	nc	nc	nc
93-318249	U raised	U raised	J added	nc
93-318250	changed to nd	detected	J added	nc
93-318251	nc	U raised	J added	nc
93-318251D	nc	U raised	J added	nc
93-318252	changed to nd	detected	J added	nc
93-318253	changed to nd	detected	J added	nc
93-318254	changed to nd	detected	J added	nc
93-318255	changed to nd	detected	J added	nc
93-318256	changed to nd	detected	J added	nc
93-318257	nc	nc	J added	nc
93-318258	nc	nc	J added	nc

nd = not detected,
nc = no changes

cc Robert Rieck - EPA
Norm Olson
Bill Kammin

RESULTS OF 1993 SCREENING SURVEY ON PCBS AND METALS IN THE SPOKANE RIVER

by
Art Johnson
Dave Serdar
Dale Davis
April 27, 1994

Washington State Department of Ecology
Environmental Investigations and Laboratory Services Program
Toxics, Compliance and Ground Water Investigations Section
Olympia, WA 98504-7710

Water Body No. WA-54-1010, WA-54-1020, WA-57-1010

ABSTRACT

Composite samples of sediment, whole largescale suckers (a bottom-feeding fish), and sport fish fillets were collected from five reaches of the Spokane River between Lake Coeur d'Alene and the Columbia River (Lake Roosevelt) during July-August 1993. The samples were analyzed for polychlorinated biphenyls (PCBs) and selected metals. The objective of this screening survey was to determine if levels of these contaminants were a significant environmental concern requiring more intensive sampling or other action.

Significant contamination by PCBs, zinc, lead, and cadmium was found. Follow-up sampling is recommended to identify PCB sources and evaluate potential sediment toxicity. The Washington State Department of Health is currently reviewing the data with regard to human health implications. Further analysis of the fish tissue samples is being conducted for planar PCBs, which are specific, toxic components of some PCB mixtures.

SUMMARY OF FINDINGS

High concentrations of PCBs were detected in sediment, whole fish, and fillet samples from the upper Spokane River. There was a clear trend toward increasing PCB concentrations moving from the lower river (Spokane Arm of Lake Roosevelt) to the reach above Upriver Dam; PCB concentrations then dropped to low levels above Post Falls Dam in Idaho (see Figures 1 and 2). Concentrations of total PCBs behind Upriver Dam were 3,200 parts per billion (ppb) in sediment, 2,775 ppb in whole largescale suckers, and 1,000-1,124 ppb in rainbow trout fillets. By way of comparison, PCB results for the Spokane Arm were 13.8 ppb in sediment, 630 ppb in whole fish, and 15-92 ppb in walleye, smallmouth bass, and kokanee fillets.

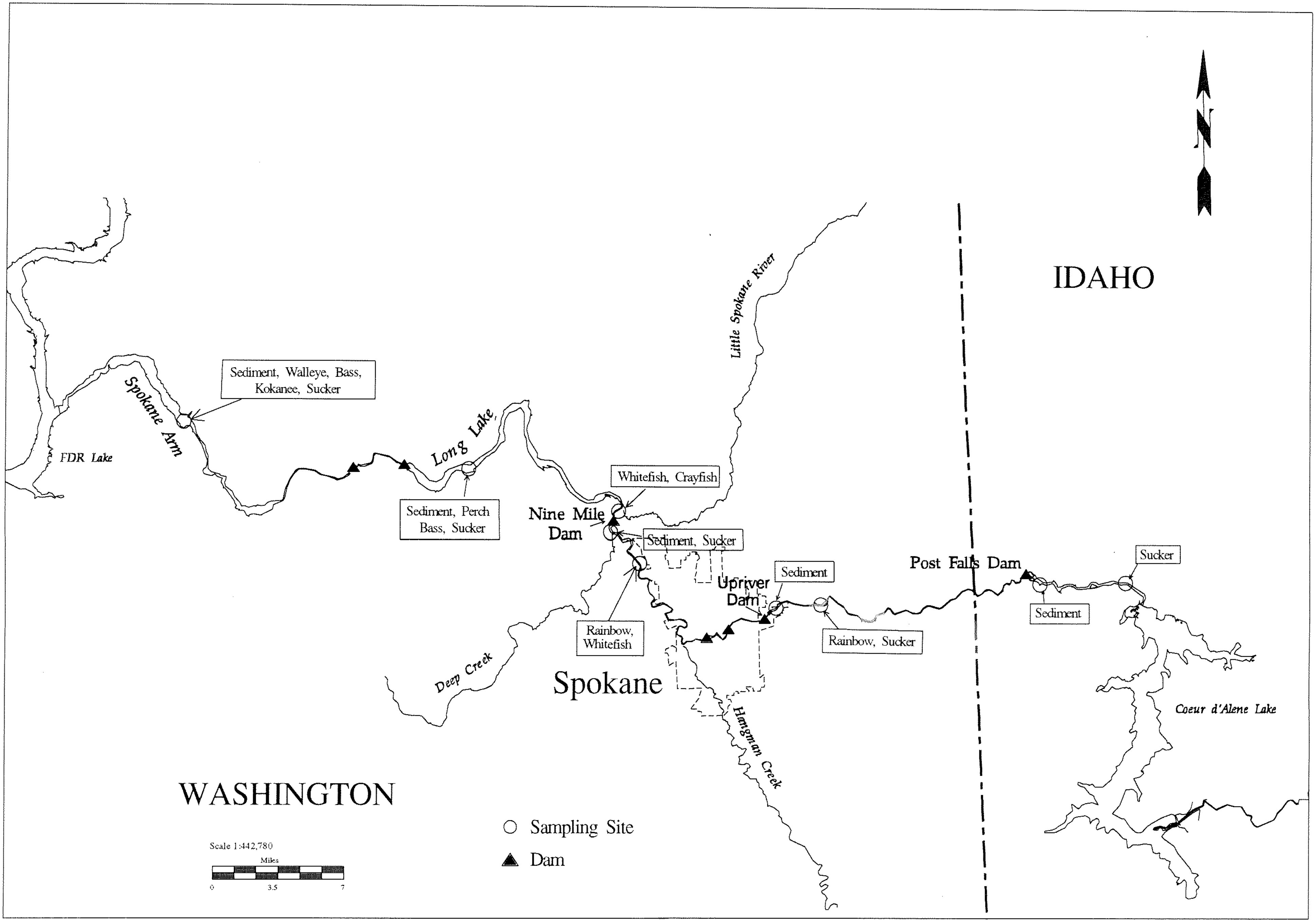

Figure 1. Location of Ecology 1993 Spokane River Sediment and Fish Samples

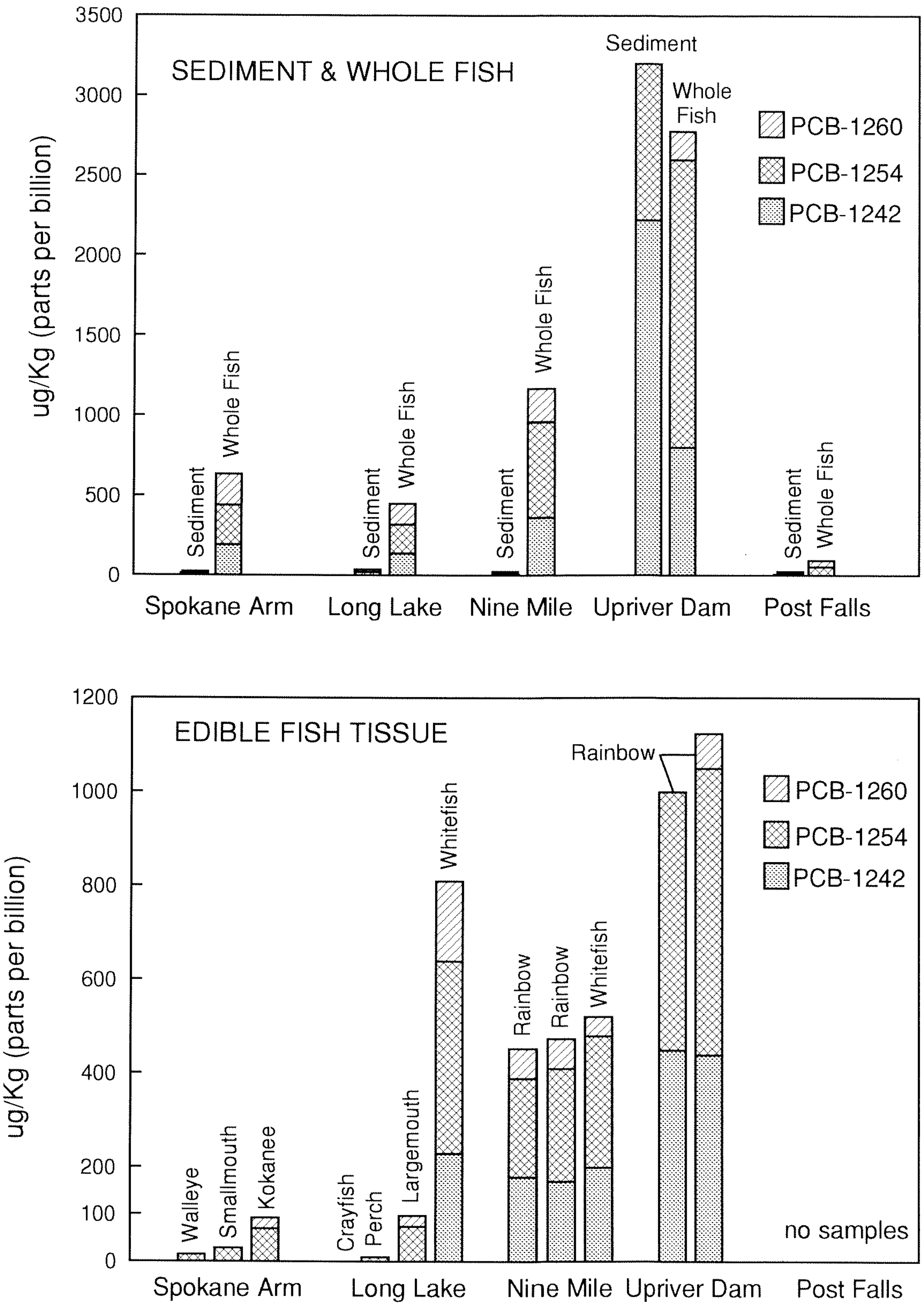

Figure 2. PCBs in Spokane River Fish and Sediment Samples

These findings indicate a major input of PCBs has occurred between Upriver Dam and Post Falls. The detection of high concentrations of PCB-1242 may furnish a clue to the source, as this mixture is less frequently detected in local waters than -1254 or -1260, the other types of PCBs detected in Spokane River sediments and fish.

Most sediment and whole fish samples also had high concentrations of zinc, lead, and cadmium. Metals concentrations were near detection limits in the majority of fillet samples. No one section of the river clearly stood out as being the most contaminated. The predominant source of elevated zinc, lead, and cadmium in the Spokane is known to be historical mining and smelting in the Coeur d'Alene drainage in Idaho.

The area above Upriver Dam had maximum or near maximum levels of metals contamination: zinc, lead, and cadmium concentrations were 3,990, 605, and 33 parts per million (ppm), respectively, in sediment and 65, 2.6, and 0.25 ppm in whole fish. Fillets from rainbow trout collected at this site had elevated lead concentrations of 0.49-0.75 ppm compared to 0.059 ppm or less in fillets collected elsewhere. This is the only instance where metals concentrations were found to be a possible concern in edible fish tissue. No efforts were made to collect sport fish samples in Idaho.

The survey results were compared to available criteria and guidelines for protecting aquatic life, wildlife, and human health. Major conclusions are summarized below. The reader should be aware that these conclusions are based on limited numbers of samples, as described later in the main body of this report.

- Sediment concentrations of zinc and cadmium at all sites, except behind Nine Mile Dam, exceeded or approached levels shown to result in severe effects to sediment-dwelling organisms. Severe effects due to lead would be predicted to occur based on sediment samples above Upriver Dam, Post Falls Dam, and, to a lesser degree, in Long Lake.

- Although relatively low metals concentrations were found in the Nine Mile sediment sample, results on other samples suggest there are probably sediments in this reach that would not support a normal benthic community because of elevated metals.

- Concentrations of PCBs in the sediment sample above Upriver Dam exceeded soil cleanup levels in the Model Toxics Control Act (MTCA).

- Lead concentrations in sediment samples above Upriver Dam and Post Falls Dam exceeded MTCA soil cleanup levels. Cadmium concentrations exceeded cleanup levels at all sites except the Nine Mile Dam sample.

- Total PCB concentrations in whole fish samples above Nine Mile and Upriver Dams substantially exceeded levels recommended to protect aquatic life and fish-eating birds and mammals. Concentrations in fillet samples suggest other fish species in this reach of the river would also exceed these recommendations when analyzed whole.

- Zinc, lead, and cadmium concentrations in Spokane River whole fish samples are high for U.S. freshwater fishes but the biological significance of this finding is uncertain.

- Concentrations of total PCBs in fillet samples, especially those from rainbow trout and mountain whitefish, were of sufficient magnitude to warrant a review of the data by the Washington State Department of Health. Lead concentrations in upper river rainbow trout should also be considered in this review.

- Zinc and cadmium do not appear to be a health concern for people eating Spokane River fish.

- The Spokane River from its confluence with the Columbia River (Lake Roosevelt) to the Idaho border qualifies for listing as water quality limited for PCBs, zinc, lead, and cadmium under Section 303(d) of the Clean Water Act.

RECOMMENDATIONS

1) Review historical information on use and discharge of PCBs by known or suspected sources to the Spokane River between Upriver Dam and Post Falls, paying particular attention to use of PCB-1242.

2) Conduct field inspections of likely sources of significance, collecting samples for PCB analysis as appropriate.

3) Screen for PCBs in sediment samples from the mouths of drains, ditches, and creeks along the Spokane River between Upriver Dam and Post Falls Dam. Conduct follow-up source-tracing as appropriate.

4) Where feasible, analyze additional bottom sediment samples to better delineate the area of concern for PCBs.

5) Survey PCB and lead concentrations in beach soils at popular swimming areas above Upriver Dam.

6) Conduct bioassays and evaluate the benthic community to determine if metal concentrations in Spokane River sediments are indeed toxic.

7) Coordinate with EPA and the State of Idaho on ways to reduce release of zinc, lead, and cadmium to the Spokane River via the Coeur d'Alene drainage.

8) Activities that re-suspend contaminated sediments, especially those behind Upriver Dam, should be minimized.

BACKGROUND

In response to a request from the Ecology Eastern Regional Office, Environmental Investigations and Laboratory Services (EILS) conducted a survey of the Spokane River during July and August of 1993 to obtain data on PCB and metal concentrations in bottom sediments and fish. Elevated PCBs had been reported sporadically in the river's fish since the early 1980's (Hopkins *et al.*, 1985; Johnson, 1991). Historical mining and related activities in the Coeur d'Alene River drainage contaminated the Spokane with zinc and other metals (Mink *et al.*, 1971; Yake, 1979).

Because the data available on these contaminants were either limited to very few samples and/or from older studies, there was a need to do a current assessment of the river. The objective of this survey was to determine if the levels of PCBs or metals were a significant concern for aquatic life, wildlife and human health. The effort was intended as a screening survey, with recommendations to be made for more intensive follow-up sampling or other action if warranted.

No water sampling was done for PCBs as their low solubility makes detection difficult. Data on zinc, copper, lead, cadmium, and mercury concentrations in Spokane River water were recently obtained as part of a separate Ecology study (Pelletier, 1994-in prep.).

SAMPLE COLLECTION AND ANALYSIS

Samples were collected from five reaches of the river (Figure 1): in the Spokane River Arm of Lake Roosevelt (Columbia River); in Long Lake; behind Nine Mile Dam; behind Upriver Dam; and in Idaho between Post Falls Dam and Lake Coeur d'Alene. Samples were not collected in parts of the river running through downtown Spokane due to lack of boat access.

Because this was a screening rather than intensive survey, the number of samples collected in each area was limited to one each for sediment and whole fish, and skin-on fillets from two-to-four species of sport fish. With one exception noted below, all samples were composites.

Sediment was collected with a stainless steel 0.05 m^2 Ponar sampler. Each sample consisted of the top 2-cm surface layer from five separate grabs. Sediment sampling sites are described in Appendix A.

Fish were caught by gill net, fyke net, or electrofishing. An effort was made to obtain four-to-five fish for each composite. Appendix B shows the number of fish per composite and their length and weight.

The whole fish samples were largescale suckers, a bottom-feeding species that occurs throughout the river. Suckers were analyzed whole to compare with recommendations for protecting fish-eating aquatic life and wildlife, and to supplement the information obtained from sediment samples. Only one largescale sucker could be collected for the whole fish sample above Post Falls.

Selection of sport fish species was based on recommendations by the Washington State Department of Wildlife (Hisata, 1993). The species analyzed were walleye, kokanee, smallmouth bass, largemouth bass, and yellow perch in the lower river; and mountain whitefish and rainbow trout in the upper river. A sample of crayfish was also obtained from Long Lake courtesy of a local citizen. No attempt was made to collect sport fish in Idaho.

The largest specimens encountered were taken for fillet samples, with rainbow trout being analyzed in two size classes. At the time of the survey, the only size limits in effect were a 16-20 inch slot limit for walleye in the Spokane Arm and a 12 inch limit for rainbow trout above Upriver Dam (Hisata, 1993). The walleye collected in the Spokane Arm were only 12-13 inches long (308-328 mm, Appendix B). Three of the eight rainbow trout analyzed above Upriver Dam were in the 9 1/2-11 inch range (240-285 mm).

The samples were analyzed at the Ecology/EPA Manchester Environmental Laboratory. Sediment and fish were analyzed for PCB -1016, -1221, -1232, -1242, -1248, -1254, and -1260[1]. Metals analyzed included the 13 EPA priority pollutant metals (sediment samples); zinc, copper, lead, cadmium, and mercury (whole fish samples); and lead, cadmium, and mercury (fillet samples). Metals analyzed in fish were selected for their bioaccumulation potential and toxicity (Callahan *et al.*, 1979; Gough *et al.*, 1979). Some additional analysis of zinc in fillets was done at the option of the laboratory.

Ancillary analyses included grain size and total organic carbon in sediment, and percent lipid (fat) in fish tissue. Because PCBs are lipophilic, their uptake by fish is generally proportional to lipid content (Kenaga and Goring, 1980). Comparisons of PCB concentrations between samples can be improved by lipid-normalizing the data, thereby removing the effect of differences in lipid content between samples.

Based on the PCB results, five fish tissue samples were selected for analysis of mono- and coplanar PCBs. Some toxic effects of PCBs are thought to be largely due to certain of these compounds (Huckins *et al.*, 1988). Results of this analysis are expected by the end of April 1994.

Except for low recovery of antimony in sediment, no significant problems were encountered in the analyses conducted for this survey. Quality assurance reviews of analytical results by Manchester Laboratory staff (Huntamer 1993a, 1993b, 1994; Kammin, 1993; McIntosh, 1994) demonstrate that the data reported here are accurate. Details of sample preparation, chemical analyses, and quality assurance are provided in Appendix C.

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[1]PCBs are mixtures of chlorinated biphenyls. Except for PCB-1016 (which retains the designation given during its development), the first two digits of the formulation number are for the 12 carbon atoms in the biphenyl molecule (two 6-carbon rings). The second two digits represent the average chlorine content by weight (e.g., PCB-1254 contains 54% chlorine, on average).

Table 1. PCB Concentrations in Spokane River Sediments (ug/Kg (ppb) dry weight)

Location	% Fines	% TOC	PCB-1242	PCB-1254	PCB-1260	Total PCBs
Spokane Arm (FDR Lake)	67	1.8	3.4 U	8.5	5.3	13.8
Long Lake	98	3.9	4.6 U	20	18	38
Above Nine Mile Dam	6	1.8	1.8 U	3.1	3.0	6.1
Above Upriver Dam	34	11	2220	980	140 U	3200
Above Post Falls (Idaho)	26	2.7	3.1 U	6.8	12.0	18.8

Fines = silt + clay (<62 um)
TOC = total organic carbon
U = not detected at or above reported value

RESULTS & DISCUSSION

I. PCBs

Concentrations - Results from analysis of Spokane River sediments are shown in Table 1. Samples from the Spokane Arm and Long Lake consisted of finer material (silt and clay fractions) than in the upper river where the samples were mostly sand. Above Upriver Dam and at Post Falls it was difficult to locate fine sediments indicative of a depositional environment. The sediments collected above Upriver Dam had a high TOC content of 11% relative to 1.8-3.9% at other sites.

Low concentrations of PCB-1254 and -1260, 3.1-20 parts per billion (ppb), were detected in sediments from Spokane Arm, Long Lake, above Nine Mile Dam and above Post Falls Dam. High concentrations of PCB-1242 and -1254, 2,220 and 980 ppb, respectively, were detected above Upriver Dam. The concentration of total PCBs at this site was 3,200 ppb compared to 6.1-38 ppb total PCBs in sediments from other parts of the river.

PCB-1242, -1254, and -1260 were also detected in Spokane River fish (Table 2). PCB-1254 was present in the largest concentrations followed closely by PCB-1242. The highest levels were found in whole fish, and in fillets from species with the higher lipid content.

Table 2. PCB Concentrations in Spokane River Fish (ug/Kg (ppb) wet weight)

Location	Species	Sample Type	% Lipid	PCB-1242		PCB-1254		PCB-1260		Total PCBs
Spokane Arm (FDR Lake)	Walleye	Fillet	0.4	8.8	U	15		8.8	U	15
	Smallmouth Bass	"	1.2	7.1	U	28		7.1	U	28
	Kokanee	"	4.4	10	U	70		22		92
	Largescale Sucker	Whole	5.1	190		250		190		630
Long Lake	Crayfish	Muscle	0.4	17	U	17	U	17	U	ND
	Yellow Perch	Fillet	0.2	6.8	U	9.4		6.8	U	9.4
	Largemouth Bass	"	0.6	15	U	74		23		97
	Mountain Whitefish	"	3.5	230		410		170		810
	Largescale Sucker	Whole	2.3	140		180		130		450
Above Nine Mile Dam	Rainbow Trout (sm)	Fillet	2.7	180		210		64		454
	Rainbow Trout (lg)	"	2.9	170		240		65		475
	Mountain Whitefish	"	2.7	200		280		42		522
	Largescale Sucker	Whole	5.6	360		600		210		1170
Above Upriver Dam	Rainbow Trout (sm)	Fillet	1.7	450		550		78	U	1000
	Rainbow Trout (lg)	"	1.9	440		610		74		1124
	Largescale Sucker	Whole	4.3	800		1800		175		2775
Above Post Falls (Idaho)	Largescale Sucker	Whole	7.2	28	U	55		41		96

U = not detected at or above reported value

ND = not detected

Concentrations of total PCBs ranged from 450-2,775 ppb in whole fish and 9.4-1,124 ppb in fillets. PCBs were not detected in the crayfish sample from Long Lake. Analysis of two size classes of rainbow trout above Nine Mile Dam and above Upriver Dam showed no strong relationship between size and PCB concentrations.

The survey results are compared graphically in Figure 2. There was a clear trend toward increasing PCB concentrations moving upstream from the Spokane Arm and peaking in the reach behind Upriver Dam. Concentrations then dropped to low levels above Post Falls, with only PCB-1254 and -1260 being detectable. Evidence for a trend is strengthened when the whole fish data (based on weight wet) are normalized to percent lipid. Beginning with the Spokane Arm and proceeding upstream, total PCB concentrations per kilogram of lipid are 12,400; 19,600; 20,900; 64,500; and 1,300 ppb.

These findings indicate a major input of PCBs has occurred between Upriver Dam and Post Falls. The presence of PCB-1242 may furnish a clue to the identity of the source as this mixture is less frequently detected in local waters than either -1254 or -1260. Figure 3 shows details of where samples were collected above Upriver Dam.

Significance - Relevant environmental criteria and guidelines for PCBs are summarized in Table 3. Washington State has not developed criteria for PCBs in freshwater sediments or fish tissue analogous to the state surface water quality standards.

The Ontario Ministry of Environment has proposed guidelines for chemical contaminants in freshwater sediments that predict when adverse effects on sediment-dwelling organisms are likely to occur (Persaud *et al.*, 1991-draft). An Ecology review of freshwater sediment criteria concluded the Ontario guidelines had the most sound scientific basis of those currently available (Bennett and Cubbage, 1991).

The Ontario severe effects levels for PCBs are normalized to the carbon content of the sediment sample in question (to a maximum of 10% TOC). Except for the sediment sample above Upriver Dam, the PCB concentrations measured in Spokane River sediments were at or near levels tolerated by most benthic organisms. The PCB-1254 concentration of 980 ppb above Upriver Dam is approximately one third of the severe effect level of 3,400 ppb (for TOC > 10%). No guidelines are given specific to PCB-1242.

Washington's Model Toxics Control Act (MTCA) gives cleanup levels for soil contaminants. Concentrations of PCBs in the sediment sample above Upriver Dam exceeded the soil cleanup level of 1,000 ppb total PCBs. The PCB cleanup level is to protect human health from direct contact with soil. As such, it would only apply in instances where the shoreline was contaminated or if river sediments were dredged and disposed upland. Exceedance of these levels does not necessarily trigger cleanup under MTCA.

Several agencies have developed recommendations for PCBs in fish tissue to protect aquatic life and wildlife. The EPA (1980) water quality criterion for chronic exposure to PCBs in freshwater, adopted as a state water quality standard, is based on a fish tissue concentration of 640 ppb. EPA (1980) cautions this value may be too high because it has been shown to affect reproduction of mink and because of the bioaccumulation data used to calculate the criterion. The International Joint Commission set a fish tissue goal for PCBs of 100 ppb to protect fish-consuming birds and mammals in the Great Lakes region (IJC, 1975). A similar value of 110 ppb was derived to protect populations of piscivorous wildlife of the Niagara River (Newell, 1987). The National Academy of Sciences (1973) has recommended that total PCB concentrations in whole fish or other aquatic organisms not exceed 500 ppb to protect aquatic life.

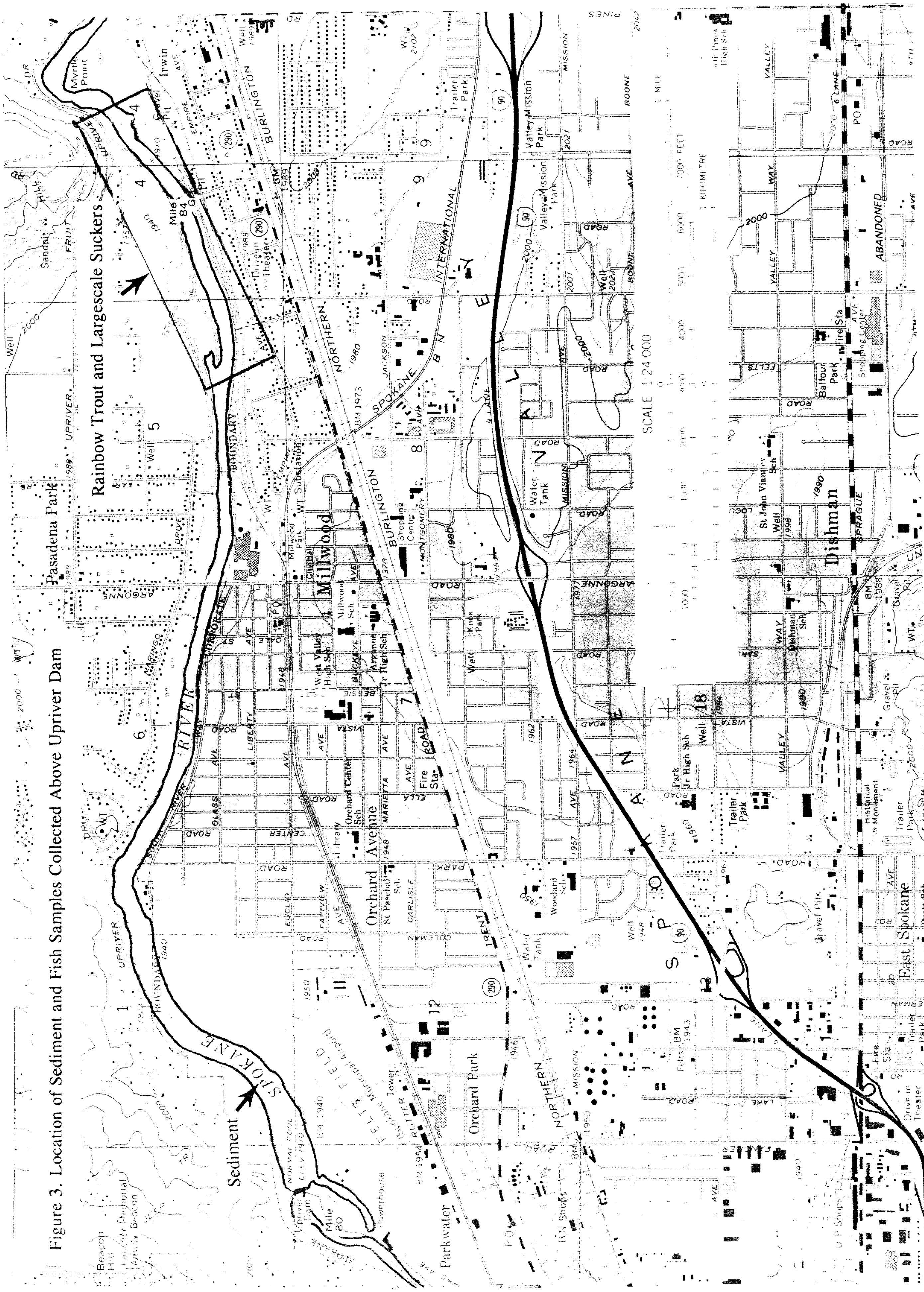

Figure 3. Location of Sediment and Fish Samples Collected Above Upriver Dam

Table 3. Environmental Criteria and Guidelines for PCBs (ug/Kg, ppb)			
Total PCBs	Criteria/Guideline	Source	Reference
1. Sediment/Soil			
70 60* 5**	Lowest Effect Level: tolerated by most benthic organisms	Ontario Guidelines	Persaud et al. (1991)
(530,000) (34,000)* (24,000)**	Severe Effect Level (TOC normalized): detrimental to most benthic organisms	Ontario Guidelines	Persaud et al. (1991)
1,000	Soil Cleanup Level	Model Toxics Control Act	WAC 173–340
10,000	Industrial Soil Cleanup Level		
2. Whole Fish			
100	To protect fish–eating birds and mammals	IJC Great Lakes goal	IJC (1975)
110	10E–2 cancer risk for fish–eating wildlife	Niagara River Fish Flesh Criteria	Newell (1987)
500	Not to be exceeded to protect aquatic life	Nat. Academy Sciences (recommendation)	NAS (1973)
3. Edible Fish Tissue			
1.4	10E–6 cancer risk; to determine need for more study	EPA Screening Level	EPA (1993)
1.4	10E–6 cancer risk; to determine if WQ limited	EPA National Toxics Rule	EPA (1992)
60–200	Lowest level where reduced consumption advised	Great Lakes Uniform Sport Fish Consumption Advisory	Anderson et al. (1993)
>1,900	Do not consume fish		
2,000	Legal limit for removing fish from marketplace	FDA Tolerance Level	FDA (1984)

*for PCB–1254

**for PCB–1260

Total PCB concentrations in whole fish samples collected from the Spokane Arm to above Upriver Dam, 450-2,775 ppb, exceeded or substantially exceeded levels considered protective of aquatic life and fish-eating birds and mammals. Concentrations in fillet samples suggest other species in the upper reaches of the river would also exceed these recommendations when analyzed whole.

Efforts to set guidelines for fish consumption to protect human health have resulted in a wide range of values for PCBs. At the low end, a screening level of 1.4 ppb (using the 10^{-6} cancer risk level adopted in Washington) is recommended by EPA (1993) to determine when more intensive fish sampling is needed to assess human health risk. The same edible tissue criterion, promulgated in the EPA (1992) National Toxics Rule, is used by Ecology to identify waterbodies not meeting state surface water quality standards under Section 303(d) of the Clean Water Act.

The most recent advice for the Great Lakes states recommends varying fish consumption rates depending on PCB residues (Anderson *et al.*, 1993). Reduced fish consumption is advised beginning at 60-200 ppb; fish are not to be consumed if concentrations exceed 1,900 ppb. The FDA legal limit for PCBs in fish and shellfish is 2,000 ppb (FDA, 1984). FDA balances economic considerations against human health risk when deriving limits for contaminants in food.

The PCB concentrations measured in fillet samples from Spokane River fish are of sufficient magnitude to warrant a more detailed evaluation of implications for human health. Of particular concern are the concentrations of 454-1,124 ppb total PCBs in rainbow trout and mountain whitefish. Based on guidance in the EPA National Toxics Rule, the Spokane River from its confluence with the Columbia River (Lake Roosevelt) to the Idaho border should be listed as water quality limited for PCBs due to levels in edible fish tissue.

II. Metals

Concentrations - Tables 4 and 5 show the results of metals analysis on the sediment and fish samples. Metals present in the highest concentrations in Spokane River sediments were zinc, lead, copper, chromium, nickel, arsenic, and cadmium. Beryllium, silver, thallium, mercury, and selenium concentrations were near or below limits of detection in all sediment samples.

As with PCBs, the higher metal concentrations occurred in whole fish samples. Except for elevated lead in the rainbow trout collected above Upriver Dam, lead, cadmium, and mercury were near detection limits in all fillet samples. Low to non-detectable concentrations of these metals were also found in the Long Lake crayfish sample. Zinc was readily quantified in all fillet samples, but fish regulate zinc levels in their muscle tissues as this is an essential trace element (Merz, 1981).

Comparison of these results to similar data on freshwater sediments and whole fish from local and national surveys indicates zinc, lead, and cadmium are metals of concern in the Spokane River (Hopkins *et al.*, 1985; Johnson *et al.*, 1988; Johnson and Norton, 1990; Schmitt and Brumbaugh, 1990; Cubbage, 1992; Serdar, 1994). Copper was also somewhat elevated in the

Table 4. Metal Concentrations in Spokane River Sediments (mg/Kg (ppm) dry weight)									
Location	% Fines	% TOC	Zn	Pb	Cu	Cr	Ni	As	Cd
Spokane Arm (FDR Lake)	67	1.8	960	81	26	18	15	8.9	7.4
Long Lake	98	3.9	1425	154	37	24	17	12	16
Above Nine Mile Dam	6	1.8	343	22	9.7	9.0	9.2 P	5.2	1.8 P
Above Upriver Dam	34	11	3990	605	69	36	24	12 P	33
Above Post Falls (Idaho)	26	2.7	1140	366	18	17	12	4.9	6.8

Fines = silt + clay (<62 um)
TOC = total organic carbon
P = detected below quantitation limit

Table 4. (continued)								
Location	% Fines	% TOC	Sb	Be	Ag	Tl	Hg	Se
Spokane Arm (FDR Lake)	67	1.8	REJ	0.8 P	0.5 P	0.5 U	0.11 P	0.4 U
Long Lake	98	3.9	REJ	1.1	0.9 P	0.5 U	0.19 P	0.4 P
Above Nine Mile Dam	6	1.8	REJ	0.4 P	0.3 U	0.5 U	0.03 P	0.4 U
Above Upriver Dam	34	11	REJ	0.7 P	1.1 P	0.5 U	0.50	0.6 P
Above Post Falls (Idaho)	26	2.7	REJ	0.6 P	0.4 P	0.5 U	0.18	0.4 U

REJ = data rejected due to low recoveries
U = not detected at or above reported value

Table 5. Metal Concentrations in Spokane River Fish (mg/Kg (ppm) wet weight)

Location	Species	Sample Type	Zn	Cu	Pb		Cd		Hg	
Spokane Arm (FDR Lake)	Walleye	Fillet	7.3	na	0.050	UJ	0.012	J	0.11	
	Smallmouth Bass	"	14	na	0.050	UJ	0.005	U	0.044	P
	Kokanee	"	10	na	0.050	UJ	0.007	J	0.040	P
	Largescale Sucker	Whole	25	0.75	0.64	J	0.12	N	0.087	
Long Lake	Crayfish	Muscle	25	na	0.050	UJ	0.021	J	0.029	P
	Yellow Perch	Fillet	12	na	0.050	UJ	0.005	U	0.040	P
	Largemouth Bass	"	10	na	0.050	UJ	0.005	U	0.082	
	Mountain Whitefish	"	21	na	0.050	UJ	0.015	J	0.030	P
	Largescale Sucker	Whole	36	0.94	0.74	J	0.11	N	0.050	P
Above Nine Mile Dam	Rainbow Trout (sm)	Fillet	12	na	0.059	J	0.010	J	0.030	P
	Rainbow Trout (lg)	"	11	na	0.054	J	0.005	U	0.037	P
	Mountain Whitefish	"	13	na	0.050	UJ	0.010	J	0.018	J
	Largescale Sucker	Whole	34	4.2	2.0	J	0.20	N	0.038	P
Above Upriver Dam	Rainbow Trout (sm)	Fillet	24	na	0.49	J	0.036	J	0.026	J
	Rainbow Trout (lg)	"	27	na	0.75	J	0.030	J	0.032	J
	Largescale Sucker	Whole	65	1.0	1.8		0.25	N	0.024	P
Above Post Falls (Idaho)	Largescale Sucker	Whole	38	0.90	2.6	J	0.21		0.049	P

na = not analyzed
U = not detected at or above reported value
J = estimated value
P = detected below quantitation limit
N = low matrix spike recovery

whole fish samples, but the concentrations are not particularly high when compared to fish analyzed from other rivers and lakes.

No one section of the Spokane River clearly stood out as being the most contaminated. The levels of zinc, lead, and cadmium were generally higher in samples from the upper river, but there were inconsistencies in this pattern. The sediment sample above Nine Mile Dam showed a relatively low degree of metals contamination not born out by the nearby whole fish sample and out of line with concentrations found in sediments above and below this site.

Significance - Table 6 summarizes environmental criteria and guidelines available for zinc, lead, and cadmium. The Ontario Guidelines and MTCA also address sediment/soil contamination by metals. However, information of the type available for PCBs in fish tissue is generally lacking for metals. Instead, Table 6 shows: recent results from a USFWS national monitoring program on contaminants in freshwater fish (Schmitt and Brumbaugh, 1990); EPA (1993) screening levels for cadmium (none are proposed for zinc or lead); and legal limits for fish marketed in countries outside the United States (Nauen, 1983). Because zinc, lead, and cadmium tend not to accumulate to problem levels in fish muscle (Phillips and Segar, 1986; Ginn and Barrick, 1988), there has been little impetus to develop advisory levels for fish consumption in the U.S.

Comparison of survey results with the above information leads to the following conclusions: Sediment concentrations of zinc, 960-3,990 ppm, and cadmium, 6.8-33 ppm, at all sites except behind Nine Mile Dam exceeded or approached levels of 820 and 10 ppm, respectively, shown to result in severe effects to sediment-dwelling organisms. Severe effects due to lead would be predicted to occur based on the sediment samples collected above Upriver Dam and Post Falls Dam (605 and 366 ppm vs. an effects level of 250 ppm). There is also potential for adverse effects due to lead in Long Lake, based on a lead concentration five times the 31 ppm level tolerated by most benthic organisms. Although relatively low metals concentrations were found in the Nine Mile sediment sample, results on other samples suggest there may be sediments in this reach that approach or exceed severe effects levels for zinc, lead, and/or cadmium.

Lead concentrations in sediment samples above Upriver Dam and Post Falls Dam also exceeded the 250 ppm soil cleanup level in MTCA. Cadmium concentrations exceeded the cleanup levels of 10 or 2.0 ppm at all sites except the Nine Mile Dam sample. These cleanup levels are to prevent unacceptable blood lead levels in humans from direct soil contact and, for cadmium, to protect terrestrial plants (2.0 ppm) or ground water (10 ppm).

The zinc, lead, and cadmium concentrations in Spokane River whole fish samples were unusually high. All of the whole fish samples exceeded 85th percentile concentrations for lead and cadmium reported by the USFWS for 109 sites surveyed in 1984-85 (Schmitt and Brumbaugh, 1990). Cadmium concentrations in the three Spokane whole fish samples between Nine Mile Dam and Lake Coeur d'Alene, 0.20-0.25 ppm, are equivalent to the national maximum value of 0.22 ppm reported by USFWS. The biological significance of these high concentrations is uncertain.

The zinc and cadmium levels in the edible tissue samples of Spokane River fish do not appear to be a human health concern. However, lead concentrations in fillets from rainbow trout above Upriver Dam, 0.49-0.75 ppm, are at legal limits of some countries. Canada, for example, set a federal limit of 0.5 ppm in edible fish tissue, although now evaluates health risk from fish consumption on a site-specific basis (Smith, 1987).

Table 6. Environmental Criteria and Guidelines for Zinc, Lead, and Cadmium (mg/Kg, ppm)				
Metal	Conc.	Criteria/Guideline	Source	Reference
1. Sediment/Soil				
Zn Pb Cd	120 31 0.6	Lowest Effect Level: tolerated by most benthic organisms	Ontario Guidelines	Persaud et al. (1991)
Zn Pb Cd	820 250 10	Severe Effect Level: detrimental to most benthic organisms	Ontario Guidelines	Persaud et al. (1991)
Pb Cd	250 2.0	Soil Cleanup Level	Model Toxics Control Act	WAC 173–340
Pb Cd	1,000 10	Industrial Soil Cleanup Level	Model Toxics Control Act	WAC 173–340
2. Whole Fish				
Zn Pb Cd	21.7 0.11 0.03	U.S. mean, 1984–85 (109 sites)	USFWS Contaminant Biomonitoring Program	Schmitt & Brumbaugh (1990)
Zn Pb Cd	34.2 0.22 0.05	U.S. 85th percentile, 1984–85 (109 sites)	USFWS Contaminant Biomonitoring Program	Schmitt & Brumbaugh (1990)
3. Edible Fish Tissue				
Cd	0.5–10	Damage to human health unlikely	EPA Screening Level	EPA (1993)
Zn Pb Cd	30–1,000 0.5–10 0.1–5.5	Legal limit for removing fish from marketplace	Limits of Other Nations	Nauen (1983)

Results from the earlier mentioned Ecology water quality study of the Spokane (Pelletier, 1994-in prep.) show zinc, lead, and cadmium are also elevated in river water. In samples collected every other month from July 1992 to September 1993, zinc almost always exceeded state surface water chronic and acute aquatic life criteria. A few of these samples approached or exceeded the chronic criteria for cadmium and lead. These data caused Ecology to include the Spokane River on the 1994 draft list of water quality limited waterbodies (Butkus, 1994-draft). Present survey findings that sediment concentrations of these metals are a significant potential concern for the well being of aquatic life further support the river's water quality limited status (WAC 173-204).

CONCLUSION

Survey results from limited numbers of sediment and fish samples indicate the Spokane River suffers significant contamination by PCBs, zinc, lead, and cadmium. The length of the river appears affected to one degree or another, with the exception of PCBs in the reach above Post Falls, Idaho. The level of contamination is sufficient to cause adverse effects on aquatic life and fish-eating birds and mammals.

PCB concentrations in fish fillets, particularly rainbow trout and mountain whitefish in the middle and upper river, warrant an evaluation of threat to human health. Limited data suggest lead in rainbow trout in the upper river should be included in this evaluation. Additionally, there may be reason to assess if the shoreline is a route of significant exposure to PCBs or lead for people swimming in or otherwise using the river.

In light of the above, the survey data have been provided to the Washington State Department of Health for their review.

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The efforts of the Ecology/EPA Manchester Environmental Laboratory are very much appreciated. The extra work undertaken by EPA's Bob Reick and his chromatography group at Manchester resulted in low detection limits for PCBs and a significantly better understanding of the distribution of PCBs within the study area.

Figure 1 was made by Ecology's Scott Breidenbach.

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Appendix A. Ecology Sediment Sample Locations in the Spokane River

Location	Description	River Mile	Depth	Date (1993)	Latitude (N) Longitude (W)
Spokane Arm (FDR Lake)	Off Laughbon's Landing, upstream of Blue Creek, center channel	13.2	69–81 ft.	7/27	47 53.0 118 09.0
Long Lake	Upstream of DNR campground, center channel	39.0	58–67 ft.	7/26	47 49.8 117 44.9
Above Nine Mile Dam	From outer margin of exposed left bank** shoal, 1/4 mi. below Deep Creek	58.7	dry*	7/28	47 45.9 117 33.0
Above Upriver Dam	Off right bank, 1/4 mi. above dam	80.5	18–21 ft.	7/27	47 41.3 117 19.2
Above Post Falls (Idaho)	Left bank embayment upstream of bridge to S. City Park	102.6	6–14 ft.	7/27	47 42.0 116 56.7

*river drawn down at time of collection

**viewed looking downstream

Appendix B. Length and Weight of Fish Used in Ecology Composite Samples

Location	Species	Total Length (mm)	Weight (grams)	Species	Total Length (mm)	Weight (grams)
Spokane Arm	Walleye	315	225	Kokanee	210	106
(FDR Lake)		328	275		270	239
		322	275			
		308	229			
		315	272			
	Smallmouth	230	186	Largescale	490	1265
	Bass	220	191	Sucker	510	1313
		226	196		497	1291
		220	195		368	978
		255	285		504	1514
samples collected July 25-27, 1993						
Long Lake	Crayfish	58*	41	Largemouth	463	1702
		58	56	Bass	457	1756
		60	53		347	677
		60	58		370	853
		62	71		332	478
	Yellow Perch	235	168	Largescale	450	867
		198	99	Sucker	487	1133
		232	158		432	760
		236	199		490	1099
		242	186		485	975
	Mountain	315	227			
	Whitefish	332	311			
		324	281			
		296	222			
		278	169			
samples collected July 26-28, 1993						

* carapace length

Appendix B. (continued)

Location	Species	Total Length (mm)	Weight (grams)	Species	Total Length (mm)	Weight (grams)
Above Nine Mile Dam	Rainbow Trout	284	221	Mountain Whitefish	249	131
		293	171		249	155
		232	135		245	122
		238	129		235	104
					232	111
	Rainbow Trout	384	608	Largescale Sucker	553	1834
		295	237		539	1691
		334	364		542	1530
		356	432		504	1354
					447	889
samples collected August 10, 1993						
Above Upriver Dam	Rainbow Trout	280	241	Largescale Sucker	505	1367
		285	255		406	637
		240	161		427	721
		331	393		410	739
		305	286		420	723
	Rainbow Trout	373	498			
		360	528			
		333	374			
		386	541			
		365	464			
samples collected July 27, 1993						
Above Post Falls (Idaho)	Largescale Sucker	411	802			
sample collected August 9, 1993						

APPENDIX C. Methods of Sample Collection, Preparation, and Analysis

Sediment was collected with a stainless steel 0.05 m^2 Ponar sampler. Each sample consisted of the top 2-cm surface layer from five separate grabs. Composites were homogenized using stainless steel spoons and beakers before being split into subsamples for analysis. All sediment sampling equipment was pre-cleaned with Liqui-Nox detergent, de-ionized water, dilute nitric acid, and acetone.

Fish were caught by gill net, fyke net, or electrofishing. Individuals selected for analysis were measured for total length and weight, then wrapped in aluminum foil and placed in polyethylene bags.

Sediment and fish samples were held on ice for transport back to Olympia. Chain-of custody was maintained. Sediments were held at 4°C until extracted. The fish were frozen pending preparation of tissue samples.

Fish collected for whole body analysis were homogenized in a Hobart commercial meat grinder. Filleting was done with stainless steel knives and included the skin. Fish were scaled and rinsed with tap water and de-ionized water prior to filleting. Instruments and equipment used to prepare the tissue samples were washed with Liqui-Nox detergent and rinsed with de-ionized water, dilute nitric acid, and acetone.

Sediment samples for PCBs were soxhlet extracted with acetone and analyzed by EPA Method 8080 using dual column capillary GC with electron capture detectors (ECD). Low detection limits were achieved by extracting 50 grams of sediment and using gel permeation chromatography (GPC) along with mercury clean-up for sulfur and concentrating samples to 2.0 mLs final volume. Fish samples were also extracted with acetone, then analyzed by a modification of Method 8080 using dual column GC and ECD. Modifications included clean-up by GPC and a zero percent florisil clean-up. Percent lipids were determined by EPA Region 10 method RX1-608.5.

For metals analysis of sediments, samples were hot plate digested by EPA Method 3050. Arsenic, selenium, and thallium were analyzed by graphite furnace atomic spectroscopy (GFAA), methods EP1-206.2, 270.2 and 279.2, respectively. Mercury was analyzed by cold vapor AA (EP1-245.5). The remaining metals in sediment were done by inductively coupled plasma emission spectroscopy (ICP), method EPA-200.7.

A microwave digestion (EPA-3051) was used to analyze metals in fish tissue. Zinc (EP1-200.7) was by ICP; cadmium (EP1-213.2), copper (EP1-220.2), and lead (EP1-239.2) were by GFAA; and mercury (EP1-245.5) was by CVAA.

The PCB and metals data were reviewed by Dickey Huntamer (1993a,b; 1994), Bill Kammin (1993), and Myrna McIntosh (1994) of the Ecology Manchester Laboratory. Their review included sample holding times, instrument calibration, laboratory blanks, recoveries of matrix and surrogate spikes, analyses of standard reference materials, and laboratory control samples.

Except for low recoveries of antimony in sediment, no significant problems were encountered in these analysis. The antimony data were not usable.

Tables C-1 through C-3 summarize accuracy and precision data obtained from analysis of reference materials, control samples, matrix spikes, and duplicate analyses of field samples. There was a slight discrepancy between Manchester PCB results and certified values for the National Research Council Canada (NRCC) standard reference materials HS-1 and HS-2. Manchester attributes this to the fact that the certified values are for PCB-1254, but that the chromatograms provided by NRCC show peaks consistent with the presence of PCB-1260, which may have been included in the certified values since these were based on packed column analyses.

Appendix C-1. Accuracy and Precision of PCB Analyses

1. Standard Reference Materials (ug/Kg, ppb)

SRM	Matrix	PCB	Analysis #1	Analysis #2	Certified Value
HS-1	Sediment	PCB-1254	25 J	27 J	21.8+/-1.1
		PCB-1254	16.5	15.3	
HS-2	Sediment	PCB-1254	99	98	111.8+/-2.5
		PCB-1254	65	na	

2. Matrix Spikes (recovery)

Sample	Matrix	PCB	Spike #1	Spike #2	RPD
31-8236	Sediment	PCB-1242	93%	99%	6.2%
		PCB-1260	95%	104%	9.0%
31-8245	Fish Muscle	PCB-1242	74%	79%	6.5%
		PCB-1260	84%	84%	0%

3. Duplicate Analyses (ug/Kg, ppb)

Sample	Matrix	PCB	Analysis #1	Analysis #2	RPD
31-8231	Sediment	PCB-1242	4.6 U	4.1 U	-
		PCB-1254	21	20	4.9%
		PCB-1260	22	14	44%
31-8243	Whole Fish	PCB-1242	770	830	7.5%
		PCB-1254	1800	1800	0%
		PCB-1260	170	180	5.7%
31-8251	Fish Muscle	PCB-1242	7.1 U	6.8 U	-
		PCB-1254	9.2	9.6	4.2%
		PCB-1260	7.1 U	6.8 U	-

J = estimated value

na = not analyzed

RPD = relative percent difference (range/mean x 100)

U = not detect at or above reported value

Appendix C-2. Accuracy and Precision of Metals Analyses: Sediment

1. Standard Reference Material/Lab Control Sample (mg/Kg, ppm)

SRM/LCS	Metal	Analysis #1	Analysis #2	Certified Value
NIST 2704	Mercury	1.41	1.75	1.47+/-0.07
ERA Lot 211	Arsenic	88	100	100
	Beryllium	23	25	25
	Cadmium	110	116	116
	Chromium	75	80	87
	Copper	75	78	93
	Lead	126	134	138
	Nickel	103	114	108
	Selenium	42	47	46
	Antimony	1.8	2.1	57
	Silver	21	23	25
	Thallium	11	12	14
	Zinc	343	372	374

2. Duplicate Analyses (mg/Kg, ppm)

Sample	Metal	Duplicate #1	Duplicate #2	RPD
31-8231	Arsenic	11.2	11.8	5.2%
	Selenium	0.43 P	0.40 U	-
	Thallium	0.50 U	0.50 U	-
	Mercury	0.051 P	0.057 P	11%
	Beryllium	1.09	1.07	1.9%
	Cadmium	15.9	15.3	3.8%
	Chromium	23.3	24.3	4.2%
	Copper	37.0	36.5	1.4%
	Lead	156	153	1.9%
	Nickel	17.3	17.5	1.1%
	Silver	0.91 P	0.87 P	4.5%
	Zinc	1440	1410	2.1%
	Antimony	3 UJ	3 UJ	-

P = detected below quantitation limit

U = not detected at or above reported value

J = estimated value

Appendix C-3. Accuracy and Precision of Metals Analyses: Fish Tissue

1. Standard Reference Material (mg/Kg, ppm)

SRM	Matrix	Metal	Analysis #1	Analysis #2	Certified Value
DORM-1	Fish Muscle	Zinc	17.9	16.7	21.3+/-1.0
		Copper	4.34	4.16	5.22+/-0.33
		Lead	0.30	0.45	0.40+/-0.12
		Cadmium	0.105	0.088	0.086+/-0.012
		Mercury	0.665	0.711	0.798+/-0.074

2. Matrix Spikes (recovery)

Sample	Matrix	Metal	Spike #1	Spike #2	RPD
31-8255	Fish Muscle	Mercury	74%	71%	4.1%
31-8243	Whole Fish	Zinc	na	na	-
		Copper	102%	99%	3.0%
		Lead	118%	209%	56%
		Cadmium	110%	128%	15%
		Mercury	78%	na	-

3. Duplicate Analyses (mg/Kg, ppm)

Sample	Matrix	Metal	Duplicate #1	Duplicate #2	RPD
31-8243	Whole Fish	Zinc	73.3	56.1	26%
		Copper	1.15	0.922	22%
		Lead	1.77 J	1.84	3.9%
		Cadmium	0.251 N	0.247 N	1.6%
		Mercury	0.027 P	0.021 P	25%
31-8255	Fish Muscle	Zinc	29.6	24.2	20 %
		Lead	0.776 J	0.730 J	6.1%
		Cadmium	0.031 J	0.030 J	3.3%
		Mercury	0.034 J	0.029 J	16%

RPD = relative percent difference (range/mean x 100)
na = not analyzed
J = estimated value
N = poor spike recovery
P = detected below quantitation limit