PRELIMINARY INVESTIGATION OF THE EXTENT OF SEDIMENT CONTAMINATION IN MONA LAKE WATERSHED, MICHIGAN

BY

Dr. Richard Rediske
Dr. Don Uzarski
Dr. Michael Chu
Matt Cooper
R. B. Annis Water Resources Institute
Grand Valley State University
740 W. Shoreline Dr.
Muskegon, MI 49441

Dr. Thomas Burton
Department of Zoology
Michigan State University
East Lansing, MI 48823-5399

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PROJECT OFFICER:

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

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Project Team

EPA Project Officer

Dr. Marc Tuchman USEPA GLNPO

Principal Scientists

Dr. Richard Rediske	AWRI/GVSU	Chemistry and Toxicology
Dr. Don Uzarski	AWRI/GVSU	Aquatic Ecology
Dr. Michael Chu	AWRI/GVSU	Hydrologic Modeling
Dr Thomas Burton	MSU	Aquatic Ecology

Project technical assistance was provided by the following individuals:

Al Steinman, James O'Keefe, Matt Cooper, Brian Scull, Royce Hughes, and Gail Smythe.

DISCLAIMER

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Executive Summary

A preliminary investigation of the nature and extent of sediment contamination in Little Black Creek, Cress Creek, and Mona Lake was performed that involved sediment chemistry and toxicity, ecological assessment, and metal transport modeling. Sediment chemistry and solid-phase toxicity were examined at 12 locations in Little Black Creek, 6 locations in Cress Creek, and 3 locations in Mona Lake. High levels of PAH compounds (40 – 60 mg/kg) were found in an area near Seaway Drive, downstream of Sherman/Getty culvert, and the stream reach between the Mona View wetlands and Airline Rd. Sediment toxicity also was observed at these locations. High levels of cadmium were found in the stream reach from Peerless Plating (1,600 mg/kg) to the creek mouth at Mona Lake (11 mg/kg). Elevated levels of chromium, lead and zinc also were present. High mortality in both test organisms was observed near Peerless Plating (0-20% survival). Based on these results, the Little Black Creek system was found to be highly impacted by metals and PAH compounds. The Peerless Plating Superfund Site appears to be the source of most of the cadmium and chromium observed in the creek, although additional sources of metals are present near the Mona View Wetlands, Seaway Drive, and the Lower Wetlands.

Contaminated sediments were present in Mona Lake, with the basin near Little Black Creek containing higher concentrations of metals than Black Creek. Although the concentrations were above PEC levels, the only toxic response noted was a small reduction in midge growth in the basin near LBC. Sediment toxicity was not present in the station near the middle of the lake. Cress Creek was found to be an acceptable control site due to the absence of sediment toxicity.

A comparative assessment of the macroinvertebrate and fish populations in Little Black Creek was conducted using Cress Creek as a control site. Stream and wetland sites within each system were evaluated individually. The two sites were found to have similar water chemistry and physical characteristics. Nitrate, dissolved oxygen, and pH were slightly higher in Cress Creek while inorganic anions were higher in Little Black Creek. With respect to toxicants, Little Black Creek contained significantly higher levels of heavy metals and PAH compounds compared to Cress Creek. Taxon richness was higher in Cress Creek than LBC. In addition, higher densities of pollution sensitive Trichoptera and Plecoptera taxa were present in Cress Creek. The gradient in macroinvertebrate communities due to stream was more important than gradients related to either month or site, suggesting that anthropogenic disturbance associated with Little Black Creek substantially altered the macroinvertebrate community and these alterations overshadowed temporal and site-specific variability. The benthic macroinvertebrate fauna of Little Black Creek was found to be negatively impacted compared to the Cress Creek control site. The wetlands in both systems showed different trends with respect to physical and chemical parameters. Turbidity and sand size fraction sediments were greater in LBC while fine grained sediments and TOC were greater in Cress Creek. Toxicant levels (metals and PAH compounds) were significantly higher in the wetlands of Little Black Creek. Macroinvertebrate communities in the two systems appeared to respond more to substrate and turbidity than toxicant concentration.

A physically-based model was developed in this study for simulating metal (cadmium) and sediment transport in a coupled stream-wetland system that consisted of the water column, the underlying active bed, and the adjacent wetland subsystems. The model was tested by applying it to Little Black Creek. The simulated cadmium and sediment concentrations were compared against the observed ones and good agreement was achieved. The modeling results suggested that cadmium sorbed to the stream bed sediments was the primary source of cadmium contamination in the system. Resuspension of the cadmium-contaminated bed sediments played a critical role in the cadmium fate and transport. The modeling particularly emphasized the importance of the long-term, persistent cadmium accumulation process in Mona Lake and the wetlands, and the relevant threat to the ecosystem.

1.0 Introduction

The Mona Lake watershed (Figure 1.1) has an extensive history of anthropogenic activity related to industrial discharges. Little Black Creek (LBC) was heavily industrialized with refineries, plating companies, and metal finishing operations. LBC flows through residential areas in Muskegon Heights and contaminated sediments are present in locations that have the potential for public exposure. The purpose of this project was to relate sediment contamination to biotic integrity while assessing the nature, extent, and ecological significance of sediment contamination in the Mona Lake watershed. The study protocol followed the sediment quality triad approach (Canfield 1998) and focused on sediment chemistry, sediment toxicity, and the status of the *in situ* benthic macroinvertebrate community. The investigative sampling coupled reference sites with regions of known sediment contamination in the tributaries, wetlands, and deposition zones in Mona Lake. An

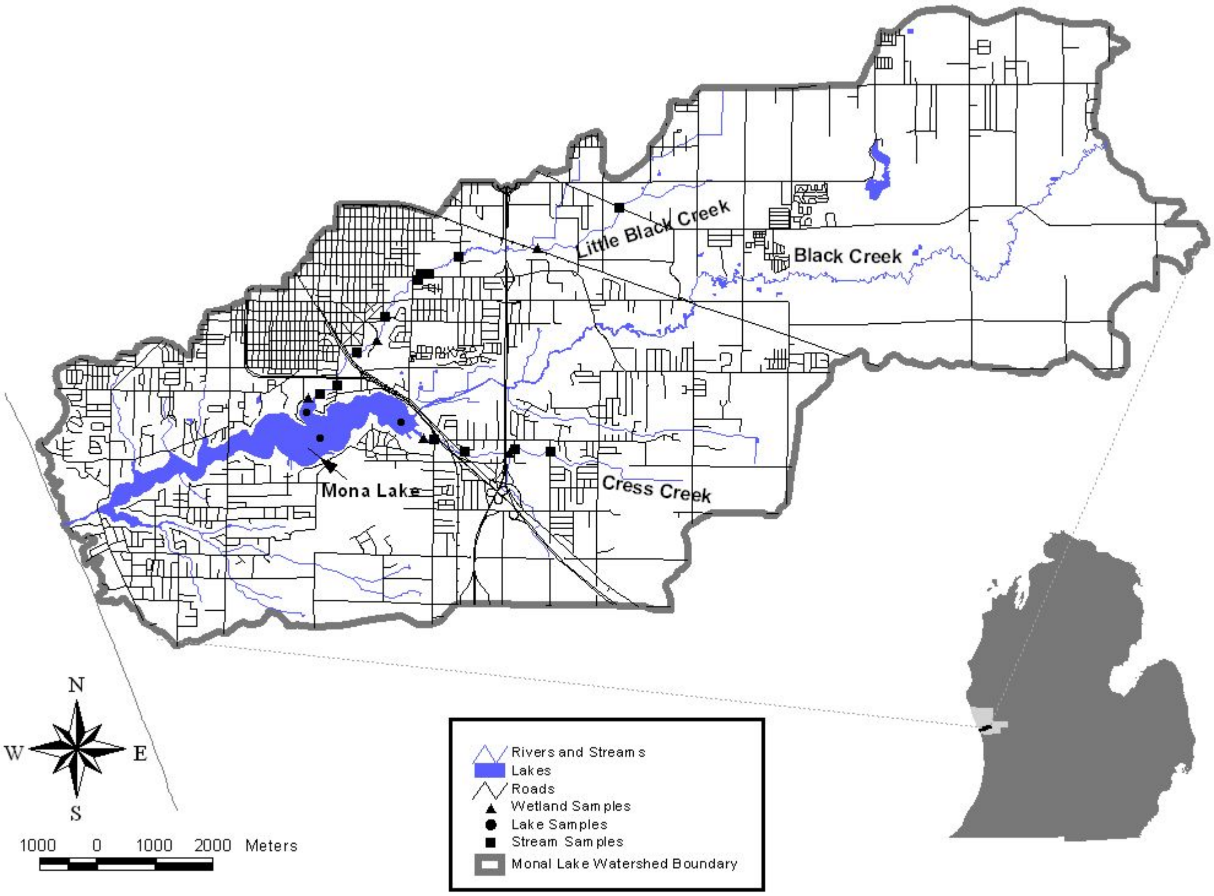

FIGURE 1.1. THE MONA LAKE WATERSHED.

initial series of sediment cores and surficial samples was collected for heavy metals, semivolatile organics, PCBs, and physical characteristics. Solid phase toxicity (sediment) was analyzed on the PONAR. Since Mona Lake has substantial wetlands associated with its tributaries, the storage and release of contaminants in these areas may play a significant role in their distribution. Issues related to contaminant flux are important in the assessment of ecological significance and the development of remediation plans. To address these concerns, a hydrologic/contaminant transport model was developed. In addition, a detailed ecological assessment of the wetlands was performed to determine the biological integrity of the system. The biological integrity of the wetlands in the contaminated LBC subwatershed was compared to the wetlands along Cress Creek, an uncontaminated subwatershed of Mona Lake. The Mona Lake watershed is targeted for considerable economic development and habitat restoration activities. Information on the distribution and flux of contaminated sediments will play an important role in the restoration process of this and similar systems in the Great Lakes.

This investigation examined specific sites of known anthropogenic activity as well as provided an overall assessment of the nature, extent, and ecological significance of sediment contamination in the Mona Lake watershed. This approach allowed us to focus on specific areas based on historical information while we concurrently examined the broad-scale distribution and impacts of sediment contamination and flux. We also examined areas of Little Black Creek that are downstream and/or downgradient of known brownfield sites identified through the Muskegon Height's inventory under their U.S. EPA CERCLA Brownfields Assessment Demonstration Pilot Grant. This project will provide the City of Muskegon Heights with a comprehensive data set that can be used as a foundation for restoration plans and requests for assistance from federal and state sources. These data also will assist the MDEQ and U.S. EPA in identifying and understanding contaminated groundwater discharges and their impact on biological integrity. Further, assessing the extent of contamination in this watershed will be useful in prioritizing future actions, and identifying potentially responsible parties.

The investigative sampling focused on reference areas as well as regions of known sediment contamination in the tributaries, potential storage areas in the wetlands, and deposition zones in Mona Lake. A series of 8 surface grab samples were collected from each of the contaminated and the reference tributaries and analyzed for heavy metals, semivolatile organics, PCBs, and physical characteristics. Physical characteristics include grain size, dry weight, and TOC. Sediment toxicity tests were conducted on the surface grab samples and were performed using the standard 10-day protocol for *Hyalella azteca* and *Chironomus tentans*. Macroinvertebrates were collected in conjunction with the samples from reference upstream and contaminated downstream areas using protocols developed by Burton et al. (1999), and Uzarski et al. (2004) for determining ecosystem health in Great Lakes coastal wetlands and IBI approaches for streams currently used by the Michigan Department of Environmental Quality. Fish also were sampled from reference upstream and contaminated downstream locations using fyke nets following protocols established for Great Lakes Coastal Wetlands by Uzarski, Burton and others as part of the U.S. EPA funded Great Lakes Commission (GLC) study of ecological indicator development for Great Lakes wetlands (Uzarski et al. 2004). A suite of water quality parameters (SRP, TP, NH_3, NO_3, DO, temperature, specific conductance, alkalinity, and pH) were collected with each replicated set of invertebrate samples. Local land use/cover parameters were determined by existing digitized maps of the watershed. Benthic macroinvertebrate and chemistry (water and sediment) samples were collected in spring, summer and fall. An additional series of 5 surface sediment samples were collected in potential contaminant source areas of Little Black Creek. These samples were analyzed for sediment toxicity

Since Mona Lake has substantial wetlands associated with its tributaries, the storage and release of contaminants in these areas may play a significant role in the distribution of chemicals. Issues related to contaminant flux are important in the assessment of ecological significance and the development of remediation plans. To address these concerns, a series of thirteen cores were collected in two large wetland areas on Little Black Creek and three cores was collected from Mona Lake. Six of these cores were collected from the wetlands near the Mona View Cemetery and the remaining seven cores were collected above the US 31 bridge. Three cores from Mona Lake were collected near the discharge zone of the tributaries. All of these cores were sectioned in 10 cm intervals and analyzed for heavy metals, semivolatile organics, PCBs, physical characteristics.

In addition to sampling and experimental work, the following modeling efforts were conducted to quantitatively characterize contaminated sediment transport and its effect on spatial and temporal variability of pollutants (e.g. cadmium) in Little Black Creek:

1. Hydrologic Modeling: Considering the dominant role of hydrologic dynamics on sediment and pollutant transport, GIS-based watershed delineation and hydrologic modeling were conducted for the Little Black Creek basin. A watershed-scale hydrologic model that integrates a rainfall-runoff model and a one-dimensional soil water flow model was developed for continuous hydrologic modeling for the LBC basin. In addition, the existing WMS (Watershed Modeling System) and HEC-HMS (Hydrologic Modeling System) was coupled and applied to the basin.

2. Erosion Modeling: A watershed erosion model was developed and three versions of the USDA Modified Universal Soil Loss Equation (MUSLE, MUSS, and MUST) was incorporated for estimating the sediment yield. Based on the hydrologic modeling and GIS information, soil erosion in the Little Black Creek basin was simulated.

3. Sediment-Metal Transport Modeling: A physically-based compartmental model was developed for simulating sediment and metal transport in stream channels and the connected wetlands in the Little Black Creek basin. Both sediment and cadmium loading potential into Mona Lake were evaluated. In particular, effects of the wetlands on sediment and metal transport and their potential ecological significance was addressed.

The hydrologic and sediment-metal transport modeling was designed to provide valuable information on the watershed characteristics, surface runoff and erosion, and detailed spatial and temporal distributions of contaminated sediments and metal (cadmium) in stream channels and wetlands. It also will provide important information for the development and analysis of remediation plans for Little Black Creek. The model was verified by collecting base flow and rain event samples of water and sediment at four locations in the Little Black Creek subwatershed.

1.1 Project Objectives and Task Elements

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

- Determine the nature and extent of sediment contamination in western Mona Lake watershed.
    - A Phase II investigation was conducted to examine the nature and extent of sediment contamination in the Mona Lake watershed. Core samples were collected to provide a historical perspective of sediment contamination. The investigation was directed at known sources of contamination in the lake and provide expanded coverage in the area of Little Black Creek. Cress Creek was used as a reference location. Arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc, selenium, mercury, TOC, semivolatile organics, PCBs and DDT compounds, and grain size were analyzed in all core samples.
    - Surface sediments were collected from the Mona Lake watershed with a hand scoop and a PONAR to provide chemical data for the sediments used in the toxicity evaluations and for the analysis of the benthic macroinvertebrate communities. The surficial sediment samples were analyzed for the same parameters as the sediment cores.
    - Critical measurements are the concentration of arsenic, barium, cadmium, chromium, copper, lead, nickel, zinc, selenium, mercury, PCBs and DDT compounds, and semivolatile organics in sediment samples. Non-critical measurements are total organic carbon, and grain size.
- Evaluate the toxicity of sediments from sites in Mona Lake watershed.
    - Sediment toxicity evaluations were performed with *Hyalella azteca* and *Chironomus tentans*.
    - Toxicity measurements in the Mona Lake watershed sediments were evaluated and compared to the two control locations in Cress Creek. These measurements were used to determine the presence and degree of toxicity associated with sediments from the Mona Lake watershed.
    - Critical measurements are 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 the Mona Lake watershed.

  - Sediment samples were collected with a PONAR in Mona Lake

  - Invertebrate collection followed protocols of Uzarski et al. (2004) in both the wetlands and streams.

  - Biotic integrity was determined using the IBI of Burton et al. (1999) and Uzarski et al.(2004) as well as GLEAS Procedure 51 modified to accept finer resolution data.

  - Critical measurements include the abundance and species composition of benthic macroinvertebrates.

- Develop, calibrate and verify hydrologic, erosion, and metal transport models for cadmium in Little Black Creek.

  - Water Discharge: stream flows at the five locations were measured monthly. Intensive observations were conducted for at least two storms to capture the response of subbasins to rainfall events at the outlets.

  - Suspended Sediment Discharge: Suspended sediment and bed sediment concentrations were measured and cross-sectional average concentrations were calculated at each observation point. The observation frequency was the same as the water discharge.

  - Cadmium Loading: Cadmium was and analyzed in surface water samples as the total and particulate metal. Generally, the cadmium sampling matched the suspended sediment in both space and time. However, to examine the effect of wetlands on the metal transport, cadmium samples in the wetlands were collected during storm periods.

  - Critical measurements include stream discharge, total cadmium, particulate cadmium, suspended solids, and cadmium in sediment

2.0 Sediment Quality Assessment

2.1 Description

Sampling locations for the assessment of contaminated sediments in Little Black Creek, Cress Creek, and Mona Lake were selected based on historical data, their potential role as sinks for contaminants, and their proximity to sources of contamination. Three types of assessments were conducted in this investigation. The first assessment was deigned to define the nature and extent of sediment contamination in Little Black Creek and the eastern part of Mona Lake. The sediment sampling locations for Little Black Creek and Mona Lake are shown in Figures 2.1 and 2.2, respectively. In addition, the accumulation of contaminants in wetlands located near US 31 and Mona View Cemetery was investigated (Figures 2.3 and 2.4, respectively). A combination of surface grab samples and cores were collected. GPS coordinates, dates, and sample types are provided in Tables 2.1 and 2.2, respectively. Core samples were not collected in Little Black Creek due to the shallow nature of the fine grained sediment and predominance of sand in the creek bed.

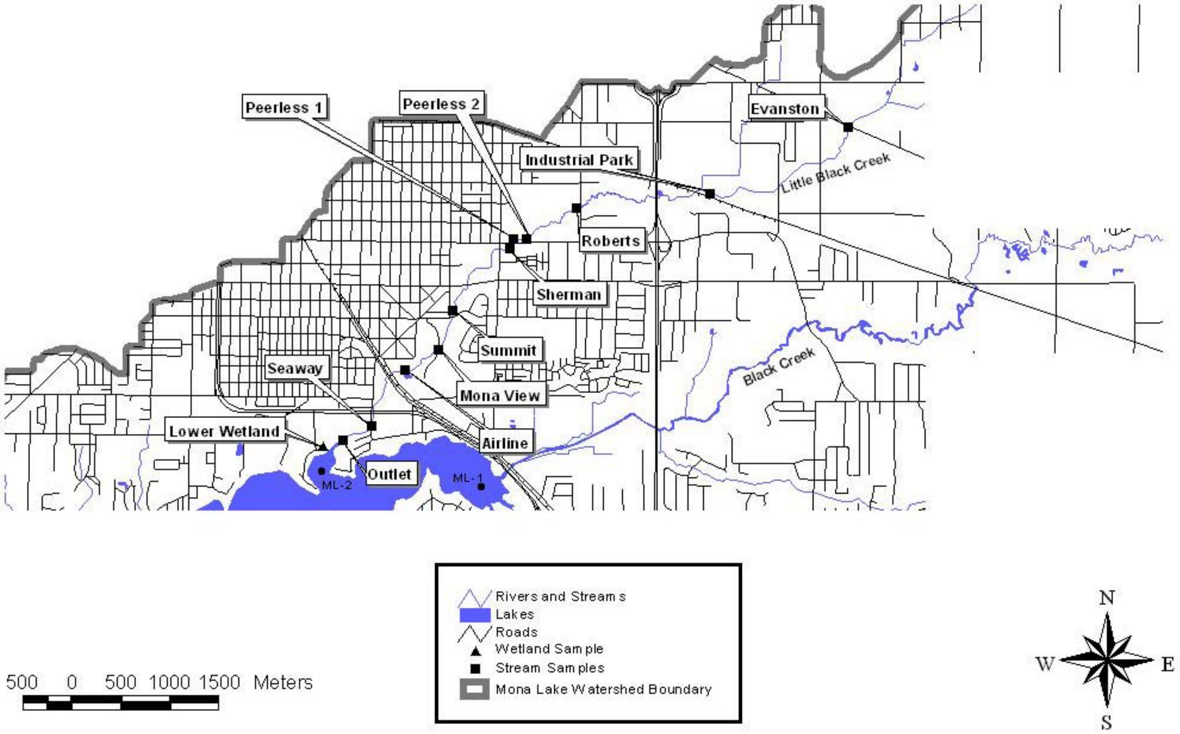

FIGURE 2. 1 SEDIMENT SURVEY SAMPLING LOCATIONS IN LITTLE BLACK CREEK (2004).

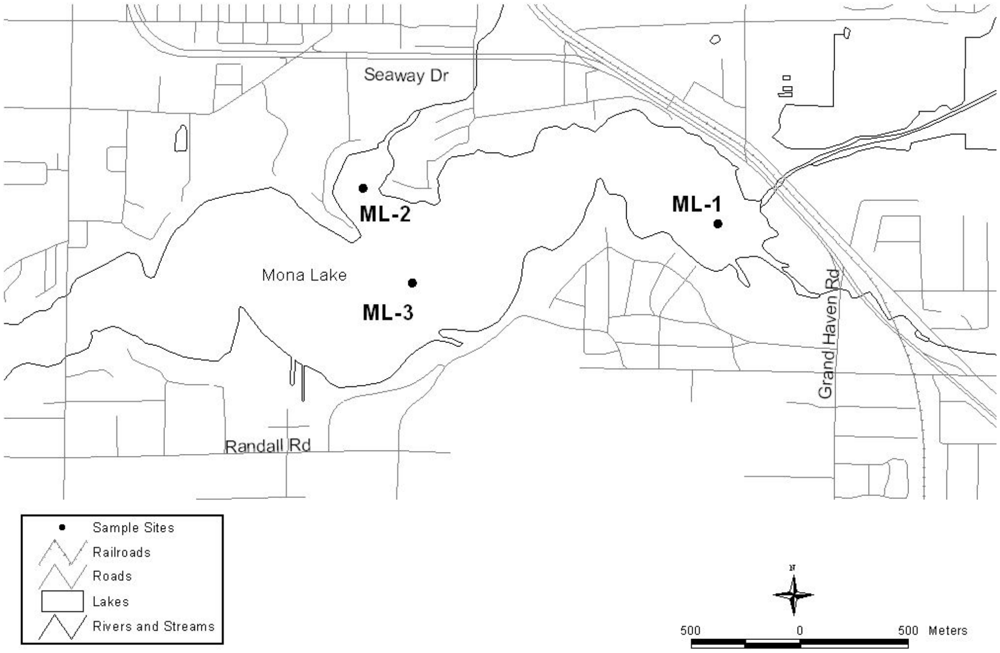

FIGURE 2. 2 SEDIMENT SURVEY SAMPLING LOCATIONS IN MONA LAKE (2005).

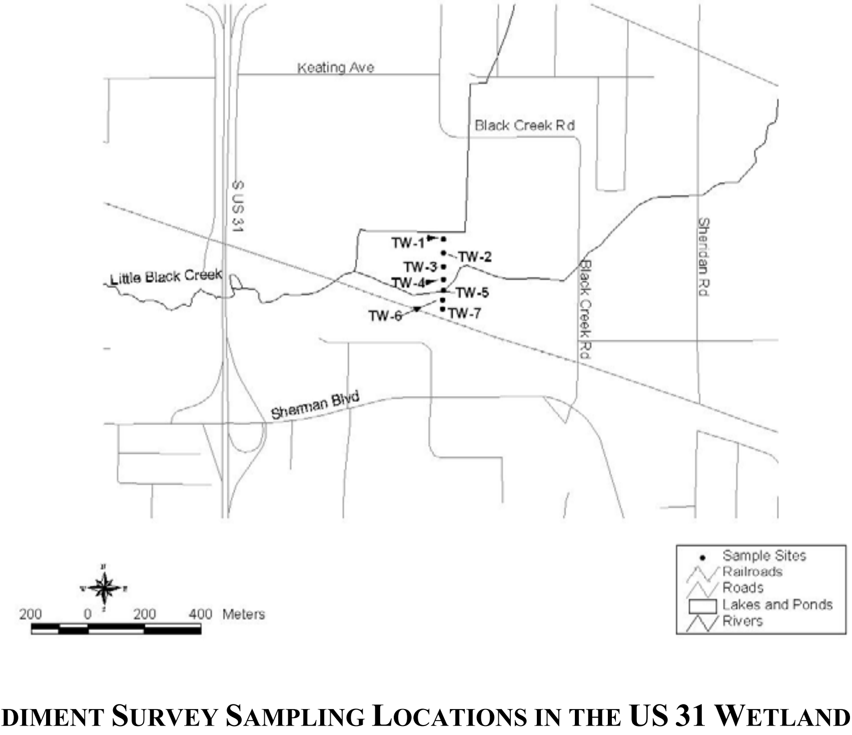

FIGURE 2. 3 SEDIMENT SURVEY SAMPLING LOCATIONS IN THE US 31 WETLANDS (2004).

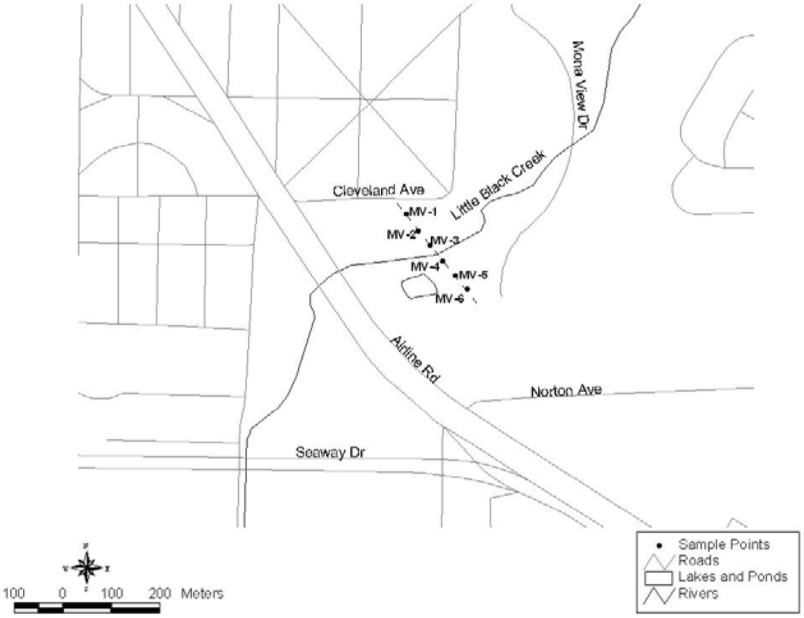

FIGURE 2. 4 SEDIMENT SURVEY SAMPLING LOCATIONS IN THE MONA VIEW WETLANDS (2004).

TABLE 2.1 SEDIMENT SURVEY SAMPLING STATION COORDINATES IN LITTLE BLACK CREEK (2004) AND MONA LAKE (2004).

LOCATION	Latitude	Longitude
Evanston Stream	43.21554	86.18101
Industrial Park	43.20940	86.19830
Roberts	43.20800	86.21510
Peerless 1	43.20520	86.22300
Peerless 2	43.20520	86.22130
Sherman & Getty Downstream	43.20433	86.22347
Summit	43.19859	86.23052
LBC Mona View Wetland	43.19506	86.23232
Airline	43.19320	86.23650
Seaway	43.18796	86.24065
LBC Lower Wetland	43.18613	86.24674
Outlet	43.18670	86.24430
Mona Lake (ML-1)	43.1839	86.2470
Mona Lake (ML-2)	43.1824	86.2270
Mona Lake (ML-2)	43.1799	86.2442

TABLE 2.2. SEDIMENT SURVEY SAMPLING STATION COORDINATES IN THE US-31 AND MONA VIEW WETLANDS (2004).

	Mona View Wetlands Latitude	Longitude
MV-1	43.1939	86.2365
MV-2	43.1936	86.2362
MV-3	43.1934	86.2359
MV-4	43.1931	86.2356
MV-5	43.1926	86.2350
MV-6	43.1928	86.2353
	US 31 Wetlands Latitude	Longitude
TW-1	43.2086	86.1956
TW-2	43.2089	86.1957
TW-3	43.2092	86.1957
TW-4	43.2096	86.1958
TW-5	43.2100	86.1958
TW-6	43.2104	86.1959
TW-7	43.2108	86.1959

2.2 Methods

2.2.1 Sediment Sampling Methods

Piston Core methods were used to collect sediment cores for chemical analysis. A 4-inch lexan tube was used for collection. A new core tube and liner were used at each location. The core samples were measured and sectioned into three equal segments corresponding to top, middle, and bottom. Each section was then homogenized in a polyethylene pan and split into sub-samples. The visual appearance of each segment was recorded along with the water depth and core depth.

PONAR samples were collected for toxicity testing and sediment chemistry. A petite PONAR sample was deposited into a polyethylene pan and split into sub-samples. The PONAR was washed with water between stations.

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

Requirements for sample volumes, containers, and holding times are listed in Table 2.3.
All sample containers for sediment chemistry and toxicity testing were purchased, precleaned, and certified as Level II by I-CHEM Inc.

TABLE 2.3. SAMPLE CONTAINERS, PRESERVATIVES, AND HOLDING TIMES.

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

2.2.3 Chemical Analysis Methods for Sediment Analysis

A summary of analytical methods and detection limits is provided in Table 2.4. Instrument conditions and a summary of quality assurance procedures are provided in the following sections.

TABLE 2.4 ANALYTICAL METHODS AND DETECTION LIMITS.

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

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

2.2.4 Sample Preparation for Metals Analysis

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

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

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

METAL ANALYSIS BY ICP

Aluminum, calcium, chromium, copper, nickel, and zinc were analyzed in accordance with EPA SW-846 method 6010A using Inductively Coupled Plasma Atomic Emission Spectroscopy. Samples were analyzed on a Perkin Elmer Optima 4000 ICP Spectrometer. The following settings were used:

Element Analyzed	Wavelength, nm
Ag	328.1
As	193.7
Ba	233.5
Cd	214.4
Cr	267.7
Cu	224.7
Pb	220.4
Se	196.0
Zn	206.2

Inter-element interference check standards were analyzed in the beginning and at the end of every analytical run, and indicated an absence of this type of interference at the given wavelength. The calibration curve was constructed from four standards and a blank, and was verified with a check standard prepared from a secondary source.

MERCURY

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

TOTAL ORGANIC CARBON

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

GRAIN SIZE ANALYSIS

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

SEMIVOLATILES ANALYSIS

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

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

MS operating conditions:

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

GC operating conditions:

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

A list of analytes and detection limits is given in Table 2.5. Surrogate standards were utilized to monitor extraction efficiency. Acceptance criteria for surrogate standards are given in Table 2.6. The GC/MS was calibrated using a 5-point curve. Instrument tuning was performed by injecting 5 ng of decafluorotriphenylphosphine and then adjusting spectra to meet method acceptance criteria. The MS and MSD samples were analyzed at a 5% frequency.

PCB ANALYSIS

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

TABLE 2.5 ORGANIC PARAMETERS AND DETECTION LIMITS.

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

TABLE 2.5 ORGANIC PARAMETERS AND DETECTION LIMITS (CONTINUED)

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

TABLE 2.6 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%

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

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

Table 2.7 presents a list of compounds and their detection limits. Two surrogate standards, tetrachloro-m-xylene and decachlorobiphenyl were used to monitor extraction efficiency. Acceptance limits for the surrogates were ± 50% for precision and accuracy.

TABLE 2.7 SEDIMENT DETECTION LIMITS FOR PCBS.

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

2.2.4 Chemical Analysis Methods for Water Analysis

The parameters, methods, and detection limits for the measurements performed on the culture water used in the sediment toxicity tests and surface water are listed in Table 2.8. All methods were performed according to procedures outlined in Standard Methods 14th Edition (APHA 1996).

TABLE 2.8 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

2.2.5 Sediment Toxicity

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

LABORATORY WATER SUPPLY

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

2.2.6 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.

EXPERIMENTAL DESIGN

For the November testing, eight replicates per sediment were set up for both *H. azteca* and *C. tentans* exposures, with the sediment from site M-15P designated as the control. In all tests, moderately hard well water was utilized as the overlying water. The experimental conditions outlined in Tables 2.9 and 2.10 were used for the toxicity evaluations.

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

STATISTICAL ANALYSIS

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

TABLE 2.9 TEST CONDITIONS FOR CONDUCTING A TEN DAY SEDIMENT TOXICITY TEST WITH *HYALELLA AZTECA*.

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

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

TABLE 2.10 RECOMMENDED TEST CONDITIONS FOR CONDUCTING A TEN 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 water:	2 volume additions/day (i.e., one volume addition every 12 hrs)
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.	# of organisms/chamber:	10
12.	Number of replicates:	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 DO in overlying water drops below 40% saturation
15.	Overlying water:	Moderately hard well water
16.	Overlying water quality:	Hardness, alkalinity, conductivity, pH, and ammonia measured at the beginning and end of test. Temp and DO measured daily.
17.	Test duration:	10 days
18.	End point:	Survival, with greater than 70% in the control. Weight > 0.6 mg per midge in the control

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

2.3 Sediment Chemistry Results

The results of sediment grain size fractions, percent solids and TOC for the surficial sediment and core samples are presented in Tables 2.11 and 2.12, respectively. Quality assurance data for TOC and grain size are listed in Appendix A. The surficial sediments can be grouped into three categories:

- Sand/Silt with TOC ≤ 5% and 0-10% < 63 *u*m grain size. Evanston, Roberts, Summit, and Seaway
- Inorganic Silt with TOC ≤ 5% and 10-40% < 63 *u*m grain size. Peerless 1 and 2, S&G DS, Airline, and Outlet
- Organic Silts with TOC ≥ 5% and ≥ 50% < 63 *u*m grain size. Industrial Park, Mona View, and LBC lower wetland.

Sediments in the Sand/Silt category will have a limited ability to sequester metals and organic contaminants. Stations at Evanston, Roberts, Summit, and Seaway all were near road/stream crossings and had evidence of coarse sand deposition. Areas of fine sediment deposition were not present. Stations at Peerless 1 and 2, S&G DS, Airline, and Outlet were collected in pool areas with visible sediment deposition. The samples from Industrial Park, Mona View, and LBC lower wetland were collected in wetland areas with visible organic deposition. In contrast to a majority of the surficial sediments, the core samples collected from Mona Lake all were consistent with the Organic Silt category. While some tendency was observed to have more sand size fractions in the bottom core sections, all samples and TOC levels > 5% and ≥ 50% < 63 *u*m grain size.

2.3.1 Little Black Creek Surficial Sediments

The results of sediment metals analyses are presented for the surficial sediment samples in Table 2.13. The results of semivolatile and PCB analyses for the same sample groupings are given in Table 2.14. Quality assurance data for organics and metals are provided in Appendix A. Arsenic, selenium, silver and most of the mercury data were below the Probable Effect Concentrations (PECs) (MacDonald et al. 2000). Figures 2.5, 2.6, and 2.7, illustrate the distribution of selected metals and organic compounds in Little Black Creek. Three potential source areas appear to be present in the metals data. The distribution of cadmium, chromium, and lead in the surficial sediments of Little Black Creek (LBC) is shown in Figures 2.5 and 2.6. Peerless Plating appears to be the sources of most of the cadmium found in LBC as the metal increase by 500x from the upstream location at Roberts (3 mg/kg) to the location adjacent to the former waste storage lagoons (1,500 mg/kg). Levels decline rapidly on the other side of the Sherman Ave culvert (102 mg/kg) and range fro 10-54 mg/kg in the sites below this location. The restriction of flow created by the culvert appears to allow for contaminated sediment accumulation in vicinity of the former Peerless Plating site. Although the contamination in the waste storage lagoons and groundwater were remediated, the stream bank soils were not removed. Since high concentrations of cadmium (2,400-4,200 mg/kg) were left in these soils (Tetra Tech 20031) the erosion of stream bank soils appears to be the source of cadmium contamination in LBC. Chromium initially follows a similar pattern with a 40x increase from the upstream (14 mg/kg) to the adjacent site (550 mg/kg) and then decrease downstream of the Sherman Ave culvert (132 mg/kg). Chromium concentrations then rise gradually from Summit (68 mg/kg) to Airline Ave (165 mg). At Seaway and the LBC lower wetlands, chromium concentrations rapidly increase to 634 mg/kg and 484 mg/kg respectively. Foundry waste (scrap iron and slag) is present at both locations, suggesting that contaminated fill materials may be the source of the elevated chromium levels. No industries were present in the area west of Seaway Drive. Lead and Zinc (Figure 2.6) follow a similar patter to chromium, except that a small source appears to be present upstream of Peerless Plating. For both lead and zinc, the highest concentrations were found at Seaway and the LBC Lower Wetland.

The distribution of PAH compounds and PCBs are shown on Figure 2.8 and 2.9. Total PAH compounds above the PEC value were found at Sherman/Getty DS, Mona View, Airline, and Seaway. The highest total PAH concentration was 60 mg/kg at Seaway. A strong odor of

TABLE 2.11 RESULTS OF GRAIN SIZE FRACTIONS, TOC, AND PERCENT SOLIDS FOR LITTLE BLACK CREEK SURFACE SEDIMENT SAMPLES, SAMPLES, APRIL 27, 2004.

Location	**% Solids**	**% TOC**	**% Grain Size (*u*m)**						
			<2000	**200-1000**	**1000-850**	**850-500**	**500-125**	**125-63**	**<63**
Evanston	50	1	1	1	0	7	66	28	0
Industrial Park	33	10	2	0	0	1	18	25	52
Roberts	50	2	1	1	1	8	44	38	7
Peerless 1	34	5	3	2	3	4	21	44	23
Peerless 1 Dup	32	4	4	2	3	5	20	39	26
Peerless 2	34	5	3	2	3	4	19	39	30
S&G DS	28	2	5	2	1	4	11	54	23
Summit	47	3	4	2	0	3	44	39	9
Mona View	10	12	6	2	0	2	14	17	59
Airline	51	3	1	2	2	11	23	43	18
Seaway	46	2	6	2	1	5	48	29	8
Seaway Dup	42	3	7	5	3	3	44	31	7
LBC Lower Wetland	41	7	4	2	1	2	10	24	57
Outlet	46	3	2	2	3	5	13	38	37

TABLE 2.12 RESULTS OF SEDIMENT GRAIN SIZE FRACTIONS, TOC, AND PERCENT SOLIDS FOR MONA LAKE CORE SAMPLES, JULY 2005.

Location	**Core Section**	**%Solids**	**%TOC**	**% Grain Size (*um*)**						
				<2000	**200-1000**	**1000-850**	**850-500**	**500-125**	**125-63**	**<63**
Mona Lake ML-1	0-20 cm	88	10	1	1	0	0	3	8	87
	20-40 cm	82	11	0	0	0	1	2	7	89
	40-80 cm	79	9	0	0	1	8	1	8	82
Mona Lake ML-2	0-20 cm	84	11	1	1	0	0	4	8	86
	20-40 cm	81	11	0	0	0	1	2	9	88
	40-80 cm	76	8	0	0	1	1	2	9	87
Mona Lake ML-3	0-20 cm	85	10	1	1	0	0	3	6	89
	20-40 cm	83	11	0	0	0	2	3	5	90
	40-80 cm	74	9	0	0	0	3	3	5	89
Mona Lake ML-3 Dup	0-20 cm	83	11	1	1	0	0	4	90	89
	20-40 cm	81	10	1	1	1	3	4	5	85
	40-80 cm	70	10	0	0	0	3	1	5	91

Table 2.13 Results of Metal Analyses for Little Black Creek Surficial Sediment Samples (Dry Weight), April 2004. Results in Bold Exceed the PEC.

Sample Site	Total Arsenic	Total Barium	Total Cadmium	Total Chromium	Total Copper	Total Lead	Total Selenium	Total Silver	Total Zinc	Total Mercury
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Evanston	20	67	0	25	22	72	<0.40	<1.0	63	<0.1
Ind. Park	16	130	2	49	32	**164**	3.8	<1.6	182	0.2
Roberts	9	124	3	14	22	36	1.2	<1.0	55	0.3
Peerless 1	12	122	**1600**	**550**	120	**150**	0.8	<1.1	**590**	0.8
Peerless 1D	11	128	**1700**	**610**	130	**175**	0.6	<1.1	**575**	0.9
Peerless 2	8	139	**1500**	**320**	**150**	**200**	<0.96	<2.4	**566**	0.3
Sherman DS	19	200	**102**	**132**	123	**275**	1.2	<1.8	**473**	<0.1
Summit	4	84	**19**	**68**	90	**275**	0.9	1.6	314	0.2
Mona View	9	114	**17**	**142**	**155**	**339**	<2.0	<5.0	**571**	0.8
Airline	10	210	**34**	**165**	132	**410**	1.5	<1.0	**660**	**1.2**
Seaway	13	491	**46**	**634**	**609**	**652**	<0.44	2.4	**4200**	1.0
Seaway Dup	9	450	**49**	**540**	**510**	**560**	1.1	2.0	**3800**	**1.1**
Lower Wetland	10	398	**54**	**484**	**304**	**596**	<2.0	<5.0	**2040**	0.7
Outlet	11	422	**11**	65	75	**180**	<1.0	4.9	310	0.7

TABLE 2. 14 RESULTS OF SEDIMENT PCB AND SEMIVOLATILE ANALYSES FOR LITTLE BLACK CREEK SURFICIAL SEDIMENT SAMPLES APRIL 2004. (CONCENTRATIONS IN BOLD EXCEED THE PEC. PARAMETERS THAT WERE NOT DETECTED WERE OMITED.)

Sample		**Evanston**	**Industrial Park**	**Roberts**	**Peerless 1**	**Peerless 1 Dup**	**Peerless 2**	**Sherman & Gety DS**	**Summit**	**Monaview Wetland**	**Airline**	**Seaway**	**Seaway Dup**	**Lower Wetland**	**Outlet**
Compound															
Naphthalene	**mg/kg***	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**0.86**	**0.74**	< 0.33	**0.74**
Acenaphthylene	**mg/kg***	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Acenaphthene	**mg/kg***	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	1.6	1.1	1.1	1.1
Fluorene	**mg/kg***	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	**1.8**	**1.5**	**0.86**	**1.5**
Phenanthrene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.75	< 0.33	0.92	**4.3**	**1.4**	**8.4**	**11**	**15**	**8.9**	0.88	**1.3**
Anthracene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.61	< 0.33	0.75	0.75	< 0.33	**5.5**	**4.4**	**3.6**	**4.9**	0.78	**1.4**
Fluoranthene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.46	0.63	0.55	**9.8**	**2.9**	1.1	0.85	0.75	0.96	0.96	0.96
Pyrene	**mg/kg***	< 0.33	< 0.33	< 0.33	1.0	0.9	1.5	**7.3**	**2.1**	**9.3**	**10**	**11**	**9.8**	0.82	**1.4**
Benzo(a)anthracene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.63	0.54	0.88	**2.9**	0.88	**6.1**	**4.5**	**5.1**	**4.2**	0.75	**1.4**
Chrysene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.58	0.49	0.58	**4.2**	1.2	**5.8**	**5.5**	**5.2**	**4.9**	0.64	**1.6**
Benzo(b)fluoranthene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.45	< 0.33	0.64	4.7	1.2	0.58	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Benzo(k)fluoranthene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.51	0.48	0.51	2.4	0.64	0.26	4.1	4.4	5.4	0.69	2.9
Benzo(a)pyrene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.38	0.36	0.38	**3.8**	1.1	**7.2**	**4.8**	**5.1**	**6.2**	0.55	**2.6**
Indeno(1,2,3-cd)pyrene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.55	0.42	0.55	2.8	0.79	2.1	1.4	2.4	2.8	1.7	2.8
Dibenzo(a,h)anthracene	**mg/kg***	< 0.33	< 0.33	< 0.33	0.44	< 0.33	0.44	0.42	< 0.33	< 0.33	0.55	0.39	0.45	< 0.33	0.45
Benzo(g,h,i)perylene	**mg/kg***	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	3.2	0.86	1.6	1.80	2.6	0.88	< 0.33	0.88
Total PAH Compounds	**mg/kg***	0.0	0.0	0.0	5.0	3.8	6.0	**47**	13	**48**	**49**	**60**	**53**	10	21
Aroclor 1016	**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
Aroclor 1221	**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
Aroclor 1232	**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
Aroclor 1242	**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
Aroclor 1248	**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
Aroclor 1254	**mg/kg***	< 0.33	< 0.33	3.0	1.3	1.6	2.0	0.94	0.42	1.2	0.64	0.70	0.45	< 0.33	0.89
Aroclor 1260	**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
Total PCBs	**mg/kg***	< 0.33	< 0.33	**3.0**	**1.3**	**1.6**	**2.0**	**0.94**	0.42	1.2	0.64	**0.70**	0.45	< 0.33	0.89

* Results on a dry weight basis

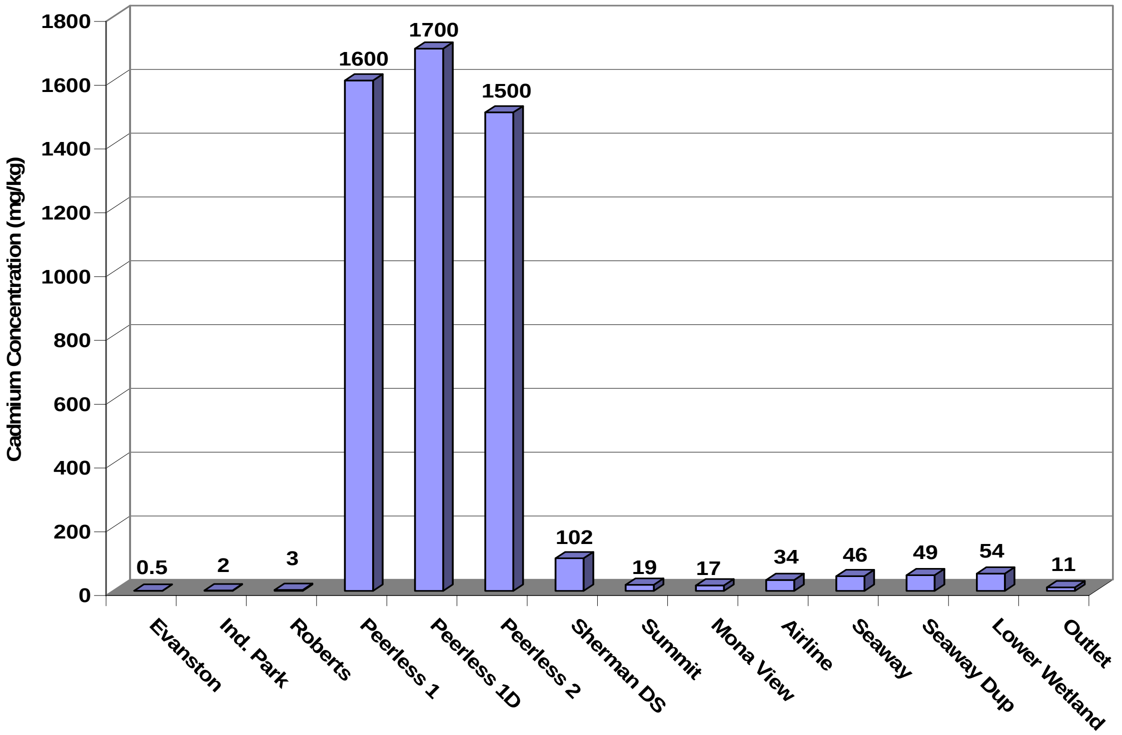

FIGURE 2. 5 DISTRIBUTION OF CADMIUM IN THE SURFICIAL SEDIMENTS OF LITTLE BLACK CREEK. APRIL 2004. (PEC=4.98 MG/KG)

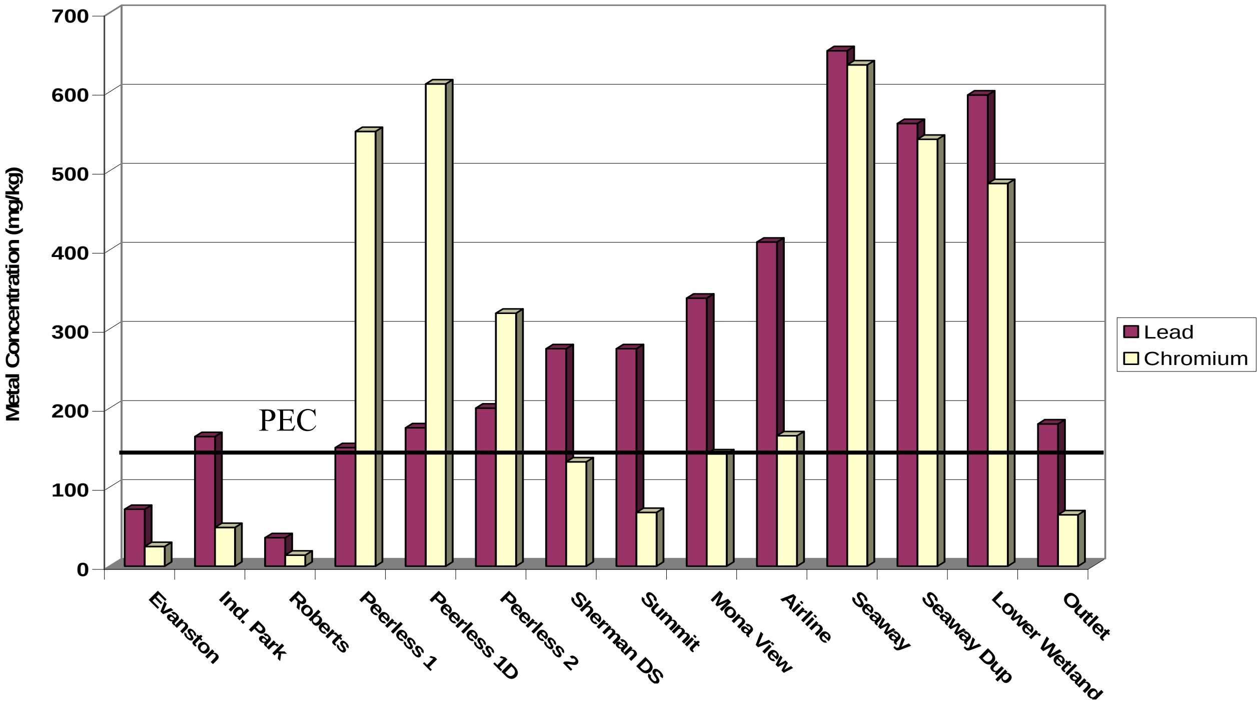

FIGURE 2. 6. DISTRIBUTION OF LEAD AND CHROMIUM IN THE SURFICIAL SEDIMENTS OF LITTLE BLACK CREEK. APRIL 2004. (LEAD PEC=128 MG/KG; CHROMIUM PEC =111 MG/KG)

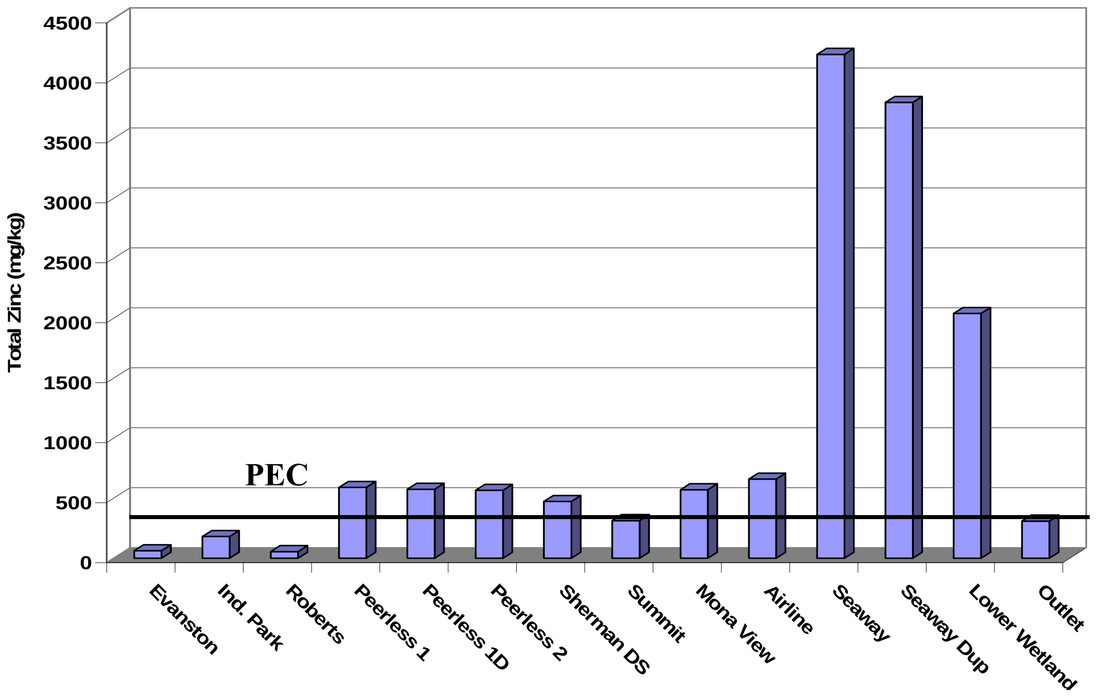

FIGURE 2. 7. DISTRIBUTION OF ZINC IN THE SURFICIAL SEDIMENTS OF LITTLE BLACK CREEK. APRIL 2004.

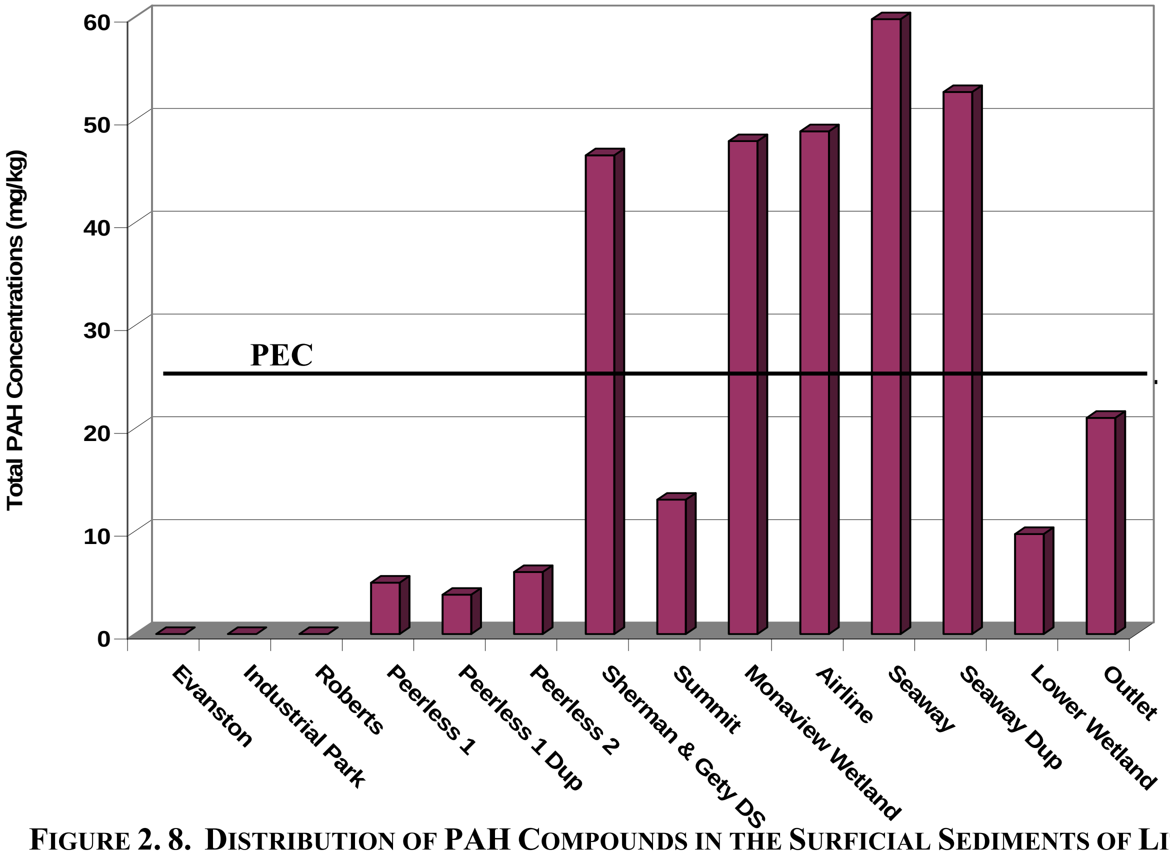

FIGURE 2. 8. DISTRIBUTION OF PAH COMPOUNDS IN THE SURFICIAL SEDIMENTS OF LITTLE BLACK CREEK. APRIL 2004.

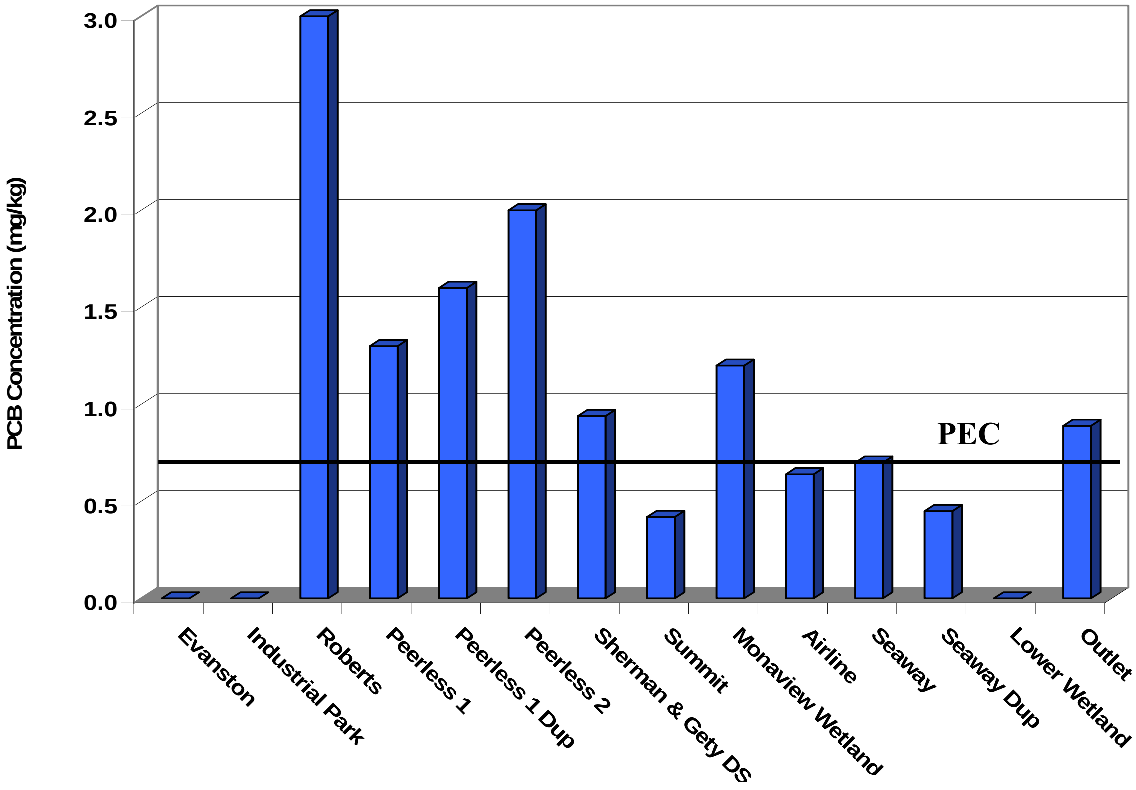

FIGURE 2. 9 DISTRIBUTION OF PCBS IN THE SURFICIAL SEDIMENTS OF LITTLE BLACK CREEK. APRIL 2004.

gasoline petroleum hydrocarbons was present at this location. The PAH compound distribution at this location contained naphthalene and other lighter fraction hydrocarbons, which suggests that gasoline seepage may be responsible. The PAH compounds present at the other locations were predominantly heavier hydrocarbons, indicating a release of fuel oil. Former automotive service facilities were located near the Seaway and Sherman/Getty DS stations. No apparent source of PCBs was present in the data as low levels were found in the sediments from Roberts to the Outlet.

A summary of locations that exceed the PEC values in Little Black Creek is presented in Table 2.15. From Peerless Plating to the mouth near Mona Lake, Little Black Creek is heavily contaminated with metals and PAH compounds. Based on the extensive contamination detected in the surficial sediments, it appears that contaminant transport is active in the system. Spearman Rank Order Correlations were developed for the physical/chemical parameters measured in the investigation (Table 2.16) to further examine the relationship between the variables. TOC was positively correlated with fine grained sediments however strong correlations between grain size and TOC were not present. The presence of significant sources of metals and PAH compounds in the vicinity of the coarse grained sediments near Peerless Plating and Seaway, respectively, created a bias in the data set. PAH compound levels were significantly correlated ($p \leq 0.01$) with lead, zinc, and copper. Lead is a common additive to fuels however the reason for the correlation with zinc and copper cannot be explained from the data. Cadmium was significantly correlated ($p \leq 0.01$) with chromium, suggesting plating waste as the source of the metal. Chromium also was significantly correlated ($p \leq 0.01$) with copper, lead, and zinc. Based on these relationships, there appears to be multiple sources of these elements.

TABLE 2.15. SUMMARY OF SURFICIAL SEDIMENT SAMPLING LOCATIONS IN LITTLE BLACK CREEK THAT EXCEED CONSENSUS BASED PEC GUIDELINES (MACDONALD ET AL. 2000).

Contaminant	Consensus-Based PEC mg/kg	Location in Little Black Creek that Exceed the PEC
Arsenic	33.0	None, highest level at Evanston (20 mg/kg)
Cadmium	4.98	All stations from Peerless Plating to the Outlet
Chromium	111	All stations from Peerless Plating to the Lower Wetlands
Copper	149	Peerless 2, Mona View, Airline, Seaway, Lower Wetlands
Lead	128	Industrial Park and all stations from Peerless Plating to the Outlet
Mercury	1.06	Airline and Seaway
Zinc	459	All stations from Peerless Plating to the Lower Wetlands
Total PAH Compounds	22.9	Sherman/Getty DS, Mona View, Airline, Seaway
Total PCBs	0.68	All stations from Roberts to the Sherman/Getty DS and Seaway

TABLE 2.16. SPEARMAN'S RANK ORDER CORRELATIONS FOR THE CHEMICAL AND PHYSICAL PARAMETERS IN LITTLE BLACK CREEK SEDIMENTS.

Spearman's rho Sig. (2-tailed) N	Total Barium / mg/kg	Total Cadmium / mg/kg	Total Chromium / mg/kg	Total Copper / mg/kg	Total Lead / mg/kg	Total Selenium / mg/kg	Total Silver / mg/kg	Total Zinc / mg/kg	Total Mercury / mg/kg	Total PAH / mg/kg	Total PCBs / mg/kg	% TOC	Grain Size (< 63 um)
Total Arsenic / mg/kg	.031	-.123	-.044	-.248	-.219	-.119	-.220	-.104	-.236	-.177	-.299	-.259	-.301
	.917	.674	.881	.392	.453	.684	.450	.724	.416	.545	.299	.371	.296
	14	14	14	14	14	14	14	14	14	14	14	14	14
Total Barium / mg/kg		.253	.442	.596(*)	.642(*)	.086	.458	.587(*)	.502	.616(*)	-.059	-.076	-.152
		.383	.114	.024	.013	.770	.100	.027	.067	.019	.840	.796	.604
		14	14	14	14	14	14	14	14	14	14	14	14
Total Cadmium / mg/kg			.807(**)	.548(*)	.282	-.137	.073	.622(*)	.412	.219	.442	.237	.075
			.000	.043	.329	.642	.804	.018	.143	.453	.113	.415	.799
			14	14	14	14	14	14	14	14	14	14	14
Total Chromium / mg/kg				.805(**)	.559(*)	-.271	.250	.908(**)	.742(**)	.479	.189	.241	-.011
				.001	.038	.349	.389	.000	.002	.083	.517	.406	.970
				14	14	14	14	14	14	14	14	14	14
Total Copper / mg/kg					.881(**)	-.083	.527	.911(**)	.682(**)	.754(**)	.029	.268	.100
					.000	.779	.053	.000	.007	.002	.923	.353	.733
					14	14	14	14	14	14	14	14	14
Total Lead / mg/kg						.061	.611(*)	.792(**)	.520	.864(**)	-.275	.120	.201
						.837	.020	.001	.056	.000	.341	.684	.491
						14	14	14	14	14	14	14	14
Total Selenium / mg/kg							-.200	-.066	.017	.033	-.061	.233	.116
							.494	.822	.955	.910	.837	.423	.693
							14	14	14	14	14	14	14
Total Silver / mg/kg								.341	.140	.542(*)	-.127	.345	.566(*)
								.233	.634	.045	.664	.227	.035
								14	14	14	14	14	14
Total Zinc / mg/kg									.817(**)	.695(**)	-.044	.208	-.035
									.000	.006	.881	.476	.905
									14	14	14	14	14
Total Mercury / mg/kg										.569(*)	.173	.214	-.146
										.034	.554	.463	.619
										14	14	14	14
Total PAH / mg/kg											-.066	-.085	.018
											.822	.772	.952
											14	14	14
Total PCBs / mg/kg												.069	-.051
												.814	.863
												14	14
% TOC													.739(**)
													.003
													14

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

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

2.3.2 Mona Lake Sediment Cores

The results of sediment metals analyses are presented for the Mona Lake core samples in Table 2.17. The results of semivolatile and PCB analyses for the same sample are given in Table 2.18. Quality assurance data for organics and metals are provided in Appendix A. Figures 2.10 and 2.11 illustrate the distribution of selected metals in Mona Lake. The only metals that exceeded PEC levels were cadmium, chromium, copper, and lead (Table 2.17). Core ML-1, collected near the mouth of Black Creek, contained the lowest levels of the above metals in all core sections. In contrast, core ML-2, collected near the mouth of LBC, contained the highest levels of the same group of metals in all sections. These data suggest that LBC was the major source of these metals for Mona Lake. Core ML-3, collected down stream of both creek mouths and in the central portion of Mona Lake contained levels of chromium and cadmium that were approximately 50% of the concentrations found at ML-2. Levels of copper and lead were similar to the other cores. Mona Lake has been treated with copper for many years to control algal blooms. The lake also has heavy recreational boating, which can contribute elevated concentrations of lead to the sediment. Concentration distributions of these elements fit a diffuse source rather than from one of the creeks. PAH compounds and PCBs (Table 2.18) showed a similar deposition pattern as the metals. PAH compounds were highest in ML-2, suggesting that LBC is the predominant sources of these hydrocarbons. PCB levels were similar at all of the core locations. These results suggest that a diffuse source, such as atmospheric deposition, may be responsible for the addition of PCBs to Mona Lake.

The deposition patterns of selected metals in the core samples are shown in Figures 2.10 and 2.11. Levels of cadmium, chromium, and lead generally increase with depth, suggesting that historical deposition rates were greater than present. Copper concentrations tend to decrease with depth, indicating that current use of copper biocides is contributing more of the metal than loadings from the creeks. A summary of concentrations and locations that exceed the PEC levels is provided in Table 2.19. Copper and PCBs exceed the PEC in all top core sections. Exceedances of the PEC for cadmium and lead are limited to ML-2 and ML-3. The PECs for metals in the lower core sections were exceeded at most locations. It is unlikely that metals in the lower core sections would become bioavailable without an extensive disturbance to the system. The presence of reduced metal concentrations in the top core sections indicated that a relatively stable deposition of less contaminated material has occurred.

TABLE 2. 17. RESULTS OF SEDIMENT METAL ANALYSES FOR MONA LAKE CORE SAMPLES (DRY WEIGHT), AUGUST 2005. RESULTS IN BOLD EXCEED THE PEC.

Location	**Core Section**	Total Arsenic	Total Barium	Total Cadmium	Total Chromium	Total Copper	Total Lead	Total Selenium	Total Silver	Total Zinc	Total Mercury
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Mona Lake ML-1	0-20	13	122	4	92	**220**	110	<2.0	<5.0	240	0.4
	20-40	16	150	**7**	**150**	**175**	**450**	<2.0	<5.0	170	0.2
	40-80	12	145	**8**	**140**	95	**580**	<2.0	<5.0	140	0.2
Mona Lake ML-2	0-20	18	135	**31**	110	**300**	**150**	<2.0	<5.0	350	**1.3**
	20-40	11	125	**55**	**275**	**220**	**650**	<2.0	<5.0	390	0.8
	40-80	15	100	**98**	**430**	115	**1200**	<2.0	<5.0	450	0.2
Mona Lake ML-3	0-20	16	110	**15**	**120**	**275**	**150**	<2.0	<5.0	220	0.7
	20-40	12	100	**20**	**275**	**190**	**260**	<2.0	<5.0	180	0.4
	40-80	10	95	**17**	**150**	78	**420**	<2.0	<5.0	130	0.2
Mona Lake ML-3 Dup	0-20	14	122	**13**	**130**	**290**	**140**	<2.0	<5.0	200	0.6
	20-40	10	115	**25**	**250**	**210**	**230**	<2.0	<5.0	175	0.4
	40-80	10	89	**15**	**135**	80	**400**	<2.0	<5.0	110	0.2

Table 2. 18. Results of Sediment PCB and Semivolatile Analyses for Mona Lake Core Samples (Dry Weight), August 2005. (Concentrations in Bold Exceed the PEC. parameters that were not detected were omited.)

Sample		Mona Lake 1			Mona Lake 2			Mona Lake 3			Mona Lake 3		
Depth		0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm
Compound	Units												
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
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
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
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
Phenanthrene	mg/kg	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	0.65	0.83	0.42	0.65	0.77	0.39
Anthracene	mg/kg	**0.98**	**1.6**	**0.45**	**2.2**	**3.5**	**1.3**	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Fluoranthene	mg/kg	0.45	0.88	0.35	**3.2**	0.4	1.9	1.4	**2.5**	0.7	1.1	1.9	0.71
Pyrene	mg/kg	< 0.33	0.55	< 0.33	**2.2**	**2.7**	1.3	1.1	**1.7**	0.8	1.4	**1.7**	0.69
Benzo(a)anthracene	mg/kg	< 0.33	< 0.33	< 0.33	**1.2**	**1.6**	1.0	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Chrysene	mg/kg	0.67	0.92	0.62	2.1	2.5	1.1	0.75	1.20	< 0.33	0.84	0.99	< 0.33
Benzo(b)fluoranthene	mg/kg	< 0.33	< 0.33	< 0.33	1.5	2.0	0.6	0.44	0.67	< 0.33	0.51	0.66	< 0.33
Benzo(k)fluoranthene	mg/kg	< 0.33	< 0.33	< 0.33	1.6	1.9	0.9	0.66	0.79	0.44	0.79	0.74	0.66
Benzo(a)pyrene	mg/kg	< 0.33	< 0.33	< 0.33	**1.8**	**2.2**	1.2	0.75	0.84	0.39	0.65	0.83	0.75
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.33	< 0.33	< 0.33	0.35	0.55	< 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	**1.4**	**2.2**	0.8	0.54	0.66	< 0.33	0.49	0.68	< 0.33
Benzo(g,h,i)perylene	mg/kg	< 0.33	< 0.33	< 0.33	1.7	1.9	1.1	0.51	0.72	< 0.33	0.48	0.63	0.44
Total PAH Compounds	mg/kg	2.1	4.0	1.4	19.2	21.5	11.2	6.2	9.1	2.3	6.3	8.1	3.3
Aroclor 1016	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
Aroclor 1221	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
Aroclor 1232	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
Aroclor 1242	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
Aroclor 1248	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
Aroclor 1254	mg/kg	1.5	1.9	0.98	1.2	2.3	1.1	1.6	1.8	1.1	1.4	1.7	0.88
Aroclor 1260	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
Total PCBs	mg/kg	**1.5**	**1.9**	**0.98**	**1.2**	**2.3**	**1.1**	**1.6**	**1.8**	**1.1**	**1.4**	**1.7**	**0.88**

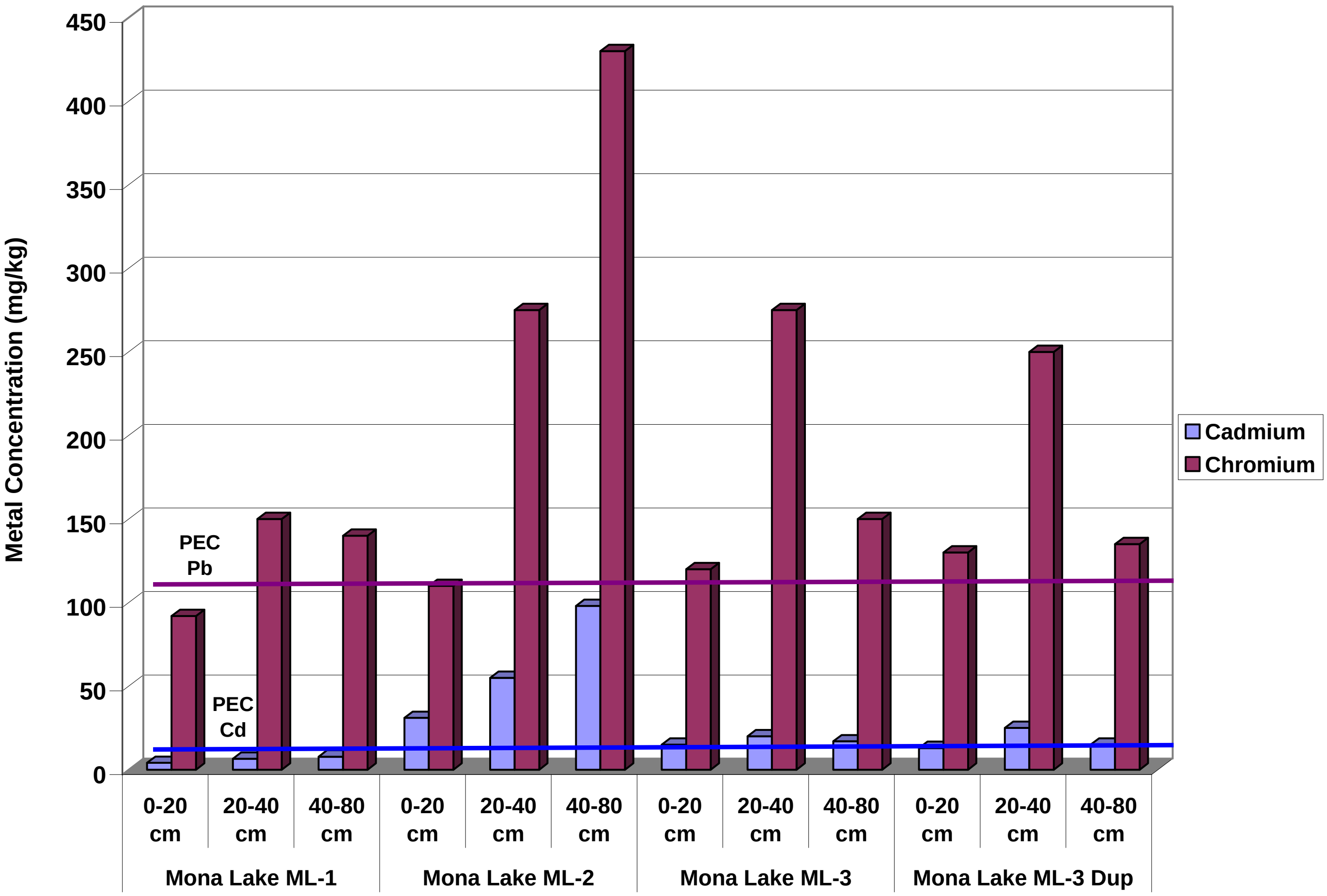

FIGURE 2. 10. DISTRIBUTION OF CADMIUM AND CHROMIUM IN CORE SAMPLES COLLECTED IN MONA LAKE, AUGUST 2005.

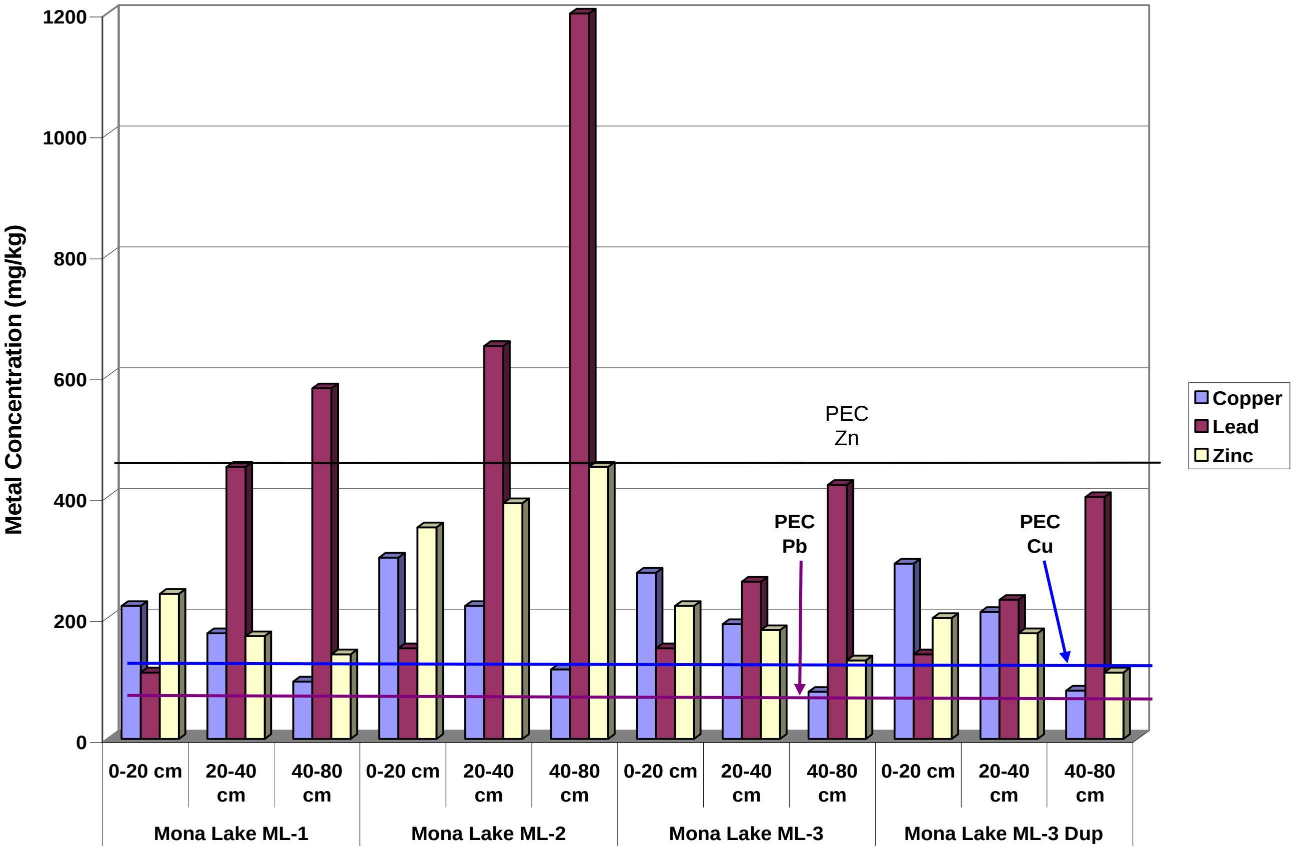

FIGURE 2. 11. DISTRIBUTION OF COPPER, LEAD, AND ZINC IN CORE SAMPLES COLLECTED IN MONA LAKE, AUGUST 2005.

TABLE 2.19. SUMMARY OF CORE SAMPLING LOCATIONS IN MONA LAKE THAT EXCEED CONSENSUS BASED PEC GUIDELINES (MACDONALD ET AL. 2000).

Contaminant	Consensus-Based PEC mg/kg	Location in Little Black Creek that Exceed the PEC
Arsenic	33.0	None
Cadmium	4.98	All locations except the 0-20 cm section of ML-1.
Chromium	111	All locations except the 0-20 cm sections of ML-1 and ML-2
Copper	149	All locations except the 40-80 cm sections of the cores
Lead	128	All locations except the 0-20 cm section of ML-1.
Mercury	1.06	The 0-20 cm section of ML-2.
Zinc	459	None
Total PAH Compounds	22.9	None

2.3.3 Mona View Sediment Cores

Since wetlands can function as sediment deposition zones, a series of core samples were collected in the Mona View wetland, located between Summit and Airline Ave. The results of chromium and cadmium analyses on the core samples are given in Table 2.20 and displayed with depth in Figures 2.12 and 2.13. The cores were collected as a transect across the wetland with the stream channel located between MV-3 and MV-4 (Figure 2.4). Cadmium and chromium levels increased with depth in the core. Concentrations also increased laterally from the stream to the midpoint, and then decreased at the outer boundary of the wetland. The highest cadmium and chromium concentrations on the 0-20 cm sections were found at the midpoint stations MV-4 (54 mg/kg and 260 mg/kg, respectively) and MV-5 (64 mg/kg and 229 mg/kg, respectively). Most of the material collected in the cores consisted of coarse plant material (*Typha*) with small amounts of black organic silts. The area sampled appeared to be a floating cattail mat that was 80-100 cm thick. There was a 0.5-1 m water space beneath the mat followed by soft sediment. We were unable to collect cores of the sediment beneath the mat due to the limitations of our hand coring device. Given the predominance of plant material in the cores, it is unknown whether the small amount of sediment was from transport/deposition or the decay of plant tissue. Given the dense structure of the cattail mat, sediment and associated metals would have limited mobility. Storm events only would be able to erode small amounts of sediment from the mat.

TABLE 2. 20 CADMIUM AND CHROMIUM RESULTS FOR CORE SAMPLES COLLECTED FROM THE MONA VIEW WETLAND (2004).

Location	Core Section	Total Cadmium mg/kg	Total Chromium mg/kg
MV-1	0-20 cm	12	43
	20-40 cm	15	85
	40-80 cm	17	62
MV-2	0-20 cm	31	190
	20-40 cm	54	260
	40-80 cm	77	411
MV-3	0-20 cm	25	155
	20-40 cm	29	168
	40-80 cm	44	186
MV-4	0-20 cm	16	143
	20-40 cm	29	190
	40-80 cm	33	222
MV-5	0-20 cm	44	166
	20-40 cm	64	229
	40-80 cm	75	310
MV-6	0-20 cm	13	66
	20-40 cm	12	75
	40-80 cm	16	54

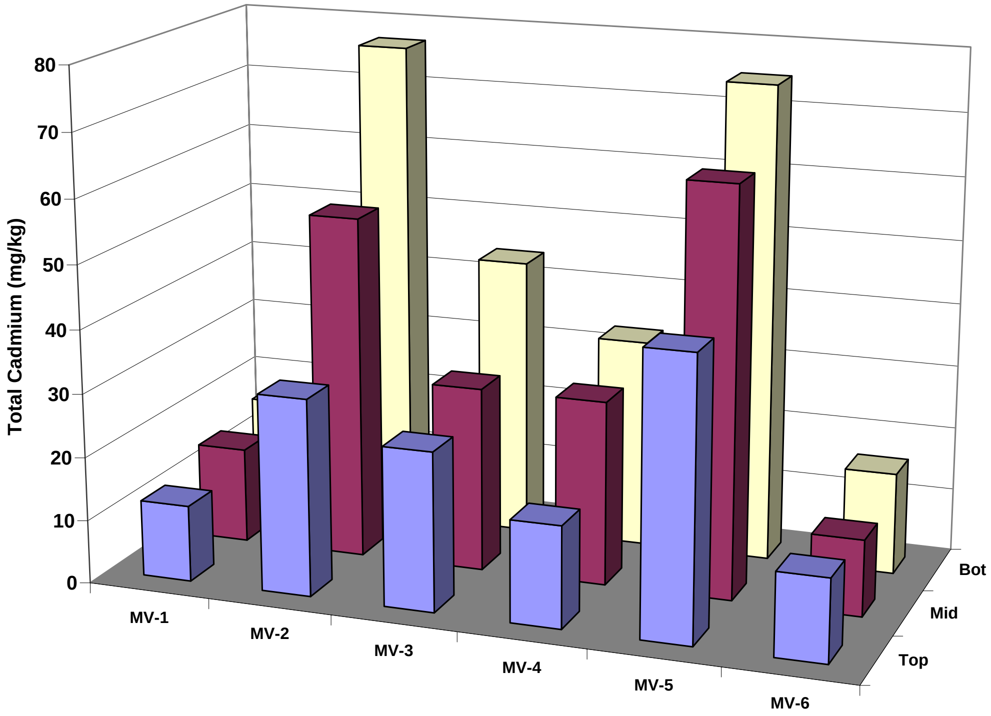

FIGURE 2. 12. CADMIUM RESULTS FOR CORE SAMPLES COLLECTED FROM THE MONA VIEW WETLANDS (2004).

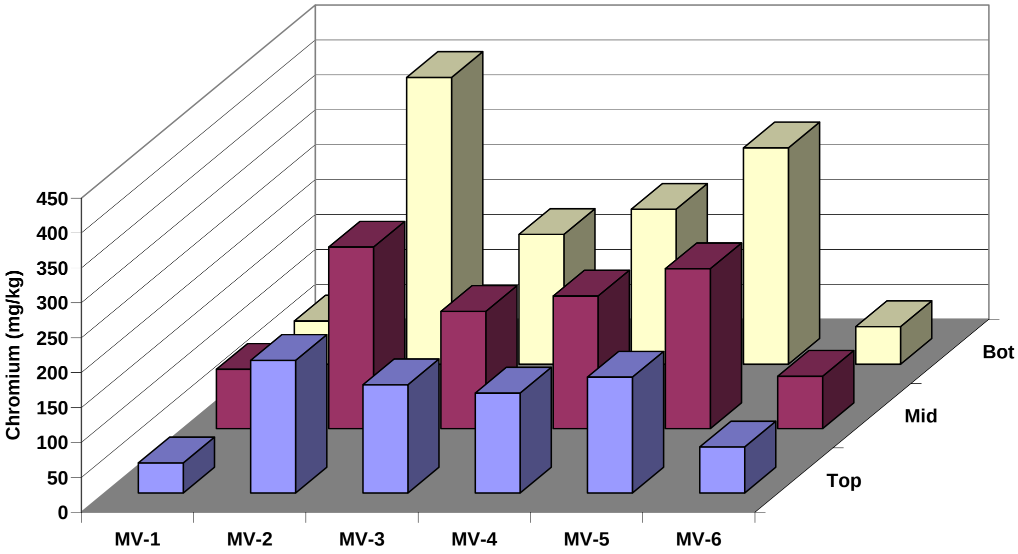

FIGURE 2. 13. CHROMIUM RESULTS FOR CORE SAMPLES COLLECTED FROM THE MONA VIEW WETLANDS (2004).

2.3.2 Industrial Park Sediment Cores

A series of core samples were collected in the Industrial Park wetland, located between Evanston and Roberts Ave. Stormwater drainage enters across the wetland from the adjacent Industrial Park. In addition, contaminated groundwater from the abandoned Marathon Refinery enters the wetland from upstream. Both of these discharges may be sources of PAH compounds. The results of PAH analyses on the core samples are given in Table 2.21 and displayed with depth in Figure 2.14. The cores were collected as a transect across the wetland with the stream channel located between TW-4 and TW-5 (Figure 2.3). The only areas of the wetland that were contaminated with PAH compounds were immediately adjacent to the stream bank (TW-4 and TW-5). PAH compounds were not detected in the transect locations. Concentrations of total PAH compounds ranged from 2 mg/kg to 7 mg/kg with the great accumulation in the 20 cm-40 cm core section. All PAH levels found in the Industrial Park wetland were below the PEC (22.9 mg/kg). The presence of PAH compounds near the stream bank implies that upstream sources are responsible for the contamination, rather than stormwater entering across the wetland. In addition, the low levels of PAH compounds suggests that groundwater from abandoned Marathon Refinery site is not a significant source of hydrocarbon pollution in the lower watershed.

2.4 Toxicity Testing Results

The toxicity evaluations of the Little Black Creek (2004) and Mona Lake (2005) sediments were conducted as part of this project. Samples collected from Cress Creek (2005) were used as a control for cological investigation (Section 3).. The locations of the sediment samples evaluated for toxicity are shown in Figures 2.1, 2.2, and 3.2. Grab sediment samples were evaluated using the EPA (1999) solid phase testing protocol with *Hyalella azteca* and *Chironomus tentans*.

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

Table 2. 21 PAH Results for Core Samples Collected from the Industrial Park Wetlands (2004).

Location	Core Section	Naphthalene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluoranthene	Benzo(k) fluoranthene	Benzo(a)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total PAH Compounds
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
TW-1	0-20 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	20-40 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	40-80 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
TW-2	0-20 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	20-40 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	40-80 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
TW-3	0-20 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	20-40 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	40-80 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
TW-4	0-20 cm	0.78	0.54	0.43	0.32	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	2.07
	20-40 cm	1.55	0.42	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	1.97
	40-80 cm	2.33	1.45	1.66	0.78	0.66	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	6.88
TW-5	0-20 cm	0.98	1.33	1.21	0.72	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	4.24
	20-40 cm	2.66	1.98	1.48	0.85	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	6.97
	40-80 cm	1.55	1.32	0.89	0.42	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	4.18
TW-6	0-20 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	20-40 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	40-80 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
TW-7	0-20 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	20-40 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00
	40-80 cm	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	<0.33	0.00

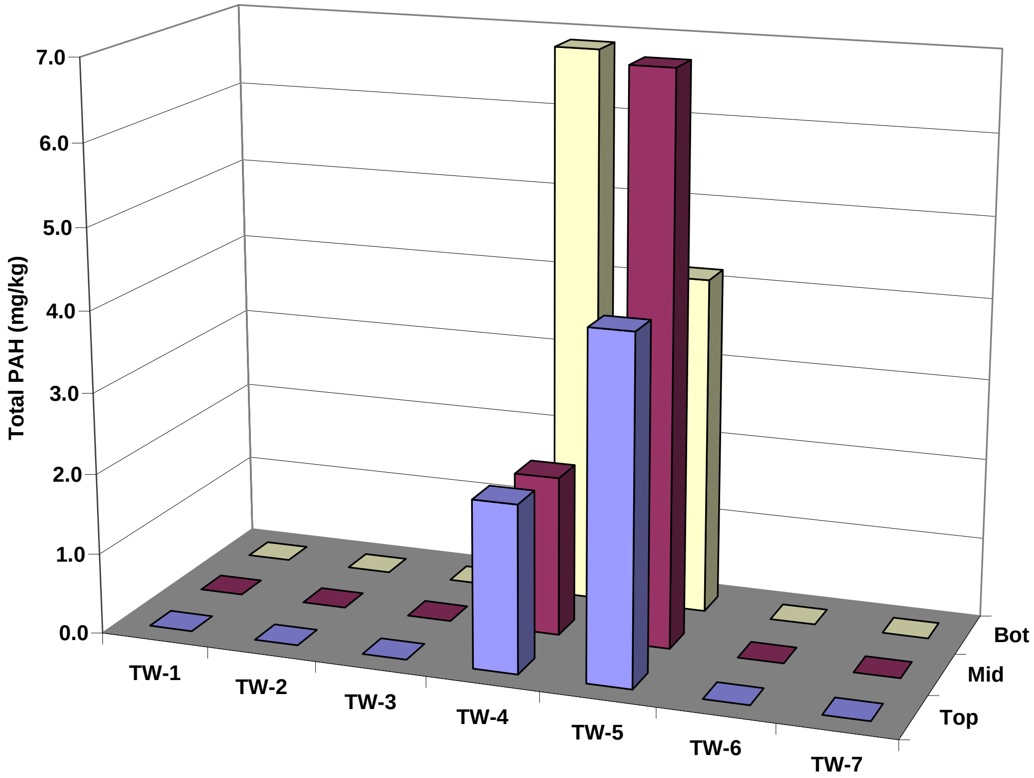

FIGURE 2. 14 TOTAL PAH RESULTS FOR THE CORE SAMPLES COLLECTED IN THE INDUSTRIAL PARK WETLANDS (2004). (TOP = 0-20 CM, MID=20-40 CM, AND BOT=40-80CM)

2.4.1 HYALELLA AZTECA IN LITTLE BLACK CREEK

Survival and weight data for solid phase toxicity tests with *Hyalella azteca* in Little Black Creek sediment are presented in Tables 2.22 and 2.23, respectively. The survival in the control treatments exceeded the required 90%. Samples collected near Peerless Plating had survival rates of 16% and 0%, indicating a high degree of toxicity. In addition, the Seaway site also had 0% survival. Un-transformed survival and growth data were evaluated with Shapiro Wilks Test for normality. The data were not normally distributed and consequently, a nonparametric statistical test was required. Steel's Many One Rank Test (Table 2.24) showed that statistically significant differences in survival and weight were noted at Peerless 1 & 2, Mona View, and Seaway. A statistically significant difference in survival was observed at the lower wetlands.

TABLE 2.22 SUMMARY OF *HYALELLA AZTECA* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LITTLE BLACK CREEK SEDIMENTS (2004).

Location	Sample ID	Added	Alive	Mean Survival	Std Dev	Mean % Survival*
Evanston Stream	A	10	9	7.9	0.9270	79
	B	10	8			
	C	10	7			
	D	10	9			
	E	10	7			
	F	10	9			
	G	10	7			
	H	10	7			
Industrial Park	A	10	7	8.0	1.1180	80
	B	10	9			
	C	10	7			
	D	10	10			
	E	10	9			
	F	10	7			
	G	10	7			
	H	10	8			
Roberts	A	10	9	8.4	0.8570	84
	B	10	7			
	C	10	7			
	D	10	9			
	E	10	9			
	F	10	8			
	G	10	9			
	H	10	9			
Peerless 1	A	10	3	1.6	0.9922	16
	B	10	3			
	C	10	2			
	D	10	1			
	E	10	0			
	F	10	1			
	G	10	2			
	H	10	1			
Peerless 2	A	10	0	0.0	0.0000	0
	B	10	0			
	C	10	0			
	D	10	0			
	E	10	0			
	F	10	0			
	G	10	0			
	H	10	0			
Sherman & Getty Downstream	A	10	7	8.0	0.7071	80
	B	10	8			
	C	10	8			
	D	10	7			
	E	10	9			
	F	10	8			
	G	10	9			
	H	10	8			

Table 2.22 (Continued). Summary of *Hyalella azteca* Survival Data Obtained During the 10 Day Toxicity Test with Little Black Creek Sediments (2004).

Location	Sample ID	Added	Alive	Mean Survival	Std Dev	Mean % Survival*
Summit	A	10	7	7.3	1.2990	73
	B	10	6			
	C	10	8			
	D	10	6			
	E	10	10			
	F	10	8			
	G	10	6			
	H	10	7			
LBC Mona View Wetland	A	10	5	4.9	0.7806	49
	B	10	4			
	C	10	5			
	D	10	6			
	E	10	4			
	F	10	4			
	G	10	6			
	H	10	5			
Airline	A	10	9	7.4	1.2183	74
	B	10	7			
	C	10	7			
	D	10	9			
	E	10	5			
	F	10	7			
	G	10	7			
	H	10	8			
Seaway	A	10	0	0.0	0.0000	0
	B	10	0			
	C	10	0			
	D	10	0			
	E	10	0			
	F	10	0			
	G	10	0			
	H	10	0			
LBC Lower Wetland	A	10	7	7.1	1.0533	71
	B	10	8			
	C	10	6			
	D	10	6			
	E	10	7			
	F	10	6			
	G	10	9			
	H	10	8			
Outlet	A	10	7	8.4	1.6536	84
	B	10	8			
	C	10	5			
	D	10	10			
	E	10	10			
	F	10	10			
	G	10	9			
	H	10	8			
Control	A	10	10	9.1	0.9270	91
	B	10	10			
	C	10	9			
	D	10	8			
	E	10	8			
	F	10	10			
	G	10	8			
	H	10	10			

Table 2. 23. Summary of *Hyalella azteca* Dry Weight Data Obtained During the 10 Day Toxicity Test with Little Black Creek Sediments.

Location	Sample ID	Organisms		Mean DW (mg)
		Alive	DW (mg)	
Evanston Stream	A	9	0.0571	0.0628
	B	8	0.0625	
	C	7	0.0571	
	D	9	0.0800	
	E	7	0.0571	
	F	9	0.0667	
	G	7	0.0500	
	H	7	0.0714	
Industrial Park	A	7	0.0743	0.0747
	B	9	0.0667	
	C	7	0.0857	
	D	10	0.0600	
	E	9	0.0667	
	F	7	0.0857	
	G	7	0.0714	
	H	8	0.0875	
Roberts	A	9	0.0778	0.0717
	B	7	0.0714	
	C	7	0.0714	
	D	9	0.0667	
	E	9	0.0778	
	F	8	0.0750	
	G	9	0.0667	
	H	9	0.0667	
Peerless 1	A	3	0.0329	0.0410
	B	3	0.0500	
	C	2	0.0344	
	D	1	0.0471	
	E	0	0.0312	
	F	1	0.0275	
	G	2	0.0400	
	H	1	0.0650	
Peerless 2	A	0	0.0000	0.0000
	B	0	0.0000	
	C	0	0.0000	
	D	0	0.0000	
	E	0	0.0000	
	F	0	0.0000	
	G	0	0.0000	
	H	0	0.0000	
Sherman & Getty Downstream	A	7	0.0775	0.0757
	B	8	0.0625	
	C	8	0.0750	
	D	7	0.0714	
	E	9	0.0667	
	F	8	0.0875	
	G	9	0.0778	
	H	8	0.0875	
Summit	A	7	0.0286	0.0540
	B	6	0.0500	
	C	8	0.0625	
	D	6	0.0500	
	E	10	0.0800	
	F	8	0.0375	
	G	6	0.0667	
	H	7	0.0571	

Location	Sample ID	Organisms		Mean DW (mg)
		Alive	DW (mg)	
LBC Mona View Wetland	A	5	0.0414	0.0428
	B	4	0.0367	
	C	5	0.0450	
	D	6	0.0557	
	E	4	0.0450	
	F	4	0.0367	
	G	6	0.0450	
	H	5	0.0367	
Airline	A	9	0.0444	0.0609
	B	7	0.0714	
	C	7	0.0571	
	D	9	0.0556	
	E	5	0.1000	
	F	7	0.0286	
	G	7	0.0429	
	H	8	0.0875	
Seaway	A	0	0.0000	0.0000
	B	0	0.0000	
	C	0	0.0000	
	D	0	0.0000	
	E	0	0.0000	
	F	0	0.0000	
	G	0	0.0000	
	H	0	0.0000	
LBC Lower Wetland	A	7	0.0711	0.0558
	B	8	0.0475	
	C	6	0.0500	
	D	6	0.0489	
	E	7	0.0500	
	F	6	0.0700	
	G	9	0.0600	
	H	8	0.0489	
Outlet	A	7	0.0857	0.0789
	B	8	0.0750	
	C	5	0.0800	
	D	10	0.0600	
	E	10	0.1000	
	F	10	0.0900	
	G	9	0.0778	
	H	8	0.0625	
Control	A	10	0.1100	0.0774
	B	10	0.0700	
	C	9	0.0667	
	D	8	0.0750	
	E	8	0.0625	
	F	10	0.0900	
	G	8	0.0750	
	H	10	0.0700	

TABLE 2. 24. RESULTS OF STEEL'S MANY-ONE RANK TEST ANALYSIS OF *HYALELLA AZTECA* SURVIVAL AND WEIGHT DATA FOR LITTLE BLACK CREEK SEDIMENTS (2004).

***Hyalella azteca* Survival– Results from Steel's Many-One Rank Test**			
Site	**Rank Sum - Control**	**Rank Sum – Treatment**	**Sig. at 0.05 alpha**
Evanston	88	48	
Industrial Park	85.5	50.5	
Roberts	81	55	
Peerless1	100	36	*
Peerless2	100	36	*
Sherman & Getty Downstream	87	49	
Summit	91	45	
LBC Mona View Wetland	100	36	*
Airline	91.5	44.5	
Seaway	100	36	*
LBC Lower Wetland	93.5	42.5	*
Outlet	75.5	60.5	
***Hyalella azteca* Average Weight – Results from Steel's Many-One Rank Test**			
Evanston	88	48	
Industrial Park	70	66	
Roberts	70	66	
Peerless1	99	37	*
Peerless2	100	36	*
Sherman & Getty Downstream	64.5	71.5	
Summit	92	44	
LBC Mona View Wetland	100	36	*
Airline	83	53	
Seaway	100	36	*
LBC Lower Wetland	92	44	
Outlet	62.5	73.5	

2.4.2 CHIRONOMUS TENTANS IN LITTLE BLACK CREEK

Survival and weight data for solid phase toxicity tests with *Chironomus tentans* in Little Black Creek sediment are presented in Tables 2.25 and 2.26, respectively. The survival in the control treatments exceeded the required 80%. Samples collected near Peerless Plating had survival rates of 28% and 0%, indicating a high degree of toxicity. In addition, the Seaway site also had 0% survival. Un-transformed survival and growth data were evaluated with Shapiro Wilks Test for normality. The data were not normally distributed and consequently, a nonparametric statistical test was required. Steel's Many One Rank Test (Table 2.27) showed that statistically significant differences in survival and weight were noted at Peerless 1, Peerless 2, and Seaway. A statistically significant difference in weight was observed at Sherman/Getty DS, Mona View, Airline, and the LBC Lower Wetland.

TABLE 2. 25. SUMMARY OF *CHIRONOMUS TENTANS* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LITTLE BLACK CREEK SEDIMENTS (2004).

Location	Sample ID	Added	Alive	Mean Survival	Std Dev	Mean % Survival*
Evanston Stream	A	10	8	7.1	2.0879	71
	B	10	9			
	C	10	4			
	D	10	8			
	E	10	8			
	F	10	10			
	G	10	4			
	H	10	6			
Industrial Park	A	10	9	8.3	1.1990	83
	B	10	9			
	C	10	8			
	D	10	7			
	E	10	6			
	F	10	8			
	G	10	9			
	H	10	10			
Roberts	A	10	7	7.4	0.8570	74
	B	10	6			
	C	10	7			
	D	10	9			
	E	10	8			
	F	10	7			
	G	10	8			
	H	10	7			
Peerless 1	A	10	3	2.8	1.5612	28
	B	10	4			
	C	10	5			
	D	10	2			
	E	10	4			
	F	10	1			
	G	10	0			
	H	10	3			
Peerless 2	A	10	0	0.0	0.0000	0
	B	10	0			
	C	10	0			
	D	10	0			
	E	10	0			
	F	10	0			
	G	10	0			
	H	10	0			
Sherman & Getty Downstream	A	10	7	7.0	1.0000	70
	B	10	7			
	C	10	6			
	D	10	7			
	E	10	6			
	F	10	6			
	G	10	8			
	H	10	9			

Table 2.25 (Continued). Summary of *Chironomus tentans* Survival Data Obtained During the 10 Day Toxicity Test with Little Black Creek Sediments

Location	Sample ID	Added	Alive	Mean Survival	Std Dev	Mean % Survival*
Summit	A	10	7	8.6	1.2183	86
	B	10	7			
	C	10	8			
	D	10	10			
	E	10	8			
	F	10	9			
	G	10	10			
	H	10	10			
LBC Mona View Wetland	A	10	3	3.6	2.8696	36
	B	10	5			
	C	10	2			
	D	10	2			
	E	10	0			
	F	10	1			
	G	10	8			
	H	10	8			
Airline	A	10	6	6.5	1.1180	65
	B	10	8			
	C	10	5			
	D	10	7			
	E	10	8			
	F	10	7			
	G	10	6			
	H	10	5			
Seaway	A	10	0	0.0	0.0000	0
	B	10	0			
	C	10	0			
	D	10	0			
	E	10	0			
	F	10	0			
	G	10	0			
	H	10	0			
LBC Lower Wetland	A	10	7	6.8	0.9682	68
	B	10	6			
	C	10	8			
	D	10	6			
	E	10	8			
	F	10	7			
	G	10	5			
	H	10	7			
Outlet	A	10	7	7.6	0.4841	76
	B	10	8			
	C	10	8			
	D	10	8			
	E	10	8			
	F	10	7			
	G	10	8			
	H	10	7			
Control	A	10	10	8.1	0.9270	81
	B	10	8			
	C	10	8			
	D	10	7			
	E	10	8			
	F	10	7			
	G	10	8			
	H	10	9			

TABLE 2. 26. SUMMARY OF *CHIRONOMUS TENTANS* DRY WEIGHT DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH LITTLE BLACK CREEK

Location	Sample ID	Organisms		Mean AFDM (mg)
		Alive	AFDM (mg)	
Evanston Stream	A	8	0.4500	0.4916
	B	9	0.4222	
	C	4	0.4250	
	D	8	0.5750	
	E	8	0.5875	
	F	10	0.4900	
	G	4	0.4500	
	H	6	0.5333	
Industrial Park	A	9	0.4333	0.5221
	B	9	0.5444	
	C	8	0.6125	
	D	7	0.6571	
	E	6	0.4000	
	F	8	0.5375	
	G	9	0.5222	
	H	10	0.4700	
Roberts	A	7	0.4143	0.4503
	B	6	0.4800	
	C	7	0.4571	
	D	9	0.4222	
	E	8	0.5000	
	F	7	0.4714	
	G	8	0.3857	
	H	7	0.4714	
Peerless 1	A	3	0.2333	0.2564
	B	4	0.3500	
	C	5	0.3444	
	D	2	0.2000	
	E	4	0.3833	
	F	1	0.3000	
	G	0	0.0000	
	H	3	0.2400	
Peerless 2	A	0	0.0000	0.0000
	B	0	0.0000	
	C	0	0.0000	
	D	0	0.0000	
	E	0	0.0000	
	F	0	0.0000	
	G	0	0.0000	
	H	0	0.0000	
Sherman & Getty Downstream	A	7	0.3200	0.4050
	B	7	0.3429	
	C	6	0.3833	
	D	7	0.4714	
	E	6	0.5500	
	F	6	0.4333	
	G	8	0.2500	
	H	9	0.4889	
Summit	A	7	0.4286	0.4468
	B	7	0.5286	
	C	8	0.3500	
	D	10	0.4800	
	E	8	0.4625	
	F	9	0.4444	
	G	10	0.3900	
	H	10	0.4900	

Location	Sample ID	Organisms		Mean AFDM (mg)
		Alive	AFDM (mg)	
LBC Mona View Wetland	A	3	0.3000	0.2494
	B	5	0.2200	
	C	2	0.3000	
	D	2	0.2500	
	E	0	0.0000	
	F	1	0.4000	
	G	8	0.2500	
	H	8	0.2750	
Airline	A	6	0.4100	0.4106
	B	8	0.4667	
	C	5	0.4000	
	D	7	0.5125	
	E	8	0.3625	
	F	7	0.3500	
	G	6	0.4333	
	H	5	0.3500	
Seaway	A	0	0.0000	0.0000
	B	0	0.0000	
	C	0	0.0000	
	D	0	0.0000	
	E	0	0.0000	
	F	0	0.0000	
	G	0	0.0000	
	H	0	0.0000	
LBC Lower Wetland	A	7	0.5143	0.4413
	B	6	0.4875	
	C	8	0.4250	
	D	6	0.4250	
	E	8	0.3750	
	F	7	0.4714	
	G	5	0.4750	
	H	7	0.3571	
Outlet	A	7	0.5143	0.5288
	B	8	0.4875	
	C	8	0.4250	
	D	8	0.4250	
	E	8	0.3750	
	F	7	0.7714	
	G	8	0.4750	
	H	7	0.7571	
Control	A	10	0.5700	0.5788
	B	8	0.4875	
	C	8	0.4250	
	D	7	0.7143	
	E	8	0.6400	
	F	7	0.5714	
	G	8	0.5625	
	H	9	0.6600	

TABLE 2. 27. RESULTS OF STEEL'S MANY-ONE RANK TEST ANALYSIS OF *HYALELLA AZTECA* SURVIVAL AND WEIGHT DATA FOR LITTLE BLACK CREEK SEDIMENTS (2004).

Site	Rank Sum - Control	Rank Sum – Treatment	Sig. at 0.05 alpha
***Chironomus tentans* Survival– Results from Steel's Many-One Rank Test**			
Evanston	74	62	
Industrial Park	64	72	
Roberts	81.5	54.5	
Peerless1	100	36	*
Peerless2	100	36	*
Sherman & Getty Downstream	86.5	49.5	
Summit	61	75	
LBC Mona View Wetland	92	44	
Airline	90	46	
Seaway	100	36	*
LBC Lower Wetland	89	47	
Outlet	77	59	
***Chironomus tentans* Average Weight – Results from Steel's Many-One Rank Test**			
Evanston	83	53	
Industrial Park	81	55	
Roberts	92	44	
Peerless1	100	36	*
Peerless2	100	36	*
Sherman & Getty Downstream	94	42	*
Summit	92	44	
LBC Mona View Wetland	100	36	*
Airline	96	40	*
Seaway	100	36	*
LBC Lower Wetland	92.5	43.5	*
Outlet	77.5	58.5	

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2.4.3 SEDIMENT TOXICITY DATA EVALUATION FOR LITTLE BLACK CREEK

Spearman Rank Order Correlations were developed for the chemical parameters measured in the investigation (Table 2.28) to further examine the relationship between these variables and toxicity. Survival and weight gain in both organisms were negatively

TABLE 2. 28. SPEARMAN'S RANK ORDER CORRELATIONS FOR THE CHEMICAL AND PHYSICAL PARAMETERS IN LITTLE BLACK CREEK SEDIMENTS.

Spearman's rho Sig. (2-tailed)	Total Chromium / mg/kg	Total Copper / mg/kg	Total Lead / mg/kg	Total Zinc / mg/kg	Total Mercury / mg/kg	Total PAH / mg/kg	Total PCBs / mg/kg	*H.a.* Survival / %	*C.t.* Survival / %	*H.a.* Growthl / %	*C.t.* Growth/ %
Total Cadmium / mg/kg	.825(**) .001	.651(*) .022	.406 .190	.671(*) .017	.165 .609	.352 .262	.082 .800	-.796(**) .002	-.766(**) .004	-.788(**) .002	-.755(**) .004
Total Chromium / mg/kg		.872(**) .000	.676(*) .016	.888(**) .000	.463 .129	.521 .082	.202 .530	-.789(**) .002	-.823(**) .001	-.795(**) .002	-.812(**) .001
Total Copper / mg/kg			.888(**) .000	.970(**) .000	.522 .082	.727(**) .007	.419 .175	-.681(*) .015	-.707(*) .010	-.676(*) .016	-.707(*) .010
Total Lead / mg/kg				.904(**) .000	.503 .096	.815(**) .001	.613(*) .034	-.423 .170	-.473 .121	-.423 .170	-.473 .121
Total Zinc / mg/kg					.537 .072	.697(*) .012	.433 .160	-.648(*) .023	-.688(*) .013	-.681(*) .015	-.688(*) .013
Total Mercury / mg/kg						.519 .083	.434 .158	-.357 .255	-.370 .236	-.357 .255	-.370 .236
Total PAH / mg/kg							.876(**) .000	-.596(*) .041	.676(*) .016	-.596(*) .041	-.651(*) .022
Total PCBs / mg/kg								-.368 .239	-.352 .262	-.368 .239	-.352 .262
H.a. Survival / %									.933(**) .000	.948(**) .000	.950(**) .000
C.t. Survival										.941(**) 0.000	.950(**) 0.000
H.a. Growthl											.946(**) 0.000

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

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

correlated with cadmium ($p < 0.01$), chromium ($p < 0.01$), zinc ($p < 0.05$), and PAH compounds ($p < 0.05$). These metals and organic compounds we found at levels significantly above the respective PECs. The high degree of toxicity at the two sites near Peerless Plating appears to be driven by cadmium and chromium while the toxicity at Seaway is from elevated PAH compounds. The mortality and growth reductions at the other sites seem to be a function of both metals and PAH compounds based on concentration.

2.4.4 HYALELLA AZTECA IN CRESS CREEK AND MONA LAKE

Survival and weight data for solid phase toxicity tests with *Hyalella azteca* in Cress Creek and Mona Lake sediment are presented in Tables 2.29 and 2.30, respectively. The survival in the control treatments exceeded the required 90%. Un-transformed survival and growth data were evaluated with Shapiro Wilks Test for normality. The data were not normally distributed and consequently, a nonparametric statistical test was required. Steel's Many One Rank Test (Table 2.31) showed that no statistically significant differences in survival and weight were present in the data.

2.4.5 CHIRONOMUS TENTANS IN CRESS CREEK AND MONA LAKE

Survival and weight data for solid phase toxicity tests with *Chironomus tentans* in Cress Creek and Mona Lake sediment are presented in Tables 2.32 and 2.33, respectively. The survival in the control treatments exceeded the required 90%. Un-transformed survival and growth data were evaluated with Shapiro Wilks Test for normality. The data were not normally distributed and consequently, a nonparametric statistical test was required. Steel's Many One Rank Test (Table 2.34) showed that a statistically significant difference for Chironomus tentans was present in Mona Lake at ML-2. No statistically significant differences in survival and weight were present for the other locations..

2.4.3 SEDIMENT TOXICITY DATA EVALUATION FOR LITTLE BLACK CREEK

No toxicity was observed in the sediments from Cress Creek. This system was used as a control for the ecological evaluation in Section 3. Based on the absence of sediment toxicity and the similarity in stream conditions discussed in the next section, Cress Creek appears to be an appropriate control system. The only toxic response observed in Mona Lake was a reduction in *Chironomus tentans* growth at ML-2. This location had the highest level of metals in the 0-20 mc core section.

TABLE 2. 29. SUMMARY OF *HYALELLA AZTECA* SURVIVAL DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH CRESS CREEK AND MONA LAKE SEDIMENTS (2005).

Sample ID	Rep.	# of organisms		Mean Survival	Std Dev	% Survival
		Added	Alive			
Cress Towner Rd impoundment Wetland	A	10	9	9.25	0.829	93
	B	10	8			
	C	10	10			
	D	10	10			
	E	10	9			
	F	10	10			
	G	10	10			
	H	10	8			
Cress Hidden Cove Wetland	A	10	10	9.25	1.090	93
	B	10	10			
	C	10	8			
	D	10	10			
	E	10	10			
	F	10	7			
	G	10	10			
	H	10	9			
Cress @ Quarterline Rd Stream	A	10	10	9.75	0.433	98
	B	10	10			
	C	10	10			
	D	10	9			
	E	10	9			
	F	10	10			
	G	10	10			
	H	10	10			
Cress @ Towner Rd Stream	A	10	9	8.75	0.829	88
	B	10	9			
	C	10	10			
	D	10	8			
	E	10	9			
	F	10	7			
	G	10	9			
	H	10	9			
Cress @ Proctors Stream	A	10	9	8.875	0.781	89
	B	10	7			
	C	10	9			
	D	10	9			
	E	10	9			
	F	10	9			
	G	10	10			
	H	10	9			
Cress @ Old Grand Haven Rd Stream	A	10	7	8.25	1.090	83
	B	10	7			
	C	10	7			
	D	10	10			
	E	10	8			
	F	10	9			
	G	10	9			
	H	10	9			
Control	A	10	9	9.125	0.927	91
	B	10	7			
	C	10	10			
	D	10	9			
	E	10	9			
	F	10	10			
	G	10	9			
	H	10	10			
ML -1	A	10	10	9	0.866	90
	B	10	9			
	C	10	8			
	D	10	10			
	E	10	9			
	F	10	10			
	G	10	8			
	H	10	8			
ML-2	A	10	10	9	0.866	90
	B	10	8			
	C	10	10			
	D	10	9			
	E	10	8			
	F	10	9			
	G	10	8			
	H	10	10			
ML-3	A	10	9	8.875	1.269	89
	B	10	8			
	C	10	10			
	D	10	9			
	E	10	10			
	F	10	10			
	G	10	6			
	H	10	9			

TABLE 2. 30. SUMMARY OF *HYALELLA AZTECA* DRY WEIGHT DATA OBTAINED DURING THE 10 DAY TOXICITY TEST WITH CRESS CREEK AND MONA LAKE SEDIMENTS (2005).

Location	Sample ID	Organisms		Mean DW (mg)
		Alive	DW (mg)	
Cress Towner Rd impoundment Wetland	A	9	0.101	0.106
	B	8	0.115	
	C	10	0.120	
	D	10	0.120	
	E	9	0.134	
	F	10	0.090	
	G	10	0.090	
	H	8	0.077	
Cress Hidden Cove Wetland	A	10	0.090	0.070
	B	10	0.080	
	C	8	0.065	
	D	10	0.080	
	E	10	0.050	
	F	7	0.047	
	G	10	0.090	
	H	9	0.057	
Cress @ Quarterline Rd Stream	A	10	0.100	0.102
	B	10	0.060	
	C	10	0.120	
	D	9	0.134	
	E	9	0.101	
	F	10	0.100	
	G	10	0.090	
	H	10	0.110	
Cress @ Towner Rd Stream	A	9	0.079	0.090
	B	9	0.068	
	C	10	0.070	
	D	8	0.077	
	E	9	0.101	
	F	7	0.119	
	G	9	0.101	
	H	9	0.101	
Cress @ Proctors Stream	A	9	0.101	0.112
	B	7	0.176	
	C	9	0.101	
	D	9	0.112	
	E	9	0.112	
	F	9	0.101	
	G	10	0.100	
	H	9	0.090	
Cress @ Old Grand Haven Rd Stream	A	7	0.133	0.087
	B	7	0.076	
	C	7	0.090	
	D	10	0.060	
	E	8	0.115	
	F	9	0.068	
	G	9	0.068	
	H	9	0.090	
Control	A	9	0.068	0.089
	B	7	0.104	
	C	10	0.110	
	D	9	0.090	
	E	9	0.079	
	F	10	0.090	
	G	9	0.090	
	H	10	0.080	
ML -1	A	10	0.070	0.077
	B	9	0.090	
	C	8	0.078	
	D	10	0.070	
	E	9	0.079	
	F	10	0.090	
	G	8	0.065	
	H	8	0.077	
ML-2	A	10	0.090	0.081
	B	8	0.090	
	C	10	0.080	
	D	9	0.079	
	E	8	0.053	
	F	9	0.101	
	G	8	0.065	
	H	10	0.090	
ML-3	A	9	0.101	0.086
	B	8	0.077	
	C	10	0.080	
	D	9	0.079	
	E	10	0.080	
	F	10	0.100	
	G	6	0.090	
	H	9	0.079	

TABLE 2. 31. RESULTS OF STEEL'S MANY-ONE RANK TEST ANALYSIS OF *HYALELLA AZTECA* SURVIVAL AND WEIGHT DATA FOR LITTLE BLACK CREEK SEDIMENTS (2004)

Site	Rank Sum - Control	Rank Sum – Treatment	Sig. at 0.05 alpha
***Hyalella azteca* Survival– Results from Steel's Many-One Rank Test**			
Cress – Towner Rd Impoundment Wetland	66	70	
Cress – Hidden Cove Wetland	63	73	
Cress – Quarterline Rd Stream	55	81	
Cress – Towner Rd Stream	77	59	
Cress – Proctors Stream	75	61	
Cress – Old Grand Haven Rd Stream	82	54	
ML-1	71.5	64.5	
ML-2	71.5	64.5	
ML-3	70.5	65.5	
***Hyalella azteca* Average Weight – Results from Steel's Many-One Rank Test**			
Cress – Towner Rd Impoundment Wetland	49	87	
Cress – Hidden Cove Wetland	84.5	51.5	
Cress – Quarterline Rd Stream	52.5	83.5	
Cress – Towner Rd Stream	70	66	
Cress – Proctors Stream	47	89	
Cress – Old Grand Haven Rd Stream	69.5	66.5	
ML-1	82.5	53.5	
ML-2	72	64	
ML-3	73	63	

Table 2. 32. Summary of *Chironomus tentans* Survival Data Obtained During the 10 Day Toxicity Test with Cress Creek and Mona Lake Sediments (2005).

Sample ID	Rep.	# of Organisms		Mean Survival	Std Dev	% Survival
		Added	Alive			
Cress Towner Rd impoundment Wetland	A	10	8	88.8	1.615	89
	B	10	10			
	C	10	9			
	D	10	10			
	E	10	9			
	F	10	10			
	G	10	5			
	H	10	10			
Cress Hidden Cove Wetland	A	10	10	8.0	1.732	80
	B	10	9			
	C	10	7			
	D	10	9			
	E	10	5			
	F	10	6			
	G	10	10			
	H	10	8			
Cress Quarterline Rd Stream	A	10	7	8.5	1.225	85
	B	10	10			
	C	10	8			
	D	10	10			
	E	10	8			
	F	10	10			
	G	10	8			
	H	10	7			
Cress Towner Rd Stream	A	10	10	9.8	0.433	98
	B	10	10			
	C	10	10			
	D	10	9			
	E	10	10			
	F	10	10			
	G	10	10			
	H	10	9			
Cress Proctors Stream	A	10	10	9.5	0.707	95
	B	10	10			
	C	10	9			
	D	10	8			
	E	10	9			
	F	10	10			
	G	10	10			
	H	10	10			
Cress Old Grand Haven Rd Stream	A	10	8	8.8	1.090	88
	B	10	10			
	C	10	10			
	D	10	9			
	E	10	10			
	F	10	7			
	G	10	8			
	H	10	8			
ML -1	A	10	10	8.4	0.857	84
	B	10	9			
	C	10	7			
	D	10	8			
	E	10	8			
	F	10	8			
	G	10	9			
	H	10	8			
ML-2	A	10	7	6.9	0.781	69
	B	10	6			
	C	10	6			
	D	10	7			
	E	10	8			
	F	10	6			
	G	10	8			
	H	10	7			
ML-3	A	10	7	7.6	0.484	76
	B	10	8			
	C	10	8			
	D	10	8			
	E	10	8			
	F	10	7			
	G	10	8			
	H	10	7			
Control	A	10	7	8.6	1.218	86
	B	10	7			
	C	10	8			
	D	10	10			
	E	10	8			
	F	10	9			
	G	10	10			
	H	10	10			

Table 2. 33. Summary of *Chironomus tentans* Ash Free Dry Mass Data Obtained During the 10 Day Toxicity Test with Cress Creek and Mona Lake Sediments (2005).

Location	Sample ID	Organisms		Mean AFDM (mg)
		Alive	AFDM (mg)	
Cress Towner Rd impoundment Wetland	A	8	0.8500	0.716
	B	10	0.7200	
	C	9	0.7667	
	D	10	0.8100	
	E	9	0.6000	
	F	10	0.7100	
	G	5	0.7000	
	H	10	0.5700	
Cress Hidden Cove Wetland	A	10	0.8100	0.726
	B	9	0.6556	
	C	7	0.8143	
	D	9	0.7889	
	E	5	0.7600	
	F	6	0.6500	
	G	10	0.6400	
	H	8	0.6875	
Cress @ Quarterline Rd Stream	A	7	0.7000	0.775
	B	10	0.5600	
	C	8	0.9750	
	D	10	0.7000	
	E	8	0.8625	
	F	10	0.7300	
	G	8	0.6750	
	H	7	1.0000	
Cress @ Towner Rd Stream	A	10	0.7400	0.666
	B	10	0.5900	
	C	10	0.6500	
	D	9	0.6333	
	E	10	0.6000	
	F	10	0.7000	
	G	10	0.6900	
	H	9	0.7222	
Cress @ Proctors Stream	A	10	0.6300	0.704
	B	10	0.6600	
	C	9	0.6556	
	D	8	0.8500	
	E	9	0.6889	
	F	10	0.6500	
	G	10	0.7400	
	H	10	0.7600	
Cress @ Old Grand Haven Rd Stream	A	8	0.6375	0.685
	B	10	0.6600	
	C	10	0.6500	
	D	9	0.6778	
	E	10	0.5200	
	F	7	0.7714	
	G	8	0.8125	
	H	8	0.7500	
Control	A	10	0.7100	0.711
	B	9	0.7667	
	C	7	0.7000	
	D	8	0.8125	
	E	8	0.6625	
	F	8	0.6500	
	G	9	0.7333	
	H	8	0.6500	
ML -1	A	7	0.6000	0.549
	B	6	0.5200	
	C	6	0.6000	
	D	7	0.5500	
	E	8	0.3000	
	F	6	0.7000	
	G	8	0.5500	
	H	7	0.5750	
ML-2	A	7	0.7143	0.729
	B	8	0.6875	
	C	8	0.6250	
	D	8	0.6250	
	E	8	0.5750	
	F	7	0.9714	
	G	8	0.6750	
	H	7	0.9571	
ML-3	A	7	0.7286	0.747
	B	7	0.8286	
	C	8	0.6500	
	D	10	0.7800	
	E	8	0.7625	
	F	9	0.7444	
	G	10	0.6900	
	H	10	0.7900	

Table 2. 34. Results of Steel's Many-One Rank Test Analysis of *Chironomus tentans* Survival and Weight Data For Little Black Creek Sediments (2004)

Chironomus tentans **Survival – Results from Steel's Many-One Rank Test**

Cress – Towner Rd Impoundment Wetland	62	74	
Cress – Hidden Cove Wetland	74	62	
Cress – Quarterline Rd Stream	69.5	66.5	
Cress – Towner Rd Stream	52	84	
Cress – Proctors Stream	55.5	80.5	
Cress – Old Grand Haven Rd Stream	66	70	
ML-1	71.5	64.5	
ML-2	91	45	
ML-3	82	54	

Chironomus tentans **Average Weight – Results from Steel's Many-One Rank Test**

Cress – Towner Rd Impoundment Wetland	74	62	
Cress – Hidden Cove Wetland	73	63	
Cress – Quarterline Rd Stream	68	68	
Cress – Towner Rd Stream	91	45	
Cress – Proctors Stream	81	55	
Cress – Old Grand Haven Rd Stream	81	55	
ML-1	79	57	
ML-2	98	38	*
ML-3	80	56	

2.5 Summary and Conclusions

A preliminary investigation of the nature and extent of sediment contamination in Little Black Creek, Cress Creek, and Mona Lake was performed that involved sediment chemistry and toxicity, ecological assessment, and metal transport modeling. Sediment chemistry and solid-phase toxicity were examined at 12 locations in Little Black Creek, 6 locations in Cress Creek, and 3 locations in Mona Lake. High levels of PAH compounds (40 – 60 mg/kg) were found in an area near Seaway Drive, downstream of Sherman/Getty culvert, and the stream reach between the Mona View wetlands and Airline Rd. Sediment toxicity also was observed at these locations. High levels of cadmium were found in the stream reach from Peerless Plating (1,600 mg/kg) to the creek mouth at Mona Lake (11 mg/kg). Elevated levels of chromium, lead and zinc also were present. High mortality in both test organisms was observed near Peerless Plating (0-20% survival). Based on these results, the Little Black Creek system was found to be highly impacted by metals and PAH compounds. The Peerless Plating Superfund Site appears to be the source of most of the cadmium and chromium observed in the creek, although additional sources of metals are present near the Mona View wetlands, Seaway Drive, and the Lower wetlands.

Contaminated sediments were present in Mona Lake, with the basin near Little Black Creek containing higher concentrations of metals than Black Creek. Although the concentrations were above PEC levels, the only toxic response noted was a small reduction in midge growth in the basin near LBC. Sediment toxicity was not present in the station near the middle of the lake. Cress Creek was found to be an acceptable control site due to the absence of sediment toxicity.

2.6 References

Chapman, P.M. 1992. Sediment quality triad approach. In: Sediment Classification Methods Compendium. EPA 823-R-92-006. USEPA. Washington, D.C.

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

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.

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3.0 Ecological Assessment

3.1 Introduction

An ecological assessment of the sediment contamination in Little Black Creek was conducted using a paired sampling approach with a similar stream, Cress Creek, as a reference. Cress Creek has similar hydrology and vegetation as Little Black Creek and is impacted by anthropologic stressors related to urban development, road/stream crossings, and a golf course. The Cress Creek watershed contains no heavy industry or point sources of heavy metals and/or organic chemicals. By using paired sampling stations with similar stream conditions and hydrology, this allows the isolation of anthropogenic factors such as sediment contamination from population changes resulting from the physical environment.

3.2 Site Selection and Time of Sampling

Since the goal of this study was to compare sediment contamination and its effects between the heavily contaminated Little Black Creek and the relatively uncontaminated Cress Creek, we chose sampling sites at comparable locations within each watershed. This pairing of sites was important because it accounted for factors associated with upstream/downstream location, allowing us to isolate anthropogenic factors such as sediment contamination. Accordingly, stream sites were chosen to cover the entire length of each stream and were located at comparable upstream/downstream distances. Wetland sites were also chosen at comparable locations within each watershed with one pair located at intermediate distances between headwaters and Mona Lake and a second pair located adjacent to the mouths of each stream. An additional wetland of Little Black Creek, the Industrial Park site, was sampled in May and July but was dry in August. The two lake sites were located within the depositional zone of each stream in Mona Lake.

Macroinvertebrate communities naturally shift in composition seasonally. Therefore, we chose to sample three different time-periods in the streams, wetlands, and lakes. In the wetlands and streams, sampling periods were chosen to represent the growing season (i.e., May through September). In the lake, we also wished to represent the growing season, but delayed our final sampling until November to represent turn-over conditions. Table 3.1 includes the location and indicates what was sampled on each date. The sampling locations are shown in Figures 3.1 and 3.2.

TABLE 3.1 SUMMARY OF DATA COLLECTION INCLUDING SITES, DATES OF SAMPLING, GEOGRAPHIC POSITION, DOMINANT VEGETATION, AND SAMPLES COLLECTED.

						Samples collected				
	Sampling dates			Lattitude	Longitude	Invertebrates	Fish	Physical	Chemical	Toxicants
Streams										
Cress Creek										
Quarterline	28-Apr	25-Jun	24-Aug	N 43.17776	W 86.19543	x		x	x	x
Towner	28-Apr	25-Jun	24-Aug	N 43.17817	W 86.20303	x		x	x	x
Proctors	28-Apr	25-Jun	24-Aug	N 43.17776	W 86.21353	x		x	x	x
Old Grand Haven	28-Apr	25-Jun	24-Aug	N 43.17970	W 86.21999	x		x	x	x
Little Black Creek										
Evanston	27-Apr	28-Jun	25-Aug	N 43.21554	W 86.18101	x		x	x	x
Sherman	27-Apr	28-Jun	25-Aug	N 43.20433	W 86.22347	x		x	x	x
Summit	27-Apr	28-Jun	25-Aug	N 43.19859	W 86.23052	x		x	x	x
Seaway	27-Apr	28-Jun	25-Aug	N 43.18796	W 86.24065	x		x	x	x
Wetlands										
Cress Creek										
Towner	19-May	1-Jul	28-Sep	N 43.17757	W 86.20413	x	x	x	x	x
Hidden Cove	18-May	30-Jun	28-Sep	N 43.17988	W 86.22253	x	x	x	x	x
Little Black Creek										
Industrial Park	2-Jun	1-Jul	NS			x		x	x	x
Mona View	19-May	30-Jun	29-Sep	N 43.19506	W 86.23232	x	x	x	x	x
Turtle Pond	18-May	30-Jun	28-Sep	N 43.18613	W 86.24674	x	x	x	x	x
Lake										
Little Black Creek	20-May	23-Aug	12-Nov	N 43.18385	W 86.24699	x		x		
Cress Creek	20-May	23-Aug	12-Nov	N 43.18243	W 86.22696	x		x		

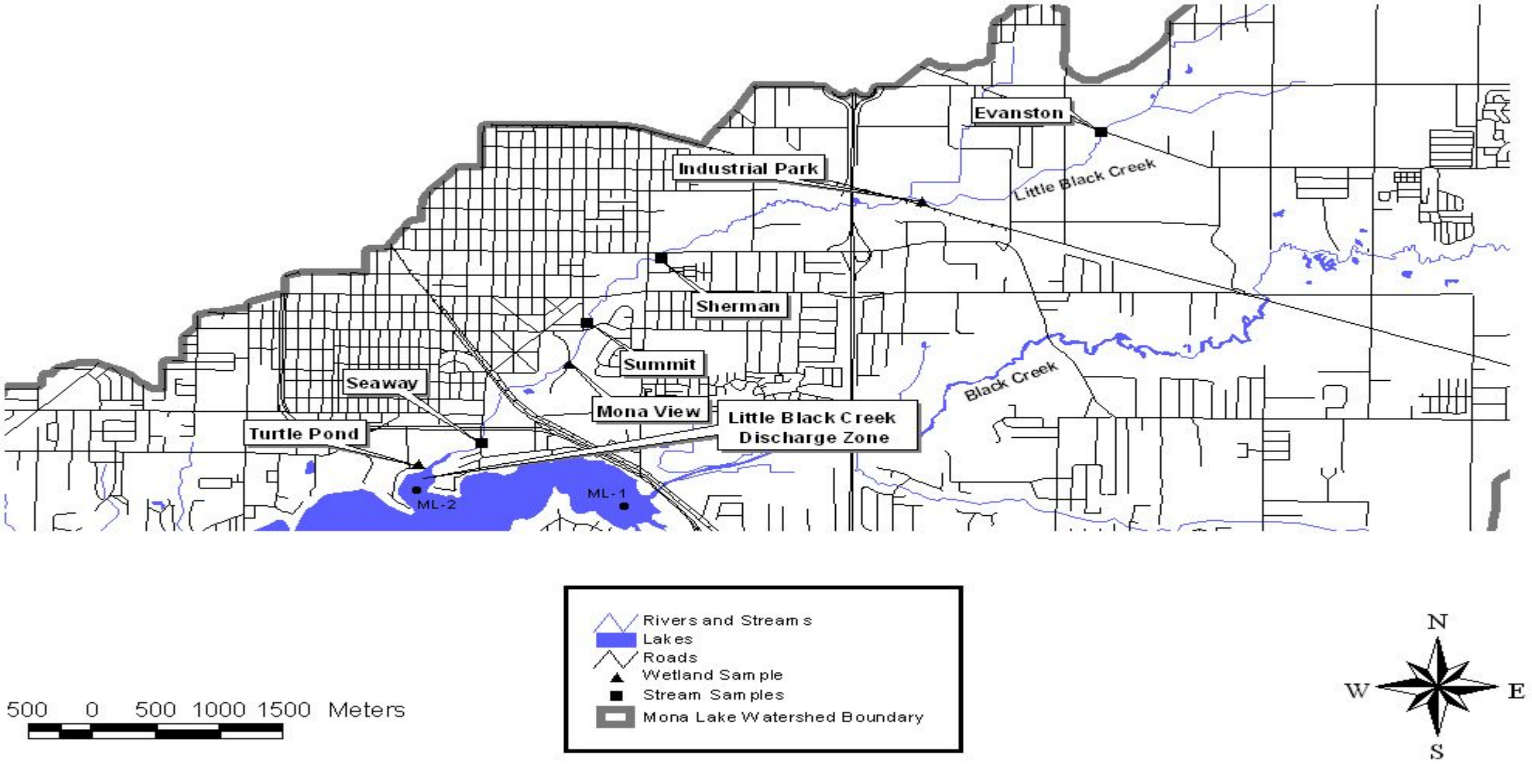

Figure 3. 1. Biological Survey Sampling Locations in Little Black Creek (2004).

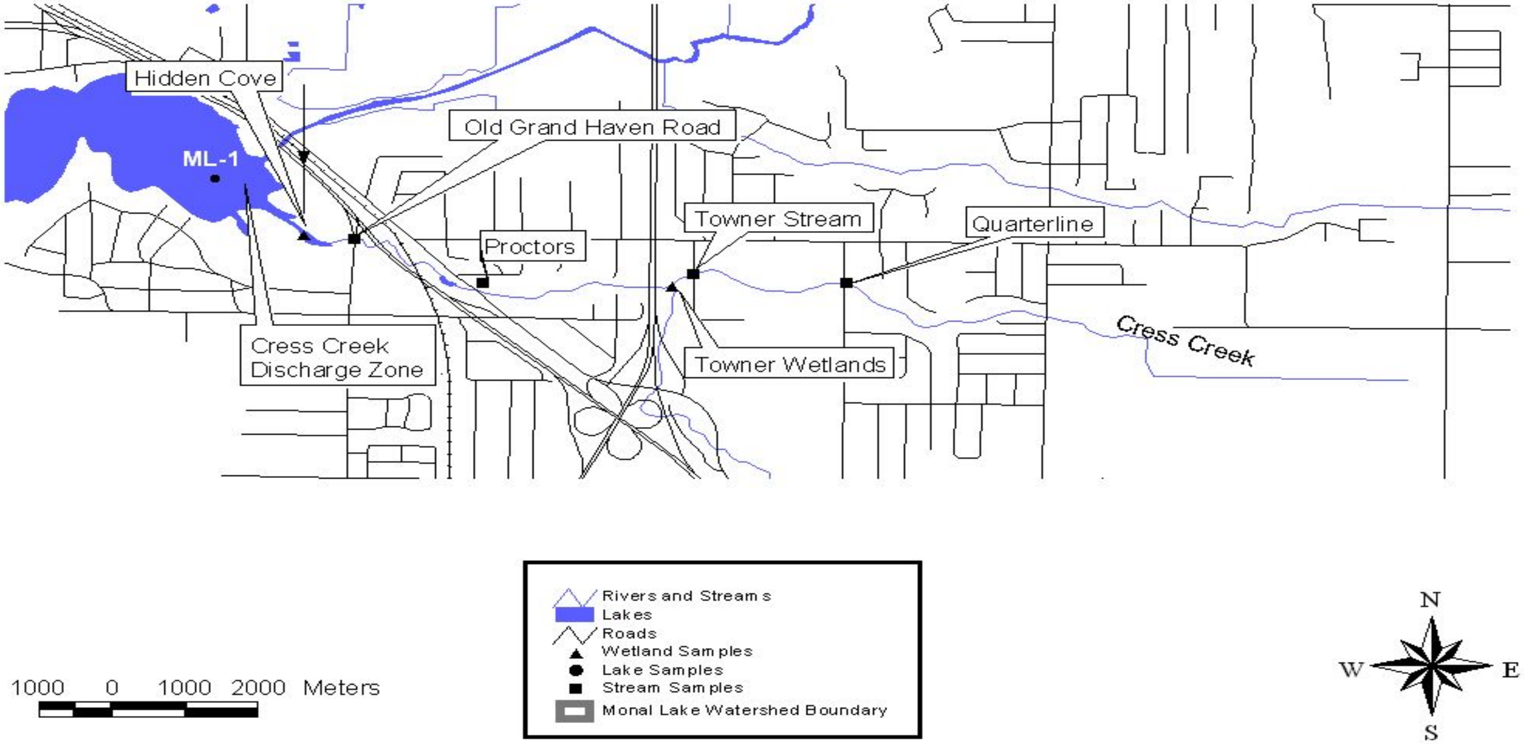

FIGURE 3. 2. BIOLOGICAL SURVEY SAMPLING LOCATIONS IN CRESS CREEK (2004).

3.3 Sampling Methods

3.3.1 MACROINVERTEBRATE SAMPLING METHODS

Macroinvertebrate samples were collected with standard D-frame dip nets with 0.5-mm mesh netting at both stream and wetland sites. At stream sites sampling consisted of sweeps through woody and non-woody debris as well as through inundated riparian vegetation. We chose dip net sampling over a more quantitative technique, such as Hess or Surber samplers, because dip nets allowed us to include considerably more spatial variability and facilitated sampling debris and vegetation whereas Hess and Surber samplers focus primarily on benthic substrate. Since both Little Black and Cress Creeks are relatively small streams, this sampling strategy was sufficient to represent all major habitats at each site.

Wetland sampling was conducted by stratifying the sites by dominant vegetation type (i.e., *Typha*, lily, etc.) and all available vegetation zones were sampled. Stratifying by vegetation type assured that variability in macroinvertebrate communities due to physical habitat structure was accounted for (Burton et al. 1999, Uzarski et al. 2004). In the wetlands, dip net sweeps were made through the vegetation from the sediment surface to the water surface. This technique ensured that organisms associated with the substrate, vegetation, and the water column, were included in samples.

After multiple sweeps were made, dip nets were emptied into white pans. Invertebrates were collected from the sample using forceps by focusing on a section of the pan and removing all specimens from that section before moving to another. Picking continued until either 150 specimens had been collected or for 30 person-minutes effort, whichever came first. After 30 person-minutes, organisms were tallied and picking continued to the next multiple of 50 resulting in replicate samples that contained 50, 100, or 150 invertebrates representing catch per unit effort. Three replicate samples were collected from each of the stream and wetland sites on each date in order to obtain a measure of variance associated with sampling. Invertebrates were preserved in 95% ethanol for transport and storage.

At the two lake sites benthic invertebrates were sampled using a petite PONAR dredge. Dredged sediment was rinsed through a 0.5-mm sieve and all retained organisms were preserved in 95% ethanol. Three replicate PONAR grabs were made at each lake site on each date.

Invertebrates were sorted to lowest operational taxonomic unit (genus or species for most specimens) in the laboratory using taxonomic keys such as Thorp and Covich (1991) and Merritt and Cummins (1996), along with specialized keys from mainstream literature. Accuracy was confirmed by expert taxonomists when possible or by comparison with a reference collection which had previously been identified by an expert.

3.3.2 FISH SAMPLING

Fish were sampled in the lower wetlands of both Little Black and Cress Creek at three separate time periods. A minimum of three replicate fyke nets with 4.8-mm mesh were set in each wetland for one net-night. Two sizes of fyke nets were used, 0.5-m x 1-m openings and 1-m x 1-m openings. Smaller nets were set in water approximately 0.25 m deep to 0.50 m; larger nets were set in water depths greater than 0.50 m. Leads were 7.3 m in length and wings were 1.8 m. The depth of water in each plant zone dictated the net size used since the only difference between large and small nets was the height. Each net was randomly placed perpendicular to the habitat of interest with leads extending into the vegetation itself. Therefore, fishes either occupying the vegetation or using the edge were likely to be caught. Wings were set at 45^o angles to the lead and connected to the outer opening on each side of the net. Fishes were identified to species, measured, enumerated, and released alive. Our fyke nets also captured a large number of turtles. These data were not included in analyses of fish community composition but are included in the database included with this report.

3.3.3 CHEMICAL AND PHYSICAL MEASUREMENTS

Basic chemical/physical water quality parameters were measured each time macroinvertebrate or fish sampling was conducted (Table 3.1). Analytical protocols followed those recommended by APHA (1998) and U.S. EPA. A quality assurance/quality control program following procedures recommended by U.S. EPA was also adopted as detailed in our Quality Assurance Project Plan approved by U.S. EPA prior to the start of this project. Measurements included discharge (stream sites only), soluble reactive phosphorus, nitrate-N, ammonium-N, chloride, sulfate-S, total dissolved solids, turbidity, alkalinity, pH, temperature, dissolved oxygen, chlorophyll-*a*, oxidation-reduction potential, and specific conductance.

A combination of field measurements and grab samples were used to assess water quality at each site. A Marsh-McBirney Flo-Mate velocity meter attached to an English top-set wading rod was used to determine discharge. A Hydrolab DataSonde 4*a* was used to measure total dissolved solids, turbidity, alkalinity, pH, temperature, dissolved oxygen, chlorophyll-*a*, oxidation-reduction potential, and specific conductance. The DataSonde was submerged to ½ the depth of the water column at stream and wetland sites. In the lake, the DataSonde was submerged to within 0.5 m of the substrate. In addition, grab samples (1 L) of surface water (stream and wetland) or bottom water (lake) were collected, stored at 4 ^oC, and transported immediately to the laboratory. A portion of this sample was used to quantify total alkalinity (sum of carbonate and bicarbonate alkalinity) via titration with 0.02N H_2SO_4 to an endpoint of pH 4.5. A 250 ml aliquot of each water sample was filtered through a 0.45 μm Millipore membrane filter and the filtrate was analyzed for dissolved solutes. Spectrophotometric procedures were used to quantify ammonium-N (phenol-hypochlorite method), soluble reactive phosphorous (ascorbic acid method). Chloride, nitrate-N, and sulfate-S were measured with ion chromatography.

Sediment samples were analyzed for grain size, TOC, heavy metals, semivolatile organics, PCBs, and solid phase toxicity. The test methods were described in Section 2.

3.3.4 STATISTICAL ANALYSES

Macroinvertebrates: Macroinvertebrate communities were analyzed using a number of different techniques. To identify overall gradients in community composition (i.e., to determine if contamination associated with specific sites can explain community composition), we used nonmetric multidimensional scaling (NMDS) ordination (Kruskal 1964, Mather 1976). NMDS was performed using Bray-Curtis distance measures (Kruskal and Wish 1978) and PC-ORD version 4.0. Mean taxon abundances of the three replicate samples collected at each site/date were used in the NMDS analyses. We used random starting coordinates in 40 runs with real data and 50 with randomized data returning 6 dimensions. Solution stability was obtained using a maximum of 400 iterations or an instability value of 0.00001. A Monte Carlo test was used to determine if a solution with comparable stress could be obtained by chance alone. Significance was set at $p < 0.05$. Dimensionality of the dataset was determined using a Scree diagram (Stress vs. Dimension). Once dimensionality was determined, the analyses were repeated calculating only the number of dimensions suggested by the Scree diagram. We then superimposed season, site, and stream (Little Black or Cress Creek) onto biplots representing the two dimensions explaining the most variation in the dataset. Separate NMDS models were derived for stream, wetland, and lake macroinvertebrates.

We also analyzed macroinvertebrate and fish communities using univariate statistics on a number of different community metrics. Non-parametric tests were used to determine if these metrics were significantly different among sites and between the two streams. Significance was set at $\alpha=0.05$ without adjusting for multiple comparisons.

Fish: Fish community data were analyzed using non-parametric statistical tests. Since a limited number of fish taxa were captured, we were able to compare abundances of all species between the two lower wetland sites (i.e., multivariate ordinations were not necessary). Again, significance was set at $\alpha=0.05$ without adjusting for multiple comparisons.

Chemical, Physical, and Toxicant Data: Since we measured many abiotic parameters, we used principal components analysis (PCA) to reduce the dimensionality of this dataset. PCA is useful for combining variables and representing gradients in ambient conditions in a reduced number of dimensions (principal components). This technique is especially useful when relating abiotic conditions to biotic communities. For both the stream and wetland datasets we conducted separate PCAs on 12 chemical parameters (dissolved oxygen, pH, sulfate-S, chloride, specific conductance, total dissolved solids, total alkalinity, SRP, ammonium-N, oxidation-reduction potential, chlorophyll *a*, and nitrate-N), 11 physical parameters (%solids, turbidity, temperature, discharge, total organic carbon, and six sediment grain size classes), and 22 toxicants (arsenic, barium, cadmium, chromium, copper, lead, selenium, silver, zinc, mercury, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene, total PAH compounds, aroclor1254, and total PCBs). These PCAs were used to describe overall gradients in abiotic conditions and were related to community attributes (i.e., NMDS axes) to identify potential drivers of community composition in the two streams.

3.4 Results and Discussion

3.4.1 STREAM ABIOTIC DATA

Chemical data are included in Table 3.2. PCA of chemical parameters revealed a dichotomy of Cress Creek sites versus Little Black Creek sites (Figure 3.3). The first two principal components (PCs) represented 31% and 19% of the variance in the chemical dataset, respectively. Little Black Creek sites tended to plot higher than Cress Creek in PC 1, and lower than Cress Creek in PC 2. Little Black Creek sites plotted in the same direction as the eigenvectors for SRP, ammonium-N, total alkalinity, total dissolved solids, total organic carbon, specific conductance, chloride, and sulfate. Cress Creek sites plotted in the same direction as the eigenvectors for nitrate-N, dissolved oxygen, and pH.

Physical data are included in Table 3.3. PCA of physical parameters also revealed a dichotomy of sites according to stream (Figure 3.4). Little Black Creek sites tended to plot higher in PC 1 which represented 36% of the variance in the physical dataset. Little Black Creek sites plotted in the same direction as the eigenvectors for temperature, discharge, and the largest four sediment grain size categories. Cress Creek sites plotted in the same direction as the eigenvector for the 63-125 μm sediment grain size category. Seasonal variability in physical parameters was minimal (i.e., PC scores for the three time periods were similar for each respective site).

Toxicant data are included in Table 3.4. PCA of toxicant data revealed the strongest dichotomy between Little Black Creek and Cress Creek (Figure 3.5). In this analysis PC 1 represented 74% of the variation in the toxicant dataset and two of the four Little Black Creek sites plotted high in PC 1. Nearly all of the toxicant eigenvectors also plotted high in PC 1 and no eigenvectors plotted in the direction of the Cress Creek sites. The Evanston Rd. site on Little Black Creek plotted among the Cress Creek sites suggesting that this site had low concentrations of most of the toxicants measured. The Summit Ave. site plotted between Cress Creek/Evanston Rd. and the other two Little Black Creek sites suggesting an intermediate level of toxicants. This analysis revealed that the Little Black Creek sites had greater concentrations of the toxicants measured. Seasonal variability in toxicant concentration was minimal as the three seasonal observations plotted within close proximity of each other for all sites.

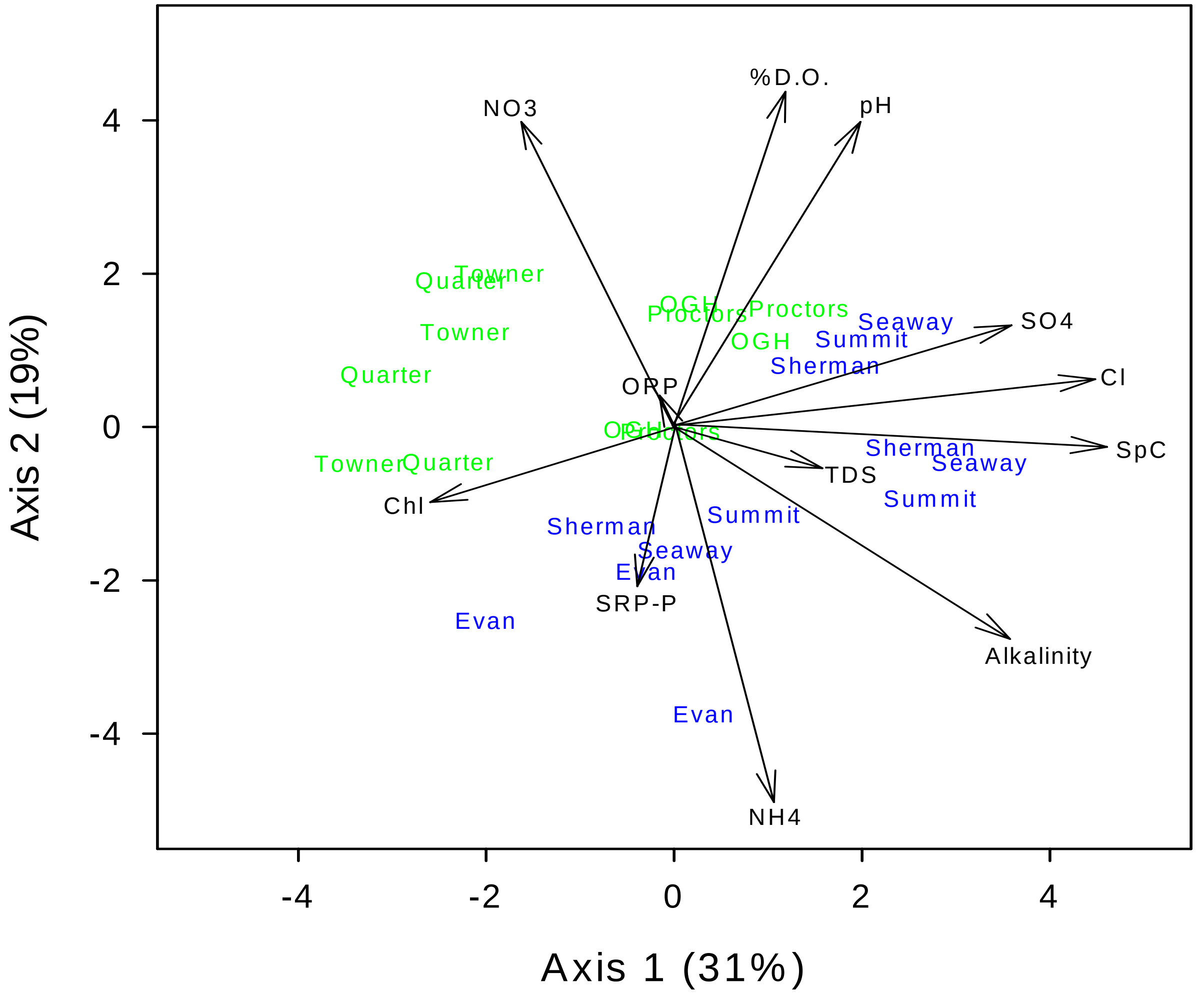

Figure 3.3. Principal components analysis of chemical data collected from eight stream sites at three time periods. Labels represent sites and are color-coded by stream (Cress: green, Little Black Creek: blue). Arrows represent eigenvectors scaled to plot area.

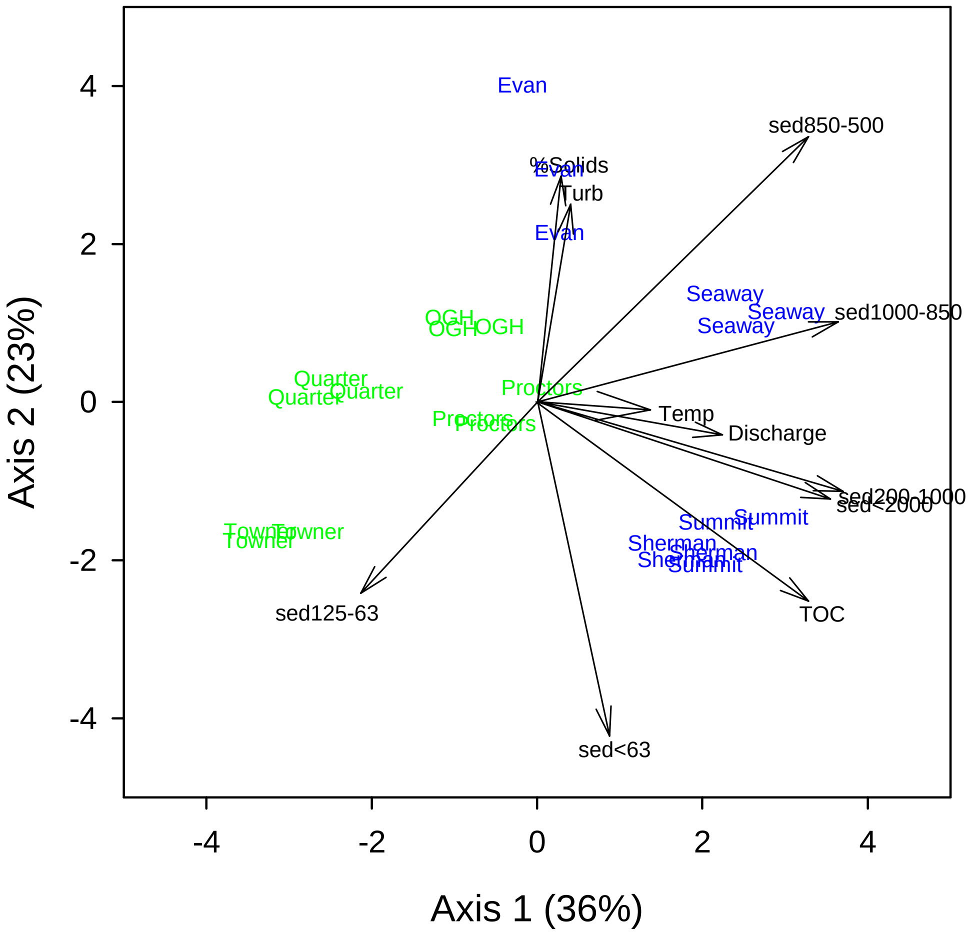

FIGURE 3.4. PRINCIPAL COMPONENTS ANALYSIS OF PHYSICAL DATA COLLECTED FROM EIGHT STREAM SITES AT THREE TIME PERIODS. LABELS REPRESENT SITES AND ARE COLOR-CODED BY STREAM (CRESS: GREEN, LITTLE BLACK CREEK: BLUE). ARROWS REPRESENT EIGENVECTORS SCALED TO PLOT AREA.

Table 3.2. Chemical data measured at eight stream sites and three time periods. Variables include dissolved oxygen (%DO and DO), specific conductance (SpC), total dissolved solids (TDS), pH, oxidation-reduction potential (ORP), chlorophyll a (Chl), total alkalinity, chloride (Cl^-), sulfate-S (SO_4-S), nitrate-N (NO_3-N), ammonium-N (NH_4-N), and soluble reactive phosphorus (SRP). Detection limit for chloride and sulfate was 0.1 mg L^{-1} and 0.01 mg L^{-1} for nitrate-N, ammonium-N, and SRP.

	Date	%DO	DO (mg/L)	SpC (uS/cm)	TDS (g/L)	pH	ORP (mV)	Chl (ug/L)	Total alkalinity (mg $CaCo_3$ L^{-1})	Cl^- (mg L^{-1})	SO_4-S (mg L^{-1})	NO_3-N (mg L^{-1})	NH_4-N (mg L^{-1})	SRP (mg L^{-1})
Little Black Creek														
Evanston	27-Apr	76.9	9.24	435.9	0.2788	8.06	289	6.0	150	39.2	25.1	0.21	0.19	<0.01
Sherman	27-Apr	104.1	12.12	610.1	0.3910	8.20	382	3.5	145	87.0	35.0	0.68	0.03	<0.01
Summmit	27-Apr	123.3	13.69	631.6	0.4036	8.37	395	5.0	150	88.6	34.9	0.77	0.10	<0.01
Seaway	27-Apr	124.2	13.20	679.7	0.4351	8.25	401	4.1	155	101.6	37.7	0.91	0.05	<0.01
Evanston	28-Jun	69.5	7.22	423.0	0.2717	7.69	315	4.9	105	37.9	1.1	0.26	0.23	<0.01
Sherman	28-Jun	85.2	8.64	564.4	0.3614	7.80	366	5.5	130	82.9	0.7	1.00	0.04	0.01
Summmit	28-Jun	87.4	8.80	586.1	0.3752	7.79	379	3.0	139	84.8	32.8	1.05	0.10	0.01
Seaway	28-Jun	87.3	8.36	610.8	0.3912	7.69	418	3.1	148	90.3	0.9	1.03	0.07	0.01
Evanston	25-Aug	65.3	6.31	513.1	0.3285	7.83	419	6.5	182	44.6	22.5	0.43	0.31	<0.01
Sherman	25-Aug	82.0	8.03	761.0	0.4871	7.92	395	2.3	138	123.6	51.4	1.57	0.06	0.01
Summmit	25-Aug	81.1	7.80	759.0	0.4859	7.88	386	3.0	152	118.0	46.9	1.69	0.17	<0.01
Seaway	25-Aug	82.1	7.76	808.4	0.5175	7.91	356	2.3	163	127.6	46.0	1.56	0.08	<0.01
Cress Creek														
Quarterline	28-Apr	91.7	10.66	315.9	0.2021	7.94	384	10.5	107	22.8	18.7	2.01	0.01	<0.01
Towner	28-Apr	92.2	10.34	329.1	0.2106	8.00	403	4.8	107	25.2	20.0	2.55	0.02	<0.01
Proctors	28-Apr	107.2	11.54	551.8	0.3532	8.25	391	6.1	117	92.4	23.0	1.63	0.02	<0.01
Old Grand Haven	28-Apr	103.8	11.35	558.2	0.3575	8.29	391	5.2	119	87.1	21.1	1.48	0.02	<0.01
Quarterline	25-Jun	87.9	9.38	298.1	0.9080	7.73	407	10.6	105	22.4	15.6	1.18	0.02	<0.01
Towner	25-Jun	89.1	9.48	306.5	0.1963	7.59	409	5.5	103	23.9	1.1	1.68	0.01	0.01
Proctors	25-Jun	87.5	9.03	534.3	0.3418	7.72	408	4.7	115	86.9	20.5	1.21	0.03	<0.01
Old Grand Haven	25-Jun	91.0	9.15	536.1	0.3431	7.77	400	4.0	120	89.0	20.6	1.21	0.02	<0.01
Quarterline	24-Aug	87.0	8.85	364.6	0.2333	7.99	408	3.1	98	32.0	20.0	4.39	0.03	<0.01
Towner	24-Aug	90.6	9.29	377.1	0.2410	8.02	400	2.5	110	31.4	21.1	4.37	0.02	<0.01
Proctors	24-Aug	88.8	8.82	624.2	0.3997	8.31	359	3.3	119	106.0	22.7	1.84	0.04	<0.01
Old Grand Haven	24-Aug	87.3	8.45	619.7	0.3966	8.66	320	3.0	124	106.4	22.8	1.83	0.04	<0.01

TABLE 3.3. PHYSICAL DATA FOR EIGHT STREAM SITES AND THREE TIME PERIODS. VARIABLES INCLUDE TEMPERATURE (TEMP), TURBIDITY (TUR), DISCHARGE, %SOLIDS, %TOTAL ORGANIC CARBON (%TOC), AND SEVEN SEDIMENT GRAIN SIZE CATEGORIES.

	Date	Temp	Turb	Discharge	%Solids	%TOC	%Grain Size						
		℃	(NTU)	m^3 sec-$^{-1}$			<2000	200-1000	1000-850	850-500	500-125	125-63	<63
Little Black Creek													
Evanston	27-Apr	7.03	33.5	0.047	50	1.0	0.7	0.8	0.4	7.0	66.2	27.9	0.0
Sherman	27-Apr	8.37	14.9	0.118	28	2.0	4.6	2.2	0.7	3.6	11.5	54.1	23.4
Summmit	27-Apr	9.93	6.1	0.143	47	3.0	3.6	1.5	0.4	3.1	13.8	19.0	58.6
Seaway	27-Apr	11.54	12.1	0.163	46	1.0	6.0	1.8	0.8	5.4	48.0	29.5	8.5
Evanston	28-Jun	12.91	30.5	0.072	53	0.9	0.7	0.7	0.5	6.5	55.2	28.6	7.9
Sherman	28-Jun	14.13	17.0	0.209	24	1.9	4.9	2.0	0.6	3.1	12.7	52.7	23.9
Summmit	28-Jun	14.60	21.5	0.259	47	2.8	3.3	1.6	0.4	3.3	15.3	18.7	57.3
Seaway	28-Jun	16.44	21.2	0.314	46	0.9	6.4	1.6	0.8	4.6	43.2	30.0	13.4
Evanston	25-Aug	16.56	14.6	0.009	44	1.0	0.7	0.8	0.4	6.0	56.9	23.6	11.7
Sherman	25-Aug	15.90	8.5	0.068	28	2.2	4.5	1.9	0.7	3.8	10.4	60.6	18.0
Summmit	25-Aug	16.27	18.0	0.101	53	2.5	3.1	1.6	0.4	3.3	12.0	21.2	58.4
Seaway	25-Aug	17.46	5.7	0.129	50	1.0	5.5	1.7	0.8	4.6	46.2	27.0	14.2
Cress Creek													
Quarterline	28-Apr	8.24	6.6	0.031	61	0.5	0.7	0.4	0.1	0.9	32.7	51.1	14.1
Towner	28-Apr	9.03	5.5	0.033	24	0.5	0.3	0.2	0.1	0.8	17.9	56.1	24.6
Proctors	28-Apr	12.17	7.7	0.116	42	0.5	0.6	0.3	0.3	2.9	50.3	26.2	19.3
Old Grand Haven	28-Apr	10.71	5.4	0.121	50	0.5	2.4	0.6	0.2	2.6	28.7	40.8	24.6
Quarterline	25-Jun	11.56	21.3	0.095	63	0.5	0.7	0.4	0.1	1.0	27.3	44.2	26.3
Towner	25-Jun	11.62	19.8	0.088	20	0.5	0.2	0.2	0.1	0.8	15.7	48.3	34.6
Proctors	25-Jun	12.87	16.5	0.254	37	0.5	0.6	0.4	0.3	3.1	46.0	27.2	22.5
Old Grand Haven	25-Jun	14.34	33.9	0.258	43	0.5	2.3	0.5	0.2	2.4	26.2	35.5	32.9
Quarterline	24-Aug	14.03	19.4	0.009	60	0.5	0.6	0.5	0.1	0.9	29.2	57.3	11.4
Towner	24-Aug	13.79	9.5	0.018	23	0.5	0.3	0.2	0.1	0.7	17.7	62.3	18.7
Proctors	24-Aug	14.69	15.5	0.079	40	0.5	0.6	0.4	0.2	3.1	44.0	29.7	21.9
Old Grand Haven	24-Aug	16.18	7.0	0.090	46	0.5	2.7	0.6	0.2	2.3	29.9	41.2	23.0

TABLE 3.4. TOXICANT DATA FOR EIGHT STREAM SITES AND THREE TIME PERIODS.

	Date	Arsenic mg kg^{-1}	Barium mg kg^{-1}	Cadmium mg kg^{-1}	Chromium mg kg^{-1}	Copper mg kg^{-1}	Lead mg kg^{-1}	Selenium mg kg^{-1}	Silver mg kg^{-1}	Zinc mg kg^{-1}	Mercury mg kg^{-1}	Naphthalene mg kg^{-1}	Acenaphthylene mg kg^{-1}
Little Black Creek													
Evanston	27-Apr	20	67	0	25	22	72	<0.40	<1.0	63	<0.10	< 0.33	< 0.33
Sherman	27-Apr	19	200	102	132	123	275	1	<1.8	473	<0.12	< 0.33	< 0.33
Summmit	27-Apr	4	84	19	68	90	275	1	2	314	0	< 0.33	< 0.33
Seaway	27-Apr	13	491	46	634	609	652	<0.44	24	4190	1	0.86	< 0.33
Evanston	28-Jun	20	59	0.5	28	19	80	<0.44	<0.44	57	<0.10	< 0.33	< 0.33
Sherman	28-Jun	20	222	108	143	139	255	1.32	<0.44	426	<0.10	< 0.33	< 0.33
Summmit	28-Jun	4	81	18	67	79	248	0.85	1.65	340	0.3	< 0.33	< 0.33
Seaway	28-Jun	13	442	45	615	654	610	<0.44	24.21	4111	1.0	0.75	< 0.33
Evanston	25-Aug	18	72	0.5	25	23	68	<0.44	<0.44	72	<0.10	< 0.33	< 0.33
Sherman	25-Aug	16	177	99	119	136	286	1.26	<0.44	468	<0.10	< 0.33	< 0.33
Summmit	25-Aug	4	90	20	64	94	277	0.94	1.41	337	0.20	< 0.33	< 0.33
Seaway	25-Aug	12	456	43	700	610	587	<0.44	20.90	4536	1.09	0.90	< 0.33
Cress Creek													
Quarterline	28-Apr	3	24	<0.1	7	4	13	<0.44	<0.82	38	<0.10	< 0.33	< 0.33
Towner	28-Apr	9	100	1	16	19	39	1	<2.1	145	<0.14	< 0.33	< 0.33
Proctors	28-Apr	4	43	<0.1	7	8	24	<0.48	<1.2	75	<0.10	< 0.33	< 0.33
Old Grand Haven	28-Apr	4	25	<0.1	6	5	20	<0.40	<1.0	36	<0.10	< 0.33	< 0.33
Quarterline	25-Jun	3	21	<0.1	7	4	11	<0.44	<0.44	42	<0.10	< 0.33	< 0.33
Towner	25-Jun	10	85	1.2	18	16	38	1.37	<0.44	154	<0.10	< 0.33	< 0.33
Proctors	25-Jun	4	38	<0.1	6	8	24	<0.44	<0.44	68	<0.10	< 0.33	< 0.33
Old Grand Haven	25-Jun	3	26	<0.1	6	4	19	<0.44	<0.44	32	<0.10	< 0.33	< 0.33
Quarterline	24-Aug	3	24	<0.1	6	3	14	<0.44	<0.44	33	<0.10	< 0.33	< 0.33
Towner	24-Aug	8	102	1.0	17	20	39	1.45	<0.44	165	<0.10	< 0.33	< 0.33
Proctors	24-Aug	4	41	<0.1	8	8	25	<0.44	<0.44	82	<0.10	< 0.33	< 0.33
Old Grand Haven	24-Aug	4	23	<0.1	7	5	22	<0.44	<0.44	34	<0.10	< 0.33	< 0.33

TABLE 3.4 (CONTINUED). TOXICANT DATA FOR EIGHT STREAM SITES AND THREE TIME PERIODS.

	Date	Acenaphthene mg kg^{-1}	Fluorene mg kg^{-1}	Phenanthrene mg kg^{-1}	Anthracene mg kg^{-1}	Fluoranthene mg kg^{-1}	Pyrene mg kg^{-1}	Benzo(a)anthracene mg kg^{-1}	Chrysene mg kg^{-1}	Benzo(b)fluoranthene mg kg^{-1}
Little Black Creek										
Evanston	27-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	27-Apr	< 0.33	< 0.33	4.3	0.75	9.8	7.3	2.9	4.2	4.7
Summmit	27-Apr	< 0.33	< 0.33	1.4	< 0.33	2.9	2.1	0.88	1.2	1.2
Seaway	27-Apr	1.6	1.8	15	3.6	0.75	11	5.1	5.2	< 0.33
Evanston	28-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	28-Jun	< 0.33	< 0.33	3.78	0.69	8.93	6.57	3.05	4.52	5.33
Summmit	28-Jun	< 0.33	< 0.33	1.20	< 0.33	2.56	1.81	0.90	1.21	1.30
Seaway	28-Jun	1.72	1.63	16.05	3.40	0.75	10.77	5.79	5.22	< 0.33
Evanston	25-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	25-Aug	< 0.33	< 0.33	4.45	0.73	8.78	6.96	3.10	4.55	3.96
Summmit	25-Aug	< 0.33	< 0.33	1.24	< 0.33	3.26	2.01	0.94	1.32	1.24
Seaway	25-Aug	1.71	1.75	14.21	3.51	0.75	9.23	4.24	4.55	< 0.33
Cress Creek										
Quarterline	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

TABLE 3.4 (CONTINUED). TOXICANT DATA FOR EIGHT STREAM SITES AND THREE TIME PERIODS.

	Date	Benzo(k)fluoranthene mg kg^{-1}	Benzo(a)pyrene mg kg^{-1}	Indeno(1,2,3-cd)pyrene mg kg^{-1}	Dibenzo(a,h)anthracene mg kg^{-1}	Benzo(g,h,i)perylene mg kg^{-1}	Aroclor 1016 mg kg^{-1}
Little Black Creek							
Evanston	27-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	27-Apr	2.4	3.8	2.8	0.42	3.2	< 0.33
Summmit	27-Apr	0.64	1.1	0.79	< 0.33	0.86	< 0.33
Seaway	27-Apr	4.4	5.1	2.4	0.39	2.6	< 0.33
Evanston	28-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	28-Jun	2.09	3.57	3.17	0.36	3.36	< 0.33
Summmit	28-Jun	0.64	1.22	0.85	< 0.33	0.92	< 0.33
Seaway	28-Jun	3.70	5.11	2.00	0.40	2.57	< 0.33
Evanston	25-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	25-Aug	2.64	3.40	3.05	0.39	2.79	< 0.33
Summmit	25-Aug	0.60	0.92	0.66	< 0.33	0.73	< 0.33
Seaway	25-Aug	4.05	4.60	2.47	0.44	2.60	< 0.33
Cress Creek							
Quarterline	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

TABLE 3.4 (CONTINUED). TOXICANT DATA FOR EIGHT STREAM SITES AND THREE TIME PERIODS.

	Date	Total PAH Compounds mg kg^{-1}	Aroclor 1221 mg kg^{-1}	Aroclor 1232 mg kg^{-1}	Aroclor 1242 mg kg^{-1}	Aroclor 1248 mg kg^{-1}	Aroclor 1254 mg kg^{-1}	Aroclor 1260 mg kg^{-1}	Total PCBs mg kg^{-1}
Little Black Creek									
Evanston	27-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	27-Apr	47	< 0.33	< 0.33	< 0.33	< 0.33	0.94	< 0.33	0.94
Summmit	27-Apr	13	< 0.33	< 0.33	< 0.33	< 0.33	0.42	< 0.33	0.42
Seaway	27-Apr	60	< 0.33	< 0.33	< 0.33	< 0.33	0.70	< 0.33	0.70
Evanston	28-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	28-Jun	45	< 0.33	< 0.33	< 0.33	< 0.33	1.04	< 0.33	1.04
Summmit	28-Jun	13	< 0.33	< 0.33	< 0.33	< 0.33	0.38	< 0.33	0.38
Seaway	28-Jun	60	< 0.33	< 0.33	< 0.33	< 0.33	0.68	< 0.33	0.68
Evanston	25-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Sherman	25-Aug	45	< 0.33	< 0.33	< 0.33	< 0.33	0.94	< 0.33	0.94
Summmit	25-Aug	13	< 0.33	< 0.33	< 0.33	< 0.33	0.44	< 0.33	0.44
Seaway	25-Aug	55	< 0.33	< 0.33	< 0.33	< 0.33	0.76	< 0.33	0.76
Cress Creek									
Quarterline	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	28-Apr	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	25-Jun	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Quarterline	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Proctors	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Old Grand Haven	24-Aug	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

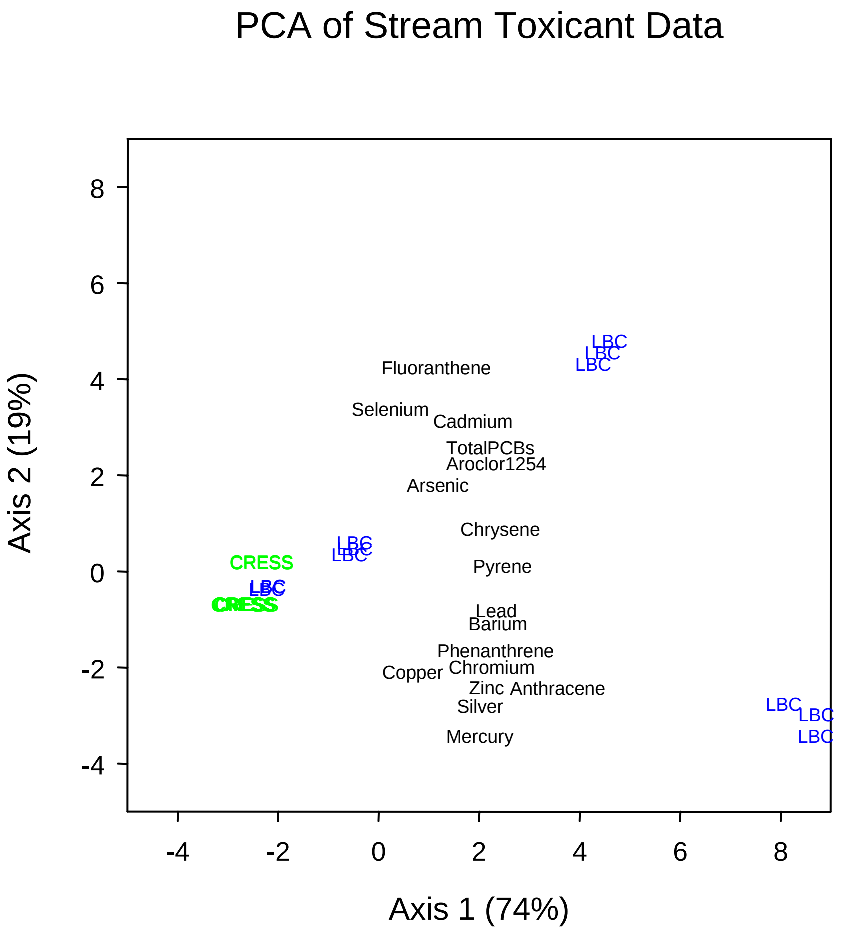

Figure 3.5. Principal components analysis of toxicant data collected from eight stream sites at three time periods. Labels are color-coded by stream (Cress: green, Little Black Creek: blue). Arrows represent eigenvectors scaled to plot area.

3.4.2 Stream Macroinvertebrates

Macroinvertebrate data are included in Appendix C. In total, 11,474 macroinvertebrates were collected from stream sites during the three sampling periods. The most abundant taxon in both streams (all seasons combined) was *Gammarus* (Amphipoda). 2,278 *Gammarus* were collected in Little Black Creek and 1,926 *Gammarus* were collected in Cress Creek. The second most abundant taxon in Little Black Creek was Orthocladiinae (Diptera, Chironomidae) (2,051), followed by Tanypodinae (Diptera, Chironomidae). The second most abundant taxon in Cress Creek was *Caecidotea* (Isopoda, Asselidae) (554), followed by Orthocladiinae (Diptera, Chironomidae) (522).

Seventy-seven taxa were collected from Cress Creek (all seasons combined) and 69 taxa were collected from Little Black Creek. In Cress Creek taxon richness was highest at the Towner Rd. site in August (33 taxa) and lowest at the Proctors' site in June (17 taxa). In Little Black Creek taxon richness was highest at the Seaway site in June (26 taxa) and lowest at the Seaway site in April (11 taxa). Our experimental design was such that sampling sites in both streams were located at comparable distances from their respective headwaters. Since stream communities often exhibit substantial variability from headwaters to mouth as well as through the growing season, we conducted pair-wise comparisons between the streams, pairing by date and by relative position from upstream to downstream. Wilcoxon signed-rank tests were used to test the null-hypothesis of no significant difference in taxon richness between Cress Creek and Little Black Creek when longitudinal distance and season were accounted for. This test was significant ($p=0.011$) indicating that taxon richness was significantly higher in Cress Creek.

Additional metrics were calculated for stream sites according to the Michigan Department of Environmental Quality's Procedure 51 rapid bioassessment protocol. These results are summarized in Table F. Comparison of metric results between the two streams using Wilcoxon signed-rank tests revealed that Cress Creek had significantly more Trichoptera taxa and higher relative abundances of Trichoptera as well as more Plecoptera taxa (Table 3.5).

Non-metric multidimensional scaling ordinations of stream macroinvertebrate data suggested that a solution with equal or less stress was not likely to occur by chance alone ($p=0.01$) and that the dataset was best represented by two dimensions. Thus, we recalculated the NMDS using only two dimensions which resulted in a final stress of 12.5799 and explained a total of 89% of the variation in the original distance matrix. By superimposing stream, season, and site onto these two NMDS axes (biplot of axes 1 x 2 scores), we identified a gradient best explained by stream (Little Black vs. Cress Creek). This gradient was represented in axis 1 with most Cress Creek sites plotting lower than Little Black Creek sites (Figure 3.6). This analysis revealed that the gradient in macroinvertebrate communities due to stream (or watershed) was more important than gradients related to either month or site (longitudinal position). This suggests that anthropogenic disturbance associated with Little Black Creek has substantially altered the macroinvertebrate community and these alterations overshadow temporal and site-specific variability.

An exception to the overall stream- or watershed-dependant gradient represented in axis 1 was the Quarterline Rd. site which plotted among the Little Black Creek sites in all three months. This site tended to have higher abundances of Naididae, *Physella*, Orthocladiinae, and Tanypodinae. These four taxa were also characteristic of Little Black Creek which explains the position of Quarterline Rd. on axis 1. The Quarterline Rd. site had relatively low specific conductance, and chloride relative to the other Cress Creek sites and all of the Little Black Creek sites (Table 3.2). Conductivity and chloride

Table 3.5. Procedure 51 rapid bioassessment metrics calculated for the eight stream sites and three time periods. Wilcoxon signed-rank tests were used to test the null-hypothesis of no significant difference between the two streams when sites were paired by longitudinal position and date. P-values are listed.

		Taxon richness	Ephemerop. richness	Trichop. richness	Plecop. richness	Ephemerop. rel. ab.	Trichop. rel. ab.	Dom. Taxon rel. ab.	Isopods, Snails, and Leaches rel. ab.	Surface dep. rel. ab.
Little Black Creek										
Evanston	27-Apr	14	1	0	1	0.18	0.00	63.09	1.93	1.05
Sherman	27-Apr	17	1	0	0	0.75	0.00	66.04	1.13	0.94
Summmit	27-Apr	17	0	0	0	0.00	0.00	57.03	2.01	0.60
Seaway	27-Apr	11	0	0	0	0.00	0.00	64.51	2.27	0.00
Evanston	28-Jun	21	1	0	0	0.20	0.00	42.80	7.30	2.17
Sherman	28-Jun	18	2	0	0	3.32	0.00	37.08	4.35	0.00
Summmit	28-Jun	20	1	0	0	1.04	0.00	32.29	32.50	1.04
Seaway	28-Jun	26	1	0	0	0.65	0.00	34.84	28.17	0.86
Evanston	25-Aug	21	2	0	0	2.80	0.00	85.49	2.62	1.40
Sherman	25-Aug	21	2	1	0	1.87	0.21	61.33	3.12	0.42
Summmit	25-Aug	19	2	0	0	3.43	0.00	42.83	11.35	0.21
Seaway	25-Aug	19	2	0	0	23.85	0.00	38.28	1.67	1.05
Cress Creek										
Quarterline	28-Apr	22	2	3	3	9.12	1.63	50.49	1.63	0.00
Towner	28-Apr	24	0	5	2	0.00	21.21	30.16	18.87	0.78
Proctors	28-Apr	30	2	6	2	2.23	9.75	26.74	3.34	3.62
Old Grand Haven	28-Apr	26	2	2	1	12.17	4.67	53.35	4.46	1.22
Quarterline	25-Jun	24	0	4	0	0.00	11.09	25.80	48.19	0.64
Towner	25-Jun	30	0	7	0	0.00	25.95	36.53	38.52	1.40
Proctors	25-Jun	17	1	2	1	16.59	2.16	50.22	17.67	1.08
Old Grand Haven	25-Jun	20	1	3	0	10.68	0.62	64.27	12.73	0.82
Quarterline	24-Aug	31	2	6	0	1.93	17.11	23.37	27.47	0.96
Towner	24-Aug	33	2	7	0	2.87	26.93	42.38	9.49	1.32
Proctors	24-Aug	22	2	4	0	37.92	1.60	51.50	5.79	0.40
Old Grand Haven	24-Aug	25	2	4	0	6.14	2.85	73.90	2.85	0.44
Wilcoxon signed-rank test p-values:			0.011	0.748	0.002	0.209	0.002	0.308	0.158	0.695

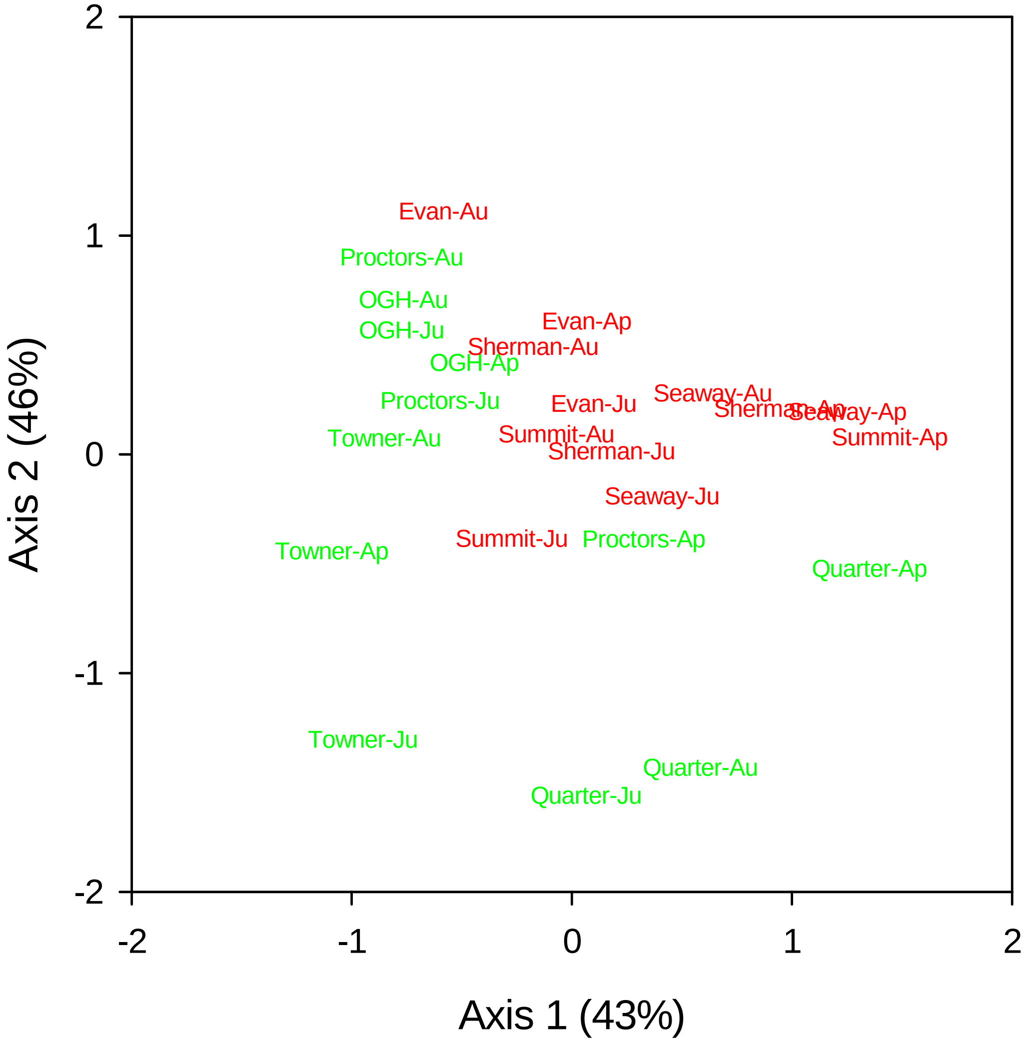

Figure 3.6. NMDS of stream macroinvertebrates (8 sites, 104 taxa) color-coded by Watershed (red, LBC; green, CC). Labels indicate site and month sampled (Ap, April; Ju, June; Au, August.

are generally associated with anthropogenic disturbance in this region so it does not seem likely that the Quarterline Rd. site was subject to anthropogenic disturbances that we were not aware of. Also, PCA of chemical data, physical data, and toxicant data all placed the Quarterline Rd. site on opposing ends of disturbance gradients from Little Black Creek sites. Therefore, the position of Quarterline Rd. on NMDS axis 1 is most likely a result of this site's upstream position in the watershed making it more subject to natural disturbances such as nearly complete drying during periods of limited precipitation (i.e., August discharge = 0.01 m^3 sec^{-1}) rather than anthropogenic disturbance. The four taxa found in relatively high abundance at this site support this hypothesis as three of the four (Naididae, Orthocladiinae, and Tanypodinae) can be considered "pioneer taxa," capable of recolonizing quickly after natural or anthropogenic disturbances. Also, the fourth taxon, *Physella*, is considered tolerant of both natural and anthropogenic disturbances. The Proctor's site in April also plotted among the Little Black Creek sites on axis 1. In April this site also had relatively high abundances of Orthocladiinae and Tanypodinae, and relatively low abundances of *Simuliidae*. These relative abundances were more characteristic of Little Black Creek than Cress Creek and may explain the position of this site on axis 1 in April. However, in June and August the Proctors' site plotted among the other Cress Creek sites indicating its position on axis 1 in April was most likely a function of seasonal variability rather than anthropogenic disturbance.

Axis 2 of the NMDS of stream macroinvertebrates (Figure 3.6) represented 46% of the variability in the original distance matrix. This axis represents a gradient of *Gammarus* abundance with sites having high *Gammarus* abundances plotting high in axis 2 and those with few *Gammarus* plotting low on axis 2. For example, few *Gammarus* were captured at the Quarterline Rd. site in any month or the Towner Rd. site in June and these sites had relatively low axis 2 scores. In contrast, Old Grand Haven Rd. (all months), Evanston Rd. (April and August), Proctors' (August), and Sherman (August) had the seven highest axis 2 scores and had the seven highest Gammarus abundances. This relationship was confirmed by a significant correlation between *Gammarus* abundance and axis 2 scores (Spearman rank-order correlation: R_s=0.813, $p<0.05$).

3.4.3 RELATING ABIOTIC CONDITIONS TO STREAM MACROINVERTEBRATE COMMUNITY COMPOSITION

To relate macroinvertebrate community composition to chemical, physical, and toxicant conditions we plotted community gradients (NMDS axes) against PCs of the abiotic data. We then calculated Pearson correlations between the gradients to determine if community composition was related to abiotic conditions. A significant correlation was found between NMDS axis 1 and physical PC 1 (p=0.050, r=0.405). Since physical PC 1 represented a gradient of sediment grain size, total organic carbon, discharge, and temperature, the relationship between NMDS axis 1 and physical PC 1 suggests that the macroinvertebrate communities responded to these factors.

A significant correlation was also found between NMDS axis 1 (Figure 3.6) and toxicant PC 1 (Figure 3.5) (p=0.017, r=0.484). Since toxicant PC 1 represented a gradient of nearly all the toxicants measured versus uncontaminated (Cress Creek) sites, this relationship suggests that macroinvertebrate community composition is also responding to the degree of contamination. However, the toxicant PCA revealed that the Sherman and Seaway sites were considerably more contaminated than all other sites yet these two sites did not form a distinct group in either axis of the NMDS. Also, the Summit site, which appears to have lower concentrations of the toxicants measured, plotted among the more contaminated sites in axis 1 of the NMDS. One potential explanation for this is that upon reaching a threshold level of contamination, additional contamination does not further alter the community. Thus, contamination associated with all of the Little Black Creek sites (but to a lesser extent, Evanston, although this site did consistently have the highest arsenic concentrations of all sites and lead concentrations were always higher than the Cress sites) may have caused a broad shift in macroinvertebrate community composition while the additional contamination at the Sherman and Seaway sites did not cause an additional shift. It is also likely that the gradient in community composition represented in axis 1 is not structured by contamination alone, but also by other factors correlated with contamination such as hydrology (i.e., flashiness).

NMDS axis 2 (Figure 3.6) showed the strongest significant correlation with chemical PC 1 (Figure 3.5) (p=0.002, r=0.593). However, those parameters that weighted heaviest in PC 1 did not likely structure invertebrate communities directly, but instead were surrogates for overall disturbance. NMDS axis 2 represented a gradient of *Gammarus* abundance with the Quarterline and Towner Rd sites plotting relatively low in axis 2. These sites were furthest upstream in Cress Creek, and therefore, were subject to a relatively low degree of anthropogenic disturbance. Accordingly, the Quarterline and Towner Rd. sites plotted low in chemical PC 1 which represented a disturbance gradient (correlated with chloride and specific conductance). Sites subject to increased anthropogenic disturbance (i.e., higher concentrations of chloride and higher conductivity) had higher chemical PC 1 scores, higher NMDS axis 2 scores and more *Gammarus*. It is not clear whether increased anthropogenic disturbance was a cause of the higher proportion of *Gammarus* at certain sites or was merely a spurious relationship. However, it seems unlikely that the cause was direct since the Evanston Rd. site had high abundances of *Gammarus* but was among the least disturbed Little Black Creek sites (relatively low chemical PC 1 scores compared to the other Little Black Creek sites) unless lead, which did not weigh heavily in PC1, was among the most important toxicants structuring these communities.

3.4.4 WETLAND ABIOTIC DATA

Wetland chemical data are included in Table 3.6. PCA of chemical parameters revealed a gradient from the Mona View and LBC Lower Wetland sites to the Industrial Park, Hidden Cove, and Towner Road sites (Figure 3.7). This gradient was evident in PC 1 which explained 43.6% of the variance in the chemical dataset. The LBC Lower Wetland and Mona View sites plotted low in PC 1 and in the same direction as the eigenvectors for total alkalinity, chloride, and total dissolved solids. The Hidden Cove, Towner Road, and Industrial Park sites plotted higher in PC 1 and in the same direction as the eigenvectors for oxidation/reduction potential, dissolved oxygen, sulfate-S, pH, and nitrate-N. This site-gradient is consistent with a watershed-gradient as Little Black Creek wetlands tended to have lower PC 1 scores than Cress Creek wetlands. A temporal gradient was not evident in these two PCs.

Physical data are included in Table 3.7. PCA of physical parameters revealed a gradient from the Towner Road site to the Hidden Cove and Industrial Park sites, to the LBC

Table 3.6. Chemical data measured at five wetland sites and three time periods. Variables include dissolved oxygen (%DO), total dissolved solids (TDS), pH, oxidation-reduction potential (ORP), chlorophyll a (Chl), total alkalinity, chloride (Cl^-), sulfate-S (SO_4-S), nitrate-N (NO_3-N), ammonium-N (NH_4-N), and soluble reactive phosphorus (SRP). Detection limit for chloride and sulfate was 0.1 mg L^{-1} and 0.01 mg L^{-1} for nitrate-N, ammonium-N, and SRP.

	Date	Vegetation	%D.O.	TDS (g/L)	pH	ORP (mV)	Chl (ug/L)	Total alkalinity (mg $CaCo_3$ L^{-1})	Cl^- (mg L^{-1})	SO_4-S (mg L^{-1})	NO_3-N (mg L^{-1})	NH_4-N (mg L^{-1})	SRP (mg L^{-1})
Little Black Creek													
LBC Lower Wetland	18-May	*Typha*	87.0	0.5431	7.72	426	13.1	244	129.1	0.8	0.01	0.01	<0.01
Mona View	19-May	*Typha*	17.0	0.8304	7.44	36	5.2	255	199.4	23.2	0.30	0.14	<0.01
Industrial Park	2-Jun	*Typha*	73.8	0.2565	7.12	407	5.2	124	40.6	23.1	0.49	0.10	<0.01
LBC Lower Wetland	30-Jun	*Typha*	18.3	0.5929	7.23	242	20.7	275	139.0	5.9	0.01	0.05	<0.01
Mona View	30-Jun	*Typha*	63.3	0.7495	7.47	144	3.6	255	202.3	22.2	0.33	0.08	<0.01
Industrial Park	1-Jul	*Typha*	65.7	0.2904	7.80	371	3.7	145	45.0	23.0	0.65	0.11	<0.01
LBC Lower Wetland	28-Sep	*Typha*	42.5	0.6914	7.71	329	16.8	250	168.1	4.7	0.01	0.22	<0.01
Mona View	29-Sep	*Typha*	28.0	0.2280	7.48	165	19.9	270	187.6	17.6	0.41	0.15	0.02
Cress Creek													
Hidden Cove	18-May	*Typha*	99.3	0.2269	7.64	413	35.8	109	15.8	16.9	0.11	0.12	0.33
Hidden Cove	18-May	*Nuphar*	77.5	0.2727	7.48	432	26.4	119	40.9	31.0	0.82	0.10	<0.01
Towner Road	19-May	*Typha*	84.6	0.1860	7.99	305	0.0	99	22.6	17.7	1.31	0.04	<0.01
Hidden Cove	30-Jun	*Typha*	53.3	0.3766	7.36	323	2.9	155	86.4	19.0	1.07	0.05	<0.01
Hidden Cove	30-Jun	*Nuphar*	142.6	0.2836	8.70	332	17.1	135	42.4	37.9	0.52	0.03	<0.01
Towner Road	1-Jul	*Typha*	77.4	0.2270	7.80	368	2.8	105	27.9	19.9	3.49	0.03	<0.01
Hidden Cove	28-Sep	*Typha*	58.2	0.3617	7.90	442	5.1	135	77.4	29.1	1.00	0.08	0.01
Hidden Cove	28-Sep	*Nuphar*	69.8	0.3380	8.97	411	7.3	131	70.2	29.1	0.98	0.13	0.01
Towner Road	28-Sep	*Typha*	90.3	0.2557	8.26	335	2.4	113	33.6	22.1	4.69	0.01	0.01

Table 3.7. Physical data for five wetland sites and three time periods. Variables include temperature (Temp), turbidity (Tur), %solids, %total organic carbon (%TOC), and seven sediment grain size categories.

	Date	Vegetation	Temp	Turb	%Solids	%TOC	%Grain Size						
			℃	(NTU)			<2000	200-1000	1000-850	850-500	500-125	125-63	<63
Little Black Creek													
LBC Lower Wetland	18-May	*Typha*	16.43	35.5	20	5.0	5.5	1.2	0.4	3.5	57.8	19.8	11.7
Mona View	19-May	*Typha*	14.60	32.5	10	12.0	6.0	2.2	0.4	1.8	14.1	16.9	58.6
Industrial Park	2-Jun	*Typha*	14.69	28.3	33	10.0	1.8	0.4	0.2	1.5	18.3	25.3	52.4
LBC Lower Wetland	30-Jun	*Typha*	19.48	97.6	21	4.9	4.9	1.1	0.4	3.4	50.1	16.8	23.4
Mona View	30-Jun	*Typha*	19.51	5.5	11	10.0	6.6	1.9	0.4	1.9	11.7	17.7	59.8
Industrial Park	1-Jul	*Typha*	16.54	37.4	30	8.3	1.9	0.4	0.2	1.4	20.4	26.7	49.0
LBC Lower Wetland	28-Sep	*Typha*	17.61	65.1	18	5.5	5.6	1.3	0.4	3.2	60.0	17.5	11.9
Mona View	29-Sep	*Typha*	11.67	22.6	11	11.1	6.2	2.4	0.4	1.9	15.1	17.4	56.7
Cress Creek													
Hidden Cove	18-May	*Typha*	19.28	7.7	28	4.0	4.5	1.4	0.4	1.9	32.7	45.6	13.5
Hidden Cove	18-May	*Nuphar*	20.04	105.8	17	3.0	3.7	1.3	0.4	1.1	33.5	31.6	28.5
Towner Road	19-May	*Typha*	17.77	19.4	24	2.0	1.5	0.7	0.2	1.7	35.3	34.6	25.9
Hidden Cove	30-Jun	*Typha*	16.25	59.6	17	2.8	3.1	1.1	0.3	1.0	32.9	27.5	34.1
Hidden Cove	30-Jun	*Nuphar*	22.32	47.5	30	3.8	4.2	1.3	0.3	1.7	32.1	50.8	9.5
Towner Road	1-Jul	*Typha*	18.70	45.1	25	1.7	1.7	0.8	0.2	1.7	33.8	38.5	23.4
Hidden Cove	28-Sep	*Nuphar*	14.57	28.7	27	3.9	4.2	1.2	0.3	2.0	33.4	46.9	11.9
Hidden Cove	28-Sep	*Typha*	13.90	19.8	18	3.3	4.1	1.3	0.5	1.3	36.7	27.2	29.0
Towner Road	28-Sep	*Typha*	13.09	13.7	21	1.9	1.5	0.7	0.2	1.8	31.1	37.5	27.2

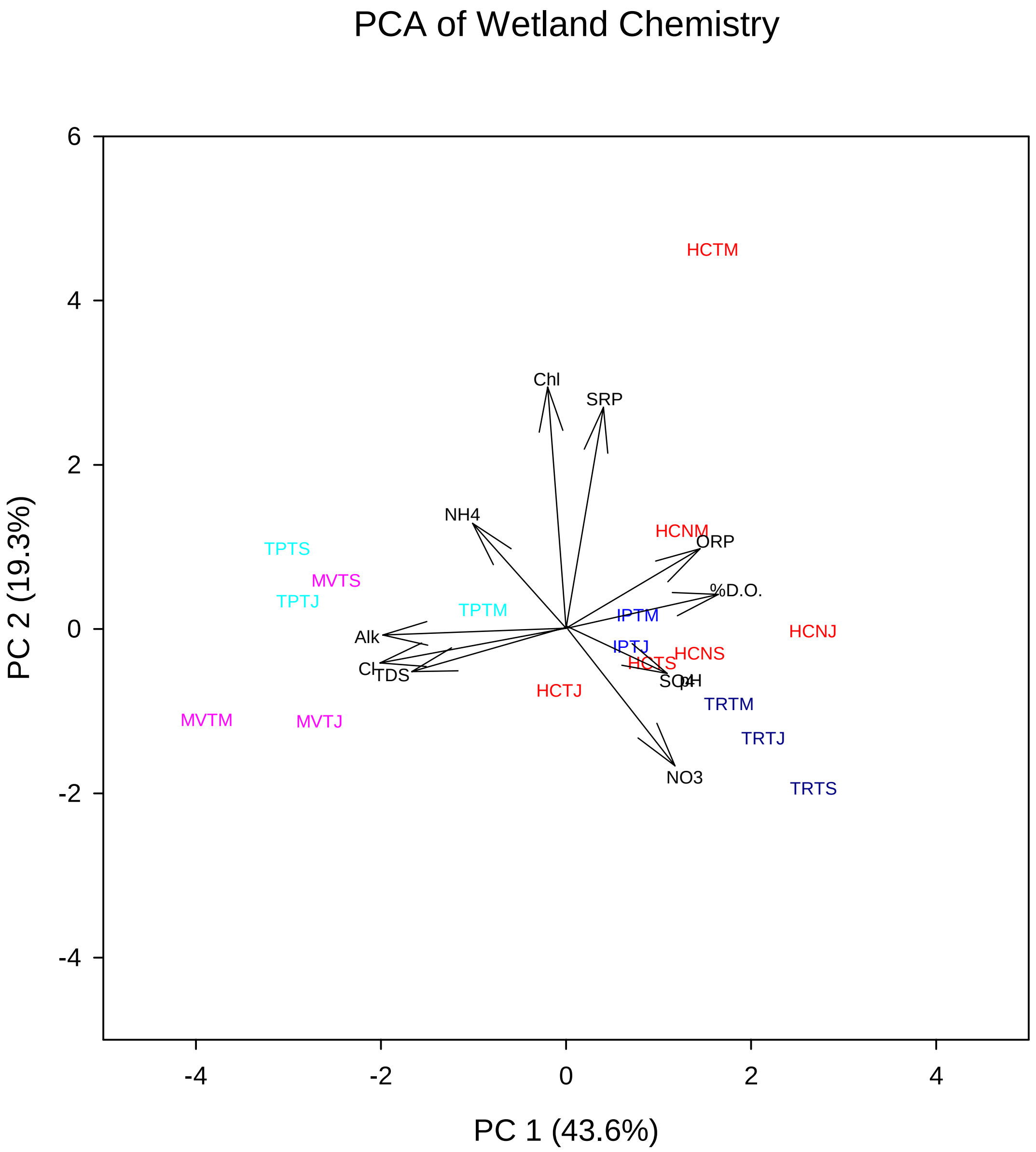

Figure 3.7. Principal components analysis of chemical data collected from five wetland sites at three time periods. The first two letters of site labels indicate site (HC: Hidden Cove, TP: LBC Lower Wetland, MV: Mona View, IP: Industrial Park, and TR: Towner Road), the third letter indicates vegetation type (T: *Typha*, N: *Nuphar*), and the fourth letter indicates month (M: May, J: June/July, and S: September). Arrows represent eigenvectors scaled to plot area.

Lower Wetland site, to the Mona View site (Figure 3.8). This gradient was evident in PC 1 which explained 39.1% of the variance in the physical dataset. The Towner Road site plotted lowest in PC 1 and in the same direction as the eigenvectors for %solids, and the 63-125 µm sediment grain size category. The Industrial Park, Hidden Cove, and LBC

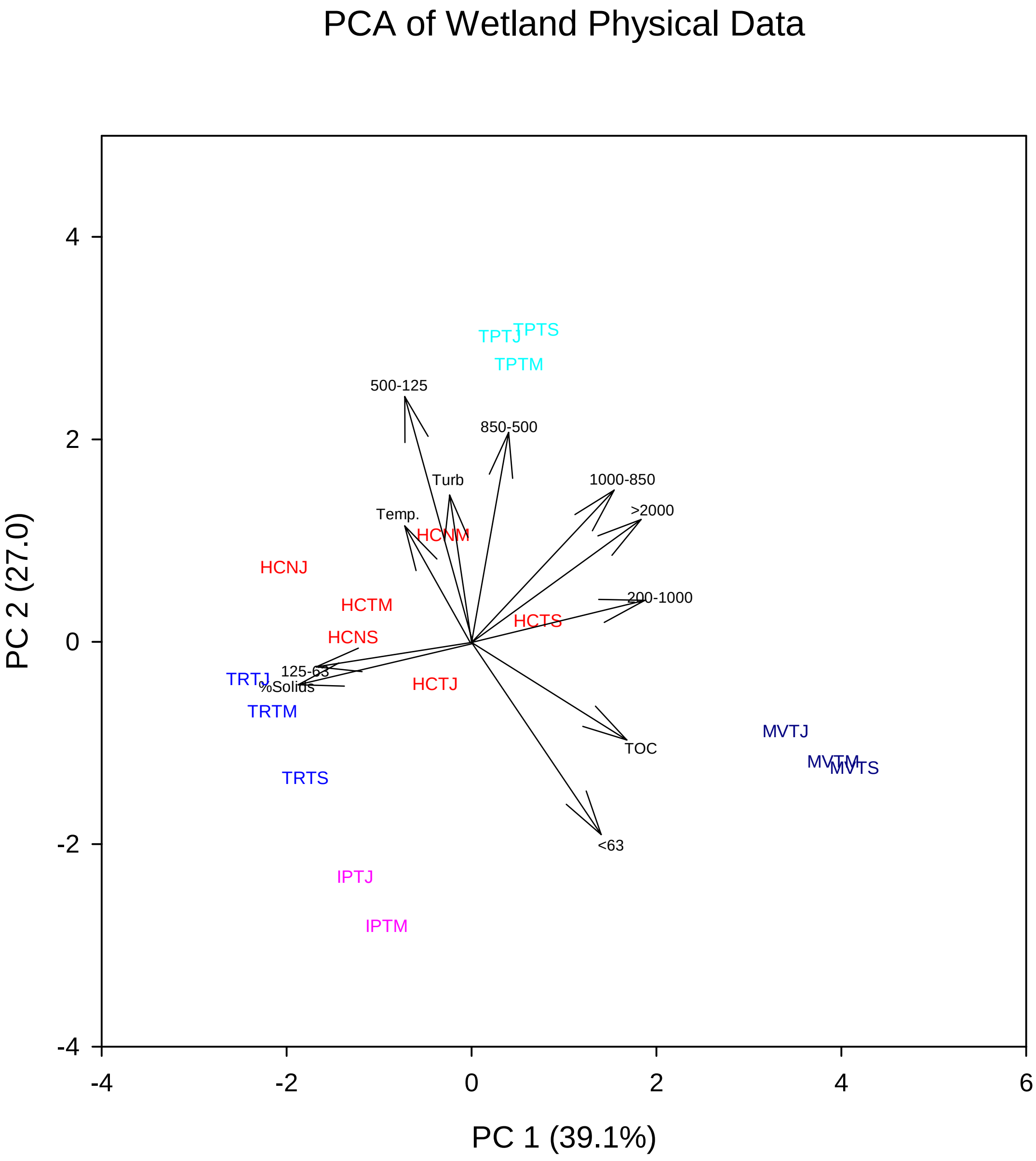

Figure 3.8. Principal components analysis of physical data collected from five wetland sites at three time periods. See Figure 3.6 for an explanation of site labels. Arrows represent eigenvectors scaled to plot area.

Lower Wetland sites were intermediate in PC 1. The Mona View site plotted highest in PC 1 and in the same direction as the eigenvectors for total organic carbon and the <63, 200-1000, 850-1000, and >2000 µm sediment grain size categories. A gradient was also evident in PC 2 which explained 27.0% of the variance in the physical dataset. The Industrial Park site was plotted lowest in PC 2 and in the same direction as the eigenvectors for the <63 µm sediment grain size category and total organic carbon. The LBC Lower Wetland site plotted highest in PC 2 and in the same direction as the eigenvectors for the 125-500, 500-850, and 850-1000 µm sediment grain size categories and the turbidity eigenvector. The Towner Road, Mona View, and Hidden Cove sites all received intermediate PC 2 scores.

Wetland toxicant data are included in Table 3.8. PCA of toxicant data revealed three distinct groupings (Figure 3.9). The Mona View site plotted highest in PC 1 which explained 60.7% of the variance in the toxicant dataset. The eigenvectors for Benzo(a)pyrene, Phenanthrene, total PCBs, Aroclor 1254, Pyrene, Chrysene, and Fluoranthene plotted in the same direction as the Mona View site. The LBC Lower Wetland site plotted highest in PC 2 which explained 31.1% of the variability in the toxicant dataset. The eigenvectors for total silver, barium, zinc, chromium, cadmium, copper, lead, and mercury plotted in the same direction as the LBC Lower Wetland site in PC 2. The remaining three sites formed a tight group that plotted low in both PC 1 and 2 and in the same direction as the eigenvectors for total arsenic, and total selenium.

3.4.5 WETLAND MACROINVERTEBRATES

Wetland macroinvertebrate data are included in Appendix C. In total 7,455 macroinvertebrates of 126 taxa were collected in wetlands of Little Black and Cress Creeks. *Caecidotea* was the most abundant taxon in wetlands of both streams. In wetlands of Little Black Creek we collected 1112 *Caecidotea*, followed by *Physella* (Gastropoda, Physidae) (991), and *Crangonyx* (Amphipoda, Crangonyctidae) (299). These three taxa comprised 66.9% of the macroinvertebrates from Little Black Creek wetlands. In wetlands of Cress Creek we collected 676 *Caecidotea*, followed by Orthocladiinae (403), and *Physella* (318). These three taxa comprised 36.1% of the macroinvertebrates captured in Cress Creek wetlands.

In Cress Creek wetlands 111 taxa were collected (all seasons combined) and in Little Black Creek wetlands 88 taxa were collected. Taxon richness ranged from 21 at the Mona View wetland in September to 56 at the Hidden Cove wetland in May. We compared taxon richness between the two watersheds using Wilcoxon signed-rank tests in which observations were paired by date and watershed position (the Industrial Park wetland of Little Black Creek was excluded because there were no comparable wetlands on Cress Creek). This analysis revealed no significant difference (p=0.462) between the two watersheds.

Non-metric multidimensional scaling was conducted on arcsine-square root transformed relative abundances of 126 wetland macroinvertebrate taxa. Transformation was required because the original dataset contained too much variability for a stable NMDS model to be derived. After transformation, Monte Carlo permutation procedures indicated that an NMDS model with equal or less stress was not likely to occur by chance alone (p=0.0196) and the scree diagram of stress vs. dimension suggested that the dataset was

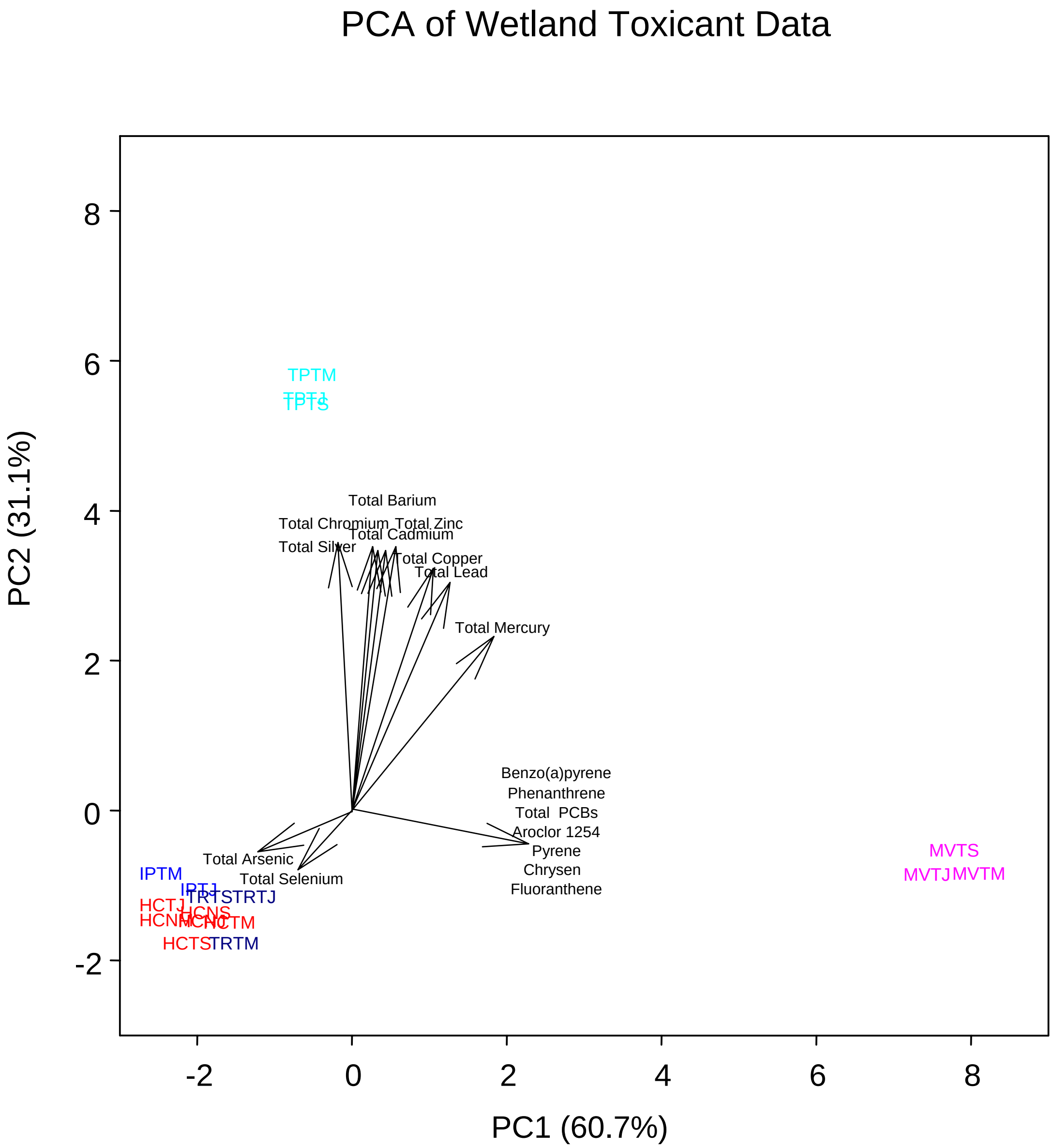

Figure 3.9. Principal components analysis of toxicant data collected from five wetland sites at three time periods. See Figure 3.6 for an explanation of site labels. Arrows represent eigenvectors scaled to plot area.

TABLE 3.8. TOXICANT DATA FOR FIVE WETLAND SITES AND THREE TIME PERIODS.

	Date	Vegetation	Arsenic mg kg^{-1}	Barium mg kg^{-1}	Cadmium mg kg^{-1}	Chromium mg kg^{-1}	Copper mg kg^{-1}	Lead mg kg^{-1}	Selenium mg kg^{-1}	Silver mg kg^{-1}	Zinc mg kg^{-1}	Mercury mg kg^{-1}	Naphthalene mg kg^{-1}
Little Black Creek													
LBC Lower Wetland	18-May	*Typha*	11	422	54	484	304	596	<0.44	5	2040	0.72	< 0.33
Mona View	19-May	*Typha*	9	114	17	142	155	339	<0.44	<0.44	571	0.78	< 0.33
Industrial Park	2-Jun	*Typha*	16	130	2	49	32	164	4	<0.44	182	0.24	< 0.33
LBC Lower Wetland	30-Jun	*Typha*	10	412	55	443	273	542	<0.44	5	1949	0.63	< 0.33
Mona View	30-Jun	*Typha*	10	106	18	120	170	342	<0.44	<0.44	495	0.64	< 0.33
Industrial Park	1-Jul	*Typha*	14	109	2	49	32	168	3	<0.44	191	0.26	< 0.33
LBC Lower Wetland	28-Sep	*Typha*	12	391	60	521	333	489	<0.44	4	1657	0.71	< 0.33
Mona View	29-Sep	*Typha*	8	112	14	147	168	364	<0.44	<0.44	465	0.71	< 0.33
Cress Creek													
Hidden Cove	18-May	*Typha*	14	97	0.8	12	17	27	<0.44	<0.44	84	<0.10	< 0.33
Hidden Cove	18-May	*Nuphar*	16	138	0.7	16	22	31	<1.2	<0.44	103	<0.10	< 0.33
Towner Road	19-May	*Typha*	9	100	1.1	16	19	39	1	<0.44	145	<0.10	< 0.33
Hidden Cove	30-Jun	*Typha*	16	154	0.6	18	23	29	<0.44	<0.44	86	<0.10	< 0.33
Hidden Cove	30-Jun	*Nuphar*	13	80	0.7	11	16	23	<0.44	<0.44	77	<0.10	< 0.33
Towner Road	1-Jul	*Typha*	8	91	0.9	14	21	33	1.4	<0.44	139	<0.10	< 0.33
Hidden Cove	28-Sep	*Nuphar*	12	105	0.7	12	19	28	<0.44	<0.44	69	<0.10	< 0.33
Hidden Cove	28-Sep	*Typha*	17	118	0.7	14	23	32	<0.44	<0.44	86	<0.10	< 0.33
Towner Road	28-Sep	*Typha*	8	82	1.2	17	16	33	1.2	<0.44	153	<0.10	< 0.33

TABLE 3.8 (CONTINUED). TOXICANT DATA FOR FIVE WETLAND SITES AND THREE TIME PERIODS.

	Date	Vegetation	Acenaphthylene mg kg^{-1}	Acenaphthene mg kg^{-1}	Fluorene mg kg^{-1}	Phenanthrene mg kg^{-1}	Anthracene mg kg^{-1}	Fluoranthene mg kg^{-1}	Pyrene mg kg^{-1}	Benzo(a)anthracene mg kg^{-1}
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	19-May	*Typha*	< 0.33	< 0.33	< 0.33	4.5	< 0.33	1.1	4.1	3.4
Industrial Park	2-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
LBC Lower Wetland	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	4.1	< 0.33	1.0	4	4
Industrial Park	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
LBC Lower Wetland	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	29-Sep	*Typha*	< 0.33	< 0.33	< 0.33	4.5	< 0.33	1.0	4	3
Cress Creek										
Hidden Cove	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	18-May	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	19-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

TABLE 3.8 (CONTINUED). TOXICANT DATA FOR FIVE WETLAND SITES AND THREE TIME PERIODS.

	Date	Vegetation	Chrysene mg kg^{-1}	Benzo(b)fluoranthene mg kg^{-1}	Benzo(k)fluoranthene mg kg^{-1}	Benzo(a)pyrene mg kg^{-1}	Indeno(1,2,3-cd)pyrene mg kg^{-1}
Little Black Creek							
LBC Lower Wetland	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	19-May	*Typha*	2.2	2.4	2.6	3.00	0.89
Industrial Park	2-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
LBC Lower Wetland	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	30-Jun	*Typha*	2	3	3	3	1
Industrial Park	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	0	< 0.33
LBC Lower Wetland	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	29-Sep	*Typha*	2	2	3	3	1
Cress Creek							
Hidden Cove	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	18-May	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	19-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

TABLE 3.8 (CONTINUED). TOXICANT DATA FOR FIVE WETLAND SITES AND THREE TIME PERIODS.

	Date	Vegetation	Dibenzo(a,h)anthracene mg kg^{-1}	Benzo(g,h,i)perylene mg kg^{-1}	Total PAH Compounds mg kg^{-1}	Aroclor 1016 mg kg^{-1}	Aroclor 1221 mg kg^{-1}	Aroclor 1232 mg kg^{-1}
Little Black Creek								
LBC Lower Wetland	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	19-May	*Typha*	< 0.33	24	48	< 0.33	< 0.33	< 0.33
Industrial Park	2-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
LBC Lower Wetland	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	30-Jun	*Typha*	< 0.33	23	28	< 0.33	< 0.33	< 0.33
Industrial Park	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
LBC Lower Wetland	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	29-Sep	*Typha*	< 0.33	24	21	< 0.33	< 0.33	< 0.33
Cress Creek								
Hidden Cove	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	18-May	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	19-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

TABLE 3.8 (CONTINUED). TOXICANT DATA FOR FIVE WETLAND SITES AND THREE TIME PERIODS.

	Date	Vegetation	Aroclor 1242 mg kg^{-1}	Aroclor 1248 mg kg^{-1}	Aroclor 1254 mg kg^{-1}	Aroclor 1260 mg kg^{-1}	Total PCBs mg kg^{-1}
Little Black Creek							
LBC Lower Wetland	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	0
Mona View	19-May	*Typha*	< 0.33	< 0.33	1.2	< 0.33	1.2
Industrial Park	2-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	0
LBC Lower Wetland	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	30-Jun	*Typha*	< 0.33	< 0.33	1.2	< 0.33	1.2
Industrial Park	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	0
LBC Lower Wetland	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Mona View	29-Sep	*Typha*	< 0.33	< 0.33	1.3	< 0.33	1.3
Cress Creek							
Hidden Cove	18-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	18-May	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	19-May	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	30-Jun	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	1-Jul	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Nuphar*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Hidden Cove	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33
Towner Road	28-Sep	*Typha*	< 0.33	< 0.33	< 0.33	< 0.33	< 0.33

best represented by three dimensions. Thus, we recalculated the NMDS using only three dimensions which resulted in a final stress of 10.34 and explained a total of 85.1% of the variation in the original distance matrix. We then superimposed watershed, month, and site onto the three NMDS axes (biplots of axes 1x2, 1x3, and 2x3). From these biplots we identified a gradient best explained by site (i.e., watershed position) in axis 1 (which explained 25.6% of the variability in the original distance matrix) (Figure 3.10) and a gradient associated with sampling month in both axis 2 and axis 3 (which explained 22.3 and 36.2% of the variability in the original distance matrix, respectively) (Figure 3.11).

The gradient in axis 1 extended from the Industrial Park site (lowest axis 1 scores) to the Mona View and Towner Road sites (intermediate axis 1 scores) to the LBC Lower Wetland and Hidden Cove sites (highest axis 1 scores) (Figure 3.10). This ordering of sites is important because it represents longitudinal position within both watersheds. That is, the Industrial Park site was the wetland furthest upstream on Little Black Creek, the Mona View and Towner Road sites were at intermediate positions within both watersheds, and the LBC Lower Wetland and Hidden Cove sites were at the mouths of each stream (i.e., confluence with Mona Lake). The effect of watershed (Little Black Creek vs. Cress Creek) was not apparent in axis 1.

In both axis 2 and axis 3, September communities plotted relatively low, June/July communities were intermediate, and May communities plotted relatively high (Figure 3.11). The effect of watershed was not apparent in either of these NMDS axes. The relationship between axes 2 and 3 and sampling month suggests that macroinvertebrate communities in the five wetlands sampled undergo substantial shifts in community composition throughout the growing season. Our results also suggest that this temporal variability is more pronounced than differences attributable to watershed.

3.4.6 RELATING WETLAND MACROINVERTEBRATE COMMUNITY COMPOSITION TO ABIOTIC CONDITIONS

To relate macroinvertebrate community composition to chemical, physical, and toxicant conditions we plotted community gradients (NMDS axes) against PCs of the wetland abiotic data. We then calculated Pearson correlations between the gradients to determine if community composition was related to abiotic conditions. Significant correlations were found between both NMDS axes 1 and 2 and physical PC 2 (NMDS axis 1: $p=0.023$, $r=0.547$, NMDS axis 2: $p=0.037$, $r=0.510$). Since physical PC 2 represented a gradient of the <63 μm sediment grain size category and total organic carbon to the 125-500, 500-850, and 850-1000 μm sediment grain size categories and turbidity, this significant correlation suggests that macroinvertebrate communities are responding to these factors. This makes sense given that the majority of macroinvertebrate taxa in these wetlands are detritivores which would respond to sediment type. Also, the relatively high turbidity measured at the LBC Lower Wetland site may be important for community

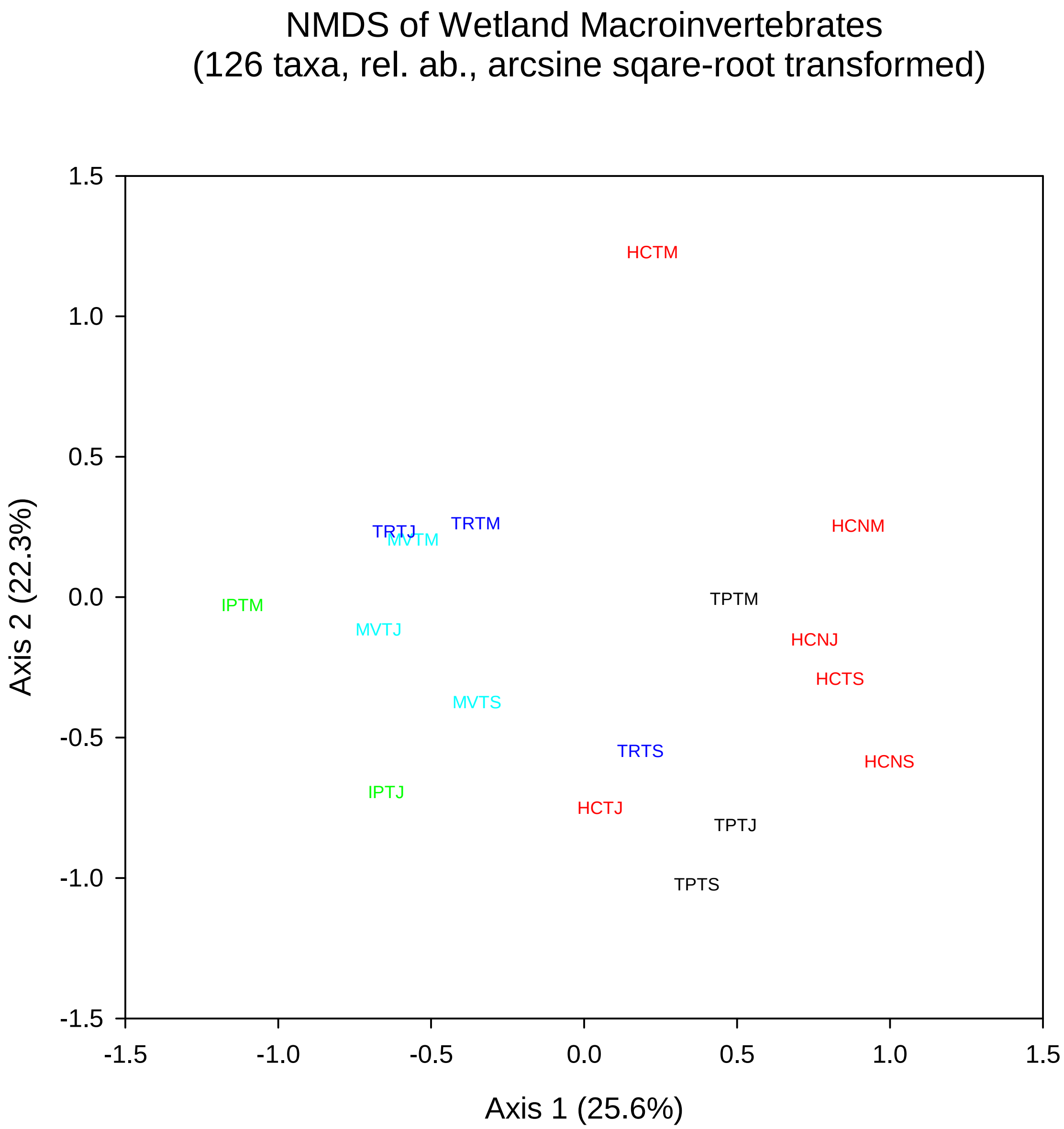

Figure 3.10. Non-metric multi-dimensional scaling ordination (axes 1 and 2) of wetland macroinvertebrate data from five sites at three time periods. See Figure 3.6 for an explanation of site labels.

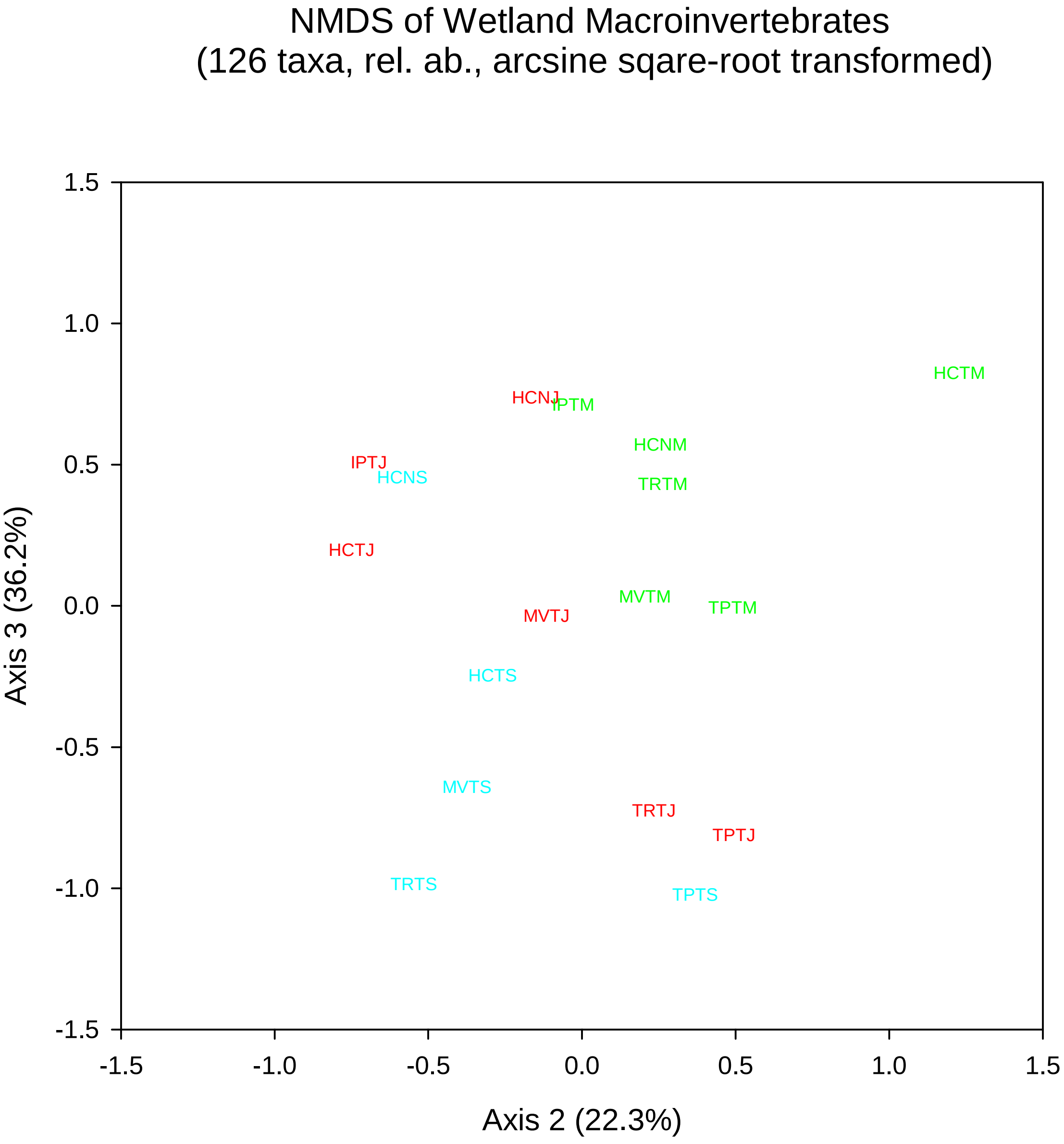

Figure 3.11. Non-metric multi-dimensional scaling ordination (axes 2 and 3) of wetland macroinvertebrate data from five sites at three time periods. See Figure 3.6 for an explanation of site labels.

composition at this site because it may lower the success of visual predators or filtering collectors. NMDS axis 2 was also significantly correlated with chemical PC 2 (p=0.005, r=0.646). This relationship suggests that macroinvertebrate communities are responding to the chemical variables responsible for the gradient in chemical PC 2 (chlorophyll and soluble reactive phosphorus versus nitrate-N). An example was the Hidden Cove *Typha* site in May which had exceptionally high chemical PC 2 and NMDS axis 2 scores. We measured high soluble reactive phosphorus and chlorophyll concentrations at this site in May and we found 13 taxa that were unique to this site in May. The unique abiotic conditions and biotic community structure of this site in May suggests that community composition may be responding to local conditions such as increased algal biomass related to increased phosphorus concentration.

Macroinvertebrate community composition, as represented by our three NMDS axes, did not correlate significantly with either of the two toxicant principal components, though a marginally-significant correlation was found between NMDS axis 3 and toxicant PC 2 ($p=0.059$, $r=-0.467$). This relationship is most likely a result of the LBC Lower Wetland site having high PC 2 scores due to relatively high concentrations of metals along with relatively low NMDS axis 3 scores. The influence that these metals have on macroinvertebrate communities, however, is difficult to determine given the incluence of physical parameters.

3.4.7 WETLAND FISH AND TURTLES

There were marked differences between the fish communities of LBC Lower Wetland and Hidden Cove. In Hidden Cove we collected a total of 121 fish (all three sampling periods combined: 10 net-nights) comprised of 19 species (Table 3.9). In LBC Lower Wetland we collected a total of 51 fish (10 net-nights) comprised of 3 species (Table 3.9). The most abundant species in Hidden Cove was bluegill (*Lepomis macrochirus*) (3.7 net-night^{-1}) followed by bluntnose minnow (*Pimephales notatus*) (3.1 net-night^{-1}) and round goby (*Neogobius melanostomus*) (2.0 net-night^{-1}). bluntnose minnow was the most abundant species (4.9 net-night^{-1}) in LBC Lower Wetland followed by brook stickleback (*Culaea inconstans*) and bowfin (*Amia calva*) (0.1 net-night^{-1} each).

Three species of turtles were also captured in Hidden Cove and LBC Lower Wetland wetlands (Table 3.9). Painted turtle (*Chrysemys picta*) was the most common species in both wetlands and 2.8 and 14.1 painted turtles per net-night were collected from Hidden Cove and LBC Lower Wetland, respectively. Musk turtle (*Sternotherus odoratus*) was the second most common species (1.0 and 1.1 net-night^{-1} from Hidden Cove and LBC Lower Wetland, respectively) followed by snapping turtle (*Chelydra serpentine*) (0.6 net-night^{-1} in both wetlands). Wilcoxon signed-rank tests revealed that there were no significant differences in catches of any of the three turtle species between Hidden Cove and LBC Lower Wetland. (snapping turtle: $p=0.99$, musk turtle: $p=0.99$, painted turtle: $p=0.105$) when paired by sampling date.

TABLE 3.9. FISH AND TURTLE CATCH PER NET-NIGHT FOR THE TWO LOWER WETLAND SITES AT THREE TIME PERIODS. FISH SPECIES COMMON NAMES ARE ACCORDING TO NELSON *ET AL.* (2004).

	Lower Wetland			Hidden Cove		
	5/19/04	7/1/04	9/28/04	5/19/04	7/1/04	9/28/04
bluntnose minnow	3.00	11.67	0.67	4.25	4.00	0.67
brook stickleback	0.25					
banded killifish				0.50	3.00	
bowfin			0.33	0.25	0.33	
emerald shiner				0.25		
spottail shiner				0.25		
black crappie				0.25		
brook silverside					1.00	
bluegill					3.67	8.67
pumpkinseed					0.33	
gizzard shad					0.67	
round goby					0.67	6.00
alewife					0.67	
golden shiner					0.33	
northern pike						0.33
white sucker						0.33
green sunfish						1.00
creek chub						0.33
largemouth bass						0.33
yellow perch						0.33
snapping turtles	1.00	0.67		0.25	1.67	
musk turtles	1.25	1.67	0.33	0.25	1.00	2.00
painted turtle	10.75	18.00	14.67	4.00	2.33	1.67

3.4.8 LAKE ABIOTIC DATA

Lake chemical data are included in Table 3.10. PCA of 14 chemical and physical parameters revealed a gradient associated with sampling month in PC 1 which explained 57.4% of the variance in the lake chemical/physical dataset (Figure 3.12). May observations plotted lowest in PC 1 and in the same direction as the eigenvectors for ammonium-N and nitrate-N. November observations plotted highest in PC 1 and in the same direction as the eigenvectors for dissolved oxygen, alkalinity, chloride, pH, sulfate, oxidation-reduction potential, and specific conductance. August observations were intermediate in PC 1. In addition to the gradient due to sampling month, the Little Black Creek site had lower PC 1 scores than the Cress Creek site for each respective month. This pattern suggests that conditions at the Little Black Creek site were more similar to those observed earlier in the year (i.e., higher ammonium and nitrate, and lower dissolved oxygen, alkalinity, and pH). In PC 2, which explained 30.3% of the variation in the Lake chemical/physical dataset, August observations plotted relatively low and in the same

TABLE 3.10. CHEMICAL AND PHYSICAL DATA MEASURED AT THE TWO LAKE SITES AT THREE TIME PERIODS. VARIABLES INCLUDE TEMPERATURE (TEMP), DISSOLVED OXYGEN (%DO, DO), SPECIFIC CONDUCTANCE (SPC), TOTAL DISSOLVED SOLIDS (TDS), TURBIDITY (TURB), PH, OXIDATION-REDUCTION POTENTIAL (ORP), CHLOROPHYLL A (CHL), TOTAL ALKALINITY, PHENOLPHTHALEIN ALKALINITY (PHENO. ALK.), CHLORIDE (CL^-), SULFATE-S (SO_4-S), NITRATE-N (NO_3-N), AMMONIUM-N (NH_4-N), AND SOLUBLE REACTIVE PHOSPHORUS (SRP). DETECTION LIMIT FOR CHLORIDE AND SULFATE WAS 0.1 MG L^{-1} AND 0.01 MG L^{-1} FOR NITRATE-N, AMMONIUM-N, AND SRP.

	Temp.	%D.O.	D.O (mg L^{-1})	SpC (uS/cm)	TDS (g/L)	Turb. NTU	pH	ORP (mV)	Chl (ug/L)	Total alkalinity (mg $CaCo_3$ L^{-1})	Pheno. Alk. (mg $CaCo_3$ L^{-1})	Cl^- (mg L^{-1})	SO_4-S (mg L^{-1})	NO_3-N (mg L^{-1})	NH_4-N (mg L^{-1})	SRP (mg L^{-1})
Little Black Creek																
5/20/04	17.90	64.7	6.05	455.6	0.2930	30.1	7.70	327	5.6	91.8	0.0	39.0	34.4	0.66	0.21	<0.01
8/23/04	21.70	121.2	10.42	468.1	0.3006	7.3	9.13	330	33.2	132.0	4.0	49.5	37.1	0.16	0.05	<0.01
11/12/04	7.73	114.5	13.63	496.3	0.3136	29.1	9.35	335	48.9	130.5	2.0	48.7	42.2	0.32	<0.01	<0.01
Cress Creek																
5/20/04	16.43	73.6	7.06	431.5	0.2746	19.1	7.89	310	8.1	125.0	0.0	35.2	43.0	0.84	0.16	<0.01
8/23/04	21.03	133.1	11.58	448.6	0.2878	10.9	9.24	323	79.1	128.0	7.0	46.5	38.4	0.10	0.03	<0.01
11/12/04	5.58	106.1	13.09	556.2	0.3570	33.7	8.89	363	34.5	136.0	3.0	49.0	50.6	0.46	<0.01	<0.01

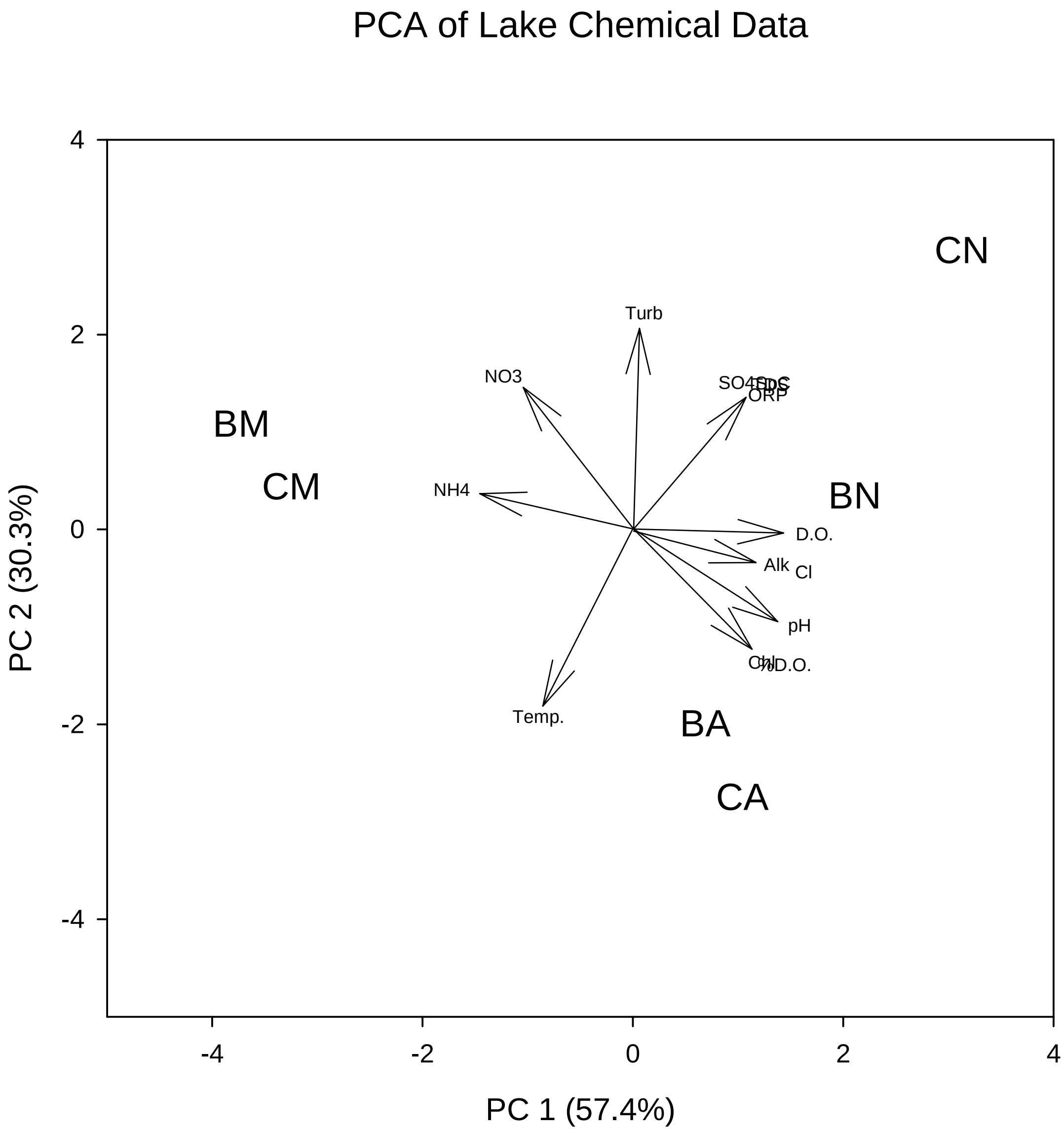

Figure 3.12. Principal components analysis of chemical and physical data collected from the two lake sites at three time periods. The first letter of site labels indicates site (C: Cress, B: Little Black Creek) and the second letter indicates sampling month (M: May, A: August, N: November). Arrows represent eigenvectors scaled to plot area.

direction as the eigenvectors for temperature, percent saturation dissolved oxygen, and chlorophyll suggesting that these parameters were higher in August.

3.4.9 LAKE MACROINVERTEBRATES

The two lake stations were sampled in May, August, and November of 2004. Three petite PONAR grab samples were collected from each of the two sites on each sampling date. Lake macroinvertebrate data are included in Table 3.11. In total, we collected 2447 organisms, 1191 from the Cress Creek site and 1256 from the Little Black Creek site. Wilcoxon signed-rank test of total macroinvertebrate abundance, paired by date, resulted in no significant difference between the two sites (p=0.593).

A total of 24 taxa were collected at the Cress Creek site and 14 were collected from the Little Black Creek site. Taxon richness per site per date ranged from eight at the Little Black Creek site in May to 17 at the Cress Creek site in May. A Wilcoxon signed-rank test revealed a marginally significant difference in taxon richness between the two sites when paired by date (p=0.109) with the Cress Creek site tending to have more taxa.

The most abundant taxon at the Cress Creek site was Tanypodinae (Diptera, Chironomidae) (relative abundance, three dates combined=31.7%), followed by Chironomini (Diptera, Chironominae) (24.7%), and Tubificidae (Oligochaeta) (23.2%). These were also the three most dominant taxa at the Little Black Creek site though Tubificidae was the most abundant (58.8%), followed by Tanypodinae (24.1%), and Chironomini (9.2%).

3.5 Conclusions

A comparative assessment of the macroinvertebrate and fish populations in Little Black Creek was conducted using Cress Creek as a control site. Stream and wetland sites within each system were evaluated individually. The two sites were found to have similar water chemistry and physical characteristics. Nitrate, dissolved oxygen, and pH were slightly higher in Cress Creek while inorganic anions were higher in Little Black Creek. With respect to toxicants, Little Black Creek contained significantly higher levels of heavy metals and PAH compounds compared to Cress Creek. Taxon richness was higher in Cress Creek than LBC. In addition, higher densities of pollution sensitive Trichoptera and Plecoptera taxa were present in Cress Creek. The gradient in macroinvertebrate communities due to stream was more important than gradients related to either month or site, suggesting that anthropogenic disturbance associated with Little Black Creek substantially altered the macroinvertebrate community and these alterations overshadowed temporal and site-specific variability. The benthic macroinvertebrate fauna of Little Black Creek was found to be negatively impacted compared to the Cress Creek control site.

TABLE 3.11. MACROINVERTEBRATE DATA FOR THE TWO LAKE SITES AND THREE TIME PERIODS. DATA ARE MEANS OF THREE REPLICATE SAMPLES COLLECTED ON EACH DATE.

Phylum:	Nematoda	Platyhelminthes	Annelida	Annelida	Annelida	Mollusca	Arthropoda	Arthropoda	Arthropoda
Class:							Hydrachnidia	Crustacea	Crustacea
Order:		Turbellaria	Hirudinea	Oligochaeta	Oligochaeta	Bivalvia	Hydracarina	Amphipoda	Amphipoda
Family:				Naididae	Tubificidae	Sphaeriidae		Gammaridae	Unknown
Genus:						*Sphaerium*		*Gammarus*	
Little Black Creek									
5/20/04	0.67			13.67	153.33				
8/23/04	0.33			0.67	40.67		0.67		
11/12/04	4.33			5.33	52.00				
Cress Creek									
5/20/04	1.00	0.33		14.33	25.67	0.33			0.33
8/23/04			1.67	1.67	23.67	0.33		0.33	
11/12/04	1.33			2.00	42.67		1.33	1.00	

Phylum:	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:	Ephemeropt	Trichoptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:	Caenidae	Leptoceridae	Ceratopogc	Ceratopogoni	Ceratopogoni	Ceratopogoni	Ceratopogonid	Ceratopogonidae	Ceratopogonidae
Genus:	*Caenis*	*Oecetis*	*Alluaudomy*	*Bezzia*	*Ceratopogon*	*Culicoides*	*Dasyhelea*	*Sphaeromias*	Unknown
Little Black Creek									
5/20/04									
8/23/04						0.67			
11/12/04	0.33					0.33		0.33	0.33
Cress Creek									
5/20/04	4.00			0.33	1.00	2.67	0.33	2.00	
8/23/04						1.00		0.33	
11/12/04	2.00	1.67	1.33	0.33		3.00	0.33		0.33

Phylum:	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:	Chironomida	Chironomidae	Chironomic	Chironomidae	Chironomidae	Tipulidae	Unknown
Genus:	Chironomini	Orthocladiinae	Tanytarsini	Tanypodinae	Unknown	Unknown	
Little Black Creek							
5/20/04	4.33	0.67	0.33	62.00	0.33		
8/23/04	10.67	0.33	1.33	22.33	0.67		0.33
11/12/04	23.33		0.67	16.67	1.00		
Cress Creek							
5/20/04	10.00		1.33	48.67	0.67		0.33
8/23/04	9.33		1.67	30.33	2.67	0.33	
11/12/04	78.67		24.67	47.00	2.67		

The wetlands in both systems showed different trends with respect to physical and chemical parameters. Turbidity and sand size fraction sediments were greater in LBC while fine grained sediments and TOC were greater in Cress Creek. Toxicant levels (metals and PAH compounds) were significantly higher in the wetlands of Little Black Creek. Macroinvertebrate communities in the two systems appeared to respond more to substrate and turbidity than toxicant concentration. Since macroinvertebrate populations were dominated by detritivores, changes in TOC and substrate would have a significant effect with respect to community structure. In addition, wetland sediments are highly reducing in nature and have low metal bioavailability due to high levels of sulfides.

Fish populations in the LBC lower wetland were significantly different that the Hidden Cove wetland of Cress Creek. Catches in the LBC wetland had lower numbers and fewer species than Hidden Cove. Turtle populations were similar in both systems. Water quality and physical parameters appeared to have a greater structuring effect on these communities than contaminated sediments.

3.6 References

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4.0 Hydrologic Model

4.1 Introduction

Little Black Creek is the second largest tributary of Mona Lake, which eventually discharges into Lake Michigan (Fig. 4.1). The Little Black Creek watershed covers an area of 19.63 km^2. Primary land use/covers in the watershed include residential, commercial, industrial, forest, and open field (Fig. 4.2) and a variety of sandy soils (e.g., Rubicon, Au Gres, and Saugatuck sands) are dominant soil types (Figure 4.3).

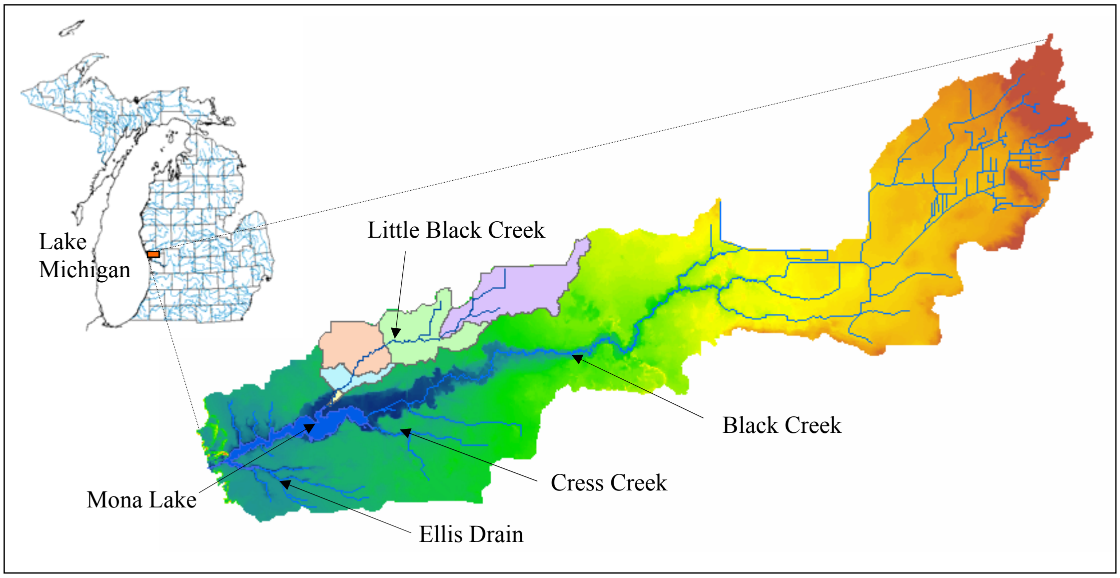


FIGURE 4. 1 LOCATION OF THE LITTLE BLACK CREEK WATERSHED

According to studies in more than one decade, the sediments throughout Little Black Creek have been heavily contaminated by a number of metals and organic chemicals and the biotic community of the creek has been adversely affected (Evans, 1982; Wuycheck, 1992; Walker, 2000 and 2002; Steinman et al., 2006). To better understand the underlying mechanisms, transport processes, and distribution of metals (e.g., cadmium) and contaminated sediments, identify their sources, and evaluate their adverse impacts on the ecosystem, comprehensive hydrologic and environmental modeling studies have been conducted in this project. Specific objectives of this project are: (1) to fill the current data gap by conducting intensive hydrologic monitoring in the watershed; (2) to provide detailed hydrologic information concerning quantity, variability, and sources of stream flow by characterizing hydrologic processes and conducting watershed GIS-based hydrologic modeling; (3) to estimate loads of the eroded sediments into the creek; and (4) to quantify the fate and transport of metal (cadmium) and sediments in the LBC stream-wetland system.

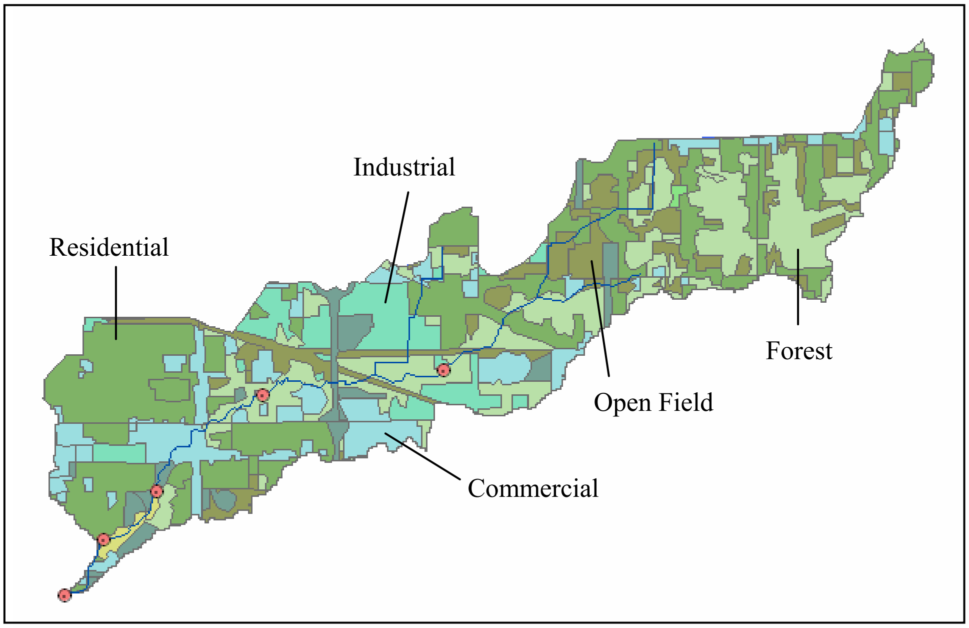


FIGURE 4. 2. LAND USE IN THE LITTLE BLACK CREEK WATERSHED.

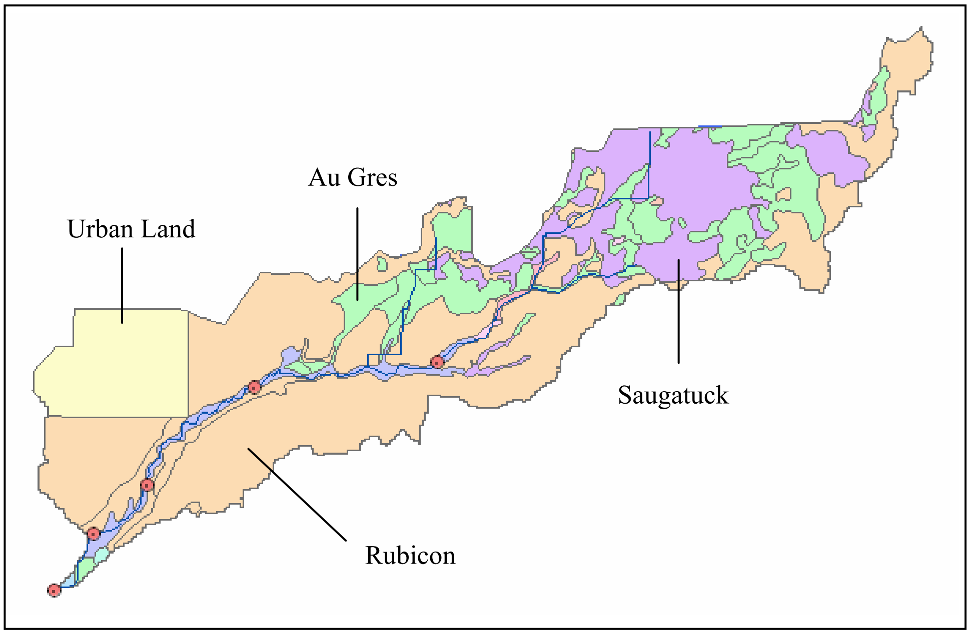


FIGURE 4. 3. SOIL TYPES IN THE LITTLE BLACK CREEK WATERSHED

4.2 Information on the Monitoring Sites

Five sites were selected for hydrologic monitoring in this project. The geographic locations of the sites (Lat-Long decimal degree) are shown in Table 4.1 and are schematically displayed in Fig. 4.4.

TABLE 4. 1. GEOGRAPHIC LOCATIONS OF THE FIVE STREAM MONITORING SITES (LAT-LONG DECIMAL DEGREE).

Site	X Coordinate	Y Coordinate	Location
Site 1	-86.1895	43.2103	Black Creek Rd
Site 2	-86.2155	43.2079	Roberts St
Site 3	-86.2330	43.1948	Mona View
Site 4	-86.2383	43.1929	Airline Rd
Site 5	-86.2406	43.1884	Hoyt St

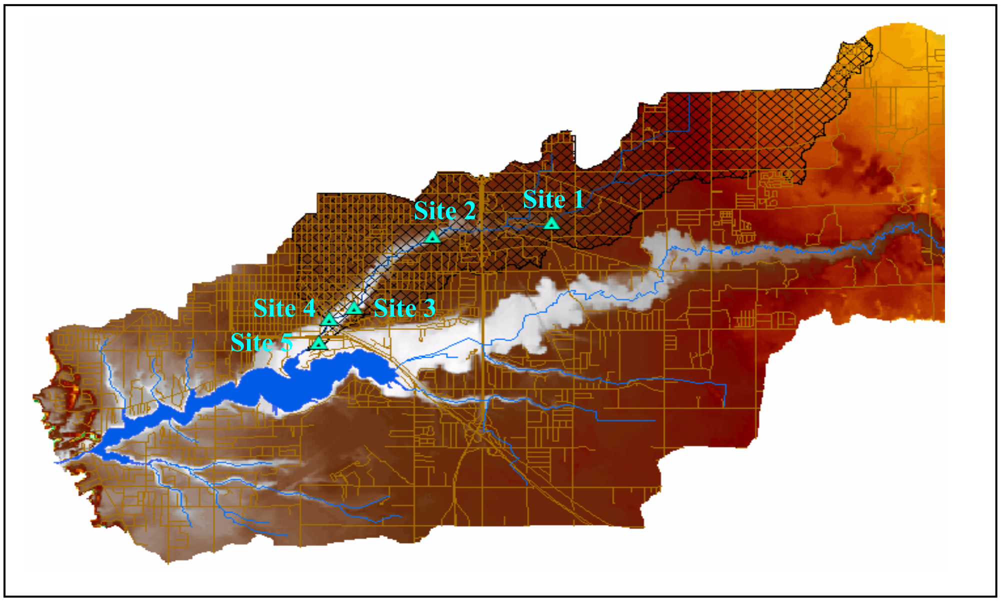


FIGURE 4. 4. LOCATION OF THE STREAM FLOW MONITORING SITES.

Hourly rainfall data at the Muskegon County Airport weather station were obtained from the NOAA National Climatic Data Center. Detailed information on the weather station is shown in Table 4.2.

TABLE 4. 2. INFORMATION ON THE WEATHER STATION AT MUSKEGON COUNTY AIRPORT.

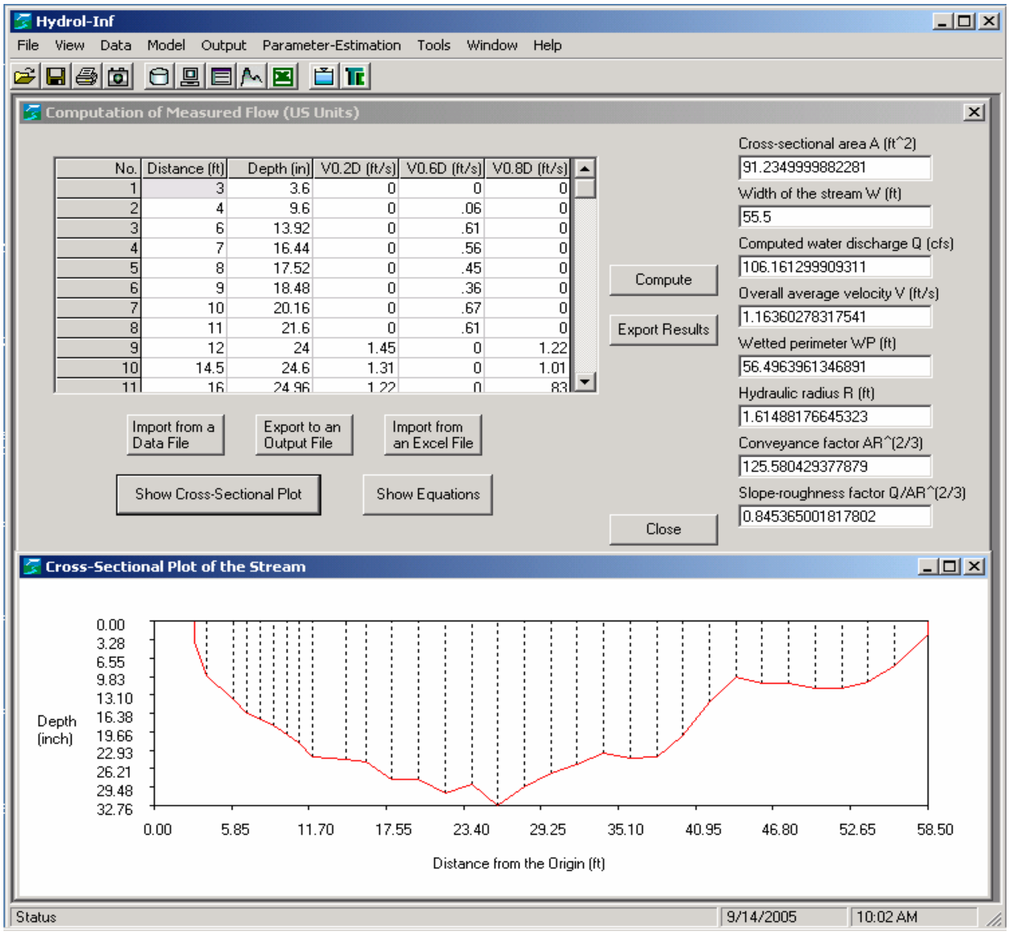
Type	ASOS-NWS FCWOS
Call Sign/ICS	MKG/KMKG
WBAN	14840
COOP ID	205712
Climate Division	MI-05 – West Central Lower
WMO ID	72636
Elevation	190.5 m (624.8´) above s/l
Lat/Lon	43º10´N/86º14´W

4.3 Methods

At each of the five sites, an Odyssey pressure and temperature recording system was installed for continuously collecting the stream water level and temperature data. The recording time interval was 10 minutes for all sites. To ensure that the pressure and temperature sensors function properly and accurately, the monitoring equipment was tested and calibrated in the laboratory before field installation. In the field, the sensors were maintained on a weekly or bi-weekly basis and the recorded data were downloaded to a laptop computer for further processing.

4.3.1 STREAM FLOW MEASUREMENT AND COMPUTATION

In order to develop rating curves that relate the stream water stage recorded by the pressure sensor to discharge, stream flow was manually measured at all sites by using a Marsh-McBirney flow meter (Flo-Mate Model 2000). A number of measurements have been collected at all sites. Basically, the measured stream stages covered the primary range of the sensor-recorded data at most sites. The Windows-based hydrologic software, HYDROL-INF (Fig. 4.5; Chu, 2006) was used for processing the measured stream data and computing stream discharges and hydraulic parameters. In the software, the midsection method was selected for calculating water discharge across a stream channel.



No.	Distance (ft)	Depth (in)	V0.2D (ft/s)	V0.6D (ft/s)	V0.8D (ft/s)
1	3	3.6	0	0	0
2	4	9.6	0	.06	0
3	6	13.92	0	.61	0
4	7	16.44	0	.56	0
5	8	17.52	0	.45	0
6	9	18.48	0	.36	0
7	10	20.16	0	.67	0
8	11	21.6	0	.61	0
9	12	24	1.45	0	1.22
10	14.5	24.6	1.31	0	1.01
11	16	24.96	1.22	0	83

Cross-sectional area A (ft^2)
91.2349999882281
Width of the stream W (ft)
55.5
Computed water discharge Q (cfs)
106.161299909311
Overall average velocity V (ft/s)
1.16360278317541
Wetted perimeter WP (ft)
56.4963961346891
Hydraulic radius R (ft)
1.61488176645323
Conveyance factor AR^(2/3)
125.580429377879
Slope-roughness factor Q/AR^(2/3)
0.845365001817802

FIGURE 4. 5. STREAM FLOW COMPUTATION TOOL IN THE HYDROL-INF SOFTWARE.

4.3.2 DEVELOPMENT OF RATING CURVES

The measured stream data were used for developing rating curves. To better reflect the relationship between the stage and discharge for different hydraulic conditions and achieve the best fitting curves, three separate rating curves were developed for each site, which correspond to low-stage, mid-stage, and high-stage conditions, respectively. Using the developed rating curves and the sensor-recorded stage data, the observed hydrographs (Q - t) at all monitoring sites for the period from May to November, 2004 were created, as shown in Fig. 4.6 (note that the observation time interval is 10 minutes).

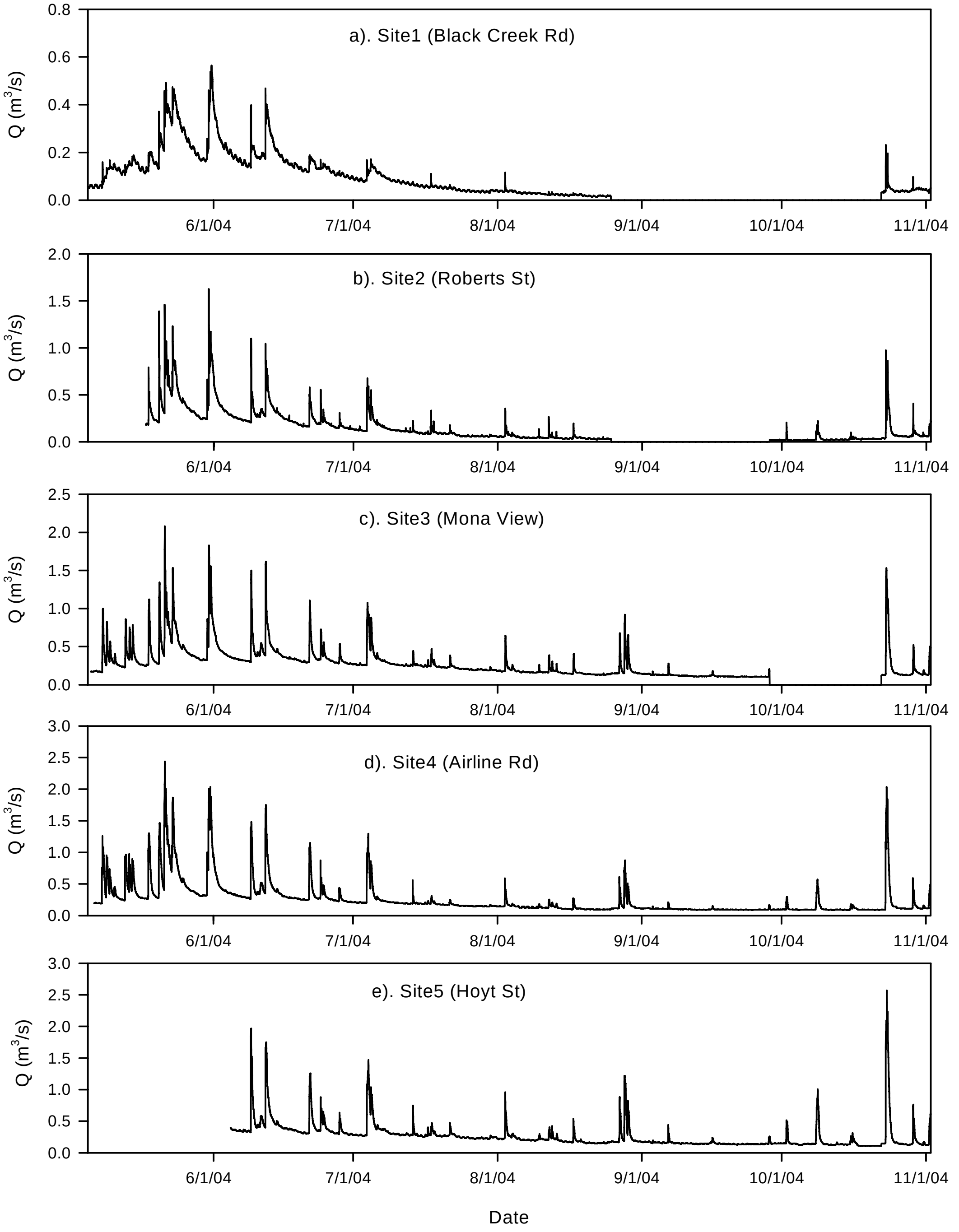


FIGURE 4. 6. TEN-MINUTE OBSERVED HYDROGRAPHS AT ALL SITES FROM MAY TO NOVEMBER, 2004.

4.4 Watershed Delineation

Watershed delineation is a fundamental step for the GIS-based hydrologic modeling. The involved work primarily includes processing of GIS data (e.g., DEM, land use, and soil type), determination of stream networks (channels and outlets) and sub-basin boundaries, and computation of geometric and hydrologic parameters. In this project, the Watershed Modeling System (WMS, 1999) was used for delineating the watershed and computing geometric and hydrologic parameters.

4.4.1 WATERSHED DELINEATION USING WMS AND DEVELOPMENT OF THE HEC-HMS CONCEPTUAL MODEL

Using the WMS software, following steps were performed for the watershed delineation:

(1) The USGS digital elevation model (DEM) for the Mona Lake watershed was first imported into WMS.
(2) Using the topographic parameterization program (TOPAZ) in WMS, which was specially developed for automated analysis of landscape topography from DEMs, overland flow directions and accumulations were computed.
(3) Based on the watershed hydrologic characteristics and distributions of actual stream channels, five outlets (Outlets 6-10) were defined and the stream network was created for the watershed (4 reaches: Reaches 5-8).
(4) After the point layer of outlets and the arc layer of the stream channels were generated, a polygon layer representing subbasin boundaries was determined. The entire watershed was then divided into five subbasins (Basins 6-10).
(5) Geometric parameters of all subbasins and stream reaches were computed.
(6) Based on the watershed delineation results, a conceptual model was created for further development of the HEC-HMS hydrologic model.

The hydrologic elements (subbasins, reaches, and outlets) are summarized in Table 4.3. Primary parameters of the subbasins and reaches are listed in Tables 4.4 and 4.5, respectively. The delineated Little Black Creek watershed and the developed HEC-HMS conceptual model are shown in Figs. 4.7 and 4.8, respectively.

TABLE 4. 3. HYDROLOGIC ELEMENT INVENTORY.

Element	Description	Element	Description
Basin6	LBC1	Outlet6	Site 1-BC Rd
Basin7	LBC2	Outlet7	Site 2
Basin8	LBC3	Outlet8	Site 3-Summit
Basin9	LBC4	Outlet9	Site 4
Basin10	LBC5	Outlet10	LBC Outlet (Site 5)
Reach5	Outlets6-7 Reach	Reach7	Outlets8-9 Reach
Reach6	Outlets7-8 Reach	Reach8	Outlets9-10 Reach

TABLE 4. 4. SUBBASINS AND THEIR PARAMETERS.

Subbasin	Area (km^2)	Perimeter (m)	AOFD(m)	BS(m/m)	MFD(m)	MFDS(m/m)	MSL(m)
Basin6	7.8187	20392.86	1171.90	0.0033	8194.10	0.0017	7906.80
Basin7	5.9118	17920.03	671.83	0.0084	4878.70	0.0030	3735.70
Basin8	4.2523	10199.51	614.17	0.0094	4925.60	0.0025	3823.30
Basin9	1.5035	9767.23	789.58	0.0170	2979.50	0.0044	906.01
Basin10	0.1438	2655.49	144.11	0.0140	1169.80	0.0110	882.37

Notations:
AOFD = Average overland flow length
BS = Basin (overland) slope
MFD = Basin length along main channel from outlet to upstream boundary
MFDS = Basin slope along main channel from outlet to upstream boundary
MSL = Maximum flow (watercourse) length

TABLE 4. 5. REACHES AND THEIR PARAMETERS.

Reach	Length(m)	Elevation1(m)	Elevation2(m)	Slope(m/m)
Reach5	2498.91	190.30	182.45	0.0031
Reach6	2026.94	182.45	179.72	0.0013
Reach7	930.22	179.72	179.54	0.0002
Reach8	905.16	179.54	177.59	0.0022

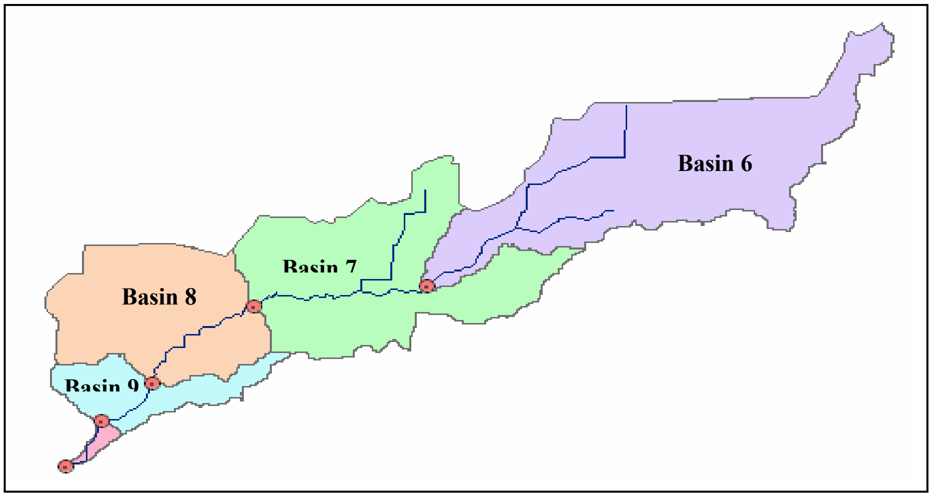


FIGURE 4. 7. SUBBASINS, CHANNELS, AND OUTLETS IN THE LITTLE BLACK CREEK WATERSHED.

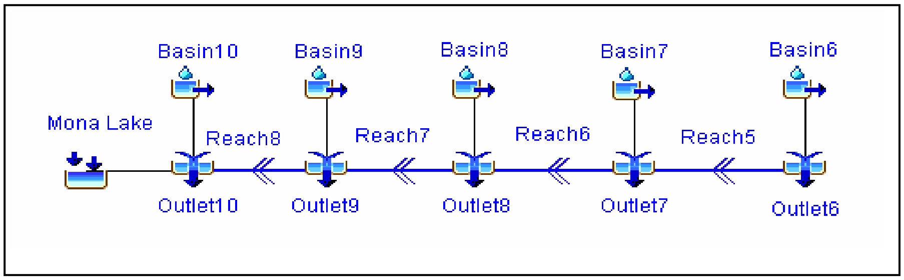


FIGURE 4. 8. HEC-HMS CONCEPTUAL MODEL FOR THE LITTLE BLACK CREEK WATERSHED.

4.4.2 COMPUTATION OF TIME-RELATED PARAMETERS FOR SUBBASINS AND REACHES

Preliminary values of lag time and/or time of concentration for each basin and the travel time for each reach were determined primarily by: (1) using the methods available in the WMS software and the geometric parameters computed in the watershed delineation (Tables 4.4 and 4.5) (e.g. basin length and slope, and reach length and slope); (2) using the observed stream flow data (e.g., average flow velocity); and (3) comparing rainfall event data with the observed hydrographs. Final parameter values were determined by the model calibration.

4.5 Hydrologic Modeling

Based on the watershed delineation described in the preceding section, a hydrologic model was developed for the Little Black Creek watershed by using the HEC-HMS software (USACE, 2006). Continuous hydrologic modeling was carried out. The simulations provided valuable information on the quantity and variability of runoff from all subbasins, as well as sources of the contributing water (direct runoff and baseflow). The details of the simulation are provided in Appendix D (D.2). A comparison of the simulated flow and actual flows are shown in Figure 4.9. The simulated results show good agreement with the actual data observed from the pressure transducers and rating curves.

4.6 Watershed Erosion Modeling

The modified universal soil loss equation (MUSLE) (Williams, 1975; 1995) was used to estimate the eroded sediment yields from the five subbasins in the Little Black Creek watershed during a storm event from 8/2/2004 0:00 to 8/4/2004 0:00 that was selected for metal and sediment transport modeling, described in Section 6. The MUSLE equation can be expressed as

$$Y_e = 11.8(Q\, q_P)^{0.56}\, K\, LS\, C\, P \qquad (5\text{-}1)$$

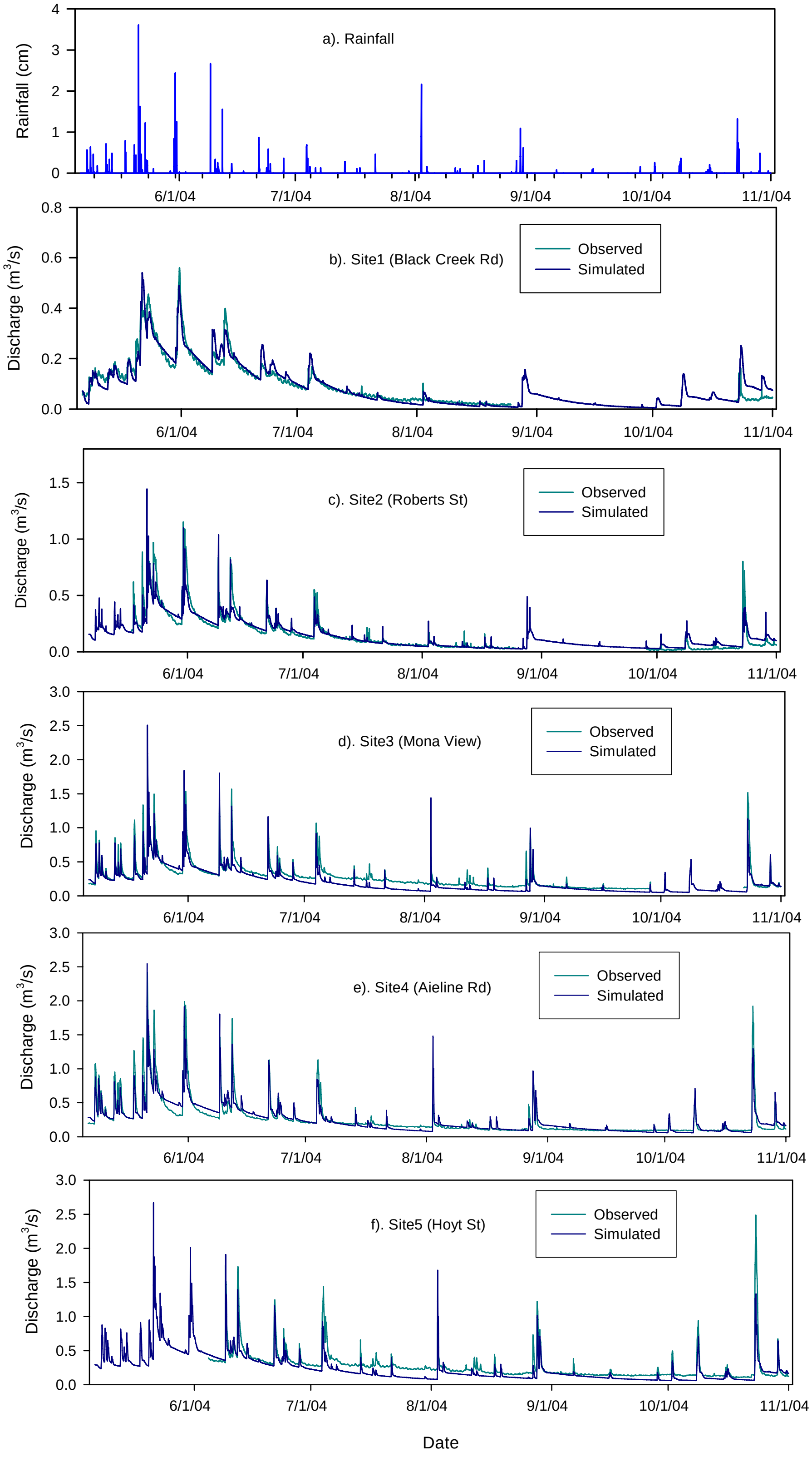


FIGURE 4. 9. COMPARISON BETWEEN THE SIMULATED AND OBSERVED HYDROGRAPHS (HOURLY FLOW).

where Y_e = eroded sediment yield (metric ton); Q = runoff volume (m^3); q_p = peak runoff rate (m^3/s); K = soil erodibility factor; LS = length-slope factor; C = soil cover factor; and P = conservation practice factor. The runoff volume Q and the peak runoff rate q_p of each subbasin for the selected rainfall event were provided by the watershed hydrologic modeling. The derivation of each of the above variables is described in Appendix D. (D.3).

The simulated sediment yields from Basins 7, 8, and 9-10 during the selected storm event are displayed in Figure 4.10 and the concentrations of sediments eroded from Basin 6 during the storm event, calculated by the simulated sediment yield and direct runoff discharge, are shown in Figure 4.11.

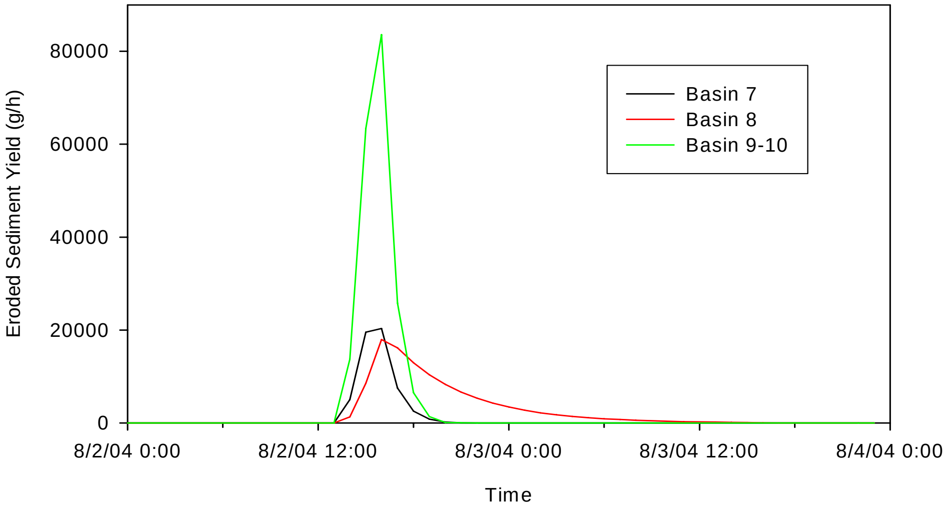


FIGURE 4. 10. SIMULATED SEDIMENT YIELD FROM SUBBASINS DURING THE SELECTED STORM EVENT.

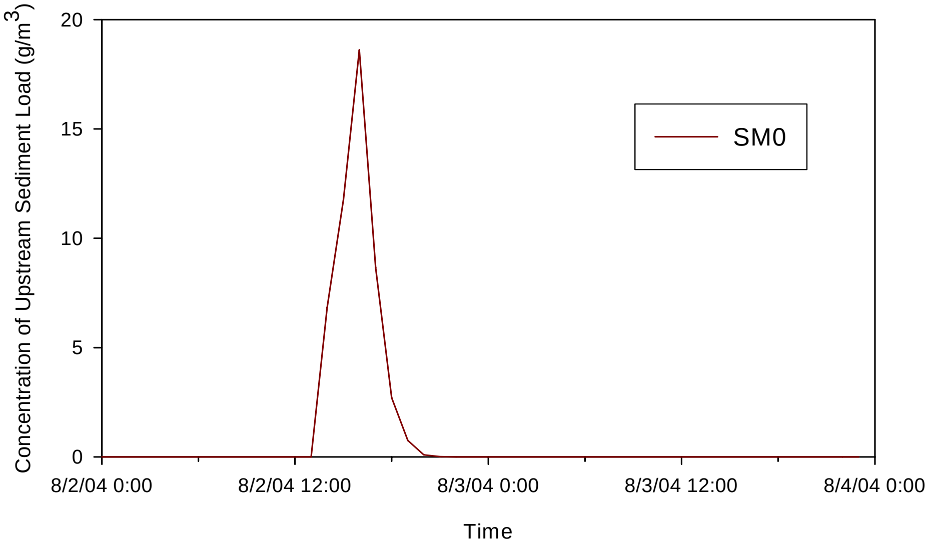


FIGURE 4. 11. SIMULATED CONCENTRATION OF SEDIMENTS LOADED FROM BASIN 6 DURING THE SELECTED STORM EVENT.

4.7 Metal and Sediment Transport Modeling in a Stream-Wetland System

4.7.1 METAL TRANSPORT MODELING IN THE STREAM-WETLAND SYSTEM

The stream-wetland system consists of the water column, the underlying active bed, and the adjacent wetlands (Figure 4.12). A physically-based model has been developed to simulate two-phase (dissolved and adsorbed phases) metal transport in the three subsystems and interactions between them. External loads of metal from surface runoff (dissolved phase), erosion (adsorbed phase), and upstream flow (dissolved and adsorbed phases) have also been taken into account. The major processes simulated in the model include advection, dispersion, sorption, settling, resuspension, sedimentation, diffusion of the dissolved-phase metals between the subsystems, and advective flux between the water column and wetlands, as shown in Figure 4.12.

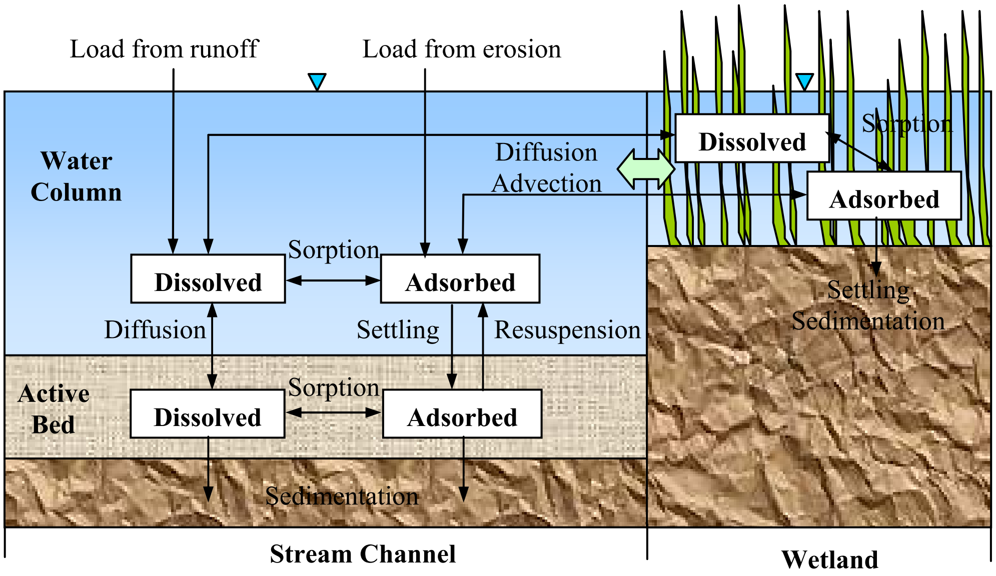


FIGURE 4. 12. METAL TRANSPORT PROCESSES IN THE STREAM-WETLAND SYSTEM.

The development of the sediment transport model and the results of simulations are presented in Appendix D (D.4). The sediment transport model was calibrated by using the data collected from Sites 3 and 5. Comparisons between the simulated and observed concentrations of suspended sediments in the water column at these two sites are shown in Fig. 4.13. Good agreement has been achieved for both sites.

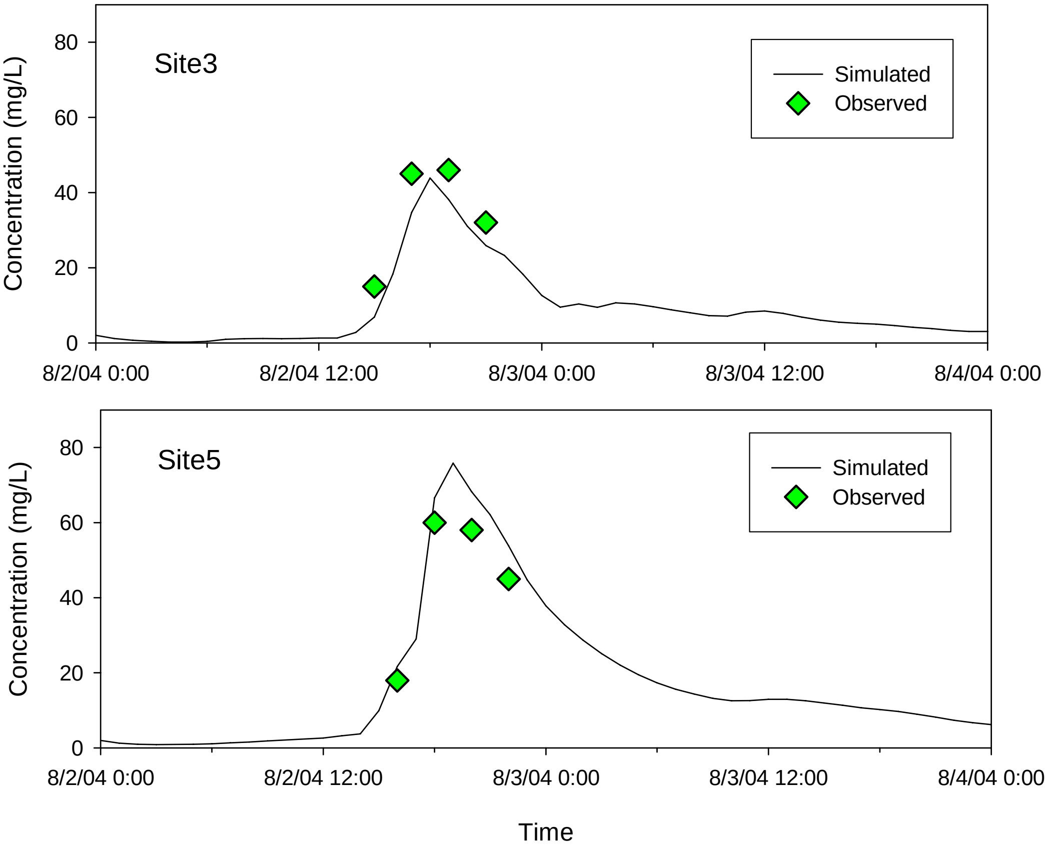


FIGURE 4. 13. COMPARISON OF THE SIMULATED AND OBSERVED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WATER COLUMN.

Comparison between the simulated and observed adsorbed cadmium concentrations in the water column (Figure 4.14) indicates that the model yielded fairly good simulations. For Site 5, the simulated cadmium concentrations are lower than the observed ones, which may be partially attributed to the assumption of zero cadmium loads from the lateral runoff and erosion in the model and zero initial cadmium concentrations in the wetland. In reality, a certain amount of cadmium, originally stored in the wetland system, could be loaded into the stream channel during the storm, which might elevate the cadmium level at downstream sites.

The simulated adsorbed-phase cadmium concentrations in the active bed are relatively stable, with the highest values at the HS compartments. Their temporal distributions only exhibit a slight decline during the storm event. Comparison between the simulated and observed adsorbed cadmium concentrations in the active bed for Sites 3 and 5 are shown in Fig. 4.15.

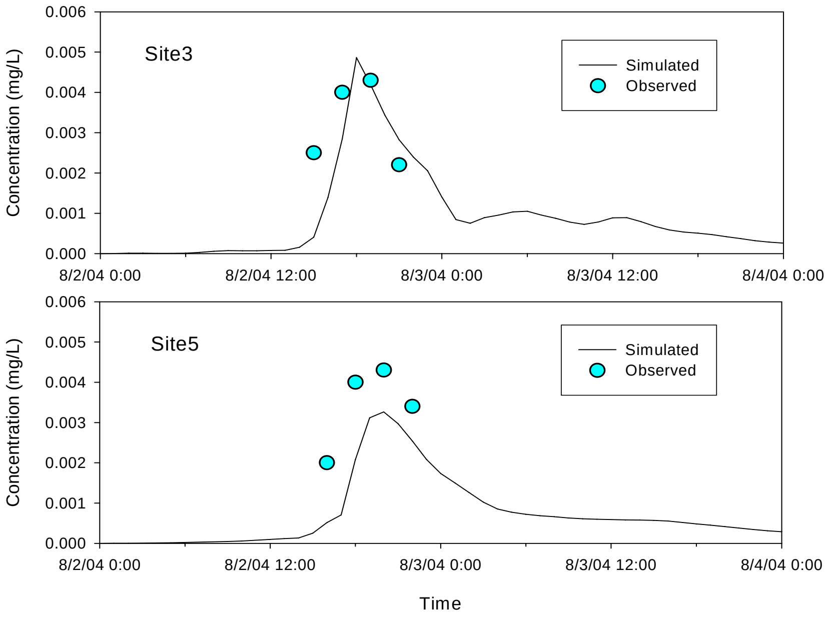


FIGURE 4. 14. COMPARISON OF THE SIMULATED AND OBSERVED ADSORBED CADMIUM CONCENTRATIONS IN THE WATER COLUMN.

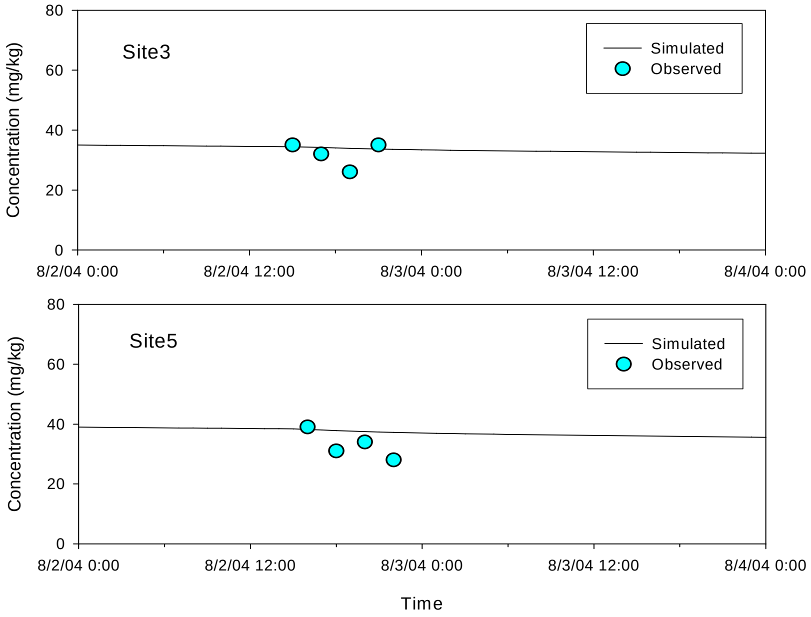


FIGURE 4. 15. COMPARISON OF THE SIMULATED AND OBSERVED ADSORBED CADMIUM CONCENTRATIONS IN THE ACTIVE BED.

4.8 Discussion

To better understand the cadmium fate and transport in the LBC stream-wetland system and identify the major sources of cadmium in Little Black Creek, overall mass balance analyses were performed based the transport modeling results (Figure 4.16). For the whole system during the entire simulation period, the water column subsystem received a 74.66g net load of cadmium from the active bed, of which 62.15g was discharged into Mona Lake and 4.49g was transferred to the wetlands. The cadmium transport from the active bed to the overlying water column was primarily attributed to resuspension of the cadmium-contaminated bed sediments (adsorbed phase). Mass exchange between the water column and the wetland was limited to certain high-flow time periods. Except for the mass flow back to the stream channel during the recession period of the storm, all cadmium (4.49g for this event; mostly in the adsorbed phase) entering the wetland subsystem was permanently accumulated in the storage. For the active bed, the cadmium loss due to sedimentation amounted to 12092.42g. Note that this amount of cadmium is still stored in the stream bed system. Thus, by the end of the simulation period, the storages of cadmium in the water column and the wetland were 8.02 and 4.49g, respectively. The stream bed storage of cadmium was as high as 142263.72g, most of which was sorbed to the bed sediments (Figure 4.17).

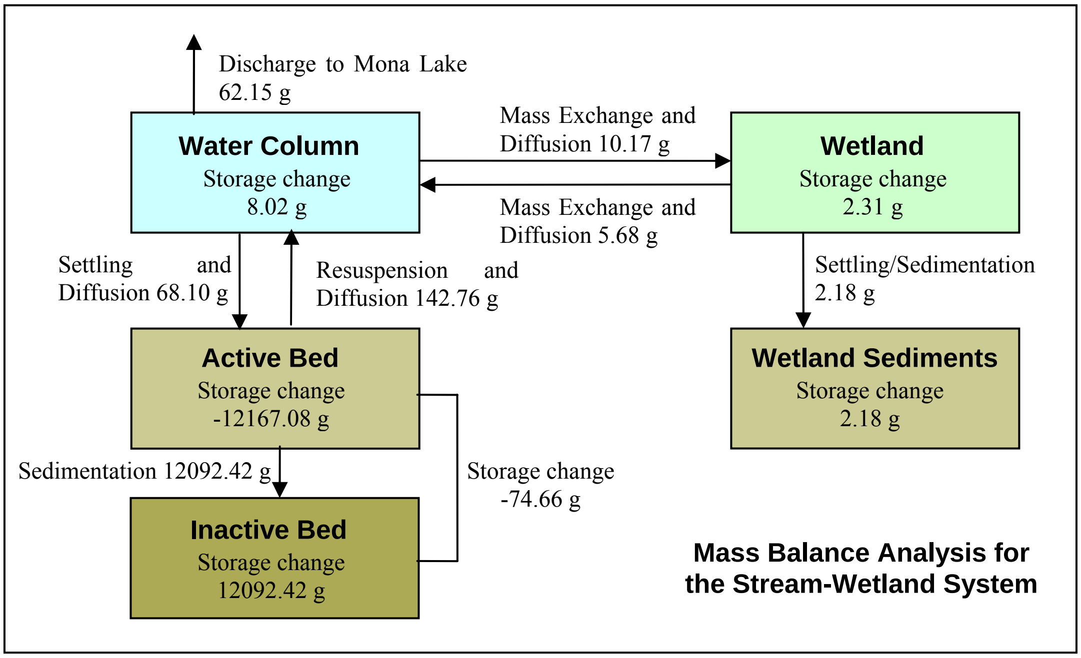


FIGURE 4. 16. MASS BALANCE ANALYSIS OF CADMIUM IN THE STREAM-WETLAND SYSTEM FOR THE ENTIRE SIMULATION PERIOD.

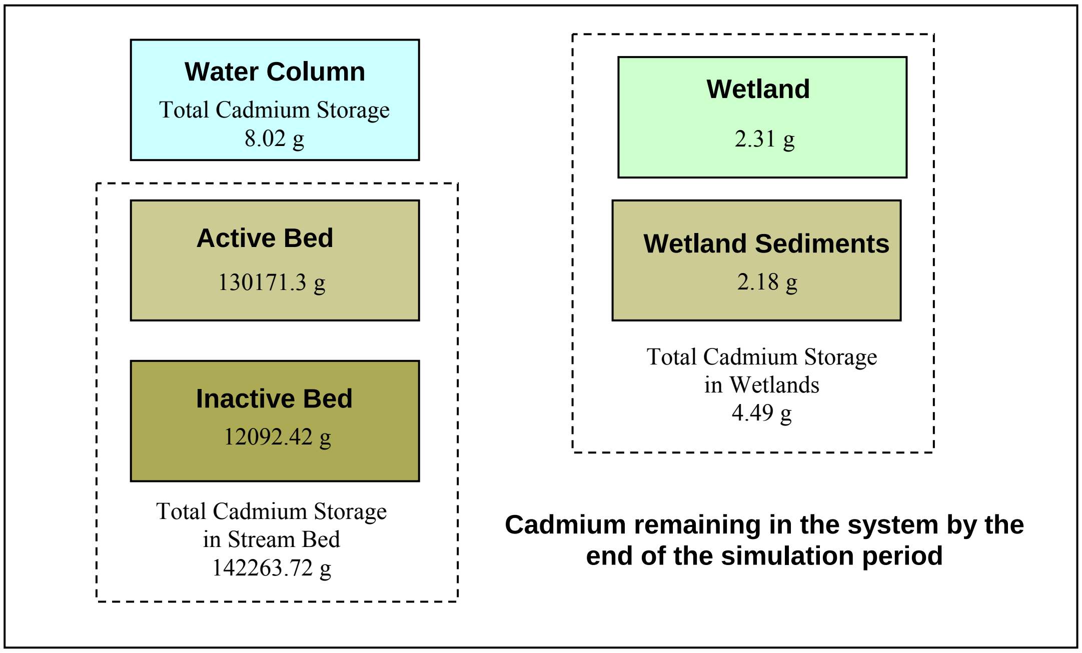


FIGURE 4. 17. CADMIUM STORAGE IN THE STREAM-WETLAND SYSTEM BY THE END OF THE SIMULATION PERIOD.

Furthermore, to identify the real dominant sources of cadmium in the system, a mass balance analysis of cadmium was conducted specially for the four HS compartments (Figure 4.18). The net loss of cadmium from the active bed to the water column in these four HS compartments was as high as 71.44g, 95.69% of the net loss of cadmium from all active bed compartments (74.66g, Figure 4.16). Thus, it can be concluded that the cadmium-contaminated stream bed sediments at the "hot spot" were primary sources of cadmium in the entire LBC stream-wetland system. Figure 4.18 also suggests that these HS compartments had much higher percentages of cadmium resuspension (more than a half of the mass transfer from the active bed to the water column) and lower percentages of cadmium settling, compared to other downstream compartments.

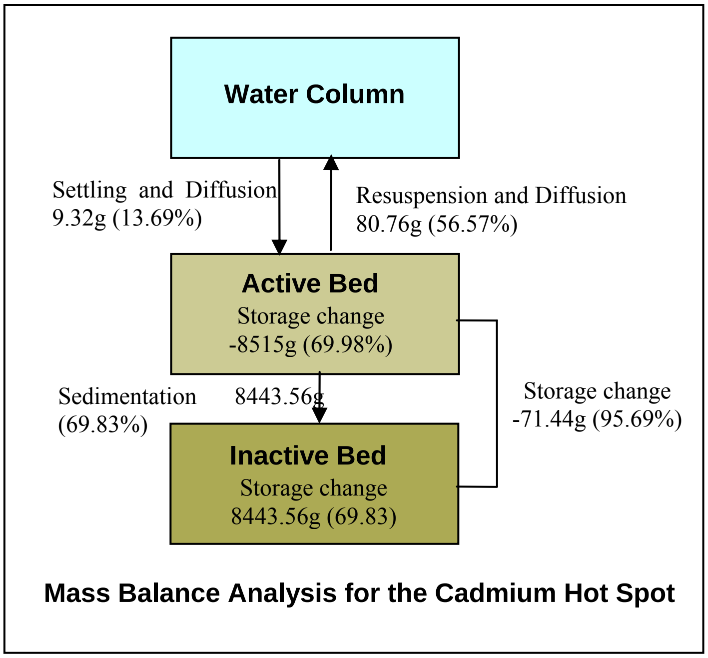


FIGURE 4. 18. MASS BALANCE ANALYSIS OF CADMIUM FOR THE HS COMPARTMENTS FOR THE ENTIRE SIMULATION PERIOD.

Due to lack of field data, the sedimentation process in the active bed was not calibrated in this modeling study. For confirmation purposes, a simulation without the sedimentation process was also carried out. It yielded very similar results (Figure 4.19). The net loss of cadmium for the active bed was 77.09g.

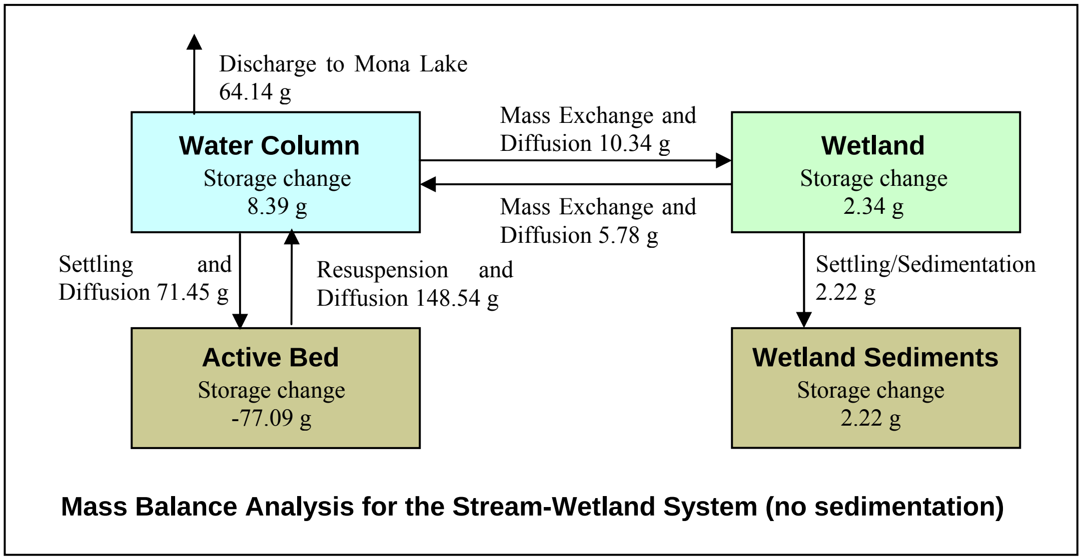


FIGURE 4. 19. MASS BALANCE ANALYSIS OF CADMIUM SIMULATED WITHOUT SEDIMENTATION IN THE STREAM-WETLAND SYSTEM FOR THE ENTIRE SIMULATION PERIOD.

4.9 Conclusions

Based on the above modeling analyses, the following points can be concluded:

- Primary Cadmium Sources: Cadmium sorbed to the sediments in the active bed is the major source of cadmium contamination in the LBC stream-wetland system. The sediment-related cadmium was primarily originated from the "hot spot" between Sites 2 and 3. The contribution of cadmium from the "hot spot" accounts for 96.34% of the net loss of cadmium from the whole active bed during the entire simulation period.
- Dominant Transport Processes: Cadmium undergoes a series of physical and chemical processes in the complex stream-wetland system. Due to its strong sorption properties, cadmium primarily exists in the adsorbed phase in the stream bed sediments and suspended sediments in the water column or wetlands. Thus, its fate and distributions are closely related to sediment transport in the system. Resuspension of the cadmium-contaminated sediments can be a dominant process.
- Threat of Cadmium Contamination to Mona Lake: According to the modeling, a large portion of cadmium from the contaminated bed sediments (62.15g out of 74.66g, Fig. 6-23) was discharged into Mona Lake during the storm event. Although a long-term cadmium transport modeling was not conducted in this study due to the lack of field data, this event simulation does suggest that such a continuous loading process and persistent accumulation of cadmium in Mona Lake can be a serious concern over a long time period.
- Role of Wetlands: During storm events, wetlands adjacent to the stream channels often play an important role in water flow, sediment movement, and metal transport. The transport modeling indicated that about a half of the cadmium transferred from the stream channels to the wetlands was permanently stored in the wetland system. The amount of cadmium (4.49g) from this single storm event may not be significant. However, a similar cadmium accumulation process in the wetlands implies a potential threat to the wetlands ecosystem.
- Water Quality Management: The simulation suggests that the sediment-associated cadmium tends to move downstream from the "hot spot", concentrate in the stream bed, and accumulate in Mona Lake and the wetlands. During the simulation period, 62.15g of cadmium left the modeling system into Mona Lake. Compared to the total storage of cadmium in the stream bed subsystem (142263.72g, Fig. 6-24), this is only a very small portion. Thus, cadmium and sediment transport in the LBC stream-wetland system is a long-term, slow process under natural conditions. In order to identify effective water quality management strategies for the LBC watershed, all above factors should be taken into account.

4.10 References

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5.0 Conclusions

A preliminary investigation of the nature and extent of sediment contamination in Little Black Creek, Cress Creek, and Mona Lake was performed that involved sediment chemistry and toxicity, ecological assessment, and metal transport modeling. Sediment chemistry and solid-phase toxicity were examined at 12 locations in Little Black Creek, 6 locations in Cress Creek, and 3 locations in Mona Lake. High levels of PAH compounds (40 – 60 mg/kg) were found in an area near Seaway Drive, downstream of Sherman/Getty culvert, and the stream reach between the Mona View wetlands and Airline Rd. Sediment toxicity also was observed at these locations. High levels of cadmium were found in the stream reach from Peerless Plating (1,600 mg/kg) to the creek mouth at Mona Lake (11 mg/kg). Elevated levels of chromium, lead and zinc also were present. High mortality in both test organisms was observed near Peerless Plating (0-20% survival). Based on these results, the Little Black Creek system was found to be highly impacted by metals and PAH compounds. The Peerless Plating Superfund Site appears to be the source of most of the cadmium and chromium observed in the creek, although additional sources of metals are present near the Mona View wetlands, Seaway Drive, and the Lower wetlands.

Contaminated sediments were present in Mona Lake, with the basin near Little Black Creek containing higher concentrations of metals than Black Creek. Although the concentrations were above PEC levels, the only toxic response noted was a small reduction in midge growth in the basin near LBC. Sediment toxicity was not present in the station near the middle of the lake. Cress Creek was found to be an acceptable control site due to the absence of sediment toxicity.

A comparative assessment of the macroinvertebrate and fish populations in Little Black Creek was conducted using Cress Creek as a control site. Stream and wetland sites within each system were evaluated individually. The two sites were found to have similar water chemistry and physical characteristics. Nitrate, dissolved oxygen, and pH were slightly higher in Cress Creek while inorganic anions were higher in Little Black Creek. With respect to toxicants, Little Black Creek contained significantly higher levels of heavy metals and PAH compounds compared to Cress Creek. Taxon richness was higher in Cress Creek than LBC. In addition, higher densities of pollution sensitive Trichoptera and Plecoptera taxa were present in Cress Creek. The gradient in macroinvertebrate communities due to stream was more important than gradients related to either month or site, suggesting that anthropogenic disturbance associated with Little Black Creek substantially altered the macroinvertebrate community and these alterations overshadowed temporal and site-specific variability. The benthic macroinvertebrate fauna of Little Black Creek was found to be negatively impacted compared to the Cress Creek control site.

The wetlands in both systems showed different trends with respect to physical and chemical parameters. Turbidity and sand size fraction sediments were greater in LBC while fine grained sediments and TOC were greater in Cress Creek. Toxicant levels (metals and PAH compounds) were significantly higher in the wetlands of Little Black Creek. Macroinvertebrate communities in the two systems appeared to respond more to substrate and turbidity than toxicant concentration. Since macroinvertebrate populations were dominated by detritivores, changes in TOC and substrate would have a significant effect with respect to community structure. In addition, wetland sediments are highly reducing in nature and have low metal bioavailability due to high levels of sulfides.

Fish populations in the LBC lower wetland were significantly different that the Hidden Cove wetland of Cress Creek. Catches in the LBC wetland had lower numbers and fewer species than Hidden Cove. Turtle populations were similar in both systems. Water quality and physical parameters appeared to have a greater structuring effect on these communities than contaminated sediments.

A physically-based model was developed in this study for simulating metal (cadmium) and sediment transport in a coupled stream-wetland system that consisted of the water column, the underlying active bed, and the adjacent wetland subsystems. The model simulated the interactions between the water column and active bed, and the mass exchange (water, sediment, and metal) between the water column and the adjacent wetlands, based on their dynamic relationships and hydraulic characteristics. The model took into account a series of transport processes related to sediments and two-phase metals (dissolved and adsorbed phases), including advection, dispersion/diffusion, sorption, settling, resuspension, and sedimentation. The metal and sediment transport models were solved by using a semidiscrete method.

The model was tested by applying it to Little Black Creek in Michigan. The simulated cadmium and sediment concentrations were compared against the observed ones and good agreement was achieved. The modeling results suggested that cadmium sorbed to the stream bed sediments was the primary source of cadmium contamination in the system. Resuspension of the cadmium-contaminated bed sediments played a critical role in the cadmium fate and transport. The modeling particularly emphasized the importance of the long-term, persistent cadmium accumulation process in Mona Lake and the wetlands, and the relevant threat to the ecosystem. Specific conclusions from this application study can be summarized as follows:

1) <u>Primary Cadmium Sources</u>: Cadmium sorbed to the sediments in the active bed is the major source of cadmium contamination in the LBC stream-wetland system. The sediment-related cadmium was primarily originated from the "Peerless" between Sites 2 and 3. The contribution of cadmium from the "hot spot" accounted for 96.34% of the net loss of cadmium from the whole active bed subsystem during the entire simulation period.
2) <u>Dominant Transport Processes</u>: Cadmium undergoes a series of physical and chemical processes in the complex stream-wetland system. Due to its strong sorption properties, cadmium primarily exists in the adsorbed phase in the stream bed sediments and suspended sediments in the water column or wetlands. Thus, its fate and distributions are closely related to sediment transport in the system. Resuspension of the cadmium-contaminated sediments can be a dominant process.
3) <u>Threat of Cadmium Contamination to Mona Lake</u>: According to the modeling results, a large portion of cadmium from the contaminated bed sediments (62.15 g out of 74.66 g; Figure 4.18) was discharged into Mona Lake during the storm event. Although a long-

term cadmium transport modeling was not conducted in this study due to a lack of field data, this event simulation does suggest that such a continuous loading process and persistent accumulation of cadmium in Mona Lake can be a serious concern for a long time period.

4) Role of Wetlands: During storm events, wetlands adjacent to the stream channels often play an important role in water flow, sediment movement, and metal transport. The transport modeling indicated that about a half of the cadmium transferred from stream channels to the wetlands was permanently stored in the wetland subsystem. The amount of cadmium (4.49 g) from this single storm event may not be significant. However, a similar cadmium accumulation process in the wetlands implies a potential threat to the wetlands ecosystem.
5) Water Quality Management: The simulation suggests that the sediment-associated cadmium tends to move downstream from the area near the Peerless Plating Superfund Site, settles out in depositional zones in the stream bed, and accumulates in Mona Lake and the wetlands. During the simulation period, 62.15 g of cadmium left the modeling system into Mona Lake. Compared to the total storage of cadmium in the stream bed subsystem (142263.72 g; Figure 4.17), this is only a very small portion. Thus, cadmium and sediment transport in the LBC stream-wetland system is a long-term, slow process under natural conditions. These factors should be taken into account so as to identify effective water quality management strategies for the watershed.

Appendices

Appendix A
Quality Control Results for Chemical Parameters

QA/QC Analysis Checklist for
SEDIMENT CHEMISTRY ANALYSIS

GRANT/IAG NUMBER: **GL-956205-01**
PROJECT NAME: Preliminary Investigation of Sediment Contamination in the Mona Lake Watershed
REVIEWER: Richard Rediske
DATE: 10-15-04

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

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

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

YES __ __
NO _ __**X___(UNACCEPTABLE two surrogate failures)**

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

YES _____
NO X (UNACCEPTABLE) (One minor organic and 3 minor metals QC failures).

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

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

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

Surrogates. Sample TW-5 0-20 cm and a Phenol-d6 recovery of 18% (limit 28-133%) and sample TW-6 0-20 cm had a 2-fluorophenol recovery of 23% (limit 31-121%). The other surrogates in the samples were within control limits. No action was taken.

Orgainc MS/MSD. Sample from station ML-2 0-20 cm had a MSD results for 2-chlorophenol as follows:

Compound	Initial	MS % Recovery	MSD % Recovery
2-Chlorophenol	<0.33mg/kg	38*	45

The control limit for 2-chlorophenol was 40%- 130%. LCS results for extraction batch were within control limits. Since the sample result was not detectable and the other MS was within the control limit, the results were not qualified.

Inorganic MS/MSD results.

Control limits for recovery (70-130%) were exceeded on the following samples:

Sample	Metal	Initial (mg/kg)	Spiked Amount (mg/kg)	MS % Recovery	MSD % Recovery
Outlet	Cu	75	30	63	103
Outlet	Zn	310	30	117	67
ML-2 0-20 cm	Zn	350	30	83	133

The LCS for the batch and the second MS were within control limits. In addition, the analyte concentration in the sample was higher (2.5X and 10X). No action was taken based on the high analyte concentrations in the sample and the fact that the second MS was within control limits.

Table A. 1. QA/AC Results of Grain Size Fractions, TOC, and Percent Solids for Little Black Creek Surface Sediment Samples, Samples, April 27, 2004.

Location	%Solids	%TOC	% Grain Size (*u* m)						
			<2000	**200-1000**	**1000-850**	**850-500**	**500-125**	**125-63**	**<63**
Evanston	50	1	1	1	0	7	66	28	0
Industrial Park	33	10	2	0	0	1	18	25	52
Roberts	50	2	1	1	1	8	44	38	7
Roberts Lab Dup	48	3	1	0	1	7	45	36	10
Peerless 1	34	5	3	2	3	4	21	44	23
Peerless 1 Dup	32	4	4	2	3	5	20	39	26
Peerless 2	34	5	3	2	3	4	19	39	30
S&G DS	28	2	5	2	1	4	11	54	23
Summit	47	3	4	2	0	3	44	39	9
Mona View	10	12	6	2	0	2	14	17	59
Airline	51	3	1	2	2	11	23	43	18
Seaway	46	2	6	2	1	5	48	29	8
Seaway Dup	42	3	7	5	3	3	44	31	7
LBC Lower Wetland	41	7	4	2	1	2	10	24	57
Outlet	46	3	2	2	3	5	13	38	37
Outlet Lab Dup	48	3	1	2	2	4	15	36	40

Table A. 2. QA/AC Results of Sediment Grain Size Fractions, TOC, and Percent Solids for Mona Lake Core Samples, July 2005.

Location	Core Section	%Solids	%TOC	% Grain Size (*u* m)						
				<2000	**200-1000**	**1000-850**	**850-500**	**500-125**	**125-63**	**<63**
Mona Lake ML-1	0-20 cm	88	10	1	1	0	0	3	8	87
	20-40 cm	82	11	0	0	0	1	2	7	89
	40-80 cm	79	9	0	0	1	8	1	8	82
Mona Lake ML-2	0-20 cm	84	11	1	1	0	0	4	8	86
	0-20 cm Lab Dup	82	10	0	1	0	0	5	9	85
	20-40 cm	81	11	0	0	0	1	2	9	88
	40-80 cm	76	8	0	0	1	1	2	9	87
Mona Lake ML-3	0-20 cm	85	10	1	1	0	0	3	6	89
	20-40 cm	83	11	0	0	0	2	3	5	90
	40-80 cm	74	9	0	0	0	3	3	5	89
Mona Lake ML-3 Dup	0-20 cm	83	11	1	1	0	0	4	90	89
	20-40 cm	81	10	1	1	1	3	4	5	85
	40-80 cm	70	10	0	0	0	3	1	5	91

TABLE A. 3. QA/AC RESULTS OF METALS ANALYSES FOR LITTLE BLACK CREEK SURFACE SEDIMENT SAMPLES, SAMPLES, APRIL 27, 2004.

Sample Site	Total Arsenic	Total Barium	Total Cadmium	Total Chromium	Total Copper	Total Lead	Total Selenium	Total Silver	Total Zinc	Total Mercury
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Evanston	20	67	0	25	22	72	<0.40	<1.0	63	<0.1
Ind. Park	16	130	2	49	32	164	3.8	<1.6	182	0.2
Roberts	9	124	3	14	22	36	1.2	<1.0	55	0.3
Peerless 1	12	122	1600	550	120	150	0.8	<1.1	590	0.8
Peerless 1D	11	128	1700	610	130	175	0.6	<1.1	575	0.9
Peerless 2	8	139	1500	320	150	200	<0.96	<2.4	566	0.3
Sherman DS	19	200	102	132	123	275	1.2	<1.8	473	<0.1
Summit	4	84	19	68	90	275	0.9	1.6	314	0.2
Summit Lab Dup	5	88	21	65	110	250	1.1	1	289	0.3
Mona View	9	114	17	142	155	339	<2.0	<5.0	571	0.8
Airline	10	210	34	165	132	410	1.5	<1.0	660	1.2
Seaway	13	491	46	634	609	652	<0.44	2.4	4200	1
Seaway Dup	9	450	49	540	510	560	1.1	2	3800	1.1
Lower Wetland	10	398	54	484	304	596	<2.0	<5.0	2040	0.7
Outlet	11	422	11	65	75	180	<1.0	4.9	310	0.7

TABLE A. 4. QA/AC RESULTS OF METALS ANALYSES FOR MONA LAKE CORE SAMPLES, JULY 2005.

Sample Site	Total Arsenic	Total Barium	Total Cadmium	Total Chromium	Total Copper	Total Lead	Total Selenium	Total Silver	Total Zinc	Total Mercury
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Evanston	20	67	0	25	22	72	<0.40	<1.0	63	<0.1
Ind. Park	16	130	2	49	32	164	3.8	<1.6	182	0.2
Roberts	9	124	3	14	22	36	1.2	<1.0	55	0.3
Peerless 1	12	122	1600	550	120	150	0.8	<1.1	590	0.8
Peerless 1D	11	128	1700	610	130	175	0.6	<1.1	575	0.9
Peerless 2	8	139	1500	320	150	200	<0.96	<2.4	566	0.3
Sherman DS	19	200	102	132	123	275	1.2	<1.8	473	<0.1
Summit	4	84	19	68	90	275	0.9	1.6	314	0.2
Summit Lab Dup	5	88	21	65	110	250	1.1	1	289	0.3
Mona View	9	114	17	142	155	339	<2.0	<5.0	571	0.8
Airline	10	210	34	165	132	410	1.5	<1.0	660	1.2
Seaway	13	491	46	634	609	652	<0.44	2.4	4200	1
Seaway Dup	9	450	49	540	510	560	1.1	2	3800	1.1
Lower Wetland	10	398	54	484	304	596	<2.0	<5.0	2040	0.7
Outlet	11	422	11	65	75	180	<1.0	4.9	310	0.7

Table A. 5. MS/MSD Results for Metals Analyses On Little Black Creek and Mona Lake Sediment.

Summit

Analyte	Sample Conc	MS Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	4	30	37.6	35	112	103	7.2	3050/6010
Ba	84	30	110	120	87	120	8.7	3050/6010
Cd	19	30	42	49	77	100	15.4	3050/6010
Cr	68	30	99	90	103	73	9.5	3050/6010
Cu	90	30	110	118	67	93	7.0	3050/6010
Pb	275	30	300	310	83	117	3.3	3050/6010
Se	0.9	1	2	1.6	110	70	22.2	3050/6010
Ag	1.6	30	33	35	105	111	5.9	3050/6010
Zn	314	30	335	350	70	120	4.4	3050/6010
Hg	0.2	0.5	0.6	0.7	80	100	15.4	7471

Outlet

Analyte	Sample Conc	MS Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	11	30	38	35	89	80	7.2	3050/6010
Ba	422	30	450	460	93	127	2.2	3050/6010
Cd	11	30	36	46	83	117	24.4	3050/6010
Cr	65	30	100	89	116	80	11.4	3050/6010
Cu	75	30	94	106	63*	103	12.0	3050/6010
Pb	180	30	205	215	83	117	4.8	3050/6010
Se	0.8	1	2	1.6	120	80	22.2	3050/6010
Ag	4.9	30	35	33	100	94	5.9	3050/6010
Zn	310	30	345	330	117	67*	4.4	3050/6010
Hg	0.7	0.5	1.1	1.2	80	100	8.7	7471

ML-2 0-20 cm

Analyte	Sample Conc	MS Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
As	18	30	47	44	97	87	6.6	3050/6010
Ba	135	30	165	160	100	83	3.1	3050/6010
Cd	31	30	58	54	90	77	7.1	3050/6010
Cr	110	30	135	141	83	103	4.3	3050/6010
Cu	300	30	338	322	127	73	4.8	3050/6010
Pb	150	30	175	180	83	100	2.8	3050/6010
Se	0	1	1	1.2	100	120	18.2	3050/6010
Ag	0	30	33	35	110	117	5.9	3050/6010
Zn	350	30	375	390	83	133*	3.9	3050/6010
Hg	1.3	0.5	1.9	1.7	120	80	11.1	7471

MW-4 0-20 cm

Analyte	Sample Conc	MS Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
	mg/kg	mg/kg	mg/kg	mg/kg	% rec	% rec	%	EPA #
Cd	11	30	37.6	35	89	80	7	3050/6010
Cr	422	30	445	460	77	127	3.3	3050/6010

MW-6 40-80 cm

Analyte	Sample Conc	MS Spike Added	MS Results	MSD Results	MS %rec	MSD %rec	RPD	Method
Cd	65	30	99.8	90	116	83	10	3050/6010
Cr	75	30	105	96	100	70	9	3050/6010

*Recovery exceeded control limit of 70-130%.

TABLE A. 6. SURROGATE STANDARD RECOVERIES FOR SEMIVOLATILE ORGANICS ANALYSES ON LITTLE BLACK CREEK AND MONA LAKE SEDIMENT.

SAMPLE ID	Evanston	Industrial Park	Roberts	Peerless 1	Peerless 1 Dup	Peerless 2	Sherman Getty DS	Summit	Mona View	Airline	Seaway	Seaway Dup	Lower Wetland
2-Fluorophenol	67	60	70	65	68	73	74	72	64	72	80	66	62
Phenol-d6	71	65	77	73	71	76	77	77	66	75	75	60	56
Nitrobenzene-d5	58	59	66	61	69	66	71	69	63	73	81	68	64
2-Fluorobiphenyl	71	66	75	73	71	75	78	79	68	75	84	76	71
2,4,6-Tribromophenol	91	94	85	76	88	74	67	89	98	71	67	85	84
Terphenyl-d14	71	67	80	80	73	77	85	73	70	77	78	73	76
			Mona Lake 1			Mona Lake 2			Mona Lake 3			Mona Lake 3 Dup	
SAMPLE ID	LBC Mouth	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm
2-Fluorophenol	69	66	50	71	56	56	63	64	79	66	65	63	72
Phenol-d6	57	52	40	60	46	40	52	70	88	70	67	64	69
Nitrobenzene-d5	76	68	51	76	61	61	69	69	85	72	69	71	77
2-Fluorobiphenyl	83	79	68	80	75	73	76	69	84	72	71	72	77
2,4,6-Tribromophenol	85	61	72	63	59	587	63	89	74	78	86	88	85
Terphenyl-d14	78	81	75	76	78	69	72	79	75	73	75	70	73
		TW-1			TW-2			TW-3			TW-4		
SAMPLE ID	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	Roberts Lab Dup
2-Fluorophenol	70	51	59	64	73	89	87	115	117	118	113	103	78
Phenol-d6	76	57	62	67	71	87	86	98	108	95	97	97	83
Nitrobenzene-d5	80	60	72	76	64	71	67	103	100	96	94	87	61
2-Fluorobiphenyl	80	75	74	81	60	68	67	105	109	104	107	109	70
2,4,6-Tribromophenol	67	74	95	78	49	79	83	101	111	99	103	165	85
Terphenyl-d14	72	79	72	77	66	71	71	84	78	81	92	105	92
		TW-5			TW-6			TW-7		Mona Lake 2 Dup	TW-1 Dup	TW-7 Dup	
SAMPLE ID	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	0-20 cm	20-40 cm	40-80 cm	20-40 cm	20-40 cm	20-40 cm	
2-Fluorophenol	33	55	76	23*	83	96	87	84	94	70	72	105	
Phenol-d6	15*	96	96	51	75	88	80	88	80	51	69	101	
Nitrobenzene-d5	48	85	93	60	73	79	75	89	84	68	65	95	
2-Fluorobiphenyl	60	98	85	61	92	99	97	84	76	81	89	99	
2,4,6-Tribromophenol	46	73	57	63	66	87	74	93	85	74	78	89	
Terphenyl-d14	61	106	104	63	96	99	95	98	89	78	98	101	

*Surrogate Recovery below control limit.

TABLE A. 7. SURROGATE STANDARD RECOVERIES FOR PCB ANALYSES ON LITTLE BLACK CREEK AND MONA LAKE SEDIMENT.

SAMPLE ID	Depth	Tetrachloro-m-xylene	Decachloro byphenyl
Evanston	Surface Grab	110	88
Industrial Park	Surface Grab	105	118
Roberts	Surface Grab	83	107
Peerless 1	Surface Grab	109	106
Peerless 1 Dup	Surface Grab	99	66
Peerless 2	Surface Grab	86	104
Sherman Getty DS	Surface Grab	76	102
Summit	Surface Grab	117	105
Mona View	Surface Grab	71	120
Airline	Surface Grab	112	66
Seaway	Surface Grab	86	86
Seaway Dup	Surface Grab	64	71
Lower Wetland	Surface Grab	91	117
LBC Mouth	Surface Grab	3	95
Mona Lake 1	0-20 cm	106	69
	20-40 cm	69	87
	40-80 cm	100	97
Mona Lake 2	0-20 cm	93	89
	20-40 cm	74	113
	40-80 cm	111	72
Mona Lake 3	0-20 cm	83	99
	20-40 cm	75	96
	40-80 cm	117	67
Mona Lake 3 Dup	0-20 cm	73	68
	20-40 cm	109	95
	40-80 cm	110	101

SAMPLE ID	Depth	Tetrachloro-m-xylene	Decachloro byphenyl
TW-1	0-20 cm	104	70
	20-40 cm	84	78
	40-80 cm	100	86
TW-2	0-20 cm	107	96
	20-40 cm	99	64
	40-80 cm	96	68
TW-3	0-20 cm	113	121
	20-40 cm	74	83
	40-80 cm	76	90
TW-4	0-20 cm	74	64
	20-40 cm	79	89
	40-80 cm	80	68
Roberts Lab Dup	Surface Grab	78	71
TW-5	0-20 cm	82	110
	20-40 cm	110	88
	40-80 cm	105	114
TW-6	0-20 cm	86	91
	20-40 cm	98	112
	40-80 cm	66	61
TW-7	0-20 cm	69	111
	20-40 cm	95	70
	40-80 cm	81	88
Mona Lake 2 Dup	20-40 cm	92	115
TW-1 Dup	20-40 cm	76	119
TW-7 Dup	20-40 cm	119	111

TABLE A. 8. MS/MSD RECOVERIES FOR SEMIVOLATILE ANALYSES ON LITTLE BLACK CREEK AND MONA LAKE SEDIMENT.

SAMPLE ID	LFB1	LFB2	LFB3	Roberts MS	Roberts MSD	Mona Lake 2 MS	Mona Lake 2 MSD	TW-1 MS	TW-1 MSD	TW-7 MS	TW-7 MSD
Phenol	78	72	54	56	64	38*	45	69	75	81	76
2-Chlorophenol	74	71	70	84	74	80	81	83	76	74	74
1,4-Dichlorobenzene	78	70	63	78	51	56	63	82	85	80	70
1,2,4-Trichlorobenzene	83	76	71	70	60	63	67	85	91	86	79
4-Chloro-3-methylphenol	68	78	66	89	82	97	89	82	90	69	82
Acenaphthene	70	63	66	99	88	72	72	94	95	72	65
4-Nitrophenol	73	75	71	79	80	65	71	73	68	75	79
2,4-Dinitrotoluene	60	70	96	103	97	89	97	110	119	61	73
Pentachlorophenol	63	66	101	126	100	78	70	101	95	67	70
Pyrene	78	67	106	117	103	73	77	97	102	80	71
Aroclor 1016	84	84	89	93	97	84	86	na	na	na	na
Aroclor 1260	81	85	85	98	88	92	98	na	na	na	na

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

Appendix B
Quality Control Results for Sediment Toxicity Testing

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

GRANT/IAG NUMBER: **GL-956205-01**
PROJECT NAME: Preliminary Investigation of Sediment Contamination in the Mona Lake Watershed
REVIEWER: Richard Rediske
DATE: 10-14-07

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

YES X
NO _____ (UNACCEPTABLE)

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

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

YES _____ (UNACCEPTABLE)
NO X

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

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

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

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

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

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

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

Maximum % Difference:

DO	30%	Alk	22%
pH	6%	NH_3	**190%**

YES __**X**__ (UNACCEPTABLE)
NO _____

Ammonia levels decreased by more than 50% due to water renewal. All initial ammnia concentrations were < 5 mg/l so the change in concentration would not impact data quality.

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

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

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

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

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

YES X
NO _____ (UNACCEPTABLE)

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

YES X
NO _____ (UNACCEPTABLE)

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

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

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

YES X
NO _____ (UNACCEPTABLE)

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

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

Table B. 1. Dissolved Oxygen and Temperature Data for *Chironomus tentans* sediment toxicity evaluations with Little Black Creek, Cress Creek, and Mona Lake Sediment.

Sample ID	Time		Day 0		Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 10	
			DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
Evanston	AM	830	5.38	23.1	5.43	22.9	8.31	23.1	6.22	22.1	5.36	23.2	5.70	23.6	5.33	23.4	5.58	23.9	3.16	22.5	3.14	19.3	3.60	22.6
	PM	1600	4.66	23.9	5.09	24.4	5.24	24.5	5.63	22.2	5.5	23.0	7.09	24.4	4.22	24.9	5.94	24.2	4.22	23.0	3.59	22.8		
Industrial Park	AM	830	5.41	23.1	5.51	23.1	6.94	22.7	5.15	23.7	4.57	23.3	4.30	23.9	4.20	23.5	4.27	24.0	5.27	23.0	5.65	19.9	5.24	22.8
	PM	1600	5.27	24.1	5.54	24.6	5.10	24.9	4.80	22.2	4.80	24.0	8.08	23.8	3.87	24.9	5.59	23.1	5.83	23.3	5.43	23.5		
Roberts	AM	830	6.23	19.9	6.23	23.0	7.22	22.3	6.01	22.0	5.24	23.2	6.12	24.0	5.34	23.6	5.44	24.1	5.22	23.2	6.05	23.8	5.03	22.9
	PM	1600	5.45	24.2	5.84	24.8	5.87	24.9	5.78	22.1	5.56	24.7	4.66	23.7	4.72	24.0	6.02	23.8	6.00	23.6	5.42	23.3		
Peerless 1	AM	830	6.10	19.9	6.12	22.9	7.91	22.8	6.92	22.8	5.68	23.3	5.66	23.9	5.13	23.7	5.53	24.2	5.29	22.9	5.94	22.1	6.11	23.1
	PM	1600	5.01	24.1	5.96	24.5	6.07	24.6	6.39	22.2	5.92	22.9	7.58	23.2	4.42	24.9	5.55	23.1	6.26	23.1	6.17	23.3		
Peerless 2	AM	830	6.31	19.5	6.44	22.1	7.61	22.3	6.93	23.4	5.95	22.5	6.02	23.0	5.80	22.6	5.95	23.0	5.28	23.0	6.39	23.6	6.22	23.2
	PM	1600	5.33	24.9	6.19	23.2	6.12	23.4	6.34	22.5	6.05	22.9	6.04	22.9	4.61	23.6	6.13	22.6	6.43	24.0	6.18	23.9		
Sherman/Getty DS	AM	830	4.28	19.7	3.79	22.3	6.04	23.9	6.09	23.3	3.69	23.0	3.51	23.0	3.02	22.7	3.28	23.1	4.65	23.7	5.93	23.7	5.20	23.4
	PM	1600	4.03	23.0	3.49	23.3	3.93	23.9	4.27	22.2	4.07	22.1	7.06	22.2	2.83	23.2	3.58	23.9	5.92	24.3	5.77	24.3		
LBC Mona View Wetland	AM	830	3.48	19.9	4.55	22.3	7.32	22.3	7.08	22.1	4.45	22.6	4.72	22.4	4.32	22.1	4.28	22.6	4.66	23.4	5.76	23.4	5.51	23.6
	PM	1600	3.63	22.7	3.35	23.8	4.81	23.3	4.89	22.3	4.30	22.5	7.37	22.5	3.77	24.7	4.62	23.3	5.83	24.7	5.60	24.8		
Airline	AM	830	5.54	19.7	5.94	22.6	7.96	22.1	6.33	23.9	5.36	22.5	5.52	22.6	5.24	22.2	5.37	22.5	4.69	24.1	5.69	23.9	5.45	23.7
	PM	1600	5.45	23.0	5.77	23.4	5.96	23.3	5.48	22.3	5.55	22.2	6.24	22.2	4.57	23.0	5.69	23.4	5.76	24.0	5.46	24.8		
Seaway	AM	830	6.74	23.0	6.47	23.2	7.89	22.0	6.47	23.1	5.72	23.4	6.07	23.4	5.40	23.2	5.55	23.5	5.32	23.5	6.85	22.3	6.05	23.5
	PM	1600	5.52	23.4	6.24	23.7	6.49	23.7	6.30	22.5	6.16	22.2	7.75	22.7	4.57	23.7	6.23	22.4	6.97	24.3	6.71	24.3		
LBC Lower Wetland	AM	830	6.04	23.0	5.95	23.2	8.40	23.5	5.83	23.1	5.66	23.3	5.81	23.2	5.57	23.2	5.59	23.4	4.89	23.6	6.06	23.9	6.22	23.2
	PM	1600	5.31	22.9	5.90	23.5	5.61	23.4	5.79	22.7	5.67	23.0	7.82	22.9	4.56	23.5	5.72	23.1	6.44	24.4	6.23	24.2		
Outlet	AM	830	6.10	23.6	6.26	22.9	7.48	22.2	6.41	23.7	5.56	23.2	6.17	23.2	5.76	23.3	6.04	23.7	4.57	23.3	5.58	23.1	5.66	22.7
	PM	1600	5.76	23.5	6.02	24.0	5.73	24.1	5.97	22.2	5.93	22.5	7.56	22.5	4.86	24.2	6.28	22.7	6.05	23.7	5.81	23.9		
Control	AM	830	5.40	23.7	5.85	23.0	7.72	22.0	6.51	23.9	5.36	23.1	5.55	23.5	5.33	23.5	5.60	23.8	4.62	23.1	5.88	23.9	5.46	23
	PM	1600	5.65	23.7	5.83	24.2	5.68	24.3	5.42	22.3	5.69	22.5	7.24	22.5	4.83	24.4	5.88	22.6	5.96	23.7	5.79	23.3		
Cress Towner Rd Impoundment Wetland	AM	830	5.66	23.7	6.18	22.9	7.66	22.4	6.45	22.3	5.70	23.2	5.96	23.7	4.80	23.4	4.95	23.7	5.23	23.2	6.57	23.3	6.12	23.2
	PM	1600	5.10	23.7	6.00	24.7	5.49	24.5	5.95	22.4	5.89	22.3	6.03	22.7	3.96	24.6	5.61	23.8	6.60	23.3	6.45	23.1		
Cress Hidden Cove Wetland	AM	830	5.73	23.8	5.90	23.2	8.07	22.0	5.22	22.5	5.50	23.3	5.58	24.0	5.42	23.8	5.46	24.3	5.41	22.8	5.55	22.9	5.56	23.3
	PM	1600	4.89	24.2	5.72	24.8	5.42	24.1	5.61	22.5	5.92	22.8	6.24	23.5	4.32	24.0	5.95	22.2	6.05	24.4	5.48	24.4		
Cress Quarterline Rd Stream	AM	830	7.06	23.6	7.02	23.1	7.42	22.6	5.98	23.6	6.24	23.4	6.47	23.8	5.69	23.7	6.08	23.9	4.69	23.4	4.45	22.0	4.17	23.5
	PM	1600	6.27	24.1	6.55	24.2	6.94	24.3	6.65	22.4	6.54	22.7	6.90	23.2	4.77	24.6	7.03	22.3	5.41	24.7	4.76	24.6		
Cress Towner Rd Stream	AM	830	5.73	23.5	6.20	22.9	7.67	22.8	5.99	22.0	6.12	23.3	6.14	23.8	5.11	23.5	5.87	23.9	5.10	23.3	5.37	22.5	4.86	23.6
	PM	1600	5.10	24.0	5.91	24.3	5.78	24.3	5.98	22.3	6.37	22.6	6.59	22.9	4.39	24.5	5.96	22.5	5.92	24.9	5.74	24.7		
Cress Proctors Stream	AM	830	5.67	23.1	5.91	22.5	6.35	22.1	6.10	22.3	5.69	23.2	5.62	23.7	4.95	22.9	5.44	23.2	5.56	23.3	5.45	22.3	5.34	22.4
	PM	1600	5.17	23.4	5.90	24.2	5.96	24.2	5.79	22.4	6.01	22.4	6.98	23.5	4.38	23.7	5.54	23.3	5.92	24.0	5.96	24.7		
Cress Old Grand Haven Rd Stream	AM	830	5.75	23.5	6.24	22.9	6.98	22.9	6.24	22.7	5.52	23.2	5.60	23.4	4.62	23.1	5.23	23.4	6.18	22.7	5.94	22.0	5.61	22.7
	PM	1600	5.45	23.6	5.95	23.7	5.93	23.7	5.95	22.3	6.49	22.7	5.90	24.1	4.61	23.2	5.40	23.0	6.33	23.4	6.03	23.1		
M-1	AM	830	6.06	23.2	6.12	22.3	7.64	22.5	5.97	23.9	6.06	23.1	6.22	23.1	5.86	22.9	6.22	23.1	3.26	23.1	3.48	19.4	3.64	23.0
	PM	1600	5.41	23.0	6.06	23.2	6.22	23.2	6.01	22.3	6.60	22.4	7.23	22.5	5.20	22.8	6.49	22.5	4.04	23.3	3.02	23.5		
M-2	AM	830	6.23	23.1	6.43	22.4	7.55	22.0	5.98	22.4	6.10	22.6	6.44	22.6	5.91	22.3	6.10	22.5	5.59	23.2	6.61	19.7	5.42	22.7
	PM	1600	5.61	22.2	6.38	22.8	6.52	22.7	6.30	22.2	6.54	22.0	7.02	23.5	4.98	22.7	6.26	22.5	6.52	22.8	6.37	22.7		
M-3	AM	830	5.71	22.0	6.02	22.8	6.45	22.8	5.39	23.6	5.42	22.9	5.73	22.8	5.35	23.1	5.45	23.0	4.69	22.8	5.37	22.8	5.12	23.2
	PM	1600	5.75	22.7	5.93	23.3	5.52	23.6	5.95	22.8	5.81	22.5	6.02	22.9	4.63	23.4	5.53	23.0	5.89	23.6	5.26	23.2		
Cotrol	AM	830	5.70	22.0	6.19	22.9	6.24	22.9	6.11	22.2	5.54	23.0	5.39	22.9	5.03	23.1	5.45	23.2	4.41	23.1	6.05	23.6	5.26	23.2
	PM	1600	5.41	23.0	5.94	23.4	5.51	23.7	5.69	22.9	5.96	22.8	6.32	23.2	4.59	23.6	5.32	23.5	5.88	23.6	5.72	23.6		

TABLE B. 2. DISSOLVED OXYGEN AND TEMPERATURE DATA FOR *CHIRONOMUS TENTANS* SEDIMENT TOXICITY EVALUATIONS WITH LITTLE BLACK CREEK, CRESS CREEK, AND MONA LAKE SEDIMENT.

Sample ID	Time		Day 0		Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 10	
			DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp	DO	Temp
Sample ID	AM	810	5.30	22.4	5.85	23.4	5.22	23.8	5.45	22.9	6.02	23.2	8.71	22.4	8.33	22.8	8.99	22.7	7.95	23.5	7.74	22.6	8.39	22.7
	PM	1600	4.81	23.7	5.83	24.2	5.58	24.1	5.73	24.2	4.82	24.2	8.06	23.2	7.48	22.1	7.40	22.9	8.84	22.2	8.38	22.8		
Evanston	AM	810	6.05	22.5	5.52	23.6	7.22	22.9	4.32	22.0	3.92	23.4	8.61	22.3	7.73	22.8	8.68	23.5	8.09	22.9	7.86	22.7	7.78	22.2
	PM	1611	4.96	23.9	5.41	24.6	4.75	24.8	4.61	24.5	3.70	24.3	8.35	22.7	6.44	22.5	7.12	18.2	9.34	18.7	8.28	22.4		
Industrial Park	AM	810	6.91	22.2	5.95	23.4	7.77	22.6	5.51	22.2	5.64	23.5	8.20	22.2	8.04	22.5	8.18	22.8	7.87	22.3	8.14	22.3	8.23	22.1
	PM	1611	4.92	24.1	5.68	25.0	5.46	24.9	5.41	24.8	4.67	24.6	8.41	22.6	6.49	22.3	7.02	22.7	7.97	22.0	8.60	22.4		
Roberts	AM	810	5.94	22.1	5.37	23.6	7.23	22.3	5.44	22.1	5.44	23.5	8.10	22.7	7.93	22.9	8.15	22.0	8.37	22.6	8.36	22.5	8.03	22.4
	PM	1611	4.46	23.8	5.58	24.6	5.25	24.6	5.40	24.4	4.63	24.2	8.28	22.1	6.46	22.6	6.58	22.4	8.15	22.2	8.14	22.8		
Peerless 1	AM	810	6.36	23.9	6.23	22.9	7.25	22.2	6.16	22.0	6.00	23.2	8.25	22.3	7.84	22.9	8.09	22.0	8.23	22.7	8.42	22.3	8.02	22.3
	PM	1611	4.79	22.9	6.09	23.4	6.10	23.8	6.08	23.7	4.82	23.1	8.35	22.1	6.63	22.0	6.84	22.3	8.34	22.8	8.36	22.0		
Peerless 2	AM	810	6.40	23.8	5.72	22.8	8.02	22.7	5.27	22.2	3.48	23.1	8.06	22.3	7.55	22.3	8.13	22.5	8.31	22.6	8.4	22.4	7.82	22.9
	PM	1611	4.78	22.8	5.74	23.3	5.03	24.1	3.87	23.8	2.91	23.5	8.55	22.9	6.50	22.3	6.95	22.7	8.29	22.9	8.79	22.2		
Sherman/Getty DS	AM	810	5.71	23.6	4.53	22.7	7.02	22.1	3.72	22.8	3.66	22.4	5.71	22.9	5.57	22.4	2.23	22.6	7.07	23.3	8.30	22.3	4.60	22.7
	PM	1611	4.40	22.6	4.43	24.0	3.62	24.2	3.61	24.0	2.51	23.6	8.59	22.6	6.12	22.3	7.20	22.7	8.15	22.4	5.96	23.3		
LBC Mona View Wetland	AM	810	6.09	23.7	5.90	22.5	7.69	22.6	5.13	22.5	4.96	22.5	5.52	22.2	7.97	22.4	6.00	22.2	5.96	22.2	8.39	22.2	5.06	22.4
	PM	1611	4.75	22.3	5.93	23.6	5.51	23.7	5.07	23.4	4.61	23.2	8.63	22.1	6.67	22.5	7.11	23.4	8.53	22.8	8.91	23.7		
Airline	AM	810	6.80	23.8	5.82	23.4	5.85	22.4	5.96	22.9	6.07	22.9	8.44	22.0	8.10	22.5	8.48	22.6	8.47	22.2	7.33	23.6	8.36	22.4
	PM	1611	5.02	22.4	6.03	23.6	5.34	23.6	5.85	23.4	5.39	23.0	8.44	22.0	6.28	22.6	6.85	22.4	8.36	22.3	8.68	22.1		
Seaway	AM	810	6.48	23.7	5.97	23.0	7.89	22.0	6.02	22.1	5.83	22.6	6.24	22.3	6.02	22.4	6.44	22.3	6.66	22.8	6.70	22.4	6.24	22.8
	PM	1611	4.95	22.6	6.07	23.1	6.05	23.2	6.25	23.0	5.18	22.9	8.25	22.1	5.4	22.0	5.49	22.0	6.72	22.7	6.41	22.3		
LBC Lower Wetland	AM	810	6.55	22.7	6.11	23.3	7.27	22.3	5.65	22.9	5.70	23.1	6.66	22.0	5.00	22.4	6.05	22.8	7.16	22.3	8.51	22.3	6.83	22.8
	PM	1611	5.62	23.2	6.07	24.0	5.58	24.2	5.74	24.0	4.88	23.8	7.07	22.0	6.73	22.8	6.61	22.5	8.25	22.1	6.39	23.2		
Outlet	AM	810	5.40	22.5	4.95	23.5	7.26	22.4	4.37	22.1	4.74	23.2	6.32	22.9	5.07	22.2	4.78	22.3	5.86	23.8	8.35	22.7	6.66	22.5
	PM	1611	4.38	23.5	5.41	24.4	4.61	24.5	4.92	24.2	4.67	24.1	8.58	23.8	6.53	22.8	7.41	23.2	8.44	22.5	5.68	23.1		
Control	AM	810	5.32	22.7	5.58	23.5	6.03	22.4	4.29	22.3	5.12	23.3	8.51	22.5	7.94	22.4	8.43	22.8	6.93	22.2	8.14	23.2	8.22	22.3
	PM	1611	4.82	23.8	5.71	24.7	5.43	24.8	5.46	24.5	4.55	24.3	8.87	23.5	6.63	22.5	5.50	22.7	8.73	22.2	8.44	23.9		
Cress Towner Rd Impoundment Wetland	AM	810	5.20	22.7	5.29	23.6	7.23	22.3	5.16	22.8	5.31	23.2	6.29	22.4	7.64	22.1	8.11	22.6	8.37	22.6	8.44	23.8	7.67	23.0
	PM	1611	5.38	23.1	5.46	23.5	4.61	23.8	4.51	23.5	3.68	23.5	8.09	22.3	5.81	22.7	7.57	22.0	8.02	22.6	7.90	23.0		
Cress Hidden Cove Wetland	AM	810	7.59	22.5	7.02	23.4	7.62	22.9	6.43	22.0	6.48	23.4	8.12	22.5	7.75	22.1	8.18	22.9	8.54	22.3	8.69	23.9	8.05	22.4
	PM	1611	5.69	23.6	6.98	24.0	6.59	24.4	6.64	24.1	5.91	24.0	8.45	22.8	7.09	22.6	6.65	22.9	8.10	22.9	8.22	22.5		
Cress Quarterline Rd Stream	AM	810	5.83	22.6	6.06	23.6	7.10	22.0	5.57	22.4	5.05	23.2	8.34	22.9	7.87	22.3	8.43	22.9	8.60	22.4	8.66	23.7	8.11	22.6
	PM	1611	5.01	23.8	5.93	25.8	5.39	24.1	5.50	23.9	4.36	23.6	8.45	22.2	6.23	22.0	6.85	22.4	8.97	23.7	8.43	22.5		
Cress Towner Rd Stream	AM	810	5.60	22.6	5.75	23.4	7.25	22.9	5.56	22.9	5.09	23.3	6.60	22.4	5.84	22.7	6.32	22.5	5.23	22.2	6.70	23.9	8.03	22.0
	PM	1611	4.73	23.6	5.56	24.2	5.05	24.4	5.02	24.1	4.44	23.6	8.33	22.0	6.83	23.6	5.31	22.8	6.50	23.5	6.46	23.0		
Cress Proctors Stream	AM	810	5.75	22.4	5.55	23.3	6.02	22.5	5.51	22.8	5.22	23.1	8.57	22.5	7.31	22.7	8.49	22.5	8.45	22.5	8.46	22.0	8.27	22.3
	PM	1611	4.61	23.2	5.79	23.8	5.30	23.9	5.22	23.7	4.41	23.5	8.05	22.0	6.49	22.8	7.11	23.6	9.16	18.7	8.50	22.0		
Cress Old Grand Haven Rd Stream	AM	810	4.92	22.1	5.24	23.0	7.30	22.6	5.76	22.9	5.69	22.6	6.35	22.2	6.20	22.1	6.53	22.1	7.04	22.6	8.32	23.7	6.37	22.5
	PM	1611	4.29	22.7	5.59	23.3	5.46	23.3	5.63	23.0	4.82	22.8	8.38	23.7	6.80	22.0	6.04	22.9	6.93	22.8	6.39	22.5		
M-1	AM	810	6.06	23.6	6.22	22.1	7.24	22.0	5.62	22.9	6.05	22.8	8.03	22.4	7.57	22.6	8.00	22.2	6.61	22.8	6.62	22.3	6.22	22.4
	PM	1611	5.09	22.6	6.01	22.6	5.38	22.7	5.51	22.6	4.97	22.1	8.25	23.8	6.59	22.7	7.00	22.8	8.47	22.9	5.97	22.9		
M-2	AM	810	5.51	22.8	5.35	22.8	7.07	22.8	5.17	22.2	4.93	22.0	6.57	22.2	6.22	22.0	6.64	22.2	8.33	22.0	8.51	22.1	8.08	22.9
	PM	1611	4.85	22.8	5.85	22.6	5.20	23.1	5.08	22.7	4.52	22.2	8.60	23.2	6.95	23.2	6.54	22.6	8.49	22.9	8.18	22.0		
M-3	AM	810	5.52	22.0	5.76	23.0	7.01	22.2	5.48	22.8	5.26	22.5	6.61	22.9	5.22	22.7	5.49	22.2	8.50	22.3	7.48	23.5	6.78	22.1
	PM	1611	5.32	22.7	5.56	23.4	5.25	23.7	5.34	23.4	4.75	23.1	8.02	22.3	4.84	22.2	5.54	22.0	9.06	18.5	8.37	22.0		
Cotrol	AM	810	5.29	22.0	5.64	22.9	7.59	22.5	5.68	22.2	5.85	22.3	8.23	22.0	7.76	22.3	8.06	22.5	8.34	23.9	5.57	23.5	2.69	22.7
	PM	1611	4.74	22.6	5.96	23.5	5.33	23.7	5.65	23.3	4.84	23.1	8.15	22.7	6.09	22.6	7.20	22.4	6.99	22.9	2.66	22.8		

TABLE B. 3. WATER QUALITY DATA FOR SEDIMENT TOXICITY EVALUATIONS WITH LITTLE BLACK CREEK, CRESS CREEK, AND MONA LAKE SEDIMENT.

Sample ID	Organism	Initial pH pH	Final pH	pH % RPD	Initial Alkalinity mg/L	Final Alkalinity mg/L	Alkalinity % RPD	Initial Hardness mg/L	Final Hardness mg/L	Hardness % RPD
Evanston	*Hyalella azteca*	8.02	8.49	5.7	126	128	2	126	127	1
Industrial Park	*Hyalella azteca*	8.03	8.18	1.9	122	126	3	130	136	5
Roberts	*Hyalella azteca*	7.98	8.04	0.7	125	127	2	125	130	4
Peerless 1	*Hyalella azteca*	8.06	8.26	2.5	122	130	6	127	132	4
Peerless 2	*Hyalella azteca*	8.09	8.28	2.3	121	132	9	124	130	5
Sherman/Getty DS	*Hyalella azteca*	8.04	8.05	0.1	127	132	4	121	124	2
LBC Mona View Wetland	*Hyalella azteca*	7.93	8.22	3.6	134	128	5	145	125	15
Airline	*Hyalella azteca*	8.08	8.33	3.0	127	131	3	111	117	5
Seaway	*Hyalella azteca*	8.13	8.22	1.1	122	127	4	117	109	7
LBC Lower Wetland	*Hyalella azteca*	8.08	8.11	0.4	129	116	11	117	111	5
Outlet	*Hyalella azteca*	8.06	8.08	0.2	134	116	15	121	115	5
Control	*Hyalella azteca*	8.06	8.07	0.1	146	117	21	121	113	7
Evanston	*Chironomus tentans*	8.02	8.25	2.8	125	128	3	126	128	2
Industrial Park	*Chironomus tentans*	8.06	8.26	2.5	126	129	2	125	132	5
Roberts	*Chironomus tentans*	7.98	8.37	4.8	122	126	3	128	130	2
Peerless 1	*Chironomus tentans*	8.05	8.38	4.0	121	128	6	126	134	6
Peerless 2	*Chironomus tentans*	7.96	8.13	2.1	124	120	3	122	129	6
Sherman/Getty DS	*Chironomus tentans*	8.06	8.19	1.6	122	126	4	128	136	6
LBC Mona View Wetland	*Chironomus tentans*	8.03	8.29	3.2	142	155	9	145	117	22
Airline	*Chironomus tentans*	8.02	8.15	1.6	136	131	4	121	129	6
Seaway	*Chironomus tentans*	8.09	8.25	2.0	123	117	4	113	133	16
LBC Lower Wetland	*Chironomus tentans*	8.04	8.15	1.4	138	128	8	125	109	14
Outlet	*Chironomus tentans*	8.00	8.11	1.4	144	127	13	145	125	15
Control	*Chironomus tentans*	8.02	8.20	2.2	135	125	8	121	121	0
Cress Towner Rd Impoundment Wetland	Hyalella azteca	8.32	8.81	5.7	128	128	0.3	127	131	4
Cress Hidden Cove Wetland	*Hyalella azteca*	8.05	8.23	2.2	123	127	2.6	135	138	2
Cress Quarterline Rd Stream	*Hyalella azteca*	8.37	8.45	1.0	128	130	1.1	127	130	2
Cress Towner Rd Stream	*Hyalella azteca*	8.41	8.56	1.7	123	131	6.3	128	136	6
Cress Proctors Stream	*Hyalella azteca*	8.34	8.53	2.2	124	135	7.9	125	131	5
Cress Old Grand Haven Rd Stream	*Hyalella azteca*	8.29	8.26	0.3	130	132	1.3	122	126	4
ML -1	*Hyalella azteca*	8.51	8.45	0.7	138	131	5.5	145	125	15
ML-2	*Hyalella azteca*	8.26	8.48	2.6	129	134	3.6	113	118	5
ML-3	*Hyalella azteca*	8.19	8.48	3.6	123	129	4.8	118	111	6
Control	*Hyalella azteca*	8.30	8.35	0.6	131	116	12.1	122	115	6
Cress Towner Rd Impoundment Wetland	Chironomus tentans	8.07	8.17	1.3	137	117	15.5	123	120	3
Cress Hidden Cove Wetland	*Chironomus tentans*	8.13	8.52	4.7	148	120	21.1	123	116	6
Cress Quarterline Rd Stream	*Chironomus tentans*	8.32	8.70	4.5	125	131	4.3	127	132	4
Cress Towner Rd Stream	*Chironomus tentans*	8.33	8.56	2.8	128	130	1.4	127	134	6
Cress Proctors Stream	*Chironomus tentans*	8.05	8.65	7.1	123	128	3.7	130	131	0
Cress Old Grand Haven Rd Stream	*Chironomus tentans*	8.29	8.66	4.4	124	129	4.1	132	135	2
ML -1	*Chironomus tentans*	8.34	8.14	2.4	124	122	2.1	122	133	9
ML-2	*Chironomus tentans*	8.02	8.54	6.2	125	126	1.2	130	137	5
ML-3	*Chironomus tentans*	8.55	8.60	0.6	143	157	9.4	141	122	15
Control	*Chironomus tentans*	8.52	8.60	1.0	139	133	3.9	125	134	7

TABLE 3. (CONTINUED). WATER QUALITY DATA FOR SEDIMENT TOXICITY EVALUATIONS WITH LITTLE BLACK CREEK, CRESS CREEK, AND MONA LAKE SEDIMENT.

Sample ID	**Organism**	**Initial NH3**	**Final NH3**	**NH3**	**Initial Cond**	**Final Cond**	**Cond**
		mg/l	**mg/l**	**% RPD**	**mg/L**	**mg/L**	**% RPD**
Evanston	*Hyalella azteca*	3.94	0.08	192.0	439.8	406.4	8
Industrial Park	*Hyalella azteca*	2.46	0.04	193.6	432.8	426.4	1
Roberts	*Hyalella azteca*	1.36	0.06	183.0	424.9	406	5
Peerless 1	*Hyalella azteca*	2.59	0.09	186.5	423.3	392.6	8
Peerless 2	*Hyalella azteca*	3.45	0.04	195.4	436.4	391.1	11
Sherman/Getty DS	*Hyalella azteca*	4.52	0.05	195.6	445.7	391.4	13
LBC Mona View Wetland	*Hyalella azteca*	2.23	0.07	188.0	441	415	6
Airline	*Hyalella azteca*	1.74	0.06	186.0	435	412	5
Seaway	*Hyalella azteca*	1.02	0.09	168.9	426	413	3
LBC Lower Wetland	*Hyalella azteca*	1.95	0.05	189.4	425	421	1
Outlet	*Hyalella azteca*	2.95	0.03	195.6	437	416	5
Control	*Hyalella azteca*	2.60	0.07	190.2	447	435	3
Evanston	*Chironomus tentans*	3.22	0.05	193.9	463.4	439	5
Industrial Park	*Chironomus tentans*	2.56	0.06	190.8	446.3	438	2
Roberts	*Chironomus tentans*	0.86	0.07	170.0	437.8	420	4
Peerless 1	*Chironomus tentans*	2.22	0.08	186.1	427.2	414	3
Peerless 2	*Chironomus tentans*	4.33	0.04	196.3	440.6	434	2
Sherman/Getty DS	*Chironomus tentans*	4.22	0.05	195.3	423.7	412	3
LBC Mona View Wetland	*Chironomus tentans*	2.04	0.06	189.1	464	456	2
Airline	*Chironomus tentans*	1.50	0.06	184.1	448	438	2
Seaway	*Chironomus tentans*	0.86	0.11	156.1	439	431	2
LBC Lower Wetland	*Chironomus tentans*	1.76	0.11	175.7	428	406	5
Outlet	*Chironomus tentans*	2.55	0.07	189.2	441	440	0
Control	*Chironomus tentans*	2.83	0.14	180.9	424	415	2
Cress Towner Rd Impoundment Wetland	Hyalella azteca	5.56	0.22	185	465	448	3.8
Cress Hidden Cove Wetland	*Hyalella azteca*	3.43	0.28	170	448	426	5.1
Cress Quarterline Rd Stream	*Hyalella azteca*	1.81	0.54	108	440	429	2.5
Cress Towner Rd Stream	*Hyalella azteca*	5.23	0.20	185	428	409	4.7
Cress Proctors Stream	*Hyalella azteca*	4.48	0.22	181	442	432	2.1
Cress Old Grand Haven Rd Stream	*Hyalella azteca*	2.88	0.31	161	425	421	1.0
ML -1	*Hyalella azteca*	2.91	0.23	171	466	455	2.3
ML-2	*Hyalella azteca*	1.80	0.27	148	449	431	4.0
ML-3	*Hyalella azteca*	3.25	0.56	141	440	428	2.9
Control	*Hyalella azteca*	2.00	0.59	108	429	420	2.1
Cress Towner Rd Impoundment Wetland	Chironomus tentans	4.85	0.31	176	443	432	2.4
Cress Hidden Cove Wetland	*Chironomus tentans*	3.13	0.33	162	425	407	4.4
Cress Quarterline Rd Stream	*Chironomus tentans*	3.45	0.46	152	467	464	0.7
Cress Towner Rd Stream	*Chironomus tentans*	3.71	0.68	138	450	443	1.5
Cress Proctors Stream	*Chironomus tentans*	3.73	0.68	138	441	432	2.1
Cress Old Grand Haven Rd Stream	*Chironomus tentans*	4.45	0.35	171	430	409	4.9
ML -1	*Chironomus tentans*	4.59	0.30	175	444	435	2.1
ML-2	*Chironomus tentans*	5.67	0.53	166	426	412	3.3
ML-3	*Chironomus tentans*	3.63	0.38	162	469	468	0.1
Control	*Chironomus tentans*	3.21	0.47	149	450	443	1.6

Appendix C
Benthic Macroinvertebrates

TABLE C. 1. BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Nematoda	Platyhelminthes	Annelida	Annelida	Annelida	Mollusca	Mollusca	Mollusca	Mollusca
Class:										
Order:			Turbellaria	Hirudinea	Oligochaeta	Oligochaeta	Bivalvia	Gastropoda	Gastropoda	Gastropoda
Family:					Naididae	Tubificidae	Sphaeriidae	Lymnaeidae	Physidae	Planorbidae
Genus:							*Sphaerium*	*Fossaria*	*Physella*	*Gyraulus*
Little Black Creek										
Evanston	27-Apr				1.67				0.33	
Sherman	27-Apr				0.67		1.67		1.67	
Summmit	27-Apr		0.67		2.67					
Seaway	27-Apr	0.33	0.33		1.33	0.33			0.33	
Evanston	28-Jun	1.00			6.67				17.33	
Sherman	28-Jun	0.67			1.67		0.33		1.67	
Summmit	28-Jun		2.00						3.67	
Seaway	28-Jun		0.67						3.67	
Evanston	25-Aug				4.33		0.33	0.67	32.33	
Sherman	25-Aug				1.00			0.33	3.67	
Summmit	25-Aug				0.33				3.67	
Seaway	25-Aug	0.33	2.67			0.33	0.33		0.33	
Cress Creek										
Quarterline	28-Apr	0.33								
Towner	28-Apr	1.00			5.00				1.67	
Proctors	28-Apr	0.33	0.33		28.33		1.33		2.00	
Old Grand Haven	28-Apr		0.67		28.67					
Quarterline	25-Jun	0.67			1.00			0.33		
Towner	25-Jun		1.00			4.33	0.33		1.33	0.33
Proctors	25-Jun		2.00			15.00			22.67	0.67
Old Grand Haven	25-Jun		1.67		1.00	0.33	0.67	1.00	18.67	
Quarterline	24-Aug				2.00					
Towner	24-Aug		1.00		2.00				4.67	
Proctors	24-Aug		2.00	0.33	18.33				6.33	
Old Grand Haven	24-Aug		2.33		1.33				0.33	

Phylum:		Mollusca	Mollusca	Mollusca	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:					Hydrachnidia	Crustacea	Crustacea	Crustacea	Crustacea	Crustacea
Order:		Gastropoda	Gastropoda	Gastropoda	Hydracarina	Amphipoda	Amphipoda	Amphipoda	Amphipoda	Decapoda
Family:		Planorbidae	Planorbidae	Unknown		Crangonyctidae	Gammaridae	Talitridae	Unknown	
Genus		*Heliosoma*	*Planorbella*			*Crangonyx*	*Gammarus*	*Hyalella*		
Little Black Creek										
Evanston	27-Apr						4.00			
Sherman	27-Apr				1.33		51.67			
Summmit	27-Apr				0.33		31.33			
Seaway	27-Apr				1.67		87.67			
Evanston	28-Jun	0.67					0.33			
Sherman	28-Jun	0.33					22.67			
Summmit	28-Jun						77.67			
Seaway	28-Jun				0.33		104.33			
Evanston	25-Aug				2.00					
Sherman	25-Aug				1.33		64.00			
Summmit	25-Aug						86.00			
Seaway	25-Aug						112.33			
Cress Creek										
Quarterline	28-Apr						119.67			
Towner	28-Apr						34.67			
Proctors	28-Apr						11.67			
Old Grand Haven	28-Apr						24.33			
Quarterline	25-Jun						72.33	1.00		
Towner	25-Jun						48.33			0.67
Proctors	25-Jun						51.67			2.33
Old Grand Haven	25-Jun			0.33		0.33	37.33		0.33	1.33
Quarterline	24-Aug						163.00			
Towner	24-Aug						98.33			
Proctors	24-Aug		0.33		1.67		66.67			
Old Grand Haven	24-Aug						31.33			0.33

TABLE C.1 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Crustacea	Crustacea	Crustacea	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Isopoda	Isopoda	Isopoda	Collembola	Collembola	Ephemeroptera	Ephemeroptera	Hemiptera	Hemiptera
Family:		Asellidae	Asellidae	Asellidae	Isotomidae	Poduridae	Baetidae	Baetidae	Belostomatidae	Corixidae
Genus		*Caecidotea*	*Lirceus*	Unknown	*Isotomurus*	*Podura*	*Baetis*	Unknown	*Belostoma*	*Sigara*
Little Black Creek										
Evanston	27-Apr	1.00	0.33				2.00	7.33		
Sherman	27-Apr	11.33		19.33						
Summmit	27-Apr	4.00					0.33	2.33		
Seaway	27-Apr	7.00					3.00	17.00		
Evanston	28-Jun	40.33	17.00							
Sherman	28-Jun	61.00	1.33							
Summmit	28-Jun	23.00	0.67				25.67			
Seaway	28-Jun	15.00	2.00				17.33			
Evanston	25-Aug	4.67	0.33				1.67	1.00		
Sherman	25-Aug	10.33					2.33	2.00		
Summmit	25-Aug	3.67		2.33	0.33		42.67	20.67		
Seaway	25-Aug	3.33	0.33	0.33			1.00	8.33		
Cress Creek										
Quarterline	28-Apr	3.67				1.00		0.33		
Towner	28-Apr	0.33				0.33		1.33		
Proctors	28-Apr	1.00	0.33							
Old Grand Haven	28-Apr	4.00		0.67						
Quarterline	25-Jun	11.67	0.33			0.33	0.33			
Towner	25-Jun	2.67	1.33				3.00	1.33		
Proctors	25-Jun	28.67					1.67			0.67
Old Grand Haven	25-Jun	23.67					1.00			0.67
Quarterline	24-Aug	3.67		1.33			4.67	0.67		0.67
Towner	24-Aug	0.33				0.33	2.33	0.67		
Proctors	24-Aug	8.33		2.33			3.00	2.33	0.33	
Old Grand Haven	24-Aug	2.33					37.33	0.67		

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Hemiptera	Hemiptera	Hemiptera	Homoptera	Odonata	Odonata	Odonata	Odonata	Odonata
Family:		Gerridae	Gerridae	Notonectidae		Aeshnidae	Aeshnidae	Aeshnidae	Aeshnidae	Calopterygidae
Genus		*Limnogonus*	*Trepobates*	*Notonecta*		*Aeshna*	*Anax*	*Boyeria*	Unknown	*Calopteryx*
Little Black Creek										
Evanston	27-Apr									0.33
Sherman	27-Apr									
Summmit	27-Apr									0.67
Seaway	27-Apr									
Evanston	28-Jun									
Sherman	28-Jun	0.33	1.00							
Summmit	28-Jun									
Seaway	28-Jun	0.33	0.67		0.33	0.33		0.67	0.33	
Evanston	25-Aug									0.33
Sherman	25-Aug		0.33							0.33
Summmit	25-Aug						0.33			
Seaway	25-Aug									
Cress Creek										
Quarterline	28-Apr					0.33				
Towner	28-Apr									0.33
Proctors	28-Apr					0.67				1.00
Old Grand Haven	28-Apr					0.33				
Quarterline	25-Jun									
Towner	25-Jun									0.67
Proctors	25-Jun							0.33		0.33
Old Grand Haven	25-Jun					0.33				0.33
Quarterline	24-Aug			1.00	1.67					
Towner	24-Aug				0.33				0.33	3.67
Proctors	24-Aug									0.33
Old Grand Haven	24-Aug		1.33		0.33	0.33				

Table C.1 (continued). Benthic Macroinvertebrates (#/m^2) in Little Black Creek and Cress Creek Stream Locations (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Odonata	Odonata	Odonata	Odonata	Odonata	Trichoptera	Trichoptera	Trichoptera
Family:		Coenagrionidae	Coenagrionidae	Cordulegastridae	Lestidae	Libellulidae	Hydropsychidae	Hydropsychidae	Hydropsychidae
Genus		*Ischnura*	Unknown	*Corduligaster*	*Lestes*	*Libellula*	*Diplectrona*	*Hydropsyche*	*Potamyia*
Little Black Creek									
Evanston	27-Apr						0.67	0.67	
Sherman	27-Apr						0.33		
Summmit	27-Apr						1.33	0.33	8.00
Seaway	27-Apr							0.67	7.00
Evanston	28-Jun			0.33			4.33	0.33	
Sherman	28-Jun						2.67		
Summmit	28-Jun						2.00		
Seaway	28-Jun							0.33	
Evanston	25-Aug					0.33	5.33		4.33
Sherman	25-Aug						4.00		21.00
Summmit	25-Aug							1.33	
Seaway	25-Aug				0.33		0.33	1.33	0.67
Cress Creek									
Quarterline	28-Apr								
Towner	28-Apr								
Proctors	28-Apr								
Old Grand Haven	28-Apr								
Quarterline	25-Jun								
Towner	25-Jun								
Proctors	25-Jun								
Old Grand Haven	25-Jun	0.33							
Quarterline	24-Aug								
Towner	24-Aug								
Proctors	24-Aug								
Old Grand Haven	24-Aug		1.67						

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Trichoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera
Family:		Hydropsychidae	Lepidostomatidae	Lepidostomatidae	Limnephilidae	Limnephilidae	Limnephilidae	Limnephilidae	Limnephilida
Genus		Unknown	*Lepidostoma*	Unknown	*Anabolia*	*Frenesia*	*Hydatophlax*	*Ironoquia*	*Neophylax*
Little Black Creek									
Evanston	27-Apr								
Sherman	27-Apr		25.33					0.67	8.33
Summmit	27-Apr		1.00		0.67				
Seaway	27-Apr								
Evanston	28-Jun		12.33						
Sherman	28-Jun	1.00	35.67			0.33			0.67
Summmit	28-Jun		1.33						
Seaway	28-Jun	0.33	0.33						
Evanston	25-Aug	12.33					0.33		
Sherman	25-Aug	13.67		0.33			0.33		
Summmit	25-Aug	0.67							
Seaway	25-Aug	2.00							
Cress Creek									
Quarterline	28-Apr								
Towner	28-Apr								
Proctors	28-Apr								
Old Grand Haven	28-Apr								
Quarterline	25-Jun								
Towner	25-Jun								
Proctors	25-Jun								
Old Grand Haven	25-Jun								
Quarterline	24-Aug								
Towner	24-Aug								
Proctors	24-Aug								
Old Grand Haven	24-Aug								

TABLE C.1 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Trichoptera	Trichoptera	Trichoptera	Trichoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera
Family:		Limnephilidae	Limnephilidae	Polycentropodidae	Psychomyiidae	Dytiscidae	Dytiscidae	Dytiscidae	Dytiscidae
Genus		*Pycnopsyche*	*Psychoglypha*	*Polycentropus*		*Agabus*	*Laccophilus*	*Lioporius*	Unknown
Little Black Creek									
Evanston	27-Apr				0.33				
Sherman	27-Apr	1.67				1.33			
Summmit	27-Apr			0.33		3.00			0.67
Seaway	27-Apr					1.67			
Evanston	28-Jun		0.33			0.33			0.67
Sherman	28-Jun	2.67	0.33			0.33			0.33
Summmit	28-Jun					0.33			1.33
Seaway	28-Jun								0.33
Evanston	25-Aug	0.33			1.00	0.33			0.33
Sherman	25-Aug	1.00	0.33						0.33
Summmit	25-Aug			0.33	0.33				
Seaway	25-Aug					0.33			
Cress Creek									
Quarterline	28-Apr					1.33		0.67	
Towner	28-Apr					1.67			
Proctors	28-Apr					0.67			
Old Grand Haven	28-Apr								
Quarterline	25-Jun					1.33			1.67
Towner	25-Jun								
Proctors	25-Jun						0.33		0.33
Old Grand Haven	25-Jun								
Quarterline	24-Aug					0.33			
Towner	24-Aug	0.33							
Proctors	24-Aug								
Old Grand Haven	24-Aug								

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera
Family:		Elmidae	Elmidae	Elmidae	Haliplidae	Haliplidae	Hydrophilidae	Hydrophilidae	Hydrophilidae	Hydrophilidae
Genus		*Optioservus*	*Oulimnius*	Unknown	*Haliplus*	*Peltodytes*	*Anacaena*	*Chaetarthria*	*Cymbiodyta*	*Derallus*
Little Black Creek										
Evanston	27-Apr									
Sherman	27-Apr									
Summmit	27-Apr									
Seaway	27-Apr	0.33	0.33							
Evanston	28-Jun									
Sherman	28-Jun									
Summmit	28-Jun									
Seaway	28-Jun									
Evanston	25-Aug						0.33			
Sherman	25-Aug								0.33	0.33
Summmit	25-Aug	0.33								
Seaway	25-Aug	0.33	0.67	0.33						
Cress Creek										
Quarterline	28-Apr									
Towner	28-Apr									
Proctors	28-Apr									
Old Grand Haven	28-Apr									
Quarterline	25-Jun						0.33			
Towner	25-Jun									
Proctors	25-Jun									
Old Grand Haven	25-Jun				0.33	0.33				
Quarterline	24-Aug									
Towner	24-Aug							0.33		
Proctors	24-Aug									
Old Grand Haven	24-Aug									0.33

TABLE C.1 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Coleoptera	Coleoptera	Coleoptera	Coleoptera	Megaloptera	Diptera	Diptera	Diptera
Family:		Hydrophilida	Hydrophilidae	Hydrophilidae	Hydrophilidae	Corydalidae	Ceratopogonidae	Ceratopogonidae	Ceratopogonidae
Genus		*Enochrus*	*Helocombus*	*Hydrobius*	*Tropisternus*	*Chauliodes*	*Alluaudomyia*	*Bezzia*	*Ceratopogon*
Little Black Creek									
Evanston	27-Apr								
Sherman	27-Apr								
Summmit	27-Apr							0.33	0.33
Seaway	27-Apr							0.33	
Evanston	28-Jun								
Sherman	28-Jun			0.33					
Summmit	28-Jun								
Seaway	28-Jun								
Evanston	25-Aug								
Sherman	25-Aug	0.33		0.33					
Summmit	25-Aug								
Seaway	25-Aug								
Cress Creek									
Quarterline	28-Apr								
Towner	28-Apr							0.33	
Proctors	28-Apr				0.33				
Old Grand Haven	28-Apr						0.33		
Quarterline	25-Jun		0.33					0.33	
Towner	25-Jun					0.33			
Proctors	25-Jun				0.33				
Old Grand Haven	25-Jun								
Quarterline	24-Aug	0.33			0.33				
Towner	24-Aug								
Proctors	24-Aug								
Old Grand Haven	24-Aug								

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:		Ceratopogonidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae	Chironomidae
Genus		*Culicoides*	Prodiamesinae	Chironomini	Corynoneura	Orthocladiinae	Tanytarsini	Tanypodinae	Unknown
Little Black Creek									
Evanston	27-Apr			0.67		51.67	0.33	0.33	
Sherman	27-Apr		17.67	1.00	0.67	5.00	3.67	1.00	
Summmit	27-Apr					32.00	3.67	6.00	0.33
Seaway	27-Apr	0.33	1.33	3.67		15.33	2.33	3.00	0.33
Evanston	28-Jun		0.67	2.67		21.67	15.00	9.33	
Sherman	28-Jun		9.67	9.33		2.00	2.00	1.00	1.00
Summmit	28-Jun		0.33	0.67	0.67	12.67		0.33	
Seaway	28-Jun			3.00		3.33			
Evanston	25-Aug		0.33	13.67	6.00	21.33	4.67	7.33	1.33
Sherman	25-Aug		3.33	1.67	1.00	4.33	0.33	1.00	0.67
Summmit	25-Aug		0.33		0.33	1.33			0.33
Seaway	25-Aug		0.33		0.33	3.33			
Cress Creek									
Quarterline	28-Apr		0.33	0.33		53.33		6.00	1.67
Towner	28-Apr		0.33	0.67		116.67		10.00	1.67
Proctors	28-Apr			0.33		94.67		20.00	2.67
Old Grand Haven	28-Apr			2.33		132.67		10.67	1.00
Quarterline	25-Jun		0.33	1.67		50.67	18.00	5.33	
Towner	25-Jun		16.67	1.00		36.33	0.33	10.33	
Proctors	25-Jun		3.00	0.67		21.33		7.33	
Old Grand Haven	25-Jun		0.33	1.67		54.00		7.67	0.33
Quarterline	24-Aug		1.67	2.00	1.00	1.33		2.67	1.33
Towner	24-Aug		6.67	0.67		32.67	0.33	4.33	0.33
Proctors	24-Aug		1.33	1.00		29.00	0.33	11.33	0.33
Old Grand Haven	24-Aug			1.33		61.00		6.67	1.67

TABLE C.1 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:		Culicidae	Culicidae	Dolichopodidae	Empididae	Nymphomyiidae	Phoridae	Psychodidae	Ptychopteridae	Sciomyzidae
Genus		*Anopheles*	*Aedes*			*Palaeodipteron*		*Pericoma*	*Ptychoptera*	
Little Black Creek										
Evanston	27-Apr									
Sherman	27-Apr								0.33	
Summmit	27-Apr			0.33	0.67					
Seaway	27-Apr									
Evanston	28-Jun									
Sherman	28-Jun									
Summmit	28-Jun									
Seaway	28-Jun									
Evanston	25-Aug				0.33					
Sherman	25-Aug									
Summmit	25-Aug				0.33					
Seaway	25-Aug									
Cress Creek										
Quarterline	28-Apr									
Towner	28-Apr									
Proctors	28-Apr			0.33						
Old Grand Haven	28-Apr									
Quarterline	25-Jun									
Towner	25-Jun									
Proctors	25-Jun						0.33	0.33		
Old Grand Haven	25-Jun		0.33							
Quarterline	24-Aug					0.33				
Towner	24-Aug									0.33
Proctors	24-Aug									
Old Grand Haven	24-Aug	3.00								

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:		Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:		Simuliidae	Simuliidae	Simuliidae	Tabanidae	Tipulidae	Tipulidae	Tipulidae	Tipulidae	Tipulidae	Unknown
Genus		*Prosimulium*	*Simulium*	Unknown	Unknown	*Dicranota*	*Hexatoma*	*Pilaria*	*Tipula*	Unknown	
Little Black Creek											
Evanston	27-Apr		18.33			1.33			0.33	0.33	
Sherman	27-Apr					0.67			0.67		
Summmit	27-Apr		2.00				0.33	0.33	0.33		
Seaway	27-Apr		1.67						0.33		
Evanston	28-Jun		3.00	0.67		0.67			0.33	0.33	
Sherman	28-Jun	0.67	3.00	1.67		1.33					
Summmit	28-Jun		2.00								
Seaway	28-Jun		8.67								
Evanston	25-Aug		10.00	0.33		0.33					
Sherman	25-Aug		6.67	0.67		3.00				0.33	
Summmit	25-Aug		0.67	0.33							0.33
Seaway	25-Aug		10.67	1.33							
Cress Creek											
Quarterline	28-Apr										
Towner	28-Apr		0.33						0.33		
Proctors	28-Apr										
Old Grand Haven	28-Apr										
Quarterline	25-Jun	0.33	0.67								
Towner	25-Jun										
Proctors	25-Jun										
Old Grand Haven	25-Jun		0.67								
Quarterline	24-Aug		0.33		0.33						
Towner	24-Aug								0.33		
Proctors	24-Aug										
Old Grand Haven	24-Aug		5.67								

TABLE C.1 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK STREAM LOCATIONS (2004).

Phylum:		Arthropoda	Arthropoda	Arthropoda	Arthropoda
Class:		Insecta	Insecta	Insecta	Insecta
Order:		Plecoptera	Plecoptera	Plecoptera	Plecoptera
Family:		Nemouridae	Perlodidae	Perlodidae	Chloroperlidae
Genus		*Amphinemura*	*Clioperla*	*Remensus*	Unknown
Little Black Creek					
Evanston	27-Apr	3.00		4.67	2.67
Sherman	27-Apr	15.00		0.33	
Summmit	27-Apr	15.00	0.33		
Seaway	27-Apr	6.67			
Evanston	28-Jun				
Sherman	28-Jun				
Summmit	28-Jun	0.33			
Seaway	28-Jun				
Evanston	25-Aug				
Sherman	25-Aug				
Summmit	25-Aug				
Seaway	25-Aug				
Cress Creek					
Quarterline	28-Apr			0.67	
Towner	28-Apr				
Proctors	28-Apr				
Old Grand Haven	28-Apr				
Quarterline	25-Jun				
Towner	25-Jun				
Proctors	25-Jun				
Old Grand Haven	25-Jun				
Quarterline	24-Aug				
Towner	24-Aug				
Proctors	24-Aug				
Old Grand Haven	24-Aug				

Table C. 2. Benthic Macroinvertebrates (#/m^2) in Little Black Creek And Cress Creek Wetland Locations (2004).

Phylum:			Nematoda	Platyhelminthes	Annelida			Mollusca			
Class:											
Order:				Turbellaria	Hirudinea	Oligochaeta	Oligochaeta	Bivalvia	Gastropoda	Gastropoda	Gastropoda
Family:						Naididae	Tubificidae	Sphaeriidae	Lymnaeidae	Lymnaeidae	Lymnaeidae
Genus:								*Sphaerium*	*Fossaria*	*Pseudosuccinea*	*Stagnicola*
Little Black Creek											
LBC Lower Wetland	18-May	*Typha*				3.60	3.00	7.80		0.20	
Mona View	19-May	*Typha*		0.33	0.33			4.33	0.33		
Industrial Park	2-Jun	*Typha*					0.67	2.33	0.33		
LBC Lower Wetland	30-Jun	*Typha*			1.00		1.00	0.33			
Mona View	30-Jun	*Typha*			0.67			1.67	2.67	0.33	
Industrial Park	1-Jul	*Typha*	0.33					0.33			0.33
LBC Lower Wetland	28-Sep	*Typha*	0.33		0.33	4.00	0.67	1.67		0.33	
Mona View	29-Sep	*Typha*	0.33			0.67					
Cress Creek											
Hidden Cove	18-May	*Nuphar*			0.60	6.20					
Hidden Cove	18-May	*Typha*	0.60			2.60	6.40	12.80	1.00	1.00	
Towner Road	19-May	*Typha*		2.00	1.00	3.00	5.33	13.67			
Hidden Cove	30-Jun	*Nuphar*	13.33			12.33	0.67			0.33	0.33
Hidden Cove	30-Jun	*Typha*	0.33			0.33			0.33		0.33
Towner Road	1-Jul	*Typha*		0.67	0.67	0.67		9.67			
Hidden Cove	28-Sep	*Typha*		2.33	0.67	1.00				0.33	
Hidden Cove	28-Sep	*Nuphar*	1.67	0.67		4.00		0.33			
Towner Road	28-Sep	*Typha*	0.33		0.33	3.00		3.00	0.33		

Phylum:									Arthropoda		
Class:									Hydrachnidia	Crustacea	Crustacea
Order:			Gastropoda	Gastropoda	Gastropoda	Gastropoda	Gastropoda	Gastropoda	Hydracarina	Amphipoda	Amphipoda
Family:			Lymnaeidae	Physidae	Planorbidae	Planorbidae	Planorbidae	Unknown		Crangonyctidae	Gammaridae
Genus			Unknown	*Physella*	*Gyraulus*	*Planorbella*	Unknown			*Crangonyx*	*Gammarus*
Little Black Creek											
LBC Lower Wetland	18-May	*Typha*		26.00	0.40		0.20		5.60	15.80	1.40
Mona View	19-May	*Typha*	0.33	21.00	1.33					2.67	2.00
Industrial Park	2-Jun	*Typha*		0.67					0.67	0.33	
LBC Lower Wetland	30-Jun	*Typha*		57.67					0.67	24.67	1.00
Mona View	30-Jun	*Typha*		43.67		3.67			0.33	0.67	20.00
Industrial Park	1-Jul	*Typha*		3.67	1.00	1.00				0.33	0.33
LBC Lower Wetland	28-Sep	*Typha*		71.33	1.00					44.67	
Mona View	29-Sep	*Typha*		89.00	0.33	2.33					
Cress Creek											
Hidden Cove	18-May	*Nuphar*		0.40					15.60	0.80	3.40
Hidden Cove	18-May	*Typha*	0.20		1.00				3.00	3.00	
Towner Road	19-May	*Typha*		13.00					1.00		22.00
Hidden Cove	30-Jun	*Nuphar*		0.33		0.33			44.33		4.00
Hidden Cove	30-Jun	*Typha*		10.00							4.00
Towner Road	1-Jul	*Typha*		37.67							1.33
Hidden Cove	28-Sep	*Typha*		2.00	0.33	0.33				7.00	14.67
Hidden Cove	28-Sep	*Nuphar*			1.67			0.67	4.00	5.67	9.33
Towner Road	28-Sep	*Typha*		42.33	0.67	0.33	0.33				

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:												
Class:			Crustacea	Crustacea	Crustacea	Crustacea	Crustacea	Crustacea	Insecta	Insecta	Insecta	Insecta
Order:			Amphipoda	Amphipoda	Decapoda	Isopoda	Isopoda	Isopoda	Collembola	Collembola	Collembola	Collembola
Family:			Talitridae	Unknown		Asellidae	Asellidae	Asellidae	Isotomidae	Poduridae	Sminthuridae	Unknown
Genus			*Hyalella*			*Caecidotea*	*Lirceus*	Unknown	*Isotomurus*	*Podura*	*Sminthurides*	
Little Black Creek												
LBC Lower Wetland	18-May	*Typha*	0.20	2.20		20.60		20.80				
Mona View	19-May	*Typha*	1.00			52.33	0.33					
Industrial Park	2-Jun	*Typha*		2.67		90.67	0.33					
LBC Lower Wetland	30-Jun	*Typha*	4.00			19.00						
Mona View	30-Jun	*Typha*	0.33			61.00				0.67		
Industrial Park	1-Jul	*Typha*	1.33	0.67	0.67	66.00						
LBC Lower Wetland	28-Sep	*Typha*	1.67			5.33		6.67				
Mona View	29-Sep	*Typha*	7.00			42.00						
Cress Creek												
Hidden Cove	18-May	*Nuphar*	1.60	0.60		6.20	0.20					
Hidden Cove	18-May	*Typha*		2.00		6.40	0.60		0.20	1.20	0.20	0.20
Towner Road	19-May	*Typha*				76.00						
Hidden Cove	30-Jun	*Nuphar*	5.00			11.33						
Hidden Cove	30-Jun	*Typha*	7.67			19.67						
Towner Road	1-Jul	*Typha*	0.67			63.67						
Hidden Cove	28-Sep	*Typha*	75.00	2.33		19.33						
Hidden Cove	28-Sep	*Nuphar*	7.33	1.67		3.33						
Towner Road	28-Sep	*Typha*	0.33		0.33	11.00			0.67	1.00		

Phylum:									
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Ephemeroptera	Ephemeroptera	Ephemeroptera	Ephemeroptera	Ephemeroptera	Ephemeroptera	Ephemeroptera
Family:			Baetidae	Baetidae	Baetidae	Baetiscidae	Caenidae	Leptophlebiidae	Unknown
Genus			*Baetis*	*Callibaetis*	Unknown	*Baetisca*	*Caenis*	*Paraleptophlebia*	
Little Black Creek									
LBC Lower Wetland	18-May	*Typha*							
Mona View	19-May	*Typha*							
Industrial Park	2-Jun	*Typha*	0.33					22.00	0.33
LBC Lower Wetland	30-Jun	*Typha*							
Mona View	30-Jun	*Typha*							
Industrial Park	1-Jul	*Typha*	0.67						
LBC Lower Wetland	28-Sep	*Typha*		0.33					
Mona View	29-Sep	*Typha*							
Cress Creek									
Hidden Cove	18-May	*Nuphar*				0.20	0.80		
Hidden Cove	18-May	*Typha*							
Towner Road	19-May	*Typha*							
Hidden Cove	30-Jun	*Nuphar*					0.33		
Hidden Cove	30-Jun	*Typha*		0.67					
Towner Road	1-Jul	*Typha*		0.33					
Hidden Cove	28-Sep	*Typha*		0.67	1.00		0.33		
Hidden Cove	28-Sep	*Nuphar*		2.33	4.67		4.33		
Towner Road	28-Sep	*Typha*		0.33	2.33				

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:											
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Hemiptera	Hemiptera	Hemiptera	Hemiptera	Hemiptera	Hemiptera	Hemiptera	Hemiptera	Hemiptera
Family:			Belostomatidae	Corixidae	Corixidae	Corixidae	Corixidae	Gerridae	Gerridae	Hebridae	Mesoveliidae
Genus			*Belostoma*	*Sigara*	*Hesperocorixa*	*Trichocorixa*	Unknown	*Trepobates*	Unknown	*Hebrus*	*Mesovelia*
Little Black Creek											
LBC Lower Wet	18-May	*Typha*		0.20			0.40	0.80			
Mona View	19-May	*Typha*									
Industrial Park	2-Jun	*Typha*									
LBC Lower Wet	30-Jun	*Typha*	0.67	0.67							
Mona View	30-Jun	*Typha*				0.67		1.33			
Industrial Park	1-Jul	*Typha*					0.33				
LBC Lower Wet	28-Sep	*Typha*									0.33
Mona View	29-Sep	*Typha*									
Cress Creek											
Hidden Cove	18-May	*Nuphar*		0.40							
Hidden Cove	18-May	*Typha*					0.20			0.40	1.00
Towner Road	19-May	*Typha*									
Hidden Cove	30-Jun	*Nuphar*					1.67				1.00
Hidden Cove	30-Jun	*Typha*					0.33				
Towner Road	1-Jul	*Typha*		1.67				0.33	0.33		
Hidden Cove	28-Sep	*Typha*									1.00
Hidden Cove	28-Sep	*Nuphar*				0.33	5.00				
Towner Road	28-Sep	*Typha*	0.33		0.33				0.67		0.33

Phylum:											
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Hemiptera	Hemiptera	Hemiptera	Hemiptera	Homoptera	Lepidoptera	Odonata	Odonata	Odonata
Family:			Notonectidae	Pleidae	Veliidae	Unknown		Nepticulidae	Aeshnidae	Aeshnidae	Coenagrionidae
Genus			*Notonecta*	*Neoplea*	*Microvelia*				*Aeshna*	*Anax*	*Ischnura*
Little Black Creek											
LBC Lower Wetland	18-May	*Typha*		0.60							
Mona View	19-May	*Typha*									
Industrial Park	2-Jun	*Typha*									
LBC Lower Wetland	30-Jun	*Typha*	1.33	5.67						4.33	
Mona View	30-Jun	*Typha*							1.00		
Industrial Park	1-Jul	*Typha*					0.33	0.33			
LBC Lower Wetland	28-Sep	*Typha*	1.67	7.00			2.00				3.33
Mona View	29-Sep	*Typha*	0.67								1.33
Cress Creek											
Hidden Cove	18-May	*Nuphar*		2.20							0.80
Hidden Cove	18-May	*Typha*									
Towner Road	19-May	*Typha*		0.67							3.67
Hidden Cove	30-Jun	*Nuphar*		2.67							
Hidden Cove	30-Jun	*Typha*		1.67							
Towner Road	1-Jul	*Typha*		24.67	0.33				1.33		2.67
Hidden Cove	28-Sep	*Typha*		1.00	1.00		0.33			0.33	14.33
Hidden Cove	28-Sep	*Nuphar*					0.33				31.00
Towner Road	28-Sep	*Typha*	1.33	1.00	0.67	2.33	7.00		0.33		15.33

Table C.2 (continued). Benthic Macroinvertebrates (#/m^2) in Little Black Creek and Cress Creek Wetland Locations (2004).

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Odonata	Odonata	Odonata	Odonata	Odonata	Trichoptera	Trichoptera	Trichoptera
Family:			Coenagrionidae	Libellulidae	Libellulidae	Libellulidae	Libellulidae	Lepidostomatidae	Leptoceridae	Limnephilidae
Genus			Unknown	*Libellula*	*Plathemis*	*Sympetrum*	Unknown	*Lepidostoma*	*Oecetis*	*Frenesia*
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*			0.20	0.20				
Mona View	19-May	*Typha*					0.33			
Industrial Park	2-Jun	*Typha*								
LBC Lower Wetland	30-Jun	*Typha*								
Mona View	30-Jun	*Typha*				0.33				
Industrial Park	1-Jul	*Typha*				1.67	0.67			
LBC Lower Wetland	28-Sep	*Typha*								
Mona View	29-Sep	*Typha*	0.67							
Cress Creek										
Hidden Cove	18-May	*Nuphar*							0.40	
Hidden Cove	18-May	*Typha*								
Towner Road	19-May	*Typha*		0.33	0.33	0.67				1.33
Hidden Cove	30-Jun	*Nuphar*								
Hidden Cove	30-Jun	*Typha*								
Towner Road	1-Jul	*Typha*			0.33			0.67		
Hidden Cove	28-Sep	*Typha*	2.00							
Hidden Cove	28-Sep	*Nuphar*	7.67							
Towner Road	28-Sep	*Typha*	13.33				0.33			

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Trichoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera
Family:			Polycentropodidae	Curculionidae	Dytiscidae	Dytiscidae	Dytiscidae	Dytiscidae	Dytiscidae	Dytiscidae
Genus			*Polycentropus*		*Agabus*	*Desmopachria*	*Graphoderus*	*Hydroporus*	*Hygrotus*	*Laccophilus*
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*		0.20					0.20	
Mona View	19-May	*Typha*		0.33	2.33					
Industrial Park	2-Jun	*Typha*	0.33		0.67					
LBC Lower Wetland	30-Jun	*Typha*				0.33		1.33	2.33	1.00
Mona View	30-Jun	*Typha*		0.33	0.67					
Industrial Park	1-Jul	*Typha*			2.33					
LBC Lower Wetland	28-Sep	*Typha*						0.33	1.00	0.67
Mona View	29-Sep	*Typha*							0.67	
Cress Creek										
Hidden Cove	18-May	*Nuphar*								
Hidden Cove	18-May	*Typha*		0.80					1.00	
Towner Road	19-May	*Typha*			1.00				0.33	
Hidden Cove	30-Jun	*Nuphar*								
Hidden Cove	30-Jun	*Typha*			0.33					1.00
Towner Road	1-Jul	*Typha*			0.33			0.67	0.33	0.33
Hidden Cove	28-Sep	*Typha*							1.00	
Hidden Cove	28-Sep	*Nuphar*								
Towner Road	28-Sep	*Typha*					0.33	1.33		0.67

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera
Family:			Dytiscidae	Dytiscidae	Haliplidae	Haliplidae	Hydrophilidae	Hydrophilidae	Hydrophilidae	Hydrophilidae
Genus			*Potamonectes*	Unknown	*Haliplus*	*Peltodytes*	*Anacaena*	*Berosus*	*Enochrus*	*Hydrochus*
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*		0.20		0.40	0.20			
Mona View	19-May	*Typha*		0.67	0.67	0.33	0.67			
Industrial Park	2-Jun	*Typha*								
LBC Lower Wetland	30-Jun	*Typha*				0.33				
Mona View	30-Jun	*Typha*			0.33					
Industrial Park	1-Jul	*Typha*			0.67					
LBC Lower Wetland	28-Sep	*Typha*	0.33	0.33	0.67	0.33				
Mona View	29-Sep	*Typha*							1.00	
Cress Creek										
Hidden Cove	18-May	*Nuphar*								
Hidden Cove	18-May	*Typha*		0.20			3.80	0.20		0.20
Towner Road	19-May	*Typha*								
Hidden Cove	30-Jun	*Nuphar*				0.33				
Hidden Cove	30-Jun	*Typha*								
Towner Road	1-Jul	*Typha*			4.00					
Hidden Cove	28-Sep	*Typha*				0.33				
Hidden Cove	28-Sep	*Nuphar*								
Towner Road	28-Sep	*Typha*		0.33	1.67				0.33	

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera
Family:			Hydrophilidae	Hydrophilidae	Hydrophilidae	Gyrinidae	Lampyridae	Noteridae	Noteridae	Salpingidae
Genus			*Hydrobius*	*Tropisternus*	Unknown	*Gyrinus*		*Hydrocanthus*	*Suphisellus*	
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*		0.60					0.60	
Mona View	19-May	*Typha*		0.33						
Industrial Park	2-Jun	*Typha*					0.33			
LBC Lower Wetland	30-Jun	*Typha*		1.33				0.67	1.67	
Mona View	30-Jun	*Typha*		2.33			0.33			0.33
Industrial Park	1-Jul	*Typha*					0.67			
LBC Lower Wetland	28-Sep	*Typha*		1.00						
Mona View	29-Sep	*Typha*		1.67						
Cress Creek										
Hidden Cove	18-May	*Nuphar*								
Hidden Cove	18-May	*Typha*		0.40	0.20		0.40			
Towner Road	19-May	*Typha*								
Hidden Cove	30-Jun	*Nuphar*	0.67	1.67						
Hidden Cove	30-Jun	*Typha*		0.33						
Towner Road	1-Jul	*Typha*		1.67						
Hidden Cove	28-Sep	*Typha*								
Hidden Cove	28-Sep	*Nuphar*								
Towner Road	28-Sep	*Typha*		2.00		0.33				

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Coleoptera	Diptera	Diptera
Family:			Scirtidae	Scirtidae	Scirtidae	Staphylinidae	Tenebrionidae	unknown	Ceratopogonidae	Ceratopogonidae
Genus			*Cyphon*	*Prionocyphon*	*Scirtes*	*Stenus*			*Alluaudomyia*	*Bezzia*
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*								2.40
Mona View	19-May	*Typha*						0.33	0.33	1.33
Industrial Park	2-Jun	*Typha*								
LBC Lower Wetland	30-Jun	*Typha*			0.33					1.00
Mona View	30-Jun	*Typha*				0.33				0.33
Industrial Park	1-Jul	*Typha*				0.33				0.33
LBC Lower Wetland	28-Sep	*Typha*								
Mona View	29-Sep	*Typha*								0.33
Cress Creek										
Hidden Cove	18-May	*Nuphar*							0.20	12.80
Hidden Cove	18-May	*Typha*	0.20	2.80	0.20	0.20	0.20	0.20	0.60	0.80
Towner Road	19-May	*Typha*								0.33
Hidden Cove	30-Jun	*Nuphar*								2.33
Hidden Cove	30-Jun	*Typha*								0.33
Towner Road	1-Jul	*Typha*			0.33					
Hidden Cove	28-Sep	*Typha*			0.33					
Hidden Cove	28-Sep	*Nuphar*			0.33					0.33
Towner Road	28-Sep	*Typha*								

Phylum:									
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:			Ceratopogonidae	Ceratopogonidae	Ceratopogonidae	Ceratopogonidae	Chironomidae	Chironomidae	Chironomidae
Genus			*Ceratopogon*	*Culicoides*	*Sphaeromias*	Unknown	Prodiamesinae	Chironomini	Corynoneura
Little Black Creek									
LBC Lower Wetland	18-May	*Typha*			0.60	0.40		2.00	
Mona View	19-May	*Typha*				1.00		0.33	
Industrial Park	2-Jun	*Typha*						1.33	3.33
LBC Lower Wetland	30-Jun	*Typha*						0.67	
Mona View	30-Jun	*Typha*		0.33		0.33		0.67	0.67
Industrial Park	1-Jul	*Typha*					0.33	1.33	7.00
LBC Lower Wetland	28-Sep	*Typha*							
Mona View	29-Sep	*Typha*						0.33	1.33
Cress Creek									
Hidden Cove	18-May	*Nuphar*				0.40		0.40	
Hidden Cove	18-May	*Typha*		0.20		0.80		2.60	
Towner Road	19-May	*Typha*	0.33			1.33	0.33	11.00	0.67
Hidden Cove	30-Jun	*Nuphar*						6.00	
Hidden Cove	30-Jun	*Typha*						4.00	
Towner Road	1-Jul	*Typha*							
Hidden Cove	28-Sep	*Typha*				0.33		3.00	
Hidden Cove	28-Sep	*Nuphar*						18.00	0.33
Towner Road	28-Sep	*Typha*						8.33	

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:											
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:			Chironomidae	Chironomidae	Chironomidae	Chironomidae	Culicidae	Culicidae	Culicidae	Culicidae	Culicidae
Genus			Orthocladiinae	Tanytarsini	Tanypodinae	Unknown	*Anopheles*	*Aedes*	*Culex*	*Culiseta*	Unknown
Little Black Creek											
LBC Lower Wetland	18-May	*Typha*	6.00		2.20	0.40					
Mona View	19-May	*Typha*	5.67	0.33	3.67	0.33					0.33
Industrial Park	2-Jun	*Typha*	5.67		0.33	0.33					
LBC Lower Wetland	30-Jun	*Typha*	0.67								
Mona View	30-Jun	*Typha*	10.33		0.67		0.67				
Industrial Park	1-Jul	*Typha*	21.67	15.00	10.00	0.67					
LBC Lower Wetland	28-Sep	*Typha*	0.33		0.67	0.33					
Mona View	29-Sep	*Typha*	1.00		0.33	0.67	0.33				
Cress Creek											
Hidden Cove	18-May	*Nuphar*	2.80		0.20						
Hidden Cove	18-May	*Typha*	0.80	2.40	1.60	2.20		2.20	1.00	0.60	1.80
Towner Road	19-May	*Typha*	3.00		4.00	3.67					
Hidden Cove	30-Jun	*Nuphar*	16.00	0.33		0.67					
Hidden Cove	30-Jun	*Typha*	70.67	7.00	0.33		1.00	0.33			
Towner Road	1-Jul	*Typha*		0.33		0.33					
Hidden Cove	28-Sep	*Typha*	2.67			1.33	0.33				
Hidden Cove	28-Sep	*Nuphar*	35.00		0.67	2.67					
Towner Road	28-Sep	*Typha*	1.00	0.33	4.33	1.00	6.33				

Phylum:										
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:			Dixidae	Dolichopodidae	Ptychopteridae	Sciomyzidae	Simuliidae	Simuliidae	Stratiomyidae	Stratiomyidae
Genus			*Dixella*		*Ptychoptera*		*Prosimulium*	*Simulium*	*Caloparyphus*	*Odontomyia*
Little Black Creek										
LBC Lower Wetland	18-May	*Typha*				0.20				
Mona View	19-May	*Typha*								0.33
Industrial Park	2-Jun	*Typha*								
LBC Lower Wetland	30-Jun	*Typha*								
Mona View	30-Jun	*Typha*								
Industrial Park	1-Jul	*Typha*		0.33		0.33	0.33	1.00		
LBC Lower Wetland	28-Sep	*Typha*								
Mona View	29-Sep	*Typha*	0.33							
Cress Creek										
Hidden Cove	18-May	*Nuphar*								
Hidden Cove	18-May	*Typha*								1.00
Towner Road	19-May	*Typha*			7.67				0.33	
Hidden Cove	30-Jun	*Nuphar*				0.33				
Hidden Cove	30-Jun	*Typha*	0.33							
Towner Road	1-Jul	*Typha*			0.33					
Hidden Cove	28-Sep	*Typha*								
Hidden Cove	28-Sep	*Nuphar*								
Towner Road	28-Sep	*Typha*	24.33							

TABLE C.2 (CONTINUED). BENTHIC MACROINVERTEBRATES (#/M^2) IN LITTLE BLACK CREEK AND CRESS CREEK WETLAND LOCATIONS (2004).

Phylum:											
Class:			Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta	Insecta
Order:			Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera	Diptera
Family:			Stratiomyidae	Stratiomyidae	Syrphidae	Tabanidae	Tabanidae	Tabanidae	Tipulidae	Tipulidae	Unknown
Genus			*Stratiomys*	Unknown		*Chrysops*	*Tabanus*	Unknown	*Tipula*	Unknown	
Little Black Creek											
LBC Lower Wetland	18-May	*Typha*									
Mona View	19-May	*Typha*									
Industrial Park	2-Jun	*Typha*					0.33				0.33
LBC Lower Wetland	30-Jun	*Typha*									
Mona View	30-Jun	*Typha*									
Industrial Park	1-Jul	*Typha*									
LBC Lower Wetland	28-Sep	*Typha*									
Mona View	29-Sep	*Typha*									
Cress Creek											
Hidden Cove	18-May	*Nuphar*	0.20		0.20					0.20	
Hidden Cove	18-May	*Typha*	0.20			0.20	0.20	0.20	0.40	1.00	0.20
Towner Road	19-May	*Typha*		0.33		0.33				0.33	0.33
Hidden Cove	30-Jun	*Nuphar*									
Hidden Cove	30-Jun	*Typha*									
Towner Road	1-Jul	*Typha*									
Hidden Cove	28-Sep	*Typha*									
Hidden Cove	28-Sep	*Nuphar*									
Towner Road	28-Sep	*Typha*									

Appendix D
Hydrologic Model

D.1. Computation of Rating Curves

Computation of Rating Curves

The general relationship between the stream discharge *Q* and the stage *D* can be mathematically expressed as:

$$Q = \alpha\left(D - d_0\right)^{\beta} \qquad (1\text{-}1)$$

i.e.,

$$Ln(Q) = Ln(\alpha) + \beta Ln\left(D - d_0\right) \qquad (1\text{-}2)$$

or

$$y = y_0 + \beta Ln\left(D - d_0\right) \qquad (1\text{-}3)$$

where α and β = parameters; d_0 = depth adjustment constant (zero-flow depth) or "scale offset" (Kennedy, 1984); $y = Ln(Q)$; and $y_0 = Ln(\alpha)$.

Nonlinear regression method was used in the analysis and a 3-parameter logarithm equation [y_0, β and d_0 in Eq. (1-3)) was fitted to each set of the measured data [*D*-*Ln*(*Q*)]. Then, the final equation for rating curve can be expressed in the form of Eq. (1-1).

Extension of Rating Curves

The low-stage measurements obtained in the field were used for developing the rating curves for the low-stage condition. The fitted curves were then extended backward. Similarly, a separate rating curve was developed for the high-stage condition for each site. The high-stage measurements were used for this purpose. The high-stage stream discharge was computed by using two methods in this study. Depending upon their performance, the better result was selected.

Method 1: In this method based on the Manning's equation, stream discharge was calculated by using the conveyance factor and slope-roughness factor, both of which were calculated and fitted by using the measured data. In particular, the channel survey data were taken into account in the computation of conveyance factor.

According to the Manning's equation (for the metric unit system),

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \qquad (1\text{-}4)$$

letting

$$f_K = AR^{2/3} \tag{1-5}$$

$$f_{sr} = \frac{1}{n}S^{1/2} = \frac{Q}{f_K} \tag{1-6}$$

we have

$$Q = f_K f_{sr} = f_K\left(Q/f_K\right) \tag{1-7}$$

where Q = stream discharge; n = Manning roughness coefficient; A = cross-sectional area; R = hydraulic radius; S = slope; f_K = conveyance factor; and f_{sr} = slope-roughness factor.

Method 2: In this method, stream discharge Q was calculated by using the area A and the flow velocity V, both of which were fitted by using the measured data. In particular, the highest depth from the channel survey was used when fitting the Da-A curves (adjusted depth: $D_a = D - d_0$). That is,

$$A = a\left(D - d_0\right)^b \tag{1-8}$$

$$V = e\left(D - d_0\right)^f \tag{1-9}$$

$$Q = AV = ae\left(D - d_0\right)^{(b+f)} \tag{1-10}$$

where a, b, e, f are the fitted parameters. For most sites, the second method generally yielded better results.

Summary of the Developed Rating Curves

To better reflect the relationship between the stage and discharge for different hydraulic conditions and achieve the best fitting curves, three separate rating curves were developed for each site, which correspond to low-stage, mid-stage, and high-stage conditions, respectively. The rating curve equations are summarized below by Site. Graphical representations of the curves for Sites 1-5 are presented in Figures D.1-DD.5, respectively.

Site 1:

Low Stage: $Q = 2.7734\left(D - 0.0596\right)^{1.6546}$ (D < 0.127m) (1-11)

Mid Stage: $Q = 3.4073\left(D - 0.0596\right)^{1.7364}$ (0.127m ≤ D ≤ 0.330m) (1-12)

High Stage: $Q = 2.2838\left(D - 0.0596\right)^{1.4625}$ (D > 0.330m) (1-13)

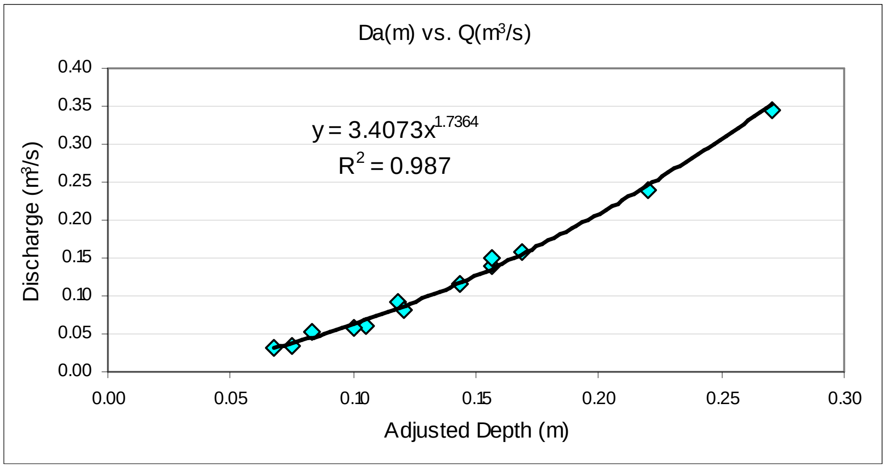

FIGURE D. 1. MID-STAGE RATING CURVE FOR SITE 1.

Site 2:

Low Stage: $Q = 2.185(D - 0.0572)^{1.5082}$ (D < 0.118m) (1-14)

Mid Stage: $Q = 2.2795(D - 0.0572)^{1.5280}$ (0.118m ≤ D ≤ 0.480m) (1-15)

High Stage: $Q = 3.873(D - 0.0572)^{2.0284}$ (D > 0.480m) (1-16)

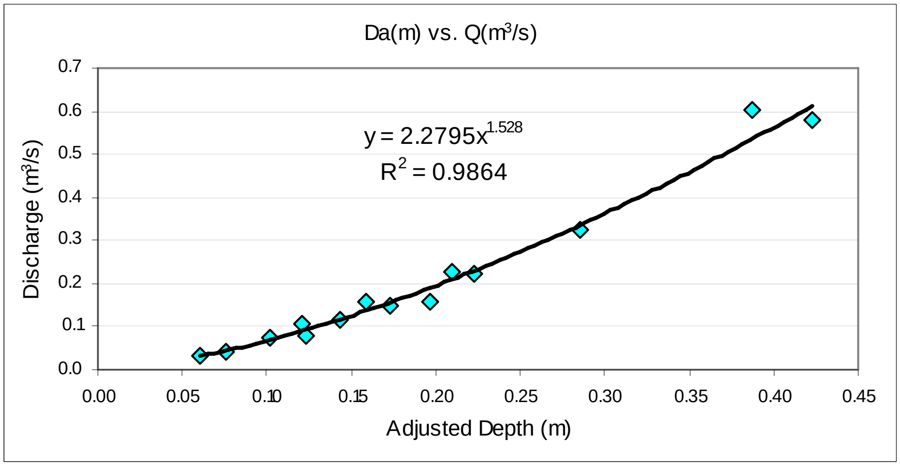

FIGURE D. 2. MID-STAGE RATING CURVE FOR SITE 2.

Site 3:

Low Stage: $Q = 1.93(D + 0.0762)^{2.3266}$ (D < 0.267m) (1-17)

Mid Stage: $Q = 1.93(D + 0.0762)^{2.3266}$ (0.267m ≤ D ≤ 0.521m) (1-18)

High Stage: $Q = 2.0417(D + 0.0762)^{2.2789}$ (D > 0.521m) (1-19)

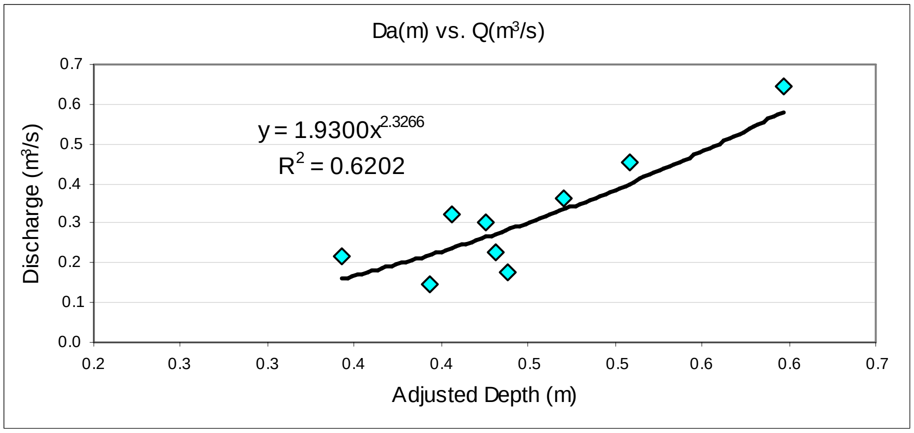

FIGURE D. 3. MID-STAGE RATING CURVE FOR SITE 3.

Site 4:

Low Stage:	$Q = 16.598(D - 0.0762)^{4.3819}$	$(D < 0.405\text{m})$	(1-20)
Mid Stage:	$Q = 4.8096(D - 0.0762)^{3.1879}$	$(0.405\text{m} \le D \le 0.683\text{m})$	(1-21)
High Stage:	$Q = 2.844(D - 0.0762)^{2.2659}$	$(D > 0.683\text{m})$	(1-22)

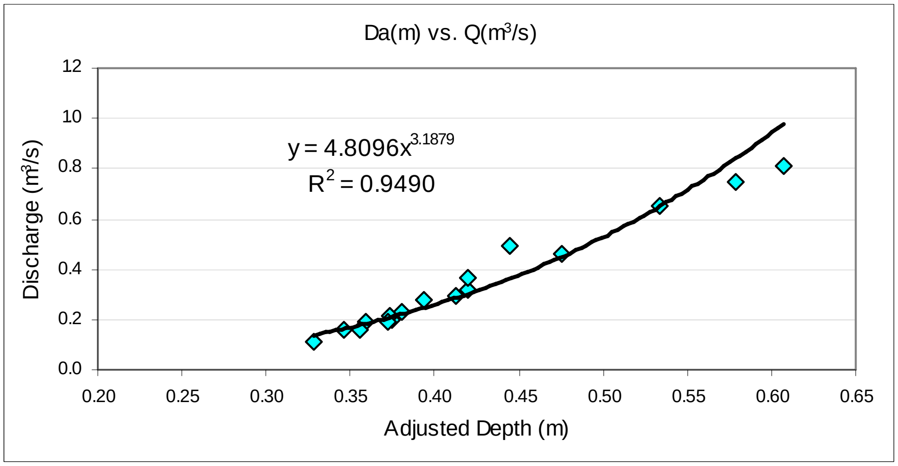

FIGURE D. 4. MID-STAGE RATING CURVE FOR SITE 4.

Site 5:

Low Stage:	$Q = 3.321(D - 0.0762)^{1.8267}$	$(D < 0.242\text{m})$	(1-23)
Mid Stage:	$Q = 3.5384(D - 0.0762)^{1.8663}$	$(0.242\text{m} \le D \le 0.626\text{m})$	(1-24)
High Stage:	$Q = 3.5798(D - 0.0762)^{1.8624}$	$(D > 0.626\text{m})$	(1-25)

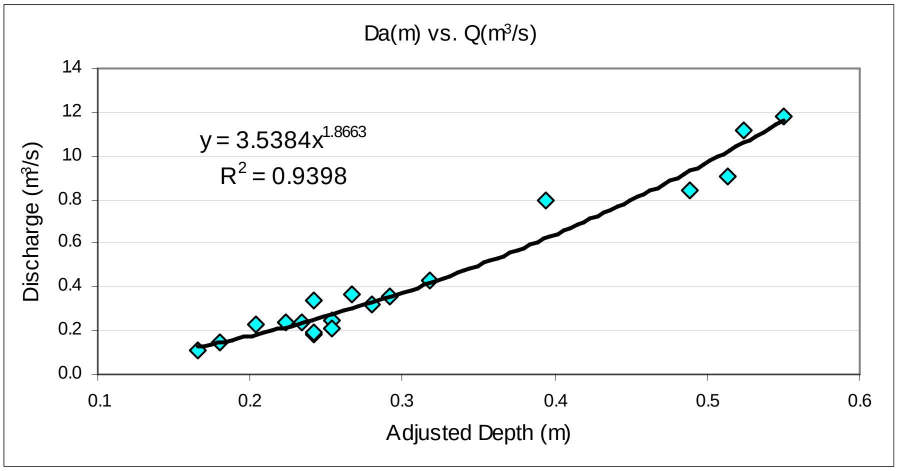

FIGURE D. 5. MID-STAGE RATING CURVE FOR SITE 5.

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D.2. Watershed Delineation

D.2. Hydrologic Modeling

Based on the watershed delineation described in the preceding section, a hydrologic model was developed for the Little Black Creek watershed by using the HEC-HMS software (USACE, 2006). Continuous hydrologic modeling was carried out. The simulations provided valuable information on the quantity and variability of runoff from all subbasins, as well as sources of the contributing water (direct runoff and baseflow).

The simulation period ranged from May 6, 2004, 9:00 to November 1, 2004, 0:00 and an hourly time step was used. The Clark transform method, recession baseflow method (linear reservoir method for Basin 6), and Muskingum reach routing method (lag method for reach 5) were selected in the model. The relevant parameters are summarized in Tables D.1 – D.3. The lumped soil moisture accounting (SMA) loss method was used for continuously simulating rainfall excess in the model. Initial estimates of the parameters involved in the SMA method were given primarily based on actual conditions and suggestions by the model developer. All parameters were then calibrated by using the real-world data. The calibrated parameters are shown in Table D.4.

TABLE D. 1. PARAMETERS FOR THE CLARK TRANSFORM METHOD AND THE RECESSION BASEFLOW METHOD.

Subbasin	Clark Transform		Recession Baseflow		
	TC (hr)	SC (hr)	QB_0 (m^3/s)	RC	RP
Basin6	1.50	2.30			
Basin7	0.38	0.92	0.0850	0.98	0.10
Basin8	0.50	1.50	0.0821	0.98	0.05
Basin9	0.67	0.70	0.0453	0.97	0.04
Basin10	0.35	0.10	0.0085	0.95	0.02

TABLE D. 2. PARAMETERS FOR THE LINEAR RESERVOIR BASEFLOW FOR BASIN 6.

GW1 QB_0 (m^3/s)	GW1 Coefficient (hr)	GW1 Routing Steps	GW2 QB_0 (m^3/s)	GW2 Coefficient (hr)	GW2 Routing Steps
0.0566	5	2	0.0142	12	2

TABLE D. 3. PARAMETERS FOR REACH ROUTING.

Reach	T_L (min)	D (min)		Method
Reach5	240			Lag Method
Reach	K(hr)	X	No-R	Method
Reach6	2	0.05	4	Muskingum Method
Reach7	3	0.005	4	Muskingum Method
Reach8	0.4	0.1	1	Muskingum Method

TABLE D. 4. MAJOR PARAMETERS FOR THE SMA LOSS METHOD.

Subbasin	Canopy Storage (cm)	Surface Storage (cm)	Maximum Infiltration (cm/hr)	Impervious (%)	Soil Percolation (cm/hr)
Basin6	0.3	2.4	15.0	1.0	5.1
Basin7	0.3	1.9	15.0	4.0	3.8
Basin8	0.1	0.6	15.0	11.0	3.8
Basin9	0.1	0.5	15.0	24.0	3.8
Basin10	0.1	0.3	15.0	30.0	3.8

The simulation results are summarized in Tables D.5 – D.9. The simulated peaks (both quantity and occurring time) for the subbasins, outlets, and reaches during the entire simulation period are shown in Table D.5. The peak flow at the final outlet of the watershed (Outlet 10) was 2.6663 m^3/s at 12:00 on May 21, 2004. The modeling suggested that the overall percentage of rainfall excess for the entire watershed was only 14.28% and the remaining portion of rainfall (85.72%) was subject to various losses (Table D.6). During the entire simulation period, 3,818,574 m^3 of water was generated from the five subbasins, of which 82.45% came from baseflow and 17.55% from direct runoff (Tables D.7 and D.8). Thus, baseflow was the primary source of runoff. The temporal distribution of contribution percentages of direct runoff and baseflow are shown in Fig. D.1. The average flow and the cumulative volume of water discharge at Outlet 10 were 0.2475 m^3/s and 3,820,173 m^3, respectively (Table D.9).

TABLE D. 5. GLOBAL SUMMARY

Hydrologic Element	Peak Discharge (m^3/s)	Peak Time	Volume (cm)
Basin6	0.5403	21May2004, 21:00	17.3
Basin7	1.2612	21May2004, 12:00	14.3
Basin8	1.9805	21May2004, 12:00	22.3
Basin9	2.0181	21May2004, 12:00	41.8
Basin10	0.2925	21May2004, 12:00	30.0
Outlet6	0.5403	21May2004, 21:00	17.3
Outlet7	1.4427	21May2004, 12:00	16.0
Outlet8	2.5046	21May2004, 12:00	17.5
Outlet9	2.5474	21May2004, 12:00	19.4
Outlet10	2.6663	21May2004, 12:00	19.5
Reach5	0.5403	22May2004, 01:00	17.3
Reach6	1.0548	21May2004, 14:00	16.0
Reach7	1.7780	21May2004, 16:00	17.5
Reach8	2.3735	21May2004, 12:00	19.4

TABLE D. 6. WATER LOSS AND EXCESS FOR ALL SUBBASINS.

Subbasin	Loss(cm)	Excess(cm)	Precipitation(cm)	Loss(%)	Excess(%)	Precipitation(%)
Basin6	53.5	0.5	53.9	99.13	0.87	100.00
Basin7	51.8	2.1	53.9	96.07	3.93	100.00
Basin8	51.0	6.3	57.3	89.08	10.92	100.00
Basin9	43.6	13.7	57.3	76.04	23.96	100.00
Basin10	39.9	17.4	57.3	69.64	30.36	100.00
Average	48.0	8.0	55.9	85.72	14.28	100.00

TABLE D. 7. DIRECT FLOW AND BASEFLOW FOR ALL SUBBASINS.

Subbasin	Direct Flow(m^3/s)	Baseflow(m^3/s)	Total Flow(m^3/s)
Basin6	0.0027	0.0849	0.0876
Basin7	0.0083	0.0464	0.0547
Basin8	0.0174	0.0442	0.0616
Basin9	0.0134	0.0273	0.0407
Basin10	0.0016	0.0012	0.0028
Sum	0.0434	0.2040	0.2474

TABLE D. 8. CUMULATIVE VOLUME AND PERCENTAGE OF DIRECT FLOW AND BASEFLOW FOR ALL SUBBASINS.

Subbasin	Direct Flow (m^3)	Baseflow (m^3)	Total Flow (m^3)	Direct Flow (%)	Baseflow (%)	Total Flow (%)
Basin6	42185	1310497	1352679	3.12	96.88	100.00
Basin7	127603	716522	844124	15.12	84.88	100.00
Basin8	267942	681987	949930	28.21	71.79	100.00
Basin9	207028	421306	628335	32.95	67.05	100.00
Basin10	25219	18285	43507	57.97	42.03	100.00
Sum	669,978	3,148,597	3,818,574	17.55	82.45	100.00

TABLE D. 9. AVERAGE FLOW AND CUMULATIVE DISCHARGE VOLUME AT ALL OUTLETS.

Outlet	Average Flow (m^3/s)	Discharge Volume (m^3)	Monitoring Site
Outlet6	0.0876	1,352,679	Site1-BC
Outlet7	0.1423	2,196,744	Site2
Outlet8	0.2039	3,147,087	Site3
Outlet9	0.2447	3,776,487	Site4
Outlet10	0.2475	3,820,173	Site5 (LBC Outlet)

The hydrologic model was calibrated by using the observed flow data at the five monitoring sites (Sites 1-5). Comparisons between the simulated stream hydrographs and the observed ones for the five sites are shown in Fig D.2. Furthermore, performance of the model was evaluated by using two quantitative methods: normalized objective function (*NOF*) and modeling efficiency (*EF*) (ASCE, 1996). The values of *NOF* and *EF* are respectively given by:

$$NOF = \frac{1}{\overline{Q}_{obs}} \sqrt{\frac{1}{n} \sum_{i=1}^{n} \left(Q_{obs,i} - Q_{sim,i} \right)^2} \qquad (2\text{-}1)$$

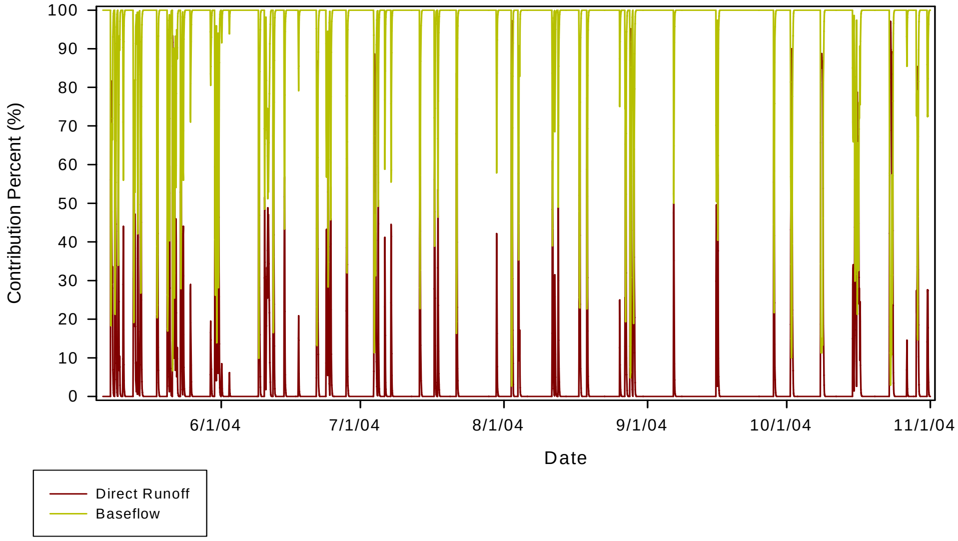

FIGURE D. 6. CONTRIBUTION PERCENTAGES OF DIRECT RUNOFF AND BASEFLOW.

$$EF = 1 - \frac{\sum_{i=1}^{n} \left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n} \left(Q_{obs,i} - \overline{Q}_{obs}\right)^2} \tag{2-2}$$

where $Q_{obs,i}$ = observed discharge; $Q_{sim,i}$ = simulated discharge; $\overline{Q}_{obs}$ = mean of the observed discharge; and n = number of the observed or simulated data set. Note that if all observed discharges are the same as the simulated ones, the *NOF* and *EF* values will be 0 and 1, respectively. Results from the two evaluation methods are shown in Table 4-10. Good results have been achieved. The average *NOF* value for all five monitoring sites is 0.392 and the average *EF* value is 0.786. These evaluation parameters suggest good agreement between the simulated and observed discharges. Basically, the simulated hydrographs for the five sites reflect the dominant trends and variations in the observed stream flows.

TABLE D. 10. NOF AND EF FOR THE MONITORING SITES.

Outlet	NOF	EF
Outlet6 (Site1-BC)	0.285	0.884
Outlet7 (Site2)	0.435	0.837
Outlet8 (Site3)	0.363	0.758
Outlet9 (Site4)	0.430	0.832
Outlet10 (Site5)	0.448	0.618
Average	0.392	0.786

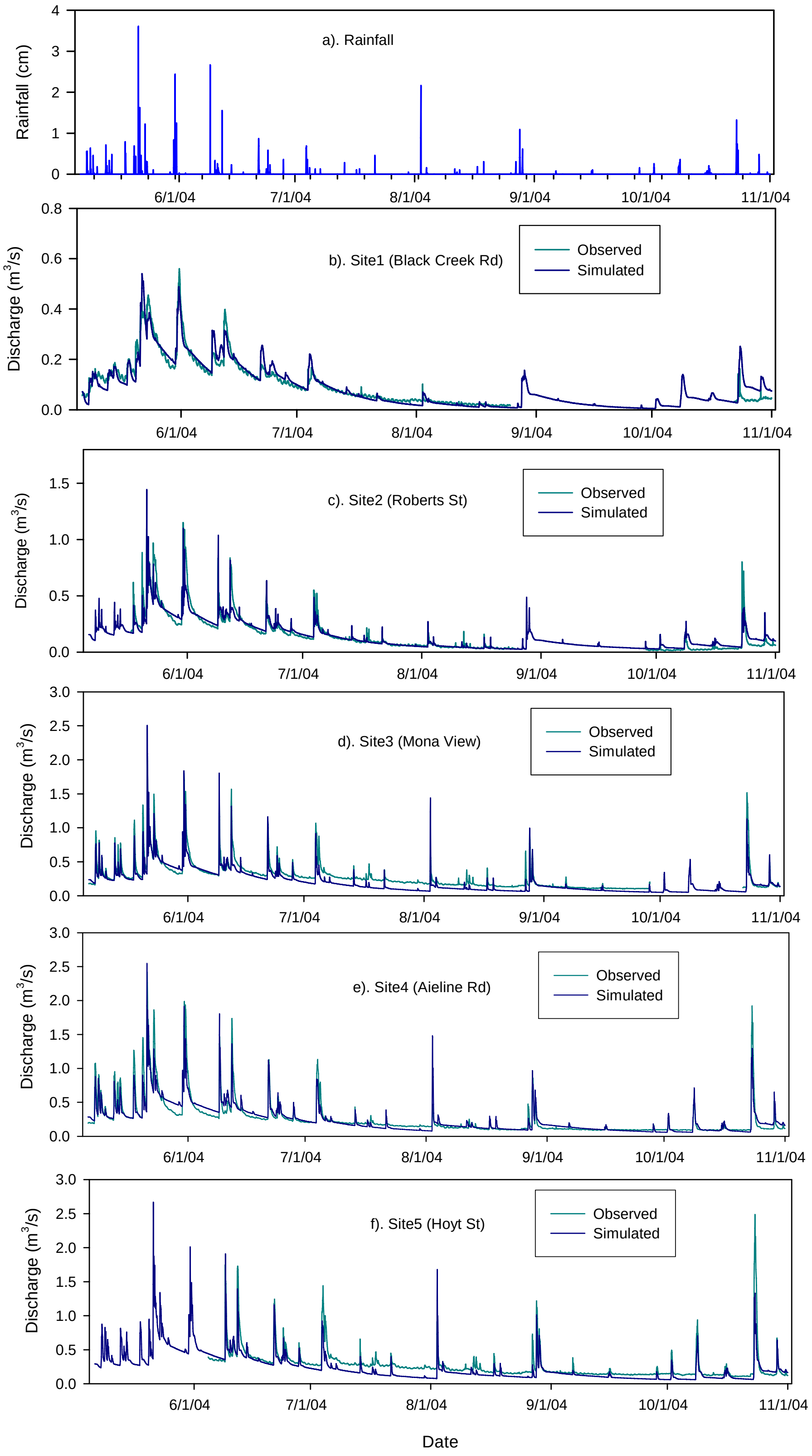

FIGURE D. 7. COMPARISON BETWEEN THE SIMULATED AND OBSERVED HYDROGRAPHS (HOURLY FLOW).

D.3 Watershed Erosion Modeling

The modified universal soil loss equation (MUSLE) (Williams, 1975; 1995) was used to estimate the eroded sediment yields from the five subbasins in the Little Black Creek watershed during a storm event from 8/2/2004 0:00 to 8/4/2004 0:00 that was selected for metal and sediment transport modeling, described in Section 6. The MUSLE equation can be expressed as

$$Y_e = 11.8(Q\, q_P)^{0.56}\, K\, LS\, C\, P \tag{3-1}$$

where Y_e = eroded sediment yield (metric ton); Q = runoff volume (m^3); q_p = peak runoff rate (m^3/s); K = soil erodibility factor; LS = length-slope factor; C = soil cover factor; and P = conservation practice factor. The runoff volume Q and the peak runoff rate q_p of each subbasin for the selected rainfall event were provided by the watershed hydrologic modeling. The erosion factors were determined as follows:

(1) Soil Erodibility Factor *K*

As shown in Fig 1-3, Rubicon (RsB), Sangatuck (AsB), and Au Gres (CrB or Ra) sands are major soil types in the Little Black Creek watershed. In the erosion computation, a soil erodibility factor of 0.15 was selected for all subbasins.

(2) Length-Slope Factor *LS*

Given the length and slope of the overland surface resulted from the watershed delineation, the length-slope erosion factor was estimated by using the following equation (Williams, 1995):

$$LS = \left(\frac{L_l}{22.1}\right)^{\omega} \left(65.41 S_l^{\,2} + 4.56 S_l + 0.065\right) \tag{3-2}$$

in which

$$\omega = \frac{0.3 S_l}{S_l + \exp(-1.47 - 61.09 S_l)} + 0.2 \tag{3-3}$$

where L_l = length of the surface land slope (m) and S_l = slope of the land surface (m/m). The computation results are shown in Table D.11.

TABLE D. 11. COMPUTATION OF THE LENGTH-SLOPE EROSION FACTOR.

Basin	L_l (m)	S_l (m/m)	ω	LS
Basin6	1171.96	0.0033	0.2052	0.18
Basin7	671.78	0.0084	0.2173	0.23
Basin8	614.17	0.0094	0.2203	0.24
Basin9	789.43	0.0170	0.2518	0.40
Basin10	144.17	0.0140	0.2376	0.22

(3) Soil Cover Factor *C* and Conservation Practice Factor *P*

Residential, commercial, forest, and open field are dominant land use/covers in the Little Black Creek watershed. In the soil erosion modeling, a preliminary soil cover factor was selected for each subbasin based on the real soil cover conditions and a preliminary conservation practice factor was also selected. Final values of these two erosion factors (0.03 and 0.10, respectively) were determined primarily based on calibration of the sediment transport modeling. The total eroded sediment yield from each subbasin during the selected rainfall event was then estimated by using Eq. (3-1). The results are shown in Table D.12.

TABLE D. 12. COMPUTATION OF SOIL EROSION FROM SUBBASINS.

Basin	A(km^2)	Q (m^3)	q_p (m^3/s)	K	LS	C	P	Y_e (metric ton)
Basin6	7.819180	1191.642	0.081383	0.15	0.18	0.03	0.10	0.012385
Basin7	5.912947	2703.398	0.342605	0.15	0.23	0.03	0.10	0.055999
Basin8	4.252764	7345.369	0.380493	0.15	0.24	0.03	0.10	0.108460
Basin9	1.504784	3669.264	0.555576	0.15	0.40	0.03	0.10	0.151487
Basin10	0.145039	1996.728	0.312873	0.15	0.22	0.03	0.10	0.042964

In the metal and sediment transport model detailed in the following section, a temporal distribution of the eroded sediment loading is needed for each subbasin. It was assumed in this study that the lateral loading of the eroded sediments from a subbasin was proportional to the corresponding surface runoff discharge during the storm event. Thus, the sediment loading at time step *k* for a subbasin can be written as:

$$y_k = Y_e \, r_k \tag{3-4}$$

in which

$$r_k = \frac{q_k}{\sum_{k=1}^{NT} q_k} \tag{3-5}$$

where y_k = sediment loading at time step k induced by direct runoff; r_k = ratio of direct runoff at time step k to the total direct runoff during the storm event; q_k = direct runoff at time step k; and NT = total number of time steps. The simulated sediment yields from Basins 7, 8, and 9-10 during the selected storm event are displayed in Fig. D.8 and the concentrations of sediments eroded from Basin 6 during the storm event, calculated by the simulated sediment yield and direct runoff discharge, are shown in Fig. D.9.

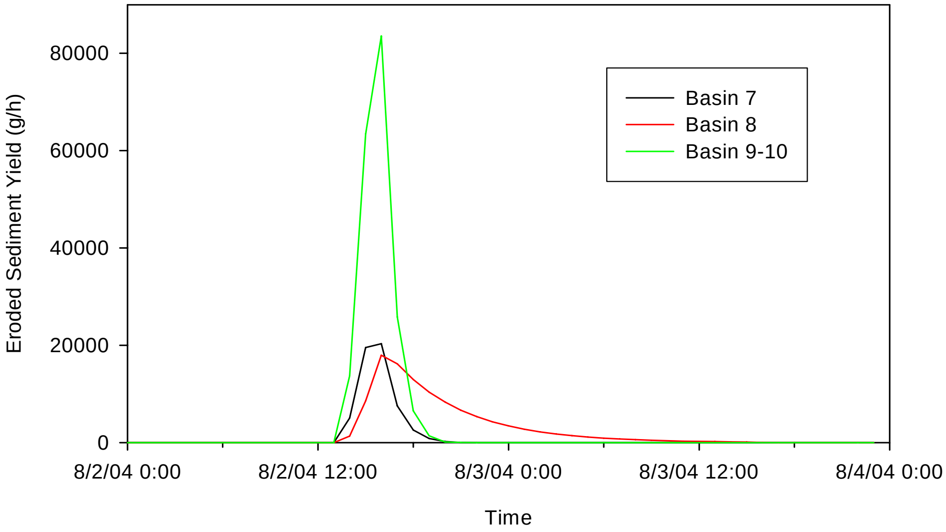

FIGURE D. 8. SIMULATED SEDIMENT YIELD FROM SUBBASINS DURING THE SELECTED STORM EVENT.

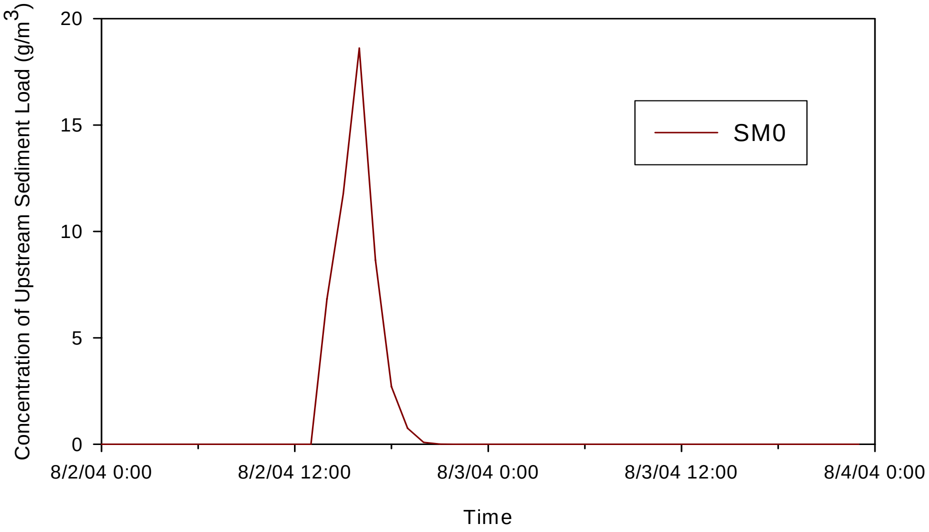

FIGURE D. 9. SIMULATED CONCENTRATION OF SEDIMENTS LOADED FROM BASIN 6 DURING THE SELECTED STORM EVENT.

D.4. Metal and Sediment Transport Modeling in a Stream-Wetland System

D.5.1 METAL TRANSPORT MODELING IN THE STREAM-WETLAND SYSTEM

The stream-wetland system consists of the water column, the underlying active bed, and the adjacent wetlands (Fig. D.10). A physically-based model has been developed to simulate two-phase (dissolved and adsorbed phases) metal transport in the three subsystems and interactions between them. External loads of metal from surface runoff (dissolved phase), erosion (adsorbed phase), and upstream flow (dissolved and adsorbed phases) have also been taken into account. The major processes simulated in the model include advection, dispersion, sorption, settling, resuspension, sedimentation, diffusion of the dissolved-phase metals between the subsystems, and advective flux between the water column and wetlands, as shown in Fig. D.10.

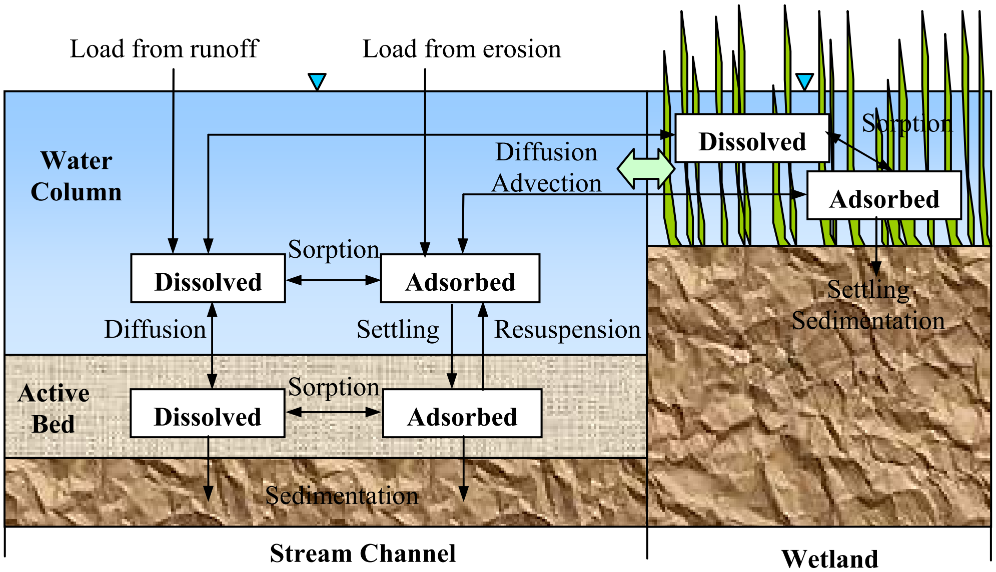

FIGURE D. 10. METAL TRANSPORT PROCESSES IN THE STREAM-WETLAND SYSTEM.

By assuming linear equilibrium sorption, the partition coefficient can be given by

$$K'_{ps} = \frac{C'_s}{C'_l} \tag{4-1}$$

where K'_{ps} = partition coefficient between the dissolved and adsorbed phases; C'_l = concentration of dissolved-phase metal in terms of water volume [$M_p/L^3{}_w$]; C'_s = concentration of adsorbed-phase metal in terms of solid mass [M_p/M_s]; subscript p = index of pollutant (metal); subscript s = index of solids; and subscript w = index of water.

For convenience, the dissolved, adsorbed, and total metal concentrations can be expressed in terms of the bulk volume (w+s) as follows (Thomann and Mueller, 1987):

$$C_l = nC'_l \tag{4-2}$$

$$C_s = SC'_s \tag{4-3}$$

$$C = C_l + C_s \tag{4-4}$$

where C_l = concentration of dissolved metal in terms of the bulk volume [$M_p/L^3{}_{w+s}$]; C_s = concentration of adsorbed metal in terms of the bulk volume [$M_p/L^3{}_{w+s}$]; C = total metal concentration [$M_p/L^3{}_{w+s}$]; S = concentration of sediment [$M_s/L^3{}_{w+s}$]; and n = porosity ($n \approx 1$ for the water column).

Substituting Eqs. (4-1) through (4-3) into Eq. (4-4), we have

$$C = (1 + K_{ps} S) C_l \tag{4-5}$$

in which the porosity-corrected partition coefficient K_{ps} is given by

$$K_{ps} = \frac{K'_{ps}}{n} \tag{4-6}$$

Thus, the dissolved and adsorbed metal concentrations C_l and C_s can also be written in terms of a fraction of the total concentration C

$$C_l = f_l C \tag{4-7}$$

$$C_s = f_s C \tag{4-8}$$

in which

$$f_l = (1 + K_{ps} S)^{-1} \tag{4-9}$$

$$f_s = \frac{K_{ps} S}{1 + K_{ps} S} \tag{4-10}$$

$$f_l + f_s = 1 \tag{4-11}$$

For the active bed

$$S = \rho_s (1 - n_b) \tag{4-12}$$

where f_l = dissolved metal fraction; f_s = adsorbed metal fraction; n_b = porosity of the bed sediments; and ρ_s = density of sediments [M/L^3].

The governing equations for metal transport in the water column, active bed, and wetland can be respectively expressed as:

For the water column

$$\begin{aligned} V_c \frac{\partial C_c}{\partial t} &= L \frac{\partial}{\partial x}\left(A_c E \frac{\partial (f_{l,c} C_c)}{\partial x} \right) - L \frac{\partial}{\partial x}(A_c q C_c) + A_{cb} K_{cb} \left(\frac{f_{l,b}}{n_b} C_b - f_{l,c} C_c \right) \\ &- A_{cb} v_s f_{s,c} C_c + A_{cb} v_r f_{s,b} C_b + A_{cw} K_{cw} (f_{l,w} C_w - f_{l,c} C_c) \\ &- A_{cw} (v_{cw} C_c - v_{wc} C_w) + (I_r + I_e) \end{aligned} \tag{4-13}$$

For the active bad

$$V_b \frac{\partial C_b}{\partial t} = -A_{cb} K_{cb} \left(\frac{f_{l,b}}{n_b} C_b - f_{l,c} C_c \right) + A_{cb} v_s f_{s,c} C_c - A_{cb} v_r f_{s,b} C_b - A_{cb} v_{sd,b} f_{s,b} C_b \quad (4\text{-}14)$$

For the wetland

$$V_w \frac{\partial C_w}{\partial t} = -A_{cw} K_{cw} \left(f_{l,w} C_w - f_{l,c} C_c \right) + A_{cw} \left(v_{cw} C_c - v_{wc} C_w \right) - A_w v_{sd,w} f_{s,w} C_w \quad (4\text{-}15)$$

where C = total metal concentration [M/L^3]; E = longitudinal dispersion coefficient [L^2/T]; q = longitudinal advective velocity [L/T]; V = bulk volume [L^3]; L = length of the stream channel along the flow direction [L]; A_c = cross-sectional area of the water column [L^2]; A_{cb} = area of the interface between the water column and active bed (product of the stream length and width [L^2]; A_{cw} = area of the interface between the water column and the adjacent wetland (product of the stream length and the interaction depth of water [L^2]; A_w = wetland area [L^2]; K_{cb} = diffusive transfer rate between the water column and active bed [L/T]; K_{cw} = diffusive transfer rate between the water column and wetland [L/T]; v_{cw} = advective flux from the water column to wetland [L/T] ($v_{cw} = 0$ if $v_{wc} \neq 0$); v_{wc} = advective flux from the wetland to water column [L/T] ($v_{wc} = 0$ if $v_{cw} \neq 0$); I_r = lateral loading rate of dissolved-phase metal from surface runoff [M/T]; I_e = lateral loading rate of adsorbed-phase metal from soil erosion [M/T]; and subscripts c, b, and w denote the water column, active bed, and wetland, respectively.

The longitudinal dispersion coefficient can be estimated by (Fischer et al., 1979)

$$E = 0.011 \frac{v^2 w^2}{d_w v^*} \quad (4\text{-}16)$$

in which

$$v^* = \sqrt{g d_w S_L} \quad (4\text{-}17)$$

where d_w = mean depth of water [L]; v^* = shear velocity [L/T]; and S_L = channel slope.

The settling velocity can be calculated by using the Stokes' Law:

$$v_s = \frac{g}{18} \left(\frac{\rho_s - \rho_w}{\mu} \right) d^2 \quad (4\text{-}18)$$

where v_s = Stokes settling velocity [L/T]; μ = dynamic viscosity [M/L/T]; g = acceleration of gravity [L/T^2]; ρ_w = density of water [M/L^3]; and d = particle diameter [L].

For $g = 981$ cm/s^2 and $\mu = 0.014$ g/cm/s, the settling velocity was expressed by Thomann and Mueller (1987) as

$$v_s = 0.033634(\rho_s - \rho_w)d^2 \tag{4-19}$$

where v_s is in m/d, ρ_s and ρ_w in g/cm^3, and d in μm.

The sediment-water diffusive transfer rate K_f (in cm/d) can be estimated by using the following empirical formula (Di Toro et al., 1981; Thomann and Mueller, 1987)

$$K_f = 19 n_b M_w^{-2/3} \tag{4-20}$$

where M_w = molecular weight of the compound.

To solve the coupled stream-wetland model [Eqs. (13)-(15)], compartmentalization is applied. The water column, active bed, and wetland are discretized into N compartments as shown in Figs. 6-2 and 6-3. The finite difference expressions for the three compartmentalized subsystems can be derived as follows (Figures D.11 and D.12):

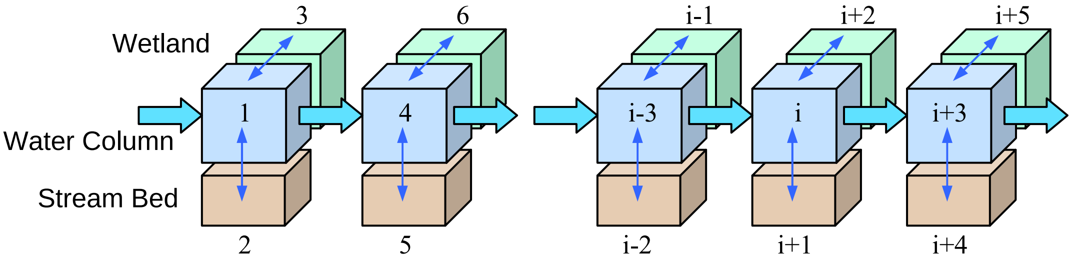

FIGURE D. 11. COMPARTMENTALIZED STREAM-WETLAND SYSTEM.

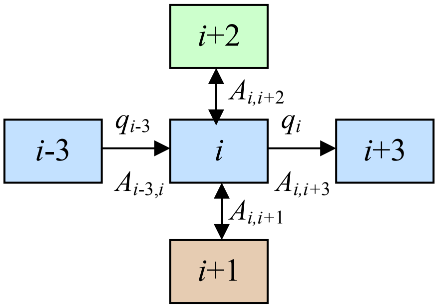

FIGURE D. 12. COMPARTMENTS AND THEIR INTERACTIONS.

For the water column compartments (i = 1, 4, 7, …, N-2)

$$\left.\frac{\partial(A_c q C_c)}{\partial x}\right|_i \approx \frac{A_{i,i+3} q_i C_i - A_{i-3,i} q_{i-3} C_{i-3}}{L_i} \tag{4-21}$$

$$\begin{aligned}
&\left.\frac{\partial}{\partial x}\left[A_c E \frac{\partial\left(f_{l,c} C_c\right)}{\partial x}\right]\right|_i \\
&\approx \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{L_i} \frac{\left(f_{l,i+3} C_{i+3} - f_{l,i} C_i\right)}{L_i + L_{i+3}} - \frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{L_i} \frac{\left(f_{l,i} C_i - f_{l,i-3} C_{i-3}\right)}{L_{i-3} + L_i} \\
&= \frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{L_i\left(L_{i-3} + L_i\right)} f_{l,i-3} C_{i-3} - \left[\frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{L_i\left(L_{i-3} + L_i\right)} + \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{L_i\left(L_i + L_{i+3}\right)}\right] f_{l,i} C_i \\
&+ \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{L_i\left(L_i + L_{i+3}\right)} f_{l,i+3} C_{i+3}
\end{aligned} \tag{4-22}$$

$$K_{cb}\left(\frac{f_{l,b}}{n_b} C_b - f_{l,c} C_c\right) = K_{i,i+1}\left(\frac{f_{l,i+1}}{n_{i+1}} C_{i+1} - f_{l,i} C_i\right) \tag{4-23}$$

$$v_s f_{s,c} C_c = v_{s,i} f_{s,i} C_i \tag{4-24}$$

$$v_r f_{s,b} C_b = v_{r,i+1} f_{s,i+1} C_{i+1} \tag{4-25}$$

$$K_{cw}\left(f_{l,w} C_w - f_{l,c} C_c\right) = K_{i,i+2}\left(f_{l,i+2} C_{i+2} - f_{l,i} C_i\right) \tag{4-26}$$

$$v_{cw} C_c - v_{wc} C_w = v_{i,i+2} C_i - v_{i+2,i} C_{i+2} \tag{4-27}$$

By substituting Eqs. (4-21) - (4-27) into Eq. (4-13), we have:

$$\begin{aligned}
\frac{\partial C_i}{\partial t} &= \frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{V_i\left(L_{i-3} + L_i\right)} f_{l,i-3} C_{i-3} - \left[\frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{V_i\left(L_{i-3} + L_i\right)} + \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{V_i\left(L_i + L_{i+3}\right)}\right] f_{l,i} C_i \\
&+ \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{V_i\left(L_i + L_{i+3}\right)} f_{l,i+3} C_{i+3} - \frac{A_{i,i+3} q_i}{V_i} C_i + \frac{A_{i-3,i} q_{i-3}}{V_i} C_{i-3} \\
&+ \frac{A_{i,i+1} K_{i,i+1}}{V_i}\left(\frac{f_{l,i+1}}{n_{i+1}} C_{i+1} - f_{l,i} C_i\right) - \frac{A_{i,i+1} v_{s,i} f_{s,i}}{V_i} C_i + \frac{A_{i,i+1} v_{r,i+1} f_{s,i+1}}{V_i} C_{i+1} \\
&+ \frac{A_{i,i+2} K_{i,i+2}}{V_i}\left(f_{l,i+2} C_{i+2} - f_{l,i} C_i\right) - \frac{A_{i,i+2} v_{i,i+2}}{V_i} C_i + \frac{A_{i,i+2} v_{i+2,i}}{V_i} C_{i+2} + \frac{1}{V_i}\left(I_r + I_e\right)
\end{aligned} \tag{4-28}$$

i.e.,

$$\frac{\partial C_i}{\partial t} = a_{i,i-3}C_{i-3} + a_{i,i}C_i + a_{i,i+1}C_{i+1} + a_{i,i+2}C_{i+2} + a_{i,i+3}C_{i+3} + m_i \tag{4-29}$$

in which

$$a_{i,i-3} = \frac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{V_i\left(L_{i-3} + L_i\right)} f_{l,i-3} + \frac{A_{i-3,i}q_{i-3}}{V_i} \tag{4-30}$$

$$a_{i,i} = -\left[\begin{array}{l} \dfrac{A_{i-3,i}\left(E_{i-3} + E_i\right)}{V_i\left(L_{i-3} + L_i\right)} f_{l,i} + \dfrac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{V_i\left(L_i + L_{i+3}\right)} f_{l,i} + \dfrac{A_{i,i+3}q_i}{V_i} + \dfrac{A_{i,i+1}K_{i,i+1}f_{l,i}}{V_i} \\ + \dfrac{A_{i,i+1}v_{s,i}f_{s,i}}{V_i} + \dfrac{A_{i,i+2}K_{i,i+2}f_{l,i}}{V_i} + \dfrac{A_{i,i+2}v_{i,i+2}}{V_i} \end{array}\right] \tag{4-31}$$

$$a_{i,i+1} = \frac{A_{i,i+1}K_{i,i+1}f_{l,i+1}}{V_i\, n_{i+1}} + \frac{A_{i,i+1}v_{r,i+1}f_{s,i+1}}{V_i} \tag{4-32}$$

$$a_{i,i+2} = \frac{A_{i,i+2}K_{i,i+2}f_{l,i+2}}{V_i} + \frac{A_{i,i+2}v_{i+2,i}}{V_i} \tag{4-33}$$

$$a_{i,i+3} = \frac{A_{i,i+3}\left(E_i + E_{i+3}\right)}{V_i\left(L_i + L_{i+3}\right)} f_{l,i+3} \tag{4-34}$$

$$m_i = \frac{1}{V_i}\left(I_{r,i} + I_{e,i}\right) \tag{4-35}$$

For $i = 1$, Eq. (4-29) becomes

$$\frac{\partial C_1}{\partial t} = a_{1,1}C_1 + a_{1,2}C_2 + a_{1,3}C_3 + a_{1,4}C_4 + m_1 \tag{4-36}$$

$$a_{1,1} = -\left[\begin{array}{l} \dfrac{A_{1,4}\left(E_1 + E_4\right)}{V_1\left(L_1 + L_4\right)} f_{l,1} + \dfrac{A_{1,4}q_1}{V_1} + \dfrac{A_{1,2}K_{1,2}f_{l,1}}{V_1} + \dfrac{A_{1,2}v_{s,1}f_{s,1}}{V_1} \\ + \dfrac{A_{1,3}K_{1,3}f_{l,1}}{V_1} + \dfrac{A_{1,3}v_{1,3}}{V_1} \end{array}\right] \tag{4-37}$$

$$m_1 = \frac{1}{V_1}\left(I_{r,1} + I_{e,1}\right) + \frac{A_0 q_0}{V_1} C_0 \tag{4-38}$$

For $i = N$-2, Eq. (4-29) becomes

$$\frac{\partial C_{N-2}}{\partial t} = a_{N-2,N-5}C_{N-5} + a_{N-2,N-2}C_{N-2} + a_{N-2,N-1}C_{N-1} + a_{N-2,N}C_N + m_{N-2} \tag{4-39}$$

$$a_{N-2,N-2} = -\left[\begin{array}{l} \dfrac{A_{N-5,N-2}\left(E_{N-5}+E_{N-2}\right)}{V_{N-2}\left(L_{N-5}+L_{N-2}\right)} f_{l,N-2} + \dfrac{A_{N-2}q_{N-2}}{V_{N-2}} + \dfrac{A_{N-2,N-1}K_{N-2,N-1}f_{l,N-2}}{V_{N-2}} \\ + \dfrac{A_{N-2,N-1}v_{s,N-2}f_{s,N-2}}{V_{N-2}} + \dfrac{A_{N-2,N}K_{N-2,N}f_{l,N-2}}{V_{N-2}} + \dfrac{A_{N-2,N}v_{N-2,N}}{V_{N-2}} \end{array}\right] \tag{4-40}$$

For the active bed compartments (i+1 = 2, 5, 8, …, N-1)

$$v_{sd,b}f_{s,b}C_b = v_{sd,i+1}f_{s,i+1}C_{i+1} \tag{4-41}$$

By substituting Eqs. (4-23) - (4-25) and (4-41) into Eq. (4-14), we have:

$$\begin{aligned} \frac{\partial C_{i+1}}{\partial t} &= -\frac{A_{i,i+1}K_{i,i+1}}{V_{i+1}}\left(\frac{f_{l,i+1}}{n_{i+1}}C_{i+1} - f_{l,i}C_i\right) + \frac{A_{i,i+1}v_{s,i}f_{s,i}}{V_{i+1}}C_i \\ &- \frac{A_{i,i+1}v_{r,i+1}f_{s,i+1}}{V_{i+1}}C_{i+1} - \frac{A_{i,i+1}v_{sd,i+1}f_{s,i+1}}{V_{i+1}}C_{i+1} \end{aligned} \tag{4-42}$$

i.e.,

$$\frac{\partial C_{i+1}}{\partial t} = a_{i+1,i}C_i + a_{i+1,i+1}C_{i+1} \tag{4-43}$$

in which

$$a_{i+1,i} = \frac{A_{i,i+1}K_{i,i+1}f_{l,i}}{V_{i+1}} + \frac{A_{i,i+1}v_{s,i}f_{s,i}}{V_{i+1}} \tag{4-44}$$

$$a_{i+1,i+1} = -\left[\frac{A_{i,i+1}K_{i,i+1}f_{l,i+1}}{V_{i+1}n_{i+1}} + \frac{A_{i,i+1}v_{r,i+1}f_{s,i+1}}{V_{i+1}} + \frac{A_{i,i+1}v_{sd,i+1}f_{l,i+1}}{V_{i+1}}\right] \tag{4-45}$$

For the wetland compartments (i+2 = 3, 6, 9, …, N)

$$v_{sd,w}f_{s,w}C_w = v_{sd,i+2}f_{s,i+2}C_{i+2} \tag{4-46}$$

By substituting Eqs. (4-26), (4-27), and (4-46) into Eq. (4-15), we have:

$$\frac{\partial C_{i+2}}{\partial t} = -\frac{A_{i,i+2}K_{i,i+2}}{V_{i+2}}\left(f_{l,i+2}C_{i+2} - f_{l,i}C_i\right) + \frac{A_{i,i+2}v_{i,i+2}}{V_{i+2}}C_i - \frac{A_{i,i+2}v_{i+2,i}}{V_{i+2}}C_{i+2} - \frac{A_{w,i+2}v_{sd,i+2}f_{s,i+2}}{V_{i+2}}C_{i+2} \tag{4-47}$$

i.e.,

$$\frac{\partial C_{i+2}}{\partial t} = a_{i+2,i}C_i + a_{i+2,i+2}C_{i+2} \tag{4-48}$$

in which

$$a_{i+2,i} = \frac{A_{i,i+2}K_{i,i+2}f_{l,i}}{V_{i+2}} + \frac{A_{i,i+2}v_{i,i+2}}{V_{i+2}} \tag{4-49}$$

$$a_{i+2,i+2} = -\left[\frac{A_{i,i+2}K_{i,i+2}f_{l,i+2}}{V_{i+2}} + \frac{A_{i,i+2}v_{i+2,i}}{V_{i+2}} + \frac{A_{w,i+2}v_{sd,i+2}f_{s,i+2}}{V_{i+2}}\right] \tag{4-50}$$

Thus, the transformed ODE system can be written in a matrix form as follows:

$$\dot{\mathbf{C}}(t) = \mathbf{A}(t)\mathbf{C}(t) + \mathbf{M}(t) \tag{4-51}$$

$$\begin{bmatrix} \dot{C}_1 \\ \dot{C}_2 \\ \dot{C}_3 \\ \dot{C}_4 \\ \dot{C}_5 \\ \dot{C}_6 \\ \dot{C}_7 \\ \vdots \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & & & & \\ a_{21} & a_{22} & 0 & 0 & & & & \\ a_{31} & 0 & a_{33} & 0 & & & & \\ a_{41} & 0 & 0 & a_{44} & a_{45} & a_{46} & a_{47} & \\ & & & a_{54} & a_{55} & 0 & 0 & \\ & & & a_{64} & 0 & a_{66} & 0 & \\ & & & a_{74} & 0 & 0 & a_{77} & \cdots \\ & & & & & & \vdots & \ddots \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ C_6 \\ C_7 \\ \vdots \end{bmatrix} + \begin{bmatrix} m_1 \\ 0 \\ 0 \\ m_4 \\ 0 \\ 0 \\ m_7 \\ \vdots \end{bmatrix} \tag{4-52}$$

The solution to the nonhomogeneous time-variant state equation system [Eq. (4-52)] is given by (Chu and Mariño, 2004):

$$\mathbf{C}(t) = \mathbf{\Phi}(t;\, t_0)\mathbf{C}(t_0) + \int_{t_0}^{t} \mathbf{\Phi}(t;\, \tau)\mathbf{M}(\tau)d\tau \tag{4-53}$$

in which the state transition matrix is expressed as (Friedly 1972)

$$\mathbf{\Phi}(t;t_0)=\lim_{j\to\infty}\left\{\mathbf{I}+\sum_{k=0}^{j-1}\int_{t_0}^{t}\mathbf{A}(\tau_1)\int_{t_0}^{\tau_1}\mathbf{A}(\tau_2)\cdots\int_{t_0}^{\tau_k}\mathbf{A}(\tau_{k+1})d\tau_{k+1}\cdots d\tau_1\right\}$$
$$=\mathbf{I}+\int_{t_0}^{t}\mathbf{A}(\tau_1)d\tau_1+\int_{t_0}^{t}\mathbf{A}(\tau_1)\left[\int_{t_0}^{\tau_1}\mathbf{A}(\tau_2)d\tau_2\right]d\tau_1+\cdots \tag{4-54}$$

By simplifying the nonhomogeneous ODE system into a set of piecewise time-invariant problems, we have

$$\dot{\mathbf{C}}(t)=\mathbf{AC}(t)+\mathbf{M}(t) \qquad t\in\left[t_{0,i},\ t_{0,i}+T_i\right];\quad i=1,\cdots,NT \tag{4-55}$$

in which

$$t_{0,i}=t_0+\sum_{j=1}^{i-1}T_j \tag{4-56}$$

Thus, the state transition matrix [Eq. (4-54)] and the solution [Eq. (4-53)] in time interval $\left[t_{0,i}, t_{0,i}+T_i\right]$ can be, respectively, simplified as

$$\mathbf{\Phi}(t;t_{0,i})=\mathbf{I}+\mathbf{A}(t-t_{0,i})+\frac{\mathbf{A}^2(t-t_{0,i})^2}{2!}+\cdots=\sum_{k=0}^{\infty}\frac{\mathbf{A}^k(t-t_{0,i})^k}{k!}=\mathbf{e}^{\mathbf{A}(t-t_{0,i})} \tag{4-57}$$

$$\mathbf{C}(t)=\mathbf{e}^{\mathbf{A}(t-t_{0,i})}\mathbf{C}(t_{0,i})+\int_{t_{0,i}}^{t}\mathbf{e}^{\mathbf{A}(t-\tau)}\mathbf{M}(\tau)d\tau \tag{4-58}$$

For an instantaneous loading of contaminant at each time interval (Dirac input)

$$\mathbf{M}(\tau)=\mathbf{m}\,\delta(\tau-t_{0,i}) \tag{4-59}$$

$$\dot{\mathbf{C}}(t)=\mathbf{AC}(t)+\mathbf{m}\,\delta(t-t_{0,i}) \tag{4-60}$$

The solution is given by

$$\mathbf{C}(t)=\mathbf{e}^{\mathbf{A}(t-t_{0,i})}\left[\mathbf{C}(t_{0,i})+\mathbf{m}\right] \tag{4-61}$$

where **m** = contaminant loading vector and $\delta(t)$ = Dirac-delta function.

D.5.2 SEDIMENT TRANSPORT MODELING IN THE STREAM-WETLAND SYSTEM

The governing equations for sediment transport in the water column, active bed, and the adjacent wetland can be respectively expressed as

$$V_c \frac{\partial S_c}{\partial t} = -L \frac{\partial}{\partial x}\left(A_c q S_c\right) - A_{cb} v_s S_c + A_{cb} v_r S_b - A_{cw} v_{cw} S_c + A_{cw} v_{wc} S_w + J_e \qquad (4\text{-}62)$$

$$V_b \frac{\partial S_b}{\partial t} = A_{cb} v_s S_c - A_{cb} v_r S_b - A_{cb} v_{sd,b} S_b \qquad (4\text{-}63)$$

$$V_w \frac{\partial S_w}{\partial t} = A_{cw} v_{cw} S_c - A_{cw} v_{wc} S_w - A_w v_{sd,w} S_w \qquad (4\text{-}64)$$

where J_e = lateral sediment load from soil erosion [M/T].

For the compartmentalized system (Figs 4-2 and 4-3),

$$\frac{\partial (A_c q S_c)}{\partial x}\Big|_i \approx \frac{1}{L_i}\left(A_{i,i+3} q_i S_i - A_{i-3,i} q_{i-3} S_{i-3}\right) \qquad (4\text{-}65)$$

Eq. (4-62) for the water column (i = 1, 4, …, N-2) can be written as,

$$\begin{aligned} \frac{dS_i}{dt} &= \frac{A_{i-3,i} q_{i-3}}{V_i} S_{i-3} - \left(\frac{A_{i,i+3} q_i}{V_i} + \frac{A_{i,i+1} v_{s,i}}{V_i} + \frac{A_{i,i+2} v_{i,i+2}}{V_i}\right) S_i + \frac{A_{i,i+1} v_{r,i+1}}{V_i} S_{i+1} \\ &+ \frac{A_{i,i+2} v_{i+2,i}}{V_i} S_{i+2} + \frac{J_{e,i}}{V_i} \end{aligned} \qquad (4\text{-}66)$$

i.e.,

$$\frac{\partial S_i}{\partial t} = b_{i,i-3} S_{i-3} + b_{i,i} S_i + b_{i,i+1} S_{i+1} + b_{i,i+2} S_{i+2} + j_{e,i} \qquad (4\text{-}67)$$

in which

$$b_{i,i-3} = \frac{A_{i-3,i} q_{i-3}}{V_i} \qquad (4\text{-}68)$$

$$b_{i,i} = -\left(\frac{A_{i,i+3} q_i}{V_i} + \frac{A_{i,i+1} v_{s,i}}{V_i} + \frac{A_{i,i+2} v_{i,i+2}}{V_i}\right) \qquad (4\text{-}69)$$

$$b_{i,i+1} = \frac{A_{i,i+1} v_{r,i+1}}{V_i} \qquad (4\text{-}70)$$

$$b_{i,i+2} = \frac{A_{i,i+2} v_{i+2,i}}{V_i} \tag{4-71}$$

$$j_{e,i} = \frac{J_{e,i}}{V_i} \tag{4-72}$$

For *i* = 1, Eqs. (4-67) and (4-72) become

$$\frac{\partial S_1}{\partial t} = b_{1,1} S_1 + b_{1,2} S_2 + b_{1,3} S_3 + j_{e,1} \tag{4-73}$$

$$j_{e,1} = \frac{J_{e,1}}{V_1} + \frac{A_0 q_0}{V_1} S_0 \tag{4-74}$$

For the active bed (*i*+1 = 2, 5, …, *N*-1), Eq. (4-63) can be written as

$$\frac{\partial S_{i+1}}{\partial t} = b_{i+1,i} S_i + b_{i+1,i+1} S_{i+1} \tag{4-75}$$

in which

$$b_{i+1,i} = \frac{A_{i,i+1} v_{s,i}}{V_{i+1}} \tag{4-76}$$

$$b_{i+1,i+1} = -\left(\frac{A_{i,i+1} v_{r,i+1}}{V_{i+1}} + \frac{A_{i,i+1} v_{sd,i+1}}{V_{i+1}} \right) \tag{4-77}$$

For the wetland (*i*+2 = 3, 6, …, *N*), Eq. (4-64) can be written as

$$\frac{\partial S_{i+2}}{\partial t} = b_{i+2,i} S_i + b_{i+2,i+2} S_{i+2} \tag{4-78}$$

in which

$$b_{i+2,i} = \frac{A_{i,i+2} v_{i,i+2}}{V_{i+2}} \tag{4-79}$$

$$b_{i+2,i+2} = -\left(\frac{A_{i,i+2} v_{i+2,i}}{V_{i+2}} + \frac{A_{i,i+2} v_{sd,i+2}}{V_{i+2}} \right) \tag{4-80}$$

Thus, the system of ODE can be written in the following matrix form:

$$\dot{\mathbf{S}}(t) = \mathbf{B}(t)\mathbf{S}(t) + \mathbf{J}(t) \tag{4-81}$$

$$\begin{bmatrix} \dot{S}_1 \\ \dot{S}_2 \\ \dot{S}_3 \\ \dot{S}_4 \\ \dot{S}_5 \\ \dot{S}_6 \\ \dot{S}_7 \\ \vdots \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & & & & & \\ b_{21} & b_{22} & 0 & & & & & \\ b_{31} & 0 & b_{33} & & & & & \\ b_{41} & 0 & 0 & b_{44} & b_{45} & b_{46} & & \\ & & & b_{54} & b_{55} & 0 & & \\ & & & b_{64} & 0 & b_{66} & & \\ & & & b_{74} & 0 & 0 & b_{77} & \cdots \\ & & & & & & \vdots & \ddots \end{bmatrix} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ S_7 \\ \vdots \end{bmatrix} + \begin{bmatrix} j_1 \\ 0 \\ 0 \\ j_4 \\ 0 \\ 0 \\ j_7 \\ \vdots \end{bmatrix} \tag{4-82}$$

Eq. (4-82) can be solved by using the same method described in Eqs. (4-53) – (4-61).

D.5.3 WATER FLOW MODELING IN THE STREAM-WETLAND SYSTEM

Wetlands adjacent to stream channels potentially change the stream hydrologic/hydraulic characteristics and alter both spatial and temporal distributions of surface water during storm events. When water level in the stream channel is higher than a threshold depth, a certain amount of stream water will be diverted into the adjacent wetlands. Such a "loss" of water continues during the rising phase of the storm event. On the other hand, a portion of the water stored in the wetlands may flow back to the channel during the decline phase. The conceptualized interactions within the stream-wetland system are shown in Fig. D.13. Based on mass balance and the measured stream flow data, a simple method has been developed in this study for simulating the interactions between the water column and the adjacent wetlands.

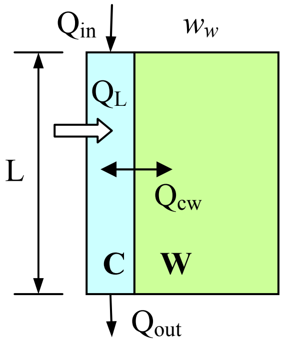

FIGURE D. 13. CONCEPTUALIZED STREAM-WETLAND SYSTEM.

The governing equation that describes mass balance in the stream-wetland system can be expressed as:

$$\frac{\partial Q}{\partial x} + \frac{\partial A_c}{\partial t} + \frac{\partial A_c^w}{\partial t} = q_L \tag{4-83}$$

where Q = discharge in the stream channel [L^3/T]; x = distance along the stream flow direction [L]; t = time [T]; A_c = cross-sectional area of the water column [L^2]; A_c^w = cross-sectional area of the wetland [L^2]; and q_L = lateral inflow [L^3/T/L].

The finite difference form of Eq. (4-83) for a stream reach of a length L can be written as:

$$\overline{Q}_{in} - \overline{Q}_{out} + \overline{Q}_L = \frac{\Delta V_c}{\Delta t} + \frac{\Delta V_w}{\Delta t} \tag{4-84}$$

where $\overline{Q}_{in}$ = average stream inflow during Δt [L^3/T); $\overline{Q}_{out}$ = average stream outflow during Δt [L^3/T]; $\overline{Q}_L$ = average lateral inflow during Δt [L^3/T]; ΔV_c = storage change in the stream channel during Δt [L^3]; and ΔV_w = storage change in the wetland during Δt [L^3].

Assuming that the inundated area of the wetland is a linear function of the water level (z) in the wetland (Fig. D.14), we have

$$w_w = \mu z = \mu(D_c - D_T) \tag{4-85}$$

where D_c = water depth in the water column of stream channel [L], D_T = threshold water depth [L], z = water level in the wetland [L]; w_w = width of the submerged wetland area [L]; and μ = linear factor for the relationship between w_w and z.

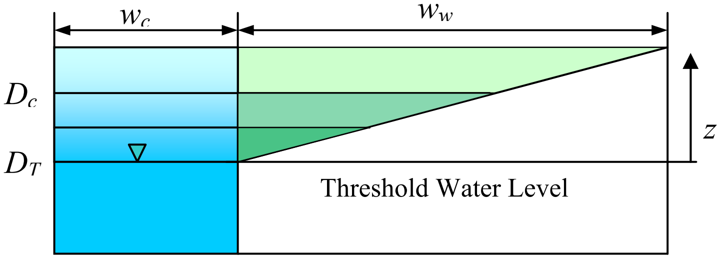

FIGURE D. 14. COMPUTATION OF THE INUNDATED WETLAND AREA.

According to the stream monitoring data collected in the field, averaged water depth, width, across-sectional area, and velocity were first computed for each stream reach (between two monitoring sites). These data were then used in the following computations. Thus, when the water depth changes from D_c^{k-1} at time step k-1 to D_c^k at time step k (the time interval is Δt), the mass balance for the stream reach of a length L can be analyzed for the following cases:

Case 1 $D_T \le D_c^{k-1} \le D_c^k$ or $D_T \le D_c^k \le D_c^{k-1}$

$$\Delta V_w^k = 0.5L\left(D_c^k - D_c^{k-1}\right)\left(w_w^k + w_w^{k-1}\right) = 0.5L\mu\left(D_c^k - D_c^{k-1}\right)\left(D_c^k + D_c^{k-1} - 2D_T\right) \tag{4-86}$$

$$\Delta V_c^k = 0.5L\left(w_c^k + w_c^{k-1}\right)\left(D_c^k - D_c^{k-1}\right) \tag{4-87}$$

$$A_w^k = Lw_w^k = L\mu\left(D_c^k - D_T\right) \tag{4-88}$$

$$Q_{cw}^k = \Delta V_w^k / \Delta t \tag{4-89}$$

$$v_{cw}^k = Q_{cw}^k / A_{cw}^k \tag{4-90}$$

$$A_{cw}^k = 0.5L\left(D_c^k + D_c^{k-1} - 2D_T\right) \tag{4-91}$$

where Q_{cw}^k = water exchange between the channel and wetland [L^3/T] (its sign indicates flow directions: + from channel to wetland; - from wetland to channel); v_{cw}^k = water exchange rate between the channel and wetland [L/T]; and A_{cw}^k = interaction area between the channel and wetland [L^2].

Case 2 $D_c^k < D_T \le D_c^{k-1}$

$$\Delta V_w^k = -0.5Lw_w^{k-1}\left(D_c^{k-1} - D_T\right) = -0.5L\mu\left(D_c^{k-1} - D_T\right)^2 \tag{4-92}$$

$$\Delta V_c^k = 0.5L\left(w_c^k + w_c^{k-1}\right)\left(D_c^k - D_c^{k-1}\right) \tag{4-93}$$

$$A_w^k = 0 \tag{4-94}$$

$$Q_{cw}^k = \Delta V_w^k / \Delta t \tag{4-95}$$

$$v_{cw}^k = Q_{cw}^k / A_{cw}^k \tag{4-96}$$

$$A_{cw}^k = 0.5L\left(D_c^{k-1} - D_T\right) \tag{4-97}$$

Case 3 $D_c^k \le D_c^{k-1} < D_T$ or $D_c^{k-1} < D_c^k < D_T$

$$\Delta V_w^k = 0 \tag{4-98}$$

$$\Delta V_c^k = 0.5L\left(w_c^k + w_c^{k-1}\right)\left(D_c^k - D_c^{k-1}\right) \tag{4-99}$$

$$A_w^k = 0 \tag{4-100}$$

$$Q_{cw}^k = 0 \tag{4-101}$$

$$v_{cw}^k = 0 \tag{4-102}$$

$$A_{cw}^k = 0 \tag{4-103}$$

<u>Case 4</u> $D_c^{k-1} < D_T < D_c^k$

$$\Delta V_w^k = 0.5 L w_w^k \left(D_c^k - D_T\right) = 0.5 L \mu \left(D_c^k - D_T\right)^2 \tag{4-104}$$

$$\Delta V_c^k = 0.5 L \left(w_c^k + w_c^{k-1}\right)\left(D_c^k - D_c^{k-1}\right) \tag{4-105}$$

$$A_w^k = L w_w^k = L \mu \left(D_c^k - D_T\right) \tag{4-106}$$

$$Q_{cw}^k = \Delta V_w^k / \Delta t \tag{4-107}$$

$$v_{cw}^k = Q_{cw}^k / A_{cw}^k \tag{4-108}$$

$$A_{cw}^k = 0.5 L \left(D_c^k - D_T\right) \tag{4-109}$$

According to Eq. (4-84), the mass balance for time interval Δt (from time step k-1 to k) can be rewritten as

$$\Delta V_L^k = \Delta V_c^k + \Delta V_w^k - \Delta V_Q^k \tag{4-110}$$

in which

$$\Delta V_L^k = \overline{Q}_L \Delta t \tag{4-111}$$

$$\Delta V_Q^k = \left[\frac{Q_{in}^{k-1} + Q_{in}^k}{2} - \frac{Q_{out}^{k-1} + Q_{out}^k}{2}\right]\Delta t \tag{4-112}$$

D.5.4 APPLICATION OF THE METAL-SEDIMENT TRANSPORT MODEL IN LITTLE BLACK CREEK

Model Input Data

The metal-sediment transport model developed in preceding sections was applied to Little Black Creek for simulating cadmium transport in the real stream-wetland system. A typical storm event from 8/2/2004 0:00 to 8/4/2004 0:00 was selected for model testing. The simulated stream channel, ranging from Site 1 (x = 0) to Site 5 (x = 6361.22m), consisted of three stream reaches. Each reach was further divided into a number of compartments in the modeling. The length, distance (x) along the flow direction, number of compartments, and the size of each compartment are shown in Table D.13. Thus, there are 105 compartments for the entire system that includes 35 water column compartments, 35 active bed compartments, and 35 wetland compartments. The simulation period (48 hours) was further divided into 288 time steps (i.e., 10-minute time interval).

TABLE D. 13. STREAM REACHES AND SPATIAL DISCRETIZATION.

Reach	Sites	Length(m)	Distance x (m)	No. of Compartments
Reach1	Site1 – Site2	2498.91	0 – 2498.91	10 (249.89m/compt)
Reach2	Site2 – Site3	2026.94	2498.91 – 4525.85	15 (135.13m/compt)
Reach3	Site3 – Site5	1835.38	4525.85 – 6361.22	10 (183.54m/compt)
HS1		346.60	2976.90	
HS2			3323.50	

According to the long-term water quality monitoring data, extremely high concentrations of cadmium in stream bed sediments have been consistently observed for a section of stream channel between Sites 2 and 3. Such a special channel of a length of 346.6m was denoted as “hot spot” (HS) that ranged from point HS1 (x = 2976.90m) to point HS2 (x = 3323.50m) (Table D.14 and Fig. D.15). The initial adsorbed-phase cadmium concentrations in the active bed for the four involved HS compartments were given based on the latest MDEQ observed data (Table D.14, average concentration is 995.8 mg/kg). The initial adsorbed cadmium concentrations for other compartments in the active bed were given based on the water quality data specially collected for the storm event in this project. The spatial distribution of initial adsorbed-phase cadmium concentrations in the active bed is shown in Fig. D.16. It was assumed in the model that the initial total cadmium concentrations in the water column and the wetland were zero, and the upstream loading of cadmium was negligible. It was also assumed that the dissolved and adsorbed cadmium concentrations from lateral surface runoff and erosion were negligible. Major parameters used in the metal and sediment transport modeling are listed in Table D.15.

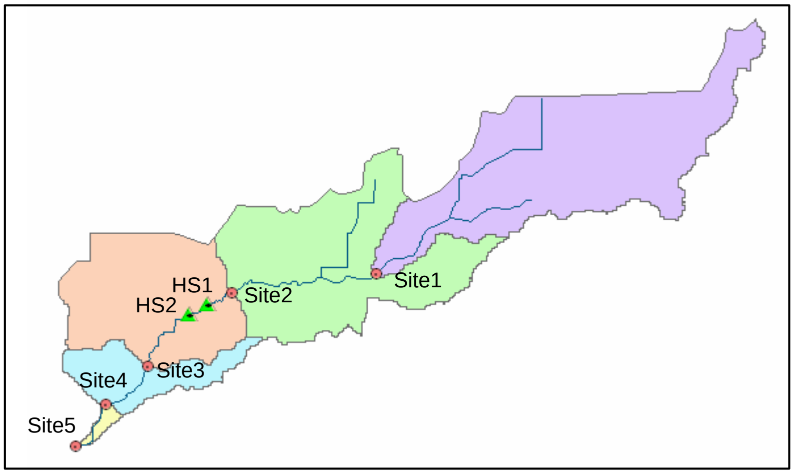

FIGURE D. 15. LOCATION OF THE CADMIUM "HOT SPOT".

TABLE D. 14. STREAM BED SEDIMENT CADMIUM CONCENTRATIONS ON JUNE 28, 2005.

MDEQ Sites	SD10	SD11	SD12	SD13	SD14	SD15	SD16	SD17	Average
Cadmium (mg/kg)	3600	68	1100	250	58	1400	190	1300	995.8

(Note that all MDEQ sites (SD10-17) in this table are located in the HS stream section)

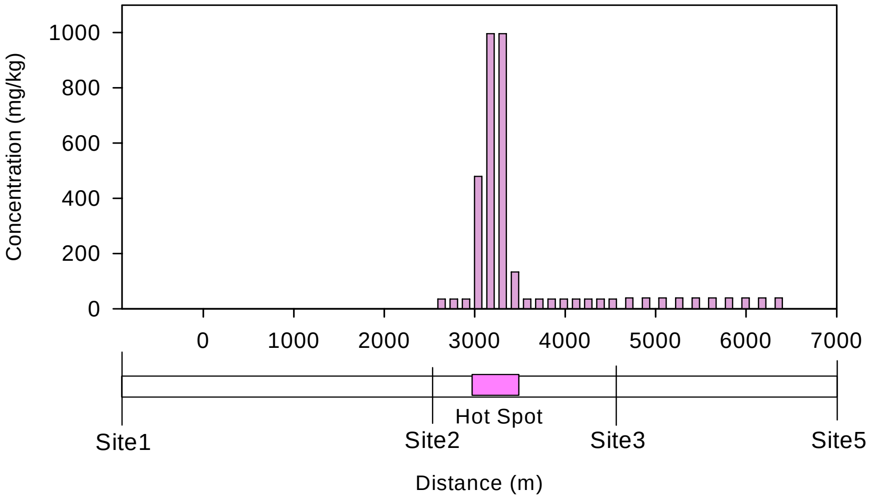

FIGURE D. 16. INITIAL ADSORBED CADMIUM CONCENTRATIONS IN THE ACTIVE BED.

TABLE D. 15. MAJOR PARAMETERS IN THE METAL-SEDIMENT TRANSPORT MODEL.

Parameter	Value
Distribution coefficient in the water column and wetland [a] (cm^3/g)	158489.0
Distribution coefficient in the active bed [a] (cm^3/g)	5011.0
Bulk density of sediments in the active bed (g/cm^3)	2.0
Thickness of the active bed (m)	0.1
Porosity of sediments in the active bed	0.55
Diffusive transfer rate between the water column and active bed [b] (m/h)	0.0002
Diffusive transfer rate between the water column and wetland (m/h)	0.00003
Settling velocity [c] (m/h)	0.14
Resuspension velocity (m/h)	$1.0\times10^{-8} - 1.9\times10^{-5}$
Sedimentation velocity of sediments in the active bed (m/h)	0.0001 – 0.0005
Settling/sedimentation velocity of sediments in the wetland (m/h)	1.0

Notes: (a). Allison, J and Allison, T. 2005; (b). calculated by using Eq. (4-20) ($n_b = 0.55$ and $M_w = 112.41$gm); and (c) calculated by using Eq. (4-19) ($\rho_s = 2.0$ g/cm^3, $\rho_s = 1.0$ g/cm^3, $d = 10.0$ μm)

The watershed erosion modeling in Section D.2 provided the lateral loads of eroded sediments from subbasins for the three reaches (D.17) and the concentrations of sediments loaded from the upstream area (Basin6) (Fig. D.18). Based on the hydrologic monitoring and modeling data in Sections 2 and 4, water flow in the LBC stream-wetland system was first simulated, which provided essential information for the metal and sediment transport modeling, including averaged flow velocity, depth, width, and cross-sectional area of the water column for all stream reaches. In particular, the flow modeling also provided the dynamic exchange between the water column and wetland (Fig. D.19) and the time-varying inundated wetland area (Fig. D.20). Note that no wetland issue was involved for Reach 1 between Sites 1 and 2. Given all input data and parameters, the metal and sediment transport model provided detailed spatial and temporal distributions of both sediments and cadmium in the water column, active bed, and the adjacent wetlands (for cadmium, the simulation provided the dissolved, adsorbed, and total concentrations in the three subsystems).

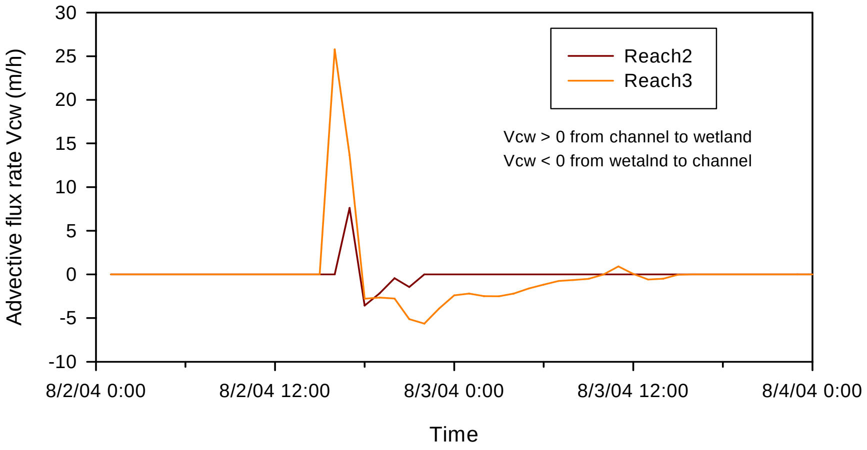

FIGURE D. 17. ADVECTIVE FLUX EXCHANGE BETWEEN THE CHANNEL WATER COLUMN AND WETLAND (+ FROM CHANNEL TO WETLAND; - FROM WETLAND TO CHANNEL).

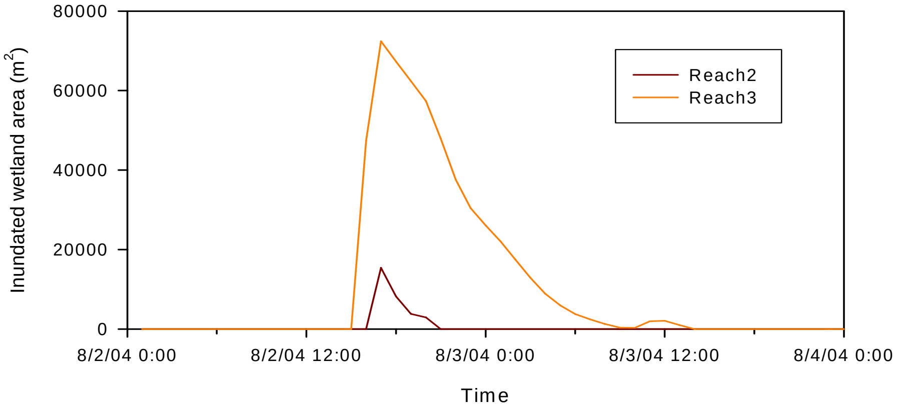

FIGURE D. 18. CHANGES IN THE INUNDATED WETLAND AREA DURING THE STORM EVENT.

D.5.5 ANALYSIS OF SEDIMENT TRANSPORT MODELING RESULTS

Since the cadmium contamination is primarily related to Reaches 2 and 3 (between Site 2 and Site 5), the following analysis focuses on the channels downstream beyond Site 2. The simulated suspended sediment concentrations in the water column between Sites 2 and 3, and between Sites 3 and 5 are shown in Figs. 6-10 and 6-11, respectively. Basically, the suspended sediment concentrations increase from upstream to downstream points/compartments and the peak suspended sediment concentrations match the storm peaks at different locations. Like the corresponding hydrographs, a time shift can be observed between upstream and downstream points.

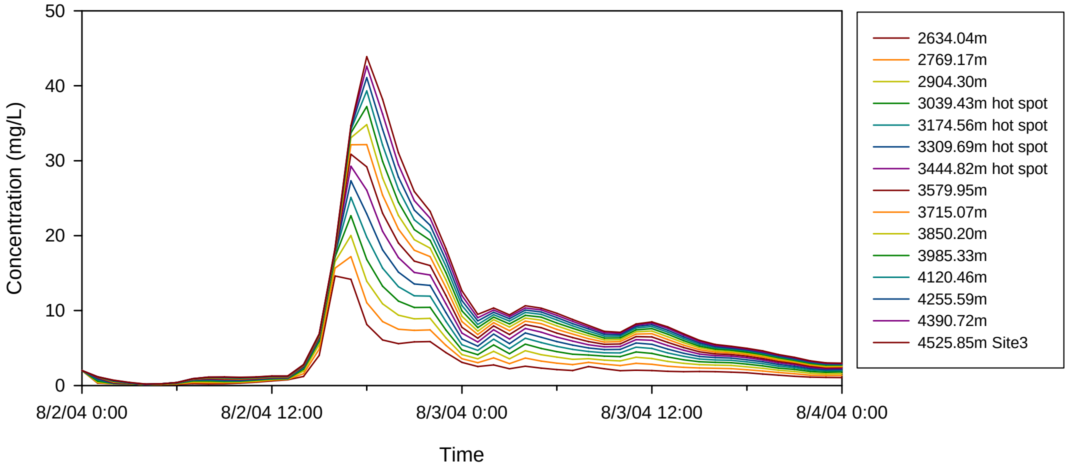

FIGURE D. 19. SIMULATED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 2 AND 3.

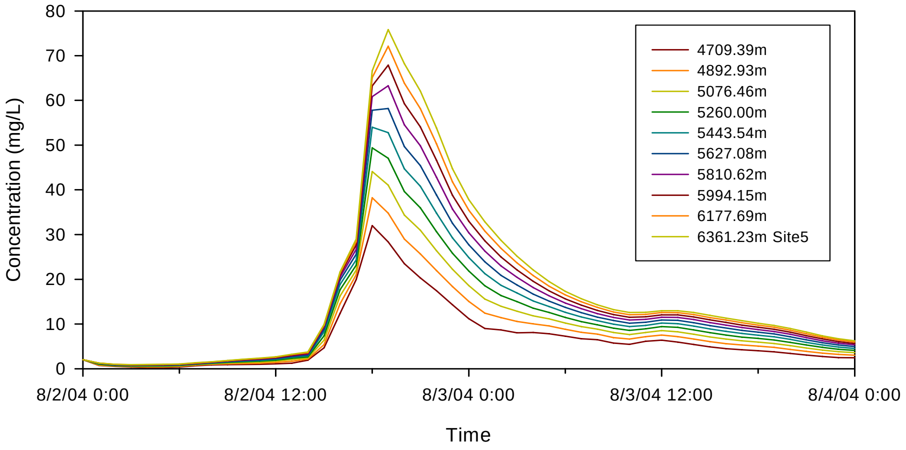

FIGURE D. 20. SIMULATED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 3 AND 5.

Due to the interaction between the water column and the adjacent wetlands, exchange of suspended sediments also occurred during the storm event. The simulated suspended sediment concentrations in the wetland between Sites 2 and 3, and between Sites 3 and 5 are shown in Figs. D.21 and D.22, respectively. Clearly, distributions of suspended sediments in the wetlands are dominated by the channel-wetland exchange that is controlled by stream hydraulic conditions during the storm event.

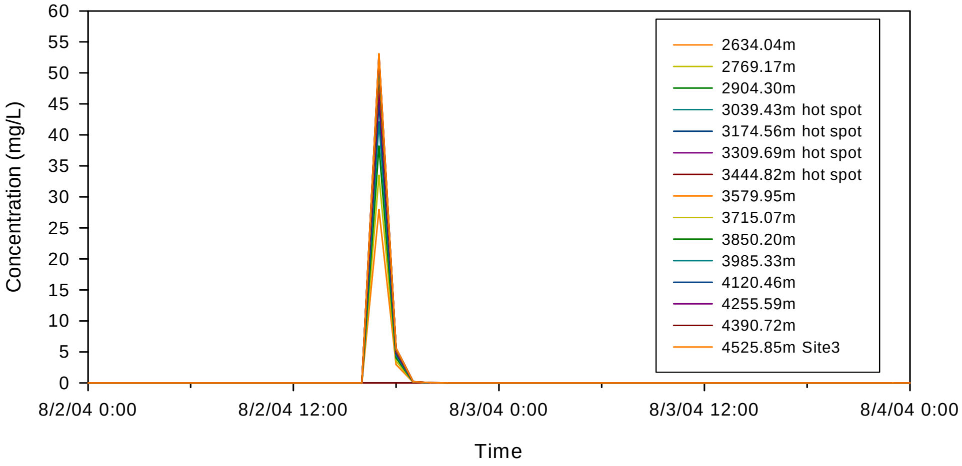

FIGURE D. 21. SIMULATED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WETLAND BETWEEN SITES 2 AND 3.

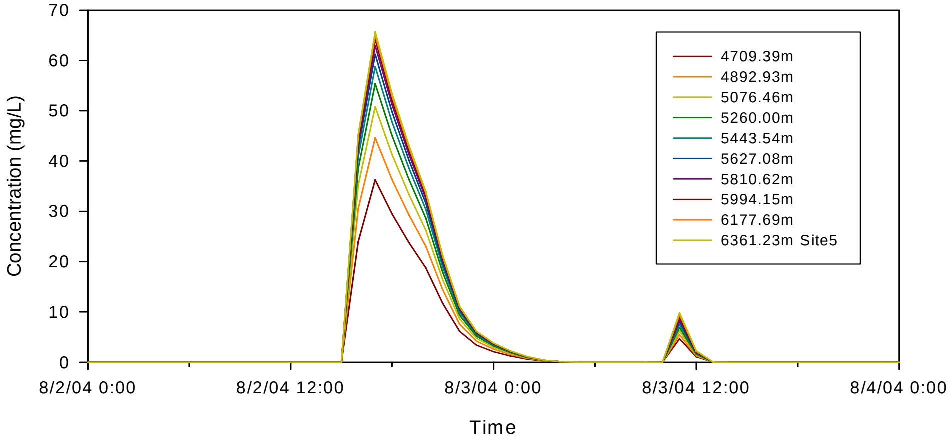

FIGURE D. 22. SIMULATED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WETLAND BETWEEN SITES 3 AND 5.

The sediment transport model was calibrated by using the data collected from Sites 3 and 5. Comparisons between the simulated and observed concentrations of suspended sediments in the water column at these two sites are shown in Fig. D.23. Good agreement has been achieved for both sites.

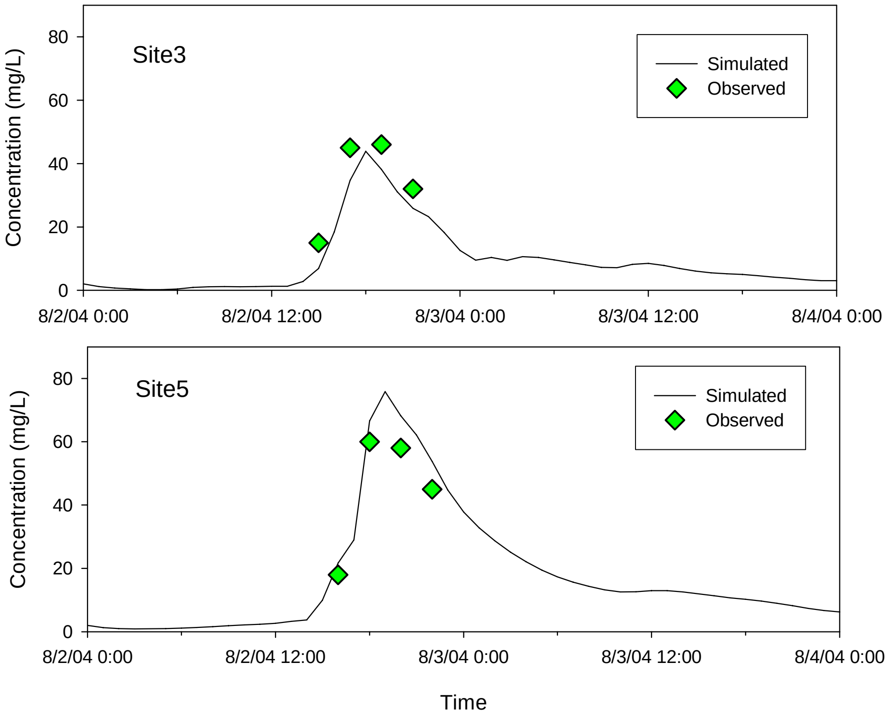

FIGURE D. 23. COMPARISON OF THE SIMULATED AND OBSERVED SUSPENDED SEDIMENT CONCENTRATIONS IN THE WATER COLUMN .

D.5.9 ANALYSIS OF CADMIUM TRANSPORT MODELING RESULTS

The simulated adsorbed and dissolved cadmium concentrations in the water column between Sites 2 and 3, and between Sites 3 and 5 are shown in Figs. D.24 – D.26, respectively. For Reach 2 between Sites 2 and 3, both adsorbed and dissolved cadmium concentrations are very low before the "hot spot" (Figs. D.24 and D.25). A significant increase can be observed for the four HS compartments. Both adsorbed and dissolved cadmium concentrations reach peaks at x = 3309.69m. Beyond this point, the two phases concentrations both decrease along the stream flow direction for all downstream compartments, including those between Sites 3 and 5 (Figs. 6-16 and D.26). Except for the portion of channel from 3309.69 to 3715.07m, the dissolved cadmium concentrations are generally smaller than 0.001 mg/L in the water column (Figs. D.25 and D.26), which is consistent with the field measurements. Comparison between the simulated and observed adsorbed cadmium concentrations in the water column (Fig. D.27) indicates that the model yielded fairly good simulations. For Site 5, the simulated cadmium concentrations are lower than the observed ones, which may be partially attributed to the assumption of zero cadmium loads from the lateral runoff and erosion in the model and zero initial cadmium concentrations in the wetland. In reality, a certain amount of cadmium, originally stored in the wetland system, could be loaded into the stream channel during the storm, which might elevate the cadmium level at downstream sites.

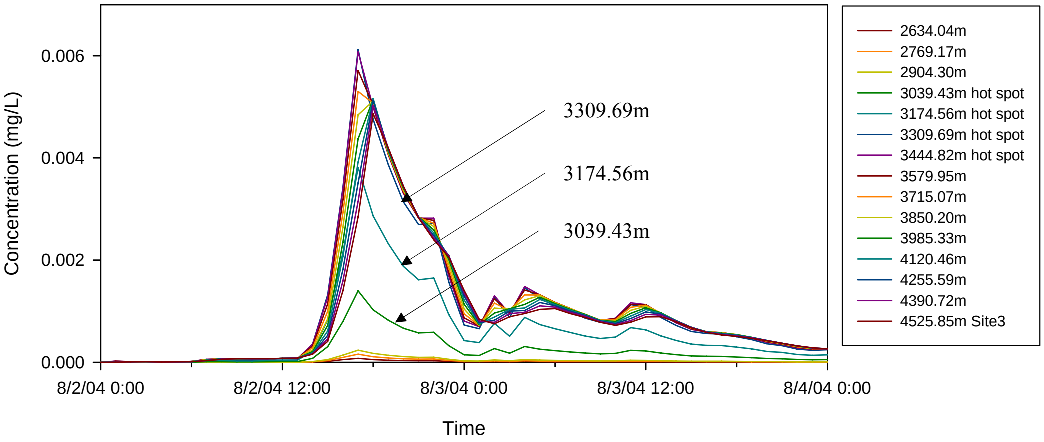

FIGURE D. 24. SIMULATED ADSORBED CADMIUM CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 2 AND 3.

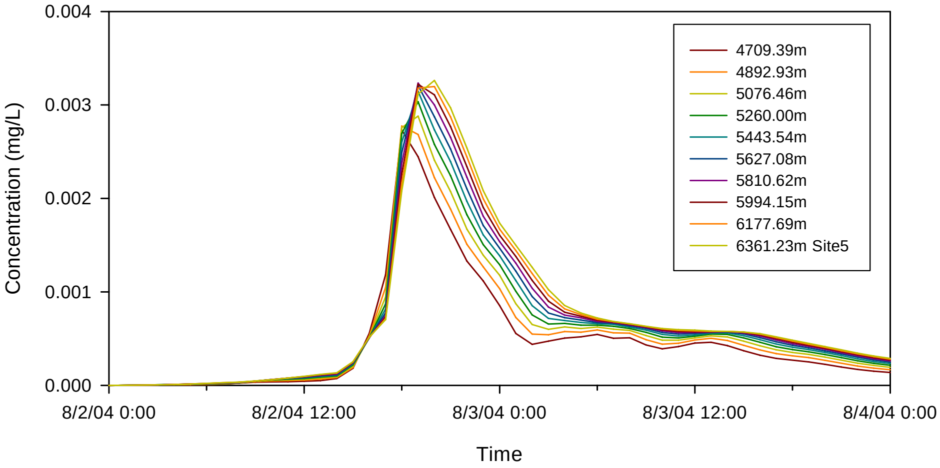

FIGURE D. 25. SIMULATED ADSORBED CADMIUM CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 3 AND 5.

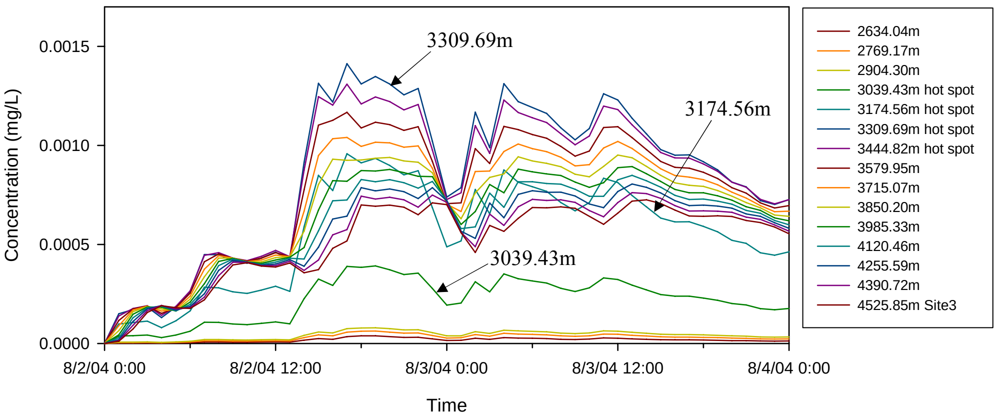

FIGURE D. 26. SIMULATED DISSOLVED CADMIUM CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 2 AND 3.

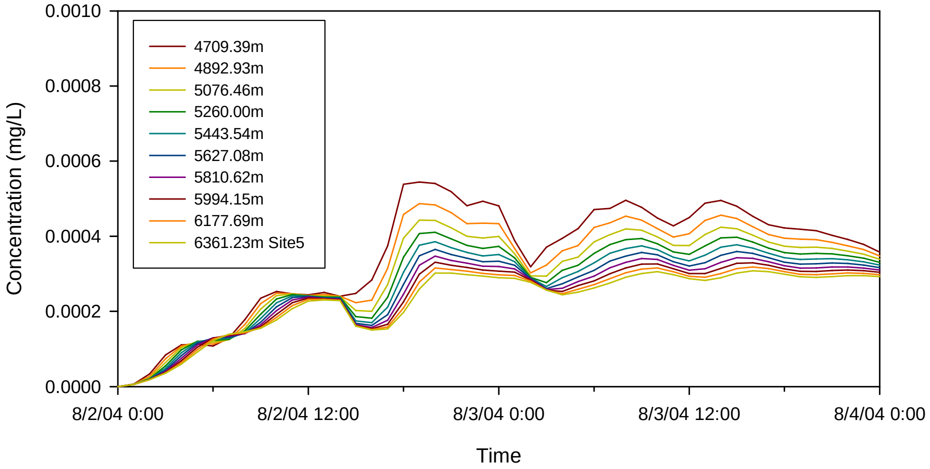

FIGURE D. 27. SIMULATED DISSOLVED CADMIUM CONCENTRATIONS IN THE WATER COLUMN BETWEEN SITES 3 AND 5.

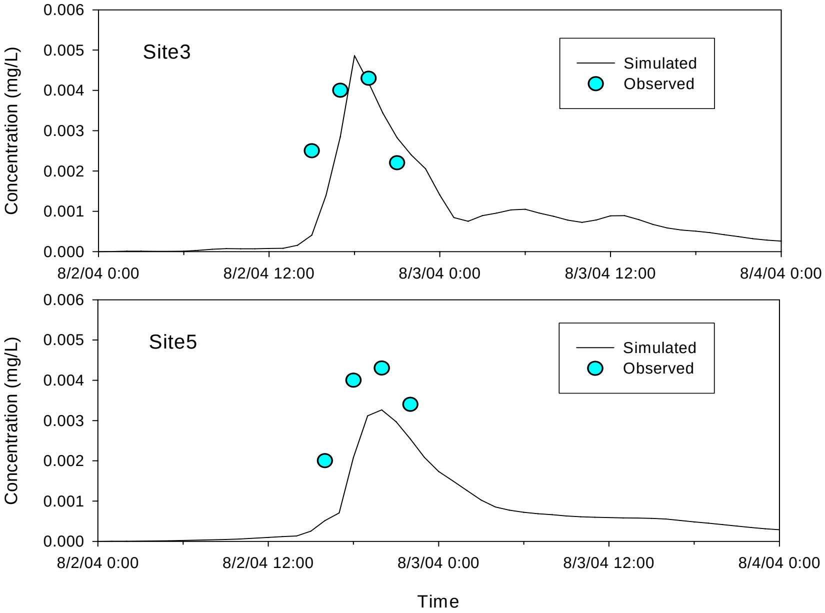

FIGURE D. 28. COMPARISON OF THE SIMULATED AND OBSERVED ADSORBED CADMIUM CONCENTRATIONS IN THE WATER COLUMN.

The simulated adsorbed-phase cadmium concentrations in the active bed are relatively stable, with the highest values at the HS compartments. Their temporal distributions only exhibit a slight decline during the storm event. Comparison between the simulated and observed adsorbed cadmium concentrations in the active bed for Sites 3 and 5 are shown in Fig. D.29.

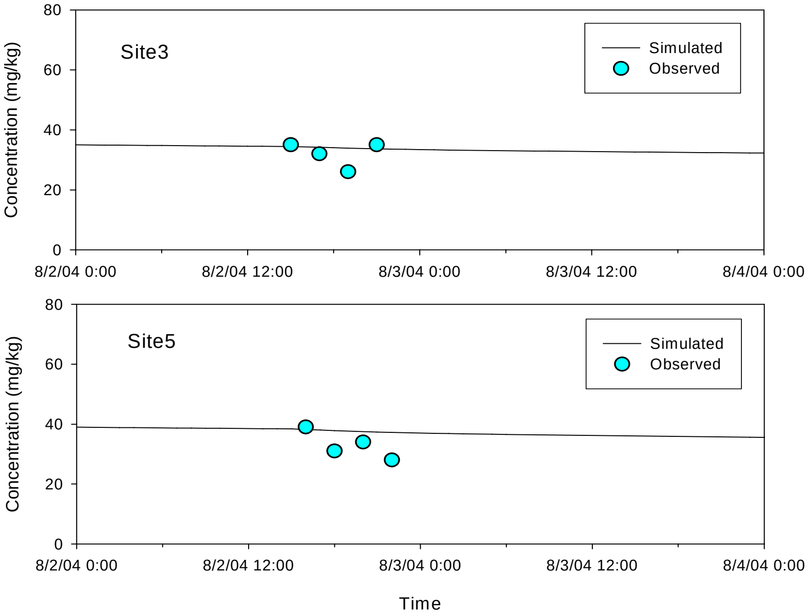

FIGURE D. 29. COMPARISON OF THE SIMULATED AND OBSERVED ADSORBED CADMIUM CONCENTRATIONS IN THE ACTIVE BED.

For the wetland subsystem, the model also provided dissolved, adsorbed, and total cadmium concentrations. Like those in the water column, the dissolved concentrations of cadmium are also very low due to its strong sorption properties (high distribution coefficient, Table 6-3). The simulated total cadmium concentrations (primarily in the adsorbed phase) in the wetlands between Sites 2 and 3, and between Sites 3 and 5 are shown in Figs. D.30 and D.31, respectively. Like the suspended sediment levels in the wetlands, the cadmium concentrations in the wetlands highly depend on the mass exchange between the stream channel and wetland that are affected by the storm characteristics and stream hydraulics.

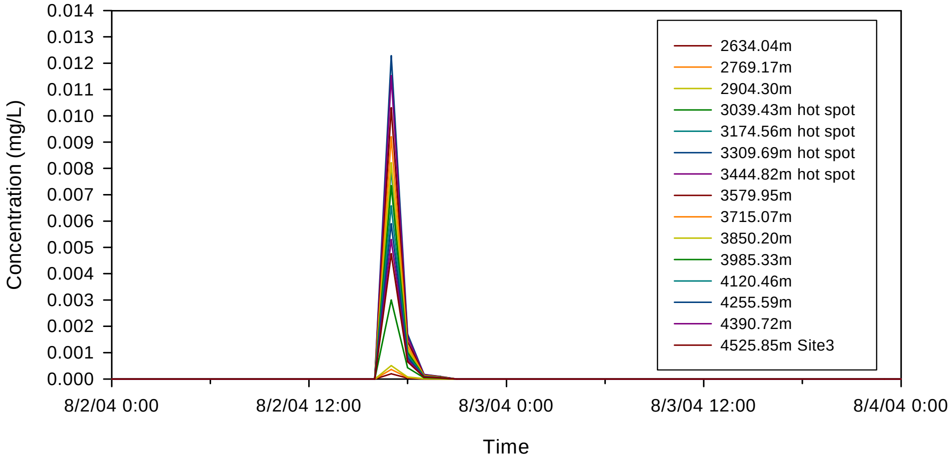

FIGURE D. 30. SIMULATED TOTAL CADMIUM CONCENTRATIONS IN THE WETLAND BETWEEN SITES 2 AND 3.

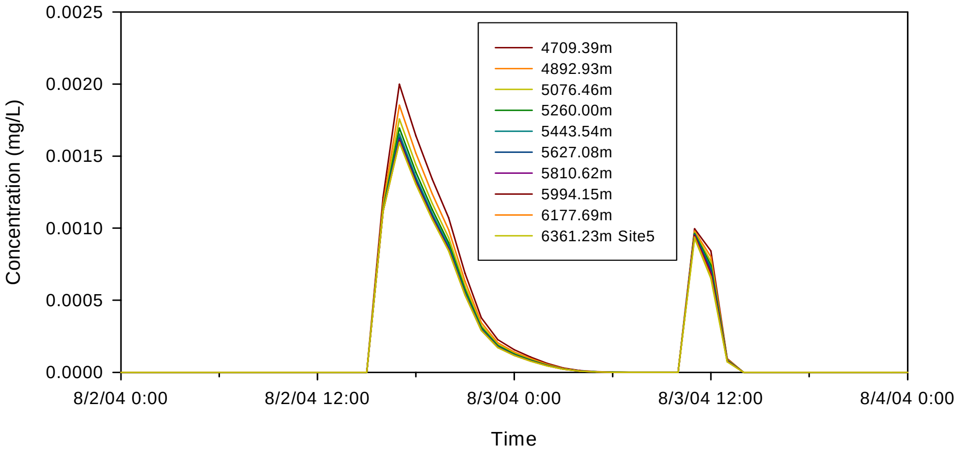

FIGURE D. 31. SIMULATED TOTAL CADMIUM CONCENTRATIONS IN THE WETLAND BETWEEN SITES 3 AND 5.

4.10 References

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