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APPLICATION OF THE TRIAD APPROACH TO FRESHWATER SEDIMENT ASSESSMENT: AN INITIAL INVESTIGATION OF SEDIMENT QUALITY NEAR GAS WORKS PARK, LAKE UNION

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ABSTRACT

The triad approach (bioassays, benthic infaunal analysis, and chemical analysis) to sediment characterization has been used previously to characterize marine sediments. This paper describes the applications of this technique to freshwater sediments. Heavily contaminated sediments from Lake Union (Washington) were compared to relatively pristine sediments from Chester Morse Lake (Washington). Both lakes are located in the same (Cedar River) drainage system. Differences between the sediments in terms of chemical contamination, response to bioassays using the amphipod *Hyalella azteca*, and benthic infaunal communities are reported and discussed. The Lake Union sediments (collected near Gas Works Park) were severely contaminated, notably with polynuclear aromatic hydrocarbons. This sediment was toxic as determined by the bioassay. Additionally, the abundance and diversity of benthic invertebrates in the Lake Union site were depressed with respect to the control site. The triad approach to sediment characterization appears to show promise for freshwater systems.

INTRODUCTION

Sediment contamination has become an issue of major concern in the Puget Sound basin over the past five years. Most of the attention has been focused on marine and estuarine sediments, where chemical contamination has been linked to toxicity as measured by sediment bioassays, perturbation of benthic infaunal communities, and as a source of chemical contaminants responsible for abnormal fish histopathology (skin and liver lesions, etc.), as well as tissue contamination of organisms (clams, fish) consumed by people.

One approach to assessing problem sediments which has been used in the marine setting and has provided a very useful tool is the "sediment quality triad." The triad approach was advocated and described by Long and Chapman (1985) and involves assessing chemical concentrations, bioassay responses, and benthic invertebrate communities in sediments. This allows simultaneous consideration of chemical contamination and its biological implications.

Gas Works Park (GWP) is a 20-acre park located on the north shore of Lake Union, Seattle, Washington. The Gas Works was developed in 1903 and coal gasification began in 1906. The Seattle Gas Company discontinued gasification operations in 1956 when natural gas became available. In 1962 it was sold to the city of Seattle. Waste materials at the site included slag, lampblack carbon, coal by-products, solvent-coated wood chips, oil, tar, ashes, and cinders. Some waste products were placed in Lake Union, extending the shoreline to the south (Tetra Tech, 1985).

Sediments adjacent to GWP are heavily contaminated with a number of potentially toxic compounds. EPA, Region 10 (Hileman, et al., 1985a) provided data on chemical concentrations in 33 Lake Union sediment samples, most of which were collected near the GWP site. These sediments had elevated concentrations of several heavy metals, cyanide, and a range of polynuclear aromatic hydrocarbons (PNA's). The PNA concentrations were of particular concern because of the extremely high concentrations reported. Subsequent review of these data, initiated in September 1986 at the request of the Department of Ecology (Ecology), revealed that many of the organics data published in the 1985 EPA report are high by a factor of three to seven because, apparently, they were normalized to a dry-weight basis twice (Hafferty, personal communication). Although correction of original values was not completed as of this writing, several sediment samples apparently approached or exceeded total PNA concentrations of 10,000 parts per million (1 percent) on a dry-weight basis after correction.

The contaminated sediments off GWP appeared to provide a good potential testing ground for applying the triad approach to freshwater sediments. After discussions with the Hazardous Waste Cleanup Program (HWCP, Ecology), primarily Megan White, a survey was proposed as an initial step in applying the triad approach to freshwater sediments in general and GWP sediments in particular. As originally conceived, this would be a two-phase effort. The first phase involved sampling a single location off GWP in the vicinity of the highest PNA contamination (based on EPA, 1985a) and at a single reference/background location (Chester Morse Lake). Both lakes are located in the Cedar River watershed. This report summarizes the results of the first phase. A second phase would involve sampling at several locations along a transect near GWP to assess the biological implications of a gradient of sediment contamination. The second phase is still under consideration.

Sediment samples collected from Lake Union near GWP and at the Chester Morse Lake reference site were analyzed for a range of organic and metallic priority pollutants, conventional parameters (grain size, organic carbon), benthic infaunal invertebrates, and sediment toxicity measured by the freshwater amphipod (*Hyalella azteca*) bioassay. A series of mixtures of GWP and Chester Morse Lake sediments were also subjected to the amphipod bioassay to estimate an LC_{50} for GWP sediments.

During the course of reconnaissance visits to the study area, two pipes with small-volume discharges were noted along the east-facing shore of GWP. These pipes were sampled and samples submitted for priority pollutant, cyanide, and selected conventionals and metals analysis. Laboratory problems resulted in loss of most of the organics data. Fragmentary conventional and metals data are reported here for these discharges.

METHODS

Study Areas, Sampling Sites

Figure 1a shows the Cedar River drainage including Chester Morse Lake, Lake Washington, and Lake Union. Chester Morse Lake and the reference sediment site (CML) are shown in Figure 1b. Lake Union, Gas Works Park, the sediment sampling site (GWP), and storm drain sampling sites (SD-1 and SD-2) are shown in Figure 1c. Table 1 gives locations of all sampling sites including latitude, longitude, and depth (for sediment stations).

Chester Morse Lake was chosen as a reference site because it is located within the protected watershed of the Seattle Water Department. Human activities that could contribute contamination to the waters and sediments of Chester Morse Lake are therefore minimized. Previous studies (e.g., Wissmar, et al., 1982) addressing the status of lakes in this drainage basin further support the assumption that Chester Morse Lake could serve well as a background sediment site.

The Lake Union (GWP) sediment site was chosen to correspond as closely as possible to the location of maximum contamination (Station 17) reported by EPA (1985a).

Two pipes located along the northeast shore of GWP were sampled on two occasions. Although these pipes were given "storm drain" designation, it is not clear precisely what the purpose and history of these pipes are. The issue of possible ground-water contamination at the GWP site has been raised, and it was hoped that analyses of the small flows coming from these pipes might provide data which would be helpful in assessing this issue. Both pipes project from the lake bank at the edge of the park and appear to be possible conduits by which shallow ground water might be discharged to the lake. SD-1 appears to be connected to a drain which is located in a swale east of the discharge location. There are two grated manhole covers located along this drainage pipe. At least a portion of the discharge appears to be surface and subsurface runoff from the sprinkler system located in this swale. Problems experienced in the laboratory with organic priority pollutant analyses of these samples limited their value.

Site Visits; Sampling Events

Chester Morse Lake sediment samples were obtained on September 16, 1985, by Dale Norton and Bill Yake. The Lake Union sediment samples and the first round of storm drain samples from GWP were collected the following day (September 17).

Table 1. Sample sites.

Name	Location	Latitude	Longitude
Chester Morse Lake Sediment (CML)	Upper end of Chester Chester Morse Lake at 12' depth	47°23'04.5"	121°39'41.0"
Gas Works Park Sediment (GWP)	25' depth contour on line between west end of concrete bulkhead and tallest radio tower on Queen Anne Hill	47°38'37.4"	122°20'6.7"
Storm Drain #1 (SD-1)	Concrete drain set in small concrete wall opposite marina docks; east shore of GWP near northern boundary	47°38'46.5"	122°19'54.0"
Storm Drain #2 (SD-2)	Concrete pipe about 75 yards south of storm drain #1; east shore of GWP	47°23'44.8"	122°19'54.0"

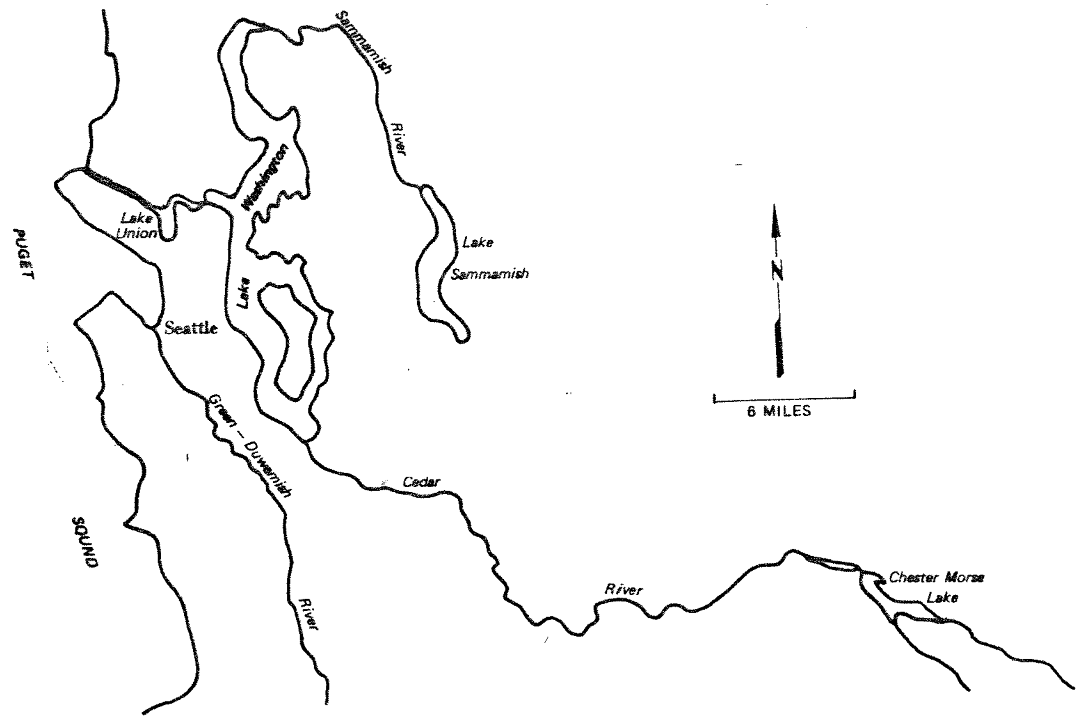

Figure 1a. Study area: Cedar River Drainage/Chester Morse Lake/Lake Union.

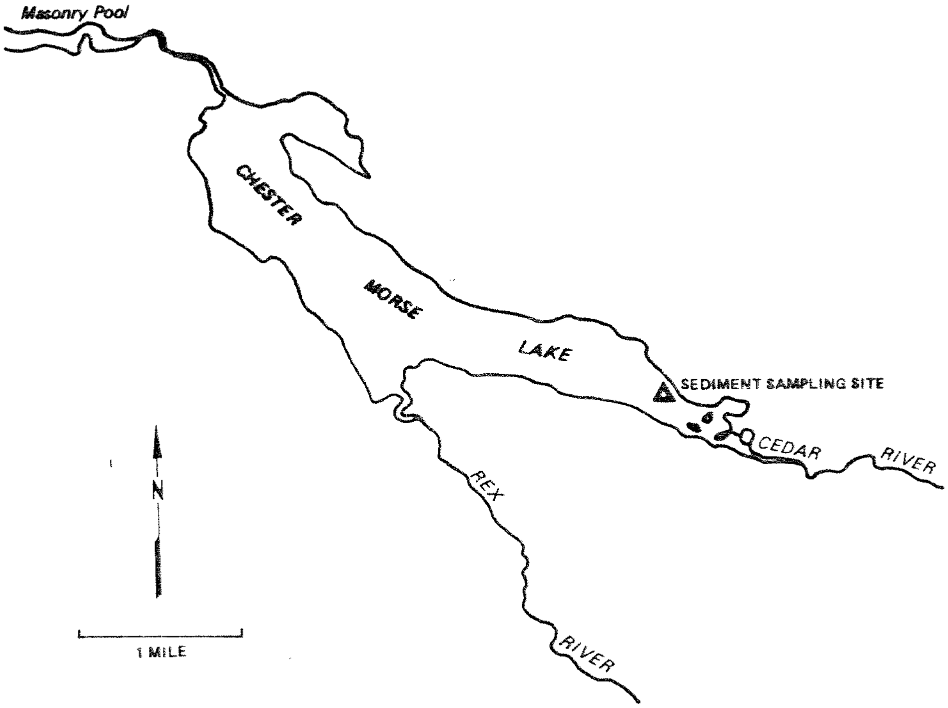

Figure 1b. Study area: Chester Morse Lake.

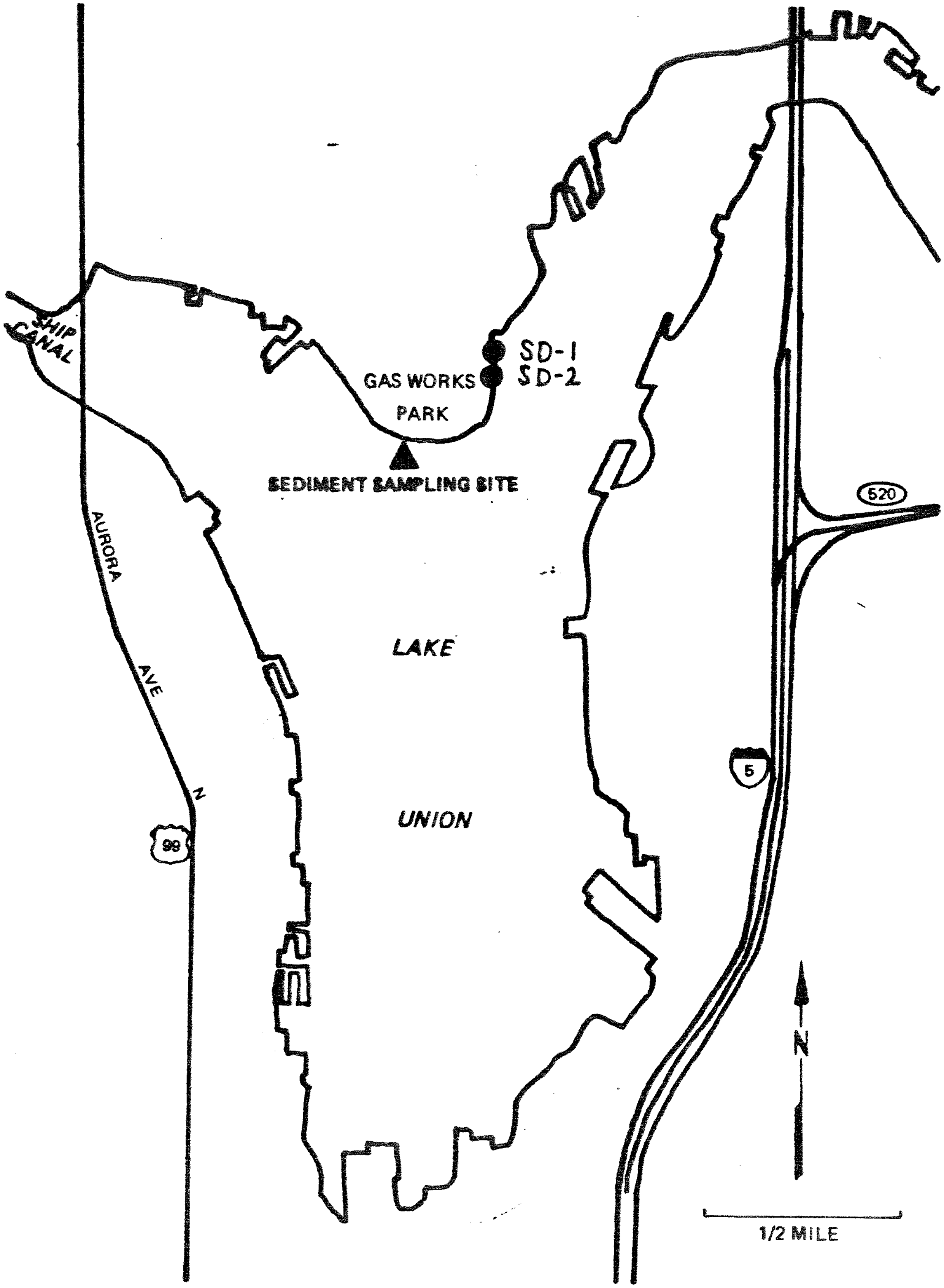

Figure 1c. Study area: Lake Union.

The water (storm drain and blank) samples collected for acid/base-neutral (ABN) organics analyses were lost in a laboratory accident so the storm drains were resampled on October 21, 1986, by Dale Norton.

Sampling Methods

Water

Water samples from the two storm drains at GWP were collected by placing sample bottles under the discharge from the pipes and filling them directly. Flows were determined using a graduated volumetric beaker and stopwatch.

Sediment

All sediment samples (chemistry, bioassay, and benthic invertebrate) obtained at Chester Morse Lake were collected with a Ponar grab (6" x 6"; 0.0232 m^2). Chemistry and bioassay samples were collected at Lake Union using a van Veen grab, while benthic invertebrate samples were obtained with the Ponar.

All equipment used to collect and process chemistry and bioassay samples were cleaned in Liquinox detergent and rinsed sequentially in distilled water, nitric acid, nanograde acetone, and nanograde methylene chloride.

Sediment chemistry, interstitial water, and bioassay aliquots were obtained from the same homogenate. At Chester Morse Lake, the top 2 centimeters of sediment from individual grabs were composited. At Lake Union, the top 3 to 5 centimeters of the sediment were lighter in color and appeared visually to be less contaminated than deeper sediments. Because the objectives of this study depended on evaluating chemical and bioassay differences between the sites, and because the EPA (1985) GWP study collected approximately the top 10 cm of sediment, we composited samples representing the top 7 to 10 centimeters of sediment at this site. Overlying water was carefully decanted from the sediment before surface sediments were removed for compositing.

Sediment samples were composited in large stainless steel beakers and homogenized by stirring with stainless steel spoons. Chemistry and bioassay aliquots were obtained from this homogenate.

As mentioned above, benthic infaunal samples were obtained using a Ponar grab. Four samples were obtained at each site. Sediment samples were seived using a 0.5 mm screen. Material retained was placed in whirl-pak bags. Buffered formalin with rose bengal dye (Mason and Yevich, 1967) was then added to preserve and stain the invertebrates.

Analytical Methods

Samples collected during this survey were analyzed for the parameters shown in Table 2.

These analyses were conducted at four laboratories/locations summarized in Table 3.

Table 3. Laboratories performing analyses.

Analyses	Laboratory; Location
Conventionals, Metals, Organics	Ecology/EPA; Manchester, WA.
Bioassay	Ecology/EPA; Manchester, WA.
Grain Size	Parametrix, Inc.; Bellevue, WA.
Benthic Invertebrates (sorting, taxonomy)	EVS Consultants; Sidney, B.C.

Conventional Analyses: Methods used for the analysis of conventional and ancillary parameters are summarized as follows:

- pH was measured with a Corning pH/ion analyzer model #155.
- Specific conductivity was determined with a Beckman model #RC20 conductivity bridge.
- Oil/grease concentrations were determined using Method 503A: Partition-gravimetric in Standard Methods for the Examination of Water and Wastewater (APHA, 1985).
- Nutrients: Ammonia - Method 350.1 - Colormetric, automated phenate in Methods for Chemical Analysis of Water and Wastes (EPA, 1979).

  Nitrate, nitrite - Method 353.2 - colormetric, automated, cadmium reduction (EPA, 1979).

  Orthophosphate - Method 365.1 - colormetric, automated, ascorbic acid (EPA, 1979).

  Total phosphate - Digestion following Method 424C - preliminary digestion steps for total phosphorus (APHA, 1985), followed by EPA Method 365.1, above.
- Suspended solids and percent solids analyses following Method 160.2 - gravimetric, and Method 160.3 - gravimetric, respectively (EPA, 1979).

Table 2. Samples submitted for analysis

Parameters	Storm Drains 9/17	Storm Drains 10/21	Sediments 9/16-17
Conventionals			
pH	X	X	
Specific conductivity	X	X	X
Suspended solids	X	X	
Percent solids			X
Hardness	X	X	
Sulfide			X
Total organic carbon			X
Total cyanide	X		(X)
Chemical oxygen demand		X	
Nutrients (5)		X	
Oil and grease		X	
Grain Size			X
Trace Metals		$\underline{X}$	X
Bioassay			X
Organics			
Volatile organics	(X)	(X)	(X)
Base/neutral/acids	(X)	$\underline{X}$	X
Pesticides/PCBs	(X)	X	X

X = Sample collected and analyzed satisfactorily.

(X) = Sample collected; lost in laboratory or data unusable due to laboratory problems.

$\underline{X}$ = Sample collected; some portion of data satisfactory.

- Grain size was analyzed by Parametrix, Inc. using the method of sieves and pipettes described by Buchanin and Kain (1971).
- Sulfide samples were extracted immediately from a whole sediment grab (prior to compositing) with a plastic syringe that had been cut off just above the needle connection. The extracted plug of sediment (~ 1/2 inch diameter by 1 inch long) was extruded into a vial containing a sulfide antioxidant buffer (SAOB). Samples were analyzed using cadmium nitrate titration. Preservation and analytical method are derived from Green and Schnitker (1974).
- Hardness was determined by EDTA titration, Method 314B (APHA, 1985).
- Total organic carbon (TOC) in sediments was determined using an adaptation of the high-temperature oxidation technique for water samples, Method 505C (APHA, 1985).
- Total cyanide was analyzed using an adaptation of a spectrophotometric titration, Method 335.2 (EPA, 1979).
- Chemical oxygen demand (COD) was determined using Method 410.1 (EPA, 1979).

Metals Analyses: Sediment and water samples were analyzed for eight metals and metalloids. Sediments were digested with redistilled nitric acid and hydrogen peroxide in accordance with EPA's contract laboratory procedures (EPA, 1985b). This digestion procedure was used for all metals except mercury. The aliquot of sediment analyzed for mercury was digested by sulfuric and nitric acids as specified in Method 245.1 (EPA, 1979). Because of contamination problems experienced in the digestion of water samples, all water samples were analyzed by direct aspiration without digestion. All metals were analyzed by atomic absorption spectrophotometry using the EPA methods summarized in Table 4.

Table 4. Analytical methods for metals analyses (EPA, 1979).

	Method	
Metal	Water	Sediment
Cadmium	213.2	213.2
Copper	220.2	220.1
Chromium	218.1	218.1
Iron	236.1	
Lead	239.2	239.2
Mercury	245.1	245.1
Nickel	249.1	249.1
Zinc	289.1	289.1

Organics: Although volatile organics (VOA) samples were submitted for all samples, analytical results are not reported here because of problems at the laboratory including loss of samples and excessive holding times prior to analysis.

Acid/Base/Neutral (A/B/N) Analyses: Water samples were extracted using methylene chloride following EPA Method 625 (Federal Register, 1984). Extracts were analyzed by gas chromatography/mass spectrophotometry (GC/MS) following Method 625, except that a capillary column was used rather than a packed column.

Sediment samples were extracted using a Soxhlet procedure (acetone solvent) following Method 3540 (EPA, 1982). This was followed by gel permeation chromatography (GPC) cleanup and GC/MS analysis following Method 8270 (EPA, 1982, capillary column).

Laboratory quality assurance/quality control (QA/QC) procedures including blanks and matrix spikes followed EPA contract laboratory program (CLP) guidelines.

Pesticide/PCB Analyses: Water samples were extracted and analyzed in accordance with Method 608 (Federal Register, 1984). Analysis was conducted by gas chromatography/electron capture detection (GC/ECD).

Sediments were extracted using Method 3540 cited above for A/B/N samples. They were analyzed by GC/ECD following Method 8080 (EPA, 1982).

As with A/B/N analyses, QA/QC procedures complied with CLP guidelines.

Bioassay: A bioassay with the amphipod *Hyalella azteca* was used to evaluate sediments collected during this survey. This work was done by Margaret Stinson of the Ecology Manchester laboratory. The method used was that published by Nebekar, *et al*. (1984) and is based on bioassay methods using the marine amphipod *Rhepoxynius abronius*. Three 1,000 mL beakers, each with 200 mL of sediment and 800 mL of dilution (overlying) water are used for each test sediment. Twenty text animals were added to each beaker. Surviving individuals were enumerated after a ten-day exposure period.

Duplicate tests of 20 individuals each were also conducted in the absence of sediment using the reference toxicant, dodecyl sodium sulfonate (DDS). DDS concentrations ranged from 0 to 160 mg/L, and tests were conducted for 96 hours.

Bioassays were conducted on Lake Union and Chester Morse Lake sediments as well as mixtures consisting of 33 percent, 10 percent, 3.3 percent, and 1.0 percent Lake Union sediments diluted with Chester Morse Lake sediments. Dilutions were made on a weight (rather than volume) basis.

Benthic Infauna: Seived benthic infaunal samples were sorted, identified, and enumerated under the direction of Ms. R. Deedee Kathman of EVS Consultants. Each sample was washed in an 0.5 mm mesh seive to remove excess preservative, placed in a glass container and water added to cover all material. Samples were sorted into major taxonomic groups. Sorting was accomplished by placing small aliquots of sample in a gridded petri dish and examining each under a stereomicroscope. This process was repeated until each sample had been fully sorted.

Identification was performed to the generic level for the major groups Mollusca, Coelenterata, Nemertea, Arachnoidea, and Insecta. Oligochnete annelids were identified to family, while leeches (Hirundinea) were identified to class only. Among crustacea, ostracods were identified to class, while amphipods were identified to genus. Bryozoans and nematodes were identified to phyla only.

RESULTS AND DISCUSSION

Chemical Analyses: The results of chemical analyses of water samples collected from the Gas Works Park drains and lake sediments from Chester Morse Lake and Lake Union are given in Tables 5a - 5c. Table 5a contains results for conventional analyses and grain size; Table 5b - metals results, and Table 5c - organic priority pollutant results.

Water Samples: Two drain pipes along the northeast shore of GWP were sampled during this investigation because some concern had been expressed about possible ground-water contamination at the GWP site. Although the source of the water discharged from the pipes was not known with certainty, it appeared likely that it included a ground-water component.

Flows from both drains were small (less than a gallon per minute) but may well be greater during wet weather. Flow measurement and sampling during this survey occurred during the late summer and fall (September, October) after minor rain events.

Loss of organics data due to laboratory problems severely limits the ability to interpret the drain discharge data. Volatiles data were lost for both pairs (9/17 and 10/21) of samples, while data for other organic priority pollutants were lost for three out of four samples. Acid/base/neutral and pesticides/PCB data for a single sample (SWD-2, 10/21) revealed no detectable concentrations.

Other data were generally unremarkable with several exceptions. Chemical oxygen demand (COD) was somewhat elevated in both drains (25 and 54 mg/L), as were iron (450 and 553 ug/L) and zinc (38 and 97 ug/L). Nitrate-N was elevated (7.4 mg/L) in SWD-2.

Perhaps of greatest concern were the concentrations of total cyanide in SWD-1 (0.09 mg/L) and SWD-2 (0.03 mg/L). Previous work by EPA (Hileman, et al., 1985) reported high total cyanide concentrations in nearshore sediments near their stations 2, 3,5, and 32 off the southeast side of GWP. The EPA receiving water criteria for the protection of freshwater aquatic life are 0.0052 mg/L (chronic) and 0.022 mg/L (acute). The criteria document (Federal Register, 1985) notes "EPA believes that a measure such as free cyanide would provide a more scientifically correct bases upon which to establish criteria for cyanide. . . . Until available, EPA recommends using the total cyanide method." Because of the elevated total cyanide concentrations in the drainage samples (both above receiving water criteria) and the high total cyanide in sediments along the shore south of the drains, a more comprehensive study of cyanides in sediments, lake waters, and ground water near the southeast quadrant of the park may be advisable. Analysis of selected ground-water samples for a scan of organic priority pollutants may also be advisable during this study.

Table 5a. Conventionals and grain size results for sediment and storm drain samples.

Media	WATER (DRAINAGE)						SEDIMENT	
Station Designation	SWD-1		SWD-2		Field Blank		CML	GWP
Sampling Date	9/17	10/21	9/17	10/21	9/17	10/21	9/16	9/17
Sample Number	8126	8152	8127	8153	8128	8154	8124	8125
Flow (gpm)	0.6	0.15	0.28	0.13				
Total Organic Carbon (%)							9.0%*	35%*
COD (mg/L)		54		25				
Oil & Grease (mg/L)		<1		2				
pH (S.U.)	7.1	7.6	7.2	7.0				
Spec. Cond. (umhos/cm)	169	202	326	366			55[1/]	947[1/]
Percent Solids (%)							28%	17%
Total Susp. Solids (mg/L)	2	6	3	8				
Hardness (as CaC03, mg/L)	71	84	140	160				
Total Cyanide (mg/L)	0.09		0.03		<0.005		*	*
Sulfide (mg/Kg, d.w.)							160 est	160 est
NH_3-N (mg/L)		0.02		0.03				
NO_2-N (mg/L)		<0.01		<0.01				
NO_3-N (mg/L)		0.62		7.4				
O-PO_4-P (mg/L)		0.31		0.13				
T-PO_4-P (mg/L)		0.40		0.14				
Grain Size (%)								
>2 mm (gravel)							0.03%	5.05%
2 mm - 62 um (sand)							27.51%	45.89%
62 um - 4 um (silt)							68.5%	36.93%
<4 um (clay)							3.96%	12.13%

Table 5b. Metals results for sediment and storm drain samples.

Media	WATER						SEDIMENT	
Units	ug/L						mg/Kg dry weight	
Station Designation	SWD-1		SWD-2		Field Blank		CML	GWP
Sampling Date	9/17	10/21	9/17	10/21	9/17	10/21	9/16	9/17
Metals								
Cadmium		<0.2		0.8		0.2	0.46	1.98
Chromium		<1		<1		<1	10	20
Copper		**		**		**	160	156
Iron		553		450		11	32,000	18,000
Lead		<1		<1		<1	13.9	300
Mercury		<0.06		<0.06		<0.06	0.019	0.173
Nickel		7		<1		<1	9.8	88.3
Zinc		38		97		<1	84	320

1/ = Interstitial waters.
* = Samples held over recommended holding times prior to analysis.
** = Data not reported due to QA/QC problems.
est = estimated value.

Table 5c. Organic priority pollutant results[1] for sediment and storm drain samples (units: water - ug/L; sediment - ug/Kg dry weight).

Media	WATER (DRAINAGE)						SEDIMENT	
Station Designation	SWD-1		SWD-2		Field Blank		CML	GWP
Sampling Date	9/17	10/21	9/17	10/21	9/17	10/21	9/16	9/17
Sample Number	8126	8152	8127	8153	8128	8154	8124	8125
Volatiles	†	†	†	†	†	*	*	*
Acid/Base/Neutrals	†	†	†		†			
Naphthalene				1u		1u	100u	40,000J
Acenaphthylene				1u		1u	100u	92,000
Fluorene				1u		1u	100u	40,000J
Phenanthrene				1u		1u	100u	410,000
Anthracene				1u		1u	100u	120,000
Fluoranthene				1u		1u	100u	570,000
Pyrene				1u		1u	100u	750,000
Benzo(a)anthracene				1u		1u	100u	170,000
Chrysene				1u		1u	100u	170,000
Benzo(k)fluoranthene				1u		1u	100u	240,000
Benzo(a)pyrene				1u		1u	100u	220,000
Indeno(1,2,3-cd)pyrene				1u		1u	100u	120,000
Benzo(g,h,i)perylene				1u		1u	100u	190,000
Benzo(j)pyrene(T)								280,000
Pesticides/PCBs	†		†	1u	†			
PCB-1242		0.02u		0.02u		0.02u	60u	4,300

1 = Only chemicals detected in at least one sample are listed. A complete list of detection limits for chemicals which were not detected is available on request.

T = Tentatively identified compound.

† = Sample lost in laboratory or data unusable due to low surrogate spike recoveries.

u = Not detected at detection limit specified.

J = Estimated value.

* = Sample held over recommended holding times prior to analysis.

Sediment Samples: Based on chemical analysis, the Chester Morse Lake and Lake Union samples were substantially different. Solids content and grain size distribution were roughly similar although the CML sediment had a higher silt content while gravel, sand, and clay fractions were more prevalent in the GWP sediment. Estimated sulfide concentrations were identical. Other conventional measures varied substantially--the GWP sediment had a much higher total organic carbon content (35 percent versus 9 percent) and specific conductivity (947 versus 55 umhos/cm) of interstitial waters. The elevated conductivity in the GWP sediment interstial waters is probably related to the historical problem of saltwater intrusion through the locks. Review of recent U.S. Army Corps of Engineers data (unpublished computer printouts) indicated the 1,000 umhos/cm is approximately the maximum conductivity which has been recorded at depth (14 to 15 meters) in Lake Union for the most recent years (1984-1985), as control of saltwater intrusion through the locks has improved.

The most notable differences between the CML and GWP sediments were concentrations of certain organic priority pollutants (polynuclear aromatics and PCB-1242) and to a lesser extent, certain metals. Tabulated metals data (Table 5b) show the GWP sediment had elevated cadmium, lead, mercury, nickel, and zinc concentrations. Concentrations of these metals in GWP sediment were approximately 4 to 20 times higher than CML sediment.

Of particular concern are the very high levels of PCBs and polynuclear aromatic hydrocarbons in the GWP sediments.

The PCB-1248 concentration of 4300 ug/Kg dry weight is well above the 90th percentile (1200 ug/Kg) and approaches the maximum 5300 ug/Kg reported for total PCBs in a compilation of Puget Sound marine sediment data (185 sediment samples from studies conducted in "non-reference" areas of the Sound; EPA, 1986). The earlier EPA work at GWP (Hileman, et al., 1985) did not find PCB concentrations in Lake Union which approached the concentration reported here. Comparison data for other freshwater sediments in Washington State is not generally available, as little of this kind of work has been conducted to date.

The PNA concentrations exceed marine maxima listed in the Pollutants of Concern Matrix (EPA, 1986) and approach the highest concentrations reported for Puget Sound hot spots like Eagle Harbor (apparent creosote contamination) and Budd Inlet (McFarland/Cascade, a pole-treating facility).

As noted in the data tables (5a, c), results for cyanide and volatile organics concentrations in sediments were lost due to laboratory problems. Based on earlier data by Hileman, et al. (1985), a total cyanide concentration of 1 to 10 mg/Kg dry weight might have been expected in the GWP sediment. In general, Hileman, et al. (1985) did not report detection of volatile compounds in sediments near the location of the GWP sample. The one exception to this was the detection of the ubiquitous contaminant methylene chloride in virtually all samples. Methylene chloride is widely used to clean sample and analytical glassware. Therefore, the actual presence of methylene chloride in Lake Union sediments near GWP is speculative at best.

As noted earlier, the GWP sediment station was placed in an attempt to duplicate the EPA (Hileman, et al., 1985) station most contaminated with PNA's. Table 6 compares the results of metals and PNA analyses for these two stations. In comparing the results of the earlier study to the results of the present study, substantial discrepancies were noted. Based on discussions with the EPA investigators, the decision was made to have Ecology & Environment, Inc. review the data from the earlier study. Although a complete review has not been completed as of this writing, initial findings indicate that PNA results for the most contaminated station (#17), and probably all stations, were corrected for percent solids (normalizing to a dry-weight basis) twice. This resulted in the results reported by EPA for station 17 being high by a factor of 5.42.

Table 6 reports the corrected values for EPA sediment PNA's. Concentrations for individual PNA's at the GWP station were generally about 10 to 12 percent of the EPA values for station 17. There are several possible explanations for this remaining discrepancy. Under CLP procedures for organics analyses, surrogate spikes in highly contaminated samples are generally diluted out to the point that accurate recoveries cannot be determined. The discrepancies, therefore, may be in part due to differential recoveries. The original EPA results indicated that samples from stations surrounding station 17 were contaminated at a level about 10 percent of station 17. Station 17 may represent a very small area which we did not find in our attempts to relocate it. After the QA/QC review of the EPA data is completed, the interpretation of our results may be enhanced.

Bioassays: CML, GWP, and a series of intermediate dilutions were analyzed for toxicity to the aquatic amphipod Hyalella azteca. Three replicates each using 20 individual amphipods were processed for each sample and dilution. The results are given in Table 7.

Table 7. Results of amphipod (Hyalella azeteca) sediment bioassay.

Percent* GWP Sediment	Percent CML Sediment	Mortality (percent)			Average Mortality (percent)
		Replicate One	Replicate Two	Replicate Three	
0	100	5	5	15	8.3
1	99	10	5	5	6.7
3.3	96.7	0	20	20	13.3
10	90	5	30	5	13.3
33	67	15	10	35	20
100	0	90	100	95	95

*Percent determined on a weight basis.

Table 6. Comparison of selected sediment results: most contaminated EPA (1985) site, present GWP site.

Study	EPA[1]	Ecology
Station Designation	17	GWP
Sampling Date	3/20/84	9/17/85
Sample Number	3117	8125
Metals (mg/Kg, d.w.)		
Cadmium	1.0	1.98
Chromium	36.5	20
Copper	120	156
Lead	199	300
Mercury	0.57	0.173
Nickel	162	88.3
Zinc	250	320
Acid-Base/Neutrals (ug/Kg, d.w.)		
Naphthalene	250,000*	40,000J
Acenaphthene	830,000*	92,000
Acenaphthylene	24,000*	40,000u
Fluorene	420,000*	40,000J
Phenanthrene	3,500,000*	410,000
Anthracene	990,000*	120,000
Fluoranthene	5,500,000*	570,000
Chrysene	1,400,000*	170,000
Pyrene	6,400,000*	750,000
Benzo(a)anthracent	1,600,000*	170,000
Benzo(b)fluoranthene	1,600,000*	240,000
Benzo(k)fluoranthene	1,700,000*	
Benzo(a)pyrene	2,600,000*	220,000
Indeno(1,2,3-cd)pyrene	2,900,000*	120,000
Benzo(g,h,i)perylene	1,800,000*	190,000
PCBs		
PCB-1248	40u*	4,300
Solids (percent)	18	17

[1] Data from Hileman, *et al*., 1985, for station with highest PNA concentrations. Organics data modified, see (*) below.

* = Data for organics reported by Hileman *et al*., 1985, divided by 5.42 based on QA/QC review by Ecology & Environment (Hafferty, personal communication).

u = Not detected at detection limit specified.

J = Estimated value.

It is apparent that the GWP sediment was much more toxic to *Hyalella* than the CML sediment, with toxicity generally increasing as the GWP content of the test sediment increased.

Using the Student-Newman-Keuls' test for one-way analysis of variance (alpha = 0.05), the mortality for the 100 percent GWP sediment was significantly higher than all other mixtures. There were no significant differences between the remaining test sediment mixtures.

The LC_{50} for the GWP sediment is plotted (Figure 2) using the graphical method suggested by EPA (1985b). The mortalities do not plot as the expected straight line. This appears to be due to a background test mortality in the range of 5 to 15 percent that was particularly apparent in the low GWP dilutions. For this reason only the two results on either side of 50 percent mortality were used to estimate the LC_{50}.

The assumption of a background test mortality is supported by the results of the 96-hour exposure of *H. azteca* to DDS (reference toxicant, see Methods). A 5 to 10 percent mortality was observed at all four DDS concentrations, ranging from 0 to 20 mg/L. The complete results of the reference toxicant results as well as results of exposure of *H. azteca* to 96-hour sodium pentachlorophenate exposure (0 to 0.10 mg/L) are available on request.

Based on Figure 2 the LC_{50} of the GWP sediment would be approximately 50 percent strength. Using a similar sediment bioassay for a *marine* amphipod and *marine* sediments (5 replicates), Mearns, *et al.* (1986) were able to classify a sediment as clearly toxic if mortality was greater than 24 percent (survival less than 76 percent). If this same relationship were to hold for the *Hyalella* bioassay, then concentrations of GWP sediment greater than approximately 34 percent would be "clearly toxic."

Benthic Infauna

Four replicate grab (0.0232 m^2) samples were processed at each (CML and GWP) sediment sampling site. Samples were screened with 0.5 mm mesh size screen. The organisms identified in each replicate are summarized in Table 8.

Some summary statistics for replicates and total samples are given in Table 9a. Comparisons between the means of the replicates using the t-test are shown in Table 9b.

The differences in benthic invertebrate communities are marked. Chester Morse Lake sediments had higher abundances, number of taxa, and diversity as measured by two indices.

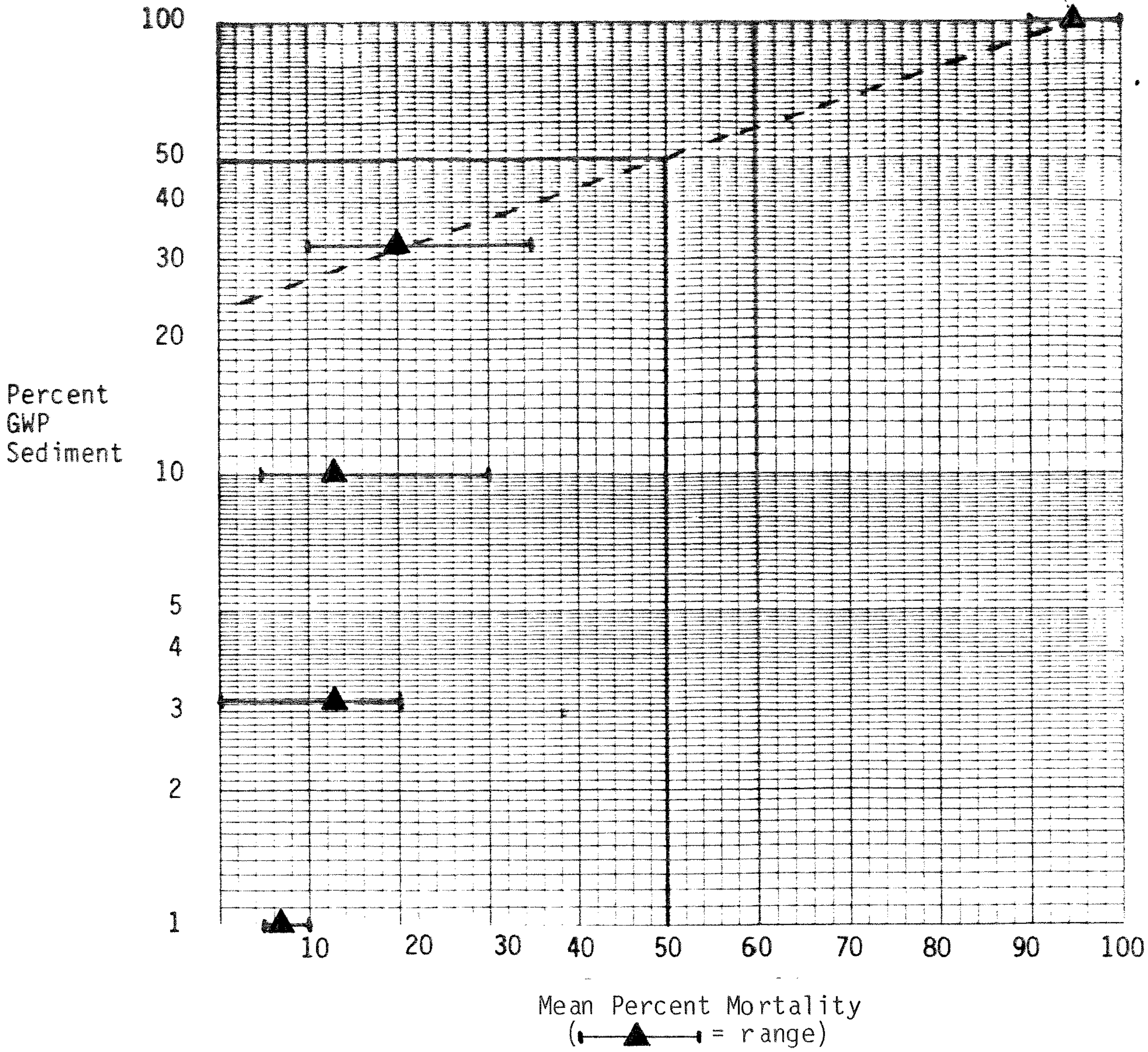

Figure 2. Amphipod mortalities in dilutions of GWP sediment.

Table 8. Benthic infaunal results from Chester Morse Lake and Lake Union (GWP) sediments (units = #/0.0232 m^2 grab).

	Chester Morse Lake (CML)					Lake Union (GWP)				
	Replicates					Replicates				
Taxa	1	2	3	4	Total	1	2	3	4	Total
Nemertea (unsegmented worms)										
Prostoma					0	2		1		3
Nematoda (nematodes)		23	7	1	31		1	2		3
Annelida (segmented worms)										
Hirudinidea (leeches)	1	2	2	10	15					0
Oligochaeta										
Tubificidae	17	33	31	47	128	35	12	23	42	112
Naididae		14	30	12	56	20	24	25	27	96
Mollusca										
Gastropoda (snails)										
Physella	2		3	2	7					0
Bivalvia (clams)										
Pisidium	14	15	3	6	38	1			17	18
Sphaerium		2			2					0
UID			1		1					0
Coelenterata										
Hydrozoa										
Hydra americana					0			1		1
Bryozoa					0			1		1
Arthropoda										
Ostracoda		1			1		1			1
Amphipoda										
Hyalella azteca	2	1	3	15	21					0
Crangonyx				2	2					0
UID				1	1					0
Arachnida										
Piona		1	2		3					0
Unionicola			1		1					0
Insecta										
Trichoptera (caddisflies)										
Oecetis				1	1					0
Diptera (flies)										
Ceratispogonidae										
Bezzia		1			1					0
Chironomidae (midges)										
Arctopelopia		2	6	3	11					0
Procladius	5	4	5		14	1				1
Cladopelma		3			3		1			1
Cryptochironomus	2	2	1	1	6					0
Dicrotendipes	18	76	9	7	110				3	3
Pagastiella	1	1	3	1	6					0
Parachironomus				1	1		1			1
Phaenopsectra			1		1					0
Tanytarsus	35	179	5	1	220			1		1

UID = Unidentified.

Table 9a. Summary of benthic invertebrate data.

	Chester Morse Lake (CML)					Lake Union (GWP)				
	Replicates				Total all Reps.	Replicates				Total all Reps.
	1	2	3	4		1	2	3	4	
Total Individuals	97	360	113	111	681	59	40	54	89	242
Number of Taxa	10	17	17	16	25	5	6	7	4	12
Brillouin's Diversity Index*	2.32	2.23	2.88	2.56	2.95	1.21	1.28	1.44	1.56	1.69
Shannon-Weaver Diversity Index*	2.53	2.33	3.19	2.83	3.04	1.34	1.50	1.64	1.65	1.79

*Zand, 1976.

Table 9b. Significance of differences between replicate means (t-test).

	CML Mean	GWP Mean	Difference Significant at:
Total Individuals (per grab)	170.25	60.5	20%
Number of Taxa (per grab)	15.0	5.5	1%
Brillouin's Diversity Index	2.50	1.37	0.1%
Shannon-Weaver Diversity Index	2.72	1.53	1%

Because this reconnaissance effort was limited to two very different sites, it is difficult to determine the causal mechanism(s) for the disparity between communities. As noted in the Methods section, surface (top 2 cm) sediments at GWP appeared visually less contaminated than deeper sediments (5 - 10 cm). Benthic organism densities typically decrease with depth into the sediment. Therefore, it may be that the benthic community might have been more severely perturbed if the contamination had been uniform over the depth sampled.

The results of two earlier studies in this drainage were reviewed: benthic communities in Lake Washington assessed by METRO's TPPS study (METRO, 1984) and bottom fauna in Lake Sammamish assessed by the University of Washington's Department of Civil Engineering (Wiederholm, 1976). Comparisons between the results of the present study and these earlier studies were limited by differences in technique. For instance, the TPPS study screened sediments to a 0.25 mm mesh size (versus 0.5 mm for the present study) and generally limited taxa identified to oligochaetas and chironomids. The finer mesh size appeared to yield much higher densities of oligochaetes. The Wiederholm study used a similar mesh size (0.4 mm) and identified a wider range of taxa, but there were some differences between the taxonomic conventions and level of identification reported by Wiederholm and those used in the present study. Table 10 compares the results of Wiederholm's three Lake Sammamish invertebrate stations to those of the present study. Taxa are limited to those which are comparable in both studies; results are converted to numbers per square meter to normalize the densities.

The chemical status of the Lake Sammamish sediments is unknown. However, based on these limited infaunal data, the Lake Sammamish benthic community appears to be intermediate with higher chironomidae densities (like Chester Morse) and low amphipod densities (like Lake Union).

One major factor in determining infaunal assemblages is the trophic status of the lake. A widely recognized measure of this relationship is the oligochaete-to-chironomid ratio which increases as lakes become more eutrophic. Wissmar, et al. (1982) state: "A progression from oligotrophy to mesotrophy exists in the order . . . Chester Morse Lake, Lake Sammamish, and Lake Washington." Lake Union's trophic status is probably quite similar to Lake Washington's.

The only previous reference to benthic invertebrate work in Lake Union found during the review of available literature was contained in a 1974 METRO baseline study of Lake Union (Tomlinson, et al., 1977). These authors report that no benthic macrofauna were found at four stations located in Lake Union. They, however, cite earlier studies by Seattle City Light which reported an "abundance of segmented worms (oligochaetes), mollusks (pelecypods and snails), and insect larvae (chironomids) . . . near the southeastern shore." The methods used by Tomlinson, et al were not rigorous (for instance,

Table 10. Comparison of selected taxa diversities: Lake Union, Lake Sammamish*, and Chester Morse Lake (units = #/m^2).

Taxon	Lake Mesh Size Station	Chester Morse 0.5 mm CML	Sammamish* 0.4 mm 2	 3	 6	Union 0.5 mm GWP
Oligochaeta		2,000	4,247	1,189	746	2,200
Mollusca						
Gastropoda		76	0	0	0	0
Bivalvia		450	343	183	381	190
Crustacea						
Amphipoda		1,300	0	0	15	0
Insecta						
Trichoptera		11	15	91	15	0
Chironomidae		4,000	9,157	6,028	9,317	75

*Wiederholm, 1976.

samples were not screened and stained prior to sorting) and Tomlinson (1986 personal communication) does not place a great deal of significance in the fact that they observed no benthic invertebrates.

One encompassing issue which deserves attention is the degree to which chemical contamination of lake sediments might adversely impact the biological or ecological functions of a limnological system. Does or could sediment contamination severely disrupt the energy flow of a lake ecosystem? Although no research focusing on this issue was located, Table 11 from Wissmar, et al. (1982) indicates that benthos supports a major food source for fish production in Lake Washington.

If benthic production were severely perturbed by sediment contamination, it appears that effects on the entire ecosystem could be substantial. This appears to be an area which deserves attention, particularly in urban lakes.

If further work is done to tie changes in benthic communities to toxic components in freshwater sediments, the following items should be considered:

- Given the visual variability in the GWP sediment (apparent greater contamination with depth), a standard depth for sampling sediments for toxic pollutant and bioassay aliquots should be chosen. A depth which contains most of the benthic invertebrates would be appropriate. The top two centimeters have been generally used for marine sediments in Puget Sound and might be appropriate for freshwater sediments.

- An internal control station (in this case, a relatively uncontaminated sediment in or near Lake Union) would be very helpful in sorting out some of the confounding variables.

- A standard mesh size for screening sediments should be chosen so the benthic invertebrate results from various studies can be compared.

- An acceptable level of detail in taxonomic identification should be determined, and taxonomic conventions should be standardized to the extent possible. This should allow for maximum differentiation of communities while simultaneously minimizing costs for keying individual samples.

One approach which has been widely used in Puget Sound for assessing the impact of contaminated sediments on biota has been histopathological studies of resident fish populations. This approach was not part of the current study, but given the apparent linkage of elevated sediment PNA's and liver carcinomas in contaminated areas of Puget Sound, it appears to have potential in assessing impacts of sites like Gas Works Park. Potential fish species which might be used in such an assessment include:

Table 11. Annual fish production and biomass and estimates of fish population attributable to specific forage items. Numbers in parentheses are percentage total production.

Fish Feeding Groups	Representative Fish	Fish Biomass (kg wet wt)	Fish Production (kg wet wt/yr)	Zooplankton	Benthos	Mysids	Fish
				(kg wet weight per year [percent])			
Obligate planktivores	Sockeye Stickleback	45,200	52,200	47,640 (91.3)	4,110 (7.9)	450 (0.9)	0 (0)
Facultative planktivores	Smelt	30,680	26,800	9,740 (36.3)	4,200 (15.7)	12,530 (46.8)	3.30 (1.2)
Facultative benthic	Sculpin	19,610	24,460	12,000 (40.0)	11,890 (48.6)	580 (2.4)	0 (0)
Obligate benthic	Peamouth Sculpin	671,980	942,100	0 (0)	768,600 (81.5)	120,700 (13.0)	53,200 (5.5)
Faculative piscivores	Yellow perch Squawfish	127,700	19,420	0 (0)	2,790 (14.4)	2,060 (10.5)	14,570 (75.0)
Total		895,170	1,158,780	69,380 (6.5)	791,590 (74.3)	136,320 (12.8)	68,100 (6.4)

From: Wissmar, *et al*., 1982.

- black bullhead -- associated with bottom sediments, subject of histopathological studies in eastern United States
- yellow perch -- not a bottom-feeder, but widely distributed and feeds on benthos
- sculpins

Obtaining adequate sample sizes (50 individuals) for these studies should be feasible (Pauley, personal communication). Crayfish may also provide a potential study species.

CONCLUSIONS AND RECOMMENDATIONS

1. Lake Union sediments off Gas Works Park are severely contaminated, most notably with polynuclear aromatic hydrocarbons. The PCB concentration for the single sample (GWP) reported here was also very high. This sediment sample was toxic to the freshwater amphipod *Hyalella azteca*. The abundance and diversity of benthic invertebrates in the GWP sediment were depressed with respect to the control sediment (CML) from the apparently uncontaminated Chester Morse Lake. The significance of benthic infaunal results, as well as a determination of causation, must await much additional research.

2. The triad approach to sediment characterization (i.e., measures of chemical contamination, bioassay response, and benthic infauna) appears to show promise for freshwater sediments. A substantial amount of work needs to be conducted with freshwater sediments before a reliable set of freshwater sediment criteria for priority pollutants can be developed using this approach. Specific items for consideration in designing future studies are given in the text at the end of the "Results and Discussion" section.

3. The Lake Union/Gas Works Park site provides an excellent opportunity for assessing the effects of PNA's in freshwater sediments on fish histopathology. This should be a high-priority site for investigations of this type in Washington State.

4. Cyanide concentrations reported earlier in sediments of the southeast corner of Gas Works Park (Hileman, *et al.*, 1985) and in storm drain discharge south of this area (in *this* report) are cause for potential concern. Based on these results a more comprehensive study of cyanides in sediments, lake waters, and ground water near the southeast quadrant of the park may be advisable.

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