# Preliminary Investigation Of The Extent Of Sediment Contamination In Manistee Lake

By
**Dr. Richard Rediske**
Principle Investigator
And
**Dr. John Gabrosek, Dr. Cynthia Thompson,**
**Carissa Bertin, and Jessica Blunt**
Annis Water Resources Institute
Grand Valley State University
One Campus Drive
Allendale, MI 49401

**Dr. Peter G. Meier**
University Of Michigan
School Of Public Health I
Ann Arbor, MI 48106

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**PROJECT OFFICER:**
Dr. Marc Tuchman
U. S. Environmental Protection Agency
Great Lakes National Program Office
77 West Jackson Boulevard
Chicago, IL 60604-3590

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## Project Team

### EPA Project Officer

Dr. Marc Tuchman USEPA GLNPO

### Principle Scientists

| | | |
|---|---|---|
| Dr. Richard Rediske | GVSU | Sediment Chemistry |
| Dr. John Gabrosek | GVSU | Statistical Methods |
| Dr. Cynthia Thompson | GVSU | Toxicology |
| Dr. Peter Meier | U of M | Benthic Macroinvertebrates |

Project technical assistance was provided by the following individuals at GVSU:

Shanna McCrumb
Mike Sweik
Eric Andrews
Betty Doyle
Tonya Cnossen

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R/V *Mudpuppy* (USEPA) J. Bohnam

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# TABLE OF CONTENTS

Appendices

# LIST OF TABLES

# LIST OF FIGURES

## Executive Summary

A preliminary investigation of the nature and extent of sediment contamination in Manistee Lake was performed. The investigation utilized the sediment quality triad approach with integrated assessments of chemistry, toxicity, and benthic macroinvertebrates. Diverse populations of benthic macroinvertebrates and limited evidence of anthropogenic chemical contamination were found in the control locations near the Manistee and Little Manistee Rivers (upper northeast and lower southeast sections of the lake). The remainder of Manistee Lake was characterized by depauperate benthic communities and sediments impacted by the influx of contaminated groundwater and the presence of oils and polycyclic aromatic hydrocarbons (PAH). The influx of contaminated groundwater and brines from surface discharge were evident by the presence of chemical stratification in the lower hypolimnion. A layer (approximately 5’) of water with high specific conductance was present at the bottom of the lake in July 1998. High levels of chloride were also found in the sediments. Areas of intense brine intrusion were found one mile north of the Martin Marietta facility where abandon brine wells and transmission pipelines were located across the lake from Hardy Salt. The chloride levels in the remaining stations suggested a more diffuse venting of contaminated groundwater and the formation of a density gradient in the sediments. Chloride concentrations increased with sediment depth.

Sediment oil contamination and the detection of elevated levels of PAH compounds indicated extensive hydrocarbon pollution was still present in Manistee Lake. The levels reported for oils were similar to the amounts found in 1975. Of the 12 sites investigated in areas of anthropogenic impact, 10 locations exceeded the Probable Effect Concentrations (PECs) for individual PAH compounds. The highest level of PAH compounds was near Morton Chemical (M-13: 29.4 mg/kg) and the highest level of oil was found near Manistee Drop Forge (M-6: 26,000 mg/kg). Elevated levels of metals were found at all stations however concentrations were below the PEC guidelines. Resin acids were found to be distributed throughout Manistee Lake. The highest levels were found in the 20”-40” core section downstream from the old PCA outfall. The distribution of resin acids in the surficial sediments also supported the hypothesis of a diffuse venting of groundwater from the PCA site. Resin acids were not detected in the fish samples collected. The diffuse nature of the groundwater influx, the presence chemical stratification during the summer, and the high levels of oil contamination in the sediments create conditions that limit the exposure of fish populations to these chemicals.

Sediment toxicity to amphipods and midges was observed at M-6 and M-13. These stations had the highest levels of hydrocarbon oils and PAH compounds. Amphipod toxicity was measured at five additional sites, all containing levels of individual PAH compounds exceeding PEC concentrations.

A variety of statistical techniques were employed to examine the difference between the control population and locations impacted by the PCA groundwater plume and the salt brine companies. The results showed a clear difference between diversity and trophic status with respect to the controls and the impacted sites. ANOVA results confirmed that the impacted populations were less diverse and dominated by pollution tolerant organisms. The ANOVA

results also suggested that the brine-impacted sites as a group, have benthic macroinvertebrate populations with a lower trophic status than benthos collected in the area influenced by the PCA/Martin Marietta groundwater plume.

## 1.0 Introduction

Manistee Lake is a large drowned river mouth (929 acres) that is directly connected to Lake Michigan by a navigation channel (Figure 1.1). The main basin of the lake is characterized by steep banks and water contours with a maximum depth of 49 feet. An extensive wetland complex is located in the northern part of the lake in the area where the Manistee River enters the system. Wetlands are also located in the southern basin of the lake near the confluence of the Little Manistee River. Water flows in a northwesterly direction in Manistee Lake up to the channel area across from the Manistee River wetlands. At this point, the water flows westward to Lake Michigan. The watershed has a drainage basin of over 2000 square miles and contains an important fishery in this region of the Great Lakes. While most rivers in this watershed are classified as relatively pristine trout streams, substantial anthropogenic activities have adversely affected Manistee Lake. For over 125 years, industrial discharges from lumbering, leather tanning, brine extraction, and pulp/cardboard production facilities have impacted water quality and contaminated the sediments. Investigations conducted by the Michigan Water Resources Commission (Surber 1953) and the Michigan Department of Natural Resources (Grant 1975) found depauperate benthic macroinvertebrate communities in a majority of Manistee Lake. The only locations that contained pollution intolerant organisms were at the mouths of the Little Manistee and the Manistee River. The Packaging Corporation of America (PCA) Superfund Site is of particular concern due to an extensive groundwater discharge of Kraft black liquor that enters the southeastern basin of the lake. Process water from the Kraft operations was discharged into a series of eight unlined lagoons approximately 2500 ft from the lake. These lagoons are hydraulically connected to Manistee Lake by a sand/gravel aquifer that ranges from 40 - 200 ft thick (FTC&H 1991). From 1951 to 1976, approximately 7 billion gallons of effluent and process wastes were discharged into the lagoons. A detailed investigation of the groundwater discharge from the lagoons was conducted in August 1993 (Camp, Dresser & McKee and Battelle Great Lakes Environmental Center 1993). Sediment pore water and groundwater collected from wells installed beneath the lake bottom (50 - 200 ft) was found to be toxic to *Ceriodaphnia dubia*. Toxicity of sediments from this area and the extent of impact on the current benthic community have not been evaluated.

Resin acids have been identified as one of the more toxic components of Kraft effluents (Zanella 1983 and Sunito et al. 1988). This group of compounds has been shown to be toxic to fish (Leach and Thankore 1976 and Johnsen et al. 1997) and to exhibit estrogenic activity in trout (Mellenen et al. 1996). Nimi and Lee (1992) found certain resin acids to bioaccumulate in caged fish studies. Burggraaf et al. (1996) found similar levels of bioaccumulation in mussels. Since resin acids were previously reported in groundwater and sediment samples near a Kraft mill (Wilkins et al. 1996 and Travendale et al. 1995), it is of ecological importance to evaluate the extent of contamination of these compounds in the sediments and biota of Manistee Lake.

In addition to the area near PCA Superfund Site, other locations in Manistee Lake are affected by historic and current discharges from several salt brine extraction facilities and

**FIGURE 1.1 MANISTEE LAKE**

foundry operations. Many of these facilities have initiated remediation programs to eliminate and/or reduce the amount of contamination entering the lake. Since the last assessment of the lake was conducted in 1975, it is important to examine the current nature and extent of sediment contamination and the status of the health of the benthic community. This project utilized a series of sampling stations that are in the area influenced by the groundwater discharge plume from the PCA lagoons. In addition, a group of sediment sampling stations that reflect deposition areas near historic industrial locations, wastewater treatment outfalls, and Michigan 307 sites were examined. The study protocol followed the sediment quality triad approach (McDonald 1991) and focused on sediment chemistry, sediment toxicity, and the health of the benthic macroinvertebrate community. The information from this investigation will be important for the determination of areas that may require further delineation and the prioritization of remedial action and habitat restoration activities.

## 1.1 History Of Anthropogenic Activities In Manistee Lake

Manistee Lake has been impacted by industrial activity since 1841 when the first sawmill was constructed on the shore (Grant 1975). The abundance of timber resources led to the construction of many sawmills and ancillary industries such as leather tanneries and pulp mills. The first pulp mill was built in 1917, after the depletion of the areas white pine trees resulted in the closing of the remaining sawmills. Wet-lap processing was used for pulp production until 1949 when the plant was converted to a neutral sulfide operation. This change resulted in the production of Kraft black liquor that was discharged directly to Manistee Lake. After numerous fish kills and odor complaints, the pulp mill discontinued the direct discharge of this material and constructed a series of eight unlined lagoons on the opposite side of the lake. Black liquor and other waste products were discharged to the lagoons from 1951 to 1976. The lagoons were closed in 1976 due to problems associated with groundwater discharges entering Manistee Lake. The mill is currently operated by the Packaging Corporation of America (PCA) and the lagoons are in the process of final closure under the Superfund Program.

In addition to the long-term impact of the pulp/box mill, industries related to the extraction and processing of salt brine have also discharged contaminants to the lake. The first brine extraction well was installed in 1881. Since then, Hardy Salt and Morton Salt have constructed facilities to extract and purify salt brine on the shores of Manistee Lake. Chemical brines containing bromide, calcium, magnesium, and potassium are also extracted and processed. Brine discharges from abandon wells, NPDES outfalls, and seeps continue to flow into Manistee Lake. Martin Marietta operates a production facility located on the southeast lakeshore. The Martin Marietta facility is located down gradient from the PCA lagoons and a combined plume of contaminated groundwater enters Manistee Lake at this location.

Petroleum hydrocarbons have also been discharged into the lake by a number of industries. PCA used kerosene as a pitch control agent and was forced to eliminate its discharge to Manistee Lake in 1967 due to fish tainting. Oil spills were reported at Manistee Drop Forge on several occasions in addition to a large release of fuel oil that was recently remediated by soil and sediment removal. In addition to discharges from industries, petroleum releases from shipping may also contribute to hydrocarbon levels in the sediments. Large vessels frequently enter Manistee Lake to transport coal for the power plant and to pick up process chemicals from the brine facilities.

### 1.2 Project Objectives And Task Elements

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

- Develop a target list of resin acids for the PCA Superfund Site.
  - A sample of contaminated groundwater was collected from the PCA Site and analyzed for a group of resin acids by GC/MS. Based on a review of the literature, the following resin acid compounds were selected: abietic acid, dehydroabietic acid, chlorodehydroabietic acid, dichlorodehydroabietic acid, neoabietic acid, pimaric acid, and isopimeric acid.
  - Critical measurements were the resin acids.
- Determine the nature and extent of sediment contamination in Manistee Lake.
  - A Phase II investigation was conducted to examine the nature and extent of sediment contamination in Manistee Lake. Core samples were collected to provide an 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 PCA Superfund site. Arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc, selenium, mercury, total organic carbon (TOC), semivolatile organics, resin acids, and grain size were analyzed in all core samples.
  - Surface sediments were collected from Manistee Lake 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, barium, cadmium, chromium, copper, lead, nickel, zinc, selenium, mercury, semivolatile organics, and resin acids in sediment samples. Non-critical measurements were total organic carbon, and grain size.
- Evaluate the toxicity of sediments from sites in the lower Manistee Lake area.
  - Sediment toxicity evaluations were performed with *Hyalella azteca* and *Chironomus tentans*.
  - Toxicity measurements in Manistee Lake sediments were evaluated and compared with the two control locations. These measurements determined the presence and degree of toxicity associated with sediments from Manistee Lake.
  - 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 Manistee Lake.
  - Sediment samples were collected with a Ponar in Manistee Lake.
  - The abundance and diversity of the benthic invertebrate communities were evaluated and compared with the two control locations.

  - Critical measurements included the abundance and species composition of benthic macroinvertebrates.
- Determine the degree of bioaccumulation of resin acids in fish from Manistee Lake.
  - Fish samples were collected from Manistee Lake
  - Size, age, species, and sex of the fish were determined. Resin acids were analyzed in the fish tissue. The final analyte list was determined by reviewing the results of the sediment samples.
  - Critical measurements were the target list of resin acids.

### 1.3 Experimental Design

This investigation was designed to examine specific sites of possible contamination as well as provide an overall assessment of the nature and extent of sediment contamination in Manistee Lake. This bifurcated approach allowed the investigation to focus on specific sites based on historical information in addition to examining the broad-scale distribution of contamination. To address contamination at specific sites, 10 core samples were collected from locations likely to have been impacted by significant anthropogenic activity. The locations were selected to target current and historical point sources and downstream sites from known industrial and municipal discharges. These sites were determined by the analysis of historical data and industrial site locations. Analysis of lake depositional areas was then used to select two locations that would reflect the general distribution of contaminants.

Sediment samples were collected using the U.S. EPA Research Vessel *Mudpuppy*. The sediment cores were collected with a VibraCore device with core lengths ranging from 6-8 ft. The core samples were then sectioned in three lengths for chemical analysis. Ponar samples were also collected at these locations to provide an assessment of the near surface zone sediments. For each core, the analytical parameters included a general series of inorganic and organic constituents as well as specific chemicals related to a particular source or area. The general chemical series for each core included the following heavy metals; arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. In addition, resin acids were analyzed on all cores. The location of the study area is shown in Figure 1.2. Analytical methods were performed according to the protocols described in SW-846 3rd edition (EPA 1994a).

Chemistry data were then supplemented by laboratory toxicity studies that utilized standardized exposure regimes to evaluate the effects of contaminated sediment on test organisms. Six Ponar samples were collected in areas that had elevated levels of contaminants in the top core sections. Standard EPA methods (1994b) using *Chironomus tentans* and *Hyalella azteca* were used to determine the acute toxicity of sediments from the Ponar samples.

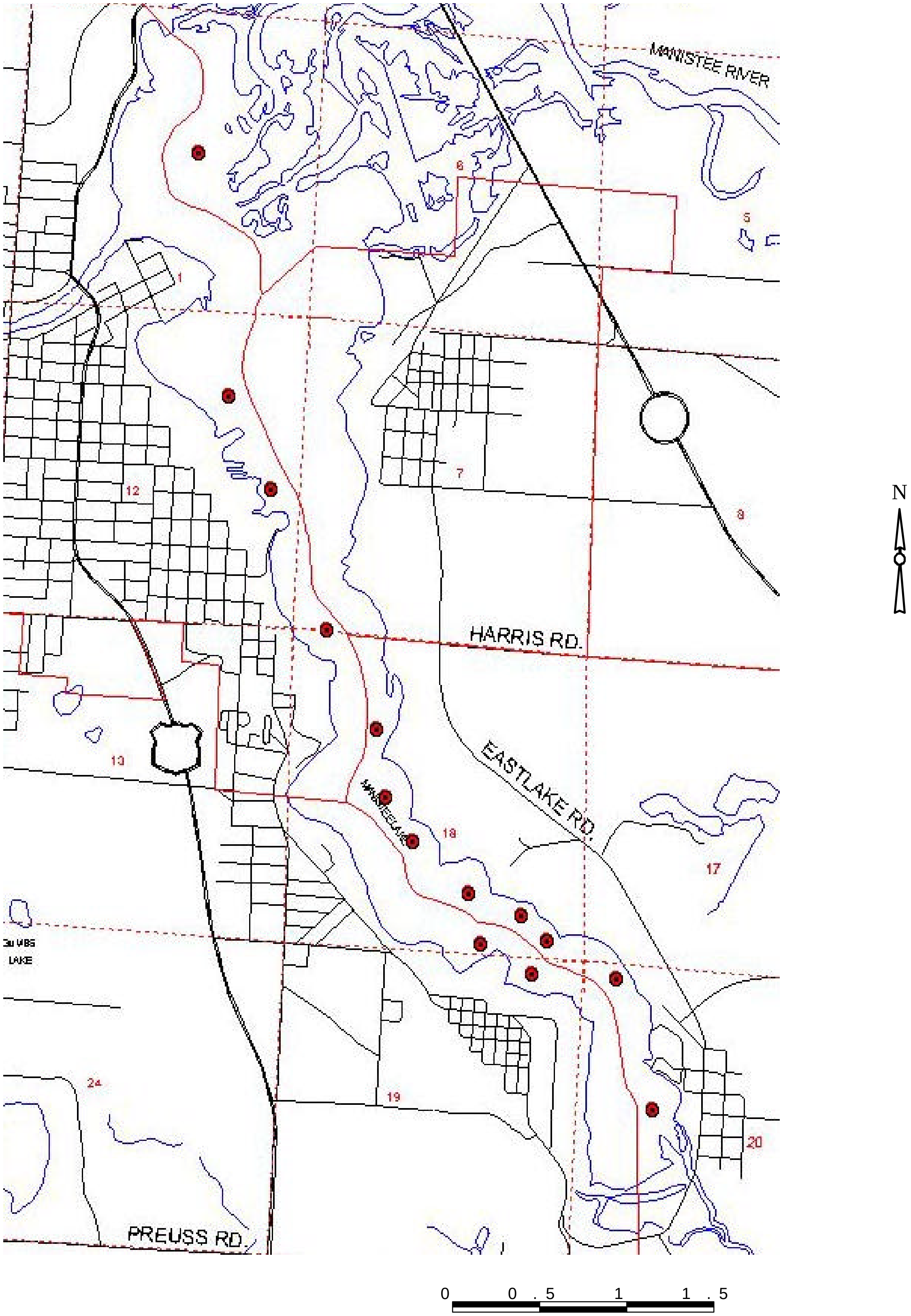


**FIGURE 1.2 MANISTEE LAKE STUDY AREA (NOVEMBER 1998).**

## 1.4 References

Burggraaf, S., Langdon, A.G., Wilkins, A.L., and D.S. Roper. 1996. Accumulation and depuration of resin acids and fichtelite by the freshwater mussel *Hyridella menziesi.* Environmental Toxicology and Chemistry 15(3):369-375.

Camp, Dresser, and McKee and Battelle Great Lakes Environmental Center. 1993. *Packaging Corporation of America/Manistee Lake Site.* 118 pp.

EPA, 1994a. *Test Methods for Evaluating Solid Waste Physical/Chemical Methods. U.S. Environmental Protection Agency*. SW-846, 3rd Edition.

EPA, 1994b. *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*. U.S. Environmental Protection Agency. EPA/600/R-94/024.

Grant, J. 1975. *Water Quality and Biological Survey of Manistee Lake.* Michigan Department of Natural Resources. Pub. 4833-9310. 56pp.

Johnsen, K., Mattsson, K., Tana, J., Stuthridge, T.R., Hemming, J., and K.J. Lehtinen. 1995. Uptake and elimination of resin acids and physiological responses in rainbow trout exposed to total mill effluent from an integrated newsprint mill. Environmental Toxicology and Chemistry 14(9):1561-1568.

Leach, J. M. and A. N. Thakore. 1976. Toxic constituents in mechanical pulping effluents. Tappi 59:129-132.

Mellanen, P., T. Petenen, J. Lehtimaki, S. Makela, G. Bylund, B. Holmbom, E. Mannila, A. Oikari, and R. Santti. 1996. Wood-derived estrogens: studies in vitro with breast cancer cell lines and in vivo in trout. Toxicol-Appl-Pharmacol 136(2):381-8.

Nimi, A. J. and H. B. Lee. 1992. Free and conjugated concentration of nine resin acids in rainbow trout (*Oncorhynchus mykiss*) following waterborne exposure. Environmental Toxicology and Chemistry 11:1403-1407.

Sunito, L. R., Shiu, W. Y., and D. Mackay. 1988. A review of the nature and properties of chemicals present in pulp mill effluents. Chemosphere 17:1249-1290.

Surber, E. 1953. *A Biological Survey of the Effects of Pollution on Manistee Lake.* September 15, 1953. Michigan Water Resources Commission.

Tavendale, M. H., Wilkins, A. L., Langdon, A. G., Mackie, K. L., Stuthridge, T. R., and P. N. McFarlane. 1995. Analytical methodology for the determination of freely available bleached Kraft mill effluent-derived organic constituents in recipient sediments. Environ. Science and Technology 29(5).

Wilkins, A. L., Davidson, J. A. C., Langdon, A. G., and C. H. Hendy. 1996. Sodium, calcium, and resin acid levels in ground water and sediments from two sites adjacent to the Tarawera River, New Zealand. Bulletin of Environmental Contamination and Toxicology 58:575-581.

Wilkins, A. L., Singh-Thandi, M., and A. G. Langdon. 1996. Pulp mill sourced organic compounds and sodium levels in water and sediments from the Tarawera River, New Zealand. Bulletin of Environmental Contamination and Toxicology 57:434-441.

Zanella, E. 1983. Effect of pH on acute toxicity of dehydroabietic acid and chlorinated dehydroabietic acid to fish and *Daphnia*. Bulletin of Environmental Contamination and Toxicology 30:133-40.

# 2.0 Sampling Locations

## 2.1 Sampling Locations And Descriptions

Sampling sites for the assessment of contaminated sediments in Manistee Lake were selected based on proximity to potential point and non-point sources of contamination and historical data. A preliminary survey was conducted in July 1998 to determine sampling locations for sediments and benthos. Shallow depths near shore (< 7 meters) contained considerable woody debris and were not suitable for core or Ponar sampling. Sample depth and conductivity profiles were also measured at this time to examine thermal and chemical stratification. Sediment samples were collected in November 1998 from areas of fine deposition. Samples from areas containing rubble and sand were excluded. In the southern Manistee Lake area, nine sites were selected that included a control location, areas influenced by the groundwater discharge plume from the PCA Superfund Site, and two other suspected sources of contamination (Figure 2.1). Specific site locations were determined by Loran. The differential GPS was not operational during the survey and consequently, coordinates are approximate. The following locations were selected for southern Manistee Lake:

| Core Identification | Potential Source |
|---|---|
| M-1 | Control Little Manistee River Mouth |
| M-2 to M-5 and M-8 to M-9 | PCA Superfund Site |
| M-7 | PCA Superfund Site and Martin Marietta Chemical |
| M-6 | Manistee Drop Forge |

Core samples collected at stations M-11 to M-14 in northern Manistee Lake represent a broad range of sources related to local industrial and municipal discharges and a second control location. Site information related to these locations is provided below:

| Station ID | Potential Source |
|---|---|
| M-10 | Abandon Brine Wells And Pipeline |
| M-11 | Manistee Wastewater Treatment Plant/Hardy Salt |
| M-12 | Hardy Salt |
| M-13 | Morton Chemical |
| M- 14 | Control |

The groundwater sample used for the development of target list compounds was collected from wells 86-2 and KMW-8D. Groundwater at these locations was found to be highly contaminated with compounds related to the former PCA storage lagoons, (VanOtteren 1998).

A map of the sampling locations and adjacent industrial facilities is provided in Figure 2.1. The Loran coordinates, depths, and visual descriptions are included in Table 2.1. Fish were collected using a gill net near station M-7. A group of 12 fish was collected including seven walleye and five common carp.

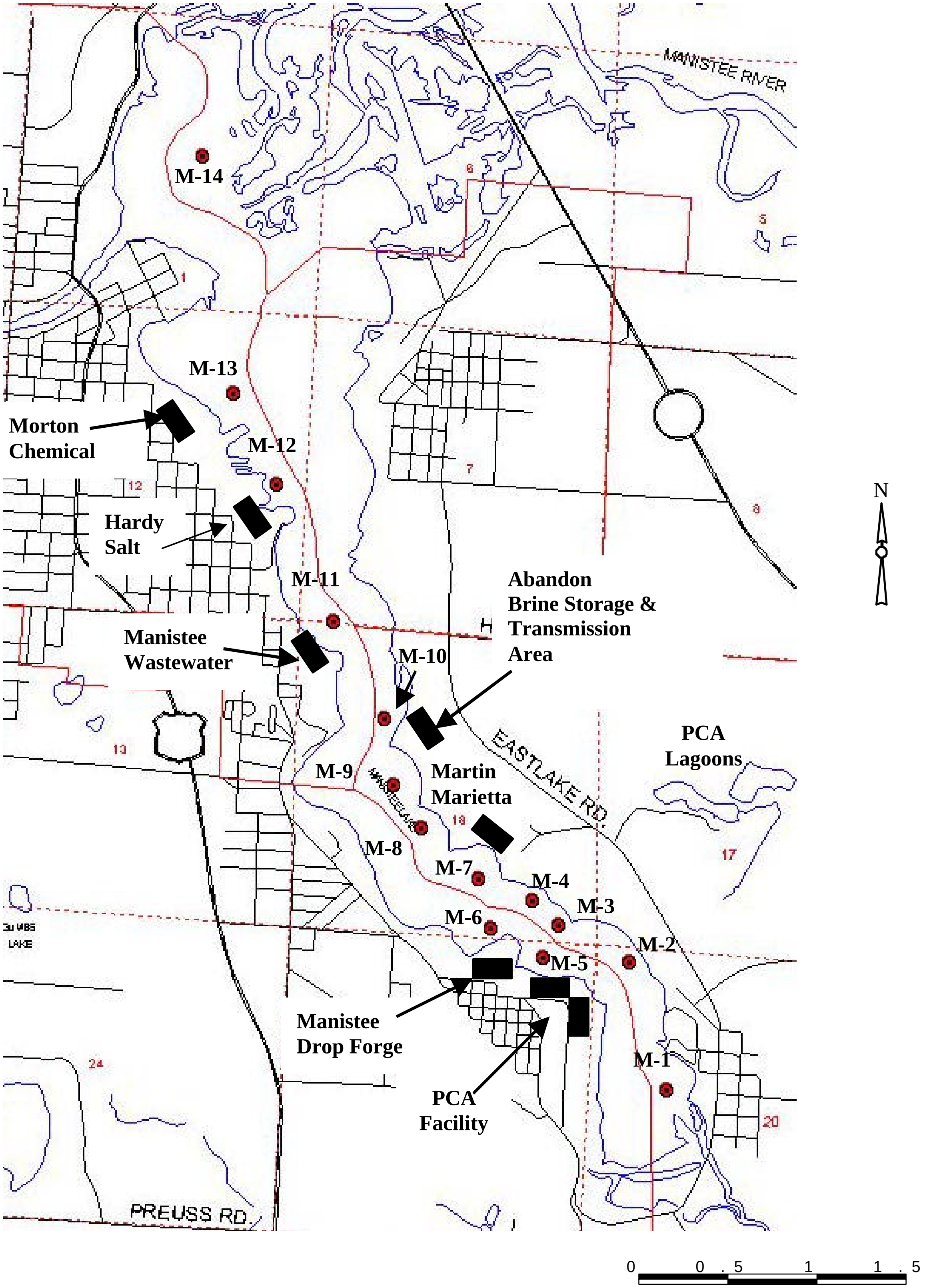


FIGURE 2.1 MANISTEE LAKE SAMPLING STATIONS (NOVEMBER 1998).

## TABLE 2.1 MANISTEE LAKE CORE SAMPLING STATIONS

| Station | Date | Water Depth | Depth of Core | Latitude | Longitude | Description |
|---|---|---|---|---|---|---|
| | | meters | inches | N | W | |
| M-1 | 10/26/98 | 5.43 | 79 | 44° 12.72' | 86° 16.83' | |
| | | 5.43 | 0-21 | | | Silt, slight oil sheen |
| | | 5.43 | 21-42 | | | Silty clay |
| | | 5.43 | 42-79 | | | Clay and silt |
| M-2 | 10/26/98 | 7.14 | 62 | 44° 13.06' | 86° 17.05' | |
| | | 7.14 | 0-20 | | | Black organic silt with wood chips and oil drops |
| | | 7.14 | 20-40 | | | Brown silt with oil drops |
| | | 7.14 | 40-62 | | | Brown Silty clay |
| M-3 | 10/26/98 | 10.24 | 90 | 44° 13.14' | 86° 17.29' | |
| | | 10.24 | 0-20 | | | Brown silt with wood chips |
| | | 10.24 | 20-50 | | | Brown silt |
| | | 10.24 | 50-90 | | | Brown silt with clay |
| M-4 | 10/26/98 | 11.15 | 100 | 44° 13.22' | 86° 17.46' | |
| | | 11.15 | 0-20 | | | Brown silt with wood chips and clay |
| | | 11.15 | 20-50 | | | Brown silt with clay |
| | | 11.15 | 50-100 | | | Brown silt with clay |
| M-5 | 10/27/98 | 9.40 | 90 | 44° 13.12' | 86° 17.24' | |
| | | 9.40 | 0-20 | | | Silt with wood chips, oil drops and hydrocarbon odor |
| | | 9.40 | 20-50 | | | Silt with oil drops and hydrocarbon odor |
| | | 9.40 | 50-90 | | | Brown silt |
| M-6 | 10/26/98 | 10.79 | 90 | 44° 13.26' | 86° 17.55' | |
| | | 10.79 | 0-20 | | | Black silt with wood chips, and heavy oil sheen |
| | | 10.79 | 20-50 | | | Silty clay |
| | | 10.79 | 50-90 | | | Silty clay |
| M-7 | 10/26/98 | 9.81 | 90 | 44° 13.26' | 86° 17.55' | |
| | | 9.81 | 0-20 | | | Silt with wood chips, heavy oil sheen. Sulfur and hydrocarbon odor |
| | | 9.81 | 20-50 | | | Silt |
| | | 9.81 | 50-90 | | | Silty clay |
| M-8 | 10/27/98 | 10.74 | 83 | 44° 13.48' | 86° 17.80' | |
| | | 10.74 | 0-20 | | | Silt with oil sheen and oil drops |
| | | 10.74 | 20-50 | | | Brown silt |
| | | 10.74 | 50-83 | | | Brown silt |

## TABLE 2.1 MANISTEE LAKE CORE SAMPLING STATIONS (CONTINUED)
## (*FIELD DUPLICATE SAMPLE)

| Station | Date | Water Depth | Depth of Core | Latitude | Longitude | Description |
|---|---|---|---|---|---|---|
| | | meters | inches | N | W | |
| M-9 | 10/27/98 | 11.84 | 83 | $44^{o}$ 13.58' | $86^{o}$ 17.93' | |
| | | 11.84 | 0-20 | | | Silt with oil sheen.<br>Sulfur and hydrocarbon odor |
| | | 11.84 | 20-50 | | | Silt with slight hydrocarbon odor |
| | | 11.84 | 50-83 | | | Brown silts |
| M-9 Dup* | 10/27/98 | 11.76 | 78 | $44^{o}$ 13.58' | $86^{o}$ 17.93' | |
| | | 11.76 | 0-20 | | | Silt with oil sheen.<br>Sulfur and hydrocarbon odor |
| | | 11.76 | 20-50 | | | Silt with slight hydrocarbon odor |
| | | 11.76 | 50-78 | | | Brown silts |
| M-10 | | 12.50 | 89 | $44^{o}$ 13.79' | $86^{o}$ 17.96' | |
| | | 12.50 | 0-20 | | | Silt with oil sheen & hydrocarbon odor |
| | | 12.50 | 20-50 | | | Brownish-black silty clay with oil sheen |
| | | 12.50 | 50-89 | | | Brown silty clay |
| M-11 | 10/27/98 | 11.25 | 71 | $44^{o}$ 14.07' | $86^{o}$ 18.11' | |
| | | 11.25 | 0-20 | | | Black Silt with oil sheen |
| | | 11.25 | 20-50 | | | Brownish black silt |
| | | 11.25 | 50-71 | | | Brownish green silty clay |
| M-12 | 10/27/98 | 14.12 | 90 | $44^{o}$ 14.46' | $86^{o}$ 18.35' | |
| | | 14.12 | 0-20 | | | Black Silt with wood chips, oil sheen and hydrocarbon odor |
| | | 14.12 | 20-50 | | | Black Silt w/ hydrocarbon odor |
| | | 14.12 | 50-90 | | | Black silts to 75 in. 75-80 in clay. 80-90 in black sand and gravel. |
| M-13 | 10/27/98 | 12.50 | 78 | $44^{o}$ 14.20' | $86^{o}$ 18.59' | |
| | | 12.50 | 0-20 | | | Clay silt with wood chips and oil sheen, hydrocarbon odor |
| | | 12.50 | 20-50 | | | Clay silt w/ wood chips |
| | | 12.50 | 50-78 | | | Silt |
| M-14 | 10/27/98 | 6.22 | 67 | $44^{o}$ 15.44' | $86^{o}$ 18.82' | |
| | | 6.22 | 0-20 | | | Grey silts and sands |
| | | 6.22 | 20-50 | | | Grey silt |
| | | 6.22 | 50-67 | | | Grey silt |

**Table 2.2 Manistee Lake Ponar Sampling Stations (*Field Duplicate Sample)**

| Station | Date | Water Depth | Latitude | Longitude | Description |
|---|---|---|---|---|---|
| | | meters | N | W | |
| M-1-P | 10/28/98 | 5.13 | 44° 12.70' | 86° 16.83' | Sandy silt |
| M-2-P | 10/28/98 | 7.67 | 44° 13.03' | 86° 17.06' | Black oily silt, wood chips |
| M-3-P | 10/28/98 | 9.75 | 44° 13.15' | 86° 17.31' | Black oily silt, wood chips |
| M-4-P | 10/28/98 | 10.06 | 44° 13.18' | 86° 17.38' | Black oily silt, wood chips |
| M-5-P | 10/28/98 | 9.14 | 44° 13.14' | 86° 17.27' | Black oily silt, wood chips, bark |
| M-6-P | 10/28/98 | 10.67 | 44° 13.20' | 86° 17.45' | Black oily silt, wood chips |
| M-7-P | 10/28/98 | 9.75 | 44° 13.26' | 86° 17.57' | Black oily silt, wood chips |
| M-8-P | 10/28/98 | 11.58 | 44° 13.47' | 86° 17.18' | Black oily silt, wood chips |
| M-9-P | 10/29/98 | 11.58 | 44° 13.62' | 86° 17.88' | Black oily silt, wood chips |
| M-9-P Duplicate* | 10/29/98 | 11.58 | 44° 13.62' | 86° 17.88' | Black oily silt, wood chips |
| M-10-P | 10/29/98 | 12.50 | 44° 13.79' | 86° 17.96' | Black oily silt, wood chips |
| M-11-P | 10/29/98 | 10.97 | 44° 14.10' | 86° 18.11' | Black oily silt, wood chips |
| M-12-P | 10/29/98 | 11.58 | 44° 14.48' | 86° 18.36' | Black oily silt, wood chips |
| M-13-P | 10/29/98 | 12.80 | 44° 14.70' | 86° 18.57' | Black oily silt, wood chips |
| M-14-P | 10/29/98 | 6.58 | 44° 15.50' | 86° 18.81' | Sandy silt |

## 2.2 References

VanOtteren, B. 1998. Michigan Department of Environmental Quality. Personal Communication.

# 3.0 Methods

## 3.1 Sampling Methods

Sediment and benthos samples were collected using the U.S. EPA Research Vessel *Mudpuppy*. Vibra Core methods were used to collect sediment cores for chemical analysis. A four-inch aluminum core tube with a butyrate liner was used for collection. A new core tube and liner was used at each location. 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 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 four sub-samples. The Ponar was washed with water in between stations. A petite Ponar was used for the collection of benthic macroinvertebrates. Three replicate grabs were taken at each of the sites. All material in the grab was washed through a Nitex screen with 500 μm openings and the residue preserved in buffered formaldehyde containing rose bengal stain.

Loran coordinates were used to record the position of the sampling locations. The GPS system was unavailable due to instrument related problems. The Loran system has less accuracy with respect to the establishment of the true coordinates and consequently, the coordinates of the sampling stations must be considered approximate. Since 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 | Resin Acids | 500 mL Amber Glass | Cool to 4$^{o}$C | 14 days | 60 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<br>Hardness<br>Conductivity<br>pH | 250 mL Wide Mouth Plastic | Cool to 4$^{o}$C | --- | 24 hrs. |
| Fish Tissue | Resin Acids | Plastic Bag | Freeze -10$^{0}$C | --- | 6 months |

### 3.2 Chemical Analysis Methods For Sediment Analysis

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

## TABLE 3.2.1 ANALYTICAL METHODS AND DETECTION LIMITS

### SEDIMENT MATRIX

| Parameter | Method Description | Analytical Method | Detection Limit |
|---|---|---|---|
| Arsenic, Cadmium, | Arsenic-Graphite Furnace | $7060^1$ | 0.10 mg/kg |
| Lead, Selenium | Atomic Absorption Spectroscopy | $3052^1$ Digestion | |
| Aluminum, Barium, Calcium, Chromium, Copper, Iron, Mercury, Magnesium, Manganese, Nickel, Zinc | Inductively Coupled Plasma Atomic Emission Spectroscopy | $6010^1$,<br>$3052^1$ 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 | $8270^1$,<br>$3550^1$ Extraction | Table 3.2.2 |
| Resin Acids | Solvent Extraction and GC/MS analysis | $GC/MS^2$, | Table 3.2.4 |

[1] - SW846 3rd. Ed. EPA 1994.
[2] - Tavendale et al. (1995)

### 3.2.1 Sample Preparation For Metals Analysis

For aluminum, arsenic, barium, calcium, cadmium, chromium, copper, iron, magnesium, manganese, nickel, lead, selenium, 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 was added to each sample. Vessels then were 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 using 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, samples were mixed, and the centrifuge tubes were returned in 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 along 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 Graphite Furnace technique. The instrument employed was Perkin Elmer 4110ZL atomic absorption spectrophotometer. An arsenic Electrodless Discharge Lamp was used as a light source at 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 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 Graphite Furnace technique. The instrument employed was Perkin Elmer 4110ZL atomic absorption spectrophotometer. A hollow cathode lamp was used as a light source at 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 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 Graphite Furnace technique. The instrument employed was Perkin Elmer 4110ZL atomic absorption spectrophotometer. A lead EDL Lamp was used as a light source at 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 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 Graphite Furnace technique. The instrument employed was Perkin Elmer 4110ZL atomic absorption spectrophotometer. An arsenic EDL Lamp was used as a light source at 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 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, barium calcium, chromium, copper, iron, magnesium, manganese, nickel and zinc were analyzed in accordance with EPA SW-846 method 6010A by 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 |
|---|---|
| Al | 308.2 |
| Ba | 233.5 |
| Ca | 315.9 |
| Cr | 267.7 |
| Cu | 324.8 |
| Fe | 259.9 |
| Mg | 279.1 |
| Mn | 257.6 |
| Ni | 231.6 |
| Zn | 213.9 |

RF Power: 1300 W

Matrix interferences were suppressed with internal standardization utilizing Myers-Tracy signal compensation. Inter-element interference check standards were analyzed in the beginning and at the end of every analytical run and indicated absence of this type of interferences 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 with 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. The samples were allowed to air dry again prior to analysis. 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).

### 3.2.10 Semivolatiles Analysis

Sediment samples were extracted for semivolatiles analysis 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 1 mL volume.

The sample extracts were analyzed by GC/MS on a Finnigan GCQ 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 ul

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 meeting method acceptance criteria. The MS and MSD samples were analyzed at a 5% frequency.

### 3.2.11 Hexane Extractable Materials

Hexane extractable Materials (HEM) was analyzed on the Ponar samples by SW-846 Method 6030. The method was modified to use a gravimetric measurement of the hydrocarbon residue. Wet sediment samples were mixed with anhydrous sodium sulfate until the mixture was dry and free flowing. The dried sediment was then placed in cellulose thimble and extracted in a soxhlet apparatus for 24 hours with hexane. After extraction, the hexane was dried with sodium sulfate and evaporated to approximately 2 mLs in a Kuderna Danish concentrator with a three-ball Snyder column. The concentrate was then placed in a preweighed aluminum pan and evaporated on a steam bath to remove the residual hexane. The pan was then cooled in a dessicator for 12 hours and weighed. For quality control purposes, a blank, blank spike, matrix spike and matrix spike duplicate were analyzed with the sample set. Mineral oil was used as the spiking compound. Acceptance limits for precision and accuracy were ± 50%.

### 3.2.12 Resin Acids

Sediment samples were analyzed according the method described by Tavendale et al. (1995). A 30-gram sample of sediment was extracted with hexane in a soxhlet extractor for 24 hrs. After water removal, 2-propanol was added to the extractor and the extraction was continue for 48 hrs. The extract was then concentrated to 5 mLs in a Kuderna Danish (KD) concentrator with a three-ball Snyder column and brought up to a volume of 10 mLs with dichloromethane in a volumetric flask. The extract was partitioned into 0.1 M potassium carbonate using 3 - 40 mL washes in a 250 mL separatory funnel. The aqueous phase was then acidified with sulfuric acid and extracted with 3 -30 mL volumes of diethyl ether. The ether was dried with sodium sulfate and concentrated to one mL as described above. The extract was then methylated with an ethereal solution of diazomethane. A 40 mL aliquot of dichloromethane was then added and the extract was concentrated to 1 mL with a KD. The methyl esters of the resin acids were analyzed by GC/MS using a DB-5 capillary column. Internal and surrogate standards were used during the analysis and are listed in Table 3.2.4. GC/MS conditions were identical to those listed in 3.2.10.

## TABLE 3.2.2 ORGANIC PARAMETERS AND DETECTION LIMITS

| | Sediment (mg/kg) |
|---|---|
| Semi-Volatile Organic Compounds (8270) | |
| 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)

| | Sediment (mg/kg) |
|---|---|
| Semi-Volatile Organic Compounds (8270) | |
| 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% |

## TABLE 3.2.4 RESIN ACID DETECTION LIMITS AND SURROGATE/INTERNAL STANDARDS FOR SEDIMENT ANALYSIS

| **Compound** | **MDL Sediment** mg/kg |
|---|---|
| Abietic Acid | 0.3 |
| Dehydroabietic acid | 0.3 |
| Chlorodehydroabietic acid | 0.3 |
| Dichlorodehydroabietic acid | 0.3 |
| Pimaric acid | 0.3 |
| Isopimeric acid | 0.3 |
| Neoabietic acid | 0.3 |
| **Internal Standard** | **% Recovery** |
| Anthracene $d_{10}$ | 60%-110% |
| **Surrogate Standards** | |
| Tetrachlorostearic acid | 40%-90% |
| Stearic acid* | 40%-90% |

* Background levels of stearic acid detected in sediment samples. Surrogate data were unusable.

## 3.3 Chemical Analysis Methods For Water Analysis

### 3.3.1 Culture Water

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 (1996).

### 3.3.2 Resin Acids In Water

Water samples were analyzed according to a method described by Wilkins and Panadam (1987). A 1-L sample was acidified to pH < 2.0 and extracted with dichloromethane with 3 - 50 mL aliquots of dichloromethane. The dichloromethane extract were concentrated, dried with sodium sulfate, and methylated with diazomethane as described in 3.2.12. The methyl esters of the resin acids were analyzed by GC/MS using a DB-5 capillary column. Internal and surrogate standards will be used during the analysis and are listed in Table 3.3.2. GC/MS conditions were identical to those listed in 3.2.10.

## 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 |

## TABLE 3.3.2 RESIN ACID DETECTION LIMITS AND SURROGATE/INTERNAL STANDARDS FOR WATER ANALYSIS

| **Compound** | **MDL Sediment*** mg/l |
|---|---|
| Abietic Acid | 0.01 |
| Dehydroabietic acid | 0.01 |
| Chlorodehydroabietic acid | 0.01 |
| Dichlorodehydroabietic acid | 0.01 |
| Pimaric acid | 0.01 |
| Isopimeric acid | 0.01 |
| Neoabietic acid | 0.01 |
| **Internal Standard** | **% Recovery** |
| Anthracene $d_{10}$ | 60%-110% |
| **Surrogate Standards** | |
| Tetrachlorostearic acid | 60%-110% |
| Stearic acid | 60%-110% |

## 3.4 Sediment Toxicity

The evaluation of the toxicity of the Manistee Lake sediments was conducted using the 10-day survival test for the amphipod *Hyalella azteca* and the dipteran *Chironomus tentans*. The procedures followed are contained in EPA/600/R-94/024, Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Fresh Water Invertebrates. All sediments were stored at 4°C prior to analysis.

### 3.4.1 Laboratory Water Supply

A moderately hard well water for *H. azteca* and *C. tentans* cultures and maintenance was employed.

### 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 G-5P 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 was also 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 was also 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 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 mLs were retained for alkalinity, pH, conductance, hardness and ammonia analysis. On the last day the same procedure was performed. On day 10, the sediments were sieved, and surviving test organisms were removed and counted. The biological endpoint for these sediment tests was mortality. The validity of the test was based on greater than 80% survival

## TABLE 3.4.1 TEST CONDITIONS FOR CONDUCTING A 10-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 (e.g., 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: | Reconstituted 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 600/R-94/024 (July 1994).

## TABLE 3.4.2 RECOMMENDED TEST CONDITIONS FOR CONDUCTING A 10-DAY SEDIMENT TOXICITY TEST WITH *CHIRONOMUS TENTANS*

| | | |
|---|---|---|
| 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 (e.g., 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: | Reconstituted 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. |

Test Method 100.2. EPA Publication 600/R-94/024 (July 1994).

in the control treatment for *H. azteca* and greater than 70% survival in the control treatment for the *C. tentans*. In addition, it was 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 the test.

### 3.4.4 Statistical Analysis

Survival data for the toxicity testing were analyzed first for normality and homogeneity employing Chi Square. 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.

### 3.4.5 Quality Assurance

Sodium chloride was used as a reference toxicant to calibrate the toxicity tests. The results are provided in Appendix D.

## 3.5 Benthic Macroinvertebrate Analysis

Samples were washed with tap water to remove formaldehyde 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% formaldehyde 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 60X dissecting microscope.

## 3.6 Fish Tissue Analysis

Fish samples were analyzed according the method described by Nimi and Lee (1992). Whole fish were ground using an Osterizer blender. A 5-gram sample of homogenized fish tissue was acidified with sulfuric acid and mixed with sodium sulfate (approximately 15 grams). The tissue mixture was then sonicated with 100 mLs of dichloromethane. The extract was then filtered through glass wool and passed through a 3-gram column of sodium sulfate. The extract was concentrated to 1 mL and passed through a gel permeation column (GPC) to remove interferences. A GPC column containing 60 grams of BioBeads (S-X3) was used with dichloromethane as the solvent at a rate of 5 mLs/min. The GPC column was calibrated using the target resin acids and the analytes were found to elute between 100 mL and 200 mL. The dichloromethane fraction was concentrated, dried with sodium sulfate, and methylated with diazomethane as described in 3.2.12. The methyl esters of the resin acids were analyzed by GC/MS using a DB-5 capillary column. Internal and surrogate standards were used during the analysis and are listed in Table 3.6.1. GC/MS conditions were identical to those listed in 3.2.10.

### TABLE 3.6.1 RESIN ACID DETECTION LIMITS AND SURROGATE/INTERNAL STANDARDS FOR FISH TISSUE ANALYSIS

| **Compound** | **MDL Fish Tissue** mg/kg |
|---|---|
| Abietic Acid | 0.5 |
| Dehydroabietic acid | 0.5 |
| Chlorodehydroabietic acid | 0.5 |
| Dichlorodehydroabietic acid | 0.5 |
| Pimaric acid | 0.5 |
| Isopimeric acid | 0.5 |
| Neoabietic acid | 0.5 |
| **Internal Standard** | **% Recovery** |
| Anthracene $d_{10}$ | 60%-110% |
| **Surrogate Standard** | |
| Tetrachlorostearic acid | 40%-90% |

## 3.7 References

EPA. 1994. Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates. EPA Publication 600/R-94/024.

Nmi, A. J. and H. B. Lee. 1992. Free and conjugated concentration of nine resin acids in rainbow trout (*Oncorhynchus mykiss*) following waterborne exposure. Environmental Toxicology and Chemistry 11:1403-1407.

Tavendale, M. H., Wilkins, A. L., Langdon, A. G., Mackie, K. L., Stuthridge, T. R., and P. N. McFarlane. 1995. Analytical methodology for the determination of freely available bleached Kraft mill effluent-derived organic constituents in recipient sediments. Environ. Science and Technology 29(5).

Wilkins, A. L. and S. S. Panadam. 1987. Extractable organic substances from the discharges of a New Zealand pulp and paper mill. Appita 40:208-212.

# 4.0 Results And Discussion

The results and discussion sections are organized according to nine sections that present and summarize the information related to the following topics:

| | |
|---|---|
| Section 4.1 | Manistee Lake Limnology |
| Section 4.2 | PCA Groundwater Target List |
| Section 4.3 | Results of Chloride Analyses in Sediment |
| Section 4.4 | Metals and General Chemistry Results |
| Section 4.5 | Organic Sediment Chemistry |
| Section 4.6 | Fish tissue Results |
| Section 4.7 | Toxicity Testing Results |
| Section 4.8 | Benthic Macroinvertebrate Results |
| Section 4.9 | Summary and Conclusions |

The conductivity/depth/temperature data for Manistee Lake are presented in the limnology section (4.1). The results of the groundwater samples are presented in Section 4.2 and the rationale for the selection of the target list. Following this section, the general chemistry and metals results are presented for the core and Ponar samples (Section 4.3). A discussion is also included related to the comparison of the data with published sediment quality guidelines. The organic chemistry data are presented in Section 4.5 and include the semivolatile, petroleum hydrocarbon, and resin acid results. Relevant sediment quality guidelines are also discussed in this section. Fish tissue data are presented in Section 4.6.
Toxicity and Benthic Macroinvertebrate results are presented in Sections 4.7 and 4.8 respectively. Statistical analyses of the data and comparisons with related chemical and biological data are also discussed. Finally, Section 4.9 provides a discussion of all the data as related to the ecological significance of the sediment contamination in Manistee Lake.

## 4.1 Manistee Lake Limnology

During the preliminary survey on July 1998 and the sediment survey in November 1998, Conductivity/Temperature/Depth profiles were measured using a SeaBird CTD system. The results of the CTD casts are presented in Figures 4.1.1 - 4.1.4. During stratification in July, a distinct chemocline was observed at M-7 and M-12 (Figures 4.1.1 and 4.1.2. respectively). The venting groundwater from the PCA plume and the brine sources (groundwater and surface water) were evident as a layer of cooler, more saline water at the bottom of the lake. The area where the greatest change in conductivity was observed was in the bottom 5 ft of the lake. Conductivity increased from 375 *u*S/cm at the surface to 450 *u*S/cm near the bottom at Station M-7. Station M-12 showed a greater change in dissolved solids as conductivity increased from 380 *u*S/cm at the surface to 650 *u*S/cm near the bottom. It is not know whether the increase in hypolimnetic conductivity at M-12 was related to the localized influx of more brine in this area or the greater depth of the station (47 ft vs 35 ft).

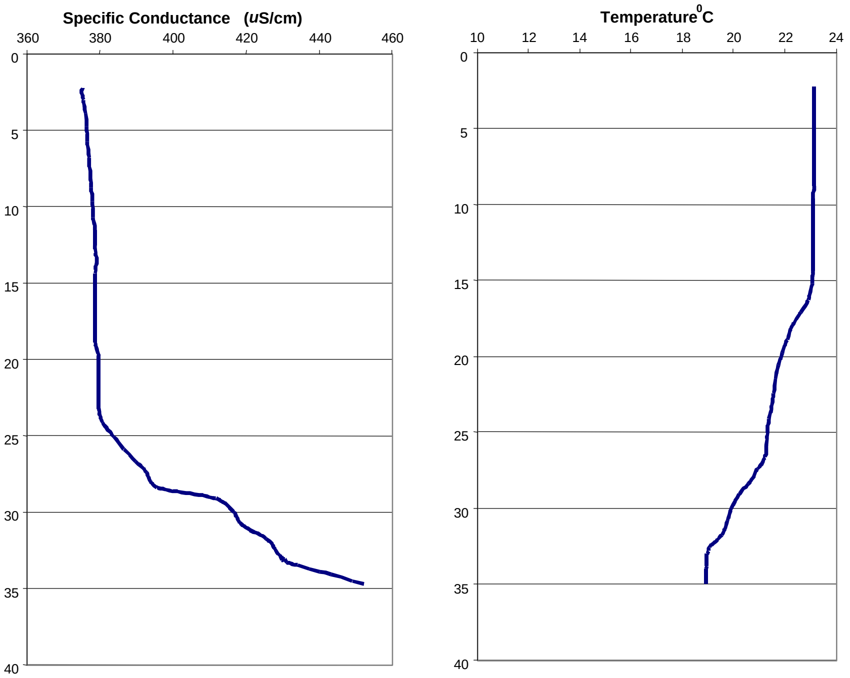


**FIGURE 4.1.1. CONDUCTIVITY AND TEMPERATURE PROFILES MEASURED AT STATION M-7 IN MANISTEE LAKE, JULY 1998.**

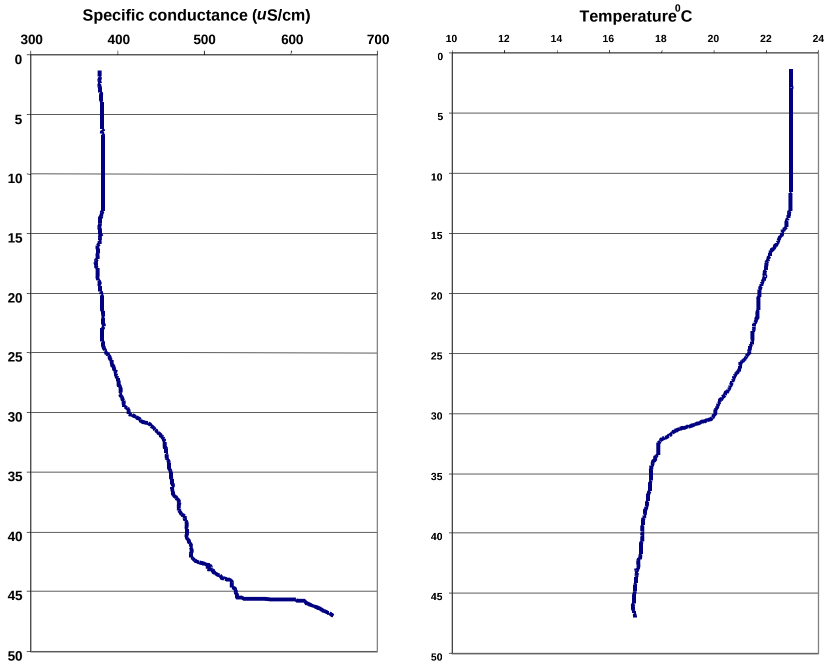


**FIGURE 4.1.2. CONDUCTIVITY AND TEMPERATURE PROFILES MEASURED AT STATION M-12 IN MANISTEE LAKE, JULY 1998.**

Conductivity/Temperature/Depth profiles during November 1998 reveal isothermal conditions with limited chemical stratification (Figs 4.1.3 and 4.1.4.). At both stations, the water at the surface was approximately 460 *u*S/cm and began to increase at 25 ft. The conductivity at the sediment/water interface of both stations approximately 475 *u*S/cm. This minor increase in conductivity indicates an almost complete mixing of the water column. In summary, the summer stratification and fall mixing suggest that venting groundwater accumulates in a thin layer near the sediment/water interface. It is also possible that some of the NPDES discharges may have sufficient density to sink to the bottom of the lake and contribute to the stratified layer. The more saline layer then mixes during isothermal conditions and is diluted with upper level lake water with less conductance. With an estimated 30-day residence time for water in Manistee Lake, the system is probably flushed with river water prior to ice cover. A similar cycle of chemical stratification and mixing is likely to occur during winter ice cover and the spring thaw. While these conditions limit the exposure of fish and planktonic organisms to the constituents found in the venting groundwater, the benthic community in Manistee Lake has the greatest potential for adverse impacts.

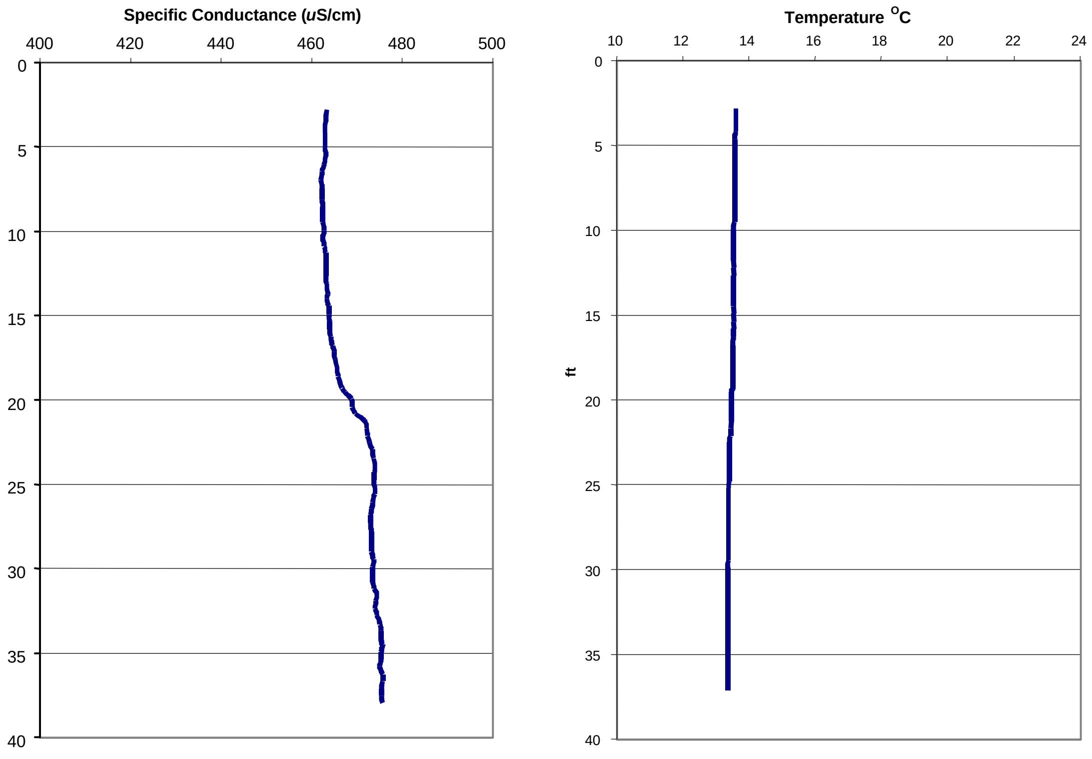


**Figure 4.1.3 Conductivity And Temperature Profiles Measured At Station M-7 In Manistee Lake, November 1998.**

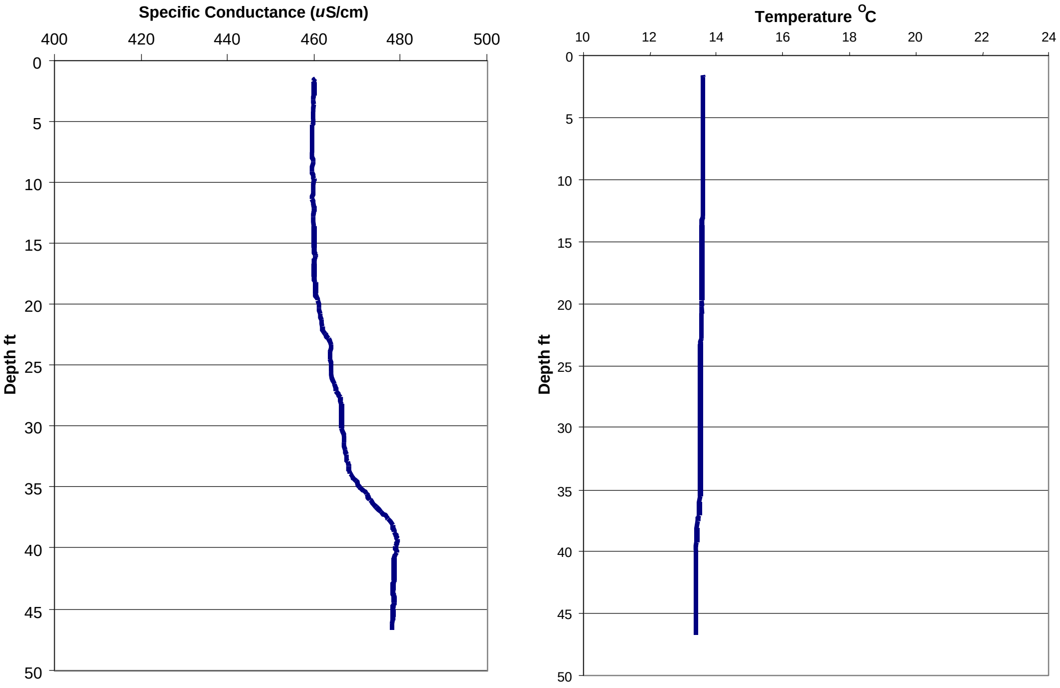


**FIGURE 4.1.4 CONDUCTIVITY AND TEMPERATURE PROFILES MEASURED AT STATION M-12 IN MANISTEE LAKE, NOVEMBER 1998.**

## 4.2 PCA Groundwater Target List

The results of the groundwater analyses conducted on the groundwater samples taken from wells 86-2 and KMW-8D are presented in Table 4.2.1. The most recent set of analyses from the MDEQ file are included for comparison purposes (VanOtteren 1998). The results show good agreement between the groundwater analyses from this project and previous results. In addition to semivolatiles, a target list of resin acid related compounds were measured and the results are also listed in Table 4.2.1. Chlorinated resin acids were not detected in the groundwater. The level of resin acids detected in the groundwater was below concentrations previously reported in paper mill effluent (Wilkins 1997 and Liss et al. 1997) and at approximately 25% of their theoretical solubility (Nyren and Black 1958). The concentrations measured in this investigation reflect dilution with groundwater and adsorption in the soil column. Resin acids have a high affinity for soils due to their hydrophobic nature (Tavendale et al. 1997). The results for phenolic compounds were similar to the July 1998 levels reported in the MDEQ database (VanOtteren 1998). Based on these analyses, chlorinated resin acids were dropped from the target list.

**TABLE 4.2.1 GROUNDWATER ANALYSES FOR MANISTEE LAKE, NOVEMBER 1998.**

| Well | 86-2 | | KMW-8D | |
|---|---|---|---|---|
| Lab | Teneco | AWRI | Teneco | AWRI |
| Date | Jul-98 | Nov-98 | Jul-98 | Nov-98 |
| Parameter | mg/l | mg/l | mg/l | mg/l |
| Benzoic Acid | 160 | 140 | 0.02 | 0.51 |
| 2-Methylphenol | 9.3 | 7.2 | 0.2 | 0.3 |
| 4-Methylphenol | 12 | 10 | 0.75 | 0.56 |
| Phenol | 81 | 64 | 1.1 | 0.9 |
| Abietic Acid | * | 0.85 | * | 0.64 |
| Dehydroabietic Acid | * | 1.6 | * | 0.97 |
| Chlorodehydroabietic Acid | * | <0.05 | * | <0.05 |
| Dichlorodehydroabietic Acid | * | <0.05 | * | <0.05 |
| Pimeric Acid | * | 0.43 | * | 0.15 |
| Isopimeric Acid | * | 0.21 | * | 0.08 |
| Neoabietic Acid | * | 0.14 | * | 0.09 |
| Chloride | 1000 | 900 | 21000 | 22000 |

* Compound not analyzed

## 4.3 Results Of Chloride Analyses In Sediment

Chloride was analyzed in core sections to provide an indication of the amount of brine present in the pore water. The results are shown in Figure 4.3.1. A high level of chloride was present at the M-10 and M-12 stations. The brine was concentrated near the surface at M-10 and at the bottom of the core at M-12. M-10 was located near the abandon brine wells and transmission pipelines that transverse the lake. M-12 was located in the deepest part of the lake between Morton Salt and Hardy Salt. The chloride results are presented on a single graph on Figure 4.3.2. With the exception of the controls and M-10, all stations show a trend of increasing chloride concentration with depth. The results suggest that a salt gradient exists in the sediments that is stratified with depth. The groundwater entering Manistee Lake in the contaminant plumes from the PCA site and the brine facilities has sufficient density to concentrate at lower sediment depths. This observation is consistent with results reported by Camp, Dresser & McKee and Battelle Great Lakes Environmental Center (1993). Specific conductance values exceeding 10,000 *u*mohs/cm were found at the 40 - 60 ft depths in the lake sediment between Stations M-7 and M-4. Pore water at these deep levels was described as black in color. The dark coloration and high specific conductance values were similar to previous characterizations of the ground water (VanOtteren 1998). In contrast, the chloride concentrations at M-10 indicate the intrusion of a brine seep in the 0 – 24 inch sediment depth or the residuals from a brine release that occurred near Hardy Salt (Myers, 2001).

| Sample ID | Chloride mg/kg |
|---|---|
| Top Core Sections | |
| M-1 | 16 |
| M-2 | 120 |
| M-3 | 190 |
| M-4 | 210 |
| M-5 | 172 |
| M-6 | 270 |
| M-7 | 300 |
| M-8 | 100 |
| M-9 | 160 |
| M-10 | 2500 |
| M-11 | 98 |
| M-12 | 980 |
| M-13 | 96 |
| M-14 | 19 |
| Middle Core Sections | |
| M-1 | 16 |
| M-2 | 180 |
| M-3 | 260 |
| M-4 | 250 |
| M-5 | 250 |
| M-6 | 430 |
| M-7 | 460 |
| M-8 | 260 |
| M-9 | 380 |
| M-10 | 470 |
| M-11 | 230 |
| M-12 | 2400 |
| M-13 | 260 |
| M-14 | 69 |
| Bottom Core Sections | |
| M-1 | 25 |
| M-2 | 180 |
| M-3 | 300 |
| M-4 | 320 |
| M-5 | 300 |
| M-6 | 530 |
| M-7 | 640 |
| M-8 | 380 |
| M-9 | 390 |
| M-10 | 550 |
| M-11 | 360 |
| M-12 | 3500 |
| M-13 | 350 |
| M-14 | 44 |

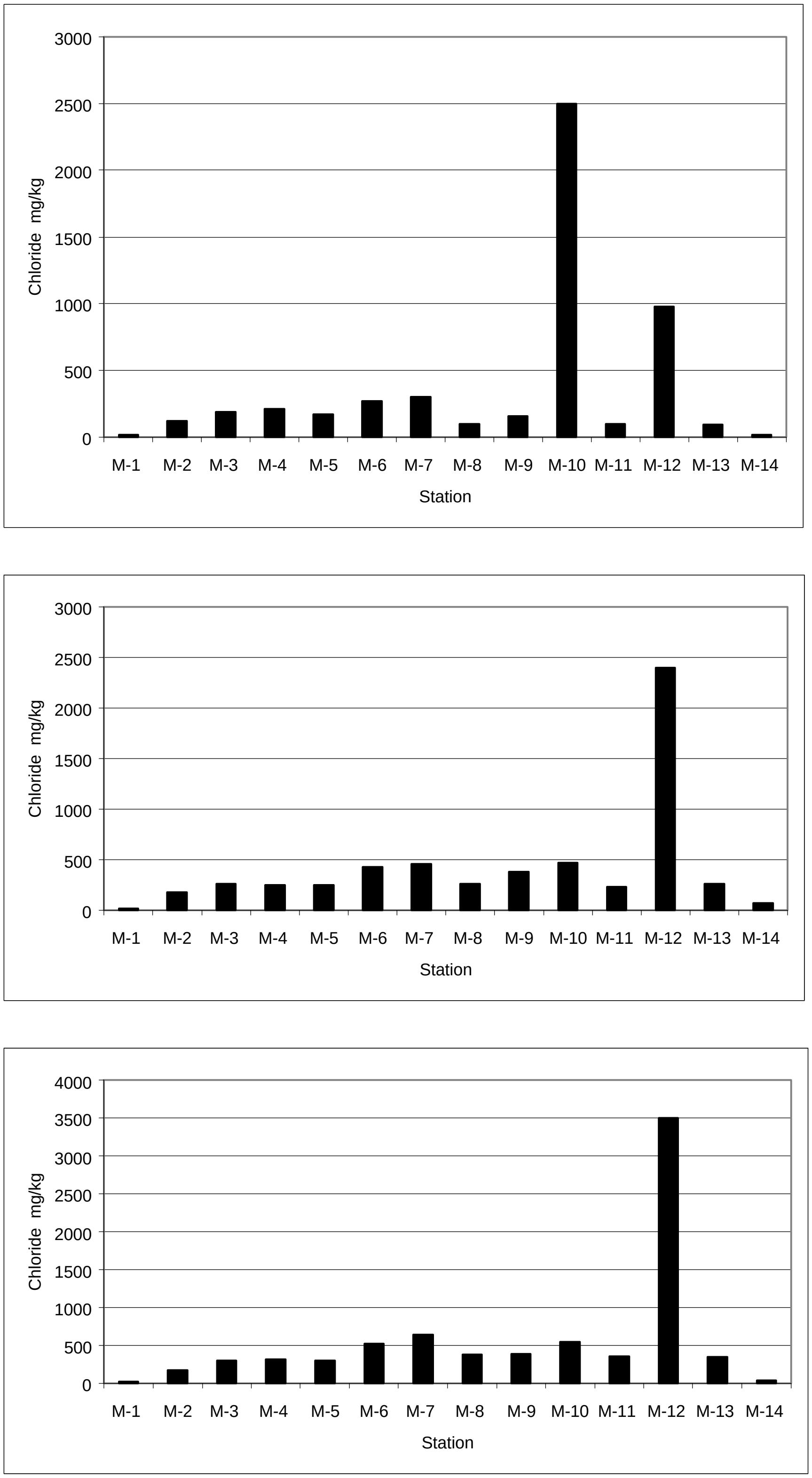


**FIGURE 4.3.1 CHLORIDE RESULTS (EXTRACTABLE) FOR THE TOP, MIDDLE, AND BOTTOM CORE SECTIONS COLLECTED IN MANISTEE LAKE, NOVEMBER 1998.**

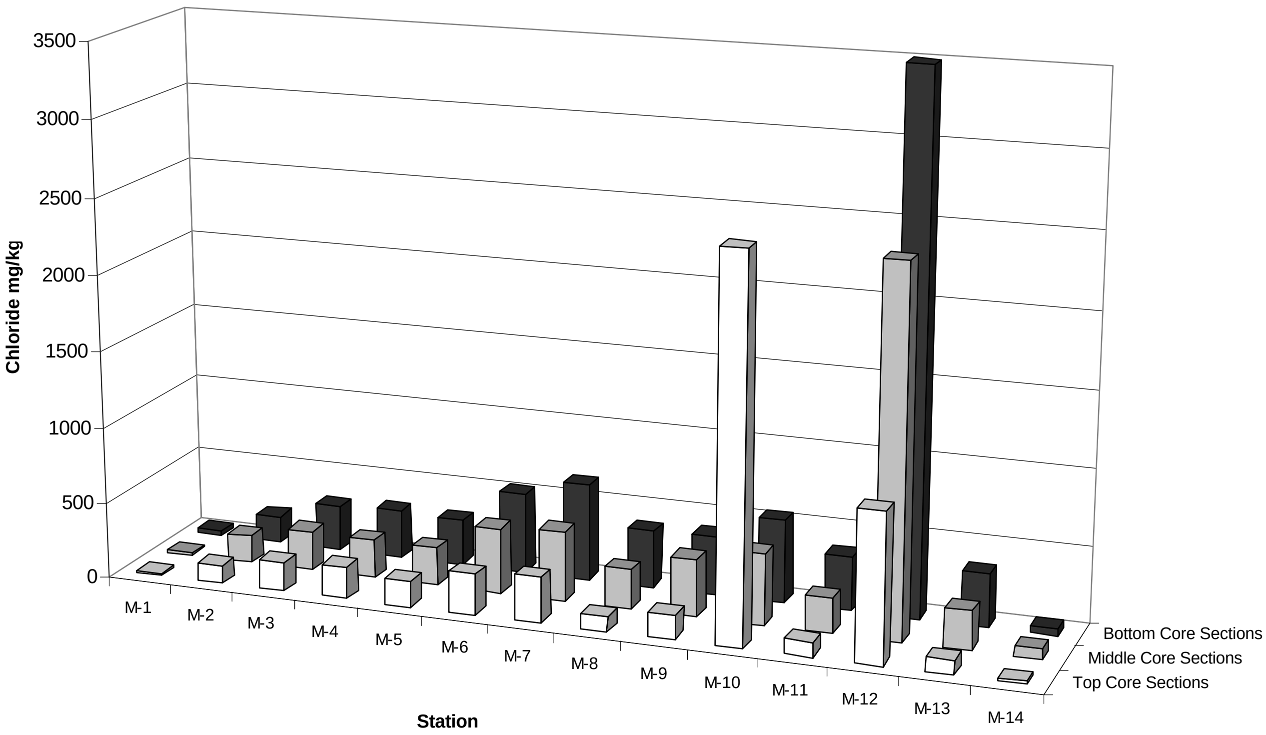


**FIGURE 4.3.2 CHLORIDE RESULTS (EXTRACTABLE) FOR MANISTEE LAKE CORE SAMPLES, NOVEMBER 1998.**

## 4.4 Metals And General Chemistry Results

The results of sediment grain size fractions, percent solids and TOC are presented in Table 4.4.1. With few exceptions, sediments from the core samples can be characterized as fine grain size (> 80% of particles < 63 *u*m) and high in total organic carbon (TOC 4% - 16%). The bottom core section from M-12 contained a high sand and gravel fraction that comprised 50% of the particle size. This sample was also high in chloride suggesting that it contains brine seepage. Ponar samples generally had a slightly larger grain size fraction due to the inclusion of more organic detritus. The Ponar samples from the control stations also contained higher sand and silt size fractions compared to the corresponding top core sections. These differences can be explained by sample depths (core samples collected from 0"-20" and Ponar samples collected from 0"-6") and differences in location due to reliance on Loran coordinates.

The results of sediment metals analyses are presented in Table 4.4.2. Figures 4.4.1, 4.4.2, and 4.4.3 illustrate the distribution of chromium, lead, and cadmium respectively in the Manistee Lake core samples. With the exception of Station M-2, the highest level of the three metals is found in the top core section between 0"-20". Station M-2 had the highest concentration of metals in the middle core section between 20"-40". This location is near the railroad tracks and down stream from the old PCA wastewater outfall. The presence of elevated metals in the deeper strata may reflect historical releases from these locations. These results are from a single core and additional samples would need to be collected from the area to verify this pattern of heavy metal deposition.

With respect to spatial distribution, Figures 4.4.4 - 4.4.7 show that different patterns of metals are associated with the two potential source areas. Elevated cadmium and chromium concentrations in Figure 4.4.4 appear to be associated with the PCA source area more than the brine companies. It is also interesting to note that the area of the combined Martin Marietta/PCA plume has the highest concentrations of these metals. Figure 4.4.6 suggests that higher levels of copper and zinc are associated with the locations near the brine companies. These results can be explained by differences in trace metal composition in the groundwater plumes from both sources. Elevated levels of chromium, arsenic, lead, and zinc have been previously reported in the PAC groundwater (VanOtteren 1998). Venting groundwater from beneath the lake, however, would tend to produce a reverse concentration gradient with higher concentrations in the bottom core sections. A more lateral venting from the sides or historical surface water discharges would tend to produce the observed patterns. A detailed hydrogeologic study of the groundwater/sediment/water interface would need to be performed to understand contaminant fate and transport.

The middle section core graphs show a different trend of distribution. Results for cadmium, chromium, and lead (Figure 4.4.6) show that the 20"-40" depth at M-2 is clearly higher that the other stations in the study. A similar pattern was noted for arsenic, copper, and zinc in the middle core section of M-12 (Figure 4.4.7). Elevated chloride levels were found in this core region, which indicated a direct connection with groundwater influx at M-12. Sediment characteristics changed from silts to sand/gravel in the bottom core section, which explains the lack of heavy metals found in the bottom core section. These results were again from single cores and more samples from these respective locations would be necessary to confirm these preliminary observations.

A comparison of the highest concentration of metals measured in the Ponar samples and recent sediment quality guidelines (MacDonald et al. 2000) is given in Table 4.3.3. All metals were below consensus based Probable Effect Concentrations (PECs). The PECs suggest that adverse ecological impacts from metals are unlikely (< 50% probability) in Manistee Lake.

## Table 4.4.1 Results Of Sediment Grain Size Fractions, Toc, And Percent Solids For Manistee Lake, November 1998.

| Location | Solids Weight % | > 2000 Weight % | 1000-2000 Weight % | 850-1000 Weight % | 500-800 Weight % | 125-500 Weight % | 63-125 Weight % | < 63 Weight % | TOC % |
|---|---|---|---|---|---|---|---|---|---|
| M-1 Top | 30 | 0.2 | 2.0 | 0.0 | 0.2 | 3.1 | 2.5 | 92 | 5.3 |
| M-1-Mid | 25 | 0.9 | 0.1 | 0.0 | 0.0 | 1.4 | 3.4 | 94 | 7.4 |
| M-1 Bot | 21 | 0.0 | 0.2 | 0.1 | 0.5 | 4.4 | 28 | 67 | 16 |
| M-2 Top | 15 | 0.1 | 0.1 | 0.0 | 0.7 | 2.0 | 4.6 | 92 | 12 |
| M-2 Mid | 14 | 0.1 | 2.0 | 0.0 | 0.0 | 0.9 | 2.7 | 94 | 12 |
| M-2 Bot | 17 | 0.5 | 1.8 | 3.0 | 0.1 | 4.3 | 8.1 | 82 | 14 |
| M-3 Top | 17 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 13 | 84 | 5.2 |
| M-3 Mid | 17 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 14 | 82 | 10 |
| M-3 Bot | 17 | 0.0 | 0.1 | 0.0 | 0.2 | 2.3 | 8.9 | 89 | 11 |
| M-4 Top | 17 | 0.0 | 0.1 | 0.1 | 0.1 | 1.4 | 6.5 | 92 | 9.4 |
| M-4 Mid | 20 | 0.5 | 0.2 | 1.0 | 1.0 | 0.5 | 1.4 | 95 | 11 |
| M-4 Bot | 21 | 0.0 | 0.0 | 0.0 | 0.5 | 3.5 | 7.0 | 89 | 8.4 |
| M-5 Top | 16 | 0.5 | 0.4 | 0.1 | 0.6 | 5.0 | 8.0 | 85 | 12 |
| M-5 Mid | 18 | 0.4 | 0.0 | 0.1 | 0.2 | 1.9 | 11 | 87 | 12 |
| M-5 Bot | 19 | 0.1 | 0.1 | 0.0 | 0.3 | 3.4 | 9.6 | 87 | 11 |
| M-6 Top | 18 | 0.8 | 0.5 | 0.2 | 1.3 | 4.7 | 8.4 | 84 | 10 |
| M-6 Mid | 17 | 0.0 | 0.1 | 0.1 | 0.1 | 0.5 | 7.1 | 92 | 9.1 |
| M-6 Bot | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 7.3 | 90 | 11 |
| M-7 Top | 20 | 4.4 | 0.6 | 0.2 | 0.8 | 5.2 | 7.5 | 81 | 10 |
| M-7 Mid | 18 | 0.8 | 0.3 | 0.1 | 0.2 | 4.1 | 5.6 | 89 | 9.0 |
| M -7 Bot | 22 | 0.1 | 0.1 | 0.1 | 0.4 | 2.9 | 4.0 | 92 | 8.8 |
| M-8 Top | 14 | 0.9 | 0.0 | 0.0 | 0.1 | 2.7 | 6.7 | 90 | 4.8 |
| M-8 Mid | 20 | 0.3 | 0.4 | 3.5 | 1.1 | 4.0 | 4.5 | 86 | 7.5 |
| M-8 Bot | 23 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 3.2 | 95 | 7.5 |
| M-9 Top | 15 | 0.3 | 0.0 | 0.0 | 0.1 | 3.9 | 5.5 | 90 | 6.5 |
| M-9 Mid | 22 | 0.6 | 0.2 | 0.0 | 0.2 | 1.7 | 3.1 | 94 | 2.9 |
| M-9 Bot | 25 | 0.0 | 0.1 | 0.0 | 0.5 | 2.1 | 3.4 | 94 | 6.4 |
| M-9 Top Dup | 16 | 1.0 | 0.3 | 0.1 | 0.6 | 5.1 | 6.1 | 87 | 10 |
| M-9 Mid Dup | 22 | 1.4 | 0.9 | 0.1 | 0.5 | 1.8 | 2.7 | 93 | 6.4 |
| M-9 Bot Dup | 24 | 0.0 | 0.0 | 0.0 | 0.1 | 1.2 | 2.5 | 96 | 6.3 |

### Table 4.4.1 Results Of Sediment Grain Size Fractions, TOC, And Percent Solids For Manistee Lake, November 1998 (Continued).

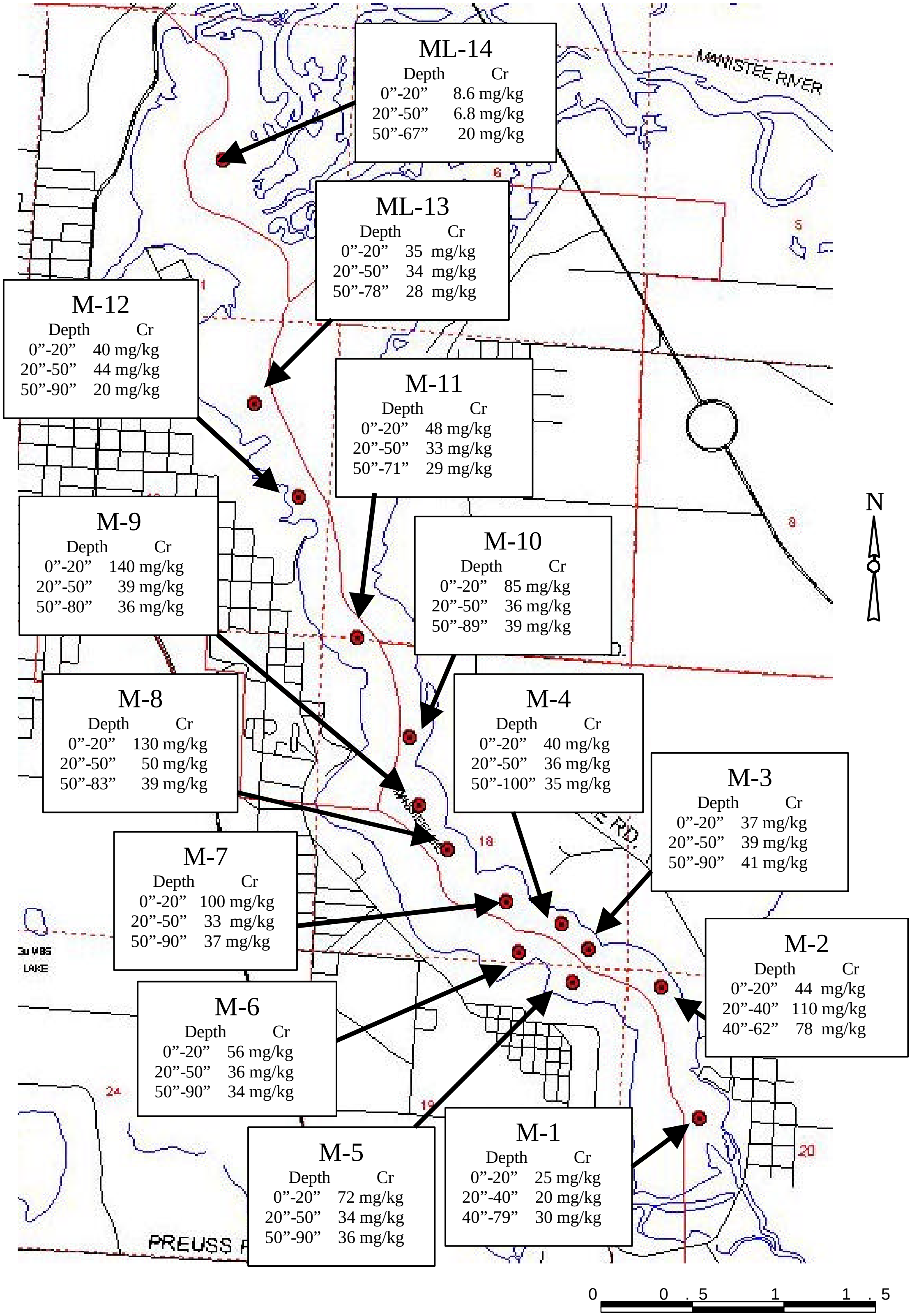
| Location | Solids Weight % | > 2000 Weight % | 1000-2000 Weight % | 850-1000 Weight % | 500-800 Weight % | 125-500 Weight % | 63-125 Weight % | < 63 Weight % | TOC % |
|---|---|---|---|---|---|---|---|---|---|
| M-10 Top | 17 | 1.2 | 2.3 | 0.1 | 0.7 | 0.8 | 3.9 | 91 | 7.7 |
| M-10 Mid | 23 | 19 | 0.5 | 0.3 | 0.8 | 2.0 | 2.9 | 75 | 5.3 |
| M-10 Bot | 26 | 0.0 | 0.0 | 0.2 | 0.0 | 1.3 | 2.6 | 96 | 5.7 |
| M-11 Top | 21 | 1.4 | 0.2 | 0.0 | 0.8 | 6.5 | 8.8 | 82 | 4.7 |
| M-11 Mid | 28 | 0.0 | 0.0 | 0.0 | 0.1 | 3.0 | 3.8 | 93 | 4.4 |
| M-11 Bot | 28 | 0.5 | 0.1 | 0.0 | 0.7 | 2.6 | 2.4 | 94 | 4.9 |
| M-12 Top | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 5.9 | 90 | 5.8 |
| M-12 Mid | 27 | 0.4 | 0.1 | 0.0 | 0.4 | 3.0 | 5.4 | 91 | 4.7 |
| M-12 Bot | 56 | 6.0 | 2.0 | 0.7 | 7.1 | 35 | 1.8 | 47 | 1.7 |
| M-13 Top | 24 | 0.7 | 0.0 | 0.0 | 0.0 | 5.9 | 8.6 | 85 | 6.2 |
| M-13 Mid | 38 | 4.1 | 0.9 | 0.2 | 1.2 | 2.6 | 3.8 | 87 | 4.6 |
| M-13 Bot | 38 | 0.6 | 0.7 | 0.2 | 0.1 | 0.7 | 2.7 | 95 | 3.1 |
| M-14 Top | 47 | 0.0 | 0.1 | 1.1 | 0.8 | 1.4 | 2.1 | 94 | 2.5 |
| M-14 Mid | 64 | 0.3 | 0.3 | 0.1 | 0.8 | 56 | 17 | 26 | 1.0 |
| M-14 Bot | 44 | 0.0 | 0.1 | 0.1 | 0.3 | 5.3 | 13 | 81 | 3.8 |
| M-1 P | 77 | 0.5 | 0.7 | 0.4 | 6.7 | 84 | 1.1 | 7 | 1.0 |
| M-2 P | 13 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 11 | 82 | 9.3 |
| M-3 P | 14 | 0.1 | 0.3 | 0.0 | 0.4 | 4.9 | 9.6 | 85 | 8.8 |
| M-4 P | 11 | 1.1 | 3.7 | 0.0 | 1.2 | 6.3 | 11 | 77 | 13 |
| M-5 P | 14 | 0.0 | 0.1 | 0.1 | 0.4 | 5.0 | 2.6 | 92 | 15 |
| M-6 P | 14 | 0.8 | 0.2 | 0.1 | 1.0 | 11 | 4.9 | 82 | 13 |
| M-7 P | 16 | 0.5 | 0.2 | 0.1 | 0.5 | 6.6 | 8.2 | 84 | 11 |
| M-8 P | 13 | 0.8 | 2.6 | 0.1 | 0.5 | 6.8 | 2.6 | 87 | 7.6 |
| M-9 P | 14 | 0.3 | 0.1 | 0.1 | 0.2 | 6.9 | 7.3 | 85 | 7.5 |
| M-9 P Dup | 13 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 6.8 | 89 | 8.1 |
| M-10 P | 17 | 0.0 | 0.1 | 0.1 | 0.3 | 10 | 9.1 | 80 | 6.5 |
| M-11 P | 23 | 0.3 | 0.0 | 0.1 | 0.6 | 2.5 | 3.8 | 93 | 8.1 |
| M-12 P | 38 | 0.0 | 0.1 | 0.0 | 0.1 | 4.2 | 10 | 86 | 5.6 |
| M-13 P | 20 | 0.0 | 0.0 | 0.1 | 0.1 | 3.2 | 6.7 | 90 | 4.7 |
| M-14 P | 38 | 0.2 | 0.3 | 0.3 | 1.0 | 0.0 | 44 | 54 | 2.3 |

## TABLE 4.4.2 RESULTS OF SEDIMENT METALS ANALYSES FOR MANISTEE LAKE, NOVEMBER 1998.

| Station | Total Barium mg/kg | Total Selenium mg/kg | Total Mercury ug/kg | Total Arsenic mg/kg | Total Cadmium mg/kg | Total Chromium mg/kg | Total Copper mg/kg | Total Lead mg/kg | Total Nickel mg/kg | Total Zinc mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|
| M-1 Top | 51 | 0.52 | 48 | 2.3 | 0.78 | 25 | 20 | 23 | 8.4 | 76 |
| M-1-Mid | 62 | 0.50 | 27 | 0.24 | 0.47 | 20 | 27 | 16 | 9.8 | 53 |
| M-1 Bot | 72 | 1.10 | <25 | 0.33 | 0.54 | 30 | 12 | 4.8 | 9.5 | 53 |
| M-2 Top | 120 | 0.33 | 45 | 9.2 | 1.7 | 44 | 53 | 78 | 20 | 200 |
| M-2 Mid | 150 | 0.30 | 22 | 11 | 3.8 | 110 | 120 | 160 | 21 | 300 |
| M-2 Bot | 94 | 0.62 | <25 | 8.6 | 0.74 | 78 | 18 | 15 | 14 | 64 |
| M-3 Top | 100 | 0.46 | <25 | 8.4 | 0.85 | 37 | 29 | 24 | 16 | 92 |
| M-3 Mid | 120 | 0.73 | <25 | 8.4 | 0.47 | 39 | 16 | 8.5 | 17 | 59 |
| M-3 Bot | 120 | 0.76 | <25 | 7.0 | 0.49 | 41 | 16 | 7 | 18 | 60 |
| M-4 Top | 110 | 0.79 | <25 | 6.7 | 0.41 | 40 | 17 | 73 | 19 | 60 |
| M-4 Mid | 110 | 0.71 | <25 | 6.5 | 0.43 | 36 | 16 | 7.6 | 18 | 58 |
| M-4 Bot | 130 | 0.71 | <25 | 6.3 | 0.47 | 35 | 16 | 8.1 | 20 | 210 |
| M-5 Top | 110 | 0.35 | <25 | 2.2 | 2.5 | 72 | 75 | 88 | 22 | 60 |
| M-5 Mid | 100 | 0.70 | 123 | 7.3 | 0.5 | 34 | 16 | 10 | 18 | 57 |
| M-5 Bot | 120 | 0.91 | <25 | 6.9 | 0.52 | 36 | 16 | 8.2 | 19 | 110 |
| M-6 Top | 93 | 0.44 | 27 | 8.1 | 1.8 | 56 | 30 | 26 | 23 | 57 |
| M-6 Mid | 110 | 0.72 | <25 | 8.2 | 0.45 | 36 | 15 | 8.4 | 20 | 56 |
| M-6 Bot | 120 | 0.74 | <25 | 6.9 | 0.5 | 34 | 17 | 7.8 | 21 | 56 |
| M-7 Top | 110 | 0.22 | 48 | 9.6 | 2.3 | 100 | 60 | 64 | 24 | 170 |
| M-7 Mid | 95 | 0.60 | <25 | 5.4 | 0.63 | 33 | 17 | 12 | 22 | 67 |
| M -7 Bot | 120 | 0.68 | <25 | 7.6 | 0.42 | 37 | 16 | 8.5 | 24 | 60 |
| M-8 Top | 110 | 0.36 | 95 | 17 | 2.6 | 130 | 100 | 91 | 26 | 230 |
| M-8 Mid | 110 | 0.52 | <25 | 8.9 | 0.61 | 50 | 21 | 16 | 21 | 79 |
| M-8 Bot | 120 | 0.60 | <25 | 7.8 | 0.35 | 39 | 16 | 8.2 | 19 | 61 |
| M-9 Top | 110 | 0.43 | 62 | 3.0 | 3.4 | 140 | 100 | 83 | 29 | 230 |
| M-9 Mid | 110 | 0.46 | <25 | 7.7 | 0.37 | 39 | 19 | 12 | 21 | 71 |
| M-9 Bot | 130 | 0.51 | <25 | 6.2 | 0.3 | 36 | 15 | 8 | 20 | 56 |
| M-9 Top Dup | 110 | 0.46 | 66 | 12 | 3.4 | 82 | 94 | 85 | 26 | 240 |
| M-9 Mid Dup | 110 | 0.46 | 26 | 5.4 | 0.3 | 31 | 15 | 10 | 18 | 54 |
| M-9 Bot Dup | 120 | 0.50 | <25 | 6.5 | 0.41 | 36 | 16 | 8.7 | 20 | 59 |

### Table 4.4.2 Results Of Sediment Metals Analyses For Manistee Lake, November 1998 (Continued).

| Station | Total Barium mg/kg | Total Selenium mg/kg | Total Mercury ug/kg | Total Arsenic mg/kg | Total Cadmium mg/kg | Total Chromium mg/kg | Total Copper mg/kg | Total Lead mg/kg | Total Nickel mg/kg | Total Zinc mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|
| M-10 Top | 120 | 0.44 | 55 | 15 | 2.5 | 85 | 120 | 87 | 34 | 330 |
| M-10 Mid | 100 | 0.3 | <25 | 6.4 | 0.36 | 36 | 21 | 20 | 24 | 30 |
| M-10 Bot | 120 | 0.38 | <25 | 7.6 | 0.36 | 39 | 17 | 9.8 | 23 | 64 |
| M-11 Top | 110 | 0.39 | 150 | 14 | 1.3 | 48 | 150 | 67 | 33 | 190 |
| M-11 Mid | 110 | 0.35 | <25 | 6.3 | 0.31 | 33 | 21 | 15 | 22 | 66 |
| M-11 Bot | 110 | 0.42 | <25 | 4.0 | 0.44 | 29 | 16 | 9.5 | 22 | 63 |
| M-12 Top | 110 | 0.33 | 53 | 9.4 | 1.1 | 40 | 98 | 81 | 30 | 200 |
| M-12 Mid | 320 | <0.20 | 152 | 17 | 1.4 | 44 | 140 | 85 | 29 | 240 |
| M-12 Bot | 67 | <0.20 | 27 | 3.7 | 0.22 | 20 | 16 | 15 | 14 | 56 |
| M-13 Top | 88 | 0.29 | 48 | 11 | 0.82 | 35 | 180 | 58 | 35 | 150 |
| M-13 Mid | 94 | 0.21 | 188 | 9.4 | 0.57 | 34 | 84 | 30 | 24 | 120 |
| M-13 Bot | 96 | 0.25 | <25 | 5.2 | 0.23 | 28 | 18 | 13 | 23 | 58 |
| M-14 Top | 46 | 0.23 | <25 | 2.1 | 0.14 | 8.6 | 7.1 | 6.1 | 7.0 | 20 |
| M-14 Mid | 25 | <0.20 | <25 | 1.6 | 0.16 | 6.8 | 5.7 | 5.8 | 8.0 | 15 |
| M-14 Bot | 63 | 0.22 | 27 | 3.5 | 0.34 | 20 | 16 | 20 | 16 | 51 |
| M-1 P | 8 | <0.20 | 29 | 0.63 | <0.050 | <2.0 | <2.0 | 1.5 | <4.0 | <4.0 |
| M-2 P | 110 | 0.65 | 39 | 9.1 | 1.7 | 38 | 45 | 54 | 18 | 160 |
| M-3 P | 110 | 0.62 | 33 | 10 | 2.6 | 38 | 49 | 54 | 19 | 160 |
| M-4 P | 120 | 0.58 | 39 | 9.9 | 1.4 | 36 | 42 | 43 | 17 | 130 |
| M-5 P | 110 | 0.51 | 230 | 9.1 | 3.1 | 38 | 72 | 85 | 16 | 190 |
| M-6 P | 84 | 0.52 | 44 | 13 | 3.1 | 68 | 71 | 71 | 19 | 160 |
| M-7 P | 83 | 1.20 | <25 | 9.4 | 3.2 | 87 | 42 | 38 | 16 | 150 |
| M-8 P | 110 | 0.50 | 50 | 12 | 2.6 | 43 | 64 | 63 | 24 | 170 |
| M-9 P | 120 | 0.49 | 36 | 10 | 1.6 | 46 | 81 | 69 | 25 | 180 |
| M-9 P Dup | 130 | 0.52 | 43 | 11 | 1.5 | 47 | 82 | 72 | 24 | 180 |
| M-10 P | 120 | 0.58 | 58 | 15 | 1.1 | 40 | 100 | 66 | 28 | 200 |
| M-11 P | 110 | 0.49 | 89 | 12 | 1.3 | 35 | 140 | 77 | 30 | 190 |
| M-12 P | 110 | 1.50 | 86 | 7.8 | 0.99 | 31 | 78 | 69 | 24 | 170 |
| M-13 P | 120 | 0.72 | 52 | 7.9 | 0.82 | 34 | 95 | 56 | 34 | 150 |
| M-14 P | 38 | <0.20 | <25 | 2.7 | 0.18 | 12 | 9.6 | 8.9 | 9.6 | 25 |



**ML-14**

| Depth | Cr |
|---|---|
| 0”-20” | 8.6 mg/kg |
| 20”-50” | 6.8 mg/kg |
| 50”-67” | 20 mg/kg |

**ML-13**

| Depth | Cr |
|---|---|
| 0”-20” | 35 mg/kg |
| 20”-50” | 34 mg/kg |
| 50”-78” | 28 mg/kg |

**M-12**

| Depth | Cr |
|---|---|
| 0”-20” | 40 mg/kg |
| 20”-50” | 44 mg/kg |
| 50”-90” | 20 mg/kg |

**M-11**

| Depth | Cr |
|---|---|
| 0”-20” | 48 mg/kg |
| 20”-50” | 33 mg/kg |
| 50”-71” | 29 mg/kg |

**M-9**

| Depth | Cr |
|---|---|
| 0”-20” | 140 mg/kg |
| 20”-50” | 39 mg/kg |
| 50”-80” | 36 mg/kg |

**M-10**

| Depth | Cr |
|---|---|
| 0”-20” | 85 mg/kg |
| 20”-50” | 36 mg/kg |
| 50”-89” | 39 mg/kg |

**M-8**

| Depth | Cr |
|---|---|
| 0”-20” | 130 mg/kg |
| 20”-50” | 50 mg/kg |
| 50”-83” | 39 mg/kg |

**M-4**

| Depth | Cr |
|---|---|
| 0”-20” | 40 mg/kg |
| 20”-50” | 36 mg/kg |
| 50”-100” | 35 mg/kg |

**M-3**

| Depth | Cr |
|---|---|
| 0”-20” | 37 mg/kg |
| 20”-50” | 39 mg/kg |
| 50”-90” | 41 mg/kg |

**M-7**

| Depth | Cr |
|---|---|
| 0”-20” | 100 mg/kg |
| 20”-50” | 33 mg/kg |
| 50”-90” | 37 mg/kg |

**M-2**

| Depth | Cr |
|---|---|
| 0”-20” | 44 mg/kg |
| 20”-40” | 110 mg/kg |
| 40”-62” | 78 mg/kg |

**M-6**

| Depth | Cr |
|---|---|
| 0”-20” | 56 mg/kg |
| 20”-50” | 36 mg/kg |
| 50”-90” | 34 mg/kg |

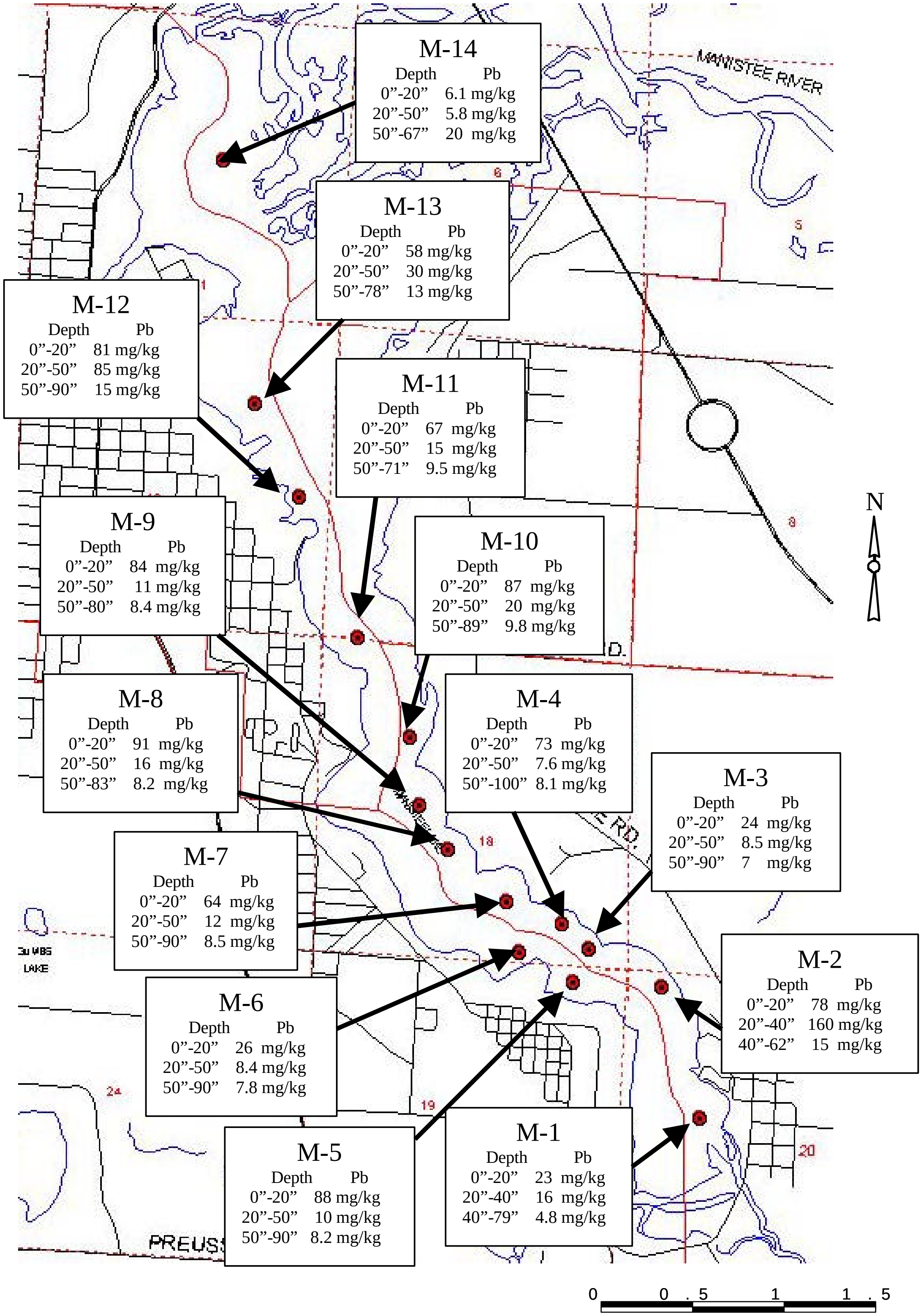
**M-1**

| Depth | Cr |
|---|---|
| 0”-20” | 25 mg/kg |
| 20”-40” | 20 mg/kg |
| 40”-79” | 30 mg/kg |

**M-5**

| Depth | Cr |
|---|---|
| 0”-20” | 72 mg/kg |
| 20”-50” | 34 mg/kg |
| 50”-90” | 36 mg/kg |

**FIGURE 4.4.1 CHROMIUM IN CORE SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998**



**M-14**

| Depth | Pb |
|---|---|
| 0”-20” | 6.1 mg/kg |
| 20”-50” | 5.8 mg/kg |
| 50”-67” | 20 mg/kg |

**M-13**

| Depth | Pb |
|---|---|
| 0”-20” | 58 mg/kg |
| 20”-50” | 30 mg/kg |
| 50”-78” | 13 mg/kg |

**M-12**

| Depth | Pb |
|---|---|
| 0”-20” | 81 mg/kg |
| 20”-50” | 85 mg/kg |
| 50”-90” | 15 mg/kg |

**M-11**

| Depth | Pb |
|---|---|
| 0”-20” | 67 mg/kg |
| 20”-50” | 15 mg/kg |
| 50”-71” | 9.5 mg/kg |

**M-9**

| Depth | Pb |
|---|---|
| 0”-20” | 84 mg/kg |
| 20”-50” | 11 mg/kg |
| 50”-80” | 8.4 mg/kg |

**M-10**

| Depth | Pb |
|---|---|
| 0”-20” | 87 mg/kg |
| 20”-50” | 20 mg/kg |
| 50”-89” | 9.8 mg/kg |

**M-8**

| Depth | Pb |
|---|---|
| 0”-20” | 91 mg/kg |
| 20”-50” | 16 mg/kg |
| 50”-83” | 8.2 mg/kg |

**M-4**

| Depth | Pb |
|---|---|
| 0”-20” | 73 mg/kg |
| 20”-50” | 7.6 mg/kg |
| 50”-100” | 8.1 mg/kg |

**M-3**

| Depth | Pb |
|---|---|
| 0”-20” | 24 mg/kg |
| 20”-50” | 8.5 mg/kg |
| 50”-90” | 7 mg/kg |

**M-7**

| Depth | Pb |
|---|---|
| 0”-20” | 64 mg/kg |
| 20”-50” | 12 mg/kg |
| 50”-90” | 8.5 mg/kg |

**M-2**

| Depth | Pb |
|---|---|
| 0”-20” | 78 mg/kg |
| 20”-40” | 160 mg/kg |
| 40”-62” | 15 mg/kg |

**M-6**

| Depth | Pb |
|---|---|
| 0”-20” | 26 mg/kg |
| 20”-50” | 8.4 mg/kg |
| 50”-90” | 7.8 mg/kg |

**M-5**

| Depth | Pb |
|---|---|
| 0”-20” | 88 mg/kg |
| 20”-50” | 10 mg/kg |
| 50”-90” | 8.2 mg/kg |

**M-1**

| Depth | Pb |
|---|---|
| 0”-20” | 23 mg/kg |
| 20”-40” | 16 mg/kg |
| 40”-79” | 4.8 mg/kg |

**FIGURE 4.4.2 LEAD IN CORE SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998**

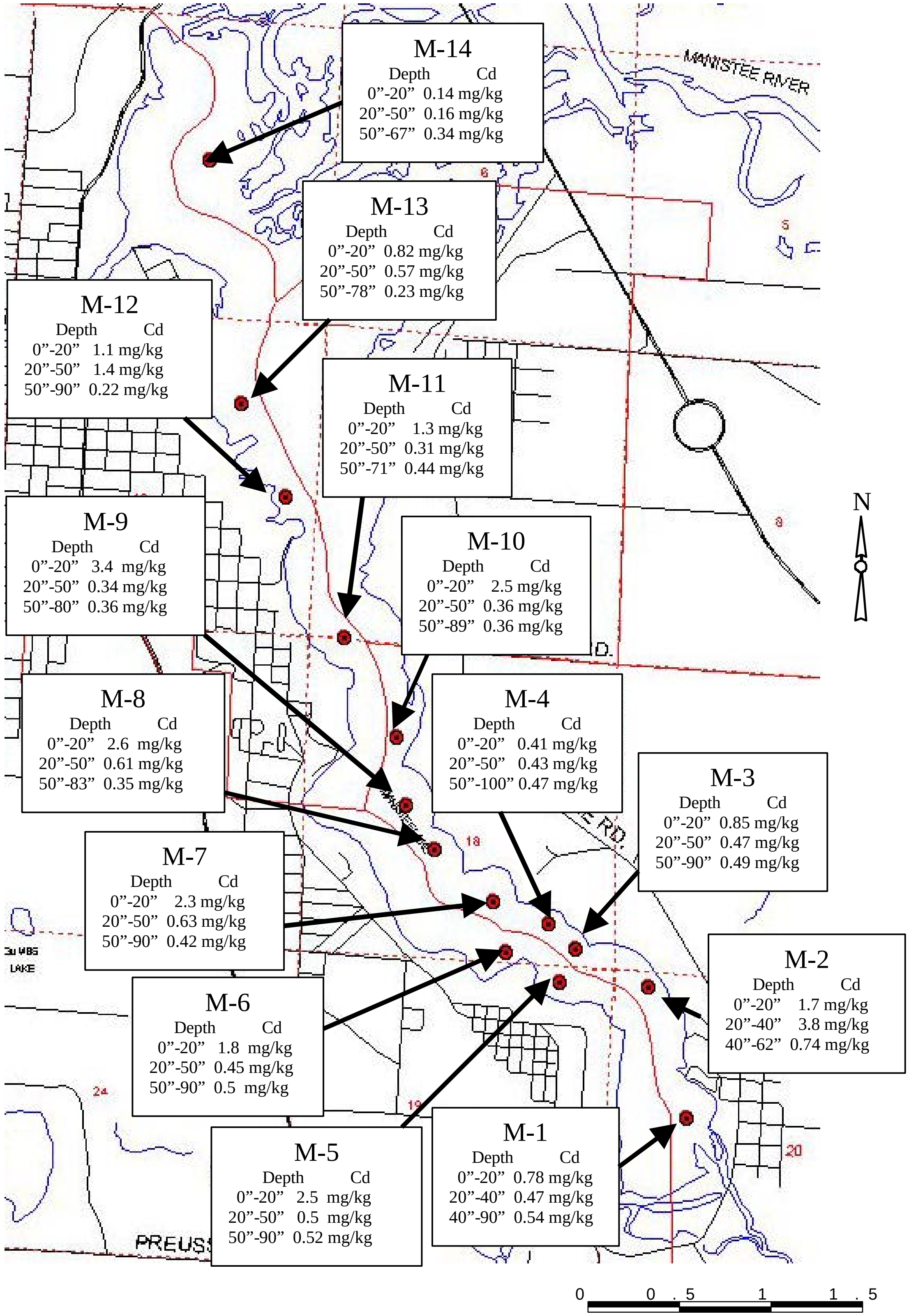


FIGURE 4.4.3 CADMIUM IN CORE SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998

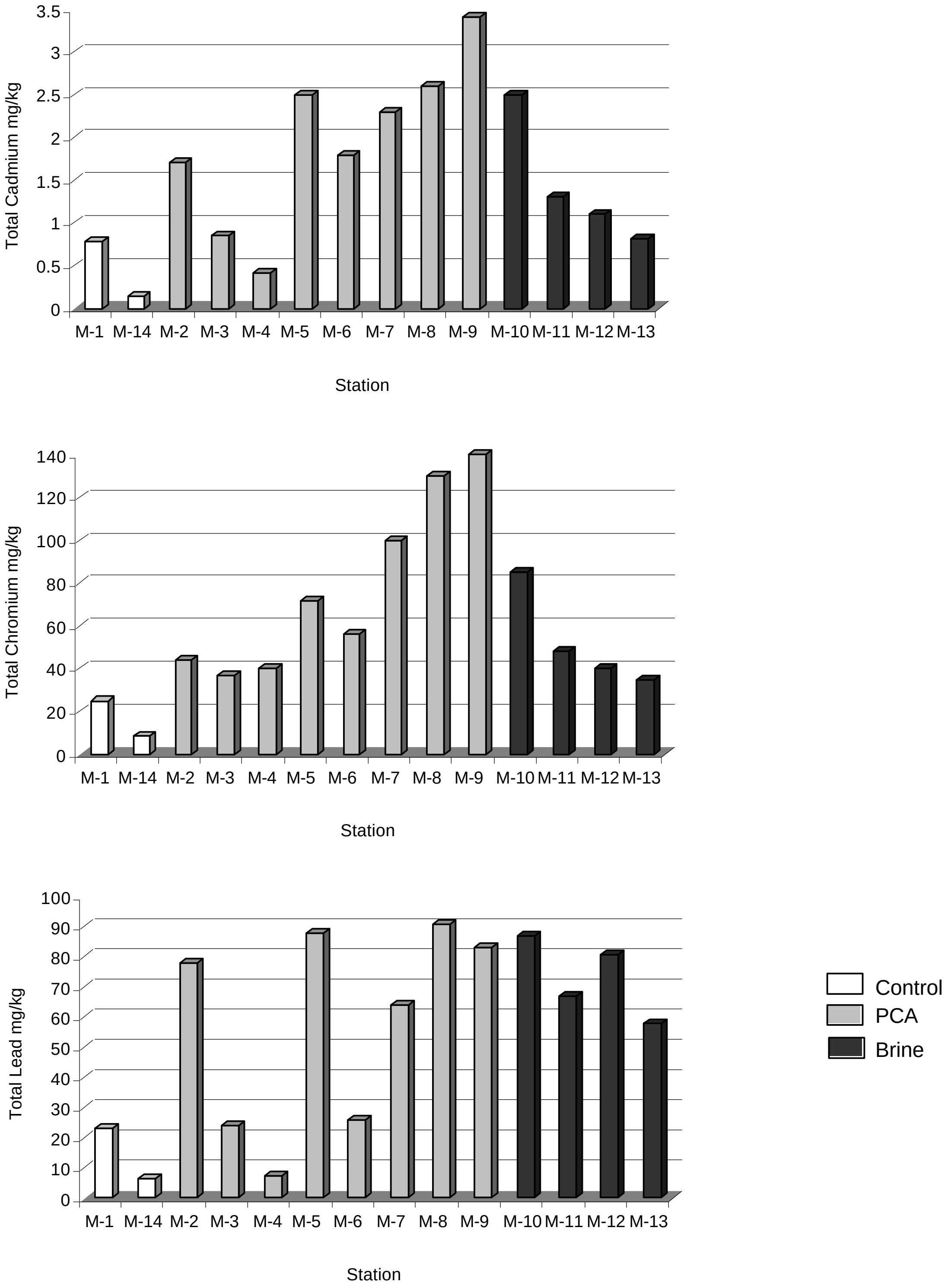


**Figure 4.4.4 Cadmium, Chromium, And Lead In Top Core Sections (0"-20") Collected From Manistee Lake, November 1998. Patterns Denote Regions Of Manistee Lake.**

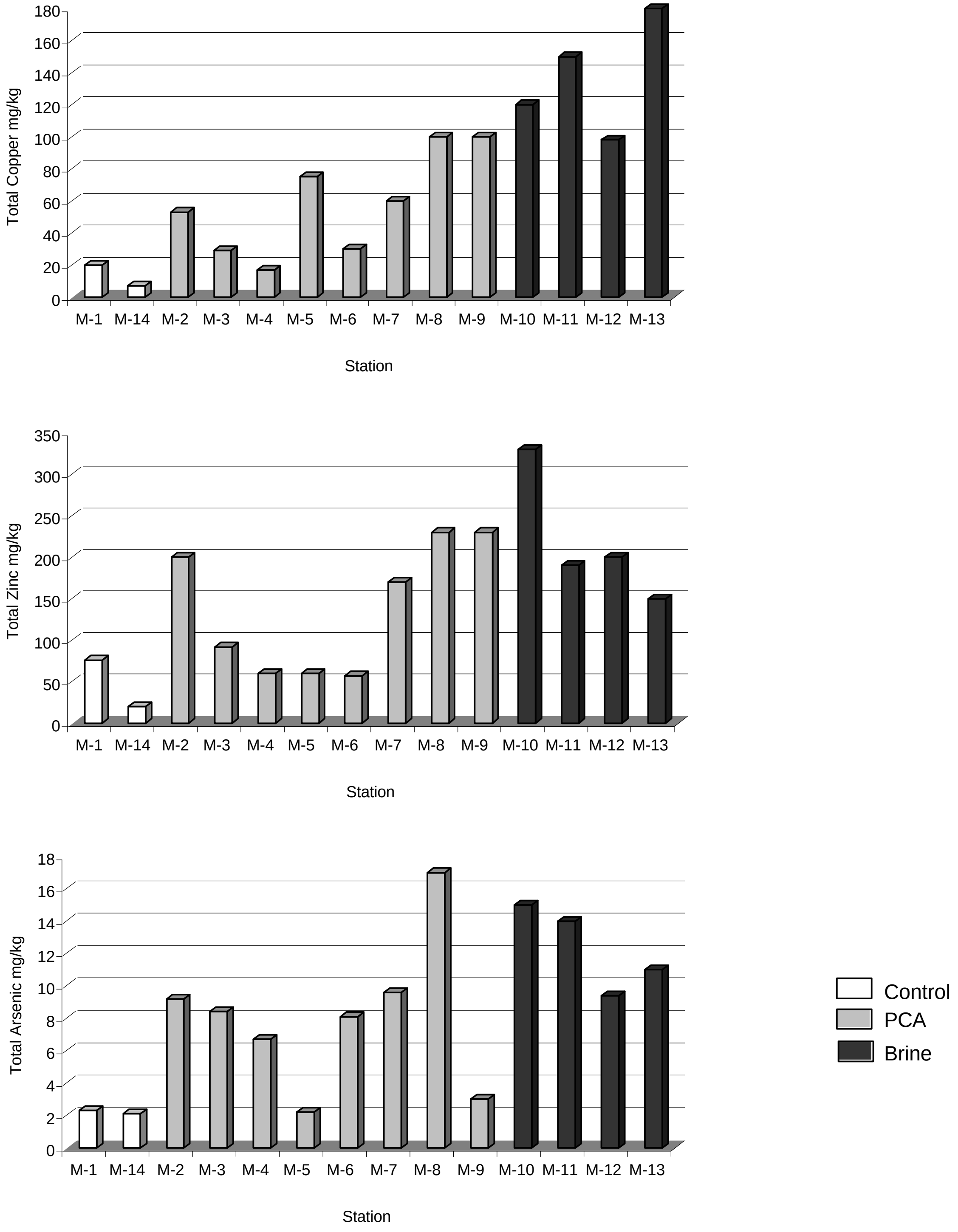


**FIGURE 4.4.5 COPPER, ZINC, AND ARSENIC IN TOP CORE SECTIONS (0"-20") COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998. PATTERNS DENOTE REGIONS OF MANISTEE LAKE.**

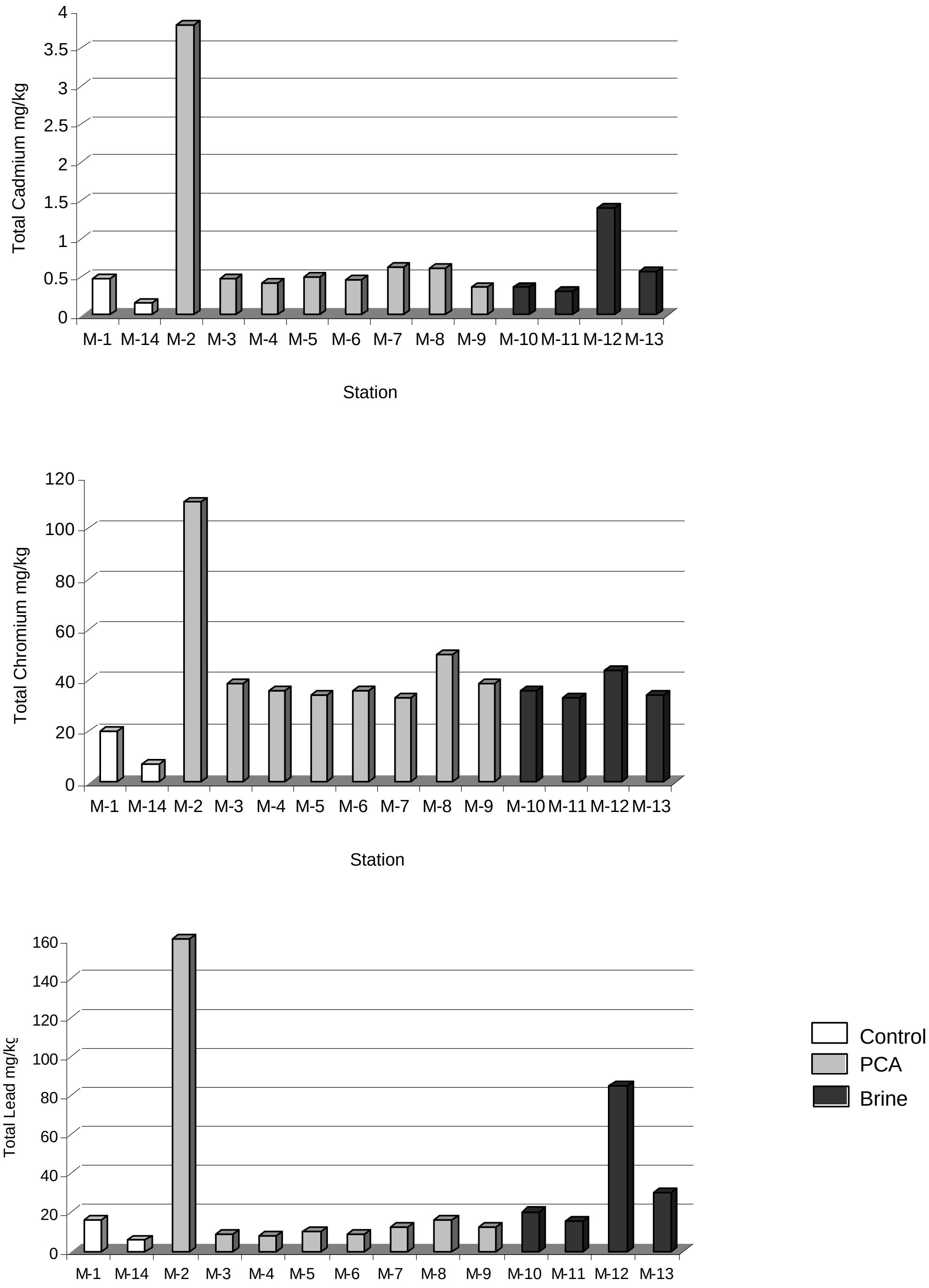


**Figure 4.4.6 Cadmium, Chromium, And Lead In Middle Core Sections (20"-40") Collected From Manistee Lake, November 1998. Patterns Denote Regions Of Manistee Lake.**

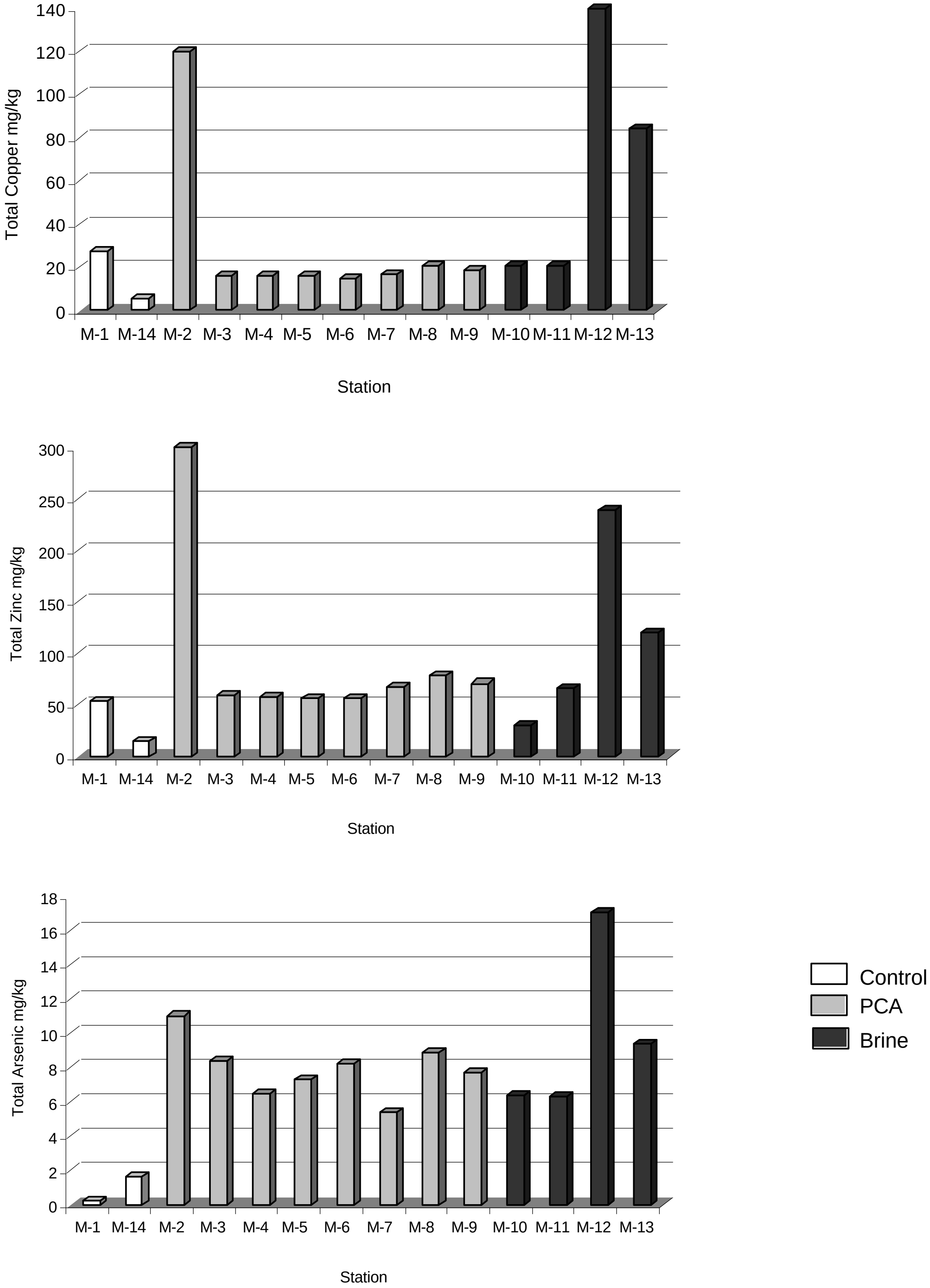


**FIGURE 4.4.7 COPPER, ZINC, AND ARSENIC IN MIDDLE CORE SECTIONS (20"-40") COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998. PATTERNS DENOTE REGIONS OF MANISTEE LAKE.**

### TABLE 4.4.3 COMPARISON OF CONSENSUS BASED PROBABLE EFFECT CONCENTRATIONS AND THE HIGHEST LEVEL OF METALS MEASURED IN PONAR SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998.

| ***Metals*** | **Highest Concentration Measured in Ponar Samples mg/kg** | **Consensus-Based PEC* mg/kg** |
|---|---|---|
| Arsenic | 15 | 33.0 |
| Cadmium | 3.1 | 4.98 |
| Chromium | 87 | 111 |
| Copper | 140 | 149 |
| Lead | 85 | 128 |
| Mercury | 0.23 | 1.06 |
| Nickel | 34 | 48.6 |
| Zinc | 200 | 459 |

* MacDonald et al. (2000)

24") samples (Figure 4.5.1.4) shows that the highest HEM concentrations are found in the surface grabs at most locations. The exceptions are M-2, M-7, and M-9 where the top core section contained higher HEM levels. This pattern suggests that higher levels of HEM are located in the older, deeper, strata of the sediment core. The flocculent nature of the sediments and the probable compression of particles during Ponar and Vibra Core sampling makes it difficult to assign any age estimates to these depths.

# Table 4.5.1.1. Results of Semivolatile and Hexane Extractable Materials (HEM) Analyses for Manistee Lake, November 1998.

| Compound | Units | Ponar Samples | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M-1P | M-2P | M-3P | M-4P | M-5P | M-6P | M-7P | M-8P | M-9P | M-9P Dup | M-10P | M-11P | M-12P | M-13P | M-14P |
| Hexane Extractables | mg/kg | 100 | 1900 | 3200 | 2600 | 4300 | 26000 | 4000 | 8800 | 3300 | 2900 | 6600 | 8300 | 7200 | 12400 | > 50 |
| Naphthalene | 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 |
| 2-Methylnaphthalene | 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 |
| 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 | <0.33 |
| 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 |
| 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 | 0.95 | <0.33 |
| Phenanthrene | mg/kg | <0.33 | 0.77 | 1.2* | 0.78 | 2.0* | 4.3* | 2* | 1.6* | 1.5* | 1.1 | 3.1* | 1.9* | 1.4* | 3.0* | <0.33 |
| Anthracene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.52 | 0.33 | 0.33 | <0.33 | <0.33 | 0.6 | 0.42 | 0.34 | 0.81 | <0.33 |
| Fluoranthene | mg/kg | <0.33 | 0.82 | 0.90 | 0.76 | 1.4 | 3* | 1.6 | 1.8 | 1.6 | 1.4 | 2.9* | 2.8* | 1.8 | 5.1* | <0.33 |
| Pyrene | mg/kg | <0.33 | 0.81 | 1.00 | 0.74 | 1.4 | 2.8* | 1.8* | 1.7* | 1.6* | 1.4 | 2.7* | 2.5* | 2.4* | 4.8* | <0.33 |
| Benzo(a)anthracene | mg/kg | <0.33 | <0.33 | 0.33 | <0.33 | <0.33 | 1.3 | 0.83 | 0.53 | 0.63 | 0.33 | 0.92 | 1.0 | 1.1* | 2.2* | <0.33 |
| Chrysene | mg/kg | <0.33 | 0.41 | 0.33 | 0.39 | <0.33 | 1.7* | 1.7* | 1.1 | 1.1 | 0.62 | 1.5* | 1.5* | 1.8* | 2.6* | <0.33 |
| Benzo(b)fluoranthene | mg/kg | <0.33 | 0.42 | 0.54 | 0.34 | <0.33 | 1.8 | 1.4 | 1.2 | 1.1 | 0.93 | 1.7 | 1.3 | 1.1 | 3.0 | <0.33 |
| Benzo(k)fluoranthene | mg/kg | <0.33 | 0.4 | <0.33 | <0.33 | <0.33 | 1.3 | 1.3 | 0.71 | 0.82 | 0.71 | 0.95 | 1.2 | 0.57 | 2.7 | <0.33 |
| Benzo(a)pyrene | mg/kg | <0.33 | <0.33 | 0.71 | <0.33 | <0.33 | 0.86 | 0.59 | 0.64 | 0.45 | 0.44 | 0.64 | 1.4* | 0.94 | 1.6* | <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 | 0.63 | <0.33 | 1.5 | <0.33 |
| Dibenzo(a,h)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 | 0.66 | <0.33 |
| Benzo(g,h,i)perylene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.34 | <0.33 | <0.33 | <0.33 | <0.33 | 0.59 | 0.56 | 0.45 | <0.33 |
| Total PAH Compounds | mg/kg | <0.33 | 3.63 | 4.81 | 3.01 | 4.8 | 17.58 | 11.89 | 9.61 | 8.8 | 6.93 | 15.01 | 15.24 | 12.01 | 29.37* | <0.33 |
| 4 - Methy phenol | mg/kg | <0.33 | 0.47 | 0.55 | <0.33 | <0.33 | 0.49 | 0.65 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 |

| Compound | Units | Top Core Sections (0-20") | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | M-7 | M-8 | M-9 | M-9 Dup | M-10 | M-11 | M-12 | M-13 | M-14 |
| Hexane Extractables | mg/kg | 130 | 2800 | 2300 | 1200 | 2900 | 15000 | 6400 | 5700 | 6700 | 5700 | 2900 | 6500 | 5400 | 9800 | 90 |
| Naphthalene | 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 |
| 2-Methylnaphthalene | 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 |
| 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 | <0.33 |
| 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 |
| 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 |
| Phenanthrene | mg/kg | <0.33 | 3.5* | 0.82 | <0.33 | 0.62 | 0.97 | 1.5* | 1.3* | 1.6* | 2.0* | 3.1* | 1.9* | 1.6* | 0.69 | <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 | 0.36 | 0.38 | <0.33 | <0.33 |
| Fluoranthene | mg/kg | <0.33 | 2.4* | 0.50 | <0.33 | 0.58 | 0.60 | 1.2 | 1.2 | 1.3 | 1.8 | 2.7* | 2.4* | 2.3* | 0.83 | <0.33 |
| Pyrene | mg/kg | <0.33 | 2.1* | 0.63 | <0.33 | 0.59 | 0.84 | 1.3 | 1.1 | 3.0* | 3.3* | 2.7* | 2.1* | 2.3* | <0.33 | <0.33 |
| Benzo(a)anthracene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.91 | <0.33 | 1.2* | 0.79 | 0.93 | 1.0 | 0.87 | <0.33 |
| Chrysene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 1.3* | <0.33 | 1.2 | 1.4* | 1.0 | 1.5* | 0.34 | <0.33 |
| Benzo(b)fluoranthene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.61 | 1.66 | 1.1 | 1.7 | 0.47 | <0.33 |
| Benzo(k)fluoranthene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.84 | <0.33 | <0.33 | 0.75 | 1.36 | 1.2 | 1.8 | 0.47 | <0.33 |
| Benzo(a)pyrene | mg/kg | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | 0.73 | <0.33 | 0.67 | 0.58 | 0.96 | 0.72 | 0.95 | 0.48 | <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 |
| Dibenzo(a,h)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 |
| 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 | 1.46 | <0.33 | <0.33 | <0.33 | <0.33 |
| Total PAH | mg/kg | <0.33 | 8.0 | 1.95 | <0.33 | 1.79 | 2.41 | 5.57 | 5.81 | 6.57 | 11.44 | 16.13 | 11.71 | 13.53 | 4.15 | <0.33 |
| 4 - Methy phenol | mg/kg | <0.33 | 0.51 | 0.47 | <0.33 | <0.33 | <0.33 | 0.60 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 | <0.33 |

* Concentration exceeds Consensus based Probable Effect Concentration (MacDonald et al. 2000)

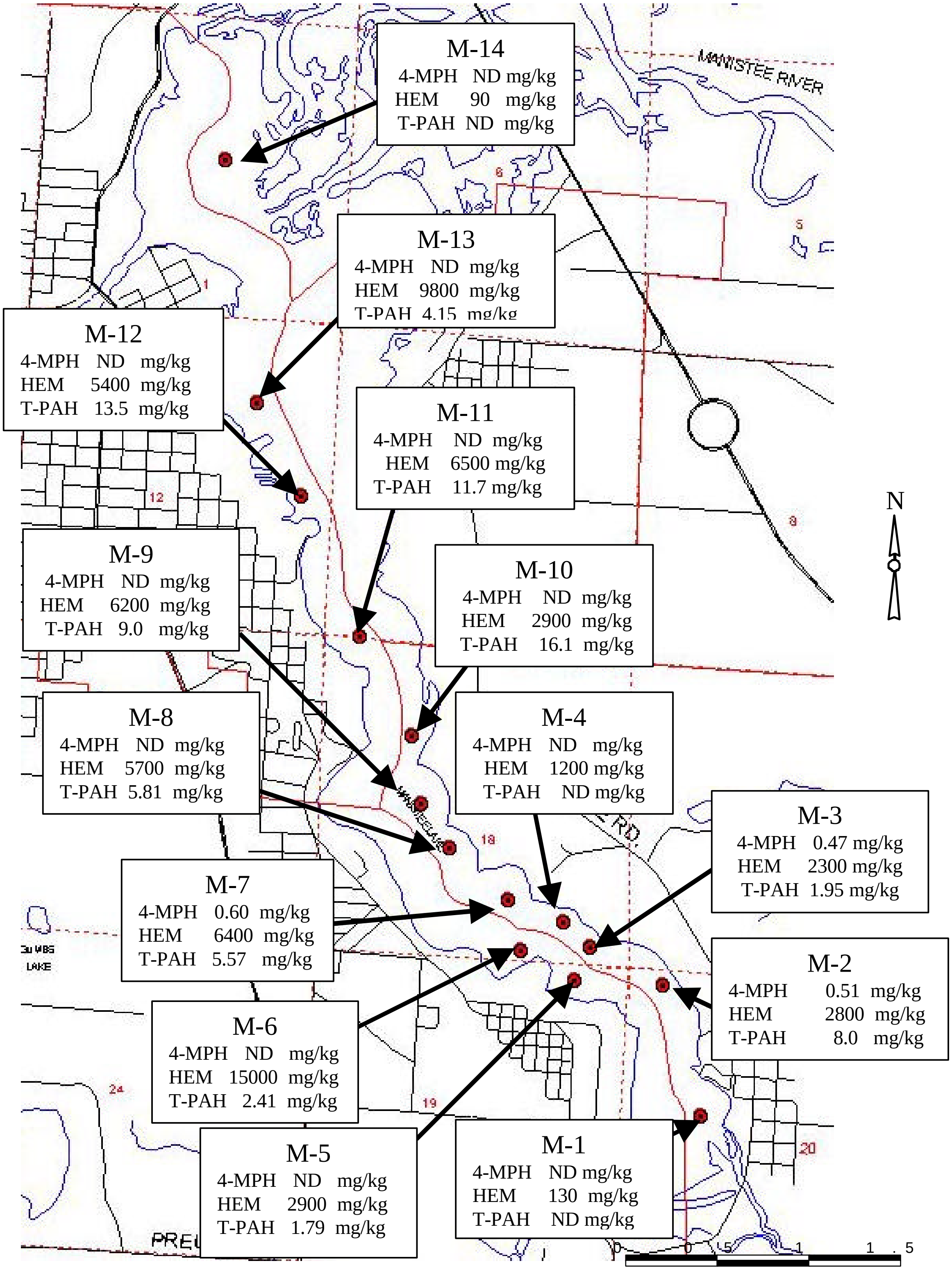


**FIGURE 4.5.1.1 HEXANE EXTRACTABLE MATERIALS, 4-METHYLPHENOL (4-MPH), AND TOTAL PAH COMPOUNDS IN TOP SECTION CORE SAMPLES (0”-20”) COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998. (ND-NOT DETECTED)**

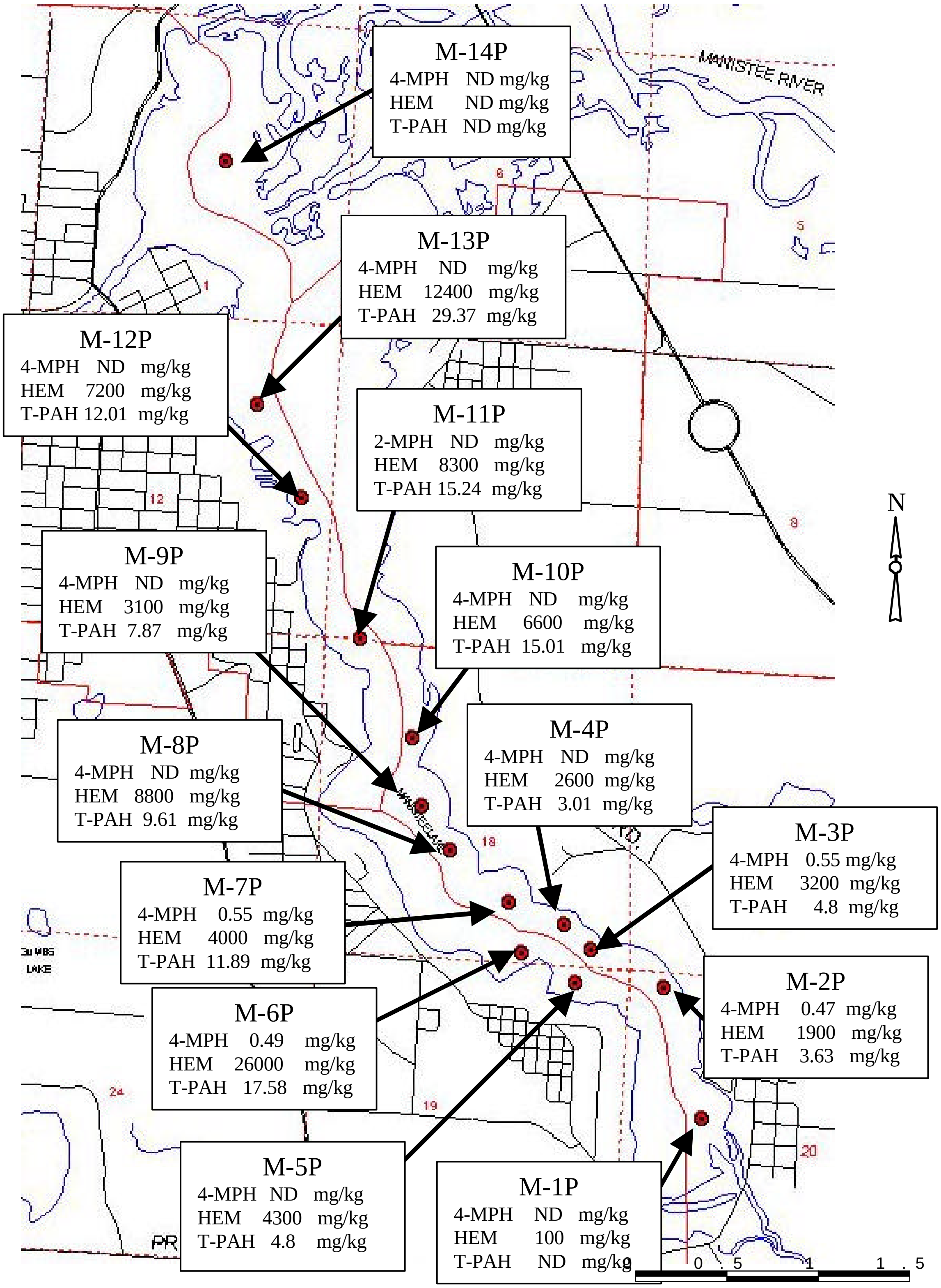
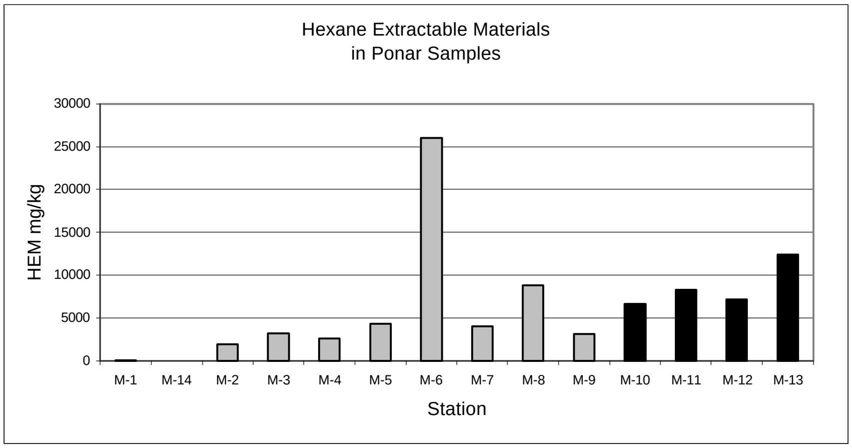
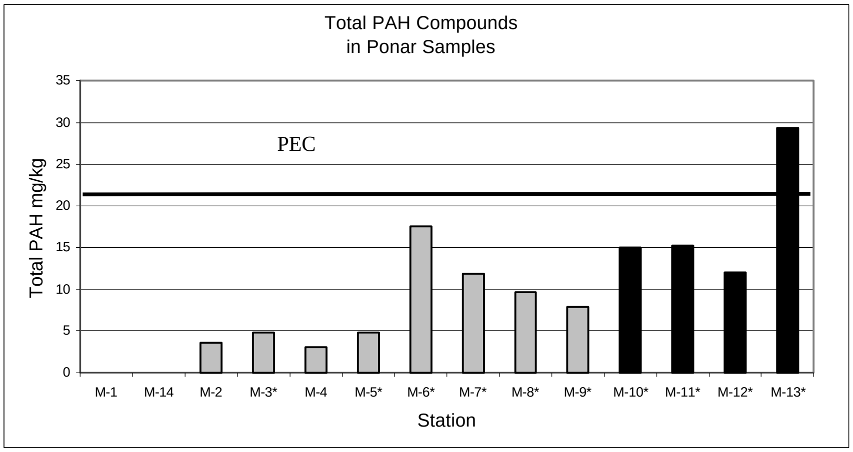


**FIGURE 4.5.1.2 HEXANE EXTRACTABLE MATERIALS, 4-METHYLPHENOL (4-MPH), AND TOTAL PAH COMPOUNDS IN PONAR SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998. (ND-NOT DETECTED)**

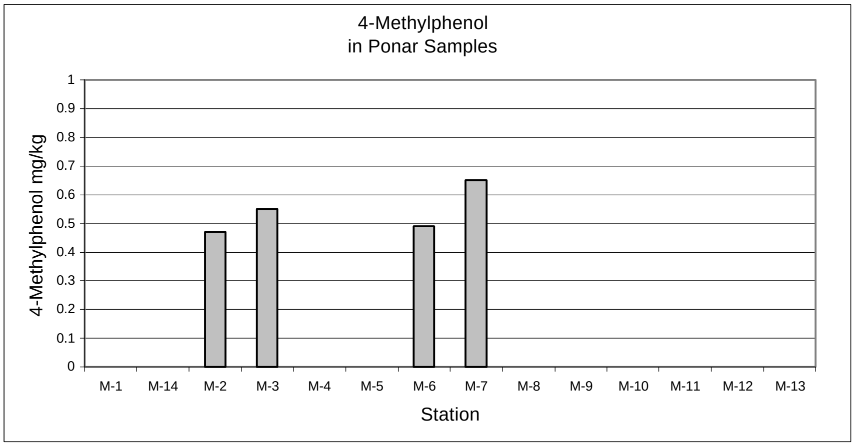
| Hexane Extractables | |
|---|---|
| Station | mg/kg |
| M-1 | 100 |
| M-14 | ND |
| M-2 | 1900 |
| M-3 | 3200 |
| M-4 | 2600 |
| M-5 | 4300 |
| M-6 | 26000 |
| M-7 | 4000 |
| M-8 | 8800 |
| M-9 | 3100 |
| M-10 | 6600 |
| M-11 | 8300 |
| M-12 | 7200 |
| M-13 | 12400 |



| Total PAH Compounds | |
|---|---|
| | mg/kg |
| M-1 | ND |
| M-14 | ND |
| M-2 | 3.63 |
| **M-3*** | **4.8** |
| M-4 | 3.01 |
| **M-5*** | **4.8** |
| **M-6*** | **17.58** |
| **M-7*** | **11.89** |
| **M-8*** | **9.61** |
| **M-9*** | **7.87** |
| **M-10*** | **15.01** |
| **M-11*** | **15.24** |
| **M-12*** | **12.01** |
| **M-13*** | **29.37** |



| 4-Methylphenol | |
|---|---|
| | mg/kg |
| M-1 | ND |
| M-14 | ND |
| M-2 | 0.47 |
| M-3 | 0.55 |
| M-4 | ND |
| M-5 | ND |
| M-6 | 0.49 |
| M-7 | 0.65 |
| M-8 | ND |
| M-9 | ND |
| M-10 | ND |
| M-11 | ND |
| M-12 | ND |
| M-13 | ND |



☐ Control ▨ PCA ■ Brine

**FIGURE 4.5.1.3 HEXANE EXTRACTABLE MATERIALS, 4-METHYLPHENOL (4-MPH), AND TOTAL PAH COMPOUNDS IN PONAR SAMPLES COLLECTED FROM MANISTEE LAKE, NOVEMBER 1998. PATTERNS DENOTE REGIONS OF MANISTEE LAKE. STATIONS IDENTIFIED IN BOLD* EXCEEDED PEC LEVELS. (ND-NOT DETECTED)**

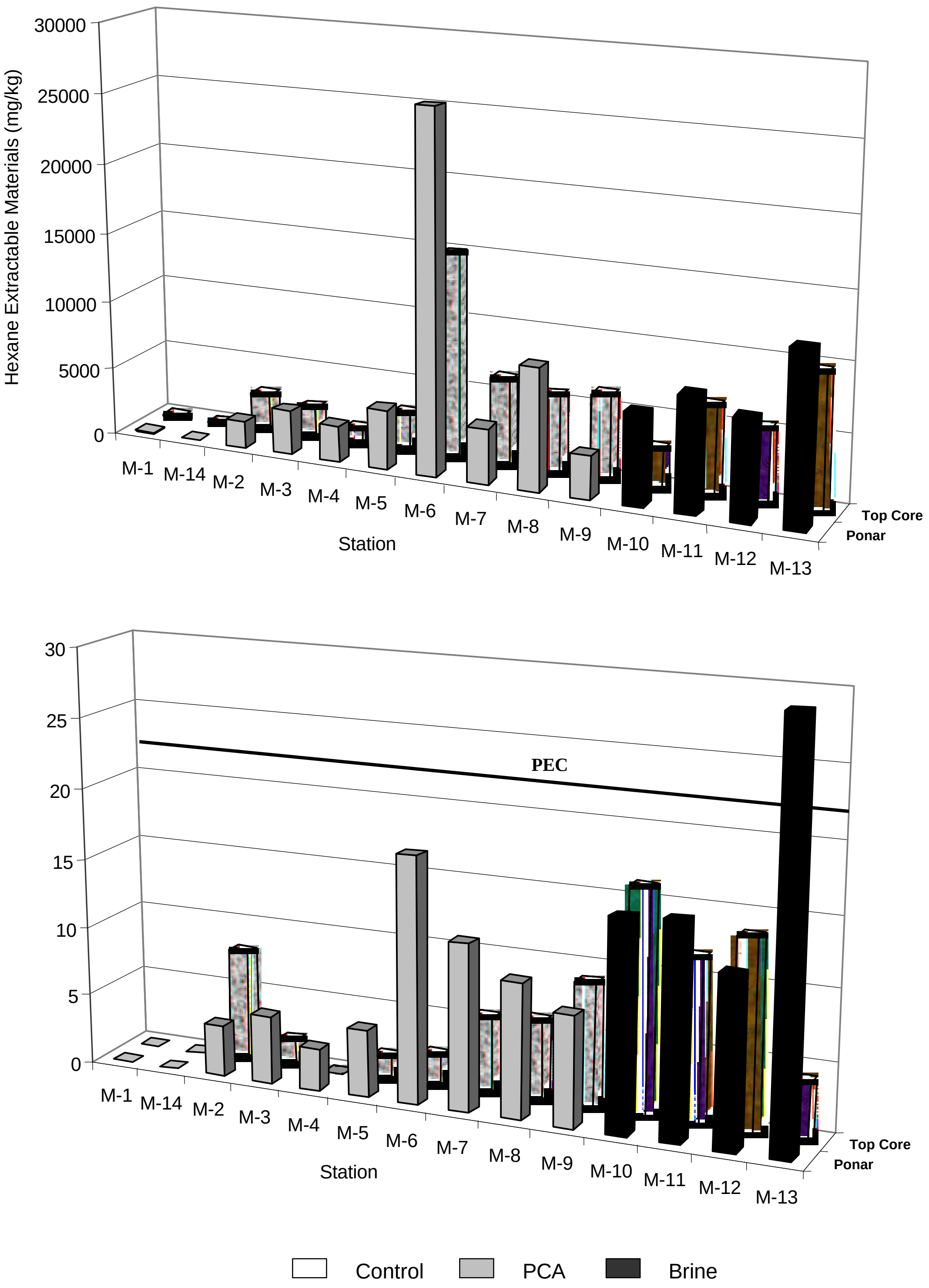


**Figure 4.5.1.4 Hexane Extractable Materials And Total PAH Compounds In Ponar And Top Core Section Samples Collected From Manistee Lake, November 1998. Patterns Denote Regions Of Manistee Lake. (PEC = Probable Effect Concentration)**

-2, which suggests that an older release of oils or fuels occurred at this location. M-2 is located near the old PCA outfall where kerosene was discharged. Levels of PAHs that exceed Probable Effect Concentrations (PECs) (MacDonald et al. 2000) are marked with an asterisk in Table 4.5.1.3. With the exception of the control stations and M-4, PECs for individual PAH compounds were exceeded at most of the sample locations. Sediment concentrations that exceed PEC levels have a 75% probability of exhibiting some type of adverse ecological effect. Correlations between PAH data and sediment toxicity are discussed in Section 4.7.

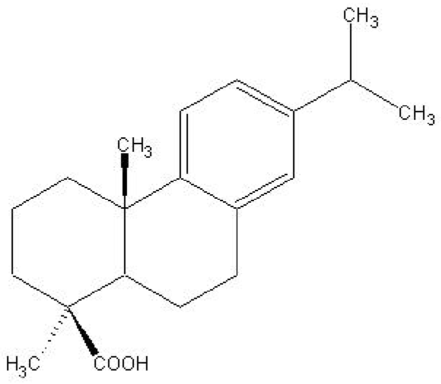
In contrast to the HEM and PAH compounds that are found at all non-control locations, 4-methyl phenol (4-MPH) appears to occur only at several locations where the PCA groundwater enters the lake (Figure 4.5.1.3) and is found at low levels. Concentrations ranged from 0.47 mg/kg at M-2P to 0.65 mg/kg at M-7P. The highest levels were found near the center of the groundwater plume (M-6, and M-7). It is interesting to note that 4-MPH was found at station M-6, which was located on the western side of the lake. Even though the PCA groundwater enters the lake along the eastern shore, this station is close enough to be influenced by the plume. Elevated chloride at this location confirms the presence of the groundwater discharge (Figure 4.3.2). The chemical stratification of Manistee Lake as shown in Figures 4.1.1 and 4.1.2 may provide a density driven mechanism for a persistent layer of contaminated groundwater to remain in the flocculent surface sediments. 4-MPH was not detected at the northern edge of the groundwater plume area (Stations M-8P and M-9P). These locations were lower in sediment chloride concentration that may illustrate a more limited influence from contaminated groundwater. Probable effect concentrations are not available for 4-MPH. Based on the laboratory toxicity tests (Section 4.6) and the analysis of the macroinvertebrate community, the presence of brine and PAH compounds appear to have a more adverse affect on benthic organisms.

In summary, the control sites near the mouths of the Manistee River and Little Manistee River showed no evidence of anthropogenic chemicals such as petroleum hydrocarbons, PAH compounds, and phenols. Oil and PAH compounds were found at elevated levels all of the sampling locations in the lake near industrial facilities. The distribution followed a pattern that indicated a combination of point and nonpoint sources were responsible for the sediment contamination. A previous investigation by Grant (1975) found oil and grease levels in the sediments to range from 3000 mg/kg to 20,000 mg/kg. These results were similar to the concentrations reported by this investigation, which suggested that minimal changes have occurred for these contaminants over the last 25 years. Basch

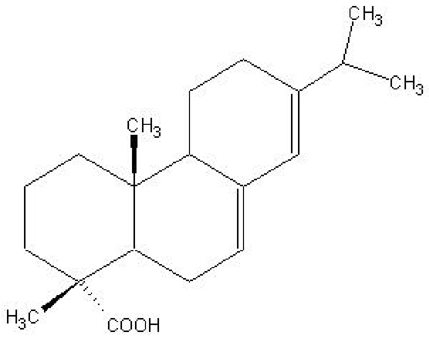
(1971) investigated total phenols and hydrogen sulfide in Manistee Lake sediments and found concentrations to range from 2 mg/kg to 27 mg/kg for total phenols and 500 mg/kg to 4500 mg/kg for hydrogen sulfide. These contaminants were directly related to the historic effluent discharge and the groundwater plume from the PCA facility. While hydrogen sulfide was not measured in this investigation, field observations revealed a slight sulfide odor in only a few samples. Camp Dresser and McKee (1993) measured semivolatiles in sediment pore water and found no detectable phenols (including 4-methyl phenol) at a reporting limit of 0.01 mg/l. The current investigation measured whole sediments and found concentrations of 4-methyl phenol in limited areas at levels ranging from 0.47 mg/kg to 0.65 mg/kg. A comparison of historical and recent/current data for phenolic compounds suggests that sediment contamination for this class of compounds has improved with the elimination of the direct effluent discharge and the closure of the lagoon system.

### 4.5.2 Resin Acids

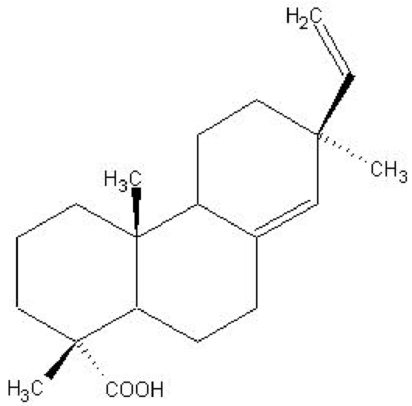
Resin acid analyses were conducted on all core and Ponar samples from Manistee Lake. The compounds included in the resin acid scan are shown in Figure 4.5.2.1. Surrogate recoveries for stearic acid exceeded 100% in most of the sediment samples due to the natural presence of this compound in sediments (Appendix B). Surrogate recoveries for the other surrogate, tetrachlorostearic acid were acceptable. Resin acids are produced during the breakdown of lignin and wood resins in the Kraft process (Stevens et al. 1997) and during natural aerobic/anaerobic degradation processes (Judd et al. 1998). Resin acids have been detected in sediments from many areas impacted by Kraft Mill effluents (Tavendale et al. 1997, Wilkins et al. 1996, and Brownlee et al. 1977). In addition anthropogenic sources, Judd et al. (1998) found resin acids in the sediments in watersheds containing conifer and hardwood forests. The results of the resin acid analyses in Manistee Lake sediment are shown in Table 4.5.2.1 and displayed graphically in Figures 4.5.2.2 - 4.5.2.5. The highest levels of total resin acids appear to be located in the top core sections and ranged from 3 mg/kg to 13 mg/kg (Figure 4.5.2.2). Areas influenced by the PCA groundwater plume had slightly higher levels of resin acids when compared with locations near the brine plumes. Two locations, M-2 and M-5, showed peaks of total resin acid concentration (11 mg/kg and 18 mg/kg) in the middle core sections. Resin acids were found at concentrations of < 5 mg/kg in the bottom core sections and at the control locations. Levels in the bottom core sections showed an even concentration in the lower strata.



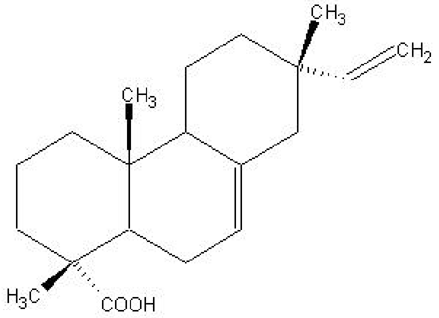
**Dehydroabietic acid**



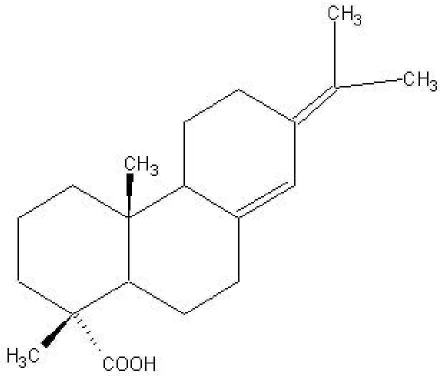
**Abietic acid**



**Pimaric acid**



**Isopimeric acid**



**Neoabietic acid**

**FIGURE 4.5.2.1 RESIN ACID COMPOUNDS ANALYZED IN MANISTEE LAKE SEDIMENTS.**

## TABLE 4.5.2.1. RESULTS OF RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Sample Number | Sample ID | Abietic Acid | Dehydroabietic Acid | Pimeric Acid | Isopimeric Acid | Neoabietic Acid | Total Resin Acids |
|---|---|---|---|---|---|---|---|
| | | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| 5069 | M-1 Top | 1.1 | 0.8 | 0.9 | 0.5 | 0.1 | 3 |
| 5070 | M-1-Mid | 0.4 | 0.8 | 0.3 | 0.3 | 0.2 | 2 |
| 5071 | M-1 Bot | 0.3 | 0.7 | 0.1 | 0.2 | 0.1 | 1 |
| 5072 | M-2 Top | 2.1 | 3.6 | 1.0 | 0.8 | 1.0 | 8 |
| 5073 | M-2 Mid | 2.4 | 4.0 | 2.3 | 1.2 | 1.0 | 11 |
| 5074 | M-2 Bot | 0.9 | 1.8 | 0.5 | 0.7 | 0.3 | 4 |
| 5075 | M-3 Top | 2.4 | 4.3 | 1.1 | 2.1 | 0.4 | 10 |
| 5076 | M-3 Mid | 1.3 | 2.9 | 0.7 | 0.6 | 0.5 | 6 |
| 5077 | M-3 Bot | 0.6 | 1.1 | 0.3 | 0.2 | 0.1 | 2 |
| 5078 | M-4 Top | 2.6 | 4.0 | 2.6 | 1.8 | 0.7 | 12 |
| 5079 | M-4 Mid | 1.4 | 2.8 | 1.0 | 1.2 | 0.9 | 7 |
| 5080 | M-4 Bot | 0.5 | 0.7 | 0.4 | 0.2 | 0.2 | 2 |
| 5081 | M-5 Top | 2.8 | 4.6 | 1.8 | 0.4 | 1.2 | 11 |
| 5082 | M-5 Mid | 2.9 | 7.8 | 2.2 | 3.6 | 1.9 | 18 |
| 5083 | M-5 Bot | 0.7 | 1.1 | 0.7 | 0.3 | 0.6 | 3 |
| 5084 | M-6 Top | 2.6 | 6.1 | 1.3 | 2.4 | 0.7 | 13 |
| 5085 | M-6 Mid | 1.5 | 2.6 | 1.4 | 0.7 | 1.2 | 7 |
| 5086 | M-6 Bot | 0.5 | 0.8 | 0.2 | 0.2 | 0.0 | 2 |
| 5087 | M-7 Top | 2.6 | 2.8 | 0.8 | 2.3 | 0.7 | 9 |
| 5088 | M-7 Mid | 1.9 | 2.7 | 0.3 | 0.7 | 0.2 | 6 |
| 5089 | M -7 Bot | 0.9 | 1.5 | 0.2 | 0.3 | 0.2 | 3 |
| 5090 | M-8 Top | 1.8 | 3.9 | 1.5 | 0.2 | 1.2 | 9 |
| 5091 | M-8 Mid | 1.3 | 1.5 | 0.5 | 0.8 | 0.3 | 4 |
| 5092 | M-8 Bot | 0.8 | 1.4 | 0.3 | 0.5 | 0.2 | 3 |
| 5093 | M-9 Top | 1.8 | 2.1 | 0.7 | 0.2 | 0.4 | 5 |
| 5094 | M-9 Mid | 0.8 | 1.6 | 0.3 | 0.3 | 0.1 | 3 |
| 5095 | M-9 Bot | 0.3 | 0.4 | 0.1 | 0.2 | 0.1 | 1 |
| 5096 | M-9 Top Dup | 0.8 | 1.3 | 0.2 | 0.3 | 0.2 | 3 |
| 5097 | M-9 Mid Dup | 1.5 | 2.7 | 0.5 | 0.6 | 0.3 | 6 |
| 5098 | M-9 Bot Dup | 0.5 | 0.7 | 0.2 | 0.2 | 0.1 | 2 |
| 5099 | M-10 Top | 1.0 | 2.4 | 0.4 | 1.0 | 0.3 | 5 |
| 5100 | M-10 Mid | 0.8 | 1.0 | 0.6 | 0.3 | 0.3 | 3 |
| 5101 | M-10 Bot | 0.5 | 1.1 | 0.4 | 0.5 | 0.1 | 3 |
| 5102 | M-11 Top | 2.1 | 3.4 | 0.7 | 1.2 | 0.4 | 8 |
| 5103 | M-11 Mid | 1.1 | 1.9 | 0.3 | 1.0 | 0.0 | 4 |
| 5104 | M-11 Bot | 0.3 | 0.4 | 0.2 | 0.3 | 0.1 | 1 |
| 5105 | M-12 Top | 1.7 | 2.1 | 1.5 | 1.6 | 0.6 | 7 |
| 5106 | M-12 Mid | 0.9 | 1.6 | 0.1 | 0.6 | 0.1 | 3 |
| 5107 | M-12 Bot | 0.5 | 0.7 | 0.3 | 0.3 | 0.1 | 2 |
| 5108 | M-13 Top | 2.0 | 2.1 | 0.2 | 0.8 | 0.2 | 5 |
| 5109 | M-13 Mid | 0.8 | 1.1 | 0.8 | 0.5 | 0.7 | 4 |
| 5110 | M-13 Bot | 0.6 | 0.9 | 0.1 | 0.4 | 0.1 | 2 |
| 5111 | M-14 Top | 1.1 | 1.5 | 1.1 | 0.9 | 0.9 | 5 |
| 5112 | M-14 Mid | 0.9 | 1.7 | 0.5 | 0.2 | 0.2 | 4 |
| 5113 | M-14 Bot | 0.2 | 0.4 | 0.1 | 0.1 | 0.1 | 1 |
| 5114 | M-1 P | 0.8 | 1.5 | 0.5 | 0.5 | 0.3 | 4 |
| 5115 | M-2 P | 1.6 | 3.3 | 2.2 | 1.4 | 1.2 | 10 |
| 5116 | M-3 P | 2.4 | 3.8 | 1.9 | 0.8 | 0.4 | 9 |
| 5117 | M-4 P | 2.1 | 3.1 | 0.2 | 1.9 | 0.2 | 8 |
| 5118 | M-5 P | 2.9 | 3.8 | 0.5 | 2.5 | 0.4 | 10 |
| 5119 | M-6 P | 2.0 | 4.8 | 1.4 | 1.7 | 1.5 | 11 |
| 5120 | M-7 P | 2.2 | 2.8 | 0.6 | 0.8 | 0.3 | 7 |
| 5121 | M-8 P | 1.5 | 2.0 | 1.4 | 1.4 | 0.8 | 7 |
| 5122 | M-9 P | 1.1 | 2.6 | 0.8 | 0.6 | 0.5 | 6 |
| 5123 | M-9 P Dup | 1.3 | 3.2 | 0.9 | 0.2 | 0.6 | 6 |
| 5124 | M-10 P | 1.8 | 3.3 | 0.5 | 1.2 | 0.2 | 7 |
| 5125 | M-11 P | 1.5 | 3.1 | 0.3 | 0.9 | 0.2 | 6 |
| 5126 | M-12 P | 2.2 | 2.2 | 0.4 | 1.3 | 0.3 | 6 |
| 5127 | M-13 P | 3.1 | 4.3 | 0.6 | 2.5 | 0.3 | 11 |
| 5128 | M-14 P | 0.7 | 1.6 | 0.3 | 0.3 | 0.3 | 3 |

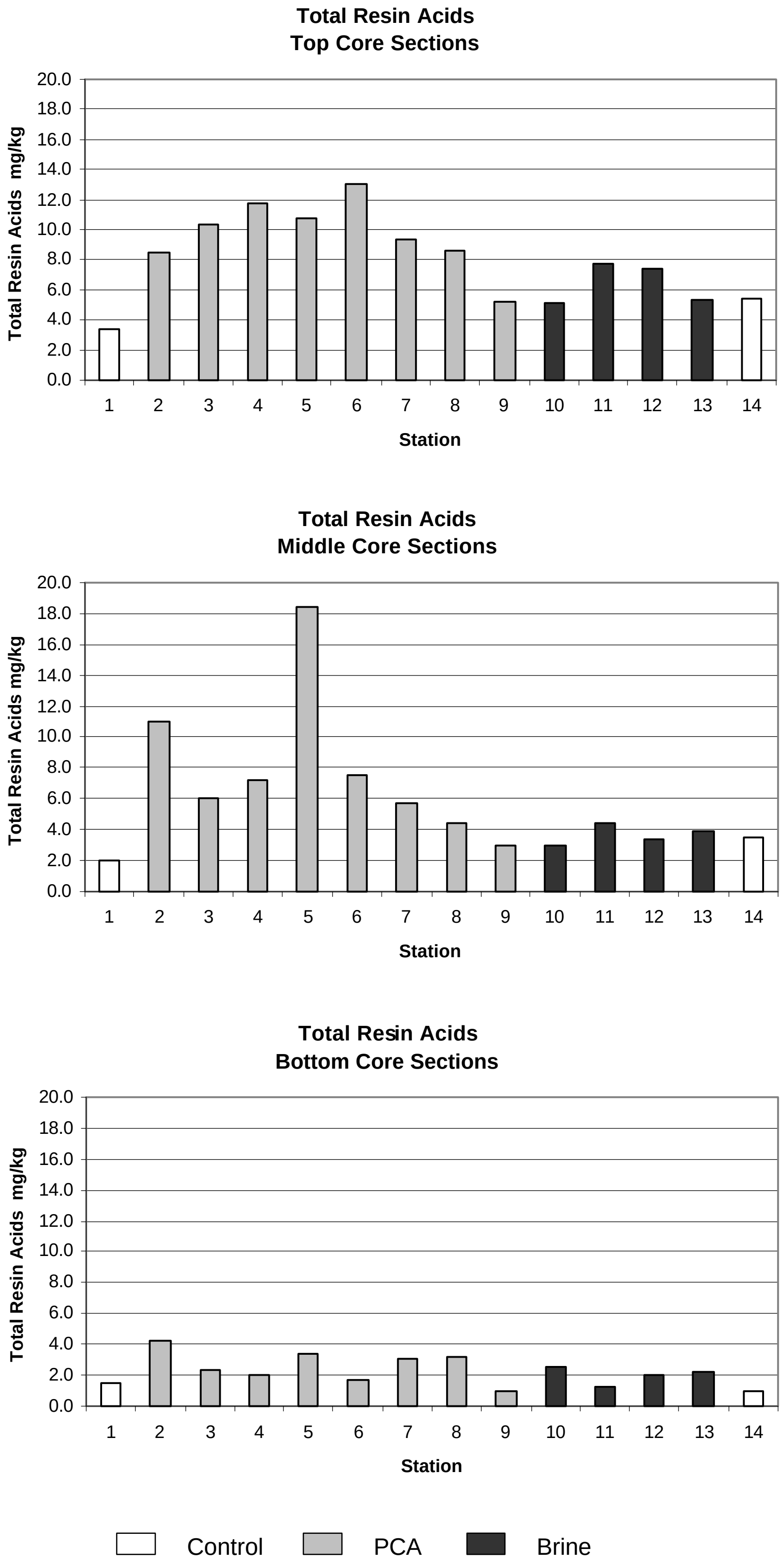


**Figure 4.5.2.2. Results Of Total Resin Acid Analyses For Manistee Lake Sediments, November 1998. Patterns Denote Regions Of Manistee Lake.**

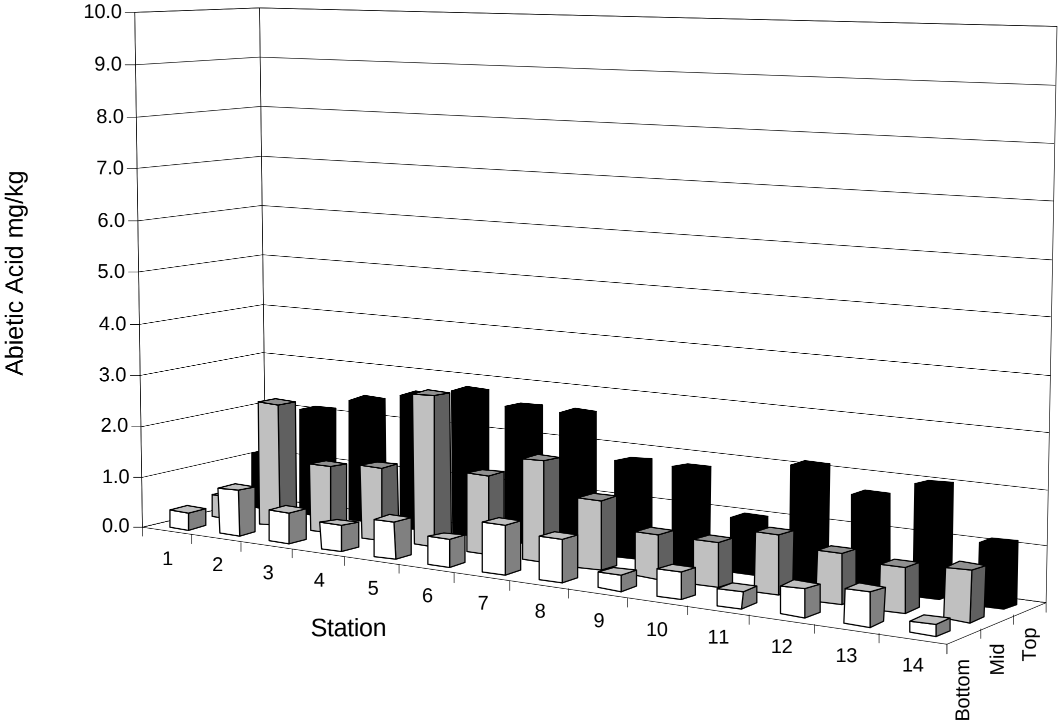


FIGURE 4.5.2.3. DISTRIBUTION OF ABIETIC ACID IN MANISTEE LAKE SEDIMENT CORES, NOVEMBER 1998.

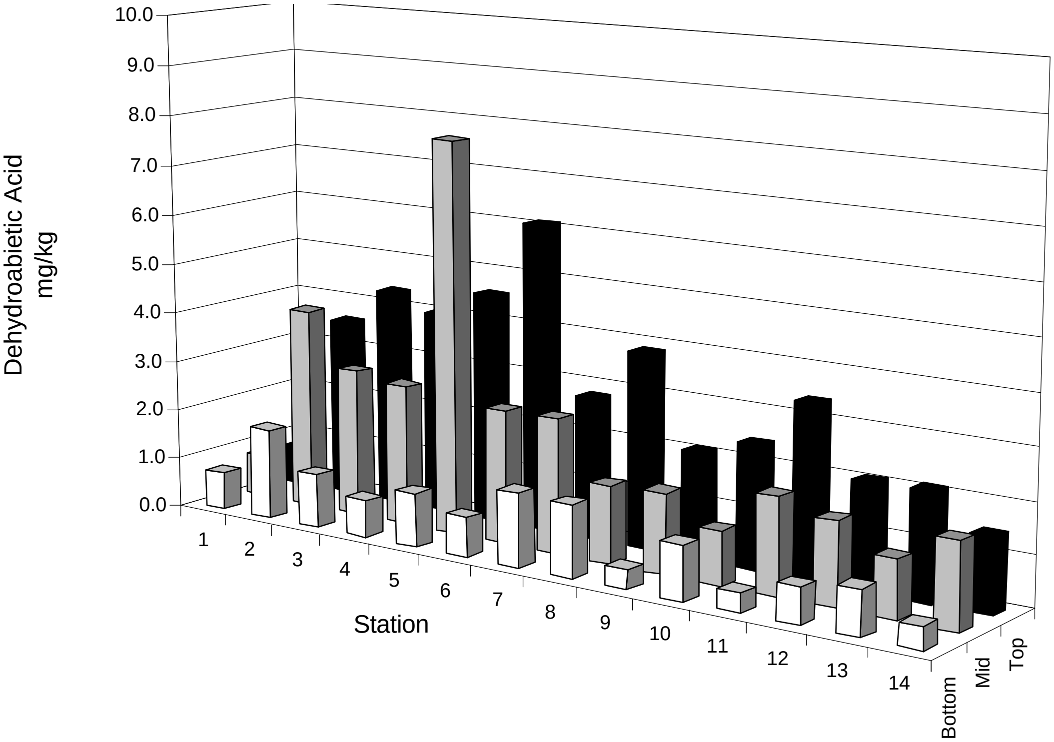


FIGURE 4.5.2.4. DISTRIBUTION OF DEHYDROABIETIC ACID IN MANISTEE LAKE SEDIMENT CORES, NOVEMBER 1998.

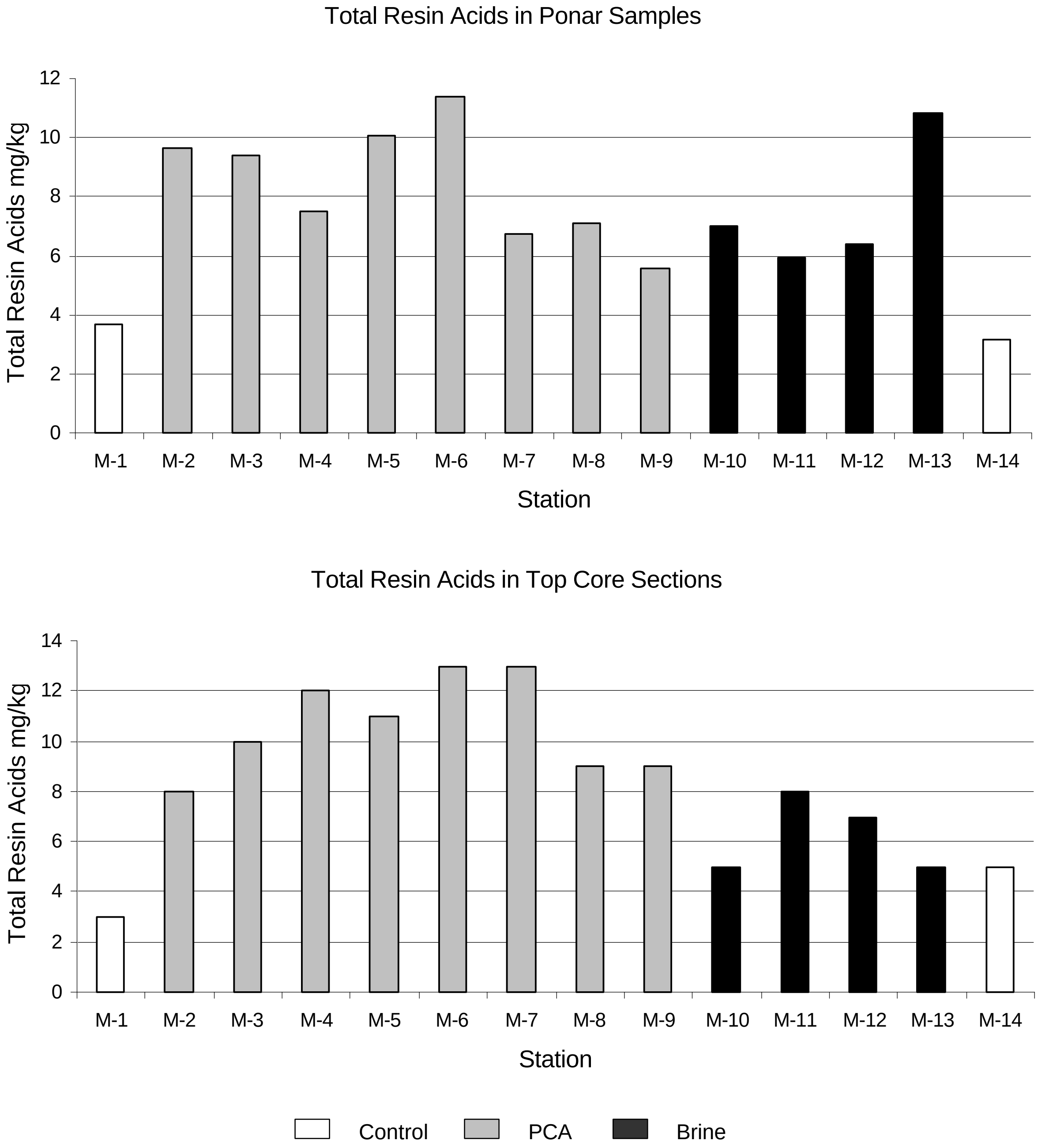


**FIGURE 4.5.2.5. RESULTS OF TOTAL RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998. PATTERNS DENOTE REGIONS OF MANISTEE LAKE.**

With respect to individual resin acid compounds, abietic and dehydroabietic acid were found at the greatest concentrations. The distribution of these resin acids is shown in Figures 4.2.5.3 and 4.2.5.4. Dehydroabietic was almost always found at higher levels than abietic acid, which probably reflects its resistance to anaerobic degradation (Tavendale et al 1997). Neoabietic acid was typically found at the lowest concentration of the resin acids analyzed. This compound undergoes an isomerization/conversition reaction to abietic acid (Leppaenen and Oikari. 1999). The distribution of dehydroabietic acid (DEHA) and abietic acid followed the same pattern as the total resin acids. The highest level of DEHA (7.8 mg/kg) was found in the middle core section at M-5. The next highest concentration (6.1 mg/kg) was found in the top core section of M-6. This station had the highest concentration of HEM (15,000 mg/kg). The high oil content present at this location may act to trap the hydrophobic DEHA molecules. There was little difference noted in the distribution of abietic acid between the PCA and brine facility impacted sites. DEHA levels however were higher (two-fold difference) in the area impacted by the PCA plume. Concentrations of the two resin acids were considerably lower in the control locations.

A comparison of total resin acids in Ponar samples and top core sections is provided in Figure 4.5.2.5. With the exception of M-13, the concentration of total resin acids was similar in both the top core sections and the Ponar samples. The Ponar sample at M-13 was high in HEM (12,400 mg/kg) and may also exhibit the phenomena of concentrating hydrophobic resin acids. These results suggest that the concentration of resin acids is uniform in the top 24” of the sediment.

The concentrations of individual and total resin acids determined in sediment samples from Manistee Lake were similar to those reported by Fox et al. (1976) in Nipigon Bay (Lake Superior) and Tian et al. (1998) in New Zealand. The area in Nipigon Bay was located downstream from a paper mill discharge. The resin acids in the study conducted in New Zealand were from a stormwater discharge from a large log handling facility. In contrast, the concentrations of resin acids in Manistee Lake were an order of magnitude less than those reported by Wilkins et al. (1997) and Leppaenen and Oikari (1999). These investigations examined sediments from the receiving waters of softwood pulp and paper mill discharges which may produce higher levels of resin acids than the hardwood box operation at PCA. Softwoods are known to contain higher levels of resin acids (Liss et al. 1997). The historical operation of the PCA facility and the nature of the current groundwater discharge also may have contributed to the lower levels of resin acids observed. Beginning in the early 1950s, the direct discharge of process effluent on the southwestern side of the lake was phased out in favor of the lagoon system. The presence of elevated levels of resin acids in the middle core sections (24” – 48”) taken downgradient from the old outfall shows the influence of the historic point-source discharge. The stratification of the plume in a layer beneath the sediment plus the hydrophobic nature of the compounds limits the migration of these compounds by groundwater advection into the sediments of Manistee Lake.

## 4.6 Fish Tissue Results

Seven walleye (*Stizostedion vitreum*) and five common carp (*Cyprinus carpio*) were harvested from Manistee Lake and analyzed for resin acids according to the methods outlined in Section 3.6. Resin acids were not detected in any of the fish samples analyzed. (Table 4.6.1.) Even though resin acids were detected in the sediments of Manistee Lake, they appear to be in a form that has limited bioavailability. The high oil content of the sediments and the hydrophobic nature of the chemicals limits the amount that can be exchanged with the water column. In addition, the chemical stratification of the water column near the sediment interface (Section 4.1) will prohibit mixing until the spring or fall isothermal conditions are achieved. Any dissolved resin acids that have accumulated in this zone would be diluted by rapid mixing of the lake.

**TABLE 4.6.1. THE RESULTS OF FISH TISSUE ANALYSES CONDUCTED ON ORGANISMS HARVESTED FROM MANISTEE LAKE, APRIL 2000.**

| Species | Size (mm) | Weight (g) | Abietic Acid (ug/g) | Dehydroabietic Acid (ug/g) | Pimeric Acid (ug/g) | Isopimeric Acid (ug/g) | Neoabietic Acid (ug/g) |
|---|---|---|---|---|---|---|---|
| Walleye | 533 | 1307 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 574 | 2009 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 610 | 2541 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 635 | 2853 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 655 | 3834 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 698 | 4935 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye | 719 | 6463 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp | 243 | 477 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp | 304 | 932 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp | 364 | 1605 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp | 405 | 2205 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp | 445 | 2909 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |

## 4.7 Toxicity Testing Results

The toxicity evaluations of the Manistee Lake sediments were completed in November 1998. Grab sediment samples collected from 14 different sites (14 samples with one additional field duplicate) were evaluated using the EPA (1994) solid phase testing protocol with *Hyalella. azteca* and *Chironomus tentans*.

Conductivity, hardness, alkalinity, ammonia, and pH were determined on the culture water at the beginning and on the tenth day of each test (Appendix D: Tables D-1, D-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. The change in conductivity and hardness was related to the high level of brine found in the sediments at Station M-10. Even after the daily water exchanges, levels of dissolved ions in the overlying water remained higher than all of the other sediments evaluated. Temperature and dissolved oxygen measurements were recorded daily throughout the duration of the tests (Appendix D: Tables D-2, D-4). Very little variation was noted with respect to temperature. The dissolved oxygen occasionally dropped slightly below 40% saturation in some of the test beakers. The lowest dissolved oxygen levels were measured in the control sediment (M-14P) and no toxicity related impacts were noted with respect to survival of the test organisms.

### 4.7.1 *Hyalella azteca*

The evaluation of Manistee Lake's sediment began on November 3, 1998 and was completed on November 13, 1998. Survival data are presented in Table 4.7.1.1. The survival in both control (M-1P and M-14P) treatments exceeded the required 80%. Survival in M-14P (83.75%) was slightly lower than in M-1P (88.75%), however the difference was not significant.

Un-transformed survival data were evaluated for normality with Anderson-Darling's Test at $\alpha = 0.01$ and the data were normally distributed. Dunnett's Test (Table 4.7.1.2) showed a statistically significant (alpha = 0.05) difference on the survival data compared with control site M-14P in 7 out of 13 sediments. Sediments from site M-5P, M-6P, M-7P, M-8P, M-10P, M-11P, and M-13P had significantly reduced survival compared to M-14P. Based on amphipod mortality, the seven sediments listed in order of increasing toxicity are M-7P, M-11P and M-13P (tie), M-8P, M-10P, M-5P, and M-6P. The control sediment from M-1P had a slightly higher survival and consequently, Dunnett's analysis of the data showed 10 of the 13 sediments to have statistically significant difference ($\alpha = 0.05$) for the survival data compared to control. The three sediments that were statistically significant with M-1P as a reference and not with M-14P: M-2P, M-3P, and M-9Pdup all had mean survival values $\geq 70\%$. Based on the high survival measured and the fact that M-1P had lower organic carbon

**TABLE 4.7.1.1 SUMMARY OF HYALELLA AZTECA SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH MANISTEE LAKE SEDIMENTS.**

| Sample ID | Number of Organisms | Replicate | | | | | | | | Survival | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | Mean | Std Dev | C.V.% |
| M-1P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 8 | 8 | 10 | 8 | 10 | 9 | 10 | 8 | 8.87 | 0.991 | 11.16 |
| M-2P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 6 | 9 | 6 | 7 | 8 | 6 | 9 | 5 | 7.00 | 1.511 | 21.59 |
| M-3P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 8 | 8 | 6 | 8 | 7 | 6 | 5 | 8 | 7.00 | 1.195 | 17.07 |
| M-4P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 7 | 6 | 6 | 7 | 8 | 7 | 6 | 7.12 | 1.356 | 19.03 |
| M-5P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 4 | 4 | 5 | 5 | 3 | 5 | 4 | 7 | 4.62 | 1.187 | 25.68 |
| M-6P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 5 | 5 | 6 | 4 | 3 | 4 | 5 | 3 | 4.37 | 1.060 | 24.24 |
| M-7P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 6 | 7 | 5 | 8 | 7 | 8 | 6 | 4 | 6.37 | 1.407 | 22.08 |
| M-8P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 7 | 6 | 4 | 7 | 5 | 7 | 5 | 6 | 5.87 | 1.126 | 19.16 |
| M-9P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 5 | 7 | 7 | 6 | 6 | 8 | 9 | 7.25 | 1.669 | 23.02 |
| M-9Pd | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 7 | 11 | 5 | 6 | 6 | 6 | 8 | 7 | 7.00 | 1.851 | 26.45 |
| M-10P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 4 | 7 | 6 | 7 | 6 | 5 | 4 | 6 | 5.62 | 1.187 | 21.11 |
| M-11P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 6 | 8 | 6 | 5 | 5 | 6 | 7 | 5 | 6.00 | 1.069 | 12.72 |
| M-12P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 8 | 7 | 8 | 9 | 9 | 7 | 6 | 8.00 | 1.309 | 16.36 |
| M-13P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 6 | 10 | 7 | 3 | 2 | 6 | 8 | 6 | 6.00 | 2.563 | 42.72 |
| M-14P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 8 | 7 | 10 | 8 | 7 | 8 | 9 | 10 | 8.37 | 1.187 | 14.18 |

## TABLE 4.7.1.2 SUMMARY OF DUNNETT'S TEST ANALYSIS OF *HYALELLA AZTECA* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH MANISTEE LAKE SEDIMENTS.

| ID | TRANS MEAN | ORIGINAL MEAN | T STAT | SIG 0.05 |
|---|---|---|---|---|
| M-1P | 8.8750 | 8.8750 | -0.6667 | |
| M-2P | 7.0000 | 7.0000 | 1.9969 | |
| M-3P | 7.0000 | 7.0000 | 1.9969 | |
| M-4P | 7.2500 | 7.2500 | 1.6339 | |
| M-5P | 4.6250 | 4.6250 | 5.4462 | * |
| M-6P | 4.3750 | 4.3750 | 5.8093 | * |
| M-7P | 6.3750 | 6.3750 | 2.9046 | * |
| M-8P | 5.8750 | 5.8750 | 3.6308 | * |
| M-9P | 7.2500 | 7.2500 | 1.6339 | |
| M-9Pd | 7.0000 | 7.0000 | 1.9969 | |
| M-10P | 5.6250 | 5.6250 | 3.6667 | * |
| M-11P | 6.0000 | 6.0000 | 3.1667 | * |
| M-12P | 8.0000 | 8.0000 | 0.5000 | |
| M-13P | 6.0000 | 6.0000 | 3.1667 | * |
| M-14P | 8.3750 | 8.3750 | 0.0000 | |

Dunnett's critical value = 2.4800. 1 Tailed, alpha = 0.05.

and a greater sand fraction than M-14P and the other Manistee Lake locations, comparisons with M-1 were not used in the data assessment.

### 4.7.2 *Chironomus tentans*

The evaluation of Manistee Lake sediments began on November 17, 1998 and was completed on November 27, 1998. Survival data are presented in 4.7.2.1. The survival in the control treatments (M-1P and M-14P) exceeded the required 70% and was similar for both sites. Un-transformed survival data were evaluated for normality with the Anderson-Darling's Test at $\alpha = 0.01$ and the data were normally distributed. Dunnett's Test (Table 4.7.2.2) showed a statistically significant ($\alpha = 0.05$) difference on the survival data compared with controls for M-6P and M-13P.

## TABLE 4.7.2.1 SUMMARY OF *CHIRONOMUS TENTANS* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH MANISTEE LAKE SEDIMENTS.

| Sample ID | Number of Organisms | Replicate | | | | | | | | Survival | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | Mean | Std Dev | C.V.% |
| M-1P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 9 | 10 | 10 | 10 | 9 | 9 | 10 | 9.50 | 0.534 | 5.62 |
| M-2P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 8 | 8 | 9 | 10 | 10 | 8 | 9 | 8.87 | 0.834 | 9.40 |
| M-3P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 8 | 9 | 9 | 10 | 8 | 10 | 9 | 9.00 | 0.755 | 8.39 |
| M-4P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 9 | 9 | 8 | 10 | 8 | 9 | 9 | 9.00 | 0.755 | 8.39 |
| M-5P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 9 | 9 | 10 | 9 | 10 | 10 | 9 | 9.37 | 0.517 | 5.52 |
| M-6P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 7 | 6 | 7 | 5 | 8 | 9 | 8 | 8 | 7.25 | 1.281 | 17.67 |
| M-7P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 8 | 8 | 9 | 8 | 10 | 8 | 9 | 10 | 8.75 | 0.886 | 10.13 |
| M-8P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 7 | 10 | 8 | 9 | 10 | 10 | 10 | 9.250 | 1.165 | 12.59 |
| M-9P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 9 | 10 | 8 | 10 | 8 | 8 | 9 | 8.8 | 0.834 | 9.40 |
| M-9Pd | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 8 | 8 | 10 | 8 | 9 | 10 | 9 | 9.00 | 0.925 | 10.28 |
| M-10P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 9 | 10 | 7 | 7 | 9 | 10 | 10 | 8.87 | 1.246 | 7.23 |
| M-11P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 9 | 9 | 9 | 10 | 10 | 9 | 10 | 9 | 9.37 | 0.517 | 2.74 |
| M-12P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 8 | 9 | 9 | 10 | 9 | 9 | 9 | 9.12 | 0.640 | 3.52 |
| M-13P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 7 | 7 | 6 | 8 | 5 | 8 | 8 | 9 | 7.25 | 1.281 | 17.67 |
| M-14P | Initial | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | | | |
| | Final | 10 | 9 | 9 | 10 | 8 | 10 | 10 | 10 | 9.50 | 0.751 | 4.06 |

### TABLE 4.7.2.2 SUMMARY OF DUNNETT'S TEST ANALYSIS OF SURVIVAL DATA *CHIRONOMUS TENTANS* OBTAINED DURING THE 10 DAY TOXICITY TEST WITH MANISTEE LAKE SEDIMENTS.

| GRP | ID | TRANS MEAN | ORIGINAL MEAN | T STAT | SIG 0.05 |
|---|---|---|---|---|---|
| 1 | M-1P | 0.9500 | 0.9500 | | |
| 2 | M-2P | 0.8875 | 0.8875 | 1.3615 | |
| 3 | M-3P | 0.9000 | 0.9000 | 1.0892 | |
| 4 | M-4P | 0.9000 | 0.9000 | 1.0892 | |
| 5 | M-5P | 0.9375 | 0.9375 | 0.2723 | |
| 6 | M-6P | 0.7250 | 0.7250 | 4.9016 | * |
| 7 | M-7P | 0.8750 | 0.8750 | 1.6339 | |
| 8 | M-8P | 0.9250 | 0.9250 | 0.5446 | |
| 9 | M-9P | 0.8875 | 0.8875 | 1.3615 | |
| 10 | M-9Pd | 0.9000 | 0.9000 | 1.4402 | |
| 11 | M-10P | 0.8875 | 0.8875 | 1.3615 | |
| 12 | M-11P | 0.9375 | 0.9375 | 0.3600 | |
| 13 | M-12P | 0.9125 | 0.9125 | 1.0801 | |
| 13 | M-13P | 0.7250 | 0.7250 | 4.9016 | * |
| 14 | M-14P | 0.9500 | 0.9500 | 0.0000 | |

Dunnett's critical value = 2.4800. 1 Tailed, alpha = 0.05

## 4.7.3 Sediment Toxicity Data Discussion

Statistically significant (alpha = 0.05) acute toxicity effects were observed in the sediments from sites M-5P, M-6P, M-7P, M-8P, M-10P, M-11P, and M-13P for the amphipod, *H. azteca*. In addition, statistically significant (alpha = 0.05) mortality was seen for the midge, *C. tentans* in sediment from site M-6P and M-13P. Sediments from stations M-6P and M-13P were toxic to both organisms and had the highest levels of hexane extractable materials (26,000 mg/kg and 12,400 mg/kg, respectively) and the highest level of total PAHs (17.6 mg/kg and 29.37 mg/kg, respectively). Stations that had PAH concentrations above PEC guidelines (MacDonald et al. 2000) are shown in Table 4.7.3.1. Sediment samples from all the sites that exhibited toxicity to amphipods all had levels of individual PAH compounds that exceeded PEC levels. Overall, resin acids did not appear to be the cause of toxicity since the samples with the highest levels (M-2, M-3, and M-9) were not toxic to amphipods and midges. The results of toxicity tests however could not rule out the fact that resin acids may act in consort with hydrocarbons and PAH compounds to produce a toxic response. These materials were widely distributed in the sediments of Manistee Lake.

The static water renewal process employed in solid phase toxicity bioassays will remove water soluble materials from the sediments. Any toxicity present in the sediments related to brine contamination would therefore be reduced or eliminated by the daily water renewal. The change in specific conductance observed from Day 0 to Day 10 (Tables D-1 and D-3) illustrates the effect of the water renewal on removing dissolved materials from the sediments. Because of the potential for water renewal to reduce the toxicity of brine impacted sediments, the results of the solid phase bioassays need to be analyzed in conjunction with the benthic macroinvertebrate data. The status of the benthic community at each station reflects the presence of the organic contaminants and the elevated dissolved solids content of the pore water.

**TABLE 4.7.3.1. SUMMARY OF PONAR SAMPLING LOCATIONS IN MANISTEE LAKE THAT EXCEED CONSENSUS BASED PEC GUIDELINES (MACDONALD ET AL. 2000).**

| PAH Compound | Consensus based PEC Guidelines (mg/kg) | Manistee Lake Stations that Exceed PEC Guidelines |
|---|---|---|
| Anthracene | 0.85 | None |
| Fluorene | 0.54 | None |
| Naphthalene | 0.56 | None |
| Phenanthrene | 1.17 | M-3P, M-5P, M-6P, M-7P, M-8P, M-9P, M-10P, M-11P, M-12P, M-13P |
| Benz[a]anthracene | 1.05 | M-6P, M-10P, M-11P, M-13P |
| Benzo(a)pyrene | 1.45 | M-11P, M-13P |
| Chrysene | 1.29 | M-6P, M-7P, M-10P, M-11P, M-12P, M-13P |
| Fluoranthene | 2.23 | M-6P, M-10P, M-11P, M-13P |
| Pyrene | 1.53 | M-6P, M-7P, M-8P, M-9P, M-10P, M-11P, M-12P, M-13P |
| Total PAHs | 22.8 | M-13P |

### 4.8 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 2.1. The population composition and abundance data are summarized in Table 4.8.1 by mean and standard deviation for each station. The results for each replicate are presented in Appendix F, Table F-1. Benthic macroinvertebrate populations were statistically analyzed in two manners. The individual samples were first analyzed to determine general trends and differences between the controls. The samples were also analyzed based on potential sources to determine if there were differences between locations impacted by the PCA groundwater plume (M-2 through M-9) and stations influenced by brine plumes (M-10 through M-13). The results of the statistical analyses of the individual and group sample data are presented in sections 4.8.1 and 4.8.2 respectively.

### 4.8.1 Benthic Macroinvertebrate Results Of Individual Samples

Control stations M-1 and M-14 near the river mouths had the greatest number of taxa with 23 and 19, respectively. On the lower end, M-10, M-12, and M-13 had only five or six taxa, reflecting some impact of contamination (Figure 4.8.1). Stations M-10 and M-12 had the highest levels of chloride in the sediments (Figure 4.3.1.). Station M-13 had the highest reported level of PAH compounds and petroleum hydrocarbons (HEM). The Student-Newman-Keuls (SNK) method, utilizing studentized range statistics, was performed on the data to determine statistically significant difference in species composition between controls and the remaining stations (Miller, 1981). The results of this analysis revealed that M-1 was significantly different from the rest (Table 4.8.2); whereas, M-14 was similar to M-2, M-3, M-5, M-11, M-9R and M-9. Also according to this procedure, M-2 was similar to the remaining sampling sites. This comparative method between sampling locations utilized total taxa and showed that all in-lake stations were similar with the exception of the controls (M-1 and M-14).

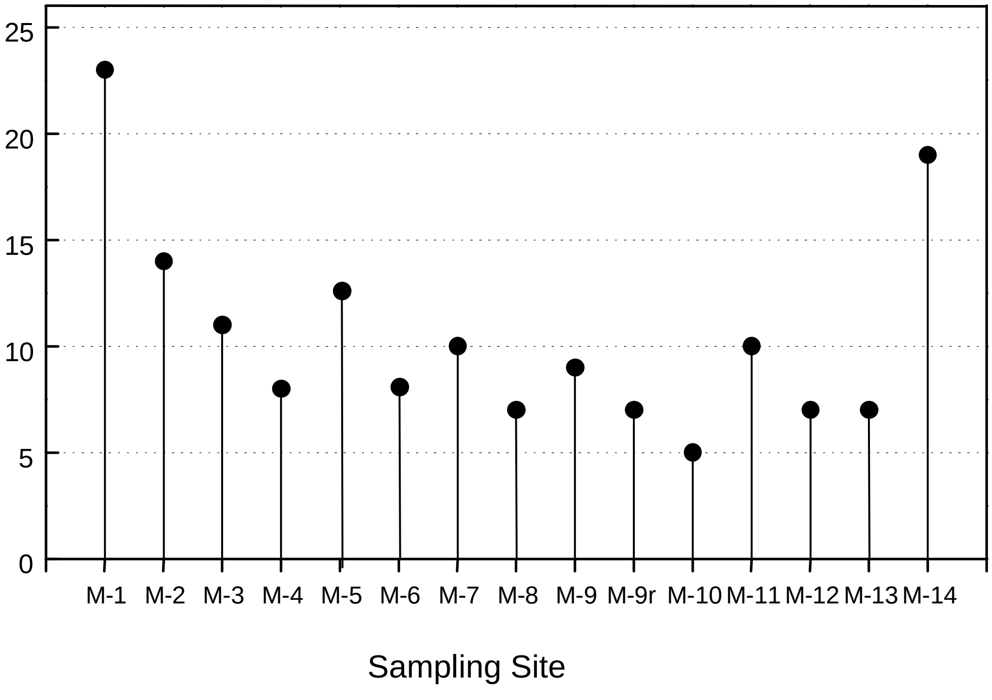


**FIGURE 4.8.1 SUMMARY COMPOSITE OF MACROINVERTEBRATE TAXA IDENTIFIED IN MANISTEE LAKE STATIONS, NOVEMBER 1998.**

Benthic macroinvertebrate assemblages at control sites M-1 and M-14 contained pollution sensitive taxa that were not found at any other locations within the lake. This included representatives of mayflies, dragonflies, caddisflies, and a beetle larva. The family Naididae was also only found at these two locations. The remainder of the population was distributed among tubificids, midges, phantom midges, pelecypods, and snails. The majority of tubificids were immatures and were found at all locations with the exception of M-6 and M-8. Only one of three samples at M-4 and M-5 (Table 4.8.1) contained tubificid worms. The absence of tubificids at these sites may be related to a combination of elevated levels of oil and PAH compounds in addition to poor substrate quality. Considerable compaction was observed in the core samples which suggests that the sediments were very flocculent.

# TABLE 4.8.1 BENTHIC MACROINVERTEBRATE DISTRIBUTION IN MANISTEE LAKE, NOVEMBER 1998. MEAN NUMBER OF ORGANISMS AND STANDARD DEVIATION REPORTED FOR EACH STATION.

| Station | M-1 | | M-2 | | M-3 | | M-4 | | M-5 | | M-6 | | M-7 | | M-8 | | M-9 | | M-9R | | M-10 | | M-11 | | M-12 | | M-13 | | M-14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD | m | SD |
| Turbellaria | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Platyhelmithes | 91 | 61 | 14 | 12 | | | | | 28 | 24 | | | | | 21 | 36 | 57 | 99 | 57 | 50 | | | | | | | 14 | 25 | 43 | 74 |
| Oligochaeta | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Naididae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Vejdovskyella intermedia* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 57 | 99 |
| *Specaria josinae* | 7 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nais elinguis* | 77 | 74 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nais communis* | 49 | 44 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Tubificidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Aulodrilus pigueti* | | | | | | | | | | | | | | | | | | | | | | | 29 | 50 | 14 | 25 | | | | |
| *Aulodrilus limnobius* | | | 7 | 12 | | | | | | | | | | | | | | | | | | | | | 29 | 50 | | | | |
| *Quistadrilus multisetosus* | | | | | 7 | 12 | | | 7 | 12 | | | | | | | 100 | 174 | 72 | 50 | 43 | 74 | 401 | 25 | | | | | 229 | 361 |
| *Limnodrilus hoffmeisterii* | 7 | 12 | 35 | 12 | 98 | 53 | | | 7 | 12 | | | 56 | 97 | | | | | | | | | | | | | | | 29 | 25 |
| *Limnodrilus cervix* | | | | | | | 7 | 12 | 7 | 12 | | | 21 | 21 | | | | | | | 14 | 25 | | | | | | | | |
| *Limnodrilus claparedianus* | | | | | | | | | | | | | | | | | 14 | 25 | | | | | | | | | | | | |
| Immatures: | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| w/o capilliform chaetae | 322 | 119 | 1624 | 885 | 1470 | 655 | 350 | 606 | 273 | 473 | | | 259 | 243 | | | 803 | 700 | 803 | 66 | 172 | 86 | 1419 | 806 | 1390 | 925 | 774 | 114 | 545 | 638 |
| with capilliform chaetae | 21 | 36 | 77 | 44 | 175 | 140 | 35 | 61 | 63 | 109 | | | 63 | 92 | | | 416 | 390 | 344 | 197 | 29 | 25 | 1046 | 776 | 186 | 174 | 143 | 138 | 315 | 439 |
| Crustacea | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Amphipoda | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Gammarus sp.* | 175 | 128 | | | | | | | 35 | 12 | | | 7 | 12 | 7 | 12 | 14 | 25 | | | | | 14 | 25 | | | | | 43 | 43 |
| *Hyalella sp.* | 294 | 76 | | | | | | | 42 | 36 | | | 35 | 61 | | | | | | | | | 29 | 25 | | | | | 29 | 50 |
| Isopoda | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Asellus sp.* | | | | | | | | | 63 | 56 | 7 | 12 | | | | | | | | | | | | | | | | | | |
| Insecta | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ephemeroptera | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Baetis sp.* | 7 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Caenis sp.* | 14 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Hexagenia sp.* | 35 | 44 | | | | | | | | | | | | | | | | | | | | | | | | | | | 946 | 129 |
| Odonata | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Gomphus sp.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 43 | 74 |
| Coleoptera | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Dubiraphia sp.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 14 | 25 |
| Diptera | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ceratopogonidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Palpomyia sp.* | 28 | 24 | 7 | 12 | | | 7 | 12 | | | 7 | 12 | | | | | | | | | | | | | | | | | | |
| Chaoboridae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Chaoborus sp.* | | | | | 7 | 12 | 7 | 12 | 14 | 24 | 14 | 24 | 14 | 24 | 56 | 24 | 72 | 50 | 86 | 43 | 14 | 25 | 29 | 50 | | | 14 | 25 | 43 | 74 |
| Chironomidae | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Chironomus sp.* | | | 161 | 32 | 539 | 202 | 434 | 95 | | | 182 | 64 | 7 | 12 | 70 | 32 | 143 | 90 | 244 | 25 | 43 | 74 | 72 | 66 | 143 | 90 | 129 | 129 | 186 | 252 |
| *Cladotanytarsus sp.* | 3640 | 1643 | 7 | 12 | 7 | 12 | | | | | | | | | | | | | | | | | 57 | 66 | 14 | 25 | 14 | 25 | | |
| *Coelotanypus sp.* | | | 161 | 158 | 77 | 80 | | | | | | | | | | | | | | | | | | | | | | | | |
| *Corynoneura sp.* | 7 | 12 | | | | | | | | | | | | | | | | | | | | | | | 29 | 25 | 115 | 199 | | |
| *Cryptochironomus sp.* | 189 | 159 | 119 | 24 | 91 | 64 | 21 | 36 | 35 | 44 | 35 | 44 | 7 | 12 | 14 | 12 | 14 | 25 | | | | | | | | | | | | |
| *Endochironomus sp.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 100 | 174 |
| *Epoicladius sp.* | 14 | 24 | | | | | | | | | | | | | | | | | | | | | | | | | | | 29 | 25 |
| *Guttipelopia sp.* | | | 35 | 61 | | | | | | | | | | | | | | | | | | | | | | | | | 215 | 197 |
| *Microtendipes sp.* | 7 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Polypedilum sp.* | 273 | 383 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Procladius sp.* | 7 | 12 | 28 | 24 | 77 | 48 | 252 | 164 | 14 | 24 | 42 | | | | | | 29 | 25 | 29 | 25 | 57 | 99 | 14 | 25 | 29 | 50 | | | 530 | 622 |
| *Robackia sp.* | 14 | 24 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Chironominae unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 43 | 0 |
| Orthocladinae unknown | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 14 | 25 |
| Pelecypoda | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Dreisena polymorpha* | 63 | 56 | 161 | 158 | 14 | 24 | | | 7 | 12 | 7 | 12 | | | 7 | 12 | | | | | | | 14 | 25 | | | | | | |
| *Sphaerium sp.* | 63 | 56 | 420 | 147 | 231 | 314 | 14 | 12 | 161 | 127 | 35 | 32 | 28 | 32 | 217 | 32 | 100 | 174 | 72 | 90 | | | 186 | 151 | | | | | 287 | 212 |
| Gastropoda | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Gyraulus sp.* | | | | | | | | | | | | | 14 | 12 | | | | | | | | | | | | | | | | |
| *Physa sp.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 14 | 25 |
| Hydracarina | 105 | 145 | 7 | 12 | 7 | 12 | | | 21 | 21 | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Organisms | 5614 | | 2870 | | 2807 | | 1127 | | 798 | | 329 | | 511 | | 392 | | 1763 | | 1706 | | 373 | | 3311 | | 1835 | | 1204 | | 3770 | |

### TABLE 4.8.2 THE STUDENT-NEWMAN-KEULS TEST VALUES DERIVED FOR BETWEEN-STATION COMPARISONS.

| SNK Grouping* | | Mean | N | ID |
|---|---|---|---|---|
| | A | 16.000 | 3 | M-1 |
| | B | 11.333 | 3 | M-14 |
| | B | | | |
| C | B | 9.333 | 3 | M-2 |
| C | B | | | |
| C | B | 8.000 | 3 | M-3 |
| C | B | | | |
| C | B | 7.667 | 3 | M-5 |
| C | B | | | |
| C | B | 6.333 | 3 | M-11 |
| C | B | | | |
| C | B | 6.000 | 3 | M-9R |
| C | B | | | |
| C | B | 5.333 | 3 | M-9 |
| C | | | | |
| C | | 4.667 | 3 | M-7 |
| C | | | | |
| C | | 4.667 | 3 | M-6 |
| C | | | | |
| C | | 4.667 | 3 | M-8 |
| C | | | | |
| C | | 4.333 | 3 | M-12 |
| C | | | | |
| C | | 4.333 | 3 | M-4 |
| C | | | | |
| C | | 4.000 | 3 | M-13 |
| C | | | | |
| C | | 3.000 | 3 | M-10 |

*Same letter indicates similar taxa composition.

The highest concentration of 5,509 organisms was found at M-1 and the population consisted mostly of midges (75%), oligochaetes (9%), and amphipods (9%). The other control site, M-14, had a density of 3755 macroinvertebrates with oligochaetes making up 31%, midges accounting for 30% and the mayfly *Hexagenia* comprising nearly 25%. The differences in control site populations were attributed to substrate variations. The sediment at M-1 was sandy and would favor midges and oligochaetes while the substrate at M-14 contained more organic detritus. This type of sediment would be more favorable to mayflies. The lowest density of 329 individuals was noted at M-6 and the midges and mussels made up 79% and 13%, respectively. M-10 had a concentration of 373 individuals and 258 were worms, with no mussels and 100 midge larvae. Again a shift in the major groups was observed at the impacted sites. The overall reduction in species composition and density as was seen at sampling sites M-6, M-7, M-8, and M-10 was attributed to toxicity.

The macroinvertebrate assemblage data in Table 4.8.1 were used to calculate the community loss index (EPA 1990) and the quantitative similarity index (Rabeni et al. 1999). These metrics were employed to evaluate the potential impact of contamination between controls and other in-lake sampling locations. The community loss matrix was calculated between the control sites (M-1, M-14) and the remaining stations (Table 4.8.3). A value of 0.6 or greater designated a significant loss of taxa. Based upon this analysis, M-1 and M-14 had a value of 0.4 and M-2 and M-5 were close in showing no taxa loss to M-14 with a 0.63 and a 0.6 value. The remaining comparisons yielded considerably larger values. Higher community loss values were observed when M-1 was compared to the other sites, and a value of 6.0 was obtained for M-10; whereas, M-8, M-9R, M-12 and M-13 had a value of 3.2. It should also be noted that these locations also produced the lowest number of taxa. The same comparison between M-14 and other sites had values greater than 1.0 and the largest number was 3.0 for M-12.

The Quantitative Similarity Index (QSI) was also determined for each collecting site (Rabeni et al. 1999). The calculations are presented in Appendix F (Table F-2) and summarized in Table 4.8.4. The QSI provides calculated values for determining if an adequate number of samples were secured. The advantage of this matrix is that the investigator can then make a decision on the number of sample analyses to be performed in order to obtain optimum information as to the community structure and respective concentration per species. Positive values for the QSI indicate that the analysis improved the reliability of the benthic data. Nine of the 15 samples had positive QSI values (Table 4.8.4). Negative QSI values indicate that the third replicate did not significantly improve the reliability of the data and that more samples would be required for a more accurate characterization. Six locations had negative values: M-5, M-6, M-7, M-8, M-9R, and M-12. Highly negative values for M-5 (-22.8) and M-7 (-64.6) indicate a larger difference between replicates and suggest that the population may not be adequately characterized. Additional samples for benthic macroinvertebrate analysis need to be collected in order to define the population at this location. The other locations had QSI values that were only slightly negative and indicate the potential for only a marginal improvement with the collection of additional samples.

## TABLE 4.8.3 A SUMMARY OF COMMUNITY LOSS VALUES DERIVED FROM COMPARING M-1 AND M-14 WITH THE REMAINING SAMPLING SITES IN MANISTEE LAKE, NOVEMBER 1998.

| | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | M-7 | M-8 | M-9 | M-9R | M-10 | M-11 | M-12 | M-13 | M-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-1 | | | | | | | | | | | | | | | |
| M-2 | 0.82 | | | | | | | | | | | | | | |
| M-3 | 1.33 | | | | | | | | | | | | | | |
| M-4 | 2.50 | | | | | | | | | | | | | | |
| M-5 | 3.00 | | | | | | | | | | | | | | |
| M-6 | 0.91 | | | | | | | | | | | | | | |
| M-7 | 1.86 | | | | | | | | | | | | | | |
| M-8 | 3.20 | | | | | | | | | | | | | | |
| M-9 | 2.00 | | | | | | | | | | | | | | |
| M-9R | 3.20 | | | | | | | | | | | | | | |
| M-10 | 6.00 | | | | | | | | | | | | | | |
| M-11 | 1.63 | | | | | | | | | | | | | | |
| M-12 | 3.20 | | | | | | | | | | | | | | |
| M-13 | 3.20 | | | | | | | | | | | | | | |
| M-14 | 0.40 | 0.63 | 1.00 | 1.83 | 0.60 | 2.75 | 1.13 | 2.40 | 1.11 | 1.50 | 2.33 | 1.00 | 3.00 | 2.40 | |

$$\text{Community Loss Index} = \frac{a - c}{b}$$

where a: number of taxa at the reference site
b: number of taxa at the impacted/recovery site
c: number of taxa common to ‘the reference site’ and ‘the impacted/recovery site’

Note : Critical value chosen is 0.60 therefore values greater than or equal to 0.60 indicate significant Community Loss

**Table 4.8.4 A Summary Quantitative Similarity Index Values For The Sampling Sites In Manistee Lake, November 1998.**

| | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M9R | M10 | M11 | M12 | M13 | M14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean QSI (3 replicates) | 0.837 | 0.748 | 0.746 | 0.433 | 0.261 | 0.633 | 0.211 | 0.771 | 0.313 | 0.782 | 0.361 | 0.674 | 0.765 | 0.666 | 0.469 |
| QSI (replicates A and B) | 0.821 | 0.719 | 0.733 | 0.337 | 0.338 | 0.667 | 0.596 | 0.788 | 0.118 | 0.842 | 0.333 | 0.663 | 0.78 | 0.572 | 0.303 |
| Improvement of Silimarity(%) | 1.9 | 4.0 | 1.8 | 28.5 | -22.8 | -5.1 | -64.6 | -2.2 | 165.3 | -7.1 | 8.4 | 1.7 | -1.9 | 16.4 | 54.8 |

In summary, the controls, M-1 and M-14, had the greatest number of taxa with 23 and 19, respectively and contained several pollution sensitive organisms. Taxa comparisons between these two locations were different as M-1 was dominated by midges and tubificids while M-14 had a greater component of mayflies. These differences are more reflective of substrate conditions (more sand and less organic carbon at M-1) than impacts related to pollution.

A comparison of the indigenous fauna between the controls and the remaining sampling sites showed a significant difference in species composition and density of organisms. A drastic reduction in taxa as was seen in M-10, M-12, and M-13 that generated only five to six species, respectively, indicated a problem with sediment contamination. Even though other in-lake stations had a somewhat higher diversity, none approached the number of taxa found in M-1 and M-14.

### 4.8.2 Benthic Macroinvertebrate Analyses Based On Location Groups

The benthic macroinvertebrate data were further analyzed to determine if statistically significant differences existed between locations impacted by the PCA groundwater plume (M-2 through M-9) and stations influenced by brine plumes (M-10 through M-13). The statistical methods are summarized in Appendix F (Tables F-3 and F-4). The following 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)
- Chironomid Index (*)
- Oligochaete + Chironomid Index (*)
- Trophic Index (*)

* Modified from Howmiller and Scott (1977)

The organism-based indices were calculated based on the formula:

$(\sum n2 + 2\sum n3) / (\sum n1 + \sum n2 + \sum n3) = \text{Index value}$

where: n1 is the number of organisms in the low pollution tolerance group,
n2 is the number of organisms in the medium pollution tolerance group
n3 is the number of organisms in the high pollution tolerance

Tolerance rankings were based on data from Winnell and White (1985), Lauritsen et al. (1985), Schloesser et al. (1995) and Barbour et al. (1999). The tolerance rankings are included in Appendix F (Table F-4). For the purpose of statistical analysis, the following groups were examined:

- Control (M-1 and M-14)
- Group 1 - PCA Ground Water Plume (M-2, M-3, M-4, M-5, M-6, M-7, M-8, M-9, M-9R)
- Group 2 – Brine Processing Sites (M-10, M-11, M-12, M-13)

Group 1 locations were in the vicinity of the PCA ground water plume and also included potential impacts from Manistee Drop Forge (M-6) and Martin Marietta (M-7 and M-8). Group 2 locations were in the vicinity of the Abandon Brine Storage/Transmission Area (M-10), Manistee Wastewater Treatment Plant/Hardy Salt (M-11), Hardy Salt (M-12) and Morton Chemical (M-13). The calculated data for the above metrics are summarized in Table 4.8.5.

A linear model with a nested design was used for the ANOVA and included the factors listed below:

- **group** (3 levels - control, group 1, group 2 as defined previously)
- **site nested within group** - that is, sites M-1 and M-14 are within the control groups, sites M-2 to M-9R are within group 1 and sites M-10 to M-13 are within group 2;
- **replicate nested within site** - there are three replicates for each site that serves as the error term for the ANOVA.

The basic procedure used was as follows:

1. Assess the normality assumption that underlies the theory of ANOVA for the data within each group
2. If the normality assumption is justified, test the significance of the model.
3. If the model is significant, then test the group and site within group factors.
4. Use post hoc multiple comparisons to assess which groups and/or sites were different if the hypothesis of no difference is rejected from the ANOVA.

All analyses were done using SAS and SPSS.

## TABLE 4.8.5 SUMMARY STATISTICS FOR THE ANALYSIS OF BENTHIC MACROINVERTEBRATE SAMPLES FROM MANISTEE LAKE, NOVEMBER 1998.

| | M-1 | | | M-2 | | | M-3 | | | M-4 | | | M-5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Trophic index | 1.09 | 0.95 | 1.04 | 1.59 | 1.73 | 1.65 | 1.76 | 1.83 | 1.62 | 1.81 | 1.00 | 1.05 | 1.29 | 1.00 | 1.50 |
| Oligochaete index | 1.84 | 1.63 | 2.00 | 1.96 | 1.95 | 1.95 | 2.00 | 1.99 | 1.81 | 1.91 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chironomid index | 0.99 | 0.88 | 0.96 | 1.28 | 1.35 | 1.46 | 1.77 | 1.55 | 1.69 | 1.75 | 1.69 | 1.43 | 1.67 | 1.67 | 1.80 |
| Oligochaete and chironomid index | 1.12 | 0.94 | 1.03 | 1.72 | 1.86 | 1.86 | 1.94 | 1.86 | 1.76 | 1.86 | 1.69 | 1.43 | 1.67 | 1.67 | 1.80 |
| Shannon-Weaver | 1.32 | 1.46 | 1.40 | 1.75 | 1.28 | 1.17 | 1.40 | 0.98 | 1.51 | 1.13 | 0.90 | 0.79 | 1.68 | 1.09 | 0.87 |
| Margalef's Richness | 1.54 | 1.99 | 1.71 | 1.15 | 1.20 | 0.66 | 1.08 | 0.65 | 0.92 | 0.67 | 0.45 | 0.30 | 1.04 | 0.50 | 0.36 |
| Eveness | 0.27 | 0.23 | 0.27 | 0.57 | 0.33 | 0.54 | 0.40 | 0.44 | 0.57 | 0.51 | 0.61 | 0.73 | 0.77 | 0.74 | 0.79 |
| J | 0.50 | 0.50 | 0.52 | 0.76 | 0.54 | 0.65 | 0.61 | 0.55 | 0.73 | 0.63 | 0.65 | 0.72 | 0.86 | 0.79 | 0.79 |

| | M-6 | | | M-7 | | | M-8 | | | M-9 | | | M-9R | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Trophic index | 1.22 | 1.22 | 1.77 | 1.12 | 1.85 | 1.40 | 1.13 | 1.29 | 1.15 | 2.00 | 0.00 | 1.61 | 1.97 | 1.97 | 1.83 |
| Oligochaete index | 0.00 | 0.00 | 2.00 | 1.20 | 1.96 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 0.00 | 1.63 | 2.00 | 2.00 | 2.00 |
| Chironomid index | 1.00 | 1.00 | 1.00 | 0.00 | 1.50 | 0.00 | 1.83 | 2.00 | 1.75 | 2.00 | 1.80 | 1.33 | 1.83 | 2.00 | 1.86 |
| Oligochaete and chironomid index | 1.00 | 1.00 | 1.93 | 1.20 | 1.92 | 0.00 | 1.83 | 2.00 | 1.75 | 2.00 | 0.00 | 1.61 | 1.97 | 2.00 | 1.97 |
| Shannon-Weaver | 1.58 | 1.42 | 1.96 | 1.30 | 1.04 | 0.67 | 1.03 | 1.10 | 1.45 | 1.01 | 1.60 | 0.99 | 1.29 | 1.43 | 1.38 |
| Margalef's Richness | 0.76 | 0.95 | 1.36 | 0.68 | 0.94 | 0.21 | 0.50 | 0.52 | 0.83 | 0.39 | 0.74 | 0.65 | 0.67 | 0.67 | 0.68 |
| Eveness | 0.97 | 0.59 | 0.65 | 0.73 | 0.41 | 0.98 | 0.70 | 0.75 | 0.71 | 0.69 | 0.82 | 0.45 | 0.61 | 0.70 | 0.67 |
| J | 0.98 | 0.73 | 0.82 | 0.81 | 0.54 | 0.97 | 0.75 | 0.80 | 0.81 | 0.73 | 0.89 | 0.55 | 0.72 | 0.80 | 0.77 |

| | M-10 | | | M-11 | | | M-12 | | | M-13 | | | M-14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Trophic index | 2.00 | 1.44 | 1.88 | 1.77 | 1.90 | 1.87 | 1.93 | 1.72 | 1.82 | 1.27 | 1.89 | 1.95 | 1.48 | 1.00 | 1.26 |
| Oligochaete index | 2.00 | 1.80 | 1.88 | 2.00 | 2.00 | 1.89 | 2.00 | 1.77 | 1.88 | 1.70 | 1.89 | 1.95 | 2.00 | 0.00 | 2.00 |
| Chironomid index | 0.00 | 1.43 | 0.00 | 1.33 | 0.00 | 1.75 | 1.80 | 1.67 | 1.00 | 0.11 | 2.00 | 2.00 | 1.23 | 1.00 | 1.29 |
| Oligochaete and chironomid index | 2.00 | 1.58 | 1.88 | 1.88 | 2.00 | 1.89 | 1.95 | 1.76 | 1.82 | 1.25 | 1.91 | 1.96 | 1.68 | 1.00 | 1.76 |
| Shannon-Weaver | 1.01 | 1.29 | 0.38 | 1.62 | 0.97 | 1.25 | 0.71 | 0.94 | 0.71 | 1.24 | 0.84 | 0.66 | 2.31 | 0.91 | 1.96 |
| Margalef's Richness | 0.36 | 0.48 | 0.17 | 0.94 | 0.36 | 0.84 | 0.30 | 0.40 | 0.63 | 0.55 | 0.43 | 0.28 | 1.91 | 0.70 | 1.39 |
| Eveness | 0.92 | 0.90 | 0.73 | 0.63 | 0.66 | 0.43 | 0.68 | 0.64 | 0.34 | 0.69 | 0.58 | 0.65 | 0.56 | 0.41 | 0.59 |
| J | 0.92 | 0.93 | 0.54 | 0.78 | 0.70 | 0.60 | 0.64 | 0.68 | 0.40 | 0.77 | 0.60 | 0.61 | 0.80 | 0.51 | 0.79 |

The data were first analyzed for normality using the Shapiro-Wilks hypothesis test. The results are summarized below:

**p-values for normality**

| Group | Trophic Index | Oligochaete Index | Chironomid Index | O + C Index | Shannon Weaver | J | Evenness | Richness |
|---|---|---|---|---|---|---|---|---|
| Control | 0.2820 | 0.0002 | 0.0076 | 0.0425 | 0.7669 | 0.0038 | 0.1821 | 0.3422 |
| 1 | 0.0048 | 0.0001 | 0.0001 | 0.0001 | 0.9323 | 0.2817 | 0.7107 | 0.6493 |
| 2 | 0.0074 | 0.1314 | 0.0186 | 0.0025 | 0.9732 | 0.6735 | 0.2931 | 0.2934 |

The data for Shannon-Weaver diversity, evenness, and richness were normally distributed (p-value > 0.05) and could be analyzed by standard ANOVA methods. If the p-value was < 0.05 for any group within the indices, the data were not normally distributed and the nonparametric ANOVA was performed on ranked data. The results of the ANOVA are summarized below:

**p-values for ANOVA**

| Group | Trophic Index | Oligochaete Index | Chironomid Index | O + C Index | Shannon Weaver | J | Evenness | Richness |
|---|---|---|---|---|---|---|---|---|
| Model | 0.0082 | 0.0402 | 0.0010 | 0.0865 | 0.0461 | 0.0579 | 0.0019 | 0.0001 |
| Group | 0.0002 | 0.1018 | 0.0035 | 0.0099 | 0.0035 | 0.0451 | 0.0006 | 0.0001 |
| Site(Group) | 0.2020 | 0.0518 | 0.0039 | 0.3274 | 0.2830 | 0.1098 | 0.0208 | 0.1754 |

Model significance and between group significance were indicated by p-values < 0.05 in both categories. These conditions were met for the trophic index, chironomid index, Shannon-Weaver diversity, evenness, and richness. With the exception of the chironomid index, variation between replicates was not significant (p-values >0.1). Variation between replicates was significant for the chironomid index.

Post hoc comparisons on the means of the above groups were then performed using the Student-Newman-Keuls (SNK) test. Means for ranked data were used for the trophic index and chironomid index since the original data did not meet the assumption of normality. The results are presented in Table 4.8.6. Columns with the same letter indicate that the groups are not significantly different. Conversely, columns with different letters indicate significant differences between groups.

### TABLE 4.8.6 SUMMARY STATISTICS FOR THE ANALYSIS OF BENTHIC MACROINVERTEBRATE SAMPLES FROM MANISTEE LAKE, NOVEMBER 1998.

### (GROUP 1 = PCA IMPACTED SITES, GROUP 2 = BRINE IMPACTED SITES)

**Student-Newman-Keuls post hoc comparisons**

| Group | Trophic Mean Rank | Trophic Ranking | Chironomid Mean Rank | Chironomid Ranking | Shannon - Weaver Mean | Shannon - Weaver Ranking |
|---|---|---|---|---|---|---|
| Control | 9.000 | A | 11.333 | A | 1.561 | A |
| Group 1 | 21.648 | B | 26.648 | B | 1.252 | B |
| Group 2 | 33.042 | C | 20.625 | B | 0.954 | B |

**Student-Newman-Keuls post hoc comparisons**

| Group | Evenness Mean | Evenness Ranking | Margalefs Richness Mean | Margalefs Richness Ranking |
|---|---|---|---|---|
| Control | 0.389 | A | 1.541 | A |
| Group 1 | 0.646 | B | 0.723 | B |
| Group 2 | 0.654 | B | 0.478 | B |

The benthic macroinvertebrate populations in the control were significantly different from both the brine-impacted group and the PCA-impacted group. With the exception of the Trophic Index, the Student-Newman-Keuls analysis showed that the PCA and brine-impacted sites had similar species evenness, species richness, Shannon-Weaver diversity and chironomids index values. The overall trophic index values showed that the benthic macroinvertebrate community near the brine sources had a significantly lower ranking (more pollution-tolerant organisms) than the locations within the PCA groundwater plume.

The actual data or ranked data for trophic index, species evenness, species richness, and Shannon-Weaver diversity values are presented in box plot format in Figures 4.8.2 – 4.8.5 respectively. Box plots provide a tool to visualize similarities and differences between the test groups. All box plots show a clear difference between the control location and the impacted sites. The benthic macroinvertebrates at the Group 1 and Group 2 locations were significantly less diverse and dominated by a few pollution tolerant taxa. With the exception of evenness, the brine-impacted sites (Group 2) showed a greater degree of degradation than the PCA groundwater locations.

### 4.8.3. Benthic Macroinvertebrate Data Summary

The benthic macroinvertebrate community of Manistee Lake is highly fragmented. The river delta areas where the control sites were located contain a diverse assemblage of pollution intolerant and tolerant organisms made up of mayflies, oligochaetes, and midges. The deposition of organic detritus by the rivers in these areas results in an environment that will support both types of organisms. The assemblage changes dramatically in the vicinity of the PCA groundwater plume and the salt brine companies to a population of pollution tolerant oligochaetes and midges. Total numbers are reduced from 5000+/m$^2$ at the northern most control (M-1) to 798-2870/ m$^2$ at M-2, M-3, M-4, and M-5. The PCA groundwater plume enters the lake in this area. A dramatic reduction to 329-511/ m$^2$ occurs in the area where the plume combines with the historical release of oil from Manistee Drop Forge (M-6) and the Martin Marietta brine plume (M-7 and M-8). Station M-9, located south of the combined plume, however still within the influence of the PCA groundwater, shows a recovery with organism counts of 1763/ m$^2$ and 1706/ m$^2$ for the two replicate stations. Organism numbers fall to 373/ m$^2$ at M-10 near the brine-contaminated area and then recover to 1835-3311/ m$^2$ near the salt brine facilities (M-11, M-12, and M-13). Organism numbers at the control location at the southern control station rise to 3770/ m$^2$ with 30% of the population consisting of mayflies. The decline in organism counts is mirrored by a decrease in taxa numbers for stations M-6, M-7, M-8, and M-10 and coincides with measurable sediment toxicity in the solid phase experiments.

As discussed in Section 4.7.3., the effects of brine contamination in the sediments were not measured in the solid phase toxicity tests due to dilution from the daily renewal of the overlying water. Consequently, the data from the sediment chemistry, solid-phase toxicity, and benthic community assessment need to be evaluated in totality. Station M-10 had the lowest number of taxa and total organisms. Levels of HEM and PAH compounds however were moderate and the station had the third highest mortality. The high level of chloride measured at this location, suggested that brine contamination had the greatest ecological effect. The results for M-12 show an apparent conflict between ecological and toxicity data as low taxa numbers were obtained and no solid phase toxicity was measured. This location was also influenced by a brine seep (high chloride levels in the sediment core) and salinity effects are probably reflected in the ecological data.

A variety of statistical techniques was employed to examine the difference between the control population and locations impacted by the PCA groundwater plume and the salt brine companies. The results showed a clear difference between diversity and trophic status with respect to the controls and the impacted sites. ANOVA results confirm that the impacted populations are less diverse and dominated by pollution-tolerant organisms. The ANOVA results also suggest that the brine-impacted sites have benthic invertebrate populations with a lower trophic status than the locations collected in the area influenced by the PCA groundwater plume.

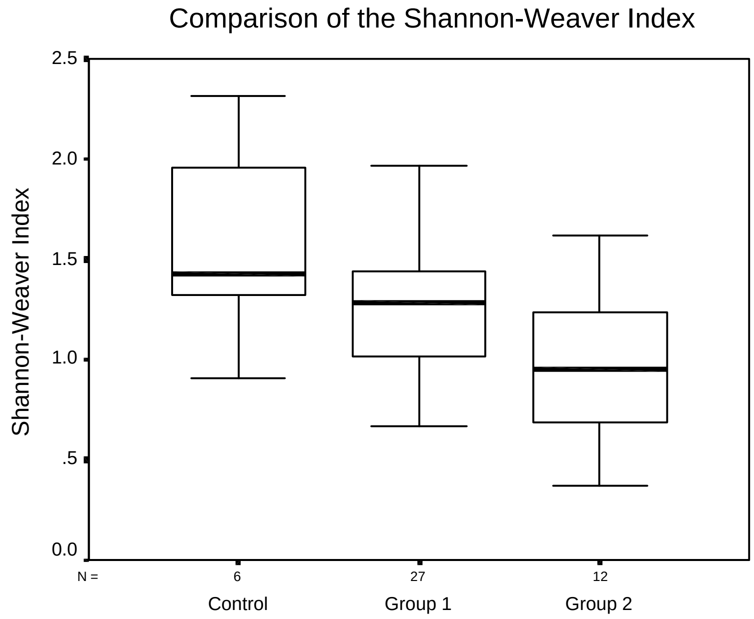


**FIGURE 4.8.2 BOX PLOT OF SHANNON-WEAVER DIVERSITY DATA FOR MANISTEE LAKE BENTHIC MACROINVERTEBRATE STATIONS (MEAN 25%-75%), NOVEMBER 1998.**

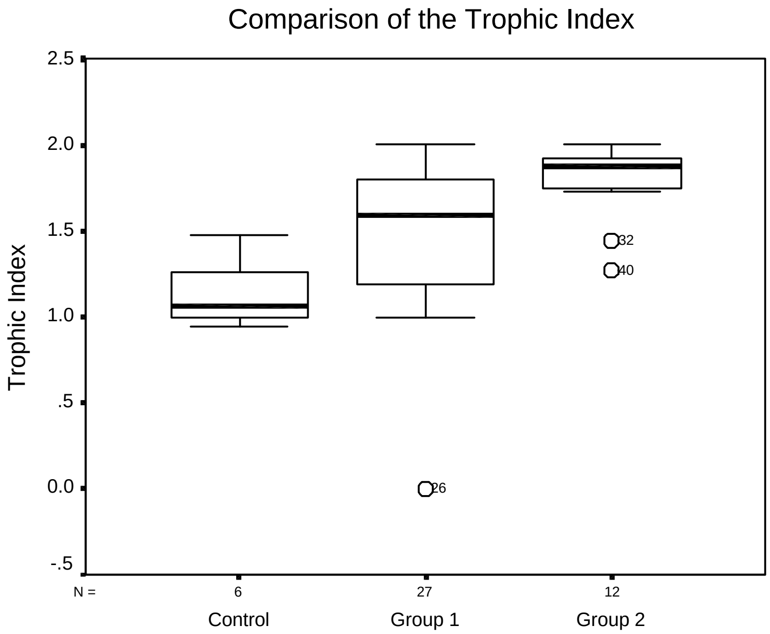


**FIGURE 4.8.3 BOX PLOT OF TROPHIC INDEX DATA FOR MANISTEE LAKE BENTHIC MACROINVERTEBRATE STATIONS (MEAN 25%-75%), NOVEMBER 1998.**

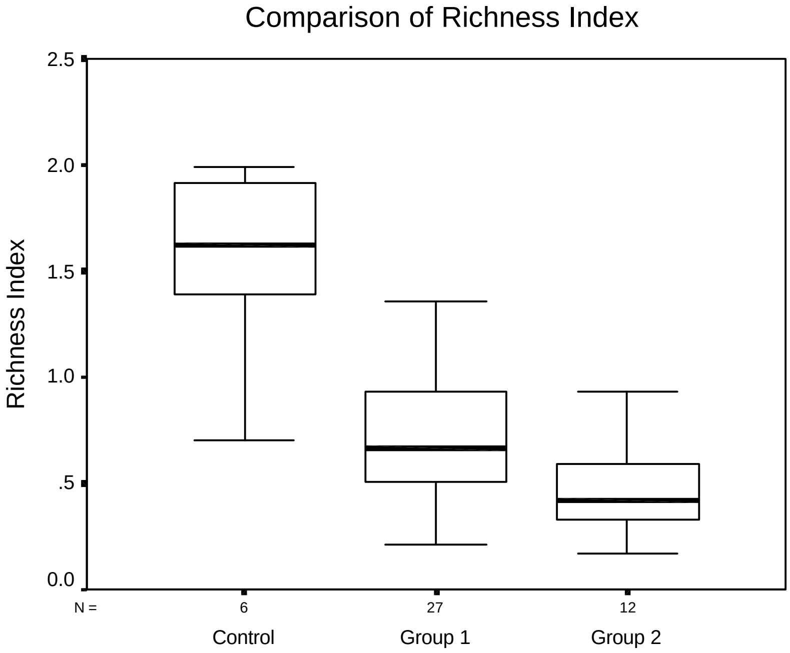


**FIGURE 4.8.4 BOX PLOT OF SPECIES RICHNESS DATA FOR MANISTEE LAKE BENTHIC MACROINVERTEBRATE STATIONS (MEAN 25%-75%), NOVEMBER 1998.**

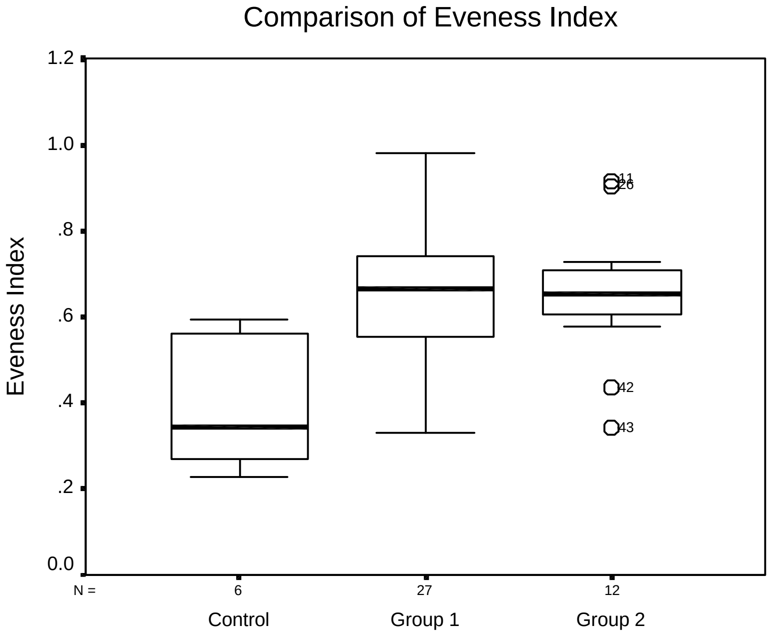


**FIGURE 4.8.5 BOX PLOT OF SPECIES EVENNESS DATA FOR MANISTEE LAKE BENTHIC MACROINVERTEBRATE STATIONS (MEAN 25%-75%), NOVEMBER 1998.**

### 4.9 Summary And Conclusions

A preliminary investigation of the nature and extent of sediment contamination in the lower Manistee Lake was performed. The investigation utilized the sediment quality triad approach with integrated assessments of chemistry, toxicity, and benthic macroinvertebrates. Diverse populations of benthic macroinvertebrates and limited evidence of anthropogenic chemical contamination were found in the control locations near the Manistee and Little Manistee Rivers (upper northeast and lower southeast sections of the lake). The remainder of Manistee Lake was characterized by depauperate benthic communities and sediments impacted by the influx of contaminated groundwater and the presence of oils and polycyclic aromatic hydrocarbons (PAH). The influx of contaminated groundwater and brines from surface discharges were evident by the presence of chemical stratification in the lower hypolimnion. A layer (approximately 5’) of water with high specific conductance was present at the bottom of the lake in July 1998. High levels of chloride were also found in the sediments. Areas of intense brine intrusion in the surficial sediments were found one mile north of the Martin Marietta facility where abandon brine wells and transmission pipelines were located across the lake from Hardy Salt. The chloride levels in the remaining stations suggested a more diffuse venting of contaminated groundwater and the formation of a density gradient in the sediments. A density gradient in the sediment pore water was described in a previous investigation (Camp, Dresser, McKee, and Battelle Great Lakes Environmental Center. 1993) with respect to specific conductance values.

Sediment oil contamination and the detection of elevated levels of PAH compounds indicated extensive hydrocarbon pollution was still present in Manistee Lake. The levels reported for oils were similar to the amounts found previously (Grant, J. 1975). Of the 12 sites investigated in areas of anthropogenic impact, 10 locations exceeded the Probable Effect Concentrations (PECs) for individual PAH compounds. The highest level of PAH compounds was near Morton Chemical (M-13: 29.4 mg/kg) and the highest level of oil was found near Manistee Drop Forge (M-6: 26,000 mg/kg). Historic releases of hydrocarbons were reported near Manistee Drop Forge. Elevated levels of metals were found at all stations with anthropogenic influences, however concentrations were below the PEC guidelines. Resin acids were found to be distributed throughout Manistee Lake. The highest levels were found in the 20”-40” core section downstream from the old PCA outfall. The distribution of resin acids in the surficial sediments also supported the hypothesis of a diffuse venting of groundwater from the PCA site. Resin acids were not detected in the fish samples collected. The diffuse nature of the groundwater influx, the presence chemical stratification during the summer, and the high levels of oil contamination in the sediments create conditions that limit the exposure of fish populations to these chemicals.

Sediment toxicity to amphipods and midges was observed at M-6 and M-13. These stations had the highest levels of hydrocarbon oils and PAH compounds. Amphipod toxicity was measured at five additional sites, all containing levels of individual PAH compounds exceeding PEC concentrations. Samples with lower concentrations of oils and PAHs and elevated resin acid levels were not toxic to amphipods.

A variety of statistical techniques was employed to examine differences in the benthic macroinvertebrate communities between the control populations and locations impacted by the PCA groundwater plume and the salt brine facilities. The results showed a clear difference between diversity and trophic status with respect to the controls and the impacted sites. ANOVA results confirmed that the impacted populations were less diverse and dominated by pollution-tolerant organisms. The ANOVA results also suggested that the brine-impacted sites as a group, had benthic invertebrate populations with a lower trophic status than benthos collected in the area influenced by the PCA/Martin Marietta groundwater plume.

The sediment quality triad approach was used to investigate Manistee Lake. Chemical analyses found elevated levels of PAH compounds above PEC guidelines, high concentrations of petroleum hydrocarbons, and areas of brine intrusion. Solid phase toxicity studies (10-day) suggest that mortality was related to the presence of elevated PAH compounds in the sediments. Since the daily water renewal in the solid phase toxicity tests would reduce any impacts related brines, the benthic macroinvertebrate data was critical to the evaluation of ecological effects. With respect to taxa numbers and abundance, brine intrusion appeared to have a greater negative affect than the presence of HEM/PAH compounds.

## 4.10 References

Barbour, M.T., J. Gerritsen, B.D. Snyder, J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Basch, R. 1971. A Survey of the Bottom Sediments in Manistee Lake in the Vicinity of the Packaging Corporation of America's Filer City Paper Mill. Michigan Water Resources Commission., October 25, 1971.

Brownlee B., M.E. Fox, W.M.J. Strachan, S.R. Joshi. 1977. Distribution of Dehydroabietic Acid in Sediments Adjacent to a Kraft Pulp and Paper Mill. J. Fish. Res. Board Can. 34: 838-843.

Camp, Dresser, McKee, and Battelle Great Lakes Environmental Center. 1993. *Packaging Corporation of America/Manistee Lake Site.* 118 pp.

EPA 1990 Macroinvertebrate Field and Laboratory Methods for Evaluating the Biological Integrity of Surface Waters. EPA/600/4-90/03.

Grant, J. 1975. *Water Quality and Biological Survey of Manistee Lake.* Michigan Department of Natural Resources. Pub. 4833-9310. 56pp.

Howmiller, R.P., M.A. Scott. 1977. An environmental index based on the relative abundance of oligochaete species. J. Water Pollut. Cont. Fed. 49: 809-815.

Johnsen, K., K. Mattsson, J. Tana, T.R. Stuthridge, J. Hemming, K.J. Lehtinen. 1995. Uptake and elimination of resin acids and physiological responses in rainbow trout exposed to total mill effluent from an integrated newsprint mill. Environ. Toxicol. Chem. 14(9):1561-1568.

Judd, M.C., T.R. Stuthridge, R.W. Price. 1998. Pulp mill sourced organic compounds from New Zealand sediments. Part 3: Mechanical pulp mills and remote sites. Chemosphere 36(10):2311-2320.

Krebs, C. J. (1989). Ecological methodology. New York: Harper & Row. 325 pgs

Lauritsen, D.D., S.C. Mozley, D.S. White. 1985. Distribution of oligochaetes in Lake Michigan and comments on their use as indices of pollution. J. Great Lakes Res. 11:67-76.

Leppaenen, H., and A. Oikari. 1999. Occurrence of retene and resin acids in sediments and fish bile from a lake receiving pulp and paper mill effluents. Environ. Toxicol. Chem 18(7) :1498-1505

Liss, S.N., P.A. Bicho, J.N. Saddler. 1997 Microbiology and biodegradation of resin acids in pulp mill effluents: a mini review. Canadian Journal of Microbiology 43 :599-611

MacDonald D.D., C.G. Ingersoll, T.A. Berger. 2000. Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems. Arch. Environ. Contam. Toxicol. 39(1):20-31.

Miller, R.C. Jr. 1981. Simultaneous Statistical Inference. Springer-Verlag. New York, NY. USA.

Myers, R. (2001). Michigan Department of Environmental Quality, Personal Communication.

Niimi, A.J., H.B. Lee. 1992. Free and conjugated concentrations of nine resin acids in rainbow trout (Oncorhynchus mykiss ) following waterborne exposure. Environ. Toxicol. Chem. 11(10):1403-1407.

Nyren, V. and E. Black. 1958. The ionization constant, solubility product and solubility of abietic and dehydroabietic acid. Acta Chem. Scand. 12(7):1516-1520.

Rabeni, C.F., N. Wang, R.J. Sarver. 1999. Evaluating adequacy of the representative stream reach used in invertebrate monitoring programs. Journal of the North American Benthological Society. 18:284-291.

Schloesser, Don W., Trefor B. Reynoldson, Bruce A. Manny. 1995, Oligochaete fauna of western Lake Erie 1961 and 1982: signs of sediment quality recovery: Journal of

Great Lakes Research, v. 21, no. 3, 294-306.

Tavendale, M.H., P.N. McFarlane, K.L. Mackie, A.L. Wilkins, A.G. Langdon. 1997. The fate of resin acids-2. The fate of resin acids and resin acid derived neutral compounds in anaerobic sediments. Chemosphere 35(10):2153-2166.

Tian, F., A. L. Wilkins, T. R. Healy. 1998 Accumulation of resin acids in sediments adjacent to a log handling area, Tauranga Harbour, New Zealand. Bull. Environ. Contam. Toxicol.. 60(3):441-7.

VanOtteren, B. 1998. Michigan Department of Environmental Quality. Personal Communication.

Wilkins, A. L., T. R. Healy, T. Leipe. 1997. Pulp mill-sourced substances in sediments from a coastal wetland . J. Coast. Res. 13(2):341-348.

Wilkins, A. L., M. Singh-Thandi, A. G. Langdon. 1996. Pulp mill sourced organic compounds and sodium levels in water and sediments from the Tarawera River, New Zealand. Bull. Environ. Contam. Toxicol.. 57:434-41.

Winnell, M. H., D. S. White. 1985. Trophic status of southeastern Lake Michigan based on the Chironomidae(Diptera). J. Great Lakes Res. 11:540-548.

Zheng, J., R. A. Nicholson. 1998 Action of resin acids in nerve ending fractions isolated from fish central nervous system. Environ. Toxicol. Chem. 17(9):1852-1859.

## 5.0 Recommendations

The presence of high quality benthic macroinvertebrate communities near the Manistee and Little Manistee Rivers indicates that the remainder Manistee Lake should also support a diverse assemblage of sediment dwelling organisms. The depauperate benthic communities that characterize the remaining regions of the lake however show a serious environmental impact from the extensive influx of contaminated groundwater and historical releases of hydrocarbons. Even though the groundwater venting appears to be diffuse, the size and number of plumes entering Manistee Lake is sufficient to induce chemical stratification during the summer. This change in salinity creates conditions that favor the survival of tolerant organisms and the reduction of biological diversity. While only two locations indicated the presence of the direct influx of a brine source, the apparent density gradient observed may be problematic because of the concentration of salts and chemicals related to the PCA facility appear to have stratified deep within the sediments. The fate of this stratified layer is not known with respect to its direction of movement and degree of confinement. In consideration of these conditions, the following recommendations are made:

- Conduct an annual monitoring program in Manistee Lake to document the extent of chemical and oxygen stratification. The thickness and composition of the chemically stratified layer is important to the assessment of the significance of the venting groundwater plumes and surface brine discharges.
- Conduct further investigation and corrective action in the locations where the influx of brine was directly observed (abandon brinewell transmission pipeline area and Morton Chemical).
- Determine the fate of the stratified chemical layer in the groundwater located in the sediments beneath Manistee Lake. The direction of flow and the endpoint of discharge are critical data gaps.
- Conduct a cost benefit analysis of a comprehensive program to reduce the influx of contaminated groundwater on a lake wide basis. Given the widespread and diffuse influx of contaminated groundwater, it is necessary to develop a strategy for Manistee Lake as a whole.

# Appendices

# Appendix A. Results Physical Analyses On Manistee Lake Sediments, November 1998.

## TABLE A-1. RESULTS OF GRAIN SIZE, TOC, AND % SOLIDS ANALYSES ON MANISTEE LAKE SEDIMENT SAMPLES. NOVEMBER 1998.

| Location | Solids Weight % | > 2000 Weight % | 1000-2000 Weight % | 850-1000 Weight % | 500-800 Weight % | 125-500 Weight % | 63-125 Weight % | < 63 Weight % | TOC % | Solids % |
|---|---|---|---|---|---|---|---|---|---|---|
| M-1 Top | 30 | 0.2 | 2.0 | 0.0 | 0.2 | 3.1 | 2.5 | 92 | 5.3 | 30 |
| M-1-Mid | 25 | 0.9 | 0.1 | 0.0 | 0.0 | 1.4 | 3.4 | 94 | 7.4 | 25 |
| M-1 Bot | 21 | 0.0 | 0.2 | 0.1 | 0.5 | 4.4 | 28 | 67 | 16 | 21 |
| M-2 Top | 15 | 0.1 | 0.1 | 0.0 | 0.7 | 2.0 | 4.6 | 92 | 12 | 15 |
| M-2 Mid | 14 | 0.1 | 2.0 | 0.0 | 0.0 | 0.9 | 2.7 | 94 | 12 | 14 |
| M-2 Bot | 17 | 0.5 | 1.8 | 3.0 | 0.1 | 4.3 | 8.1 | 82 | 14 | 17 |
| M-3 Top | 17 | 0.0 | 0.0 | 0.0 | 0.0 | 3.4 | 13 | 84 | 5.2 | 17 |
| M-3 Mid | 17 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 14 | 82 | 10 | 17 |
| M-3 Bot | 17 | 0.0 | 0.1 | 0.0 | 0.2 | 2.3 | 8.9 | 89 | 11 | 17 |
| M-4 Top | 17 | 0.0 | 0.1 | 0.1 | 0.1 | 1.4 | 6.5 | 92 | 9.4 | 17 |
| M-4 Mid | 20 | 0.5 | 0.2 | 1.0 | 1.0 | 0.5 | 1.4 | 95 | 11 | 20 |
| M-4 Bot | 21 | 0.0 | 0.0 | 0.0 | 0.5 | 3.5 | 7.0 | 89 | 8.4 | 21 |
| M-5 Top | 16 | 0.5 | 0.4 | 0.1 | 0.6 | 5.0 | 8.0 | 85 | 12 | 16 |
| M-5 Mid | 18 | 0.4 | 0.0 | 0.1 | 0.2 | 1.9 | 11 | 87 | 12 | 18 |
| M-5 Bot | 19 | 0.1 | 0.1 | 0.0 | 0.3 | 3.4 | 9.6 | 87 | 11 | 19 |
| M-6 Top | 18 | 0.8 | 0.5 | 0.2 | 1.3 | 4.7 | 8.4 | 84 | 10 | 18 |
| M-6 Mid | 17 | 0.0 | 0.1 | 0.1 | 0.1 | 0.5 | 7.1 | 92 | 9.1 | 17 |
| M-6 Bot | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 | 7.3 | 90 | 11 | 20 |
| M-7 Top | 20 | 4.4 | 0.6 | 0.2 | 0.8 | 5.2 | 7.5 | 81 | 10 | 20 |
| M-7 Mid | 18 | 0.8 | 0.3 | 0.1 | 0.2 | 4.1 | 5.6 | 89 | 9.0 | 18 |
| M -7 Bot | 22 | 0.1 | 0.1 | 0.1 | 0.4 | 2.9 | 4.0 | 92 | 8.8 | 22 |
| M-8 Top | 14 | 0.9 | 0.0 | 0.0 | 0.1 | 2.7 | 6.7 | 90 | 4.8 | 14 |
| M-8 Mid | 20 | 0.3 | 0.4 | 3.5 | 1.1 | 4.0 | 4.5 | 86 | 7.5 | 20 |
| M-8 Bot | 23 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 3.2 | 95 | 7.5 | 23 |
| M-9 Top | 15 | 0.3 | 0.0 | 0.0 | 0.1 | 3.9 | 5.5 | 90 | 6.5 | 15 |
| M-9 Mid | 22 | 0.6 | 0.2 | 0.0 | 0.2 | 1.7 | 3.1 | 94 | 2.9 | 22 |
| M-9 Bot | 25 | 0.0 | 0.1 | 0.0 | 0.5 | 2.1 | 3.4 | 94 | 6.4 | 25 |
| M-9 Top Dup | 16 | 1.0 | 0.3 | 0.1 | 0.6 | 5.1 | 6.1 | 87 | 10 | 16 |
| M-9 Mid Dup | 22 | 1.4 | 0.9 | 0.1 | 0.5 | 1.8 | 2.7 | 93 | 6.4 | 22 |
| M-9 Bot Dup | 24 | 0.0 | 0.0 | 0.0 | 0.1 | 1.2 | 2.5 | 96 | 6.3 | 24 |
| M-10 Top | 17 | 1.2 | 2.3 | 0.1 | 0.7 | 0.8 | 3.9 | 91 | 7.7 | 17 |
| M-10 Mid | 23 | 19 | 0.5 | 0.3 | 0.8 | 2.0 | 2.9 | 75 | 5.3 | 23 |
| M-10 Bot | 26 | 0.0 | 0.0 | 0.2 | 0.0 | 1.3 | 2.6 | 96 | 5.7 | 26 |
| M-11 Top | 21 | 1.4 | 0.2 | 0.0 | 0.8 | 6.5 | 8.8 | 82 | 4.7 | 21 |
| M-11 Mid | 28 | 0.0 | 0.0 | 0.0 | 0.1 | 3.0 | 3.8 | 93 | 4.4 | 28 |
| M-11 Bot | 28 | 0.5 | 0.1 | 0.0 | 0.7 | 2.6 | 2.4 | 94 | 4.9 | 28 |
| M-12 Top | 20 | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 5.9 | 90 | 5.8 | 20 |
| M-12 Mid | 27 | 0.4 | 0.1 | 0.0 | 0.4 | 3.0 | 5.4 | 91 | 4.7 | 27 |
| M-12 Bot | 56 | 6.0 | 2.0 | 0.7 | 7.1 | 35 | 1.8 | 47 | 1.7 | 56 |
| M-13 Top | 24 | 0.7 | 0.0 | 0.0 | 0.0 | 5.9 | 8.6 | 85 | 6.2 | 24 |
| M-13 Mid | 38 | 4.1 | 0.9 | 0.2 | 1.2 | 2.6 | 3.8 | 87 | 4.6 | 38 |
| M-13 Bot | 38 | 0.6 | 0.7 | 0.2 | 0.1 | 0.7 | 2.7 | 95 | 3.1 | 38 |
| M-14 Top | 47 | 0.0 | 0.1 | 1.1 | 0.8 | 1.4 | 2.1 | 94 | 2.5 | 47 |
| M-14 Mid | 64 | 0.3 | 0.3 | 0.1 | 0.8 | 56 | 17 | 26 | <0.5 | 64 |
| M-14 Bot | 44 | 0.0 | 0.1 | 0.1 | 0.3 | 5.3 | 13 | 81 | 3.8 | 44 |
| M-1 P | 77 | 0.5 | 0.7 | 0.4 | 6.7 | 84 | 1.1 | 7 | <0.5 | 77 |
| M-2 P | 13 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 11 | 82 | 9.3 | 13 |
| M-3 P | 14 | 0.1 | 0.3 | 0.0 | 0.4 | 4.9 | 9.6 | 85 | 8.8 | 14 |
| M-4 P | 11 | 1.1 | 3.7 | 0.0 | 1.2 | 6.3 | 11 | 77 | 13 | 11 |
| M-5 P | 14 | 0.0 | 0.1 | 0.1 | 0.4 | 5.0 | 2.6 | 92 | 15 | 14 |
| M-6 P | 14 | 0.8 | 0.2 | 0.1 | 1.0 | 11 | 4.9 | 82 | 13 | 14 |
| M-7 P | 16 | 0.5 | 0.2 | 0.1 | 0.5 | 6.6 | 8.2 | 84 | 11 | 16 |
| M-8 P | 13 | 0.8 | 2.6 | 0.1 | 0.5 | 6.8 | 2.6 | 87 | 7.6 | 13 |
| M-9 P | 14 | 0.3 | 0.1 | 0.1 | 0.2 | 6.9 | 7.3 | 85 | 7.5 | 14 |
| M-9 P Dup | 13 | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 6.8 | 89 | 8.1 | 13 |
| M-10 P | 17 | 0.0 | 0.1 | 0.1 | 0.3 | 10 | 9.1 | 80 | 6.5 | 17 |
| M-11 P | 23 | 0.3 | 0.0 | 0.1 | 0.6 | 2.5 | 3.8 | 93 | 8.1 | 23 |
| M-12 P | 38 | 0.0 | 0.1 | 0.0 | 0.1 | 4.2 | 10 | 86 | 5.6 | 38 |
| M-13 P | 20 | 0.0 | 0.0 | 0.1 | 0.1 | 3.2 | 6.7 | 90 | 4.7 | 20 |
| M-14 P | 38 | 0.2 | 0.3 | 0.3 | 1.0 | 0.0 | 44 | 54 | 2.3 | 38 |

## TABLE A-2. TOC MATRIX SPIKE AND MATRIX SPIKE DUPLICATE RESULTS FOR MANISTEE LAKE SEDIMENT SAMPLES. NOVEMBER 1998.

Matrix Spike Data

| Sample ID | Sample TOC mg/kg | MS TOC mg/kg | MS Conc. mg/kg | % Recovery |
|---|---|---|---|---|
| M-11 Mid | 5.76 | 25.54 | 19.88 | 98 |
| M-14 Bot | 4.65 | 16.91 | 12.40 | 97 |
| M-9 P | 9.95 | 22.20 | 13.760 | 85 |
| M-13 P | 5.46 | 20.70 | 13.20 | 137 |
| M-4 Mid | 15.47 | 25.34 | 12.18 | 85 |
| M-7 Top | 11.46 | 26.62 | 13.76 | 112 |
| M-8 Bot | 10.25 | 28.83 | 19.44 | 92 |

**Matrix Spike Duplicate Data**

| Sample ID | Sample TOC mg/kg | MSD TOC mg/kg | MS Conc. mg/kg | % Recovery | RPD |
|---|---|---|---|---|---|
| M-11 Mid | 5.76 | 22.77 | 16.52 | 109 | 11 |
| M-14 Bot | 4.65 | 19.72 | 14.64 | 109 | 15 |
| Mid-9 P | 9.95 | 24.39 | 14.96 | 95 | 9.4 |
| Mid-13 P | 5.46 | 21.22 | 14.12 | 130 | 2.5 |
| M-4 Mid | 15.47 | 27.03 | 14.76 | 79 | 6.5 |
| M-7 Top | 11.46 | 29.24 | 17.48 | 103 | 9.4 |
| M-8 Bot | 10.25 | 23.35 | 15.04 | 81 | 21 |

# TABLE A-3. QUALITY CONTROL RESULTS FOR GRAIN SIZE ANALYSES ON MANISTEE LAKE SEDIMENT SAMPLES. NOVEMBER 1998.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| M-6 Top | 0 | 0 | 0 | 1 | 5 | 8 | 84 |
| M-6 Top Dup | 0 | 0 | 0 | 1 | 5 | 10 | 82 |
| M-8 Bot | 0 | 0 | 0 | 0 | 1 | 3 | 96 |
| M-8 Bot Dup | 0 | 0 | 0 | 0 | 3 | 5 | 92 |
| M-10 Med | 19 | 0 | 0 | 0 | 2 | 3 | 75 |
| M-10 Med | 5 | 0 | 0 | 1 | 2 | 3 | 88 |
| M-11 Mid | 0 | 0 | 0 | 0 | 3 | 4 | 93 |
| M-11 Mid Dup | 0 | 0 | 0 | 0 | 3 | 5 | 92 |
| M-13-Bot | 0 | 0 | 0 | 0 | 0 | 3 | 95 |
| M-13 Bot Dup | 0 | 1 | 0 | 0 | 0 | 3 | 95 |
| M-1 P | 0 | 1 | 0 | 7 | 84 | 1 | 7 |
| M-1 P Dup | 1 | 1 | 0 | 7 | 81 | 1 | 9 |
| M-9 P Dup | 0 | 0 | 0 | 0 | 4 | 7 | 91 |
| M-9 P Dup/Dup | 0 | 0 | 0 | 0 | 3 | 5 | 91 |
| M-11 P | 0 | 0 | 0 | 0 | 2 | 4 | 93 |
| M-11 P Dup | 0 | 0 | 0 | 0 | 2 | 4 | 93 |

# Appendix B. Organic Analyses On Manistee Lake Sediments, Groundwater, And Fish, November 1998.

# TABLE B-1. RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | M-1 | M-1 | M-1 | M-2 | M-2 | M-2 | M-3 | M-3 | M-3 | M-4 | M-4 | M-4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core Section | Top | Mid | Bottom | Top | Mid | Bottom | Top | Mid | Bottom | Top | Mid | Bottom |
| Units | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Hexane Extractables | 130 | | | 2800 | | | 2300 | | | 1200 | | |
| Naphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-methylnaphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthylene | < 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 | < 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 | < 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 | < 0.33 | < 0.33 | < 0.33 | 3.5 | 0.85 | < 0.33 | 0.82 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Anthracene | < 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 | < 0.33 | < 0.33 | < 0.33 | 2.4 | < 0.33 | < 0.33 | 0.50 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pyrene | < 0.33 | < 0.33 | < 0.33 | 2.1 | < 0.33 | < 0.33 | 0.63 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(a)anthracene | < 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 | < 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 | < 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(k)fluoranthene | < 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 | < 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 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzo(a,h)anthracene | < 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 | < 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 PHA Compounds | < 0.33 | < 0.33 | < 0.33 | 8.0 | < 0.33 | < 0.33 | 1.9 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Methy Phenol | < 0.33 | < 0.33 | < 0.33 | 0.51 | < 0.33 | < 0.33 | 0.47 | < 0.33 | < 0.33 | < 0.63 | < 0.33 | < 0.33 |
| Bis(2-chlorethyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,3-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,4-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,2-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroisopropyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3/4-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| N-Nitroso-di-n-propylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloroethane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Nitrobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Isophorone | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Nitrophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dimethylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroethoxy)methane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzoic Acid | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| 1,2,4-Trichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloro-1,3-butadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-chloro-3-methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorocyclopentadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,6-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,5-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chloronaphalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dimethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,6-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzofuran | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Nitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| 2,4-Dinitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Diethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Chlorophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4,6-Dinitro-2-methylphenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| N-Nitrosodiphenylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pentachlorophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Di-n-butylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Butylbenzylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3,3'-Dichlorobenzidine | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| bis(2-Ethylhexyl)phalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Di-n-octylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |

# TABLE B-1 (CONTINUED). RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | M-5 | M-5 | M-5 | M-6 | M-6 | M-6 | M-7 | M-7 | M-7 | M-8 | M-8 | M-8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core Section | Top | Mid | Bottom | Top | Mid | Bottom | Top | Mid | Bottom | Top | Mid | Bottom |
| Units | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Hexane Extractables | 2900 | | | 15000 | | | 6400 | | | 5700 | | |
| Naphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-methylnaphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthylene | < 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 | < 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 | < 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 | 0.62 | < 0.33 | < 0.33 | 0.97 | < 0.33 | < 0.33 | 1.5 | < 0.56 | < 0.33 | 1.3 | < 0.33 | < 0.33 |
| Anthracene | 0.58 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.33 | < 0.33 | < 0.33 |
| Fluoranthene | 0.59 | < 0.33 | < 0.33 | 0.60 | < 0.33 | < 0.33 | 1.2 | < 0.33 | < 0.33 | 1.2 | < 0.33 | < 0.33 |
| Pyrene | < 0.33 | < 0.33 | < 0.33 | 0.84 | < 0.33 | < 0.33 | 1.3 | < 0.41 | < 0.33 | 1.1 | < 0.33 | < 0.33 |
| Benzo(a)anthracene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.91 | < 0.33 | < 0.33 |
| Chrysene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 1.3 | < 0.33 | < 0.33 |
| Benzo(b)fluoranthene | < 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(k)fluoranthene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.84 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(a)pyrene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.73 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Indeno(1,2,3-cd)pyrene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzo(a,h)anthracene | < 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 | < 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 PHA Compounds | 1.79 | < 0.33 | < 0.33 | 2.41 | < 0.33 | < 0.33 | 5.57 | 0.97 | < 0.33 | 5.81 | < 0.33 | < 0.33 |
| 4-Methy Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-chlorethyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,3-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,4-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,2-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroisopropyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3/4-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| N-Nitroso-di-n-propylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloroethane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Nitrobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Isophorone | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Nitrophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dimethylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroethoxy)methane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzoic Acid | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| 1,2,4-Trichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloro-1,3-butadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-chloro-3-methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorocyclopentadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,6-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,5-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chloronaphalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dimethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,6-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzofuran | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Nitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| 2,4-Dinitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Diethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Chlorophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4,6-Dinitro-2-methylphenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| N-Nitrosodiphenylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pentachlorophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Di-n-butylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Butylbenzylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3,3'-Dichlorobenzidine | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| bis(2-Ethylhexyl)phalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Di-n-octylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |

# TABLE B-1 (CONTINUED). RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | M-9 | M-9 DUP | M-9 | M-9 DUP | M-9 | M-9 DUP | M-10 | M-10 | M-10 | M-11 | M-11 | M-11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core Section | Top | Top | Mid | Mid | Bottop | Bottop | Top | Mid | Bottom | Top | Mid | Bottom |
| Units | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Hexane Extractables | 6700 | 5700 | | | | | 2900 | | | 6500 | | |
| Naphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-methylnaphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.33 | 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthylene | < 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 | < 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 | < 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 | 1.6 | 2.0 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 3.1 | 1.4 | < 0.33 | 1.9 | < 0.33 | < 0.33 |
| Anthracene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.36 | < 0.33 | < 0.33 |
| Fluoranthene | 1.3 | 1.8 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 2.7 | < 0.33 | < 0.33 | 2.4 | < 0.33 | < 0.33 |
| Pyrene | 3.0 | 3.3 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 2.7 | 0.55 | < 0.33 | 2.1 | < 0.33 | < 0.33 |
| Benzo(a)anthracene | < 0.33 | 1.2 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.79 | < 0.33 | < 0.33 | 0.93 | < 0.33 | < 0.33 |
| Chrysene | < 0.33 | 1.2 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 1.4 | < 0.33 | < 0.33 | 1 | < 0.33 | < 0.33 |
| Benzo(b)fluoranthene | < 0.33 | 0.61 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 1.66 | < 0.33 | < 0.33 | 1.1 | < 0.33 | < 0.33 |
| Benzo(k)fluoranthene | < 0.33 | 0.75 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 1.36 | < 0.33 | < 0.33 | 1.2 | < 0.33 | < 0.33 |
| Benzo(a)pyrene | 0.67 | 0.58 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.96 | < 0.33 | < 0.33 | 0.72 | < 0.33 | < 0.33 |
| Indeno(1,2,3-cd)pyrene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzo(a,h)anthracene | < 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 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 1.46 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Total PHA Compounds | 6.57 | 11.44 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 16.13 | 1.95 | < 0.33 | 11.71 | < 0.33 | < 0.33 |
| 4-Methy Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-chlorethyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,3-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,4-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,2-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroisopropyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3/4-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| N-Nitroso-di-n-propylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloroethane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Nitrobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Isophorone | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Nitrophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dimethylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroethoxy)methane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzoic Acid | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| 1,2,4-Trichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloro-1,3-butadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-chloro-3-methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorocyclopentadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,6-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,5-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chloronaphalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dimethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,6-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzofuran | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Nitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| 2,4-Dinitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Diethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Chlorophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4,6-Dinitro-2-methylphenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| N-Nitrosodiphenylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pentachlorophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Di-n-butylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Butylbenzylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3,3'-Dichlorobenzidine | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2 | < 2 | < 2 |
| bis(2-Ethylhexyl)phalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Di-n-octylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |

## TABLE B-1 (CONTINUED). RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | M-12 | M-12 | M-12 | M-13 | M-13 | M-13 | M-14 | M-14 | M-14 |
|---|---|---|---|---|---|---|---|---|---|
| Core Section | Top | Mid | Bottom | Top | Mid | Bottom | Top | Mid | Bottom |
| Units | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Hexane Extractables | 5400 | | | 9800 | | | 90 | | |
| Naphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-methylnaphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthylene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Fluorene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenanthrene | 1.6 | 0.78 | < 0.33 | 0.69 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Anthracene | 0.38 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Fluoranthene | 2.3 | < 0.33 | < 0.33 | 0.83 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pyrene | 2.3 | < 0.53 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(a)anthracene | 1 | < 0.33 | < 0.33 | 0.87 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Chrysene | 1.5 | < 0.33 | < 0.33 | 0.34 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(b)fluoranthene | 1.7 | < 0.33 | < 0.33 | 0.47 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(k)fluoranthene | 1.8 | < 0.33 | < 0.33 | 0.47 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(a)pyrene | 0.95 | < 0.33 | < 0.33 | 0.48 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Indeno(1,2,3-cd)pyrene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzo(a,h)anthracene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzo(g,h,I)perylene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Total PHA Compounds | 13.53 | 1.1 | < 0.33 | 4.15 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Methy Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-chlorethyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,3-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,4-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,2-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroisopropyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3/4-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| N-Nitroso-di-n-propylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloroethane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Nitrobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Isophorone | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Nitrophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dimethylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroethoxy)methane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzoic Acid | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| 1,2,4-Trichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloro-1,3-butadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-chloro-3-methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorocyclopentadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,6-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,5-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chloronaphalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dimethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,6-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzofuran | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Nitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| 2,4-Dinitrophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Diethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Chlorophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4,6-Dinitro-2-methylphenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| N-Nitrosodiphenylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pentachlorophenol | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 | < 1.7 |
| Di-n-butylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Butylbenzylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3,3'-Dichlorobenzidine | < 2 | < 2 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| bis(2-Ethylhexyl)phalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Di-n-octylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |

# TABLE B-1 (CONTINUED). RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | | M-1P | | M-2P | | M-3P | | M-4P | | M-5P | | M-6P | | M-7P | | M-8P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | mg/kg | | mg/kg | | mg/kg | | mg/kg | | mg/kg | | mg/kg | | mg/kg | | mg/kg |
| Hexane Extractables | | 100 | | 1900 | | 3200 | | 2600 | | 4300 | | 26000 | | 4000 | | 8800 |
| Naphthalene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2-methylnaphthalene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Acenaphthylene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Acenaphthene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Fluorene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Phenanthrene | < | 0.33 | | 0.77 | | 1.2 | | 0.78 | | 2.0 | | 4.3 | | 2.0 | | 1.6* |
| Anthracene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | | 0.52 | | 0.33 | | 0.33 |
| Fluoranthene | < | 0.33 | | 0.82 | | 0.90 | | 0.76 | | 1.4 | | 3.0 | | 1.6 | | 1.8 |
| Pyrene | < | 0.33 | | 0.81 | | 1.00 | | 0.74 | | 1.4 | | 2.8 | | 1.8 | | 1.7 |
| Benzo(a)anthracene | < | 0.33 | < | 0.33 | | 0.33 | < | 0.33 | < | 0.33 | | 1.3 | | 0.83 | | 0.53 |
| Chrysene | < | 0.33 | | 0.41 | | 0.33 | | 0.39 | < | 0.33 | | 1.7 | | 1.7 | | 1.1 |
| Benzo(b)fluoranthene | < | 0.33 | | 0.42 | | 0.54 | | 0.34 | < | 0.33 | | 1.8 | | 1.4 | | 1.2 |
| Benzo(k)fluoranthene | < | 0.33 | | 0.4 | < | 0.33 | < | 0.33 | < | 0.33 | | 1.3 | | 1.3 | | 0.71 |
| Benzo(a)pyrene | < | 0.33 | < | 0.33 | | 0.71 | < | 0.33 | < | 0.33 | | 0.86 | | 0.59 | | 0.64 |
| Indeno(1,2,3-cd)pyrene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Dibenzo(a,h)anthracene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Benzo(g,h,I)perylene | < | 0.33 | < | 0.33 | < | 00.33 | < | 0.33 | < | 0.33 | < | 0.33 | | 0.34 | < | 0.33 |
| Total PHA Compounds | < | 0.33 | | 3.63 | | 4.81 | | 3.01 | | 4.8 | | 17.6 | | 11.9 | | 9.61 |
| 4-Methy Phenol | < | 0.33 | | 0.47 | | 0.55 | < | 0.33 | < | 0.33 | | 0.49 | | 0.65 | < | 0.33 |
| Bis(2-chlorethyl)ether | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2-Chlorophenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Phenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 1,3-Dichlorobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 1,4-Dichlorobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 1,2-Dichlorobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Bis(2-Chloroisopropyl)ether | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2-Methylphenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 3/4-Methylphenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| N-Nitroso-di-n-propylamine | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Hexachloroethane | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Nitrobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Isophorone | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2-Nitrophenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,4-Dimethylphenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Bis(2-Chloroethoxy)methane | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Benzoic Acid | < | 3.3 | < | 3.3 | < | 3.3 | < | 3.3 | < | 3.3 | < | 3.3 | < | 3.3 | < | 3.3 |
| 1,2,4-Trichlorobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,4-Dichlorophenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Hexachloro-1,3-butadiene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 4-chloro-3-methylphenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Hexachlorocyclopentadiene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,4,6-Trichlorophenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,4,5-Trichlorophenol | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2-Chloronaphalene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Dimethylphthalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,6-Dinitrotoluene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Dibenzofuran | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 2,4-Dinitrotoluene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 4-Nitrophenol | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 |
| 2,4-Dinitrophenol | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 |
| Diethylphthalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 4-Chlorophenyl-phenylether | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 4,6-Dinitro-2-methylphenol | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 |
| N-Nitrosodiphenylamine | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 4-Bromophenyl-phenylether | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Hexachlorobenzene | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Pentachlorophenol | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 | < | 1.7 |
| Di-n-butylphthalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Butylbenzylphthalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| 3,3'-Dichlorobenzidine | < | 2.0 | < | 2.0 | < | 2.0 | < | 2.0 | < | 2.0 | < | 2.0 | < | 2.0 | < | 2.0 |
| bis(2-Ethylhexyl)phalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |
| Di-n-octylphthalate | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 | < | 0.33 |

# TABLE B-1 (CONTINUED). RESULTS HEM AND SEMIVOLATILE ORGANIC ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Station | M-9P | M-9P DUP | M-10P | M-11P | M-12P | M-13P | M-14P |
|---|---|---|---|---|---|---|---|
| Units | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| Hexane Extractables | 3300 | 2900 | 6600 | 8300 | 12400 | 12400 | > 50 |
| Naphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-methylnaphthalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthylene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Acenaphthene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Fluorene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | 0.95 | < 0.33 |
| Phenanthrene | 1.5 | 1.1 | 3.1 | 1.9 | 1.4 | 3 | < 0.33 |
| Anthracene | < 0.33 | < 0.33 | 0.6 | 0.42 | 0.34 | 0.81 | < 0.33 |
| Fluoranthene | 1.6 | 1.4 | 2.9 | 2.8 | 1.8 | 5.1 | < 0.33 |
| Pyrene | 1.6 | 1.4 | 2.7 | 2.5 | 2.4 | 4.8 | < 0.33 |
| Benzo(a)anthracene | 0.63 | 0.33 | 0.92 | 1.0 | 1.1 | 2.2 | < 0.33 |
| Chrysene | 1.1 | 0.62 | 1.5 | 1.5 | 1.8 | 2.6 | < 0.33 |
| Benzo(b)fluoranthene | 1.1 | 0.93 | 1.7 | 1.3 | 1.1 | 3 | < 0.33 |
| Benzo(k)fluoranthene | 0.82 | 0.71 | 0.95 | 1.2 | 0.57 | 2.7 | < 0.33 |
| Benzo(a)pyrene | 0.45 | 0.44 | 0.64 | 1.4 | 0.94 | 1.6 | < 0.33 |
| Indeno(1,2,3-cd)pyrene | < 0.33 | < 0.33 | < 0.33 | 0.63 | < 0.33 | 1.5 | < 0.33 |
| Dibenzo(a,h)anthracene | < 0.33 | < 0.33 | < 0.33 | 0.33 | < 0.33 | 0.66 | < 0.33 |
| Benzo(g,h,I)perylene | < 0.33 | < 0.33 | < 0.33 | 0.59 | 0.56 | 0.45 | < 0.33 |
| Total PHA Compounds | 8.8 | 6.93 | 15.0 | 15.2 | 12 | 29.4 | < 0.33 |
| 4-Methy Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-chlorethyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Phenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,3-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,4-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 1,2-Dichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroisopropyl)ether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3/4-Methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| N-Nitroso-di-n-propylamine | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloroethane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Nitrobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Isophorone | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Nitrophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dimethylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Bis(2-Chloroethoxy)methane | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Benzoic Acid | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 | < 3.3 |
| 1,2,4-Trichlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachloro-1,3-butadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-chloro-3-methylphenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorocyclopentadiene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,6-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4,5-Trichlorophenol | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2-Chloronaphalene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dimethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,6-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Dibenzofuran | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 2,4-Dinitrotoluene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Nitrophenol | < 1.7 | < 1.7 | < 1.7 | 1.7 | < 1.7 | 1.7 | < 1.7 |
| 2,4-Dinitrophenol | < 1.7 | < 1.7 | < 1.7 | 1.7 | < 1.7 | 1.7 | < 1.7 |
| Diethylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Chlorophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4,6-Dinitro-2-methylphenol | < 1.7 | < 1.7 | < 1.7 | 1.7 | < 1.7 | 1.7 | < 1.7 |
| N-Nitrosodiphenylamine | < 0.33 | < 0.33 | < 0.33 | 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 4-Bromophenyl-phenylether | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Hexachlorobenzene | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Pentachlorophenol | < 1.7 | < 1.7 | < 1.7 | 1.7 | < 1.7 | 1.7 | < 1.7 |
| Di-n-butylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Butylbenzylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| 3,3'-Dichlorobenzidine | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 | < 2.0 |
| bis(2-Ethylhexyl)phalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |
| Di-n-octylphthalate | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 | < 0.33 |

# TABLE B-2. SURROGATE STANDARD RECOVERIES FOR SEMIVOLATILE ORGANICS ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

| Sample | 2-Fluoro biphenyl | 2-Fluoro phenol | d5-Nitro benzene | d6-Phenol | o-Terphenyl | 2,4,6-Tribromo phenol |
|---|---|---|---|---|---|---|
| % Recovery | % | % | % | % | % | % |
| Control Limit | 42-99 | 38-76 | 40-97 | 43-84 | 45-90 | 45-89 |
| M-1 Top | 77 | 79 | 61 | 72 | 66 | 59 |
| M-1-Mid | 97 | 89 | 72 | 84 | 71 | 72 |
| M-1 Bot | 89 | 92 | 77 | 80 | 70 | 67 |
| M-2 Top | 84 | 82 | 72 | 76 | 68 | 63 |
| M-2 Mid | 83 | 82 | 80 | 79 | 66 | 63 |
| M-2 Bot | 86 | 81 | 73 | 79 | 70 | 63 |
| M-3 Top | 83 | 81 | 68 | 76 | 67 | 62 |
| M-3 Mid | 72 | 70 | 64 | 68 | 61 | 48 |
| M-3 Bot | 89 | 79 | 73 | 78 | 69 | 63 |
| M-4 Top | 82 | 77 | 77 | 75 | 66 | 57 |
| M-4 Mid | 89 | 83 | 79 | 78 | 73 | 60 |
| M-4 Bot | 81 | 67 | 67 | 63 | 67 | 46 |
| M-5 Top | 90 | 74 | 61 | 72 | 65 | 58 |
| M-5 Mid | 63 | 52 | 49 | 53 | 52 | 53 |
| M-5 Bot | 56 | 46 | 36 | 46 | 45 | 45 |
| M-6 Top | 56 | 44 | 34* | 45 | 47 | 47 |
| M-6 Mid | 75 | 71 | 68 | 67 | 65 | 54 |
| M-6 Bot | 77 | 73 | 59 | 73 | 70 | 58 |
| M-7 Top | 83 | 66 | 73 | 65 | 71 | 56 |
| M-7 Mid | 91 | 71 | 54 | 68 | 64 | 73 |
| M -7 Bot | 84 | 69 | 63 | 70 | 68 | 70 |
| M-8 Top | 80 | 69 | 60 | 71 | 67 | 55 |
| M-8 Mid | 53 | 41 | 57 | 43 | 46 | 34 |
| M-8 Bot | 70 | 58 | 53 | 56 | 57 | 55 |
| M-9 Top | 65 | 46 | 52 | 52 | 52 | 52 |
| M-9 Mid | 63 | 51 | 56 | 52 | 51 | 47 |
| M-9 Bot | 64 | 45 | 65 | 51 | 41 | 65 |
| M-9 Top Dup | 82 | 56 | 65 | 65 | 68 | 61 |
| M-9 Mid Dup | 85 | 60 | 65 | 65 | 68 | 65 |
| M-9 Bot Dup | 86 | 70 | 70 | 66 | 61 | 62 |
| M-10 Top | 81 | 61 | 78 | 69 | 65 | 70 |
| M-10 Mid | 94 | 70 | 77 | 72 | 72 | 73 |
| M-10 Bot | 91 | 72 | 75 | 78 | 61 | 73 |
| M-11 Top | 81 | 73 | 70 | 73 | 58 | 67 |
| M-11 Mid | 87 | 80 | 76 | 73 | 64 | 68 |
| M-11 Bot | 91 | 69 | 72 | 76 | 63 | 71 |
| M-12 Top | 87 | 73 | 79 | 76 | 58 | 66 |
| M-12 Mid | 85 | 77 | 66 | 74 | 55 | 65 |
| M-12 Bot | 78 | 75 | 79 | 70 | 52 | 70 |
| M-13 Top | 86 | 69 | 61 | 77 | 54 | 58 |
| M-13 Mid | 72 | 63 | 65 | 65 | 61 | 57 |
| M-13 Bot | 69 | 64 | 85 | 62 | 48 | 60 |
| M-14 Top | 76 | 69 | 62 | 80 | 66 | 56 |
| M-14 Mid | 63 | 58 | 77 | 63 | 49 | 66 |
| M-14 Bot | 82 | 77 | 83 | 75 | 57 | 73 |
| M-1 P | 89 | 79 | 67 | 78 | 60 | 67 |
| M-2 P | 81 | 67 | 74 | 63 | 46 | 65 |
| M-3 P | 90 | 61 | 52 | 72 | 58 | 52 |
| M-4 P | 63 | 49 | 46 | 53 | 53 | 45 |
| M-5 P | 56 | 36 | 44 | 46 | 45 | 47 |
| M-6 P | 56 | 44 | 32* | 45 | 47 | 65 |
| M-7 P | 75 | 68 | 69 | 67 | 54 | 67 |
| M-8 P | 80 | 60 | 41 | 71 | 55 | 46 |
| M-9 P | 53 | 42 | 57 | 43 | 59 | 57 |
| M-9 P Dup | 70 | 58 | 53 | 56 | 56 | 55 |
| M-10 P | 65 | 46 | 52 | 52 | 52 | 52 |
| M-11 P | 63 | 51 | 56 | 52 | 51 | 47 |
| M-12 P | 64 | 45 | 65 | 51 | 41 | 65 |
| M-13 P | 82 | 56 | 79 | 65 | 34* | 68 |
| M-14 P | 85 | 60 | 67 | 65 | 68 | 61 |

## TABLE B-3. RESULTS OF MATRIX SPIKE/MATRIX SPIKE DUPLICATE ANALYSES FOR SEMIVOLATILE ORGANICS ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

M-7 MID Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.51 | 68 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 6.11 | 92 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.80 | 84 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.72 | 82 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.86 | 86 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.96 | 89 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 5.90 | 88 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 2.86 | 86 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 3.99 | 60 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.84 | 85 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 5.38 | 81 | 20-143 |
| Pyrene | <0.33 | 3.33 | 2.33 | 70 | 42-129 |

M-7 MID Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.91 | 74 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 5.29 | 79 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.25 | 68 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.34 | 70 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.59 | 78 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.64 | 79 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 5.39 | 81 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 2.41 | 72 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 3.20 | 48 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.51 | 75 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 4.47 | 67 | 20-143 |
| Pyrene | <0.33 | 3.33 | 2.04 | 61 | 42-129 |

M-7 MID MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Phenol | 4.51 | 4.91 | 8 | 0-19 |
| 2-Chlorophenol | 6.11 | 5.29 | 14 | 0-20 |
| 1,4-Dichlorobenzene | 2.80 | 2.25 | 22 | 0-27 |
| N-Nitrosodi-n-Propylamine | 2.72 | 2.34 | 15 | 0-23 |
| 1,2,4-Trichlorobenzene | 2.86 | 2.59 | 10 | 0-24 |
| Naphthalene | 2.96 | 2.64 | 11 | 0-20 |
| 4-Chloro-3-Methylphenol | 5.90 | 5.39 | 9 | 0-18 |
| Acenaphthene | 2.86 | 2.41 | 17 | 0-22 |
| 4-Nitrophenol | 3.99 | 3.20 | 22 | 0-24 |
| 2,4-Dinitrotoluene | 2.84 | 2.51 | 12 | 0-22 |
| Pentachlorophenol | 5.38 | 4.47 | 18 | 0-36 |
| Pyrene | 2.33 | 2.04 | 13 | 0-20 |

# TABLE B-3 (CONTINUED). RESULTS OF MATRIX SPIKE/MATRIX SPIKE DUPLICATE ANALYSES FOR SEMIVOLATILE ORGANICS ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

M-13 TOP Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.51 | 68 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 5.88 | 88 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.60 | 78 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.35 | 71 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.52 | 76 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.69 | 81 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 5.63 | 84 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 2.34 | 70 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 3.55 | 53 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.63 | 79 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 5.08 | 76 | 20-143 |
| Pyrene | <0.33 | 3.33 | 2.78 | 83 | 42-129 |

M-13 TOP Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.22 | 63 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 5.15 | 77 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.56 | 77 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.23 | 67 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.40 | 72 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.43 | 73 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 4.84 | 73 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 2.72 | 82 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 2.98 | 45 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.41 | 72 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 4.30 | 64 | 20-143 |
| Pyrene | <0.33 | 3.33 | 3.16 | 95 | 42-129 |

M-13 TOP MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Phenol | 4.51 | 4.22 | 7 | 0-19 |
| 2-Chlorophenol | 5.88 | 5.15 | 13 | 0-20 |
| 1,4-Dichlorobenzene | 2.60 | 2.56 | 2 | 0-27 |
| N-Nitrosodi-n-Propylamine | 2.35 | 2.23 | 5 | 0-23 |
| 1,2,4-Trichlorobenzene | 2.52 | 2.40 | 5 | 0-24 |
| Naphthalene | 2.69 | 2.43 | 10 | 0-20 |
| 4-Chloro-3-Methylphenol | 5.63 | 4.84 | 15 | 0-18 |
| Acenaphthene | 2.34 | 2.72 | 15 | 0-22 |
| 4-Nitrophenol | 3.55 | 2.98 | 17 | 0-24 |
| 2,4-Dinitrotoluene | 2.63 | 2.41 | 9 | 0-22 |
| Pentachlorophenol | 5.08 | 4.30 | 17 | 0-36 |
| Pyrene | 2.78 | 3.16 | 13 | 0-20 |

# TABLE B-3 (CONTINUED). RESULTS OF MATRIX SPIKE/MATRIX SPIKE DUPLICATE ANALYSES FOR SEMIVOLATILE ORGANICS ANALYSES ON MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

M-14 Bottom Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.96 | 74 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 6.47 | 97 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.86 | 86 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.59 | 78 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.77 | 83 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.96 | 89 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 5.19 | 78 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 2.57 | 77 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 3.91 | 59 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.89 | 87 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 5.59 | 84 | 20-143 |
| Pyrene | <0.33 | 3.33 | 3.06 | 92 | 42-129 |

M-14 Bottom Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Phenol | <0.33 | 6.67 | 4.51 | 68 | 58-126 |
| 2-Chlorophenol | <0.33 | 6.67 | 5.78 | 87 | 51-126 |
| 1,4-Dichlorobenzene | <0.33 | 3.33 | 2.54 | 76 | 43-122 |
| N-Nitrosodi-n-Propylamine | <0.33 | 3.33 | 2.69 | 81 | 48-120 |
| 1,2,4-Trichlorobenzene | <0.33 | 3.33 | 2.86 | 86 | 57-116 |
| Naphthalene | <0.33 | 3.33 | 2.52 | 76 | 55-129 |
| 4-Chloro-3-Methylphenol | <0.33 | 6.67 | 4.65 | 70 | 61-125 |
| Acenaphthene | <0.33 | 3.33 | 3.18 | 96 | 47-112 |
| 4-Nitrophenol | <1.70 | 6.67 | 3.23 | 48 | 34-128 |
| 2,4-Dinitrotoluene | <0.33 | 3.33 | 2.42 | 73 | 52-128 |
| Pentachlorophenol | <1.70 | 6.67 | 5.03 | 75 | 20-143 |
| Pyrene | <0.33 | 3.33 | 3.70 | 111 | 42-129 |

M-14 Bottom MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Phenol | 4.96 | 4.51 | 10 | 0-19 |
| 2-Chlorophenol | 6.47 | 5.78 | 11 | 0-20 |
| 1,4-Dichlorobenzene | 2.86 | 2.54 | 12 | 0-27 |
| N-Nitrosodi-n-Propylamine | 2.59 | 2.69 | 4 | 0-23 |
| 1,2,4-Trichlorobenzene | 2.77 | 2.86 | 3 | 0-24 |
| Naphthalene | 2.96 | 2.52 | 16 | 0-20 |
| 4-Chloro-3-Methylphenol | 5.19 | 4.65 | 11 | 0-18 |
| Acenaphthene | 2.57 | 3.18 | 21 | 0-22 |
| 4-Nitrophenol | 3.91 | 3.23 | 19 | 0-24 |
| 2,4-Dinitrotoluene | 2.89 | 2.42 | 18 | 0-22 |
| Pentachlorophenol | 5.59 | 5.03 | 10 | 0-36 |
| Pyrene | 3.06 | 3.70 | 19 | 0-20 |

# Table B-4 Results Of Resin Acid Analyses For Manistee Lake Sediments, November 1998.

| Sample ID | Abietic Acid | Dehydroabietic Acid | Pimeric Acid | Isopimeric Acid | Neoabietic Acid | Total Resin Acids |
|---|---|---|---|---|---|---|
| | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg | mg/kg |
| M-1 Top | 1.1 | 0.8 | 0.9 | 0.5 | 0.1 | 3 |
| M-1-Mid | 0.4 | 0.8 | 0.3 | 0.3 | 0.2 | 2 |
| M-1 Bot | 0.3 | 0.7 | 0.1 | 0.2 | 0.1 | 1 |
| M-2 Top | 2.1 | 3.6 | 1.0 | 0.8 | 1.0 | 8 |
| M-2 Mid | 2.4 | 4.0 | 2.3 | 1.2 | 1.0 | 11 |
| M-2 Bot | 0.9 | 1.8 | 0.5 | 0.7 | 0.3 | 4 |
| M-3 Top | 2.4 | 4.3 | 1.1 | 2.1 | 0.4 | 10 |
| M-3 Mid | 1.3 | 2.9 | 0.7 | 0.6 | 0.5 | 6 |
| M-3 Bot | 0.6 | 1.1 | 0.3 | 0.2 | 0.1 | 2 |
| M-4 Top | 2.6 | 4.0 | 2.6 | 1.8 | 0.7 | 12 |
| M-4 Mid | 1.4 | 2.8 | 1.0 | 1.2 | 0.9 | 7 |
| M-4 Bot | 0.5 | 0.7 | 0.4 | 0.2 | 0.2 | 2 |
| M-5 Top | 2.8 | 4.6 | 1.8 | 0.4 | 1.2 | 11 |
| M-5 Mid | 2.9 | 7.8 | 2.2 | 3.6 | 1.9 | 18 |
| M-5 Bot | 0.7 | 1.1 | 0.7 | 0.3 | 0.6 | 3 |
| M-6 Top | 2.6 | 6.1 | 1.3 | 2.4 | 0.7 | 13 |
| M-6 Mid | 1.5 | 2.6 | 1.4 | 0.7 | 1.2 | 7 |
| M-6 Bot | 0.5 | 0.8 | 0.2 | 0.2 | 0.0 | 2 |
| M-7 Top | 2.6 | 2.8 | 0.8 | 2.3 | 0.7 | 9 |
| M-7 Mid | 1.9 | 2.7 | 0.3 | 0.7 | 0.2 | 6 |
| M -7 Bot | 0.9 | 1.5 | 0.2 | 0.3 | 0.2 | 3 |
| M-8 Top | 1.8 | 3.9 | 1.5 | 0.2 | 1.2 | 9 |
| M-8 Mid | 1.3 | 1.5 | 0.5 | 0.8 | 0.3 | 4 |
| M-8 Bot | 0.8 | 1.4 | 0.3 | 0.5 | 0.2 | 3 |
| M-9 Top | 1.8 | 2.1 | 0.7 | 0.2 | 0.4 | 5 |
| M-9 Mid | 0.8 | 1.6 | 0.3 | 0.3 | 0.1 | 3 |
| M-9 Bot | 0.3 | 0.4 | 0.1 | 0.2 | 0.1 | 1 |
| M-9 Top Dup | 0.8 | 1.3 | 0.2 | 0.3 | 0.2 | 3 |
| M-9 Mid Dup | 1.5 | 2.7 | 0.5 | 0.6 | 0.3 | 6 |
| M-9 Bot Dup | 0.5 | 0.7 | 0.2 | 0.2 | 0.1 | 2 |
| M-10 Top | 1.0 | 2.4 | 0.4 | 1.0 | 0.3 | 5 |
| M-10 Mid | 0.8 | 1.0 | 0.6 | 0.3 | 0.3 | 3 |
| M-10 Bot | 0.5 | 1.1 | 0.4 | 0.5 | 0.1 | 3 |
| M-11 Top | 2.1 | 3.4 | 0.7 | 1.2 | 0.4 | 8 |
| M-11 Mid | 1.1 | 1.9 | 0.3 | 1.0 | 0.0 | 4 |
| M-11 Bot | 0.3 | 0.4 | 0.2 | 0.3 | 0.1 | 1 |
| M-12 Top | 1.7 | 2.1 | 1.5 | 1.6 | 0.6 | 7 |
| M-12 Mid | 0.9 | 1.6 | 0.1 | 0.6 | 0.1 | 3 |
| M-12 Bot | 0.5 | 0.7 | 0.3 | 0.3 | 0.1 | 2 |
| M-13 Top | 2.0 | 2.1 | 0.2 | 0.8 | 0.2 | 5 |
| M-13 Mid | 0.8 | 1.1 | 0.8 | 0.5 | 0.7 | 4 |
| M-13 Bot | 0.6 | 0.9 | 0.1 | 0.4 | 0.1 | 2 |
| M-14 Top | 1.1 | 1.5 | 1.1 | 0.9 | 0.9 | 5 |
| M-14 Mid | 0.9 | 1.7 | 0.5 | 0.2 | 0.2 | 4 |
| M-14 Bot | 0.2 | 0.4 | 0.1 | 0.1 | 0.1 | 1 |
| M-1 P | 0.8 | 1.5 | 0.5 | 0.5 | 0.3 | 4 |
| M-2 P | 1.6 | 3.3 | 2.2 | 1.4 | 1.2 | 10 |
| M-3 P | 2.4 | 3.8 | 1.9 | 0.8 | 0.4 | 9 |
| M-4 P | 2.1 | 3.1 | 0.2 | 1.9 | 0.2 | 8 |
| M-5 P | 2.9 | 3.8 | 0.5 | 2.5 | 0.4 | 10 |
| M-6 P | 2.0 | 4.8 | 1.4 | 1.7 | 1.5 | 11 |
| M-7 P | 2.2 | 2.8 | 0.6 | 0.8 | 0.3 | 7 |
| M-8 P | 1.5 | 2.0 | 1.4 | 1.4 | 0.8 | 7 |
| M-9 P | 1.1 | 2.6 | 0.8 | 0.6 | 0.5 | 6 |
| M-9 P Dup | 1.3 | 3.2 | 0.9 | 0.2 | 0.6 | 6 |
| M-10 P | 1.8 | 3.3 | 0.5 | 1.2 | 0.2 | 7 |
| M-11 P | 1.5 | 3.1 | 0.3 | 0.9 | 0.2 | 6 |
| M-12 P | 2.2 | 2.2 | 0.4 | 1.3 | 0.3 | 6 |
| M-13 P | 3.1 | 4.3 | 0.6 | 2.5 | 0.3 | 11 |
| M-14 P | 0.7 | 1.6 | 0.3 | 0.3 | 0.3 | 3 |

# TABLE B-5. RESULTS SURROGATE STANDARD RECOVERIES FOR RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998

| Sample | Tetrachlorosteric acid | Steric Acid* | Sample | Tetrachlorosteric acid | Steric Acid* |
|---|---|---|---|---|---|
| % Recovery | % | % | % Recovery | % | % |
| Control Limit | 40-90 | 40-90 | Control Limit | 40-90 | 40-90 |
| M-1 Top | 79 | 146 | M-10 Top | 61 | 142 |
| M-1-Mid | 89 | 169 | M-10 Mid | 70 | 160 |
| M-1 Bot | 92 | 164 | M-10 Bot | 72 | 166 |
| M-2 Top | 82 | 146 | M-11 Top | 73 | 148 |
| M-2 Mid | 82 | 157 | M-11 Mid | 80 | 148 |
| M-2 Bot | 81 | 164 | M-11 Bot | 69 | 146 |
| M-3 Top | 81 | 157 | M-12 Top | 73 | 146 |
| M-3 Mid | 70 | 153 | M-12 Mid | 77 | 126 |
| M-3 Bot | 79 | 140 | M-12 Bot | 75 | 142 |
| M-4 Top | 77 | 155 | M-13 Top | 69 | 139 |
| M-4 Mid | 83 | 130 | M-13 Mid | 63 | 149 |
| M-4 Bot | 67 | 124 | M-13 Bot | 64 | 121 |
| M-5 Top | 74 | 137 | M-14 Top | 69 | 133 |
| M-5 Mid | 52 | 113 | M-14 Mid | 58 | 94 |
| M-5 Bot | 46 | 148 | M-14 Bot | 77 | 83 |
| M-6 Top | 44 | 160 | M-1 P | 79 | 79 |
| M-6 Mid | 71 | 146 | M-2 P | 67 | 128 |
| M-6 Bot | 73 | 162 | M-3 P | 61 | 131 |
| M-7 Top | 66 | 113 | M-4 P | 49 | 119 |
| M-7 Mid | 71 | 101 | M-5 P | 36 | 128 |
| M -7 Bot | 69 | 101 | M-6 P | 44 | 124 |
| M-8 Top | 69 | 135 | M-7 P | 68 | 124 |
| M-8 Mid | 41 | 144 | M-8 P | 60 | 74 |
| M-8 Bot | 58 | 95 | M-9 P | 42 | 104 |
| M-9 Top | 46 | 126 | M-9 P Dup | 58 | 83 |
| M-9 Mid | 51 | 117 | M-10 P | 46 | 92 |
| M-9 Bot | 45 | 113 | M-11 P | 51 | 81 |
| M-9 Top Dup | 56 | 115 | M-12 P | 45 | 101 |
| M-9 Mid Dup | 60 | 148 | M-13 P | 56 | 108 |
| M-9 Bot Dup | 70 | 153 | M-14 P | 60 | 126 |

* Stearic acid detected in project samples. Surrogate data not used.

# TABLE B-6. MATRIX SPIKE/MATRIX SPIKE DUPLICATE RESULTS FOR RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998

M-7 MID Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 1.9 | 5.00 | 6.51 | 94 | 40-90 |
| Dehydroabietic Acid | 2.7 | 5.00 | 7.11 | 93 | 40-90 |
| Pimeric Acid | 0.3 | 5.00 | 4.80 | 90 | 40-90 |
| Isopimeric Acid | 0.7 | 5.00 | 4.72 | 83 | 40-90 |
| Neoabietic Acid | 0.2 | 5.00 | 3.86 | 74 | 40-90 |

M-7 MID Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 1.9 | 5.00 | 6.91 | 100 | 40-90 |
| Dehydroabietic Acid | 2.7 | 5.00 | 6.49 | 85 | 40-90 |
| Pimeric Acid | 0.3 | 5.00 | 4.45 | 84 | 40-90 |
| Isopimeric Acid | 0.7 | 5.00 | 4.64 | 82 | 40-90 |
| Neoabietic Acid | 0.2 | 5.00 | 3.59 | 69 | 40-90 |

M-7 MID MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Abietic Acid | 6.51 | 6.91 | 6 | 0-20 |
| Dehydroabietic Acid | 7.11 | 6.49 | 9 | 0-20 |
| Pimeric Acid | 4.80 | 4.45 | 8 | 0-20 |
| Isopimeric Acid | 4.72 | 4.64 | 2 | 0-20 |
| Neoabietic Acid | 3.86 | 3.59 | 7 | 0-20 |

## TABLE B-6 (CONTINUED). MATRIX SPIKE/MATRIX SPIKE DUPLICATE RESULTS FOR RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

M-13 TOP Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 2.0 | 5.00 | 5.91 | 84 | 40-90 |
| Dehydroabietic Acid | 2.1 | 5.00 | 6.04 | 85 | 40-90 |
| Pimeric Acid | 0.2 | 5.00 | 3.76 | 72 | 40-90 |
| Isopimeric Acid | 0.8 | 5.00 | 3.54 | 61 | 40-90 |
| Neoabietic Acid | 0.2 | 5.00 | 3.42 | 66 | 40-90 |

M-13 TOP Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 2.0 | 5.00 | 6.88 | 98 | 40-90 |
| Dehydroabietic Acid | 2.1 | 5.00 | 6.18 | 87 | 40-90 |
| Pimeric Acid | 0.2 | 5.00 | 3.64 | 70 | 40-90 |
| Isopimeric Acid | 0.8 | 5.00 | 3.38 | 58 | 40-90 |
| Neoabietic Acid | 0.2 | 5.00 | 3.19 | 62 | 40-90 |

M-13 TOP MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Abietic Acid | 5.91 | 6.88 | 15 | 0-20 |
| Dehydroabietic Acid | 6.04 | 6.18 | 2 | 0-20 |
| Pimeric Acid | 3.76 | 3.64 | 3 | 0-20 |
| Isopimeric Acid | 3.54 | 3.38 | 5 | 0-20 |
| Neoabietic Acid | 3.42 | 3.19 | 7 | 0-20 |

## TABLE B-6 (CONTINUED). MATRIX SPIKE/MATRIX SPIKE DUPLICATE RESULTS FOR RESIN ACID ANALYSES FOR MANISTEE LAKE SEDIMENTS, NOVEMBER 1998.

M-14 Bottom Matrix Spike

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 0.7 | 5.00 | 5.53 | 97 | 40-90 |
| Dehydroabietic Acid | 1.6 | 5.00 | 6.11 | 93 | 40-90 |
| Pimeric Acid | 0.3 | 5.00 | 3.92 | 74 | 40-90 |
| Isopimeric Acid | 0.3 | 5.00 | 3.51 | 66 | 40-90 |
| Neoabietic Acid | 0.3 | 5.00 | 2.99 | 56 | 40-90 |

M-14 Bottom Matrix Spike Duplicate

| Parameter | Initial Sample Concentration mg/kg | Spiked Quantity mg/kg | Final Sample Concentration mg/kg | Spike Recovery % | Control Limit % |
|---|---|---|---|---|---|
| Abietic Acid | 0.7 | 5.00 | 5.19 | 91 | 40-90 |
| Dehydroabietic Acid | 1.6 | 5.00 | 5.88 | 89 | 40-90 |
| Pimeric Acid | 0.3 | 5.00 | 3.35 | 63 | 40-90 |
| Isopimeric Acid | 0.3 | 5.00 | 3.05 | 58 | 40-90 |
| Neoabietic Acid | 0.3 | 5.00 | 2.59 | 49 | 40-90 |

M-14 Bottom MS/MSD Relative Percent Difference

| Parameter | MS Result mg/kg | MSD Result mg/kg | RPD % | Control Limit % |
|---|---|---|---|---|
| Abietic Acid | 5.53 | 5.19 | 6 | 0-20 |
| Dehydroabietic Acid | 6.11 | 5.88 | 4 | 0-20 |
| Pimeric Acid | 3.92 | 3.35 | 16 | 0-20 |
| Isopimeric Acid | 3.51 | 3.05 | 14 | 0-20 |
| Neoabietic Acid | 2.99 | 2.59 | 14 | 0-20 |

## TABLE B-7. RESULTS OF RESIN ACID ANALYSES FOR MANISTEE LAKE FISH, APRIL 2000.

| Species | Size (mm) | Weight (g) | Abietic Acid (ug/g) | Dehydroabietic Acid (ug/g) | Pimeric Acid (ug/g) | Isopimeric Acid (ug/g) | Neoabietic Acid (ug/g) |
|---|---|---|---|---|---|---|---|
| Walleye 1 | 533 | 1307 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 2 | 574 | 2009 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 3 | 610 | 2541 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 4 | 635 | 2853 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 5 | 655 | 3834 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 6 | 698 | 4935 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Walleye 7 | 719 | 6463 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp 1 | 243 | 477 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp 2 | 304 | 932 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp 3 | 364 | 1605 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp 4 | 405 | 2205 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |
| Carp 5 | 445 | 2909 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 |

## TABLE B-8. RESULTS OF RESIN ACID SURROGATE STANDARD ANALYSES FOR MANISTEE LAKE FISH, APRIL 2000.

| Sample | Tetrachlorostearic acid | Stearic Acid* |
|---|---|---|
| % Recovery | % | % |
| Control Limit | 40-90 | 40-90 |
| Walleye 1 | 77 | 233 |
| Walleye 2 | 83 | 271 |
| Walleye 3 | 67 | 262 |
| Walleye 4 | 74 | 233 |
| Walleye 5 | 52 | 251 |
| Walleye 6 | 69 | 262 |
| Walleye 7 | 71 | 251 |
| Carp 1 | 82 | 245 |
| Carp 2 | 73 | 225 |
| Carp 3 | 71 | 248 |
| Carp 4 | 83 | 207 |
| Carp 5 | 67 | 199 |

* Stearic acid detected in project samples. Surrogate data not used.

# TABLE B-9 RESULTS OF TARGET COMPOUND ANALYSES IN GROUNDWATER SAMPLES COLLECTED NEAR MANISTEE LAKE, NOVEMBER 1998.

| Well |  | 86-2 |  | KMW-8D |  | KMW-8D Dup |
|---|---|---|---|---|---|---|
| Units |  | mg/l |  | mg/l |  | mg/l |
| Naphthalene | < | 1.0 | < | 0.3 | < | 0.3 |
| 2-methylnaphthalene | < | 1.0 | < | 0.3 | < | 0.3 |
| Acenaphthylene | < | 1.0 | < | 0.3 | < | 0.3 |
| Acenaphthene | < | 1.0 | < | 0.3 | < | 0.3 |
| Fluorene | < | 1.0 | < | 0.3 | < | 0.3 |
| Phenanthrene | < | 1.0 | < | 0.3 | < | 0.3 |
| Anthracene | < | 1.0 | < | 0.3 | < | 0.3 |
| Fluoranthene | < | 1.0 | < | 0.3 | < | 0.3 |
| Pyrene | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzo(a)anthracene | < | 1.0 | < | 0.3 | < | 0.3 |
| Chrysene | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzo(b)fluoranthene | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzo(k)fluoranthene | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzo(a)pyrene | < | 1.0 | < | 0.3 | < | 0.3 |
| Indeno(1,2,3-cd)pyrene | < | 1.0 | < | 0.3 | < | 0.3 |
| Dibenzo(a,h)anthracene | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzo(g,h,I)perylene | < | 1.0 | < | 0.3 | < | 0.3 |
| 4-Methy Phenol |  | 10.0 |  | 0.6 |  | 0.5 |
| Bis(2-chlorethyl)ether | < | 1.0 | < | 0.3 | < | 0.3 |
| 2-Chlorophenol | < | 1.0 | < | 0.3 | < | 0.3 |
| Phenol |  | 64.0 |  | 0.9 |  | 0.8 |
| 1,3-Dichlorobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| 1,4-Dichlorobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| 1,2-Dichlorobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| Bis(2-Chloroisopropyl)ether | < | 1.0 | < | 0.3 | < | 0.3 |
| 2-Methylphenol |  | 7.2 |  | 0.3 |  | 0.3 |
| 3/4-Methylphenol | < | 1.0 | < | 0.3 | < | 0.3 |
| N-Nitroso-di-n-propylamine | < | 1.0 | < | 0.3 | < | 0.3 |
| Hexachloroethane | < | 1.0 | < | 0.3 | < | 0.3 |
| Nitrobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| Isophorone | < | 1.0 | < | 0.3 | < | 0.3 |
| 2-Nitrophenol | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,4-Dimethylphenol | < | 1.0 | < | 0.3 | < | 0.3 |
| Bis(2-Chloroethoxy)methane | < | 1.0 | < | 0.3 | < | 0.3 |
| Benzoic Acid |  | 140.0 |  | 0.5 |  | 0.4 |
| 1,2,4-Trichlorobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,4-Dichlorophenol | < | 1.0 | < | 0.3 | < | 0.3 |
| Hexachloro-1,3-butadiene | < | 1.0 | < | 0.3 | < | 0.3 |
| 4-chloro-3-methylphenol | < | 1.0 | < | 0.3 | < | 0.3 |
| Hexachlorocyclopentadiene | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,4,6-Trichlorophenol | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,4,5-Trichlorophenol | < | 1.0 | < | 0.3 | < | 0.3 |
| 2-Chloronaphalene | < | 1.0 | < | 0.3 | < | 0.3 |
| Dimethylphthalate | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,6-Dinitrotoluene | < | 1.0 | < | 0.3 | < | 0.3 |
| 2,4-Dinitrotoluene | < | 1.0 | < | 0.3 | < | 0.3 |
| 4-Nitrophenol | < | 5.2 | < | 1.3 | < | 1.3 |
| 2,4-Dinitrophenol | < | 5.2 | < | 1.3 | < | 1.3 |
| Diethylphthalate | < | 1.0 | < | 0.3 | < | 0.3 |
| 4-Chlorophenyl-phenylether | < | 1.0 | < | 0.3 | < | 0.3 |
| 4,6-Dinitro-2-methylphenol | < | 5.2 | < | 1.3 | < | 1.3 |
| N-Nitrosodiphenylamine | < | 1.0 | < | 0.3 | < | 0.3 |
| 4-Bromophenyl-phenylether | < | 1.0 | < | 0.3 | < | 0.3 |
| Hexachlorobenzene | < | 1.0 | < | 0.3 | < | 0.3 |
| Pentachlorophenol | < | 5.2 | < | 1.3 | < | 1.3 |
| Di-n-butylphthalate | < | 1.0 | < | 0.3 | < | 0.3 |
| Butylbenzylphthalate | < | 1.0 | < | 0.3 | < | 0.3 |
| 3,3'-Dichlorobenzidine | < | 6.1 | < | 1.6 | < | 1.6 |
| bis(2-Ethylhexyl)phalate | < | 1.0 | < | 0.3 | < | 0.3 |

## TABLE B-9 (CONTINUED) RESULTS OF TARGET COMPOUND ANALYSES IN GROUNDWATER SAMPLES COLLECTED NEAR MANISTEE LAKE, NOVEMBER 1998.

| Well | 86-2 | 86-2 Dup | KMW-8D |
|---|---|---|---|
| Parameter | mg/l | mg/l | mg/l |
| Abietic Acid | 0.85 | 0.7 | 0.64 |
| Dehydroabietic Acid | 1.6 | 1.7 | 0.97 |
| Chlorodehydroabietic Acid | <0.5 | <0.5 | <0.05 |
| Dichlorodehydroabietic Acid | <0.5 | <0.5 | <0.05 |
| Pimeric Acid | 0.43 | 0.55 | 0.15 |
| Isopimeric Acid | 0.21 | 0.13 | 0.08 |
| Neoabietic Acid | 0.14 | 0.21 | 0.09 |
| Resin Acid Surrogates | | | |
| Tetrachlorostearic acid | 53 | 58 | 51 |
| Steric acid | 70 | 46 | 45 |

Semivolatile surrogates could not be quantitated because of dilution

# Appendix C. Results Of Metals Analyses For Manistee Lake Sediments, November 1998.

## Table C-1. Results Of Metals Analyses In Manistee Lake Sediment, November 1998.

| Sample ID | Total Barium mg/kg | Total Selenium mg/kg | Total Mercury ug/kg | Total Arsenic mg/kg | Total Cadmium mg/kg | Total Chromium mg/kg | Total Copper mg/kg | Total Lead mg/kg | Total Nickel mg/kg | Total Zinc mg/kg |
|---|---|---|---|---|---|---|---|---|---|---|
| M-1 Top | 51 | 0.52 | 48 | 2.3 | 0.78 | 25 | 20 | 23 | 8.4 | 76 |
| M-1-Mid | 62 | 0.50 | 27 | 0.24 | 0.47 | 20 | 27 | 16 | 9.8 | 53 |
| M-1 Bot | 72 | 1.10 | <25 | 0.33 | 0.54 | 30 | 12 | 4.8 | 9.5 | 53 |
| M-2 Top | 120 | 0.33 | 45 | 9.2 | 1.7 | 44 | 53 | 78 | 20 | 200 |
| M-2 Mid | 150 | 0.30 | 22 | 11 | 3.8 | 110 | 120 | 160 | 21 | 300 |
| M-2 Bot | 94 | 0.62 | <25 | 8.6 | 0.74 | 78 | 18 | 15 | 14 | 64 |
| M-3 Top | 100 | 0.46 | <25 | 8.4 | 0.85 | 37 | 29 | 24 | 16 | 92 |
| M-3 Mid | 120 | 0.73 | <25 | 8.4 | 0.47 | 39 | 16 | 8.5 | 17 | 59 |
| M-3 Bot | 120 | 0.76 | <25 | 7.0 | 0.49 | 41 | 16 | 7 | 18 | 60 |
| M-4 Top | 110 | 0.79 | <25 | 6.7 | 0.41 | 40 | 17 | 7.3 | 19 | 60 |
| M-4 Mid | 110 | 0.71 | <25 | 6.5 | 0.43 | 36 | 16 | 7.6 | 18 | 58 |
| M-4 Bot | 130 | 0.71 | <25 | 6.3 | 0.47 | 35 | 16 | 8.1 | 20 | 210 |
| M-5 Top | 110 | 0.35 | <25 | 2.2 | 2.5 | 72 | 75 | 88 | 22 | 60 |
| M-5 Mid | 100 | 0.70 | 123 | 7.3 | 0.5 | 34 | 16 | 10 | 18 | 57 |
| M-5 Bot | 120 | 0.91 | <25 | 6.9 | 0.52 | 36 | 16 | 8.2 | 19 | 110 |
| M-6 Top | 93 | 0.44 | 27 | 8.1 | 1.8 | 56 | 30 | 26 | 23 | 57 |
| M-6 Mid | 110 | 0.72 | <25 | 8.2 | 0.45 | 36 | 15 | 8.4 | 20 | 56 |
| M-6 Bot | 120 | 0.74 | <25 | 6.9 | 0.5 | 34 | 17 | 7.8 | 21 | 56 |
| M-7 Top | 110 | 0.22 | 48 | 9.6 | 2.3 | 100 | 60 | 64 | 24 | 170 |
| M-7 Mid | 95 | 0.60 | <25 | 5.4 | 0.63 | 33 | 17 | 12 | 22 | 67 |
| M -7 Bot | 120 | 0.68 | <25 | 7.6 | 0.42 | 37 | 16 | 8.5 | 24 | 60 |
| M-8 Top | 110 | 0.36 | 95 | 17 | 2.6 | 130 | 100 | 91 | 26 | 230 |
| M-8 Mid | 110 | 0.52 | <25 | 8.9 | 0.61 | 50 | 21 | 16 | 21 | 79 |
| M-8 Bot | 120 | 0.60 | <25 | 7.8 | 0.35 | 39 | 16 | 8.2 | 19 | 61 |
| M-9 Top | 110 | 0.43 | 62 | 3.0 | 3.4 | 140 | 100 | 83 | 29 | 230 |
| M-9 Mid | 110 | 0.46 | <25 | 7.7 | 0.37 | 39 | 19 | 12 | 21 | 71 |
| M-9 Bot | 130 | 0.51 | <25 | 6.2 | 0.3 | 36 | 15 | 8 | 20 | 56 |
| M-9 Top Dup | 110 | 0.46 | 66 | 12 | 3.4 | 82 | 94 | 85 | 26 | 240 |
| M-9 Mid Dup | 110 | 0.46 | 26 | 5.4 | 0.3 | 31 | 15 | 10 | 18 | 54 |
| M-9 Bot Dup | 120 | 0.50 | <25 | 6.5 | 0.41 | 36 | 16 | 8.7 | 20 | 59 |
| M-10 Top | 120 | 0.44 | 55 | 15 | 2.5 | 85 | 120 | 87 | 34 | 330 |
| M-10 Mid | 100 | 0.3 | <25 | 6.4 | 0.36 | 36 | 21 | 20 | 24 | 30 |
| M-10 Bot | 120 | 0.38 | <25 | 7.6 | 0.36 | 39 | 17 | 9.8 | 23 | 64 |
| M-11 Top | 110 | 0.39 | 150 | 14 | 1.3 | 48 | 150 | 67 | 33 | 190 |
| M-11 Mid | 110 | 0.35 | <25 | 6.3 | 0.31 | 33 | 21 | 15 | 22 | 66 |
| M-11 Bot | 110 | 0.42 | <25 | 4.0 | 0.44 | 29 | 16 | 9.5 | 22 | 63 |
| M-12 Top | 110 | 0.33 | 53 | 9.4 | 1.1 | 40 | 98 | 81 | 30 | 200 |
| M-12 Mid | 320 | <0.20 | 152 | 17 | 1.4 | 44 | 140 | 85 | 29 | 240 |
| M-12 Bot | 67 | <0.20 | 27 | 3.7 | 0.22 | 20 | 16 | 15 | 14 | 56 |
| M-13 Top | 88 | 0.29 | 48 | 11 | 0.82 | 35 | 180 | 58 | 35 | 150 |
| M-13 Mid | 94 | 0.21 | 188 | 9.4 | 0.57 | 34 | 84 | 30 | 24 | 120 |
| M-13 Bot | 96 | 0.25 | <25 | 5.2 | 0.23 | 28 | 18 | 13 | 23 | 58 |
| M-14 Top | 46 | 0.23 | <25 | 2.1 | 0.14 | 8.6 | 7.1 | 6.1 | 7.0 | 20 |
| M-14 Mid | 25 | <0.20 | <25 | 1.6 | 0.16 | 6.8 | 5.7 | 5.8 | 8.0 | 15 |
| M-14 Bot | 63 | 0.22 | 27 | 3.5 | 0.34 | 20 | 16 | 20 | 16 | 51 |
| M-1 P | 8 | <0.20 | 29 | 0.63 | <0.05 | <2.0 | <2.0 | 1.5 | <4.0 | <4.0 |
| M-2 P | 110 | 0.65 | 39 | 9.1 | 1.7 | 38 | 45 | 54 | 18 | 160 |
| M-3 P | 110 | 0.62 | 33 | 10 | 2.6 | 38 | 49 | 54 | 19 | 160 |
| M-4 P | 120 | 0.58 | 39 | 9.9 | 1.4 | 36 | 42 | 43 | 17 | 130 |
| M-5 P | 110 | 0.51 | 230 | 9.1 | 3.1 | 38 | 72 | 85 | 16 | 190 |
| M-6 P | 84 | 0.52 | 44 | 13 | 3.1 | 68 | 71 | 71 | 19 | 160 |
| M-7 P | 83 | 1.20 | <25 | 9.4 | 3.2 | 87 | 42 | 38 | 16 | 150 |
| M-8 P | 110 | 0.50 | 50 | 12 | 2.6 | 43 | 64 | 63 | 24 | 170 |
| M-9 P | 120 | 0.49 | 36 | 10 | 1.6 | 46 | 81 | 69 | 25 | 180 |
| M-9 P Dup | 130 | 0.52 | 43 | 11 | 1.5 | 47 | 82 | 72 | 24 | 180 |
| M-10 P | 120 | 0.58 | 58 | 15 | 1.1 | 40 | 100 | 66 | 28 | 200 |
| M-11 P | 110 | 0.49 | 89 | 12 | 1.3 | 35 | 140 | 77 | 30 | 190 |
| M-12 P | 110 | 1.50 | 86 | 7.8 | 0.99 | 31 | 78 | 69 | 24 | 170 |
| M-13 P | 120 | 0.72 | 52 | 7.9 | 0.82 | 34 | 95 | 56 | 34 | 150 |
| M-14 P | 38 | <0.20 | <25 | 2.7 | 0.18 | 12 | 9.6 | 8.9 | 9.6 | 25 |

### Table C-2. Results Of Quality Control Analyses For Metals In Manistee Lake Sediment, November 1998. (NA= Not Analyzed. Units Are Mg/Kg Except Where Noted)

| Sample ID | As | Ba | Cd | Cr | Cu | Pb | Ni | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Spiked amount | 1.0 | 40 | 0.1 | 40 | 40 | 40 | 40 | 1.0 | 40 |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 98% | NA | 112% | NA | NA | 101% | NA | 101% | NA |
| LCS ICP | NA | 108% | 110% | 106% | 100% | 108% | 108% | NA | 108% |
| M-1 Top | 2.3 | 51 | 0.78 | 25 | 20 | 23 | 8.4 | 0.52 | 76 |
| M-1 Top MS | 117% | 75% | 64% | 103% | 101% | 111% | 109% | 110% | 103% |
| M-1 Top MSD | 136% | 89% | 68% | 97% | 94% | 100% | 103% | 120% | 95% |
| % RSD | 15% | 17% | 6% | 6% | 7% | 10% | 6% | 9% | 8% |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 104% | NA | 110% | NA | NA | 107% | NA | 104% | NA |
| LCS ICP | NA | 110% | 112% | 107% | 99% | 111% | 110% | NA | 108% |
| M-4 Mid | 6.5 | 110 | 0.43 | 36 | 16 | 7.6 | 18 | 0.71 | 58 |
| M-4 Mid MS | NA | 89% | NA | 102% | 99% | NA | 103% | NA | 100% |
| M-4 Mid MSD | NA | 99% | NA | 99% | 96% | NA | 101% | NA | 103% |
| % RSD | NA | 11% | NA | 3% | 3% | NA | 2% | NA | 3% |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 107% | NA | 112% | NA | NA | 108% | NA | 108% | NA |
| LCS ICP | NA | 110% | 114% | 108% | 100% | 112% | 110% | NA | 108% |
| M-7 Bot | 7.6 | 120 | 0.42 | 37 | 16 | 8.5 | 24 | 0.68 | 60 |
| M-7 Bot MS | 89% | 93% | 156% | 97% | 95% | 103% | 99% | 88% | 101% |
| M-7 Bot MSD | 101% | 82% | 125% | 95% | 93% | 128% | 97% | 79% | 102% |
| % RSD | 13% | 13% | 22% | 2% | 2% | 22% | 2% | 11% | 1% |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 110% | NA | 112% | NA | NA | 113% | NA | 110% | NA |
| LCS ICP | NA | 100% | 111% | 107% | 100% | 112% | 110% | NA | 108% |
| M-10 Top | 15 | 120 | 2.5 | 85 | 120 | 87 | 34 | 0.44 | 330 |
| M-10-Top MS | 100% | 96% | 101% | 80% | 89% | 96% | 97% | 89% | 89% |
| M-10-Top MSD | 89% | 79% | 99% | 79% | 87% | 94% | 96% | 104% | 89% |
| % RSD | 12% | 19% | 2% | 1% | 2% | 2% | 1% | 16% | 0% |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 96% | NA | 113% | NA | NA | 116% | NA | 99% | NA |
| LCS ICP | NA | 108% | 116% | 113% | 105% | 116% | 116% | NA | 114% |
| M-13 Mid | 9.4 | 94 | 0.57 | 34 | 84 | 30 | 24 | 0.21 | 120 |
| M-13 Mid MS | 98% | 94% | 99% | 94% | 98% | 101% | 99% | 99% | 106% |
| M-13 Mid MSD | 137% | 87% | 104% | 95% | 100% | 102% | 98% | 127% | 107% |
| % RSD | 33% | 8% | 5% | 1% | 2% | 1% | 1% | 25% | 1% |
| Method Blank | <0.20 | <2.0 | <0.050 | <2.0 | <2.0 | <1.0 | <4.0 | <0.20 | <4.0 |
| LCS GFAA | 106% | NA | 113% | NA | NA | 118% | NA | 106% | NA |
| LCS ICP | NA | 114% | 116% | 114% | 106% | 114% | 116% | NA | 113% |
| M-6 P | 13 | 84 | 3.1 | 68 | 71 | 71 | 19 | 0.52 | 160 |
| M-6 P MS | 67% | 95% | 101% | 89% | 95% | 95% | 98% | 72% | 99% |
| M-6 P MSD | 89% | 92% | 100% | 94% | 94% | 94% | 96% | 86% | 99% |
| % RSD | 28% | 3% | 1% | 5% | 1% | 1% | 2% | 18% | 0% |

## Table C-3. Results Of Quality Control Analyses For Mercury In Manistee Lake Sediment, November 1998. (NA= Not Analyzed. Units Are Ug/Kg Except Where Noted. Spiked Amount = 0.11 Ug/Kg).

| Sample | Hg | Sample | Hg |
|---|---|---|---|
| M-4 Top | < 25 | M-13 Top | 46 |
| M-4 Top MS | 101% | M-13 Top MS | 105% |
| M-4 Top MSD | 104% | M-13 Top MSD | 104% |
| % RSD | 3% | % RSD | 1% |
| M-7 Mid | < 25 | M-5 P | 230 |
| M-7 Top MS | 108% | M-5 P MS | 110% |
| M-7 Top MSD | 107% | M-5 P MSD | 82.0% |
| % RSD | 1% | % RSD | 29% |
| M-9 Dup Bot | < 25 | M-14 P | < 25 |
| M-9 Dup Bot MS | 107% | M-14 P MS | 110% |
| M-9 Dup Bot MSD | 106% | M-14 P MSD | 116% |
| % RSD | 1% | % RSD | 5% |

## Table C-4. Results Of Standard Reference Material Analyses For Metals (Results In Mg/Kg Except Where Noted).

| Sample ID | As | Hg | Cd | Cr | Cu | Pb | Ni | Zn |
|---|---|---|---|---|---|---|---|---|
| ERA-1 | 190 | 1.8 | 120 | 180 | 90 | 72 | 71 | 200 |
| % RSD | 95% | 90% | 86% | 95% | 82% | 80% | 89% | 89% |
| ERA-2 | 160 | 1.8 | 110 | 150 | 76 | 58 | 60 | 170 |
| % RSD | 80% | 90% | 79% | 79% | 69% | 64% | 75% | 76% |
| ERA-3 | 200 | 1.6 | 120 | 180 | 89 | 72 | 70 | 200 |
| % RSD | 100% | 80% | 86% | 95% | 81% | 80% | 88% | 89% |

# Appendix D. Summary Of Chemical Measurements For The Toxicity Test With Sediments From Manistee Lake, November 1998.

| | | | |
|---|---|---|---|
| Test No: | | Analyst: | jab, mtv, cb |
| Toxicant: | Manistee Lake Sediment | Test Start: | 11/03/1998 |
| Organism: | *Hyalella azteca* | Test Stop: | 11/13/1998 |

### Table D-1. Summary Of Initial And Final Chemical Measurements For *Hyalella azteca* In Manistee Lake Sediments

| | | Day | | Difference |
|---|---|---|---|---|
| **Sample** | **Parameter** | **0** | **10** | **(%)** |
| **M-1P** | pH | 7.9 | 7.8 | 1 |
| | Conductivity (umhos/cm) | 561 | 563 | 1 |
| | Alkalinity (mg/l CaCO3) | 182 | 186 | 2 |
| | Hardness (mg/l CaCO3) | 197 | 190 | 4 |
| | Ammonia (mg/l NH3) | 0.90 | 0.10 | 89 |
| **M-2P** | pH | 7.6 | 7.2 | 5 |
| | Conductivity (umhos/cm) | 621 | 553 | 12 |
| | Alkalinity (mg/l CaCO3) | 166 | 190 | 14 |
| | Hardness (mg/l CaCO3) | 210 | 200 | 5 |
| | Ammonia (mg/l NH3) | 0.70 | 0.20 | 71 |
| **M-3P** | pH | 7.6 | 7.5 | 1 |
| | Conductivity (umhos/cm) | 621 | 572 | 9 |
| | Alkalinity (mg/l CaCO3) | 173 | 192 | 11 |
| | Hardness (mg/l CaCO3) | 210 | 203 | 3 |
| | Ammonia (mg/l NH3) | 0.80 | 0.30 | 63 |
| **M-4P** | pH | 7.5 | 7.6 | 1 |
| | Conductivity (umhos/cm) | 616 | 626 | 2 |
| | Alkalinity (mg/l CaCO3) | 173 | 196 | 13 |
| | Hardness (mg/l CaCO3) | 197 | 197 | 0 |
| | Ammonia (mg/l NH3) | 0.60 | 0.20 | 67 |
| **M-5P** | pH | 7.4 | 7.5 | 1 |
| | Conductivity (umhos/cm) | 628 | 624 | 1 |
| | Alkalinity (mg/l CaCO3) | 196 | 198 | 1 |
| | Hardness (mg/l CaCO3) | 232 | 204 | 12 |
| | Ammonia (mg/l NH3) | 2.50 | 0.80 | 68 |
| **M-6P** | pH | 7.9 | 7.6 | 4 |
| | Conductivity (umhos/cm) | 666 | 638 | 4 |
| | Alkalinity (mg/l CaCO3) | 190 | 193 | 2 |
| | Hardness (mg/l CaCO3) | 229 | 208 | 9 |
| | Ammonia (mg/l NH3) | 2.90 | 0.90 | 69 |
| **M-7P** | pH | 8.0 | 7.8 | 3 |
| | Conductivity (umhos/cm) | 888 | 586 | 34 |
| | Alkalinity (mg/l CaCO3) | 193 | 182 | 6 |
| | Hardness (mg/l CaCO3) | 236 | 190 | 19 |
| | Ammonia (mg/l NH3) | 2.70 | 1.20 | 56 |
| **M-8P** | pH | 8.1 | 7.6 | 6 |
| | Conductivity (umhos/cm) | 852 | 613 | 36 |
| | Alkalinity (mg/l CaCO3) | 192 | 193 | 1 |
| | Hardness (mg/l CaCO3) | 236 | 204 | 14 |
| | Ammonia (mg/l NH3) | 1.40 | 0.50 | 64 |

Test No: Analyst: jab, mtv, cb
Toxicant: Manistee Lake Sediment Test Start: 11/03/1998
Organism: *Hyalella azteca* Test Stop: 11/13/1998

### Table D-1 (Cont). Summary Of Initial And Final Chemical Measurements For *Hyalella azteca* In Manistee Lake Sediments

| | | Day | | Difference |
|---|---|---|---|---|
| **Sample** | **Parameter** | **0** | **10** | **(%)** |
| **M-9P** | pH | 8.0 | 7.9 | 1 |
| | Conductivity (umhos/cm) | 634 | 615 | 3 |
| | Alkalinity (mg/l CaCO3) | 174 | 200 | 15 |
| | Hardness (mg/l CaCO3) | 224 | 205 | 8 |
| | Ammonia (mg/l NH3) | 1.30 | 0.60 | 54 |
| **M-9Pd** | pH | 8.0 | 7.6 | 5 |
| | Conductivity (umhos/cm) | 611 | 604 | 1 |
| | Alkalinity (mg/l CaCO3) | 176 | 196 | 11 |
| | Hardness (mg/l CaCO3) | 217 | 200 | 8 |
| | Ammonia (mg/l NH3) | 1.40 | 0.60 | 57 |
| **M-10P** | pH | 7.9 | 7.5 | 5 |
| | Conductivity (umhos/cm) | 2320 | 972 | 58 |
| | Alkalinity (mg/l CaCO3) | 160 | 187 | 17 |
| | Hardness (mg/l CaCO3) | 965 | 313 | 68 |
| | Ammonia (mg/l NH3) | 2.70 | 0.90 | 67 |
| **M-11P** | pH | 7.8 | 7.9 | 1 |
| | Conductivity (umhos/cm) | 758 | 717 | 6 |
| | Alkalinity (mg/l CaCO3) | 191 | 214 | 12 |
| | Hardness (mg/l CaCO3) | 231 | 225 | 3 |
| | Ammonia (mg/l NH3) | 2.98 | 1.45 | 51 |
| **M-12P** | pH | 7.8 | 7.4 | 5 |
| | Conductivity (umhos/cm) | 721 | 613 | 18 |
| | Alkalinity (mg/l CaCO3) | 188 | 212 | 13 |
| | Hardness (mg/l CaCO3) | 222 | 227 | 2 |
| | Ammonia (mg/l NH3) | 0.60 | 0.70 | 17 |
| **M-13P** | pH | 7.9 | 7.5 | 5 |
| | Conductivity (umhos/cm) | 721 | 671 | 7 |
| | Alkalinity (mg/l CaCO3) | 202 | 212 | 5 |
| | Hardness (mg/l CaCO3) | 266 | 224 | 16 |
| | Ammonia (mg/l NH3) | 1.10 | 0.90 | 18 |
| **M-14P** | pH | 7.6 | 7.4 | 82 |
| | Conductivity (umhos/cm) | 579 | 560 | 2 |
| | Alkalinity (mg/l CaCO3) | 168 | 216 | 29 |
| | Hardness (mg/l CaCO3) | 214 | 223 | 4 |
| | Ammonia (mg/l NH3) | 0.60 | 0.80 | 33 |

| | | | |
|---|---|---|---|
| Test No: | | Analyst: | mtv, jab, cb |
| Toxicant: | Manistee Lake Sediments | Test Start: | 11/03/1998 |
| Organism: | *Hyalella azteca* | Test Stop: | 11/13/1998 |

## Table D-2. Summary Of Daily Temperature And Dissolved Oxygen Measurements For *Hyallela azteca* In The Solid Phase Toxicity Tests For Manistee Lake Sediments

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-1P** | 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 |
| | °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 |
| | nd | 4.90 | 24.2 | 5.61 | 22.9 | 6.39 | 22.6 | 6.30 | 23.5 | 5.70 | 23.2 | 6.08 | 23.0 | 6.07 | 23.1 | 5.06 | 23.3 | 6.04 | 23.3 | 4.81 | 23.0 | 6.25 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-2P** | 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 |
| | °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 |
| | nd | 2.60 | 24.1 | 5.55 | 23.6 | 6.21 | 22.7 | 5.66 | 23.1 | 5.66 | 23.2 | 5.56 | 22.7 | 5.98 | 23.6 | 4.45 | 22.5 | 5.48 | 23.8 | 4.03 | 23.0 | 4.95 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-3P** | 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 |
| | °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 |
| | nd | 5.10 | 24.4 | 5.45 | 23.0 | 5.96 | 22.8 | 5.81 | 23.1 | 5.81 | 22.9 | 5.04 | 22.7 | 5.57 | 23.2 | 4.44 | 23.0 | 5.63 | 23.5 | 4.32 | 23.4 | 5.02 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-4P** | 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 |
| | °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 |
| | nd | 4.78 | 24.3 | 5.55 | 23.1 | 5.89 | 22.6 | 6.14 | 23.1 | 6.14 | 23.3 | 5.24 | 22.8 | 5.84 | 23.4 | 4.86 | 23.5 | 5.45 | 23.4 | 4.44 | 23.2 | 5.03 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-5P** | 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 |
| | °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 |
| | nd | 4.70 | 23.4 | 5.83 | 23.6 | 5.52 | 22.6 | 5.88 | 22.5 | 5.88 | 23.3 | 5.00 | 22.7 | 5.63 | 23.4 | 3.65 | 23.5 | 4.52 | 23.5 | 3.25 | 23.3 | 4.57 |

Test No:
Toxicant: Manistee Lake Sediments
Organism: *Hyalella azteca*

Analyst: mtv, jab, cb
Test Start: 11/03/1998
Test Stop: 11/13/1998

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

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-6P** | 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 |
| | °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 |
| | nd | 4.61 | 23.6 | 5.20 | 23.2 | 5.28 | 23.1 | 5.96 | 23.0 | 5.96 | 23.4 | 4.46 | 22.4 | 5.73 | 23.8 | 4.77 | 23.6 | 5.11 | 23.2 | 4.01 | 23.0 | 4.71 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-7P** | 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 |
| | °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 |
| | nd | 4.51 | 23.9 | 5.21 | 22.6 | 5.67 | 22.6 | 6.03 | 22.7 | 6.03 | 22.7 | 5.06 | 22.6 | 5.91 | 23.7 | 4.06 | 23.2 | 5.12 | 22.7 | 3.52 | 22.6 | 3.72 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-8P** | 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 |
| | °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 |
| | nd | 4.63 | 24.4 | 5.25 | 23.0 | 6.10 | 21.6 | 6.71 | 21.2 | 6.71 | 21.7 | 5.61 | 21.9 | 6.20 | 21.7 | 4.28 | 21.6 | 5.26 | 23.9 | 3.78 | 21.4 | 4.68 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-9P** | 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 |
| | °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 |
| | nd | 4.76 | 21.8 | 5.95 | 22.4 | 5.84 | 23.2 | 6.53 | 23.2 | 6.53 | 23.0 | 5.45 | 22.7 | 6.64 | 23.2 | 5.07 | 23.7 | 5.41 | 23.1 | 4.24 | 23.1 | 5.12 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-9Pdup** | 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 |
| | °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 |
| | nd | 4.55 | 23.2 | 5.56 | 24.0 | 5.65 | 23.7 | 5.62 | 23.5 | 5.62 | 23.3 | 4.90 | 24.3 | 5.53 | 23.5 | 4.39 | 22.9 | 5.34 | 22.7 | 3.60 | 21.6 | 4.53 |

Test No:
Toxicant: Manistee Lake Sediments
Organism: *Hyalella azteca*

Analyst: mtv, jab, cb
Test Start: 11/03/1998
Test Stop: 11/13/1998

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

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-10P** | 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 |
| | °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 |
| | nd | 5.35 | 22.7 | 6.25 | 22.8 | 5.89 | 23.3 | 4.58 | 23.1 | 4.58 | 22.9 | 5.09 | 23.0 | 5.57 | 22.9 | 4.24 | 24.2 | 4.86 | 23.6 | 3.87 | 23.0 | 3.43 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-11P** | 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 |
| | °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 |
| | nd | 4.63 | 23.5 | 5.46 | 22.4 | 5.94 | 23.0 | 6.00 | 22.9 | 6.00 | 22.9 | 4.28 | 23.9 | 4.67 | 23.3 | 2.59 | 23.1 | 3.82 | 23.4 | 2.87 | 23.2 | 3.93 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-12P** | 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 |
| | °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 |
| | nd | 4.38 | 22.1 | 5.63 | 23.7 | 5.54 | 23.4 | 6.27 | 23.1 | 6.27 | 23.6 | 4.59 | 23.2 | 5.15 | 23.8 | 3.39 | 22.0 | 4.59 | 23.8 | 3.91 | 21.5 | 4.73 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-13P** | 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 |
| | °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 |
| | nd | 4.81 | 23.7 | 5.19 | 22.5 | 5.95 | 22.8 | 6.25 | 22.4 | 6.25 | 22.8 | 4.61 | 22.5 | 5.69 | 22.8 | 3.30 | 23.9 | 4.11 | 22.3 | 3.51 | 22.9 | 4.07 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-14P** | 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 |
| | °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 |
| | nd | 5.65 | 23.5 | 5.62 | 22.3 | 5.74 | 21.8 | 6.48 | 21.8 | 6.48 | 21.8 | 4.80 | 22.1 | 5.43 | 22.1 | 3.27 | 22.8 | 3.55 | 22.9 | 3.07 | 22.5 | 3.78 |

| | | | |
|---|---|---|---|
| Test No: | | Analyst: | mtv, jab, cb |
| Toxicant: | Manistee Lake Sediment | Test Start: | 11/17/1998 |
| Organism: | *Chironomus tentans* | Test Stop: | 11/27/1998 |

### Table D-3. Summary Of Initial And Final Chemical Measurements For Chironomus tentans In Manistee Lake Sediments

| | | **Day** | | **Difference** |
|---|---|---|---|---|
| **Sample** | **Parameter** | **0** | **10** | **(%)** |
| **M-1P** | pH | 7.8 | 7.7 | 1 |
| | Conductivity (umhos/cm) | 566 | 560 | 1 |
| | Alkalinity (mg/l CaCO3) | 172 | 186 | 8 |
| | Hardness (mg/l CaCO3) | 189 | 191 | 1 |
| | Ammonia (mg/l NH3) | 2.00 | 0.00 | 100 |
| **M-2P** | pH | 7.9 | 7.5 | 5 |
| | Conductivity (umhos/cm) | 630 | 571 | 9 |
| | Alkalinity (mg/l CaCO3) | 148 | 187 | 26 |
| | Hardness (mg/l CaCO3) | 205 | 188 | 8 |
| | Ammonia (mg/l NH3) | 0.30 | 0.00 | 100 |
| **M-3P** | pH | 7.8 | 7.9 | 1 |
| | Conductivity (umhos/cm) | 690 | 582 | 16 |
| | Alkalinity (mg/l CaCO3) | 158 | 190 | 20 |
| | Hardness (mg/l CaCO3) | 207 | 207 | 0 |
| | Ammonia (mg/l NH3) | 0.50 | 0.10 | 80 |
| **M-4P** | pH | 7.6 | 7.5 | 1 |
| | Conductivity (umhos/cm) | 670 | 617 | 8 |
| | Alkalinity (mg/l CaCO3) | 161 | 180 | 12 |
| | Hardness (mg/l CaCO3) | 223 | 192 | 14 |
| | Ammonia (mg/l NH3) | 2.50 | 0.00 | 100 |
| **M-5P** | pH | 7.7 | 7.8 | 1 |
| | Conductivity (umhos/cm) | 700 | 608 | 13 |
| | Alkalinity (mg/l CaCO3) | 148 | 192 | 30 |
| | Hardness (mg/l CaCO3) | 194 | 206 | 6 |
| | Ammonia (mg/l NH3) | 0.30 | 0.50 | 67 |
| **M-6P** | pH | 7.7 | 7.5 | 3 |
| | Conductivity (umhos/cm) | 717 | 700 | 2 |
| | Alkalinity (mg/l CaCO3) | 179 | 184 | 3 |
| | Hardness (mg/l CaCO3) | 259 | 203 | 22 |
| | Ammonia (mg/l NH3) | 2.30 | 0.50 | 78 |
| **M-7P** | pH | 7.7 | 7.7 | 0 |
| | Conductivity (umhos/cm) | 898 | 700 | 22 |
| | Alkalinity (mg/l CaCO3) | 182 | 184 | 1 |
| | Hardness (mg/l CaCO3) | 256 | 225 | 12 |
| | Ammonia (mg/l NH3) | 2.90 | 0.20 | 93 |
| **M-8P** | pH | 7.9 | 7.8 | 1 |
| | Conductivity (umhos/cm) | 935 | 690 | 26 |
| | Alkalinity (mg/l CaCO3) | 182 | 182 | 0 |
| | Hardness (mg/l CaCO3) | 223 | 212 | 5 |
| | Ammonia (mg/l NH3) | 1.00 | 0.20 | 80 |

Test No:
Toxicant: Manistee Lake Sediment
Organism: *Chironomus tentans*

Analyst: mtv, jab, cb
Test Start: 11/17/1998
Test Stop: 11/27/1998

## Table D-3 (cont). Summary Of Initial And Final Chemical Measurements For Chironomus tentans In Manistee Lake Sediments

| | | Day | | Difference |
|---|---|---|---|---|
| **Sample** | **Parameter** | **0** | **10** | **(%)** |
| **M-9P** | pH | 7.6 | 7.8 | 3 |
| | Conductivity (umhos/cm) | 710 | 601 | 15 |
| | Alkalinity (mg/l CaCO3) | 164 | 177 | 8 |
| | Hardness (mg/l CaCO3) | 221 | 211 | 5 |
| | Ammonia (mg/l NH3) | 1.10 | 0.10 | 91 |
| **M-9Pd** | pH | 7.7 | 7.5 | 3 |
| | Conductivity (umhos/cm) | 690 | 601 | 13 |
| | Alkalinity (mg/l CaCO3) | 154 | 181 | 18 |
| | Hardness (mg/l CaCO3) | 212 | 226 | 7 |
| | Ammonia (mg/l NH3) | 1.30 | 0.00 | 100 |
| **M-10P** | pH | 7.7 | 7.9 | 3 |
| | Conductivity (umhos/cm) | 2700 | 1000 | 63 |
| | Alkalinity (mg/l CaCO3) | 123 | 176 | 43 |
| | Hardness (mg/l CaCO3) | 1083 | 316 | 71 |
| | Ammonia (mg/l NH3) | 2.70 | 0.10 | 96 |
| **M-11P** | pH | 8.0 | 7.8 | 3 |
| | Conductivity (umhos/cm) | 730 | 636 | 13 |
| | Alkalinity (mg/l CaCO3) | 163 | 206 | 26 |
| | Hardness (mg/l CaCO3) | 224 | 231 | 3 |
| | Ammonia (mg/l NH3) | 0.70 | 0.20 | 71 |
| **M-12P** | pH | 8.0 | 7.6 | 5 |
| | Conductivity (umhos/cm) | 710 | 604 | 15 |
| | Alkalinity (mg/l CaCO3) | 150 | 196 | 31 |
| | Hardness (mg/l CaCO3) | 207 | 249 | 20 |
| | Ammonia (mg/l NH3) | 0.30 | 0.20 | 33 |
| **M-13P** | pH | 7.8 | 7.5 | 4 |
| | Conductivity (umhos/cm) | 720 | 526 | 27 |
| | Alkalinity (mg/l CaCO3) | 192 | 189 | 2 |
| | Hardness (mg/l CaCO3) | 229 | 227 | 1 |
| | Ammonia (mg/l NH3) | 0.90 | 0.60 | 33 |
| **M-14P** | pH | 7.8 | 7.8 | 0 |
| | Conductivity (umhos/cm) | 573 | 566 | 1 |
| | Alkalinity (mg/l CaCO3) | 176 | 199 | 13 |
| | Hardness (mg/l CaCO3) | 215 | 243 | 13 |
| | Ammonia (mg/l NH3) | 0.80 | 0.90 | 13 |

Test No:
Toxicant: Manistee Lake Sediment
Organism: *Chironomus tentans*

Analyst: mtv,jab,cb
Test Start: 11/17/1998
Test Stop: 11/27/1998

## Table D-4. Summary Of Daily Temperature And Dissolved Oxygen Measurements For *Chironomus tentans* In The Solid Phase Toxicity Tests For Manistee Lake Sediments

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-1P** | 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 |
| | °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 |
| | 22.7 | 6.22 | 22.8 | 6.05 | 23.1 | 6.18 | 23.5 | 5.91 | 23.2 | 6.15 | 23.2 | 5.93 | 23.2 | 5.92 | 23.7 | 5.66 | 23.1 | 4.08 | 23.1 | 5.97 | 23.5 | 6.00 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-2P** | 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 |
| | °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 |
| | 23.4 | 5.23 | 23.3 | 5.36 | 23.2 | 5.47 | 23.1 | 5.48 | 22.9 | 5.74 | 22.9 | 5.47 | 23.3 | 5.65 | 23.4 | 5.43 | 23.0 | 4.30 | 23.0 | 5.12 | 23.1 | 5.55 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-3P** | 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 |
| | °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 |
| | 22.5 | 0.59 | 23.3 | 5.39 | 22.5 | 5.87 | 23.4 | 5.38 | 23.2 | 5.76 | 22.7 | 5.75 | 22.9 | 6.65 | 23.0 | 5.51 | 23.4 | 4.21 | 22.8 | 4.95 | 22.6 | 5.49 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-4P** | 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 |
| | °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 |
| | 23.2 | 5.75 | 23.5 | 5.25 | 23.2 | 5.28 | 23.5 | 5.15 | 23.4 | 5.23 | 23.3 | 5.51 | 23.5 | 5.68 | 23.5 | 5.20 | 23.1 | 4.18 | 22.6 | 5.09 | 23.1 | 5.46 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-5P** | 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 |
| | °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 |
| | 23.1 | 2.25 | 23.3 | 5.34 | 23.1 | 5.61 | 23.1 | 5.47 | 23.8 | 5.37 | 23.0 | 5.45 | 23.5 | 5.19 | 23.5 | 4.72 | 23.9 | 3.39 | 23.4 | 4.13 | 22.8 | 4.76 |

Test No:
Toxicant: Manistee Lake Sediment
Organism: *Chironomus tentans*

Analyst: mtv,jab,cb
Test Start: 11/17/1998
Test Stop: 11/27/1998

## Table D-4 (Cont). Summary Of Daily Temperature And Dissolved Oxygen Measurements For *Chironomus tentans* In The Solid Phase Toxicity Tests For Manistee Lake Sediments

| **Sample: M-6P** | Day | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | °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 |
| | 23.5 | 4.99 | 23.8 | 4.90 | 23.4 | 4.95 | 23.5 | 5.18 | 23.5 | 5.31 | 23.3 | 5.24 | 23.5 | 5.62 | 23.2 | 5.12 | 23.2 | 3.79 | 23.2 | 4.72 | 22.9 | 4.87 |

| **Sample: M-7P** | Day | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | °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 |
| | 23.3 | 5.11 | 26.2 | 5.21 | 23.3 | 5.44 | 24.3 | 5.39 | 23.5 | 5.85 | 23.9 | 5.91 | 23.3 | 6.08 | 22.7 | 5.87 | 23.0 | 3.42 | 23.0 | 4.15 | 23.1 | 4.48 |

| **Sample: M-8P** | Day | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | °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 |
| | 22.8 | 5.83 | 22.4 | 6.00 | 21.9 | 5.75 | 22.8 | 5.71 | 22.0 | 6.07 | 22.8 | 5.83 | 22.0 | 6.36 | 22.9 | 5.59 | 22.4 | 3.12 | 21.2 | 4.60 | 21.1 | 5.05 |

| **Sample: M-9P** | Day | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | °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 |
| | 22.9 | 6.06 | 23.1 | 5.31 | 23.4 | 5.51 | 23.2 | 5.65 | 23.5 | 5.74 | 23.4 | 5.87 | 23.1 | 6.46 | 23.7 | 5.71 | 23.1 | 3.89 | 22.8 | 4.97 | 23.1 | 5.46 |

| **Sample: M-9Pdup** | Day | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| | °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 |
| | 23.5 | 4.99 | 23.3 | 4.66 | 23.3 | 5.17 | 23.8 | 5.17 | 23.6 | 5.53 | 23.6 | 5.08 | 23.0 | 5.47 | 24.2 | 5.25 | 24.6 | 3.57 | 25.7 | 4.29 | 24.2 | 4.80 |

Test No:
Toxicant: Manistee Lake Sediment
Organism: *Chironomus tentans*

Analyst: mtv,jab,cb
Test Start: 11/17/1998
Test Stop: 11/27/1998

## Table D-4 (Cont). Summary Of Daily Temperature And Dissolved Oxygen Measurements for *Chironomus tentans* In The Solid Phase Toxicity Tests For Manistee Lake Sediments

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-10P** | 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 |
| | °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 |
| | 23.0 | 3.42 | 23.6 | 4.80 | 23.9 | 4.84 | 23.3 | 4.95 | 23.2 | 5.13 | 23.3 | 5.26 | 23.7 | 5.36 | 23.0 | 4.96 | 23.8 | 3.54 | 23.9 | 4.61 | 24.0 | 4.73 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-11P** | 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 |
| | °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 |
| | 21.8 | 4.89 | 23.6 | 5.16 | 23.4 | 5.44 | 23.7 | 5.74 | 23.8 | 5.61 | 23.4 | 5.60 | 22.8 | 5.60 | 23.6 | 5.24 | 23.7 | 3.61 | 23.5 | 4.56 | 23.6 | 4.49 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-12P** | 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 |
| | °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 |
| | 23.3 | 5.33 | 23.0 | 5.25 | 22.1 | 5.84 | 22.4 | 5.90 | 23.1 | 5.37 | 23.0 | 5.57 | 21.9 | 6.11 | 23.7 | 5.24 | 23.4 | 2.85 | 24.0 | 3.37 | 22.0 | 4.56 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-13P** | 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 |
| | °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 |
| | 23.4 | 5.54 | 22.3 | 5.17 | 22.6 | 4.96 | 22.8 | 5.26 | 22.2 | 5.71 | 22.4 | 5.32 | 24.3 | 5.54 | 21.7 | 5.26 | 22.3 | 2.83 | 22.2 | 3.69 | 22.4 | 3.26 |

| **Sample:** | Day | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **M-14P** | 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 |
| | °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 |
| | 22.7 | 5.01 | 23.5 | 3.97 | 23.1 | 4.00 | 21.9 | 5.25 | 24.0 | 3.37 | 24.4 | 3.48 | 22.4 | 4.06 | 23.0 | 3.10 | 22.2 | 2.71 | 23.9 | 2.60 | 23.3 | 2.52 |

# Appendix E. Summary Of Reference Toxicity Test For The Sediments From Manistee Lake, November 1998

## 1.0 INTRODUCTION

This report contains the reference toxicity methods and data interpretation for the 96hour acute tests for *Hyalella azteca* and *Chironomus tentans* when exposed to various concentrations of potassium chloride (KCl).

## 2.0 PROCEDURES AND METHODS

A 96-hour acute static renewal survival test was performed with both *Hyalella azteca* and *Chironomus tentans*. The procedures followed are contained in EPA/600/R-94/024, Methods for Measuring the Toxicity and Bioaccumulation of Sediment-associated Contaminants with Fresh Water Invertebrates.

### 2.1 Laboratory Water Supply

A moderately hard well water is employed for *H. azteca* and *C. tentans* cultures and maintenance. The water is obtained from R. Rediske and is checked quarterly for water quality parameters. This moderately hard water was utilized as the culture water as well as the overlying renewal water.

### 2.2 Test Organisms

*H azteca* and *C. tentans* used in these reference toxicity tests were from the same stock as those organisms employed in the sediment toxicity tests. The original stocks were obtained from the USEPA laboratory in Columbia, Missouri. Both are currently maintained in the Institute's facilities. The *H. azteca* cultures are kept in a ~15L plastic rectangular storage boxes with lids. Maple leaves and "coiled web material" (Aquatic Ecosystems, Inc.) are used as substrates. The food source is a suspension of Tetrafin® goldfish food. The culture of *C. tentans* is maintained in a 36L glass aquarium using shredded paper toweling as a substrate and is also fed a suspension of Tetrafin® goldfish food. The *H. azteca* used were 7-14 days old and the *C. tentans* were third instar larvae (12-14 days old).

### 2.3 Experimental Design

The purpose of these tests was to evaluate the "relative sensitivity" of both organisms to our reference toxicant, potassium chloride. *H. azteca* were exposed to seven different concentrations of potassium chloride and one control with 4 replicates, 10 organism per replicate for each treatment. The organism were fed 2 drops of Tetrafin® (4 g/L) at the beginning of the test and after 48 hours. The C. *tentans* test followed the same procedure as described above, except only 6 concentrations of KCl were used and the concentrations were different. Routine water quality parameters were measured at the beginning and end of the tests. In all tests, moderately hard well water was utilized as dilution water. *Hyalella* and *Chironomus* tests were run concurrently during December 1998.

## 2.4 Statistical Analysis

Because survival data were not normally distributed according to Chi-square analysis, estimated $EC_{50}$ values were calculated using the Trimmed Spearman-Karber Method. TOXSTAT® 3.5 was used in these evaluations.

## 3.0 RESULTS AND DISCUSSION

Reference toxicity evaluations with *Hyalella* and *Chironomus* began on December 14, 1998. The results of the reference test are given in Table E-1 and E-2. Statistical analyses are presented in Tables E-3 E-4. Both tests satisfied the validity requirement of 90% or greater survival in the control. Temperature, dissolved oxygen, pH, conductivity, alkalinity and hardness varied little over the test period; however ammonia levels increased over the test period. As expected conductivity increased with increasing KCl concentrations. Chemistry data are presented in Tables E-1 and E-2.

## 3.1 *Hyalella azteca*

Survival data are presented in Table E-1. The survival in the control treatment exceeded the required 90%. The Trimmed Spearman-Karber 96-hour EC50 estimate was 432 mg/L KCL with a 95% confidence interval ranging from 410 to 456 mg/L. Statistical analyses are presented in Table E-3.

## 3.2 *Chironomus tentans*

Survival data are presented in Table E-2. The survival in the control treatment exceeded the required 90%. The Trimmed Spearman-Karber 96-hour EC50 estimate was 4.14 g/L KCL with a 95% confidence interval ranging from 3.69 to 4.64 g/L. Statistical analyses are presented in Table E-4.

## 4.0 SUMMARY

Reference toxicity evaluations with *Hyalella azteca* and *Chironomus tentans* were carried out with potassium chloride in December 1998. Both tests satisfied the validity requirement of 90% or greater survival in the control. In addition, *Hyalella azteca* appears to be more sensitive to potassium chloride than *Chironomus tentans*

|  |  |  |  |  |
|---|---|---|---|---|
| Test No. |  |  | Analyst: |  |
| Toxicant: | Potassium chloride |  | Test Start - Date/Time: | 12/14/1998 |
| Test Species: | *Hyalella azteca* |  | Test Stop - Date/Time: | 12/18/1998 |
| No. of Organisms per Replicate |  | 10 | EC Calculation Method: | Probit |
| No. of Replicates |  | 4 |  |  |

**Table E-1. Summary Of Results Of Reference Toxicity Test For *Hyalella azteca***

0 hr

| Concentration (mg/l) | Control | 150 | 300 | 400 | 500 | 600 | 900 | 1200 |
|---|---|---|---|---|---|---|---|---|
| No. of Individuals | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| Temperature (oC) | 22 | 22 | 22 | 21.8 | 21.5 | 21.6 | 21.5 | 21.4 |
| Dissolved Oxygen (mg/l) | 8.12 | 7.5 | 7.7 | 7.8 | 7.6 | 7.5 | 7.5 | 7.5 |
| pH | nd | 8.55 | 8.66 | 8.66 | 8.66 | 8.64 | 8.18 | 8.21 |
| Conductivity (umhos/cm) | nd | 1004 | 1297 | 1511 | 1750 | 1975 | 2800 | 3490 |
| Alkalinity (mg/l as CaCO3) | nd | 88 | 82 | 84 | 80 | 80 | 96 | 96 |
| Hardness (mg/l as CaCO3) | nd | 158 | 162 | 162 | 165 | 160 | 204 | 200 |
| Ammonia (ppm) | nd | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | 0.4 | 0.4 |

48 hr

| Concentration (mg/l) | Control | 150 | 300 | 400 | 500 | 600 | 900 | 1200 |
|---|---|---|---|---|---|---|---|---|
| No. of Individuals Surviving | nd | nd | nd | nd | nd | nd | 0 | 0 |
| Temperature (oC) | 23.5 | 23.6 | 23.6 | 23 | 22.8 | 22.6 | 23.4 | 23.9 |
| Dissolved Oxygen (mg/l) | 7.54 | 7.57 | 7.52 | 7.66 | 7.8 | 7.51 | 7.23 | 7.48 |

96 hr

| Concentration (mg/l) | Control | 150 | 300 | 400 | 500 | 600 | 900 | 1200 |
|---|---|---|---|---|---|---|---|---|
| No. of Individuals Surviving | 40 | 40 | 39 | 28 | 11 | 0 | 0 | 0 |
| Temperature (oC) | 19.9 | 19.6 | 19.7 | 20.0 | 19.8 | 19.9 | 20.1 | 20.3 |
| Dissolved Oxygen (mg/l) | 6.30 | 6.63 | 6.24 | 6.23 | 4.50 | 5.58 | 5.07 | 5.6 |
| pH | 8.4 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 |
| Conductivity (umhos/cm) | 490 | 990 | 1300 | 1530 | 1790 | 1970 | 2500 | 3120 |
| Alkalinity (mg/l as CaCO3) | 139 | 199 | 218 | 219 | 232 | 228 | 225 | 224 |
| Hardness (mg/l as CaCO3) | 140 | 216 | 205 | 207 | 218 | 214 | 213 | 215 |
| Ammonia (ppm) | 0.5 | 0.7 | 0.8 | 0.9 | 1.1 | 1.2 | 1.2 | 1.2 |

note: temperature and dissolved oxygen values are the mean of the four replicates;
water quality parameters were determined on a composite sample

## Table E-2. Summary Of Results Of Reference Toxicity Test For *Chironomus tentans.*

0 hr

| Concentration (g/l) | Control | 1.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 |
|---|---|---|---|---|---|---|---|
| No. of Individuals | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| Temperature (oC) | 21.4 | 21.3 | 21.4 | 21.4 | 21.5 | 21.4 | 21.1 |
| Dissolved Oxygen (mg/l) | 8.12 | 8.04 | 8.11 | 8.09 | 8.19 | 8.19 | 8.19 |
| pH | 7.9 | 8.14 | 8.19 | 8.18 | 8.09 | 8.09 | 8.10 |
| Conductivity (umhos/cm) | nd | 2920 | 5260 | 9090 | 12830 | 16030 | 18870 |
| Alkalinity (mg/l as CaCO3) | nd | 98 | 96 | 96 | 36080 | 102 | 100 |
| Hardness (mg/l as CaCO3) | nd | 200 | 206 | 201 | 201 | 201 | 201 |
| Ammonia (ppm) | nd | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |

48 hr

| Concentration (g/l) | Control | 1.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 |
|---|---|---|---|---|---|---|---|
| No. of Individuals Surviving | nd | nd | nd | nd | nd | 0 | 0 |
| Temperature (oC) | 22.6 | 22.3 | 23.5 | 24.3 | 24.3 | 24.5 | 24.9 |
| Dissolved Oxygen (mg/l) | 6.13 | 5.91 | 5.39 | 5.92 | 5.70 | 5.08 | 5.41 |

96 hr

| Concentration (g/l) | Control | 1.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 |
|---|---|---|---|---|---|---|---|
| No. of Individuals Surviving | 40 | 40 | 35 | 29 | 8 | 0 | 0 |
| Temperature (oC) | 19.9 | 19.5 | 19.8 | 19.9 | 19.7 | 19.8 | 20.0 |
| Dissolved Oxygen (mg/l) | 4.02 | 3.70 | 3.95 | 2.91 | 4.36 | 3.16 | 4.54 |
| pH | 8.3 | 8.3 | 8.1 | 8.1 | 8.0 | 8.2 | 7.9 |
| Conductivity (umhos/cm) | 680 | 2630 | 4310 | 8310 | 11830 | 15350 | 18870 |
| Alkalinity (mg/l as CaCO3) | 182 | 215 | 193 | 201 | 200 | 202 | 203 |
| Hardness (mg/l as CaCO3) | 179 | 211 | 194 | 202 | 205 | 218 | 218 |
| Ammonia (ppm) | 0.6 | 0.7 | 0.3 | 0.5 | 0.7 | 0.3 | 0.4 |

note: temperature and dissolved oxygen values are the mean of the four replicates;
water quality parameters were determined on a composite sample

## Table E-3 Potassium Chloride Reference Test
## 96-Hour $EC_{50}$ for *Hyalella azteca*

Probit Analysis - Using Smoothed Proportions - Transform: LOG 10 DOSE

| DOSE | NUMBER SUBJECTS | NUMBER OBSERVED | OBS PROP | SMOOTH PROP | PRED PROP |
|---|---|---|---|---|---|
| 150.00 | 40 | 40 | 1.0000 | 1.0000 | 1.0000 |
| 300.00 | 40 | 39 | 0.9750 | 0.9750 | 0.9860 |
| 400.00 | 40 | 28 | 0.7000 | 0.7000 | 0.6980 |
| 500.00 | 40 | 11 | 0.2750 | 0.2750 | 0.2170 |
| 600.00 | 40 | 0 | 0.0000 | 0.0000 | 0.0325 |
| 900.00 | 40 | 0 | 0.0000 | 0.0000 | 0.0000 |
| 1200.00 | 40 | 0 | 0.0000 | 0.0000 | 0.0000 |

Est. Mu = 2.6407 Est. Sigma = 0.0745
sd = 0.0102 sd = 0.0098
Chi-Square lack of fit = 2.4827 Likelihood lack of fit = 3.6733

Table Chi-square = 15.0863 (alpha = 0.01, df = 5)
Table Chi-square = 11.0705 (alpha = 0.05, df = 5)

Trimmed Spearman - Karber Estimate Using Smoothed Proportions

Transform: LOG 10 DOSE WITH CONTROL DATA

| Trimmed Spearman - Karber Estimate | | 95% C.I. | UNCONDITIONAL 95% C.I. |
|---|---|---|---|
| 10.00% | 439.6974 | (416.28, 464.44) | (415.81, 464.96) |
| 20.00% | 442.6492 | (417.40, 469.43) | (416.90, 469.99) |
| HIGH CALC 2.50% | 437.1476 | (416.35, 458.99) | (415.93, 459.45) |
| LOW CALC 0.00% | 432.6390 | (410.87, 455.56) | (410.44, 456.04) |

## Table E-4 Potassium Chloride Reference Test
## 96-Hour EC50 for *Chironomus tentans*

Probit Analysis - Using Smoothed Proportions - Transform: LOG 10 DOSE

| DOSE | NUMBER SUBJECTS | NUMBER OBSERVED | OBS PROP | SMOOTH PROP | PRED PROP |
|---|---|---|---|---|---|
| 1.00 | 40 | 40 | 1.0000 | 1.0000 | 0.9995 |
| 2.00 | 40 | 35 | 0.8750 | 0.8750 | 0.9544 |
| 4.00 | 40 | 29 | 0.7250 | 0.7250 | 0.5246 |
| 6.00 | 40 | 8 | 0.2000 | 0.2000 | 0.1867 |
| 8.00 | 40 | 0 | 0.0000 | 0.0000 | 0.0588 |
| 10.00 | 40 | 0 | 0.0000 | 0.0000 | 0.0184 |

Est. Mu = 0.6135 Est. Sigma = 0.1850
sd = 0.0232 sd = 0.0206

Chi-Square lack of fit = 15.5343 Likelihood lack of fit = 17.1291

Table Chi-square = 13.2767 (alpha = 0.01, df = 4)
Table Chi-square = 9.4877 (alpha = 0.05, df = 4)

Trimmed Spearman - Karber Estimate Using Smoothed Proportions

Transform: LOG 10 DOSE WITH CONTROL DATA

| Trimmed Spearman - Karber | Estimate | 95% C.I. | UNCONDITIONAL 95% C.I. |
|---|---|---|---|
| 10.00% | 4.4380 | ( 3.93, 5.02) | ( 3.92, 5.03) |
| 20.00% | 4.6740 | ( 4.16, 5.25) | ( 4.15, 5.26) |
| HIGH CALC 12.50% | 4.5034 | ( 3.99, 5.09) | ( 3.98, 5.10) |
| LOW CALC 0.00% | 4.1398 | ( 3.70, 4.63) | ( 3.69, 4.64) |

# Appendix F. Summary Of Benthic Macroinvertebrate Results For Manistee Lake, November 1998

# TABLE F-1. BENTHIC MACROINVERTEBRATE RESULTS FOR MANISTEE LAKE, NOVEMBER 1998

| Station | M-1 | | | M-2 | | | M-3 | | | M-4 | | | M-5 | | | M-6 | | | M-7 | | | M-8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| Turbellaria | | | | | | | | | | | | | | | | | | | | | | | | |
| Platyhelmithes | 126 | 126 | 21 | 21 | 21 | | | | | | | | | | | | 42 | 42 | | | | | | 63 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Oligochaeta | | | | | | | | | | | | | | | | | | | | | | | | |
| Naididae | | | | | | | | | | | | | | | | | | | | | | | | |
| Vejdovskyella intermedia | | | | | | | | | | | | | | | | | | | | | | | | |
| Specaria josinae | 21 | | | | | | | | | | | | | | | | | | | | | | | |
| Nais elinguis | 84 | 147 | | | | | | | | | | | | | | | | | | | | | | |
| Nais communis | | 84 | 63 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Tubificidae | | | | | | | | | | | | | | | | | | | | | | | | |
| Aulodrilus pigueti | | | | | | | | | | | | | | | | | | | | | | | | |
| Aulodrilus limnobius | | | | | 21 | | | | | | | | | | | | | | | | | | | |
| Quistadrilus multisetosus | | | | | | | 21 | | | | | | | | | | | 21 | | | | | | |
| Limnodrilus hoffmeisterii | 21 | | | 21 | 42 | 42 | 105 | 147 | 42 | | | | | | | | | 21 | | 168 | | | | |
| Limnodrilus cervix | | | | | | | | | | 21 | | | | | | | | 21 | 42 | 21 | | | | |
| Limnodrilus claparedianus | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Immatures: | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| w/o capilliform chaetae | 420 | 357 | 189 | 1113 | 2646 | 1113 | 2163 | 1386 | 861 | 1050 | | | | | | | | 819 | 483 | 294 | | | | |
| with capilliform chaetae | | 63 | | 42 | 126 | 63 | 294 | 21 | 210 | 105 | | | | | | | | 189 | 168 | 21 | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Crustacea | | | | | | | | | | | | | | | | | | | | | | | | |
| Amphipoda | | | | | | | | | | | | | | | | | | | | | | | | |
| Gammarus sp. | 315 | 147 | 63 | | | | | | | | | | | | | 42 | 42 | 21 | 21 | | | | 21 | |
| Hyalella sp. | 231 | 378 | 273 | | | | | | | | | | | | | 21 | 21 | 84 | 105 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Isopoda | | | | | | | | | | | | | | | | | | | | | | | | |
| Asellus sp. | | | | | | | | | | | | | 21 | | | | 105 | 84 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| Insecta | | | | | | | | | | | | | | | | | | | | | | | | |
| Ephemeroptera | | | | | | | | | | | | | | | | | | | | | | | | |
| Baetis sp. | 21 | | | | | | | | | | | | | | | | | | | | | | | |
| Caenis sp. | 21 | 21 | | | | | | | | | | | | | | | | | | | | | | |
| Hexagenia sp. | | 21 | 84 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |

# TABLE F-1 (CONTINUED). BENTHIC MACROINVERTEBRATE RESULTS FOR MANISTEE LAKE, NOVEMBER 1998

| Station | M1 | | | M2 | | | M3 | | | M4 | | | M5 | | | M6 | | | M7 | | | M8 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| **Insecta (Continued)** | | | | | | | | | | | | | | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Gomphus sp.*** | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Trichoptera** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Oecetis sp.*** | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Coleoptera** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Dubiraphia sp.*** | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Diptera** | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Palpomyia sp.*** | | 42 | 42 | | 21 | | | | | 21 | | | 21 | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Chaoborus sp.*** | | | | | | | 21 | | | | | 21 | | | 42 | 42 | | | | | 42 | 42 | 84 | 42 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Chironomus sp.*** | | | | 189 | 168 | 126 | 756 | 357 | 504 | 441 | 525 | 336 | 126 | 252 | 168 | | | | | 21 | | 105 | 42 | 63 |
| ***Cladotanytarsus sp.*** | 3024 | 5502 | 2394 | 21 | | | 21 | | | | | | | | | | | | | | | | | |
| ***Coelotanypus sp.*** | | | | 315 | 168 | | 42 | 168 | 21 | | | | | | | | | | | | | | | |
| ***Corynoneura sp.*** | | 21 | | | | | | | | | | | | | | | | | | | | | | |
| ***Cryptochironomus sp.*** | 42 | 357 | 168 | 147 | 105 | 105 | 147 | 21 | 105 | | 63 | | 21 | 84 | | | 21 | 84 | | 21 | | 21 | | 21 |
| ***Endochironomus sp.*** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Epoicladius sp.*** | | 42 | | | | | | | | | | | | | | | | | | | | | | |
| ***Guttipelopia sp.*** | | | | 105 | | | | | | | | | | | | | | | | | | | | |
| ***Microtendipes sp.*** | | | 21 | | | | | | | | | | | | | | | | | | | | | |
| ***Polypedilum sp.*** | 21 | 714 | 84 | | | | | | | | | | | | | | | | | | | | | |
| ***Procladius sp.*** | | | 21 | | 42 | 42 | 21 | 105 | 105 | 147 | 168 | 441 | 42 | 42 | 42 | 42 | | | | | | | | |
| ***Robackia sp.*** | | 42 | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Pelecypoda** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Dreisena polymorpha*** | 126 | 42 | 21 | 315 | 168 | | 42 | | | | | | 21 | | | | | 21 | | | | | | 21 |
| ***Sphaerium sp.*** | 42 | 21 | 126 | 273 | 567 | 420 | 588 | | 105 | 21 | 21 | | 63 | 42 | | 42 | 294 | 147 | | 21 | 63 | 252 | 189 | 210 |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Gastropoda** | | | | | | | | | | | | | | | | | | | | | | | | |
| ***Gyraulus sp.*** | | | | | | | | | | | | | | | | | | | 21 | 21 | | | | |
| ***Physa sp.*** | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Hydracarina** | 21 | 273 | 21 | | 21 | | | | 21 | | | | | | | | 21 | 42 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | |
| **Total number of Taxa** | 16 | 22 | 18 | 12 | 14 | 8 | 12 | 7 | 10 | 7 | 5 | 4 | 7 | 5 | 3 | 6 | 9 | 13 | 7 | 9 | 3 | 6 | 5 | 8 |
| **Number of Taxa per Station** | | 26 | | | 15 | | | 13 | | | 9 | | | 9 | | | 17 | | | 13 | | | 9 | |

# TABLE F-1 (CONTINUED). BENTHIC MACROINVERTEBRATE RESULTS FOR MANISTEE LAKE, NOVEMBER 1998

| **Station** | M-9 | | | M-9R | | | M-10 | | | M-11 | | | M-12 | | | M-13 | | | M-14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| **Turbellaria** | | | | | | | | | | | | | | | | | | | | | |
| **Platyhelmithes** | | 172 | | 86 | 86 | | | | | | | | | | | | 43 | | | | 129 |
| | | | | | | | | | | | | | | | | | | | | | |
| **Oligochaeta** | | | | | | | | | | | | | | | | | | | | | |
| **Naididae** | | | | | | | | | | | | | | | | | | | | | |
| ***Vejdovskyella intermedia*** | | | | | | | | | | | | | | | | | | | 172 | | |
| ***Specaria josinae*** | | | | | | | | | | | | | | | | | | | | | |
| ***Nais elinguis*** | | | | | | | | | | | | | | | | | | | | | |
| ***Nais communis*** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Tubificidae** | | | | | | | | | | | | | | | | | | | | | |
| ***Aulodrilus piqueti*** | | | | | | | | | | | | 86 | | | 43 | | | | | | |
| ***Aulodrilus limnobius*** | | | | | | | | | | | | | | | 86 | | | | | | |
| ***Quistadrilus multisetosus*** | 301 | | | 129 | 43 | 43 | 129 | | | 387 | 430 | 387 | | | | | | | 645 | | 43 |
| ***Limnodrilus hoffmeisterii*** | | | | | | | | | | | | | | | | | | | 43 | | 43 |
| ***Limnodrilus cervix*** | | | | | | | | | 43 | | | | | | | | | | | | |
| ***Limnodrilus claparedianus*** | 43 | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Immatures:** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **w/o capilliform chaetae** | 1118 | | 1290 | 860 | 731 | 817 | 86 | 172 | 258 | 516 | 2064 | 1677 | 602 | 1161 | 2408 | 688 | 731 | 903 | 1247 | | 387 |
| **with capilliform chaetae** | 473 | | 774 | 387 | 516 | 129 | | 43 | 43 | 301 | 989 | 1849 | | 344 | 215 | 301 | 86 | 43 | 817 | | 129 |
| | | | | | | | | | | | | | | | | | | | | | |
| **Crustacea** | | | | | | | | | | | | | | | | | | | | | |
| **Amphipoda** | | | | | | | | | | | | | | | | | | | | | |
| ***Gammarus sp.*** | | 43 | | | | | | | | | 43 | | | | | | | | 86 | 43 | |
| ***Hyalella sp.*** | | | | | | | | | | 43 | | 43 | | | | | | | 86 | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Isopoda** | | | | | | | | | | | | | | | | | | | | | |
| ***Asellus sp.*** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Insecta** | | | | | | | | | | | | | | | | | | | | | |
| **Ephemeroptera** | | | | | | | | | | | | | | | | | | | | | |
| ***Baetis sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Caenis sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Hexagenia sp.*** | | | | | | | | | | | | | | | | | | | 817 | 946 | 1075 |
| | | | | | | | | | | | | | | | | | | | | | |

# TABLE F-1 (CONTINUED). BENTHIC MACROINVERTEBRATE RESULTS FOR MANISTEE LAKE, NOVEMBER 1998

| **Station** | M9 | | | M9R | | | M10 | | | M11 | | | M12 | | | M13 | | | M14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C | A | B | C |
| **Insecta (Continued)** | | | | | | | | | | | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | | | | | | | | | | | |
| ***Gomphus sp.*** | | | | | | | | | | | | | | | | | | | 129 | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Trichoptera** | | | | | | | | | | | | | | | | | | | | | |
| ***Oecetis sp.*** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Coleoptera** | | | | | | | | | | | | | | | | | | | | | |
| ***Dubiraphia sp.*** | | | | | | | | | | | | | | | | | | | 43 | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Diptera** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| ***Palpomyia sp.*** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| ***Chaoborus sp.*** | 43 | 129 | 43 | 43 | 129 | 86 | 43 | | | 86 | | | | | | 43 | | | 129 | | |
| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| ***Chironomus sp.*** | 215 | 172 | 43 | 215 | 258 | 258 | | 129 | | 86 | | 129 | 172 | 215 | 43 | | 129 | 258 | 473 | | 86 |
| ***Cladotanytarsus sp.*** | | | | | | | | | | 129 | | 43 | 43 | | | 43 | | | | | |
| ***Coelotanypus sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Corynoneura sp.*** | | | | | | | | | | | | | | 43 | 43 | 344 | | | | | |
| ***Cryptochironomus sp.*** | | | 43 | | | | | | | | | | | | | | | | | | |
| ***Endochironomus sp.*** | | | | | | | | | | | | | | | | | | | 301 | | |
| ***Epoicladius sp.*** | | | | | | | | | | | | | | | | | | | 43 | | 43 |
| ***Guttipelopia sp.*** | | | | | | | | | | | | | | | | | | | 430 | 43 | 172 |
| ***Microtendipes sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Polypedilum sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Procladius sp.*** | | 43 | 43 | 43 | | 43 | | 172 | | 43 | | | | | 86 | | | | 1247 | 129 | 215 |
| ***Robackia sp.*** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | 43 | 43 | 43 |
| | | | | | | | | | | | | | | | | | | | | | 43 |
| | | | | | | | | | | | | | | | | | | | | | |
| **Pelecypoda** | | | | | | | | | | | | | | | | | | | | | |
| ***Dreisena polymorpha*** | | | | | | | | | | | | 43 | | | | | | | | | |
| ***Sphaerium sp.*** | | 301 | | | 43 | 172 | | | | 172 | 344 | 43 | | | | | | | 430 | 43 | 387 |
| | | | | | | | | | | | | | | | | | | | | | |
| **Gastropoda** | | | | | | | | | | | | | | | | | | | | | |
| ***Gyraulus sp.*** | | | | | | | | | | | | | | | | | | | | | |
| ***Physa sp.*** | | | | | | | | | | | | | | | | | | | 43 | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Hydracarina** | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| **Total number of Taxa** | 6 | 8 | 9 | 8 | 9 | 8 | 6 | 6 | 5 | 10 | 7 | 10 | 4 | 6 | 8 | 7 | 6 | 5 | 21 | 8 | 13 |
| **Number of Taxa per Station** | | 13 | | | 10 | | | 10 | | | 13 | | | 8 | | | 8 | | | 24 | |

# Table F- 2  QSI (Quantitative Similarity Index; Percentage Similarity Index) For Manistee Lake, November 1998

| | M-1A | M-1B | M1-C | M-2A | M-2B | M-2C | M-3A | M-3B | M-3C | M-4A | M-4B | M-4C | M-5A | M-5B | M-5C | M-6A | M-6B | M-6C | M-7A | M-7B | M-7C | M-8A | M-8B | M-8C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-1A | | | | | | | | | | | | | | | | | | | | | | | | |
| M-1B | **0.821** | | | | | | | | | | | | | | | | | | | | | | | |
| M1-C | 0.827 | **0.863** | | | | | | | | | | | | | | | | | | | | | | |
| M-2A | 0.160 | 0.116 | 0.154 | | | | | | | | | | | | | | | | | | | | | |
| M-2B | 0.153 | 0.098 | 0.140 | **0.719** | | | | | | | | | | | | | | | | | | | | |
| M-2C | 0.116 | 0.095 | 0.140 | 0.686 | **0.838** | | | | | | | | | | | | | | | | | | | |
| M-3A | 0.131 | 0.097 | 0.138 | 0.699 | 0.782 | 0.812 | | | | | | | | | | | | | | | | | | |
| M-3B | 0.106 | 0.060 | 0.068 | 0.612 | 0.750 | 0.711 | **0.733** | | | | | | | | | | | | | | | | | |
| M-3C | 0.120 | 0.106 | 0.146 | 0.650 | 0.622 | 0.685 | 0.809 | **0.697** | | | | | | | | | | | | | | | | |
| M-4A | 0.102 | 0.058 | 0.082 | 0.536 | 0.680 | 0.714 | 0.766 | 0.800 | 0.803 | | | | | | | | | | | | | | | |
| M-4B | 0.019 | 0.045 | 0.080 | 0.158 | 0.104 | 0.170 | 0.246 | 0.219 | 0.389 | **0.337** | | | | | | | | | | | | | | |
| M-4C | 0.000 | 0.000 | 0.006 | 0.074 | 0.051 | 0.088 | 0.189 | 0.210 | 0.309 | 0.326 | **0.637** | | | | | | | | | | | | | |
| M-5A | 0.046 | 0.055 | 0.105 | 0.304 | 0.260 | 0.343 | 0.368 | 0.219 | 0.415 | 0.349 | 0.627 | 0.533 | | | | | | | | | | | | |
| M-5B | 0.019 | 0.045 | 0.088 | 0.231 | 0.177 | 0.243 | 0.319 | 0.219 | 0.415 | 0.337 | 0.808 | 0.521 | **0.667** | | | | | | | | | | | |
| M-5C | 0.000 | 0.000 | 0.006 | 0.074 | 0.051 | 0.088 | 0.189 | 0.210 | 0.309 | 0.326 | 0.833 | 0.614 | 0.533 | **0.700** | | | | | | | | | | |
| M-6A | 0.130 | 0.065 | 0.135 | 0.107 | 0.148 | 0.242 | 0.149 | 0.048 | 0.106 | 0.093 | 0.243 | 0.249 | 0.333 | 0.200 | 0.333 | | | | | | | | | |
| M-6B | 0.159 | 0.144 | 0.141 | 0.153 | 0.173 | 0.258 | 0.174 | 0.010 | 0.102 | 0.012 | 0.065 | 0.000 | 0.305 | 0.138 | 0.000 | **0.338** | | | | | | | | |
| M-6C | 0.224 | 0.199 | 0.218 | 0.625 | 0.695 | 0.704 | 0.737 | 0.545 | 0.672 | 0.595 | 0.080 | 0.000 | 0.211 | 0.145 | 0.000 | 0.158 | **0.287** | | | | | | | |
| M-7A | 0.169 | 0.113 | 0.146 | 0.451 | 0.606 | 0.608 | 0.582 | 0.585 | 0.543 | 0.645 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.136 | 0.063 | 0.711 | | | | | | |
| M-7B | 0.116 | 0.088 | 0.123 | 0.566 | 0.638 | 0.662 | 0.667 | 0.621 | 0.600 | 0.595 | 0.098 | 0.036 | 0.107 | 0.107 | 0.036 | 0.036 | 0.071 | 0.633 | **0.596** | | | | | |
| M-7C | 0.009 | 0.003 | 0.035 | 0.107 | 0.138 | 0.220 | 0.144 | 0.000 | 0.053 | 0.012 | 0.027 | 0.026 | 0.200 | 0.100 | 0.167 | 0.444 | 0.538 | 0.092 | 0.000 | 0.036 | | | | |
| M-8A | 0.019 | 0.045 | 0.082 | 0.230 | 0.204 | 0.336 | 0.358 | 0.171 | 0.353 | 0.256 | 0.327 | 0.276 | 0.500 | 0.400 | 0.350 | 0.322 | 0.577 | 0.142 | 0.000 | 0.107 | 0.700 | | | |
| M-8B | 0.072 | 0.020 | 0.053 | 0.180 | 0.179 | 0.286 | 0.269 | 0.125 | 0.178 | 0.137 | 0.152 | 0.151 | 0.325 | 0.225 | 0.292 | 0.507 | 0.601 | 0.105 | 0.025 | 0.071 | 0.813 | **0.788** | | |
| M-8C | 0.074 | 0.065 | 0.094 | 0.289 | 0.250 | 0.336 | 0.339 | 0.160 | 0.253 | 0.162 | 0.227 | 0.176 | 0.450 | 0.300 | 0.250 | 0.322 | 0.615 | 0.182 | 0.000 | 0.107 | 0.600 | 0.800 | **0.725** | |
| M-9A | 0.093 | 0.050 | 0.053 | 0.525 | 0.581 | 0.609 | 0.687 | 0.617 | 0.641 | 0.666 | 0.098 | 0.118 | 0.098 | 0.098 | 0.118 | 0.020 | 0.000 | 0.641 | 0.710 | 0.571 | 0.020 | 0.118 | 0.118 | 0.118 |
| M-9B | 0.087 | 0.035 | 0.064 | 0.189 | 0.194 | 0.308 | 0.328 | 0.210 | 0.303 | 0.262 | 0.277 | 0.276 | 0.450 | 0.350 | 0.400 | 0.472 | 0.477 | 0.132 | 0.025 | 0.071 | 0.500 | 0.650 | 0.675 | 0.750 |
| M-9C | 0.102 | 0.069 | 0.078 | 0.489 | 0.656 | 0.668 | 0.631 | 0.634 | 0.600 | 0.674 | 0.058 | 0.058 | 0.058 | 0.058 | 0.058 | 0.038 | 0.019 | 0.651 | 0.775 | 0.574 | 0.019 | 0.058 | 0.038 | 0.058 |
| M-9RA | 0.120 | 0.065 | 0.064 | 0.533 | 0.575 | 0.609 | 0.694 | 0.644 | 0.689 | 0.692 | 0.146 | 0.171 | 0.146 | 0.146 | 0.171 | 0.049 | 0.049 | 0.646 | 0.688 | 0.559 | 0.024 | 0.146 | 0.146 | 0.195 |
| M-9RB | 0.130 | 0.068 | 0.082 | 0.527 | 0.505 | 0.527 | 0.651 | 0.557 | 0.678 | 0.617 | 0.167 | 0.169 | 0.167 | 0.167 | 0.214 | 0.095 | 0.071 | 0.586 | 0.605 | 0.500 | 0.095 | 0.238 | 0.220 | 0.286 |
| M-9RC | 0.102 | 0.053 | 0.094 | 0.631 | 0.721 | 0.760 | 0.875 | 0.727 | 0.767 | 0.792 | 0.221 | 0.221 | 0.306 | 0.294 | 0.250 | 0.194 | 0.111 | 0.702 | 0.611 | 0.607 | 0.167 | 0.333 | 0.292 | 0.317 |
| M-10A | 0.093 | 0.043 | 0.053 | 0.333 | 0.333 | 0.333 | 0.343 | 0.333 | 0.333 | 0.333 | 0.000 | 0.026 | 0.000 | 0.000 | 0.167 | 0.167 | 0.000 | 0.346 | 0.333 | 0.333 | 0.167 | 0.100 | 0.167 | 0.100 |
| M-10B | 0.093 | 0.050 | 0.058 | 0.423 | 0.415 | 0.454 | 0.587 | 0.552 | 0.720 | 0.717 | 0.466 | 0.583 | 0.383 | 0.350 | 0.417 | 0.222 | 0.000 | 0.417 | 0.417 | 0.405 | 0.000 | 0.250 | 0.125 | 0.150 |
| M-10C | 0.093 | 0.050 | 0.053 | 0.451 | 0.673 | 0.615 | 0.582 | 0.638 | 0.543 | 0.651 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.645 | 0.750 | 0.571 | 0.000 | 0.000 | 0.000 | 0.000 |
| M-11A | 0.199 | 0.150 | 0.191 | 0.464 | 0.472 | 0.494 | 0.529 | 0.375 | 0.525 | 0.436 | 0.100 | 0.099 | 0.171 | 0.171 | 0.122 | 0.195 | 0.122 | 0.541 | 0.488 | 0.400 | 0.146 | 0.195 | 0.195 | 0.195 |
| M-11B | 0.113 | 0.064 | 0.099 | 0.540 | 0.653 | 0.655 | 0.676 | 0.543 | 0.596 | 0.603 | 0.027 | 0.000 | 0.089 | 0.089 | 0.000 | 0.100 | 0.100 | 0.745 | 0.744 | 0.571 | 0.089 | 0.089 | 0.100 | 0.089 |
| M-11C | 0.132 | 0.078 | 0.088 | 0.465 | 0.471 | 0.463 | 0.520 | 0.430 | 0.536 | 0.488 | 0.040 | 0.030 | 0.050 | 0.040 | 0.030 | 0.020 | 0.020 | 0.552 | 0.600 | 0.466 | 0.010 | 0.040 | 0.040 | 0.050 |
| M-12A | 0.145 | 0.095 | 0.105 | 0.516 | 0.684 | 0.648 | 0.697 | 0.790 | 0.647 | 0.792 | 0.211 | 0.211 | 0.211 | 0.211 | 0.211 | 0.000 | 0.000 | 0.513 | 0.575 | 0.536 | 0.000 | 0.211 | 0.125 | 0.150 |
| M-12B | 0.093 | 0.053 | 0.053 | 0.525 | 0.714 | 0.681 | 0.704 | 0.760 | 0.665 | 0.761 | 0.122 | 0.122 | 0.122 | 0.122 | 0.122 | 0.000 | 0.000 | 0.632 | 0.770 | 0.571 | 0.000 | 0.122 | 0.122 | 0.122 |
| M-12C | 0.093 | 0.053 | 0.058 | 0.466 | 0.703 | 0.652 | 0.602 | 0.682 | 0.554 | 0.684 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.029 | 0.000 | 0.587 | 0.649 | 0.550 | 0.000 | 0.015 | 0.015 | 0.015 |
| M-13A | 0.123 | 0.083 | 0.083 | 0.459 | 0.515 | 0.518 | 0.564 | 0.494 | 0.543 | 0.543 | 0.000 | 0.026 | 0.000 | 0.000 | 0.030 | 0.030 | 0.000 | 0.603 | 0.685 | 0.521 | 0.030 | 0.030 | 0.030 | 0.030 |
| M-13B | 0.120 | 0.065 | 0.058 | 0.533 | 0.719 | 0.681 | 0.713 | 0.769 | 0.654 | 0.770 | 0.130 | 0.130 | 0.130 | 0.130 | 0.130 | 0.000 | 0.043 | 0.626 | 0.662 | 0.571 | 0.000 | 0.130 | 0.125 | 0.174 |
| M-13C | 0.093 | 0.050 | 0.053 | 0.525 | 0.714 | 0.681 | 0.727 | 0.800 | 0.686 | 0.831 | 0.214 | 0.214 | 0.214 | 0.214 | 0.214 | 0.000 | 0.000 | 0.549 | 0.611 | 0.571 | 0.000 | 0.214 | 0.125 | 0.150 |
| M-14A | 0.130 | 0.084 | 0.141 | 0.361 | 0.320 | 0.359 | 0.383 | 0.301 | 0.457 | 0.389 | 0.265 | 0.238 | 0.258 | 0.225 | 0.232 | 0.256 | 0.083 | 0.388 | 0.310 | 0.286 | 0.060 | 0.125 | 0.137 | 0.125 |
| M-14B | 0.044 | 0.023 | 0.081 | 0.069 | 0.045 | 0.056 | 0.039 | 0.048 | 0.088 | 0.093 | 0.130 | 0.103 | 0.138 | 0.134 | 0.103 | 0.172 | 0.069 | 0.048 | 0.025 | 0.034 | 0.034 | 0.034 | 0.069 | 0.034 |
| M-14C | 0.134 | 0.075 | 0.123 | 0.350 | 0.363 | 0.378 | 0.379 | 0.242 | 0.337 | 0.304 | 0.135 | 0.108 | 0.246 | 0.208 | 0.108 | 0.215 | 0.185 | 0.329 | 0.185 | 0.256 | 0.138 | 0.169 | 0.169 | 0.215 |

# TABLE F- 2 (CONTINUED). QSI (QUANTITATIVE SIMILARITY INDEX; PERCENTAGE SIMILARITY INDEX) FOR MANISTEE LAKE, NOVEMBER 1998

| | M-9A | M-9B | M-9C | M-9RA | M-9RB | M-9RC | M-10A | M-10B | M-10C | M-11A | M-11B | M-11C | M-12A | M-12B | M-12C | M-13A | M-13B | M-13C | M-14A | M-14B | M-14C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M-1A | | | | | | | | | | | | | | | | | | | | | |
| M-1B | | | | | | | | | | | | | | | | | | | | | |
| M1-C | | | | | | | | | | | | | | | | | | | | | |
| M-2A | | | | | | | | | | | | | | | | | | | | | |
| M-2B | | | | | | | | | | | | | | | | | | | | | |
| M-2C | | | | | | | | | | | | | | | | | | | | | |
| M-3A | | | | | | | | | | | | | | | | | | | | | |
| M-3B | | | | | | | | | | | | | | | | | | | | | |
| M-3C | | | | | | | | | | | | | | | | | | | | | |
| M-4A | | | | | | | | | | | | | | | | | | | | | |
| M-4B | | | | | | | | | | | | | | | | | | | | | |
| M-4C | | | | | | | | | | | | | | | | | | | | | |
| M-5A | | | | | | | | | | | | | | | | | | | | | |
| M-5B | | | | | | | | | | | | | | | | | | | | | |
| M-5C | | | | | | | | | | | | | | | | | | | | | |
| M-6A | | | | | | | | | | | | | | | | | | | | | |
| M-6B | | | | | | | | | | | | | | | | | | | | | |
| M-6C | | | | | | | | | | | | | | | | | | | | | |
| M-7A | | | | | | | | | | | | | | | | | | | | | |
| M-7B | | | | | | | | | | | | | | | | | | | | | |
| M-7C | | | | | | | | | | | | | | | | | | | | | |
| M-8A | | | | | | | | | | | | | | | | | | | | | |
| M-8B | | | | | | | | | | | | | | | | | | | | | |
| M-8C | | | | | | | | | | | | | | | | | | | | | |
| M-9A | | | | | | | | | | | | | | | | | | | | | |
| M-9B | **0.118** | | | | | | | | | | | | | | | | | | | | |
| M-9C | 0.764 | **0.058** | | | | | | | | | | | | | | | | | | | |
| M-9RA | 0.894 | 0.220 | 0.765 | | | | | | | | | | | | | | | | | | |
| M-9RB | 0.762 | 0.286 | 0.729 | **0.842** | | | | | | | | | | | | | | | | | |
| M-9RC | 0.739 | 0.361 | 0.669 | 0.770 | **0.734** | | | | | | | | | | | | | | | | |
| M-10A | 0.490 | 0.150 | 0.353 | 0.431 | 0.429 | 0.417 | | | | | | | | | | | | | | | |
| M-10B | 0.515 | 0.250 | 0.455 | 0.563 | 0.560 | 0.611 | **0.333** | | | | | | | | | | | | | | |
| M-10C | 0.635 | 0.000 | 0.702 | 0.613 | 0.530 | 0.611 | 0.333 | **0.417** | | | | | | | | | | | | | |
| M-11A | 0.669 | 0.220 | 0.521 | 0.634 | 0.609 | 0.623 | 0.561 | 0.449 | 0.418 | | | | | | | | | | | | |
| M-11B | 0.837 | 0.100 | 0.789 | 0.780 | 0.708 | 0.728 | 0.444 | 0.417 | 0.658 | **0.663** | | | | | | | | | | | |
| M-11C | 0.726 | 0.040 | 0.755 | 0.713 | 0.740 | 0.541 | 0.423 | 0.447 | 0.515 | 0.613 | **0.746** | | | | | | | | | | |
| M-12A | 0.608 | 0.200 | 0.596 | 0.610 | 0.548 | 0.694 | 0.333 | 0.544 | 0.737 | 0.394 | 0.533 | 0.430 | | | | | | | | | |
| M-12B | 0.803 | 0.122 | 0.791 | 0.805 | 0.722 | 0.733 | 0.333 | 0.539 | 0.784 | 0.512 | 0.728 | 0.615 | **0.780** | | | | | | | | |
| M-12C | 0.598 | 0.044 | 0.684 | 0.600 | 0.493 | 0.644 | 0.333 | 0.451 | 0.824 | 0.405 | 0.607 | 0.493 | 0.752 | **0.761** | | | | | | | |
| M-13A | 0.717 | 0.030 | 0.716 | 0.721 | 0.647 | 0.598 | 0.364 | 0.417 | 0.610 | 0.524 | 0.697 | 0.612 | 0.515 | 0.704 | 0.573 | | | | | | |
| M-13B | 0.695 | 0.174 | 0.683 | 0.740 | 0.666 | 0.742 | 0.333 | 0.547 | 0.826 | 0.428 | 0.620 | 0.507 | 0.867 | 0.867 | 0.827 | **0.572** | | | | | |
| M-13C | 0.644 | 0.200 | 0.632 | 0.645 | 0.583 | 0.730 | 0.333 | 0.583 | 0.786 | 0.377 | 0.569 | 0.456 | 0.947 | 0.816 | 0.800 | 0.521 | **0.905** | | | | |
| M-14A | 0.440 | 0.187 | 0.324 | 0.449 | 0.399 | 0.437 | 0.262 | 0.494 | 0.286 | 0.520 | 0.446 | 0.425 | 0.238 | 0.351 | 0.290 | 0.286 | 0.325 | 0.274 | | | |
| M-14B | 0.000 | 0.119 | 0.019 | 0.024 | 0.024 | 0.062 | 0.000 | 0.103 | 0.000 | 0.059 | 0.046 | 0.010 | 0.000 | 0.000 | 0.029 | 0.000 | 0.000 | 0.000 | **0.303** | | |
| M-14C | 0.231 | 0.265 | 0.223 | 0.301 | 0.301 | 0.370 | 0.154 | 0.292 | 0.185 | 0.353 | 0.289 | 0.240 | 0.169 | 0.215 | 0.229 | 0.185 | 0.259 | 0.205 | 0.558 | **0.546** | |