SURVEY OF CONTAMINANTS IN SEDIMENTS
IN LAKE UNION AND ADJOINING WATERS
(Salmon Bay, Lake Washington Ship Canal, and Portage Bay)

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ABSTRACT

Lake Union, an urban lake in the center of Seattle, and the surrounding fresh water bodies, has been the site of industrial and commercial use for over 75 years. These operations have degraded water quality and have contaminated sediments in some areas of the lake. To determine representative concentrations of contaminants in sediments in the lake, 22 sites in Lake Union and adjacent fresh water bodies (Salmon Bay, Lake Washington Ship Canal, and Portage Bay) as well as a reference site in Lake Washington, were sampled for priority pollutant metals and organics. Nine sites were tested with three bioassays (*Hyalella*, *Daphnia*, and Microtox®) and were examined for benthic macroinvertebrate abundance and diversity.

Heavy metals were highest in Lake Union and the study found the following ranges all reported in dry weight basis:

Arsenic:	non-detected to 1200 mg/kg
Cadmium:	non-detected to 2.3 mg/kg
Chromium:	20 to 120 mg/kg
Copper:	11 to 640 mg/kg
Mercury:	0.04 to 2.9 mg/kg
Nickel:	23 to 130 mg/kg
Lead:	26 to 830 mg/kg
Zinc:	40 to 900 mg/kg

We found no volatile organics except 2-butanone and acetone and these were concluded to be introduced in sampling or analysis. Several sites in Lake Union had polychlorinated biphenyls (PCBs) at concentrations from 93 to 640 μg/kg dry weight. Chlorinated pesticides were found at only one site. Polycyclic aromatic hydrocarbons (PAH) occurred at all sites with concentrations varying widely (110 to 803,000 μg/kg dry weight). The highest concentration of PAH was near Gas Works Park in Lake Union. The two sites with elevated PAH near Gas Works Park killed significant numbers of *Hyalella* in laboratory bioassays. The site with the highest PAH, arsenic and sulfides concentrations caused significant *Daphnia* mortality. Microtox® bioassay results showed toxicity at all sites except the reference site in Lake Washington. Diversity and abundance in benthic invertebrate communities showed little relation to contaminant concentrations. Heavy metals concentrations showed a robust correlation to percent fines. Those sites with high concentrations of any one metal tended to have the higher concentrations of other metals as well.

With some exceptions, the metals concentrations roughly equalled those found in earlier studies of the Lake Union area. Metals concentrations in the study area greatly exceeded the median concentrations from sites throughout Washington State. The PAH concentrations found in this study were roughly equivalent to earlier studies in the area. All study sites in Lake Union and west of Lake Union had chemical concentrations that exceeded at least one guideline for a metal or PAH produced by Wisconsin and Ontario for individual metals and PAH in sediments. Several sites exceeded guidelines for the majority of metals examined. The concentrations of metals, and at some sites PAH, in the study area are substantially elevated above reference areas, sediment quality guidelines, and other freshwater areas of Washington State.

INTRODUCTION

Lake Union is located in the center of the city of Seattle and its extent and character have been dramatically altered by human activity in the past 75 years. The 600-acre lake receives water of relatively good quality from Lake Washington and discharges into Puget Sound through the industrialized Ship Canal and the Hiram Chittenden Locks. The lake basin was originally carved by glaciers and until about 75 years ago, when the Montlake Cut was constructed, Lake Union was isolated from Lake Washington and was fed solely by runoff and springs. The Fremont Cut and the east end of the Ship Canal, the Locks and the Ship Canal were constructed at the same time as the Montlake Cut between Portage Bay and Lake Union and expanded the area of fresh water to include Salmon Bay. The Army Corps of Engineers dredges the Ship Canal, controls the water level in Lake Washington/Lake Union system, and monitors saltwater intrusion through the locks.

The shoreline has been changed by fill, and now has steep sides that extend to depths of 35-50 feet. The lake is evolving from a "working lake" to one where marine-oriented commercial and industrial uses are mixed with marinas, houseboats, offices, restaurants and shoreside residences (City of Seattle, 1988). The majority of the remaining water-related industries reside along the Ship Canal.

Lake Union and adjoining waters have a long history of operations that reduced water and sediment quality. Foster (1943) documented numerous potential sources of pollution in Lake Union including storm sewer and combined sewer outfalls, shipbuilding activities, and the coal gasification plant on the North Central Shore. Later sediment investigations showed high concentrations of polychlorinated biphenyls (PCBs) near the Seattle City Light Steam Plant on the southeast shore of the lake, high concentrations of polycyclic aromatic hydrocarbons (PAH) near Gas Works Park, and high concentrations of several metals throughout the lake (Hileman et al., 1985; city of Seattle, 1988). Yake et al. (1986) showed concentrations of PAH adjacent to Gas Works Park to be toxic to biota. They evaluated sediment quality with the triad approach which examines bioassay, benthic macroinvertebrate diversity, and chemistry data in sediments (Long and Chapman, 1985).

To determine the ambient concentrations of contaminants in sediments in the lake, the Northwest Regional Office of the Washington State Department of Ecology (Ecology) requested a study of sediments at several locations. The goals of this study were to: 1) determine concentrations of chemical contaminants in the sediments in the Lake Union area, 2) determine the toxicity of these sediments, and 3) compare concentrations to other studies inside and outside of the study area.

With the exception of sites near Gas Works Park, we chose sample locations to depict the ambient concentrations of contaminants in Lake Union and were not selected to include "hot spots" or areas adjacent to known or suspected areas of historic sources of contaminants. We sought sites that portrayed the average concentration of contaminants in the lake. The results of this study will provide information on the general condition of sediments throughout the lake,

show spacial trends in contamination, and provide information on the ambient concentrations and toxicity of contaminants in the lake system.

METHODS

Study Sites

We selected 22 sediment sites for this study. Table 1 lists the locations of the sample sites. Figure 1 shows the sample site locations on a map of Lake Union. Sites 1-5 sampled the industrial area from the locks to the Ship Canal. Due to dredging and possible prop scour, only sand and gravel and no depositional sediment could be taken off the hard-packed bottom of Fremont Cut. Sites 6-18 represented Lake Union. Sites 9 and 11, adjacent to Gas Works Park, were the only sites intentionally located near "hot spots" or known sources of contamination to the lake. Site 16 was situated near the NOAA docks and light repair yard. We assumed Sites 13, 15, and 17, owing to their central location within the lake distant from direct sources of contaminants, represented the overall concentrations of contaminants within the lake. Sites 19-21 were up current from the Lake Union industrial areas. Six combined sewer overflows (CSOs) and four storm drains empty into Portage Bay (Site 20). Site 22, in Lake Washington, was up current from all the other sites and has served as a reference area for the other studies to gauge the relative increase in contamination in Lake Union.

Of these 22 sites, nine were selected for bioassay tests and benthic macroinvertebrate analysis. These nine sites were chosen to measure both the overall effects of contamination in the lake as well as verify earlier chemical and bioassay results off Gas Works Park (at Sites 9 and 11). Sites 1-6 were not considered for bioassay tests or benthic macroinvertebrate analysis because they lie in areas that are regularly exposed to saline conditions, due to the combination of low flow in the watershed and frequent operation of the locks. The Ship Canal experiences these impacts during the dry season from late spring through early fall. Increased mortality in the bioassays or reduced benthic diversity at these locations could not be ascribed solely to either contamination or chronically increased salinity.

Sample Collection Methods

Samples were collected on June 18-20, 1990, from a 20-foot skiff equipped with a davit, winch and a 0.1 m² modified van Veen grab made from stainless steel. The field crew located sites with distances from landmarks measured with an optical range finder. These distances helped pinpoint locations on nautical charts and topographic maps. With the exception of Sites 9 and 11, the first adequate grab taken from an area was kept for analysis. A grab was considered adequate if it was filled with sediment and both the grab as well as access doors on top of the grab were closed tightly. At Sites 9 and 11, where areas of high contamination were sought, a number of grabs were taken to locate areas of visible contamination.

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Table 1. Sample site locations for Lake Union sediment study.

Site	Latitude (Deg.)	Latitude (Min.)	Longitude (Deg.)	Longitude (Min.)	Yr	Mo	Day	Depth (Feet)	Bioassay	Location
1	47	39.90	122	23.75	90	6	19	25	N	At east entrance of locks
2	47	39.94	122	23.59	90	6	19	32	N	Off 28th Ave. NW just north of locks
3	47	39.87	122	23.26	90	6	19	31	N	Salmon Bay
4	47	39.54	122	22.61	90	6	19	21	N	Fisherman's Terminal
5	47	39.55	122	22.22	90	6	19	33	N	W Union Street
6	47	38.79	122	20.85	90	6	19	40	N	Between Freemont and 99 bridge
7	47	37.61	122	20.27	90	6	20	19	N	"Navy Cove" (Cove near Navy Pier on south side of Lake)
8	47	38.69	122	20.57	90	6	20	41	Y	Ship Canal west of Gas Works Park
9	47	38.70	122	20.18	90	6	20	28	Y	W Gas Works Park adjacent to Seattle Police Department
10	47	38.51	122	20.40	90	6	20	41	N	Westlake off West Yacht Sales
11	47	38.75	122	19.90	90	6	20	26	Y	East side of Gas Works Park off Playbarn
12	47	39.13	122	19.56	90	6	18	32	N	Lake Washington Ship Canal
13	47	38.43	122	20.08	90	6	20	47	N	Center of Lake Union
14	47	38.21	122	20.29	90	6	18	51	N	West side of Lake Union
15	47	38.06	122	20.10	90	6	20	43	Y	Mid Lake Union
16	47	38.20	122	19.83	90	6	20	49	N	East side of Lake Union north of NOAA Ships
17	47	37.81	122	20.08	90	6	20	42	N	South center Lake Union
18	47	37.68	122	20.11	90	6	20	40	Y	South side of Lake Union just North of Naval Reserve
19	47	39.17	122	19.10	90	6	19	23	Y	East of University Bridge
20	47	38.87	122	18.72	90	6	18	29	Y	Portage Bay
21	47	38.84	122	18.30	90	6	18	34	Y	Montlake Cut
22	47	38.89	122	16.43	90	6	18	42	Y	Lake Washington, East of Union Bay
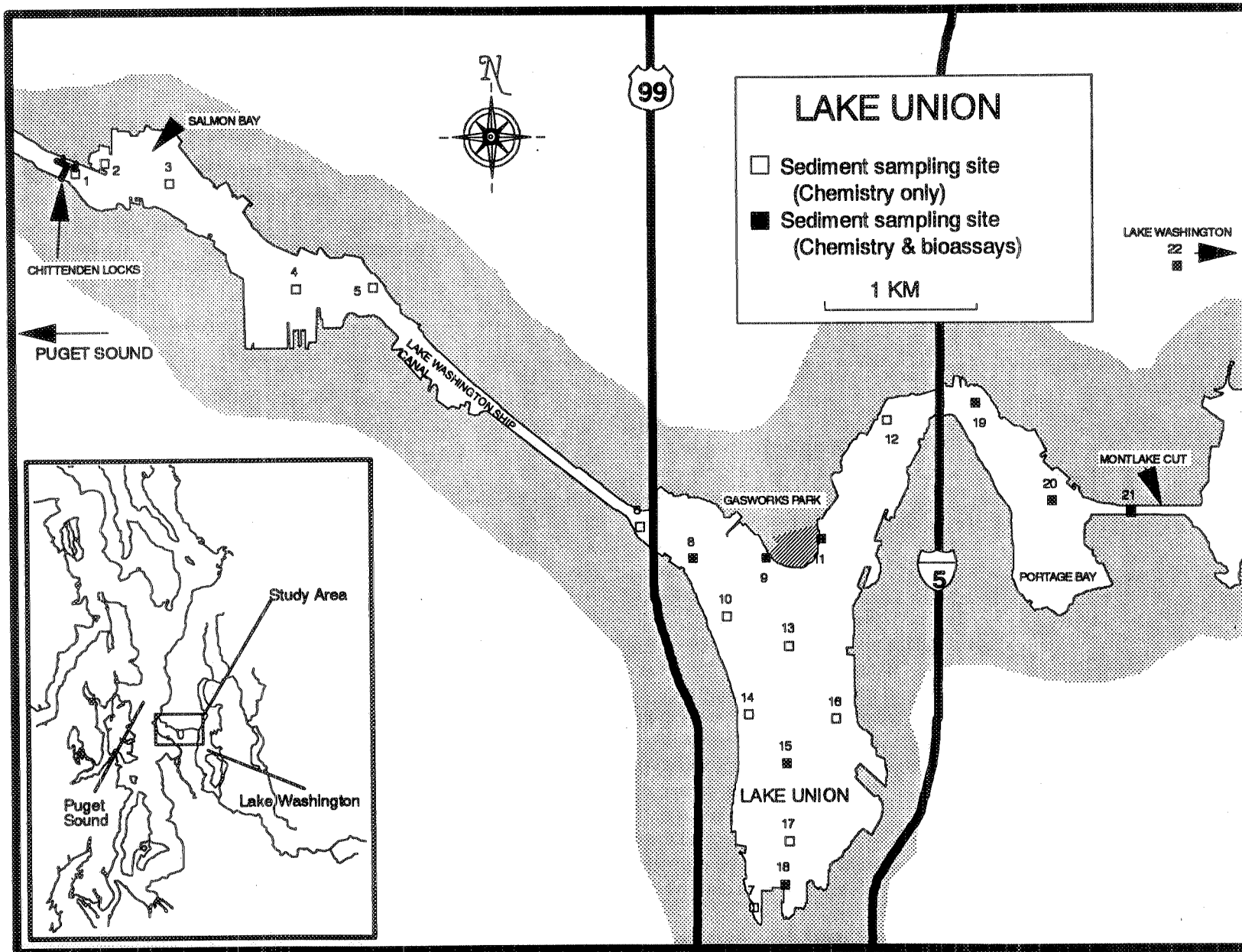
Figure 1. Study area and sampling sites.

For each grab, the top 2 cm of sediment not touching the walls of the grab were scooped out of the top doors of the sampler and placed in a stainless steel beaker. Volatile organics were collected directly from the sediments in the sampler before compositing or stirring. To reduce space where volatiles could collect volatile organic analysis (VOA) containers were filled to the top. After one to two grabs were collected (two grabs for bioassay stations), the beaker contents were stirred and the subsamples for the different analyses were dispensed into 8 ounce priority-pollutant cleaned glass jars capped with teflon lid liners (ICHEM 300 series). All stainless steel tools (beakers and spoons) were decontaminated prior to use with the following procedure:

1. Wash in hot water and Liquinox® detergent,
2. rinse in tap water,
3. rinse in 10% nitric acid,
4. rinse with deionized water,
5. rinse with pesticide analysis grade acetone,
6. air dry, and
7. wrap in aluminum foil.

Between grabs, the sampler was thoroughly brushed and rinsed with on-site water between grabs. The field crew collected samples in a west to east direction with the Gas Works Park samples collected last. All samples were placed in coolers on ice until refrigerated in the evening after sampling. On the following day, all samples were transported to the lab for analysis. Bioassay samples were never frozen.

Samples for benthic macroinvertebrate analysis were collected with a petite Ponar® grab (0.02 m²). Four replicate grabs were collected at each site. The entire contents of each grab was sieved in the field through 0.59 mm mesh and the retained material gently rinsed with freshwater into one quart glass jars. Samples were preserved in 10% formaldehyde solution buffered with sodium borate. After 48 hours, the samples were drained and transferred to 70 percent ethanol.

Sample Analysis

Table 2 describes analyses conducted in this study. All sediment samples were analyzed for the following: Volatile organics (VOAs), semivolatile organics (also called base neutral and acids [BNA] analysis), pesticides/PCBs, total metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc), total organic carbon (TOC), and grain size distribution.

To assess toxicity, samples from nine site were tested with several bioassays: *Daphnia magna, Hyalella azteca* and Microtox®. The endpoint of both the *Daphnia* and *Hyalella* bioassays is percent mortality of the organisms. *Daphnia magna,* a water flea that dwells in the water column was exposed to water overlying test sediment for 48 hours. *Hyalella azteca,* a freshwater amphipod that burrows in sediments, was exposed to test sediments for 10 days. Microtox®, a marine bioluminescent bacteria, indicates stress or impairment in respiration

Table 2. Analytical methods used in Lake Union sediment investigation.

Analysis	Method	Reference	Laboratory
Total organic carbon	Persulfate-UV	APHA 1985	Analytical Resources Inc.
Grain size	Seives and pipettes	Holme and McIntyre 1971	Hart-Crowser
Salinity	Refractometric		Ecology/EPA (Manchester Lab.)
Sulfides	Idometric Method 9030	EPA 1986a	AMTest Laboratories
% Moisture	Dry @ 105 degrees C	APHA 1985	Ecology/EPA (Manchester Lab.)
Arsenic	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Cadmium	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Chromium	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Copper	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Mercury	Cold Vapor Atomic Absorption	EPA 1986a	Ecology/EPA (Manchester Lab.)
Lead	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Nickel	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Zinc	Inductively Coupled Argon Plasma	EPA 1986a	Ecology/EPA (Manchester Lab.)
Semivolatiles (PAH)	GC/MS Method 8270	EPA 1986a	Weyerhaeuser Laboratories
Pest/PCB	GC/EC Method 8080	EPA 1986a	Weyerhaeuser Laboratories
VOAs	GC/MS Method 8240	EPA 1986a	Weyerhaeuser Laboratories
Bioassay	*Daphnia magna* 48 hour acute	ASTM 1990	Ecology/EPA (Manchester Lab.)
Bioassay	*Hyalella azteca* 10 day chronic	ASTM 1990	Ecology/EPA (Manchester Lab.)
Bioassay	Microtox™ (light reduction)	EPA 1986b	ECOVA Laboratories

when light output decreases in the controlled conditions of the test. The concentration of sediment extract that reduces light by 50 percent (EC_{50}) is reported.

Also at these nine bioassay sites, macroinvertebrates were collected and identified to the lowest practical level to provide benthic diversity information. Four replicates were analyzed separately and in some cases, samples were subsampled and analyzed. At the bioassay sites, sulfides samples were also collected. Salinity of the water mixed with the sediment samples was also measured to determine which sample sites were influenced by sea water intrusion.

The analyses were done with standard methods with the following exceptions:

1. For metals analyses, samples were extracted with nitric acid and hydrogen peroxide. The Puget Sound Protocols (EPA, 1986b) call for digestion with nitric and perchloric acid, but they also allow nitric acid/peroxide digestion. The peroxide digestion has produced acceptable recoveries in other studies (EPA, 1986b).

2. Sediment samples for semivolatile analysis were extracted with a 50:50 mixture of methylene chloride and acetone using the Environmental Protection Agency (EPA)/Ecology Manchester Laboratory modification of the EPA Contract Lab Program (CLP) and Method 8270 procedures. Since PAH were the primary target chemicals, the laboratory cleaned up the samples with gel permeation chromatography (GPC) at molecular weight cutoffs of both 2000 and 1000 (Method 3640) followed by Silica Gel Cleanup Method 3630.

3. PCBs analysis initially showed high detection limits. To lower detection limits, aliquots of selected samples were cleaned up with an acid cleanup method that removed many interfering compounds. The detection limits were lowered with this method on 14 of the 22 samples. For clarity, results from the eight samples that were not cleaned up are not shown in graphics but detection limits are shown in tables.

Laboratory Quality Assurance

Several analyses performed on these sediments are complex and require several different measurements and interpretations by skilled personnel. Because of variability between laboratories, most analyses of the type in this study undergo a quality assurance/quality control (QA/QC) review to determine if accuracy and precision are within acceptable standards. Appendix B and Appendix Tables B-1 and B-2 contain the quality assurance review.

The laboratories and the QA/QC review report no major problems with the analyses. The precision and accuracy of the analyses are within conventionally acceptable limits prescribed by EPA (EPA, 1986a) and the Puget Sound Guidelines (EPA, 1989). Overall, the data are usable with little qualification. A few qualifiers that were appended to the data include the following:

"U": No target chemical was found at or above the concentration shown. The number is the quantification limit. The target chemical may or may not be present below the quantification limit.

"J": The concentration shown is an estimate. Most of the "J" qualifiers have been added because the concentration found is less than five times the quantification limit (see above) and thus may be inaccurate due to the low signal to noise ratio.

"B": The analyzed chemical was found in the blank run during analysis. The blank is a jar of water or solvent that is run through the analysis process with the field samples. Contamination at the laboratory may appear in this method blank sample.

Data Analysis

Most data analysis in this study consisted of tabling and mapping chemical concentrations. A few statistical techniques were used and are described in this section. To compare the many measurements of chemicals at different sites within this study, correlations between different chemicals by site were calculated. Probabilities of these correlations were calculated to determine significance. If the odds were less than 1 in 20 ($p < 0.05$) that the correlation was the result of randomness, the correlation was considered significant and probably reflected some true relationship. Probability values were corrected for the multiple comparisons with the Bonferroni correction whereby the probability is multiplied by the number of multiple comparisons to yield a true probability. This precaution is necessary to avoid an error of ascribing significant correlations where there are none.

To find covariations in different sediment measures, PCA (principle components analysis) was conducted. This method reduces the number of variables to two major axes or factors so that those variables that covary are portrayed close to each other on graphics. This method can also plot sites so that sites that have similar levels of different contaminants are near each other.

To determine if observed mortality and effects in bioassays were simply the result of random variation, the results were tested for statistical significance. *Daphnia* and *Hyalella* bioassays were tested for significance by comparison against controls with Dunnet's test. Two replicates of Microtox® analyses were tested against replicate laboratory controls with a paired T test. Significance was ascribed at the $p < 0.05$ (less than a 1 in 20 chance the observed effect was random).

Because of the variety of species, abundance and diversity of benthic invertebrates are difficult to compare among sites. Researchers have reduced abundance and diversity measures to a few indices for comparisons. In this study, we used the ubiquitous Shannon's H' (Washington, 1984) which is based on information theory and Swartz's index (Swartz *et al.*, 1985). The

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Shannon's H' in this study was calculated on a $\log_{base\ 2}$ basis. To determine the type of communities present, the Hilsenhoff biotic index (Hilsenhoff, 1987) was calculated for each site. This index scores each species present based on pollution tolerance with 1 being highly intolerant to 10 being highly tolerant. The index is then based on the average of these scores.

RESULTS

Conventionals

Results of TOC, grain size, and sulfides analyses are shown in Table 3. Because grain size and TOC are often correlated with metals and organics respectively, these analyses can help to discern patterns of contamination. TOC varied from 0.6 percent at the reference site to 19 percent on the east end of the lake near the I-5 bridge. Grain size characteristics of all the sites are shown in a trilineal diagram in Figure 2. Silt or sand predominated at most sites. Sites in the center of the lake (10, 13-18) were similar in their grain size characteristics and were mostly silt with some clay. Sites at Portage Bay (21) and Lake Washington (22) were the sandiest of the sites. Sulfides are products of anaerobic (without oxygen) metabolism by bacteria in sediments. They are toxic to most biota in the sediments. Salinity was below 2 parts per thousand at all nine bioassay sites.

Metals

The results of metals analysis of sediments from Lake Union are listed in Table 4. Concentrations of individual metals are also shown in Figures 3-10. Metals concentrations ranged as follows:

Arsenic:	non-detected to 1200 mg/kg
Cadmium:	non-detected to 2.3 mg/kg
Chromium:	20 to 120 mg/kg
Copper:	11 to 640 mg/kg
Mercury:	0.04 to 2.9 mg/kg
Nickel:	23 to 130 mg/kg
Lead:	26 to 830 mg/kg
Zinc:	40 to 900 mg/kg

The Salmon Bay area had the highest concentrations of chromium and copper. The Gas Works Park area showed the highest concentrations of arsenic, mercury, nickel, and zinc. The south end of the lake was highest in cadmium and lead. The lowest concentrations for all metals were measured at the reference site in Lake Washington (Site 22).

To compare the relative spatial distribution of metals, sites were ranked according to concentrations of each metal and then sites were ranked according to the average of ranks for individual metals. The results of this ranking (Table 4) is shown in Figure 11 by location.

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Table 3. Physical characteristics and sulfides of
sediments in the Lake Union area.

| Site | Percent | | | | | mg/kg dry wt. |
	TOC	Solids	Sand	Silt	Clay	Sulfide
1	0.81	67	82	12	6	1
2	5.3	27	29	58	13	N/A
3	4.1	29	20	63	17	N/A
4	3.8	53	60	31	9	N/A
5	4.9	35	82	15	3	N/A
6	5.2	46	30	57	13	N/A
7	5.1	32	47	41	12	N/A
8	12	16	11	66	23	900
9	12	30	61	30	9	450
10	7.4	17	6	70	24	N/A
11	18	19	45	48	7	7700
12	15	19	61	33	6	N/A
13	12	17	8	71	21	N/A
14	7.3	15	4	67	29	N/A
15	5.1	19	7	67	26	703
16	5.7	20	9	68	23	N/A
17	5.3	22	5	72	23	N/A
18	5.9	18	6	79	15	920
19	19	10	36	51	13	130
20	9.0	21	54	39	7	31
21	12	33	88	8	4	34
22	0.60	67	95	3	2	6

N/A = Not analyzed

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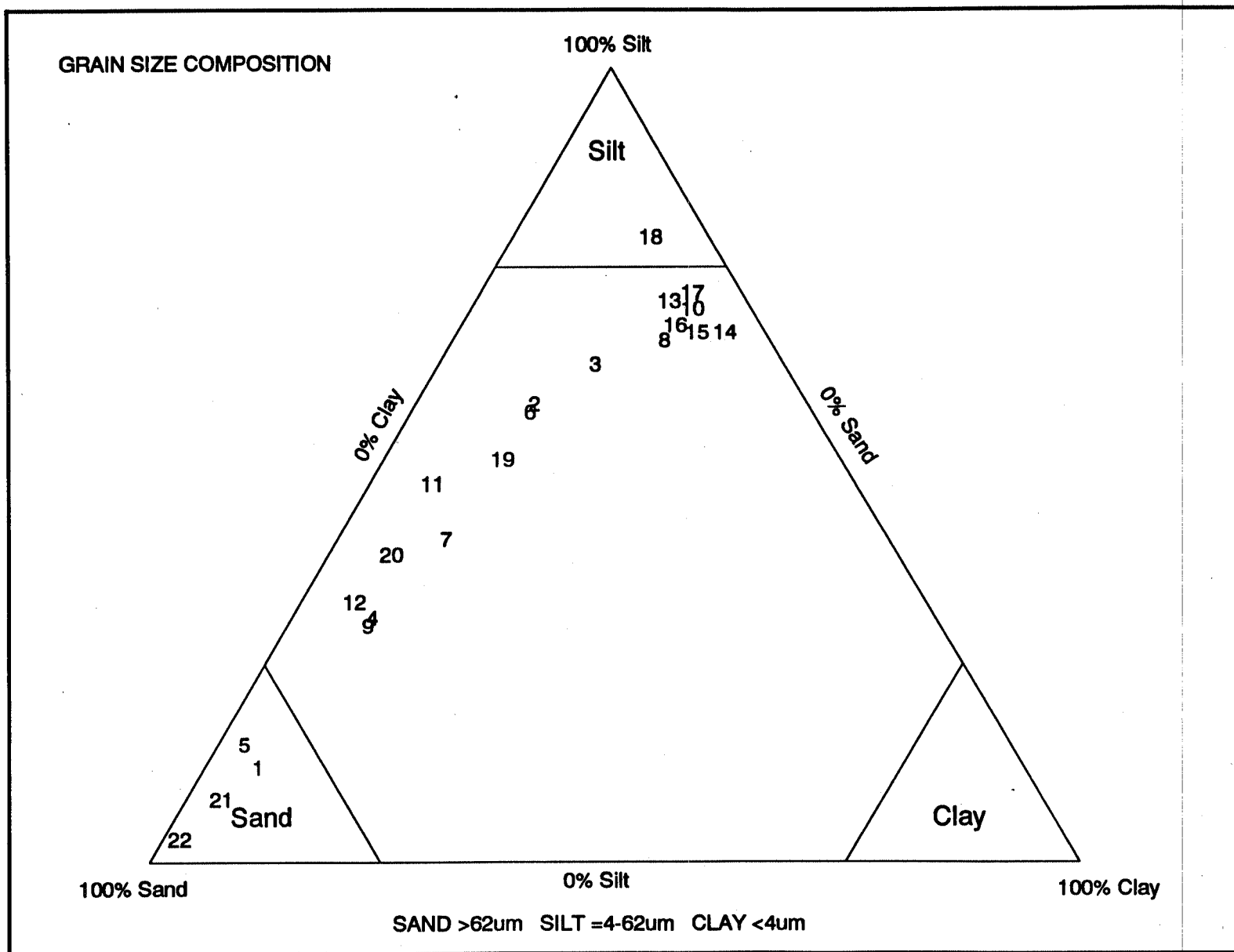
Figure 2. Grain size composition of sediments from Lake Union and adjacent waters. Site numbers are shown.

Table 4. Metals concentrations in sediment from the Lake Union area. Outlined sites are in main body of lake.

Site	\<concentration\> As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	\<rank\> As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	Mean of ranks	Overall rank*	Rank index**
1	20 U	0.5 U	47.9 J	51	0.11	44.7	33	87	14	14	16	20	21	17	21	20	17.9	20	2.0
2	50	0.5 U	66.4 J	557	1.90	46.6	366	685	9	14	7	3	6	14	11	4	8.5	9	11.4
3	29 J	0.5 U	124.0 J	638	1.36	90.6	272	564	13	14	1	1	13	2	13	7	8	7	11.9
4	20 U	0.5 U	49.0 J	92	0.47	46.6	82	118	14	14	15	16	18	15	20	19	16.4	17	3.5
5	52	0.5 U	65.6 J	275	1.42	45.0	163	368	8	14	9	11	11	16	16	13	12.3	13	7.6
6	39 J	0.9 J	57.6 J	171	1.47	55.3	286	297	12	10	10	14	10	10	12	14	11.5	12	8.4
7	20 U	1.1 J	54.6 J	189	0.87	47.3	497	531	14	8	13	13	15	13	9	10	11.9	14	8.0
8	149	1.7 J	83.0 J	526	2.07	63.9	715	904	2	4	3	4	3	3	5	1	3.1	1	16.8
9	20 U	0.5 U	19.2 J	68	1.41	56.8	124	286	14	14	22	18	12	9	17	15	15.1	15	4.8
10	62	1.9 J	70.4 J	310	2.07	61.1	641	533	6	2	6	9	4	6	7	9	6.1	5	13.8
11	1150	0.5 U	51.2 J	213	2.93	133.0	470	470	1	14	14	12	1	1	10	12	8.1	10	11.8
12	20 U	0.5 U	38.9 J	144	0.51	37.2	206	250	14	14	17	15	17	19	15	16	15.9	18	4.0
13	46 J	1.8 J	56.1 J	398	1.25	50.8	598	521	11	3	12	5	14	12	8	11	9.5	11	10.4
14	96	1.4 J	66.0 J	360	1.65	56.8	736	630	4	7	8	7	8	8	3	5	6.3	6	13.6
15	61	0.7 J	75.7 J	382	2.00	61.9	678	562	7	11	5	6	5	5	6	8	6.6	4	13.3
16	120	1.45 J	77.0 J	599	2.40	58.3	790	855	3	6	4	2	2	7	2	2	3.5	2	16.4
17	68	1.5 J	113.0 J	285	1.51	63.8	831	591	5	5	2	10	9	4	1	6	5.3	3	14.6
18	49	2.3 J	56.9 J	338	1.72	52.3	719	689	10	1	11	8	7	11	4	3	6.9	8	13.0
19	20 U	0.7 J	33.8 J	77	0.46	39.2	93	136	14	12	19	17	19	18	18	18	16.9	19	3.0
20	20 U	1.0 J	36.8 J	62	0.52	33.7	223	193	14	9	18	19	16	20	14	17	15.9	16	4.0
21	20 U	0.6 J	27.4 J	30	0.16	26.8	91	84	14	13	20	21	20	21	19	21	18.6	21	1.3
22	20 U	0.5 U	19.7 J	11	0.04	22.6	26	40	14	14	21	22	22	22	22	22	19.9	22	0.0

U = Not detected at detection limit shown. In rank analysis all 'U' values given same rank.
J = Estimated concentrations (acceptable for use).
* = Overall rank: Rank of mean of ranks. The lower numbers reflect higher concentrations.
** = Rank Index: The highest mean rank – mean ranks for different sites. This index reverses the the mean rank so that the site with the highest concentrations has the highest rank index.

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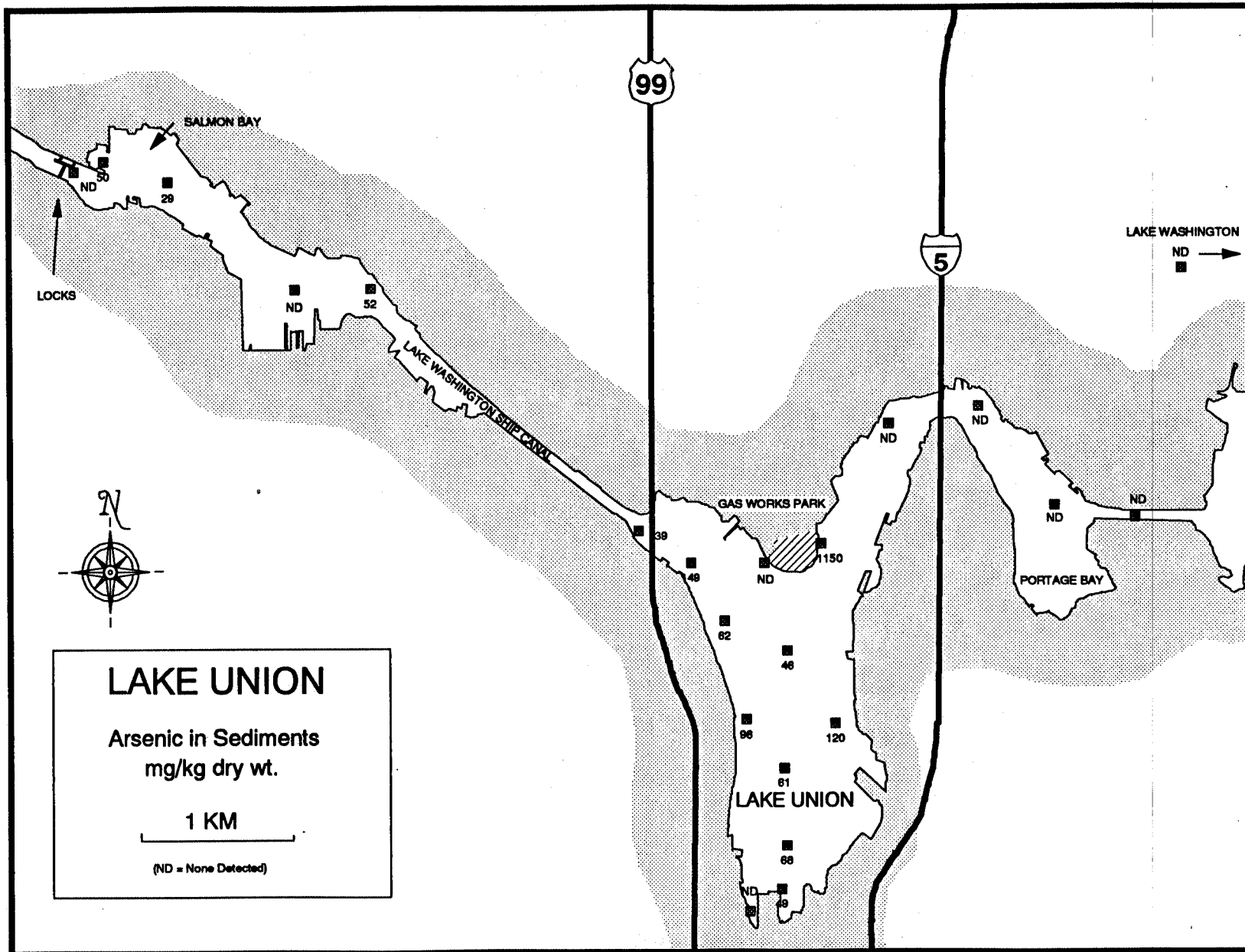
Figure 3. Arsenic concentrations in sediments from Lake Union
and adjoining waters.
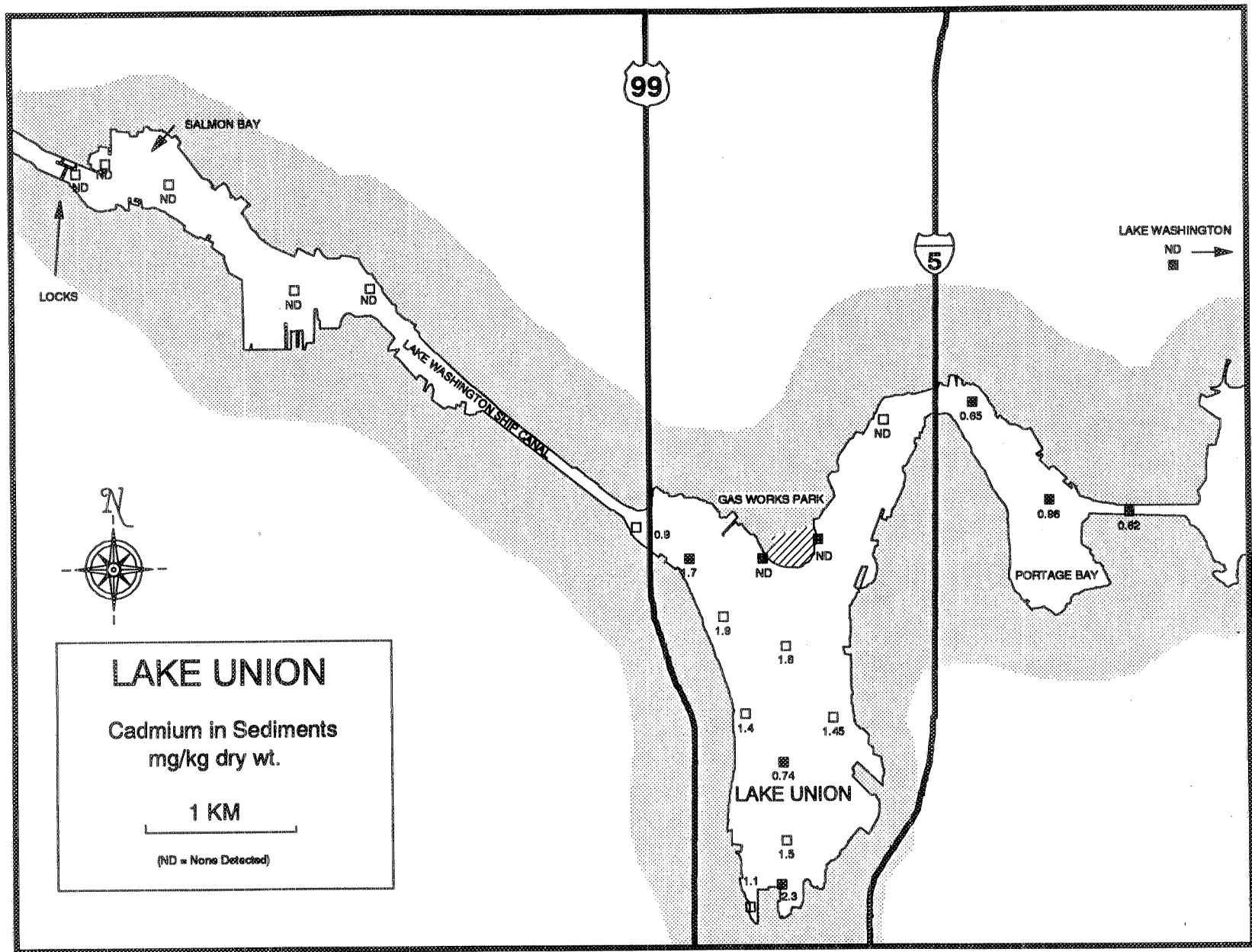
Figure 4. Cadmium concentrations in sediments from Lake Union and adjoining waters.
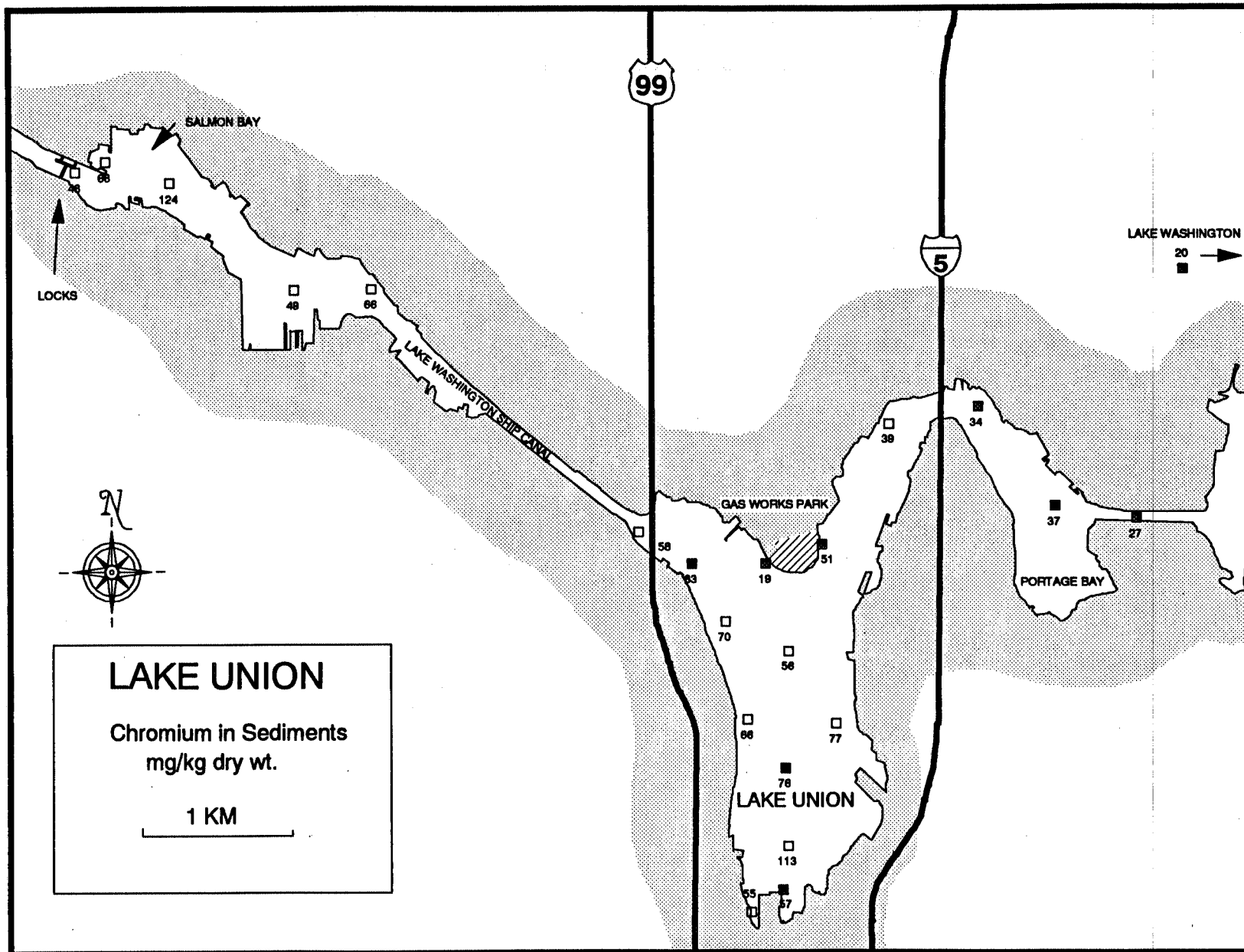
Figure 5. Chromium concentrations in sediments from Lake Union and adjoining waters.
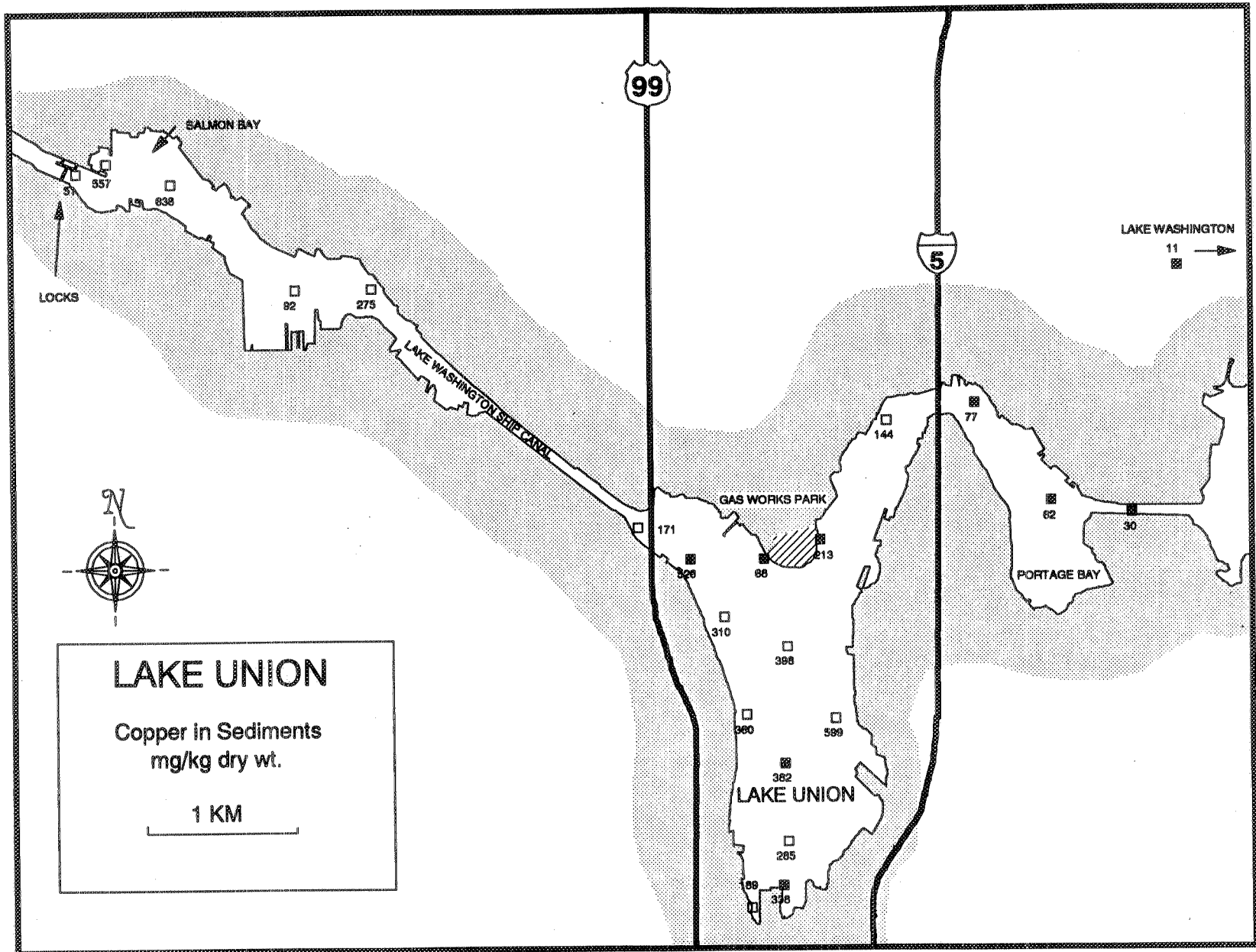
Figure 6. Copper concentrations in sediments from Lake Union
and adjoining waters.
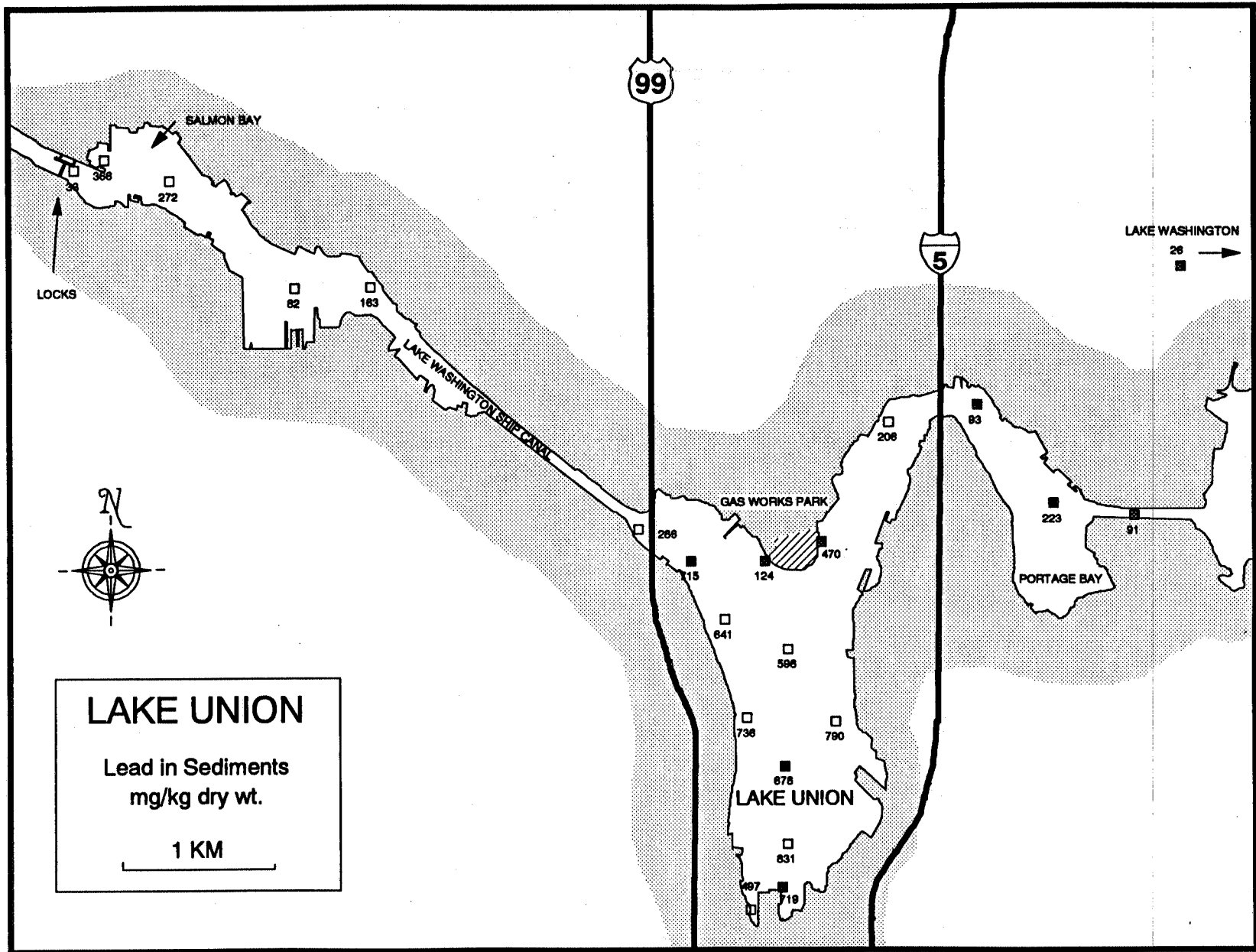
Figure 7. Lead concentrations in sediments from Lake Union and adjoining waters.
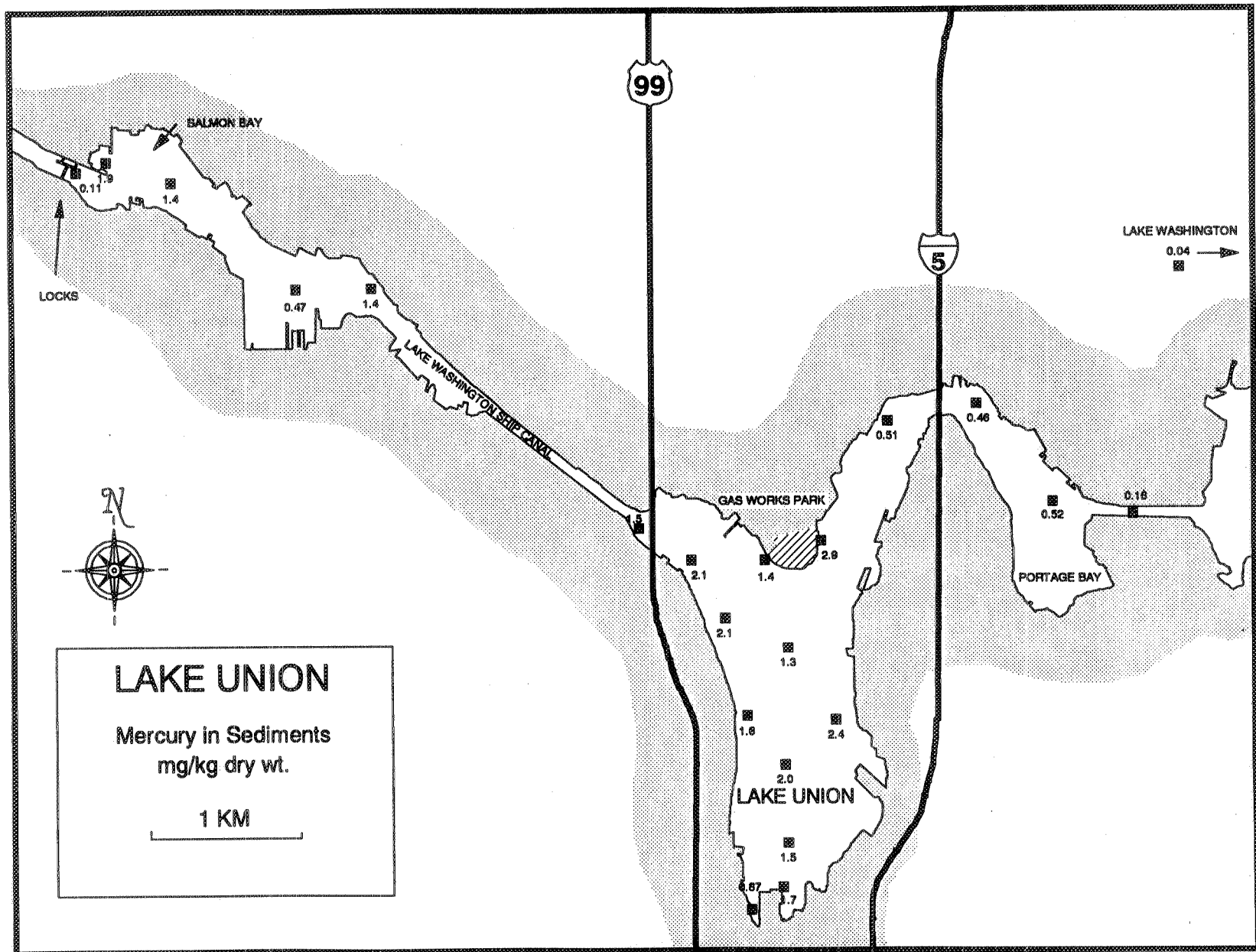
Figure 8. Mercury concentrations in sediments from Lake Union and adjoining waters.
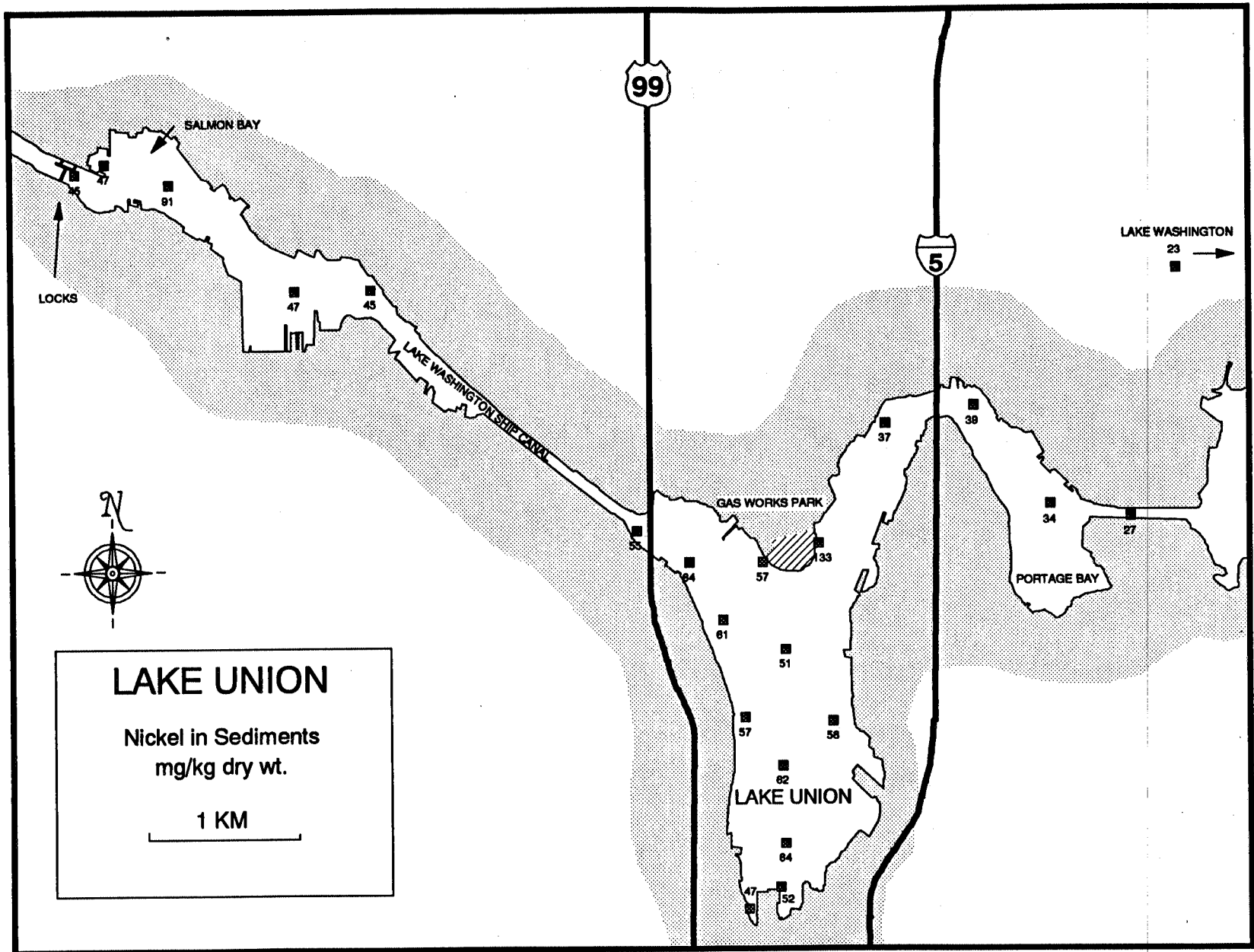
Figure 9. Nickel concentrations in sediments from Lake Union and adjoining waters.

19

SALMON BAY

LAKE WASHINGTON
40

LOCKS

97 685

584

116 368

LAKE WASHINGTON SHIP CANAL

250 138

GAS WORKS PARK

193

84

207

270

204 286

PORTAGE BAY

N

533

521

630 655

562

LAKE UNION

591

531 589

LAKE UNION

Zinc in Sediments
mg/kg dry wt.

1 KM
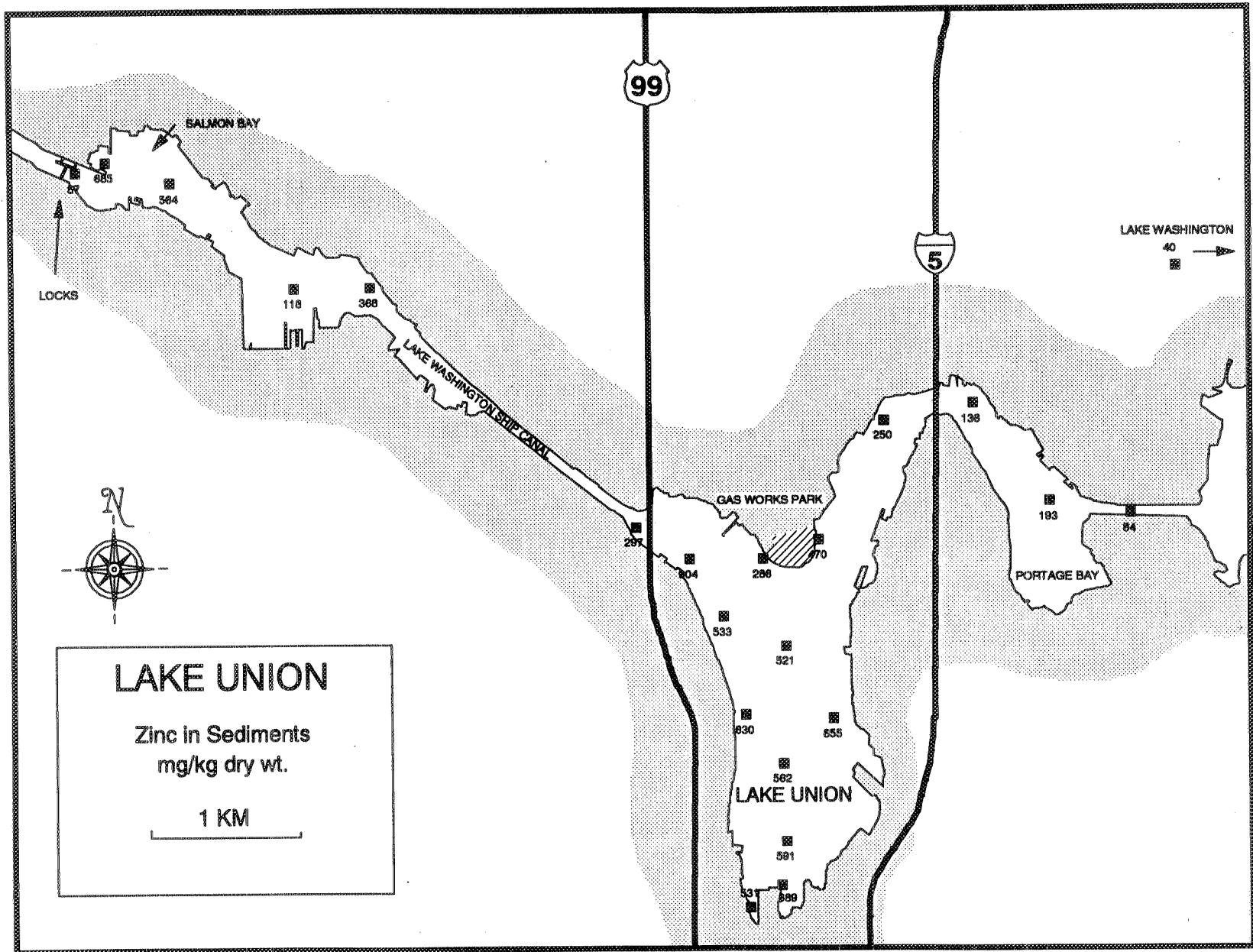
Figure 10. Zinc concentrations in sediments from Lake Union
and adjoining waters.
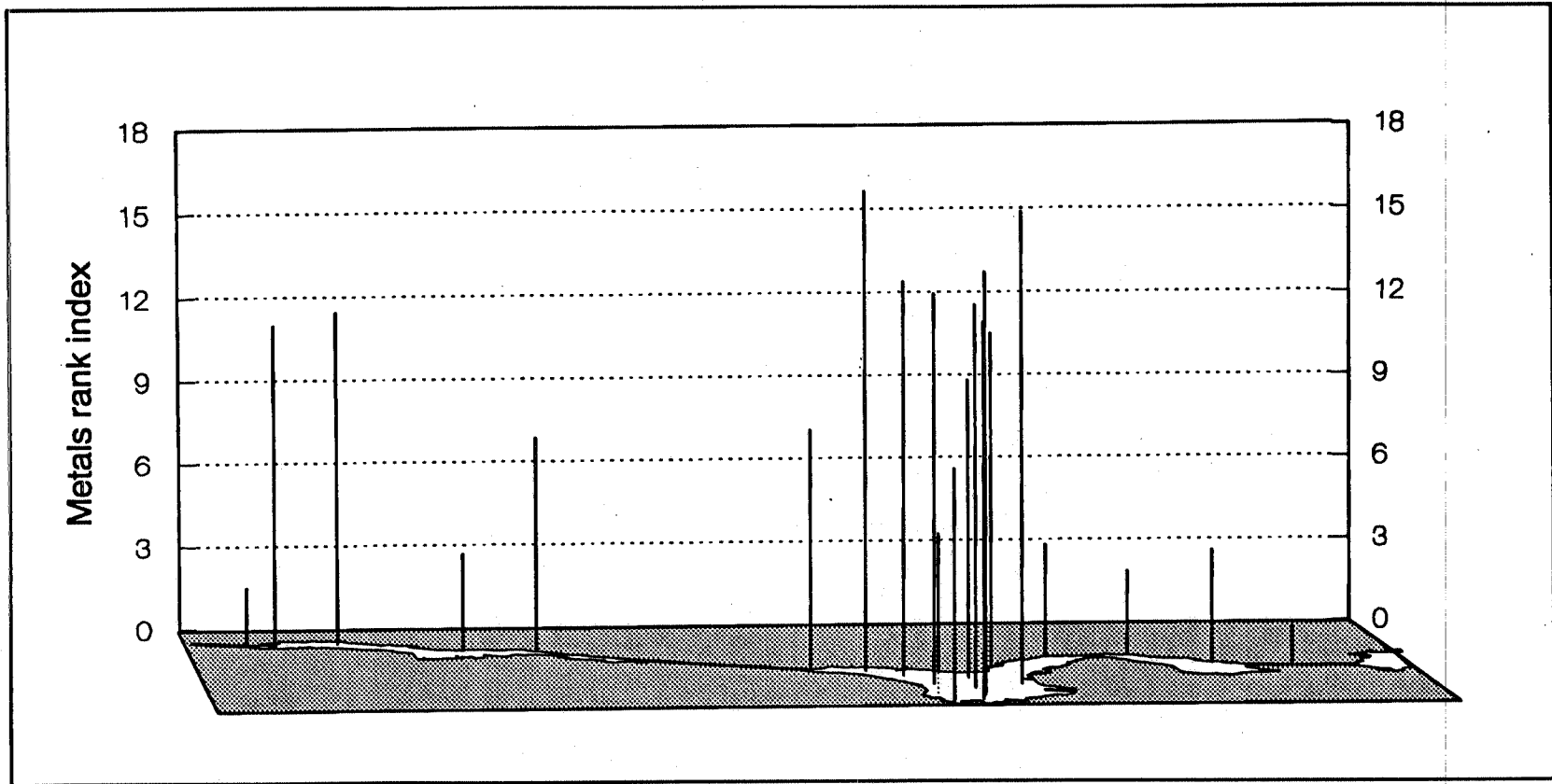
Figure 11. Map showing metals index ranks at different locations in the study area. Lower index indicates lower concentrations of seven metals relative to sites in the study area. See text for full explanation of metals rank index.

Overall, the metals rank index shows the highest levels of most metals are near Gas Works Park and the south end of the Lake. The site with the highest rank in metals contamination rank is at Site 8, west of Gas Works Park.

The sites that reflect ambient concentrations in Lake Union, due to their location away from pollution sources, are Sites 13, 15, 17 and to a lesser extent 10, 14, 16, and 18. All these sites are in the central basin of the Lake. These sites are outlined in Table 4. The variation of concentrations is low between these sites particularly copper, lead, and zinc which are all relatively high. The two sites furthest "upstream" (includes reference site) in the lake system ranked lowest in overall metals contamination. The next highest area of metals concentrations is in Salmon Bay. Therefore, with the exception of the southern end of Lake Union (Site 7) and the area around Gas Works Park the overall metals concentrations within the lake are equivalent and high. The metals concentrations in Portage Bay were uniformly lower than in either the lake or Salmon Bay. Metals in the Salmon Bay area were variable.

Figure 12 shows the correlation of the rank index for metals with percent clay in sediments. The relationship appears robust so that one might reasonably predict, in this study, the relative total metals concentrations by the percent clay. This relationship may occur because clay has greater surface area on which metals can sorb or it may reflect a depositional area. Areas of fine particles may denote an area of deposition and low current and disturbance. The overall circulation patterns, current, and sediment loading in the lake system are not well known.

Volatile Organics (VOAs)

With the exception of acetone and 2-butanone (methyl ethyl ketone), no volatile organic compounds were found in sediments in this study. Appendix Table A-1 reports detection limits of VOAs found in the study. Acetone, but not methyl ethyl ketone was found in the laboratory method blank samples. Acetone was used to clean sampling equipment and is considered a common contaminant in VOA analysis. The 2-butanone is found in plastic plumbing cement and can also be considered a common contaminant in analyses of this kind. A strong correlation was found between acetone and 2-butanone concentrations. This relationship supports the conclusion that both acetone and 2-butanone represent an artifact of some contamination and acetone and 2-butanone probably do not exist in high concentrations in sediments in the study area.

Pesticides and PCBs

Chlorinated pesticides and PCBs measured in the study area sediments are shown in Table 5. Detection limits of pesticides not found in the study are shown in Appendix Table A-2. With the exception of one site (20), in Portage Bay near the largest combined sewer overflow (CSO) in the study area, no chlorinated pesticides were found above detection limits throughout the lake system. Improvements in cleanup procedures (see Methods) allowed lower detection limits of PCBs at 14 of the 22 sites. Polychlorinated biphenyls were found at all sites in samples that

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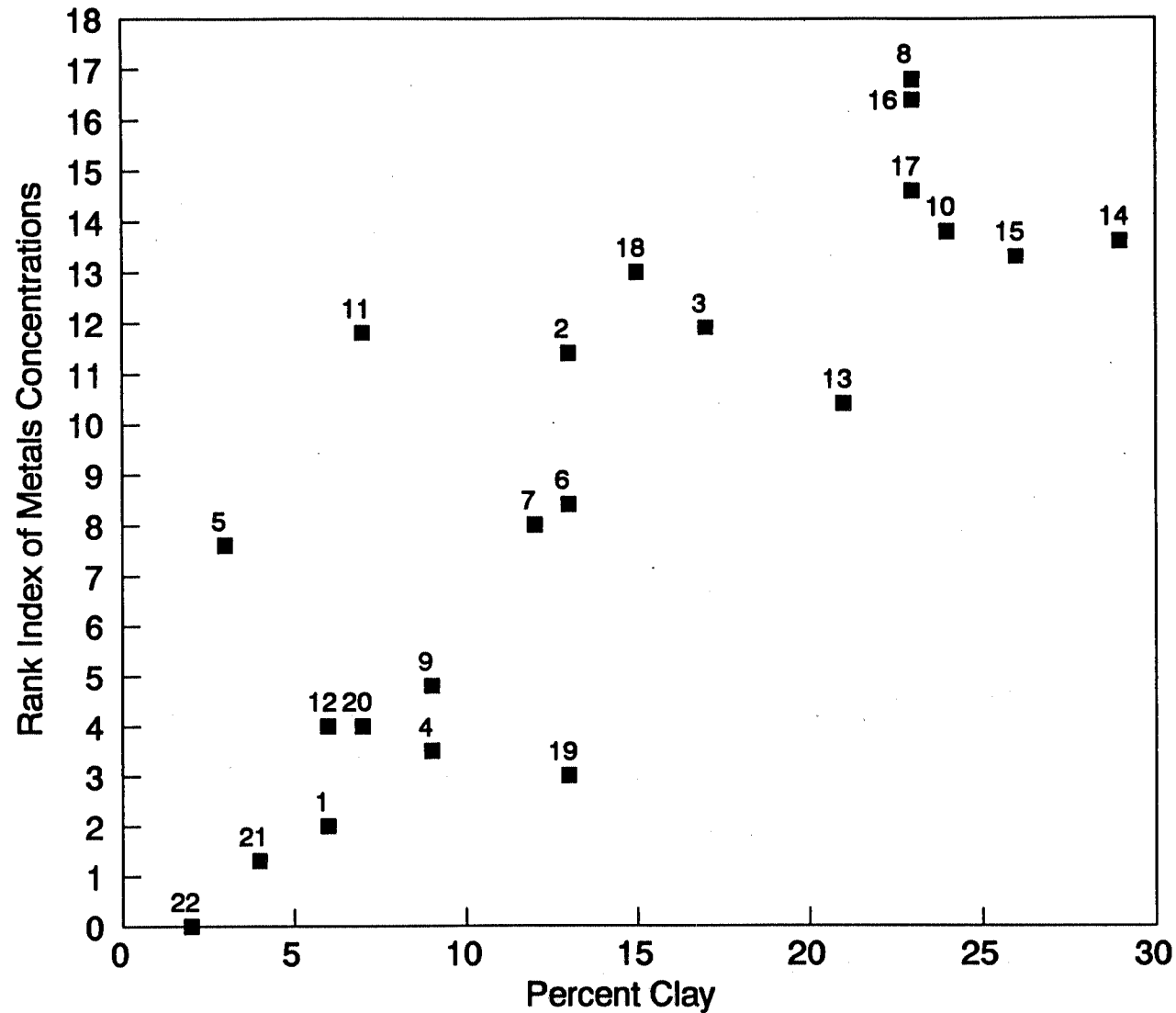
Figure 12. Relationship between percent clay and metals rank index. Higher rank index indicates higher concentrations of seven metals in sediments in Lake Union area. Site number is shown above marks in figure. See text for explanation of rank index. (n=22, r=.86, p<0.001)

Table 5. Pesticides and PCBs in sediments from Lake Union area (µg/kg dry weight).

Site	1	2	3	4	5	6	7	8	9	10	11
Lab Number	8230	8231	8232	8233	8234	8235	8236	8237	8238	8239	8240
4,4'-DDD	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
4,4'-DDT	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
Aroclor-1260	490 U	240 J	210 J	650 U	93 J	130 J	200 J	460 J	310 J	430 J	310 J
Total PCBs		240 J	210 J		93 J	130 J	200 J	460 J	310 J	430 J	310 J

U= No contaminant found at detection limit shown
J= Value is estimate due to low signal to noise ratio
▓▓▓ = Found above detection limits

Table 5 (con't). Pesticides and PCBs in sediments from Lake Union area (µg/kg dry weight).

Site	12	13	14	15	16	17	18	19	20	21	22
Lab Number	8241	8242	8243	8244	8245	8246	8247	8248	8249	8250	8251
4,4'-DDD	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	310	94 U	49 U
4,4'-DDT	450 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	140 J	94 U	49 U
Aroclor-1260	1700 U	2400 U	380 J	340 J	640 J	280 J	330 J	3200 U	1600 U	940 U	490 U
Total PCBs			380 J	340 J	640 J	280 J	330 J				

U= No contaminant found at detection limit shown
J= Value is estimate due to low signal to noise ratio
▓▓▓ = Found above detection limits

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were cleaned up with acid. Figure 13 maps PCBs concentrations in the study area. The highest concentration of 640 μg/kg was found in the eastern portion of the Lake Union basin (Site 16) and the lowest concentration was 93 μg/kg was present at the western entrance to the Ship Canal (Site 5). As found for the metals, PCB concentrations in the main body of the lake were consistent between locations.

Semivolatile Organics

Table 6 shows the results of semivolatile organics analysis of Lake Union sediments. The primary class of chemicals found in this analysis is PAH. Other semivolatile organics found included various chlorophenols and phthalates. The site with the most variety of compounds is located in the eastern portion of Salmon Bay near Fishermen's Terminal and the Ballard Bridge (Site 4). This was the only site where chlorophenols were detected. Gas Works Park Sites 9 and 11 were the only locations with dibenzofurans. These variations between sites show that, in contrast to metals, there is probably no overall ambient or representative concentration of semivolatiles in the study area.

PAH levels ranged widely throughout the study area. The highest concentrations were found in the Gas Works Park area (800,000 μg/kg total PAH) and the lowest at the reference site in Lake Washington (110 μg/kg). The distribution of PAH in Lake Union sediments normalized for TOC is shown in Figure 14. TOC normalization reduces the variability in PAH concentrations associated with differences in sediment TOC content. The overall pattern is consistent with the non-normalized pattern of substantially more PAH near Gas Works Park.

Bioassays

Bioassay test results are shown in Table 7. *Hyalella* showed significant mortality at both Gas Works Park Sites 9 and 11 while *Daphnia* was affected only at Site 11. With the exception of the Lake Washington reference site, all sites showed significant reduction in luminescence produced by Microtox® within 15 minutes after being exposed to an extract of the sediment, an indication of toxicity. These bioassay results show unequivocal toxicity as indicated by mortality at Sites 9 and 11. The Microtox® results suggest toxicity throughout the study area.

Benthic Macroinvertebrate Diversity

Table 8 summarizes the number of different invertebrates found in four replicate samples at the bioassay sites as well as diversity calculations. Paradoxically, one of the sites most heavily contaminated with PAH (Site 11) shows the greatest diversity. The greatest number of organisms appear at the Montlake Cut (Site 21). Figure 15 portrays these benthic measures by site. The highest abundance and near highest diversity was present in the Montlake Cut (Site 21), an area of relatively low contaminant concentrations. The most depleted sites appear in the middle and west sides of the lake. The Hilsenhoff biotic index, based on the character of communities rather than abundance and diversity, showed little difference among sites.
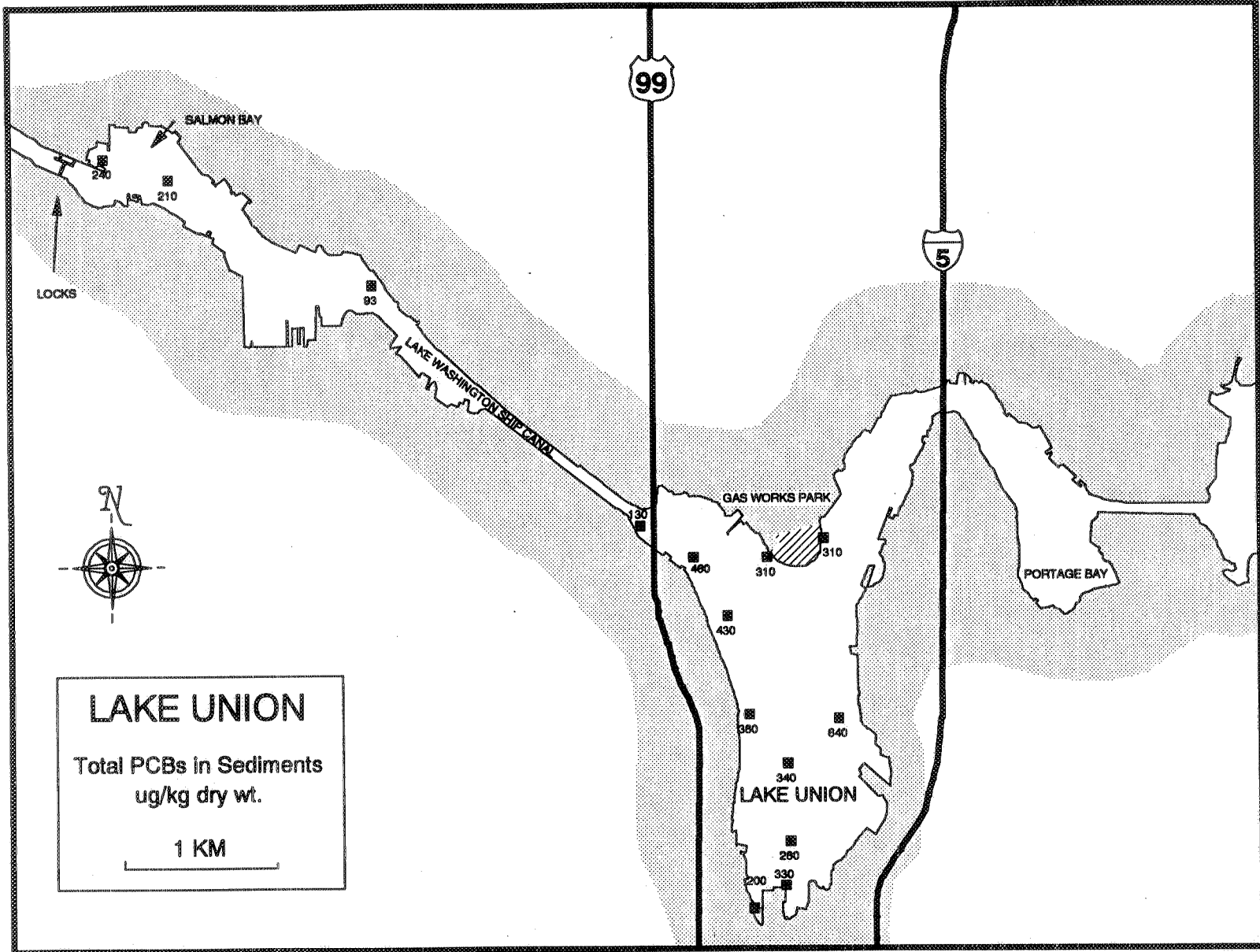
Figure 13. PCBs concentrations in sediments from Lake Union and adjoining waters. Only those sites analyzed with rigorous laboratory procedures are shown. See text for explanation.

Table 6. Semivolatile organics in sediments from the Lake Union area (μg/kg dry weight)

Site	1	2	3	4	5	6	7	8	9	10	11
Lab number	8230	8231	8232	8233	8234	8235	8236	8237	8238	8239	8240
2-Chlorophenol	1000 U	2100 U	2100 U	300 J	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
1,4-Dichlorobenzene	1000 U	2100 U	2100 U	150 J	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
4-Methylphenol	1000 U	230 J	2100 U	1300 U	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
N-Nitroso-Di-n-Propylamine	1000 U	2100 U	2100 U	150 J	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
Benzoic Acid	4900 U	10000 U	10000 U	6500 U	6700 U	26000 U	9100 U	19000 U	34000 U	20000 U	75000 U
1,2,4-Trichlorobenzene	1000 U	2100 U	2100 U	150 J	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
4-Chloro-3-Methylphenol	4900 U	10000 U	10000 U	240 J	6700 U	26000 U	9100 U	19000 U	34000 U	20000 U	75000 U
Dibenzofuran	1000 U	2100 U	2100 U	1300 U	1400 U	2100 J	1900 U	3900 U	10000 J	4100 U	7800 J
N-Nitrosodiphenylamine (1)	1000 U	2100 U	2100 U	1300 U	1400 U	5500 U	1900 U	3900 U	4300 J	4100 U	16000 U
Pentachlorophenol	4900 U	10000 U	10000 U	260 J	6700 U	26000 U	9100 U	19000 U	34000 U	20000 U	75000 U
Di-n-Butylphthalate	1000 U	2100 U	2100 U	1300 U	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
Butylbenzylphthalate	1000 U	310 J	330 J	1300 U	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
bis(2-Ethylhexyl)phthalate	390 UJ	7300 B	6000 B	680 UJ	6600 B	780 UJ	17000 B	5800 B	10000 BJ	3100 BJ	2400 J
Di-n-Octyl Phthalate	1000 U	450 J	2100 U	1300 U	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
Napthalene	1000 U	410 J	220 J	350 J	1400 U	5100 J	330 J	1600 J	12000 J	480 J	21000 J
2-Methylnapthalene	1000 U	2100 U	2100 U	1300 U	1400 U	2500 U	1900 U	710 J	110000	1800 J	4700 J
Acenaphthylene	1000 U	2100 U	2100 U	1300 U	1400 U	1800 J	1900 U	990 J	6100 J	4100 U	11000 J
Acenapthene	1000 U	380 J	320 J	290 J	180 J	1800 J	1900 U	2700 J	48000 U	820 J	20000 J
Fluorene	1000 U	2100 U	2100 U	1300 U	1400 U	2700 J	1900 U	3900 U	41000 U	4100 U	17000 J
Phenanthrene	1000 U	2600 J	1600 J	750 J	1000 J	25000	1500 J	5700 J	100000	2800 J	67000
Anthracene	1000 U	500 J	530 J	170 J	280 J	2700 J	280 J	2000 J	36000	830 J	35000
Total LPAH	0	3890 J	2670 J	1560 J	1460 J	39100 J	2110 J	13700 J	264100 J	6730 J	175700 J
Fluoranthene	220 J	4800	3700	1100 J	2100 J	35000	2200 J	21000	86000	7500	120000
Pyrene	210 J	4900	3900	1500 J	2300 J	42000	3100 J	26000	100000	9500	130000
Benzo(a)Anthracene	1000 U	2000 J	2000 J	370 J	1300 J	13000	1200 J	10000	49000	3000 J	58000
Chrysene	110 J	2300 J	2000 J	510 J	1400 U	18000	1300 J	11000	49000	3600 J	60000
Benzo(b)Fluoranthene	1000 U	2600 J	2400 J	330 J	1100 J	16000	2300 J	12000	53000	3600 J	66000
Benzo(k)Fluoranthene	1000 U	2000 J	2000 J	320 J	970 J	9900	1900 U	5900	32000	2900 J	35000
Benzo(a)Pyrene	1000 U	1600 J	1700 J	360 J	1100 J	18000	1000 J	12000	51000	4400 J	63000
Ideno(1,2,3-cd)Pyrene	1000 U	1700 J	1800 J	260 J	690 J	16000	1200 J	11000	43000	3500 J	46000
Dibenz(a,h)Anthracene	1000 U	2100 U	2100 U	1300 U	1400 U	5500 U	1900 U	3900 U	7100 U	4100 U	16000 U
Benzo(g,h,i)Perylene	1000 U	1700 J	1900 J	320 J	650 J	18000	1500 J	12000	48000	4000 J	49000
Total HPAH	540 J	13900 J	21400 J	5100 J	10200 J	186000	13800 J	121000	511000	42000 J	627000

U= No contaminant found at detection limit shown
J= Value is estimate due to low signal to noise ratio
B= Contaminant found in blank
░░░ = Found above detection limits

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Table 6 (con't). Semivolatile organics in sediments from the Lake Union area (µg/kg dry weight)

Site	12	13	14	15	16	17	18	19	20	21	22
Lab number	8241	8242	8243	8244	8245	8246	8247	8248	8249	8250	8251
2-Chlorophenol	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
1,4-Dichlorobenzene	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
4-Methylphenol	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
N-Nitroso-Di-n-Propylamine	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Benzoic Acid	380 J	25000 U	20000 U	16000 U	20000 U	15000 U	17000 U	29000 U	15000 U	9400 U	4900 U
1,2,4-Trichlorobenzene	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
4-Chloro-3-Methylphenol	17000 U	25000 U	20000 U	16000 U	20000 U	15000 U	17000 U	29000 U	15000 U	9400 U	4900 U
Dibenzofuran	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
N-Nitrosodiphenylamine (1)	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Pentachlorophenol	17000 U	25000 U	20000 U	16000 U	20000 U	15000 U	17000 U	29000 U	15000 U	9400 U	4900 U
Di-n-Butylphthalate	3400 U	5100 U	470 J	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Butylbenzylphthalate	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
bis(2-Ethylhexyl)phthalate	9900 J	3200 J	5000 J	3000 J	4850 J	4300 J	5700	2400 J	2200 J	720 J	230 J
Di-n-Octyl Phthalate	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 J	6000 U	3100 U	1900 U	1000 U
Napthalene	3400 U	600 J	4100 U	3200 U	460 J	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
2-Methylnapthalene	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Acenaphthylene	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Acenapthene	3400 U	5100 U	460 J	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Fluorene	370 J	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Phenanthrene	2400 J	1900 J	1800 J	1100 J	1450 J	840 J	1000 J	6000 U	440 J	420 J	1000 U
Anthracene	400 J	650 J	640 J	370 J	2305 U	360 J	3400 U	6000 U	410 J	1900 U	1000 U
Total LPAH	3170 J	3150 J	2900 J	1470 J	1910 J	1200 J	1000 J	0	850 J	420 J	0
Fluoranthene	3600 J	5700 J	4800 J	3300 J	4800 J	3100 U	2600 J	6000 U	950 J	690 J	1000 U
Pyrene	4100 J	7300 J	5600 J	4300 J	5000 J	3500 J	3200 J	730 J	1200 J	830 J	110 J
Benzo(a)Anthracene	1400 J	2500 J	1700 J	1300 J	1700 J	1100 J	1100 J	6000 U	470 J	350 J	1000 U
Chrysene	1700 J	2700 J	2700 J	1800 J	2500 J	1600 J	1600 J	6000 U	620 J	430 J	1000 U
Benzo(b)Fluoranthene	1100 J	2900 J	2600 J	2200 J	1950 J	2600 J	1500 J	6000 U	420 J	290 J	1000 U
Benzo(k)Fluoranthene	1300 J	2800 J	1800 J	1500 J	1890 J	3100 U	1700 J	6000 U	470 J	270 J	1000 U
Benzo(a)Pyrene	1600 J	4000 J	2400 J	2100 J	1800 J	1500 J	1500 J	6000 U	390 J	310 J	1000 U
Ideno(1,2,3-cd)Pyrene	1200 J	3200 J	1800 J	1600 J	1340 J	990 J	1200 J	6000 U	3100 U	1900 U	1000 U
Dibenz(a,h)Anthracene	3400 U	5100 U	4100 U	3200 U	4150 U	3100 U	3400 U	6000 U	3100 U	1900 U	1000 U
Benzo(g,h,i)Perylene	1500 J	4100 J	1900 J	1700 J	1400 J	1100 J	1200 J	6000 U	330 J	200 J	1000 U
Total HPAH	17500 J	35200 J	25300 J	19800 J	22400 J	12400 J	15600 J	730 J	4850 J	3370 J	110 J

U= No contaminant found at detection limit shown
J= Value is estimate due to low signal to noise ratio
B= Contaminant found in blank

▨ = Found above detection limits
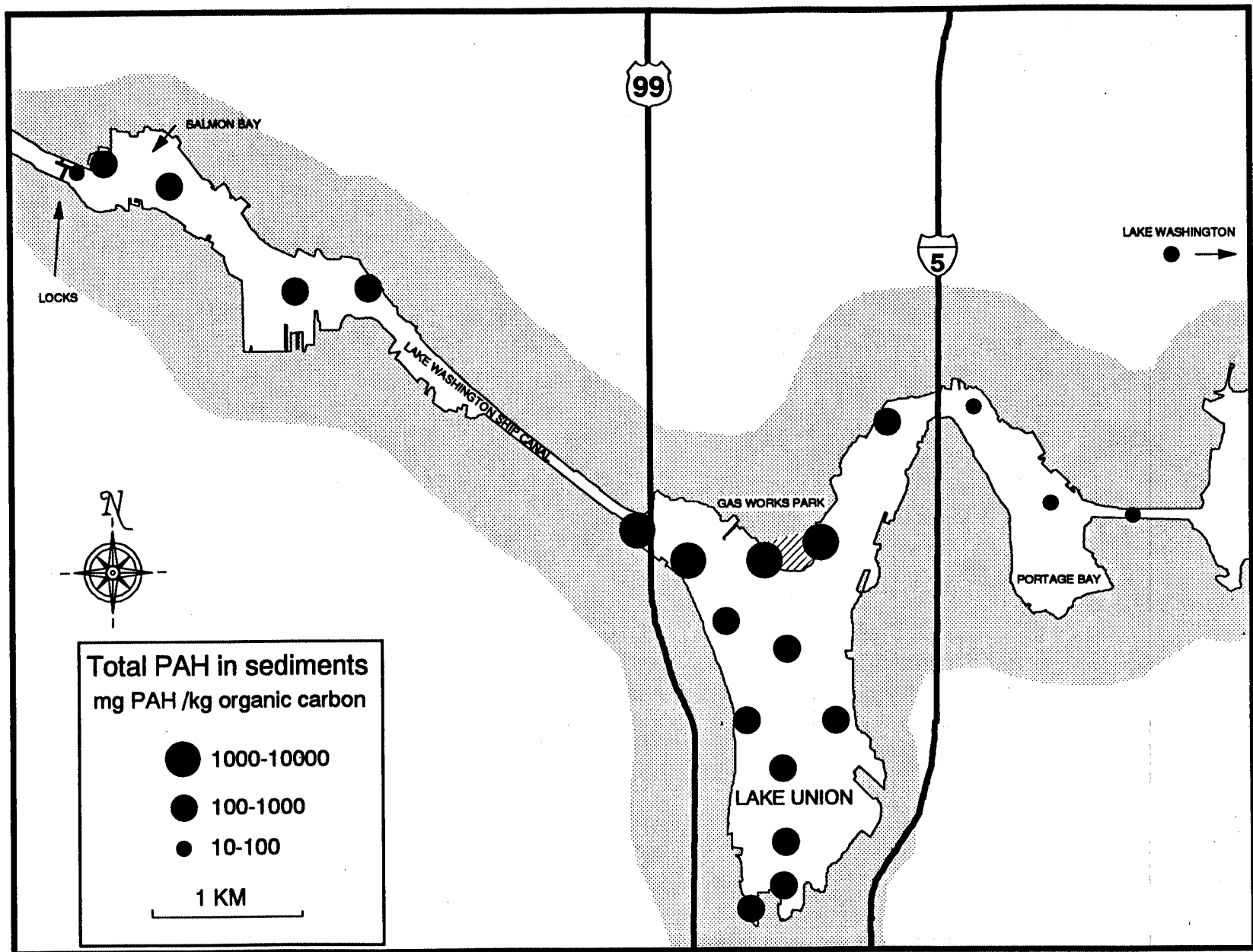
Figure 14. PAH concentrations in sediments on an organic carbon basis by class in Lake Union and adjoining waters.

Table 7. Sediment bioassays in the Lake Union area.

Site	Lab No.	Microtox™		D. magna		H. azteca	
		EC50	Sig?	Surv.	Sig?	Surv.	Sig?
8	8237	24.9%	*	96%		88%	
9	8238	9.7%	*	88%		8%	*
11	8240	56.6%	*	18%	*	0%	*
15	8244	56.0%	*	94%		76%	
18	8247	41.9%	*	98%		82%	
19	8248	14.2%	*	100%		80%	
20	8249	59.7%	*	98%		74%	
21	8250	35.4%	*	100%		90%	
22	8251	100.0%		92%		84%	

EC50= Concentration of extract that produces 50% reduction in light output.

Sig?= * = Significant at $p < 0.05$ (less than 1 chance in 20 the result could be random)

    For Microtox™, significance tested by pairwise comparison with control (see text)

    For other tests, survival compared with control with Dunnett's test:

      D. magna = significant mortality at $p < 0.05$ after 48 hours

      H. azteca = significant mortality at $p < 0.05$ after 10 days

Surv. = % survival

Table 8. Summary of benthic community data from Lake Union area.

General	Lowest taxon	Tolerance*	8	9	11	15	18	19	20	21	22
			Average number of organisms / square meter)(n=4) Site								
Annelida	Hurididae	10			25			50			
Oligochaeta	Naididae	8	75	500	25	200	200			200	200
	Tubificidae	10	13								175
	Branchiura	10			25		13				
Crustacea	Mysid	6									25
	Taphromysis	6			25						
	Daphnia					1800	63		50	200	
	Copepoda			25		125	13			100	50
Coleoptera	Zaitzevia	4								200	
Chironomidae	Chironomus	8	125	25	25	75	50		50	200	
	Dicrotendipes	8			50						
	Heterotrissocladius	6									25
	Macropelopia	6		75	25			100	100	200	
	Orthocladius	6									25
	Paracladopelma	8									25
	Phaenopsectra	8		125						100	
	Polypedilum	8		25					50	100	
	Tanytarsus	6								200	
Mollusca	Pisidium	8		25	100			150		1300	100
Porifera			50				13	150	200	800	800
Abundance Estimates											
	Number of taxa		4	6	9	4	6	4	5	11	9
	Total density of organisms		260	770	330	2200	350	450	450	3600	1400
Diversity Indices			(Higher number = more diversity)								
	Shannon's H'		1.7	1.6	2.9	1.0	1.8	1.9	2.1	2.8	2.1
	J (percent of H'max)		0.39	0.37	0.67	0.22	0.42	0.43	0.47	0.65	0.48
	Swartz's index		2	2	6	1	2	3	3	5	3
Biotic Index			(Higher number = more pollution tolerant)								
	Hilsenhoff Biotic Index		8.1	7.8	8.0	8.0	8.1	7.7	7.0	7.4	8.3

*Tolerance: Index assigned to taxa to calculate Hilsenhoff Index. Higher number = more pollution tolerant.

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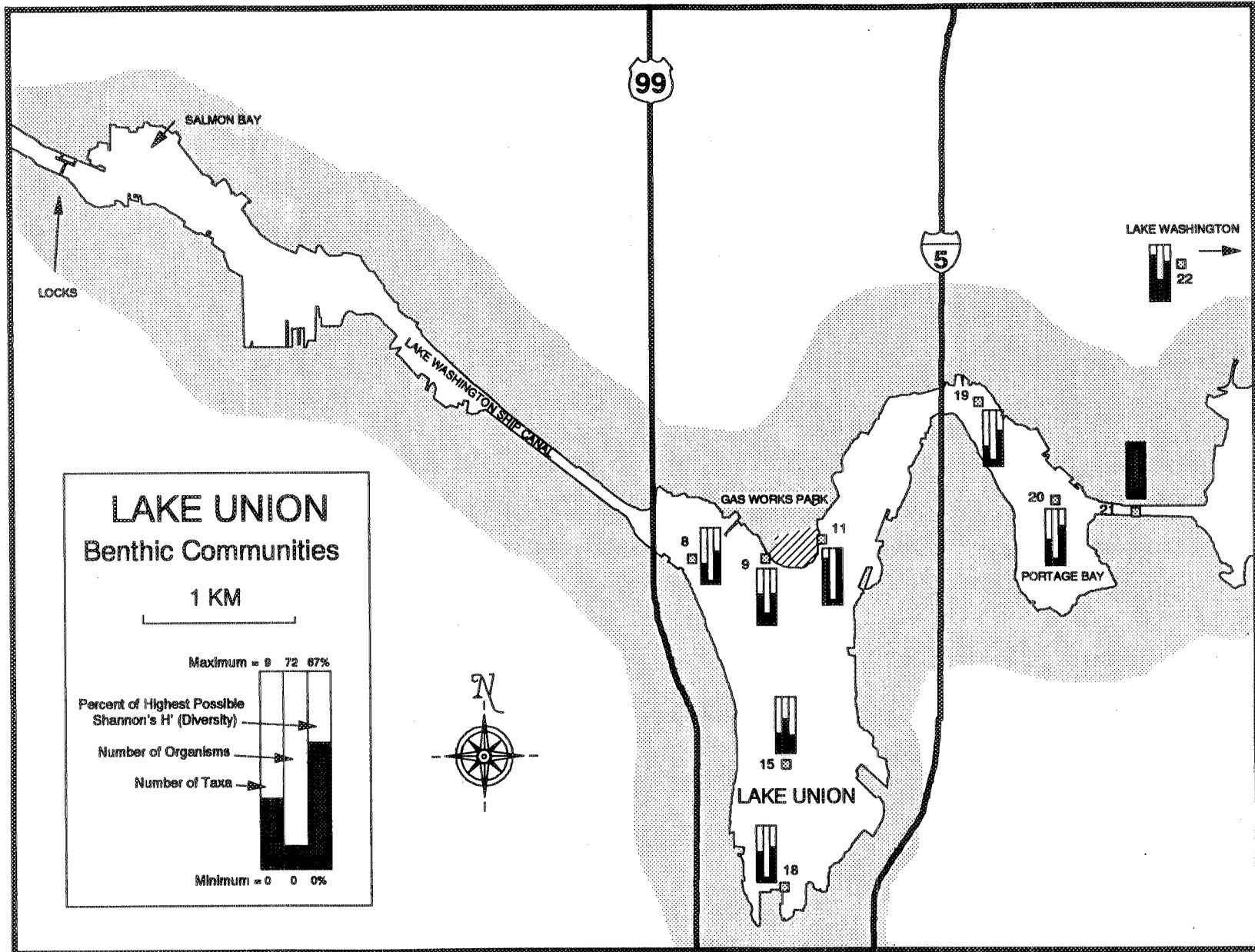
Figure 15. Benthic macroinvertebrate community measures at study sites.

Analysis of Relationships

Many of the measurements in the lake appear to be related to each other (Table 9). Strong correlations were apparent between several metals and percent clay in sediments. Because graphical representation of the correlations showed that Sites 9 and 11 near Gas Works Park were outliers in many measurements and had undue influence in creating or diluting correlations, correlations were reevaluated without those sites (Table 10). Strong relationships exist between the metals concentration with the possible exceptions of cadmium and nickel. This relationship suggests common sources of most of the metals.

To further understand the relationships of these chemicals and the relationships of the sites, the data were evaluated using principle components analysis (PCA) (see methods). PCA tries to reduce variance of the measures to a few major dimensions. The model shows what variables tend to covary with each other, that is, which contaminants are found at relatively equivalent concentrations at the same sites. Figure 16 plots all sites in relation to each other. Proximity between sites on the figure corresponds to similarity between sites so that close relation in the contaminant "mix" is reflected in close proximity between sites. This model accounts for 70 percent of the variance in the differences between samples. Sites close together (in Figure 16) are closely related in the type and amount of their contamination. Sites near Gas Works Park (Sites 9 and 11) are distant from the other sites; a pattern consistent with their status as outliers in the earlier correlation analysis. Factor 1 is linked with metals concentration, Factor 2 with organics. Thus the sites at the top of graph are high in organics, while sites at the right are high in metals. The reference site (Site 22) was lowest in both factors. Sites in the middle of the lake (Sites 10, 13-18) are closely placed in this model and reflect similar contaminant levels. Sites in Salmon Bay are distributed throughout the graph, indicating the variability of contaminants there.

A second kind of PCA was run that shows relationships between the contaminants rather than the site. In this model, vectors that are plotted close to each other are closely related. The length of the vector shows how much the variable contributes to the model. If a vector is short, it has little relationship to the rest of the model. Figure 17 shows the PCA of 20 sites (excluding Sites 9 and 11) for the parameters shown. This model accounted for 70 percent of the variance in the relationships between measurements (a good score for a two-dimensional model). Copper, chromium, lead, zinc, and percent clay are highly interrelated. Metals and PAH show no relationship to each other (they are portrayed at near right angles to each other in the model). Thus, there is little relationship in concentrations between the PAH and the metals. Arsenic and zinc likewise have little relationship. Mercury and nickel apparently do not covary with the other contaminants. TOC contributes little to the pattern (short axis). This analysis integrates the correlation work into one pattern which depicts the strong relationship among the metals contaminants.

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Table 9. Correlations between parameters in sediment from Lake Union area.
(Pearson correlation coefficient, n=22)

	As	Cd	Cu	Cr	Hg	Ni	Pb	Zn	SumPAH	%Fines	Clay
Cd	-0.12	–	–	–	–	–	–	–	–	–	–
Cu	0.08	0.34	–	–	–	–	–	–	–	–	–
Cr	0.04	0.29	0.78	–	–	–	–	–	–	–	–
Hg	0.58	0.34	0.69	0.52	–	–	–	–	–	–	–
Ni	0.82	-0.02	0.42	0.48	0.74	–	–	–	–	–	–
Pb	0.20	0.78	0.66	0.61	0.73	0.39	–	–	–	–	–
Zn	0.19	0.58	0.89	0.68	0.81	0.45	0.88	–	–	–	–
SumPAH	0.67	-0.26	-0.16	-0.24	0.43	0.61	-0.06	0.00	–	–	–
%Fines	0.21	0.52	0.46	0.29	0.55	0.31	0.62	0.59	0.09	–	–
%Clay	-0.05	0.67	0.69	0.63	0.58	0.27	0.85	0.76	-0.19	–	–
TOC	0.43	0.04	-0.14	-0.29	0.15	0.25	-0.01	-0.03	0.44	-0.64	-0.08

☐ = Significant at $p < 0.05$ (Bonferroni corrected)
☐ = Significant at $p < 0.01$ (Bonferroni corrected)

Table 10. Correlations between parameters in sediment from Lake Union area.
(Pearson correlation coefficient, n=20, excludes sites 9 and 11)

	As	Cd	Cu	Cr	Hg	Ni	Pb	Zn	SumPAH	%Fines	Clay
Cd	0.56	–	–	–	–	–	–	–	–	–	–
Cu	0.58	0.22	–	–	–	–	–	–	–	–	–
Cr	0.75	0.30	0.77	–	–	–	–	–	–	–	–
Hg	0.86	0.55	0.85	0.67	–	–	–	–	–	–	–
Ni	0.56	0.29	0.84	0.67	0.69	–	–	–	–	–	–
Pb	0.79	0.81	0.59	0.65	0.82	0.57	–	–	–	–	–
Zn	0.86	0.60	0.69	0.89	0.91	0.68	0.88	–	–	–	–
SumPAH	0.39	0.26	0.18	0.18	0.37	0.30	0.20	0.24	–	–	–
%Fines	0.47	0.59	0.32	0.49	0.56	0.34	0.63	0.60	0.01	–	–
%Clay	0.78	0.65	0.63	0.69	0.79	0.70	0.87	0.78	0.22	–	–
TOC	-0.00	0.22	-0.25	-0.08	0.09	-0.19	0.00	-0.03	0.05	0.04	-0.67

☐ = Significant at $p < 0.05$ (Bonferroni corrected)
☐ = Significant at $p < 0.01$ (Bonferroni corrected)
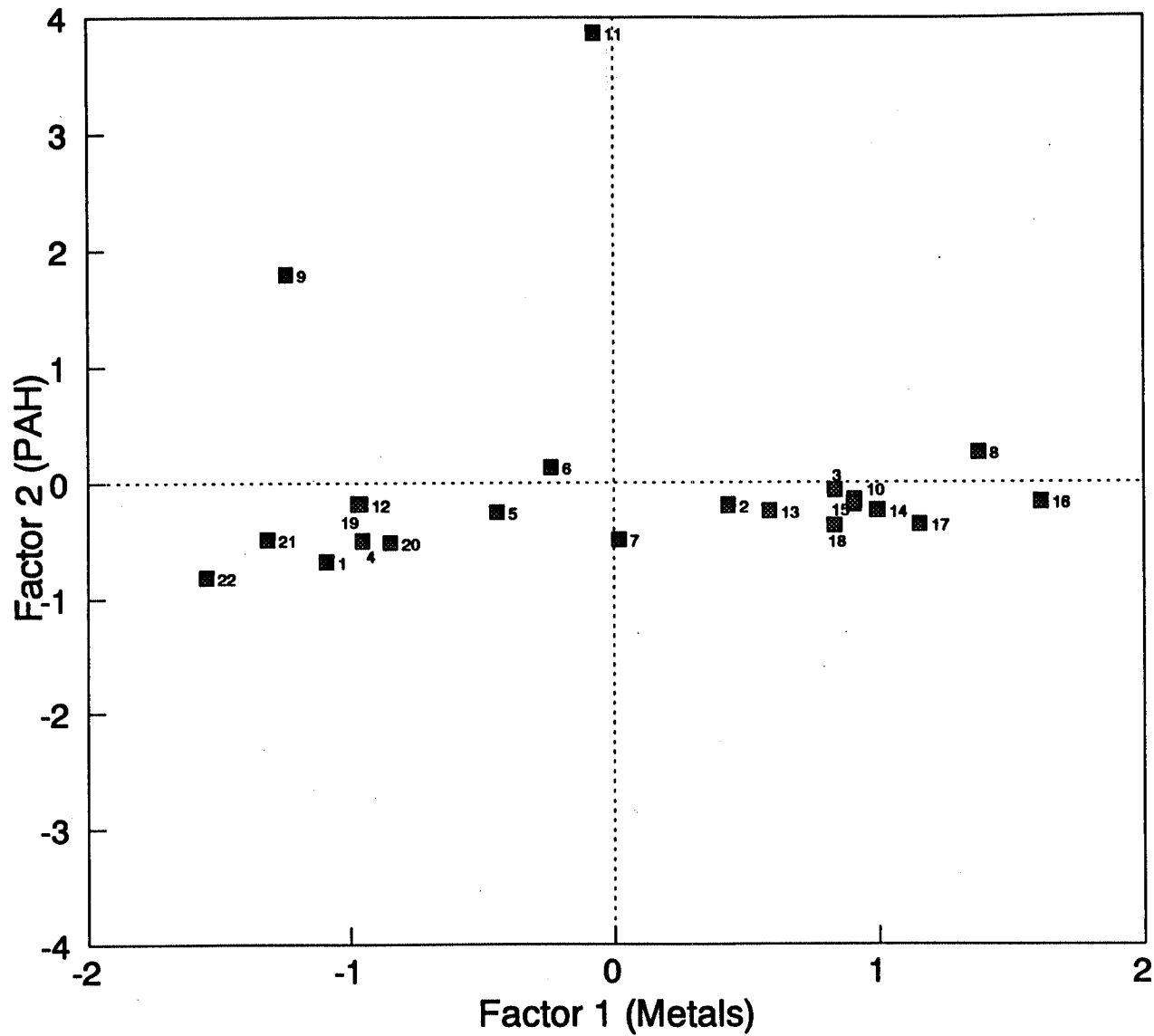
Figure 16. Results of principal components analysis by site. Sites close to each other in the figure have an equivalent mixture and amount of contaminants. Note that site 22 (reference site) is lowest in both factors.
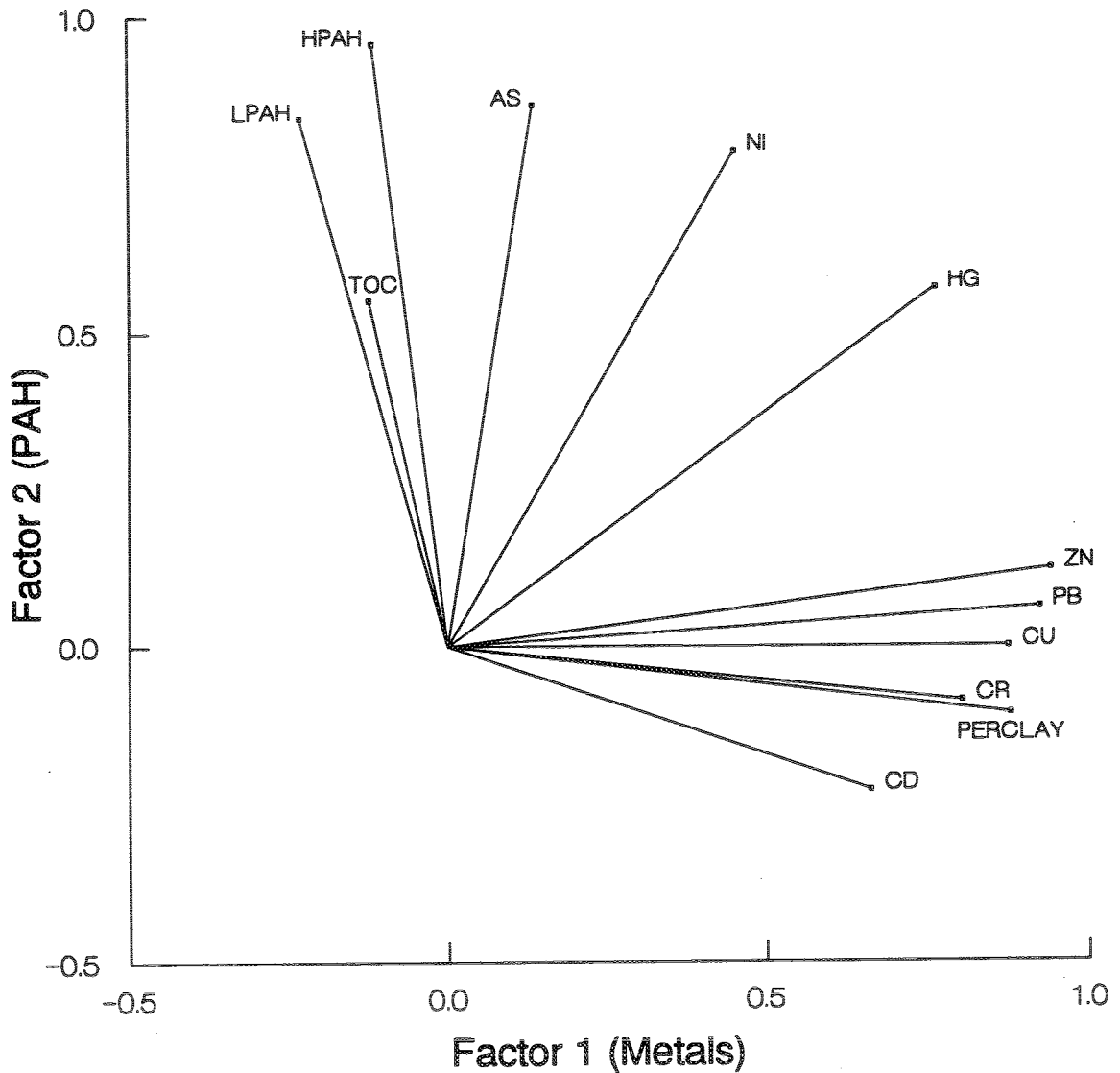
Figure 17. Principal components analysis of all chemical measures for all sites except sites 9 and 11 (considered outliers in correlation analysis) in this study. Near parallel components vary similarly by site. Note relationship among metals and between metals and percent clay.

Biological measures were taken at nine of the 22 sites. To examine the relationship between these measures and the contaminants, PCA was run at these nine sites and Figure 18 shows the principle components. The biological measures and indices were transformed so that their numerical value would increase with increasing contaminants concentrations. The transformations performed were:

1. Percent mortality: For *Hyalella* and *Daphnia*, the percent mortality (1-percent survival) is shown in the model. For Microtox, $1-EC_{50}$ is shown in the model.

2. Diversity: The Shannon H' index of diversity was transformed to $1-(H'/H'_{max})$ and was called impoverishment (IMPOVRSHMNT).

3. Number of taxa: The average number of taxa found at each site was transformed to $1-(N/N_{max})$, where N=number of taxa and N_{max}=maximum number of taxa found at any of the sites and was called reduction in taxa (REDUCETAXA).

4. Number of organisms: The average number of organisms found at each site was transformed to $1-(N/N_{max})$, where N=number of organisms and N_{max}=maximum number of organisms found at any of the sites and was called reduction in organisms (REDUCEORGS).

Hyalella mortality and LPAH are closely linked. *Daphnia*, HPAH and TOC are also closely related. Microtox® bioassays results explain little in the model (short vector). Another way to look at the Microtox® bioassays is that there is no strong relation between any one contaminant and the Microtox® response. For these nine sites copper, chromium, lead, and zinc are still closely related, but mercury, nickel, and arsenic are poorly related. Sulfides, arsenic, and bioassay mortality appear linked as well. This may reflect the fact that arsenic and sulfides were found at high levels at Site 11, the only site with *Daphnia* mortality. The apparent link of cadmium with reduction in taxa and impoverishment is interesting, but due to the small variation in cadmium concentrations that only span an order of two and the relatively low density of organisms, conclusions about this relationship would be weak. Overall, the bioassay mortality in both *Hyalella* and *Daphnia* seen at the two Gas Works Park sites is undoubtedly linked to PAH concentrations. The biological diversity measures are equivocal and inconclusive.

Through this analysis, the source of the toxicity at Sites 9 and 11 are clear. The relationship of several metals concentrations are linked to each other and could reflect a common source of contamination. Microtox® bioassays show some level of toxicity throughout the Lake Union area, but this toxicity is not related to any one contaminant concentration. The LPAH and HPAH concentrations are closely linked.
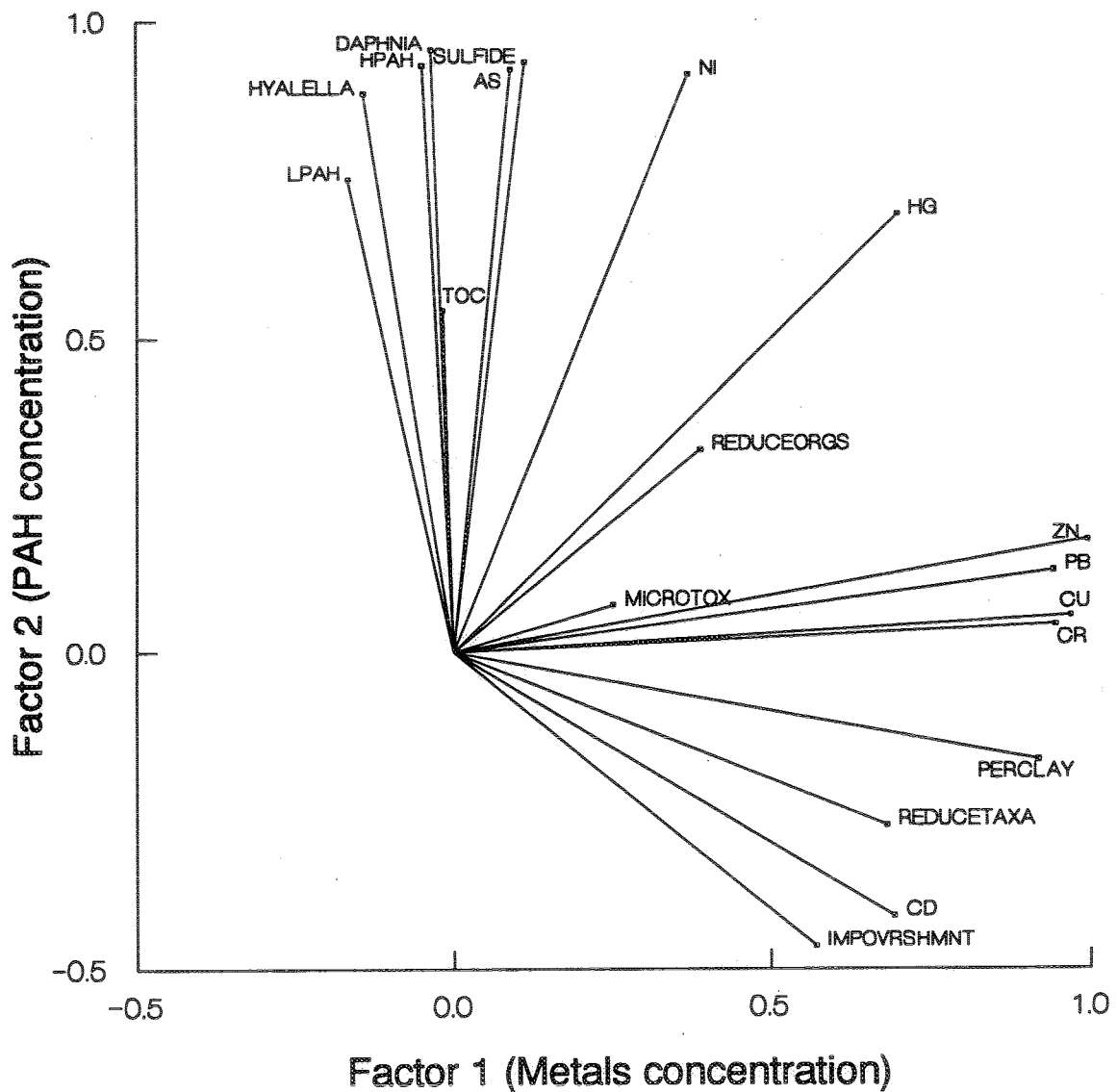
Figure 18. Principal components analysis of all bioassay sites in this study. Near parallel components vary similarly by site. Note close relationship of HPAH and LPAH to mortality in Daphnia and Hyalella bioassays. Short vectors at TOC and Microtox denote no strong relationship to any one component. See text for explanation of all variable names.

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DISCUSSION

Comparison to Other Studies

Several studies have examined sediments in portions of Lake Union. As part of a Puget Sound-wide study of contaminants in sediment, Metro (Romberg *et al.*, 1984) sampled sediments in the Lake Union area for metals and organics. To help determine the feasibility of developing a city park at the south end of Lake Union, the city of Seattle (Solomon, 1986) sampled sediment from several sites in the south part of the lake. As part of a comprehensive study of contamination around Gas Works Park, EPA conducted sediment sampling throughout Lake Union (Hileman *et al.*, 1984). Most of the samples (24 of 33) were collected within 500 feet of Gas Works Park. These earlier analyses show varying degrees of comparability to the current study. Variable sample locations could account for some of these differences. To examine concentration differences on a site by site basis, adjacent sites between these investigations were compared. Figure 19 shows the locations of samples in Lake Union from the four studies.

Metals

Table 11 shows metals concentrations found in sediments in various studies. In addition, a summary of freshwater sediment values from a search of all available data in Washington that does not include the other studies is shown (Cubbage and Bennett, in prep). These summary values from throughout Washington were gathered from several sources including EPA's STORET database, USGS reports, and Ecology reports. These sites were often selected for sampling because of a potential problem and they do not represent a background concentration of these metals. Figure 20 depicts comparisons of median concentrations of metals in Lake Union by study. The current study found higher concentrations of arsenic, copper, lead, and zinc than found by Hileman (1984); cadmium, chromium, mercury, and nickel were found at lower concentrations. The Hileman (1984) study was focused on the Lake Union area. The Solomon (1986) study found lower concentrations of all metals except mercury which was four times lower in the current study. The Romberg (1984) study found similar concentrations of all metals except copper, which was higher in this study.

No clear explanation can be found for the comparatively higher concentrations of copper found in the current study nor the overall lower concentrations reported in the 1986 study. Field collection techniques could be different and are not clearly specified in earlier studies. For example, collection of samples from different depositional layers in the sediment could vary the results of metals analyses. Analysis methods appeared equivalent between studies. However, the 1986 study never specified whether metals were reported on a wet weight or dry weight basis. The laboratory performing these analyses is apparently no longer in business and could not be contacted. The discrepancy could be narrowed considerably if the metals in the 1986 study reflect wet weight basis. However, if the mercury concentrations are converted to dry weight basis, concentrations in the Solomon (1986) study would be considerably higher. Variations between study techniques and locations in these studies render conclusions about temporal trends in the concentrations of contaminants in the sediments of Lake Union dubious. Overall, these concentrations are far higher than those found in other areas of Washington State.
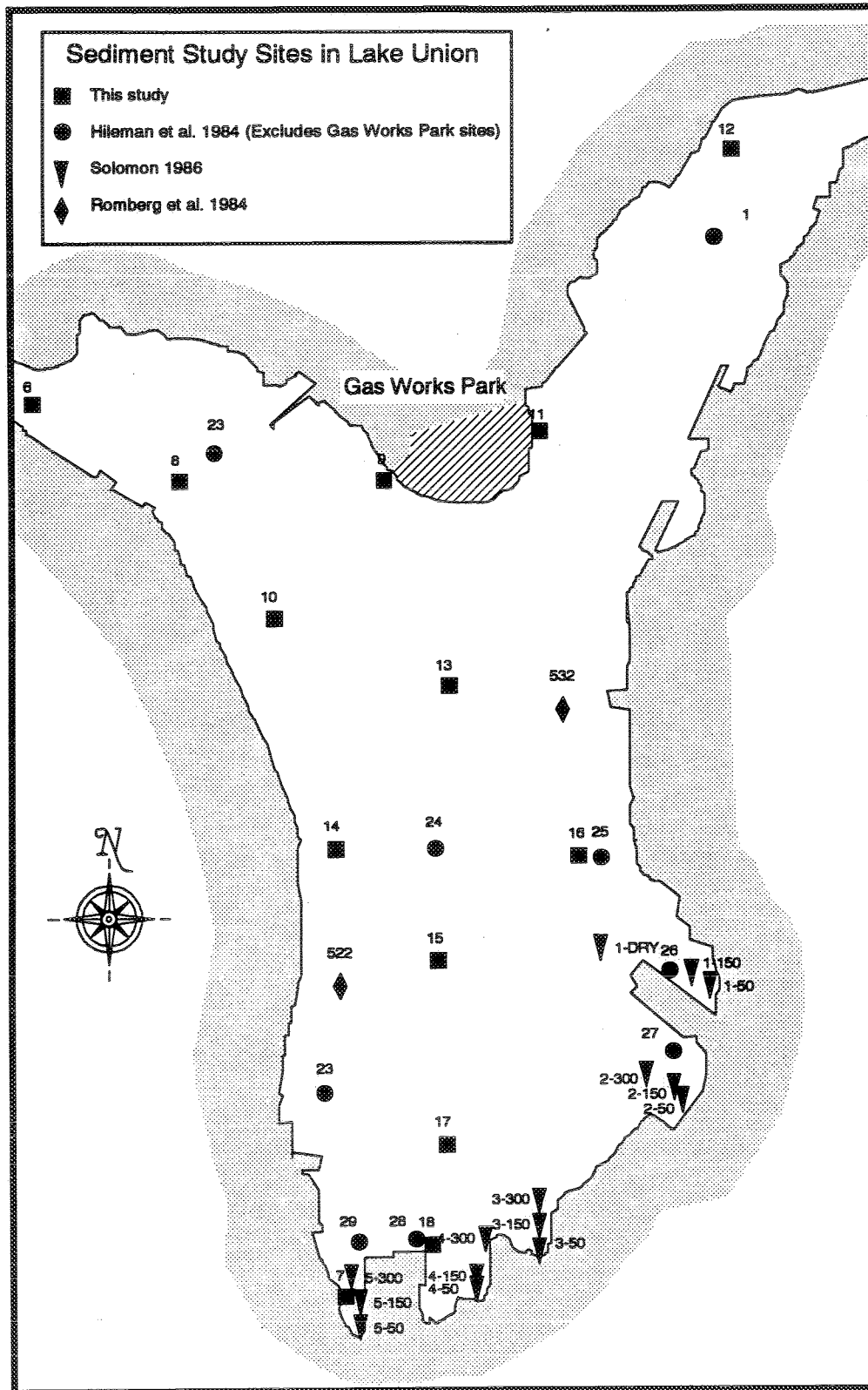
Figure 19. Locations of sediment sampling sites from previous studies and this study in Lake Union.

Table 11. Comparison of metals concentrations in sediments from the present study with other studies in Lake Union and adjoining waters, and other areas of Washington State.

	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
				Concentration mg/kg dry weight				
This study (Lake Union only)				**LAKE UNION**				
N	13	13	13	13	13	13	13	13
Min	20	0.5	19	68	0.5	37	124	250
Max	1150	2.3	113	599	2.9	133	831	904
Median	61	1.4	58	310	1.7	57	641	533
Romberg et al. 1984								
N	2	2	2	2	2	2	2	2
Min	77	1.7	53	140	2.2	62	440	460
Max	158	2.4	55	170	5.5	68	590	530
Median	118	2.1	54	155	3.9	65	515	495
Hileman et al. 1984								
N	33	33	33	33	33	33	33	33
Min	0	0.1	14	23	0.03	47	28	51
Max	284	2.4	87	587	4.3	291	962	1058
Median	28	1.5	54	168	1.1	92	319	382
Solomon 1986								
N	15	15	15	15	15	15	15	15
Min	3	0.4	5	19	0.4	5	14	6
Max	247	1.5	57	471	27.3	18	634	1107
Median	11	0.8	9	46	6.6	12	114	133
This study				**SHIP CANAL**				
N	5	5	5	5	5	5	5	5
Min	20	0.5	48	51.3	0.1	45	33	87
Max	52	0.5	124	638	1.9	91	366	685
Median	29	0.5	66	275	1.4	47	163	368
Romberg et al. 1984								
N	2	2	2	2	2	2	2	2
Min	49	0.8	31	45	3.1	37	208	135
Max	83	0.9	57	220	7.2	56	230	420
Median	66	0.8	44	132.5	5.2	47	219	278
Cubbage and Bennett in prep				**FRESHWATER SEDIMENTS IN WASHINGTON**				
N	155	28	119	161	114	91	150	39
Min	0.8	0.1	0.0	1	0.00	5.8	0.0	47
Max	80	2.6	740	4870	0.70	154	900	813
Median	8.7	0.4	21.0	36	0.04	25	18.9	104
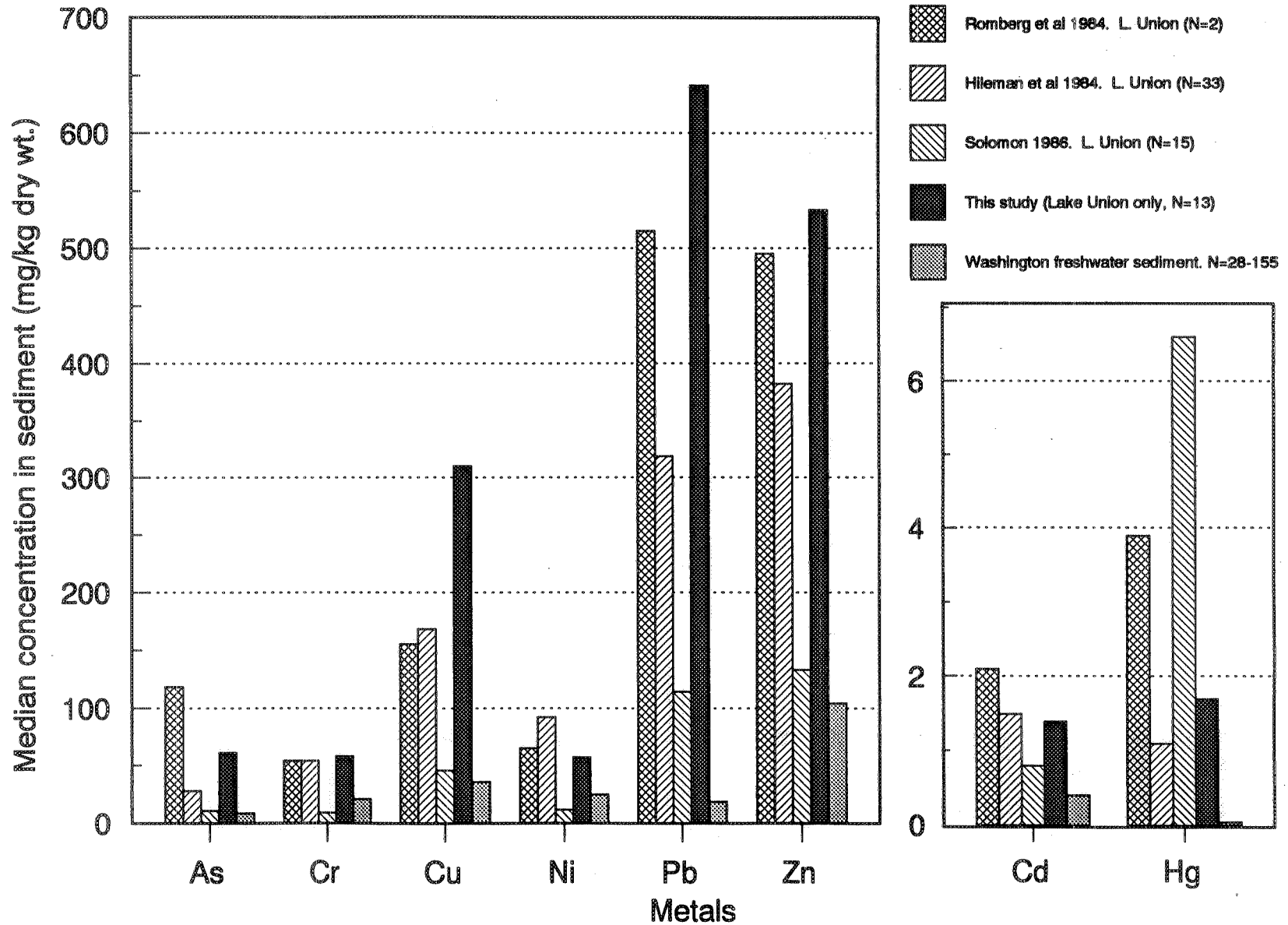
Figure 20. Median metals concentrations in Lake Union area and all freshwater sediments in Washington State.

Organics

Organics concentrations (PAH and PCBs) found in other studies are summarized in Table 12. Due to errors in the data reported in Hileman (1984), corrections were made by multiplying all organics data reported in Hileman (1984) by the percent moisture at each site. This correction was due to the data being corrected for dry weight measure twice (Yake *et al.*, 1986; Hileman, personal communication). Because of the exceptionally high concentrations of PAH found near Gas Works Park, PAH concentrations from sites within 500 feet of the park were excluded from review in order to give a representation of PAH levels in the body of Lake Union. In Table 12, sites outside of Lake Union are also excluded in order to compare equivalent areas between studies. Figure 21 compares the medians of these studies. With the exception of the Romberg (1984) study, the median LPAH concentrations are roughly equivalent. HPAH median concentrations are similar among all studies except the Hileman (1984) work. PCBs were markedly higher in the Solomon (1986) study of southern Lake Union that had several sites near the old power generation facility on the east shore of the lake, a documented historical source of PCBs.

Paired comparisons between nearest sites were made. The PAH appear to vary more on a site by site basis than metals in a comparable analysis. These variations could be caused by both differences in laboratory technique as well as variations in depth of sampling (unspecified in some studies). These differences may also reflect the patchy distribution of organics contamination in Lake Union.

Bioassays

Bioassay studies have shown the usefulness of *Hyalella* as a bioassay organism for freshwater sediments (Bennett and Cubbage, 1992). Yake *et al.* (1986) used *Hyalella* bioassays and found significant toxicity at a Gas Works Park Site and none at a reference site in Chester Morse Reservoir. Microtox® tests were used in Lake Union by Solomon (1986). That study found indications of toxicity at 11 of 15 sites in South Lake Union. The present study found sediment from all sites tested to have some toxicity except the reference in Lake Washington when tested with Microtox®. The specific cause of the toxicity is not known and it may be a combination of several contaminants.

Benthic Invertebrate Diversity

The benthic macroinvertebrate diversity analysis was inconclusive in this study and showed no clear relationship to concentrations of contaminants. Yake *et al.* (1986) found benthic diversity was low at the Gas Works Park Site compared with the reference site whereas this study found highest diversity measures at one of the more highly contaminated sites near Gas Works Park. These diversity measurements are sensitive to changes in habitat beyond concentrations of contaminants including salinity, grain-size structure, substrate, total organic carbon, and oxygen availability. The biotic index measurements for all these sites are comparatively high and indicate a predominance of pollution-tolerant species.

Table 12. PAH concentrations in sediments from different studies in Lake Union.

	SumLPAH	SumHPAH	SumPCBS	TOC
	(μg/kg dry wt.)			%
This study (Lake Union only; excludes sites within 500 feet of Gas Works Park)				
N	10	10	8	10
Minimum	900	12400	200	5%
Maximum	13700	121000	640	15%
Median	2500	18600	360	7%
Hileman et al 1984 (excludes sites within 500 feet of Gas Works Park)				
N	8	8	N/R	N/R
Minimum	0	0	N/R	N/R
Maximum	9455	188976	N/R	N/R
Median	601	8054	N/R	N/R
Solomon 1986				
N	14	14	14	14
Minimum	1310	3800	240	1%
Maximum	10500	33300	12500	8%
Median	3350	10600	3420	5%
Romberg et al. 1984				
N	2	2	2	2
Minimum	0	0	55	2%
Maximum	31	35400	203	3%
Median	15	17700	129	3%

N/R = Not reported
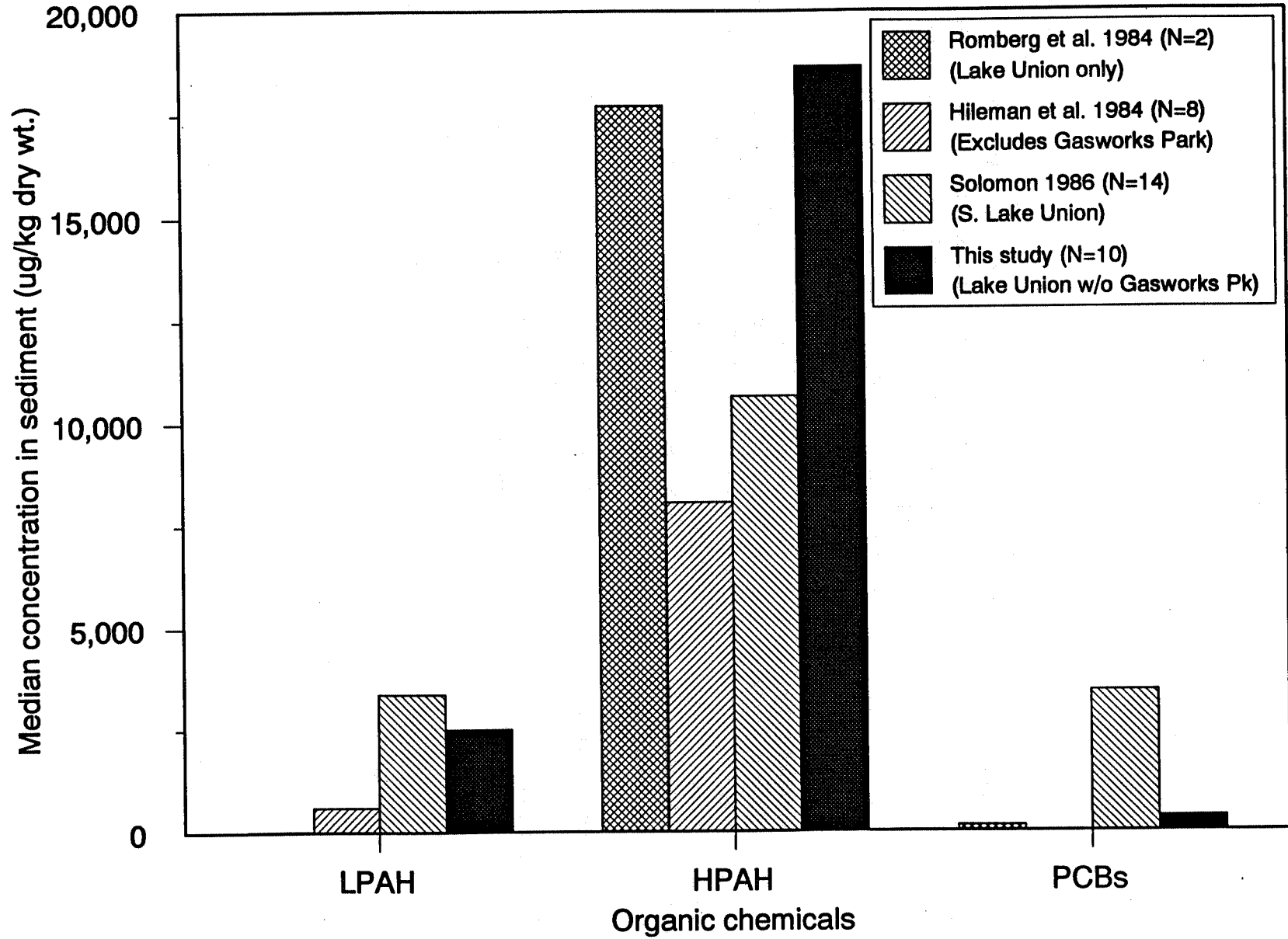
Figure 21. Median organics concentrations in Lake Union.

Legend:
- Romberg et al. 1984 (N=2) (Lake Union only)
- Hileman et al. 1984 (N=8) (Excludes Gasworks Park)
- Solomon 1986 (N=14) (S. Lake Union)
- This study (N=10) (Lake Union w/o Gasworks Pk)

Y-axis: Median concentration in sediment (ug/kg dry wt.)

X-axis: Organic chemicals — LPAH, HPAH, PCBs

Comparison to Criteria

At the time of this report, no standards have been adopted by Washington State for freshwater sediments. Initial guidelines may be issued in 1993. For marine sediments, criteria have been established and used to determine potential of biological harm caused by various concentrations of contaminants (Washington Administrative Code 173-204).

Other governmental bodies have published guidelines for the classification of freshwater sediments based on concentrations of contaminants though none of the guidelines have been included as rules or regulations from the issuing agency. The developmental methods, as well as the guidelines reported by different government agencies, are reviewed by Bennett and Cubbage (1991) and the published guidelines germane to the chemicals examined in this study appear in Table 13. These guidelines vary substantially with several criteria differing by over one order of magnitude. These variations reflect the different methods used to determine the criteria. The guidelines were developed using one of three primary approaches: 1) *in situ* biological effects, 2) conversion of EPA water quality criteria to sediment values based on equilibrium partitioning, and 3) elevation above background concentration.

The Provincial Sediment Quality Guidelines (Persaud *et al.*, 1991) are the most comprehensive of these guidelines. They are based on *in situ* biological effects and, when adopted by Ontario, will govern several aspects of freshwater sediment management including remediation and disposal. Values greater than the Severe Effect Level (the guideline reported in Table 13) can be expected to cause harm to benthic biota. At this point, the Provincial Guidelines appear closest to regulatory use by government agencies.

Table 14 shows the results of this study compared with two guidelines: The Provincial guidelines and the Wisconsin Department of Natural Resources (DNR) criteria. The Wisconsin DNR criteria are compared here because they review the most chemicals. The Provincial guidelines for arsenic, copper, lead, and mercury are exceeded at most sites in Lake Union and the Ship Canal. TOC guidelines are exceeded at several sites as well. The Wisconsin DNR limits show the Lake Union area has similar exceedences with the addition of PAH and zinc in the Ship Canal and Lake Union. The last column (average) shows that arsenic, copper, lead, mercury, zinc, and PAH are problems in the Ship Canal and Lake Union with an average of 50-92 percent of the sites exceeding guidelines for these chemicals. For sites east of Lake Union (Sites 19-22, including the reference site), with the exception of lead, few concentrations were above criteria. Lead concentrations exceeded all guidelines at most sites.

Table 13. Review of proposed criteria and guidelines for contaminated freshwater sediments. Derived from sediment quality review by Bennett and Cubbage 1991.

	(Persaud, et al. 1991) Provincial Sediment Quality Guidelines Severe Effect	(WDNR,1985,1990) Wisconsin Dept. of Natural Resources	(Hart et al. 1988) Sediment Quality Guidelines	(EPA, 1977) Region V Guidelines Pollution Class. Heavily Polluted	(Neff et al. 1986) SLC for Freshwater Sediments	(EPA, 1988) Interim Sed. Crit. Nonpolar Organics	(Anon., 1988) Ont. Min. Environ. Dredge Disposal Crit Restricted Land	WA WAC 173-204 MARINE Sediment quality Standards
METALS	mg/kg dry wt.	mg/kg dry wt.	mg/kg dry wt.	mg/kg dry wt.			mg/kg dry wt.	mg/kg dry wt.
Arsenic	33	10	17	>8	–	–	20	57
Cadmium	10	1	2.5	>6	–	–	4	5
Chromium	110	100	100	>75	–	–	120	260
Copper	110	100	85	>50	–	–	100	390
Lead	250	50	55	>60	–	–	500	450
Mercury	2	0.1	0.6	>1	–	–	0.5	0.41
Nickel	75	100	92	>50	–	–	60	–
Zinc	820	100	143	>200	–	–	500	410
ORGANICS	mg/kg OC	mg/kg OC	mg/kg OC		mg/kg OC	mg/kg OC	mg/kg dry	mg/kg OC
PCB	530	0.05	4.00	–	0.29	–	>2.0	12
PCB-1260	24	–	–	–	–	–	–	
PAH (Total)	11000	89	–	–	–	–	–	–
Naphthalene	–	1240	–	–	–	–	–	99
Acenapthene	–	92	–	–	–	732	–	16
Phenanthrene	–	–	–	–	–	139	–	100
Fluoranthene	–	1216	–	–	–	1883	–	160
Pyrene	–	–	–	–	–	1311	–	1000
Benzo(a)anthracene	–	–	–	–	–	1317	–	110
Benzo(a)pyrene	–	89	–	–	–	1063	–	99
TOC (%)	10	–	–	–	–	–	–	–

mg/kg OC = mg/kg organic carbon

Table 14. Comparison of contamination at Lake Union sites with guidelines and criteria proposed from other selected studies. Derived from sediment quality review by Bennett and Cubbage, 1991.

	Number of sites exceeding guideline/number of sites examined								
	(Persaud, 1991) Provincial Sediment Quality Guidelines			(WDNR,85,90) Wisconsin Dept. of Natural Resources			Average percent of sites exceeding guideline**		
Sites*	I	II	III	I	II	III	I	II	III
METALS									
Arsenic	3/6	9/12	0/4	4/6	9/12	0/4	58%	75%	0%
Cadmium	0/6	0/12	0/4	0/6	8/12	0/4	0%	33%	0%
Chromium	1/6	1/12	0/4	1/6	1/12	0/4	17%	8%	0%
Copper	4/6	11/12	0/4	4/6	11/12	0/4	67%	92%	0%
Lead	3/6	10/12	0/4	5/6	12/12	3/4	67%	92%	38%
Mercury	0/6	4/12	0/4	6/6	12/12	3/4	50%	67%	38%
Nickel	1/6	1/12	0/4	0/6	1/12	0/4	8%	8%	0%
Zinc	0/6	2/12	0/4	5/6	12/12	2/4	42%	58%	25%
ORGANICS									
PCB	0/4	0/10	0/0	0/4	0/10	0/0	0%	0%	0%
PCB-1260	0/4	0/10	0/0	–	–	–	0%	0%	0%
PAH (Total)	0/6	0/12	0/4	5/6	12/12	0/4	42%	50%	0%
Naphthalene	–	–	–	0/6	0/12	0/4	0%	0%	0%
Acenapthene	–	–	–	0/6	1/12	0/4	0%	8%	0%
Fluoranthene	–	–	–	0/6	0/12	0/4	0%	0%	0%
Benzo(a)pyrene	–	–	–	1/6	3/12	0/4	17%	25%	0%
TOC	0/6	5/12	2/4	–	–	–	0%	42%	50%

* =Site Codes: I = Ship canal sites (1–6);

II = Lake Union sites (7–18);

III East sites (19–22);

** = Average number of sites exceeding guideline/total number of sites examined *100

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CONCLUSIONS

Due to a long history of industrial uses and location within a large city, sediments in Lake Union and the Ship Canal are contaminated with high concentrations of a variety of chemicals. Areas of highest contamination in the study area are in Lake Union. Within the lake, sediments are relatively uniformly contaminated. PAH, arsenic, and sulfide concentrations are highest at Sites 9 and 11 adjacent to Gas Works Park. These sites are also the two sites where significant bioassay mortality occurred. In the rest of lake, PAH concentrations were moderate compared to sites near Gas Works Park, but they were higher than sites east of the I-5 Bridge (Portage Bay and east).

Metals concentrations are uniformly high in the middle of the lake (Sites 10, 13-18) and at Salmon Bay (Sites 2 and 3). The highest ranking metals site was Site 8, on the west end of Lake Union, the next highest site on the east shore of the lake (site 16, near the NOAA shipyard). To the west, the Ship Canal and Salmon Bay show high concentrations of metals, but at lower concentrations than the central part of the lake. PCBs are found in sediments throughout Lake Union. No relationship was found between specific contaminants and Microtox® response though Microtox® showed toxicity at all eight sites tested in Lake Union and the Montlake Cut area. The overall spacial pattern shows the highest concentrations of pollutants are within the lake, followed by the sites downstream of the lake in the Ship Canal and Salmon Bay. The areas of lowest contamination were east of the I-5 bridge. The lowest concentration for all parameters was at a reference site in Lake Washington, upstream of all other other sites. None of the three bioassays showed toxicity at this site.

A comparison with previous studies shows some differences in concentrations of contaminants between studies, but all studies confirm that sediments within the lake are contaminated with high concentrations of several metals, particularly copper, lead, zinc, arsenic, and mercury. Those sites with high concentrations of any one metal tended to have the higher concentrations of other metals as well. Metals concentrations correlate well with the percent clay found in the sediments. Most of the sites studied exceed several freshwater sediment guidelines derived by Ontario Provincial Government and could be expected to severely affect organisms in the sediment. The results from this study can serve to provide the representative concentrations of sediment contaminants in the study area.

RECOMMENDATIONS

1. Consider using the metals values found in this study as ambient concentrations for the lake system to guide and rank cleanup at specific sites.

2. To reduce impacts on aquatic life near the Gas Works Park area, the sediments near the park with high PAH concentrations should be either cleaned up or capped.

3. Determine the amount of contamination in the sediment currently being deposited in the study area. This could be done with sediment traps and an analysis of storm drain sediments. A comparison study of currents and depositional areas within the study area would help determine fate of contaminants discharged into the lake. This study could be focused at specific sources or it could be broadened to include an understanding of contaminant circulation and deposition throughout the lake.

4. Continue with all available procedures and programs to reduce the amount of contaminants that enter the lake.

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APPENDIX A: LABORATORY QUALITY ASSURANCE

Several tests were used to assess laboratory accuracy and precision. Following are reviews of the quality assurance tests and laboratory reports. Overall, the data are useable and have few qualifications. The data review performed by Manchester Laboratory follows Tables A-1 and A-2.

Matrix Spike: Matrix spikes were performed for each of the four types of analyses (Metals, PCBs, VOAs, BNAs). A known amount of the target compound was added to the matrix (sediment) and the recovery of the compound was a measure of extraction efficiency and analytical accuracy. Matrix recoveries showed acceptable extraction and analysis accuracy. Table A-1 shows a review of metals recovery information. Table A-2 presents the results of matrix spike tests for the organics.

Replicate Analysis: Relative percent difference (RPD) was calculated from results of replicate analyses as a measure precision. The formula for RPD is

$$RPD = (S1-S2)/((S1+S2)/2) * 100$$

where S1 and S2 are the duplicate samples. Matrix spike samples were analyzed in duplicate so that there were two RPD measurements.

Surrogate recovery: For the Gas Chromatography analyses, recovery of surrogates added before extraction were analyzed. Surrogates have similar chemical structure to the analytes of interest but are not expected to be found in the environment. The volatile organic compounds were tested with three surrogates: toluene-d8, bromofluorobenzene and 1,2-dichloroethane-d4. For the pesticides, one surrogate, dibutylchlorendate, was used. In the base, neutral and acid extraction, six surrogates, nitrobenzene-d5, 2-fluorobiphenyl, terphenyl, phenol-d5, 2-fluorophenol, and 2,4,6-tribromophenol were tested. Most surrogate recoveries were within EPA Contract Laboratory Program guidelines for sediment and in the opinion of the data reviewer, the few that exceeded guidelines did not warrant qualification.

Method Blanks: Analysis of method blanks showed some laboratory contamination of acetone in the VOA analysis. As acetone is the primary solvent used to clean some sampling gear there may have been some contamination that occurred before analysis. Though 2-Butanone was not found in the method blanks, its high correlation with acetone by site suggests contaminantion in the analysis or handling. The acetone and 2-Butanone results in this study should not be taken to accurately reflect concentrations in the study area. No other problems with laboratory or sample handling contamination were apparent.

Table A-1. Laboratory accuracy and precision for metals.

	Lab #	Spike Recovery						Precision Blind(2)		
		8236	8236	RPD(1)	8244	8244	RPD(1)	8245	8252	RPD(1)
As		109%	100%	9%	107%	101%	6%	122	118	3%
Cd		101%	95%	6%	74%	77%	4%	1.2 J	1.7 J	34%
Cu		94%	88%	7%	–	–	–	591	606	3%
Cr		101%	101%	0%	106%	88%	19%	81.4 J	72.6 J	11%
Ni		103%	102%	1%	106%	88%	19%	60.9	55.6	9%
Pb		72%	70%	3%	114%	96%	17%	778	801	3%
Zn		82%	85%	4%	99%	84%	16%	489	860	55%
		8239	8239							
Hg		97%	81%	18%						

(1) Relative Percent Difference: $(X-Y)/((X+Y)/2)$ where X and Y are two measurements.

(2) Homogenized split of sample submitted to laboratory as separate sample.

J= Concentration is estimate due to low signal to noise ratio or marginally
   unacceptable calibration results.

Table A–2. Matrix spike recovery tests for organics.

	Lab number	Percent Spike Recovery			Recommended
		8252	8252	RPD (1)	Range for spike(2)
PESTICIDES					
gamma–BHC		96%	95%	1%	46%–127%
Heptachlor		62%	70%	12%	35%–130%
Aldrin		78%	79%	1%	34%–132%
Dieldrin		86%	92%	7%	31%–134%
Endrin		102%	104%	2%	42%–139%
4,4'–DDT		87%	94%	8%	23%–134%
BNAs					
Phenol		58%	68%	16%	26%–90%
2–Chlorophenol		58%	66%	13%	25%–102%
1,4–Dichlorobenzene		64%	72%	12%	28%–104%
N–nitroso–di–n–prop.		64%	80%	22%	41%–126%
1,2,4–Trichlorobenzene		68%	83%	20%	38%–107%
4–Chloro–3–methylphenol		59%	65%	10%	26%–103%
Acenapthene		68%	81%	17%	31%–137%
4–Nitrophenol		56%	68%	19%	11%–114%
2,4–Dinitrotoluene		61%	69%	12%	28%–89%
Pentachlorophenol		73%	79%	8%	17%–109%
Pyrene		68%	68%	0%	35%–142%
VOAs		8230	8230	RPD	
1,1–Dichloroethene		97%	90%	7%	59%–172%
Trichloroethene		109%	107%	2%	62%–137%
Benzene		113%	110%	3%	66%–142%
Toluene		103%	106%	3%	59%–139%
Chlorobenzene		104%	109%	5%	60%–133%

(1) Relative Percent Difference: ((X–Y)/((X+Y)/2))*100 where X and Y are two
    recovery measurements.
(2) From EPA (1986a) (SW 846)

State of Washington Department of Ecology
Manchester Environmental Laboratory
P.O Box 307 Manchester, WA. 98353

Data Review
December 5, 1990

Project: Lake Union

Samples: 258230   258231   258232   258233   258234   258235   258237   258238
258239   258240   258241   258242   258243   258244   258245   258246
258247   258248   258249   258250   258251   258252

Laboratory: Weyerhaeuser Analytical and Testing Service   2991

By: Stuart Magoon

Case Summary

These analyses were reviewed for qualitative and quantitative accuracy, validity, and usefulness. Specific methods used and problems incurred during the analysis are detailed in the Case Narrative and will not be addressed here. Specific problems with the QC will be noted and referenced to the Case Narrative.

The forms used to report this data are from the US EPA SOW for the CLP. Where a reference such as "EPA Sample no." is used, take this to mean "DOE Sample no.". This data is from a Washington State Department of Ecology project, not part of an EPA case. References to EPA sample numbers are built into the forms being used to report this data, and any references to EPA sample numbers are unintentional.

There is no need to assimilate the "dilution factor" or "sample wt/vol" into the final values reported; these calculations have already been figured into the reported values.

DATA QUALIFIER DEFINITIONS

U   -   The material was analyzed for but was not detected, the associated numerical value is the sample quantitation limit; this means that the compound is not present in the sample at or above the reported level.

R   -   The data are unusable (compound may or may not be present). Resampling and reanalysis is necessary for verification.

J   -   The associated numerical value is an estimated quantity.

UJ -   The material was analyzed for, but was not detected. The sample quantitation limit is an estimated quantity.

X   -   The "X" flag is an artifact from the computer that occurs when generating a value from a manual integration of the quantitation peak. This flag carries no significance as to the usefulness of the associated value.

NR -   Not Reported

Note: If this data is entered into some other format an "N" flag should be added to the compounds reported as tentatively identified compounds. The "N" flag indicates that the compound is "tentatively identified."

Holding Times

Sample	Date Collect	Date Man Lab Rec'd	Date Cntr Lab Rec'd	Date Extd	Date Anlz	#Days From Collect
258230	6/19	6/21	6/22	NA	6/30	9 of 14
258231	6/19	6/21	6/22	NA	6/30	9 of 14
258232	6/19	6/21	6/22	NA	6/30	9 of 14
258233	6/19	6/21	6/22	NA	6/30	9 of 14
258234	6/19	6/21	6/22	NA	6/30	9 of 14
258235	6/19	6/21	6/22	NA	6/30	9 of 14
258236	6/20	6/21	6/22	NA	6/30	9 of 14
258237	6/20	6/21	6/22	NA	6/30	9 of 14
258238	6/20	6/21	6/22	NA	6/30	10 of 14
258239	6/20	6/21	6/22	NA	7/2	10 of 14
258240	6/20	6/21	6/22	NA	6/30	9 of 14
258241	6/18	6/21	6/22	NA	7/1	9 of 14
258242	6/20	6/21	6/22	NA	6/30	9 of 14
258243	6/18	6/21	6/22	NA	6/30	9 of 14
258244	6/20	6/21	6/22	NA	7/1	9 of 14
258245	6/20	6/21	6/22	NA	7/1	9 of 14
258246	6/20	6/21	6/22	NA	7/1	9 of 14
258247	6/20	6/21	6/22	NA	7/1	10 of 14
258248	6/19	6/21	6/22	NA	7/1	9 of 14
258249	6/18	6/21	6/22	NA	7/1	9 of 14
258250	6/18	6/21	6/22	NA	7/1	9 of 14
258251	6/18	6/21	6/22	NA	7/1	9 of 14
258252	6/20	6/21	6/22	NA	7/1	9 of 14

Surrogates:

All surrogate recoveries for these samples, the matrix spikes, and the method blanks are within the QC recovery limits.

Matrix Spike/Matrix Spike Duplicate (MS/MSD):

Water MS/MSD precision and recovery data are acceptable and within the QC limits

The soil MS/MSD recoveries and precision data are acceptable and within the QC limits, with one exception. The RPD (relative percent difference), a measure of precision, for Benzene was 24; slightly outside the QC limit of 21. This outlier is consistent with all the other RPD values.

The chromatograms for sample 388563 and the matrix spikes did not show any significant amount of material that would have contributed to enhanced spike recoveries. These recoveries may be high due to the laboratory analytical procedures that resulted in a dilution or measurement error. This outlier does not signal the need for corrective action and the usefulness of this data should not be compromised by this outlier.

Sample Data:

This data is acceptable for use. Note that data qualifiers may modify the usefulness of the individual values.

Some of the "B" qualifiers associated with the Acetone values have been changed to "UJ". This was done because the Acetone is probably the result of contamination and not native to the sample.

The "B" qualifiers associated with Acetone in samples 258232, 258234, and 258238 was not changed to "UJ", because the Acetone value detected in these samples is five to ten times more than that detected in the associated method blank. These samples are borderline cases as to whether or not the "B" qualifier could be dropped or not. I elected to leave the "B" qualifier in these cases because, the values may be somewhat elevated due to lab contamination. However, because the Acetone levels in some samples is five to ten times that of the associated method blank, this strongly suggests that all the Acetone detected in these samples is not the result of laboratory contamination.

The "B" qualifier was dropped from the Acetone values for samples 258233 and 258280 because the value was grater than ten times that found in the associated method blank.

A "J" qualifier was added to several Acetone and 2-Butanone values because the result was either calculated from a value below the known linear range or the continuing calibration standard response for these compounds deviate by more than 25% from the initial calibration standard.

Holding Times:

Sample	Date Collect	Date Man Lab Rec'd	Date Cntr Lab Rec'd	Date Extd	Date Anlz	#Days Collect to ext	#Days ext to Analysis
258230	6/19	6/21	6/22	7/2	8/16	13 of 14	45 of 40
258231	6/19	6/21	6/22	7/2	8/25	13 of 14	54 of 40
258232	6/19	6/21	6/22	7/2	8/25	13 of 14	54 of 40
258233	6/19	6/21	6/22	7/2	8/16	13 of 14	45 of 40
258234	6/19	6/21	6/22	7/2	8/16	13 of 14	45 of 40
258235	6/19	6/21	6/22	7/2	8/25	13 of 14	54 of 40
258236	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40
258237	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40
258238	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40
258239	6/20	6/21	6/22	7/2	8/26	12 of 14	55 of 40
258240	6/20	6/21	6/22	7/2	8/29	12 of 14	57 of 40
258241	6/18	6/21	6/22	7/2	8/16	14 of 14	45 of 40
258242	6/20	6/21	6/22	7/2	8/16	12 of 14	45 of 40
258243	6/18	6/21	6/22	7/2	8/29	12 of 14	57 of 40
258244	6/20	6/21	6/22	7/2	8/29	12 of 14	57 of 40
258246	6/20	6/21	6/22	7/2	8/29	12 of 14	57 of 40
258247	6/20	6/21	6/22	7/2	8/29	12 of 14	57 of 40
258248	6/19	6/21	6/22	7/2	8/16	13 of 14	45 of 40
258249	6/18	6/21	6/22	7/2	8/17	14 of 14	46 of 40
258250	6/18	6/21	6/22	7/2	8/17	14 of 14	46 of 40
258251	6/18	6/21	6/22	7/2	8/17	14 of 14	46 of 40
258252	6/20	6/21	6/22	7/2	8/30	12 of 14	58 of 40

These samples were extracted within SW-846 recommended holding times. All the extracts were analyzed after the SW-846 holding time of forty days. A half life study has not been done to determine what is a realistic holding time on a compound by compound basis. Currently SW-846 recommends that an extract holding time (not to be confused with an extraction holding time) be forty days. See PCB analyses on page 6 for more information.

Surrogates:

Most surrogate recoveries for the samples, matrix spikes, and the method blanks are within QC recovery limits. There are two outliers that can be considered anomalies. These outliers do not signal the need for data qualifiers.

Matrix Spike/Matrix Spike Duplicate (MS/MSD):

All matrix spike/spike duplicate precision and recovery data are acceptable and within the QC limits compounds.

Sample Data:

This data is acceptable for use. Note that data qualifiers may modify the usefulness of the individual values.

Holding Times:

Sample	Date Collect	Date Man Lab Rec'd	Date Cntr Lab Rec'd	Date Extd	Date Anlz	#Days Collect to ext	#Days ext to Analysis
258230	6/19	6/21	6/22	7/2	8/23	13 of 14	52 of 40
258231	6/19	6/21	6/22	7/2	8/24	13 of 14	53 of 40
258232	6/19	6/21	6/22	7/2	8/24	13 of 14	53 of 40
258233	6/19	6/21	6/22	7/2	8/23	13 of 14	52 of 40
258234	6/19	6/21	6/22	7/2	8/23	13 of 14	52 of 40
258235	6/19	6/21	6/22	7/2	8/25	13 of 14	54 of 40
258236	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258237	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258238	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40
258239	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258240	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40
258241	6/18	6/21	6/22	7/2	8/23	14 of 14	52 of 40
258242	6/20	6/21	6/22	7/2	8/23	12 of 14	52 of 40
258243	6/18	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258244	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258245	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258246	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258247	6/20	6/21	6/22	7/2	8/24	12 of 14	53 of 40
258248	6/19	6/21	6/22	7/2	8/23	13 of 14	52 of 40
258249	6/18	6/21	6/22	7/2	8/23	14 of 14	52 of 40
258250	6/18	6/21	6/22	7/2	8/23	14 of 14	52 of 40
258251	6/18	6/21	6/22	7/2	8/23	14 of 14	52 of 40
258252	6/20	6/21	6/22	7/2	8/25	12 of 14	54 of 40

These samples were extracted within SW-846 recommended holding times. All the extracts were analyzed after the SW-846 holding time of forty days. It is not likely that exceeding the extract holding times for these compounds resulted in any measurable differences. The forty day extract holding time was established as a guideline and does not constitute a black or white, in or out, situation. Experience with these types of extracts has demonstrated that they can remain stable much longer than forty days. Standards for the US EPA CLP can be kept for as long as six months. These standards can be stored in the same type of container used to store organic extracts. The forty day holding time is mainly useful for contract and litigation purposes, such that it can be said that the extracts were not held for an excessive length of time, and or the contractual agreement has been met (no room for negotiation). No qualifiers have been added to these results due to holding times. The reanalysis of some of the samples for PCBs were also done after the forty day SW-846 holding time, however, as explained above this time lapse probably has had no measurable effect on the results.

Surrogates:

Most surrogate recoveries for the samples, matrix spikes, and the method blanks are within QC recovery limits. A few of the DBC surrogate recoveries were above the upper advisory QC limits. These outliers are likely the result of matrix enhancement, and do not signal the need for data qualifiers.

Matrix Spike/Matrix Spike Duplicate (MS/MSD):

Matrix spike/spike duplicate precision and recovery data are acceptable and within the QC limits.

Sample Data:

This data is acceptable for use. Note that data qualifiers may modify the usefulness of the individual values.

Some of the sample extracts were acid cleaned and further concentrated by a factor of ten to achieve better detection limits for the PCBs. There is a separate report included for these samples.

There was some severe chemical interference by some unknown compounds that eluted in the retention time region where the majority of the PCB pattern for Aroclors 1221, 1016, 1232, 1242 are expected.

Chemical interference was also present for the other aroclors, although the amount of interference was not nearly as severe.

The quantitation limits reported for the aroclors that were effected by this chemical interference probably do not accurately or precisely represent the concentration necessary to detect these Aroclors in the affected samples, therefore a "J" qualifier was added to these aroclors.

September 21, 1990

TO: Jim Cubbage

THROUGH: Steve Twiss

FROM: Cheryl Vezzani

SUBJECT: Chromium Data for Lake Union Samples 90258230-52

Included is the chromium and nickel data you requested after receiving
your other data. When I ran the samples originally, I ran them on the
ICP and chromium and nickel were included in the run. However, since
you did not request them initially, I did not worry when the last
control for chromium was out of our 10% window. In our phone
conversation I explained since the last control was only out by 11%,
I could qualify the data as an estimate (J). You indicated this was
fine in this case. The nickel data was fine and needs no qualifiers.
If you have any questions, please call.

CV:mb

APPENDIX B: DETECTION LIMITS OF VOLATILE ORGANICS AND PESTICIDES/PCBS

Table B-1. Volatile organic compounds in sediments from Lake Union (μg/kg dry weight)

Site	1		2		3		4		5		6		7		8		9		10		11	
Lab number	8230		8231		8232		8233		8234		8235		8236		8237		8238		8239		8240	
Chloromethane	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Bromomethane	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Vinyl chloride	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Chloroethane	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Methylene chloride	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Acetone	13	J	230	U	490	DJ	31	J	50	J	75	J	43	J	1300	DJ	30	J	1100	DJ	830	DJ
Carbon disulfide	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,1-Dichloroethene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,1-Dichloroethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,2-Dichloroethene (total)	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Chloroform	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,2-Dichloroethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
2-Butanone	8	U	55	J	140	D	10	U	10	U	10	U	14	U	510	DJ	14	U	260	DJ	280	J
1,1,1-Trichloroethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Carbon tetrachloride	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Vinyl acetate	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Bromodichloromethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,2-Dichloropropane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
cis-1,2-Dichloropropene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Trichloroethene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Dibromochloromethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,1,2-Trichloroethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Benzene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
trans-1,3-Dichloropropene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Bromoform	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
4-Methyl-2-pentanone	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
2-Hexanone	8	U	17	U	16	U	10	U	10	U	10	U	14	U	29	U	14	U	31	U	29	U
Tetrachloroethene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
1,1,2,2-Tetrachloroethane	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Toluene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Chlorobenzene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Ethylbenzene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Styrene	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U
Xylene (total)	4	U	8	U	8	U	5	U	5	U	5	U	7	U	15	U	7	U	16	U	15	U

U= Not found at detection limit shown.
J= Concentration is estimate due to low signal to noise ratio.
D= Concentration determined through dilution of extract.

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Table B-1 (con't). Volatile organic compounds in sediments from Lake Union (μg/kg dry weight)

Site	12		13		14		15		16		17		18		19		20		21		22	
Lab number	8241		8242		8243		8244		8245		8246		8247		8248		8249		8250		8251	
Chloromethane	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	11	U
Bromomethane	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	11	U
Vinyl chloride	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	11	U
Chloroethane	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	6	U
Methylene chloride	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	15	J
Acetone	430		1500	DJ	1200	DJ	1900	DJ	4700	D	1400	D	2100	DJ	270	J	63	J	36	J	15	J
Carbon disulfide	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,1-Dichloroethene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,1-Dichloroethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,2-Dichloroethene (total)	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Chloroform	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,2-Dichloroethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	45	U	34	U	22	U	11	U
2-Butanone	77		370	DJ	370	J	220	J	890	D	330	D	520	DJ	23	U	17	U	11	U	6	U
1,1,1-Trichloroethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Carbon tetrachloride	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	11	U
Vinyl acetate	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	6	U
Bromodichloromethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,2-Dichloropropane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
cis-1,2-Dichloropropene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Trichloroethene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Dibromochloromethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,1,2-Trichloroethane	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Benzene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
trans-1,3-Dichloropropene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Bromoform	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
4-Methyl-2-pentanone	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	11	U
2-Hexanone	26	U	38	U	31	U	25	U	29	U	24	U	26	U	45	U	34	U	22	U	11	U
Tetrachloroethene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
1,1,2,2-Tetrachloroethane	13	U	19	U	16	U·	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Toluene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Chlorobenzene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Ethylbenzene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Styrene	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U
Xylene (total)	13	U	19	U	16	U	13	U	15	U	12	U	13	U	23	U	17	U	11	U	6	U

U= Not found at detection limit shown.
J= Concentration is estimate due to low signal to noise ratio.
D= Concentration determined through dilution of extract.

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Table B-2. Pesticides and PCBs in sediments from Lake Union area (µg/kg dry weight).

Site	1	2	3	4	5	6	7	8	9	10	11
Lab Number	8230	8231	8232	8233	8234	8235	8236	8237	8238	8239	8240
alpha-BHC	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
beta-BHC	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
delta-BHC	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
gamma-BHC	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
Heptachlor	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
Aldrin	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
Heptachlor epoxid	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
Endosulfan I	24 U	520 U	510 U	33 U	340 U	340 U	450 U	1000 U	430 U	1100 U	940 U
Dieldrin	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
4,4'-DDE	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
Endrin	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
Endosulfan II	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
4,4'-DDD	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
Endosulfan sulfate	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
4,4'-DDT	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
Methoxychlor	240 U	5200 U	5100 U.	330 U	3400 U	3400 U	4500 U	10000 U	4300 U	11000 U	9400 U
Endrin ketone	49 U	1000 U	1000 U	65 U	680 U	680 U	910 U	2000 U	860 U	2100 U	1900 U
alpha-Chlordane	240 U	5200 U	5100 U	330 U	3400 U	3400 U	4500 U	10000 U	4300 U	11000 U	9400 U
gamma-Chlordan	240 U	5200 U	5100 U	330 U	3400 U	3400 U	4500 U	10000 U	4300 U	11000 U	9400 U
Toxaphene	490 U	10000 U	10000 U	650 U	6800 U	6800 U	9100 U	20000 U	8600 U	21000 U	19000 U
Aroclor-1016	240 U	110 U	110 U	330 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1221	240 U	110 U	110 U	330 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1232	240 U	110 U	110 U	330 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1242	240 U	110 U	110 U	330 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1248	240 U	110 U	110 U	330 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1254	490 U	110 U	110 U	650 U	71 U	71 U	95 U	210 U	90 U	220 U	200 U
Aroclor-1260	490 U	240 J	210 J	650 U	93 J	130 J	200 J	460 J	310 J	430 J	310 J
Total PCBs		240 J	210 J		93 J	130 J	200 J	460 J	310 J	430 J	310 J

U = No contaminant found at detection limit shown
J = Value is estimate due to low signal to noise ratio

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Table B-2 (con't). Pesticides and PCBs in sediments from Lake Union area (µg/kg dry weight).

Site	12	13	14	15	16	17	18	19	20	21	22
Lab Number	8241	8242	8243	8244	8245	8246	8247	8248	8249	8250	8251
alpha-BHC	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
beta-BHC	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
delta-BHC	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
gamma-BHC	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
Heptachlor	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
Aldrin	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
Heptachlor epoxid	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
Endosulfan I	83 U	120 U	1100 U	830 U	110 U	800 U	880 U	160 U	79 U	47 U	25 U
Dieldrin	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
4,4'-DDE	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
Endrin	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
Endosulfan II	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
4,4'-DDD	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	310	94 U	49 U
Endosulfan sulfate	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
4,4'-DDT	450 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	140 J	94 U	49 U
Methoxychlor	830 U	1200 U	11000 U	8300 U	1100 U	8000 U	8800 U	1600 U	790 U	470 U	250 U
Endrin ketone	170 U	240 U	2100 U	1700 U	210 U	1600 U	1800 U	320 U	160 U	94 U	49 U
alpha-Chlordane	830 U	1200 U	11000 U	8300 U	1100 U	8000 U	8800 U	1600 U	790 U	470 U	250 U
gamma-Chlordan	830 U	1200 U	11000 U	8300 U	1100 U	8000 U	8800 U	1600 U	790 U	470 U	250 U
Toxaphene	1700 U	2400 U	21000 U	17000 U	2100 U	16000 U	18000 U	3200 U	1600 U	940 U	490 U
Aroclor-1016	830 U	1200 U	220 U	170 U	210 U	170 U	180 U	1600 U	790 U	470 U	250 U
Aroclor-1221	830 U	1200 U	220 U	170 U	210 U	170 U	180 U	1600 U	790 U	470 U	250 U
Aroclor-1232	830 U	1200 U	220 U	170 U	210 U	170 U	180 U	1600 U	790 U	470 U	250 U
Aroclor-1242	830 U	1200 U	220 U	170 U	210 U	170 U	180 U	1600 U	790 U	470 U	250 U
Aroclor-1248	830 U	1200 U	220 U	170 U	210 U	170 U	180 U	1600 U	790 U	470 U	250 U
Aroclor-1254	1700 U	2400 U	220 U	170 U	210 U	170 U	180 U	3200 U	1600 U	940 U	490 U
Aroclor-1260	1700 U	2400 U	380 J	340 J	640 J	280 J	330 J	3200 U	1600 U	940 U	490 U
Total PCBs			380 J	340 J	640 J	280 J	330 J				

U= No contaminant found at detection limit shown
J= Value is estimate due to low signal to noise ratio

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