PRELIMINARY INVESTIGATION OF THE EXTENT OF SEDIMENT CONTAMINATION IN LAKE MACATAWA

BY

Dr. Richard Rediske
Mike Buth
James O'Keefe
Gail Smythe
R. B. Annis Water Resources Institute
Grand Valley State University
740 W. Shoreline Dr.
Muskegon, MI 49441

Dr. Graham Peaslee
Chemistry Department
Hope College
35 E. 12th St.
Holland, MI 49423

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PROJECT OFFICER:

Dr. Marc Tuchman
U. S. Environmental Protection Agency
Great Lakes National Program Office
77 West Jackson Blvd.
Chicago IL 60604-3590

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Project Team

EPA Project Officer

Dr. Marc Tuchman	USEPA GLNPO

Principal Scientists

Dr. Richard Rediske	AWRI/GVSU	Sediment Chemistry
James O'Keefe	AWRI/GVSU	Organic Chemistry
Mike Buth	AWRI/GVSU	Benthic Macroinvertebrates
Gail Smythe	AWRI/GVSU	Statistical Methods
Dr. Graham Peaslee	Hope College	Metals Chemistry

Project technical assistance was provided by the following individuals:

Al Steinman, Shana McCrumb, Betty Doyle, and Brian Scull (GVSU)
Natalie Hoogeveen, Christopher Avery and Heather Mentzer (Hope College)
Trace Analytical

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DISCLAIMER

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Executive Summary

A preliminary investigation of the nature and extent of sediment contamination in Lake Macatawa was performed using Sediment Quality Triad methodology. Sediment chemistry, solid-phase toxicity, and benthic macroinvertebrates were examined at 13 locations. High levels of PAH compounds were found in an area along the southern shore near a petroleum storage facility (LM-7). These levels exceeded the Probable Effect Concentrations (PECs) for current sediment quality guidelines. Sediment toxicity to amphipods (mortality) and chironomids (growth) also was observed at this location in addition to an impacted benthic community. Based on the Sediment Quality Triad, the area around LM-7 should be investigated in more detail to determine the extent of contamination and the need for remediation. With respect to the rest of the lake, significant levels of metals and organic chemicals that exceeded the PEC guidelines were not observed in surficial sediments and core samples. This suggests that from both a current and historical perspective, significant sediment contamination was not present at the locations sampled. Benthic macroinvertebrate communities throughout Lake Macatawa were found to be indicative of organically enriched conditions. Tubificids and chironomids were the dominant taxa groups at all stations. The only areas with Shannon-Weaver diversity above 2 were the control location near Pine Creek and two stations near the mouth of the Macatawa River. These locations contained a greater diversity of organisms with moderate to high pollution tolerance. The remainder of the locations in Lake Macatawa contained mostly pollution tolerant genera comprising fewer taxometric groups. Given the absence of elevated contaminant levels and sediment toxicity in the remainder of the lake, benthic community impacts appear to be related to cultural eutrophication.

1.0 Introduction

Lake Macatawa, Michigan is a medium-sized drowned river mouth lake (1800 acres) that is directly connected to Lake Michigan by a navigation channel (Figure 1.1). The watershed has a drainage basin of 110,000 square miles and includes mostly agricultural lands. The lake is classified as hypereutrophic because of excessive phosphorous loading. Historically, significant anthropogenic activity has impacted the water and sediment of the lake. These discharges included effluents from BASF (dyes and pigments), Pfizer (organic chemicals/pharmaceuticals), manufacturing (Chris Craft and Padnos Iron), food processing (Heinz), petroleum storage, and leather tanning facilities (Figure 1.2). In addition, diffuse sources of contamination continue to enter the lake from tributaries, local runoff, and impacted groundwater plumes. There is, however, very little information on the current nature and extent of sediment contamination in the lake. In addition, the toxicity of these sediments and the integrity of the benthic macroinvertebrate community are unknown. This project provided a detailed investigation of the nature, extent, and ecological significance of contaminated sediments in Lake Macatawa. These data are important to the EPA and MDEQ in the development of remediation plans for the lake and adjacent Brownfield sites. This information also is important for the determination of areas that may require further delineation and habitat restoration efforts. Additionally, these data will further our understanding of the ecological significance of contaminated sediments in drowned river mouth systems.

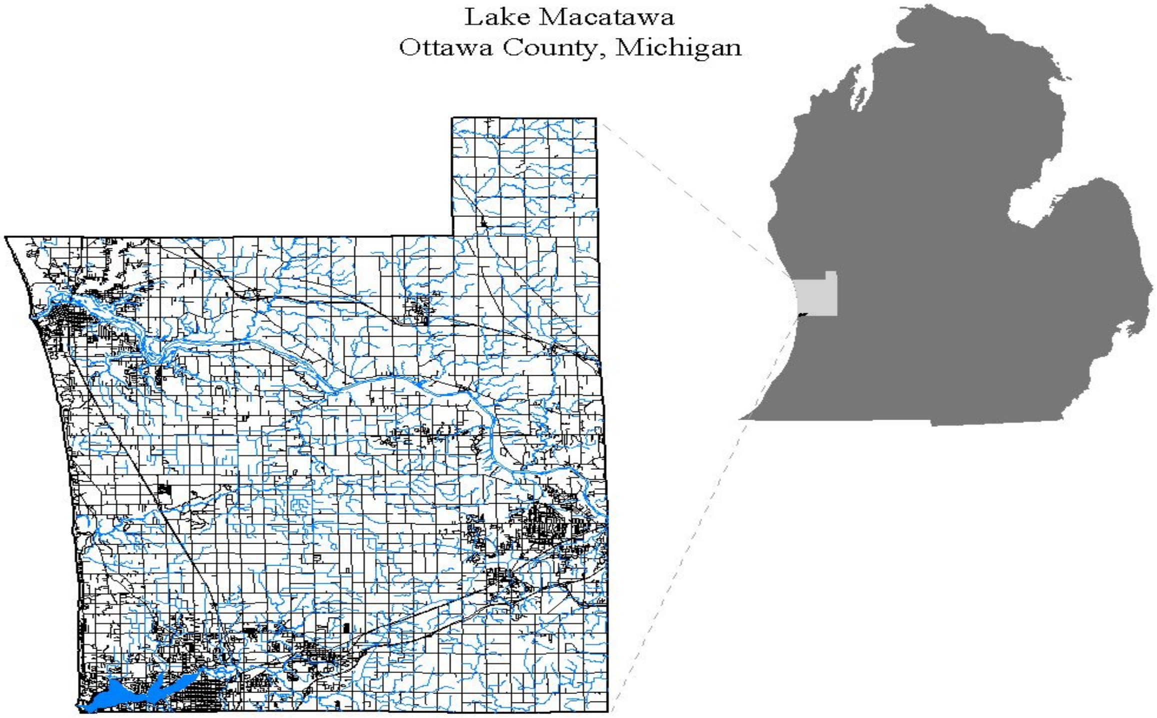

FIGURE 1.1 LAKE MACATAWA.

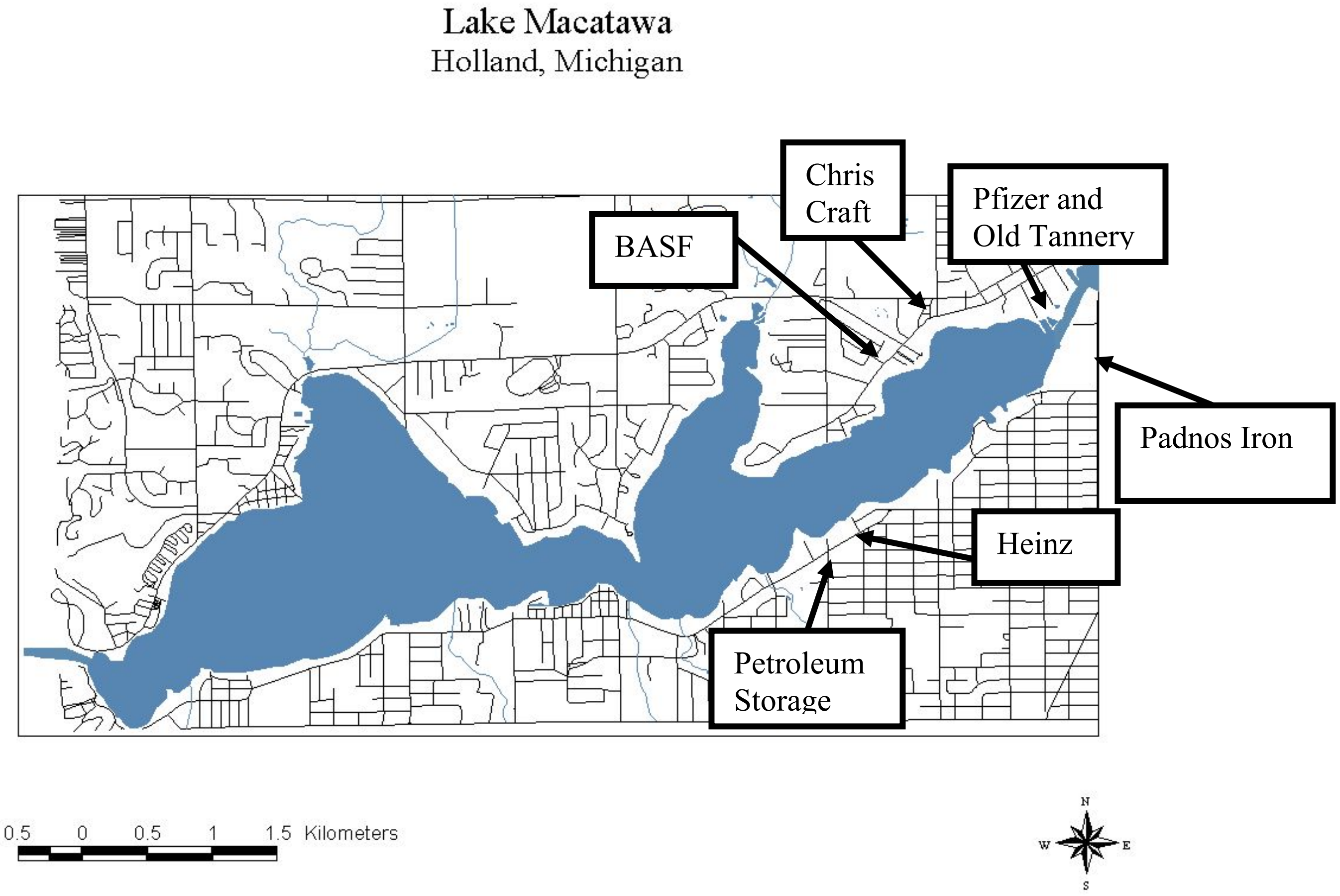

FIGURE 1.2 LOCATION OF INDUSTRIAL SITES NEAR LAKE MACATAWA.

This investigation examined specific sites of known anthropogenic activity as well as provided an overall assessment of the nature, extent, and ecological significance of sediment contamination in Lake Macatawa. This bifurcated approach allowed us to focus on specific areas based on historical information while we concurrently examined the broad-scale distribution and impacts of sediment contamination. A series of 14 sediment cores and 13 PONAR samples were analyzed for heavy metals, semivolatiles, PCBs, and physical characteristics. PONAR samples were analyzed for benthic macroinvertebrates and sediment toxicity. The study protocol followed the sediment quality triad approach (Canfield 1998) and focused on sediment chemistry, sediment toxicity, and the status of the *in situ* benthic macroinvertebrate community.

1.1 Project Objectives and Task Elements

The objective of this investigation is to conduct a Category II assessment of sediment contamination in Lake Macatawa. Specific objectives and task elements are summarized below:

- Determine the nature and extent of sediment contamination in Lake Macatawa.
  - A preliminary investigation was conducted to examine the nature and extent of sediment contamination in western Lake Macatawa. Core samples were collected to provide a historical perspective of sediment contamination. The investigation was directed at known sources of contamination in the lake and provided expanded coverage in the area of the old Occidental Chemical facility outfall and the DuPont lime pile groundwater plume. Arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury, TOC, semivolatile organics, PCBs/DDT analogs, and grain size were analyzed in all core samples.
  - Surface sediments were collected from western Lake Macatawa with a PONAR to provide chemical data for the sediments used in the toxicity evaluations and for the analysis of the benthic macroinvertebrate communities. The PONAR samples were analyzed for the same parameters as the sediment cores.
  - Critical measurements were the concentration of arsenic, cadmium, chromium, copper, lead, nickel, zinc, mercury, semivolatile organics, and PCBs/DDT analogs in sediment samples. Non-critical measurements were total organic carbon, percent solids, and grain size.

- Evaluate the toxicity of sediments from sites in Lake Macatawa.
  - Sediment toxicity evaluations were performed with *Hyalella azteca* and *Chironomus tentans*.
  - Toxicity measurements in Lake Macatawa sediments were evaluated and compared to control locations. These measurements determined the presence and degree of toxicity associated with sediments from Lake Macatawa.
  - Critical measurements were the determination of lethality during the toxicity tests and the monitoring of water quality indicators during exposure (ammonia, dissolved oxygen, temperature, conductivity, pH, and alkalinity).

- Determine the abundance and diversity of benthic invertebrates in Lake Macatawa.
  - Sediment samples were collected with a PONAR in Lake Macatawa
  - The abundance and diversity of the benthic invertebrate communities were evaluated and compared to control locations.
  - Critical measurements included the abundance and species composition of benthic macroinvertebrates.

1.2 Experimental Design

To determine the nature and extent of sediment contamination in western Lake Macatawa, 14 core samples were collected from locations that have been impacted by anthropogenic activity. Two cores were taken from deep depositional zones near the western section of the lake. Seven cores were collected from shallow areas in the eastern area near Pfizer (2), BASF (3), and Heinz/Petroleum Storage Area (1), Padnos Iron (1). Two additional cores were collected from down gradient locations. A control was collected in the residential area near Pine Creek. These core samples were analyzed for heavy metals (arsenic, cadmium, chromium, copper, lead, nickel, and mercury), semivolatile organics, PCBs/DDT homologs, and physical characteristics (grain size distribution, TOC, and percent solids). PONAR samples were collected at the same locations. Benthic macroinvertebrate and sediment toxicity samples also were collected at the PONAR sites. A complete listing of locations and sample types is provided in Section 2.0.

The final locations of the core and PONAR samples were determined in cooperation with the USEPA. Core samples at the above locations were collected by VibraCore techniques using the R/V *Mudpuppy*. This part of the project provided both historical and current information related to the nature and extent of sediment contamination in Lake Macatawa. The benthic macroinvertebrate and toxicity evaluations were used to support this information and for the evaluation of ecological effects and the prioritization areas for remediation. Analytical methods were performed according to the protocols described in SW-846 3rd edition (EPA 1999a). Chemistry data were then supplemented by laboratory toxicity studies that utilized standardized exposure regimes to evaluate the effects of contaminated sediment on test organisms. Standard EPA methods (1999b) using *Chironomus tentans* and *Hyalella azteca* were used to determine the acute toxicity of sediments from the PONAR samples.

1.3 References

Canfield, T. J., E.L Brunson, and F.J Dwyer, 1998. Assessing sediments from upper Mississippi River navigational pools using a benthic invertebrate community evaluation and the sediment quality triad approach. *Arch. Environ. Contam. Toxicol.* 35 (2):202-212.

EPA 1999a. Test Methods for Evaluating Solid Waste Physical/Chemical Methods. U.S. Environmental Protection Agency. SW-846, 3rd Edition.

EPA 1999b. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates. 2nd Edition. EPA Publication EPA/600/R-99/064.

2.0 Sampling Locations

Sampling locations for the assessment of contaminated sediments in Lake Macatawa were selected based on proximity to potential point and nonpoint sources of contamination. The locations of these sites were determined by review of historical records. Sediment samples were collected in areas of fine sediment deposition. Samples from areas containing rubble and sand were excluded. A total of 14 locations were selected for the collection of core samples and PONAR samples. The sampling locations are listed below and displayed on Figure 2.1. GPS coordinates, depths, and visual descriptions are included in Tables 2.1 and 2.2, respectively, for core and PONAR samples. A PONAR was not collected at Station LM-5. Although we returned to the same GPS coordinates as the core sample, the sediments at the location were hard and could not be sampled.

Core and PONAR Identification	Description
LM-1 and LM -2	Pfizer/Tannery
LM -3, LM –4 and LM -6	BASF
LM -5	Padnos Iron
LM -7	Heinz/Petroleum Storage
LM-9	Storm Drain
LM -8, LM -10, and LM -11	Down Gradient Locations
LM -14 and LM -15	Depositional Areas
LM -12	Control Location

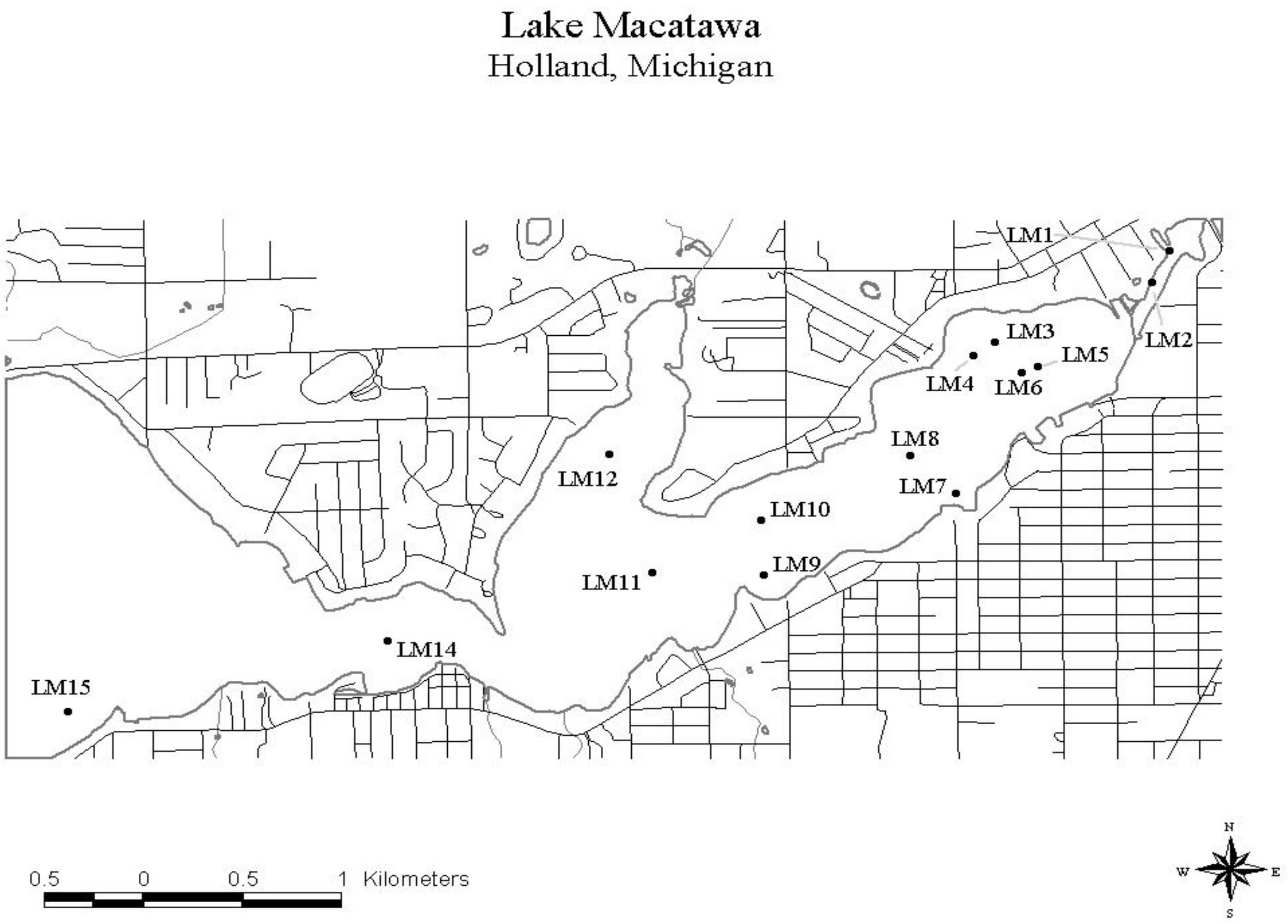

FIGURE 2.1 LAKE MACATAWA CORE SAMPLING STATIONS.

TABLE 2.1 LAKE MACATAWA CORE SAMPLING STATIONS.

Station	Date	Section	Section Length	Latitude	Longitude	Depth to Core	Depth of core	Visual Description
			cm			meters	cm	
LM-1	7/8/2002			42 47.910	86 06.812	3.3	198	
LM-1		Top	0-51					grey/black silt
LM-1		Middle	51-102					grey/black silt
LM-1		Middle	102-152					grey/black silt
LM-1		Bottom	152-198					grey/black silt
LM-2	7/8/2002			42 47.815	86 06.881	2.6	193	
LM-2		Top	0-51					black silt
LM-2		Middle	51-102					black silt
LM-2		Middle	102-152					black silt
LM-2		Bottom	152-180					black silt
LM-3	7/8/2002			42 47.632	86 07.470	2.7	211	
LM-3		Top	0-51					black silt
LM-3		Middle	51-102					silt/clay
LM-3		Bottom	102-211					clay
LM-4	7/8/2002			42 47.592	86 07.5536	2.7	178	
LM-4		Top	0-51					black silt
LM-4		Middle	51-102					silt/clay
LM-4		Bottom	102-152					brown clay
LM-5	7/9/2002			42 47.5720	86 07.5042	2.9	183	
LM-5		Top	0-51					clay, silt, sand, stone
LM-5		Middle	51-102					silt/clay to silt/sand
LM-5		Bottom	102-178					silt
LM-6	7/9/2002			42 47.5425	86 07.7305	3.0	216	
LM-6		Top	0-51					black silt
LM-6		Middle	51-102					black silt
LM-6		Bottom	102-178					black silt
LM-6 Dup	7/9/2002			42 47.529	86 07.375	3.0	224	
LM-6 Dup		Top	0-51					black organic silt
LM-6 Dup		Middle	51-102					black organic silt
LM-6 Dup		Bottom	102-178					black organic silt
LM-7	7/9/2002			42 47.176	86 07.616	3.8	150	
LM-7		Top	0-51					black organic silt
LM-7		Bottom	51-102					black organic silt
LM-7			102-150					sand--no sample
LM-8	7/9/2002			42 47.290	86 07.782	4.4	234	
LM-8		Top	0-51					grey silt
LM-8		Middle	51-102					grey silt
LM-8		Middle	102-152					grey silt
LM-8		Bottom	152-234					grey silt
LM-9	7/9/2002			42 46.936	86 08.321	4.9	218	
LM-9		Top	0-51					black silt
LM-9		Middle	51-102					black silt
LM-9		Bottom	102-178					clay
LM-10	7/9/2002			42 47.102	86 08.336	4.6	239	
LM-10		Top	0-51					black organic silt
LM-10		Middle	51-102					black organic silt
LM-10		Middle	102-152					black organic silt
LM-10		Bottom	152-229					black organic silt
LM-11	7/9/2002			42 46.939	86 08.740	5.1	249	
LM-11		Top	0-51					black organic silt
LM-11		Middle	51-102					black organic silt
LM-11		Middle	102-152					black organic silt
LM-11		Bottom	152-229					black organic silt
LM-12	7/9/2002			42 47.296	86 08.907	3.1	102	
LM-12		Top	0-51					black silt
LM-12		Bottom	51-102					silt
LM-14	7/9/2002			42 46.772	86 09.715	5.1	203	
LM-14		Top	0-51					grey/black silt
LM-14		Middle	51-102					green/grey silts "oil"
LM-14		Bottom	102-178					grey silt
LM-15	7/9/2002			42 46.517	86 10.941	10.1	224	
LM-15		Top	0-51					grey silt
LM-15		Middle	51-102					grey silt
LM-15		Middle	102-152					grey silt
LM-15		Bottom	152-224					grey silt

TABLE 2.2 LAKE MACATAWA PONAR CORE SAMPLING STATIONS.

Station	Date	Latitude	Longitude	Depth (m)	Visual Description
LM-1	7/10/2002	42 47.911	86 06.822	2.6	Black silts
LM-2	7/10/2002	42 47.816	86 06.877	3.5	Black silts
LM-3	7/11/2002	42 47.6350	86 7.4700	2.7	Black silts
LM-4	7/11/2002	42 47.5930	86 7.5530	2.6	Black silts
LM-6	7/11/2002	42 47.5730	86 7.5051	2.9	Black silts
LM-6 Dup	7/11/2002	42 47.5420	86 7.7300	3.1	Black silts
LM-7	7/11/2002	42 47.178	86 07.615	3.7	Black silts
LM-8	7/11/2002	42 47.293	86 07.784	4.3	Grey silts
LM-9	7/11/2002	42 46.932	86 08.326	4.4	Black silts
LM-10	7/12/2002	42 47.098	86 08.339	4.6	Black silts
LM-11	7/12/2002	42 46.940	86 08.738	4.9	Black silts
LM-12	7/12/2002	42 47.296	86 08.901	3.1	Black silts
LM-14	7/12/2002	42 46.733	86 09.721	5.0	Black silts
LM-15	7/12/2002	42 46.517	86 10.906	9.9	Black silts

3.0 Methods

3.1 Sampling Methods

Sediment and benthos samples were collected using the U.S. EPA Research Vessel *Mudpuppy*. VibraCore methods were used to collect sediment cores for chemical analysis. A 4-inch aluminum core tube with a butyrate liner was used for collection. A new core tube and liner were used at each location. The core samples were measured and sectioned into three equal segments corresponding to top, middle, and bottom. Each section was then homogenized in a polyethylene pan and split into sub-samples. The visual appearance of each segment was recorded along with the water depth and core depth.

PONAR samples were collected for toxicity testing, sediment chemistry, and benthic macroinvertebrates. For sediment chemistry and toxicity testing, a standard PONAR sample was deposited into a polyethylene pan and split into sub-samples. The PONAR was washed with water between stations. A petite PONAR was used for the collection of benthic macroinvertebrates. Three replicate grabs were taken at each of the sites and treated as discrete samples. All material in the grab was washed through a Nitex screen with 500 μm openings and the residue preserved in buffered formalin containing rose bengal stain.

GPS system coordinates were used to record the position of the sampling locations. Because the core and PONAR samples were collected on different days, some variation in the location may have occurred.

3.1.2 SAMPLE CONTAINERS, PRESERVATIVES, AND VOLUME REQUIREMENTS

Requirements for sample volumes, containers, and holding times are listed in Table 3.1.
All sample containers for sediment chemistry and toxicity testing were purchased, precleaned, and certified as Level II by I-CHEM Inc.

TABLE 3.1 SAMPLE CONTAINERS, PRESERVATIVES, AND HOLDING TIMES.

Hold Times					
Matrix	***Parameter***	***Container***	***Preservation***	***Extraction***	***Analysis***
Sediment	Metals	250 mL Wide Mouth Plastic	Cool to 4^{o}C	---	6 months, Mercury-28 Days
Sediment	TOC	250 mL Wide Mouth Plastic	Freeze -10^{0}C	---	6 months
Sediment	Semi-Volatile Organics	500 mL Amber Glass	Cool to 4^{o}C	14 days	40 days
Sediment	Grain Size	1 Quart Zip-Lock Plastic Bag	Cool to 4^{o}C	---	6 months
Sediment	Toxicity	4 liter Wide Mouth Glass	Cool to 4^{o}C	---	45 days
Water	Semi-Volatile Organics and Resin Acids	1000 mL Amber Glass	Cool to 4^{o}C	14 days	40 days
Culture	Alkalinity	250 mL Wide Mouth Plastic	Cool to 4^{o}C	---	24 hrs.
Water	Ammonia Hardness Conductivity pH	250 mL Wide Mouth Plastic	Cool to 4^{o}C	---	24 hrs.

3.2 Chemical Analysis Methods for Sediment Analysis

A summary of analytical methods and detection limits is provided in Table 3.2.1. Instrument conditions and a summary of quality assurance procedures are provided in the following sections.

TABLE 3.2.1 ANALYTICAL METHODS AND DETECTION LIMITS.

Parameter	Method Description	Analytical Method	Detection Limit
Arsenic, Lead, Cadmium	Arsenic-Graphite Furnace	7060[1] 3051[1] Digestion	0.10 mg/kg
Lead, Chromium, Cadmium , Copper, Nickel, Zinc	Inductively Coupled Plasma Atomic Emission Spectroscopy	6010[1], 3052[1] Digestion	2.0 mg/kg
Mercury	Mercury Analysis of Soils, Sludges and Wastes by Manual Cold Vapor Technique	7471[1], Prep Method in 7471[1]	0.10 mg/kg
Grain Size	Wet Sieve	WRI Method PHY-010	1 %
Total Organic Carbon	Combustion/IR	9060[1]	0.1%
USEPA Semivolatiles	Solvent Extraction and GC/MS analysis	8270[1], 3550[1] Extraction	Table 3.2.2
PCBs and DDT compounds	Solvent Extraction and GC/ECD analysis	8080[1], 3050[1] Extraction	Table 3.2.4

[1] - SW846 3rd. Ed. (EPA 1999a).

3.2.1 SAMPLE PREPARATION FOR METALS ANALYSIS

For arsenic, calcium, cadmium, chromium, copper, nickel, lead, and zinc analysis, sediment samples were digested according to a modified version of EPA SW-846 method 3052 "Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils." Samples were air-dried prior to digestion. A Questron (Mercerville, NJ) Q-4000 microwave system was used. The system provided a controlled temperature and pressure in each digestion vessel. Approximately 0.25 g of sediment was weighed into a Teflon liner. 4 mL Type 1 deionized water, 3 mL of concentrated nitric acid, 6 mL of concentrated hydrochloric acid, and 4 mL of hydrofluoric acid were added to each sample. Vessels were then capped and placed into the microwave cavity. The program was set to raise the temperature inside the vessels to 200°C for 20.0 minutes. After completion of the run, vessels were cooled and vented. Then 15 mL of saturated boric acid was added to each sample in place of hydrogen peroxide. The vessels were recapped and placed into the microwave cavity. The program was set to raise the temperature inside the vessels to 180°C for 15.0 minutes. After completion of the second run, the vessels were cooled and vented. The contents were transferred into 50 mL centrifuge tubes and brought up to 50 mL with Type I deionized water. Samples were centrifuged for 5 minutes at 3000 rpm before analysis. For every batch of 20 samples at least one set of the following quality control samples was prepared:

> Method Blank (4 mL of Type 1 deionized water, 3 mL of nitric acid and 6 mL of hydrochloric acid);
> Laboratory Control Spike (Blank Spike);
> Matrix Spike;
> Matrix Spike Duplicate.

For determining total mercury the samples were prepared by EPA SW-846 method 7471A, "Mercury in Solid and Semisolid Waste". Approximately 0.2 g of wet sediment was weighed into a 50 mL centrifuge tube. 2.5 mL of Type I deionized water and 2.5 mL of aqua regia were then added to the tube. Samples were heated in a water bath at 95°C for 2 minutes. After cooling, the volume of the samples was brought up to 30 mL with Type I deionized water. Then 7.5 mL of 5% potassium permanganate solution was added to each sample, the samples were mixed, and the centrifuge tubes were returned to the water bath for a period of 30 minutes. Three mL of 12% hydroxylamine chloride solution was added to each sample after cooling. Finally, the samples were mixed and centrifuged for 5 minutes at 3,000 rpm. Calibration standards were digested concurrent with the samples. Quality control samples were prepared as stated previously for every batch of 10 samples or less.

3.2.2 ARSENIC ANALYSIS BY FURNACE

Arsenic was analyzed in accordance with the EPA SW-846 method 7060A utilizing the Graphite Furnace technique. The instrument employed was a Perkin Elmer 4110ZL atomic absorption spectrophotometer. An arsenic EDL Lamp was used as a light source at a wavelength of 193.7 nm. The instrument utilized a Zeeman background correction that reduces the non-specific absorption caused by some matrix components. The temperature program is summarized below:

Step	Temp, °C	Time, sec.		Gas Flow, mL/min	Read
		Ramp	Hold		
1	110	1	35	250	
2	130	15	37	250	
3	1300	10	20	250	
4	2100	0	5	0	X
5	2500	1	3	250	

A Pd/Mg modifier was used to stabilize As during the pyrolysis step. The calibration curve was constructed from four standards and a blank. Validity of calibration was verified with a check standard prepared from a secondary source. This action was taken immediately after calibration, after every 20 samples, and at the end of each run. At least 1 post-digestion spike was performed for every analytical batch of 20 samples.

3.2.3 CADMIUM ANALYSIS BY FURNACE

Cadmium was analyzed in accordance with the EPA SW-846 method 7060A utilizing the Graphite Furnace technique. The instrument employed was a Perkin Elmer 4110ZL atomic absorption spectrophotometer. A hollow cathode lamp was used as a light source at a wavelength of 228.8 nm. The instrument utilized a Zeeman background correction that reduces the non-specific absorption caused by some matrix components. The temperature program is summarized below:

Step	Temp, °C	Time, sec.		Gas Flow, mL/min	Read
		Ramp	Hold		
1	110	1	40	250	
2	130	15	45	250	
3	500	10	20	250	
4	1550	0	5	0	X
5	2500	1	3	250	

A Pd/Mg modifier was used to stabilize Cd during the pyrolysis step. The calibration curve was constructed from four standards and a blank. Validity of calibration was verified with a check standard prepared from a secondary source. This action was taken immediately after calibration, after every 20 samples, and at the end of each run. At least 1 post-digestion spike was performed for every analytical batch of 20 samples.

3.2.4 LEAD ANALYSIS BY FURNACE

Lead was analyzed in accordance with the EPA SW-846 method 7060A utilizing the Graphite Furnace technique. The instrument employed was a Perkin Elmer 4110ZL atomic absorption spectrophotometer. A lead EDL Lamp was used as a light source at a wavelength of 283.3 nm. The instrument utilized a Zeeman background correction that reduces the non-specific absorption caused by some matrix components. The temperature program is summarized below:

Step	Temp, °C	Time, sec.		Gas Flow, mL/min	Read
		Ramp	Hold		
1	120	1	20	250	
2	140	5	40	250	
3	200	10	10	250	
4	850	10	20	250	
5	1900	0	5	0	X
6	2500	1	3	250	

A Pd/Mg modifier was used to stabilize Pb during the pyrolysis step. The calibration curve was constructed from four standards and a blank. Validity of calibration was verified with a check standard prepared from a secondary source. This action was taken immediately after calibration, after every 20 samples, and at the end of each run. At least 1 post-digestion spike was performed for every analytical batch of 20 samples.

3.2.5 SELENIUM ANALYSIS BY FURNACE

Selenium was analyzed in accordance with the EPA SW-846 method 7060A utilizing the Graphite Furnace technique. The instrument employed was a Perkin Elmer 4110ZL atomic absorption spectrophotometer. An arsenic EDL Lamp was used as a light source at a wavelength of 196.0 nm. The instrument utilized a Zeeman background correction that reduces the non-specific absorption caused by some matrix components. The temperature program is summarized below:

Step	Temp, °C	Time, sec.		Gas Flow, mL/min	Read
		Ramp	Hold		
1	120	1	22	250	
2	140	5	42	250	
3	200	10	11	250	
4	1300	10	20	250	
5	2100	0	5	0	X
6	2450	1	3	250	

A Pd/Mg modifier was used to stabilize Se during the pyrolysis step. The calibration curve was constructed from four standards and a blank. Validity of calibration was verified with a check standard prepared from a secondary source. This action was taken immediately after calibration, after every 20 samples, and at the end of each run. At least 1 post-digestion spike was performed for every analytical batch of 20 samples.

3.2.6 METAL ANALYSIS BY ICP

Aluminum, calcium, chromium, copper, nickel, and zinc were analyzed in accordance with EPA SW-846 method 6010A using Inductively Coupled Plasma Atomic Emission Spectroscopy. Samples were analyzed on a Perkin Elmer P-1000 ICP Spectrometer with Ebert monochromator and cross-flow nebulizer. The following settings were used:

Element Analyzed	Wavelength, nm
Ba	233.5
Ca	315.9
Cr	267.7
Cu	324.8
Ni	231.6
Zn	213.9

Matrix interferences were suppressed with internal standardization utilizing Myers-Tracy signal compensation. Interelement interference check standards were analyzed in the beginning and at the end of every analytical run, and indicated an absence of this type of interference at the given wavelength. The calibration curve was constructed from four standards and a blank, and was verified with a check standard prepared from a secondary source.

3.2.7 MERCURY

After the digestion procedure outlined in 3.2.1, sediment samples were analyzed for total mercury by cold vapor technique according to SW-846 Method 7471. A Perkin Elmer 5100ZL atomic absorption spectrophotometer with FIAS-200 flow injection accessory was used. Mercury was reduced to an elemental state using stannous chloride solution, and atomic absorption was measured in a quartz cell at an ambient temperature and a wavelength of 253.7 nm. A mercury electrodeless discharge lamp was used as a light source. The calibration curve consisted of four standards and a blank, and was verified with a check standard prepared from a secondary source.

3.2.8 TOTAL ORGANIC CARBON

Total Organic Carbon analysis of sediments was conducted on a Shimadzu TOC-5000 Total Organic Carbon Analyzer equipped with Solid Sample Accessory SSM-5000A. Samples were air dried and then reacted with phosphoric acid to remove inorganic carbonates. Prior to analysis, the samples were air dried a final time. Calibration curves for total carbon were constructed from three standards and a blank. Glucose was used as a standard compound for Total Carbon Analysis (44% carbon by weight).

3.2.9 GRAIN SIZE ANALYSIS

Grain size was performed by wet sieving the sediments. The following mesh sizes were used: 2 mm (granule), 1 mm (very coarse sand), 0.85 mm (coarse sand), 0.25 mm (medium sand), 0.125 mm (fine sand), 0.063 (very fine sand), and 0.031 (coarse silt). After sieving, the fractions were dried at 105°C and analyzed by gravimetric methods to determine weight percentages.

3.2.10 SEMIVOLATILES ANALYSIS

Sediment samples were extracted for analysis of semivolatiles using SW-846 Method 3050. The sediment samples were dried with anhydrous sodium sulfate to form a free flowing powder. The samples were then serially sonicated with 1:1 methylene chloride/acetone and concentrated to a volume of 1 mL.

The sample extracts were analyzed by GC/MS on a HeLMett Packard 5895 MSD Mass Spectrometer according to Method 8270. Instrumental conditions are itemized below:

MS operating conditions:

- Electron energy: 70 volts (nominal).
- Mass range: 40-450 amu.
- Scan time: 820 amu/second, 2 scans/sec.
- Source temperature: 190° C
- Transfer line temperature: 250°C

GC operating conditions:

- Column temperature program: 45°C for 6 min., then to 250°C at 10°C/min, then to 300°C at 20°C/min hold 300°C for 15 min.
- Injector temperature program: 250°C
- Sample volume: 1 µl

A list of analytes and detection limits is given in Table 3.2.2. Surrogate standards were utilized to monitor extraction efficiency. Acceptance criteria for surrogate standards are given in Table 3.2.3. The GC/MS was calibrated using a 5-point curve. Instrument tuning was performed by injecting 5 ng of decafluorotriphenylphosphine and then adjusting spectra to meet method acceptance criteria. The MS and MSD samples were analyzed at a 5% frequency.

TABLE 3.2.2 ORGANIC PARAMETERS AND DETECTION LIMITS.

Semi-Volatile Organic Compounds (8270)	Sediment (mg/kg)
Phenol	0.33
Bis(2-chloroethyl)ether	0.33
2-Chlorophenol	0.33
1,3-Dichlorobenzene	0.33
1,4-Dichlorobenzene	0.33
1,2-Dichlorobenzene	0.33
2-Methylphenol	0.33
4-Methylphenol	0.33
Hexachloroethane	0.33
Isophorone	0.33
2,4-Dimethylphenol	0.33
Bis(2-chloroethoxy)methane	0.33
2,4-Dichlorophenol	0.33
1,2,4-Trichlorobenzene	0.33
Naphthalene	0.33
Hexachlorobutadiene	0.33
4-Chloro-3-methylphenol	0.33
2-Methylnaphthalene	0.33
Hexachlorocyclopentadiene	0.33
2,4,6-Trichlorophenol	0.33
2,4,5-Trichlorophenol	0.33
2-Chloronaphthalene	0.33
Dimethylphthalate	0.33
Acenaphthylene	0.33
Acenaphthene	0.33
Diethylphthalate	0.33
4-Chlorophenyl-phenyl ether	0.33
Fluorene	0.33
4,6-Dinitro-2-methylphenol	1.7
4-Bromophenyl-phenyl ether	0.33

TABLE 3.2.2 ORGANIC PARAMETERS AND DETECTION LIMITS (CONTINUED)

Semi-Volatile Organic Compounds (8270)	Sediment (mg/kg)
Hexachlorobenzene	0.33
Pentachlorophenol	1.7
Phenanthrene	0.33
Anthracene	0.33
Di-n-butylphthalate	0.33
Fluoranthene	0.33
Pyrene	0.33
Butylbenzylphthalate	0.33
Benzo(a)anthracene	0.33
Chrysene	0.33
Bis(2-ethylhexyl)phthalate	0.33
Di-n-octylphthalate	0.33
Benzo(b)fluoranthene	0.33
Benzo(k)fluoranthene	0.33
Benzo(a)pyrene	0.33
Indeno(1,2,3-cd)pyrene	0.33
Dibenzo(a,h)anthracene	0.33
Benzo(g,h,i)perylene	0.33
3-Methylphenol	0.33

TABLE 3.2.3 DATA QUALITY OBJECTIVES FOR SURROGATE STANDARDS CONTROL LIMITS FOR PERCENT RECOVERY.

Parameter	Control Limit
Nitrobenzene-d_5	30%-97%
2-Fluorobiphenyl	42%-99%
o-Terphenyl	60%-101%
Phenol-d_6	43%-84%
2-Fluorophenol	33%-76%
2,4,6-Tribromophenol	58%-96%

3.2.11 PCB/DDT ANALYSIS

The sediment samples were extracted for PCBs and DDT compounds using SW-846 Method 3050. Sediment samples were air dried for 24 hours, and then equal weights of the dried soil and anhydrous sodium sulfate were mixed together. The samples were then extracted using 50 mL of methanol and 100 mL of hexane. The samples were sonicated for 3 minutes, and then the hexane layer was removed and filtered through anhydrous sodium sulfate. The process was repeated two more times, adding 50 mL of hexane each time. The hexane extract was concentrated to 1 mL in the Turbovap, and then run through a chromatography column packed with 2% deactivated florisil and anhydrous sodium sulfate. Copper turnings cleaned with 1 M hydrochloric acid were added to remove sulfur. The eluent was concentrated to 1 mL using the Turbovap, and concentrated sulfuric acid was added as a final clean-up step. Solvent transfer to iso-octane was achieved under a flow of nitrogen gas and condensed to a final volume of 1 mL.

Sample extracts were analyzed using gas chromatography with a Ni^{63} electron capture detector and RTX-5 capillary column. Helium and nitrogen were used as the carrier gas and makeup gas, respectively. Instrumental operating conditions were as follows:

- Column temperature program: 80°C for 2 min., 10°C/min to 160°C, 1.5°C/min to 190°C, 2°C/min to 256°C and hold at 256°C for 6 min.
- Injector temperature: 260°C
- Detector temperature: 330°C
- Sample volume: 1 µl.

Table 3.2.4 presents a list of compounds and their detection limits. Two surrogate standards, tetrachloro-m-xylene and decachlorobiphenyl were used to monitor extraction efficiency. Acceptance limits for the surrogates were ± 50% for precision and accuracy.

TABLE 3.2.4 SEDIMENT DETECTION LIMITS FOR PCBS.

PCB Formulation	Detection Limit (mg/kg)
Aroclor 1221	0.33
Aroclor 1232	0.33
Aroclor 1242	0.33
Aroclor 1248	0.33
Aroclor 1254	0.33
Aroclor 1260	0.33
DDT	0.33
DDD	0.33
DDE	0.33

3.3 Chemical Analysis Methods for Water Analysis

The parameters, methods, and detection limits for the measurements performed on the culture water used in the sediment toxicity tests are listed in Table 3.3.1. All methods were performed according to procedures outlined in Standard Methods 14th Edition (APHA 1996).

TABLE 3.3.1 ANALYTICAL METHODS AND DETECTION LIMITS FOR CULTURE WATER.

Parameter	Method	Detection Limit
Specific Conductance	Standard Methods 2510 B.	NA
Alkalinity	Standard Methods 2320	10 mg/l
Temperature	Standard Methods 2550	NA
Dissolved Oxygen	Standard Methods 4500-O G.	0.5 mg/l
Ammonia Electrode	Standard Methods 4500-NH_3 F.	0.05 mg/l
Hardness	Standard Methods 2340 C.	10 mg/l

3.4 Sediment Toxicity

The evaluation of the toxicity of the Lake Macatawa sediments was conducted using the ten-day survival test for the amphipod *Hyalella azteca* and the dipteran *Chironomus tentans*. The procedures followed are contained in EPA (1999b). All sediments were stored at 4°C prior to analysis.

3.4.1 LABORATORY WATER SUPPLY

Moderately hard well water was employed for the culture and maintenance of *H. azteca* and *C. tentans*.

3.4.2 TEST ORGANISMS

The original stock of *H. azteca* was obtained from the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan. The *H. azteca* culture was maintained in four 20 L glass aquaria using maple leaves as a substrate and as a food source. The food source was supplemented with a suspension of Tetramin® fish food. The original stock of *C. tentans* was obtained from the University of Michigan Department of Environmental Health in Ann

Arbor, Michigan. The culture of *C. tentans* was maintained in 36 L glass aquaria using shredded paper toweling as a substrate and was fed a suspension of Tetrafin® goldfish food.

3.4.3 EXPERIMENTAL DESIGN

For the November testing, eight replicates per sediment were set up for both *H. azteca* and *C. tentans* exposures, with the sediment from site M-15P designated as the control. In all tests, moderately hard well water was utilized as the overlying water. The experimental conditions outlined in Tables 3.4.1 and 3.4.2 were used for the toxicity evaluations.

One day prior to the start of the test (day –1), the sediment from each site was mixed thoroughly and a 100 mL aliquot was transferred to each of the eight test chambers. Additionally, visual observations of the sediments were made. Moderately hard well water also was added at this time. On day 0, the overlying water was renewed once before the test organisms were introduced into each of the glass beakers. Measurement of water quality parameters also was initiated on this day. Ten 7-14 day old *H. azteca* and 10 third instar *C. tentans* larvae were randomly added to their respective test chambers. At this time the organisms were fed 1.5 mL of Tetrafin®. The glass beakers were placed in a rack and transferred to a temperature controlled room (23 ± 1°C). The light cycle was 16 hours on and 8 hours off. Temperature and dissolved oxygen measurements were taken from one randomly selected beaker for each sediment sample every 12 hours, after which the overlying water was renewed in all the beakers. Feeding with the Tetrafin® suspension occurred after the morning renewal. This procedure was repeated daily through day 10, at which point the test was terminated. On day 0, the overlying water from the beakers was composited from each sediment sample and 250 mL were retained for alkalinity, pH, conductance, hardness and ammonia analysis. On the last day the same procedure was carried out. On day 10, the sediments were sieved, and the surviving test organisms were removed and counted. The biological endpoint for these sediment tests was mortality. The validity of the test was based on EPA (1999) criteria of greater than 80% survival in the control treatment for *H. azteca* and greater than 70% survival in the control treatment for the *C. tentans*. In addition, EPA (1999) recommended that the hardness, alkalinity, pH, and ammonia in the overlying water within a treatment should not vary by more than 50% over the duration of the test.

3.4.4 STATISTICAL ANALYSIS

Survival data for the toxicity testing were analyzed first for normality with Chi Square and then for homogeneity using Bartlett's Test. All data passed the normality and homogeneity tests without transformation. The data were then examined using Dunnett's Procedure to determine whether there was a significant difference in survival between the designated control sediment and those sediments containing pollutants. The TOXSTAT® 3.5 Computer Program was used for the statistical evaluations.

Table 3.4.1 Test Conditions for Conducting a Ten Day Sediment Toxicity Test with *Hyalella azteca*.

1.	Test Type:	Whole-sediment toxicity test with renewal of overlying water
2.	Temperature (°C):	23 ± 1°C
3.	Light quality:	Wide-spectrum fluorescent lights
4.	Illuminance:	About 500 to 1000 lux
5.	Photoperiod:	16 h light, 8 h darkness
6.	Test chamber size:	300 mL high-form lipless beaker
7.	Sediment volume:	100 mL
8.	Overlying water volume:	175 mL
9.	Renewal of overlying water:	2 volume additions per day (i.e., one volume addition every 12 hours)
10.	Age of test organisms:	7 to 14 days old at the start of the test
11.	Number of organisms per chamber:	10
12.	Number of replicate chambers per treatment:	8
13.	Feeding:	Tetramin® fish food, fed 1.5 mL daily to each test chamber
14.	Aeration:	None, unless dissolved oxygen in overlying water drops below 40% of saturation
15.	Overlying water:	Moderately hard well water
16.	Overlying water quality:	Hardness, alkalinity, conductivity, pH, and ammonia measured at the beginning and end of a test. Temperature and dissolved oxygen measured daily.
17.	Test duration:	10 days
18.	End point:	Survival, with greater than 80% in the control

Test Method 100.1. EPA Publication: EPA/600/R-99/064 (July 1999).

TABLE 3.4.2 RECOMMENDED TEST CONDITIONS FOR CONDUCTING A TEN DAY SEDIMENT TOXICITY TEST WITH *CHIRONOMUS TENTANS*.

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1. Test Type: ....Whole-sediment toxicity test with renewal of overlying water
2. Temperature (°C): ....23 ± 1°C
3. Light quality:..........................Wide-spectrum fluorescent lights
4. Illuminance: ....About 500 to 1000 lux
5. Photoperiod:...........................16 h light, 8 h darkness
6. Test chamber size: ....300 mL high-form lipless beaker
7. Sediment volume: ....100 mL
8. Overlying water volume: ....175 mL
9. Renewal of overlying water: ....2 volume additions per day (i.e., one volume addition every 12 hours)
10. Age of test organisms: ....Third instar larvae (All organisms must be third instar or younger with at least 50% of the organisms at third instar)
11. Number of organisms per chamber:...........................10
12. Number of replicate chambers per treatment:.........8
13. Feeding: ....Tetrafin® goldfish food, fed 1.5 mL daily to each test chamber (1.5 mL contains 4.0 mg of dry solids)
14. Aeration: ....None, unless dissolved oxygen in overlying water drops below 40% of saturation
15. Overlying water: ....Moderately hard well water
16. Overlying water quality: ....Hardness, alkalinity, conductivity, pH, and ammonia measured at the beginning and end of a test. Temperature and dissolved oxygen measured daily.
17. Test duration: ....10 days
18. End point:...............................Survival, with greater than 70% in the control. Weight > 0.6 mg per midge in the control

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Test Method 100.2. EPA Publication: EPA/600/R-99/064 (July 1999).

3.5 Benthic Macroinvertebrate Analysis

Samples were washed with tap water to remove formalin and extraneous debris through a USGS #30 mesh screen. The retained portion was poured into a white enamel pan from which the organisms were picked into two groups. These were oligochaetes and "other". The worms were preserved with 4% formalin and later identified to the lowest practical level. The worms were mounted separately and examined under 100X and 400X. The "other" group was preserved in 70% ethanol. Midges were removed from this group and a head mount of each midge was made and examined under 100X and 400X. The number and taxa were reported. The remainder of the organisms were identified and enumerated utilizing a 60X dissecting microscope.

3.6 Statistical Analysis

Multivariate analyses were conducted using SAS version 8.0 (Cary, North Carolina). Principal Components Analysis (PCA) was conducted on the physical/chemical parameters. Correspondence Analysis (CA) was conducted on the benthic macroinvertebrate data using the individual taxa.

Spearman Rank Correlation was used to determine significant relationships between individual physical and chemical parameters and the trophic status indices. Pearson correlation analysis was conducted using SYSTAT version 5.0 (Evanston, Illinois).

3.7 References

APHA 1996. Standard Methods for the Analysis of Water and Wastewater. 14th ed. American Public Health Association. New York.

EPA 1999a. Test Methods for Evaluating Solid Waste Physical/Chemical Methods. U.S. Environmental Protection Agency. SW-846, 3rd Edition.

EPA 1999b. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates. 2nd Edition. EPA Publication EPA/600/R-99/064.

4.0 Results and Discussion

The results and discussion section is organized according to 6 sections that present and summarize the information related to the following topics:

Section 4.1	Sediment Chemistry Results
Section 4.2	Toxicity Testing Results
Section 4.3	Benthic Macroinvertebrate Results
Section 4.4	Sediment Quality Triad Assessment
Section 4.5	Summary and Conclusions

The sediment chemistry results are presented for the core and PONAR samples (Section 4.1) and include metals, semivolatiles, and physical parameters. A discussion also is included related to the comparison of the data with published sediment quality guidelines. Toxicity and Benthic Macroinvertebrate results are presented in Sections 4.2 and 4.3, respectively. Statistical analyses of the data and comparisons to related chemical and biological data also are discussed. An assessment of the data using the Sediment Quality Triad approach (Chapman 1992) is provided in Section 4.4. The project summary and conclusions are provided in section 4.5.

The project data were reviewed for compliance with the Data Quality Objectives outlined in the Quality Assurance Project Plan. Low matrix spike recoveries were obtained on one sample for semivolatiles and one sample for metals. Acceptable recoveries were obtained in the laboratory control sample, suggesting that the problem was matrix related. The data were not qualified due to the fact that the project was a preliminary investigation. The results of the Quality Assurance reviews are summarized in Appendix A.

4.1 Sediment Chemistry Results

The results of sediment grain size fractions, percent solids and TOC for the core and PONAR samples are presented in Tables 4.1.1 and 4.1.2, respectively. Quality assurance data for TOC and gerain size are listed in Appendix B. The sediments from most of the core samples can be characterized as having fine grain size (> 70% of particles < 63 μm) and moderate to high in total organic carbon (TOC 1% - 10%) in the top 52 cm. Grain size distributions changed to include a greater sand fraction (125-500 μm range) in the middle (52-102 cm) and bottom (102-152 cm) sections. This pattern is consistent with historical industrial development of the shoreline. Much of the lake shoreline was modified by logging in the 1800s and urban/industrial development in the 1900s. Erosion and runoff probably resulted in a sand layer being deposited throughout the near shore area. The presence of the finer grained material is consistent with the recent history of a more stable shoreline and eutrophic conditions present in the lake. Stations LM-1, LM-2, and LM-12 were different

TABLE 4.1.1 RESULTS OF SEDIMENT GRAIN SIZE FRACTIONS, TOC, AND PERCENT SOLIDS FOR LAKE MACATAWA CORE SAMPLES, SAMPLES, JULY 2002. (TOP = 0-51 CM, MID = 52-102 CM, BOT = 102-152 CM).

Station		2000 Weight %	1000 Weight %	850 Weight %	500 Weight %	250 Weight %	63 Weight %	< 63 Weight %	Solids %	TOC %
LM-1	Top	0.5	0.4	0.2	0.7	5.8	20.8	71.7	45.7	1.8
LM-1	Middle	0.6	0.3	0.2	0.3	1.0	7.3	90.3	46.8	2.1
LM-1	Middle	0.1	0.1	0.1	0.2	0.7	8.9	89.9	52.4	1.6
LM-1	Bottom	0.1	0.1	0.1	0.2	0.6	9.8	89.3	51.8	2.1
LM-2	Top	0.7	1.1	0.4	1.7	13.5	30.7	52.0	51.0	2.6
LM-2	Middle	1.1	0.7	0.4	1.0	9.4	48.6	38.8	55.9	1.8
LM-3	Top	0.1	0.1	0.1	0.3	1.0	5.7	92.7	38.3	1.8
LM-3	Middle	0.1	0.1	0.1	0.1	0.3	1.7	97.5	41.6	2.5
LM-3	Bottom	0.1	0.1	0.1	0.2	0.5	8.1	90.9	38.7	3.5
LM-4	Top	0.1	0.1	0.1	0.3	1.0	5.3	93.0	34.1	2.4
LM-4	Middle	0.1	0.1	0.0	0.2	0.4	2.3	96.9	41.2	2.4
LM-4	Bottom	0.1	0.1	0.1	0.2	0.4	2.1	97.0	41.3	2.5
LM-5	Top	1.8	0.5	0.2	0.7	2.9	23.6	70.1	50.0	6.2
LM-5	Middle	9.2	2.6	0.8	3.1	12.3	17.9	54.0	59.4	0.5
LM-5	Bottom	0.2	0.1	0.1	0.4	0.9	4.8	93.4	44.6	2.4
LM-6	Top	0.5	0.2	0.1	0.1	1.2	16.2	81.7	41.7	2.8
LM-6	Middle	0.2	0.1	0.1	0.2	0.4	6.1	92.8	40.2	2.1
LM-6	Bottom	1.1	0.2	0.3	0.1	0.6	7.5	90.2	42.3	3.6
LM-7	Top	0.2	0.1	0.1	0.4	2.2	25.3	71.8	39.2	2.9
LM-7	Bottom	0.2	0.2	0.1	0.9	4.1	20.7	73.8	40.7	4.1
LM-8	Top	0.0	0.1	0.0	0.1	0.3	1.3	98.1	36.7	1.8
LM-8	Middle	0.0	0.0	0.0	0.1	0.2	0.9	98.8	37.5	2.6
LM-8	Middle	0.0	0.0	0.0	0.0	0.1	2.0	97.8	40.3	3.4
LM-8	Bottom	0.4	0.2	0.0	0.2	0.5	4.2	94.5	32.9	5.2
LM-6 Dup	Top	0.1	0.1	0.1	0.2	0.9	16.4	82.2	41.2	3.2
LM-6 Dup	Middle	0.0	0.0	0.0	0.1	0.3	4.6	94.8	43.3	4.3
LM-6 Dup	Bottom	0.0	0.1	0.2	0.3	0.5	6.7	92.3	39.4	4.3
LM-9	Top	0.1	0.1	0.1	0.4	2.0	6.2	91.2	33.3	2.6
LM-9	Middle	0.0	0.0	0.0	0.1	0.2	3.8	95.8	32.5	4.4
LM-9	Bottom	0.0	0.1	0.1	0.3	0.9	5.7	92.9	29.3	3.5
LM-10	Top	0.1	0.1	0.1	0.2	0.7	2.2	96.7	30.1	2.2
LM-10	Middle	0.1	0.1	0.1	0.1	0.3	2.3	97.1	36.7	2.6
LM-10	Middle	0.1	0.1	0.1	0.2	0.5	9.7	89.4	33.3	3.7
LM-10	Bottom	0.1	0.1	0.1	0.1	0.4	5.8	93.3	28.1	5.5
LM-11	Top	0.1	0.1	0.1	0.2	0.4	1.7	97.4	30.3	2.4
LM-11	Middle	0.0	0.0	0.1	0.1	0.2	2.8	96.8	36.3	2.8
LM-11	Middle	0.0	0.1	0.0	0.1	0.2	3.5	96.1	31.8	5.4
LM-11	Bottom	0.0	0.1	0.1	0.2	0.4	9.2	90.0	25.0	8.5
LM-12	Top	0.1	0.3	0.3	3.0	30.8	25.3	40.3	40.0	1.3
LM-12	Middle	0.1	0.7	0.5	5.1	60.6	29.1	3.9	80.9	0.5
LM-14	Top	0.1	0.0	0.0	0.2	1.2	5.1	93.3	26.6	3.8
LM-14	Middle	0.2	0.0	0.0	0.1	0.7	2.5	96.5	34.3	3.0
LM-14	Bottom	0.1	0.2	0.2	0.5	1.9	10.5	86.6	23.9	5.8
LM-15	Top	0.0	0.1	0.0	0.5	0.9	2.6	95.8	26.4	2.7
LM-15	Middle	0.0	0.1	0.0	0.1	0.4	2.4	97.0	29.4	2.8
LM-15	Middle	0.1	0.0	0.0	0.0	0.2	2.9	96.7	28.0	3.5
LM-15	Bottom	0.0	0.1	0.1	0.1	0.2	2.9	96.5	33.7	2.1

TABLE 4.1.2 RESULTS OF SEDIMENT GRAIN SIZE FRACTIONS, TOC, AND PERCENT SOLIDS FOR LAKE MACATAWA PONAR SAMPLES, JULY 2002.

Station	2000 Weight %	1000 Weight %	850 Weight %	500 Weight %	250 Weight %	63 Weight %	< 63 Weight %	% Solids	TOC %
LM-1	0.8	0.6	0.4	3.3	52.7	36.1	6.1	67	0.5
LM-2	13.0	3.6	1.7	8.2	34.6	37.7	1.1	45	0.9
LM-3	0.1	0.2	0.1	0.5	2.3	13.5	83.4	32	3.4
LM-4	0.2	0.2	0.2	0.4	2.0	11.1	86.0	33	4.2
LM-6	0.3	0.2	0.2	0.5	1.9	16.8	80.2	35	3.4
LM-6 Dup	0.5	0.2	0.1	0.5	2.2	17.4	79.1	37	3.6
LM-7	0.2	0.2	0.1	0.6	3.6	42.6	52.7	38	4.3
LM-8	0.0	0.0	0.0	0.0	0.3	1.4	98.3	28	2.0
LM-9	0.1	0.1	0.1	0.2	1.5	3.9	94.1	27	1.7
LM-10	0.0	0.0	0.0	0.0	0.7	1.4	97.9	27	1.9
LM-11	0.1	0.0	0.0	0.1	0.4	1.0	98.3	24	2.5
LM-12	0.0	0.0	0.0	0.1	2.7	8.7	88.4	25	3.1
LM-14	0.0	0.1	0.0	0.2	0.8	1.5	97.4	23	2.3
LM-15	0.1	0.1	0.0	0.0	0.3	1.5	97.8	23	2.4

with respect to grain size distribution as they contained a higher sand fraction in the top 51 cm. LM-1 and LM-2 were collected near the river mouth and LM-12 was collected in a residential area. Sand transport from the Macatawa River, recreational activities, and sedimentation related to impervious surfaces may have increased sand deposition in these areas. Since the particle size and TOC characteristics of sediments will influence their ability to retain metals and organic chemicals, these data will be important in explaining the distribution of anthropogenic contaminants.

Very little difference was noted between the grain size and TOC content of the PONAR samples (Table 4.1.2) and the top core sections (Table 4.1.1) for all samples except LM-1 and LM-2. The PONAR samples collected at these locations were very high in sand fraction sediments (60% and 40%, respectively) suggesting that increased coarse sedimentation occurred in recent years. Since these samples were used for chemical analysis in addition to the assessment of sediment toxicity and benthic invertebrate diversity, the influence of particle size and TOC content will also be an important factor in the evaluation of the project data. Chemical and ecological results from LM-1 and LM-2 will be influenced to a large extent by the physical characteristics of the substrate.

The results of sediment metals analyses are presented for the core and PONAR samples in Tables 4.1.3 and 4.1.4 respectively. The results of semivolatile and PCB analyses for the same sample groupings are given in Tables 4.1.5 and 4.1.6. Quality assurance data for organics and metals are provided in Appendices C and D, respectively. Figures 4.1.1, 4.1.2, 4.1.3, 4.1.4, 4.1.5, 4.1.6, and 4.1.7 illustrate the distribution of arsenic, cadmium, copper, chromium, nickel, lead, and zinc, respectively, in core samples collected from Lake Macatawa. In general, arsenic concentrations in the three core sections showed little variation (± 6 mg/kg) with depth (Figure 4.1.1). Uniform deposition rates over an extended period of time are usually related to regional geology and do not indicate anthropogenic pollution. These data suggest a relatively constant deposition rate of arsenic in the lake occurred over time. An exception to this pattern was observed in the 52-102 cm section of the core at LM-4 (23 mg/kg). This location was near the power plant and the elevated arsenic may be due to an historic release of fly ash. The results for the other metals show a more site-specific pattern. The highest concentrations of chromium, cadmium, copper, and nickel in the 0-51 cm core sections were found at Station 2, adjacent to the Pfizer facility. This facility was built at the same location as the historic tannery. The highest level of lead was found at Station 7, which was located down gradient from a petroleum storage facility. Elevated total PAH compounds also were found at this site (Figure 4.1.8) suggesting that fuel releases may be responsible for the levels of both materials. With the exception of chromium and nickel at LM-2 and total PAH compounds at LM-7, all organic compounds and metals were below their respective Probable Effect Concentrations (PECs) (MacDonald et al. 2000). PECs are consensus based guidelines that indicate a >75% probability that adverse ecological effects may be observed when the concentrations are exceeded. A summary of PEC values and highest 0-51 cm core section metal and organic chemical concentrations are provided in Table 4.1.7.

In addition to PAH compounds, low levels of PCBs, DDE, and phthalate esters were detected in the core samples (Table 4.1.6). The highest concentration of PCBs was found at Station LM-2

Table 4.1.3 Results of Sediment Metal Analyses for Lake Macatawa Core Samples (mg/kg Dry Weight), July 2002. (Top = 0-52 cm, Mid = 52-102 cm, Bot = 102-152 cm).

Site	As (mg/kg)			Cd (mg/kg)			Cr (mg/kg)			Cu (mg/kg)		
	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
LM-1	7.8	7.3	6.6	1.1	1.2	1.2	51	60	56	28	33	30
LM-2	6.7	8.4		2.4	2.0		134	123		92	68	
LM-3	8.3	7.8	7.0	1.5	0.94	0.9	83	61	50	48	38	14
LM-4	11	23	9.9	1.9	1.5	0.8	106	109	45	66	56	23
LM-5	12	8.0	7.6	1.3	1.3	1.0	82	63	51	48	37	23
LM-6	10	6.9	7.4	1.3	0.91	1.0	83	66	57	40	26	16
LM-6 Dup	10	7.3	6.9	1.2	1.0	0.9	79	60	55	44	32	21
LM-7	8.9	8.4		1.5	2.8		98	69		73	54	
LM-8	9.4	6.6	8.6	1.1	1.3	0.78	62	90	62	51	56	23
LM-9	7.8	8.3	7.7	1.7	1.3	1.1	75	50	73	46	34	34
LM-10	6.7	6.0	6.8	1.7	1.1	1.1	78	68	55	52	32	21
LM-11	8.6	7.9	7.5	1.8	1.2	1.4	86	71	67	52	30	21
LM-12	12	9.4		1.0	1.8		54	27		24	1.0	
LM-14	7.9	8.8	7.2	1.5	0.72	0.9	67	80	145	44	30	17
LM-15	9.2	9.3	8.6	1.5	1.4	1.5	105	96	101	47	45	37

Site	Hg (mg/kg)			Ni (mg/kg)			Pb (mg/kg)			Zn (mg/kg)		
	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom	Top	Middle	Bottom
LM-1	0.28	0.14	< 0.05	24	32	31	27	31	37	150	178	201
LM-2	0.29	0.18		95	53		52	40		219	157	
LM-3	0.32	0.15	< 0.05	32	28	28	49	28	8	224	211	122
LM-4	0.27	0.16	< 0.05	45	33	30	63	49	25	243	231	162
LM-5	0.29	0.18	< 0.05	45	37	29	43	70	24	186	142	134
LM-6	0.29	0.11	< 0.05	35	27	25	51	20	10	198	158	144
LM-6 Dup	0.31	0.16	< 0.05	32	26	22	59	26	15	188	154	132
LM-7	0.45	0.21		43	31		104	106		197	133	
LM-8	0.28	0.16	< 0.05	45	40	30	56	68	18	210	236	170
LM-9	0.23	0.14	< 0.05	42	35	29	51	36	22	234	172	214
LM-10	0.21	0.11	< 0.05	43	32	38	55	28	11	262	208	159
LM-11	0.22	0.15	< 0.05	45	35	35	52	27	5	260	203	221
LM-12	0.21	0.14		21	3		24	1		172	28	
LM-14	0.20	0.16	< 0.05	42	32	29	60	38	5	221	205	190
LM-15	0.26	0.19	< 0.05	39	43	38	50	71	77	241	234	236

TABLE 4.1.4 RESULTS OF SEDIMENT METAL ANALYSES FOR LAKE MACATAWA PONAR SAMPLES (MG/KG DRY WEIGHT), JULY 2002.

	Metal Concentration (mg/kg)													
Site	**LM-1**	**LM-2**	**LM-3**	**LM-4**	**LM-6**	**LM-6 Dup**	**LM-7**	**LM-8**	**LM-9**	**LM-10**	**LM-11**	**LM-12**	**LM-14**	**LM-15**
Hg	0.25	0.23	0.28	0.22	0.26	0.24	0.35	0.21	0.2	0.19	0.16	0.29	0.23	0.22
As	2.2	2.8	2.3	19	25	15	5.6	2.4	4.5	5.6	5.9	11	8.8	7.5
Cd	0.34	0.48	1.6	1.3	1.8	1.2	1.3	1.0	1.5	1.1	1.6	1.4	1.3	1.2
Cr	37	61	75	89	60	66	70	80	72	85	74	70	67	77
Cu	5.3	22	61	88	59	44	64	60	59	52	89	46	37	43
Ni	4.6	20	41	48	49	39	34	34	36	40	63	33	34	35
Pb	3.8	17	54	56	48	41	87	37	29	39	46	25	18	37
Zn	58	88	240	241	208	199	193	242	250	256	257	238	215	222

Table 4.1.5 Results of Sediment PCB and Semivolatile Analyses for Lake Macatawa Core Samples (mg/kg Dry Weight), July 2002. (Positive data in bold. Samples and parameters that were not detected were omited.) (Top = 0-52 cm, Mid = 52-102 cm, Bot = 102-152 cm).

Site		LM-1				LM-2		LM-3			LM-4			LM-5			LM-6			LM-6 DUPLICATE		
Sample		Top	Mid-1	Mid-2	Bot	Top	Mid	Top	Mid	Bot	Top	Mid	Bot	Top	Mid	Bot	Top	Mid	Bot	Top	Mid	Bot
Compound	Units																					
Acenaphthene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluorene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Phenanthrene	mg/kg	**0.29**	< 0.33	**0.26**	< 0.33	**0.24**	**0.25**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Anthracene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluoranthene	mg/kg	**0.73**	**0.56**	**0.57**	**0.57**	**0.40**	**0.42**	**0.68**	< 0.33	< 0.33	**0.63**	**0.48**	< 0.33	**0.40**	< 0.33	< 0.33	**0.42**	< 0.33	< 0.33	**0.44**	< 0.33	< 0.33
Pyrene	mg/kg	< 0.33	**0.43**	**0.44**	**0.46**	**0.36**	**0.37**	**0.61**	< 0.33	< 0.33	**0.57**	**0.47**	< 0.33	**0.40**	< 0.33	< 0.33	**0.40**	< 0.33	< 0.33	**0.43**	< 0.33	< 0.33
Benzo(a)anthracene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Chrysene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(b)fluoranthene	mg/kg	**0.52**	**0.33**	< 0.33	**0.35**	< 0.33	< 0.33	**0.52**	< 0.33	< 0.33	**0.44**	**0.35**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(k)fluoranthene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(a)pyrene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(g,h,i)perylene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Total PAH Compounds	mg/kg	**1.5**	**1.3**	**1.3**	**1.4**	**1.0**	**1.0**	**1.8**	< 0.33	< 0.33	**1.6**	**1.3**	< 0.33	**0.8**	< 0.33	< 0.33	**0.8**	< 0.33	< 0.33	**0.9**	< 0.33	< 0.33
Di-n-butyl phthalate	mg/kg	< 0.33	**1.1**	< 0.33	< 0.33	< 0.33	< 0.33	**0.97**	**0.72**	**0.59**	**1.1**	**0.54**	**0.81**	**0.50**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Bis(2-ethylhexyl)phthalate	mg/kg	**0.85**	**0.67**	**1.0**	**1.4**	**0.72**	< 0.33	**1.5**	**1.0**	< 0.33	**1.2**	< 0.33	< 0.33	**0.61**	< 0.33	< 0.33	**0.92**	< 0.33	< 0.33	**0.74**	< 0.33	< 0.33
Compound	Units																					
4,4'-DDE	ug/kg	**2.5**	**3.8**	**4.8**	**5.4**	**17**	**15**	**10**	< 0.50	**0.65**	**25**	**4.8**	**4.6**	**15**	**6.9**	**5.3**	**12**	**0.50**	**2.3**	**10**	< 0.50	< 0.50
4,4'-DDD	ug/kg	**0.64**	**0.91**	**1.3**	**1.2**	**4.0**	**7.4**	**6.2**	**0.62**	**0.66**	**27**	**2.1**	< 0.50	**2.9**	**1.1**	< 0.50	**2.2**	< 0.50	< 0.50	**1.8**	< 0.50	< 0.50
Total PCBs	ug/kg	< 500	< 500	< 500	< 500	**3000**	**1200**	< 500	< 500	< 500	**600**	< 500	< 500	**730**	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500

Table 4.1.5 (continued) Results of Sediment PCB and Semivolatile Analyses for Lake Macatawa Core Samples (mg/kg Dry Weight), July 2002. (Positive data in bold. Samples and parameters that were not detected were omited.) (Top = 0-52 cm, Mid= 52-102 cm, Bot = 102-152 cm).

Site		LM-7		LM-8				LM-9			LM-10				LM-11				LM-12		LM-14			LM-15			
Sample		Top	Bot	Top	Mid-1	Mid-2	Bot	Top	Mid	Bot	Top	Mid-1	Mid-2	Bot	Top	Mid-1	Mid-2	Bot	Top	Mid	Top	Mid	Bot	Top	Mid-1	Mid-2	Bot
Compound	Units																										
Acenaphthene	mg/kg	**0.36**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluorene	mg/kg	**0.36**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Phenanthrene	mg/kg	**4.0**	**2.3**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Anthracene	mg/kg	**0.90**	**0.60**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluoranthene	mg/kg	**6.2**	**3.4**	< 0.33	**0.40**	< 0.33	< 0.33	**0.59**	< 0.33	< 0.33	**0.35**	< 0.33	< 0.33	< 0.33	**0.40**	**0.43**	< 0.33	< 0.33	< 0.33	< 0.33	**0.46**	< 0.33	< 0.33	< 0.33	< 0.33	**0.34**	**0.53**
Pyrene	mg/kg	**5.1**	**3.0**	< 0.33	**0.35**	< 0.33	< 0.33	**0.50**	< 0.33	< 0.33	**0.34**	< 0.33	< 0.33	< 0.33	**0.39**	**0.42**	< 0.33	< 0.33	< 0.33	< 0.33	**0.45**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.53**
Benzo(a)anthracene	mg/kg	**2.8**	**1.6**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Chrysene	mg/kg	**2.5**	**1.4**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.38**
Benzo(b)fluoranthene	mg/kg	**3.8**	**2.1**	< 0.33	< 0.33	< 0.33	< 0.33	**0.46**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.35**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.58**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.41**
Benzo(k)fluoranthene	mg/kg	**1.3**	**0.70**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.54**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(a)pyrene	mg/kg	**3.0**	**1.8**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Indeno(1,2,3-cd)pyrene	mg/kg	**2.0**	**1.1**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(g,h,i)perylene	mg/kg	**1.8**	**1.0**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Total PAH Compounds	mg/kg	**34**	**19**	< 0.33	**0.8**	< 0.33	< 0.33	**1.6**	< 0.33	< 0.33	**0.7**	< 0.33	< 0.33	< 0.33	**1.1**	**0.9**	< 0.33	< 0.33	< 0.33	< 0.33	**2.0**	< 0.33	< 0.33	< 0.33	< 0.33	**0.34**	**1.9**
Di-n-butyl phthalate	mg/kg	**1.2**	< 0.33	**1.3**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.70**	**0.50**	**2.1**	**1.3**	**0.50**	**1.3**	**0.73**	**0.30**	**0.42**	< 0.33	**4.5**	**0.68**	< 0.33	**0.84**	**5.8**	**1.2**	< 0.33
Bis(2-ethylhexyl)phthalate	mg/kg	**0.96**	< 0.33	**0.90**	< 0.33	< 0.33	< 0.33	**0.58**	**8.3**	**2.1**	**3.5**	**0.92**	**7.4**	**5.9**	**1.6**	**0.87**	< 0.33	< 0.33	< 0.33	< 0.33	**2.6**	< 0.33	< 0.33	**2.0**	**1.9**	**0.81**	< 0.33
Compound	Units																										
4,4'-DDE	ug/kg	**16**	< 0.50	**4.1**	**13**	< 0.50	< 0.50	**9.4**	< 0.50	< 0.50	**9.0**	< 0.50	< 0.50	< 0.50	**12**	**5.5**	< 0.50	< 0.50	**5.1**	**2.5**	**12**	< 0.50	< 0.50	< 0.50	**8.2**	**31**	**17**
4,4'-DDD	ug/kg	**6.5**	< 0.50	< 0.50	**2.3**	< 0.50	< 0.50	**1.1**	< 0.50	< 0.50	**0.75**	< 0.50	< 0.50	< 0.50	**1.4**	**3.1**	< 0.50	< 0.50	0.50	< 0.50	**3.3**	< 0.50	< 0.50	< 0.50	**1.8**	**7.7**	**13**
Total PCBs	ug/kg	**830**	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500	< 500

TABLE 4.1.6 RESULTS OF SEDIMENT PCB AND SEMIVOLATILE ANALYSES FOR LAKE MACATAWA PONAR SAMPLES (DRY WEIGHT), JULY 2002. (POSITIVE DATA IN BOLD. SAMPLES AND PARAMETERS THAT WERE NOT DETECTED WERE OMITED.).

Site		LM-1	LM-2	LM-3	LM-4	LM-6	LM-6 Dup	LM-7	LM-8	LM-9	LM-10	LM-11	LM-12	LM-14	LM-15
Compound	Units														
Naphthalene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.67**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Acenaphthylene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Acenaphthene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**1.1**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluorene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**1.2**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Phenanthrene	mg/kg	< 0.33	**0.49**	**0.43**	**0.34**	**0.44**	**0.38**	**10**	< 0.33	**0.38**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Anthracene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**10**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluoranthene	mg/kg	< 0.33	**1.1**	**0.99**	**0.92**	**1.2**	**0.95**	**14**	**0.74**	**1.2**	< 0.33	**0.60**	**0.45**	< 0.33	< 0.33
Pyrene	mg/kg	< 0.33	**1.0**	**0.92**	**0.91**	**1.0**	**0.93**	**12**	**0.60**	**0.96**	< 0.33	**0.49**	**0.41**	< 0.33	< 0.33
Benzo(a)anthracene	mg/kg	< 0.33	**0.46**	< 0.33	< 0.33	**0.58**	< 0.33	**5.7**	**0.38**	**0.60**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Chrysene	mg/kg	< 0.33	**0.53**	0.64	**0.57**	**0.67**	**0.52**	**6.8**	**0.47**	**0.69**	< 0.33	**0.36**	< 0.33	< 0.33	< 0.33
Benzo(b)fluoranthene	mg/kg	< 0.33	**0.48**	**0.58**	**0.54**	**1.0**	**0.45**	**6.0**	**0.45**	**0.79**	< 0.33	**0.47**	**0.62**	**0.42**	< 0.33
Benzo(k)fluoranthene	mg/kg	< 0.33	< 0.33	**0.40**	**0.35**	**0.94**	< 0.33	**4.6**	**0.38**	**0.52**	< 0.33	< 0.33	**0.57**	< 0.33	< 0.33
Benzo(a)pyrene	mg/kg	< 0.33	0.38	**0.39**	< 0.33	**0.35**	< 0.33	**5.4**	< 0.33	**0.53**	< 0.33	**0.33**	< 0.33	< 0.33	< 0.33
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.33	**< 0.33**	< 0.33	< 0.33	< 0.33	< 0.33	**4.3**	**0.35**	**0.55**	< 0.33	**0.38**	< 0.33	< 0.33	< 0.33
Dibenzo(a,h)anthracene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.34**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(g,h,i)perylene	mg/kg	< 0.33	< 0.33	**0.36**	< 0.33	< 0.33	< 0.33	**0.60**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Total PAH Compounds	mg/kg	< 0.33	**4.4**	**4.7**	**3.6**	**6.2**	**3.2**	**82.7**	**3.4**	**6.2**	< 0.33	**2.6**	**2.1**	**0.4**	< 0.33
Di-n-butyl phthalate	mg/kg	< 0.33	< 0.33	**0.92**	< 0.33	**0.59**	< 0.33	< 0.33	< 0.33	< 0.33	**0.40**	< 0.33	< 0.33	**0.40**	< 0.33
Butyl benzyl phthalate	mg/kg	< 0.33	< 0.33	**0.70**	< 0.33	**0.48**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Bis(2-ethylhexyl)phthalate	mg/kg	**0.66**	**1.6**	**7.8**	**2.3**	**2.4**	**2.0**	**1.9**	**2.4**	**1.9**	**0.58**	**1.7**	**1.5**	**1.2**	**1.2**
Compound	Units														
4,4'-DDE	ug/kg	< 0.50	**10**	**21**	**10**	**7.3**	**6.4**	**20**	**4.6**	**5.4**	**2.6**	**5.0**	**4.9**	**5.1**	< 0.50
4,4'-DDD	ug/kg	< 0.50	**1.8**	**12**	**4.4**	**1.5**	**1.2**	**8.2**	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
4,4'-DDT	ug/kg	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50	< 0.50
Total PCBs	ug/kg	< 500	**2600**	< 500	< 500	< 500	< 500	**1100**	< 500	< 500	< 500	< 500	< 500	< 500	< 500

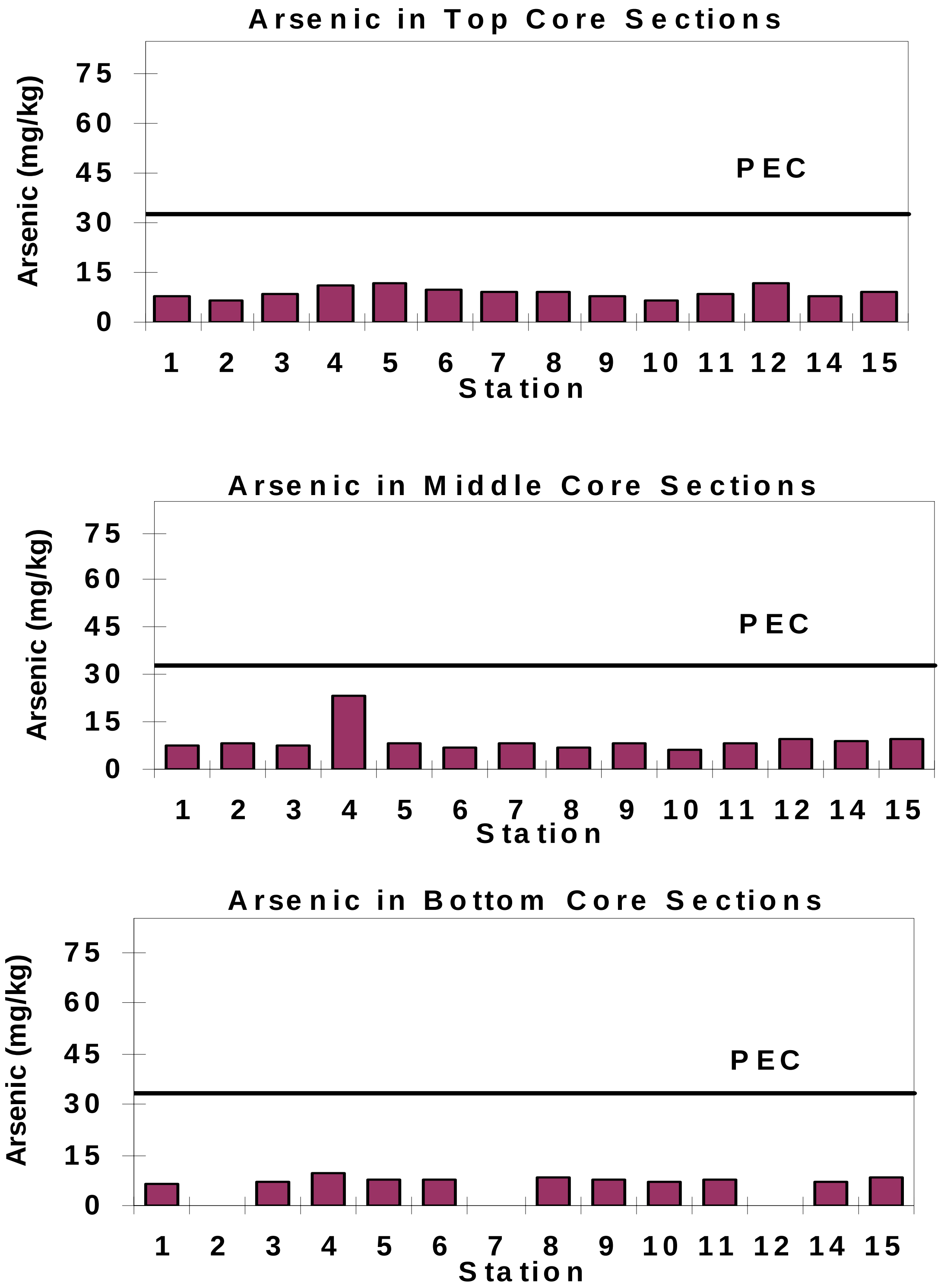
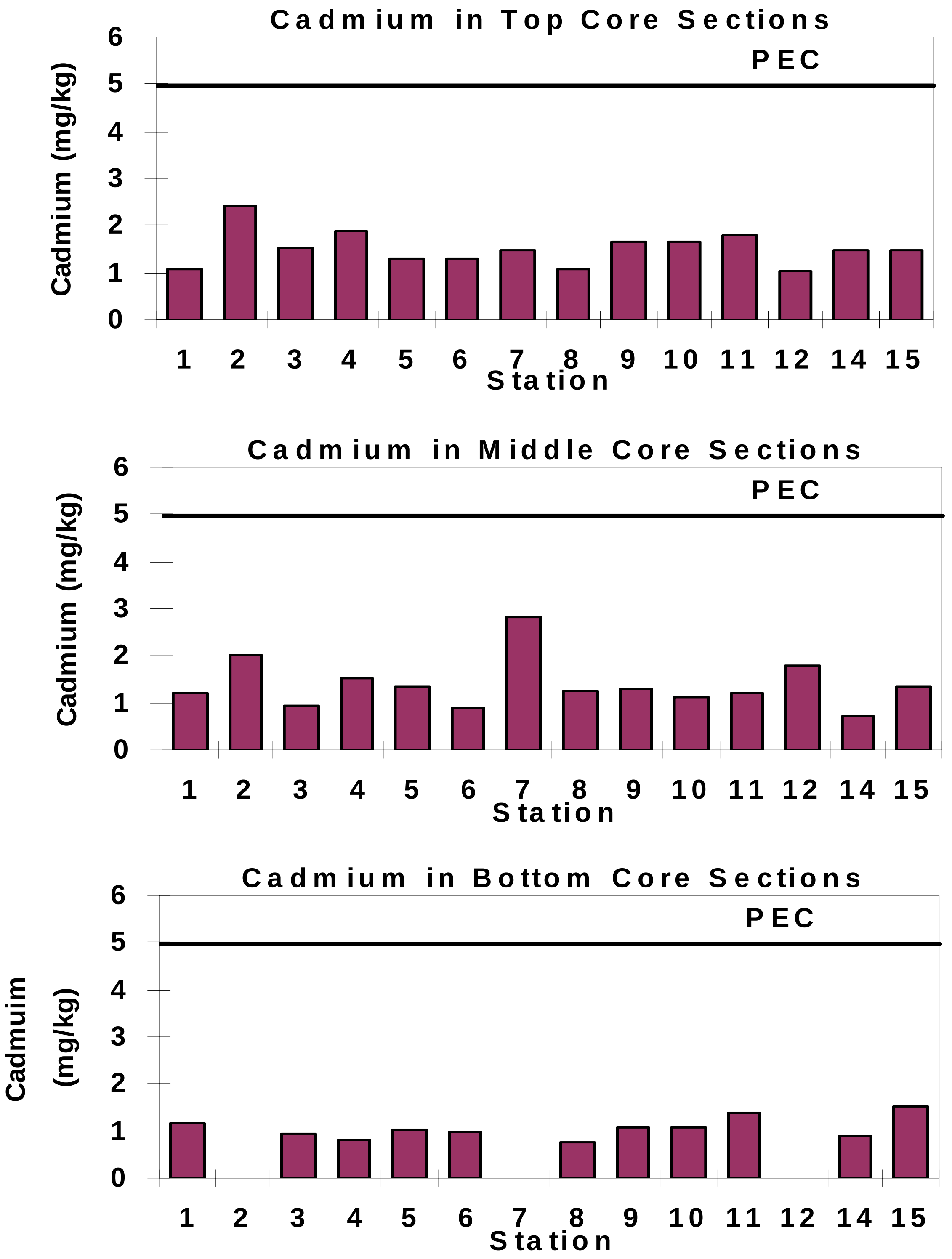


Figure 4.1.1 Distribution of Arsenic in Core Samples Collected in Lake Macatawa, July 2002. (Top Core 0-51 cm, Middle Core 51-102 cm, Bottom Core 102-152 cm.).


Cadmium in Top Core Sections

Cadmium in Middle Core Sections

Cadmium in Bottom Core Sections

FIGURE 4.1.2 DISTRIBUTION OF CADMIUM IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

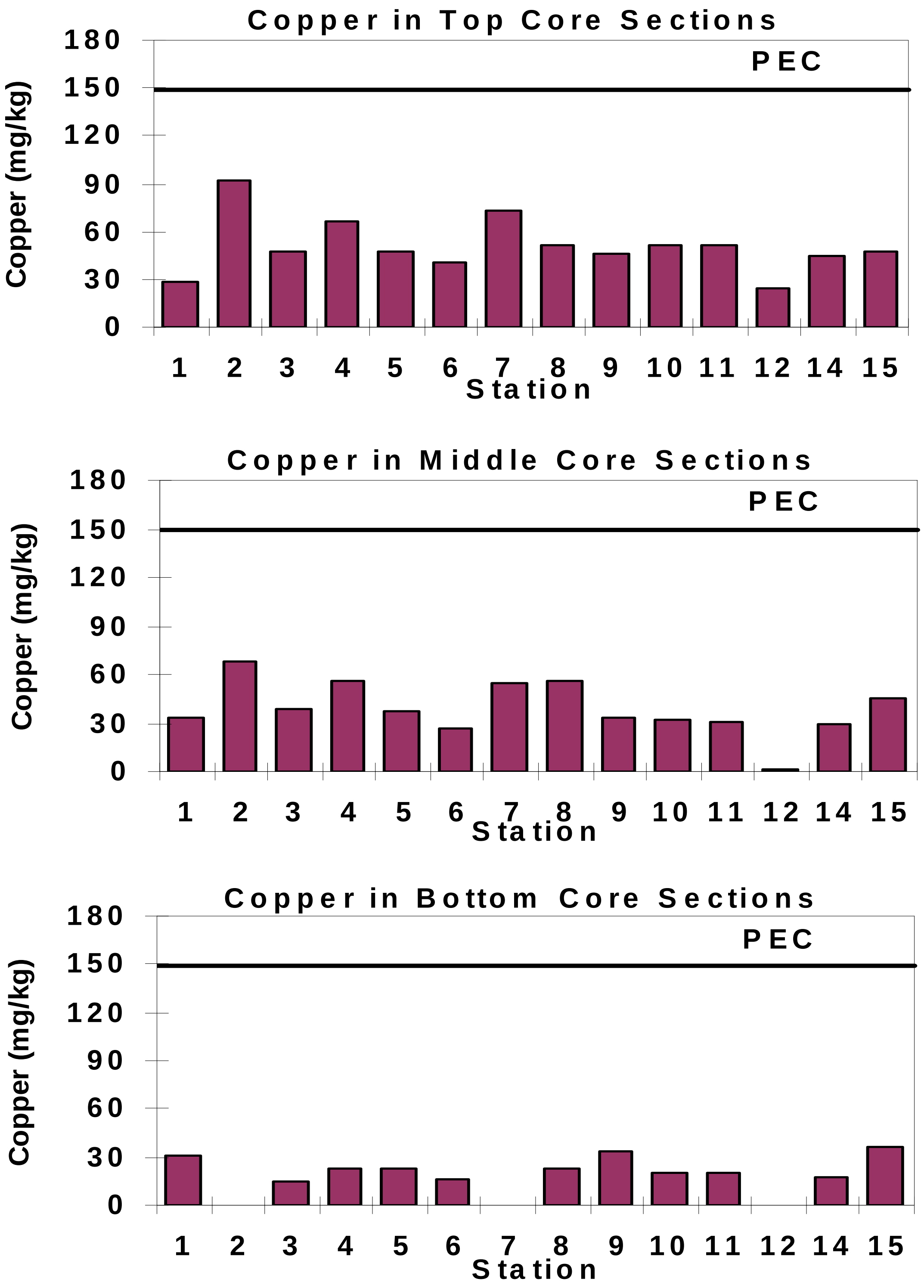


FIGURE 4.1.3 DISTRIBUTION OF COPPER IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

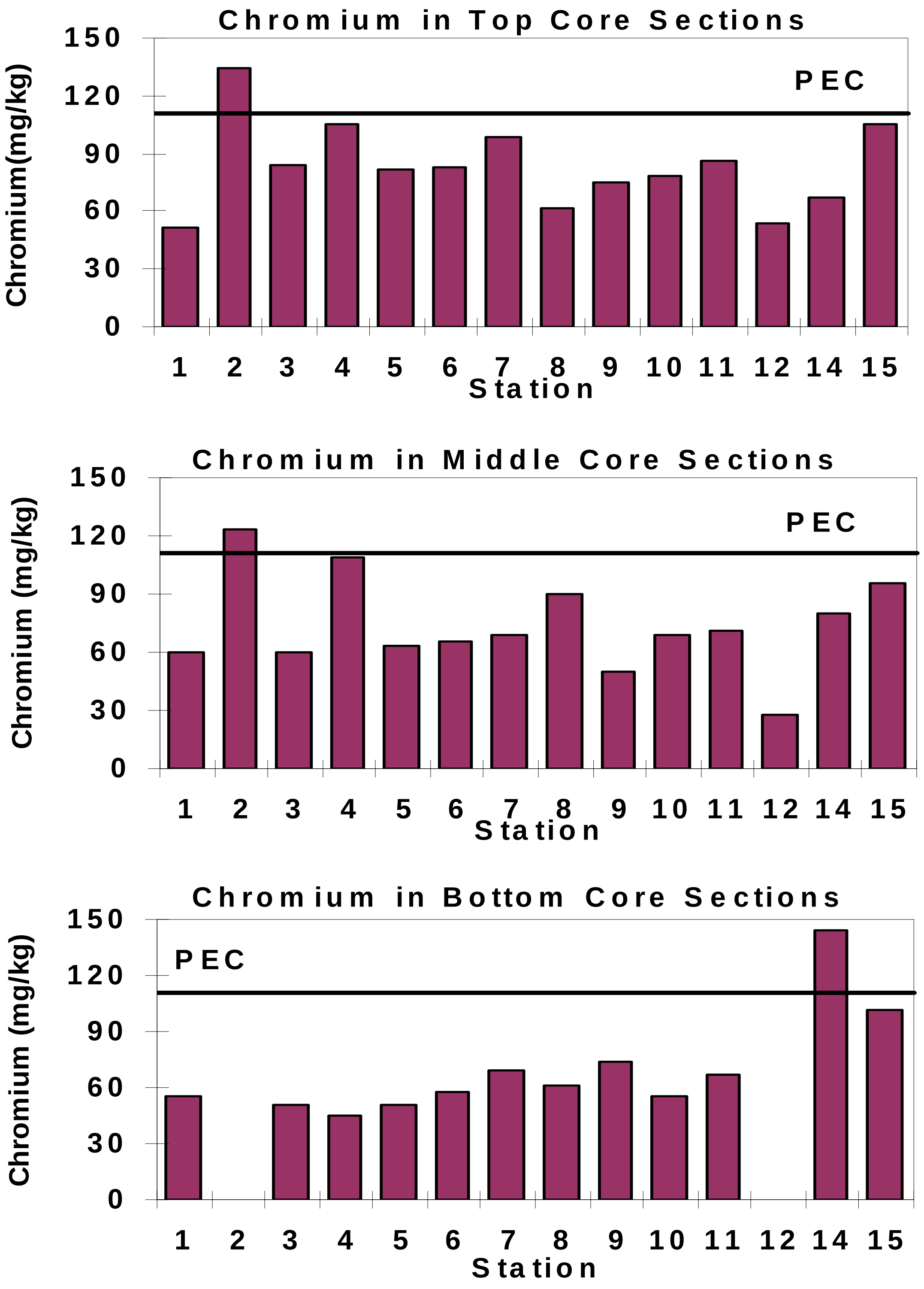


FIGURE 4.1.4 DISTRIBUTION OF CHROMIUM IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

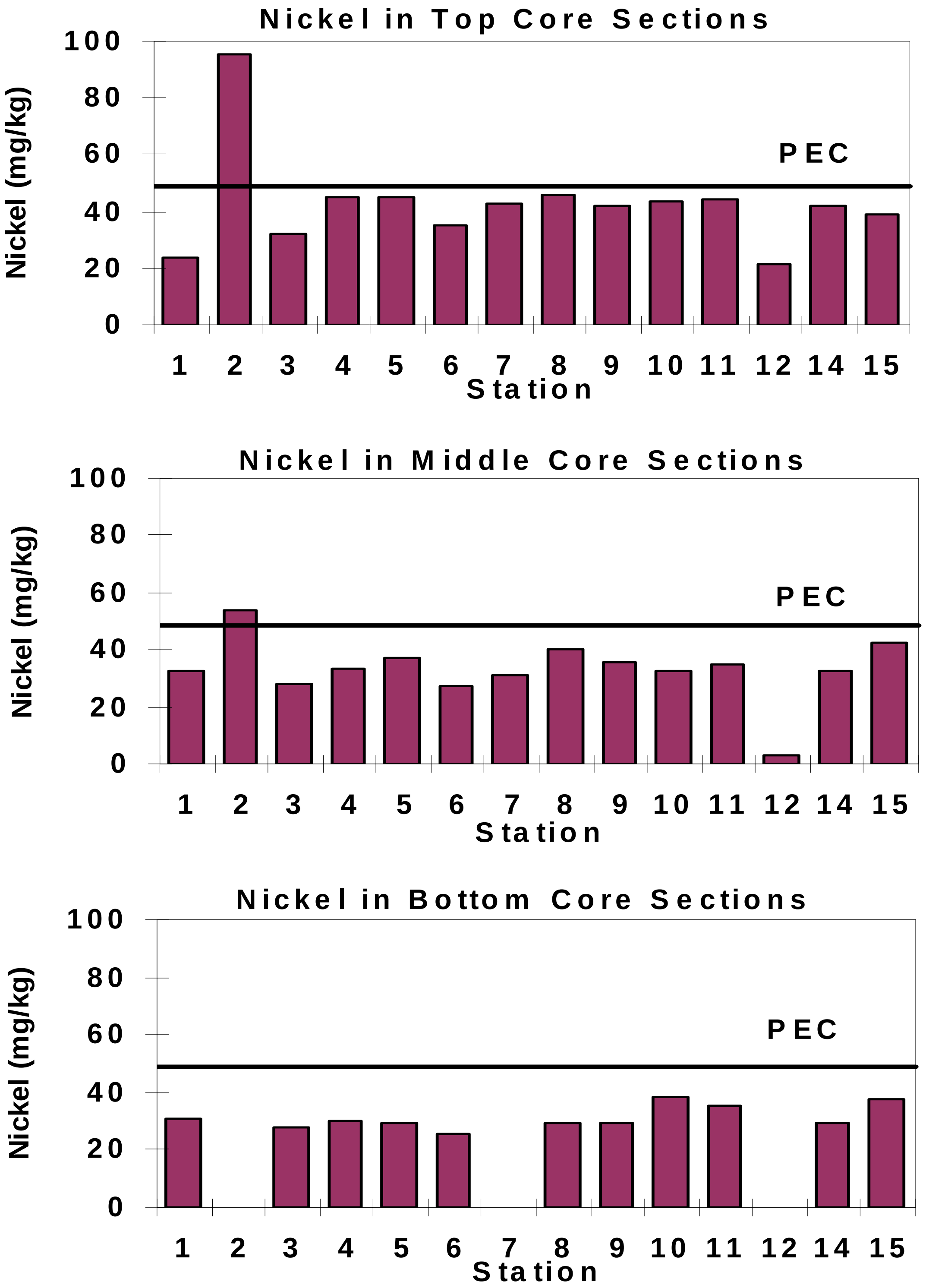


FIGURE 4.1.5 DISTRIBUTION OF NICKEL IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

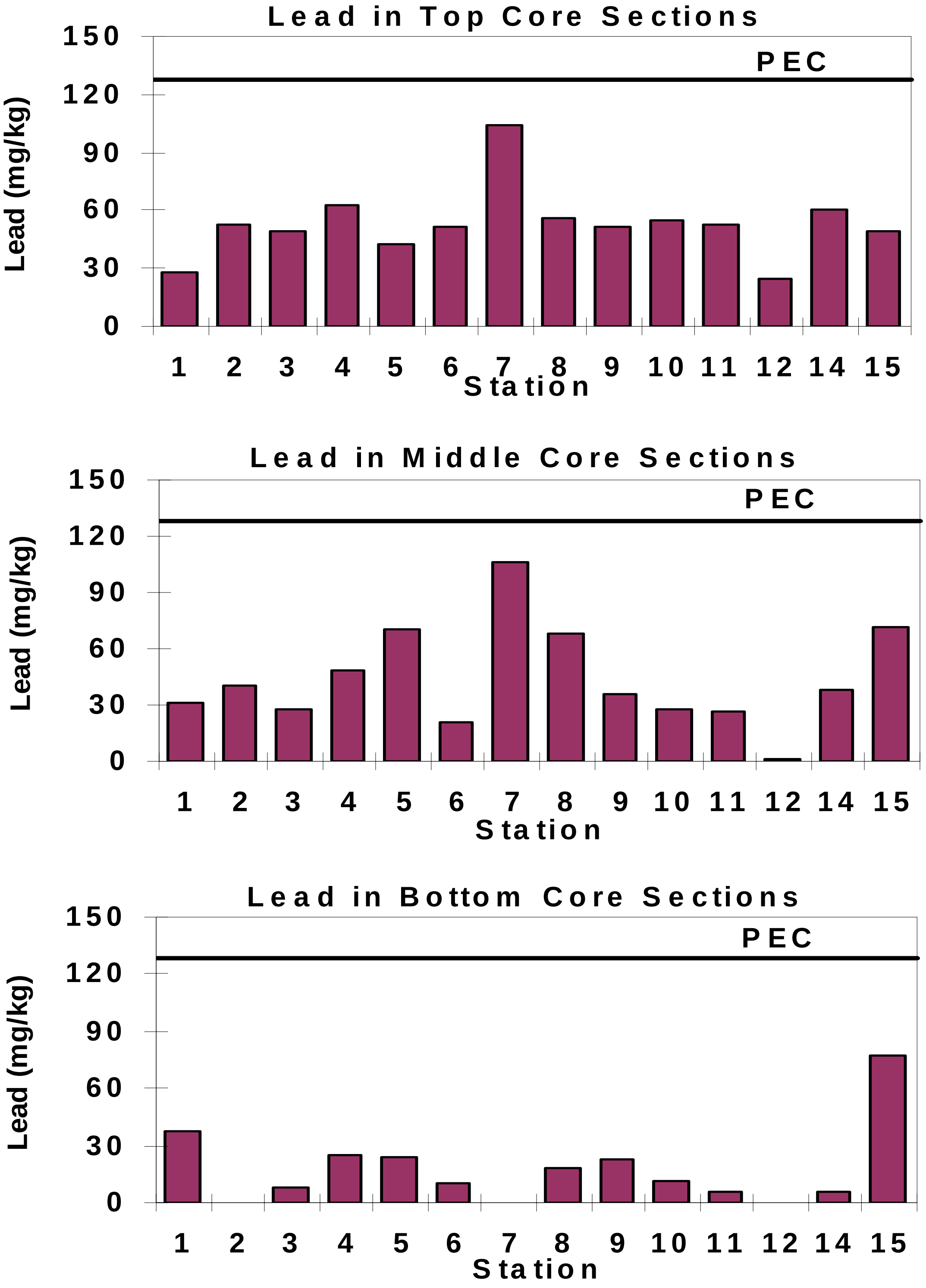


FIGURE 4.1.6 DISTRIBUTION OF LEAD IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

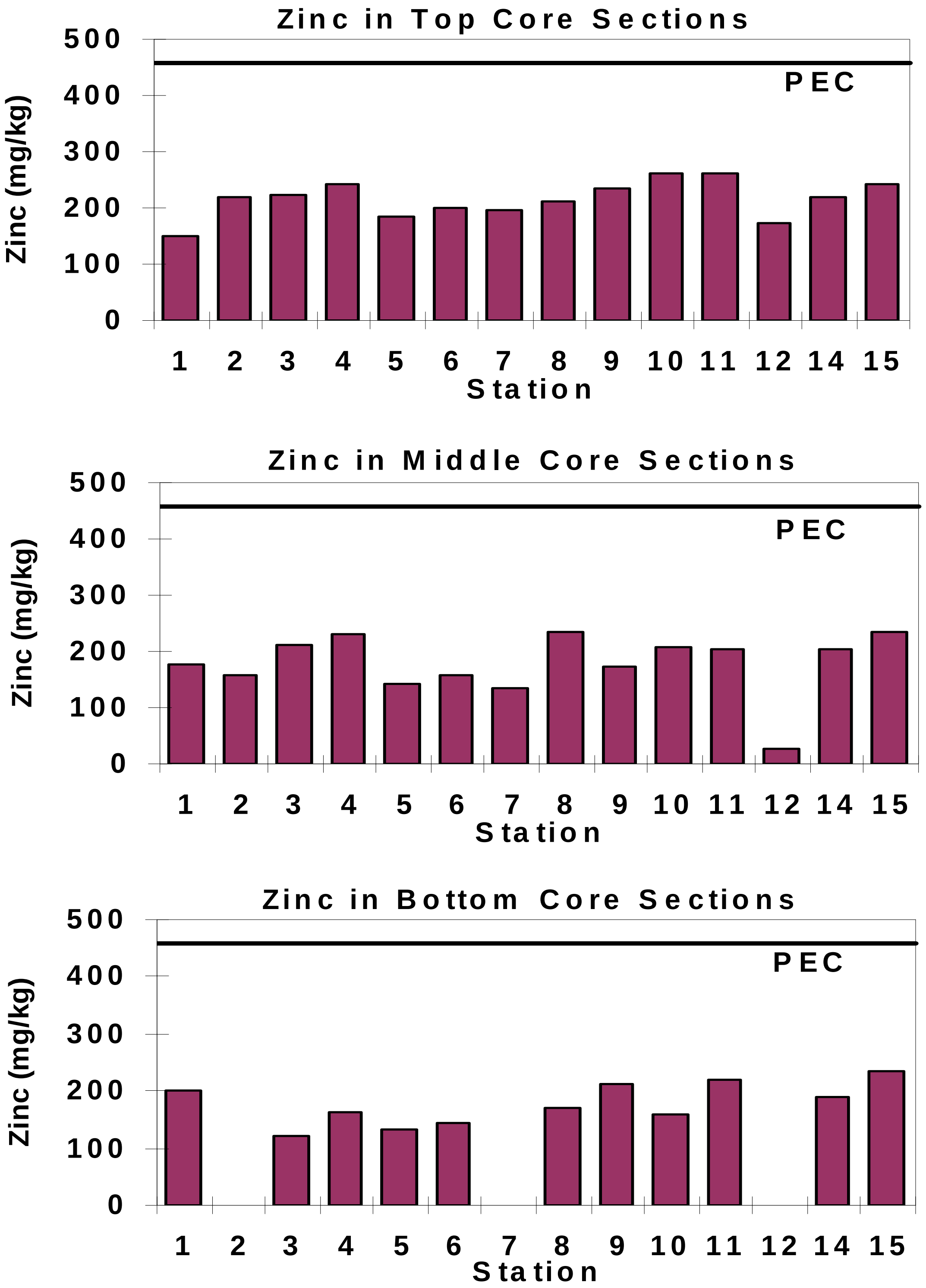


FIGURE 4.1.7 DISTRIBUTION OF ZINC IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

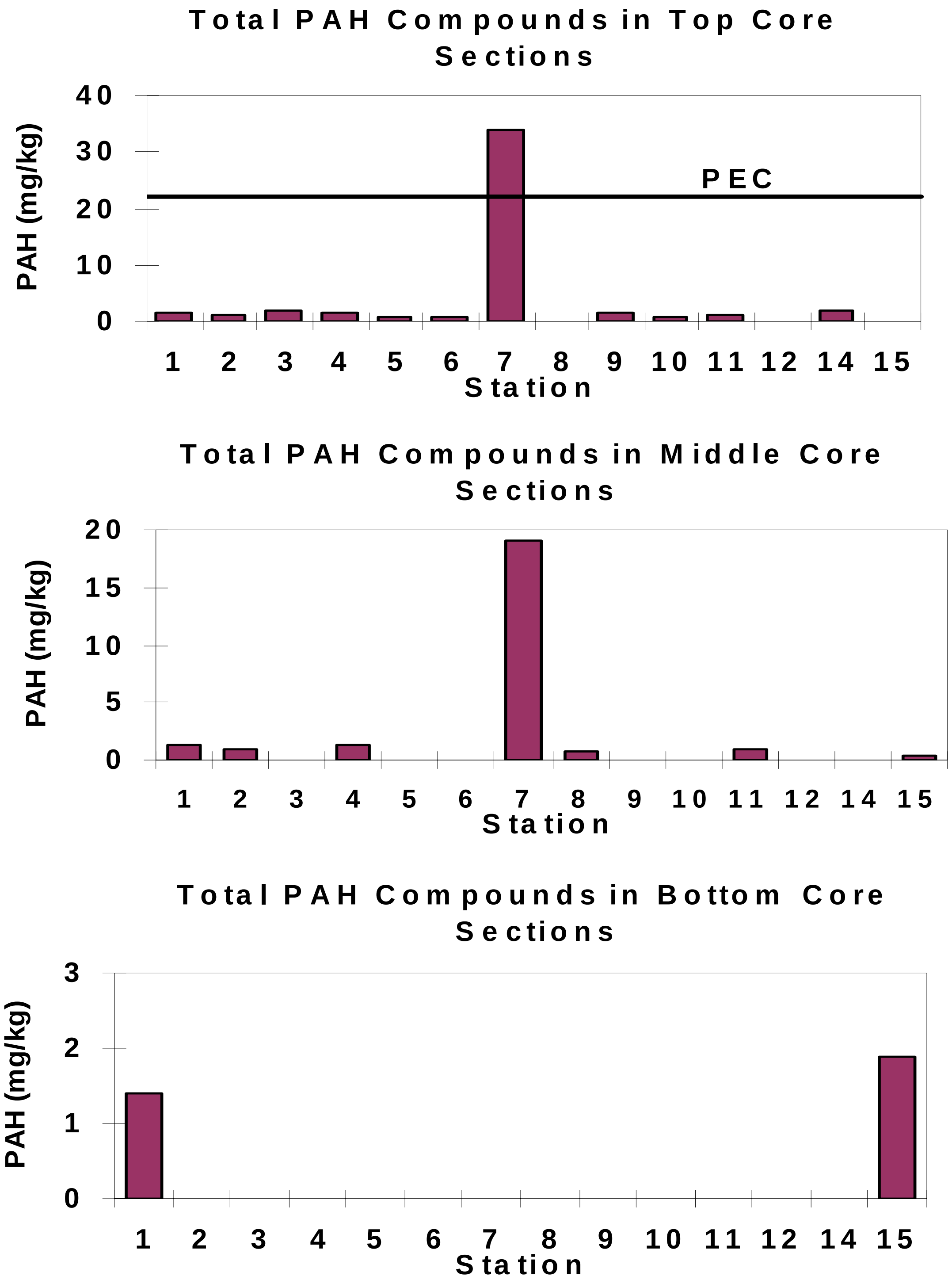


FIGURE 4.1.8 DISTRIBUTION OF PAH COMPOUNDS IN CORE SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002. (TOP CORE 0-51 CM, MIDDLE CORE 51-102 CM, BOTTOM CORE 102-152 CM.).

TABLE 4.1.7 SUMMARY OF CORE SAMPLING LOCATIONS IN LAKE MACATAWA THAT EXCEED CONSENSUS BASED PEC GUIDELINES (MACDONALD ET AL. 2000).

Contaminant	Consensus-Based PEC mg/kg	Location in Lake Macatawa that Exceed the PEC
Arsenic	33.0	None (Highest LM-12; 12 mg/kg)
Cadmium	4.98	None (Highest LM-2; 2.0 mg/kg)
Chromium	111	LM-2 (123 mg/kg)
Copper	149	None (Highest LM-2; 92 mg/kg)
Lead	128	None (Highest LM-7; 104 mg/kg)
Mercury	1.06	None (Highest LM-7; 0.45 mg/kg)
Nickel	48.6	LM-2 (95 mg/kg)
Zinc	459	None (Highest LM-10; 262 mg/kg)
Total PAH Compounds	22.9	LM-7 (34 mg/kg)
Total PCBs	0.68	LM-2 (3 mg/kg)
DDE	0.031	None (Highest LM-4; 25 mg/kg)

(3,000 μg/kg). This level exceeded the PEC concentration (Table 4.1.7). DDE concentrations all were below the PEC.

The results of sediment metals and organic chemical analyses are presented for the PONAR samples in Tables 4.1.4 and 4.1.6, respectively. Figures 4.1.9, 4.1.10, 4.1.11, 4.1.12, 4.1.13, 4.1.14, and 4.1.15 illustrate the distribution of arsenic, cadmium, copper, chromium, nickel, lead, and zinc, respectively, in the PONAR samples collected from Lake Macatawa. Metals results for Station LM-2 were different with respect to 0-51 cm core sections and the PONARs. Cadmium, chromium, copper, and nickel were lower in the PONARs as a result of the higher sand fraction discussed previously. With the exception of nickel, all of the metals were below the PEC guidelines. Nickel exceeded the PEC at Station LM-11, which is located in the middle of the lake. The highest level of lead was again found at Station 7, down gradient from the petroleum storage facility. Elevated total PAH compounds above the PEC also were found at this site (Figure 4.1.16) suggesting that fuel releases may be responsible for the levels of both materials. A summary of PEC values and highest PONAR metal and organic chemical concentrations are provided in Table 4.1.8.

Spearman Rank Order Correlations were developed for the physical/chemical parameters measured in the investigation (Table 4.1.9) to further examine the relationship between the variables. Fine grained sediments were positively correlated with distance from the river mouth, depth, chromium, and zinc. The relationships between physical parameters fit the depth profile of the lake as the deepest part is located near LM-15 and coarse particles would tend to settle in the vicinity of LM–1 and LM-2 as they are transported from the river into the lake. Chromium and zinc are elements that have a high affinity for fine particulates. TOC was positively correlated with lead, fine grained sediments, and DDT compounds. The

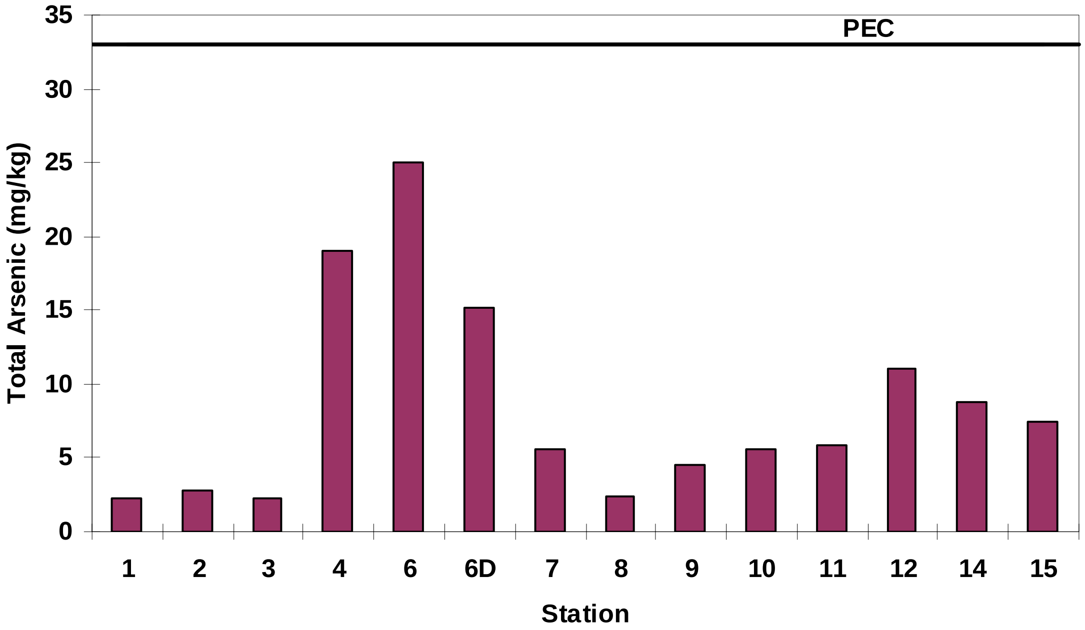


FIGURE 4.1.9 DISTRIBUTION OF ARSENIC IN PONAR SAMPLES FOR LAKE MACATAWA, JULY 2002. LINE DENOTES PROBABLE EFFECT CONCENTRATION (PEC) (MACDONALD ET AL. 2000).

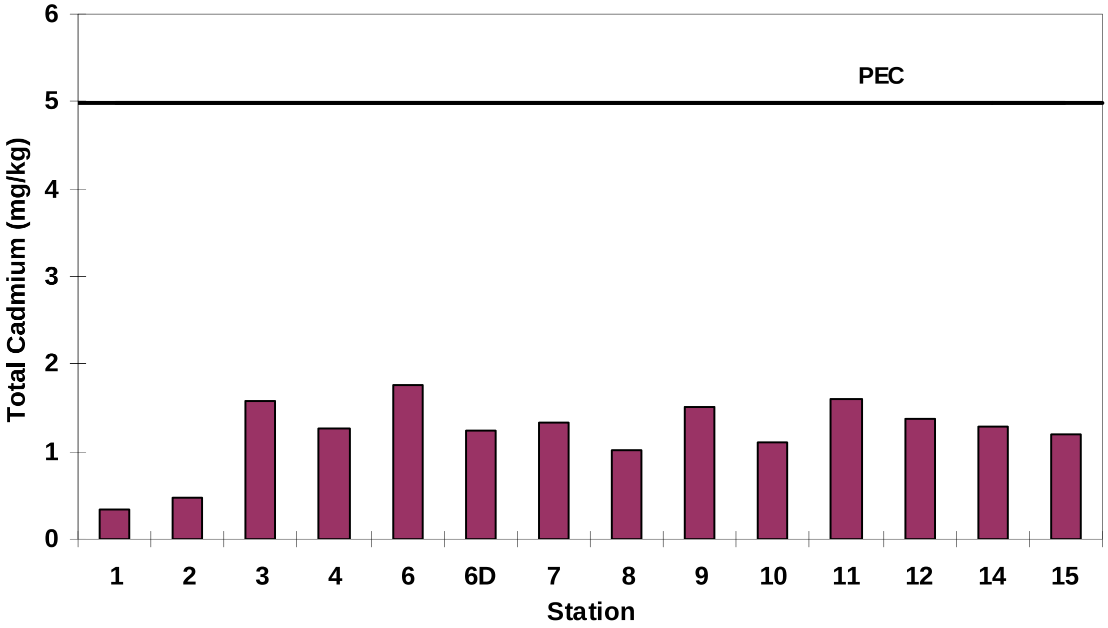


FIGURE 4.1.10 DISTRIBUTION OF CADMIUM IN PONAR SAMPLES FOR LAKE MACATAWA, JULY 2002. LINE DENOTES PROBABLE EFFECT CONCENTRATION (PEC) (MACDONALD ET AL. 2000).

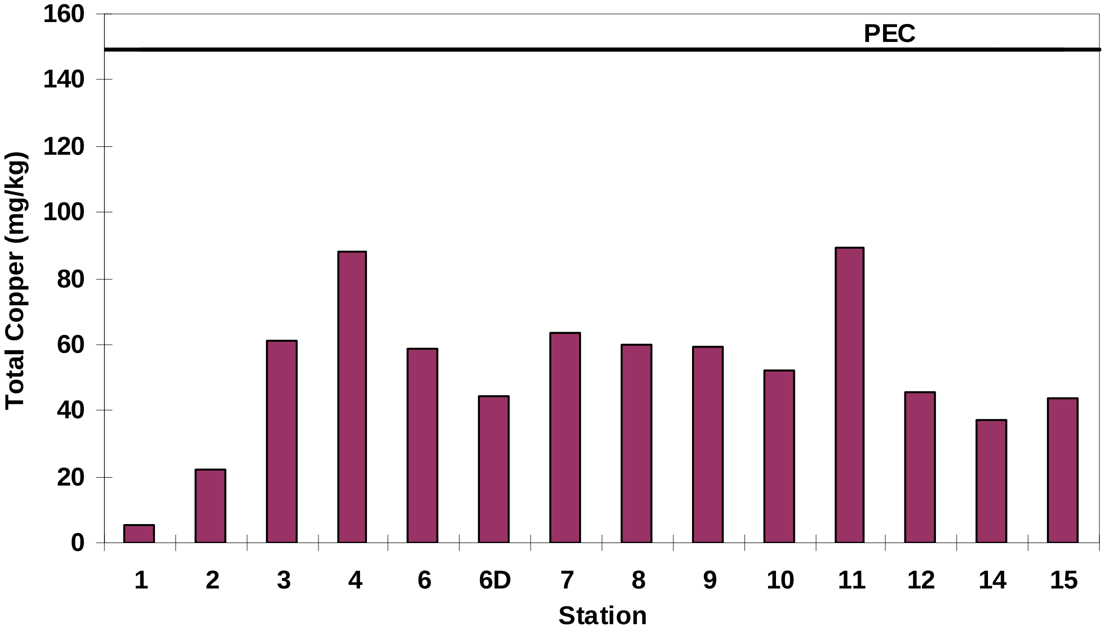


FIGURE 4.1.11 DISTRIBUTION OF COPPER IN PONAR SAMPLES FOR LAKE MACATAWA, JULY 2002. LINE DENOTES PROBABLE EFFECT CONCENTRATION (PEC) (MACDONALD ET AL. 2000).

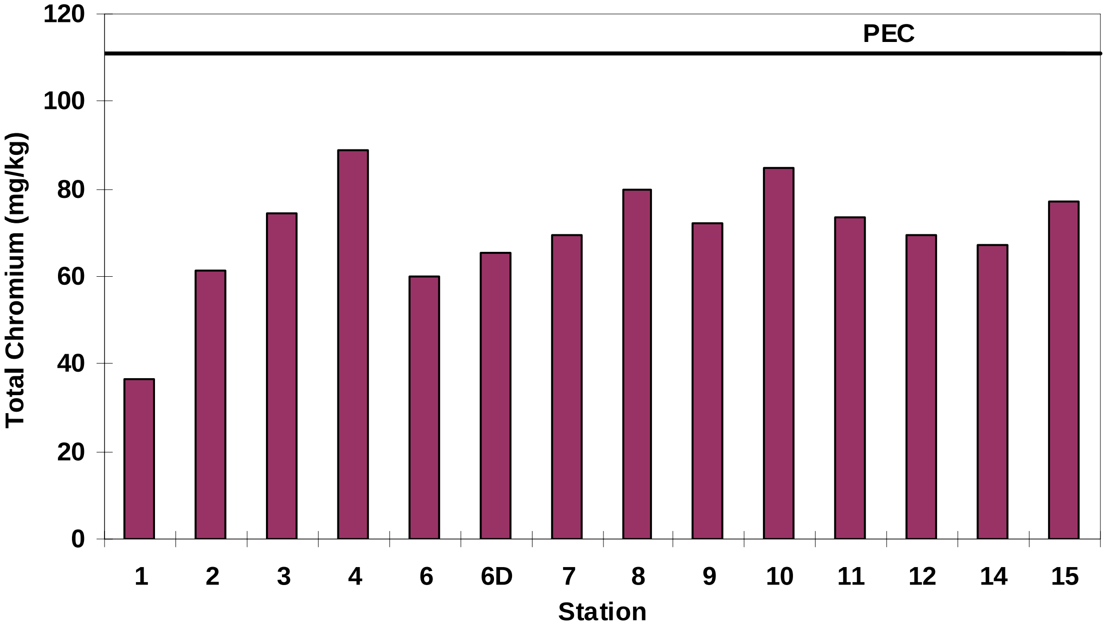


FIGURE 4.1.12 DISTRIBUTION OF CHROMIUM IN PONAR SAMPLES FOR LAKE MACATAWA, JULY 2002. LINE DENOTES PROBABLE EFFECT CONCENTRATION (PEC) (MACDONALD ET AL. 2000).

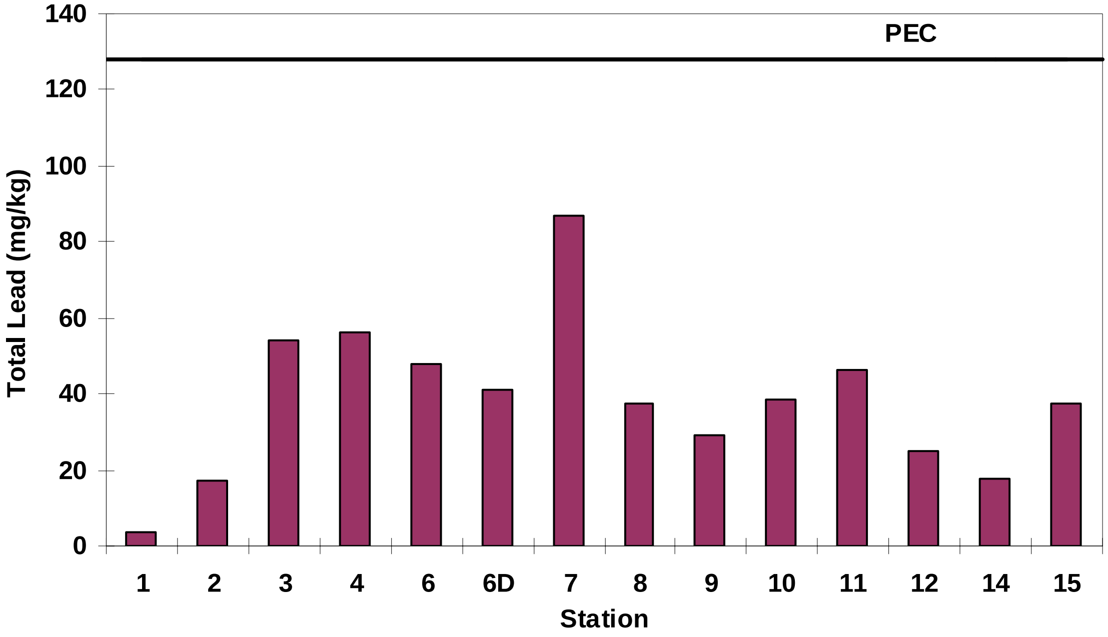


Figure 4.1.13 Distribution of Nickel in PONAR Samples for Lake Macatawa, July 2002. Line Denotes Probable Effect Concentration (PEC) (MacDonald et al. 2000).

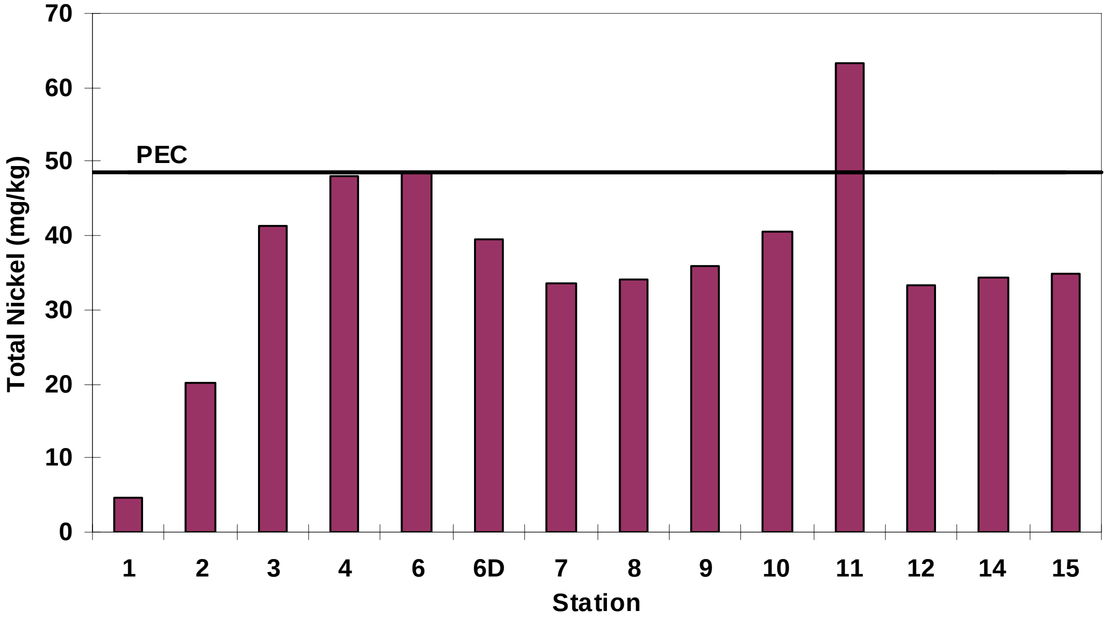


Figure 4.1.14 Distribution of Lead in PONAR Samples for Lake Macatawa, July 2002. Line Denotes Probable Effect Concentration (PEC) (MacDonald et al. 2000).

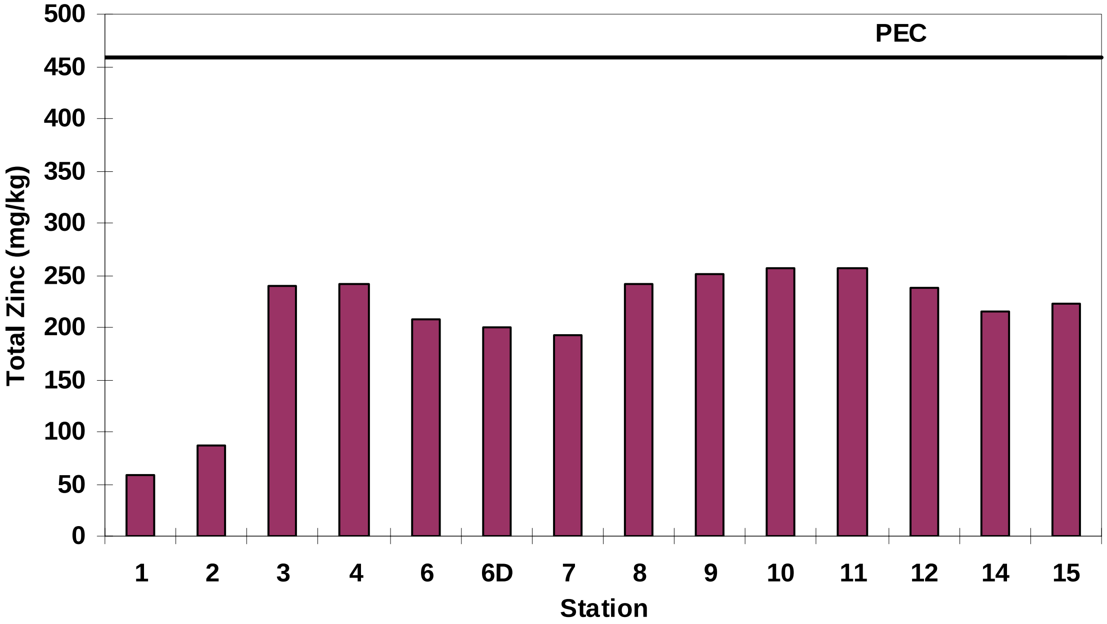


FIGURE 4.1.15 DISTRIBUTION OF ZINC IN PONAR SAMPLES FOR LAKE MACATAWA, JULY 2002. LINE DENOTES PROBABLE EFFECT CONCENTRATION (PEC) (MACDONALD ET AL. 2000).

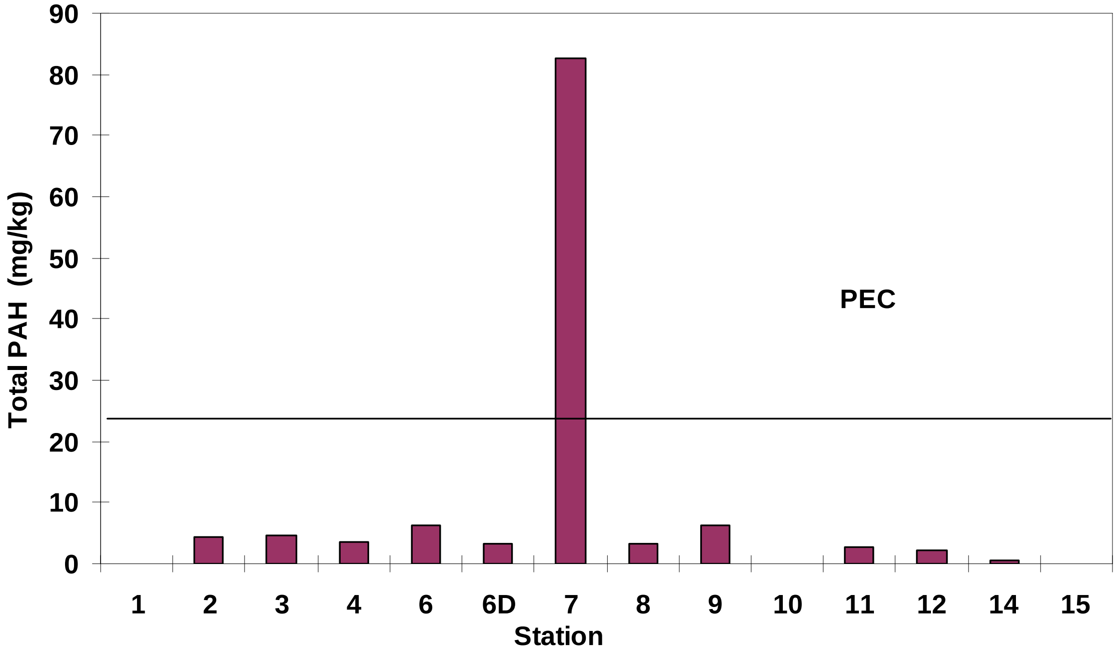


FIGURE 4.1.16 DISTRIBUTION OF PAH COMPOUNDS IN PONAR SAMPLES COLLECTED IN LAKE MACATAWA, JULY 2002.

TABLE 4.1.8 SUMMARY OF PONAR SAMPLING LOCATIONS IN LAKE MACATAWA THAT EXCEED CONSENSUS BASED PEC GUIDELINES (MACDONALD ET AL. 2000).

Contaminant	**Consensus-Based PEC mg/kg**	**Location in Lake Macatawa that Exceed the PEC**
Arsenic	33.0	None (Highest LM-6; 25 mg/kg)
Cadmium	4.98	None (Highest LM-3; 1.6 mg/kg)
Chromium	111	None(LM-4; 89 mg/kg)
Copper	149	None (Highest LM-11; 89 mg/kg)
Lead	128	None (Highest LM-7; 87 mg/kg)
Mercury	1.06	None (Highest LM-7; 0.35 mg/kg)
Nickel	48.6	LM-11 (63 mg/kg)
Zinc	459	None (Highest LM-10; 256 mg/kg)
Total PAH Compounds	22.9	LM-7 (83 mg/kg)
Total PCBs	0.68	LM-2 (2.6 mg/kg)
DDE	0.031	None (Highest LM-7; 20 mg/kg)

TABLE 4.1.9 SPEARMAN'S RANK ORDER CORRELATIONS FOR THE CHEMICAL AND PHYSICAL PARAMETERS IN LAKE MACATAWA SEDIMENTS. (VALUES IN BOLD DENOTE STATISTICALLY SIGNIFICANT CORRELATIONS).

Spearman's Rank Order Correlations	TOC %	Grain Size < 63 um	Distance from River Mouth / Km	Depth / m	Arsenic / mg/Kg	Cadmium / mg/Kg	Chromium / mg/Kg	Mercury / mg/Kg	Lead / mg/Kg	Zinc / mg/Kg	Total PAH / mg/Kg
Grain Size < 63 um	**.886** **(**)**										
Distance from River Mouth/ km	.085	**.786** **(**)**									
Depth / m	-.206	**.724** **(**)**	**.775** **(**)**								
Arsenic / mg/Kg	.509	**-.625** **(*)**	**-.672** **(**)**	**-.701** **(**)**							
Cadmium / mg/Kg	.545	.209	.244	.007	.056						
Chromium / mg/Kg	.303	**.660** **(*)**	.473	.278	-.218	.002					
Mercury / mg/Kg	.383	**-.711** **(**)**	-.357	**-.549** **(*)**	.518	.165	-.524				
Lead / mg/Kg	**.820** **(**)**	.114	-.081	-.198	.479	.521	.442	.121			
Zinc / mg/Kg	.061	**.777** **(**)**	**.552** **(*)**	.379	-.438	.345	**.767** **(**)**	**-.700** **(**)**	.270		
Total PAH / mg/Kg	.426	-.396	-.327	-.278	**.605** **(*)**	.530	-.095	.333	**.565** **(*)**	-.099	
Total DDT / ug/Kg	**.579** **(*)**	-.515	-.387	-.416	**.621** **(*)**	.451	-.051	.418	**.594** **(*)**	-.165	**.851** **(**)**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

correlation of TOC and lead is probably related to the presence of petroleum residue at Station LM-7 as this location had the highest PAH concentration and TOC. With respect to the individual metals and organic compounds, the following positive correlations were present:

- lead and PAH compounds,
- chromium and zinc, and
- arsenic and PAH and
- arsenic and DDT.

While the relationship between lead and PAH compounds can be readily attributed to a common petroleum source, the correlations between the other variables are not clear.

In summary, Station LM-7 is the only location that shows a level of organic compounds significantly above the PEC (Total PAH). While evidence of anthropogenic enrichment of chromium, lead, zinc, nickel, and cadmium is present, the concentrations are not high enough to exceed the PEC guidelines.

4.2 Toxicity Testing Results

The toxicity evaluations of the Lake Macatawa sediments were performed during July 2002. Grab sediment samples collected from 21 different sites were evaluated using the EPA (1999) solid phase testing protocol with *Hyalella azteca* and *Chironomus tentans*.

Conductivity, hardness, alkalinity, ammonia, and pH were determined for the culture water at the beginning and on the tenth day of each test (Appendix E: Tables E-1, E-3). With the exception of ammonia in most of the sediments and conductivity and hardness in M10-P, these parameters remained relatively constant. Variations of less than 50% from initial to final measurements for both test species were observed. Based on the initial pH values (all < 8.00) and the fact that the overlying water was exchanged prior to adding the organisms, toxicity related to unionized ammonia was not anticipated to be a factor in these experiments. Temperature and dissolved oxygen measurements were recorded daily throughout the duration of the tests (Appendix E: Tables E-2, E-4). Very little variation was noted with respect to temperature. The dissolved oxygen remained above 40% saturation in all of the test beakers.

4.2.1 *HYALELLA AZTECA*

Survival data for solid phase toxicity tests with *Hyalella azteca* are presented in Table 4.2.1.1. The survival in the control (LM-12) treatments exceeded the required 80%. Untransformed survival data were evaluated to determine whether they were consistent with a normal distribution. The Chi-Squared distribution was used to compare the expected count of data values at the 10th, 20th, …, and 90th percentiles with the observed count. The sample data from both groups were found to be consistent with those drawn from a normal population ($p > 0.01$). Dunnett's Test showed a statistically significant ($p < 0.05$) difference for the survival data compared to control site LM-12 at station LM-7. Sediments from site LM-7 had significantly reduced survival compared to LM-12 (59% vs 84%, respectively). All of the other stations had greater than 80% survival.

4.2.2 *CHIRONOMUS TENTANS*

Survival data for solid phase toxicity tests with *Chironomus tentans* are presented in Table 4.2.2.1. The survival in the control treatments (LM-12) exceeded the required 70%. Un-transformed survival data were evaluated as described above with the Chi-Squared distribution. The sample data were found to be consistent with those drawn from a normal population ($p > 0.01$). Dunnett's Test showed no statistically significant ($p < 0.05$) difference for the survival data compared to control site LM-12.

Chironomus tentans growth data are presented in Table 4.2.2.2. Un-transformed survival data were evaluated to determine whether they were consistent with a normal distribution. The Chi-Squared distribution was used to compare the expected count of data values at the 10th, 20th, …, and 90th percentiles with the observed count. The sample data from both groups were found to be consistent with those drawn from a normal population ($p > 0.01$). Dunnett's Test showed a statistically significant ($p < 0.05$) difference for the survival data compared to control site LM-12 at station LM-7. Sediments from site LM-7 had significantly reduced *Chironomus* growth compared to LM-12 (0.427 mg vs 0.705 mg, respectively). All of the other stations had greater than 0.630 mg.

4.2.3 SEDIMENT TOXICITY DATA DISCUSSION

Statistically significant ($p < 0.05$) acute toxicity effects were observed in the sediments from Station LM-7 for the amphipod, *H. azteca*. In addition, statistically significant ($p < 0.05$) reduced growth rates were noted for the midge, *C. tentans* in sediment from the same site. Sediment from station LM-7, located down gradient of a petroleum storage area and the Heinz facility, had levels of total PAH compounds that were above PEC guidelines (MacDonald et al. 2000). A total PAH compound concentration of 82.7 mg/kg was found at LM-7, which was approximately 4X greater than the PEC (22.9 mg/kg). Given the high level of toxicity measured in this study, a more detailed assessment of this part of Lake Macatawa is warranted.

TABLE 4.2.1.1 SUMMARY OF *HYALELLA AZTECA* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LAKE MACATAWA SEDIMENTS.

Sample ID	**Number of Organisms**	**Replicate**								**Survival**	
		A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Mean**	**Std Dev**
LM-1	Initial	10	10	10	10	10	10	10	10		
	Final	9	8	9	9	9	10	10	10	9.250	0.7071
LM-2	Initial	10	10	10	10	10	10	10	10		
	Final	9	9	10	8	10	8	7	6	8.375	1.4079
LM-3	Initial	10	10	10	10	10	10	10	10		
	Final	8	10	7	10	10	10	8	9	9.000	1.1952
LM-4	Initial	10	10	10	10	10	10	10	10		
	Final	10	9	9	10	9	10	9	9	9.375	0.5175
LM-6	Initial	10	10	10	10	10	10	10	10		
	Final	10	10	10	8	10	9	9	7	9.125	1.1260
LM-7	Initial	10	10	10	10	10	10	10	10		
	Final	6	8	5	7	3	7	5	6	**5.875****	1.5526
LM-8	Initial	10	10	10	10	10	10	10	10		
	Final	7	8	9	10	9	9	9	9	8.750	0.8864
LM-9	Initial	10	10	10	10	10	10	10	10		
	Final	9	8	9	9	9	8	8	9	8.625	0.5175
LM-10	Initial	10	10	10	10	10	10	10	10		
	Final	9	8	9	10	9	10	10	9	9.250	0.7071
LM-11	Initial	10	10	10	10	10	10	10	10		
	Final	8	8	10	9	9	8	7	10	8.625	1.0607
LM-12	Initial	10	10	10	10	10	10	10	10		
	Final	9	9	10	9	4	10	9	7	8.375	1.9955
LM-14	Initial	10	10	10	10	10	10	10	10		
	Final	8	9	10	8	6	9	9	9	8.500	1.1952
LM-15	Initial	10	10	10	10	10	10	10	10		
	Final	9	8	10	9	9	8	9	7	8.625	0.9161

**** Statistically Significant Toxicity from the Control with Dunnett's Test ($p < 0.05$)**

TABLE 4.2.2.1 SUMMARY OF *CHIRONOMUS TENTANS* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LAKE MACATAWA SEDIMENTS (LM-12 IS THE CONTROL.)

Sample ID	Number of Organisms	Replicate								Survival	
		A	B	C	D	E	F	G	H	Mean	Std Dev
LM-1	Initial	10	10	10	10	10	10	10	10		
	Final	7	8	8	9	9	8	9	8	8.250	0.7071
LM-2	Initial	10	10	10	10	10	10	10	10		
	Final	6	6	7	10	8	10	10	7	8.000	1.7728
LM-3	Initial	10	10	10	10	10	10	10	10		
	Final	7	7	8	9	10	8	10	9	8.500	1.1952
LM-4	Initial	10	10	10	10	10	10	10	10		
	Final	6	9	8	7	10	9	7	10	8.250	1.4880
LM-6	Initial	10	10	10	10	10	10	10	10		
	Final	8	8	6	9	4	6	8	8	7.125	1.6421
LM-7	Initial	10	10	10	10	10	10	10	10		
	Final	8	7	8	9	6	7	6	6	7.125	1.1260
LM-8	Initial	10	10	10	10	10	10	10	10		
	Final	8	7	7	6	8	6	8	9	7.375	1.0607
LM-9	Initial	10	10	10	10	10	10	10	10		
	Final	7	8	7	6	6	8	8	8	7.250	0.8864
LM-10	Initial	10	10	10	10	10	10	10	10		
	Final	7	10	6	10	6	10	10	8	8.375	1.8468
LM-11	Initial	10	10	10	10	10	10	10	10		
	Final	8	8	9	8	9	8	9	9	8.500	0.5345
LM-12	Initial	10	10	10	10	10	10	10	10		
	Final	7	9	9	8	8	8	7	8	8.000	0.7559
LM-14	Initial	10	10	10	10	10	10	10	10		
	Final	8	11	8	8	6	9	6	5	7.625	1.9226
LM-15	Initial	10	10	10	10	10	10	10	10		
	Final	3	9	8	9	8	8	10	9	8.000	2.1381

TABLE 4.2.2.2 SUMMARY OF *CHIRONOMUS TENTANS* DRY WEIGHT DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LAKE MACATAWA SEDIMENTS.

Sample ID	Rep	# Survivors	Mean wt (mg) per survivor	Sample Mean	Sample Std Dev	Sample ID	Rep	# Survivors	Mean wt (mg) per survivor	Sample Mean	Sample Std Dev
LM-1	a	7	1.0286	0.738	0.1228	LM-9	a	7	0.9000	0.668	0.1527
	b	8	0.6750				b	8	0.5625		
	c	8	0.7375				c	7	0.6000		
	d	9	0.6556				d	6	0.7667		
	e	9	0.7000				e	6	0.7000		
	f	8	0.7250				f	8	0.5875		
	g	9	0.6444				g	8	0.8000		
	h	8	0.7375				h	8	0.4250		
LM-2	a	6	0.6167	0.687	0.0970	LM-10	a	7	0.9571	0.861	0.1369
	b	6	0.8167				b	10	0.7400		
	c	7	0.5429				c	6	1.0833		
	d	10	0.6000				d	10	0.8600		
	e	8	0.6750				e	6	0.9500		
	f	10	0.8000				f	10	0.6500		
	g	10	0.7200				g	10	0.8600		
	h	7	0.7286				h	8	0.7875		
LM-3	a	7	0.8143	0.667	0.1004	LM-11	a	8	0.4125	0.821	0.2286
	b	7	0.6286				b	8	0.6625		
	c	8	0.7625				c	9	0.8889		
	d	9	0.6000				d	8	0.7500		
	e	10	0.5700				e	9	0.8222		
	f	8	0.6000				f	8	0.9875		
	g	10	0.5800				g	9	0.8556		
	h	9	0.7778				h	9	1.1889		
LM-4	a	6	0.6167	0.639	0.1493	LM-12	a	7	0.8143	0.705	0.1026
	b	9	0.9000				b	9	0.7333		
	c	8	0.7000				c	9	0.6556		
	d	7	0.7714				d	8	0.6875		
	e	10	0.6000				e	8	0.5625		
	f	9	0.4444				f	8	0.5750		
	g	7	0.6000				g	7	0.7857		
	h	10	0.4800				h	8	0.8250		
LM-6	a	8	0.5625	0.676	0.1785	LM-14	a	8	0.5375	0.768	0.3084
	b	8	0.6500				b	11	0.4727		
	c	6	0.9000				c	8	0.7375		
	d	9	0.4111				d	8	0.7500		
	e	4	0.5750				e	6	0.9500		
	f	6	0.9500				f	9	0.6222		
	g	8	0.6375				g	6	0.6333		
	h	8	0.7250				h	5	1.4400		
LM-7	a	8	0.3125	**0.427****	0.1650	LM-15	a	3	0.6333	0.824	0.1072
	b	7	0.3429				b	9	0.8000		
	c	8	0.1375				c	8	0.9250		
	d	9	0.4889				d	9	0.7333		
	e	6	0.5667				e	8	0.9625		
	f	7	0.6143				f	8	0.8250		
	g	6	0.3667				g	10	0.8100		
	h	6	0.5833				h	9	0.9000		
LM-8	a	8	0.9500	0.786	0.2173						
	b	7	0.7714								
	c	7	0.6857								
	d	6	0.9667								
	e	8	1.1375								
	f	6	0.4667								
	g	8	0.6250								
	h	9	0.6889								

**** Statistically Significant Toxicity from the Control with Dunnett's Test ($p < 0.05$)**

4.3 Benthic Macroinvertebrate Results

Triplicate PONAR grab samples were used to characterize the benthic macroinvertebrate populations at each of the investigative stations. The locations, depths, and physical characteristics of the sediments are given in Table 2.2. Benthic macroinvertebrate populations were assessed by three methods. These data were first analyzed for differences in taxa and total number of organisms and the results summarized in Section 4.4.1. A further analysis of these data using trophic indices and diversity metrics was then conducted and presented in Section 4.3.2.

4.3.1 BENTHIC MACROINVERTEBRATE RESULTS OF INDIVIDUAL SAMPLES

The population composition and abundance data are summarized in Table 4.3.1.1 by mean and standard deviation for each station. The results for each replicate are presented in Appendix F, Table F-1. The general distribution of organisms is shown in Figure 4.3.1.1. Tubificids dominated the benthic macroinvertebrate assemblages at most stations. Chironomids were the dominant taxon at LM-1 and LM-12. Chironomids also were abundant at most stations. A summary of total organisms and taxometric groups is presented in Table 4.3.1.2. Total density was generally high and ranged between 1,364/m^2 and 7,988/m^2 with 7 of 13 sites having >3000 organisms/m^2. Tubificidae was the most abundant group at all but two of the sites sampled, comprising between 531/m^2 and 3,754/m^2. Eight of the locations had tubificid populations that accounted for over 60% of the total organisms. Four species, *Quistadrilus multisetosus, Aulodrilus pigueti, Limnodrilus hoffmeisteri*, and *Limnodrilus claparedeianus* were found at most sites (Table 4.4.1). One of the more pollution tolerant species, *L. hoffmeisteri*, was found at all sites and was the dominant tubificid taxon. Howmiller and Scott (1977) and Milbrink (1983) classified benthic macroinvertebrate assemblages dominated by these species as enriched with organic (nutrient) materials.

Densities of Chironomidae ranged between 158/m^2 and 3.947/m^2 and this taxa group was the third most abundant group at 3 of 13 of the stations sampled (Table 4.3.1.2). A total of 15 taxa were identified (Table 4.3.1.1). *Chironomus* spp. and *Cryptochironomus* spp. were found at 12 of 13 sites. Abundance of *Chironomus* spp. ranged from 31/m^2 to 3,244/m^2 and was generally the most common chironomid encountered. *Cryptochironomus* spp. abundance was lower and did not exceed 316/m^2. With the exception of *Procladius* spp., the remaining species were found infrequently and were generally low in abundance. Organisms from this genera are predatory in nature and do not exclusively feed on organic detritus like *Chironomus* spp. (Berg 1995). *Chironomus* was the most abundant midge genus in the enriched stations with the highest oligochaete densities.

TABLE 4.3.1.1 BENTHIC MACROINVERTEBRATE DISTRIBUTION IN LAKE MACATAWA (#/M^2), JULY 2002. MEAN NUMBER OF ORGANISMS AND STANDARD DEVIATION REPORTED FOR EACH STATION.

Location	LM-1		LM-2		LM-3		LM-4		LM-6		LM-7	
Taxa	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tubificidae	#/m^3		#/m^2		#/m^2		#/m^2		#/m^2		#/m^2	
Limnodrilus hoffmeisteri	383	18	259	50	1392	163	149	18	564	90	439	25
Limnodrilus cervix	274	66			219	43			56	25		
Limnodrilus claparedeianus	492	74	646	124	146	25	15	25	117	155	439	66
Limnodrilus sp.	164	43	129	25			74	25	112	50	175	25
Aulodrilus pigueti	164	43	388	43								
Aulodrilus limnobius												
Aulodrilus pluriseta												
Ilyodrilus templetoni									56	25		
Potamothrix moldaviensis			11	25								
Quistadrilus multisetosus			259	50	88	129	74	25			35	25
Branchiura sowerbyi												
Tubifex tubifex									56	25		
Tubificidae w/ HC	72	25		43			14	25	44	43		
Nadidae												
Nais pardalis			14	25								
Nais pseudobtusa	187	174										
Nais variabilis			29	25								
Naididae sp.	44	74	29	50								
Enchytraeidae sp.			14	25								
Lumbriculidae sp.			14	25								
Nematoda sp.							14	25				
Pelecypoda												
Sphaerium	14	25										
Juvenile			14	25					29	25	14	25
Gastropoda												
Bithyniidae			29	50								
Diptera												
Chironomidae (pupae)	29	50	29	25	1	66	44	74			57	25
Chironomidae (mature) n/a	14	25			144	99			14	25		
Unidentified pupae							14	25				
Ceratopognidae probezzia												
Chironomidae												
Ablabesmyia sp.	29	25	962	366								
Chironomus	689	31			474	149	158	124	57	25	129	86
Clinotanypus sp.											14	25
Coelotanypus sp.					72	25	86	43	57	66	245	90
Cryptochironomus sp.	316	66	373	312	1	50	158	90	14	25	3	199
Cryptocladopelma sp.	29	50	14	25	29	50					14	25
Dicrotendipes sp.	44	43	14	25								
Glyptotendipes sp.	14	25	57	50					14	25		
Paracladopelma sp.	14	25										
Paratendipes sp.	14	25										
Polypedilum sp.	29	25	86	43								
Procladius sp.	3	151	44	43	33	194	344	341	258	86	230	18
Psectrotanypus sp.									44	25		
Tanypus sp.	14	25	14	25								
Thienemannemyia sp.	86	114	14	25								
unknown	230	90	129	114	172	129	44	43	44	25	57	66
Gammaridae												
Gammarus sp.	14	25										
Isopoda												
Asellus caecidotea	14	25										
Trichoptera												
Leptoceridae setodes		25		25								
Coleoptera												
Larvae (unidentifiable)			14	25								

TABLE 4.3.1.1 (CONTINUED) BENTHIC MACROINVERTEBRATE DISTRIBUTION IN LAKE MACATAWA (#/M^2), JULY 2002. MEAN NUMBER OF ORGANISMS AND STANDARD DEVIATION REPORTED FOR EACH STATION.

Location	**LM-8**		**LM-9**		**LM-10**		**LM-11**		**LM-12**		**LM-14**		**LM-15**	
Taxa	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tubificidae	#/m^2		#/m^2		#/m^2		#/m^2		#/m^2		#/m^2		#/m^2	
Limnodrilus hoffmeisteri	1333	50	73	86	79	66	328	25			31	43	632	66
Limnodrilus cervix			367	43	87	25							78	25
Limnodrilus claparedeianus	1938	151	281	174	234	216	1149	90	517	25	93	114	245	452
Limnodrilus sp.	24	50	857	90	263	43							551	138
Aulodrilus pigueti														
Aulodrilus limnobius														
Aulodrilus pluriseta			122	25										
Ilyodrilus templetoni														
Potamothrix moldaviensis														
Quistadrilus multisetosus					87	25					1	25		
Branchiura sowerbyi											1	25		
Tubifex tubifex														
Tubificidae w/ HC	14	25	86	74	14	25	14	25	14	25	14	25	44	43
Nadidae														
Nais pardalis														
Nais pseudobtusa														
Nais variabilis							14	25						
Naididae sp.														
Enchytraeidae sp.														
Lumbriculidae sp.	14	25												
Nematoda sp.														
Pelecypoda														
Sphaerium			14	25	144	212	52	517	44	43	115	131	288	237
Juvenile	14	25												
Gastropoda														
Bithyniidae														
Diptera														
Chironomidae (pupae)	14	25	44	74	29	25							14	25
Chironomidae (mature) n/a	14	25							14	25			44	43
Unidentified pupae													14	25
Ceratopognidae probezzia									14	25	14	25		
Chironomidae														
Ablabesmyia sp.														
Chironomus	57	25	31	43	187	138	359	18	273	25	746	124	3244	612
Clinotanypus sp.	29	25												
Coelotanypus sp.	14	25					29	25	3	25				
Cryptochironomus sp.	14	25	86	43	29	50			29		245	66	44	43
Cryptocladopelma sp.			14	25					29	25	14	25	14	25
Dicrotendipes sp.														
Glyptotendipes sp.														
Paracladopelma sp.														
Paratendipes sp.														
Polypedilum sp.														
Procladius sp.	44	43	29	25									115	66
Psectrotanypus sp.											44	43		
Tanypus sp.									14	25				
Thienemannemyia sp.														
unknown			57	25	29	25	14		230	50	44		532	312
Gammaridae														
Gammarus sp.														
Isopoda														
Asellus caecidotea														
Trichoptera														
Leptoceridae setodes											14			
Coleoptera														
Larvae (unidentifiable)														

TABLE 4.3.1.2 MEAN ABUNDANCE (#/M2) AND RELATIVE DENSITIES (%) OF MAJOR TAXONOMIC GROUPS IN LAKE MACATAWA, JULY 2002.

Location	Total Organisms #/m^2	Total Tubificidae #/m^2	% Tubificidae	Total Chironomidae #/m^2	% Chironomidae
LM-1	3530	1549	44%	1708	48%
LM-2	3648	1782	49%	1708	47%
LM-3	3814	2637	69%	1177	31%
LM-4	2165	1361	63%	789	36%
LM-6	2421	1904	79%	488	20%
LM-7	2307	1403	61%	890	39%
LM-8	3712	3525	95%	158	4%
LM-9	5474	4972	91%	488	9%
LM-10	3852	3464	90%	244	6%
LM-11	2410	1491	62%	402	17%
LM-12	1364	531	39%	775	57%
LM-14	2653	1418	53%	1091	41%
LM-15	7988	3754	47%	3947	49%

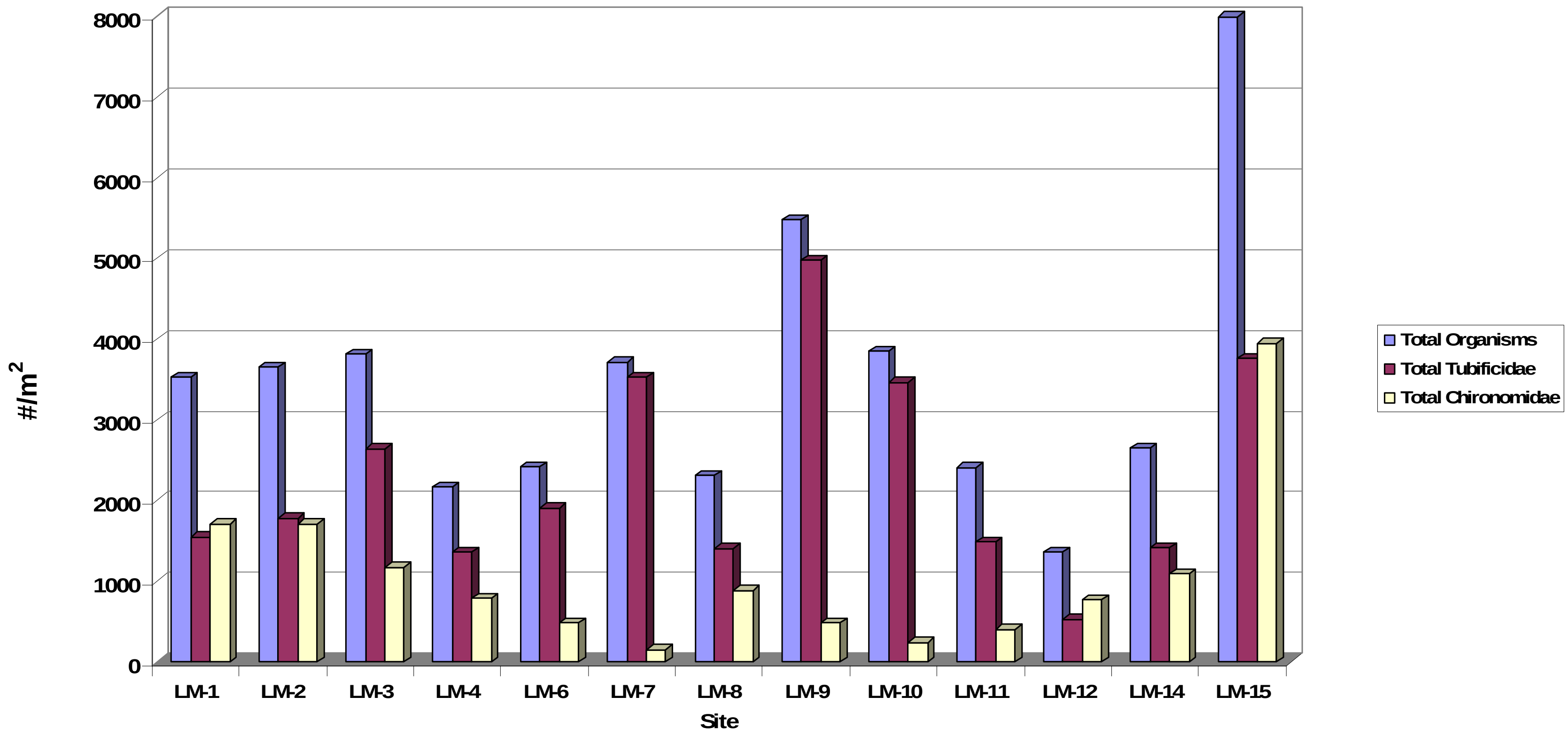


FIGURE 4.3.1.1 GENERAL DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN LAKE MACATAWA, JULY 2002.

4.3.2 ANALYSIS OF MACROINVERTEBRATE RESULTS USING TROPHIC INDICES AND DIVERSITY METRICS

The benthic macroinvertebrate data were analyzed by a variety of trophic status indices and diversity metrics. The following indices and metrics were utilized:

- Shannon Weaver Diversity (Krebs 1989)
- Margalef's Richness (Krebs 1989)
- Evenness (Krebs 1989)
- Pielou's J (Krebs 1989)
- Oligochaete Index (Howmiller and Scott 1977, Hilsenhoff 1987)
- Chironomid Index (Hilsenhoff 1987)
- Oligochaete + Chironomid Index (*)
- Trophic Index (Hilsenhoff 1987)

* Modified from Howmiller and Scott (1977)

Tolerance values used to calculate the Trophic Index and the individual indices for Chironomids, while Oligochaetes were taken from Winnell and White (1985), Lauritsen et al. (1985), Hilsenhoff (1987), Schloesser et al. (1995), and Barbour et al. (1999). The results of the population metrics are summarized in Table 4.4.2.1. Summaries of Trophic Indices for the benthic populations are shown in Figure 4.4.2.1. Stations LM-2 and LM-12 had the most favorable trophic index scores for overall community structure (Hilsenhoff) and chironomids. All of the other stations and the deep stations exhibited high scores for the Hilsenhoff index, indicating enriched conditions. Chironomid index values for the shallow stations WL-18, LM-2 and LM-12 were all <7.5. Deep stations had higher chironomid index values that were again representative of organic enrichment. It is interesting to note that the stations LM-1, LM-2, and LM-7 had similar Shannon-Weaver scores, indicating a more balanced community structure (>2.0). Stations LM-1 and LM-2 were near the river mouth and had a contained a mixture of sands, organic silt, and small stones. The variety of substrates present at these locations probably influenced species diversity. In contrast, Station LM-7 consisted of organic silts, was toxic to amphipods, and contained PAH compounds above the PEC guideline. Predatory genera, *Cryptochironomus* spp., *Procladius* spp. and *Coelotanypus spp.*, were more abundant than detritus feeding dipterans such as *Chironomus spp*. Organisms from these predatory genera do not exclusively feed on organic detritus like *Chironomus* spp. (Berg 1995). A shift from detritus feeding genera to predatory species that live at the surface may be the result of avoidance due to sediment toxicity. Shannon-Weaver scores for the other stations ranged from 1.15-1.82, indicating a more limited diversity, which also was reflected by the dominance of tubificids.

TABLE 4.3.2.1 SUMMARY OF DIVERSITY AND TROPHIC STATUS METRICS FOR THE BENTHIC MACROINVERTEBRATES IN LAKE MACATAWA, JULY 2002.

Station	LM-1	LM-2	LM-3	LM-4	LM-6	LM-7	LM-8	LM-9	LM-10	LM-11	LM-12	LM-14	LM-15
Hilsenhoff index	8.49	7.04	9.42	9.19	9.35	8.93	9.62	9.53	9.55	9.21	8.29	9.01	9.30
Oligochaete index	9.18	8.59	9.87	9.77	9.67	9.77	9.68	9.63	9.67	9.64	9.58	9.41	9.65
Chironomid index	8.10	5.41	8.41	8.25	8.18	7.63	8.60	8.61	8.87	9.23	7.47	8.70	9.06
Shannon- Weaver	2.58	2.36	1.81	1.71	1.85	2.14	1.15	1.56	1.34	1.38	1.69	1.82	1.59
Margalef's richness	2.82	2.80	1.09	1.30	1.80	1.42	1.22	1.28	1.09	0.90	1.25	1.52	1.11
Evenness	0.55	0.44	0.61	0.50	0.42	0.71	0.29	0.40	0.38	0.50	0.54	0.47	0.44
J	0.81	0.74	0.79	0.71	0.68	0.86	0.48	0.63	0.58	0.66	0.73	0.71	0.66
Taxa richness	24	24	10	11	15	12	11	12	10	8	10	13	11
Chiro/Oligo	1.10	0.96	0.45	0.58	0.26	0.63	0.04	0.10	0.07	0.27	1.46	0.77	1.05

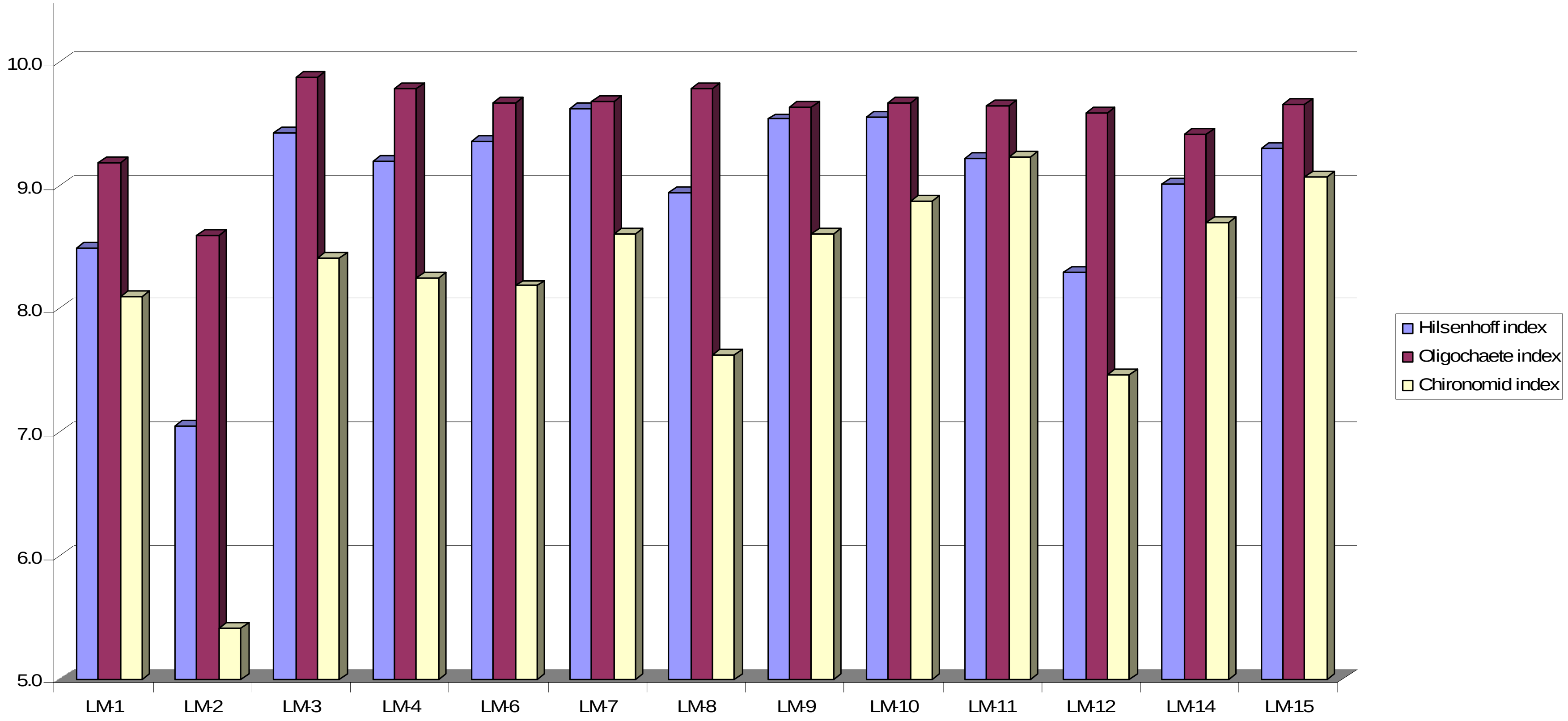


FIGURE 4.3.1.2 SUMMARY OF TROPHIC INDICES FOR THE BENTHIC MACROINVERTEBRATES IN LAKE MACATAWA, JULY 2002.

Spearman Rank Order Correlations were developed for the indices and physical/chemical parameters (Table 4.4.2.2) to determine variables that help define community structure. Depth and distance from the river mouth appear to be significantly correlated with Shannon-Weaver diversity and the Chironomid index. Increasing values for the chironomid index (more pollution tolerance) were correlated with increasing water depth ($p \leq 0.01$) and distance from the river mouth ($p \leq 0.05$). Shannon-Weaver diversity was negatively correlated (less diversity) with distance from the river mouth ($p \leq 0.05$). With respect to sediment chemistry, Shannon-Weaver diversity was negatively correlated with chromium and zinc ($p \leq 0.01$) while the other biological indices showed the following correlations with metals:

- Zinc - positive correlation with Hilsenhoff and Chironomid indices ($p \leq 0.05$); negative correlation with total Chironomidae, taxa richness, and Margalefs richenss, and J ($p \leq 0.01$)
- Chromium - positive correlation with Hilsenhoff and Oligochaete indices ($p \leq 0.05$); negative correlation with taxa richness and J ($p \leq 0.01$)
- Lead - positive correlation with Oligochaete index ($p \leq 0.01$)
- Cadmium- negative correlation with taxa richness ($p \leq 0.05$)

TOC and grain size (% <63 μm) also were correlated with biological metrics. Shannon-Weaver diversity ($p \leq 0.01$), taxa richness ($p \leq 0.05$), and Margalefs richness ($p \leq 0.01$), and J ($p \leq 0.01$) all were negatively correlated with fine grain sediments. In addition, the chironomid and Hilsenhoff index values ($p \leq 0.01$ and $p \leq 0.05$, respectively) were positively correlated with fine grain sediments, indicating greater pollution tolerance. The fact that all metals except for nickel at Station LM-11 were below their respective PECs, it appears that the dominant factors influencing the benthic community are a combination of organic enrichment, depth (lack of dissolved oxygen) and sediment grain size.

4.4 Sediment Quality Triad Assessment

In order to determine the significance of the areas of sediment contamination, an assessment matrix (Chapman 1992) can be used to examine the relationship between chemistry, toxicity, and benthic macroinvertebrate data. An assessment matrix for the Lake Macatawa data is presented in Table 4.4.1. Stations exceeding the PEC (MacDonald et al. 2000) were classified as having a potential impact from sediment chemistry. Toxicity and benthic community impacts were based on observing a statistically significant difference in mortality and diversity/trophic status metrics, respectively.

TABLE 4.3.2.2 SPEARMAN RANK ORDER CORRELATIONS FOR ECOLOGICAL, CHEMICAL, AND PHYSICAL PARAMETERS FOR LAKE MACATAWA. (SIGNIFICANT CORRELATION IN BOLD.).

Spearman's Rank Order Correlations	% TOC	% Grain Size < 63	Distance from River Mouth / m	Depth / m	Arsenic / mg/Kg	Cadmium / mg/Kg	Chromium / mg/Kg	Mercury / mg/Kg	Lead / mg/Kg	Zinc / mg/Kg	Chironomidae / #/ m^2	Tubficidae / #/ m^2	Hilsenhof Index	Oligochaete Index	Chironomid Index	Shannon-Weaver	Margalef's Richness	Evenness	J	N #/ m^2	Taxa Richness	Chironomid/Oligochaete	Total PAH / mg/Kg
Chironomidae #/ m^2	-.070	-.508	-.163	-.157	.031	-.209	-.405	.512	-.328	**-.716 (**)**													
Tubficidae / #/ m^2	-.465	.357	.055	.383	-.373	-.203	.247	-.482	-.126	.280	-.116												
Hilsenhoff Index	-.014	**.618 (*)**	.170	.298	-.220	.104	**.643 (*)**	**-.562 (*)**	.363	**.676 (*)**	**-.595 (*)**	**.731 (**)**											
Oligochaete Index	**.732 (**)**	.142	-.099	-.207	.447	.297	**.681 (*)**	.052	**.901 (**)**	.341	-.284	.071	.544										
Chironomid Index	-.094	**.858 (**)**	**.621 (*)**	**.725 (**)**	**-.706 (**)**	.264	.549	**-.752 (**)**	.170	**.681 (*)**	-.295	.462	**.632 (*)**	.143									
Shannon-Weaver	.044	**-.905 (**)**	**-.599 (*)**	-.507	.435	-.247	**-.758 (**)**	**.730 (**)**	-.225	**-.912 (**)**	**.697 (**)**	-.418	**-.720 (**)**	-.275	**-.687 (**)**								
Margalef's Richness	-.198	**-.774 (**)**	-.544	-.435	.447	-.484	**-.747 (**)**	.501	-.445	**-.841 (**)**	.438	-.286	**-.582 (*)**	-.423	**-.681 (*)**	**.830 (**)**							
Evenness	.490	-.493	-.170	-.452	.226	.363	-.236	**.702 (**)**	.242	-.396	.526	**-.654 (*)**	**-.593 (*)**	.137	-.374	**.560 (*)**	.148						
J	.283	**-.830 (**)**	-.495	**-.603 (*)**	.435	.060	-.533	**.829 (**)**	.022	**-.703 (**)**	**.636 (*)**	**-.621 (*)**	**-.753 (**)**	-.060	**-.698 (**)**	**.852 (**)**	.516	**.874 (**)**					
N #/ m^2	**-.553 (*)**	.326	.110	.427	-.509	-.247	.225	-.416	-.247	.187	.121	**.934 (**)**	**.582 (*)**	-.044	.473	-.313	-.269	-.516	-.484				
Taxa Richness	-.365	**-.655 (*)**	-.501	-.219	.292	**-.571 (*)**	**-.702 (**)**	.323	-.493	**-.794 (**)**	.443	.025	-.387	-.443	-.493	y	**.939 (**)**	-.061	.329	.039			
Chiron/Oligoc (Ratio)	-.011	-.426	.044	-.204	.000	-.121	-.511	**.598 (*)**	-.451	**-.659 (*)**	**.785 (**)**	-.522	-.y	-.495	-.445	**.604 (*)**	.418	**.621 (*)**	**.659 (*)**	-.319	.265		
Total PAH/ mg/Kg	.426	-.396	-.327	-.278	**.605 (*)**	.530	-.095	.333	**.565 (*)**	-.099	-.052	-.005	.038	.418	-.346	.154	.093	.159	.258	-.121	.084	-.269	
Total DDT / *u*g/Kg	**.579 (*)**	-.515	-.387	-.416	**.621 (*)**	.451	-.051	.418	**.594 (*)**	-.165	.084	-.286	-.124	.448	-.385	.363	.168	.366	.473	-.319	.077	-.129	**.851 (**)**

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

TABLE 4.4.1 SEDIMENT QUALITY ASSESSMENT MATRIX FOR LAKE MACATAWA DATA, JULY 2002. ASSESSMENT MATRIX FROM CHAPMAN (1992).

Station	Sediment Chemistry	Toxicity Test	Benthic Community	Possible Conclusions
LM-7	+	+	+	Impact highly likely; contaminant induced degradation of sediment dwelling organisms evident
LM-1, LM-2, and LM-12	-	-	-	Impact highly unlikely; contaminant degradation of sediment dwelling organisms not likely
No Stations	+	-	-	Impact unlikely; contaminants unavailable to sediment dwelling organisms
No Stations	-	+	-	Impacts possible; Unmeasured contaminants or conditions exist that have the potential to cause toxicity
LM-3, LM-4, LM-5, LM-6, LM-8, LM-9, LM-10, LM-11, LM-14, and LM-15	-	-	+	Impacts unlikely; no degradation of sediment dwelling organisms in the field apparent relative to sediment contamination; physical factors may be influencing benthic community
No Stations	+	+	-	Impact likely; toxic chemicals probably stressing system
No Stations	-	+	+	Impact likely; unmeasured toxic chemicals contributing to the toxicity
No Stations	+	-	+	Impact likely; sediment dwelling organisms degraded by toxic chemical, but toxicity tests not sensitive to chemicals present

+ = Indicator classified as affected; as determined based on comparison to the PEC or control site
- = Indicator not classified as affected; as determined based on comparison to the PEC or control site

Using this assessment methodology, the station near the petroleum storage facility, LM-7, is the only location likely to be impacted by contaminated sediments. At this location, levels of PAH compounds exceeded the PEC, the sediments were toxic to amphipods (mortality) and chironomids (growth), and the benthic community was impacted by a predominance of pollution tolerant organisms. None of the other stations were positive for all three components of the triad. Given the organically enriched conditions present in the sediment, it is difficult to detect a toxic response in the benthos above effects caused by eutrophication. Based on the Assessment Matrix, ecological impairments observed at most of the sites were the result of eutrophication as sediment toxicity and exceedances of the PEC guidelines were not present.

4.5 Summary and Conclusions

A preliminary investigation of the nature and extent of sediment contamination in Lake Macatawa was performed using Sediment Quality Triad methodology. Sediment chemistry, solid-phase toxicity, and benthic macroinvertebrates were examined at 13 locations. High levels of PAH compounds were found in an area along the southern shore near a petroleum storage facility (LM-7). These levels exceeded the Probable Effect Concentrations (PECs) for current sediment quality guidelines. Sediment toxicity to amphipods (mortality) and chironomids (growth) also was observed at this location in addition to an impacted benthic community. Based on the Sediment Quality Triad, the area around LM-7 should be investigated in more detail to determine the extent of contamination and the need for remediation. With respect to the rest of the lake, significant levels of metals and organic chemicals that exceeded the PEC guidelines were not observed in surficial sediments and core samples. This suggests that from both a current and historical perspective, significant sediment contamination was not present at the locations sampled. Benthic macroinvertebrate communities throughout Lake Macatawa were found to be indicative of organically enriched conditions. Tubificids and chironomids were the dominant taxa groups at all stations. The only areas with Shannon-Weaver diversity indices above 2 were the control location near Pine Creek and two stations near the mouth of the Macatawa River. These locations contained a greater diversity of organisms with moderate to high pollution tolerance. The remainder of the locations in Lake Macatawa contained mostly pollution tolerant genera comprising fewer taxometric groups. Given the absence of elevated contaminant levels and sediment toxicity in the remainder of the lake, benthic community impacts appear to be related to cultural eutrophication.

4.6 References

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Appendices

Appendix A. Quality Assurance Review of the Project Data.

QA/QC Analysis Checklist for
SEDIMENT CHEMISTRY ANALYSIS

GRANT/IAG NUMBER: **GL-97568501-1**
PROJECT NAME: Preliminary Investigation of Sediment Contamination in Lake Macatawa
REVIEWER: Richard Rediske
DATE: 10-15-04

1. What sediment chemistry data has been collected (CHECK ALL THAT APPLY)?

Total Metals ___X__ PCBs _____ pH _____ TOC _X____
Dioxins/Furans _____ PAHs ___X__Pesticides ___X__ DO _____AVS _____
SEM Metals _____ Particle Size _X____ Other Semivolatile Organics X

2. Were the target detection limits met for each parameter?

YES X
NO _____ (UNACCEPTABLE)

3. Were the Method Blanks less than the established MDL for each parameter?

YES X
NO _____ (UNACCEPTABLE)

4. Did the results of Field Duplicate Analysis vary by less than the % RPD specified in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

5. Did the results of the Field Replicates Analysis vary by less than the % RPD specified in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

6. Did the surrogate spike recoveries meet the limits set forth in the QAPP?

YES ____
NO X (UNACCEPTABLE) (Two samples had single surrogate recoveries outside of QAPP limits)

7. Did the MS/MSD recoveries meet the limits set forth in the QAPP?

YES _____
NO X (UNACCEPTABLE) (One organic QC failure).

8. Did the RPD (%) of the MS/MSD sample set meet the limits set forth in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

9. Did the initial calibration verification standards meet the requirements set forth in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

10.. Were any level of contaminants detected above the MDL for the trip blanks and storage blanks?

YES _____ (UNACCEPTABLE)
NO X Trip and Storage blanks were not required in the QAPP

11. Did all required analysis take place within the required holding time protocols set forth in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

12. Did the laboratory duplicates vary by less than the % RPD specified in the QAPP?

YES X
NO _____ (UNACCEPTABLE)

13. Are measured dry weight contaminant concentrations reported? (Note: Conversion from wet weight to dry weight concentration may occur ONLY if data on moisture or TOC are provided. Nominal concentrations are unacceptable.)

YES X
NO _____ (UNACCEPTABLE)

14. Please provide details for all of the "UNACCEPTABLE" marked above. Include details on the specific analytes affected by any QA/QC discrepancies, and recommendations regarding usability of data.

Sample from station LM-15 had a MSD results for 4-nitrophenol as follows:

Compound	Initial	MS % Recovery	MSD % Recovery
4-Nitrophenol	<0.33mg/kg	126	134*

The control limit for 4-nitrophenol was 40%- 130%. LCS results for extraction batch were within control limits. Since the sample result was not detectable and the other MS was withing the control limit, the results were qualified.

Surrogate recoveries in the following samples were outside control limits:

Compound	Station	% Recovery
2-Fluorophenol	LM-14 Bottom	23.3
Phenol d6	LM-11 Bottom	14.6

The other surrogates were within the control limits (30%-140%). Since only one surrogate was out of compliance, no qualification was necessary.

QA/QC Analysis Checklist for
ACUTE AND CHRONIC WHOLE SEDIMENT TOXICITY TESTS
(10-day*C. tentans* and 10-day or 28-day *H. azteca*)

GRANT/IAG NUMBER: **GL-97568501-1**
PROJECT NAME: Preliminary Investigation of Sediment Contamination in Lake Macatawa
REVIEWER: Richard Rediske
DATE: 10-14-04

1. Did toxicity tests employ appropriate procedures? [ASTM: E1367, E1611, E1706, USEPA (2000)]

YES X
NO _____ (UNACCEPTABLE)

2. Does sample storage time exceed the allowable storage time specified in the QAPP?

Allowable Storage Days Specified in QAPP 45
Number of Storage Days Prior to Testing 14 DYAS AND 30 DAYS

YES _____ (UNACCEPTABLE)
NO X

3. Was the age for H. azteca organisms between 7- to 14-days at the start of the test with an age range less than 2-days?

YES X
NO _____ (UNACCEPTABLE)

4A. Were all of the C. tentans organisms second- to third-stage larvae with at least 50% at the third instar?

YES X
NO _____ (UNACCEPTABLE)

4B. How was the developmental stage of the C. tentans larvae measured?

Head Capsule Width _____ (See Table 10.2 of EPA/600/R-99/064, March 2000)
Length X (Should fall between 4 mm to 6 mm)
Weight _____ (Should fall between 0.08 to 0.23 mg/individual)

5. Do flow rates through the different test chambers differ by more than 10% at any particular time during the test?

YES _____ (UNACCEPTABLE)
NO X (QAPP REQUIRED 2X DAILY RENEWAL OF OVERLYING WATER INSTEAD OF FLOW THROUGH)

6. Did Dissolved Oxygen remain above 2.5 mg/L?

YES X
NO _____ (Provide Explanation at end of Checklist)

7. Does daily mean Temperature remain at 23 ± 1°C?

YES X
NO _____ (UNACCEPTABLE)

8. Does the instantaneous Temperature remain in the range of 23 ± 3EC?

YES X
NO _____ (UNACCEPTABLE)

9. Do the Ranges of for Hardness, Alkalinity, pH, and Ammonia fluctuate more than 50% from the mean?

Maximum % Difference:

DO ____30%_____ Alk ____22%__
pH ____6%_____ NH_3 _50%

YES _____ (UNACCEPTABLE)
NO _____

10. Was the Ammonia concentration ever greater than 20 mg/L?

YES _____ (See EPA/600/R-99/064, March 2000 to determine if ammonia contributed to toxicity of H. azteca.)
NO X

11. Was the Ammonia concentration greater than 82 mg/L?

YES _____ (See EPA/600/R-99/064, March 2000 to determine if ammonia contributed to toxicity of C. tentans)
NO X

12. Was the Mean Control Survival in the *H. azteca* Control Sediments greater than or equal to 80%?

YES X
NO _____ (UNACCEPTABLE)

13. Was the Mean Control Survival in the *C. tentans* Control Sediments greater than or eqaul to 70%?

YES X
NO _____ (UNACCEPTABLE)

14. Was the mean weight per surviving C. tentans control organism greater than 0.48 mg (ash-free dry weight)?

YES X QAPP used dry weight of 0.8 mg/ individual. This was achieved.
NO _____ (UNACCEPTABLE)

15. Was the overlying water renewed at a rate of 2 volumes per day?

YES X
NO _____ (UNACCEPTABLE)

16. Please provide details for all of the "UNACCEPTABLE" responses marked above. Include details on the specific results that potentially may be affected by any QA/QC discrepancies, and recommendations regarding usability of data.

All discrepancies were related to following methods approved in the project QAPP.

Appendix B. Quality Assurance Results for Physical Analyses On Lake Macatawa Sediments, July 2002

TABLE B-1. RESULTS OF DUPLICATE GRAIN SIZE, TOC, AND % SOLIDS ANALYSES ON LAKE MACATAWA SEDIMENT SAMPLES. JULY 2002.

Station	2000 Weight %	1000 Weight %	850 Weight %	500 Weight %	250 Weight %	63 Weight %	< 63 Weight %	% Solids	TOC %
M-9 Top	15	0.3	0.0	0.0	0.1	3.9	5.5	90	6.5
M-9 Top Dup	16	1.0	0.3	0.1	0.6	5.1	6.1	87	10
M-9 Mid	22	0.6	0.2	0.0	0.2	1.7	3.1	94	2.9
M-9 Mid Dup	22	1.4	0.9	0.1	0.5	1.8	2.7	93	6.4
M-9 Bot	25	0.0	0.1	0.0	0.5	2.1	3.4	94	6.4
M-9 Bot Dup	24	0.0	0.0	0.0	0.1	1.2	2.5	96	6.3
LM-6	0.3	0.2	0.2	0.5	1.9	16.8	80.2	35	3.4
LM-6 Dup	0.5	0.2	0.1	0.5	2.2	17.4	79.1	37	3.6
LM-8	0.0	0.0	0.0	0.0	0.3	1.4	98.3	28	2.0
LM-8 Dup	0.1	0.0	0.0	0.0	0.3	1.2	98.3	28	2.1
LM-10	0.0	0.0	0.0	0.0	0.7	1.4	97.9	27	1.9
LM-10 Dup	0.0	0.0	0.0	0.0	0.6	1.3	97.9	27	1.9
LM-12	0.0	0.0	0.0	0.1	2.7	8.7	88.4	25	3.1
LM-12 Dup	0.0	0.1	0.0	0.1	3.3	9.8	86.6	25	2.9

Appendix C. Quality Assurance Results for Organic Analyses On Lake Macatawa Sediments, July 2002.

TABLE C-1. SURROGATE STANDARD RECOVERIES FOR SEMIVOLATILE ORGANICS ANALYSES ON LAKE MACATAWA SEDIMENTS, JULY 2002

SAMPLE ID	**LM1 TOP**	**LM1 MID-1**	**LM1 MID-2**	**LM1 BOTTOM**	**LM-2 TOP**	**LM-2 MID**	**LM-3 TOP**	**LM-3 MID**	**LM-3 BOTTOM**	**LM-4 TOP**	**LM-4 MID**
2-Fluorophenol	66.5	59.7	70.0	65.2	67.6	73.0	73.6	72.4	64.5	72.1	79.7
Phenol-d6	71.3	65.3	77.0	73.0	70.6	75.5	77.0	76.8	66.2	74.6	75.4
Nitrobenzene-d5	58.3	59.0	66.0	60.6	68.6	66.3	70.7	68.7	63.3	73.1	81.0
2-Fluorobiphenyl	70.6	66.0	75.5	73.0	70.6	74.7	77.6	78.7	67.9	74.6	84.1
2,4,6-Tribromophenol	90.5	94.1	106.1	316.0	105.9	107.4	121.8	113.6	97.6	116.1	113.7
Terphenyl-d14	70.6	66.7	80.2	80.0	72.5	77.2	85.1	73.0	70.3	76.7	78.5
SAMPLE ID	**LM-12 MID**	**LM-5 TOP**	**LM-5 MID**	**LM-5 BOTTOM**	**LM-6 TOP**	**LM-6 MID**	**LM-6 BOTTOM**	**LM-7 TOP**	**LM-7 BOTTOM**	**LM-8 TOP**	**LM-8 MID-1**
2-Fluorophenol	69.2	66.0	49.9	71.0	55.7	56.1	63.5	63.5	78.8	65.5	64.7
Phenol-d6	57.0	51.7	40.1	60.2	45.7	40.4	52.0	70.0	87.9	70.5	66.9
Nitrobenzene-d5	76.5	68.2	50.8	76.3	61.3	60.9	68.5	69.4	85.5	72.1	69.2
2-Fluorobiphenyl	82.5	79.5	67.7	79.7	75.1	73.0	76.1	69.4	83.6	71.6	71.4
2,4,6-Tribromophenol	95.9	110.9	100.7	104.4	100.8	85.0	100.9	89.4	106.8	100.8	95.6
Terphenyl-d14	77.7	81.0	74.9	75.6	77.6	68.8	72.3	79.4	75.1	73.2	74.8
SAMPLE ID	**LM-6 TOP DUP**	**LM-6 MID DUP**	**LM-6 BOT DUP**	**LM-9 TOP**	**LM-9 MID**	**LM-9 BOTTOM**	**LM-10 TOP**	**LM-10 MID-1**	**LM-10 MID-2**	**LM-10 BOTTOM**	**LM-11 TOP**
2-Fluorophenol	69.8	50.6	58.5	63.5	73.0	89.0	86.9	114.5	116.5	117.6	112.7
Phenol-d6	76.0	57.1	62.1	66.5	71.1	87.3	86.5	98.0	108.0	94.5	96.8
Nitrobenzene-d5	80.3	59.7	71.5	75.5	63.7	70.6	66.7	103.0	100.0	95.8	93.6
2-Fluorobiphenyl	80.3	75.3	74.5	80.5	60.3	68.4	67.1	104.6	108.5	103.8	107.3
2,4,6-Tribromophenol	105.1	109.1	94.6	107.5	49.0	79.4	83.3	121.0	113.0	122.5	102.7
Terphenyl-d14	72.3	79.2	71.5	77.0	65.7	71.1	71.2	102.4	110.0	110.5	103.2
SAMPLE ID	**LM-11 BOTTOM**	**LM-14 TOP**	**LM-14 MID**	**LM-14 BOTTOM**	**LM-15 TOP**	**LM-15 MID-1**	**LM-15 MID-2**	**LM-15 BOTTOM**	**LM-1P**	**LM-2P**	**LM-3P**
2-Fluorophenol	32.6	102.8	112.7	23.3*	83.3	96.0	87.0	107.2	94.4	108.4	93.3
Phenol-d6	14.6*	96.0	96.2	51.4	75.0	88.1	80.3	88.5	80.3	103.7	97.6
Nitrobenzene-d5	47.7	85.2	92.6	60.4	73.0	79.2	75.2	89.5	84.3	90.4	88.9
2-Fluorobiphenyl	59.9	98.4	109.6	60.8	92.1	98.7	96.6	101.1	100.4	97.7	97.6
2,4,6-Tribromophenol	45.9	124.4	132.8	62.9	113.7	94.4	106.6	121.1	90.5	113.2	110.5
Terphenyl-d14	61.4	106.0	104.4	63.3	96.4	104.9	95.0	97.6	102.4	102.4	99.5
SAMPLE ID	**LM-6P DUP**	**LM-7P**	**LM-8P**	**LM-9P**	**LM-10P**	**LM-11P**	**LM-12P**	**LM-14P**	**LM-15P**	**LM-15 BOTTOM**	**LM-15 BOTTOM**
2-Fluorophenol	106.9	95.1	104.6	101.6	42.7	109.9	113.3	93.0	96.9	96.6	71.8
Phenol-d6	110.2	93.4	102.9	100.4	39.5	109.2	111.9	93.4	94.9	93.0	68.8
Nitrobenzene-d5	91.9	83.8	87.8	91.2	39.1	93.3	100.7	79.4	79.8	89.5	64.7
2-Fluorobiphenyl	99.7	88.9	95.0	95.6	40.3	101.4	107.4	90.2	92.5	108.2	89.0
2,4,6-Tribromophenol	113.6	94.9	123.1	122.8	62.1	110.7	118.5	114.1	138.0	106.7	96.5
Terphenyl-d14	100.2	87.2	89.9	102.8	46.0	106.0	101.5	97.9	99.0	107.7	97.6
SAMPLE ID	**BLANK1**	**BLANK2**	**BLANK3**	**LFB1**	**LFB2**	**LFB3**					
2-Fluorophenol	70.5	68.8	39.4	77.0	71.1	61.0					
Phenol-d6	82.0	68.3	44.0	84.0	83.1	67.0					
Nitrobenzene-d5	81.5	79.0	40.6	80.0	87.0	76.0					
2-Fluorobiphenyl	90.5	72.5	42.4	88.5	81.1	85.0					
2,4,6-Tribromophenol	50.5	95.0	30.0	54.5	82.1	62.0					
Terphenyl-d14	88.0	75.0	42.4	83.5	74.6	118.0					

* Recovery outside of control limit (30%-150%)

Table C-2. Surrogate Standard Recoveries For PCB and Pesticide Analyses On Lake Macatawa Sediments, July 2002

SAMPLE ID	Tetrachloro-m-xylene	Decachlorobyphenyl
LM1 TOP	107	87
LM1 MID-1	105	118
LM1 MID-2	82	104
LM1 BOTTOM	108	105
LM-2 TOP	97	64
LM-2 MID	84	104
LM-3 TOP	74	102
LM-3 MID	115	103
LM-3 BOTTOM	69	117
LM-4 TOP	112	64
LM-4 MID	85	83
LM-4 BOTTOM	62	70
LM-12 TOP	89	116
LM-12 MID	96	93
LM-5 TOP	84	91
LM-5 MID	83	98
LM-5 BOTTOM	105	67
LM-6 TOP	67	86
LM-6 MID	98	94
LM-6 BOTTOM	91	87
LM-7 TOP	73	113
LM-7 BOTTOM	110	70
LM-8 TOP	83	97
LM-8 MID-1	73	95
LM-8 MID-2	115	65
LM-8 BOTTOM	71	65
LM-6 TOP DUP	108	95
LM-6 MID DUP	109	98
LM-6 BOT DUP	104	61
LM-9 TOP	75	106
LM-9 MID	90	72
LM-9 BOTTOM	86	110
LM-10 TOP	114	102
LM-10 MID-1	71	88
LM-10 MID-2	77	114
LM-10 BOTTOM	83	108
LM-11 TOP	102	69
LM-11 MID-1	82	77
LM-11 MID-2	98	84
LM-11 BOTTOM	105	95
LM-14 TOP	96	63
LM-14 MID	93	66
LM-14 BOTTOM	113	119
LM-15 TOP	73	80
LM-15 MID-1	74	88
LM-15 MID-2	72	61
LM-15 BOTTOM	78	86
LM-1P	80	65
LM-2P	77	70
LM-3P	80	108
LM-4P	107	77
LM-6P	103	85
LM-6P DUP	85	87
LM-7P	96	112
LM-8P	64	90
LM-9P	67	110
LM-10P	94	60
LM-11P	80	110
LM-12P	92	69
LM-14P	74	87
LM-15P	117	114
LM-15 BOTTOM	61	117
LM-15 BOTTOM	109	108
LM-15P	60	107
LM-15P	70	66
BLANK1	114	62
BLANK2	96	87
BLANK3	105	90
LFB1	96	114
LFB2	110	100
LFB3	73	105

TABLE C-3. RESULTS OF MATRIX SPIKE/MATRIX SPIKE DUPLICATE ANALYSES FOR SEMIVOLATILE ORGANICS AND PCB ANALYSES ON LAKE MACATAWA SEDIMENTS, JULY 2002

SAMPLE ID	LFB1	LFB2	LFB3	LM-15 BOTTOM	LM-15 BOTTOM	LM-11 Top	LM-11 Top	LM-15P	LM-15P
Phenol	76	70	51	82	62	74	78	97	101
2-Chlorophenol	73	68	37	86	63	76	79	99	102
1,4-Dichlorobenzene	77	67	61	74	47	56	59	79	82
1,2,4-Trichlorobenzene	80	73	67	81	60	62	65	85	88
4-Chloro-3-methylphenol	68	75	44	120	102	96	101	119	124
Acenaphthene	70	59	66	99	85	70	70	93	93
4-Nitrophenol	60	84	108	113	114	103	111	126	134*
2,4-Dinitrotoluene	59	66	92	103	94	85	95	108	118
Pentachlorophenol	62	63	99	125	99	76	69	99	92
Pyrene	75	65	102	113	103	70	76	93	99
Aroclor 1016	81	81	85	89	96	84	83	105	98
Aroclor 1260	80	83	82	94	87	91	98	67	86

* Recovery outside of control limit (40%-130%)

Appendix D. Quality Assurance Results for Metals Analyses For Lake Macatawa Sediments, July 2002.

TABLE D-1. RESULTS OF QUALITY CONTROL ANALYSES FOR METALS IN LAKE MACATAWA SEDIMENT, JULY 2002.

LCS – 1

Analyte	Method Blank Result	Spike Added	LCS	LCSD	LCS	LCSD	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	U	150	143.5	157.0	96	105	9.0	3050/6010
Cd	U	150	150.8	154.0	101	103	2.1	3050/6010
Cr	U	150	151.6	151.6	100	101	0.0	3050/6010
Cu	U	150	153.6	157.8	102	105	2.7	3050/6010
Ni	U	150	154.9	157.3	103	105	1.6	3050/6010
Zn	U	150	148.6	150.4	99	100	1.2	3050/6010

LM -2 TOP

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	6.7	30	30	36.4	37.2	99	102	13.5	3050/6010
Cd	2.42	30	30	32.7	32.8	101	101	1.9	3050/6010
Cr	134	30	30	164.3	164.2	101	101	0	3050/6010
Cu	91.6	30	30	121.6	121.5	100	100	0.1	3050/6010
Hg	0.29	0.5	0.5	0.75	0.81	92	104	7.7	7471
Ni	95.1	30	30	125.2	124.9	100	99	0.2	3050/6010
Pb	52	30	30	85	81	110	97	4.8	3050/6010
Zn	219	30	30	249.2	249.1	101	100	0.0	3050/6010

LM -4 PONAR

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	19	30	30	48.5	47.2	98	94	13.5	3050/6010
Cd	1.8	30	30	31.5	31.4	99	99	1.9	3050/6010
Cr	89	30	30	118.7	118.3	99	98	0	3050/6010
Cu	88	30	30	117.5	117.8	98	99	0.1	3050/6010
Hg	0.22	0.5	0.5	0.69	0.65	94	86	6.0	7471
Ni	48	30	30	78	77.6	100	99	0.5	3050/6010
Pb	56	30	30	85	81	97	83	4.8	3050/6010
Zn	241	30	30	271	271.3	100	101	0.1	3050/6010

TABLE D-1 (CONTINUED). RESULTS OF QUALITY CONTROL ANALYSES FOR METALS IN LAKE MACATAWA SEDIMENT, JULY 2002.

LCS – 2

Analyte	Method Blank Result	Spike Added	LCS	LCSD	LCS	LCSD	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	U	30	29.41	19.95	98	106	38.3	3050/6010
Cd	U	30	29.70	30.41	99	101	2.4	3050/6010
Cr	U	30	29.16	29.74	97	99	2.0	3050/6010
Cu	U	30	30.01	30.42	100	101	1.4	3050/6010
Ni	U	30	30.02	30.57	100	102	1.8	3050/6010
Zn	U	30	28.90	29.71	96	99	2.8	3050/6010

LM -7 TOP

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	8.9	30	30	30.7	32.4	73	78	13.5	3050/6010
Cd	1.46	30	30	32.3	30.7	103	97	1.9	3050/6010
Cr	98.1	30	30	128.7	127.6	102	98	0	3050/6010
Cu	73.3	30	30	104	102.8	102	98	0.1	3050/6010
Hg	0.45	0.5	0.5	0.89	0.93	88	96	4.4	7471
Ni	42.6	30	30	73.2	71.5	102	96	2.3	3050/6010
Pb	104	30	30	129	133	83	97	3.1	3050/6010
Zn	197	30	30	227.8	226.7	103	99	0.5	3050/6010

LM -7 PONAR

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	5.58	30	30	37.6	35	107	98	13.5	3050/6010
Cd	1.34	30	30	31.9	32	102	102	1.9	3050/6010
Cr	69.6	30	30	99.8	99.7	101	100	0	3050/6010
Cu	63.8	30	30	94	93.9	101	100	0.1	3050/6010
Hg	0.35	0.5	0.5	0.72	0.83	74	96	14.2	7471
Ni	33.7	30	30	64	63.8	101	100	0.3	3050/6010
Pb	87	30	30	120	108	110	70	10.5	3050/6010
Zn	193	30	30	223.3	223.4	101	101	0.0	3050/6010

TABLE D-1 (CONTINUED). RESULTS OF QUALITY CONTROL ANALYSES FOR METALS IN LAKE MACATAWA SEDIMENT, JULY 2002.

LCS –3

Analyte	Method Blank Result	Spike Added	LCS	LCSD	LCS	LCSD	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	U	30	32.53	29.30	108	98	10.4	3050/6010
Cd	U	30	30.00	30.05	100	100	0.2	3050/6010
Cr	U	30	29.94	29.98	100	100	0.1	3050/6010
Cu	U	30	29.93	29.99	100	100	0.2	3050/6010
Ni	U	30	29.95	29.96	100	100	0.1	3050/6010
Zn	U	30	29.95	29.87	100	100	0.3	3050/6010

LM -14 BOTTOM

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	7.2	30	30	28.1	24.5	70	58	13.5	3050/6010
Cd	0.89	30	30	31.6	31	102	100	1.9	3050/6010
Cr	145	30	30	174.9	174.9	100	100	0	3050/6010
Cu	17.3	30	30	47.6	47.5	101	101	0.1	3050/6010
Hg	<0.05	0.5	0.5	0.52	0.6	104	120	14.3	7471
Ni	29.1	30	30	59.4	59.5	101	101	0.2	3050/6010
Pb	87	30	30	120	108	110	70	10.5	3050/6010
Zn	191	30	30	220.6	221	99	100	0.2	3050/6010

LM -15 MIDDLE

Analyte	Sample Conc	MS Spike Added	MSD Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	9.32	30	30	41.7	33.5	108	81	13.5	3050/6010
Cd	1.35	30	30	31.4	30.9	100	99	1.9	3050/6010
Cr	96	30	30	126.3	126	101	100	0	3050/6010
Cu	44.8	30	30	75.2	74.8	101	100	0.1	3050/6010
Hg	0.19	0.5	0.5	0.59	0.66	80	94	11.2	7471
Ni	42.8	30	30	72.9	73.1	100	101	0.3	3050/6010
Pb	71	30	30	98	106	90	117	7.8	3050/6010
Zn	234	30	30	264.1	263.9	100	100	0.1	3050/6010

TABLE D-2. RESULTS OF STANDARD REFERENCE MATERIAL ANALYSES FOR METALS (RESULTS IN MG/KG EXCEPT WHERE NOTED).

Sample ID	**As**	**Cd**	**Cr**	**Cu**	**Ni**	**Zn**
Nist 2-1	5.14	3.44	17.2	68.0	56.7	33.4
Nist 2-2	6.31	3.01	17.2	63.4	49.6	32.8
Nist 2-3	4.39	2.78	19.1	73.4	51.1	31.9
Nist 3-1	10.53	3.11	16.9	57.9	48.2	31.8
Nist 3-2	3.98	2.95	15.6	64.0	45.9	30.9
Nist 3-3	4.09	2.91	16.6	61.3	47.5	31.8
Nist 2586	2.28	3.39	17.9	65.4	44.8	33.1
NIST 2586 1	3.44	2.86	16.4	56.8	48.5	17.8
NIST 2586 2	6.47	2.46	16.2	62.3	42.2	30.7
NIST 2586 3	6.97	2.87	14.0	75.3	48.7	31.0
Average	5.36	2.98	15.9	64.8	48.3	30.5
Nominal	4.31	2.71	17.8	69.5	50.8	33.6
%Nominal	124%	110%	89%	93%	95%	91%
%RSD	44%	10%	9%	9%	8%	15%

Appendix E. Summary Of Chemical Measurements For The Toxicity Test With Sediments From Lake Macatawa July 2002.

Table E-1. Summary of Initial and Final Chemical Measurements for *Hyalella azteca* in Lake Macatawa Sediments

		Day		Difference
Sample	**Parameter**	**0**	**10**	**(%)**
LM-1	pH	7.7	7.3	6
	Conductivity (umhos/cm)	425.4	324.3	24
	Alkalinity (mg/l CaCO3)	148	124	16
	Hardness (mg/l CaCO3)	118	91	23
	Ammonia (mg/l NH3)	4.37	0.13	97
LM-2	pH	7.7	7.5	3
	Conductivity (umhos/cm)	446.6	339.4	24
	Alkalinity (mg/l CaCO3)	134	112	16
	Hardness (mg/l CaCO3)	121	99	18
	Ammonia (mg/l NH3)	2.83	0.17	94
LM-3	pH	7.9	6.7	15
	Conductivity (umhos/cm)	501.0	382.7	24
	Alkalinity (mg/l CaCO3)	162	164	1
	Hardness (mg/l CaCO3)	168	101	40
	Ammonia (mg/l NH3)	3.47	0.11	97
LM-4	pH	7.8	7.3	6
	Conductivity (umhos/cm)	450.2	343.2	24
	Alkalinity (mg/l CaCO3)	164	134	18
	Hardness (mg/l CaCO3)	113	85	25
	Ammonia (mg/l NH3)	3.70	0.05	99
LM-6	pH	8.2	7.8	4
	Conductivity (umhos/cm)	510.0	397.2	22
	Alkalinity (mg/l CaCO3)	168	129	23
	Hardness (mg/l CaCO3)	146	117	20
	Ammonia (mg/l NH3)	3.90	0.29	93
LM-7	pH	7.9	7.0	11
	Conductivity (umhos/cm)	446.7	344.8	23
	Alkalinity (mg/l CaCO3)	156	152	3
	Hardness (mg/l CaCO3)	112	89	21
	Ammonia (mg/l NH3)	2.58	0.06	98
LM-8	pH	7.6	8.1	7
	Conductivity (umhos/cm)	467.0	366.7	21
	Alkalinity (mg/l CaCO3)	134	111	17
	Hardness (mg/l CaCO3)	123	97	21
	Ammonia (mg/l NH3)	3.86	0.31	92
LM-9	pH	8.0	8.2	3
	Conductivity (umhos/cm)	458.0	388.6	15
	Alkalinity (mg/l CaCO3)	183	145	21
	Hardness (mg/l CaCO3)	111	93	16
	Ammonia (mg/l NH3)	3.60	0.02	99

Table E-1. (Cont.) Summary of Initial and Final Chemical Measurements for *Hyalella azteca* in Lake Macatawa Sediments

		Day		Difference
Sample	**Parameter**	**0**	**10**	**(%)**
LM-10	pH	7.8	8.1	4
	Conductivity (umhos/cm)	455.0	351	23
	Alkalinity (mg/l CaCO3)	119	105	12
	Hardness (mg/l CaCO3)	105	97	8
	Ammonia (mg/l NH3)	6.30	0.05	99
LM-11	pH	7.8	8.0	3
	Conductivity (umhos/cm)	406.0	336.4	17
	Alkalinity (mg/l CaCO3)	122	97	20
	Hardness (mg/l CaCO3)	103	85	17
	Ammonia (mg/l NH3)	3.94	0.03	99
LM-12	pH	8.2	8.1	2
	Conductivity (umhos/cm)	417.0	362	13
	Alkalinity (mg/l CaCO3)	132	111	16
	Hardness (mg/l CaCO3)	117	101	14
	Ammonia (mg/l NH3)	5.40	0.08	99
LM-14	pH	7.6	8.1	7
	Conductivity (umhos/cm)	410.0	339.1	17
	Alkalinity (mg/l CaCO3)	140	99	29
	Hardness (mg/l CaCO3)	102	89	13
	Ammonia (mg/l NH3)	3.08	0.10	97
LM-15	pH	7.8	8.1	4
	Conductivity (umhos/cm)	445.0	356.1	20
	Alkalinity (mg/l CaCO3)	114	109	4
	Hardness (mg/l CaCO3)	122	97	20
	Ammonia (mg/l NH3)	6.10	0.19	97

Table E-2. Summary Of Daily Temperature And Dissolved Oxygen Measurements For Hyallela azteca In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-1	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.8	5.84	22.5	6.44	22.6	6.15	23.1	5.71	22.0	5.82	22.0	5.77	23.7	6.27	23.1	6.67	22.9	6.93	22.4	6.94
PM	22.9	5.69	22.4	4.61	23.5	4.26	22.6	6.35	24.0	5.86	22.8	5.47	22.3	6.66	22.4	5.41	21.9	7.34	22.1	7.67	22.8	7.85
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-2	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.3	5.95	22.3	6.51	22.6	6.38	22.4	5.71	22.3	5.51	23.4	5.49	23.1	6.14	23.2	6.52	23.3	6.46	22.3	7.08
PM	22.0	6.16	23.8	4.90	23.3	4.18	22.0	6.38	23.8	5.86	22.5	2.34	23.4	6.36	22.4	5.32	22.5	7.26	22.3	7.66	23.4	7.50
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-3	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			24.1	5.29	23.3	6.35	23.1	6.55	23.1	5.75	22.4	5.59	22.9	5.40	23.1	6.08	23.1	6.47	23.1	6.40	22.2	7.19
PM	22.1	6.03	22.9	4.81	22.7	4.82	22.0	6.57	24.6	5.65	22.1	6.10	22.7	6.58	22.4	5.62	22.4	7.38	22.1	7.77	22.6	7.60
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-4	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.5	5.50	22.7	3.38	22.5	6.80	22.9	6.23	22.4	6.32	22.4	5.44	23.1	6.18	23.6	6.47	23.2	6.97	22.3	7.48
PM	22.9	5.66	22.9	4.81	23.9	4.34	22.0	8.65	23.5	5.68	22.2	5.99	22.5	6.75	22.1	5.81	22.4	7.28	22.3	7.57	22.0	7.77
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-6	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.8	7.52	21.9	8.18	22.6	8.26	22.6	7.91	22.5	7.22	22.7	7.33	22.3	7.83	22.2	8.46	21.8	9.14	22.3	8.90
PM	21.9	0.45	22.5	6.52	23.1	5.25	22.7	6.45	24.6	6.45	22.0	7.68	19.7	8.74	22.4	6.74	22.7	9.05	21.8	9.55	22.1	7.32

Table E-2 (Cont). Summary Of Daily Temperature And Dissolved Oxygen Measurements For Hyallela azteca In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-7	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.8	5.56	23.5	6.15	23.2	6.23	22.1	5.98	22.5	6.06	21.9	5.42	23.1	6.37	23.4	6.51	23.5	6.60	22.6	7.39
PM	22.9	5.69	22.6	5.02	22.5	4.16	22.5	8.32	24.2	5.81	22.4	5.81	22.7	6.78	22.6	5.54	22.3	7.25	22.5	7.97	22.6	8.21

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-8	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.9	5.39	22.0	6.03	23.0	6.13	22.5	5.50	22.4	5.73	22.0	5.16	22.9	6.04	22.8	6.44	22.3	6.40	22.1	7.42
PM	22.4	5.56	21.9	4.86	22.8	4.66	22.5	6.20	22.8	5.80	22.4	5.36	22.5	5.63	22.2	5.41	22.0	7.20	21.9	7.99	22.0	7.03

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-9	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.2	5.70	23.1	6.35	22.5	6.44	22.7	6.06	22.4	5.74	22.2	4.19	22.8	6.27	22.9	6.68	22.5	6.22	22.4	6.85
PM	22.4	5.80	21.9	4.71	23.0	5.03	22.2	6.52	22.9	5.29	22.1	5.88	22.6	6.74	22.4	5.79	21.8	7.38	21.9	7.83	22.4	7.39

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-10	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.9	5.61	22.7	6.26	22.7	6.78	22.6	5.24	22.0	5.64	23.0	5.52	22.2	6.01	23.3	6.58	23.3	6.97	21.8	7.18
PM	22.6	5.72	21.9	5.15	23.0	5.08	21.9	6.53	23.3	5.94	22.4	6.27	21.9	7.24	22.6	6.03	21.8	7.25	22.5	7.57	22.1	7.49

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-11	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.3	5.83	22.2	6.38	22.9	6.33	22.7	6.06	22.6	5.66	22.4	5.74	22.2	5.61	22.7	6.84	22.0	7.04	21.8	7.64
PM	22.9	5.99	22.3	4.79	23.0	5.63	22.5	6.28	23.8	6.37	22.3	6.16	22.7	6.90	22.4	5.69	22.4	7.42	22.7	7.29	22.0	7.74

Table E-2 (Cont). Summary Of Daily Temperature And Dissolved Oxygen Measurements For Hyallela azteca In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-12	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.5	5.94	22.6	6.39	22.6	6.73	22.1	6.09	21.8	5.90	22.5	5.98	22.2	6.25	22.5	6.59	22.2	6.56	22.1	7.49
PM	22.7	5.67	22.6	5.21	23.3	5.34	22.6	6.58	24.3	5.98	22.2	6.00	22.5	6.69	21.9	5.62	22.5	7.66	22.4	7.85	22.7	8.30
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-14	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.7	6.14	23.1	6.03	22.9	6.62	22.9	5.76	22.5	5.57	22.2	5.43	23.1	5.89	23.3	6.23	22.7	6.86	21.9	7.19
PM	22.1	5.80	22.0	5.04	23.0	5.22	23.5	5.99	23.2	6.14	22.5	5.86	21.9	6.43	22.5	5.48	22.5	7.72	22.1	7.66	22.4	7.89
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-15	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.7	5.51	22.2	6.24	22.2	5.97	22.0	5.89	22.3	4.98	22.4	5.62	22.6	5.75	23.4	6.23	22.3	6.85	22.4	7.15
PM	22.4	5.21	22.3	4.90	23.0	5.38	21.8	6.26	23.3	6.00	22.0	5.35	22.7	6.26	22.6	5.60	22.1	7.10	22.7	7.92	21.8	7.11

Table E-3. Summary of Initial and Final Chemical Measurements for *Chironomus tentans* in Lake Macatawa Sediments

		Day		Difference
Sample	**Parameter**	**0**	**10**	**(%)**
LM-1	pH	8.2	8.2	0
	Conductivity (umhos/cm)	408.2	309.1	24
	Alkalinity (mg/l CaCO3)	132	103	22
	Hardness (mg/l CaCO3)	123	91	26
	Ammonia (mg/l NH3)	4.37	0.09	98
LM-2	pH	8.2	8.3	0
	Conductivity (umhos/cm)	469	354.2	24
	Alkalinity (mg/l CaCO3)	137	113	18
	Hardness (mg/l CaCO3)	119	97	18
	Ammonia (mg/l NH3)	3.17	0.07	98
LM-3	pH	8.2	8.2	0
	Conductivity (umhos/cm)	410.0	379.9	7
	Alkalinity (mg/l CaCO3)	131	117	11
	Hardness (mg/l CaCO3)	122	101	17
	Ammonia (mg/l NH3)	3.89	0.07	98
LM-4	pH	8.3	8.2	2
	Conductivity (umhos/cm)	454.3	387	15
	Alkalinity (mg/l CaCO3)	144	115	20
	Hardness (mg/l CaCO3)	119	103	13
	Ammonia (mg/l NH3)	4.21	0.07	98
LM-6	pH	8.6	8.5	1
	Conductivity (umhos/cm)	451.0	380.8	16
	Alkalinity (mg/l CaCO3)	160	140	13
	Hardness (mg/l CaCO3)	327	105	68
	Ammonia (mg/l NH3)	3.23	0.01	100
LM-7	pH	8.3	8.1	3
	Conductivity (umhos/cm)	478.9	426.6	11
	Alkalinity (mg/l CaCO3)	148	113	24
	Hardness (mg/l CaCO3)	127	112	12
	Ammonia (mg/l NH3)	2.82	0.07	98
LM-8	pH	8.2	8.0	3
	Conductivity (umhos/cm)	466.8	395.5	15
	Alkalinity (mg/l CaCO3)	140	115	18
	Hardness (mg/l CaCO3)	118	108	8
	Ammonia (mg/l NH3)	5.52	0.06	99
LM-9	pH	8.2	8.2	1
	Conductivity (umhos/cm)	443.0	389.7	12
	Alkalinity (mg/l CaCO3)	131	117	11
	Hardness (mg/l CaCO3)	120	108	10
	Ammonia (mg/l NH3)	3.97	0.08	98

Table E-3. (Cont.) Summary of Initial and Final Chemical Measurements for *Chironomus tentans* in Lake Macatawa Sediments

		Day		Difference
Sample	**Parameter**	**0**	**10**	**(%)**
LM-10	pH	8.3	8.0	3
	Conductivity (umhos/cm)	423.0	397.6	6
	Alkalinity (mg/l CaCO3)	144	117	19
	Hardness (mg/l CaCO3)	121	105	13
	Ammonia (mg/l NH3)	7.46	0.07	99
LM-11	pH	8.3	8.1	2
	Conductivity (umhos/cm)	488.3	400	18
	Alkalinity (mg/l CaCO3)	140	119	15
	Hardness (mg/l CaCO3)	120	109	9
	Ammonia (mg/l NH3)	4.09	0.05	99
LM-12	pH	8.2	8.2	0
	Conductivity (umhos/cm)	507.0	417.4	18
	Alkalinity (mg/l CaCO3)	130	129	1
	Hardness (mg/l CaCO3)	118	110	7
	Ammonia (mg/l NH3)	5.72	0.04	99
LM-14	pH	8.6	8.2	5
	Conductivity (umhos/cm)	474.6	380.6	20
	Alkalinity (mg/l CaCO3)	142	113	20
	Hardness (mg/l CaCO3)	127	107	16
	Ammonia (mg/l NH3)	3.86	0.03	99
LM-15	pH	8.3	8.1	2
	Conductivity (umhos/cm)	418.0	384.1	8
	Alkalinity (mg/l CaCO3)	156	125	20
	Hardness (mg/l CaCO3)	129	110	15
	Ammonia (mg/l NH3)	8.62	0.04	100

Table E-4. Summary Of Daily Temperature And Dissolved Oxygen Measurements For Chironomus tentans In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-1	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			23.3	5.40	23.7	5.28	22.1	5.89	22.0	4.26	23.0	5.31	23.0	6.52	22.4	7.39	23.6	6.56	24.0	7.00	22.9	2.81
PM	22.8	6.68	22.3	5.21	22.2	4.70	22.7	4.26	22.6	5.54	22.1	6.27	22.1	6.19	22.5	7.49	22.8	6.37	22.3	6.54	22.2	8.12

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-2	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.8	5.63	22.4	5.37	23.1	5.90	22.6	4.93	22.4	5.27	22.8	6.63	23.7	7.23	23.4	6.78	23.5	7.27	22.8	7.15
PM	23.0	7.22	21.9	5.66	22.2	4.91	21.9	4.93	22.3	5.60	22.3	6.02	22.0	6.67	22.8	7.62	22.2	6.76	22.6	7.30	22.5	8.15

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-3	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.3	5.15	22.4	4.93	22.2	5.86	23.1	4.65	22.7	5.35	23.6	6.49	23.7	6.45	23.4	6.59	24.4	6.85	23.1	5.66
PM	22.8	7.09	22.4	5.29	22.4	4.90	22.0	4.65	21.9	5.51	22.5	6.02	22.9	5.92	22.6	7.25	22.2	5.92	22.1	7.33	21.8	6.29

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-4	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.3	5.49	22.0	5.10	22.1	6.08	22.0	4.65	23.1	5.15	23.7	6.65	23.9	6.65	23.4	6.75	22.3	6.78	23.2	7.08
PM	21.8	7.45	21.9	5.42	22.6	5.05	22.0	4.65	22.5	5.36	22.7	6.01	22.7	6.47	22.4	6.88	22.4	7.20	22.3	5.42	21.9	6.16

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-6	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.8	6.52	22.9	6.11	22.4	7.40	21.8	5.30	23.3	5.76	22.8	5.50	22.3	4.57	23.4	9.33	21.9	10.0	22.6	10.6
PM	22.6	1.72	22.5	3.31	22.5	5.19	22.6	5.30	22.3	5.86	21.8	8.37	22.0	9.10	22.2	9.87	22.3	5.29	18.7	10.9	22.4	10.1

Table E-4. Summary Of Daily Temperature And Dissolved Oxygen Measurements For Chironomus tentans In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-7	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.7	5.30	22.1	4.91	22.8	5.59	22.2	4.90	23.1	5.32	23.7	6.12	23.4	6.69	22.9	6.45	23.1	6.48	23.6	5.77
PM	22.0	7.05	22.4	5.34	22.7	4.72	22.1	4.90	22.4	5.52	22.3	6.11	22.0	6.70	21.8	4.47	22.0	6.87	22.6	7.04	22.5	6.42
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-8	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.0	5.13	22.5	4.31	22.3	5.04	22.3	4.44	22.4	4.94	23.5	4.81	22.7	5.60	22.7	4.62	22.3	4.15	22.9	3.58
PM	21.8	6.97	22.1	4.97	22.6	5.19	21.9	4.44	22.7	5.18	22.4	4.90	22.5	5.92	21.8	5.84	22.5	4.68	22.3	6.18	22.6	4.86
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-9	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.7	5.10	21.8	5.15	22.2	6.08	22.1	4.93	21.9	5.30	22.9	6.53	22.8	6.28	23.2	5.82	22.6	6.98	22.0	6.75
PM	22.5	6.59	22.5	4.94	22.6	5.61	21.9	4.93	22.3	5.53	22.1	6.67	22.0	6.93	21.8	6.74	22.8	6.28	19.9	7.18	22.6	6.69
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-10	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.6	5.38	22.4	5.26	21.9	6.11	22.5	4.55	23.6	5.10	23.4	6.52	23.2	6.45	22.6	6.27	23.4	6.07	23.2	6.50
PM	22.0	6.78	22.4	5.08	22.7	5.19	21.9	4.55	22.7	5.13	22.0	6.62	22.7	6.50	22.4	6.83	19.6	7.08	19.9	6.78	22.0	6.60
Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-11	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.6	5.51	22.7	5.20	22.1	6.01	22.7	4.64	22.3	5.23	22.7	6.59	22.5	6.91	22.8	5.91	22.7	6.12	22.3	6.68
PM	21.8	7.86	23.6	4.99	22.2	5.38	22.9	4.64	22.7	5.44	22.0	6.43	22.0	6.88	22.0	6.75	22.4	7.39	18.8	8.10	22.4	7.50

Table E-4. Summary Of Daily Temperature And Dissolved Oxygen Measurements For Chironomus tentans In The Solid Phase Toxicity Tests For Lake Macatawa Sediments

Sample:	Day																					
	0		1		2		3		4		5		6		7		8		9		10	
LM-12	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
AM			22.3	5.60	22.5	5.12	22.7	6.20	22.5	4.63	22.5	2.04	22.6	6.50	22.5	6.37	22.6	6.11	22.7	6.79	22.3	6.77
PM	22.5	7.47	23.6	4.98	22.1	6.70	22.8	4.63	22.8	5.42	21.8	6.11	22.3	6.83	22.3	6.97	22.1	6.35	22.3	7.91	22.6	7.00
Sample:																						
	Day																					
LM-14	0		1		2		3		4		5		6		7		8		9		10	
	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
AM	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
PM			22.4	5.34	22.2	2.30	22.2	6.02	21.9	4.52	22.3	2.18	23.2	6.35	23.2	5.63	22.7	6.64	23.3	5.94	22.1	6.84
Sample:	21.8	7.37	22.5	5.36	22.1	6.60	22.2	4.52	22.4	5.56	22.9	6.73	21.9	6.62	22.4	7.13	22.0	6.60	22.2	7.84	22.5	7.22
	Day																					
LM-15	0		1		2		3		4		5		6		7		8		9		10	
	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO
AM	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l	°C	mg/l
PM			22.3	4.75	22.4	4.67	21.8	5.60	22.3	4.40	22.3	5.02	22.9	5.04	22.9	4.66	22.6	5.49	22.9	5.23	22.3	5.08
PM	22.7	7.32	21.8	5.16	22.1	5.81	22.2	4.40	22.3	5.31	22.0	5.28	22.6	5.40	21.8	5.26	19.9	5.62	22.1	5.67	22.3	5.84

Appendix F. Summary Of Benthic Macroinvertebrate Results For Lake Macatawa July 2002

TABLE F-1. BENTHIC MACROINVERTEBRATE RESULTS FOR LAKE MACATAWA JULY 2002.

Site ID	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
Species:												
Tubificidae												
Limnodrilus hoffmeisteri	218	87	0	0	87	0	392	348	87	87	218	305
Limnodrilus cervix	131	87	0	0	0	0	0	87	44	0	0	0
Limnodrilus claparedeianus	174	44	174	218	0	0	44	0	44	0	44	44
Limnodrilus sp.	87	44	0	44	0	0	0	0	0	0	0	44
Aulodrilus pigueti	0	87	44	0	44	87	0	0	0	0	0	0
Aulodrilus limnobius	0	0	0	0	0	0	0	0	0	0	0	0
Aulodrilus pluriseta	0	0	0	0	0	0	0	0	0	0	0	0
Ilyodrilus templetoni	0	0	0	0	0	0	0	0	0	0	0	0
Potamothrix moldaviensis	0	0	0	0	44	0	0	0	0	0	0	0
Quistadrilus multisetosus	0	0	0	0	87	0	174	305	44	44	0	0
Branchiura sowerbyi	0	0	0	0	0	0	0	0	0	0	0	0
Tubifex tubifex	0	0	0	0	0	0	0	0	0	0	0	0
Tubificidae w/o HC	827	1871	609	1523	2219	783	2784	2349	1305	392	1305	1610
Tubificidae w/ HC	44	87	87	131	87	44	0	0	0	0	0	44
Nadidae	0	0	0	0	0	0	0	0	0	0	0	0
Nais pardalis	0	0	0	0	0	44	0	0	0	0	0	0
Nais pseudobtusa	0	348	218	0	0	0	0	0	0	0	0	0
Nais variabilis	0	0	0	0	44	44	0	0	0	0	0	0
Naididae sp.	0	131	0	87	0	0	0	0	0	0	0	0
Enchytraeidae sp.	0	0	0	44	0	0	0	0	0	0	0	0
Lumbriculidae sp.	0	0	0	0	0	44	0	0	0	0	0	0
Nematoda sp.	0	0	0	0	0	0	0	0	0	44	0	0
Pelecypoda	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae *Sphaerium*	44	0	0	0	0	0	0	0	0	0	0	0
Juvenile	0	0	0	44	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0
Bithyniidae	0	0	0	0	87	0	0	0	0	0	0	0
Diptera	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae (pupae)	0	87	0	0	44	44	174	44	87	0	0	131
Chironomidae (mature) n/a	0	44	0	0	0	0	87	261	87	0	0	0
Unidentified pupae	0	0	0	0	0	0	0	0	0	44	0	0
Ceratopognidae probezzia	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae Head Mounts	0	0	0	0	0	0	0	0	0	0	0	0
Ablabesmyia	44	44	0	1392	827	696	0	0	0	0	0	0
Chironomus	348	914	827	0	0	0	392	653	392	87	87	305
Clinotanypus	0	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus	0	0	0	0	0	0	87	44	87	44	131	87
Cryptochironomus	261	305	392	218	740	174	131	131	44	261	131	87
Cryptocladopelma	0	0	87	0	0	44	87	0	0	0	0	0
Dicrotendipes	0	44	87	44	0	0	0	0	0	0	0	0
Glyptotendipes	44	0	0	0	87	87	0	0	0	0	0	0
Paracladopelma	0	44	0	0	0	0	0	0	0	0	0	0
Paratendipes	0	44	0	0	0	0	0	0	0	0	0	0
Polypedilum	0	44	44	131	44	87	0	0	0	0	0	0
Procladius	44	348	218	87	44	0	522	131	348	87	218	740
Psectrotanypus	0	0	0	0	0	0	0	0	0	0	0	0
Tanypus	0	0	44	0	44	0	0	0	0	0	0	0
Thienemannemyia	0	44	218	44	0	0	0	0	0	0	0	0
unknown	305	261	131	261	44	87	174	44	305	44	87	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus	0	44	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Asellus caecidotea	44	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0	0	0	0	0	0	0
Empty Case	0	0	44	0	44	0	0	0	0	0	0	0
Leptoceridae setodes	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0
Larvae (unidentifiable)	0	0	0	44	0	0	0	0	0	0	0	0

TABLE F-1 (CONTINUED). BENTHIC MACROINVERTEBRATE RESULTS FOR LAKE MACATAWA JULY 2002.

Site ID	6a	6b	6c	7a	7b	7c	8a	8b	8c	9a	9b	9c
Species:												
Tubificidae												
Limnodrilus hoffmeisteri	218	44	174	87	44	87	131	218	131	87	0	174
Limnodrilus cervix	0	44	0	0	0	0	0	0	0	0	87	44
Limnodrilus claparedeianus	392	87	305	0	87	131	392	87	218	522	305	174
Limnodrilus sp.	87	0	0	44	44	0	0	87	0	131	174	0
Aulodrilus pigueti	0	0	0	0	0	0	0	0	0	0	0	0
Aulodrilus limnobius	0	0	0	0	0	0	0	0	0	0	0	0
Aulodrilus pluriseta	0	0	0	0	0	0	0	0	0	0	44	0
Ilyodrilus templetoni	0	0	44	0	0	0	0	0	0	0	0	0
Potamothrix moldaviensis	0	0	0	0	0	0	0	0	0	0	0	0
Quistadrilus multisetosus	0	0	0	87	44	44	0	0	0	0	0	0
Branchiura sowerbyi	0	0	0	0	0	0	0	0	0	0	0	0
Tubifex tubifex	0	44	0	0	0	0	0	0	0	0	0	0
Tubificidae w/o HC	1349	1479	1392	2306	522	740	4872	2741	1784	2262	5786	5046
Tubificidae w/ HC	0	87	44	0	0	0	44	0	0	0	131	131
Nadidae	0	0	0	0	0	0	0	0	0	0	0	0
Nais pardalis	0	0	0	0	0	0	0	0	0	0	0	0
Nais pseudobtusa	0	0	0	0	0	0	0	0	0	0	0	0
Nais variabilis	0	0	0	0	0	0	0	0	0	0	0	0
Naididae sp.	0	0	0	0	0	0	0	0	0	0	0	0
Enchytraeidae sp.	0	0	0	0	0	0	0	0	0	0	0	0
Lumbriculidae sp.	0	0	0	0	0	0	44	0	0	0	0	0
Nematoda sp.	0	0	0	0	0	0	0	0	0	0	0	0
Pelecypoda	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae *Sphaerium*	0	0	0	0	0	0	0	0	0	44	0	0
Juvenile	44	0	44	0	0	44	0	44	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0
Bithyniidae	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae (pupae)	0	0	0	44	87	44	0	0	44	0	0	131
Chironomidae (mature) n/a	44	0	0	0	0	0	0	0	44	0	0	0
Unidentified pupae	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopognidae probezzia	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae Head Mounts	0	0	0	0	0	0	0	0	0	0	0	0
Ablabesmyia	0	0	0	0	0	0	0	0	0	0	0	0
Chironomus	87	44	44	218	131	44	87	44	44	261	305	348
Clinotanypus	0	0	0	0	0	44	44	44	0	0	0	0
Coelotanypus	0	44	131	348	174	218	0	0	44	0	0	0
Cryptochironomus	0	0	44	87	435	87	0	0	44	44	131	87
Cryptocladopelma	0	0	0	44	0	0	0	0	0	0	0	44
Dicrotendipes	0	0	0	0	0	0	0	0	0	0	0	0
Glyptotendipes	44	0	0	0	0	0	0	0	0	0	0	0
Paracladopelma	0	0	0	0	0	0	0	0	0	0	0	0
Paratendipes	0	0	0	0	0	0	0	0	0	0	0	0
Polypedilum	0	0	0	0	0	0	0	0	0	0	0	0
Procladius	174	0	87	131	218	348	87	0	44	0	44	44
Psectrotanypus	0	44	0	0	0	0	0	0	0	0	0	0
Tanypus	0	0	0	0	0	0	0	0	0	0	0	0
Thienemannemyia	0	0	0	0	0	0	0	0	0	0	0	0
unknown	44	0	0	44	0	131	0	0	0	44	87	44
Gammaridae	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0
Asellus caecidotea	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0	0	0	0	0	0	0
Empty Case	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae setodes	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0
Larvae (unidentifiable)	0	0	0	0	0	0	0	0	0	0	0	0

TABLE F-1 (CONTINUED). BENTHIC MACROINVERTEBRATE RESULTS FOR LAKE MACATAWA JULY 2002.

Site ID	10a	10b	10c	11a	11b	11c	12a	12b	12c	14a	14b	14c	15a	15b	15c
Species:															
Tubificidae															
Limnodrilus hoffmeisteri	131	174	44	44	44	0	0	0	0	44	87	0	44	174	131
Limnodrilus cervix	0	44	0	0	0	0	0	0	0	0	0	0	0	44	0
Limnodrilus claparedeianus	174	609	348	174	131	0	44	0	0	261	44	87	0	914	435
Limnodrilus sp.	0	87	44	0	0	0	0	0	0	0	0	0	0	44	261
Aulodrilus pigueti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulodrilus limnobius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aulodrilus pluriseta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilyodrilus templetoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potamothrix moldaviensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Quistadrilus multisetosus	0	0	44	0	0	0	0	0	0	0	0	44	0	0	0
Branchiura sowerbyi	0	0	0	0	0	0	0	0	0	44	0	0	0	0	0
Tubifex tubifex	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tubificidae w/o HC	1218	5525	2045	2219	1653	218	522	914	87	1740	870	1044	870	4785	3567
Tubificidae w/ HC	0	44	0	44	0	0	0	44	0	44	0	0	0	44	87
Nadidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nais pardalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nais pseudobtusa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nais variabilis	0	0	0	44	0	0	0	0	0	0	0	0	0	0	0
Naididae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enchytraeidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbriculidae sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pelecypoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae *Sphaerium*	392	44	0	1044	479	0	44	87	0	87	261	0	522	305	44
Juvenile	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bithyniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae (pupae)	44	44	0	0	0	0	0	0	0	0	0	0	0	44	0
Chironomidae (mature) n/a	0	0	0	0	0	0	0	44	0	0	0	0	44	87	0
Unidentified pupae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44
Ceratopognidae probezzia	0	0	0	0	0	0	0	44	0	0	44	0	0	0	0
Chironomidae Head Mounts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ablabesmyia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomus	87	348	131	348	261	479	261	261	305	827	827	609	2567	3698	3567
Clinotanypus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coelotanypus	0	0	0	0	44	44	218	174	218	0	0	0	0	0	0
Cryptochironomus	0	87	0	0	0	0	0	0	87	261	174	305	0	87	44
Cryptocladopelma	0	0	0	0	0	0	0	44	44	0	0	44	0	0	44
Dicrotendipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyptotendipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paracladopelma	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paratendipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polypedilum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Procladius	0	0	0	0	0	0	0	0	0	0	0	0	131	174	44
Psectrotanypus	0	0	0	0	0	0	0	0	0	87	44	0	0	0	0
Tanypus	0	0	0	0	0	0	0	44	0	0	0	0	0	0	0
Thienemannemyia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
unknown	44	0	44	0	0	44	261	261	174	44	44	44	174	740	696
Gammaridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asellus caecidotea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Empty Case	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae setodes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Larvae (unidentifiable)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0