WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

SURVEY OF CHEMICAL CONTAMINANTS IN TEN WASHINGTON LAKES

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Water Body Nos. (See Abstract, Page v)

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SURVEY OF CHEMICAL CONTAMINANTS IN TEN WASHINGTON LAKES

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Table of Contents

List of Tables

List of Figures

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Abstract

A survey of chemical contaminants was conducted for ten Washington lakes as part of the Washington State Department of Ecology's 1992 Lake Water Quality Assessment Project. Whole bottom-feeding fish, predator fish muscle, and bottom sediments from Potholes Reservoir, Long Lake (Spokane River), Roses Lake, Lake Sammamish, and Ward Lake were analyzed for a variety of organic compounds and metals. Duck, Spanaway, Ohop, Ketchum, and Silver Lakes were sampled for copper in sediments.

The objectives of the survey were to assess the occurrence of potentially toxic chemicals in lake sediments and fish and evaluate the significance of the findings. Concentrations of chemicals in fish were compared to results of national and statewide surveys, and criteria for protection of human health. Chemical concentrations in sediments were compared to freshwater sediments in Washington and guidelines established for the management of contaminated sediments.

The Water Body Numbers for the ten lakes are:

Potholes Reservoir:	WA-41-9280
Long Lake:	WA-42-9120
Roses Lake:	WA-40-9040
Sammamish Lake:	WA-08-9270
Ward Lake:	WA-13-9200
Duck Lake	WA-22-9030
Spanaway Lake:	WA-12-9070
Ohop Lake:	WA-11-9150
Ketchum Lake:	WA-03-9110
Silver Lake:	WA-08-9300

Summary of Findings

Potholes Reservoir, Long Lake (Spokane River), Roses Lake, Lake Sammamish, and Ward Lake were selected for extensive chemical analysis mainly due to their potential for toxic chemical contamination. Except for selenium and mercury, whole bottom fish from Long Lake had the highest concentrations of EPA priority pollutant metals. Lead and cadmium concentrations were three-to-four times higher than mean values reported during a 1984 survey of metals in whole fish nationwide. Average zinc, copper, selenium, and mercury concentrations in whole bottom fish from the other four lakes were similar to national concentrations. Mercury concentrations were generally low in predator fish muscle, with the exception of a moderately elevated 0.35 mg/Kg (parts per million, ppm) in Ward Lake bass.

DDT and its metabolites (DDE and DDD) were the most frequently detected organic compounds in fish. All samples, whole and muscle tissue, had measurable concentrations of at least one of these chemicals. Total DDT concentrations were highest in Roses Lake brown bullhead analyzed whole (480 ug/Kg [parts per billion, ppb]) and as muscle (186 ppb).

Other organic compounds detected in whole bottom fish included PCBs, dieldrin, methoxychlor, DDMU (a breakdown product of DDT), alpha-chlordene, gamma-chlordene, hexachlorobenzene, pentachloroanisole, and dacthal. With the exception of PCBs in largescale suckers from Long Lake (720 ppb total PCB) and Lake Sammamish (170 ppb total PCB), these other compounds were detected at relatively low concentrations (<40 ppb). The PCB levels in Long Lake fish are similar to those found during previous Ecology investigations, and suggest that PCB levels have not declined significantly since 1980.

Compounds other than DDT and its metabolites detected in predator muscle included PCBs, hexachlorobenzene, dieldrin, DDMU, and dacthal. Concentrations were relatively low (<70 ppb). None of the five organophosphorous pesticides analyzed were detected in either muscle or whole fish samples.

Potholes Reservoir, Roses Lake, and Ward Lake should be considered for listing as "water quality limited" under section 303(d) of the Clean Water Act based on dieldrin, DDE, and PCB residues in muscle, respectively. Concentrations of these compounds and EPA's human health criteria from the National Toxics Rule are shown below:

Lake	Species	Concentration (ppb)	EPA Human Health Criteria (ppb)
Potholes	Lake whitefish	Dieldrin - 32	0.6
"	Largemouth bass	Dieldrin - 5	0.6
Roses	Brown bullhead	DDE - 165	32
"	Rainbow trout	DDE - 75	32
Ward	Rainbow trout	PCB - 8	1.4

Zinc was found at the highest concentrations among the thirteen priority pollutant metals analyzed in bottom sediments, followed by lead, copper, nickel, and arsenic. Long Lake had high zinc, cadmium, and lead concentrations compared to sediments from the other lakes surveyed here, and when compared to freshwater sediments statewide. Ward and Sammamish Lakes had the highest concentrations of copper, chromium, nickel, and arsenic. Selenium, beryllium, and mercury were detected in at least half the sediment samples, but at very low concentrations. Antimony, silver, and thallium were not detected in any of the samples.

Based on a comparison to Ontario provincial guidelines for sediment quality, zinc and cadmium concentrations from Long Lake would be expected to cause pronounced impacts to benthic organisms. Impacts to benthic organisms would also be expected at one site in Lake Sammamish and both sites sampled in Ward Lake due to elevated arsenic levels in sediments.

Bis(2-ethylhexyl)phthalate, diethylphthalate, DDT, DDE, and DDD were the only organic compounds detected in bottom sediments. None of the six chlorophenoxy herbicides, twenty-four organophosphorous pesticides, or six PCB mixtures analyzed in sediments were detected, possibly due to high detection limits in some cases.

Roses Lake had extremely high concentrations of total DDT at both sites sampled (1,760 and 1,490 ppb). These levels, adjusted for organic carbon, would be expected to cause pronounced impacts to benthic organisms. Ward Lake had the only other detectable concentration of a DDT compound in sediment (DDD at 42 ppb).

Duck, Spanaway, Ohop, Ketchum, and Silver Lakes were sampled for copper only, based on historical usage of copper to control aquatic plants. Copper concentrations were compared to the level at which severe effects to benthic organisms are expected to occur (110 ppm), based on sediment quality guidelines developed by Ontario. Ketchum Lake had the highest concentrations of copper, ranging from 260 to 600 ppm at the five sites sampled. Mean copper concentrations in Spanaway Lake were 185 ppm, with concentrations near developed areas much higher than those in undeveloped areas. Ohop Lake had mean copper concentrations slightly below the 110 ppm severe effects level. Copper in sediments from all sites in Duck and Silver Lakes were well below the severe effects level.

Recommendations

1. Analyze additional fish tissue samples from Roses Lake to determine if DDT levels pose a threat to human health and wildlife. Also investigate the possibility of DDT in Roses Lake as a contributing factor to the periodic fish kills.

2. Conduct a two-tiered survey of DDT in the lower Lake Chelan basin. Initial investigation should focus on the extent of DDT contamination. In areas where DDT concentrations are high, follow-up studies should focus on possible threats to human health, wildlife, and benthic organisms.

3. Consider including Potholes, Roses, and Ward Lakes on Washington State's final "water quality limited" list.

4. Investigate the extent and significance of metals and PCBs in Long Lake pending results of Ecology's ongoing investigation.

5. Discontinue copper treatments in Ketchum Lake.

6. Conduct bioassays and benthic invertebrate surveys to determine if copper concentration in Spanaway and Ohop Lake sediments are toxic.

Introduction

As part of the Washington State Department of Ecology's Lake Water Quality Assessment Project, a survey of chemical contaminants was conducted for ten Washington lakes during 1992-1993. Bottom sediments and fish tissue were analyzed for persistent organic compounds and trace metals in five lakes. An additional five lakes were surveyed for sediment copper concentrations only. Such data are presently available for very few Washington lakes. The survey of organics and metals was similar in design to one completed under the Clean Lakes Program in 1989 (Johnson and Norton, 1990).

The objectives of the survey were to assess the occurrence of potentially toxic chemicals in lake sediments and fish and evaluate the significance of the findings. The results will be used to identify and prioritize lakes needing more detailed assessments. A summary by lake is included at the end of this report.

Methods

Selection of Lakes

Lakes selected for analysis of trace metals and organic chemicals are listed in Table 1. Locations are shown in Figure 1. Appendix A-1 describes the sediment sampling sites for each lake. The following criteria, in order of priority, were used for selecting these lakes:

- Potential for toxic contamination;

- Little or no existing data on toxic contaminants;

- Used for recreation and with public access; and

- Availability of at least two predatory and one bottom-feeding fish species.

In addition to these criteria, an effort was made to choose lakes of various size (surface area) and location with respect to population centers. Lakes were also selected to represent different geographical regions of the state.

Potholes Reservoir and Roses Lake (also called Alkali Lake) were selected mainly because of the potential for contamination with pesticides: Potholes receives several irrigation return flows (wasteways) and Roses Lake is in a small valley with many fruit orchards on the surrounding slopes. Roses Lake and other small lakes nearby have experienced periodic fish kills, but the cause of the kills is unclear (L. Brown, personal communication). Long Lake, an impoundment of the Spokane River, is downstream of industrial and municipal discharges

Table 1. Lakes Sampled for Metals and Organic Chemicals in Bottom Sediments and Fish.

Lake Name	County	Area (acres)	Mean Depth (ft)	Potential Contaminant Sources
Potholes Reservoir	Grant	28200	N/A	receives irrigation water return flow
Long Lake (Spokane R.)	Spokane/Stevens	5020	51	downstream of large urban area and Coeur d'Alene mining
Roses lake	Chelan	130	23	surrounded by orchards; history of fish kills
Lake Sammamish	King	4897	N/A	experiencing rapid urban development
Ward Lake	Thurston	65	33	residential; large nursery adjacent to lake

N/A = Not Available

Table 2. Lakes Sampled for Copper in Bottom Sediments.

Lake Name	County	Area (acres)	Mean Depth (ft)
Duck Lake	Grays Harbor	280	11
Spanaway Lake	Pierce	320	16
Ohop Lake	Pierce	230	17
Ketchum	Snohomish	20	N/A
Silver	Snohomish	110	24

N/A = Not Available

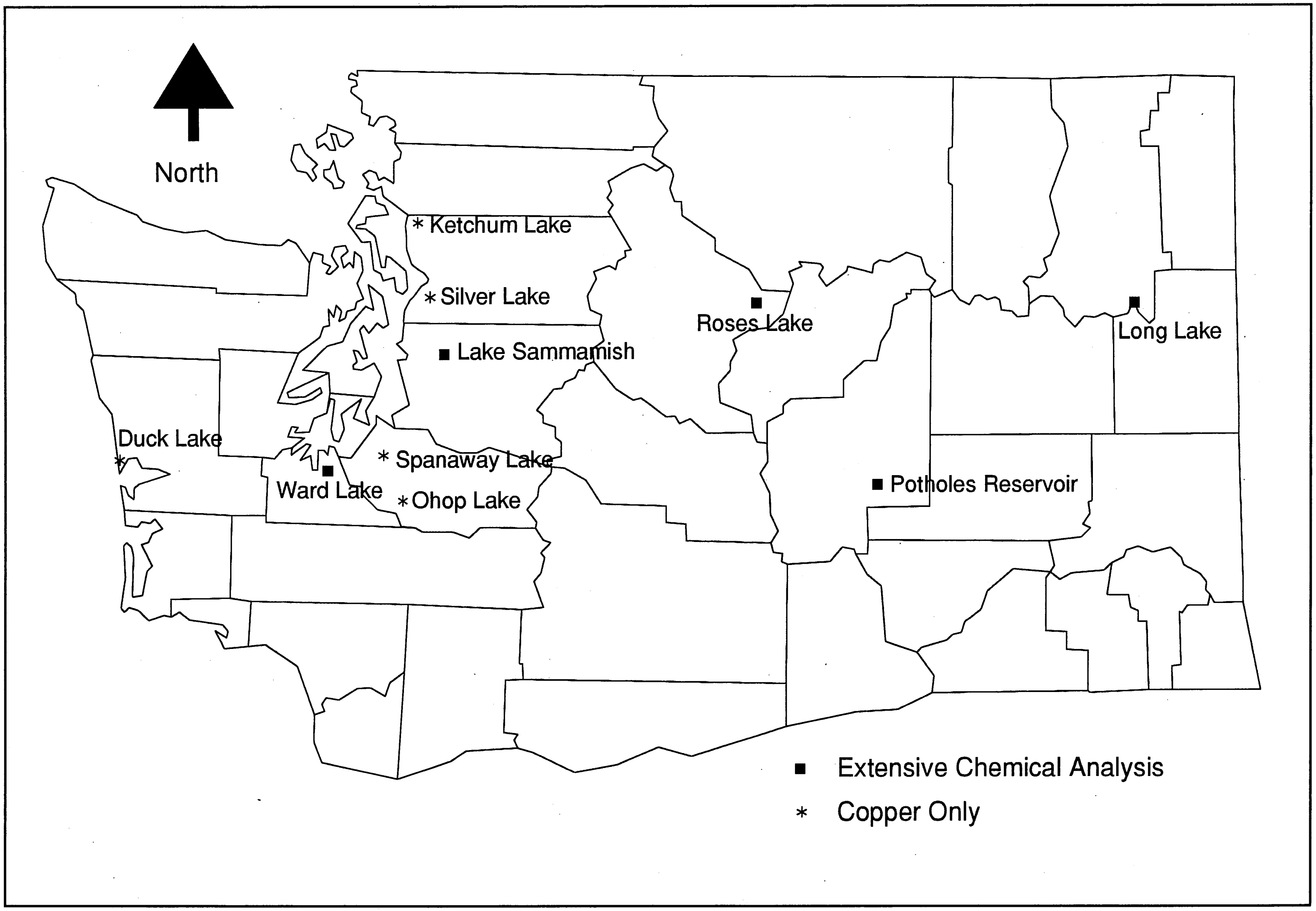

Figure 1. Locations of Lakes Surveyed for Chemical Contaminants

from the vicinity of Spokane (URS Co., 1981). Metals contamination from historical mining activity upstream in the Coeur d'Alene drainage has been documented throughout the Spokane River (Yake, 1979). Lake Sammamish is a large lake in King County whose shoreline and adjacent drainage have experienced rapid urban development during the past decade. Ward Lake in Thurston County was chosen because of the potential for pesticide contamination from an adjacent plant nursery and because its drainage is largely developed (residential). Unlike the other four lakes, Ward Lake has strict regulations regarding the use of motorboats.

Lakes sampled for copper in sediments had a high potential for elevated concentrations based on previous treatments with copper sulfate to control nuisance algal growth. These lakes are listed in Table 2 and locations shown in Figure 1. To identify candidate lakes, Ecology records were reviewed for permits allowing treatment with copper sulfate. Because Ecology has only recently begun systematic record-keeping for herbicide treatments in surface waters, historic records are incomplete. Therefore, anecdotal information was also used to piece together a history of copper usage in various lakes.

Heavy copper treatment in lakes tends to coincide with substantial recreational use and residential development. Spanaway Lake in Pierce County and Silver Lake in Snohomish County appeared to be the most heavily used for recreation among the five lakes sampled. No lakes on the east side of the Cascades were identified as having a potential for serious copper contamination, possibly due to low copper usage or inadequate information on copper usage.

Sampling Design and Collection

Table 3 shows the sampling scheme for the survey. Two sediment samples, two predator muscle samples, and one whole bottom fish sample were analyzed from each of the lakes selected for organics/metals evaluation. Bottom fish samples could not be obtained from Ward Lake and only one predator species was obtained in Roses and Sammamish Lakes. Muscle from a bottom-feeder (brown bullhead) was analyzed in addition to the predator species in Roses and Sammamish Lakes. Five sediment samples were collected from each of the lakes selected for investigation of copper contamination.

In lakes selected for organics and metals analysis, sediment samples were collected near the inlet and outlet ends of the lakes. In Ward Lake, which is spring-fed and has no outlet, sediment samples were collected near the ends of the longest axis. For the copper investigation, an effort was made to distribute the sampling throughout the lake, with three of the sampling sites located near heavily developed areas (docks, swimming beaches), and the other two samples coming from the lake centers or other relatively undisturbed areas.

Each sediment sample was a composite of the top 2 cm surface layer from three grabs taken with a 0.05 m^2 or 0.02 m^2 stainless steel Ponar. Composites were homogenized in stainless steel beakers using stainless steel spoons. Subsamples for metals and organics analyses were placed in I-Chem series 300 (or equivalent) glass jars with teflon lid liners and held on ice.

Table 3. Sampling Scheme for 1992-1993 Survey of Toxic Chemicals in Lakes

Lake	Sample Type	No. of Samples	Priority Pollutant Metals	Semivolatile Organics	Chlorophenoxy Herbicides	Organophosphorous Pesticides	Chlorinated Pesticides and PCBs
Potholes Reservoir	BS	2	X	X	X	X	X
	MT	2	Hg only			X	X
	WF	1	X			X	X
Long Lake	BS	2	X	X	X	X	X
	MT	2	Hg only			X	X
	WF	1	X			X	X
Roses Lake	BS	2	X	X	X	X	X
	MT	2	Hg only			X	X
	WF	1	X			X	X
Lake Sammamish	BS	2	X	X	X	X	X
	MT	2	Hg only			X	X
	WF	1	X			X	X
Ward Lake	BS	2	X	X	X	X	X
	MT	2	Hg only			X	X
Duck Lake	BS	5	Cu only				
Spanaway Lake	BS	5	Cu only				
Ohop Lake	BS	5	Cu only				
Ketchum Lake	BS	5	Cu only				
Silver Lake	BS	5	Cu only				

BS = Bottom Sediment
MT = Muscle Tissue
WF = Whole Fish

Fish were collected by electroshocking, gill net, or fyke net. Fish selected for analysis were measured for total length and weight, wrapped in aluminum foil, placed in polyethylene bags, and held on ice. Biological information on fish sampled is shown in Appendix A-2. On return to the laboratory, muscle tissue samples were prepared by compositing approximately 40 gm of skinless epaxial muscle from each of five individual fish. Stainless steel scalpels and forceps were used. Sample containers were as described above.

Whole fish were frozen solid, then homogenized with a Hobart meat grinder. As with muscle samples, each whole fish sample was a composite of five individual fish.

All sediment sampling and fish dissecting equipment was cleaned by scrubbing with Liqui-Nox® detergent, followed by sequential rinses with tap water, 10% nitric acid, de-ionized water, and pesticide-grade acetone.

Target Chemicals and Analytical Procedures

Sediment samples were analyzed for EPA priority pollutant metals, semivolatile organics, and three classes of pesticides, all of which include chemicals expected to persist in sediments (Callahan *et al.*, 1979; Tetra Tech, Inc., 1988). Analytical methods and analyte quantitation limits are shown in Appendices A-3 and A-4, respectively. Quantitation limits were higher than expected for analysis of chlorophenoxy herbicides, PCBs, and semivolatile organics. The reason for higher-than-expected quantitation limits was not given by the laboratory conducting the analysis. Grain size, total organic carbon, and percent solids were also analyzed in each sediment sample to aid in data interpretation.

Whole fish were analyzed for EPA priority pollutant metals. Muscle samples were analyzed mercury for only because it is one of the few metals which accumulate in this tissue and because of potential human health concerns. Target organic chemicals for fish tissue were based on the results of sediment analysis and the potential for bioaccumulation. The target analyte list for pesticides/PCBs in fish was developed by Ecology's Manchester Laboratory for the Washington State Pesticide Monitoring Program (WSPMP). Results may be compared directly with those generated by WSPMP (Davis and Johnson, 1994-in prep.).

Another non-standard analysis - percent non-polar lipid - was conducted. This technique, described by Schneider (1982), uses a chromatographic column filled with florisil to separate the polar and non-polar fractions of lipid in a sample extract. Studies have shown non-polar lipid correlates better with organochlorine levels in fish tissue than does total lipid and may be the preferable way to normalize organics data on fish tissue (Schneider, 1982; Schmitt *et al.*, 1990).

Quality of the Data

Quality assurance/quality control review of the data was conducted by staff at the Manchester Laboratory. It included evaluation of sample condition on receipt, holding times, instrument calibration, procedural blanks, matrix spikes, standard reference material, and precision data. Overall quality of the data was good. Qualification of some data is noted in the tables.

Manchester's analysis of a cod liver oil standard reference material for chlorinated pesticides and PCBs (NIST 1588) is compared to certified values in Appendix A-5. Analysis of the cod liver oil generally yielded good results, although more than half the values were outside the narrow window of certified values. Overall accuracy of the analyses was acceptable.

Precision, as measured by duplicate analyses of field samples, was excellent in most cases (Appendix A-6). Relative percent differences (RPDs) were 0-13% for metals in sediments (low RPDs indicate high precision), and 8-64% for metals in fish tissue. Precision of organics analysis was more difficult to assess since relatively few compounds were detected. Duplicate analysis of sediment yielded an RPD of 86% for bis(2-ethylhexyl)phthalate. RPDs for chlorinated pesticides in fish samples were very low (3-15%). Precision of cod liver oil reference material analysis was also good (RPDs of 23-44%).

Results And Discussion

Metals and Organics in Whole Bottom Fish

Concentrations of metals detected in whole bottom fish are shown in Table 4. In general, metals concentrations in whole fish were low. Zinc was found at the highest concentrations, followed by chromium, nickel, and copper. Arsenic, beryllium, antimony, silver, and thallium were not detected in any samples.

Except for selenium and mercury, whole fish from Long Lake had the highest concentrations of all metals which were detected. Largescale suckers from Long Lake yielded the only measurable cadmium and lead concentrations; 0.10 and 0.44 mg/Kg (parts per million or ppm), respectively. Lead and cadmium concentrations in Long Lake fish were three-to-four times higher than mean values reported during a 1984 U.S. Fish & Wildlife Service survey of metals in whole fish nationwide (Schmitt and Brumbaugh, 1990).

Average zinc, copper, selenium, and mercury concentrations in whole fish from Potholes, Roses, and Sammamish Lakes were similar to national concentrations. Zinc, chromium, and copper concentrations were also similar to concentrations in whole fish from eight Washington rivers analyzed during Ecology's 1989 Basic Water Monitoring Program (Hopkins, 1991).

Appendix B-1 shows all organic compounds detected in whole bottomfish. DDT and its metabolites, DDE and DDD, were the most frequently detected of the 49 organic compounds targeted in fish tissue analysis. DDT compounds were detected in each of the four whole bottom fish samples (Table 5).

Table 4. Metals Detected in Whole Fish During Present Survey and Previous Nationwide and Statewide Surveys (mg/Kg [ppm], wet weight basis).

Sample Number	Lake	Species		Zn	Pb	Cu	Cr	Ni	Cd	Se	Hg
PRESENT SURVEY											
358089	Potholes Reservoir	Largescale sucker		20.3	<0.05	0.64	<0.25	<0.5	<0.10	0.26J	0.028J
438048	Long Lake	Largescale sucker		29.5	0.44J	1.4	2.9	2.1J	0.10J	0.22J	0.025J
438046	Roses Lake	Brown bullhead		25.4	<0.05	0.57	2.58	1.2J	<0.10	0.19J	<0.005
438047	Lake Sammamish	Largescale sucker		23.0	<0.05	0.9	0.74J	0.81J	<0.10	0.17J	0.09
U.S. Fish & Wildlife Service			mean =	21.7	0.11	0.65	N/A	N/A	0.03	0.42	0.1
1984 National Survey*			range =	9.6-118	0.01-4.9	0.06-23			<0.01-0.22	0.08-2.3	0.01-0.37
(315 samples from 110 sites)											
Ecology 1989 Basic Water			mean =	19.6	ND	0.74	0.71	N/A	0.04	N/A	N/A
Monitoring Program**			range =	2.3-45	<0.09-0.44	0.12-1.1	0.33-1.0		<0.01-0.07		
(8 samples from 7 sites)											

< = Not detected at concentration shown

J = Estimated Concentration

N/A = Not Analyzed

ND = Not Detected on average. Lead was detected in two samples at 0.18 and 0.44 ppm.

* Schmitt and Brumbaugh, 1990

** Hopkins, 1991

Table 5. DDT and DDT Metabolites Detected in Whole Bottom Fish (ug/Kg [ppb], wet weight basis).

Sample Number	Lake	Species	Percent Lipid	Percent Non-Polar Lipid	4,4'-DDT	4,4'-DDE	4,4'-DDD	Total DDT	lipid-normalized t-DDT (ppb)	non-polar lipid-normalized t-DDT (ppb)
358089	Potholes	Largescale sucker	8.6	7.3	10	82	37	134*	1,560	1,840
438048	Long	Largescale sucker	N/A	N/A	7J	91J	9J	107	-	-
438046	Roses	Brown bullhead	1.5	0.6	6J	388	86	480	32,000	80,000
438047	Sammamish	Largescale sucker	4.5	3.6	3J	35	19	57	1,270	1,580

J = Estimated concentration
* 3 ppb 2,4' DDE and 2 ppb 2,4' DDD also detected in this sample.
N/A = Not Analyzed

Table 6. PCBs in Spokane River Whole Bottom Fish (ug/Kg [ppb], wet weight basis).

Approximate River Mile	Species	No. of samples	Total PCB
Present Survey			
37	Largescale sucker	1	724
Ecology 1990 (Johnson, 1991)			
37	Largescale sucker	1	337
Ecology 1980-1983 (Hopkins et al., 1985)			
66	Largescale sucker	2	195
66	Bridgelip sucker	2	598
87	Longnose sucker	3	133

The highest concentrations of DDT compounds were found in fish from Roses Lake - total DDT (t-DDT; DDT + DDE + DDD) was 480 ug/kg (parts per billion or ppb) in whole brown bullhead. Fish from other lakes had t-DDT concentrations less than one-third of those in the Roses Lake sample. Roses Lake was also the only site where DDMU, a breakdown product of DDT, was detected.

DDT has historically been applied to orchard lands in the lower Chelan basin which encompasses Roses Lake. Fourteen Lake Chelan whole fish samples analyzed by Ecology between 1982 and 1987 had a geometric mean of 1,200 ppb t-DDT, more than double the concentration found in the Roses Lake sample (Hopkins *et al.*, 1985; Patmont *et al.*, 1989). On a total lipid-normalized basis, eight of these fourteen samples for which lipid data were available had a mean of 29,500 ppb t-DDT, similar to the 32,000 ppb t-DDT found in the Roses Lake bullhead.

Other organochlorine compounds detected in whole bottom fish during this survey included PCBs, dieldrin, methoxychlor, alpha-chlordene, gamma-chlordene, hexachlorobenzene (HCB), pentachloroanisole, and dacthal (DCPA). None of the five organophosphorous pesticides analyzed were detected. Aside from PCBs in fish from Long lake and Lake Sammamish, these other compounds were detected at low concentrations (less than 40 ppb).

Potholes fish contained DDT compounds, dieldrin (37 ppb), dacthal (19 ppb), methoxychlor (7 ppb), and HCB (2 ppb). These results are consistent with a recent screening of pesticides in Potholes following a May 1993 fish kill (Block, 1993), in which DDE, dieldrin, methoxychlor, and heptachlor epoxide were all detected at low concentrations (approximately 10 ppb) in yellow perch. Block did not rule out the possibility that pesticides caused the fish kill, although she did suggest that if toxic levels of pesticides were introduced to the reservoir, it was not via the wasteways.

Total PCB concentrations of 720 ppb and 170 ppb were detected in whole largescale suckers from Long Lake and Lake Sammamish, respectively. Like DDT, PCBs are persistent and ubiquitous in the environment. Although their production in the U.S. has been banned since 1977, they were detected in over 91% of the 362 sites sampled during EPA's national study of chemical residues in fish (EPA, 1992).

PCB contamination of Long Lake and other Spokane River sites has been documented by Ecology in the past (Hopkins *et al.*, 1985; Johnson, 1991). Table 6 shows the total PCB concentration in Long Lake suckers in the present survey compared to whole bottom fish data from previous Ecology surveys. It appears that PCB concentrations in Spokane River fish have not changed substantially since 1980. In response to these results, Ecology is currently conducting a follow-up survey to evaluate the extent and significance of PCBs in fish and sediment from the Spokane River (Johnson *et al.*, 1994).

To put whole fish DDT and PCB concentrations in perspective, they were compared to results of national and Washington state surveys (Table 7). Except for DDT in Roses Lake and PCBs in Long Lake, concentrations of these compounds are generally below the averages found in whole fish during the state and national surveys. DDT concentrations found during the 1992 Washington State Pesticide Monitoring Program were elevated, probably due to selection of sites where high potential for contamination existed (Davis and Johnson, 1994). Results reported here may also reflect an overall decreasing trend in DDT and PCB concentrations since the mid-1970s. Schmitt *et al.* (1990) found a 30% decline in DDT concentrations and a 56% decline in PCB concentrations nationwide since the USF&WS conducted their initial survey of organochlorines during 1976-1977.

Table 7. DDT and PCB Concentrations in Whole Fish Analyzed During the Present Survey, and in Nationwide and Statewide Surveys (ug/Kg [ppb], wet weight basis).

PRESENT SURVEY			Total DDT	Total PCB
Potholes	Largescale sucker		134	<71
Long	Largescale sucker		107	724
Roses	Brown bullhead		480	<74
Sammamish	Largescale sucker		57	169
U.S. Fish & Wildlife Service 1984 National Survey[1] (321 samples from 112 sites)		mean =	260	390
Ecology 1989 Basic Water Monitoring Program[2] (8 samples from 7 sites)		mean =	104	<80[4]
Ecology 1992 Washington State Pesticide Monitoring Program[3] (6 samples from 6 sites)		mean =	432	156

[1] Schmitt *et al.*, 1990
[2] Hopkins, 1991
[3] Davis and Johnson, 1994-in prep.
[4] PCB-1260 detected in one sample at 55 ppb

Mercury and Organics in Predator Fish Muscle

Mercury concentrations were generally low in predator fish muscle, with the exception of a moderately elevated 0.35 mg/Kg (parts per million, ppm) in Ward Lake bass (Table 8). Concentrations of mercury in all other samples were less than 0.1 ppm. Piscivorous species such as largemouth bass would be expected to have higher concentrations due to mercury's tendency to biomagnify. However, largemouth bass and yellow perch (another piscivorous species) from the other lakes had low mercury concentrations.

Table 8. Mercury Concentrations in Fish Muscle (mg/Kg [ppm], wet weight basis).

Sample No.	Lake	Species	Hg
358555	Long lake	Yellow perch	0.035J
358557	"	Largemouth bass	0.024J
358551	Potholes Reservoir	Lake whitefish	0.039
358553	"	Largemouth bass	0.082J
358559	Roses lake	Brown bullhead	0.010J
358561	"	Rainbow trout	0.026J
358563	Lake Sammamish	Brown bullhead	0.066J
358565	"	Largemouth bass	0.092J
438042	Ward Lake	Largemouth bass	0.35J
438044	"	Rainbow trout	0.053

J = Estimated Concentration

The FDA has set an "action level" for mercury in fish at 1.0 ppm. If samples exceed the action level, the FDA can legally have fish removed from the market. Aside from the Ward Lake largemouth bass, concentrations reported here were one-to-two orders of magnitude below the FDA action level.

Concentrations of all organic compounds detected in muscle samples are shown in Appendix B-1 and Table 9. DDE was detected in all muscle samples. Concentrations of t-DDT ranged from a low of 2 ppb in several samples to 186 ppb in Roses Lake bullhead and 103 ppb in Roses Lake rainbow trout.

PCBs were not detected in any predator muscle samples except for 8 ppb PCB-1260 in rainbow trout from Ward Lake. Other pesticides detected in muscle were HCB (30% of samples), dieldrin (20%), DDMU (20%), and dacthal (20%). Concentrations were less than 70 ppb.

Ecology is currently developing water quality standards to protect human health from the effects of toxic chemicals in edible fish tissue. In the interim, the EPA National Toxics Rule (40 CFR 131) is used to define levels considered protective of human health. These criteria are based on an average fish muscle consumption of 6.5 grams/day, an average adult body weight of 70 kilograms, and an average lifetime exposure to carcinogens and non-carcinogens of 70 years. Under the National Toxics Rule, Washington State has set an upper-bound excess lifetime cancer risk of one in a million (10^{-6}; one additional case of cancer per million people exposed) as the acceptable level of risk (WAC 173-201A).

Table 9. Organic Compounds Detected in Predator Fish Muscle (ug/Kg [ppb], wet weight basis).

Sample Number	Lake	Species	4,4'-DDT	4,4'-DDE	4,4'-DDD	Dieldrin	PCB-1260	DDMU	Hexa-chloro-benzene	Dacthal (DCPA)
358551	Potholes	Lake whitefish	6J	28	8	[32]	<73	<36	2J	62J
358553	"	Largemouth bass	<7	4J	<7	[5J]	<69	<35	<7	5J
358555	Long	Yellow perch	<8	2J	<8	<8	<75	<38	<8	<38
358857	"	Largemouth bass	<7	2J	<7	<7	<75	<37	<7	<37
358559	Roses	Brown bullhead	2J	[165]	19	<10	<97	5J	<10	<48
358561	"	Rainbow trout	2J	[75]	26	<7	<67	15J	<7	<34
358563	Sammamish	Brown bullhead	<8	2J	<8	<8	<77	<38	<8	<38
358565	"	Largemouth bass	<11	3J	<11	<11	<110	<55	0.4J	<55
438042	Ward	Largemouth bass	<10	4J	<10	<10	<99	<50	<10	<50
438044	"	Rainbow trout	3J	7	3J	<7	[8J]	<35	2J	<35
Human Health Criteria (EPA National Toxics Rule-40 CFR Part 131)			32	32	45	0.6	1.4	N/A	6.7	N/A

< = Not detected at concentration shown
J = Estimated concentration
[ ] Exceeds Human Health Criteria
N/A = Not Available

Table 9 shows organic chemicals detected in predator fish muscle and applicable EPA criteria at a 10^{-6} risk level. Samples from Potholes, Roses, and Ward Lakes exceed the EPA human health criteria for dieldrin, DDE, and PCB-1260, respectively. These compounds are all considered carcinogens.

Because fish muscle from Potholes, Roses, and Ward Lakes exceed EPA National Toxics Rule criteria, they are being considered for inclusion on Washington State's final "water quality limited" list. The "water quality limited" list is comprised of surface waters exceeding state water quality standards, and is used to help set priorities for controlling sources of water pollution.

Metals and Organic Compounds in Sediment

As previously mentioned, two sediment samples were analyzed for metals and organic compounds from five lakes. Samples were also analyzed for percent solids, grain size, and total organic carbon (TOC). Results of these analyses are shown in Appendix C-1.

TOC ranged from 1.7 to 4.8 percent of the dry weight of all samples except for sediments from Ward Lake, which had much higher TOC (11.9 and 13.4%). Grain size fractions were also generally consistent for each sample (Figure 2) All samples contained greater than 50% silt, defined as the fraction with particle sizes between 1.9 and 62.5 microns (μm). At time

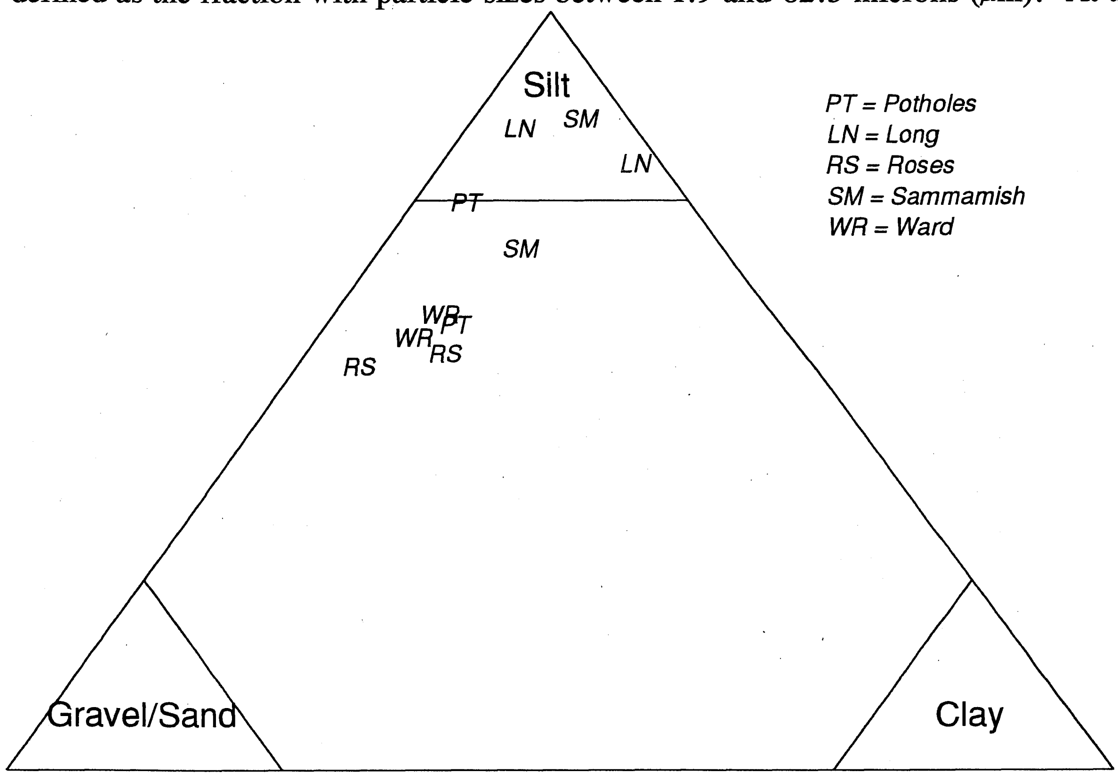

Figure 2. Grain Size Composition of Bottom Sediments
SAND >62um SILT =2-62um CLAY <2um

of collection, Roses Lake sediments appeared to be substantially different from those from the other lakes. Roses Lake sediments had a golden color, an extremely soft, "fluffy" texture, and a strong sulfur smell. It is surprising that these samples had a high sand fraction since they appeared to be composed of very fine particles. One possible explanation is that colloidal material remained in the larger meshes during grain size analysis, yielding an elevated false reading of the sand fraction.

EPA priority pollutant metals detected in sediment samples are shown in Table 10. Zinc was generally found at the highest concentrations, followed by lead, copper, nickel, and arsenic. Long Lake had high zinc and cadmium concentrations and somewhat elevated lead concentrations compared to sediments from the other lakes. Zinc, cadmium, and lead were higher at Mile 39 (1,660, 19, and 160 ppm, respectively) compared to the Mile 50 site upstream (1,270, 14, and 76 ppm, respectively). Investigations by Yake (1979) and Johnson *et al.* (1988 and 1994) have shown high concentrations of these metals throughout the Spokane River down to its confluence with the Columbia River.

Ward and Sammamish Lakes had the highest concentrations of copper, chromium, nickel, and arsenic. Only Long Lake sediments exceeded zinc and lead concentrationsfrom these lakes. Urban runoff is a potential source of these metals to Lake Sammamish, since it situated in an urban environment and these contaminants are common constituents of street runoff. High levels of arsenic in Lake Sammamish, and to a lesser extent, Ward Lake, may also be due to its use as a preservative in wood for docks, piers, and other marine applications.

Selenium, beryllium, and mercury were detected in at least half of the sediment samples, but at very low levels. Antimony, silver, and thallium were not detected in any of the samples.

Figure 3 shows metals concentrations in this study compared to medians of freshwater sediments statewide, compiled by Bennett and Cubbage (as cited in Cubbage, 1992). Cubbage notes that the Washington freshwater sediment data do not necessarily reflect background conditions, since data are often from sites with potential or known metals contamination. Zinc, lead, and cadmium in Long Lake sediments were elevated an order of magnitude above Washington median values. Lead, arsenic, and cadmium in Ward Lake sediments were elevated approximately five-fold above statewide levels. Arsenic concentrations in Lake Sammamish sediments were also much higher than the median state level. In most instances, metals concentrations in the present survey were similar to other Washington sediments.

There are presently no numerical federal or Washington State criteria for freshwater sediment quality. A review of various criteria and guidelines for contaminated freshwater sediments conducted by Bennett and Cubbage (1991) concluded that the guidelines developed for the province of Ontario (Persaud *et al.*, 1992, revised March 1993) were best supported by evidence of *in situ* impacts. Results of metals in the present survey are compared to the severe effects levels derived by Persaud *et al.* (Table 10). Severe effects levels are

Table 10. Chemical Concentrations in Lake Sediments Compared to Ontario Sediment Quality Guidelines.

		Metals (mg/Kg[ppm], dry)										Organics (ug/Kg OC)		
Lake	Station	Zn	Pb	Cu	Cr	Ni	As	Cd	Se	Be	Hg	bis-(2-Ethylhexyl) Phthalate	Diethyl-Phthalate	t-DDT
Potholes	Frenchman Hills	54	8.8J	31	12	14J	5.0	<1.0	0.64	0.52J	<0.01	<11,000	<11,000	<1,100
"	Lind Coulee	53	7.2J	29	13	13J	5.2	<1.0	0.53	0.60J	<0.01	11,000 J	<12,000	<1,200
Long	Mile 39	1,660	165J	44	32	25J	13	19	0.26J	1.4J	0.044J	15,000 J	7,300	<810
"	Mile 50	1,270	76J	28	21	18J	7.6	14	0.23J	0.91J	0.039J	13,000 J	<7,800	<780
Roses	Outlet	50	26J	13	5.2J	8.4J	12	<1.0	0.47J	<0.50	<0.01	24,000 J	<35,000	88,000
"	East End	44	25J	15	5.6J	5.3J	10	<1.0	0.53	<0.50	<0.01	<12,000	<12,000	37,000
Sammamish	Greenwood Pt.	76	11J	43	45	43	72	<1.0	0.22J	0.66J	0.053	5,000 J	<6,400	<640
"	Adelaide	121	64J	61	52	53	20	1.7J	0.51	0.81J	0.039J	8,100 J	<10,000	<1,000
Ward	North End	149	92J	66	44	46	41	2.3J	0.51	0.79J	0.036J	6,900 J	<5,000	<520
"	South End	146	94J	66	47	46	34	2.2J	0.46J	0.89J	0.025J	3,100 J	<4,900	350
Ontario Provincial Guidelines: Severe Effects Levels (Persaud et al., 1992)		820	250	110	110	N/A	33	10	N/A	N/A	2	N/A	N/A	12,000

< = Not detected at concentration shown
[box] Exceeds Guidelines
OC = Organic Carbon
J = Estimated concentration
N/A = Not Available

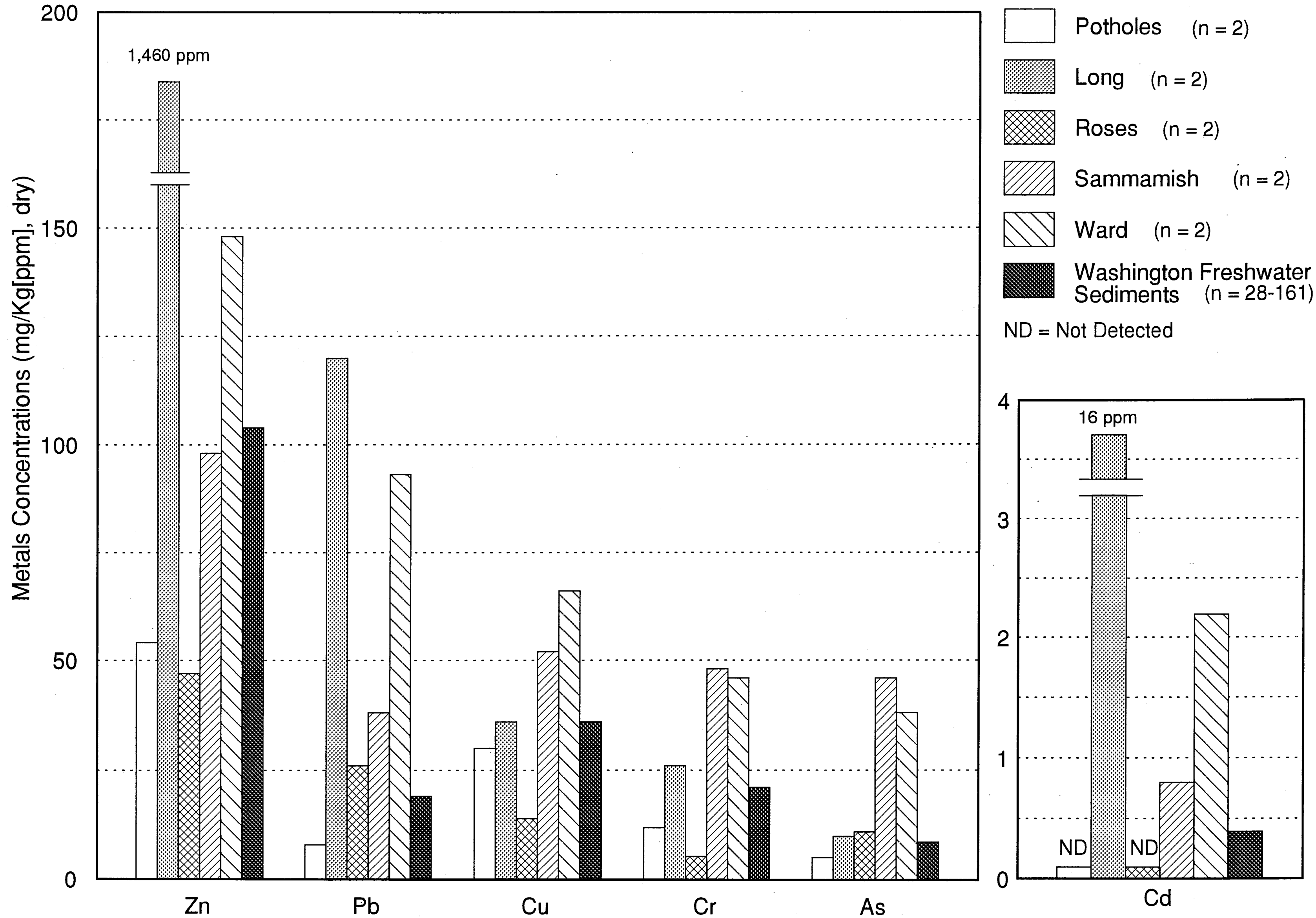

Figure 3. Metals Concentrations in Present Survey Compared to Freshwater Sediments in Washington (adapted from Cubbage, 1992).

concentrations at which pronounced impacts to benthic organisms can be expected. Long Lake sediments exceeded the severe effects levels for both zinc and cadmium. Arsenic levels were exceeded at one site in Lake Sammamish and both sites in Ward Lake.

Sediments were also analyzed for semivolatile organics, organophosphorous and chlorinated pesticides, PCBs, and chlorophenoxy herbicides. Organic chemicals detected in sediments are shown in Appendix C-2. None of the six chlorophenoxy herbicides, twenty-four organophosphorous pesticides, or six PCB compounds were detected. However, the detection limits achieved for chlorophenoxy herbicides and PCBs were an order of magnitude higher than desired.

Detection limits for the semivolatile compounds were also an order of magnitude higher than desired, and probably as a result only two of these compounds were detected in any of the samples. Bis(2-ethylhexyl)phthalate, a plasticizer and common field and laboratory contaminant, was found at all lakes at concentrations ranging from 110 to 920 ppb. Diethylphthalate was also detected at one site - Long Lake at Mile 39 (190 ppb).

DDT and its derivatives were the only other organic compounds detected in sediments. Roses Lake had extremely high concentrations of t-DDT at both sites sampled (1,760 and 1,490 ppb). These levels, adjusted for organic carbon, exceeded severe effects levels for freshwater sediments (Table 10). DDT concentrations were more than double those found at the most contaminated site sampled in Lake Chelan during 1986 (Patmont *et al.*, 1989) and more than six times higher than the most contaminated site in the Yakima River basin, an area with well-documented DDT contamination from historical usage (Johnson *et al.*, 1986). The only other site where a DDT compound was detected in sediment was at the south end of Ward Lake (DDD = 42 ppb).

It is unusual that a highly lipophilic compound such as DDT (and metabolites) was found at much higher levels in Roses Lake sediments than fish. One possible explanation is that the fish specimens obtained had not been in the lake long enough to come to equilibrium with ambient sediment concentrations. Another possibility is that the fish samples did not contain enough fatty tissue to accumulate substantial concentrations of DDT compounds. Patmont *et al.* (1989) reported that t-DDT concentrations in Lake Chelan were positively correlated with fish length and lipid content. They also suggested that large piscivorous fish, unlike the rainbow trout and bullhead from Roses Lake, may demonstrate a biomagnification effect. Juvenile rainbow trout are stocked yearly in Roses Lake by the Washington State Department of Wildlife and therefore may only spend part of their life exposed to significant DDT concentrations, a variable which further confounds any conclusions about uptake of sediment DDT by fish.

Copper in Bottom Sediments of Treated Lakes

Five lakes in western Washington were sampled for copper in bottom sediments. These lakes had a history of copper sulfate treatments for algal control. Five composite sediment samples were collected from each lake: three of which were from areas of known or suspected treatment. A detailed description of each sampling location is included in Appendix A-1.

A summary of copper concentrations is shown in Table 11. Complete results of these sediment analyses are shown in Appendix C-3. Ketchum Lake had the highest copper concentrations, followed by Spanaway, Ohop, Silver, and Duck Lakes. Ketchum Lake is the smallest of the lake surveyed, and one of the most heavily developed. Review of Ecology records suggests that it has been treated with copper sulfate during four or more years in the past decade. Water in Ketchum Lake was murky during sample collection (2 February 1993), possibly due to dense algal growth. This suggests that Ketchum Lake continues to have a serious algal problem and may be eutrophic.

Table 11. Summary of Copper Concentrations in Lakes Sampled for Copper Only (mg/Kg[ppm], dry weight basis; n=5).

Lake	Mean	Range
Duck	27	13 - 36
Spanaway	185	89 - 308
Ohop	106	73 - 149
Ketchum	480	260 - 600
Silver	51	32 - 80

High copper concentrations in sediments have been shown to cause toxic effects to bioassay organisms in some cases (Bennett and Cubbage, 1992). Persaud *et al.* (1992) have established a severe effect level for copper at 110 ppm, above which pronounced disturbances to benthic organisms can be expected. Mean copper levels in Ketchum and Spanaway Lakes exceed this level, and Ohop Lake sediments approach it. Copper concentrations from all sites at Duck and Silver Lakes were below the severe effects level (Figure 4).

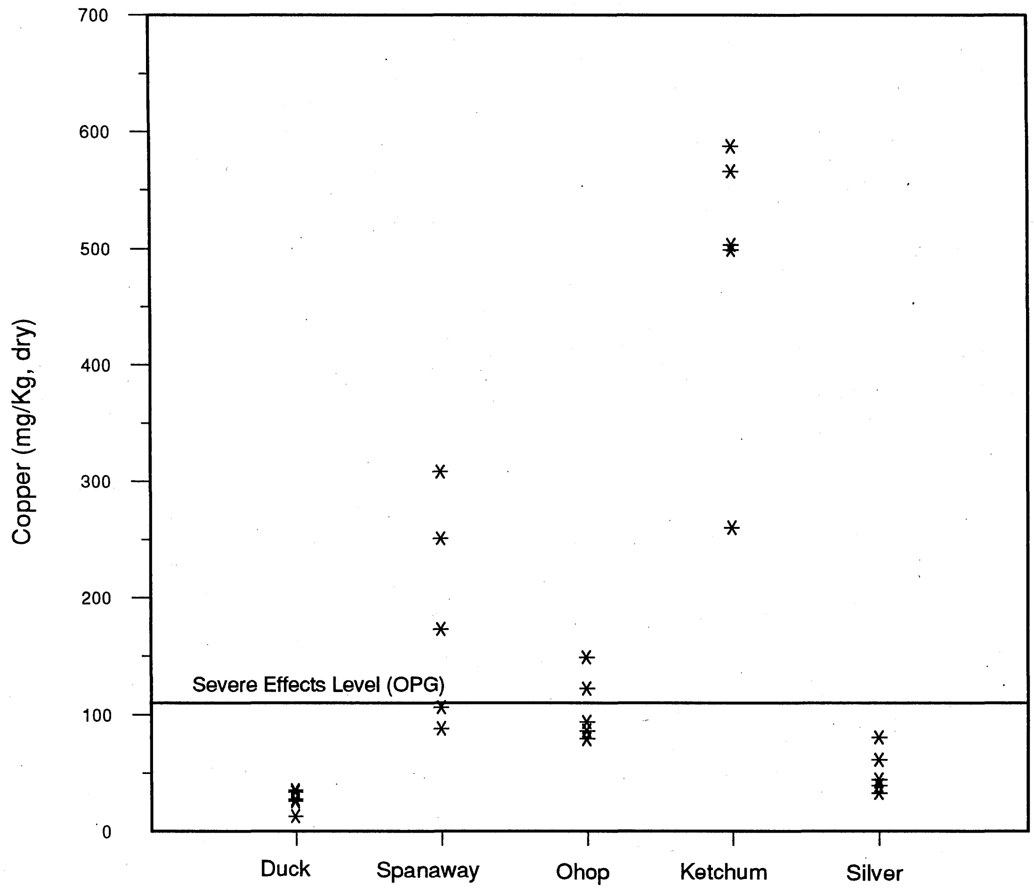

Figure 4. Copper Concentrations in Sediments
(OPG = Ontario Provincial Guidelines)

Long-term treatment of lakes with copper sulfate to control algae has been shown to produce detrimental effects to lake ecosystems. Hanson and Stefan (1984) reported that shallow lakes in Minnesota treated with copper sulfate over six decades resulted in a shift of species from green to blue-green algae; a shift from game fish to rough fish; reductions in benthic macroinvertebrates; disappearance of macrophytes; and occasional oxygen depletion and fish kills following treatments. Mean copper concentrations in surficial sediments of these lakes ranged from 162 to 943 ppm two years after copper treatments were suspended. This may suggest that impacts of the sort described above may be occurring in Ketchum Lake, and possibly at some sites in Spanaway Lake.

Summary By Lake

I. Lakes Sampled For Metals And Organics

Potholes Reservoir

Overall contamination of sediment and fish was the lowest of any of the five lakes surveyed. None of the sediment samples exceeded sediment quality guidelines for metals or organic compounds. Low concentrations of nine chlorinated pesticides, including five DDT compounds, were detected in Potholes fish. The significance of this finding is uncertain. Muscle tissues of lake whitefish and largemouth bass exceed human EPA health criterion for dieldrin.

Long Lake (Spokane River)

Fish and sediments from Long Lake showed the highest concentrations of several priority pollutant metals. Lead and cadmium concentrations in Long Lake fish were three-to-four times higher than mean values reported during a 1984 U.S. Fish & Wildlife Service survey of metals in whole fish nationwide. Concentrations of zinc, lead, and cadmium in sediment were an order of magnitude higher than freshwater sediments statewide and the other four lakes surveyed here. Zinc and cadmium in sediments are present at levels which may cause pronounced disturbances to benthic organisms. Elevated PCBs in whole fish tissue (720 ppb total PCBs) also represent a possible concern. These levels suggest that PCB concentrations have not decreased significantly in the Spokane River during the past decade.

Roses Lake

Sediments from Roses Lake have extremely high concentrations of DDT compounds (1,490 - 1,760 total DDT) and exceed sediment quality guidelines. Two species of fish collected from the lake have muscle DDT concentrations exceeding the EPA human health criterion for DDE. Total DDT concentrations in fish were elevated compared to other lakes sampled during this study, but concentrations did not appear to be elevated on a statewide or national scale. DDT levels in Roses Lake are apparently a result of historical DDT usage in the southern Lake Chelan basin, and are probably indicative of widespread contamination in this area.

Sammamish and Ward Lakes

Priority pollutant metals and organic compound levels in these urban lakes were generally low. Concentrations of copper, chromium, nickel, and arsenic in sediment were elevated compared to other lakes, possible as a result of inputs from urban runoff. Arsenic concentrations exceeded sediment quality guidelines at both sites in Ward Lake (34 and

41 ppm) and at one site in Lake Sammamish (72 ppm). PCBs were detected in Lake Sammamish whole fish at 170 ppb total PCB. Ward Lake rainbow trout muscle also had PCB concentrations (8 ppb) in excess of the EPA human health criterion for PCB. DDD was detected in Ward Lake sediment at 42 ppb. Except for arsenic and possibly PCBs in Ward Lake, concentrations of chemicals in these two lakes are of little significance.

II. Lakes Sampled For Copper Only

Duck and Silver Lakes

Results of copper analyses in sediments from five sites in each lake indicate that levels are low and of no concern.

Spanaway Lake

Three of five sediment samples from Spanaway Lake exceeded sediment quality guidelines, by as much as three times (173 - 308 ppm). Two sites with the lowest concentrations were from undeveloped areas of the lake, suggesting copper sulfate treatment is responsible for high concentrations at other sites.

Ketchum Lake

All sites at this small, heavily developed lake had high copper levels in sediment (260 - 600 ppm), which may indicate that the entire lake has contaminated sediments. Adverse effects to benthic organisms and other components of the lake ecosystem may be occurring as a result of these copper concentrations. Poor water clarity observed in mid-winter may also indicate that Ketchum Lake continues to have excessive algal production.

Ohop Lake

Copper concentrations in sediments appear to be similar throughout this two-and-one-half mile-long lake. Mean concentrations are nearly equal the 110 ppm severe effect level. Samples collected near developed areas tended to have the highest copper concentrations.

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APPENDIX A

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Table A-1. Description of Sediment Sampling Locations.

Sample Number	Lake	Station	Date Sampled	Description	Depth (ft)	Latitude x Longitude
248130	Potholes Reservoir	Frenchman Hills	8Jun92	400 m off mouth of wasteway	44	46 55'13"x119 20'31"
248131	"	Lind Coulee	8Jun92	300 m off spillway	73	46 59'19"x119 15'57"
248132	Long Lake	Mile 39	9Jun92	mid-channel at RM 39	64	47 49'48"x117 45'13"
248133	(Spokane R.)	Mile 39-Dupl.	9Jun92			
248134	"	Mile 50	9Jun92	150 m off R. bank at RM 50	50	47 50'06"x117 38'01"
248135	Roses Lake	Outlet	9Jun92	400 m offshore midway between outlet and bay on north side	28	47 54'20"x120 09'27"
248136	"	East End	9Jun92	200 m off house at east end of lake	23	47 54'05"x120 08'52"
248137	Lake Sammamish	Greenwood Pt.	10Jun92	middle of lake midway between Greenwood Pt. and State Park	74	47 34'01"x122 04'21"
248138	"	Adelaide	10Jun92	middle of lake midway between Adelaide and Weber Pt.	54	47 38'18"x122 04'57"
248139	Ward lake	North End	10Jun92	50 m offshore at north end of lake	46	47 00'38"x122 52'25"
248140	"	South End	10Jun92	50 m offshore at	50	47 00'28"x122 52'31"
248141	"	South End-Dupl.	10Jun92			
048230	Duck	DC-1	25Jan93	@ southern outlet	9	46 57'39"x124 08'18"
048231	"	DC-2	25Jan93	off northermost islet	10	46 58'30"x124 08'46"
048232	"	DC-3	25Jan93	open water south of park	10	46 59'34"x124 08'50"
048233	"	DC-4	25Jan93	north end near channel	15	47 00'18"x124 08'57"
048234	"	DC-5	25Jan93	off northern boat ramp	7	46 59'50"x124 08'47"
048235	Spanaway	SP-1	26Jan93	shallow bay @ south end	6	47 06'13"x122 26'29"
048236	"	SP-1 Dupl.	26Jan93			
048237	"	SP-2	26Jan93	center lake	24	47 06'37"x122 26'43"
048238	"	SP-3	26Jan93	small bay on west side	8	47 06'39"x122 27'06"
048239	"	SP-4	26Jan93	@ outlet	5	47 07'09"x122 26'48"
048240	"	SP-5	26Jan93	off public bathing beach	8	47 07'04"x122 26'46"
048241	Ohop	OH-1	29Jan93	near outlet	N/A	46 53'09"x122 16'36"
048242	"	OH-1 Dupl.	29Jan93			
048243	"	OH-2	29Jan93	center of north lobe	18	46 54'21"x122 16'11"
048244	"	OH-3	29Jan93	near west shore at mid-lake	8	46 54'18"x122 16'35"
048245	"	OH-4	29Jan93	in embayment on west shore	10	46 54'00"x122 16'47"
048246	"	OH-5	29Jan93	near east shore at mid-lake	15	46 53'59"x122 16'40"
048247	Ketchum	KT-1	2Feb93	center lake	17	48 16'57"x122 20'41"
048248	"	KT-2	2Feb93	off wetland @ NE corner	10	48 16'58"x122 20'30"
048249	"	KT-3	2Feb93	near SE inlet	6	48 16'51"x122 20'25"
048250	"	KT-4	2Feb93	near shore @ NW corner	6	48 16'58"x122 20'47"
048251	"	KT-4 Dupl.	2Feb93			
048252	"	KT-5	2Feb93	in cove at SW end	9	48 16'54"x122 20'44"
048353	Silver	SL-1	2Feb93	center lake	52	47 53'34"x122 12'29"
048354	"	SL-2	2Feb93	near wetlands @ south side	6	47 53'25"x122 12'31"
048355	"	SL-3	2Feb93	off RV park on west side	6	47 53'25"x122 12'45"
048356	"	SL-4	2Feb93	@ water slide on NW shore	16	47 53'43"x122 12'31"
048357	"	SL-5	2Feb93	off eastern shore near road	11	47 53'35"x122 12'16"

N/A = Not Available

Table A-2. Biological Information on Fish Samples (each sample a composite of 5 individuals).

Sample Number	Lake	Date Collected	Species	Scientific Name	Sample Type	Total Length in mm (mean ± SD)	Weight in grams (mean ± SD)
358551	Potholes Reservoir	25Aug92	Lake whitefish	*Coregonus clupeaformis*	fillet	465 ± 39	1,222 ± 316
358553	"	24Aug92	Largemouth bass	*Micropterus salmoides*	fillet	300 ± 27	508 ± 125
358089	"	24Aug92	Largescale sucker	*Catostomus macrocheilus*	whole	425 ± 55	900 ± 306
358555	Long Lake (Spokane R.)	26Aug92	Yellow perch	*Perca flavescens*	fillet	259 ± 13	247 ± 27
358857	"	26Aug92	Largemouth bass	*Micropterus salmoides*	fillet	331 ± 28	657 ± 114
438048	"	26Aug92	Largescale sucker	*Catostomus macrocheilus*	whole	459 ± 37	967 ± 184
358559	Roses Lake	26Aug92	Brown bullhead	*Ictalurus nebulosus*	fillet	202 ± 38	119 ± 65
358561	"	27Aug92	Rainbow trout	*Oncorhynchus mykiss*	fillet	327 ± 61	364 ± 289
438046	"	26Aug92	Brown bullhead	*Ictalurus nebulosus*	whole	209 ± 39	134 ± 75
358563	Lake Sammamish	27Aug92	Brown bullhead	*Ictalurus nebulosus*	fillet	234 ± 14	171 ± 31
358565	"	27Aug92	Largemouth bass	*Micropterus salmoides*	fillet	177 ± 34	86 ± 62
438047	"	27Aug92	Largescale sucker	*Catostomus macrocheilus*	whole	442 ± 46	865 ± 230
438042	Ward Lake	12Nov92	Largemouth bass	*Micropterus salmoides*	fillet	224 ± 6	150 ± 7
438044	"	12Nov92	Rainbow trout	*Oncorhynchus mykiss*	fillet	301 ± 22	259 ± 70

Table A-3. Analytical Methods Used.

Analysis	Method	EPA Method Number	Laboratory
BOTTOM SEDIMENTS			
% Solids	Dry	160.3	Soil Technology, Inc., Bainbridge Is., WA
TOC	CO2 generation	PSEP (a)	Analytical Resources, Inc., Seattle WA
Grain Size	sieve-pipet	PSEP (a)	Soil Technology, Inc., Bainbridge Is., WA
P.P Metals			
As	GFAA	206.2/7060	EPA/Ecology Environmental Lab., Manchester, WA
Se	"	270.2/7740	EPA/Ecology Environmental Lab., Manchester, WA
Tl	"	7841	EPA/Ecology Environmental Lab., Manchester, WA
Sb,Be,Cd,Cr	ICP	200.7/6010	EPA/Ecology Environmental Lab., Manchester, WA
Cu,Ni,Ag,Zn	"	"	EPA/Ecology Environmental Lab., Manchester, WA
Hg	CVAA	245.1,245.5 7470/7471	EPA/Ecology Environmental Lab., Manchester, WA
Semivolatiles	GC/MS	625/8270	Analytical Resources, Inc., Seattle WA
Chlor. Pest./PCBs	GC/ECD	608/8080	Analytical Resources, Inc., Seattle WA
OP Pesticides	GC/NPD	614/8141 (mod.)	Analytical Resources, Inc., Seattle WA
Chlorophenoxy Herbicides	GC/ECD	615/8150	Analytical Resources, Inc., Seattle WA
FISH TISSUE			
% Lipid		RX1-608.5	EPA/Ecology Environmental Lab., Manchester, WA
% Non-Polar Lipid		Schneider (b)	EPA/Ecology Environmental Lab., Manchester, WA
P.P Metals			
As	GFAA	206.2/7060	EPA/Ecology Environmental Lab., Manchester, WA
Se	"	270.2/7740	EPA/Ecology Environmental Lab., Manchester, WA
Tl	"	7841	EPA/Ecology Environmental Lab., Manchester, WA
Pb	"	239.2/7421	EPA/Ecology Environmental Lab., Manchester, WA
Sb,Be,Cd,Cr	ICP	200.7/6010	EPA/Ecology Environmental Lab., Manchester, WA
Cu,Ni,Ag,Zn	"	"	EPA/Ecology Environmental Lab., Manchester, WA
Hg	CVAA	245.1,245.5 7470/7471	EPA/Ecology Environmental Lab., Manchester, WA
Chlor. Pest./PCBs	GC/AED	608/1618	EPA/Ecology Environmental Lab., Manchester, WA
OP Pesticides	GC/AED	608/1618	EPA/Ecology Environmental Lab., Manchester, WA

(a) Puget Sound Protocols, from Tetra Tech (1986)
(b) from Schneider (1982)

Table A-4. Target Chemicals and (Quantitation Limits).

Fish Tissue

1. Metals (mg/Kg, wet)

Antimony	(1.5)
Arsenic	(0.15)
Beryllium	(0.050)
Cadmium	(0.10)
Chromium	(0.25)
Copper	(0.15)
Lead	(0.05)
Mercury	(0.005)
Nickel	(0.25 - 0.50)
Selenium	(0.10)
Silver	(0.15)
Thallium	(0.13 - 0.25)
Zinc	(1.3)

2. Organophosphorous Pesticides (ug/Kg, wet)

Chloropyrifos	(67 - 110)
Ethion	(67 - 110)
Diazinon	(67 - 110)
Methyl Parathion	(67 - 110)
Parathion	(67 - 110)

3. Chlorinated Pesticides/PCBs (ug/Kg, wet)

alpha-BHC	(7 - 11)
beta-BHC	(7 - 11)
gamma-BHC (Lindane)	(7 - 11)
delta-BHC	(7 - 11)
Heptachlor	(7 - 11)
Aldrin	(7 - 11)
Heptachlor Epoxide	(7 - 11)
Endosulfan I	(7 - 11)
4,4'-DDE	(7 - 11)
Dieldrin	(7 - 11)
Endrin	(7 - 11)
Endosulfan II	(7 - 11)
4,4'-DDD	(7 - 11)
Endrin Aldehyde	(7 - 11)
4,4'-DDT	(7 - 11)
Endosulfan Sulfate	(7 - 11)
Endrin Ketone	(7 - 11)
Methoxychlor	(7 - 11)
Chlordane	(67 - 110)
Toxaphene	(337 - 550)
PCB-1248	(67 - 110)
PCB-1221	(67 - 110)
PCB-1232	(135 - 220)
PCB-1242	(67 - 110)
PCB-1254	(67 - 110)
PCB-1260	(67 - 110)
gamma-Chlordene	(7 - 11)
alpha-Chlordene	(7 - 11)
alpha-Chlordane	(7 - 11)
gamma-Chlordane	(7 - 11)
Trans-Nonachlor	(7 - 11)
Cis-Nonachlor	(7 - 11)
Kelthane	(34 - 55)
2,4'-DDE	(7 - 11)
2,4'-DDD	(7 - 11)
2,4'-DDT	(7 - 11)
DDMU	(35 - 55)
Mirex	(17 - 28)
Chlorbenside	(34 - 55)
Hexachlorobenzene	(7 - 10)
Pentachloroanisole	(7 - 11)
Tetradifon (Tedion)	(34 - 55)
4,4'-Dichlorobenzophenone	(34 - 55)
Dacthal (DCPA)	(34 - 55)

Table A–4 (Cont'd). Target Chemicals and (Quantitation Limits).

Sediment

1. Metals (mg/Kg, dry)

Antimony	(15)
Arsenic	(0.15)
Beryllium	(0.10 – 0.50)
Cadmium	(0.20 – 1.0)
Chromium	(0.50)
Copper	(0.30)
Lead	(2.0)
Mercury	(0.010)
Nickel	(1.0)
Selenium	(0.20)
Silver	(1.5)
Thallium	(0.25)
Zinc	(0.73)

2. Organophosphorous Pesticides (ug/Kg, dry)

Dichlorvos	(25)
Mevinphos	(73)
Demeton–O	(23)
Ethoprop	(12)
Phorate	(15)
Demeton–S	(90)
Diazinon	(40)
Disulfoton	(100)
Atrazine	(90)
Simazine	(180)
Monochrotophos	(500)
Dimethoate	(90)
Ronnel	(12)
Chloropyrifos	(18)
Methyl Parathion	(12)
Fenthion	(12)
Malathion	(12)
Ethyl Parathion	(12)
Tokuthion	(23)
Tetrachlorvinphos	(48)
Bolstar	(15)
Fensulfothion	(93 – 240)
EPN	(25)
Coumaphos	(33)

3. Chlorophenoxy Herbicides (ug/Kg, dry)

Silvex	(30 –90)
2,4,5–T	(60 – 180)
Dinoseb	(60 – 180)
Dicamba	(60 – 180)
2,4–D	(120 – 630)
2,4–DB	(600 – 1,800)

4. Chlorinated Pesticides/PCBs (ug/Kg, dry)

alpha–BHC	(7.0 – 35)
beta–BHC	(7.0 – 35)
delta–BHC	(7.0 – 35)
gamma–BHC (Lindane)	(7.0 – 35)
Heptachlor	(7.0 – 35)
Aldrin	(7.0 – 35)
Heptachlor Epoxide	(7.0 – 35)
Endosulfan I	(7.0 – 35)
Dieldrin	(14 – 70)
4,4'–DDE	(14 – 70)
Endrin	(14 – 70)
Endosulfan II	(14 – 70)
4,4'–DDD	(14 – 70)
Endosulfan Sulfate	(14 – 70)
4,4'–DDT	(14 – 70)
Methoxychlor	(70 – 350)
Endrin Ketone	(14 – 70)
Endrin Aldehyde	(14 – 70)
gamma–Chlordane	(7.0 – 35)
alpha–Chlordane	(7.0 – 35)
Toxaphene	(700 – 3,500)
PCB–1242	(140 – 700)
PCB–1248	(140 – 700)
PCB–1254	(140 – 700)
PCB–1260	(140 – 700)
PCB–1221	(280 – 1,400)
PCB–1232	(140 – 700)

5. Semivolatile Organics (ug/Kg, dry)

Phenol	(280 – 1,400)
Bis(2–Chloroethyl)Ether	(140 – 700)
2–Chlorophenol	(140 – 700)
1,3–Dichlorobenzene	(140 – 700)
1,4–Dichlorobenzene	(140 – 700)
Benzyl Alcohol	(690 – 3,500)
1,2–Dichlorobenzene	(140 – 700)
2–Methylphenol	(140 – 700)
2,2'–Oxybis(1–Chloropropane)	(140 – 700)
4–Methylphenol	(140 – 700)
N–Nitroso–di–n–Propylamine	(140 – 700)
Hexachloroethane	(280 – 1,400)
Nitrobenzene	(140 – 700)
Isophorone	(140 – 700)
2–Nitrophenol	(690 – 3,500)
2,4–Dimethylphenol	(280 – 1,400)
Benzoic Acid	(1,400 – 7,000)
Bis(2–Chloroethoxy)Methane	(140 – 700)
2,4–Dichlorophenol	(420 – 2,100)
1,2,4–Trichlorobenzene	(140 – 700)
Naphthalene	(140 – 700)
4–Chloroaniline	(420 – 2,100)
Hexachlorobutadiene	(280 – 1,400)
4–Chloro–3–Methylphenol	(280 – 1,400)
2–Methylnaphthalene	(140 – 700)
Hexachlorocyclopentadiene	(690 – 3,500)
2,4,6–Trichlorophenol	(690 – 3,500)
2,4,5–Trichlorophenol	(690 – 3,500)
2–Chloronaphthalene	(140 – 700)
2–Nitroaniline	(690 – 3,500)
Dimethyl Phthalate	(140 – 700)
Acenaphthylene	(140 – 700)
3–Nitroaniline	(690 – 3,500)
Acenaphthene	(140 – 700)
2,4–Dinitrophenol	(1,400 – 7,000)
4–Nitrophenol	(690 – 3,500)
Dibenzofuran	(140 – 700)
2,6–Dinitrotoluene	(690 – 3,500)
2,4–Dinitrotoluene	(690 – 3,500)
Diethyl Phthalate	(140 – 700)
4–Chlorophenyl Phenylether	(140 – 700)
Fluorene	(140 – 700)
4–Nitroaniline	(690 – 3,500)
4,6–Dinitro–2–Methylphenol	(1,400 – 7,000)
N–Nitrosodiphenylamine	(140 – 700)
4–Bromophenyl Phenylether	(140 – 700)
Hexachlorobenzene	(140 – 700)
Pentachlorophenol	(690 – 3,500)
Phenanthrene	(140 – 700)
Carbazole	(140 – 700)
Anthracene	(140 – 700)
Di–n–Butyl Phthalate	(100 – 420)
Fluoranthene	(140 – 700)
Pyrene	(140 – 700)
Butylbenzyl Phthalate	(140 – 700)
3,3'–Dichlorobenzidine	(690 – 3,500)
Benzo(a)Anthracene	(140 – 700)
Bis(2–Ethylhexyl)Phthalate	(140 – 700)
Chrysene	(140 – 700)
Di–n–Octyl Phthalate	(140 – 700)
Benzo(b)Fluoranthene	(140 – 700)
Benzo(k)Fluoranthene	(140 – 700)
Benzo(a)Pyrene	(140 – 700)
Indeno(1,2,3–cd)Pyrene	(140 – 700)
Dibenzo(a,h)Anthracene	(140 – 700)
Benzo(g,h,i)Perylene	(140 – 700)

Table A-5. Duplicate Analysis of Standard Reference Material NIST 1588
(Cod Liver Oil; ug/Kg, wet).

Compound	Analysis #1	Analysis #2	Certified Value
Alpha-BHC	87	66	86 ± 19
Gamma-BHC (Lindane)	22	16	N/C
4,4'-DDT	465	380	529 ± 45
4,4'-DDE	635	470	641 ± 62
4,4'-DDD	253	190	277 ± 15
2,4'-DDT	<200	<200	156 ± 5
Dieldrin	241	160	150 ± 12
PCB-1254	2,900	2,310	N/C
PCB-1260	1,630	1,040	N/C
Trans-Chlordane (Gamma)	75	55	50 ± 13
Cis-Chlordane (Alpha)	265	175	158 ± 8
Trans-Nonachlor	265	200	209 ± 12
Hexachlorobenzene (HCB)	110	86	148 ± 21

N/C = Not Certified

< = Not detected at concentration shown

= outside of certified range

Table A-6. Results of Duplicate Analyses of Field Samples.

1. Long Lake (Mile 39) Sediment (sample #s 248132 and 248133).

	Percent	Grain Size (%)				TOC	Metals (mg/Kg, dry)										Organics (ug/Kg, dry)	
	Solids	Gravel	Sand	Silt	Clay	(%, dry)	Zn	Pb	Cu	Cr	Ni	As	Cd	Se	Be	Hg	Bis (2-Ethylhexyl) Phthalate	Diethyl-phthalate
	27	0	2	82	16	2.9	1680	165	44	32	26	13	19	0.26	1.5	0.17	550	190
	27	0	1	79	20	2.3	1640	154	44	31	24	13	19	0.26	1.4	0.15	220	<200
RPD =	0%	0%	67%	4%	22%	23%	2%	7%	0%	3%	8%	0%	0%	0%	7%	13%	86%	ND

2. Long Lake Fish Tissue (sample # 438048)

	Metals (mg/Kg, wet)							
	Zn	Pb	Cu	Cr	Ni	Cd	Se	Hg
	31.2	0.47	1.2	2.0	2.3	0.1	0.23	0.026
	27.8	0.41	1.6	3.9	1.9	<0.10	0.20	0.024
RPD =	12%	14%	30%	64%	19%	ND	14%	8%

3. Roses Lake Fish Tissue (sample # 438046)

	Chlorinated Pesticides (ug/Kg, wet)			
	4,4'-DDT	4,4'-DDE	4,4'-DDD	DDMU
	6	393	83	23
	7	383	89	25
RPD =	15%	3%	7%	8%

< = Not detected at concentration shown

ND = Not Detected

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APPENDIX B

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Table B-1. Organic Compounds Detected in Fish Tissue (ug/Kg, wet weight basis).

Sample Number	Lake	Species	Sample Type	Percent Lipid	Percent Non-Polar Lipid	4,4'-DDT	4,4'-DDE	4,4'-DDD	2,4'-DDE	2,4'-DDD	Dieldrin	Methoxy-chlor	PCB-1248	PCB-1242	PCB-1254	PCB-1260	Gamma-chlordene	Alpha-chlordene	DDMU	Hexa-chloro-benzene	Penta-chloro-anisole	Dacthal (DCPA)
358551	Potholes	Lake whitefish	fillet	7.3	N/A	6J	28	8	<7	<7	32	<7	<73	<73	<73	<73	<7	<7	<36	2J	<7	62J
358553	"	Largemouth bass	fillet	0.3	N/A	<7	4J	<7	<7	<7	5J	<7	<69	<69	<69	<69	<7	<7	<35	<7	<7	5J
358089	"	Largescale sucker	whole	8.6	7.3	10	82	37	3J	2J	37	7J	<71	<71	<71	<71	<7	<7	<35	2J	<7	19J
358555	Long	Yellow perch	fillet	0.2	N/A	<8	2J	<8	<8	<8	<8	<8	<75	<75	<75	<75	<8	<8	<38	<8	<8	<38
358557	"	Largemouth bass	fillet	2.1	N/A	<7	2J	<7	<7	<7	<7	<7	<75	<75	<75	<75	<7	<7	<37	<7	<7	<37
438048	"	Largescale sucker	whole	N/A	N/A	7J	91J	9J	<7	<7	<7	<7	287	<69	208J	229	<7	<7	<35	<9	<7	<35
358559	Roses	Brown bullhead	fillet	0.7	N/A	2J	165	19	<10	<10	<10	<10	<97	<97	<97	<97	<10	<10	5J	<10	<10	<48
358561	"	Rainbow trout	fillet	0.9	N/A	2J	75	26	<7	<7	<7	<7	<67	<67	<67	<67	<7	<7	15J	<7	<7	<34
438046*	"	Brown bullhead	whole	1.5	0.6	6J	388	86	<7	<7	<7	<7	<74	<74	<74	<74	<7	<7	24J	<7	<7	<37
358563	Sammamish	Brown bullhead	fillet	0.5	N/A	<8	2J	<8	<8	<8	<8	<8	<77	<77	<77	<77	<8	<8	<38	<8	<8	<38
358565	"	Largemouth bass	fillet	0.4	N/A	<11	3J	<11	<11	<11	<11	<11	<110	<110	<110	<110	<11	<11	<55	0.4J	<11	<55
438047	"	Largescale sucker	whole	4.5	3.6	3J	35	19	<8	<8	<8	<8	<75	21J	86J	62J	4J	10J	<38	4J	2J	<38
438042	Ward	Largemouth bass	fillet	0.1	N/A	<10	4J	<10	<10	<10	<10	<10	<99	<99	<99	<99	<10	<10	<50	<10	<10	<50
438044	"	Rainbow trout	fillet	1	N/A	3J	7	3J	<7	<7	<7	<7	<71	<71	<71	8J	<7	<7	<35	2J	<7	<35

< = Not detected at concentration shown

J = Estimated concentration

* result of duplicate analyses

N/A = Not Analyzed

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APPENDIX C

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Table C-1. Conventional Parameters of Lake Sediments

				Grain Size (%)				
Sample Number	Lake	Station	Percent Solids	Gravel (>2000 um)	Sand (2000-62.5 um)	Silt (62.5-1.9 um)	Clay (<1.9 um)	TOC (%, dry)
248130	Potholes Reservoir	Frenchman Hills	24	0	20	74	5	2.2
248131	"	Lind Coulee	29	0	29	58	12	1.7
248132/33	Long Lake (Spokane R.)	Mile 39	27*	0*	2*	80*	18*	2.6*
248134	"	Mile 50	42	0	10	82	5	1.8
248135	Roses Lake	Outlet	9	1	30	53	13	2.0
248136	"	East End	13	0	40	52	6	4.0
248137	Lake Sammamish	Greenwood Pt.	44	0	4	84	10	2.2
248138	"	Adelaide	13	1	17	68	13	4.8
248139	Ward lake	North End	9	0	34	57	9	13.4
248140	"	South End	11	2	28	60	10	11.9

* result of duplicate analyses

Table C-2. Organic Compounds Detected in Lake Sediments (ug/Kg, dry weight basis).

Sample Number	Lake	Station	bis-(2-Ethylhexyl) Phthalate	Diethyl-Phthalate	4,4'-DDT	4,4'-DDE	4,4'-DDD
248130	Potholes Reservoir	Frenchman Hills	<240	<240	<24	<24	<24
248131	"	Lind Coulee	**180 J**	<200	<21	<21	<21
248132/33	Long Lake	Mile 39	**385*J**	**190*J**	<21*	<21*	<21*
248134	"	Mile 50	**240 J**	<140	<14	<14	<14
248135	Roses Lake	Outlet	**480 J**	<700	**77**	**890**	**790**
248136	"	East End	<470	<470	**48 J**	**670**	**770**
248137	Lake Sammamish	Greenwood Pt.	**110 J**	<140	<14	<14	<14
248138	"	Adelaide	**390 J**	<500	<50	<50	<50
248139	Ward lake	North End	**920 J**	<670	<70	<70	<70
248140	"	South End	**370 J**	<580	<70	<70	**42 J**

< = Not detected at concentration shown

J = Estimated concentration

* result of duplicate analyses

Table C-3. Copper Concentrations in Lakes Sampled for Copper Only (mg/Kg, dry weight basis).

Sample Number	Lake	Station	Percent Solids	Cu
048230	Duck	DC-1	15	25.3
048231	Duck	DC-2	10	34.0
048232	Duck	DC-3	14	35.6
048233	Duck	DC-4	11	13.0
048234	Duck	DC-5	11	27.5
048235	Spanaway	SP-1	8	89.1
048236	Spanaway	SP-1 Dupl.	8	86.9
048237	Spanaway	SP-2	7	106
048238	Spanaway	SP-3	10	173
048239	Spanaway	SP-4	15	308
048240	Spanaway	SP-5	23	251
048241	Ohop	OH-1	15	121
048242	Ohop	OH-1 Dupl.	15	122
048243	Ohop	OH-2	16	86.2
048244	Ohop	OH-3	13	149
048245	Ohop	OH-4	15	93.4
048246	Ohop	OH-5	17	79
048247	Ketchum	KT-1	8	260
048248	Ketchum	KT-2	6	503
048249	Ketchum	KT-3	8	566
048250	Ketchum	KT-4	8	599
048251	Ketchum	KT-4 Dupl.	8	575
048252	Ketchum	KT-5	6	503
048353	Silver	SL-1	10	80.5
048354	Silver	SL-2	10	61.0
048355	Silver	SL-3	20	39.2
048356	Silver	SL-4	14	44.1
048357	Silver	SL-5	19	32.4