Preliminary Watershed Assessment:

Mona Lake Watershed

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Executive Summary

The Mona Lake watershed, located in Muskegon and Newaygo Counties in west Michigan, is relatively small in area (~ 200 km^2 or 48,000 acres), but faces a large number of environmental challenges. An ecological assessment of the watershed was conducted to provide a new baseline of information, in the hope that this effort would catalyze actions to improve the health of the watershed. The assessment included the following elements:

- GIS-based analysis of environmental resources in the watershed (Appendix 6.1)
- Water quality analysis of Mona Lake
- Nutrient bioassays to assess nutrient limitation in Mona Lake
- Water quality analysis of all tributary and storm drain inflows to Mona Lake
- Development of a hydrologic model for the Mona Lake watershed
- Contaminated sediment characterization in Little Black Creek, Cress Creek, and Mona Lake
- Identify sources of contamination in Little Black Creek (Appendix 6.5)
- Fish and macroinvertebrate survey at selected locations in the watershed

The GIS analysis revealed that, between 1978 and 1997/98, agricultural land use (mostly cropland) declined by 32.4%, natural cover (mostly open field) increased by 5.4%, and developed use (mostly commercial and residential) increased by 18%. These changes are reflected in a strong gradient of % impervious surface in the watershed, with the largely agricultural subbasins near the top of the watershed having low percentages of impervious surface (<5%) and the more developed subbasins near Mona Lake having high percentages of impervious surface (>20%).

The water quality of Mona Lake has shown improvement since the early 1970s, although nutrient concentrations, especially nitrogen and phosphorus, are still far above water quality standards and impair the ecological integrity of the lake. Diversion of wastewater to the Muskegon County Wastewater Management System was responsible for the reductions in phosphorus and nitrogen in Mona Lake. In addition, phosphorus and ammonia concentrations remain much greater in the bottom waters than the surface waters, especially during times of anoxic conditions, suggesting internal loading is an important source of nutrients to Mona Lake.

Nutrient bioassays revealed that algal biomass and productivity were limited by: P or N+P in spring, N or N+P in summer, and neither in fall. This is in contrast to studies conducted in 1972, when N was clearly the limiting nutrient in Mona Lake. The reduction in phosphorus levels over the past 30 years has resulted in this response change, but additional bioassays should be conducted to confirm the 2003 results.

Nutrient concentrations and loads in the inflows to Mona Lake indicate that the watershed is contributing relatively high levels of total phosphorus, ammonia, and fecal coliforms. Distinct seasonal patterns were not apparent, although concentrations of some constituents did increase after storm or rain events, as might be expected for chemicals that adsorb to particles. Although some of the storm drains contribute high concentrations of stressors at certain times of the year, the overall loads from these drains are small (due to low discharges on an annual basis). Hence, they may affect Mona Lake on a localized basis (near their discharge point), but it is unlikely that they are having severe lake-wide impacts. Black Creek is the largest contributor, by mass, of materials to Mona Lake; even though the concentrations in Black Creek are comparable to other inflows, its high discharge results in the greatest loads.

A GIS-based hydrologic model was developed for the Mona Lake watershed. The model couples WMS, for watershed delineation, to HEC-HMS, for hydrologic modeling to derive output. Modeling results indicated that most of the water entering Mona Lake comes from: Black Creek (80%), Little Black Creek (5.6%), Cress Creek (5.3%), and Ellis Drain (3.0%). According to the overall water budget analysis, more than 70% of the stream flows originated from baseflow for all subbasins in the watershed.

Sediments were found to be highly contaminated with cadmium, chromium, lead, PAH compounds, benzo(a)pyrene, and PCBs in Little Black Creek. Samples collected from Cress Creek failed to find contaminant levels of concern. Results provided preliminary evidence that contaminated sediments are being transported within Little Black Creek, and within Mona Lake, as well. Contaminant concentrations at one station in Mona Lake are higher now than in 1980. Additional sampling is needed to confirm these results.

The fish and macroinvertebrate survey indicated that Black Creek and Little Black Creek are impaired systems. Macroinvertebrates were impacted both by poor quality habitat and poor water quality, as pollution tolerant taxa dominated in most sites. Sculpin dominated the fish community in Black Creek, suggesting that water temperature and water quality are sufficient to sustain populations of cold-water fishes. In contrast, the fishes collected in Little Black Creek were indicative of warmer water, as the most common taxa were creek chub, stickleback, and mudminnow.

Changing land use patterns, excessive nutrients, excessive sedimentation, and contaminated sediments are the major environmental problems facing the Mona Lake watershed. Specific recommendations are provided for each problem. The recommendations are varied, depending on the nature of the problem, and include public engagement and education, policy initiatives, additional research, and implementation of best management practices. The formation and incorporation of the Mona Lake Watershed Council, along with recently approved funding of several new projects in the watershed, will help sustain the momentum that has been generated from this project. A watershed management plan, which integrates the existing information on the watershed, identifies the critical issues in the watershed, and lays the groundwork for future implementation needs, is the critical next step in sustaining and restoring the ecosystem services and functions in the Mona Lake watershed.

1.0 Introduction

1.1 Watershed Background

Approximately 11,000 years ago, the glacial activity that formed the Great Lakes also created the Mona Lake watershed. Wind-induced erosion of coastal sand dunes, in combination with large scale fluctuations in Lake Michigan water levels, resulted in the formation of the Mona Lake drowned rivermouth and the wetland complexes associated with the lower reaches of Little Black Creek and Black Creek. In its natural state, the Mona Lake watershed was a complex ecosystem of dense riparian pine and hardwood forests, sprawling wetlands and marshes, inland ponds, and meandering streams. The system was drastically changed first in the late 1800s as the region's timber resources were harvested, leaving behind either barren riparian zones or agricultural fields. This was followed in the 1900s by an era of development that resulted in the filling of wetlands, the channelization of streams, and the construction of urban and industrial centers with a host of problems related to sewage discharges and the release of hazardous materials.

The soils in the watershed are mostly Spodosols and Histosols, and the dominant forest type is oak-hickory. The Mona Lake Watershed is relatively small in area (~ 200 km^2 or 48,000 acres), and is located almost entirely within Muskegon County, except for a small section that is located in Newaygo County (Fig. 1.1). The watershed consists of three major hydrographic features: Mona Lake, Black Creek, and Little Black Creek, although there are a number of smaller tributaries and storm drains that enter the north and south sides of Mona Lake (Fig. 1.2).

Like most aquatic ecosystems in the Great Lakes, the Mona Lake watershed is being impacted by a variety of stressors. Whereas the generic problems facing the Great Lakes include cultural eutrophication, invasive species, and loss of habitat associated with changing land use patterns (Wiley et al. 1997, Carpenter et al. 1998, Vanderploeg et al. 2002), specific challenges facing the Mona Lake watershed include past industrial and wastewater activities and current trends of increasing urbanization and exurbanization (see Section 3.1 for more details).

Today, the Mona Lake watershed is a divergent system of scenic and biologically productive areas contrasted with locations that are subject to the adverse impacts of excessive sedimentation and nutrient loading, the presence of contaminated sediments, the continued release of hazardous materials from abandoned industrial sites, and pressures related to population expansion. The continued development of the riparian zone plus the uncontrolled input of nutrients, hazardous contaminants, and sediment has resulted in significant degradation of this valuable resource and impeded restoration efforts.

Figure 1.1. Location of Mona Lake Watershed.

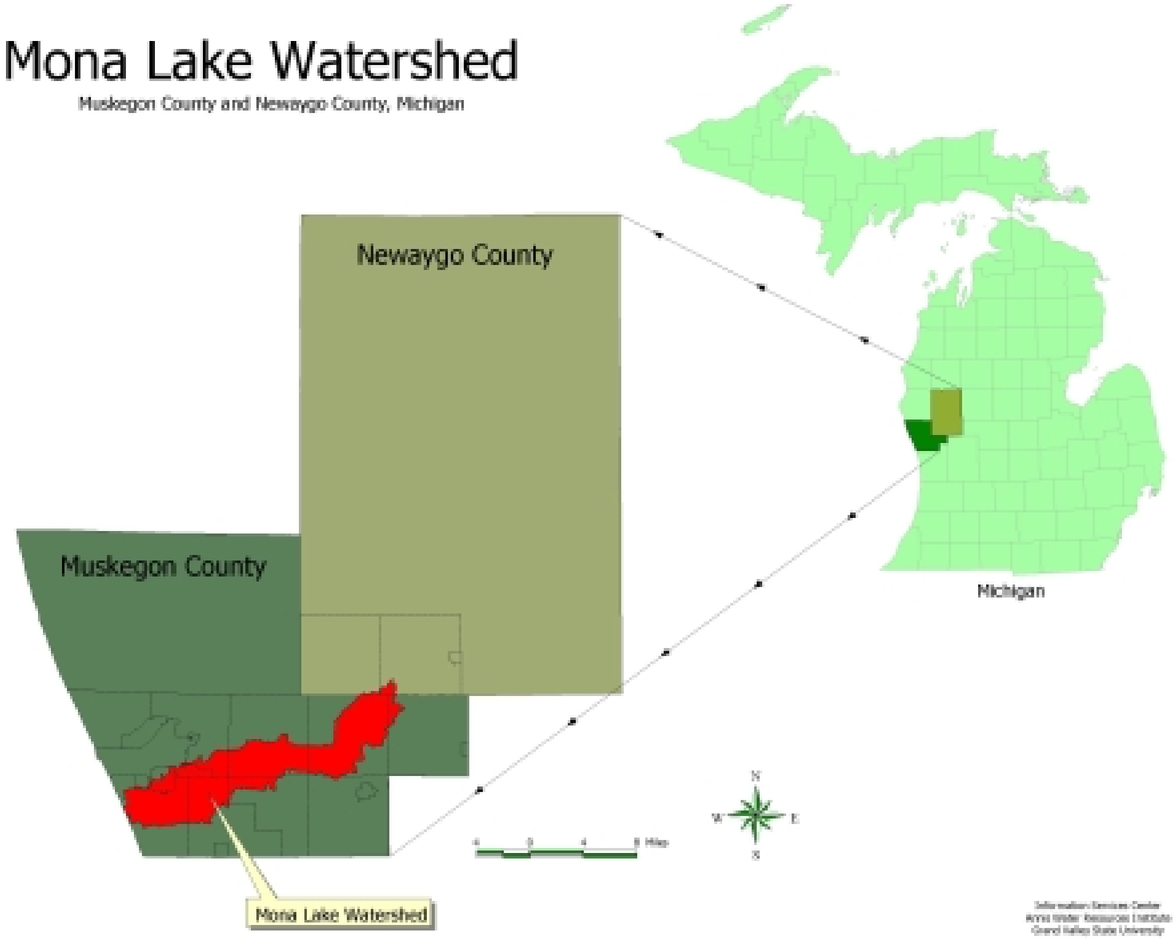
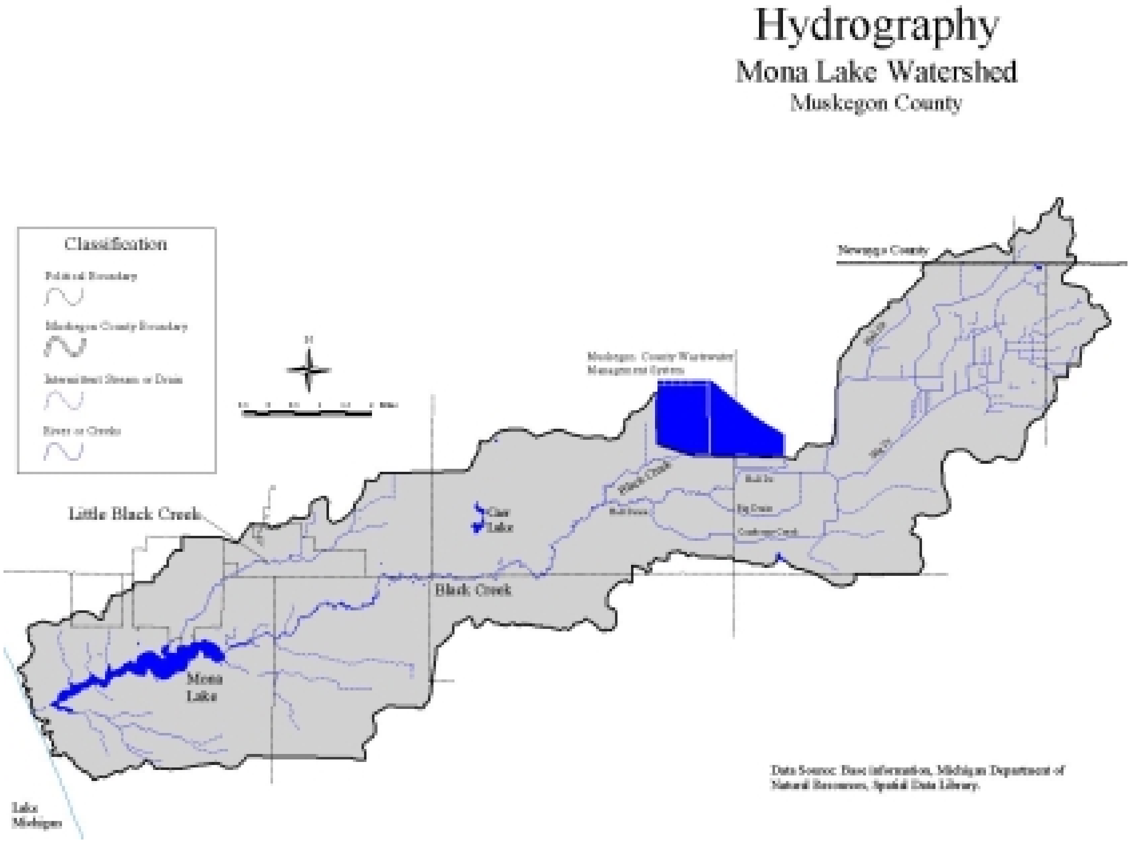


Figure 1.2. Hydrography of Mona Lake Watershed.



Data Source: Base information, Michigan Department of Natural Resources, Spatial Data Library.

Each of the main water bodies suffers from chemical and biological degradation, and are described in more detail below.

Mona Lake:

Mona Lake has a surface area of approximately 2.65 km^2 (~ 655 acres), or about 1.4% of the total watershed area. Based on surveys conducted in the 1970s, mean hydraulic retention times (i.e. how long a molecule of water entering into the lake would reside there before being discharged to Lake Michigan) varied from 105 to 160 days during low flow periods to less than 35 days during high flow periods (Evans 1992).

Very high concentrations of phosphorus have been recorded in Mona Lake, including averages of 387 parts per billion (ppb) prior to wastewater diversion to the Muskegon County Wastewater Management System (USEPA 1975) and 134 ppb in 1975 following diversion (Freedman et al. 1979). These concentrations of phosphorus in the water column greatly exceed total phosphorus water quality standards, which generally vary from 15 ppb (CWP 2000) to 25 ppb (EEA 1999).

Documented impacts on biota in Mona Lake extend back to 1956, when fish kills were frequently reported presumably because of low dissolved oxygen concentrations (as reported in Evans 1992). In 1971, fish surveys indicated few game fish present. Phytoplankton (floating, microscopic plants) and benthic macroinvertebrates (growing in sediments) are often used as indicators of water quality (Hellawell 1986, Rosenberg and Resh 1993). In the early 1970s, Mona Lake was dominated by cyanobacteria (Meier 1979), which are usually indicative of excessive phosphorus concentrations. The benthic macroinvertebrate data also indicated degraded water quality, as denoted by low density of animals, low diversity of animals, an absence of mollusks, and very sparse amphipod (scud) populations (Evans 1992).

Black Creek:

Black Creek is the major tributary to Mona Lake (Fig. 1.2), and discharges into the lake at its east end. Based on data collected prior to the construction of the Muskegon County Wastewater Management System, Black Creek accounted for approximately 75% (1.3 m/s) of the surface water discharge to Mona Lake (Evans 1992). One of the major sources of industrial wastewater to Black Creek at that time was Lakeway Chemical (4875 m^3/d; Evans 1992). Simulation results from a newly developed hydrologic model (see Section 3.5) suggest that Black Creek accounts for about 80% of the total surface water discharge to Mona Lake on an annual basis.

Black Creek is a designated coldwater stream, although it does not meet its designation. Its headwaters have been converted to drains over the years, and were significantly altered with the construction of the Muskegon County Wastewater Management System (WWMS; Fig. 1.2). Two CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) superfund sites with contaminated (volatile organic compounds) groundwater capture and treatment facilities (Bofors-Nobel, Inc. [previously Lakeway Chemical] and Thermo-Chem, Inc.) adjacent to the stream are located between Wolf Lake and Mill Iron Roads (MDEQ 2002). Control measures, especially at the WWMS and the former Lakeway Chemical site, have reduced the input of toxic contaminants to the creek, although contaminated groundwaters are still suspected of venting to the creek (MDEQ 2002). Defined sources of discharge to Black Creek include the WWMS, the two EPA superfund sites (above), Bekaert Corporation (an industrial storm water permit) and 39 storm water runoff sites during wet weather events (i.e. classified under the Phase II program—municipal, township, road commission, county drain commission, and/or private).

A fish consumption advisory was issued for Black Creek based on PCB concentrations in carp and white sucker that were collected in 1987. However, given the absence of known PCB sources on Black Creek, it is possible that the fish came from Mona Lake or Lake Michigan (MDEQ 2002). Black Creek is not actively managed as a trout stream by the MDNR Fisheries Division; the last native trout presence in the creek was in the early to mid-1960s (MDEQ 2000). Brown and brook trout were planted in the creek from 1987-1989, but these trout apparently disappeared within 2-3 years of the plantings.

A TMDL (Total Maximum Daily Load) was developed for Black Creek in 2003. The creek was placed on the section 303(d) list (indicating it does not meet Water Quality Standards) because of a poor rated fish community and insufficient numbers of individual fish. MDEQ's review of available data suggested that the primary reason for the presence of a poor fish community is excessive sand bed load in the channel. MDEQ recommends two Best Management Practices (BMPs) to reduce soil erosion and excessive runoff rates to Black Creek: 1) upgrade and maintain the current vegetative riparian zone; and 2) changes in the storm water permits program to reduce sediment loadings and excessive runoff; specific activities or locations are not identified.

Little Black Creek:

Little Black Creek is a first order stream that flows through heavily urbanized areas, including sections of Muskegon and Muskegon Heights. Hydrologic model simulations (see Section 3.5) indicate that Little Black Creek contributes approximately 5.6% of the surface water discharge to Mona Lake on an annual basis. A number of industries are located adjacent to this waterway, and discharge directly into the creek (see Appendix 6.5: Williams and Beck 2003), although clean-up activities have been initiated at some of these sites (MDEQ 2000).

Historically, sources of contamination and impaired water quality included the following:

- Marathon Petroleum refinery site
- Keating Avenue storm sewer (oils, grease, heavy metals, PCBs)
- Peerless Plating site (cadmium, chromium, copper, nickel, zinc; pickling operations)
- Municipal sanitary/industrial wastewater pump station at Getty Road
- Municipal landfill upstream of Broadway
- Merriam Street storm sewer

The Marathon Petroleum, Peerless Plating, and landfill sites are all no longer in operation, but they remain sites of environmental concern because contaminants continue to impair water quality in Little Black Creek. Based on surveys conducted in 1996 and 2001, the sediments throughout Little Black Creek are heavily contaminated with a number of metals and organic chemicals (MDEQ 2000, 2002). Concentrations of PAH compounds, cadmium, zinc, and arsenic exceed sediment quality guidelines (MacDonald et al. 2000) at many of the sampling locations. Levels of heavy metals and solvents were also found in the water samples collected at the same locations. Ambient water concentrations did not exceed their respective Michigan Water Quality Standards. MDEQ (2000, 2002) surmised that the number and concentration of metals and organic chemicals in the sediments were sufficient to impact the biotic community of the creek. In addition, the 2001 data showed little improvement in levels of chemical contamination compared to the data from the previous surveys in 1991 and 1996.

As in the case of Black Creek, Little Black Creek does not meet its coldwater designation, with very limited numbers of fish collected at 2 of the 3 sites and the macroinvertebrate community scoring a poor or acceptable rating at all three sites

(MDEQ 2000, 2002). A fish taint (taste) test was conducted in 1977 using caged brown bullhead catfish placed in Little Black Creek near Seaway Drive for two weeks. The test indicated a discernible tainting of the flavor (Kenaga 1977).

A TMDL (Total Maximum Daily Load) was developed for Little Black Creek in 2003. The creek was placed on the section 303(d) list, indicating it does not meet Water Quality Standards. The impaired designated uses include the lack of support of coldwater fish and other aquatic life (macroinvertebrates). MDEQ's review of available data suggested that the primary reason for the biological impairment is excessive sedimentation and flashy flow conditions due to elevated runoff/washoff and associated TSS loads from the impervious urban areas in the watershed. Despite the presence of toxic sediments, MDEQ believes these deposits are too localized to have widespread impact. MDEQ recommends the same two Best Management Practices (BMPs) for Little Black Creek as those they recommended for Black Creek. In order to reduce soil erosion and excessive runoff rates to Black Creek, they recommend the following: 1) upgrade and maintain the current vegetative riparian zone; and 2) changes in the storm water permits program to reduce sediment loadings and excessive runoff; specific activities or locations are not identified.

In summary, both Mona Lake and its major tributaries, Black Creek and Little Black Creek, are suffering from chemical and biological degradation (Evans 1992; MDEQ 2000, 2002). Although a number of studies have been carried out in either the lake or the tributaries, many were conducted over two decades ago and none were well integrated. Over 20 years ago, the West Michigan Shoreline Regional Development Commission (WMSRDC 1982) identified the following important issues in the watershed:

- Mona Lake – nuisance algal blooms, excessive phosphorus loading, sediment contamination
- Little Black Creek and Black Creek – sediment contamination with heavy metals and organic chemicals, uncontrolled contaminant sources including landfills, storm sewer outfalls, and groundwater infiltration, high phosphorus and bacterial levels.

The data presented in the current study reveal that some progress has been made in the past 20 years, although it is clear that many problems still persist.

1.2 Project Objectives and Task Elements

The objectives of this project were to conduct a preliminary assessment of the aquatic and terrestrial habitats and contamination sites present in the Mona Lake watershed and to identify areas of significant change and degradation. This included a comprehensive set of biological and water chemistry samples on all inflows to Mona Lake and on Mona Lake, itself. These samples were collected to assist in our understanding of the consequences of specific land use stressors on the ecological integrity of the watershed. Change analyses in land use and watershed characteristics were based on GIS, comparing 1978 data (Michigan Resource Information System [MIRIS]) with data from

1996/1997/1998, developed by AWRI's Information Services Center. Specific objectives and task elements are summarized below:

- Review existing hydrology and ecology data and identify significant data gaps;
- Review and compare 1978 MIRIS data with 1996/1997/1998 AWRI data, and determine areas that have undergone significant landcover changes;
- Inventory environmental conditions and develop an assessment of current status. The environmental inventory consisted of the following parts:
  1) Assessment of current landcover conditions on a regional basis
  2) Sources of contamination such as landfills, abandoned industrial sites, groundwater plumes, and storm sewer outfalls
  3) Sampling and analysis of selected locations in the watershed for anthropogenic contaminants and biological impacts.
     - A limnological assessment of Mona Lake, consisting of a) monthly surveys of water quality in the lake, and
       b) quarterly nutrient enrichment experiments to determine what nutrient, if any, limits the growth of phytoplankton in Mona Lake;
- Identify key issues and areas of concern in the Mona Lake watershed

2.0 Existing Information

A considerable number of studies have been conducted in the Mona Lake Watershed over the past three decades. In this section, we discuss the purpose, scope, strengths, weaknesses, and overall conclusions of these studies. It should be noted that the results from these studies have not been published in the peer-reviewed literature. This does not imply that the data and conclusions are erroneous or suspect, but due caution should be applied.

2.1 Mona Lake Rehabilitation. 1975? West Michigan Shoreline Regional Development Commission.

Purpose: This report from WMSRDC, written either in 1974 or 1975 (J. Koches, pers. comm.), addresses possible solutions to the internal load from sediments in Mona Lake. With the diversion of municipal sewage from the Muskegon Heights sewage treatment plant to the Muskegon Wastewater Management System, there was a concern that the pollution that had been retained in the bottom sediments over the years must be addressed.

Scope: The report looks first at the feasibility of removing the sediments, and associated legal constraints, economic costs, and environmental concerns. It then discusses briefly possible alternatives to dredging, including nutrient inactivation, dilution/flushing, biotic harvesting, selective discharge, and lake bottom sealing. Finally, the report addresses ways to manage a eutrophic system, without regard to the actual sources, including aeration and circulation, biocides, and biologic controls.

Two appendices are included as part of this report, one containing Public Acts 345 and 346 from the Michigan State Legislature, dealing with inland lakes and streams, and the other two technical reports dealing with Mona Lake: 1) Mona Lake, its waters and sediments by Donald H. Williams (1974); and 2) Preliminary report on Mona Lake, Michigan by the EPA, Region V (1974). Williams analyzed the sediments and concluded that none of the metals present in Mona Lake muck were present in quantities that he deemed dangerous. Anomalously high lead concentrations from an earlier MDNR report were dismissed. The EPA study is discussed in more detail below (Report II).

Conclusions: WMSRDC recommended 5 steps to rehabilitate Mona Lake:

- Formulate a lake board
- Identify all sources of pollution before implementing large scale restoration efforts
- Prepare an engineering feasibility report to examine all possible alternatives for restoration
- Evaluate a combination of restoration techniques
- Investigate use of Muskegon Heights waste treatment facility for Mona Lake purposes

Strengths: This report was, in many ways, ahead of its time. The identification of internal loading as a potential future problem for the lake and the need to assess ways to control it, are only now being addressed some 30 years later. The report also highlights a variety of possible restoration techniques, and identifies potential issues associated with each one. Mona Lake homeowners did form an improvement association as recommended in this study; in addition, the Mona Lake Watershed Council was formed in 2003 to address issues at the watershed scale.

Weaknesses: The report, presumably by design, only scraped the surface of the ecological, economic, and engineering issues associated with various restoration approaches. This was an important first step, but these issues would need to be fleshed out in much greater detail, and updated with current regulations and better information, if they were to be implemented today.

2.2 USEPA. 1975. National Eutrophication Survey. Mona Lake, Muskegon County, Michigan. Working Paper No. 202. Pacific Northwest Environmental Research Laboratory, Corvallis, Oregon. 29 pp.

Purpose: This survey of Mona Lake was part of the EPA's National Eutrophication Survey, which was initiated in 1972 in response to a federal commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

Scope: Two stations in Mona Lake were sampled three times, and both Black Creek and Little Black Creek were sampled monthly in 1972, to develop information on nutrient sources, concentrations, and impact. This information, in turn, served as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point source and nonpoint source pollution abatement in lake watersheds.

Conclusions: The report concludes that Mona Lake is eutrophic; in fact, of the 35 Michigan lakes surveyed as part of this study, only one had greater concentrations of TP and dissolved phosphorus. However, the Mona Lake survey occurred prior to wastewater diversion from the Muskegon Heights sewage treatment plant (STP), so it is not surprising that these numbers represent more eutrophic conditions. Phosphorus loading to Mona Lake was dominated by the Muskegon Heights STP (84% of annual load), followed by Black Creek (12%) and Little Black Creek (1%). A bioassay indicated that phytoplankton in Mona Lake were nitrogen-limited, which is to be expected when phosphorus concentrations become excessive.

Strengths: This study provides important baseline information on Mona Lake water quality conditions and watershed loadings prior to diversion of the Muskegon Heights STP. In addition, the bioassay shows that the phytoplankton were nitrogen limited. Data appendices provide useful information.

Weaknesses: Lake sampling was limited: only two sites on three dates. In addition, comparisons with present conditions are constrained because the Muskegon Heights STP is now off-line. Only the major tributaries (Little Black Creek and Black Creek) were sampled.

2.3 WMSRDC (West Michigan Shoreline Regional Development Commission). 1978. The Region 14 Areawide Water Quality Management Plan. Parts One and Two.

Purpose: This two-part plan was intended to summarize background information related to water quality issues in the Oceana, Muskegon, and Ottawa Counties (Region 14).

Scope: The plan covers all the major drainage basins in the three-county region. For the Mona Lake drainage basin, details are provided for 1) planning area description; 2) population and housing; 3) land cover and use; 4) assessment of water quality; 5) sources of pollution; and 6) phosphorus loadings to Mona Lake.

Conclusions: The Mona Lake drainage basin is beset with serious water quality issues, including excessive nutrients from both point and nonpoint sources, fecal coliform levels above state standards, and chemical contaminant concentrations in violation of state water quality standards in Little Black Creek, Black Creek, and Mona Lake itself.

Specific recommendations for the Mona Lake drainage basin include: 1) extension of interceptor and collection systems; 2) reduce infiltration and inflow into wastewater collection systems; 3) rehabilitate existing collection systems; 4) research fate of influent pollutants, and monitor groundwater wells for toxic or hazardous pollutants, in the Muskegon County Wastewater System; 5) a series of recommendations for NPDES dischargers dealing with specific pollutants; 6) develop a Mona Lake urban stormwater project; 7) fund a Mona Lake toxics survey; 8) fund Little Black, Big Black Creek, and Mona Lake rehabilitation feasibility surveys and projects; 9) designate Muskegon County as regulator of on-site wastewater disposal systems; and 10) designate South Muskegon County Soil Conservation District as regulator for agriculturally-related sources of water pollution; among others.

Strengths: This plan provides a holistic view of the watershed, focusing on the social, economic, and natural resource sectors. It contains a comprehensive overview of conditions up through February, 1977, and is a valuable resource for locating a variety of data. Part II of the report contains an array of management recommendations to improve water quality in the region.

Weaknesses: The study does not provide any new limnological information. The recommendations will need to be updated if implementation is considered, due to changes in laws, local ordinances, and reorganization.

2.4 Freedman, P.L., Canale, R.P. and Auer, M.T. 1979. Applicability of Land Treatment of Wastewater in the Great Lakes Area Basin. Impact of Wastewater Diversion, Spray Irrigation on Water Quality in the Muskegon County, Michigan Lakes. EPA-905/9-79-006-A.

Purpose: This study was one of three reports, as part of a 3-year study (1972-1975), to obtain background and early operational data for a large land application system in Muskegon County conducted for EPA, Region V, by the Michigan Water Resources Commission. Observed and projected effects of wastewater diversion and treatment on water quality and ecosystem responses are described for lakes that drain into Lake Michigan.

Scope: The report covers the tributary-related considerations (hydrology, chemical concentrations, nutrient loads) and lake considerations (spatial and seasonal distributions, long-term changes) for Mona Lake, Muskegon Lake, and White Lake. Although additional studies were conducted in Muskegon Lake (nutrient bioassays) and White Lake (submerged aquatic vegetation), none was conducted in Mona Lake.

Conclusions: Mona Lake had the greatest nutrient concentrations and algae levels of the three lakes sampled. Prior to diversion, Little Black Creek contributed most of the phosphorus to Mona Lake (65%), although nutrient loads from nonpoint sources also were considered significant. Nutrient limitation of algal growth in Mona Lake was not expected because nutrient concentrations were excessively high.

Strengths: This is a very comprehensive study that complements the findings in Study II (above), although it should be noted that not all findings are consistent with that study, presumably reflecting different sampling times in the two studies, and different methods. It provides an important baseline against which to compare present-day conditions, and because sampling bracketed the period of diversion from the Muskegon Heights STP, the data can be used to address the initial efficacy of this diversion.

Weaknesses: No studies were conducted on organic chemicals, trace metals, suspended solids, pesticides, or other contaminants. Only the major tributaries (Little Black Creek and Black Creek) were sampled.

2.5 Mona, White, and Muskegon Lakes in Muskegon County, Michigan. The 1950s to the 1980's. 1982. Michigan Department of Natural Resources.

Purpose: The objective of this study was to determine the changes in Muskegon County lakes as a function of wastewater diversion to the Muskegon Wastewater Treatment System. Whereas other reports dealt with water chemistry and general limnology (USEPA 1979) and plankton dynamics (Meier 1979), this report focused on benthic community structure and sediment contamination. A final version was published in 1992 (Evans 1992).

<u>Scope:</u> The report provides information on the changes in benthic community structure and sediment contamination in Mona Lake, Muskegon Lake, and White Lake from 1972 to 1980, illustrating changes in these parameters following wastewater diversion. Additionally, historical data are given on these systems to provide perspective on the results of water pollution abatement activities in Muskegon County.

<u>Conclusions:</u> Benthic diversity and species richness have increased since wastewater diversion (as of 1980) and indicate partial recovery, but the benthos still reflects impaired water quality. Toxic sediment contaminants were still entering Mona Lake via Little Black Creek, but most sampling sites had reduced levels of heavy metals, with the exception of zinc.

<u>Strengths:</u> This report provides important baseline information on benthic invertebrates in Mona Lake, which will be helpful in establishing current status and trends for an important indicator. The report also provides a number of references to DNR studies in the Mona Lake watershed, which may be of value for establishing historical conditions. These internal documents have not been obtained as of yet, but should be pursued by the Mona Lake Watershed Council for their files (e.g. Evans 1976a, Evans 1976b, Evans 1979, Evans 1981, Sylvester 1977a, Sylvester 1977b).

<u>Weaknesses:</u> The taxonomic information is relatively coarse, so very few genera or species are included. No information is provided for the tributaries, so it impossible to evaluate fate and transport of the contaminants.

2.6 The Muskegon County Surface Water Toxics Study. 1982. West Michigan Shoreline Regional Development Commission, Muskegon, MI.

<u>Purpose:</u> This report had 3 main goals: 1) determine the concentrations of organic toxins and toxic metals in selected lakes and streams in Muskegon County; 2) evaluate the necessity, desirability, and feasibility of rehabilitation procedures for selected lakes; and 3) evaluate the necessity, desirability, and feasibility of additional stream pollution control measures.

<u>Scope:</u> The report consists of 3 separate documents: 1) Toxics Survey Technical Report; 2) Toxics Survey General Summary; and 3) Control Measure Options. The Technical Report contains a toxicological evaluation of test results and a review of biological data. The General Summary summarizes test results from each of the five program phases. The Control Measure Options offers general recommendations regarding pollution controls and further study.

<u>Conclusions:</u> The report found the Mona Lake drainage basin to be severely polluted, and identified 5 recommendations: 1) remove contaminated hot spots from Little Black Creek, Black Creek, and Mona Lake based on a comprehensive sampling and analysis strategy; 2) construct one or more sediment traps on Black Creek; 3) reoxygenate Mona Lake’s hypolimnion; 4) study the influence of upstream nonpoint sources and the urban

storm sewer system as pollutant sources; and 5) improve street sweeping, maintain catch basins, and enforce litter ordinances as better management practices.

Strengths: This study provides important data on toxic substances in the basin, and identifies a comprehensive list of management practices to improve water quality.

Weaknesses: No ecotoxicology tests were performed. Although the concentration data for contaminants are valuable, toxicology tests help provide additional evidence regarding the toxicity of the samples.

2.7 The Effects of Wastewater Land Treatment on Eutrophication in Muskegon County Lakes. 1982. LimnoTech, Inc, Ann Arbor, MI.

Purpose: This study was a follow-up to the one conducted between 1972 and 1975 to assess the immediate effects of the wastewater diversion and treatment on Muskegon County lakes receiving the wastewaters (see Study IV above).

Scope: This study updates the data originally collected between 1972 and 1975, including a screening of these prior data to remove anomalies, as well as new data collected in 1980 and 1981 on: 1) reductions in pollutant loads, 2) lake water quality trends; and 3) application of simple phosphorus models.

Conclusions: Mona Lake water quality improved in response to point source load reductions achieved through wastewater diversion. In particular, phosphorus concentrations declined 75-80% and dissolved inorganic nitrogen concentration declined 55-65%. An increase in the N:P ratio suggests algal species composition should result in fewer blue-green algae, although this was not examined as part of this study. However, chlorophyll and water transparency data were inconclusive because of the confounding effect of algicide applications in the lake.

Strengths: The updated data provide a better picture of how Mona Lake responded to wastewater diversion, and helps fill in the gaps between pre-diversion data and the present. The Vollenweider model data give a general idea of how much further load reduction is needed to achieve water quality standards in Mona Lake.

Weaknesses: There are no data on contaminants in Mona Lake, and the load data do not include continuous flow measurements.

2.8 A Limnological Survey of Mona Lake, Muskegon County, Michigan. 1996. Aquest Corporation, Flint, MI.

Purpose: Concern over growth of aquatic vegetation in Mona Lake resulted in this study, funded by the Mona Lake Improvement Association.

Scope: The report describes the aquatic vegetation of Mona Lake in 1995 and includes measurements of basic water quality parameters, including total phosphorus concentrations in select tributaries following dry and wet conditions.

Conclusions: Rooted macrophytes have the potential to become a nuisance in Mona Lake, with Eurasian watermilfoil identified as the problem species. Phosphorus loading data identified several hot spots, including Black Creek below U.S. Highway 31 as a major source.

Strengths: This is the first report providing information on submerged aquatic plants in Mona Lake. Also, the report provides more recent information on phosphorus loading data from the watershed, including both dry and wet periods.

Weaknesses: No abundance or biomass data were collected on the rooted macrophytes, only presence and absence. Some of the tributary locations are not clearly marked on their map.

2.9 The Mona Lake Watershed Study: An Analysis of Change. 1996. The West Michigan Shoreline Regional Development Commission.

Purpose: This report was intended to be a policy guide for elected and staff decision makers, and a reference tool regarding watershed conditions. It was an outgrowth of data collected previously for proposals regarding Mona Lake, which were not funded. The report differs from prior studies in that it focuses on 1) what can be done in the future to prevent increased degradation of water quality in the Mona Lake watershed, and 2) the land use patterns.

Scope: The report consists of: 1) a general background of the area; 2) socio-economic characteristics of the watershed, including political entities, current and projected population, housing distribution, and employment centers; 3) land use patterns in the watershed; 4) soils and land use models of projected water quality; 5) a survey of lake carrying capacity (i.e. human use); 6) best management practices; and 7) recommendations for zoning and land use modifications.

Conclusions: The study is intended to provide a baseline of information for decision makers, and does not draw scientific conclusions about the ecological health of the watershed, per se. It refers to Study VIII (above) for ecological status of Mona Lake.

Strengths: The study addresses the geographic and socio-economic characteristics of the watershed, and identifies a number of recommendations for improving watershed health in the long-term.

Weaknesses: The geographic data need to be updated and reliance on Study VIII for ecological status of Mona Lake is not recommended given the limited scope of that study.

2.10 MDNR/MDEQ Surveys of Little Black Creek and Black Creeks (including the following reports):

1) Biological Community Assessments of Black Creek, Muskegon County, Michigan. June 27-28, 1991 (as reported in MI/DEQ/WD-03/051).

The Michigan Department of Natural Resources (MDNR) used their Procedure #51 (P51) to assess the fish and macroinvertebrate communities, as well as habitat quality in Black Creek. Also, water and sediment samples were collected from 6 sites for chemical contaminants. Fish communities at all 7 stations were rated as poor due to the absence of trout. Macroinvertebrate communities at the 6 stations had ratings of acceptable to excellent. Overall habitat quality had ratings of fair to good, but the lack of exposed gravel beds, increased embeddedness of available substrate, and elevated amounts of sand, all indicated habitat impairment. Chemical contaminants were not detected in water samples. In sediments, none of the organic compounds analyzed showed high levels; however, chromium, copper, nickel, lead, and zinc exceeded statewide background concentrations but were substantially lower than probable effect concentrations (MacDonald et al. 2000) used to evaluate potential sediment toxicity to benthic organisms.

2) A Biological Survey of Big Black Creek, Muskegon County. August 1, 1996. MI/DEQ/SWQ-00/050.

This report is a follow-up to the 1991 survey, and includes the same parameters, although only 3 (instead of 7) stations were sampled in 1996. The fish community data indicate the creek is not supporting its coldwater designation (no trout). The macroinvertebrate community was rated excellent at the two upstream sites (Barnes and Wolf Lake Road stream crossings) and acceptable at the Mill Iron Road stream crossing. Presence of macroinvertebrates was constrained to small patches of good quality habitat. Habitat quality was rated fair at all 3 sites; the relatively high quality riparian component was offset by poor quality instream channel features (e.g. lack of exposed gravel, embeddedness, excessive sand). The water sample chemistry data suggest that the creek was meeting water quality standards. The sediment samples showed elevated concentrations of copper, arsenic, and phthalates (plasticizer chemicals); copper was about 2.5X greater than in 1991. Prior studies had indicated possible sources of contamination from the Lakeway Chemical facility (between Wolf Lake and Mill Iron Roads) and the Muskegon County Wastewater Treatment Plant, although control measures have been implemented.

3) A Biological and Chemical Assessment of Big Black Creek, Muskegon County. August 29, 2001. MI/DEQ/SWQ-02/030.

This report documents the macroinvertebrate community, habitat conditions, and concentrations of selected water and chemical constituents. Fish were not sampled, as there was no information to suggest the fish community had changed since the 1996 survey. Black Creek was supporting an acceptable macroinvertebrate community at 3 stations, however limited availability of high quality habitat (gravel, large woody debris) and the presence of excessive sand deposits constrain macroinvertebrate productivity. The water sample chemistry data indicate that the creek is generally meeting its water quality standards, although one station (a drain from the WWMS) had elevated total phosphorus and mercury concentrations. Sediment samples indicated possible problems with lead, zinc, and arsenic.

4) A Biological and Chemical Assessment of Little Black Creek, Muskegon County, August 2001. Michigan Department of Environmental Quality. MI/DEQ/SWQ-02/029.

This report updates information collected from previous surveys conducted in 1991 (Wuycheck 1992) and 1996 (Walker 2000). The fish community was rated poor at all 3 sites sampled, with no trout or sculpin present. The macroinvertebrate community was rated poor at 2 stations and acceptable at 1 station, showing some improvement from 1996 when all 3 stations were rated poor. Habitat quality ranged from fair to good, with habitat quality declining as one traveled from upstream to downstream. Water chemistry data from 6 sites indicated atypically high levels (although not in excess of water quality standards) for certain ions, metals, and volatile organic chemicals. Problems were site-specific, presumably representing localized sources of contamination. Sediment chemistry data were confounded by the absence of organic carbon data, which are used to normalize chemical concentration information in order to account for differences in sediment characteristics, which can bias the data. With this caveat in mind, the sediments remain contaminated with high concentrations of metals and organic chemicals, similar to what was found in 1996. Of particular concern was the site just downstream from Peerless Plating, where very high cadmium, copper, cobalt, nickel, and zinc concentrations were found. Elevated amounts of other contaminants, including polycyclic aromatic hydrocarbons, phthalates, and PCBs, were found in varying concentrations throughout the creek, many of which exceeded concentrations above which a toxic response would be expected. The report concluded that given the number and the concentrations of the metals and organic chemicals in Little Black Creek sediments, it is likely that the biological community is being negatively impacted.

5) In addition, a number of earlier reports were cited in the above literature, but AWRI was not able to obtain them for the purposes of this report. We list them here in chronological order for future reference, but are not able to describe their content or quality.

Willson, R. 1970. Biological investigation of Black Creek, vicinity of Lakeway Chemicals, Inc. Muskegon, Michigan. August 4, 1970. Bureau of Water Management, Michigan Department of Natural Resources. Report #001580, 7 pp.

Sylvester, S. 1977. Water Quality and Biological Survey of Little Black Creek. Michigan Department of Natural Resources Report #02870.

Evans, E. 1979. A biological evaluation of the Big Black Creek Basin, Muskegon County, Michigan. July 10 to September 7, 1978. Water Quality Division, Michigan Department of Natural Resources. Report #003460, 58 pp.

Evans, E. 1982. Sediments, water, and biota of Little Black Creek, Muskegon Heights, Michigan, June 11, 1982. Michigan Department of Natural Resources Report #04100.

2.11 The Mona Lake Stewardship Assessment. 2003. The Delta Institute.

Purpose: This study was a pilot project conducted by the Lake Michigan Forum, a committee of public stakeholders providing input to USEPA on the Lake Michigan Lakewide Management Plan. The Mona Lake Stewardship Assessment was geared at creating a permanent ethic of environmental stewardship in the local watershed. The Lake Michigan Forum characterized current existing stewardship activities in the watershed, and compared those against a "best-case stewardship scenario" for any watershed.

Scope: The report identifies clusters of recommendations under the following categories: 1) existing laws and planning efforts; 2) legacy pollution and remediation efforts; 3) pollution prevention and waste minimization; 4) stormwater management and nonpoint source pollution; 5) conservation and biodiversity; and 6) community engagement.

Conclusions: The report provides recommendations in each of the 6 categories listed above. It is recognized that implementation will be difficult, but it is recommended that stakeholders meet to discuss them and possibly prioritize their importance.

Strengths: The report is holistic in nature, and builds on previous efforts by WMSRDC to engage the public and all stakeholders in the solution process. The appendices summarize a considerable amount of useful information.

Weaknesses: The report, by design, is not meant to delve into fine detail on any one component. Not all information is specific to the Mona Lake watershed, as the report was designed to have transferability to other systems.

3.0 Inventory of Environmental Conditions

3.1 Land Use/Land Cover

3.1.1 Introduction

Land cover analyses were conducted for the entire watershed using MIRIS data from 1978 and updated data from 1997/1998. The 1997/98 data sets were compared to the 1978 information to assess changes in land patterns over time. These data are presented in Table 3.1.1 and Figures 3.1.1 and 3.1.2. It should be emphasized that although these are the most recent data available, land use changes in this watershed are occurring at a rapid pace. New commercial, retail, and residential developments are commonplace, especially around Norton Shores and the Fruitport Township, associated with the construction of The Lakes Mall. We suspect that because of rapid changes in the past five years that the net declines in agricultural use (Table 3.1.3) and net increases in developed use (Table 3.1.4) are underestimates relative to present conditions.

3.1.2 Land Use Patterns

In 1978, the percent of watershed under natural cover, agricultural use, and developed use was 49.0%, 24.4%, and 26.6%, respectively. This changed by 1997/98 to 51.8%, 16.5%, and 31.7%, respectively. Hence, the greatest degree of change was the loss of agricultural use (by almost one-third) and the increase in developed use.

Table 3.1.1. Percent change in major land use/land cover categories in Mona Lake watershed from 1978 to 1997/98.

Category	**% Total: 1978**	**% Total: 1997/98**	**% Change**
Natural Cover	49.0	51.8	+ 5.4
Agricultural Use	24.4	16.5	- 32.4
Developed Use	26.6	31.5	+ 15.6

Each major land use category can be broken down into finer classifications, which is helpful in determining the exact types of land use change over the past 20 years. For example, the natural cover data (Table 3.1.2) clearly show that in terms of acreage, the small overall increase in natural cover was largely attributable to the increase in open field. Overall, natural cover increased by 1282 acres from 1978 to 1998.

Table 3.1.2. Percent change in natural cover categories in Mona Lake watershed from 1978 to 1997/98.

Category	Acres: 1978	Acres: 1997/98	Net Change (Acres)	Net Change (%)
Barren/Sand Dune	70	99	29	41
Forest	16,655	16,511	-144	-1
Open Field	4591	5726	1135	25
Water	725	917	192	26
Wetland	279	349	70	25

Figure 3.1.1. Land Use/Land Cover from 1978 for the Mona Lake Watershed.

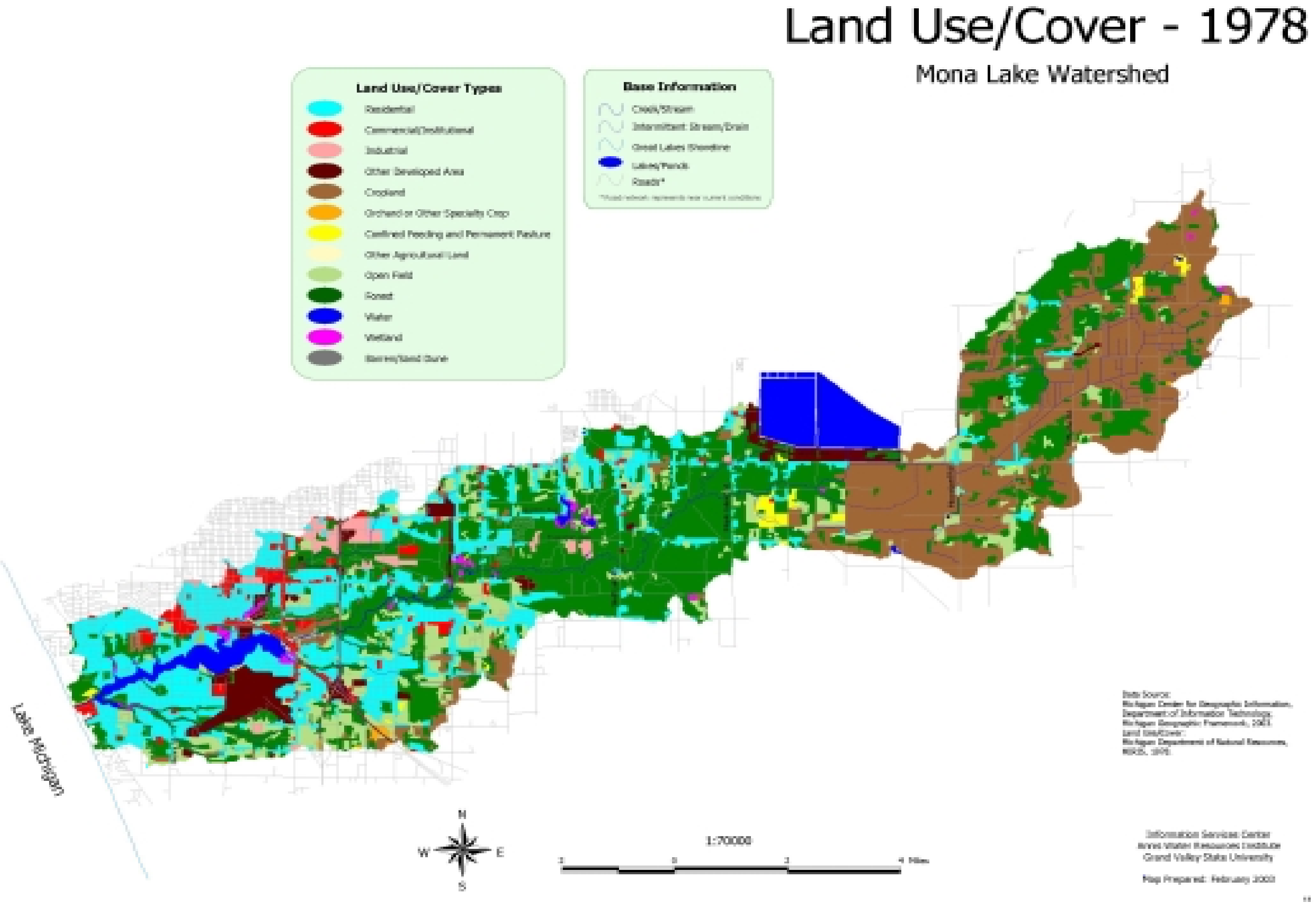
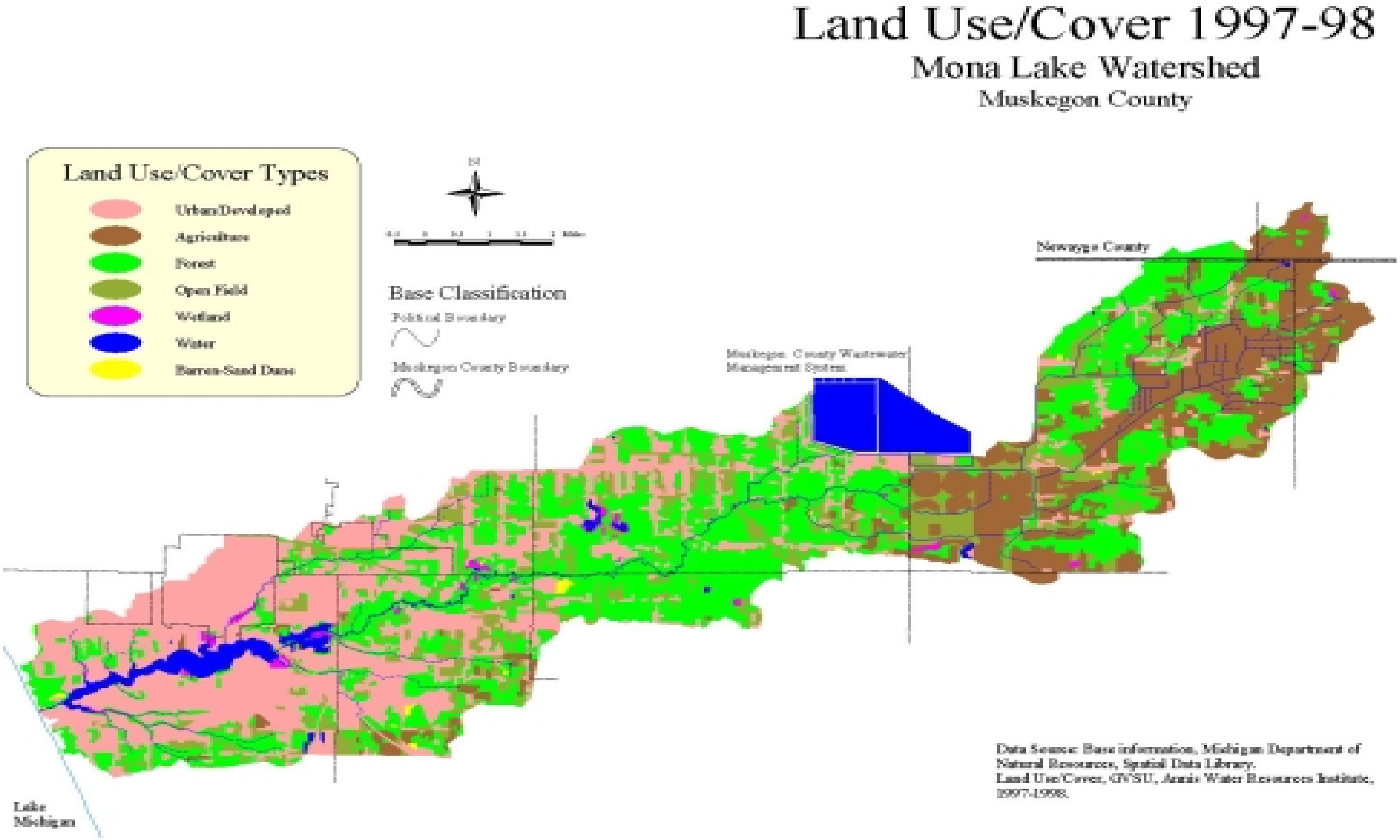


Figure 3.1.2. Land Use/Land Cover from 1997-98 for the Mona Lake Watershed.



Data Source: Base information, Michigan Department of Natural Resources, Spatial Data Library.
Land Use/Cover, GVSU, Annis Water Resources Institute, 1997-1998.

The agricultural use data (Table 3.1.3) show that in terms of acreage, the most substantial decline occurred in cropland with a loss of 3613 acres between 1978 and 1998. A relatively small decline in acreage devoted to confined feeding operations or permanent pasture was offset by acreage increases in orchard/specialty crop or other agricultural land. Overall, there was a net decline of 3611 acres in agricultural land use from 1978 to 1998.

Table 3.1.3. Percent change in agricultural use categories in Mona Lake watershed from 1978 to 1997/98.

Category	Acres: 1978	Acres: 1997/98	Net Change (Acres)	Net Change (%)
Confined feeding or permanent pasture	305	82	-223	-73
Cropland	10,711	7098	-3613	-34
Orchard or other specialty crop	88	283	195	222
Other agricultural lands	0	40	40	100

The developed use data (Table 3.1.4) reveal increases in all categories between 1978 and 1998, with an overall net increase of 2320 acres. The majority of this was due to an increase in residential land use, followed by commercial/institutional.

Table 3.1.4. Percent change in developed use categories in Mona Lake watershed from 1978 to 1997/98.

Category	Acres: 1978	Acres: 1997/98	Net Change (Acres)	Net Change (%)
Commercial/Institutional	1184	1733	549	46
Industrial	614	706	92	15
Other developed areas	1935	2092	157	8
Residential	8413	9935	1522	18

3.1.3 Summary

In summary, the Mona Lake watershed experienced a significant decline in agricultural land use between 1978 and 1998, especially with respect to loss of cropland. Presumably, most of this loss was converted to increases in developed land use (especially residential) and natural cover (largely open field). These changes are likely harbingers of future land use patterns unless steps are taken. This pattern should be of concern to advocates of farmland preservation and those attempting to mitigate the impacts of nonpoint source pollution from impervious surfaces.

3.2 Lake Water Quality

3.2.1 Introduction

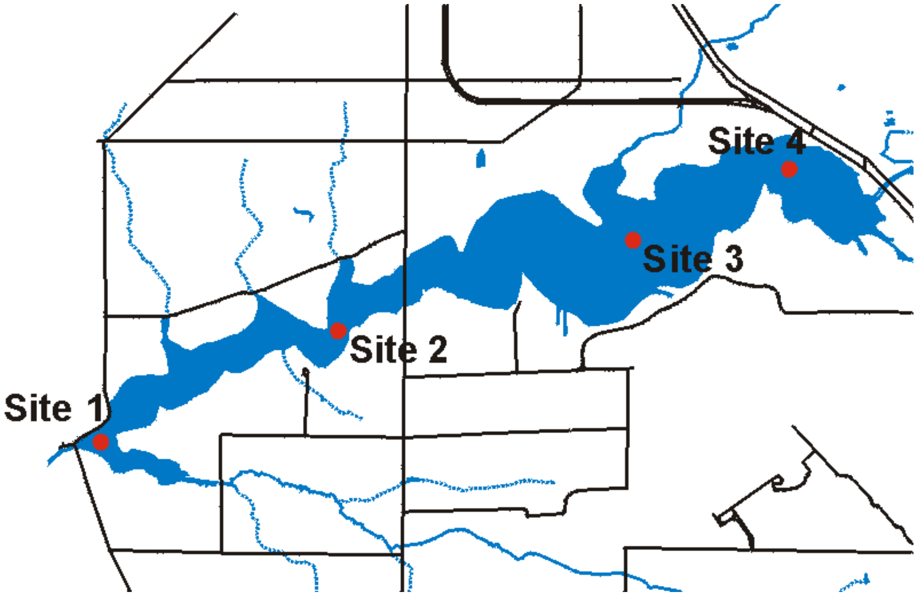
Early studies on Mona Lake showed that it suffered from excessive nutrients, degraded benthos, and sediment contamination (e.g. USEPA 1975, Freedman et al. 1979). However, results from later studies provided indications that conditions were improving, especially with respect to the nutrient levels in the lake, presumably as a function of wastewater diversion from the Muskegon Heights sewage treatment plant to the Muskegon County Wastewater Management System (LTI 1982, WMSRDC 1982, Aquest 1996)).

In this current study, our goal was to evaluate how Mona Lake has changed since the previous comprehensive study in 1982 (LTI 1982). This would help us determine if the initial benefits observed from wastewater diversion were being sustained. In addition, by sampling on a much more comprehensive temporal basis (monthly during ice-free season and once during ice cover) than prior studies, we could evaluate the effect of season on ecological processes in Mona Lake.

3.2.2 Methods

The four sampling sites reflected a compromise between choosing sites that were sampled in previous studies (Freedman et al. 1979) and our desire to sample where the Lake was being influenced by inflows of Black Creek and Little Black Creek. This decision process resulted in the selection of 4 sites (Fig. 3.2.1).

Figure 3.2.1. Sampling sites (red dots) in Mona Lake sampled on a monthly or bimonthly basis from May 2002 through August 2003.



The four sites, with corresponding latitude and longitude coordinates, included the following:

- Site 1: uplake of the Mona Lake Channel: 43.168889, 86.289167
- Site 2: mid-lake, west of the Henry Street Bridge: 43.175564, 86.269311
- Site 3: mid-lake, down-lake of Little Black Creek inflow: 43.180903, 86.244614
- Site 4: mid-lake, down-lake of Black Creek inflow: 43.185172, 86.23155

Physical and chemical parameters were measured at each site. Sampling occurred between 9:00 and 15:00 hours each day. A Hydrolab DataSonde 4a was used to measure depth, dissolved oxygen, pH, temperature, specific conductance, chlorophyll *a*, and total dissolved solids. A secchi disk was used to measure water clarity and a Li-Cor quantum sensor and data logger was used to measure incident and underwater irradiance. Water samples for nutrient analysis were collected with a van Dorn bottle and maintained at 4ºC until delivery to the laboratory. Nutrient analyses were performed on a BRAN+LUEBBE Autoanalyzer or by IC. Details of each analytical procedure are listed in Table 3.2.1.

Table 3.2.1. Analytical methods for chemical analyses.

Parameter	**Preparation**	**Preservation**	**Holding Time (d)**	**Reference or method**
Ammonia	--	Cool to 4°C	28	350.1*
NO_3	0.45 µm filter	Cool to 4°C	28	353.2*
SRP	0.45 µm filter	Freeze –10°C	28	365.4*
TP	--	H_2SO_4 Cool to 4°C	28	365.4*
Chloride and Sulfate				4110**

* USEPA (1983)
**AWWA (1989)

3.2.3 Results and Discussion

A. Physical Measurements

Water depth varied throughout the lake. The sites became progressively more shallow as one moved from west to east (Table 3.2.2). There were no obvious seasonal patterns in depth (Appendix 6.3).

Table 3.2.2. Mean and range (minimum to maximum) values for water depth (m), measured from May 2002 to August 2003 at 4 sites in Mona Lake.

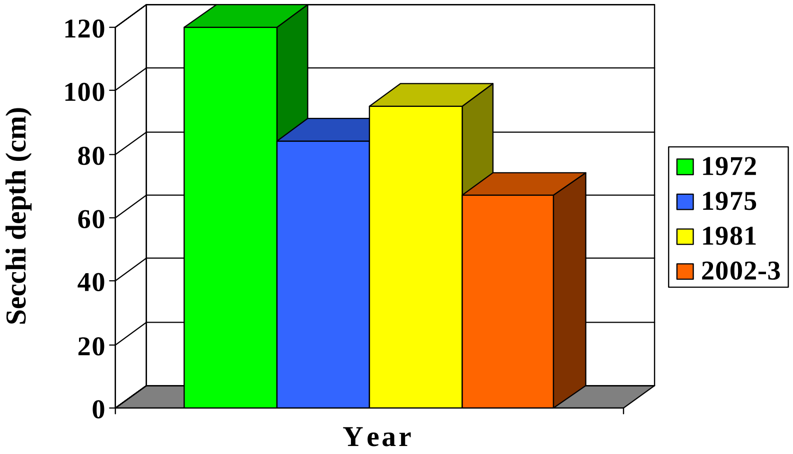
Site	Mean	Range (min-max)
Site 1	7.9	6.5-8.3
Site 2	6.9	5.5-7.6
Site 3	5.6	5.0-6.0
Site 4	4.1	3.5-5.0

Secchi disk depth is an indicator of water clarity. Mean secchi depth was less than 1 m at all sites (Table 3.2.3). In general, the lowest levels were observed during the summer, presumably due to phytoplankton growth (Appendix 6.3). Caution must be used when comparing secchi disk values from different studies in Mona Lake because readings were not taken at either the same stations or at the same times of the year, and some readings may have followed algicide applications. However, the data do suggest that water clarity has not improved since the early 1970s (Fig. 3.2.2); it does not appear that this reduction in clarity is due to more algal growth in the lake (see Fig. 3.2.8). Rather, it may be due to greater amounts of sediment entering Mona Lake from its tributaries or more resuspension of sediments due to lower lake levels.

Table 3.2.3. Mean and range (minimum to maximum) values for Secchi disk depth (cm), measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1	75	40 - 120
Site 2	63	25 - 95
Site 3	68	35 - 120
Site 4	60	40 - 100

Figure 3.2.2. Secchi disk readings (cm) from 1972 (Freedman et al. 1979), 1975 (Freedman et al. 1979), 1981 (LTI 1982), and 2002-3 (this study).



B. Hydrolab Measurements

The mean value and ranges for measurements taken by the Hydrolab in the tributaries are listed in Tables 3.2.4-3.2.7. Seasonal (5/10/02-8/12/03) changes in these parameters are provided in Figures 3.2.3-3.2.7.

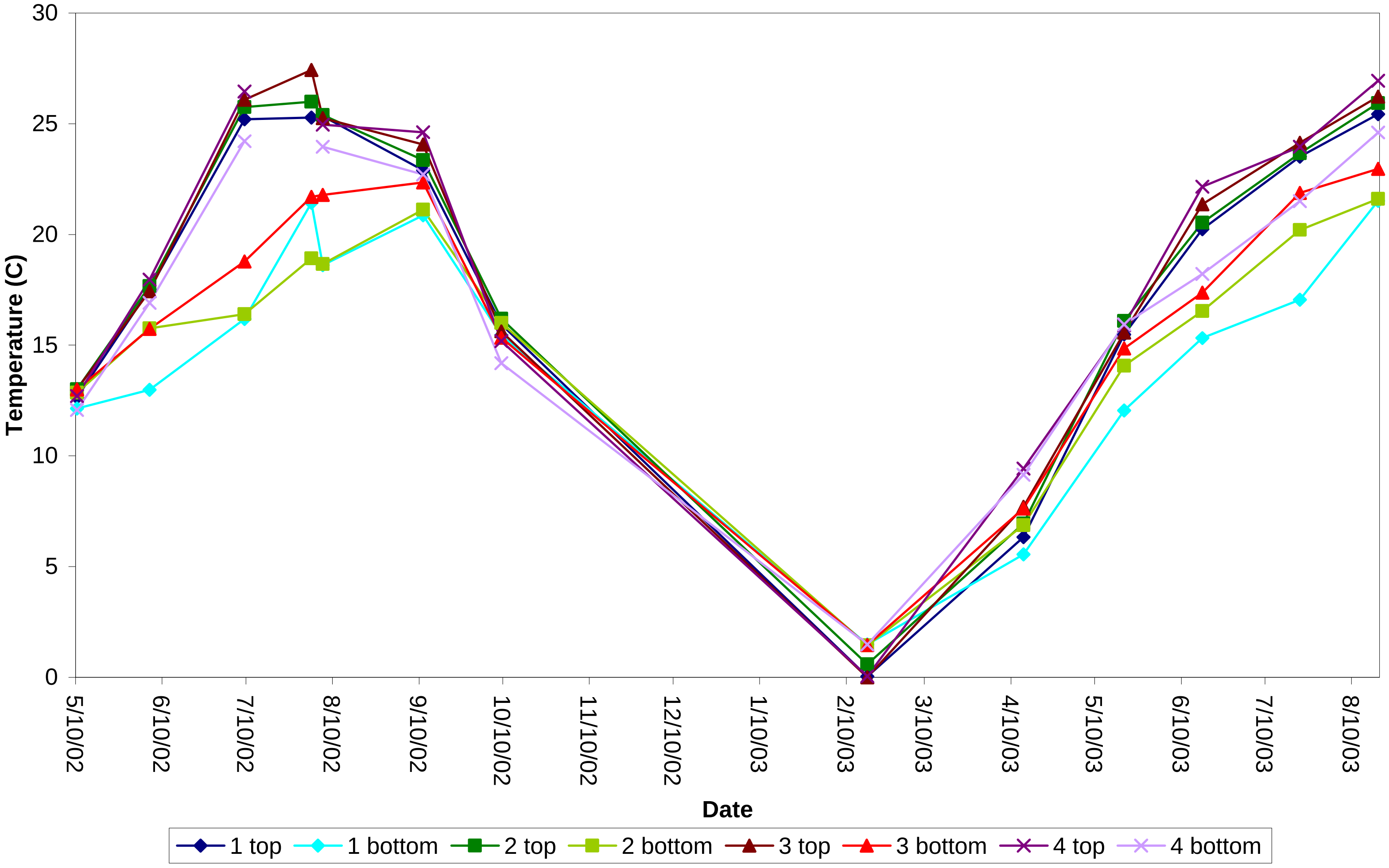
Temperature means at the surface were fairly similar across sites (Table 3.2.4), but bottom means showed a distinct gradient, with mean temperatures increasing as one moved eastward. This probably reflects a depth gradient. Seasonal patterns reflected a typical warm-summer, cold-winter cycle (Fig. 3.2.3).

Table 3.2.4. Mean and range (minimum to maximum) values for temperature (ºC), measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	18.14	0.04-25.43
Site 1 – bottom	14.67	1.48-21.52
Site 2 – top	18.55	0.59-25.99
Site 2 – bottom	15.42	1.44-21.61
Site 3 – top	18.76	0.00-27.42
Site 3 – bottom	16.52	1.46-22.96
Site 4 – top*	18.36	0.05-26.94
Site 4 – bottom	17.08	1.48-24.21

*Missing data for Site 4 (surface) on 8/2/02

Figure 3.2.3. Monthly temperatures (ºC): 5/10/02-8/19/03.



Dissolved Oxygen is often used as an indicator of water quality, with higher absolute levels and percent saturation reflecting better water quality conditions. Values less than 5 ppm are indicative of impaired water quality. Mean DO and percent saturated DO at both the surface and bottom water layers showed similar trends, with dissolved oxygen increasing as one moved from west to east in Mona Lake (Table 3.2.5). Anoxic conditions were observed at the lake bottom during the summer months (Fig. 3.2.4), with Site 1 experiencing the earliest onset of anoxia in both 2002 and 2003, and Site 4 experiencing the latest onset of anoxia in both years. 100% saturation or supersaturation was most frequent at surface samples; percent saturation in bottom samples approached that in surface samples during fall and spring turnover, but otherwise was either somewhat lower in winter months or very low during summer months (Fig. 3.2.5).

Table 3.2.5. Mean and range (minimum to maximum) values for dissolved oxygen (ppm) and percent saturation (%), measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean DO	Range (min-max)	Mean % Saturation**	Range (min-max)
Site 1 – top	9.40	5.82-13.69	97.4	65.3-128.5
Site 1 – bottom	2.84	0.00-12.09	26.0	0.0-94.7
Site 2 – top	9.59	5.75-15.26	100.5	67.9-134.5
Site 2 – bottom	3.71	0.00-13.75	33.7	0.0-111.3
Site 3 – top	9.90	6.71-13.97	106.7	83.6-130.9
Site 3 – bottom	4.09	0.00-13.02	38.2	0.0-107.7
Site 4 – top*	10.40	5.81-13.33	109.0	71.9-132.0
Site 4 – bottom	5.83	1.48-24.21	52.7	2.9-102.3

*Missing data for Site 4 (surface) on 8/2/02

**Missing data for Percent Saturation on 6/5/02 (all sites) and Site 4 (surface) on 8/2/02

Figure 3.2.4. Monthly dissolved oxygen (ppm): 5/10/02-8/19/03.

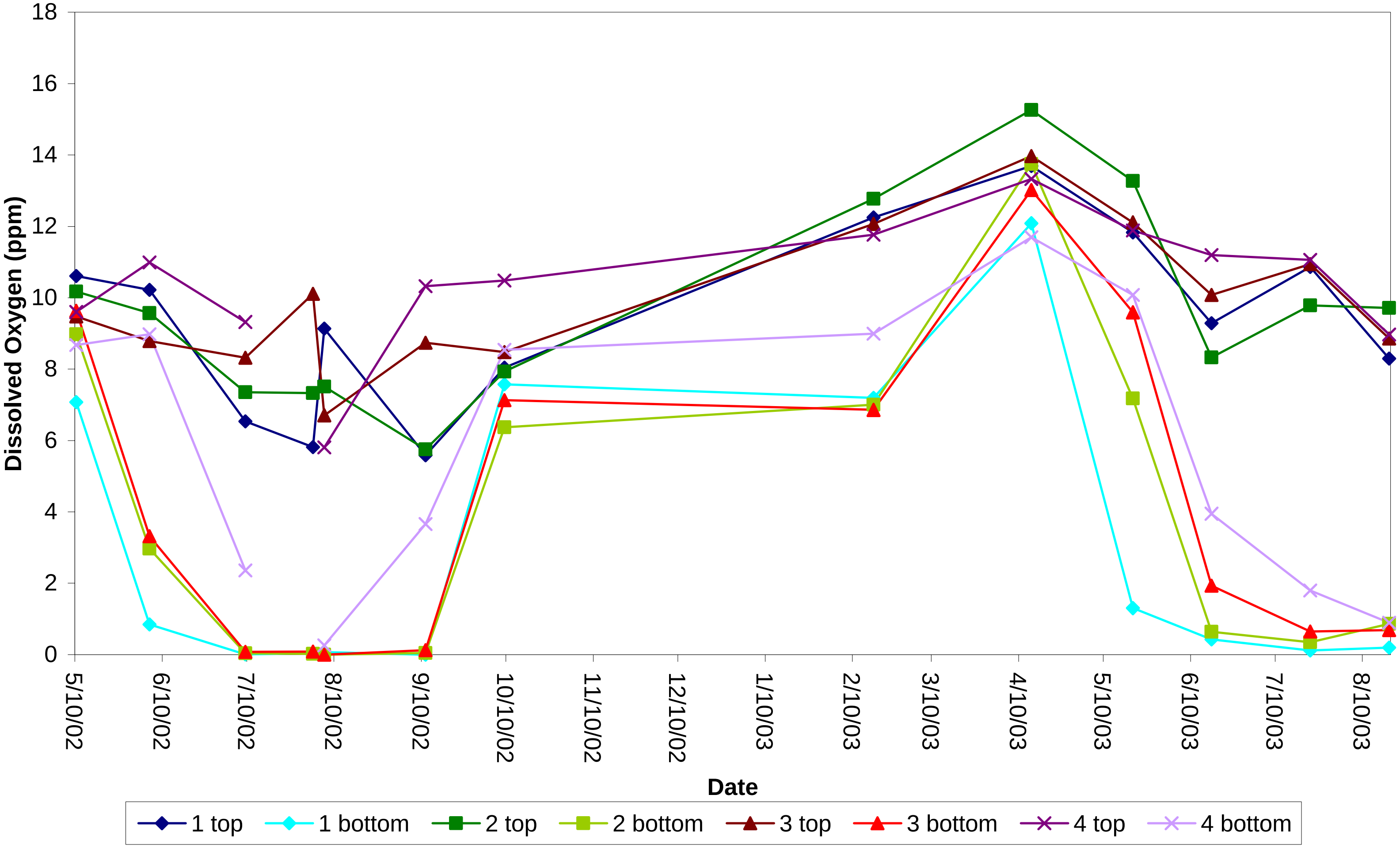
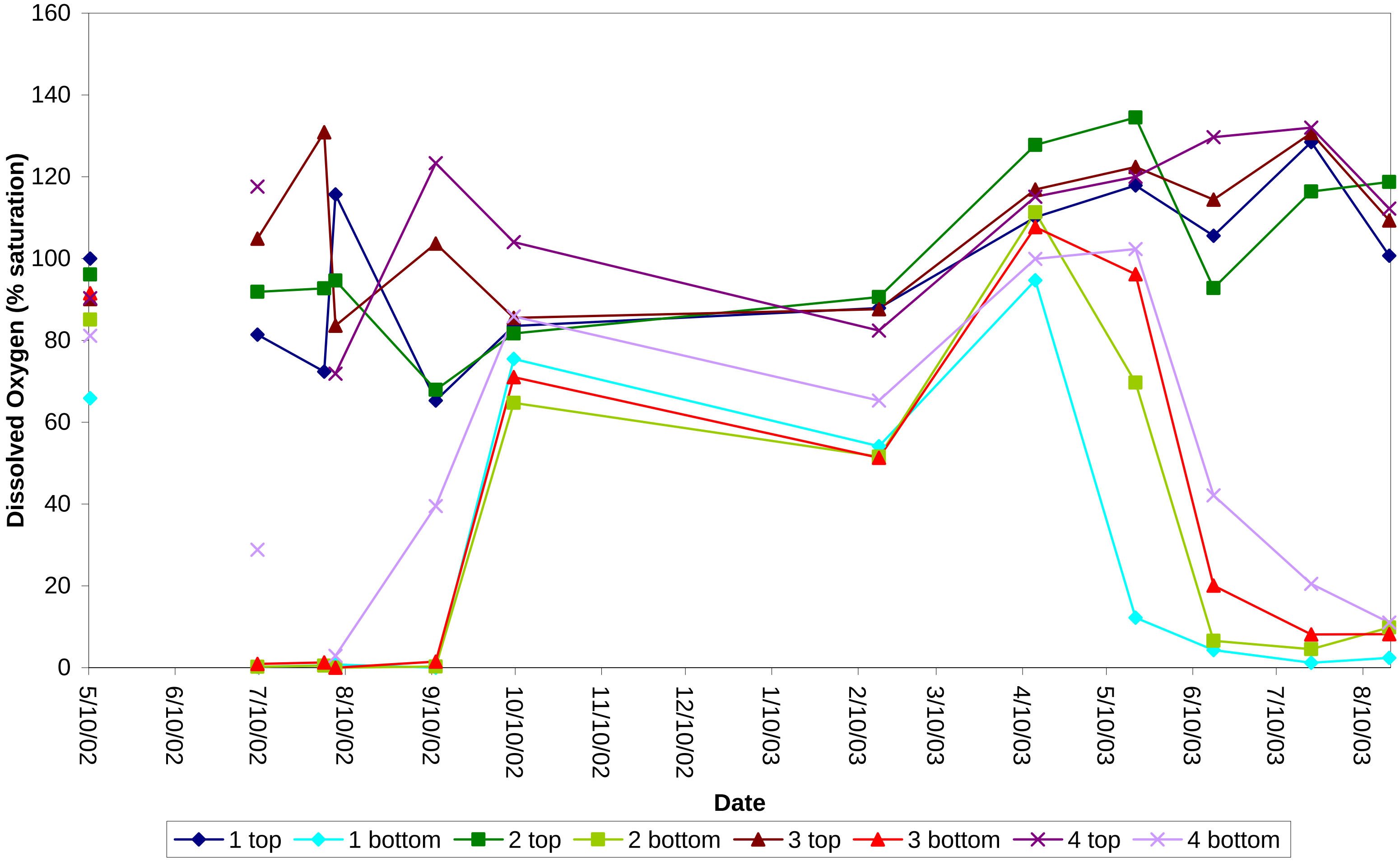


Figure 3.2.5. Monthly DO percent saturation (%): 5/10/02-8/19/03.



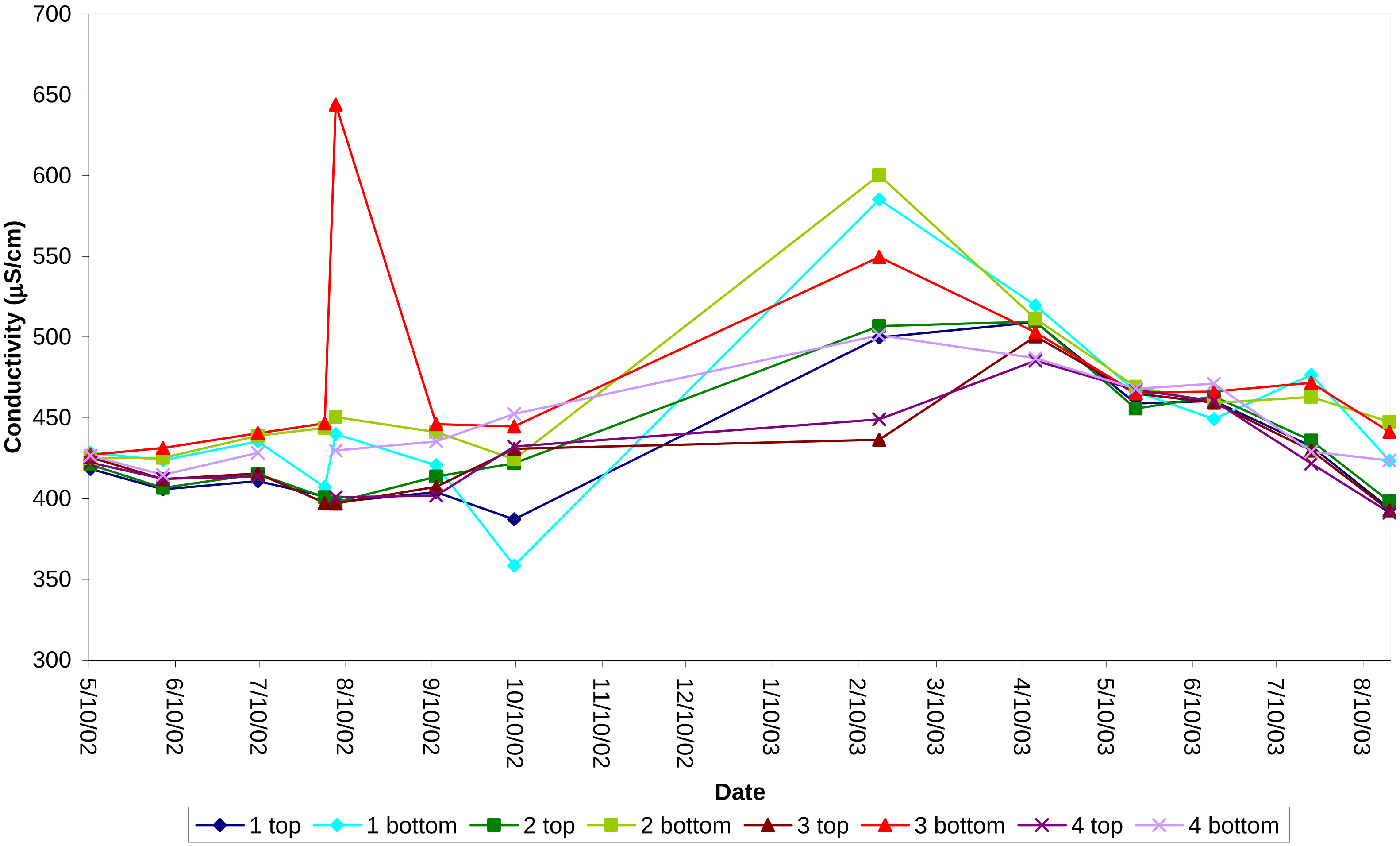
Specific conductance reflects the amount of ionized salts in solution. The values in Mona Lake were similar among sites, with bottom values typically 20-30 µS/cm greater than surface values (Table 3.2.6). There was evidence of seasonality, as the largest values were observed in February and April, presumably due to road salt runoff (Fig. 3.2.6; Appendix 6.3).

Table 3.2.6. Mean and range (minimum to maximum) values for specific conductance (µS/cm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	429.2	387.1-509.3
Site 1 – bottom	448.8	358.5-585.2
Site 2 – top	434.3	397.5-509.6
Site 2 – bottom	461.5	424.3-600.2
Site 3 – top	428.3	392.7-500.3
Site 3 – bottom	475.2	427.0-644.0
Site 4 – top*	429.8	391.2-485.4
Site 4 – bottom	447.2	414.7-501.2

*Missing data for Site 4 on 8/2/02

Figure 3.2.6. Monthly specific conductance readings (µS/cm): 5/10/02-8/19/03.



Chlorophyll *a* is the principal pigment used by plants and algae to absorb sunlight in the process of photosynthesis. As a consequence, chlorophyll *a* is often used as a proxy for algal biomass. Different standards exist for what level of chlorophyll indicates water quality impairment; a visible algal bloom is usually apparent at 20 ppb or above, and the USEPA has a threshold of approximately 3 ppb for lakes in this region of the United States. Muskegon Lake, another drowned river mouth lake just north of Mona Lake, averaged chlorophyll readings of 7 ppb in 2003. Mona Lake was considerably above the USEPA standard, with the lowest mean values at Site 1 (Table 3.2.7). This may be because Site 1 is most distant from many of the inflows contributing nutrients (see Section 3.4) or because this site is diluted with low-chlorophyll water from Lake Michigan when the wind is from the west. Chlorophyll *a* values peaked in the spring and fall; low summer values may be due to the applications of algicide (Fig. 3.2.7). As noted for the secchi disk data, caution must be applied when comparing water quality data from studies conducted in prior years, given potential differences in sampling sites and dates. This is particularly true for chlorophyll, as algicide applications will create artificially low chlorophyll concentrations. The data suggest that algal biomass is declining in Mona Lake relative to 1981, although chlorophyll concentrations still suggest water quality impairment (Fig. 3.2.8).

Table 3.2.7. Mean and range (minimum to maximum) values for chlorophyll *a* (ppb) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	14.3	3.2-44.6
Site 1 – bottom	10.1	0.0-41.2
Site 2 – top	17.4	2.5-45.5
Site 2 – bottom	15.7	0.0-56.6
Site 3 – top	17.1	6.5-41.0
Site 3 – bottom	20.5	0.0-54.2
Site 4 – top*	21.3	2.2-45.2
Site 4 – bottom	24.3	0.0-74.1

*Missing data for Site 4 on 8/2/02

Figure 3.2.7. Monthly chlorophyll *a* concentrations (ppb): 5/10/02-8/19/03.

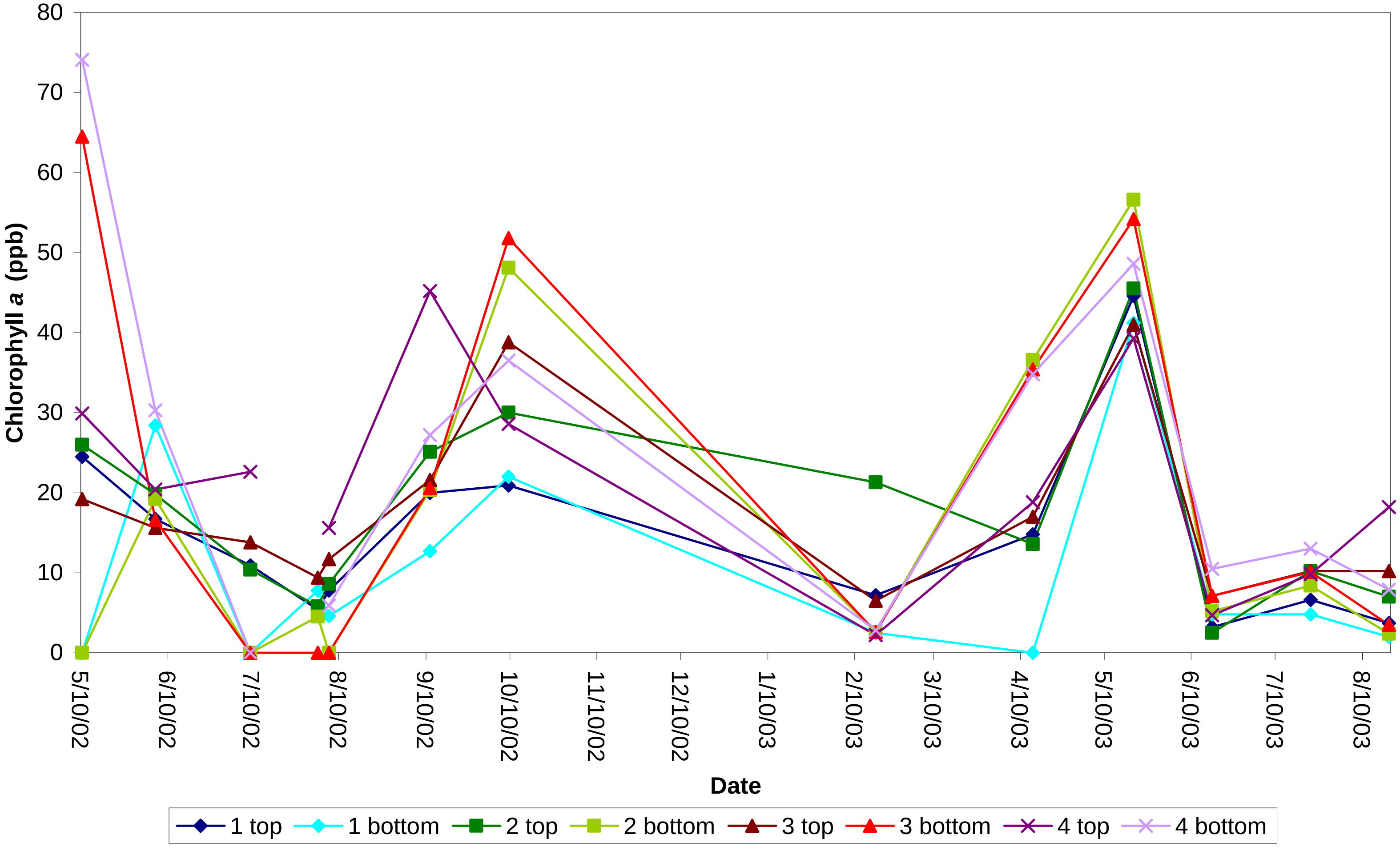
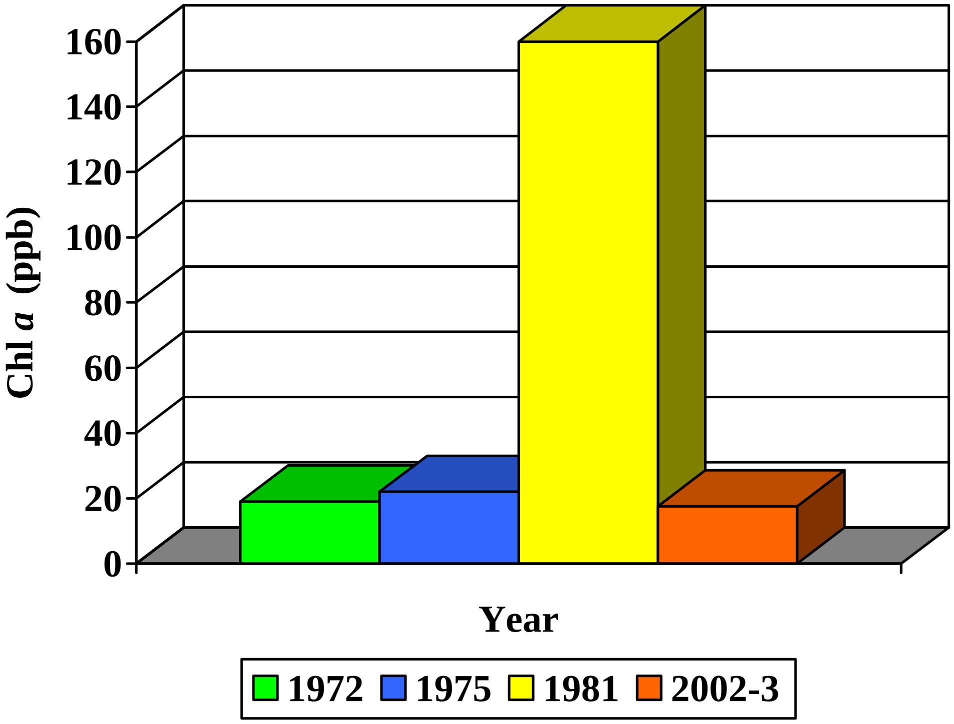


Figure 3.2.8. Chlorophyll *a* concentrations (ppb) from 1972 (Freedman et al. 1979), 1975 (Freedman et al. 1979), 1981 (LTI 1982), and 2002-3 (this study).



C. Nutrient Measurements

The mean value and ranges for the water quality and nutrient parameters measured at the four lake sites are listed in Tables 3.2.8-3.2.17. Seasonal (6/02-8/03) changes in major nutrient concentrations are provided in Figures 3.2.9-3.2.17.

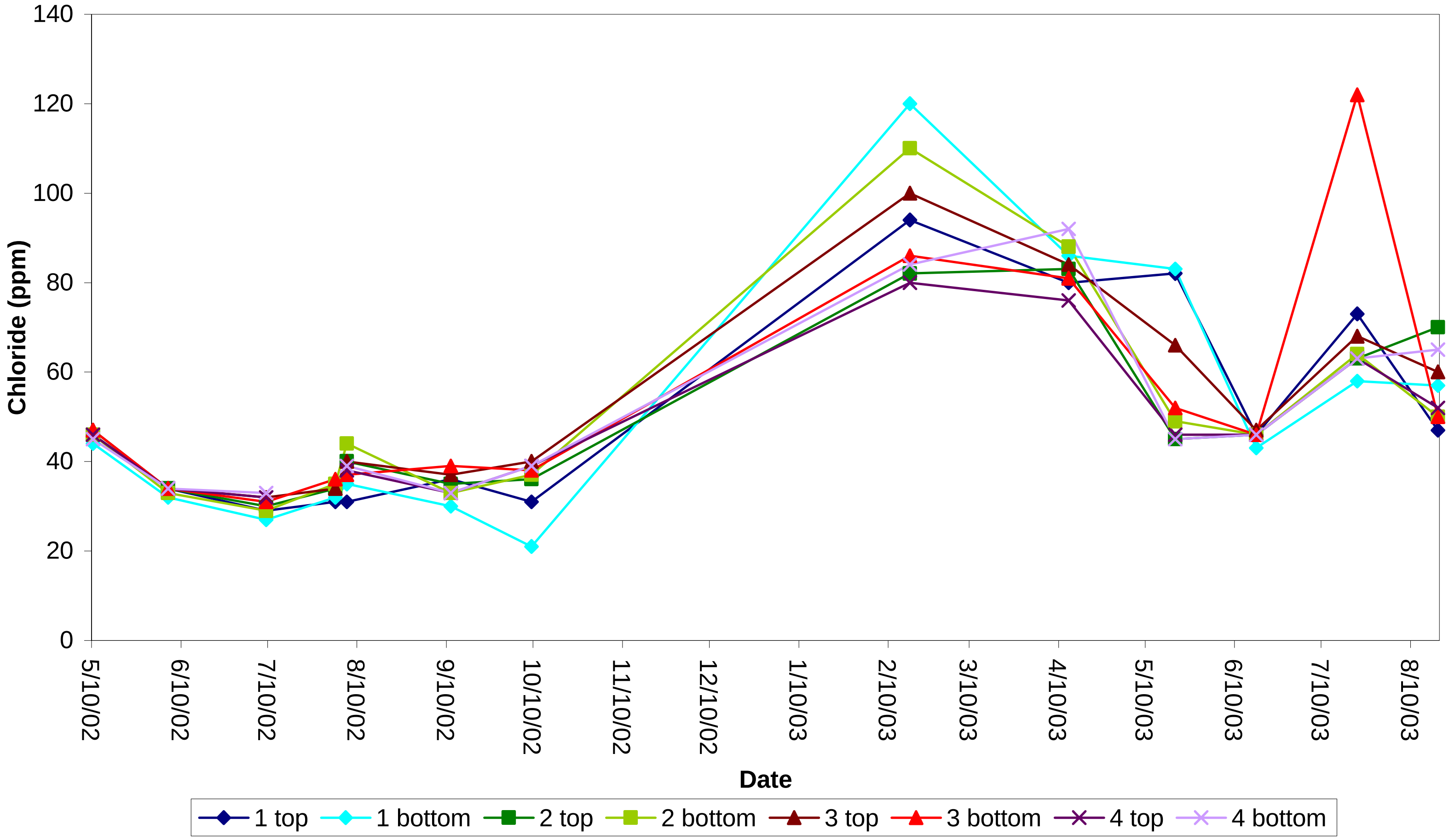
Chloride is often used as an indicator of human disturbance to freshwaters; industrial sources, road salting, and municipal wastewater operations all contribute chloride to waters. An approximate average concentration of chloride in pristine fresh water is 8.3 ppm (from Wetzel 1975); none of the values measured in Mona Lake approached that level, but that is not surprising given the urban and suburban land use/cover in the region. The USEPA drinking water standard for chloride is 250 ppm. Mean chloride concentrations were very consistent among all sites (Table 3.2.8) and very close to the chloride concentration entering the Lake from Black Creek, which accounts for approximately 80% of the discharge into Mona Lake (Table 3.4.6). Chloride concentrations were greatest in the winter, as one might expect from road salt runoff (Fig. 3.2.9).

Table 3.2.8. Mean and range (minimum to maximum) values for chloride (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	51	29-94
Site 1 – bottom	51	21-120
Site 2 – top	50	30-82
Site 2 – bottom	51	29-110
Site 3 – top	53	32-100
Site 3 – bottom	54	31-122
Site 4 – top*	49	32-80
Site 4 – bottom	52	33-92

*Missing data for Site 4 on 8/2/02

Figure 3.2.9. Monthly chloride concentrations (ppm): 5/10/02-8/19/03.



Sulfate is the oxidized form of sulfur, an essential element for all living organisms. The relative contribution of sulfur compounds to natural waters varies with local geology, application of sulfate-containing fertilizers, and atmospheric sources (e.g. production of sulfur dioxide from combustion of fossil fuels). The USEPA drinking water standard for sulfate is 150 ppm. Mean sulfate concentrations were similar among all sites (Table 3.2.9) and close to the sulfate concentration entering the Lake from Black Creek (44 ppm), which accounts for approximately 80% of the discharge into Mona Lake (Table 3.4.6). The lower mean value at Site 1-bottom may be due to advection of colder, sulfate-poor water from Lake Michigan. Sulfate concentrations did not vary much throughout the year in absolute values, although higher amounts tended to be measured in winter/early spring (Appendix 6.3).

Table 3.2.9. Mean and range (minimum to maximum) values for sulfate (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	35	25-44
Site 1 – bottom	30	17-44
Site 2 – top	35	26-45
Site 2 – bottom	35	17-67
Site 3 – top	36	27-45
Site 3 – bottom	35	19-46
Site 4 – top*	38	29-47
Site 4 – bottom	38	28-46

*Missing data for Site 4 on 8/2/02

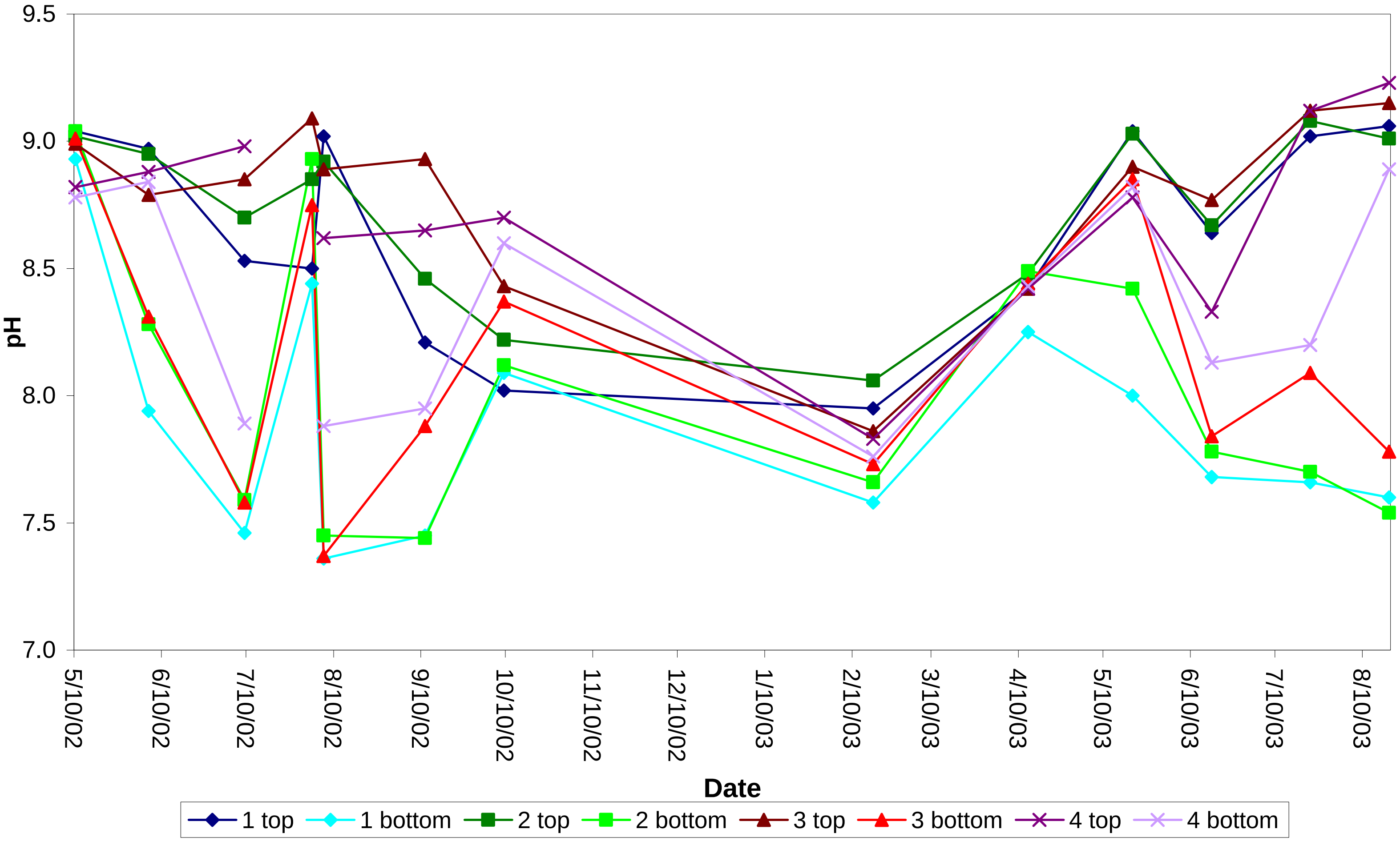
pH is an indicator of the hydrogen ion content in water. Water with a pH of 7.0 indicates a neutral solution. A pH less than 7.0 indicates acidic conditions, while a pH above 7.0 indicates alkaline conditions. The USEPA drinking water standard for pH is 6.5 to 8.5. Mean pH values were similar for the surface samples at all sites (Table 3.2.10), but pH values at bottom sites increased the further east the site was located. This may reflect greater photosynthetic activity throughout the water column (corroborated by chlorophyll data in Table 3.2.7), which uses dissolved inorganic carbon and results in higher pH values. The greater activity may be due to the shallower depths at Sites 3 and 4, allowing more light penetration to the bottom and greater benthic production. pH was consistently greater at the surface than bottom, reflecting greater photosynthetic activity in the upper reaches of the water column, where light was more available. Bottom pH values were quite variable throughout the year (Fig. 3.2.10), but surface pH values were greater in the summer than winter, again reflecting the greater photosynthetic activity during the summer months.

Table 3.2.10. Mean and range (minimum to maximum) values for pH measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	8.65	7.95-9.06
Site 1 – bottom	7.88	7.36-8.93
Site 2- top	8.73	8.06-9.08
Site 2 – bottom	8.03	7.44-9.04
Site 3 – top	8.78	7.86-9.15
Site 3 – bottom	8.15	7.37-9.01
Site 4 – top*	8.70	7.83-9.23
Site 4 – bottom	8.35	7.76-8.89

*Missing data for Site 4 on 8/2/02

Figure 3.2.10. Monthly pH readings: 5/10/02-8/19/03.



Alkalinity is a measure of the negative ions that are available to react and neutralize free hydrogen ions. Some of the most common of these include bicarbonate (HCO_3) and carbonate (CO_3) ions. Mean akalinity values were similar at the surface for all sites and lower than the bottom samples (Table 3.2.11). This may reflect greater biological activity in the upper portions of the water column due to consumption of phosphate or dissolved inorganic carbon. There was a slight decline in alkalinity in the bottom samples as one moved eastward. Alkalinity was variable throughout the year (Appendix 6.3).

Table 3.2.11. Mean and range (minimum to maximum) values for alkalinity (mg/L as $CaCO_3$) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	119	94-143
Site 1 – bottom	129	113-151
Site 2 – top	119	92-144
Site 2 – bottom	129	111-145
Site 3 – top	119	105-143
Site 3 – bottom	126	111-147
Site 4 – top*	118	88-139
Site 4 – bottom	123	91-155

*Missing data for Site 4 on 8/2/02

Total dissolved solids (TDS) refer to any minerals, salts, metals, cations, or anions that are dissolved in water. Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and some small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water (i.e. the plumbing). In the United States, elevated TDS has been due to natural environmental features such as mineral springs, carbonate deposits, salt deposits, and sea water intrusion, but other sources may include: salts used for road de-icing, anti-skid materials, drinking water treatment chemicals, stormwater and agricultural runoff, and point/nonpoint wastewater discharges.

Mean TDS values were greater in the bottom samples than the surface samples (Table 3.2.12), which may reflect release from decaying organic matter at the lake bottom. There was no obvious east-west gradient in TDS. As with TSS in the tributaries (Table 3.4.10), we noted two events with extremely high values, but because sampling in the lake and tributaries did not correspond, these events do not overlap: on 8/6/02 at site 3 bottom (0.4067 g/L) and on 2/17/03 at Site 2 bottom (0.3848 g/L). The August 2002 spike corresponded to a lift station failure on Little Black Creek, so those data may reflect the sewage inflow at this site. This event was localized, however; other sites did not show an obvious increase in TDS on this date. The February 2003 spike was noticeable at all sites to some degree (Appendix 6.3), although the cause is not clear.

Table 3.2.12. Mean and range (minimum to maximum) values for total dissolved solids (g/L) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	0.2748	0.2471-0.3264
Site 1 – bottom	0.2871	0.2294-0.3753
Site 2 – top	0.2780	0.2525-0.3267
Site 2 – bottom	0.2955	0.2721-0.3848
Site 3 – top	0.2746	0.2510-0.3205
Site 3 – bottom	0.3038	0.2733-0.4067
Site 4 – top*	0.2750	0.2505-0.3105
Site 4 – bottom	0.2859	0.2651-0.3206

*Missing data for Site 4 on 8/2/02

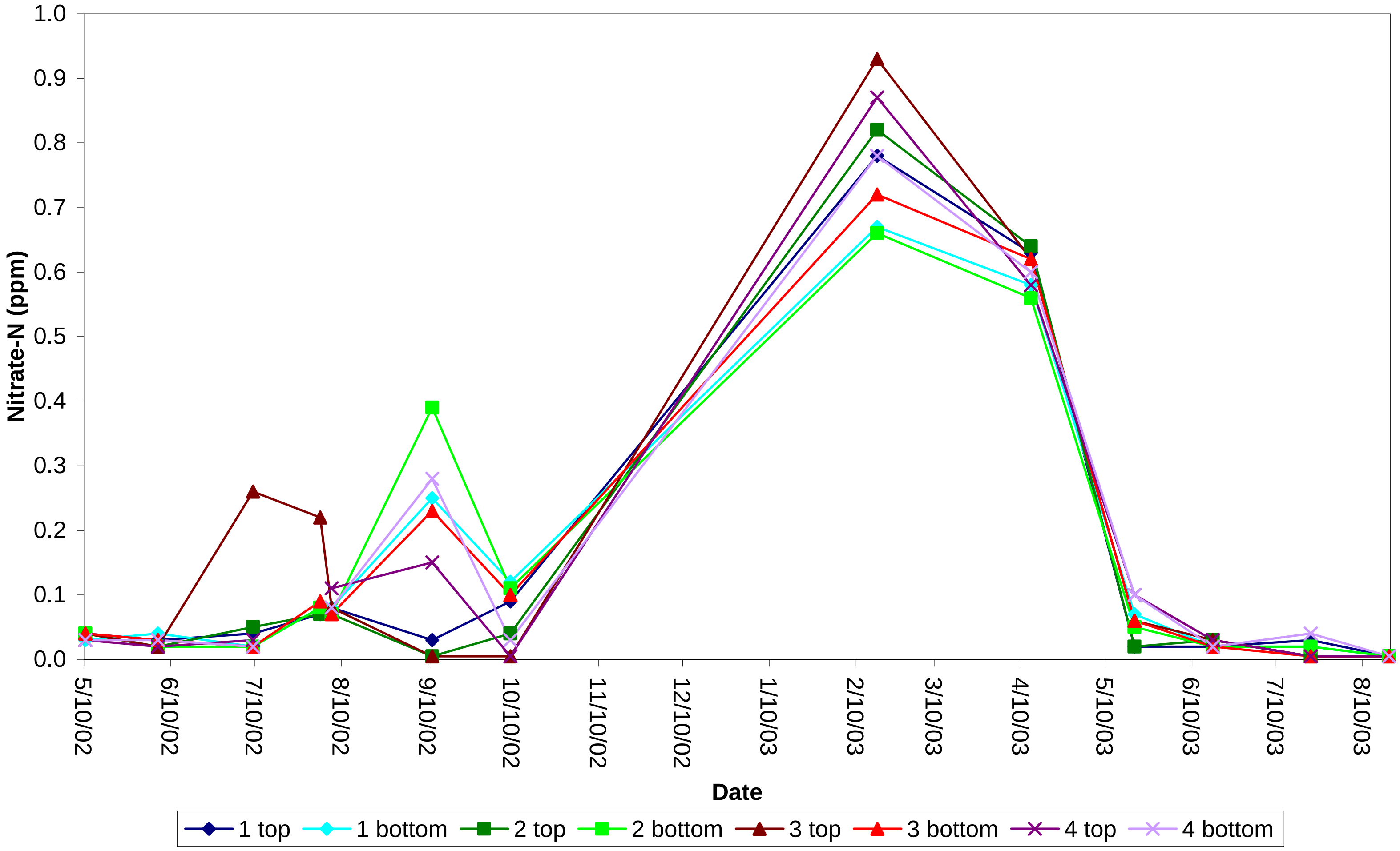
Nitrate (NO_3) is created by bacterial action on ammonia, by lightning, or through artificial processes involving extreme heat and pressure. Nitrate can be found in fertilizers, such as potassium or sodium nitrate. In appropriate amounts, nitrates are beneficial but excessive concentrations in water can cause health problems. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 ppm) under certain conditions. The natural level of nitrate in surface water is typically low (less than 1 ppm); however, in the effluent of wastewater treatment plants, it can range up to 30 ppm. The USEPA safe drinking water standard is 10 ppm of NO_3-N. In general, mean nitrate concentrations were similar at all sites and at both depths (Table 3.2.13). There was a distinct seasonal pattern, with the highest concentrations at all sites occurring during the winter months (Fig. 3.2.11; Appendix 6.3). This is likely due to oxidation of the ammonia that has built up during the summer months under reduced oxygen conditions; once the lake turns over in the fall and the hypolimnion becomes exposed to oxygen, the ammonia becomes oxidized and forms nitrate.

Table 3.2.13. Mean and range (minimum to maximum) values for nitrate (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	0.14	0.01-0.78
Site 1 – bottom	0.15	0.01-0.67
Site 2 – top	0.14	0.005-0.82
Site 2 – bottom	0.16	0.01-0.66
Site 3 – top	0.18	0.005-0.93
Site 3 – bottom	0.15	0.01-0.72
Site 4 – top*	0.16	0.005-0.87
Site 4 – bottom	0.17	0.01-0.78

*Missing data for Site 4 on 8/2/02

Figure 3.2.11. Monthly concentrations of NO_3-N (ppm): 5/10/02-8/19/03.



Ammonia (NH_3) is a byproduct of decaying plant tissue and decomposition of animal waste. Because ammonia is rich in nitrogen, it is also used as fertilizer. Ammonia levels at 0.1 ppm usually indicate polluted surface waters, whereas concentrations > 0.2 ppm can be toxic for some aquatic animals (Cech 2003). High levels of ammonia are typically found downstream of wastewater treatment plants and near water bodies that harbor large populations of waterfowl, who produce large amounts of waste.

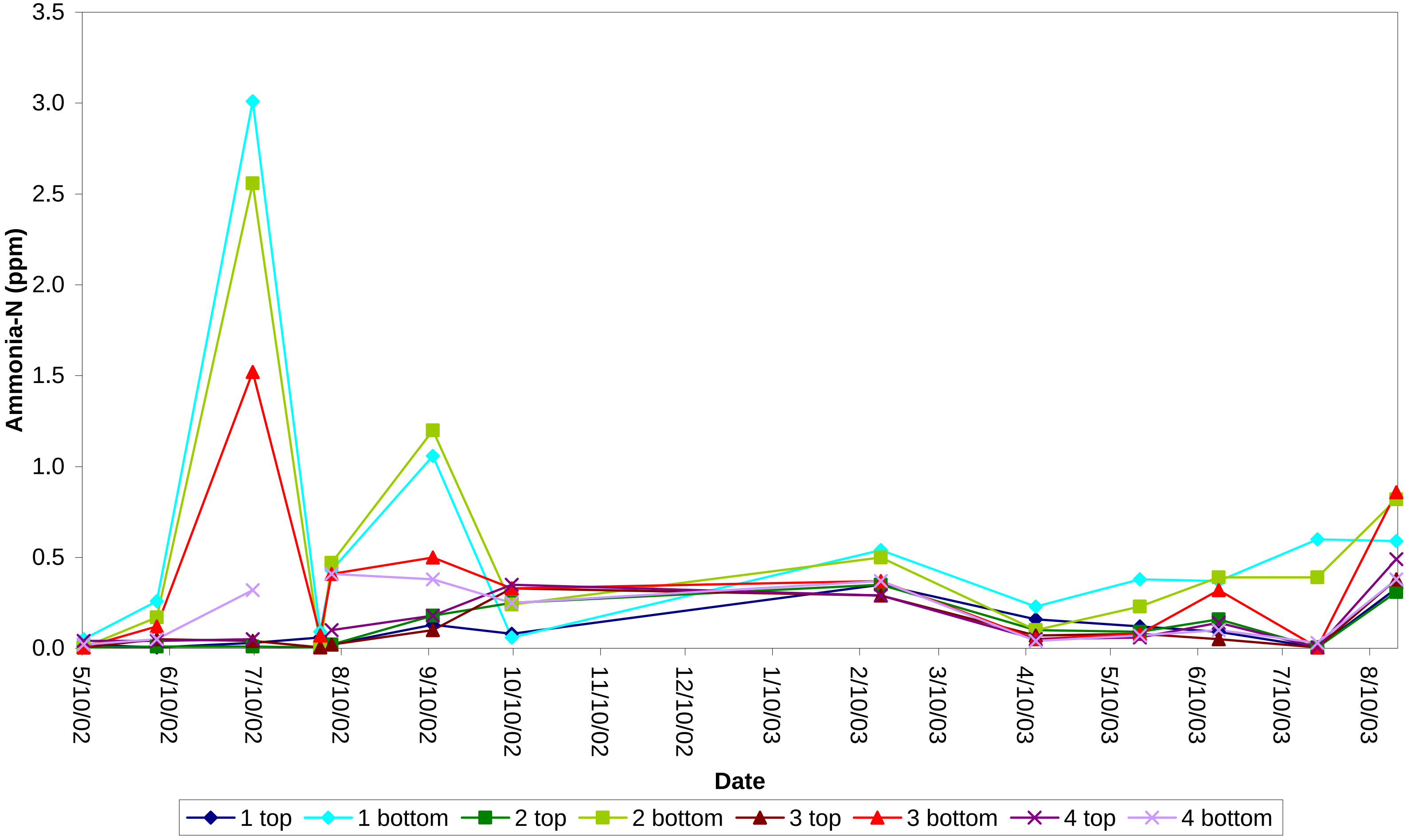
Ammonia levels were consistently higher in the bottom samples compared to surface samples at all sites (Table 3.2.14), most likely due to ammonification under anoxic conditions in the sediments, and its subsequent diffusion into the overlying water. In addition, the ammonia concentration in the bottom samples declined the further east one sampled in the lake, presumably due to less frequent anoxia (which would allow ammonification to take place) in these shallower waters. Ammonia concentrations were higher in the summer than winter months (Fig. 3.2.12), but only in the bottom samples, and the concentrations were higher in 2002 than 2003. Interestingly, ammonia concentrations declined dramatically on the August 2, 2002 sampling date at all sites. This suggests the reduction was associated with the application of algicide (applied late July), and not due to the lift station failure in Little Black Creek (on July 28), since the algicide was applied lake-wide whereas the introduction of raw sewage (approximately 200,000 gallons) was via Little Black Creek. There was no association between seasonal patterns of ammonia in the lake vs. the tributaries (Fig. 3.4.3).

Table 3.2.14. Mean and range (minimum to maximum) values for ammonia (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	Mean	Range (min-max)
Site 1 – top	0.11	0.005-0.35
Site 1 – bottom	0.59	0.05-3.01
Site 2 – top	0.12	0.005-0.35
Site 2 – bottom	0.54	0.005-2.56
Site 3 – top	0.11	0.005-0.33
Site 3 – bottom	0.36	0.005-1.52
Site 4 – top*	0.15	0.04-0.35
Site 4 – bottom	0.20	0.02-0.41

*Missing data for Site 4 on 8/2/02

Figure 3.2.12. Monthly concentrations of NH_3-N (ppm): 5/10/02-8/19/03.



Total Kjeldahl Nitrogen (TKN) is a measurement of the amount of organic nitrogen and ammonia in a sample. As a consequence, it is expected that TKN concentrations will track ammonia, at least to some degree.

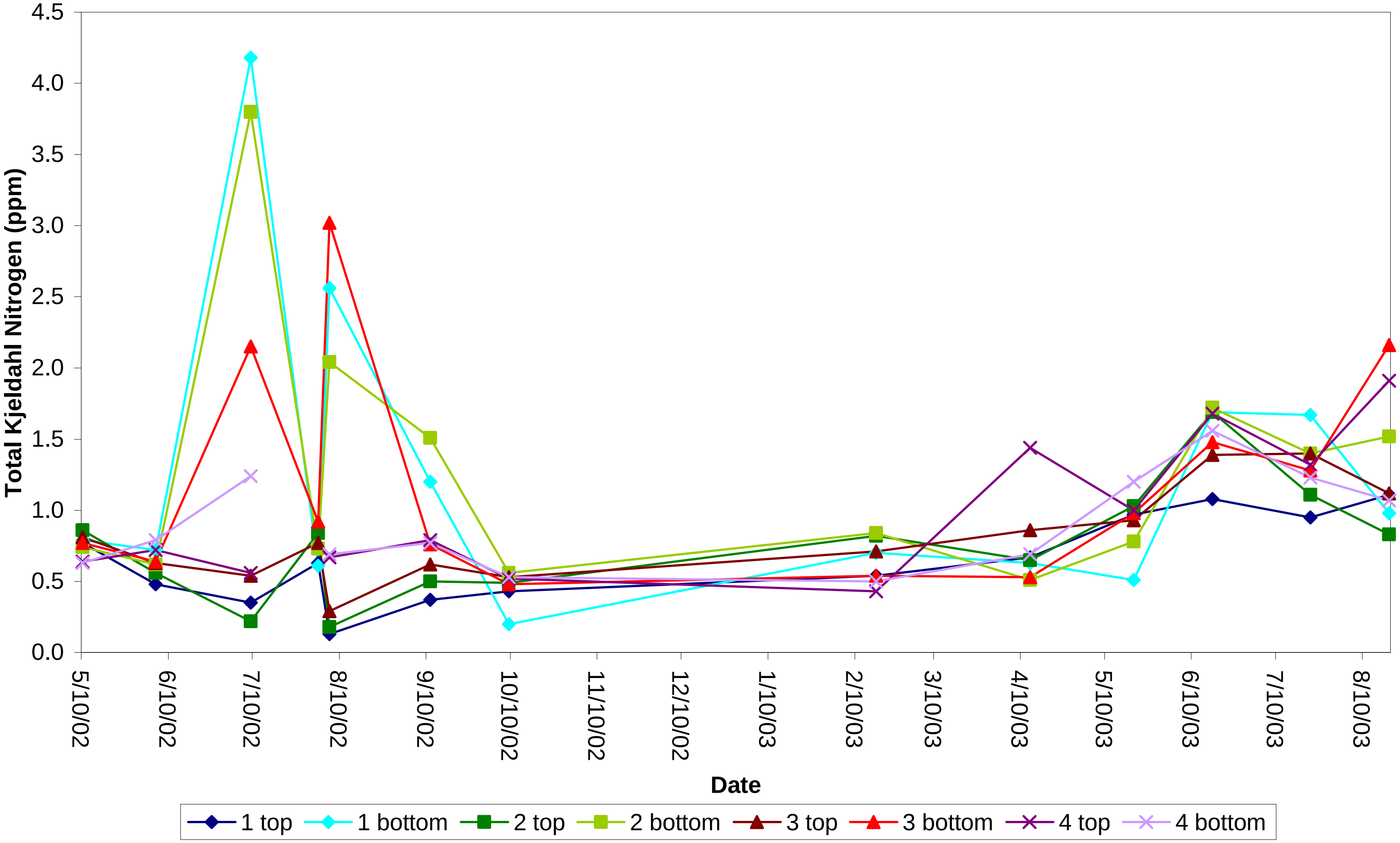
TKN levels were higher in the bottom samples compared to surface samples at all sites except Site 4 (Table 3.2.15); as with the ammonia data, this was most likely due to ammonification under anoxic conditions in the sediments, and its subsequent diffusion into the overlying water. Whereas ammonia concentrations in the bottom samples declined from west to east (Table 3.2.14), TKN in bottom samples were similar at Sites 1-3 and did not show a decline until Site 4, near the Black Creek inflow. As with ammonia, TKN concentrations were higher in the summer than winter months (Fig. 3.2.13), but only in the bottom samples, and the concentrations were higher in 2002 than 2003. TKN showed the same decline as ammonia on the August 2, 2002 sampling date at all sites. There was no apparent association between seasonal patterns of TKN in the lake vs. the tributaries (Fig. 3.4.4).

Table 3.2.15. Mean and range (minimum to maximum) values for TKN (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	0.65	0.13-1.11
Site 1 – bottom	1.26	0.20-2.56
Site 2 – top	0.75	0.18-1.69
Site 2 – bottom	1.29	0.51-3.08
Site 3 – top	0.82	0.29-1.40
Site 3 – bottom	1.21	0.48-3.02
Site 4 – top*	0.97	0.43-1.91
Site 4 – bottom	0.91	0.50-1.56

*Missing data for Site 4 on 8/2/02

Figure 3.2.13. Monthly concentrations of TKN (ppm): 5/10/02-8/19/03.



Soluble reactive phosphorus (SRP) is a measurement of the bioavailable phosphorus in water. Although a high concentration is indicative of enrichment, a low concentration may be due either to nutrient-poor conditions or to all the SRP being actively taken up by the plants and algae in the water body. Therefore, caution must be used when evaluating the significance of SRP levels.

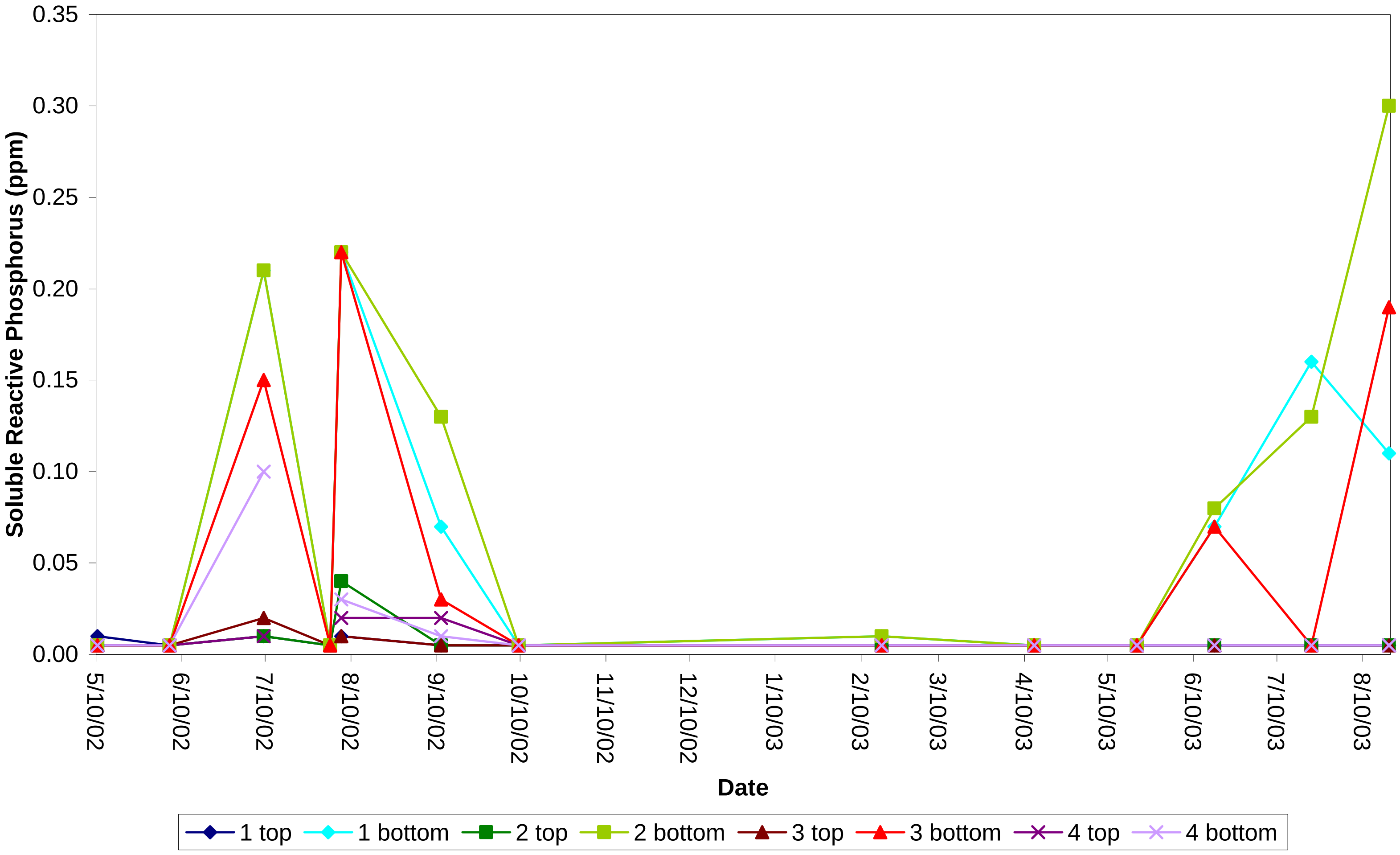
The mean SRP value at all surface samples was 0.01 ppm (Table 3.2.16). However, as with ammonia and TKN, SRP concentrations in the bottom samples were greater than surface samples. This is most likely associated with anoxic release of phosphorus from sediments, due either to reduction of ferric to ferrous iron with the subsequent release of phosphorus or to pH-mediated release of phosphorus from sediments (Bostrom et al. 1982). Site 4 exhibited the smallest difference between surface and bottom samples, similar to the ammonia and TKN data, presumably because of the greater mixing of water at this shallow site, and less opportunity for anoxia to develop. Unlike the nitrogen data, SRP values from the bottom samples were similar in magnitude between 2002 and 2003 (Fig. 3.2.14). However, the SRP data did show the same dramatic reduction as ammonia and TKN on August 2, 2002, suggesting the algicide application had system-wide effects on lake biogeochemistry.

Table 3.2.16. Mean and range (minimum to maximum) values for SRP (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	0.01	0.005-0.01
Site 1 – bottom	0.07	0.005-0.22
Site 2 – top	0.01	0.005-0.04
Site 2 – bottom	0.09	0.005-0.30
Site 3 – top	0.01	0.005-0.02
Site 3 – bottom	0.05	0.005-0.22
Site 4 – top*	0.01	0.005-0.02
Site 4 – bottom	0.02	0.005-0.10

*Missing data for Site 4 on 8/2/02

Figure 3.2.14. Monthly concentrations of SRP (ppm): 5/10/02-8/19/03.



Total phosphorus (TP) is a measurement of all the various forms of phosphorus (inorganic, organic, dissolved, and particulate) in the water. TP standards have been established for lakes; for the west Michigan ecoregion, the TP standard for lakes is 0.015 ppm, or the equivalent of 15 ppb (USEPA 2000).

Mean TP values exceeded USEPA standards at all sites, at all depths, at all times. This is not particularly surprising given that Mona Lake is in an urbanized watershed, where higher TP concentrations are to be expected (Table 3.2.17). And although the grand mean of 0.10 ppm is still 8 times the EPA standard, the data do indicate that TP concentrations are declining over time (Fig. 3.2.15). The overall TP patterns are very similar to those of SRP. On average, SRP comprised approximately 15% of TP in the surface samples, suggesting that most of the TP in the surface was in the form of particulate phosphorus. In the bottom sediments, more of the total phosphorus was in the form of SRP (40%), presumably due to diffusion from the sediments. This is very evident in Fig. 3.2.16, which shows the release of TP was high during periods of low DO and vice versa. Seasonal patterns were very similar to those of SRP (Fig. 3.2.17).

Table 3.2.17. Mean and range (minimum to maximum) values for TP (ppm) measured from May 2002 to August 2003 at 4 sites in Mona Lake.

Site	**Mean**	**Range (min-max)**
Site 1 – top	0.06	0.04-0.09
Site 1 – bottom	0.14	0.04-0.42
Site 2 – top	0.07	0.03-0.11
Site 2 – bottom	0.16	0.03-0.40
Site 3 – top	0.07	0.03-0.11
Site 3 – bottom	0.13	0.03-0.38
Site 4 – top*	0.08	0.03-0.13
Site 4 – bottom	0.10	0.03-0.23

*Missing data for Site 4 on 8/2/02

Figure 3.2.15. Total phosphorus (ppb) concentrations from Mona Lake (composite of multiple sites and dates within a year). Data extracted from same sources as in Fig. 3.2.2.

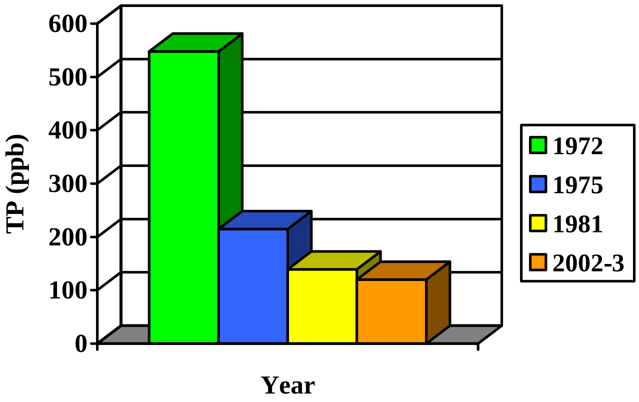


Figure 3.2.16. Monthly concentrations of TP (ppm) and DO (ppm): 5/10/02-8/19/03.

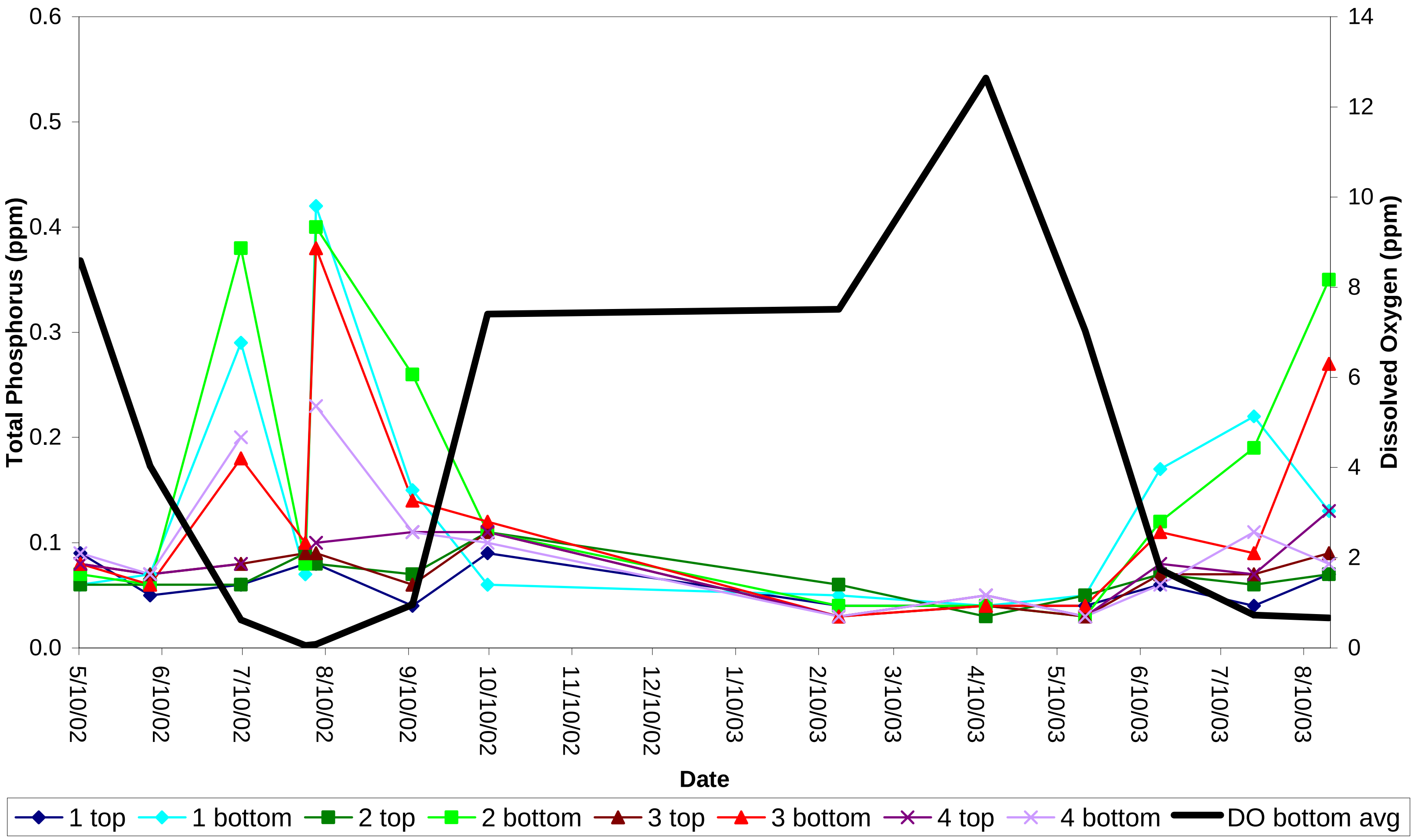
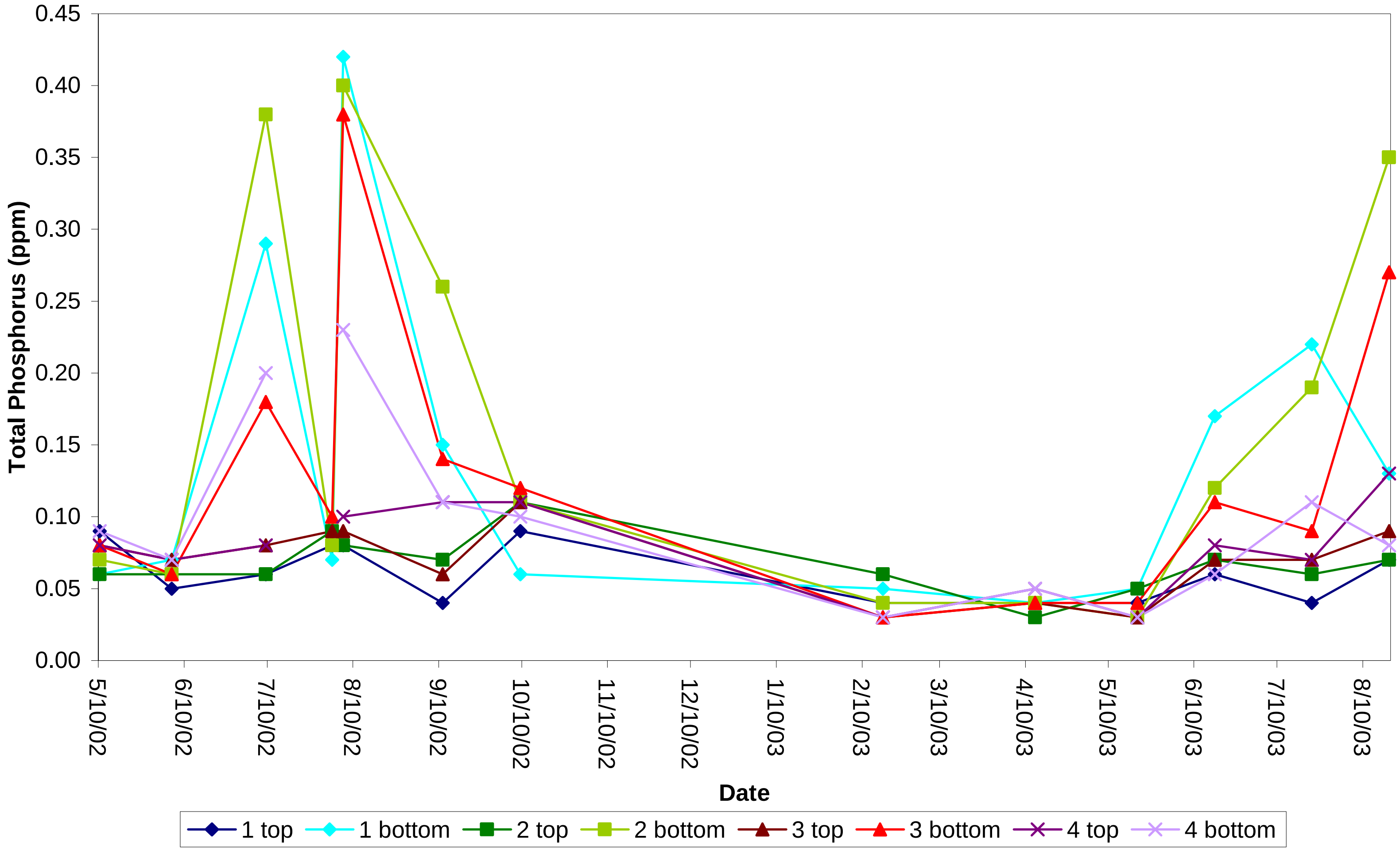


Figure 3.2.17. Monthly concentrations of TP (ppm): 5/10/02-8/19/03.



D. TN:TP ratio

Total nitrogen to total phosphorus ratios (TN:TP) are often used as a relative indicator of nitrogen or phosphorus limitation in aquatic ecosystems. Although the ratio is most effectively used for nutrients within the tissue of an organism, it also can be used for the ambient water (cf. Smith 1982, Downing and McCauley 1992). However, because each phytoplankton species has its own optimum N:P ratio for growth, one composite N:P ratio in the water column must be viewed with caution as an overall indicator of nutrient limitation.

A number of studies have attempted to determine the ratio at which phytoplankton are most likely to be nitrogen or phosphorus limited (Sakamoto 1966, Forsberg 1981, Smith 1982, 1983). In general, these studies suggest that for phytoplankton growing during the summer, N-limitation was most likely when the epilimnion TN:TP ratio (molar) was less than 22:1, whereas P-limitation was most likely when the epilimnion TN:TP ratio was greater than 37:1. Table 3.2.18 lists the molar TN:TP ratios for all seasons and both eiplimnetic and hypolimnetic layers, and just for the summer epilimnetic layers. These data suggest that the phytoplankton are neither strongly N nor P limited. The bioassay data corroborate that suggestion (Section 3.3). However, given the relatively high absolute concentrations of nitrogen and phosphorus, combined with the low transparency of the water, the phytoplankton also may be light limited during parts of the year.

Table 3.2.18. Mean molar TN:TP ratios measured from all dates (May 2002 to August 2003; n =13) and just summer dates in the epilimnion (May-Aug, 2002 and 2003; n = 7) at 4 sites in Mona Lake.

Site	Mean (all dates)	Mean (summer only)
Site 1 – top	29.16	27.49
Site 1 – bottom	22.29	
Site 2 – top	28.14	26.14
Site 2 – bottom	20.06	
Site 3 – top	31.64	27.64
Site 3 – bottom	23.16	
Site 4 – top*	31.28	25.58
Site 4 – bottom	23.91	
Grand Mean	25.24	

*Missing data for Site 4 on 8/2/02

3.2.4 Summary

Table 3.2.19 summarizes the changes in selected water quality parameters from EPA's earliest sampling of Mona Lake to the present. Comparisons between the 1970s and 2000 data must be viewed with caution because of differences in sampling sites, seasons, and methods, but they do give a general idea of how the lake has changed in the past 30 years. There have been clear improvements in the concentration of ammonia (especially in the bottom samples), nitrate, total phosphorus, and soluble reactive phosphorus. The most dramatic improvements occurred immediately after the diversion of wastewater to the Muskegon Wastewater Management System, but reductions still appear to be continuing. Nonetheless, even with these reductions, the ambient nutrient concentrations suggest impaired water quality conditions in Mona Lake.

The chlorophyll *a* concentrations also have declined over time, although these data are difficult to interpret given the influence of algicide applications in the lake. It is interesting, and counterintuitive, that secchi disc readings would continue to decline as chlorophyll *a* levels decline. This suggests that Mona Lake is experiencing an increase in suspended solids, which is accounting for the decreased water transparency. TMDLs are currently being developed for Black Creek and Little Black Creek due to excessive sedimentation, which is impairing the invertebrate and fish communities. It may be that this sediment is also reaching Mona Lake, and causing impairments there, as well.

Table 3.2.19. Selected water quality parameters in Mona Lake. 1972-1975 data from USEPA (Freedman et al. 1979). 2002-03 data are from current study. Nutrients and chlorophyll *a* are in units of ppb. Secchi disk units are cm.

Parameter	**1972**	**1973**	**1974**	**1975**	**2002-03**
Surface					
Ammonia	126	183	160	156	123
Nitrate	321	367	417	337	155
DIN*	447	550	577	493	278
TP**	338	226	108	134	70
SRP***	86	95	25	49	10
Chl a	17.6	40.0	34.4	29.8	17.5
Secchi Disc	1.21	0.92	1.05	0.92	0.67
Bottom					
Ammonia	1374	1199	389	476	423
Nitrate	321	362	451	353	158
DIN*	1695	1561	840	829	581
TP**	675	380	158	259	133
SRP***	116	302	64	172	58
Chl a					
Secchi Disc					

*Dissolved Inorganic Nitrogen
**Total Phosphorus
***Soluble Reactive Phosphorus

The following problems have been identified for Mona Lake based, in part, on the data presented in this Section:

- Excessive nutrient loading from inflows and storm drains: Black Creek should be a targeted priority, given its large nutrient contribution to the lake, but other inflows can be problematic on a localized scale
- Internal loading from the sediments: There is a strong need to determine how much of the N and P entering the lake's water column, and thereby fueling algal blooms, is coming from the sediments vs. the watershed
- Invasive species: This problem was not investigated as part of this study, but given the prevalence of this problem in nearby lakes (Lake Michigan, Muskegon Lake), management actions should be considered for the invasive species already present in the lake (Eurasian watermilfoil) and others that are likely to invade in the near future, if not already present (round goby).
- Contaminated sediments: see Section 3.6.

3.3 Lake Nutrient Bioassays

3.3.1 Background and Rationale

A common cause of eutrophication in streams and lakes is the excessive addition of nutrients, which in turn can fuel excessive phytoplankton growth. Both nitrogen (N) and phosphorus (P) are essential nutrients for plant growth and are present in most fertilizers, as well as in agricultural and municipal waste (Bennett et al. 2001). Excessive concentrations of nutrients can result in algal blooms, decreased water quality (unpleasant color, high turbidity, high nutrient levels), increased anoxia (fish kills), and loss of biodiversity (Nosengo, 2003).

Lakes vary in productivity due to parent geology, the extent of nutrient enrichment from the surrounding watershed, and lake morphometry (Wetzel, 2001). Oligotrophic (low productivity) lakes tend to be nutrient limited because the connecting watersheds are characterized by reduced nutrient inflow; in addition, oligotrophic lakes often have large depth:surface area ratios, resulting in reduced sediment-water interactions (Vadeboncoeur and Steinman 2002). In contrast, eutrophic lakes are often found in areas of heavy human development with nutrient enrichment, and the lakes are generally shallow with strong sediment-water interactions. The trophic nature of lakes affects various physical, chemical, and biological qualities, including light penetration and oxygen content of bottom waters. Thus, understanding what controls eutrophication in a lake is critical to managing this emerging problem in urban and coastal environments worldwide.

In shallow, nutrient-rich eutrophic lakes such as Mona Lake, it is often unclear what resource (phosphorus, nitrogen, light) limits algal growth, and whether limitation of the plankton changes with the season. An understanding of which nutrient(s) limit(s) algal growth is essential in developing strategies to control eutrophication, as nutrients may have different sources, and loads may change seasonally (see Section 3.4). To address these issues, we have carried out field experiments of nutrient enrichment under controlled conditions to determine which major nutrient may limit the productivity of phytoplankton in Mona Lake during three different seasons in 2003. Nutrient enrichment bioassays are a powerful way of assessing the nutrient status of natural waters, and are based on the assumption that releasing the limitation(s) will induce a measurable positive growth response by the plankton community.

3.3.2 Hypotheses

1. Phytoplankton growth in Mona Lake is limited by the availability of N, P or both.

2. The nature of nutrient limitation will vary during different seasons.

3.3.3 Methods

A nutrient-enrichment bioassay is a water sample taken from the source and divided into subsamples that are amended with inorganic nutrients (N, P), alone or in combinations. The control treatment is a natural water sample that is not amended with any nutrients. The response is measured after incubation for some time. This approach has been widely used by other researchers (Morris and Lewis 1992; Havens et al. 1996; Chrzanowski and Grover 2001; Wilhelm et al. 2003).

Field Sampling and Experimental set-up

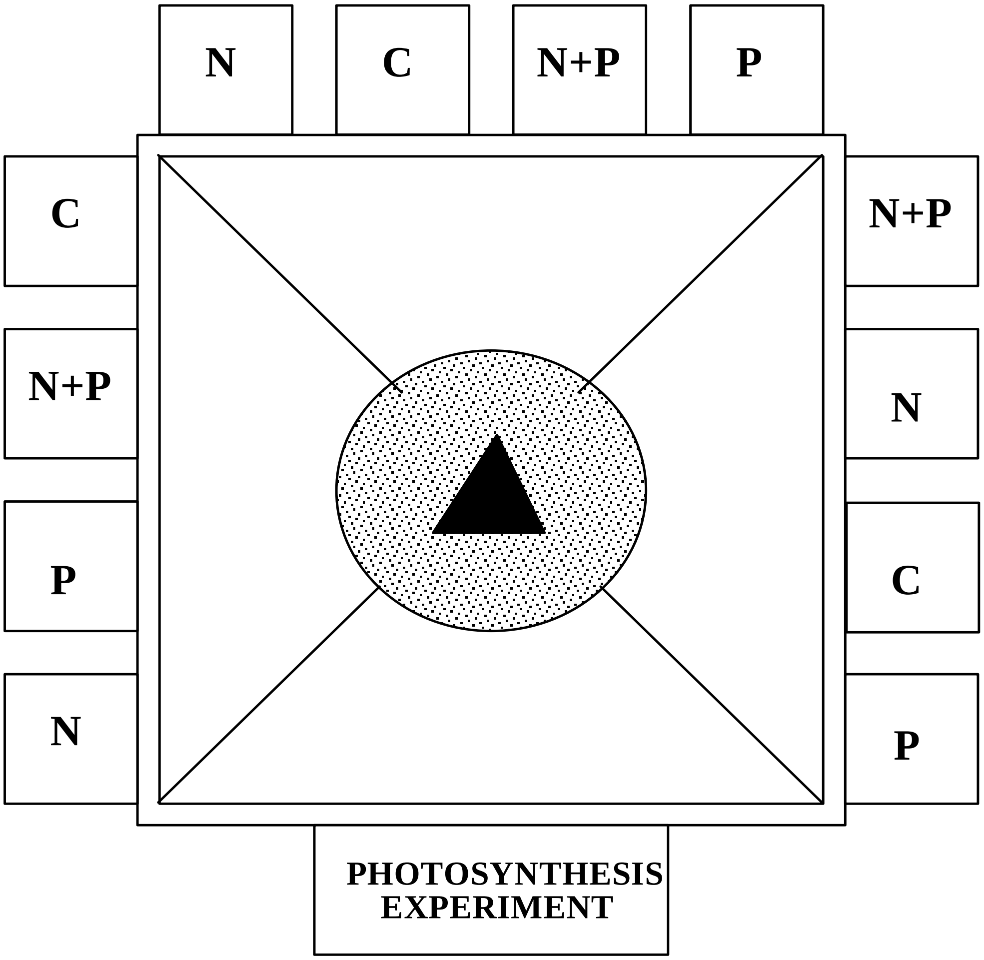
Approximately 200 L of surface water was collected from Site 3 (Fig. 3.2.1) in Mona Lake, brought back to the lab in carboys, and pooled into a 250 L barrel. Ambient N and P concentrations were measured as soon as possible; if no immediate tests could be run, ambient concentrations were assumed to be the same as the last measured value (generally a month prior to experiment). While constantly being mixed with a paddle, the integrated water sample was dispensed into 12 acid-cleaned 10 L polycarbonate bottles. Concentrated solutions of potassium nitrate and potassium phosphate were added to the treatment carboys to achieve nutrient concentrations that were approximately 10-fold the ambient levels in Mona Lake (Table 3.3.1). Each of the four treatments consisted of three replicates, for a total of 12 carboys. No nutrients were added to the controls, the corresponding nutrient was added to the N and P treatments in concentrations 10-fold higher than ambient, and the N+P treatment received both N and P (each 10-fold higher than ambient). A similar experimental design was employed by Havens and colleagues in their work in Lake Okeechobee, Florida (Havens et al. 1996). The carboys were attached to the sides of a floating rack held in place by a float and anchor assembly, and left in the lake for 4 days (Fig. 3.3.1).

A biological oxygen demand (BOD) experiment to determine photosynthesis and respiration rates was carried out concurrently with the carboy experiment. Additional water samples containing the four treatments were placed in stoppered BOD bottles. Several replicates of initial dissolved oxygen conditions were measured, and 6 replicates (3 light, 3 dark) of each treatment were placed in a rack and suspended from the float in the lake for a period of 24 hours. The BOD bottles exposed to natural light conditions represent the photosynthesis rate. Respiration rates are not examined in this report.

Table 3.3.1. Experimental design for Mona Lake nutrient bioassays.

Treatment	Increase above ambient levels
C (Control)	No change
N (Nitrogen)	10X
P (Phosphorus)	10X
N+P (Nitrogen + Phosphorus)	10X each

Figure 3.3.1. Schematic of the bioassay experiment moored on a floating rack in the lake, as viewed from above. The dotted circle at the center represents the flotation buoy and the dark triangle represents the anchor weight. Experiments were run for 4 days during three seasons: Spring (May 5-9), Summer (July 28-Aug 1) and Fall (Sept 8-12) in 2003. Actual placement of the treatments was assigned randomly for each experiment.



Measurements

Chlorophyll fluorescence: The fluorescence of chlorophyll *a* in the carboy water was monitored using a Hydrolab Data Sonde Instrument equipped with a Turner Designs SCUFA probe. In this study, we have compared the change in chlorophyll concentrations in the different treatment bottles from the beginning to the end of the experiment.

Photosynthesis rate: The rate of photosynthesis was measured by following the changes in dissolved oxygen over 24 hours in BOD bottles that were suspended in the lake. A Radiometer Analytical Titralab 850 capable of high precision titration was used to determine dissolved oxygen concentration using Winkler chemistry (Biddanda and

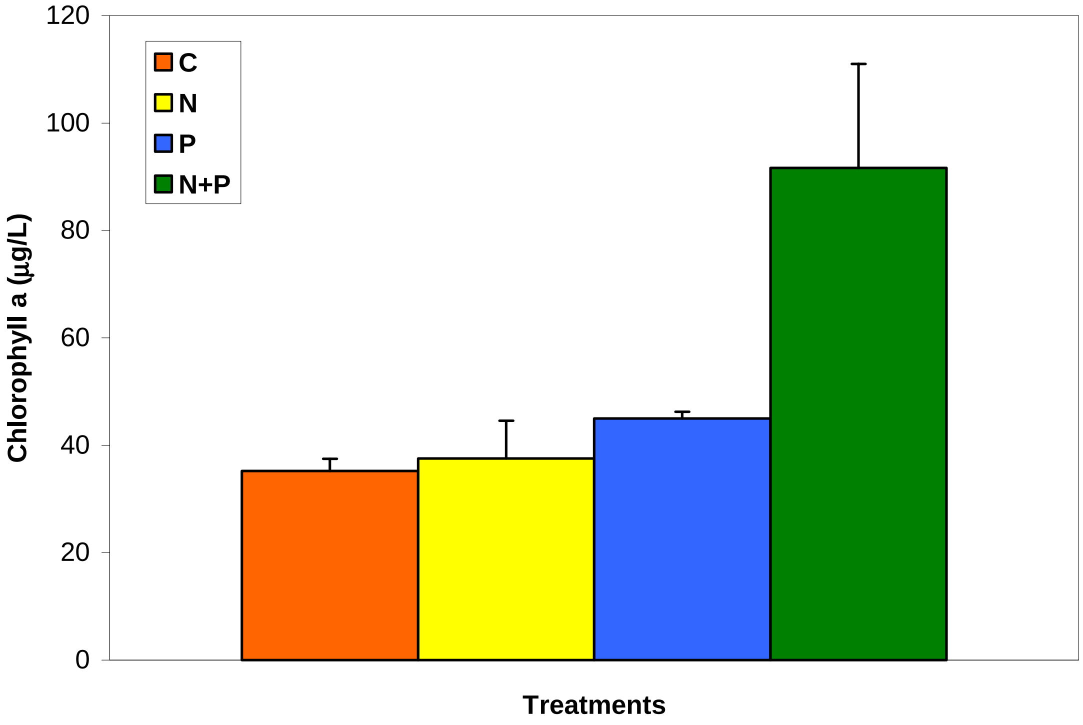
Cotner 2002). A photosynthetic quotient of 1.00 was used to calculate carbon synthesized from the measured increase in dissolved oxygen concentration. Net carbon production from photosynthesis (primary production) was estimated from production of dissolved oxygen in light bottles.

Experimental differences were analyzed by ANOVA, followed by a Tukey post-hoc comparision test if appropriate. Statistical significance was assigned at $\alpha = 0.05$.

3.3.4 Results

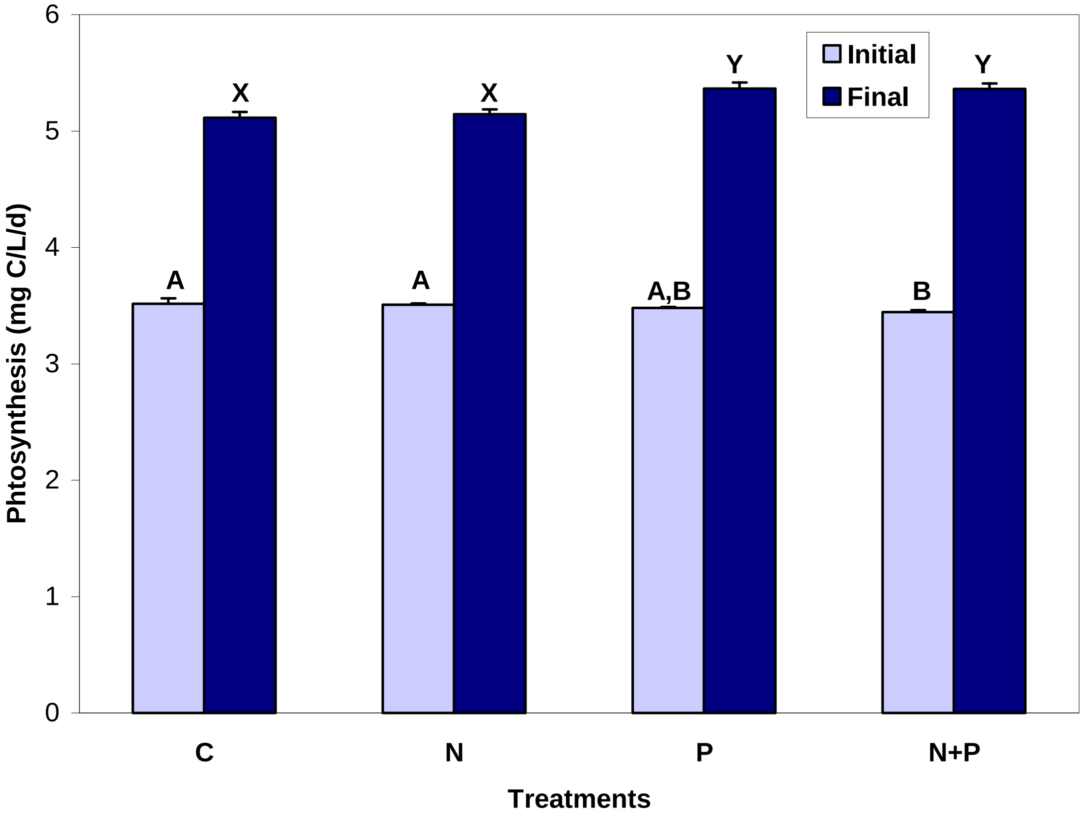
During the spring experiment, ambient levels of nitrate and soluble reactive phosphorus were 0.19 mg/L and 0.01 mg/L, respectively. The bioassay concentrations for the 10X N and 10X P treatments were 0.75 mg/L nitrate-N and 0.36 mg/L phosphate-P, respectively. Initial chlorophyll *a* measurements were unreliable so only final concentrations are reported for the spring experiment, and no inferential statistics were applied to the data. Chlorophyll *a* concentrations were elevated slightly under the P treatment, and were substantially greater in the N+P treatments compared to the control and the N alone treatments (Fig. 3.3.2). These data suggest the algal growth was limited to a small degree by phosphorus, but the large response to the N+P treatment suggest both nitrogen and phosphorus were co-limiting algal growth.

Figure 3.3.2. Final chlorophyll *a* concentrations (μg/L) in the different nutrient treatments during Spring 2003. Initial chlorophyll a measurements were unreliable so change in concentration could not be determined. Error bars represent 1 standard deviation.



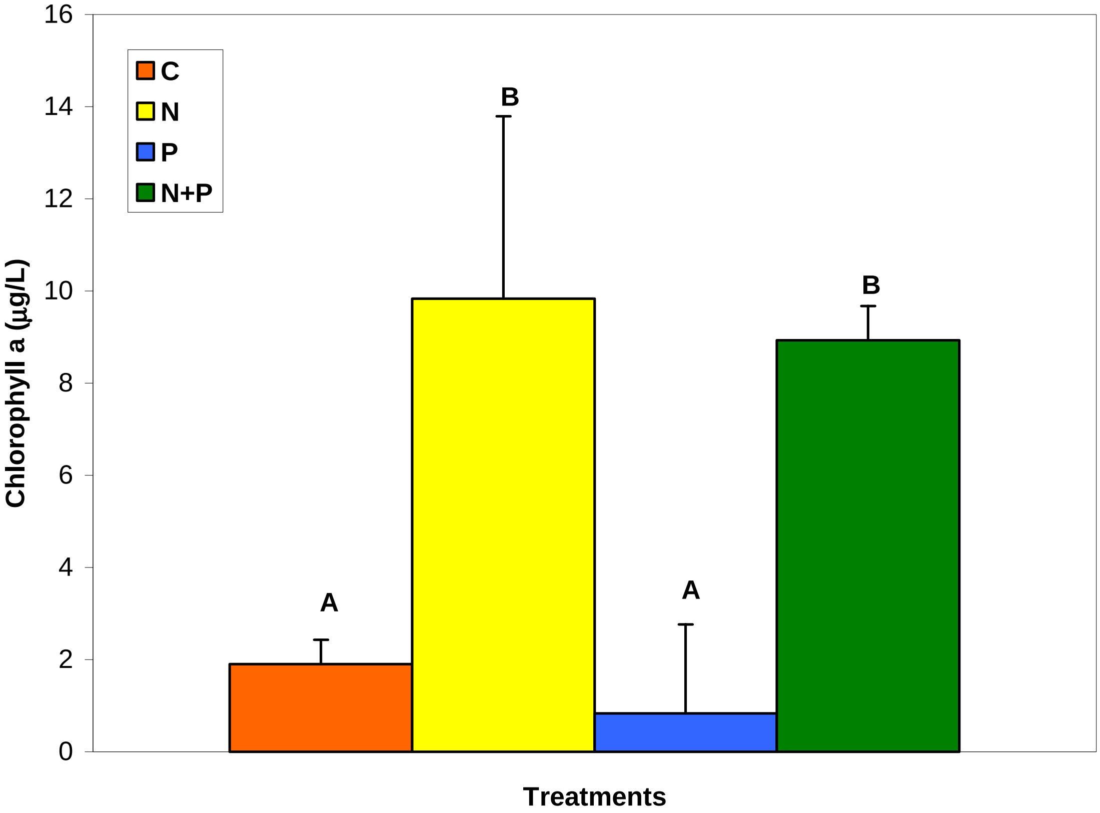
Primary production in the spring experiment, as estimated from changes in dissolved oxygen, increased significantly in all treatments. Patterns of photosynthesis rates were generally similar for the initial and final measurements (Fig. 3.3.3). In both cases, photosynthesis was greater in the P and N+P treatments compared to the control and N treatments, with no statistically significant difference between the P vs. N+P treatments. These data suggest that photosynthesis during the spring was P-limited.

Figure 3.3.3. Photosynthesis rates (mg C/L/d) in the different nutrient treatments during Spring 2003. Error bars represent 1 standard deviation. Letters designate which groups are statistically different from each other – A,B for the initials and X,Y,Z for the finals.



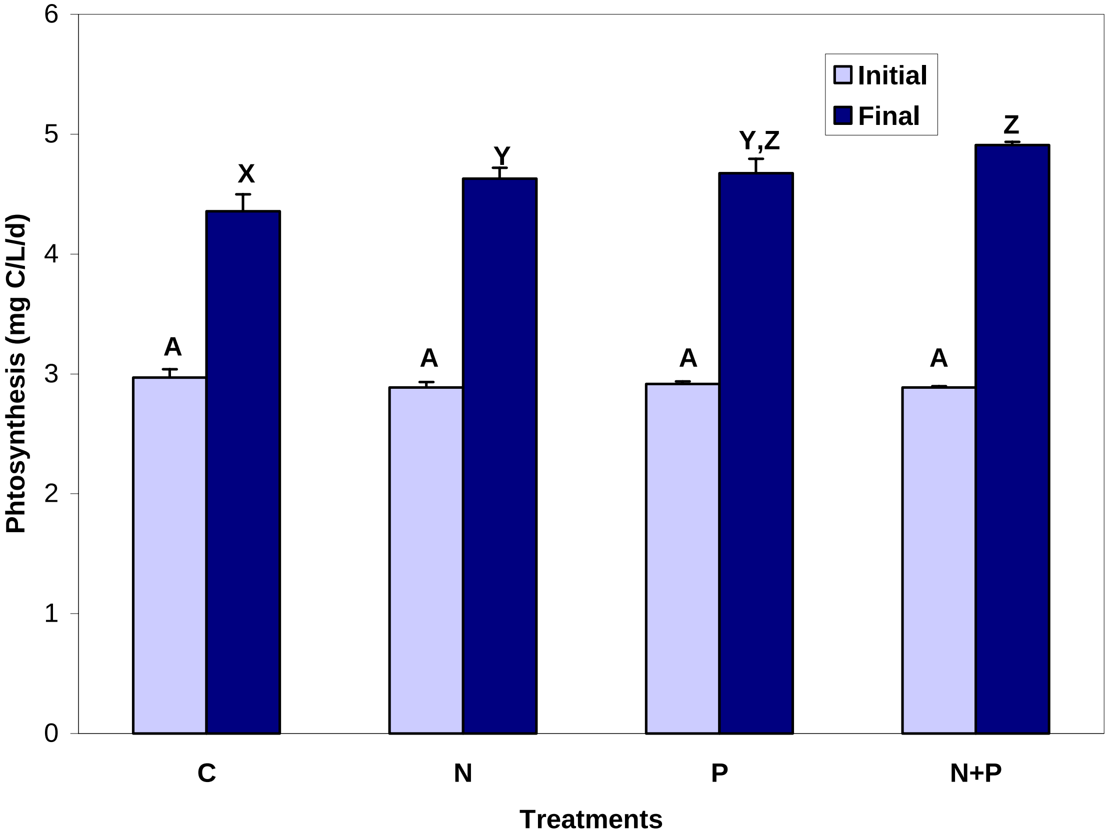
During the summer experiment, ambient chlorophyll levels in the lake at sample collection time were ~10 µg/L. Ambient levels of nitrate and soluble reactive phosphorus were less than or equal to 0.02 mg/L and 0.01 mg/L (detection limits), respectively. The bioassay concentrations for the10X N and the 10X P treatments were 0.25 mg/L nitrate-N and 0.1 mg/L phosphate-P, respectively. Chlorophyll concentrations in the N and N+P treatments were significantly greater than the control or P treatments (Fig. 3.3.4), suggesting N-limitation of algal growth during summer.

Figure 3.3.4. Change in chlorophyll concentrations (µg/L) from initials to finals in the different nutrient treatments during Summer 2003. Error bars represent 1 standard deviation. Letters designate which groups are statistically different from each other.



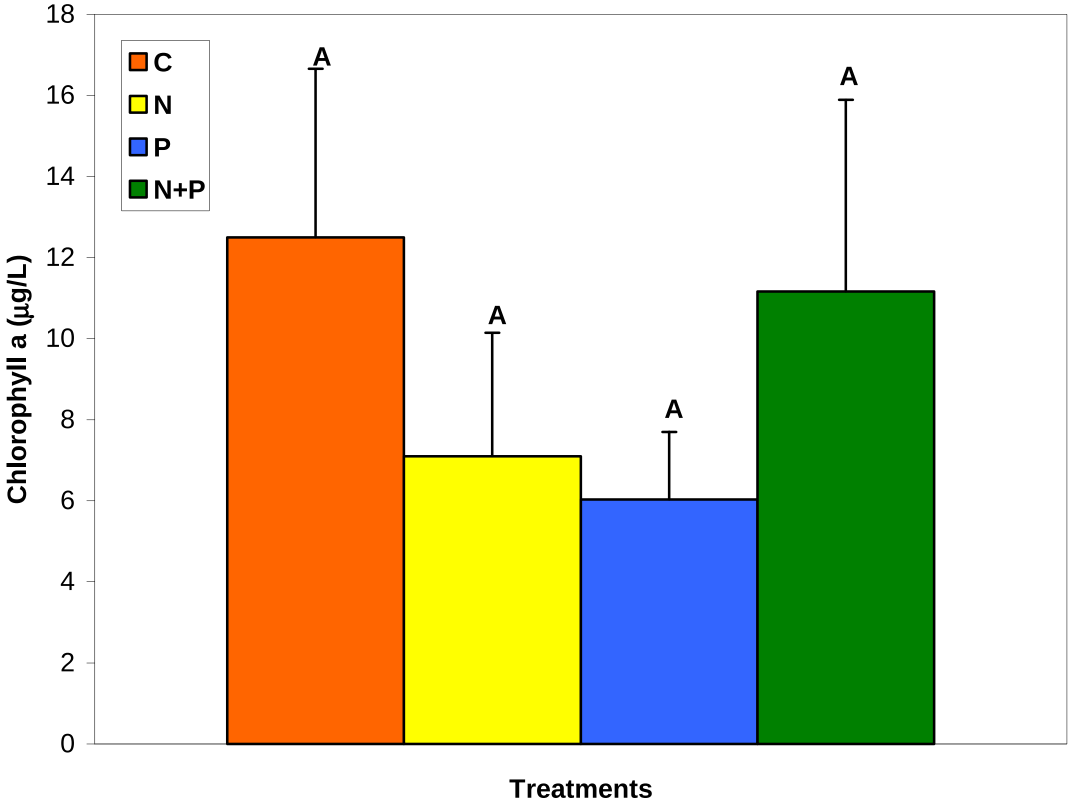
Initial photosynthetic rates were not statistically different from one another in the summer experiment (Fig. 3.3.5). However, all nutrient treatments resulted in a statistically significant increase relative to the control treatment (Fig. 3.3.5). The largest mean increase was in the N+P treatment, which was not statistically different from the P alone treatment, but was significantly greater than the N alone treatment. These data suggest that photosynthesis during the summer was co-limited by nitrogen and phosphorus.

Figure 3.3.5. Photosynthesis rates (mg C/L/d) in the different nutrient treatments during Summer 2003. Error bars represent 1 standard deviation. Letters designate which groups are statistically different from each other – A,B for the initials and X,Y,Z for the finals.



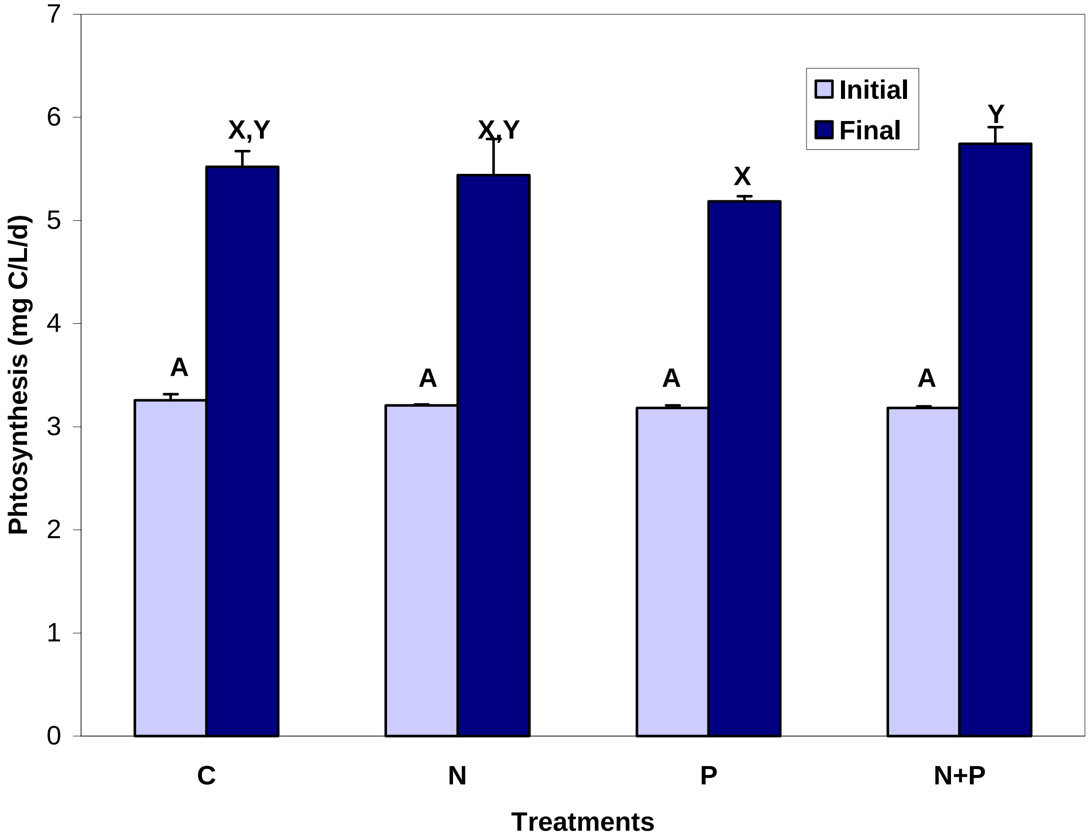
During the fall experiment, ambient chlorophyll levels in the lake at sample collection time were ~11 µg/L. Ambient levels of nitrate and soluble reactive phosphorus were below the detection limit of 0.01 mg/L. The bioassay concentrations for the 10X N and the 10X P treatments were 0.2 mg/L nitrate-N and 0.1 mg/L phosphate-P, respectively. Interestingly, mean chlorophyll a concentrations declined over the 5-day bioassay in the fall. Although the mean values for each treatment were not statistically different from one another (Fig. 3.3.6), the largest mean decline was in the control treatment, and the smallest mean decline was in the N+P treatment (Fig. 3.3.6).

Figure 3.3.6. Change in chlorophyll concentrations (µg/L) from initials to finals in the different nutrient treatments during Fall 2003. Error bars represent 1 standard deviation. Letters designate which groups are statistically different from each other.



Initial photosynthetic rates were not statistically different from one another in the fall experiment (Fig. 3.3.7). Similar to our observations with chlorophyll, there was no apparent effect of nutrient amendment on photosynthetic rates during the fall, although mean photosynthetic rates in the N+P treatment were significantly greater than those in the P alone treatment (Fig. 3.3.7).

Figure 3.3.7. Photosynthesis rates (mg C/L/d) in the different nutrient treatments during Fall 2003. Error bars represent 1 standard deviation. Letters designate which groups are statistically different from each other – A,B for the initials and X,Y,Z for the finals.



3.3.5 Discussion

Plankton link terrestrial nutrients derived from the watershed to lake productivity (Biddanda and Cotner 2002). Typically, phytoplankton will utilize available N and P and grow until some other factor such as light or trace metal availability becomes a limiting factor. Thus, most algal bloom occurrences in coastal waters of the world can usually be linked to the availability of excessive nutrients.

Our bioassay experiments in Mona Lake showed a variety of responses. The chlorophyll data indicated P or N+P co-limitation in spring, N-limitation in summer, and no limitation in fall. The spring chlorophyll response to nutrients appeared to be the strongest, although without initial chlorophyll *a* levels, it is impossible to determine the net response. This response was unexpected given the high ambient nutrient concentrations compared to the other seasons. It is possible that the algal species growing in the lake at that time were capable of very rapid growth. The primary productivity rates indicated P and N+P co-limitation in spring and summer, respectively, and an apparent absence of limitation by N and P in fall. Thus, there was some correspondence in patterns between chlorophyll and productivity, but the correspondence was not complete.

The different responses among seasons suggest that Mona Lake cannot be thought of as a constant system—algal growth may vary with season, and nutrient reduction strategies may target different times of year. For example, fertilizer applications in spring may have greater consequences on algal growth than applications in fall.

USEPA (1975) conducted an algal bioassay in Fall 1972 using Mona Lake water and a cultured alga (unlike this study, which used natural plankton communities); they found the strongest algal biomass response in a nitrogen-amended medium. Hence, those authors concluded that the algae in Mona Lake were nitrogen-limited, which was logical given the very high phosphorus concentrations in the water (cf. Fig. 3.2.14) and very low N:P ratios of 4:1 (USEPA 1975) at that time. However, TN:TP ratios in Mona Lake averaged about 25:1 in 2002-2003 (see Table 3.2.18), and the data from the current bioassays are consistent with algal limitation that switches between N, P, and co- or no-limitation, depending on the time of year.

3.3.6 Summary

Mona Lake phytoplankton biomass and biomass production rate were limited by the availability of N, P or both during at least two out of the three seasons we conducted the bioassay studies in 2003. That the plankton can be limited by the availability of N and P suggests that nutrient source control should form an integral part of any effective management strategy that is aimed at addressing the problem of continuing eutrophication in this drowned river lake ecosystem. It is recommended that bioassays be conducted in additional years to determine longer-term trends and ensure that the 2003 results are not anomalous.

3.4 Tributary Water Quality

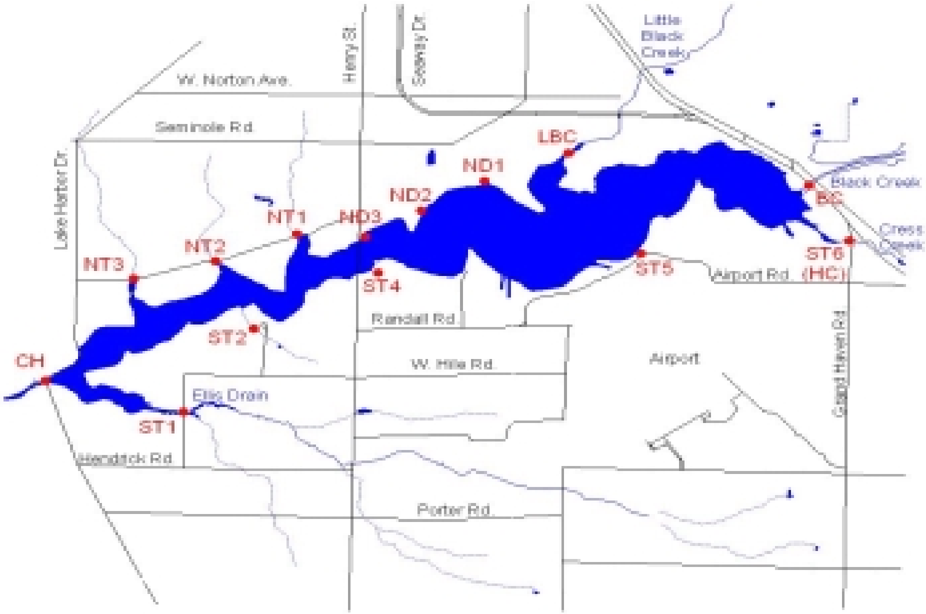
3.4.1 Introduction

Although previous studies have shown ecological impacts to Mona Lake due to high levels of external loading (e.g. USEPA 1975, Freedman et al. 1982, Aquest 1996), these studies focused mainly on Black Creek and Little Black Creek. None of the previous studies included a comprehensive survey of the inflows to Mona Lake. This type of survey is essential to determine which subbasins contribute the greatest concentration of contaminants, as well as the greatest amount of load (concentration multiplied by discharge). Inflows with very high concentrations may result in localized impacts to the Lake, but if their discharges are low, the overall amount of material they contribute to Mona Lake will be relatively low. In contrast, inflows with high discharges may have relatively modest concentrations, but because their total load is so high, they have considerable influence on lake ecology. Even a small reduction in contaminant concentration in these high load inflows may result in a large reduction in the overall mass of the contaminants entering Mona Lake. As a consequence, our synoptic survey was designed to identify which subbasins contribute the most contaminants to Mona Lake, allowing us to determine optimal strategies for remediation.

3.4.2 Methods

Preliminary surveys were conducted by land and water in Spring 2002 to evaluate all obvious inflows and outflows to Mona Lake. Based on this survey, as well as historical information from prior studies, we selected 14 sites to monitor on a monthly basis (Figure 3.4.1).

Figure 3.4.1. Inflows and outflow (channel) monitored on a monthly basis from June 2002 through August 2003.



The fourteen sites included the following:

- ST1: Ellis Drain at Rood Road crossing
- ST2: Creek off of Hackley Point Lane
- ST4: Creek to east of Bridgeview Bay Lane
- ST5: Storm drain on Wellesley Drive adjacent to airport
- ST6: Cress Creek off of Old Grand Haven Road, at turn in to Hidden Cove Apartments
- BC: Black Creek at Seaway crossing
- LBC: Little Black Creek at mouth to Mona Lake (access from Fischer Ave.)
- ND1: drain behind greenhouses on Seminole; access from Mona Kai Blvd.
- ND2: storm drain off of Waterstone Court
- ND3: Henry Street storm drain on east side of Henry Street Bridge
- NT1: tributary off of Forest Park Drive between Harbor Point Drive (west side) and Forest Point Drive (east side)
- NT2: tributary off of Forest Park Drive just west of Lake Point Drive
- NT3: tributary off of Forest Park Drive between Lin-Nan Lane (west side) and Braeburn Drive (east side)
- Channel: in Mona Lake channel below the Lake Harbor bridge

Physical and chemical parameters were measured at each site. Sampling occurred between 9:00 and 15:00 hours each day. A Hydrolab DataSonde 4a was used to measure dissolved oxygen, pH, temperature, specific conductance, chlorophyll *a*, and total dissolved solids. Current velocity was measured with a Marsh-McBirney Flow-Mate Flometer 2000 at several points across the stream channel. Simultaneously, we measured stream width and depth to generate discharge calculations. Grab samples for nutrients were collected in acid-washed 1-liter bottles. Nutrient analyses were performed on a BRAN+LUEBBE Autoanalyzer or by IC. Details of each analytical procedure are listed in Table 3.4.1.

Table 3.4.1. Analytical methods for chemical analyses.

Parameter	**Preparation**	**Preservation**	**Holding Time (d)**	**Reference or method**
Ammonia	--	Cool to 4°C	28	350.1*
NO_3	0.45 µm filter in lab	Cool to 4°C	28	353.2*
SRP	0.45 µm filter in lab	Freeze –10°C	28	365.4*
TP	--	H_2SO_4 Cool to 4°C	28	365.4*
Chloride and Sulfate	--			4110**
Fecal Coliforms	--			9222-D***

* USEPA (1983)
**AWWA (1989)
***Standard Methods (1992)

3.4.3 Results and Discussion

A. Hydrolab Measurements

The mean value and ranges for measurements taken by the Hydrolab in the tributaries are listed in Tables 3.4.2-3.4.5. Seasonal (6/19/02-8/12/03) changes in these parameters are provided in Figures 3.4.2-3.4.5.

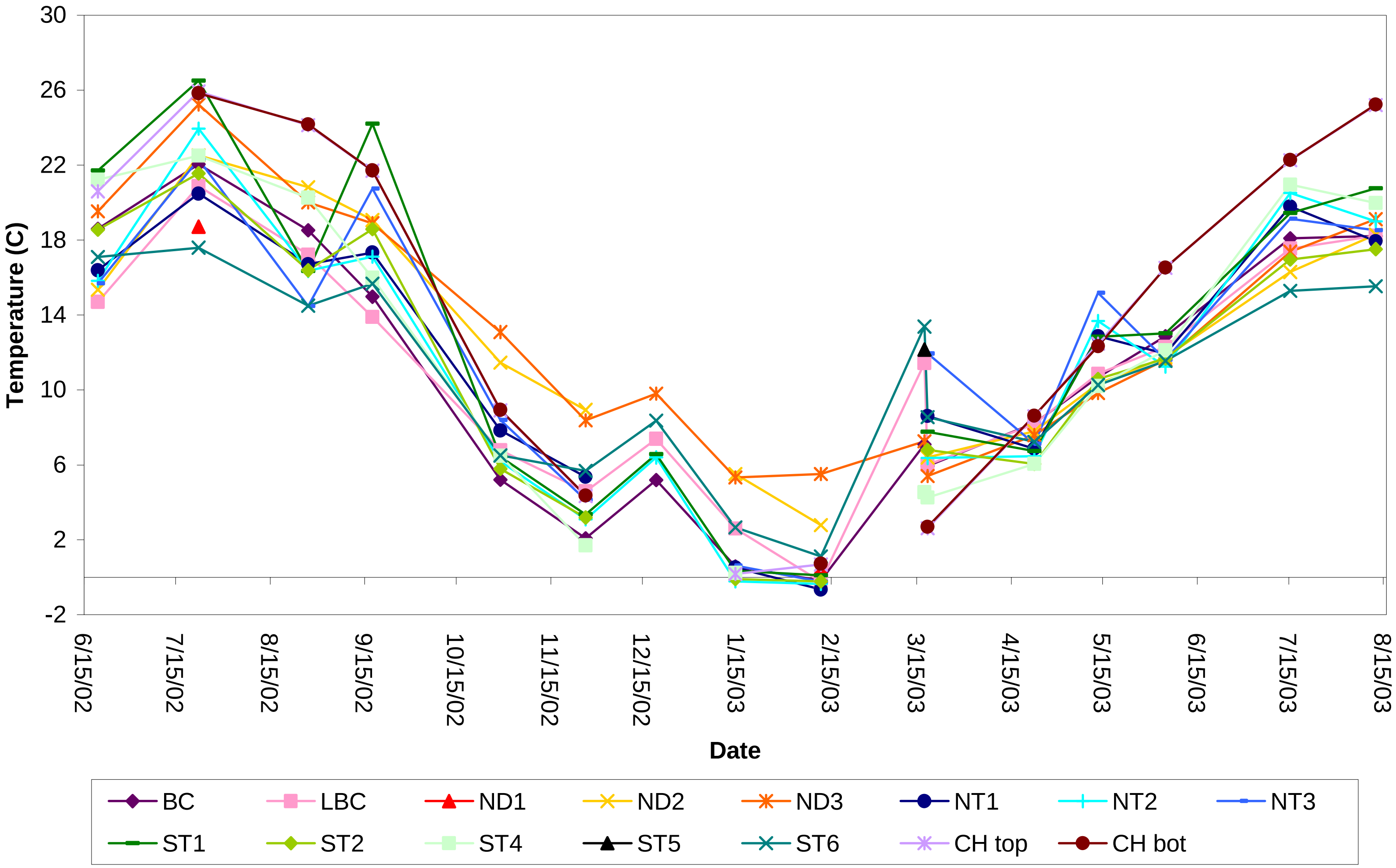
Temperature means were fairly similar across sites (Table 3.4.2), except for the channel which showed warmer tendencies, presumably due to advection of Lake Michigan water. Seasonal patterns reflected a typical warm-summer, cold-winter cycle (Fig. 3.4.2); temperatures in ST6 were relatively cool in the summer and warm in the winter, indicative of a strong groundwater influence.

Table 3.4.2. Mean and range (minimum to maximum) values for temperature (ºC), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	Mean	Range (min-max)
ST1	12.41	0.1-26.5
ST2	10.95	-0.2-21.6
ST4	11.89	0.2-22.5
ST5	12.16*	N/A
ST6	10.69	1.1-17.6
Black Creek	10.51	-0.2-22.0
Little Black Creek	10.77	-0.2-20.9
ND1	10.41**	0.5-18.7**
ND2	12.66	2.8-22.5
ND3	12.75	5.3-25.2
NT1	11.57	-0.7-20.5
NT2	11.04	-0.4-24.0
NT3	12.12	-0.2-22.3
Channel	13.86	0.2-25.9

*ST5 had detectable flow on only one date (3/17/03)
**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

Figure 3.4.2. Monthly temperatures (ºC): 6/19/02-8/12/03.



Dissolved Oxygen is often used as an indicator of water quality, with higher absolute values and percent saturation reflecting better water quality conditions. Values less than 5 ppm are indicative of impaired water quality. Mean DO was relatively high in the Channel, Black Creek, ST1, ST6, and the tributaries on the north side of Mona Lake; conversely, DO was relatively low in ND1 (but based on only three samples), ND2, ND3, and Little Black Creek (Table 3.4.3). Seasonal patterns were evident in DO concentration, as colder temperatures are capable of holding more dissolved oxygen (Fig. 3.4.3); percent saturation was variable among streams (Fig. 3.4.4).

Table 3.4.3. Mean and range (minimum to maximum) values for dissolved oxygen (ppm) and percent saturation (%), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	Mean DO (ppm)	Range (min-max)	Mean % saturation	Range (min-max)
ST1	10.79	8.39-14.09	100.5	83.8-126.3
ST2	9.70	7.41-14.31	87.8	64.2-105.2
ST4	8.50	3.97-14.41	76.6	45.0-119.7
ST5*	11.55	N/A	112.3	NA
ST6	10.44	8.45-13.89	94.7	85.4-113.1
Black Creek	11.11	8.48-14.78	99.2	84.1-126.4
Little Black Creek	9.09	6.16-12.08	82.1	66.0-94.8
ND1**	7.26	5.90-8.04	65.9	55.0-86.0
ND2	9.84	7.55-12.35	92.0	82.4-102.4
ND3	9.64	6.59-14.05	91.0	72.6-120.7
NT1	10.48	8.10-13.72	95.2	87.0-103.4
NT2	10.17	7.11-12.97	91.4	83.1-101.6
NT3	10.62	7.78-13.74	98.1	80.6-132.1
Channel***	11.57	5.50-15.97	109.8	63.1-173.2

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

***Channel surface measurement

Figure 3.4.3. Monthly dissolved oxygen concentration (ppm): 6/19/02-8/12/03.

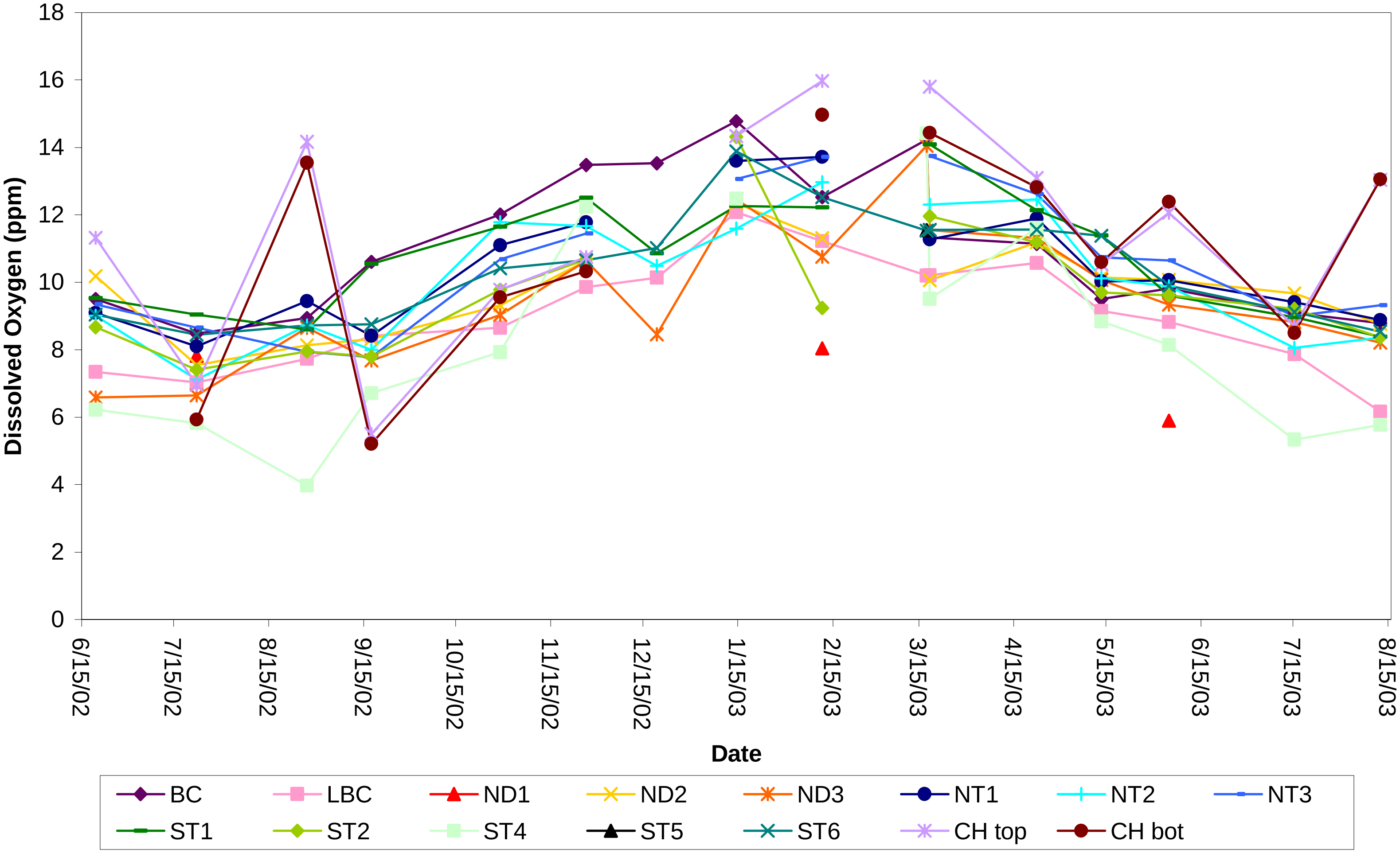
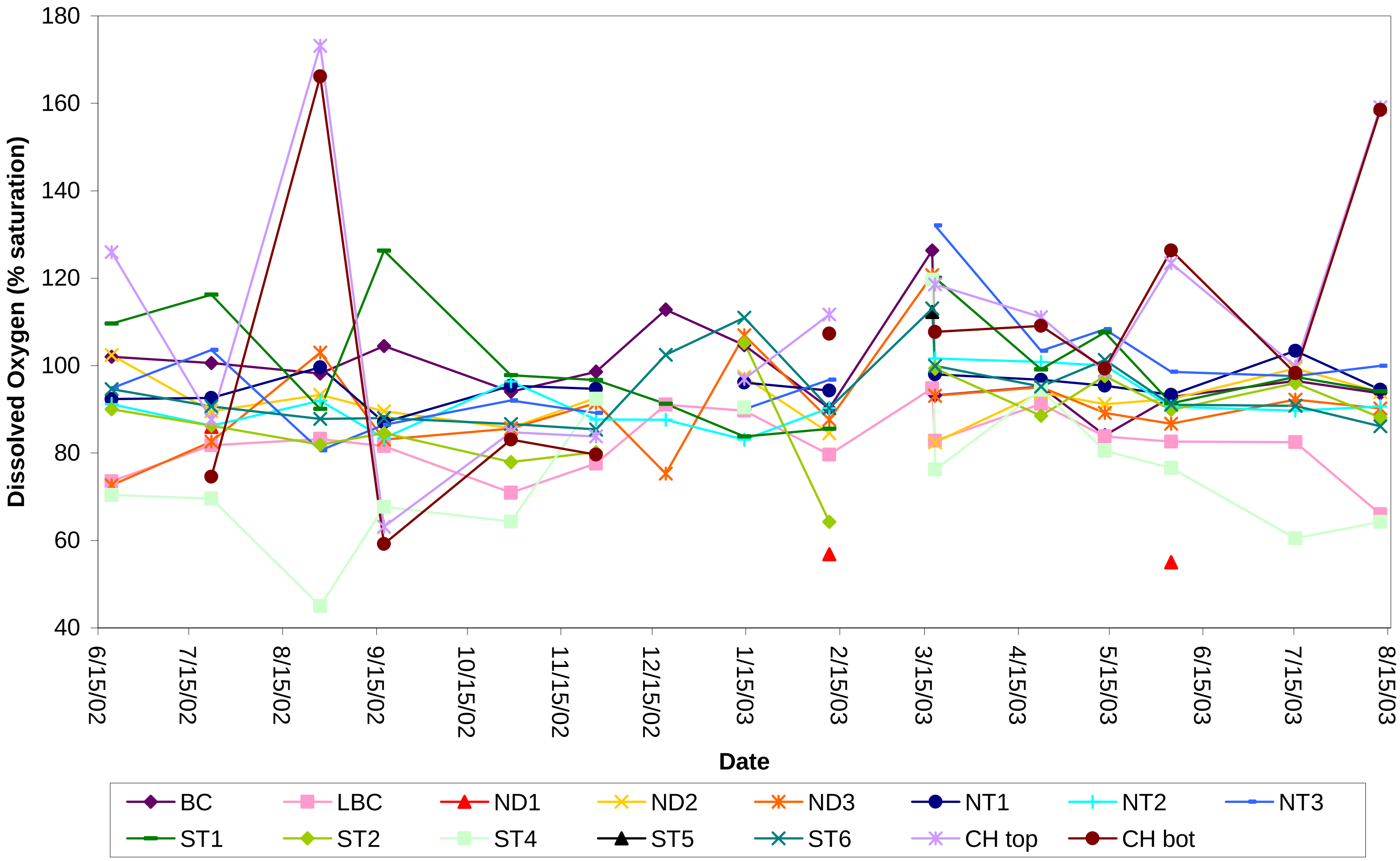


Figure 3.4.4. Monthly percent saturated dissolved oxygen (%): 6/19/02-8/12/03.



Specific Conductance (or conductivity) reflects the amount of ionized salts in solution. As chloride is often one of the most common salts, there is usually a strong positive relationship between specific conductance and chloride (see Table 3.4.6). The storm drains had the highest mean specific conductance readings, reflecting runoff from impervious surfaces (Table 3.4.4). Little Black Creek had the highest specific conductance of the tributaries, reflecting also its largely urban surroundings, and high inputs of surface runoff. There was little evidence of seasonality in the specific conductance data (Fig. 3.4.5); the large spike on 2/11/03 at ND3 is presumably related to runoff associated with salt applied to road ice.

Table 3.4.4. Mean and range (minimum to maximum) values for specific conductance (µS/cm) measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

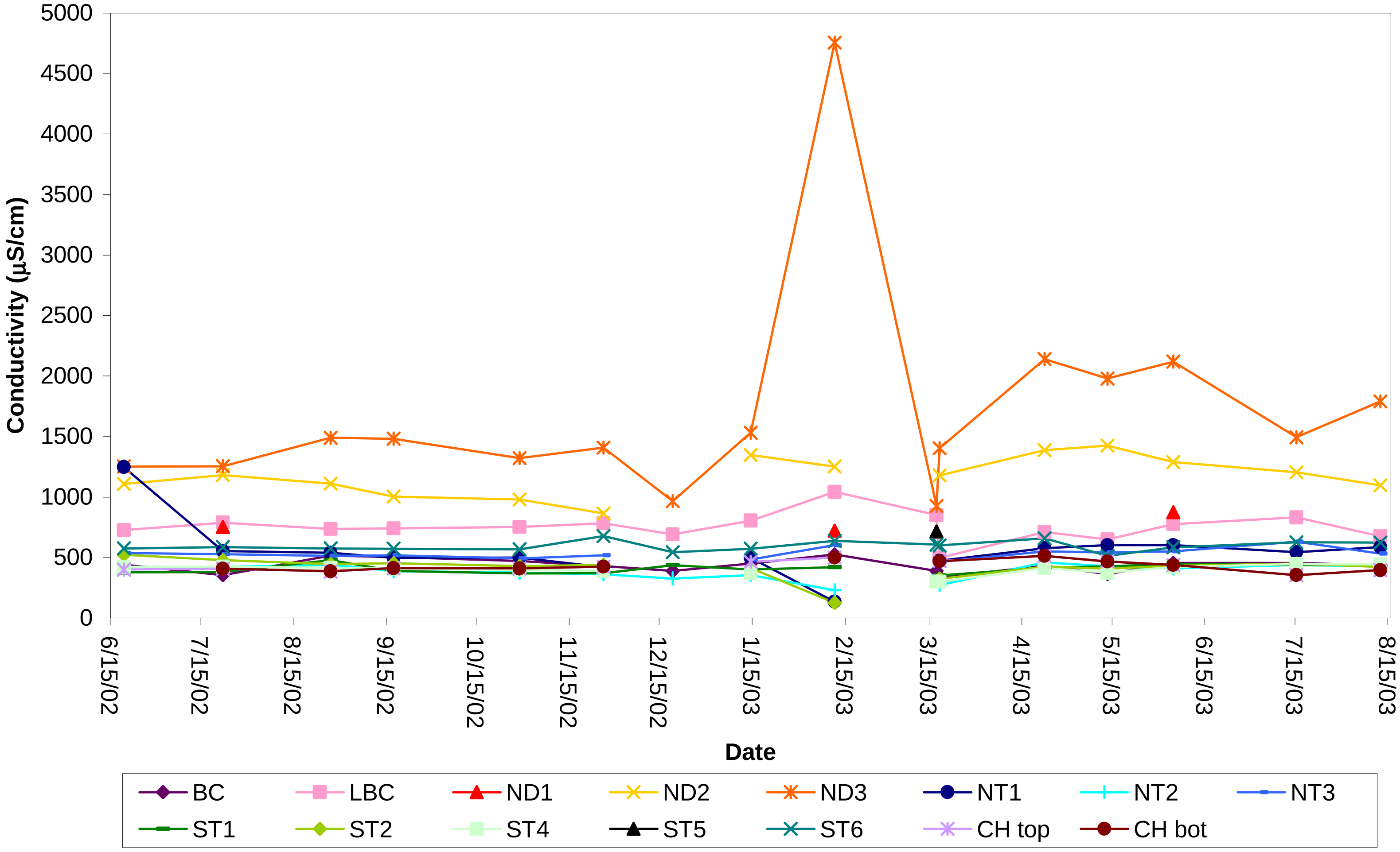
Site	Mean	Range (min-max)
ST1	408.6	353.2-477.6
ST2	411.3	125.0-523.8
ST4	394.3	299.9-445.9
ST5	715.3*	N/A
ST6	595.2	513.4-677.6
Black Creek	434.1	336.3-525.0
Little Black Creek	753.6	497.9-1042.0
ND1	782.8**	721.0-873.9
ND2	1173.2	863.0-1426.0
ND3	1706.8	925.9-4755.0
NT1	555.4	135.7-1247.0
NT2	383.3	228.8-459.6
NT3	533.1	464.4-630.0
Channel***	431.5	355.0-514.3

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

***Measured at surface

Figure 3.4.5. Monthly specific conductance readings (µS/cm): 6/19/02-8/12/03.



Chlorophyll *a* is the principal pigment used by plants and algae to absorb sunlight in the process of photosynthesis. As a consequence, chlorophyll *a* is often used as a proxy for algal biomass. Water column chlorophyll is usually low in small, flowing streams, as most of the algal biomass is attached to surfaces, not suspended in the water. The data in Table 3.4.5 reflect this, as mean levels from the smaller tributaries were usually low. Exceptions included ST5 (based on only one sample) and ND2 (mean heavily skewed by an anomalously high reading of 34.6 ppb on 1/14/03). The higher concentrations in Black Creek and the Mona Lake Channel reflect the fact that these sites were large and deep enough to sustain populations of phytoplankton in the water column. For the most part, chlorophyll a values were low and relatively constant throughout the year (Fig. 3.4.6), with the exception of the Channel and Black Creek.

Table 3.4.5. Mean and range (minimum to maximum) values for chlorophyll *a* (ppb) measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

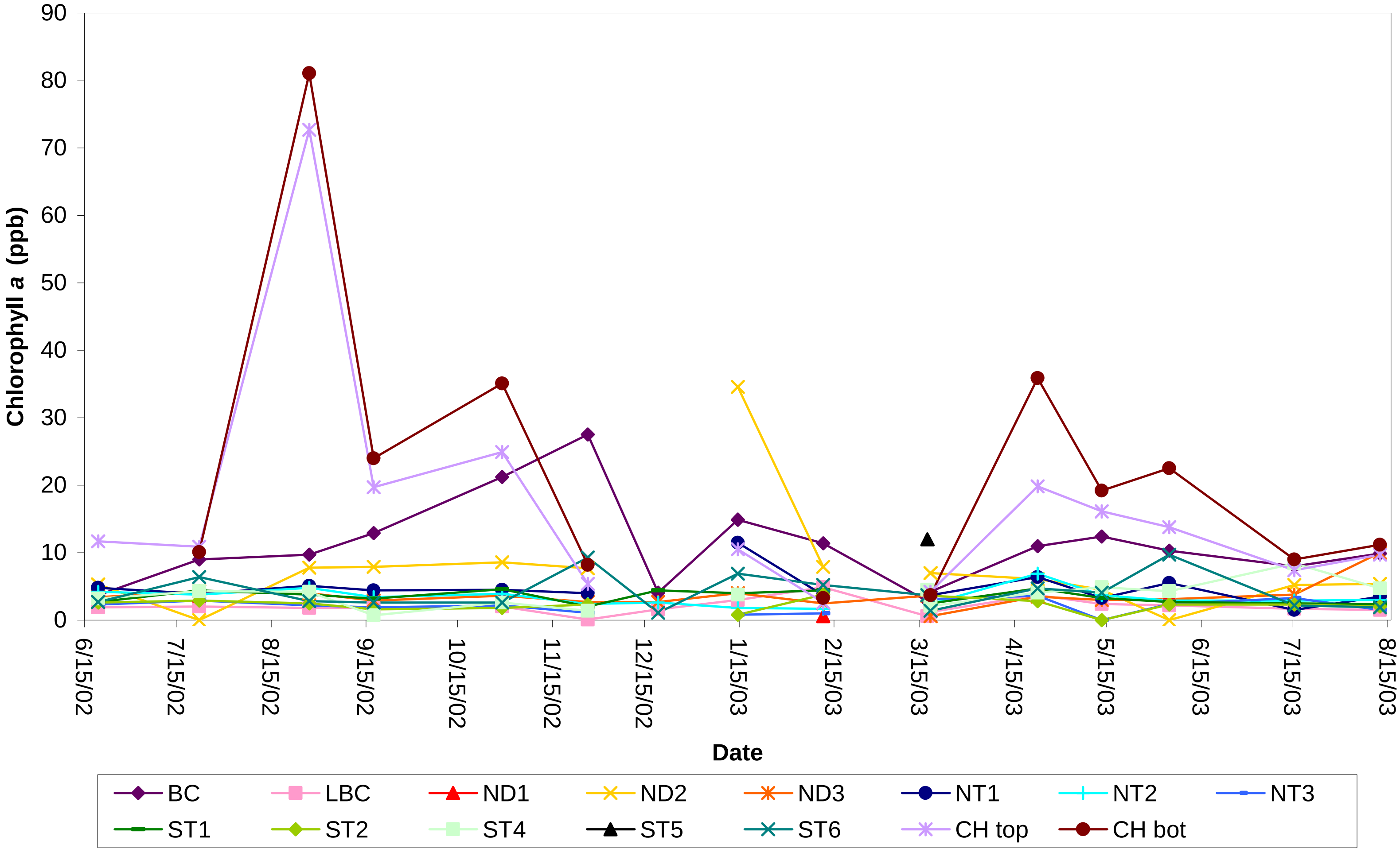
Site	Mean	Range (min-max)
ST1	3.4	2.0-4.6
ST2	2.2	0.0-3.8
ST4	3.8	0.7-8.4
ST5	12.0*	N/A
ST6	4.2	1.1-9.7
Black Creek	10.8	2.8-27.5
Little Black Creek	2.0	0.1-4.9
ND1	2.6**	0.6-3.7
ND2	7.7	0.0-34.6
ND3	3.6	0.6-10.0
NT1	4.7	1.5-11.5
NT2	3.4	1.7-6.9
NT3	2.0	0.0-3.6
Channel***	16.4	2.6-72.7

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

***Measured at surface

Figure 3.4.6. Monthly chlorophyll *a* concentrations (ppb): 6/19/02-8/12/03.



B. Nutrient Measurements

The mean value and ranges for the grab sample water quality and nutrient parameters measured in the tributaries are listed in Tables 3.4.6-3.4.16. Seasonal (7/1/02-7/1/03) changes in major nutrient concentrations are provided in Figures 3.4.2-3.4.11.

Chloride is often used as an indicator of human disturbance to freshwaters; industrial sources, road salting, and municipal wastewater operations all contribute chloride to waters. An approximate average concentration of chloride in pristine fresh water is 8.3 ppm (from Wetzel 1975); none of the values measured in the Mona Lake watershed approached that level, but that is not unexpected given the developed land use in the region. The USEPA drinking water standard for chloride is 250 ppm. Mean chloride concentrations were highest in the storm sewer drains (Table 3.4.6), and the highest concentrations typically were measured in winter (see Appendix 6.2 for monthly values). These data suggest that road salt is a significant source of chloride to Mona Lake, and that direct runoff from impervious surfaces contributes to this source.

Table 3.4.6. Mean and range (minimum to maximum) values for chloride (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	Mean	Range (min-max)
ST1	56	23-90
ST2	71	37-150
ST4	49	20-94
ST5	210*	N/A
ST6	105	60-148
Black Creek	51	19-100
Little Black Creek	123	31-270
ND1	109**	70-140
ND2	215	39-340
ND3	360	70-1300
NT1	84	49-160
NT2	44	26-92
NT3	79	42-127
Channel	49	26-85

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Sulfate is the oxidized form of sulfur, an essential element for all living organisms. The relative contribution of sulfur compounds to natural waters varies with local geology, application of sulfate-containing fertilizers, and atmospheric sources (e.g. production of sulfur dioxide from combustion of fossil fuels). The USEPA drinking water standard for sulfate is 150 ppm. Sulfate concentrations were somewhat lower in the tributaries than the storm sewer drains (if the one anomalous reading of 360 ppm from NT1 on 6/19/02 is excluded, the mean for this tributary declines from 59 to 36 ppm; Table 3.4.7). No strong seasonal signal was apparent in the sulfate data (Appendix 6.2).

Table 3.4.7. Mean and range (minimum to maximum) values for sulfate (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	18	10-26
ST2	24	14-30
ST4	15	8-24
ST5	32*	N/A
ST6	19	13-22
Black Creek	44	26-64
Little Black Creek	39	20-53
ND1	32**	25-36
ND2	39	21-48
ND3	41	22-58
NT1	59	28-360
NT2	24	17-30
NT3	21	13-25
Channel	34	23-40

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

pH is an indicator of the hydrogen ion content in water. Water with a pH of 7.0 indicates a neutral solution. pH values less than 7.0 indicate acidic conditions, while pH values above 7.0 indicate alkaline conditions. The USEPA drinking water standard for pH is 6.5 to 8.5. Mean pH values were similar for all regularly sampled tributaries and drains, with the exception of the Mona Lake channel, which was substantially higher than the other sites (Table 3.4.8). In addition, the Channel was the only site with a distinct seasonality, as pH was greater in warm-weather months (April – October: 8.76 ± 0.34) than cold-weather months (November – March: 7.87 ± 0.08). This may reflect the greater biological activity in the water column of the channel during warm weather months; photosynthetic activity requires the uptake of dissolved inorganic carbon, which results in a more alkaline environment.

Table 3.4.8. Mean and range (minimum to maximum) values for pH, measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	7.90	7.34-8.44
ST2	7.74	7.28-7.75
ST4	7.90	7.28-8.20
ST5	7.82*	N/A
ST6	7.98	7.65-8.41
Black Creek	8.04	7.62-8.31
Little Black Creek	7.75	7.51-7.86
ND1	7.59**	7.56-7.66
ND2	7.95	7.65-8.98
ND3	7.84	7.55-8.31
NT1	7.90	7.45-8.23
NT2	7.74	7.46-8.02
NT3	7.90	7.56-8.09
Channel	8.56	7.36-9.31

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Alkalinity is a measure of the negative ions that are available to react and neutralize free hydrogen ions, such as bicarbonate (HCO_3) and carbonate (CO_3). In general, alkalinity values were higher at the storm drains than the tributaries (Table 3.4.9). There were no seasonal patterns in alkalinity, although levels did decline after a rain event (12/19/02; Appendix 6.2), presumably because of dilution.

Table 3.4.9. Mean and range (minimum to maximum) values for alkalinity (ppm $CaCO_3$), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	99	74-119
ST2	82	54-102
ST4	125	76-154
ST5	54*	N/A
ST6	118	105-125
Black Creek	124	105-148
Little Black Creek	155	123-173
ND1	216**	199-230
ND2	155	113-174
ND3	182	45-300
NT1	115	87-144
NT2	116	71-131
NT3	121	101-128
Channel	118	99-138

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Total suspended solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life. High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water. The TSS data were extremely variable (Table 3.4.10). We did note two events with extremely high values: on 3/17/03 at ST5 (528 ppm) and on 8/12/03 at ND3 (304 ppm). However, other sites sampled on those dates showed either average or slightly elevated TSS, suggesting these events are extremely localized.

TMDLs (total maximum daily loads) for sediment are being developed by the MDEQ for Black Creek and Little Black Creek. The TSS standard in these TMDLs are 80 ppm, levels much greater than what was observed from these inflows, at least at the mouth of Mona Lake. However, impairment may be occurring further upstream, where sediment levels are greater; much of the sediment likely settles out before it reaches Mona Lake itself.

Table 3.4.10. Mean and range (minimum to maximum) values for total suspended solids (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	21	3-140
ST2	34	2-191
ST4	23	5-46
ST5	528*	N/A
ST6	6	1-19
Black Creek	10	3-22
Little Black Creek	5	1-21
ND1	5**	1-13
ND2	2	0-8
ND3	22	1-304
NT1	5	1-12
NT2	26	5-65
NT3	11	2-47
Channel	8	1-32

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Nitrate (NO_3) is created by bacterial action on ammonia, by lightning, or through artificial processes involving extreme heat and pressure. Nitrate can be found in fertilizers, such as potassium or sodium nitrate. In appropriate amounts, nitrates are beneficial but excessive concentrations in water can cause health problems. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 ppm) under certain conditions. The natural level of nitrate in surface water is typically low (less than 1 ppm); however, in the effluent of wastewater treatment plants, it can range up to 30 ppm. The USEPA safe drinking water standard is 10 ppm of NO_3-N. In general, higher nitrate concentrations were measured at the storm drain sites than the tributaries, with the Henry Street drain (ND3) showing the highest mean (Table 3.4.11). No obvious seasonal pattern was detected (Fig. 3.4.7; Appendix 6.2).

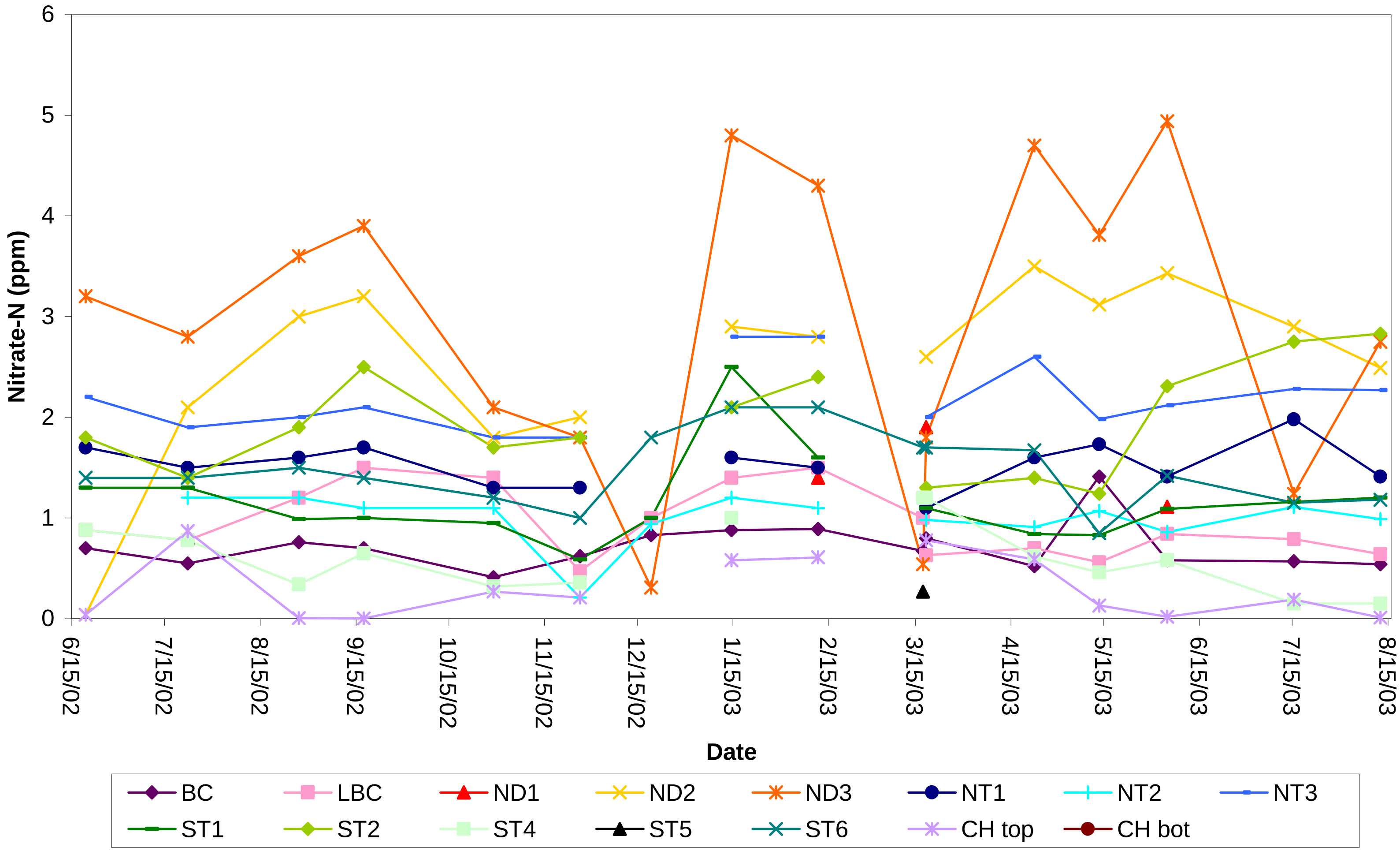
Table 3.4.11. Mean and range (minimum to maximum) values for nitrate (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	1.16	0.59-2.50
ST2	1.96	1.24-2.83
ST4	0.62	0.15-1.20
ST5	0.27*	N/A
ST6	1.47	0.85-2.10
Black Creek	0.71	0.41-1.41
Little Black Creek	0.96	0.47-1.50
ND1	1.3**	0.80-1.90
ND2	2.56	0.04-3.50
ND3	2.91	0.31-4.94
NT1	1.53	1.10-1.98
NT2	1.00	0.21-1.20
NT3	2.19	1.80-2.80
Channel	0.31	0.0-0.87

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Figure 3.4.7. Monthly concentrations of NO_3-N (ppm): 6/19/02-8/12/03.



Ammonia (NH_3) is a byproduct of decaying plant tissue and decomposition of animal waste. Because ammonia is rich in nitrogen, it is also used as fertilizer. Ammonia levels at 0.1 ppm usually indicate polluted surface waters, whereas concentrations > 0.2 ppm can be toxic for some aquatic animals (Cech 2003). High levels of ammonia are typically found downstream of wastewater treatment plants and near water bodies that harbor large populations of waterfowl, who produce large amounts of waste. Ammonia levels tended to be highest in the Mona Lake storm drains, especially at the ND1 and ST5 (Table 3.4.12). ND1 drains a wetland associated with a greenhouse operation, while ST5 drains runoff adjacent to the Muskegon County Airport. Anaerobic conditions probably dominate in these systems, which favors the decomposition of organic matter and subsequent production of ammonia. The high mean concentration at the Channel was unexpected, but was strongly influenced by high concentrations during fall and winter (Appendix 6.2). Concentrations were high at ND1 on all sampling dates, whereas ammonia concentrations were high at Black Creek and ND3 during the fall-winter months (Fig. 3.4.8).

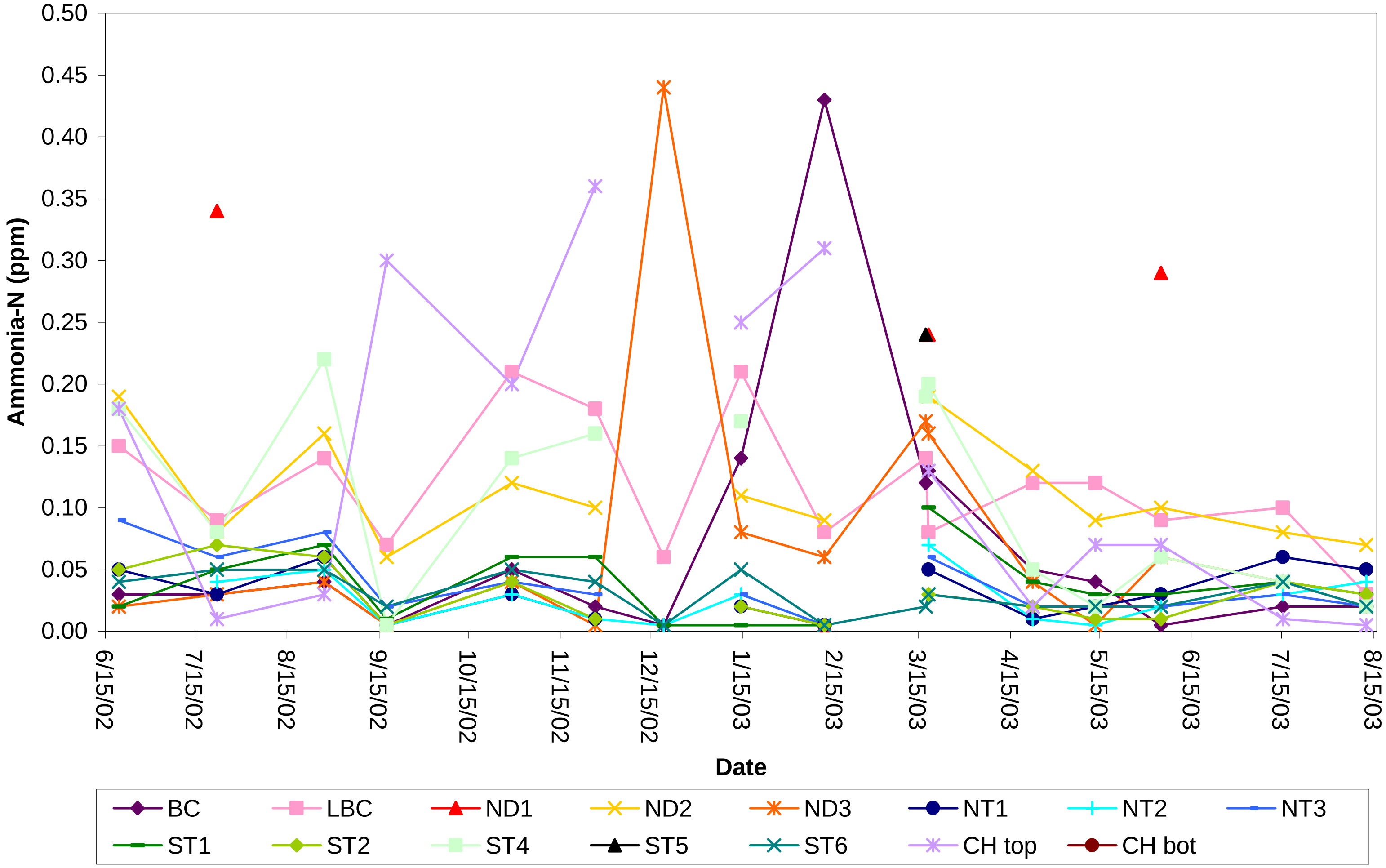
Table 3.4.12. Mean and range (minimum to maximum) values for ammonia (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	0.04	0.01-0.10
ST2	0.03	0.01-0.07
ST4	0.11	0.01-0.22
ST5	0.24*	N/A
ST6	0.03	0.01-0.05
Black Creek	0.07	0.01-0.43
Little Black Creek	0.12	0.03-0.21
ND1	0.22**	0.01-0.34
ND2	0.11	0.06-0.19
ND3	0.08	0.01-0.44
NT1	0.03	0.01-0.06
NT2	0.03	0.01-0.07
NT3	0.04	0.01-0.09
Channel	0.14	0.01-0.36

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Figure 3.4.8. Monthly concentrations of NH_3-N (ppm): 6/19/02-8/12/03.



Total Kjeldahl Nitrogen (TKN) is a measurement of the amount of organic nitrogen and ammonia in a sample. Mean values were fairly similar at all sites except ST5, the airport site that was sampled on only one occasion (Table 3.4.13), which also had a high ammonia concentration. There was no obvious seasonality in the data, although some of the inflows showed distinct peaks in November and January (Fig. 3.4.9; Appendix 6.2).

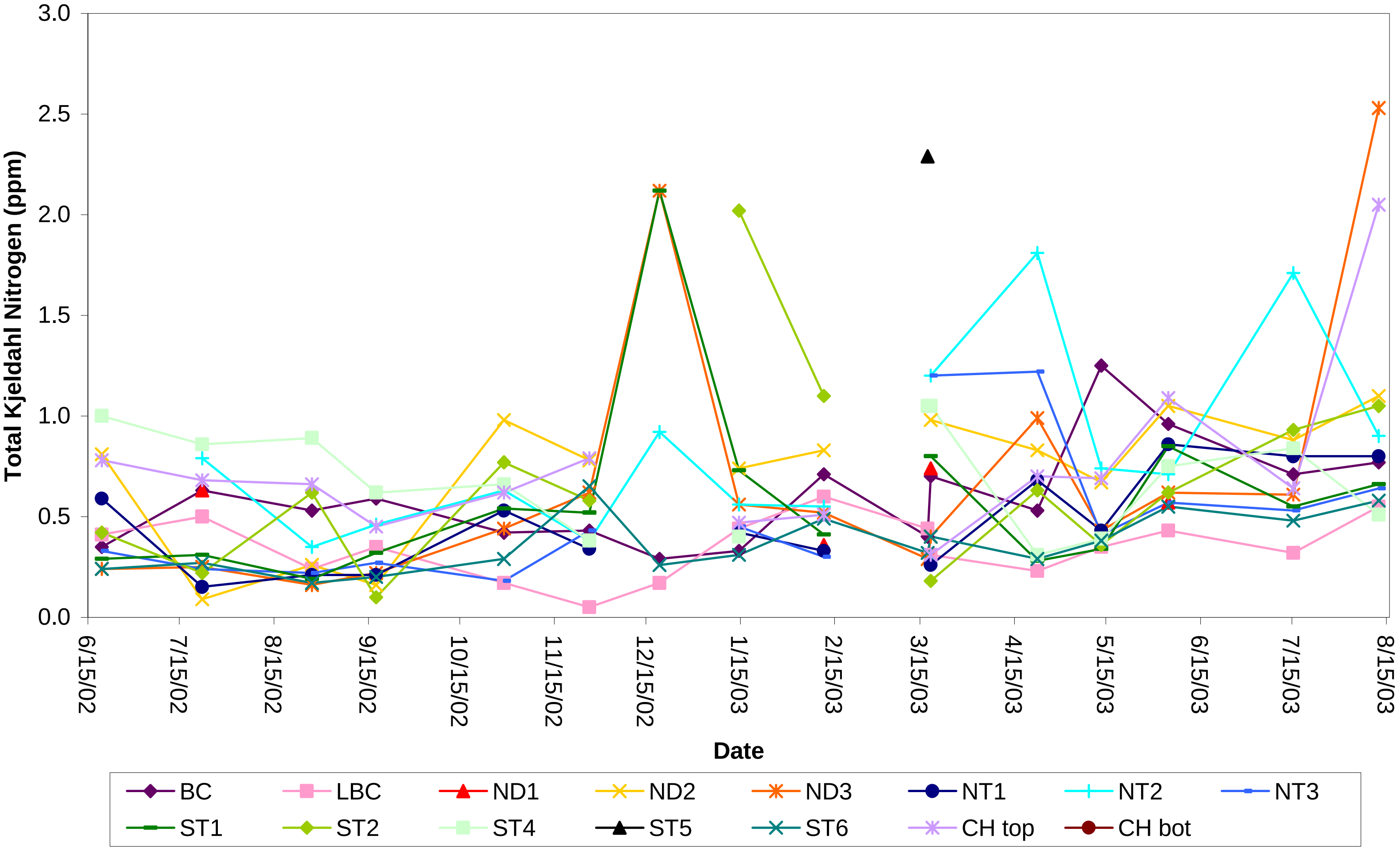
Table 3.4.13. Mean and range (minimum to maximum) values for total kjeldahl nitrogen (ppm), measured from June 2002 to August 2003 at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	0.59	0.19-2.12
ST2	0.69	0.10-2.02
ST4	0.69	0.31-1.03
ST5	2.29*	N/A
ST6	0.37	0.17-0.65
Black Creek	0.60	0.29-1.25
Little Black Creek	0.35	0.05-0.60
ND1	0.58**	0.36-0.74
ND2	0.73	0.09-1.10
ND3	0.69	0.16-2.53
NT1	0.47	0.15-0.86
NT2	0.84	0.35-1.81
NT3	0.50	0.18-1.22
Channel	0.75	0.31-2.05

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Figure 3.4.9. Monthly concentrations of TKN (ppm): 6/19/02-8/12/03.



Soluble reactive phosphorus (SRP) is a measurement of the bioavailable phosphorus in water. Although a high concentration is indicative of enrichment, a low concentration may be due to nutrient-poor conditions or due to all the SRP being actively taken up by the plants and algae in the water body. Therefore, caution must be used when evaluating the significance of SRP levels. Mean values were either 0.01 or 0.02 ppm at all sites except ST5 and ND1, the sites with high levels of ammonia (Table 3.4.14). SRP concentrations were generally higher in the spring/summer perhaps due to fertilizer runoff (Fig. 3.4.10; Appendix 6.2).

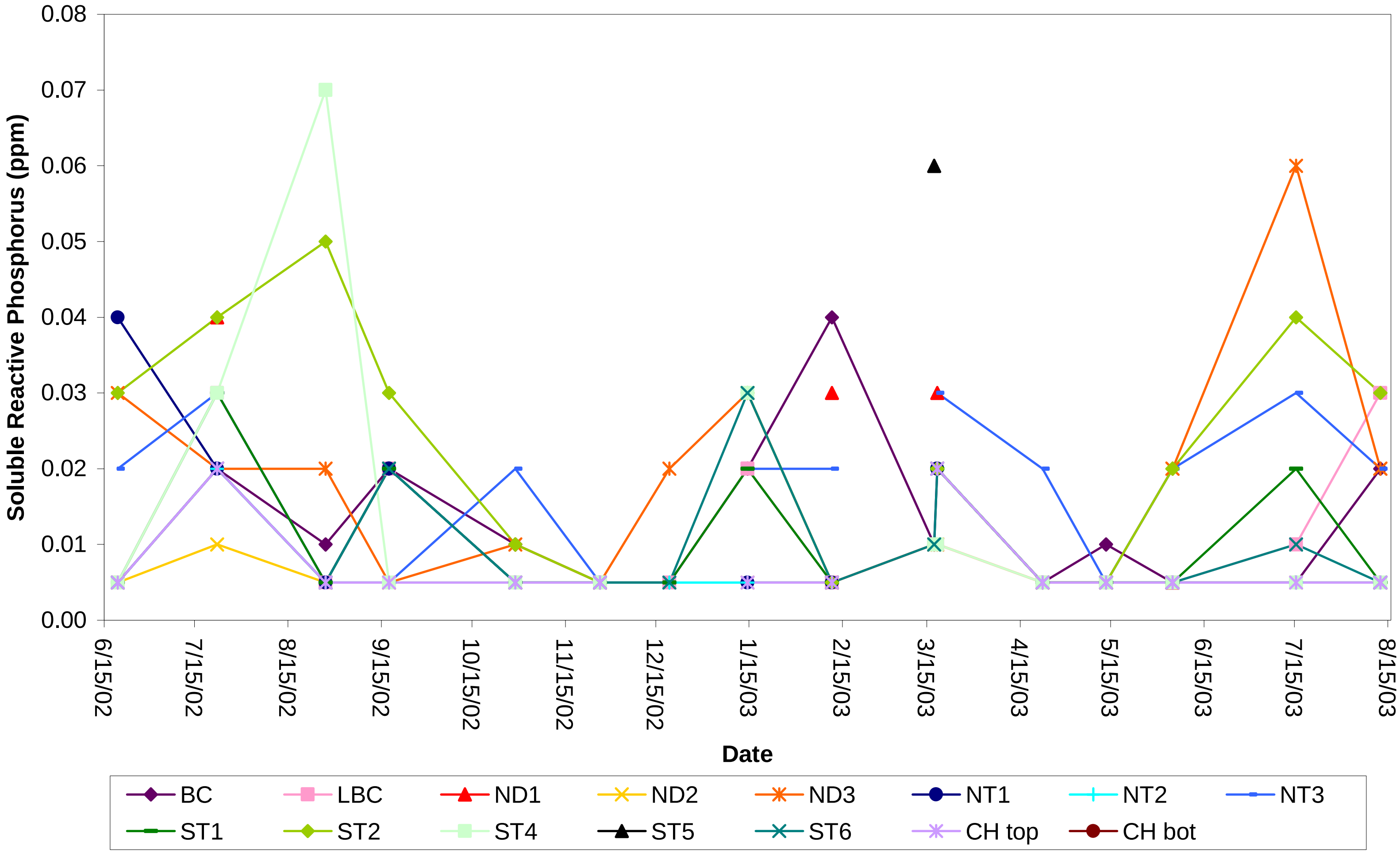
Table 3.4.14. Mean and range (minimum to maximum) values for soluble reactive phosphorus (ppm), measured from June 2002 to August 2003, at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	0.01	0.01-0.03
ST2	0.02	0.01-0.05
ST4	0.01	0.01-0.07
ST5	0.06*	N/A
ST6	0.01	0.01-0.03
Black Creek	0.01	0.01-0.04
Little Black Creek	0.01	0.01-0.03
ND1	0.03**	0.01-0.04
ND2	0.01	0.01-0.02
ND3	0.02	0.01-0.06
NT1	0.01	0.01-0.04
NT2	0.01	0.01-0.02
NT3	0.02	0.01-0.03
Channel	0.01	0.01-0.02

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Figure 3.4.10. Monthly concentrations of SRP (ppm): 6/19/02-8/12/03.



Total phosphorus (TP) is a measurement of all the various forms of phosphorus (inorganic, organic, dissolved, and particulate) in the water. TP standards have been established for some running waters, as filamentous green algae became abundant at TP concentrations of 0.01-0.02 ppm (USEPA 2000). Mean values ranged from 0.02 (ND2) to 0.82 (ST5) ppm at all sites (Table 3.4.15), and were suggestive of eutrophic conditions. Although TP values can get as high as 10-20 ppm downstream of livestock operations, the 0.82 ppm value at ST5 and values of 0.49 ppm (ND3 on 8/12/03) or 0.33 ppm (ST2 on 1/14/03) indicate that problematic TP inflows to Mona Lake still occur on occasion. There was little evidence of a seasonal pattern in TP concentrations (Fig. 3.4.11), although a few inflows had spikes of TP during the winter months.

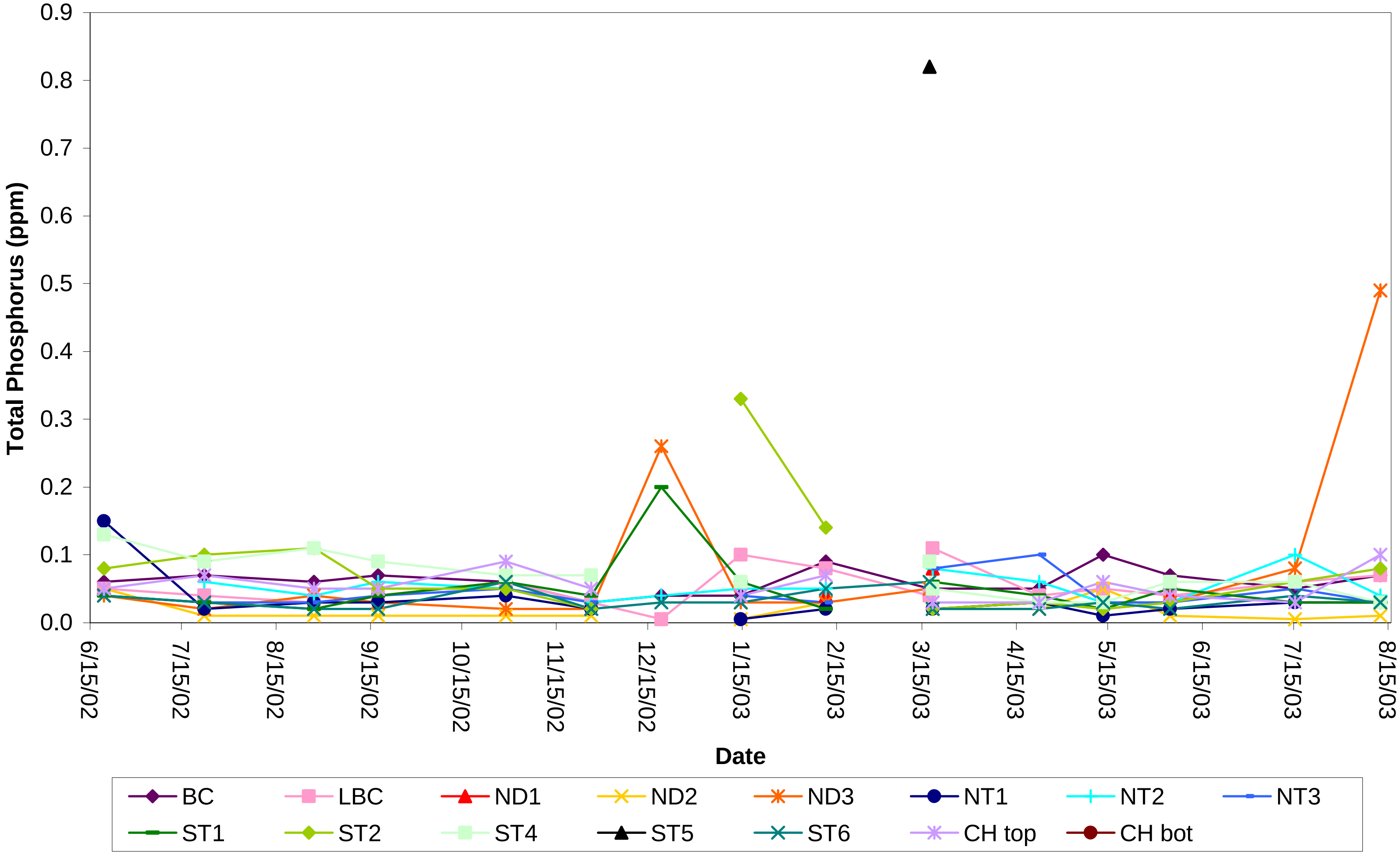
Table 3.4.15. Mean and range (minimum to maximum) values for total phosphorus (ppm), measured from June 2002 to August 2003, at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	0.05	0.02-0.20
ST2	0.08	0.02-0.33
ST4	0.07	0.03-0.13
ST5	0.82*	N/A
ST6	0.03	0.02-0.06
Black Creek	0.06	0.03-0.10
Little Black Creek	0.05	0.03-0.11
ND1	0.07**	0.04-0.10
ND2	0.02	0.01-0.05
ND3	0.08	0.02-0.49
NT1	0.03	0.01-0.15
NT2	0.05	0.01-0.10
NT3	0.04	0.03-0.10
Channel	0.05	0.03-0.10

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

Figure 3.4.11. Monthly concentrations of TP (ppm): 6/19/02-8/12/03.



Fecal coliforms are a class of coliform bacteria, which are present in the digestive tract and feces of all warm-blooded animals, including humans, poultry, livestock, and wild animals. Fecal coliform bacteria themselves generally are not harmful, but their presence indicates that surface waters may contain pathogenic microbes. Diseases that can be transmitted to humans through contaminated water are the primary concern. At present, it is difficult to distinguish between waters contaminated by human vs. animal waste. We considered impairment to exist when samples exceeded 200 colonies per 100 ml of water sample, which was the MDEQ standard prior to 1996. All sites except the Channel exceeded the former MDEQ standard on at least one date (Table 3.4.16). Several of the sites also had mean values that exceeded the 200 colony standard, as well, although there was no apparent spatial pattern to the exceedances. Temporally, the highest values were generally measured during summer months (Appendix 6.2).

Table 3.4.16. Mean and range (minimum to maximum) values for fecal coliform colonies (#/100 ml), measured from June 2002 to August 2003, at all measurable inflows and outflows to Mona Lake.

Site	**Mean**	**Range (min-max)**
ST1	130	16-980
ST2	155	16-1000
ST4	341	50-3200
ST5	16*	N/A
ST6	171	16-2690
Black Creek	150	16-2600
Little Black Creek	321	16-5800
ND1	220**	17-680
ND2	31	10-2200
ND3	244	16-2500
NT1	398	16-2400
NT2	259	33-2100
NT3	150	16-1400
Channel	19	16-67

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03); a sample was collected from the holding pond on 3/18/03

C. Chemical Loads

Load is calculated as the concentration of a chemical multiplied by the water discharge. It provides an estimate of the total mass of a material in the system. For this analysis, five major nutrients were analyzed: nitrate (NO_3-N), ammonia (NH_3-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), and total phosphorus (TP).

The time period for analyzing the chemical and hydrologic data ranged from July 1, 2002 to June 30, 2003. A total of 13 tributaries of Mona Lake were evaluated, but ND1 and ST5 were excluded because their observed discharges were mostly zero. Based on the hydrologic modeling results, multiple linear regression models were developed for all subbasins.

$$Q_k = \beta_0 + \sum_{i=1}^{7} \beta_i P_{k-i+1}$$

where Q_k = water discharge of a tributary at time k; P_{k-i+1} = precipitation at time k-i+1; β_0 = baseflow; and β_i = regression coefficient.

Table 3.4.17. Parameters for the multiple regression model used to calculate nutrient loads from inflows to Mona Lake.

Coefficient	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7
BC	21.962	3.295	12.535	24.260	12.987	8.978	7.343	7.713
LBC	1.411	1.923	3.344	0.435	0.327	0.245	0.188	0.186
6B	1.548	4.093	2.016	0.556	0.390	0.424	0.176	0.188
17C (ST6)	1.434	2.424	1.781	0.327	0.293	0.265	0.140	0.144
20C (ST1)	0.647	2.048	1.348	0.420	0.303	0.296	0.146	0.145

Daily average water discharges from 7/1/2002 to 6/30/2003 for BC, LBC, ST1, ST6, and 6B were predicted by using the developed multiple linear regression models. First, the water inflow for the lake area was deducted from the total simulated water discharge for 6B based on the percentage of the area (A_{6B} = 6.87 mi^2 and A_{ML} = 1.025 mi^2). The remaining amount of the water discharge was then divided into individual discharges from ND2, ND3, NT1, NT2, NT3, ST2, and ST4 based on ratios that were determined by field measurements of water flow at several times (note that discharges from ND1 and ST5 were assumed zero). The ratios for these tributaries are shown in the following table:

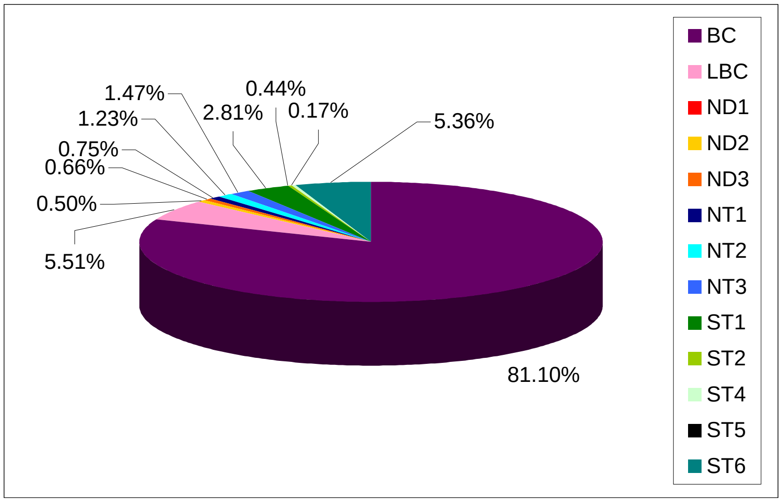
Table 3.4.18. Ratios indicating partitioning of water flow among tributaries in Subbasin 6B to calculate loads.

ND1	ND2	ND3	NT1	NT2	NT3	ST2	ST4	ST5
0	0.0952	0.1272	0.1446	0.2350	0.2819	0.0839	0.0321	0

Because (1) the measured flow and concentration for each tributary did not show any direct correlation and (2) changes in the measured concentrations at different times were not significant for all tributaries, the monthly average concentrations of pollutants were used to compute loads of contaminants. Since we have only one measured concentration for each month, to eliminate the possible observation errors, the monthly averaged concentration was computed by using a weighted method based on three observed concentrations corresponding to the current month (weight: 50%), preceding month (weight: 25%), and following month (weight: 25%). Finally, we ended up with daily loads of 5 contaminants for all 13 tributaries of Mona Lake. From these simulated daily loads, we also computed yearly loads and percentages.

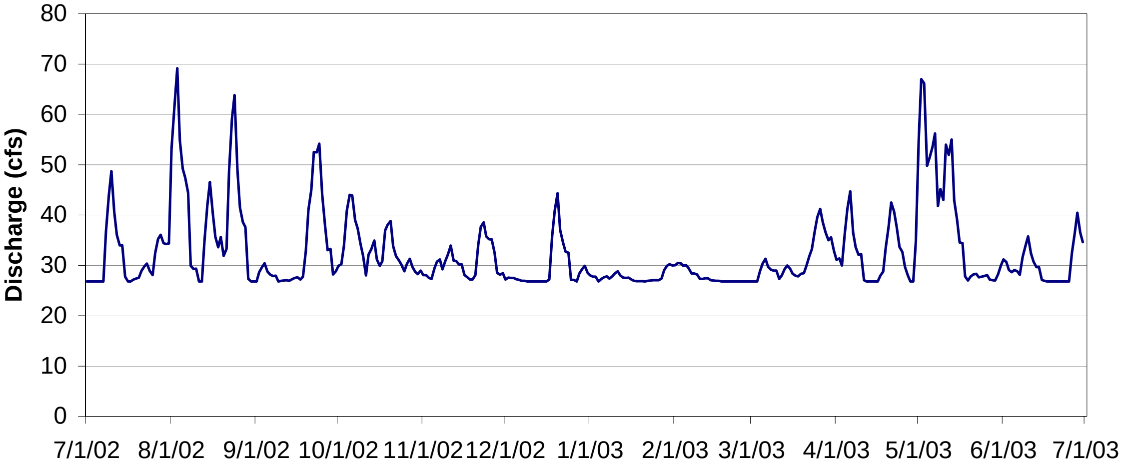
Four tributaries dominated discharge to Mona Lake: Black Creek (81.10%), Little Black Creek (5.51%), ST1 (2.81%), and ST6 (Cress Creek; 5.36%)(Figure 3.4.12).

Figure 3.4.12. Percent discharge from the 13 inflows to Mona Lake: 7/1/02-7/1/03.



The time series of discharge for the period of record reveals that most of the flow (Fig. 3.4.13) occurred in the spring and summer months.

Figure 3.4.13. Hydrograph of inflows (cfs) to Mona Lake: 7/1/02-7/1/03.



Nitrate loads were highest in Black Creek, accounting for more than 69% of the total nitrate load into Mona Lake. However, the percent nitrate in the Black Creek load was less than the percent flow from Black Creek (Table 3.4.19). It is unclear if this is due to relatively less nitrate entering this subbasin or loss of nitrate in the subbasin perhaps through reduction to ammonia or biotic uptake. This contrasts with ST6, whose percent nitrate load was almost double its percent flow to Mona Lake.

Table 3.4.19. Absolute nitrate load (kg/yr), relative nitrate load (%), and relative discharge (%), measured from June 2002 to June 2003, at all measurable inflows to Mona Lake.

Site	NO_3	Percent NO_3 Load	Percent Flow
ST1	906	3.62	2.81
ST2	237	0.95	0.44
ST4	29	0.12	0.17
ST5	<0.1*	<0.1	<0.1
ST6	2299	9.19	5.36
Black Creek	17,350	69.33	81.10
Little Black Creek	1598	6.39	5.51
ND1	<0.1**	<0.1	<0.1
ND2	390	1.56	0.50
ND3	606	2.42	0.66
NT1	333	1.33	0.76
NT2	353	1.41	1.23
NT3	923	3.69	1.47

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

Ammonia loads were highest in Black Creek, accounting for more than 83% of the total ammonia load into Mona Lake (Table 3.4.20). In contrast to nitrate, percent ammonia at ST6 was lower than the percent flow. Little Black Creek has more percent ammonia than percent flow, indicating it was a relative source to Mona Lake. Some of this may be due to reduction of nitrate, but given that Little Black Creek also had higher percent nitrate than flow, it is apparent that this subbasin is a net exporter of inorganic nitrogen to Mona Lake.

Table 3.4.20. Absolute ammonia load (kg/yr), relative ammonia load (%), and relative discharge (%), measured from June 2002 to June 2003, at all measurable inflows to Mona Lake.

Site	**NH_3**	**Percent NH_3 Load**	**Percent Flow**
ST1	30	1.48	2.81
ST2	3	0.17	0.44
ST4	5	0.26	0.17
ST5	<0.1*	<0.1	<0.1
ST6	47	2.30	5.36
Black Creek	1713	83.33	81.10
Little Black Creek	198	9.61	5.51
ND1	<0.1**	<0.1	<0.1
ND2	16	0.77	0.50
ND3	14	0.70	0.66
NT1	6	0.27	0.76
NT2	8	0.38	1.23
NT3	15	0.75	1.47

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

TKN loads were highest in Black Creek, accounting for more than 85% of the total ammonia load into Mona Lake (Table 3.4.21), compared to 81% flow. Similar to ammonia, percent TKN at ST6 was lower than the percent flow. This is to be expected, given that TKN includes ammonia in its measurement. Little Black Creek also has less percent TKN than percent flow.

Table 3.4.21. Absolute TKN load (kg/yr), relative TKN load (%), and relative discharge (%), measured from June 2002 to June 2003, at all measurable inflows to Mona Lake.

Site	**TKN**	**Percent TKN Load**	**Percent Flow**
ST1	460	2.78	2.81
ST2	83	0.50	0.44
ST4	31	0.19	0.17
ST5	<0.1*	<0.1	<0.1
ST6	533	3.23	5.36
Black Creek	14,143	85.59	81.10
Little Black Creek	507	3.07	5.51
ND1	<0.1**	<0.1	<0.1
ND2	94	0.57	0.50
ND3	112	0.68	0.66
NT1	92	0.56	0.76
NT2	270	1.64	1.23
NT3	199	1.20	1.47

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

SRP loads were highest in Black Creek, accounting for more than 84% of the total SRP load into Mona Lake (Table 3.4.22). Most of the inflows had similar percent loads as percent flows, although Black Creek has slightly greater load than flow, while Little Black Creek has slightly less load than flow.

Table 3.4.22. Absolute SRP load (kg/yr), relative SRP load (%), and relative discharge (%), measured from June 2002 to June 2003, at all measurable inflows to Mona Lake.

Site	SRP	Percent SRP Load	Percent Flow
ST1	8.3	2.20	2.81
ST2	2.6	0.70	0.44
ST4	0.8	0.21	0.17
ST5	<0.1*	<0.1	<0.1
ST6	15.6	4.17	5.36
Black Creek	316.5	84.68	81.10
Little Black Creek	15.3	4.11	5.51
ND1	<0.1**	<0.1	<0.1
ND2	0.9	0.23	0.50
ND3	2.6	0.70	0.66
NT1	2.0	0.54	0.76
NT2	2.4	0.64	1.23
NT3	6.7	1.80	1.47

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

Total phosphorus (TP) loads were highest in Black Creek, accounting for almost 86% of the TP load into Mona Lake (Table 3.4.23). Percent TP load at ST6 and Little Black Creek were slightly lower than the percent flow. Given that more than 85% of the total phosphorus coming from the Black Creek subbasin, implementation efforts to reduce phosphorus loading to Mona Lake should be focused in this area.

Table 3.4.23. Absolute TP load (kg/yr), relative TP load (%), and relative discharge (%), measured from June 2002 to June 2003, at all measurable inflows to Mona Lake.

Site	TP	Percent TP Load	Percent Flow
ST1	40.6	2.45	2.81
ST2	10.1	0.61	0.44
ST4	3.4	0.20	0.17
ST5	<0.1*	<0.1	<0.1
ST6	47.9	2.89	5.36
Black Creek	1424.5	85.97	81.10
Little Black Creek	77.8	4.69	5.51
ND1	<0.1**	<0.1	<0.1
ND2	2.6	0.16	0.50
ND3	8.9	0.54	0.66
NT1	5.8	0.35	0.76
NT2	17.1	1.03	1.23
NT3	18.4	1.11	1.47

*ST5 had detectable flow on only one date (3/17/03)

**ND1 had detectable flow on only three dates (7/22/02, 2/11/03, 6/4/03)

D. Summary

Nutrient concentrations and loads in the inflows to Mona Lake indicate that the watershed is contributing substantial amounts of materials to the Lake. The relatively high levels of total phosphorus, ammonia, and fecal coliforms all contribute to lake impairment; best management practices are needed to reduce the levels of these stressors. Distinct seasonal patterns were not apparent, although concentrations of some constituents did increase after storm or rain events, as might be expected for chemicals that adsorb to particles.

Although some of the storm drains contribute high concentrations of stressors at certain times of the year, the overall loads from these drains are small (due to low discharges on an annual basis). Hence, they may affect Mona Lake on a localized basis (near their discharge point), but it is unlikely that they are having severe lake-wide impacts. Nonetheless, storm drain retrofits and continued education about the function and operation of storm drains are recommended to minimize discharge concentrations and impacts. Black Creek is the largest contributor, by mass, of materials to Mona Lake; even though the concentrations in Black Creek are comparable to other inflows, its high discharge results in the greatest loads. As a consequence, even a small reduction in the concentration of a material in Black Creek will result in a large reduction in overall mass entering Mona Lake. Therefore, we recommend that nutrient-related watershed management improvements be focused, at least initially, in this subbasin.

3.5 Hydrologic Model

3.5.1 Introduction

Watershed-scale hydrologic modeling often involves dealing with a large set of spatially distributed data, which may require geographic information system (GIS) technology for subsequent analysis and application. Much attention has been paid in the past decade to the linkage of GIS and watershed hydrologic modeling (DeVantier and Feldman 1993; Ross and Tara 1993; Olivera and Maidment 2000; Olivera 2001; Vieux 2001). Ogden et al. (2001) summarized GIS-based hydrologic modeling and applications, and discussed a series of key implementation issues associated with the use of GIS in watershed hydrologic modeling. Among the significant efforts towards enhancing the application of GIS technology in hydrologic modeling is the development of the Watershed Modeling System (WMS, 1999). WMS is a comprehensive modeling environment for watershed-scale hydrologic analysis that incorporates several commonly-used hydrologic models, such as HEC-1, TR-20, TR-55, NFF, and HSPF. In particular, the WMS, together with the WMS-Hydro extension for ArcView (WMS-Hydro, 1999), facilitates processing of various raster and vector GIS data, automated watershed delineation, and computation of hydrologic parameters.

The Hydrologic Modeling System (HEC-HMS), the successor to the HEC-1 (USACE 1998), is a precipitation-runoff-routing model that represents a drainage basin as an interconnected system of hydrologic and hydraulic components and simulates the surface runoff response to precipitation. In particular, the new HEC-HMS improves upon the capabilities of HEC-1 and provides additional capabilities for distributed modeling and continuous simulation (USACE 2001). HEC-HMS/HEC-1 has been widely used for watershed hydrologic modeling (e.g. Bedient 2000; Olivera 2001; Anderson et al. 2002). The current study took advantage of the aforementioned capabilities of the WMS and HEC-HMS and coupled the two modeling systems for watershed characterization and continuous GIS-based hydrologic modeling for the Mona Lake watershed (Fig. 3.5.1).

Clearly, knowledge of hydrologic processes in the Mona Lake watershed is necessary to better understand the underlying mechanisms, transport, and distribution of a variety of pollutants and contaminated sediments. This information will further help to identify water-quality management strategies and environmental practices. However, little information is available concerning the magnitude, variability, and sources of the water discharges from the tributaries of Mona Lake. The objective of this study is to provide such hydrologic information for the water quality management of the lake by characterizing the Mona Lake watershed and quantitatively modeling hydrologic processes by coupling WMS and HEC-HMS. Our specific analyses include the quantity (how much water drains from tributaries into Mona Lake), variability (how water discharges vary temporally and spatially), and sources of the water.

3.5.2 Methodology and Model Development

Although WMS is capable of performing hydrologic modeling by using the built-in HEC-1, such a simulation is limited to one rainfall event. For the purposes of GIS-based watershed characterization and continuous hydrologic modeling, the WMS was coupled with the latest HEC-HMS in this study. The WMS, together with the WMS-Hydro GIS extension, was used for processing GIS data (e.g. DEMs, various point, arc, and polygon shapefiles representing outlets, stream channels, drainage boundaries, as well as land use and soil type), dealing with watershed delineation, generating stream networks and subbasin boundaries, and computing hydrologic parameters (e.g. composite curve numbers and lag times). The output of the WMS was then transferred to HEC-HMS. By incorporating the basin model developed with WMS, importing precipitation gauge(s) and discharges gauge(s), and specifying simulation control and other parameters (e.g., starting and ending date and time, time interval, and SMA units and relevant coefficients), hydrologic modeling was eventually implemented for the Mona Lake watershed by using HEC-HMS.

Watershed Delineation

WMS was used to characterize the Mona Lake watershed. Specifically, based on the 30-meter USGS DEM (Digital Elevation Model) of the Mona Lake watershed (Fig. 3.5.2), overland flow directions were first computed using the TOPAZ program (Topographic Parameterization) (Garbrecht and Martz 2000) that has been incorporated in the WMS. The flow accumulations were then determined. After specifying a set of outlets (a point layer), a stream network (an arc layer) was created and a polygon layer representing subbasin boundaries was also determined. With the watershed delineated, all basin geometric parameters, such as the area of a subbasin, overland flow length, basin slope, stream channel length and slope, etc. were computed.

Based on the water flow directions and accumulations, stream network and channel distributions, and other hydrologic features, seven outlets were defined in this case study and thus the entire watershed was divided into eight subbasins (Fig. 3.5.2). In addition to subbasin 6B that directly discharges into Mona Lake, four outlets around the lake contribute water from the subbasins to Mona Lake. The water ultimately drains through the outlet of Mona Lake into Lake Michigan.

Computation of Curve Numbers and Travel Times

GIS spatially distributed land use and soil type data are essential to the estimation of hydrologic parameters, such as the curve numbers that are used in the SCS (Soil Conservation Service) method. The 97-98 land use shapefile of the watershed, used herein, was created by the AWRI Information Services Center of Grand Valley State University and the soil type shapefile was obtained from the Center for Geographic Information, Michigan. In the WMS, two new coverages were created for land use and soil type, respectively. The GIS polygon shapefiles of land use and soil type for the Mona Lake watershed, as well as the corresponding information on hydrologic groups, were then imported into the WMS modeling system. By superposing the drainage, land use, and soil type coverages, composite curve numbers for all subbasins were computed using an area-weighted averaging method:

$$CN_i = \frac{\sum_{j=1}^{N_i} A_j^i \, CN_j^i}{\sum_{j=1}^{N_i} A_j^i}$$

where CN_i is the composite curve number for subbasin i; A_j^i is the area of subdivision *j* of uniform land use and soil type in subbasin *i*; CN_j^i is the curve number of subdivision *j* of uniform land use and soil type in subbasin *i*; and N_i is the total number of subdivisions in subbasin *i*.

Lag time, which quantifies the response time of water discharge at the outlet of a watershed to a rainfall event, was also required for hydrologic modeling. In this study, the most commonly used SCS method was selected for computing the lag time.

$$T_{Li} = L_i^{0.8} \frac{(S_i + 1)^{0.7}}{1900 s_{bi}^{0.5}}$$

in which

$$S_i = \frac{1000}{CN_i} - 10$$

where T_{Li} is the lag time of subbasin *i* (hr); L_i is the hydraulic length of subbasin *i* (ft); S_i is the potential retention of subbasin *i* (in); and s_{bi} is the average slope of subbasin *i* (%).

Watershed Hydrologic Modeling Using HEC-HMS

The hydrologic modeling for the Mona Lake watershed was implemented by HEC-HMS. The conceptual HEC-HMS modeling structure, developed herein, is illustrated in Fig. 3.5.3. In the Mona Lake watershed, Black Creek drains the largest region, which consists of the following model elements: subbasins 3B, 4B, 5B, and 8B; channels 15R and 16R; and outlets 15C, 16C, and 18C (Fig. 3.5.3). This region also receives treated wastewater discharges from the Muskegon Wastewater Management System (WWMS). The simulation period ranged from 1 May 2001, 0:00 to 20 August 2002, 0:00 and the computation time step was 1 hour. Precipitation data at the Muskegon County Airport weather station (WBAN ID: 14840; WMO ID: 72636; Lat/Lon: 43°10′N/86°14′W), obtained from NOAA's National Climatic Data Center, were used in the simulation. The model also took into account an additional source term of water that discharged directly from the Muskegon Wastewater Management System into Black Creek.

For the purpose of continuous hydrologic simulations, the soil moisture accounting (SMA) loss method was selected for estimating rainfall excess. The SMA is essentially a lumped storage model that represents a subbasin with linked storage layers (canopy storage, surface storage, soil storage, and groundwater storage) in the vertical direction accounting for canopy interception, surface depression, infiltration, evapotranspiration, as well as soil and groundwater percolation during rainfall events. Water flow into or out of the storages is simulated for each time step in the SMA model. To transform the computed rainfall excess into direct runoff at the outlet of a subbasin, the following SCS parametric UH (Unit Hydrograph) model was employed in this study (USACE, 2001).

$$Q_k = \sum_{j=1}^{J_k} R_j U_{k-j+1}$$

Where Q_k is the water flow at the subbasin outlet at the end of time step k [L^3/T]; R_j is the rainfall excess for time step j [L]; U_{k-j+1} is the UH discharge at the end of time step ($k-j+1$) [$L^3/T/L$]; and J_k is the total number of rainfall time steps before the end of time step k. In HEC-HMS, the UH peak and the time of the UH peak are calculated and a dimensionless, single-peaked UH is hence generated, from which the UH value at any time can be computed.

In addition to the direct runoff generated by storms, baseflow also contributes to the streamflow hydrographs. In this hydrologic modeling, the recession method was chosen for estimating the baseflow in subbasins as follows:

$$Q_{bt} = Q_{b0} k_r^{\,t}$$

Where Q_{bt} is the baseflow of a subbasin at time t; Q_{b0} is the initial baseflow of a subbasin; and k_r is the recession constant for the subbasin under consideration.

Stream routing was simulated by using a simple lag model. Mona Lake itself was conceptualized as a reservoir. For the purpose of modeling, the surface area of the lake was assumed constant although it may change within a small range with the variation of the water level of the lake. Most of the spatially-distributed input data in HEC-HMS were processed and provided by the linked WMS. Initial estimates of other parameters were given primarily based on the known information or obtained from the literature and then calibrated during the modeling.

3.5.3 Analysis of Results

The primary geometric parameters (e.g., areas, slopes, and runoff distances) and hydrologic parameters (composite curve numbers and lag times) for the subbasins, computed by the WMS, are listed in Table 3.5.1. The overall average curve number for the entire watershed was 58.6 and the lag time of a subbasin ranged from 4.4 hours (6B) to 19.49 hours (8B). In the simulation of stream routing, lag times for 15R (8.26 km) and 16R (15.98 km) were 15.05 hours and 29.13 hours, respectively.

Simulated flow from the most upstream outlet (15C; Fig. 3.5.4b) was approximately one order of magnitude lower than those at the outlets located directly downstream (16C and 18C; Figures 4c and 4d), as one would expect. Discharge from the WWMS was the major source of water at outlet 15C, with subbasin 3B contributing 13.12% on average (Fig. 3.5.4b). Simulated flow at outlet 16C was very similar to that at outlet 18C, indicating that the flow contribution from subbasin 8B to outlet 18C was relatively minor (only 31%) (Figs. 3.5.4c and 3.5.4d) [Note that subbasin 8B has the smallest curve number (Table 3.5.1)]. More than 50% of the flow at outlet 18C was contributed, through stream channel 16R, by subbasin 4B, which also was the largest subbasin in terms of area within the watershed (Table 3.5.1).

The simulation also indicated that base flow contributed a substantial portion of the surface water. The average contribution percentage of base flow for a subbasin ranged from 74.01% (10B) to 83.52% (8B). However, the percentages of base flow changed significantly in time. In dry time periods, nearly 100% of stream water originated from base flow while the contribution percentage of base flow decreased dramatically to a value of less than 10% during rainfall events.

The water budget analysis for Mona Lake revealed that 79.92% and 5.56% of the lake water came from Black Creek (3B, 4B, 5B, 8B, and WWMS) and Little Black Creek (9B), respectively (Fig. 3.5.5). Subbasin 6B, which includes the lake itself and a number of small tributaries around the lake, contributed 6.24% of the water, and the remaining 8.28% of the water came from subbasins 7B and 10B (Fig. 3.5.5).

Significantly, the percent contributions from subbasins/tributaries were not constant over time. On average, the flow of water was approximately 1 m^3/s at the outlet of the Black Creek tributary (18C), compared to flows of less than 0.1 m^3/s from the other tributaries entering into Mona Lake (Fig. 3.5.6a). However, during storm events, it was clear that flow from a smaller subbasin around the lake (such as 6B) could contribute close to 1 m^3/s (Fig. 3.5.6a). More than 30% of the inflow water of the lake came from subbasin 6B at those time steps although such a situation lasted only several hours (Fig. 3.5.6b). On the other hand, the percentage of the lake inflow for the largest tributary, Black Creek, could be lower than 40% during the short initial stage of storm events due to the longer lag time of response, even though its overall percentage averaged close to 80% (Fig. 3.5.6b).

To better understand how these subbasins/tributaries of varying size, land use, soil type, and other hydrologic features respond to a rainfall event, a 72-hour time period lasting from 7 September 2001, 0:00 to 10 September 2001, 0:00 was selected. The observed rainfall, simulated water flows, and percentages of the lake inflow for the five subbasins/tributaries are shown in Fig. 3.5.7. Smaller subbasins responded quickly to the rainfall event due to short lag times; this was especially evident for subbasin 6B, which includes the lake itself. In contrast, it took a much longer time (about 48 hours) for the primary peak to develop at the outlet of the Black Creek basin (Fig. 3.5.7a). The major rainfall occurred from 6:00 am to 8:00 am, 7 September 2001. At 9:00-10:00 am on 7 September, subbasin 6B and the Black Creek tributary contributed approximately the same amount of flow to Mona Lake (about 35%; Figure 7b). However, after 48 hours (at 7:00 am, 9 September), 94.7% of the water flowing into Mona Lake came from the Black Creek tributary, when its major peak arrived at the outlet (Figure 3.5.7b).

3.5.4 Conclusions

In this study, the WMS and HEC-HMS were coupled and GIS-based hydrologic modeling was performed for the Mona Lake watershed, located in western Michigan. The modeling system incorporated the USGS DEM of the watershed, land use, and soil type GIS data and integrated watershed characterization and hydrologic simulation. This modeling effort provided fundamental hydrologic information pertinent to quantity, variability, and sources of the tributary stream water and inflows of Mona Lake. The simulation indicated that Black Creek contributed 79.9% of the lake inflow on the average. However, due to dissimilar land use, soil type, and hydrologic characteristics of the subbasins, significant variations in the percent contribution of the lake water were also observed from the simulation results. According to the overall water budget analysis, more than 70% of the stream flows originated from baseflow for all subbasins. The detailed information on the watershed hydrology, obtained from this modeling effort, could be further used for water quality management studies of Mona Lake and the related ecosystem assessment, as well as investigations for evaluating the loading potential of various pollutants and sediments into Lake Michigan.

Table 3.5.1. Basic geometric and hydrologic parameters.

Subbasins	A (km^2)	L_c (km)	S_c	CN	T_L (hr)
3B	8.43	8.15	0.00124	50.9	16.30
4B	62.32	23.66	0.00197	61.3	19.41
5B	5.22	5.38	0.00212	56.9	6.48
6B	17.80	8.49	0.00151	68.9	4.40
7B	11.01	7.08	0.00226	58.8	8.01
8B	50.02	18.34	0.00152	47.5	19.49
9B	17.96	12.89	0.00202	59.1	13.36
10B	11.65	7.28	0.00192	65.7	5.76
Total	184.40				
Average		11.41	0.00182	58.6	11.65

Notes: A = basin area; L_c = basin length along main channel from outlet to upstream boundary; S_c = basin slope along main channel from outlet to upstream boundary; CN = composite curve number; and T_L = Lag Time.

Figure 3.5.1. Geographic location of the Mona Lake watershed.

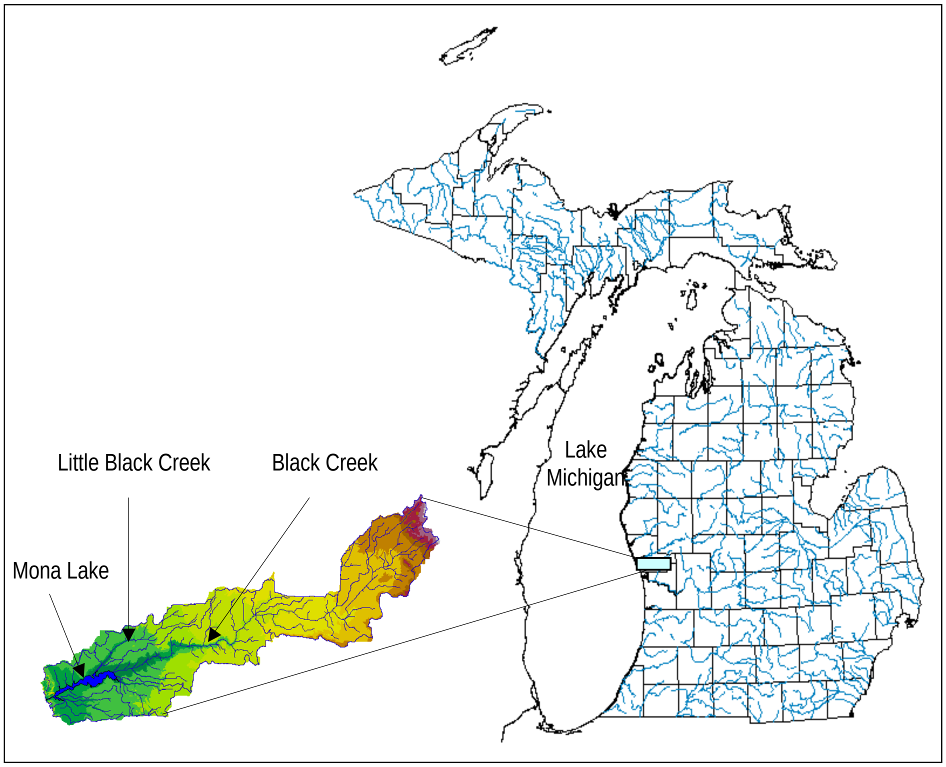


Figure 3.5.2. DEM, stream network, and drainage boundaries of the Mona Lake watershed.

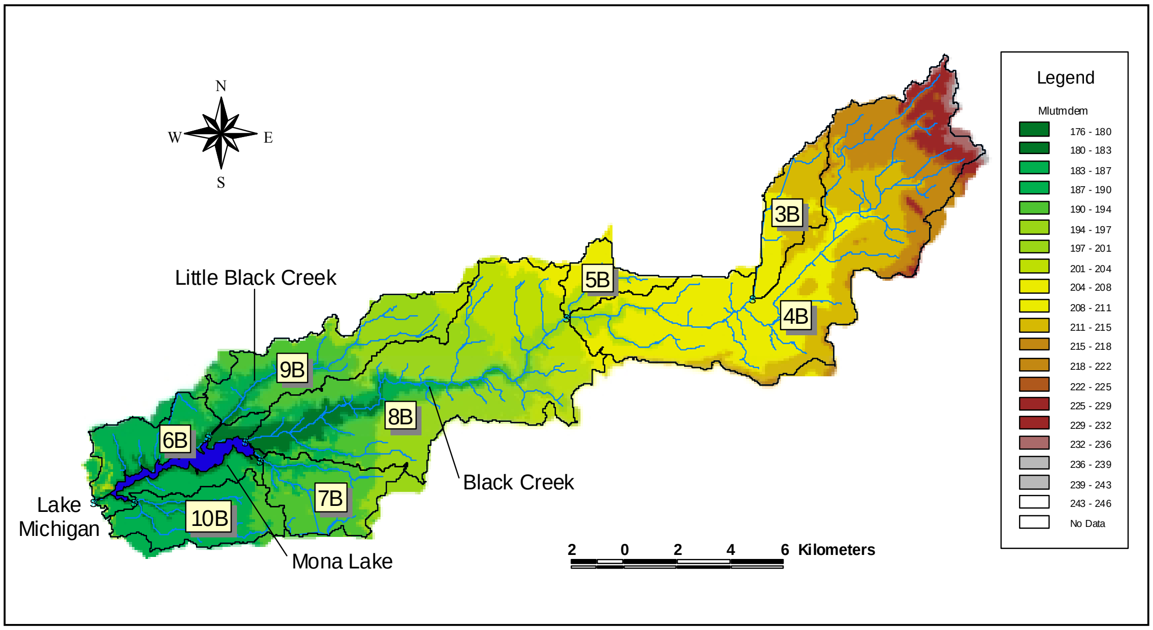


Figure 3.5.3. HEC-HMS modeling structure.

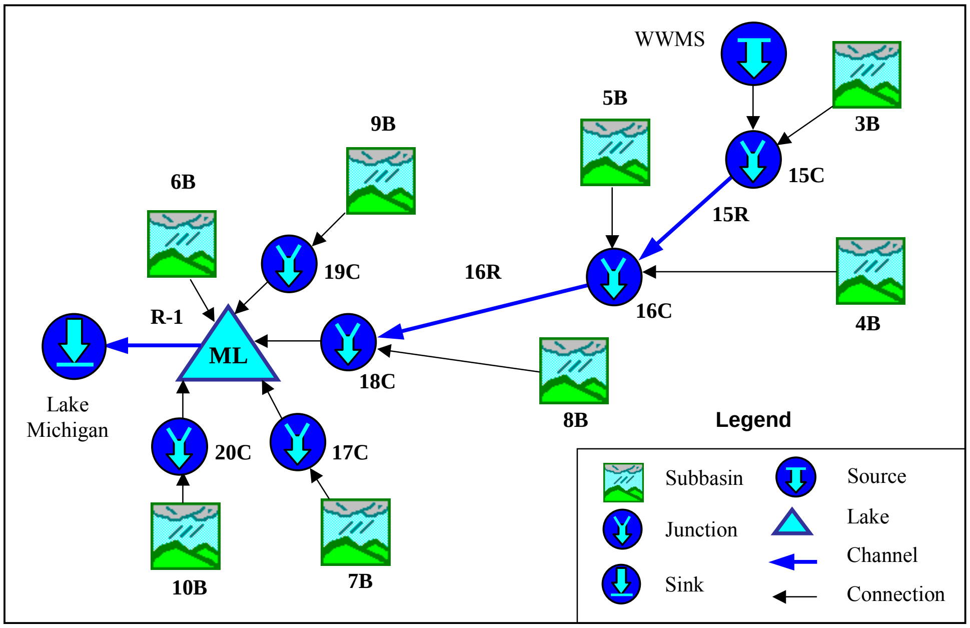


Figure 3.5.4. Simulated hydrographs at outlets 15C, 16C and 18C (Note different scale for flow in 4b compared to 4c and 4d).

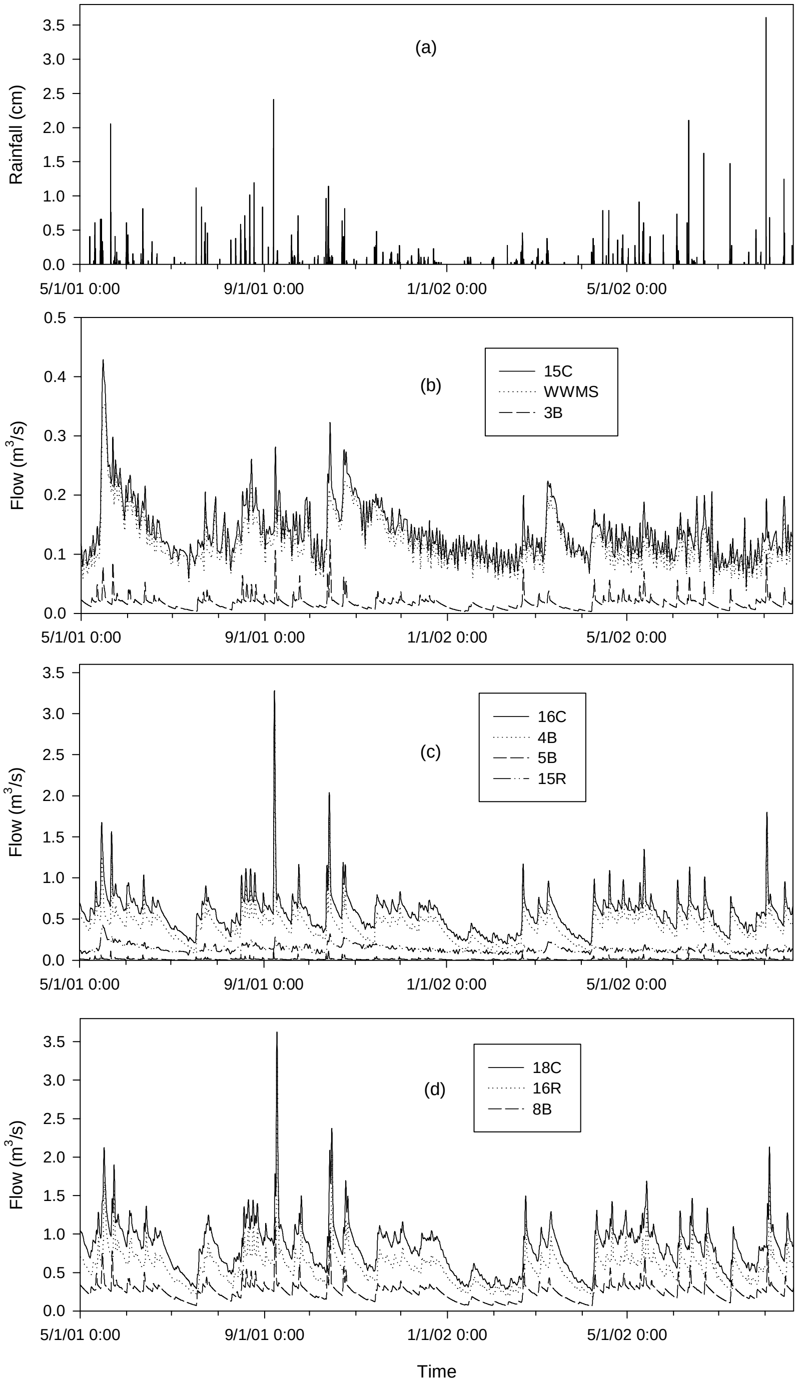


Figure 3.5.5. Water sources of Mona Lake.

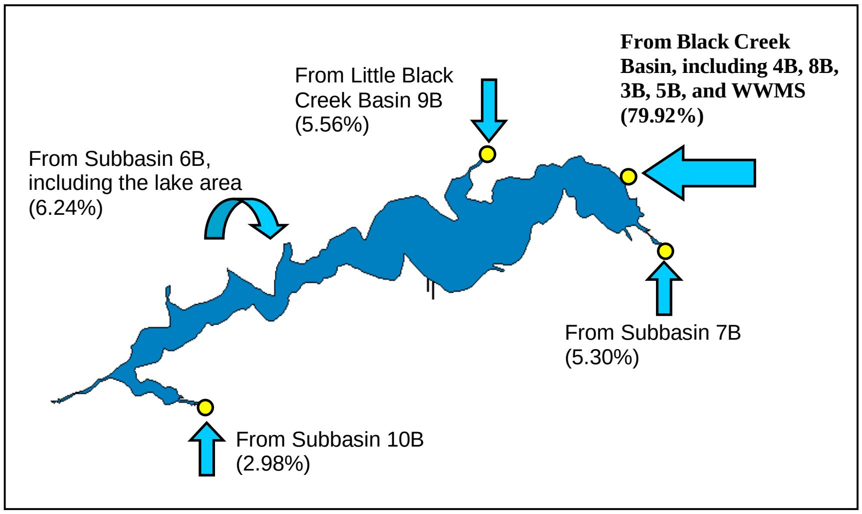


Figure 3.5.6. Simulated inflows of Mona Lake and contribution percentages of tributaries.

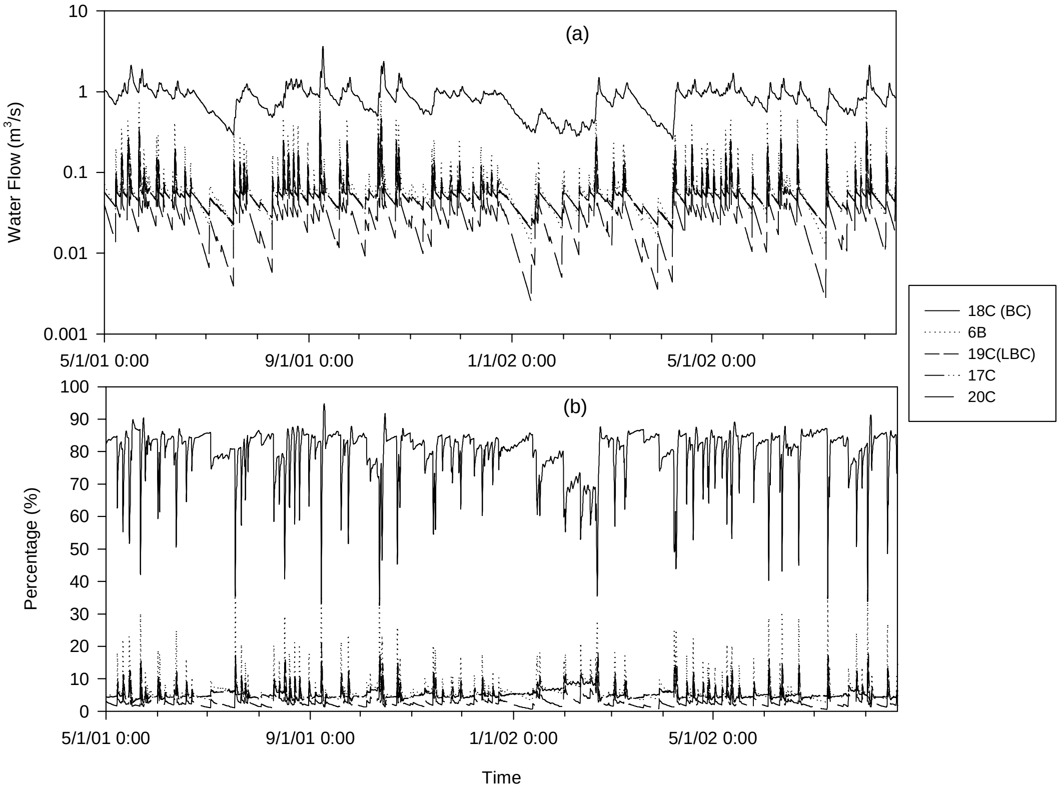
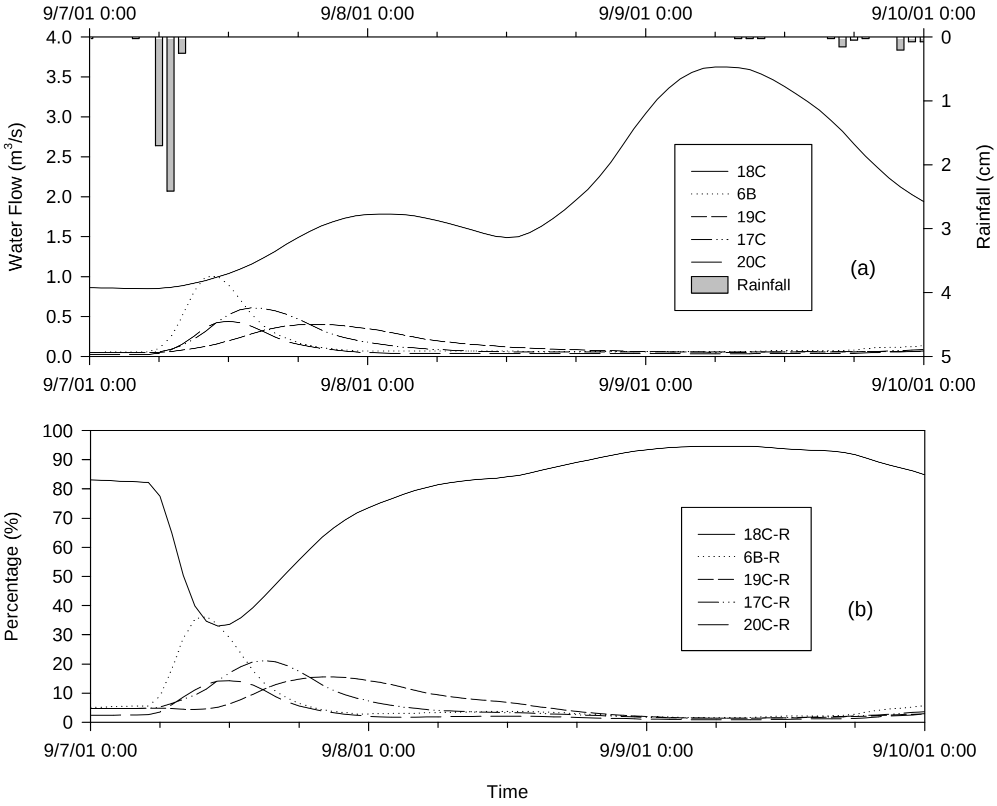


Figure 3.5.7. Water discharges and percentages of the tributaries from 9/7/2001 00:00 to 9/10/2001 00:00 (72 hours)



3.6 Sediment Conditions

3.6.1 Introduction

The major tributaries of Mona Lake have an extensive history of anthropogenic activity related to industrial discharges. Little Black Creek and Black Creek were heavily industrialized with chemical production facilities, plating companies, and metal finishing operations. Both streams contain extensive areas of wetlands that are located near Mona Lake and extend upstream into the middle of the drainage basins. Historical discharges to Little Black Creek included effluents from specialty organic chemicals, foundries, machining, electroplating, and petroleum processing. In addition, diffuse sources of contamination continue to enter the creek from storm sewers, local runoff, and impacted groundwater plumes. Little Black Creek runs through the commercial and residential districts of Muskegon Heights before entering Mona Lake near Mona Lake Park. Within this basin, 19 stormwater outfalls enter the stream. In addition, several parks and two abandoned landfills are located along the stream banks.

The need to address the sediment contamination in Little Black Creek and Mona Lake is a critical issue for the City of Muskegon Heights. This primarily African-American federal Enterprise Community has over 180 potential brownfield sites in a four square mile area. Vital economic development will not occur in this community unless problems associated with contaminated sediments and industrial property are addressed. In addition, the public is very concerned about sediment and water pollution in the stream with respect to exposure to children in the city parks. Recently, a cadmium level of 2,300 mg/kg was measured in the stream near an abandoned plating company (MDEQ 2001). Comparison of recent and historic sediment quality data suggests that ambient contaminant levels are increasing even though the industrial facilities have been inactive for over 20 years. This pattern suggests that nonpoint sources of pollution continue to enter the stream and contaminants are being stored and redistributed within the system. 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.

Contaminated sediments were previously reported in Mona Lake (WMSRDC 1982). Elevated levels of heavy metals and petroleum hydrocarbons were detected in the sediments associated with the discharge zones of Little Black Creek and Black Creek. The continued expansion of impervious surfaces in the watershed plus the increasing level of contaminants in the sediments of Little Black Creek may result in the continued transport of hazardous materials to the lake. The continued migration of contaminants from the Little Black Creek watershed poses a long-term threat to the ecological integrity of Mona Lake and the enjoyment of this resource by the community.

The investigative sampling in this study coupled a reference site (Cress Creek or ST6: see Section 3.4) with regions of known sediment contamination in the tributaries, wetlands, and deposition zones in Little Black Creek and Mona Lake. A series of sediment samples were collected from these locations and analyzed for heavy metals, semivolatile organics, and PCBs. Contaminant concentrations in Little Black Creek were compared to sediment quality guidelines (MacDonald et al. 2000) and chemical distributions found in the relatively unimpacted watershed of Cress Creek. In addition, three sediment cores were collected in Mona Lake to provide a preliminary assessment of current conditions and to determine if significant changes in historical concentrations occurred. A series of water samples also were collected in Little Black Creek to determine the concentration of suspended cadmium that was transported downstream after a mild rain event. The Mona Lake watershed is targeted for considerable economic development and habitat restoration activities. Information on the distribution of contaminated sediments will play an important role in the restoration process and assist the local governmental units in obtaining the necessary funding and political support.

3.6.2 Project Objectives and Task Elements

Specific objectives and task elements for this investigation are summarized below:

- Determine the nature and extent of sediment contamination in Little Black Creek and Cress Creek.

  - Surface sediments were collected at eight locations in each stream system to provide a preliminary assessment of current status and to evaluate environmental risk with respect to sediment quality guidelines. Cadmium, chromium, lead, semivolatile organics, and PCBs were analyzed in all sediment samples.

- Determine the nature and extent of sediment contamination in eastern Mona Lake.
  - Sediment core samples were collected at three locations to provide a preliminary assessment of current status and to evaluate environmental risk with respect to sediment quality guidelines. Cadmium, chromium, lead, semivolatile organics, and PCBs were analyzed in all core samples.

- Determine the concentration of suspended cadmium that was transported in Little Black Creek after a mild rain event.
  - Water samples were collected at eight locations in Little Black Creek after a 1.3 cm (0.5 in) rain event. The water samples were filtered and the filter content was analyzed for cadmium.

3.6.3 Sampling Locations and Descriptions

Sampling locations for the assessment of contaminated sediments in Little Black Creek, Cress Creek, and Mona Lake were selected based on proximity to potential point and nonpoint sources of contamination. The locations of these sites on Little Black Creek were determined by review of historical records. The station at Evanston Ave. was located upstream of all known industrial sources and was considered as a background location for this creek. Sediment samples were collected in areas of fine sediment deposition. Samples from areas containing rubble and sand were excluded. A total of eight locations were selected for sediment sample collection in each creek. A description of the sites and GPS coordinates are described in Table 3.6.1. Sampling locations for Little Black Creek and Cress Creek are shown in Figs. 3.6.1 and 3.6.2, respectively. Water samples for suspended cadmium were collected at the same locations in Little Black Creek.

Table 3.6.1. Sample location descriptions and coordinates for Little Black Creek and Cress Creek.

Location:	Date:	Zone:	Latitude:	Longitude:
Little Black Creek				
Evanston Rd.	9/3/2002	Woody Debris and Riparian Vegetation	N 43.21554	W 86.18101
Sherman and Getty - Upstream	9/3/2002	Woody Debris and Riparian Vegetation	N 43.20440	W 86.22351
Sherman and Getty - Downstream	9/3/2002	Woody Debris and Riparian Vegetation	N 43.20433	W 86.22347
Summit	9/3/2002	Woody Debris and Riparian Vegetation	N 43.19859	W 86.23052
Mona View Wetland Channel	9/3/2002	Typha	N 43.19506	W 86.23232
Seaway	9/3/2002	Watercress	N 43.18796	W 86.24065
Little Black Creek Mouth	9/3/2002	Typha and Sparganium	N 43.18613	W 86.24674
Cress Creek				
Quarterline Rd.	7/29/2003	Woody Debris and Riparian Vegetation	N 43.17776	W 86.19543
Towner St.	7/29/2003	Woody Debris and Riparian Vegetation	N 43.17817	W 86.20303
Proctors'	7/29/2003	Woody Debris and Riparian Vegetation	N 43.17776	W 86.21353
Old Grand Haven Rd.	7/29/2003	Woody Debris and Riparian Vegetation	N 43.17970	W 86.21999
Towner Wetland	7/30/2003	Typha and Grasses	N 43.17757	W 86.20413
South Branch	7/30/2003	Woody Debris and CPOM	N 43.17760	W 86.20409
Hidden Cove	7/30/2003	Loosestrife and Typha	N 43.17988	W 86.22253

Sediment samples from Mona Lake were also collected in depositional basins. A description of the sites and GPS coordinates are described in Table 3.6.2 and shown in Fig. 3.6.3.

Table 3.6.2 Sample location descriptions and coordinates for Mona Lake.

Location:	Date:	Zone:	Latitude:	Longitude:
Little Black Creek Basin	7/30/2003	Black Organic Silts Petroleum Odor	N 43.18365	W 86.24721
Black Creek Basin	7/30/2003	Black Organic Silts	N 43.18479	W 86.23571
Mid Lake Basin	7/30/2003	Black Organic Silts Petroleum Odor	N 43.18037	W 86.25134

Figure 3.6.1 Sediment and water sampling locations in Little Black Creek (September 2002).

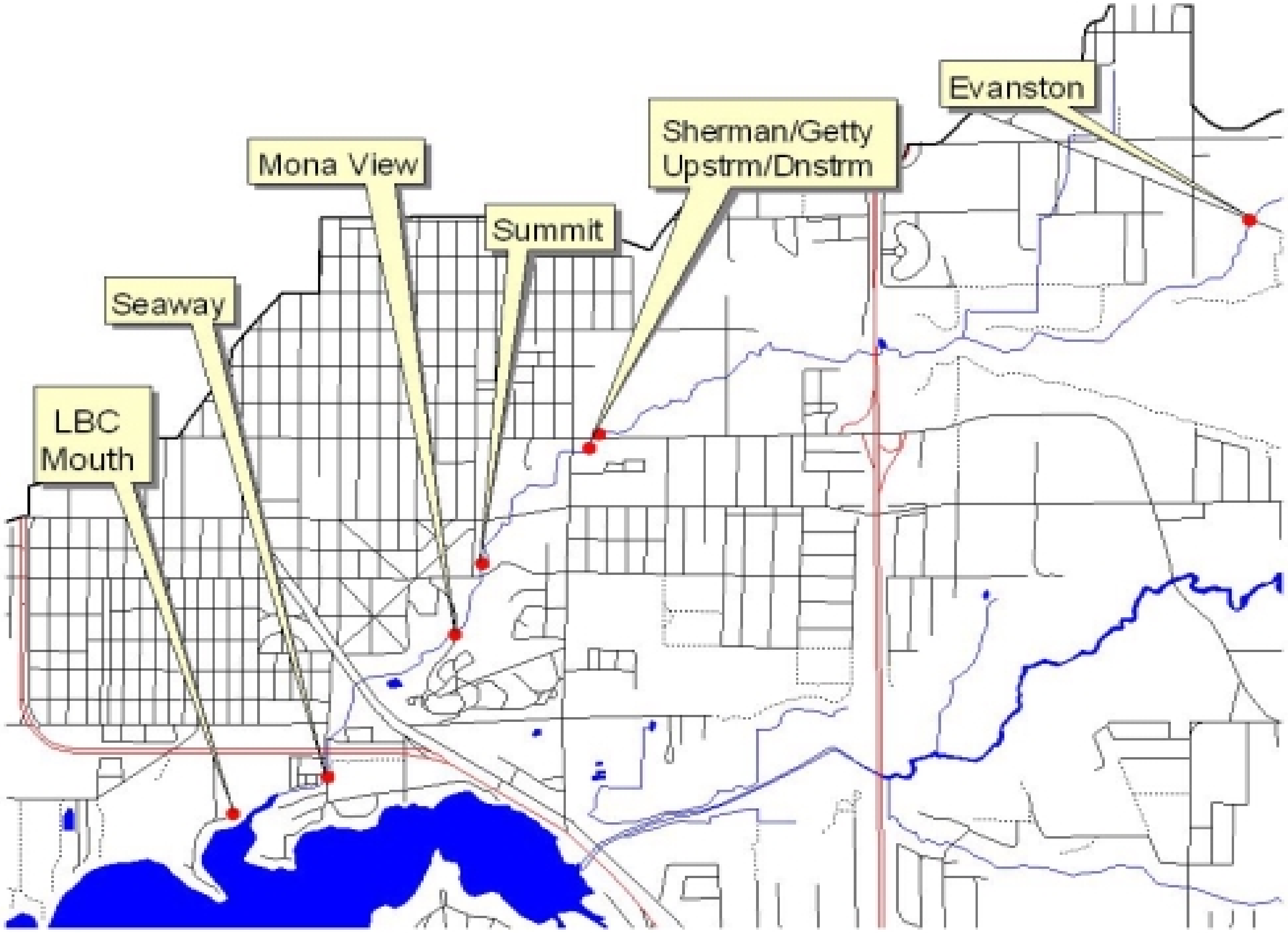


Figure 3.6.2. Sediment and water sampling locations in Cress Creek (July 2003).

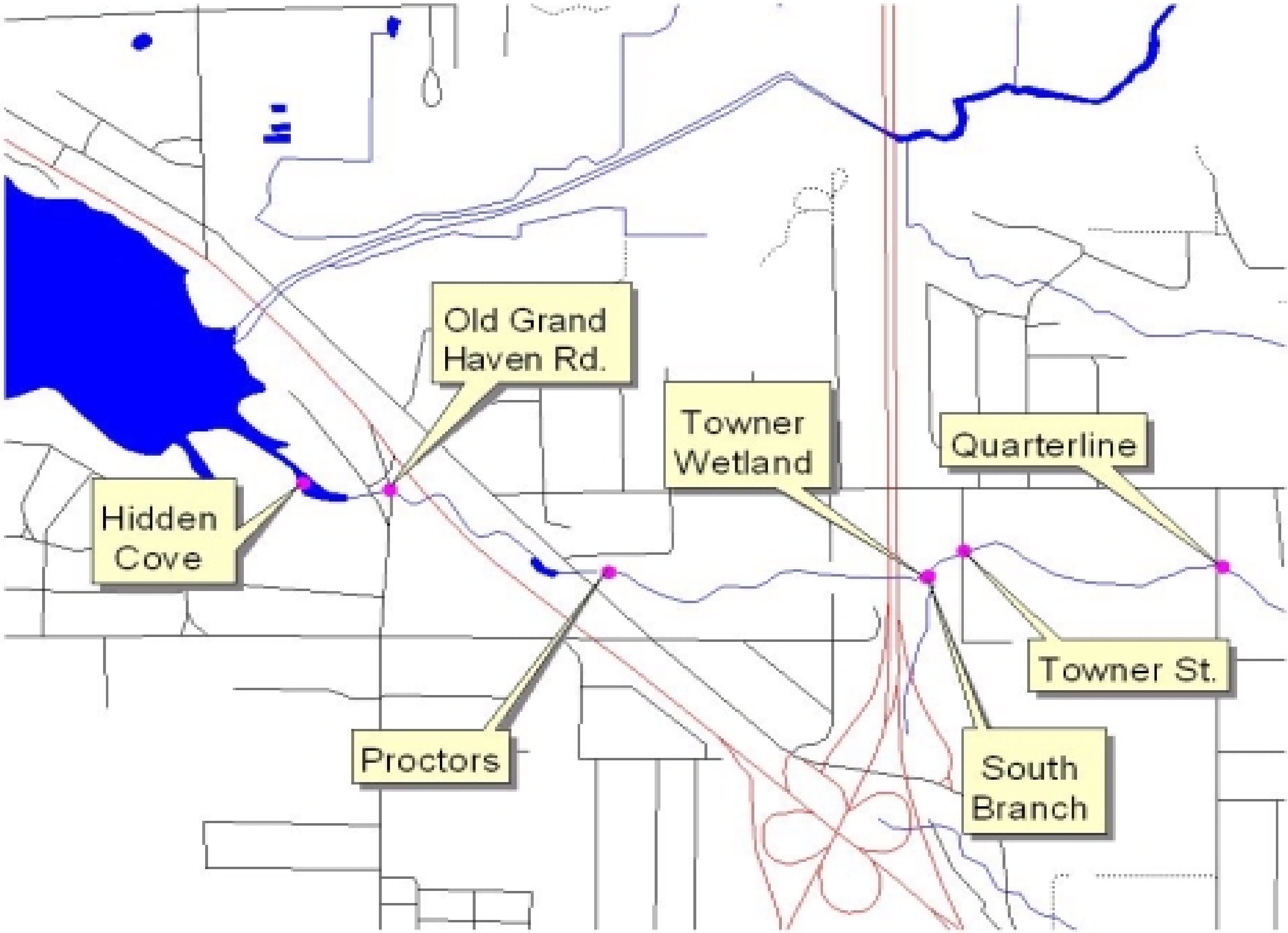
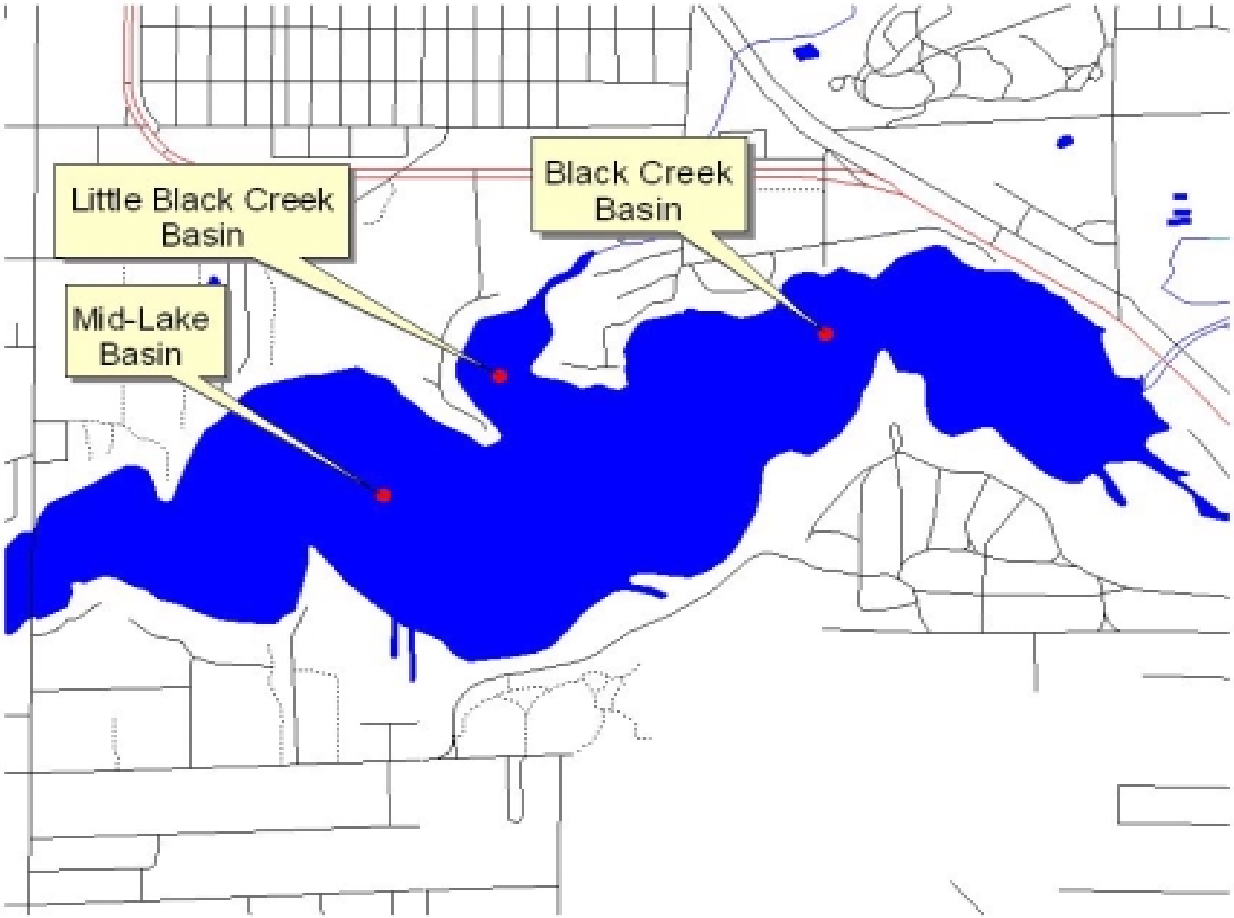


Figure 3.6.3. Sediment and water sampling locations in Mona Lake (July 2003).



3.6.4 Methods

Sampling Methods

Sediment samples from Little Black Creek and Cress Creek were collected using a stainless steel trowel. Eight samples were collected at each site, composited in the field, and transferred to a pre-cleaned 4-L glass jar. Samples were collected in depositional areas containing silts and organic sediments. Sediment samples from Mona Lake were collected using a piston corer (Fisher et al. 1992). The core tube was set at the sediment-water interface and advanced to approximately 0.4 m depth. Sediment cores were homogenized in the field and transferred to pre-cleaned 500 ml plastic and 1000 ml amber glass bottles.

Water samples were collected at mid depth in polyethylene bottles.

Analytical Methods

A summary of analytical methods for sediment and detection limits is provided in Tables 3.6.3 and 3.6.4.

Table 3.6.3. Analytical methods and detection limits.

Parameter	Method Description	Analytical Method	Detection Limit
	SEDIMENT MATRIX		
Cadmium, Lead, Chromium	Inductively Coupled Plasma Atomic Emission Spectroscopy	6010[1], 3052[1] Digestion	2.0 mg/kg
USEPA Semivolatiles	Solvent Extraction and GC/MS analysis	8270[1], 3550[1] Extraction	Table 3.6.4
PCBs	Solvent Extraction and GC/MS analysis	8081[1], 3550[1] Extraction	Table 3.6.4
	WATER MATRIX		
Cadmium	Inductively Coupled Plasma Atomic Emission Spectroscopy	6010[1], 3050[1] Digestion	0.1 mg/1

[1] - SW846 3rd. Ed. EPA 1999.

Table 3.6.4. 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
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

Table 3.6.4.(Continued) Organic parameters and detection limits.

	Sediment (mg/kg)
Semi-Volatile Organic Compounds (8270)	
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
PCBs (8081)	
Aroclor 1212	0.50
Aroclor 1232	0.10
Aroclor 1242	0.10
Aroclor 1248	0.10
Aroclor 1254	0.10
Aroclor 1260	0.10

3.6.5 Results and Discussion

The results of sediment metals analyses for Little Black Creek are presented in Table 3.6.5. Figures 3.6.4, 3.6.5, and 3.6.6 illustrate the distribution of cadmium, chromium, and lead respectively in Little Black Creek. The figures also include comparisons with sediment quality criteria for aquatic life (MacDonald et al. 2000) and direct contact criteria for human health (MDEQ 2000). The Probable Effect Concentration (PEC)

Table 3.6.5. Results of metals analyses in Little Black Creek sediments (September 2002).

Station	Cadmium (mg/kg)	Chromium (mg/kg)	Lead (mg/kg)
Evanston	0.064	5	11
Sherman/Getty Upstream	940	180	220
Sherman/Getty Downstream	150	140	230
Summit	39	57	170
Mona View Wetland	67	400	370
Seaway	11	160	410
Little Black Creek Mouth	2.6	26	50

Figure 3.6.4. Total cadmium in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 4.98 mg/kg).

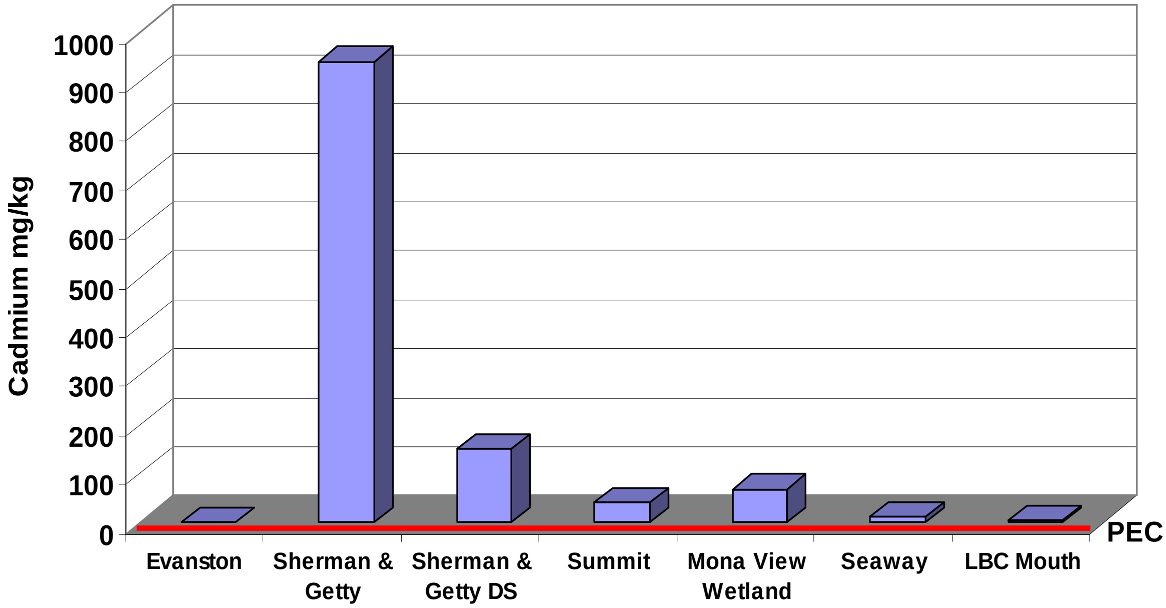


Figure 3.6.5. Total chromium in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 111 mg/kg).

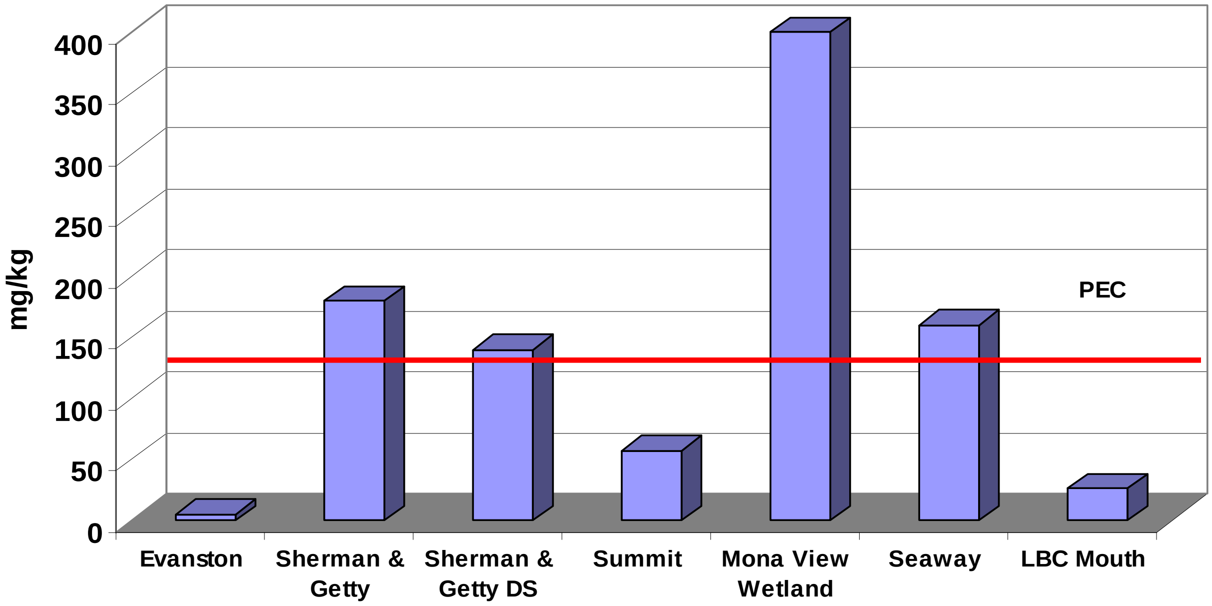
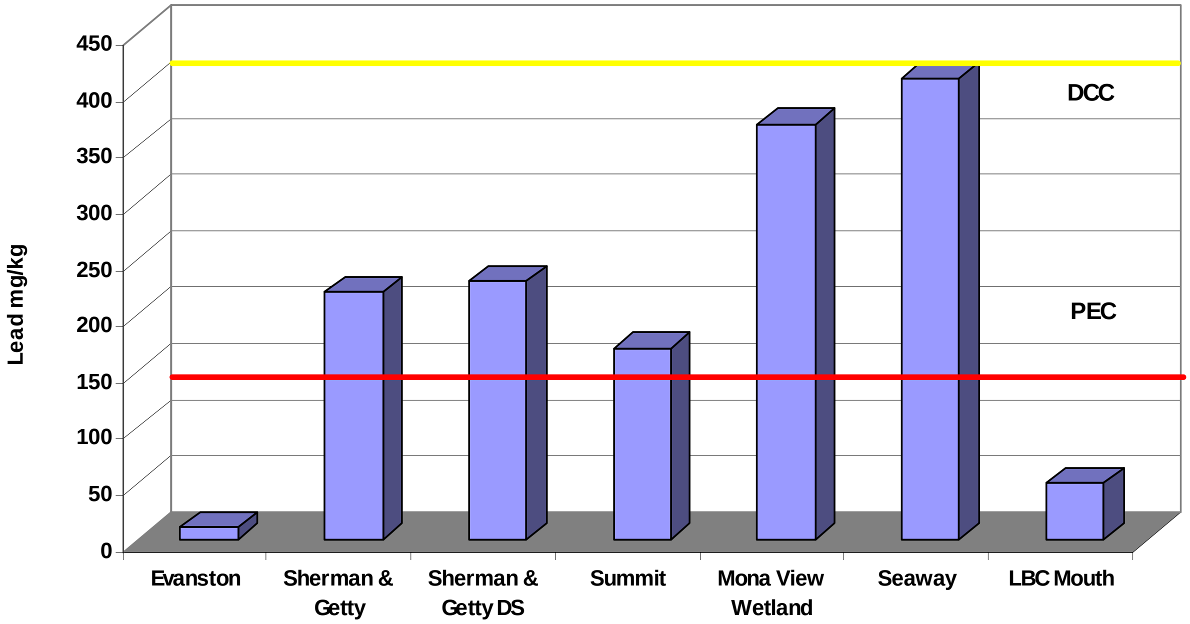


Figure 3.6.6. Total lead in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 128 mg/kg. DCC = Direct Contact Criteria, 400 mg/kg.).



represents the level where adverse ecological effects are likely (MacDonald et al. 2000). PEC values were established by the statistical analysis of a large database of samples from the Great Lakes region and signify a 75% probability of adverse ecological effects. The Direct Contact Criteria (DCC) represents the soil concentration that is safe for daily incidental contact by humans (MDEQ 20001). The DCC is based on a daily exposure to contaminated soil by dermal contact and incidental ingestion (0.2 g/d) for 31 years. Since human contact with sediments is infrequent, the DCC represents an overestimation of potential risk. With the exception of the background station at Evanston Ave. and wetland area at the mouth of Little Black Creek, all locations exceed the PEC values for cadmium, chromium, and lead. The site at Seaway Drive exceeds the DCC value for lead. Cadmium profiles (Fig. 3.6.4) show a large increase in concentration at the upstream location at Sherman/Getty. This location is adjacent to the Peerless Plating Superfund Site and the local surface soils and groundwater have been highly contaminated with cadmium, chromium, and lead (EPA 2000). This location was previously sampled by the MDEQ (1996 and 2001) and high levels of cadmium were detected. Concentrations decrease with distance downstream and then rebound slightly at the Mona View wetland. This wetland may function as a sink for heavy metals or may be impacted by local sources. Chromium (Fig. 3.6.5) follows a different pattern as an initial increase is noted at upstream Sherman/Getty location and a larger spike in concentration is observed at the Mona View wetland. These data suggest that a source other than

Peerless has influenced the system. The source appears to be located between Summit Ave. and the lower reaches of the Mona View wetlands. Alternatively, Peerless may be the main source of chromium, but most of this metal may have moved downstream from the site and has accumulated at the wetland. Lead concentrations follow a similar pattern as chromium with the exception of the occurrence of a third source area at Seaway (Fig. 3.6.6). Lead concentrations at Seaway exceed the DCC and the sediment samples were collected within 50 ft of a baseball field. A petroleum odor was noted in the sediment, which suggests that the source of lead may be from an historic release of gasoline.

The results of selected organic chemistry analyses for Little Black Creek sediments are presented in Table 3.6.6. Figures 3.6.7, 3.6.8, and 3.6.9 illustrate the distribution of total PAH compounds, benzo(a)pyrene, and PCBs, respectively, in Little Black Creek. The figures also include comparisons with sediment quality criteria for aquatic life (MacDonald et al. 2000) and direct contact criteria for human health (MDEQ 2000). PAH compounds (Polycyclic Aromatic Compounds) are found in crude and refined petroleum products and produced by combustion of organic matter.

Table 3.6.6. Results of organic chemistry analyses in Little Black Creek sediments (September 2002).

Station	Total PAH mg/kg	Benzo(a)pyrene mg/kg	PCBs mg/kg
Evanston	0.2	0.00	0.34
Sherman & Getty Upstream	63.3	4.61	1.9
Sherman & Getty Downstream	82.5	5.62	0.8
Summit	43.3	3.00	8.9
Mona View Wetland	56.1	4.44	6.3
Seaway	29.3	1.96	1.0
LBC Mouth	2.5	0.26	0.48

Figure 3.6.7. Total PAH compounds in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 22 mg/kg).

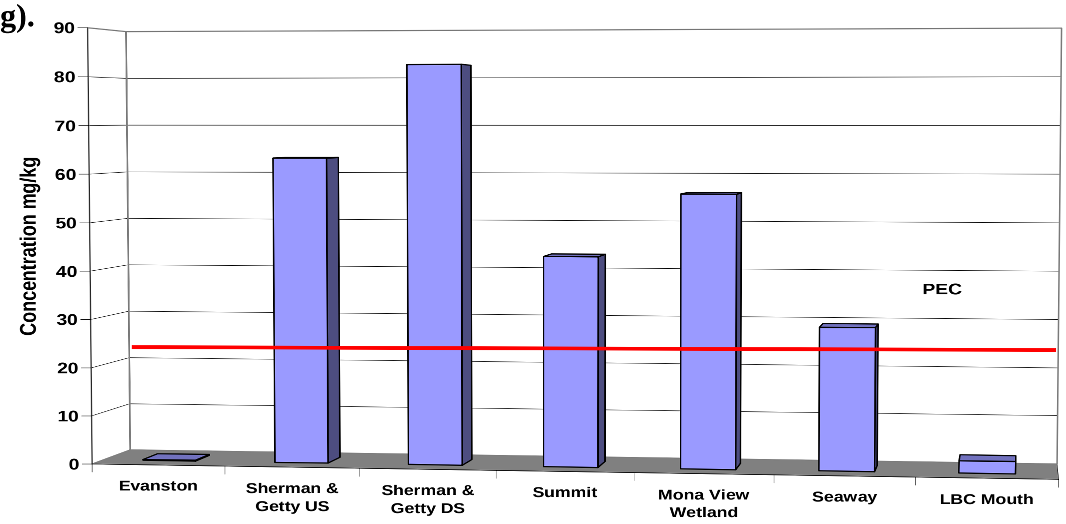


Figure 3.6.8. Benzo(a)pyrene in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 1.4 mg/kg. DCC = Direct Contact Criteria, 2.0 mg/kg).

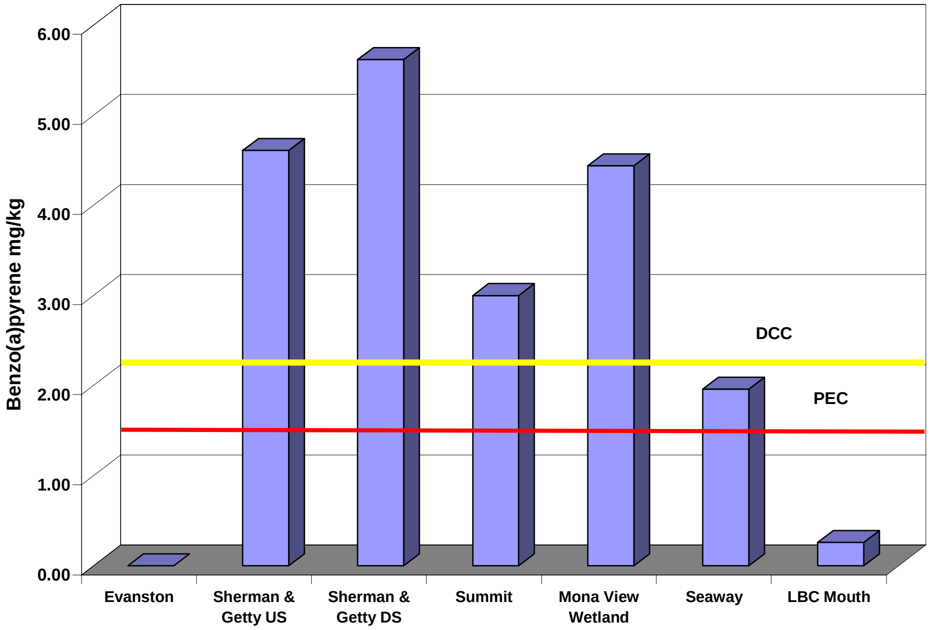
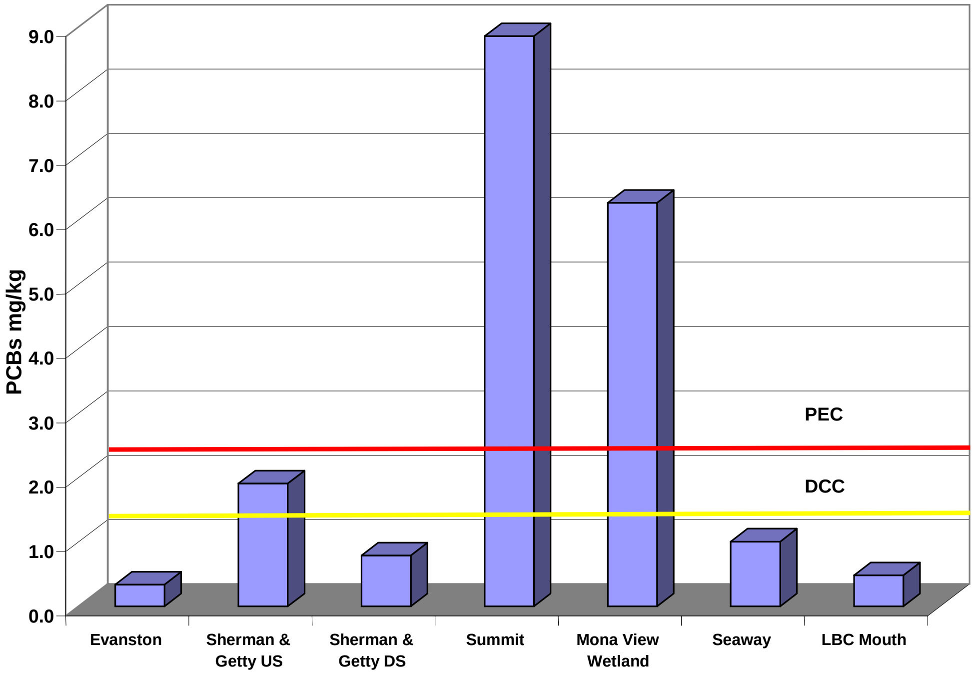


Figure 3.6.9. PCBs in surface sediment samples collected from Little Black Creek (September 2002). (PEC = Probable Effect Concentration, 2 mg/kg. DCC = Direct Contact Criteria, 1.0 mg/kg).



Benzo(a)pyrene (BAP) is a compound in this grouping that is classified as a human carcinogen. PAH compounds and BAP are toxic to aquatic life and have PEC values of 22 mg/kg and 1.8 mg/kg, respectively (MacDonald et al. 2000). BAP also has a DCC value of 2.0 mg/kg due to its potential to cause cancer (MDEQ 2001). With the exception of the background station at Evanston Ave. and wetland area at the mouth of Little Black Creek, all locations exceed the PEC values for total PAH compounds and benzo(a)pyrene. The sites at Summit Ave. and the Mona View wetlands were the only locations that exceeded the PEC for PCBs.

The distribution of total PAH compounds (Fig 3.6.7) shows a large increase in concentration at both Sherman/Getty stations. This location is downstream from a closed refinery with a history of petroleum releases (MDEQ 2001). In contrast to the cadmium distribution (Fig 3.6.4), total PAH compound levels are higher downstream of Sherman and Getty. An old service station was located near this area and may represent an additional source of these compounds. Concentrations decrease with distance downstream and then increase slightly at the Mona View wetland. This wetland may function as a sink for organic chemicals or may be impacted by local sources. Benzo(a)pyrene (Fig 3.6.8) follows a similar pattern, as an initial increase is noted at upstream Sherman/Getty location and a larger spike in concentration is observed at the downstream location. A second spike on concentration is also noted at the Mona View wetland. The DCC level for BAP is exceeded at both Sherman and Getty locations, Summit Ave, and the Mona View wetlands. The level at the Summit site is of particular concern as it is located near a baseball field. PCB concentrations follow a different pattern as the highest concentrations are observed at Summit and the Mona View wetlands (Fig. 3.6.9). An old solid waste landfill is located in the vicinity of Summit Ave. and may be contributing to the observed PCB concentrations. The Mona View wetland again appears to be a sink for contaminants as concentrations show only a slight decrease from the previous location. PCB levels also exceed the DCC at these two locations. As previously mentioned, the Summit location is near a baseball field and presents the possibility of human exposure. Lead concentrations at Seaway exceed the DCC in the sediment samples collected (Fig. 3.6.6).

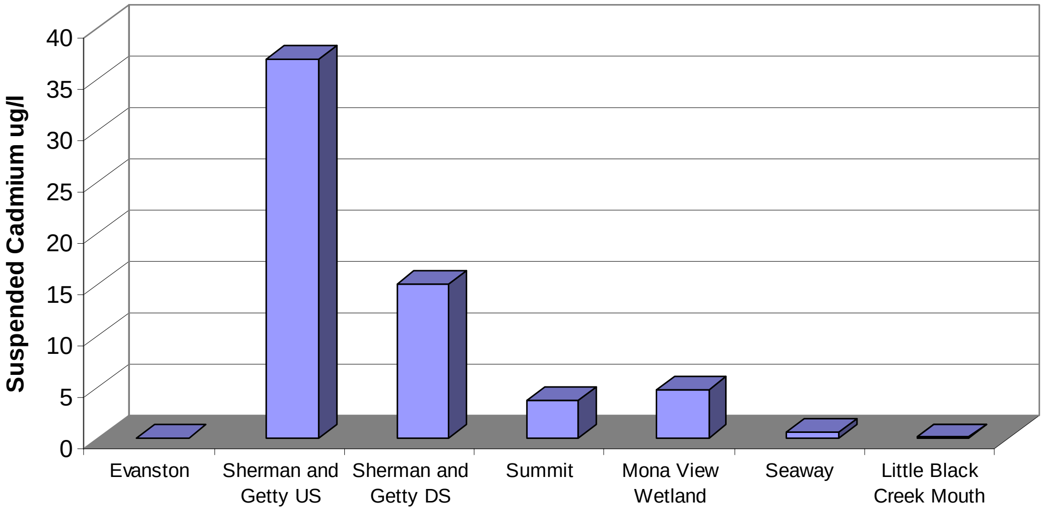
To further investigate the issue of contaminant storage in the Mona View wetland, a second sample was collected in an inundated pocket located 10 meters from the channel sampling location. The results of this sample are presented below:

Compound	Concentration (mg/kg)
Lead	430
Cadmium	47
Chromium	2000

The concentrations of lead and chromium in the wetland location were the highest levels observed in this investigation. While additional samples are required to further investigate and define the storage of contaminants in this area, these results clearly suggest that metals are retained in the Mona View wetlands.

An investigation of the potential of Little Black Creek to transport cadmium associated with suspended sediment also was conducted. Water samples were collected 1 day after a 1.3 cm (0.5 in) rain event and analyzed for total cadmium in the suspended particulate matter. The results of the sampling event are shown in Fig. 3.6.10. Suspended cadmium is clearly mobilized at the upstream location of Sherman and Getty adjacent to the Peerless Plating Superfund Site. It is critical to determine what stream velocities are capable of eroding contaminated sediments at this location and transporting them downstream. Over 50% of the suspended cadmium is lost as the stream passes through the Sherman Ave. site and reaches the downstream station. Concentrations are relatively consistent at Summit and the Mona View wetlands. After passage through the wetlands, very little suspended cadmium is observed at the Seaway and the Little Black Creek mouth sites. These results suggest that 50% of the suspended cadmium is deposited before the Sherman Ave culvert. The remaining suspended cadmium is deposited in the stream channel prior to Summit Ave and in the Mona View wetlands. A more detailed hydrologic investigation is necessary to estimate cadmium transport on an annual basis. However, these results suggest that the reservoir of contaminated sediments near the Peerless Plating site can be mobilized during a moderate rain event and transported downstream.

Figure 3.6.10. Suspended cadmium transport in Little Black Creek (September 2002).



In contrast to Little Black Creek, the levels of metals and organic chemicals in the Cress Creek system were considerably lower. The results of selected organic chemistry analyses and metals for the Cress Creek sediments are presented in Table 3.6.7. A complete summary of all organic parameters is included in Appendix 6.4. Figures 3.6.11 and 3.6.12 illustrate the distribution of metals and organic chemicals, respectively, in Cress Creek.

Table 3.6.7. Results of metals and organic chemistry analyses in Cress Creek sediments (September 2002).

Station	Cadmium (mg/kg)	Chromium (mg/kg)	Lead (mg/kg)	Benzo(a) pyrene (mg/kg)	Total PAH (mg/kg)	PCBs (mg/kg)
Quarterline Road	0.085	4.0	1.1	0.02	0.15	0.18
Towner Street	0	1.5	0	0.01	0.03	0.50
Towner Wetland	0.15	2.8	2.0	0.01	0.19	0.60
South Branch	0.089	4.6	5.3	0.03	0.24	0.45
Old Grand Haven Road	0.088	3.3	1.8	0.07	0.82	0.45
Hidden Cove	0.26	6.5	5.2	0.07	1.01	0.72

Figure 3.6.11. Metals in surface sediment samples collected from Cress Creek (July 2003).

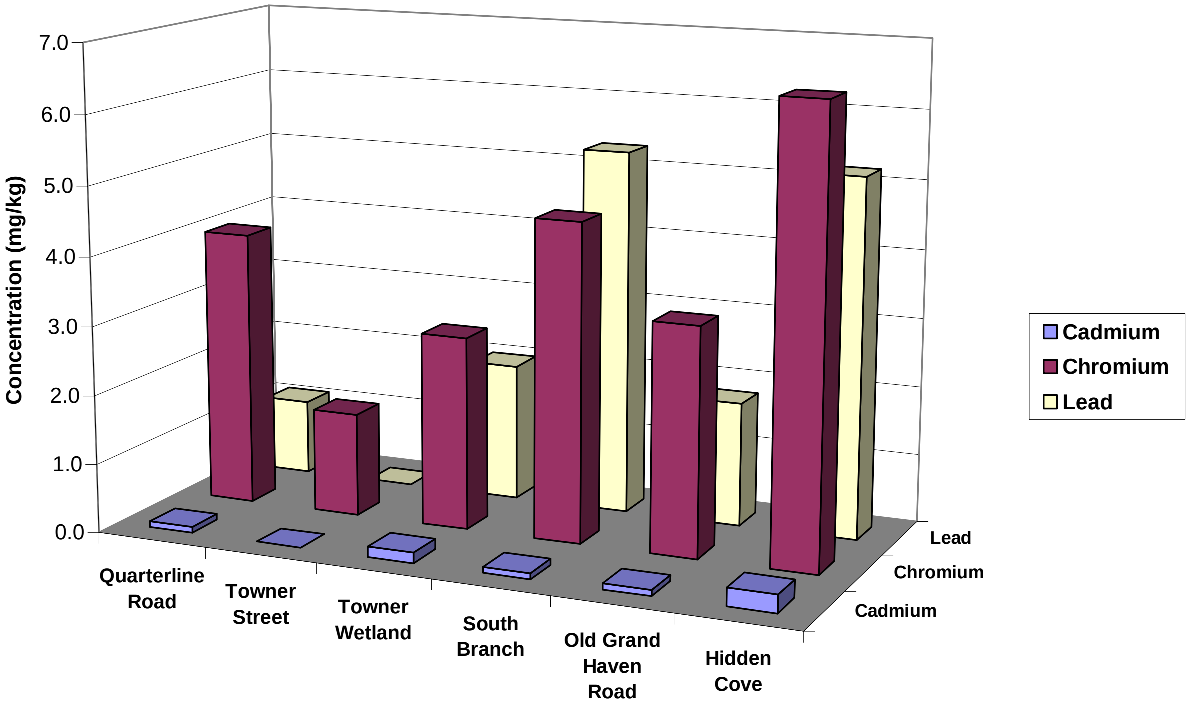
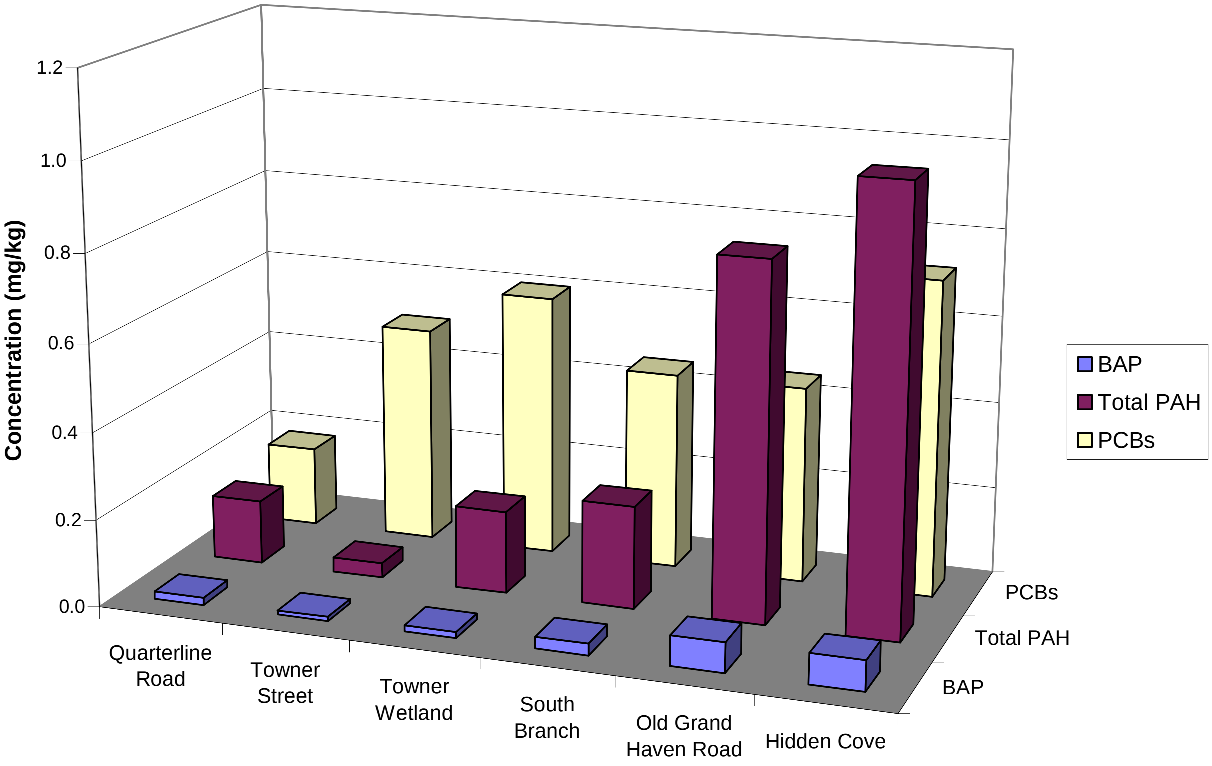


Figure 3.6.12. Organic chemicals in surface sediment samples collected from Cress Creek (July 2003).



Concentrations of metals, total PAH compounds, and BAP are several orders of magnitude lower in Cress Creek than in Black Creek. The probable sources of contaminants in the Cress Creek system are road runnoff and atmospheric deposition. The pattern of road runnoff is evident for Total PAH and BAP (Fig 3.6.12). The stations at Quarterline Road, the South Branch, Old Grand Haven Road, and Hidden Cove are adjacent to major road systems. In contrast, PCB concentrations appear to be more of a function of wetland size as the highest concentrations were found in the Towner wetlands and at Hidden Cove. These wetlands have the greatest area in the Cress Creek System. This pattern suggests that PCBs are related to atmospheric deposition as wetland storage appears to be more significant than the relative position with respect to roadways.

Based on concentration trends for both systems, the impact of the discharge of industrial wastes is clearly evident in Little Black Creek. Concentrations exceed the PECs at most locations and are likely to show evidence of ecological impairment. The upstream station at Evanston Ave. is similar in concentration to the locations in Cress Creek, an indication that road runoff and atmospheric deposition represent the major sources of contaminants in this system. Based on the fact that concentrations of most contaminants in Cress Creek are several orders of magnitude below the PEC, ecological impairment from anthropogenic chemicals is unlikely.

The results of metals and selected organic chemistry analyses for Mona Lake sediments are presented in Table 3.6.8. A complete summary of all organic parameters is included in Appendix 6.4. Figures 3.6.13, 3.6.14, and 3.6.15 illustrate the distribution of cadmium, chromium, and lead respectively in Mona Lake. Figure 3.6.16 presents the distribution of total PAH compounds and benzo(a)pyrene. PCB concentrations are displayed in Fig. 3.6.17. The figures also include comparisons with sediment quality criteria for aquatic life (MacDonald et al. 2000) and historical metals results from 1980 (Evans 1992). Organic chemicals were not analyzed in the 1980 study.

Table 3.6.8. Results of metals and organic chemistry analyses in Cress Creek sediments (September 2002). 1980 Data from Evans (1992).

Compound	Yr	Black Creek Basin (mg/kg)	Little Black Creek Basin (mg/kg)	Mid Basin (mg/kg)
Lead	1980	580	1100	240
	2003	110	150	420
Cadmium	1980	14	50	10
	2003	4.1	13	31
Chromium	1980	130	520	120
	2003	92	110	670
Total PAH	2003	3.1	26	9.6
BAP	2003	0.34	2.1	0.72
PCBs	2003	0.70	1.1	3

Sediment cadmium concentrations have decreased markedly in the Little Black Creek basin (Fig. 3.6.13) as levels dropped from 50 mg/kg in 1980 to 13 mg/kg in 2003. Cadmium concentrations also decreased in the Black Creek basin. In contrast, sediment cadmium concentrations increased in the middle basin of Mona lake from 10 mg/kg in 1980 to 31 mg/kg in 2003. While these results suggest that cadmium loading from Little Black Creek has decreased over the last 23 years, the apparent increase in metal concentration in the middle of the lake may indicate a westerly migration of contaminated sediments from the historic deposition area. Chromium and lead follow a similar pattern, as sediment concentrations have decreased in the Little Black Creek and

Figure 3.6.13. Comparison of cadmium concentrations in sediment core samples collected from Mona Lake (1980 and 2003 Data).

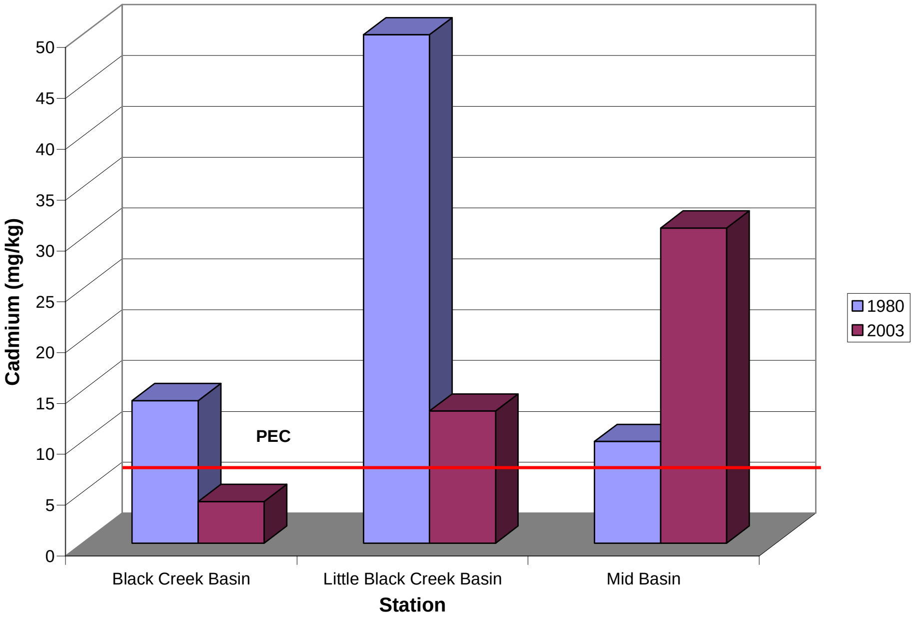


Figure 3.6.14. Comparison of chromium concentrations in sediment core samples collected from Mona Lake (1980 and 2003 data).

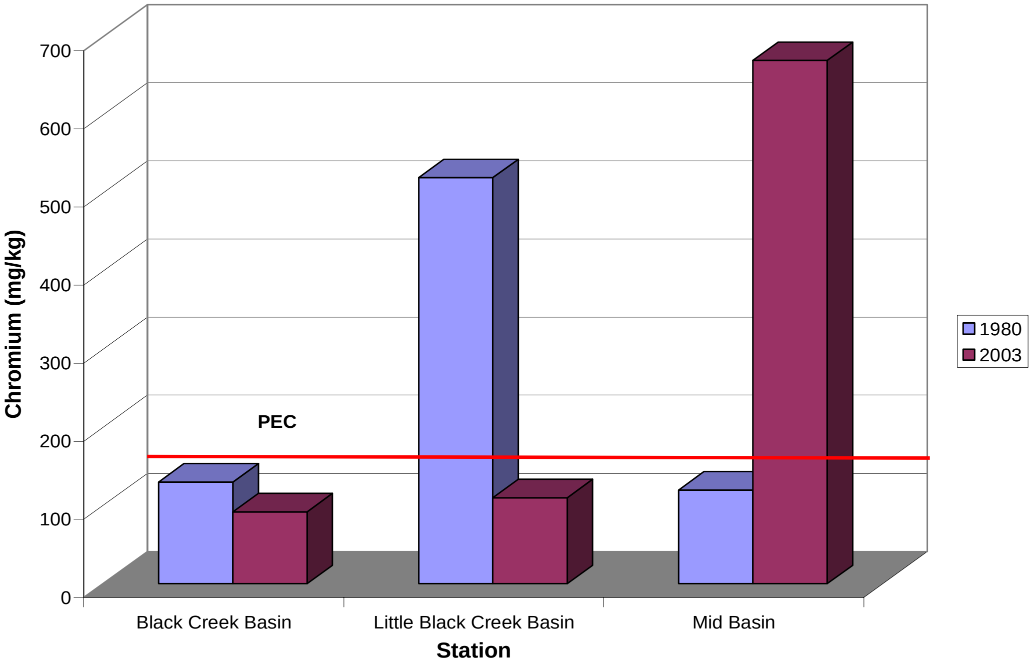


Figure 3.6.15. Comparison of lead concentrations in sediment core samples collected from Mona Lake (1980 and 2003 Data).

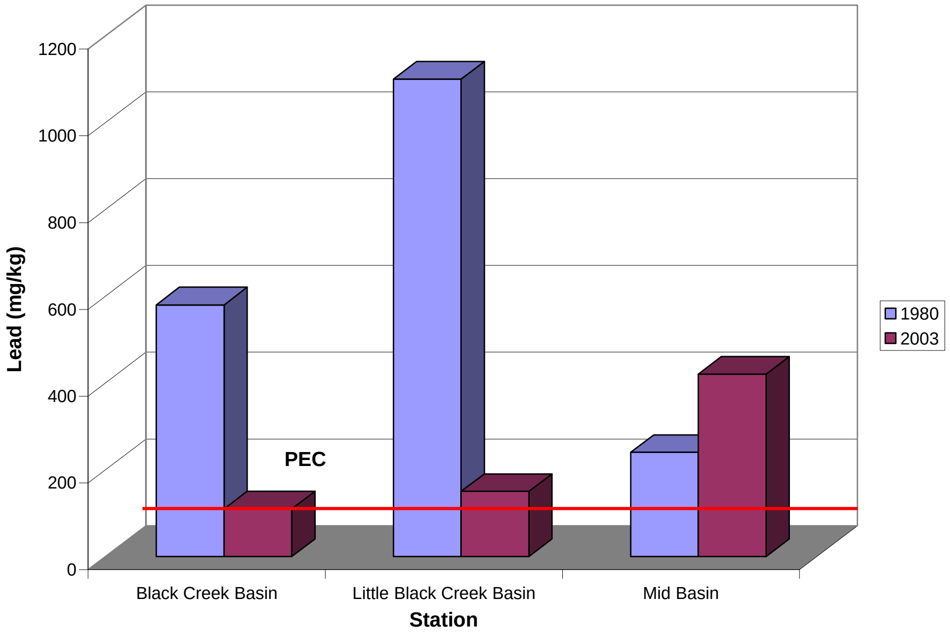


Figure 3.6.16. Total PAH and BAP concentrations in sediment core samples collected from Mona Lake (July 2003).

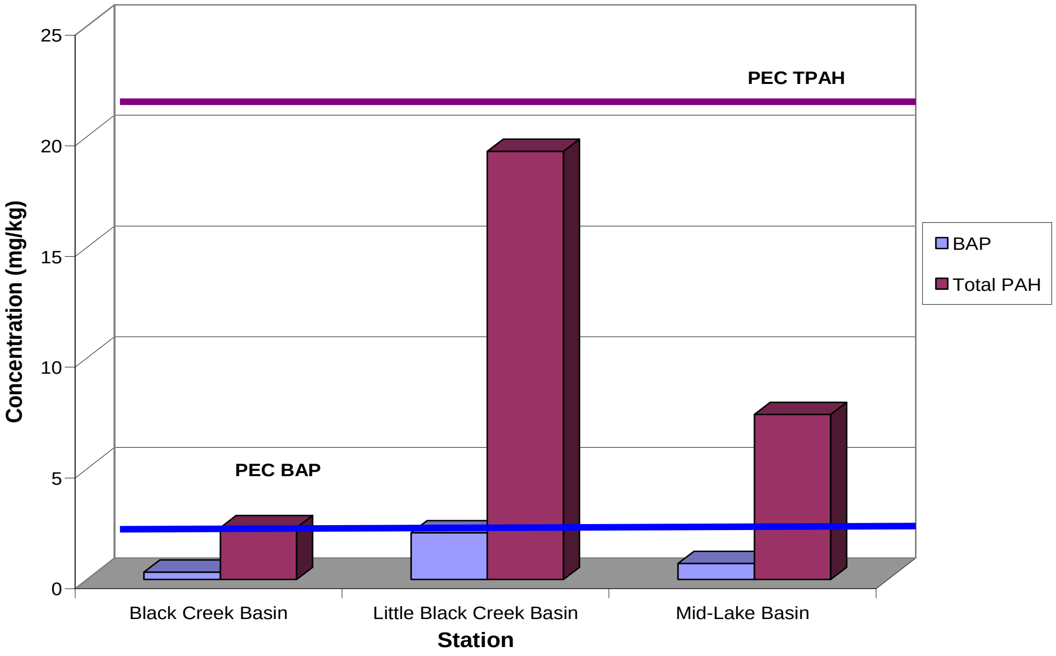
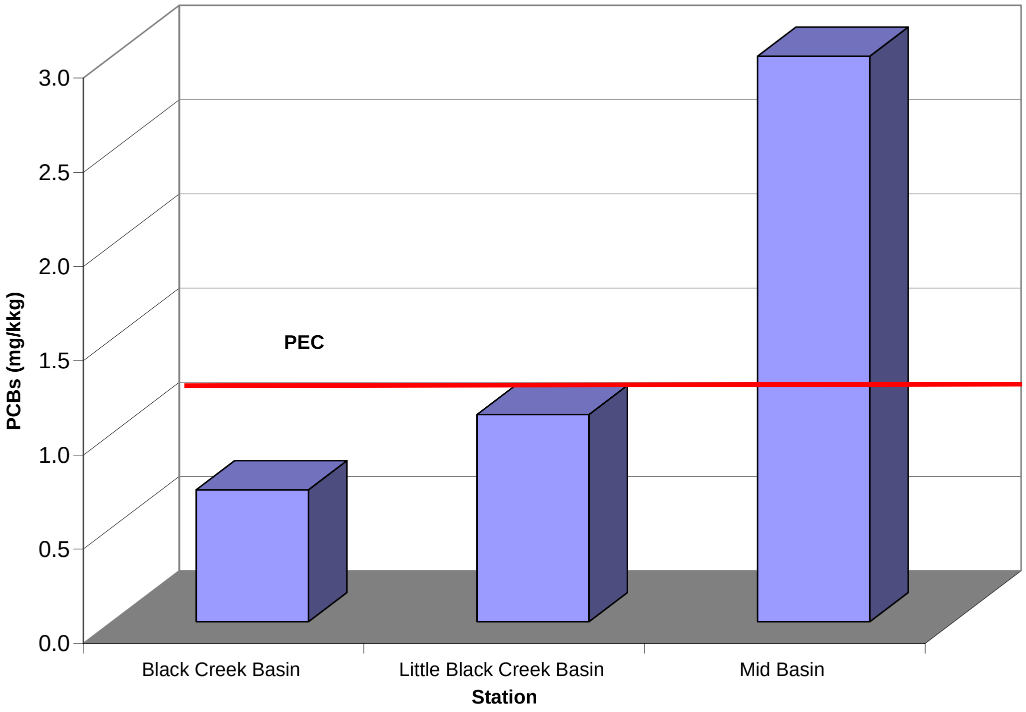


Figure 3.6.17. PCB concentrations in sediment core samples collected from Mona Lake (July 2003).



Black Creek basins while an increasing trend is noted in the main lake (Figs. 3.6.13 and 3.6.14, respectively). Current sediment concentrations of cadmium and lead exceed the PEC in the Little Black Creek basin and in the mid-lake station, while chromium exceeds this level only in the mid basin.

Historic data were not available for PAH compounds, BAP, and PCBs for the locations sampled. PAH compounds and BAP were present at concentrations below the PEC (Fig. 3.6.16). The Little Black Creek basin had the highest concentration of these contaminants. The presence of these materials at this location may be due to releases of stored contaminants from the Mona View wetland or an active groundwater plume. Sediment PCB concentrations (Fig. 3.6.17) were below the PEC in the two creek basins and slightly above this level in the main lake. A more detailed investigation of contaminants in the sediments of Mona Lake and its tributaries would be required to develop an understanding of contaminant fate and transport in the system. On a preliminary basis, the results of this investigation suggest that contaminant transport and deposition is occurring and needs to be investigated in more detail.

3.6.6 Conclusions

A preliminary investigation of contaminated sediments was conducted in Little Black Creek and Mona Lake. The stream segment on Little Black Creek from the crossing at Sherman and Getty to Seaway Drive was found to be highly contaminated with cadmium, chromium, lead, PAH compounds, benzo(a)pyrene, and PCBs. Most of the samples had contaminant concentrations that exceeded the PECs for the protection of aquatic life. In addition, concentrations of lead, benzo(a)pyrene and PCBs were at levels that exceed human health criteria for long term direct contact. Since only one set of samples was collected, it is difficult to formulate conclusions about contaminant fate and transport, ecological integrity, and potential human health impacts. However, the results clearly demonstrate the existence of a significant environmental contamination problem that should be investigated in a more detailed manner. While problems associated with environmental contamination have been reported previously in Little Black Creek, this investigation provides preliminary evidence that contaminant transport mechanisms are active in Mona Lake and sediment concentrations of metals appear to have increased from levels reported in 1980. Again, the results from this project represent a single set of samples and cannot be used to draw conclusions about the contaminant transport processes affecting Mona Lake. The results, however, do support the need to conduct a more comprehensive investigation.

The presence of an active source of cadmium (Peerless Plating) and PAH compounds (the closed refinery) present additional problems for the City of Muskegon Heights and residents of Norton Shores that have riparian ownership of the frontage on Mona Lake. Redevelopment efforts to improve economic and living conditions in the City of Muskegon Heights are linked to restoring the environmental quality of Little Black Creek. This restoration process must involve the remediation of contaminated areas of Little Black Creek within the city and eliminating the contaminant source areas in the upper watershed.

3.7 Macroinvertebrate and Fish Survey

Aquatic organisms can serve as important indicators of water quality (Karr et al. 1986, Lenat 1988, Resh and Jackson 1993). Previous studies by MDEQ (MDEQ 1991, 2000, 2002) in the Mona Lake Watershed have exploited this relationship, and have provided the basis for declaring both Black and Little Black Creeks impaired. Biological sampling was conducted in the present study to update the prior MDEQ studies and complement the current sediment condition analysis (Section 3.6).

3.7.1 Macroinvertebrates

Methods

Site Selection: Six sites along a continuum of disturbance were selected for study. Four stream sites and two wetland sites were selected along Little Black Creek (LBC), to represent a reference site and then a downstream gradient from the Superfund site of Peerless Plating at Sherman and Getty:

- (Evanston (N43.21554 W86.18093) – reference
- Sherman (N43.20437 W086.22361) – immediately downstream from Peerless
- Summit (N43.19843 W086.23052)
- Mona View (N43.19515 W086.23275)
- Seaway (Coordinates Not Available)
- Mouth of LBC site (N43.18610 W086.24681)

Sites were chosen to contain comparable habitat types. Macrophytes and large woody debris were sampled from the sandy bottom stream sites, while mono-dominant stands of *Typha* were sampled in the wetlands.

Invertebrate Sampling: Macroinvertebrate samples were collected with standard D-frame dip nets with 0.5-mm mesh netting. At least three replicate samples were collected from each site to obtain a measure of sampling variance within the specified habitat.

Dip net sampling included sweeps just below the surface of the water, at mid-depths and at the sediment surface in each available habitat type. Dip nets were emptied into white enamel pans that were subdivided into sections using grid lines, and 150 invertebrates were collected from the sample by focusing on a section of the pan and removing all of the specimens from it before moving on to the next grid. Picking continued until 150 invertebrates were collected or until samples were picked for 30 person minutes. As a means of semi-quantifying samples, picking of specimens was timed. Individual replicates were picked for 30 person-minutes of effort, after which, organisms were tallied and picking continued to the next multiple of 50. Three replicates were collected in each habitat type.

Invertebrates were preserved in a 70% ethanol solution and returned to the laboratory. There, they were sorted to lowest operational taxonomic unit (genus or species for most specimens) using taxonomic keys such as Thorp and Covich (1991) and Merritt and

Cummins (1996), along with specialized keys for species level identification from mainstream literature. Accuracy was confirmed by expert taxonomists whenever possible.

Data Analysis: Stream data were analyzed using correspondence analysis as well as the State of Michigan's GLEAS procedure 51. Wetland data were analyzed using the Wetland IBI of Burton et al. (1999) and Uzarski et al. (accepted).

Results

Nearly all of the replicate samples collected contained 150 organisms, with the exceptions of the Sherman and Mona View sites, where only 50 organisms per replicate could be obtained. The Mouth of LBC produced two of the three replicates with only 50 organisms. In total, 2096 organisms were collected.

Correspondence Analysis: Correspondence analysis explained 47% of the variation in the dataset in the first dimension (Fig. 3.7.1). The second dimension explained an additional 29% of the variation providing an excellent two-dimensional representation of the dataset. The Summit site had the most unique community, separating this site from the other three along the x-axis. Evanston Rd. was located upstream of the point and nonpoint sources of pollution. The pronounced shift in invertebrate taxa from Evanston Rd. to the other three sites was observed along the y-axis. The shift was from an insect-dominated community to non-insects such as Nematoda, Turbellaria, Hirudinea, Naididae, Tubificidae and Sphaeriidae.

GLEAS Procedure 51: GLEAS procedure 51 placed every site in the 'poor' category. This was even after artificially inflating the scores because metrics were based on genera instead of family-level data to obtain a better resolution among sites. Evanston Rd. scored highest followed by Summit Rd. and finally Sherman and Seaway sites both had the lowest scores. Key indicators of high water quality, mayflies and caddisflies, were only found at two sites. Both mayflies and caddisflies were found at Evanston while only mayflies were found at Summit. A total of 19 mayflies and caddisflies were collected in all. Neither mayflies nor caddisflies were found at Sherman and Seaway, and stoneflies were not collected from any site.

Wetland IBI: Both wetlands were placed into 'Moderately Degraded' category scoring between 30 and 50 % of the possible score. The two systems scored nearly identical with only the relative abundance of amphipods being slightly higher at Mona View. Fewer organisms were collected at Mona View as well.

Discussion

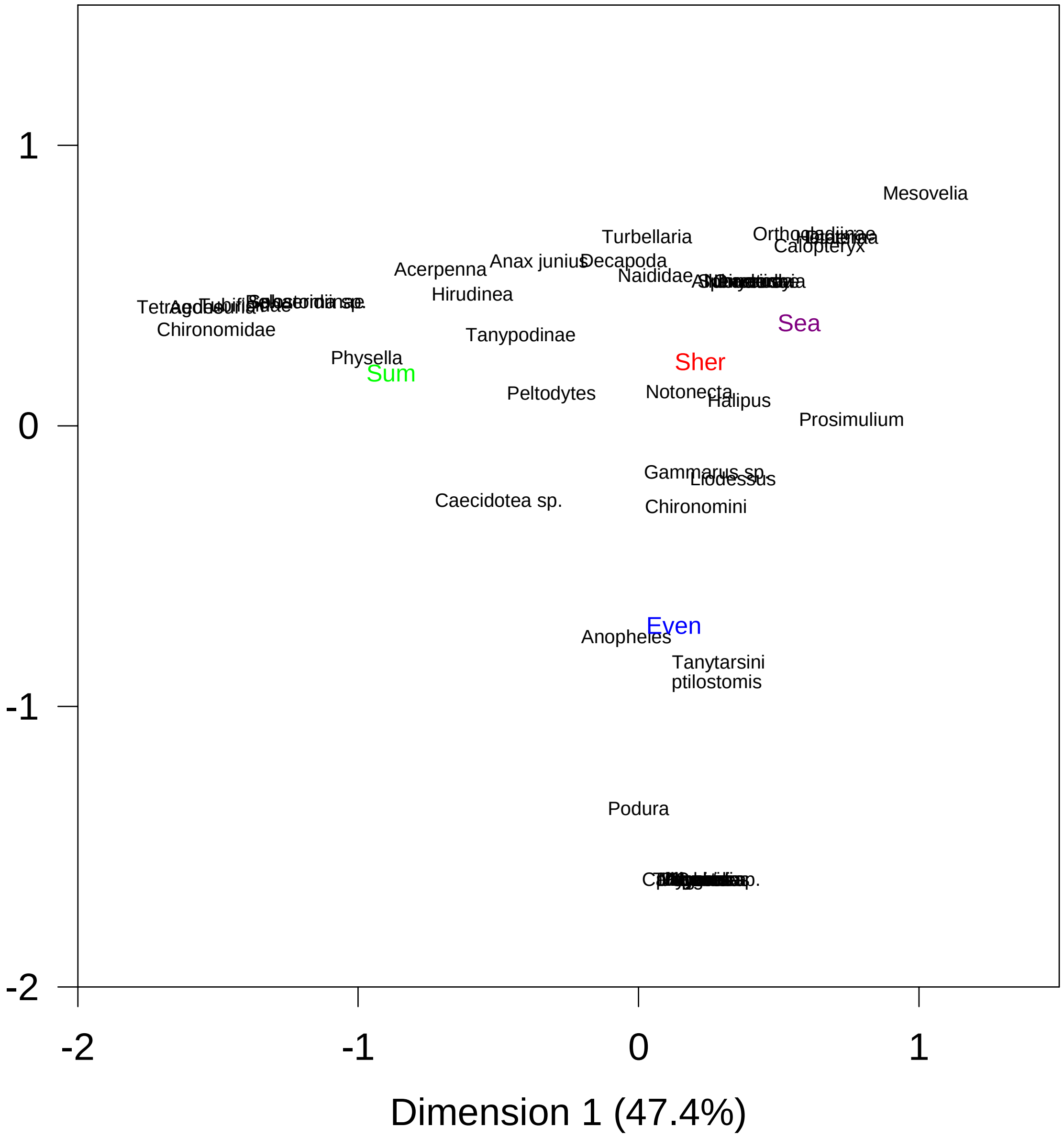
Correspondence Analysis: The first dimension of the correspondence analysis likely represented a habitat gradient. Summit Rd. had unusually high macrophyte biomass and this seemed to outweigh the effects of water quality on overall community composition. However, it is important to note that the community was relatively depopulated, even at the reference site. This is probably due to sedimentation eliminating suitable habitat for many organisms. Very few areas containing substrate other than sand could be found throughout the entire system. The vegetation that could be found served as biological 'hot spots', housing nearly all of the macroinvertebrates found in the system. Most of the organisms collected from these areas of high productivity are considered to be pollution-tolerant in most literature, explaining why habitat seems to be so crucial to community composition as a whole.

While habitat quality had a greater impact on overall community composition, there was a notable shift due to water quality. The second dimension likely represented this shift in water quality. This shift went from relatively pollution-tolerant insects to pollution-tolerant non-insects.

GLEAS Procedure 51: The Summit Rd. site likely had a higher score than Sherman and Seaway only because of increased habitat heterogeneity and not necessarily because of higher water quality. These metrics do not necessarily separate variation due to water versus habitat quality. The protocol attempts to remove variability associated with habitat type, but in habitat-poor environments such as LBC, small variations in habitat may have large impacts on communities.

Wetland IBI: These scores were somewhat inflated due to a strong flowing-water influence on the wetlands. Many poor stream-water quality indicators such as dragonflies, snails, and amphipods are actually indicators of good water quality in wetlands. Incidental transport of these organisms from the stream to the wetland can artificially raise the score of the wetland. This transport likely occurred in both wetlands.

Figure 3.7.1. Correspondence analysis using 2002 macroinvertebrate data from Little Black Creek.



3.7.2 Fish

The fishes, like other groups of organisms, exhibit environmental preferences among groups. For example, some fish survive in warmer water with reduced oxygen concentrations, whereas other fish only survive if temperatures are relatively cold and oxygen concentrations are relatively high. Because of this, fish provide information regarding the condition of aquatic systems.

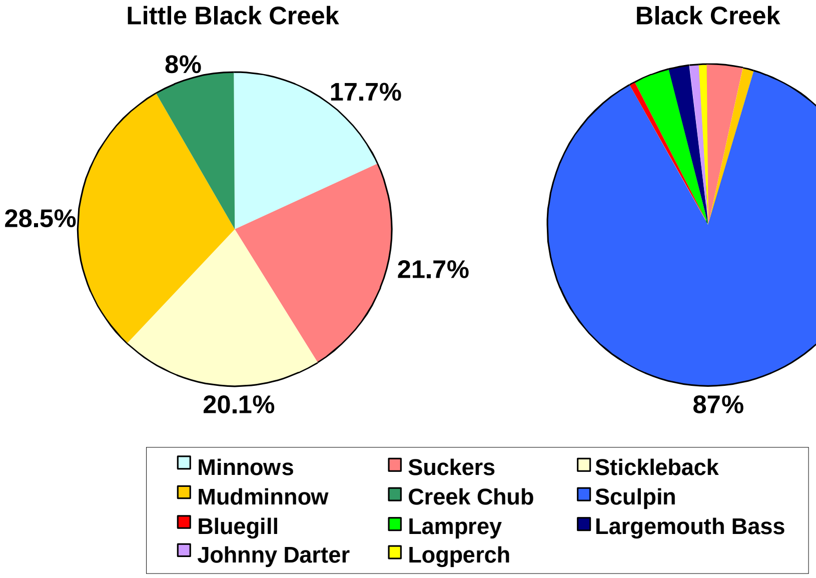
Methods and Results

As part of the Mona Lake Watershed project, fish communities in Black and Little Black Creeks were surveyed during summer 2002. Surveys were conducted using a backpack electroshocker, with surveys among sites standardized by distance surveyed and duration of survey.

A total of eight species were collected at three sample sites on Black Creek. The fish community in Black Creek was dominated by sculpin, a small bottom dwelling fish (Fig. 3.7.2). Other common fishes included lampreys (juvenile stage), white suckers and largemouth bass. The relative proportions of species varied among sample sites, however, sculpin were consistently the most common group of fish at each of the three sample sites (Fig. 3.7.2).

Five species of fish were collected at sites surveyed on Little Black Creek (Fig. 3.7.2). Central mudminnow was the predominate species whereas stickleback, white suckers and minnows were all common (Fig. 3.7.2). Unlike Black Creek, each sample site on Little Black Creek was dominated by a different species. Sticklebacks, central mudminnows, and minnows were the most abundant species at Evanston, Sherman, and Seaway, respectively.

Figure 3.7.2. Distribution of fish from June 2002 in Little Black Creek and Black Creek.



Discussion

Sculpin, the dominant species throughout Black Creek, is considered a cold water fish and is often associated with trout. Sculpin (and trout) survive if average July water temperatures remain below 20^{o} C and the weekly temperature range is no more than 10^{o} C. The relative abundance of sculpin in Black Creek indicated that water temperature and quality are sufficient to sustain populations of cold water fishes. The presence of riparian vegetation, particular mature trees, and adequate groundwater discharge probably contribute to the temperature regime of Black Creek.

In contrast, the presence of creek chubs, mudminnows, suckers, and largemouth bass suggest that temperature in localized pockets may be cool (rather than cold) or even warm. Creek chubs and suckers are considered cool water species and their presence may indicate a transition from cold to warm conditions. Largemouth bass are warm water fish and are rarely associated with cold water species unless pockets of warmer water are available. Thus, based on fish community surveys, Black Creek appears to have good volumes of cold water, suitable for cold water fishes, but may be warming slightly in limited locations.

Although temperature is suitable to support sculpin populations, other factors may limit the actual number of sculpin present in Black Creek. Specifically, the excessive amount of sand present has probably reduced the available spawning habitat. In addition, sand may reduce the abundance of invertebrates, an important food resource for sculpin. In general, invertebrates require substrata such as rocks and logs for attachment; when sand covers these substrata they are unavailable to invertebrates.

Little Black Creek exhibited considerable variation among survey sites with each site dominated by a different species. The presence of stickleback, mudminnow, and creek chubs at the Evanston site indicated that this site is relatively warm. Plants in the water along the banks and accumulations of organic material are characteristic of areas occupied by these two species. The dominance of mudminnows and white suckers at Sherman confirm warm water conditions persist throughout this section of Little Black Creek. The fish community observed at Seaway Drive also suggests this system is warm and impacted by accumulating organic sediment. The minnows (genus Notropis) collected at Seaway may have migrated into Little Black Creek from Mona Lake and may or may not be present throughout the year.

4.0 Conclusions and Recommendations

4.1 Conclusions

The Mona Lake watershed is a relatively small watershed (48,000 acres) that contains a number of environmentally important natural resources, but also faces a number of environmental challenges. Both historic and current practices have resulted in a watershed exposed to point and nonpoint source pollutants, including excessive sediments, nutrients, toxic metals, and organic chemicals. Changes in land use patterns over the past few decades have magnified these challenges. Nonetheless, this watershed provides a number of important ecosystem services. It is critical that the necessary steps be taken, in as expedient a fashion as practicable, to implement best management practices where there is reasonable certainty that benefits will occur, and to conduct the appropriate studies to generate the necessary information when uncertainty is still high. Below, the major problems in the watershed are identified based on this study, and possible solutions recommended.

Problem 1: Changing Land Use patterns

The Mona Lake watershed experienced a significant decline in agricultural land use between 1978 and 1998, especially with respect to loss of cropland. Most of this loss was offset by increases in developed land use (especially residential) and natural cover (largely open field). Given the continued development in this region in the past five years, it is likely that current land use maps would show even larger conversion percentages from agriculture to residential and developed land uses. These changes are likely harbingers of future land use patterns unless steps are taken. This pattern should be of concern to those advocates of green infrastructure and farmland preservation.

Problem 2: Nutrient Loading within the Mona Lake Watershed

Excessive phosphorus entering Mona Lake has been identified as a problem for over 30 years. The diversion of wastewater from the Muskegon Heights sewage treatment plant to the Muskegon Wastewater Management System has reduced phosphorus loads to Mona Lake substantially, but phosphorus concentrations in the Lake still far exceed water quality standards. In addition, nitrogen concentrations in Mona Lake are high. These nutrients can impair water quality, stimulate algal blooms, change the invertebrate and fish communities, impair lake aesthetics, and result in taste and odor problems in the water. Nutrients come from both point (e.g. from pipe) and nonpoint (e.g. runoff from farms, lawns, and impervious surfaces) sources; regulation of point sources has become so successful that nonpoint sources are now the major source of nutrient pollution in most US watersheds (Carpenter et al. 1998).

In addition to the nutrient loads coming from the watershed (external loading), nutrients may also come from the sediments of water bodies (internal loading). In the latter case, nutrients become stored in the sediments over time, and may either become resuspended or diffuse into the water column under appropriate environmental conditions.

Observational data collected during this study suggest that internal loading may be a significant source of phosphorus and ammonia to Mona Lake.

Problem 3: Sediment loading within the Mona Lake Watershed

Both Black Creek and Little Black Creek have been placed on Michigan's Section 303(d) list of impaired water bodies. Both creeks fail to meet Michigan's WQS, with excessive sediment identified as the primary contributor to poor stream quality and impaired biota (J. Wuycheck, pers. comm.). The TMDLs for both creeks call for reductions in storm sewer runoff rates and solids loads from controllable industrial and municipal storm water runoff sites. In addition, the TMDL for Little Black Creek calls for reduced stream bank erosion through more stable flow management, while the TMDL for Black Creek calls for reduced loads from agricultural sources in the upper reaches of the subbasin.

Sediment is the most common agricultural pollutant (USEPA 1996). Although some sediment input to streams is normal, excessive sediment can have negative impacts on biota (Waters 1995). Excess fine sediment loads reduce habitat heterogeneity resulting in a shift in invertebrate and fish communities (Schlosser 1991, Richards and Host 1993), while suspended sediments can impair fish respiration, reduce feeding rates, and increase physiological stress (Newcombe and Jensen 1996).

Problem 4: Contaminated sediments within the Mona Lake Watershed

The major tributaries of Mona Lake have an extensive history of anthropogenic activity related to industrial discharges. Little Black Creek and Black Creek were heavily industrialized with chemical production facilities, plating companies, and metal finishing operations. Both streams contain extensive areas of wetlands that are located near Mona Lake and extend upstream into the middle of the drainage basins. Historical discharges to Little Black Creek included effluents from specialty organic chemicals, foundries, machining, electroplating, and petroleum processing. In addition, diffuse sources of contamination continue to enter the creek from storm sewers, local runoff, and impacted groundwater plumes. Although contaminated sediments were previously reported in Mona Lake (WMSRDC 1982), it is unclear whether: 1) these contaminants are being transported within the tributaries and accumulating either in downstream wetlands or the lake itself; and 2) these contaminants are moving within Mona Lake. Given the public access and recreational use of these water bodies, the answers to these questions have both human health and ecological implications.

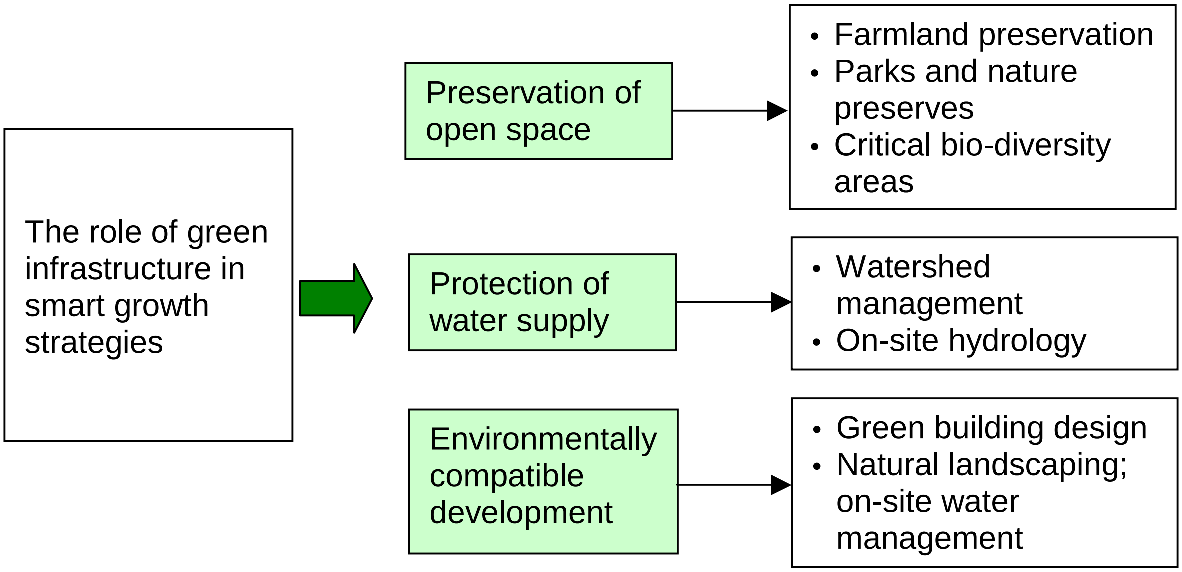
4.2 Recommendations

Recommendation for Problem #1:

Although the watershed assessment conducted in the present study was able to update data on existing environmental problems in the watershed, as well as identify new ones, it is clear that a comprehensive watershed management plan is needed for the Mona Lake watershed. One of the key elements that this plan should address is changing land use patterns in the watershed, since land use/land cover has such broad implications for water quality, water quantity, terrestrial and aquatic habitat, sustainable economic development, and social equity.

Both the West Michigan Strategic Alliance's Green Infrastructure Task Force (GITF) and the Muskegon Areawide Planning (MAP) process are addressing land use, and the need for a more holistic land use planning approach. The recommendations from the GITF are not specific to the Mona Lake watershed, but they clearly are applicable, and can be modified as needed for local implementation (Fig. 4.1).

Figure 4.1. Smart growth strategies for addressing land use patterns. (Adapted from the West Michigan Strategic Alliance - Green Infrastructure Task Force's Final Report, November, 2003.)



The GITF developed a suite of tools and possible financing sources for these activities (WMSA 2003). The tools include both regulatory oversight and non-regulatory programs, such as voluntary restrictions and acquisition strategies. Examples of regulatory protection fall within local, state, and federal domains:

I. Regulatory

Local protection:

- Urban growth boundaries
- Large lot zoning
- Planned Unit Development
- Mandatory dedication of open space
- Cluster development options
- Performance zoning
- Bonus/incentive zoning
- Conservation overlay zoning
- Voluntary agricultural districts

State protection:

- Natural Resources and Environmental Protection Act
- Water resources protection
- Floodplain protection
- Soil erosion and sediment control
- Inland lakes and streams
- Wetland protections
- Natural rivers
- Shoreland and sand dune protection

Federal Protection

- Clean Water Act
- Coastal Zone Management
- Endangered Species Act
- National Wild and Scenic Rivers Act
- Wetlands Reserve Program
- Cooperative Forestry Assistance

II. Non-Regulatory

Voluntary Restrictions on Owners

- Transfer/purchase of development rights
- Purchase of timber rights or other easements
- Conservation easements
- Leases; management agreements
- Mutual covenants; limited development techniques
- Technical assistance programs

Property Acquisition

- Fee simple acquisition or donation
- Acquisition and saleback/lease
- Land banking
- Land exchange
- Eminent domain

None of the non-regulatory strategies will be feasible without financial support. The GITF identified a number of possible funding strategies and opportunities (WMSA 2003):

- Bond issues
- General fund appropriations and revolving funds
- Preferential tax treatment
- Tax increment finance district
- Development impact fees
- Other taxes and fees
- State and federal grants
- Foundations
- Private individuals
- Corporations
- Land conservancies

Ultimately, these activities are going to be dependent on regional cooperation, both within the watershed and within west Michigan, as a whole. Establishing model ordinances and providing incentives to implement these strategies (Delta Institute 2003) are immediate needs.

Recommendation for Problem #2

External loading: Based on the loading calculations, the Black Creek subbasin is, by far, the dominant source of phosphorus and nitrogen to Mona Lake. Therefore, nutrient reduction activities focused in this subbasin are going to have the greatest impact per unit dollar expended. This does not mean that other inflows should be ignored, simply that the Black Creek subbasin should have the highest priority for external nutrient load reduction activities.

The present study focused exclusively on the inflows to Mona Lake in order to identify which subbasins contributed the most nutrients from the watershed. As a consequence, a series of recommendations are provided for the Black Creek subbasin:

- A thorough assessment of the upper reaches of the Black Creek subbasin is needed. This inventory should identify critical areas of highly erodable lands, reaches for Best Management Practices (BMPs), possible in-stream restoration activities, and nutrient sources (sample water quality in a spatially explicit fashion within subbasin).

- Although cropland is declining in the watershed, it is likely that agricultural BMPs in this subbasin, such as reduced tillage or no-tillage management, contour strips, crop rotation, winter cover crops, and riparian buffer strips, will reduce whatever nutrient loads are coming from this land use (Allan et al. 1997, Larson et al. 1997). The Mona Lake Watershed Council should work aggressively with the Muskegon Conservation District and the local NRCS to encourage producers to adopt these BMPs.
- A feasibility study is recommended to evaluate converting the abandoned celery fields adjacent to Black Creek, at its mouth to Mona Lake, to a constructed wetland. This feasibility study would include the following elements:
    - Develop an agreement with landowners (Workmans) regarding wetland restoration activities on this site. Initial conversations have already begun between Mr. Workman and James Fortney from MDEQ regarding: 1) the removal of a portion of the dike separating the flooded fields from the Creek and 2) the installation of a more permanent water control structure at the location of the current breech in the dike (pers. comm., James Fortney).
    - Conduct studies to assess the ability of the site to serve as a nutrient sink. Many abandoned agricultural fields, once flooded, serve as a source of nutrients to the water column (cf. Pant and Reddy 2003) because of the high concentrations of nutrients stored in the soils. In addition, the 1996 study by Aquest (Section 2.VIII) suggested that a major source of P to Mona Lake occurred in Black Creek between Highway 31 and the mouth to the lake, which corresponds to the location of these celery fields. Laboratory studies should be conducted to determine the nutrient release potential of these soils, and their likelihood of serving as sinks or sources.
    - Assuming that an agreement can be reached with the landowner, and that the site serves as a nutrient sink (or can be modified to serve as a sink via nutrient “mining” over time), develop engineering plans to optimize site as a constructed wetland (Kadlec and Knight 1995). These plans will focus on water detention, nutrient retention, and multiple use options (e.g. birding, fishing, education).

Although Black Creek accounts for most of the nutrient loads to Mona Lake, it is evident that some of the smaller inflows also can account for high concentrations of contaminants at certain times of the year. Because the flows at these sites are low relative to Black Creek, their overall contribution of load is small, but they may represent localized “hot spots” of biological impairment. Inflows of particular concern include: Henry Street Drain for most contaminants, ND1 and ST2 for phosphorus, and Little Black Creek, NT1, and ST4 for fecal coliforms. In addition, the inflow from ST5 (by the airport) showed very high levels of contaminants, but flow was detected there only once, so it is unclear whether those levels were representative of other times of the year.

Implementation of BMPs, including retrofits of storm drains, at the above sites will help reduce the level of contaminants from entering Mona Lake. The watershed council should work with local units of government to identify funding sources for these projects, which could include detention and infiltration areas to pre-treat the runoff before it enters into the lake. This need was first recommended 25 years ago (WMSRDC 1978, see Section 2.III).

Internal Loading: Almost 30 years ago, WMSRDC published a report (see Section 2.I) identifying internal loading from Mona Lake as a potential problem, and recommended studies be conducted to address this issue. The data from the current study strongly suggest that internal loading is a substantial source of nutrients to Mona Lake. This is not surprising because in highly eutrophic lakes, internal loading can account for a substantial amount of the total load. Indeed, many studies have shown that reductions in external loading do not result in a reduction of algal growth because phosphorus continues to be released from sediments, counteracting the external load reductions (Bjork 1985, Graneli 1999, Steinman et al. 1999). This, in turn, can result in stakeholder frustration because of public expectations that the implementation of (often expensive) BMPs will result in better lake water quality, fewer algal blooms and more aesthetically pleasing lake conditions.

As a consequence, it is recommended that a study be conducted to evaluate whether internal loading of phosphorus from sediments to the water column is a significant source of phosphorus to Mona Lake. A similar study recently completed by AWRI on nearby Spring Lake indicated that internal phosphorus loading accounted for almost two-thirds of the total P loading to this lake (unpubl. data).

If internal loading is found to be a significant source of phosphorus to Mona Lake, various remediation strategies could be investigated. These strategies might include chemical binding, dredging, and/or aeration.

Recommendation for Problem 3:

Dealing with the suspended solids problem requires a multidisciplinary approach that integrates implementation, education, and research.

Implementation: The Muskegon County Stormwater Committee is a coordinating body through which Phase II Stormwater Management permits can be handled. Although not all the municipalities in the Mona Lake watershed are participating, this Committee is an important step in providing a coordinated approach for dealing with stormwater issues in the watershed. This committee should be utilized to assess stormwater problems (inventory) and implement BMPs through the Phase II permit.

Agricultural BMPs for the Black Creek subbasin should emphasize reduction of bare soils. Possible approaches include reduced tillage or no-tillage management, contour strips, crop rotation, winter cover crops, or grass/forested buffer strips. The Delta

Institute report (2003) identifies a number of assistance programs through the USDA that can help in these implementation activities.

BMPs are also needed for industrial and commercial discharges. This may involve a combination of source controls and in-stream devices, such as sediment traps in optimal locations.

Education: The Phase II Stormwater permit requires a Public Education Strategy, which presumably will be coordinated through the Stormwater Committee. Training sessions for agencies, groups, or individuals (Delta Institute 2003) will help create an awareness in the watershed for the importance of these BMPs and permit requirements.

Research: The TMDL is based on very coarse-scale modeling (P-load) and a mean annual total suspended solids target of 80 mg/L for wet-weather events. Both modeling and the TSS target have not been validated in the Mona Lake watershed. Indeed, Minnesota uses a standard of approximately 46 mg/L, and even that lower standard may be too high to ensure that stream fishes are not negatively impacted by suspended sediment (Vondracek et al. 2003). It is recommended that both the modeling approach and TSS target be investigated in more detail.

A hydrologic model for the Mona Lake watershed is under development at AWRI; a proposal is being developed to calibrate and verify the model. If funded, the proposal will allow the TMDL for Black Creek and Little Black Creek to be assessed in much greater detail and with much greater confidence.

Recommendation for Problem 4:

Little Black Creek: The stream segment on Little Black Creek from the crossing at Sherman and Getty to Seaway Drive was found to be highly contaminated with cadmium, chromium, lead, PAH compounds, benzo(a)pyrene, and PCBs. Most of the samples had contaminant concentrations that exceeded the PECs for the protection of aquatic life. In addition, concentrations of lead, benzo(a)pyrene and PCBs were at levels that exceed human health criteria for long term direct contact. Since only one set of samples was collected, it is difficult to formulate conclusions about contaminant fate and transport, ecological integrity, and potential human health impacts. However, the results clearly demonstrate the existence of a significant environmental contamination problem. Specific steps that need to be taken include:

- The toxicity of the sediments in this stream segment should be investigated in a more detailed manner. Depositional areas with high concentrations of contaminants, of known toxicity, should be removed and the sites remediated to retain ecological function.
- Fate and transport of contaminants in this stream are still poorly understood, and should be investigated in a more detailed manner.
- The hydrology of the stream should be restored to its natural condition to the greatest extent practicable. The lack of adequate stormwater detention results in a flashier stream hydrology (faster peak flows), which promotes erosion,

and increased transport of contaminants. Best management practices for urban streams (swales, detention basins, etc.) will help attenuate flow. However, a much more detailed hydrologic analysis is needed to determine the optimal number and location of BMPs to limit contaminant transport.

<u>Mona Lake:</u> Results from this study provide preliminary evidence that contaminant transport mechanisms are active in Mona Lake. As with Little Black Creek, the results represent a single set of samples and caution should be exercised about the extent of contaminant transport processes affecting Mona Lake. The results, however, support the need to conduct a more comprehensive investigation.

- Additional sediment sampling of locations in Mona Lake is needed to establish the extent of contaminant transport. In particular, are the sediments moving further west toward Lake Michigan, or have they become concentrated in a particular basin with the lake?
- The toxicity of the sediments in Mona Lake should be investigated in a more detailed manner. Depositional areas with high concentrations of contaminants, of known toxicity, should be removed and the sites remediated, if necessary, to retain ecological function.

Future Developments:

A number of activities have either begun, or will begin in 2004, to address some of these recommendations.

1) The Mona Lake Watershed Council has been formed and been granted 501(c)(3) status. This council will provide continuity and a centralized structure for activities within the watershed. The watershed council will be submitting a proposal to the Michigan Department of Quality in early 2004 to develop a watershed management plan.
2) The USEPA, Great Lakes National Program Office, has approved funding of a proposal by AWRI to investigate sediment chemistry, toxicity, and ecological effects, and develop a contaminant transport model. This $138,000 grant will focus primarily on Little Black Creek, and provide additional information on the severity of contamination in this system, and how best to remediate.
3) The USEPA, Great Lakes National Program Office, has approved funding of a proposal by the Lake Michigan Federation for education and capacity building for contaminated sediment removal in Little Black Creek. This $38,000 grant will focus primarily on human health issues related to contaminated sediments, and will work closely with the previously mentioned grant.
4) The MDEQ, via CMI (Clean Michigan Initiative) funds, has approved funding of a proposal by AWRI to investigate the importance of internal phosphorus loading in Mona Lake. This $33,000 grant will compare internal vs. external loading to Mona Lake. In addition, the data will help in the refinement of the hydrologic model for Mona Lake (Section 3.5).

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6.0 Appendices

Appendix 6.1	Map Atlas of Mona Lake watershed (list of figures).
Appendix 6.2	Chemical data for inflows and outflow (channel only), Mona Lake: June 2002 through August 2003.
Appendix 6.3	Chemical and physical data for 4 sampling sites in Mona Lake: May 2002 through August 2003.
Appendix 6.4	Organic analytical results for Little Black Creek, Cress Creek, and Mona Lake.
Appendix 6.5	Potential Pollution Sources to Little Black Creek, Muskegon County, Michigan. October 28, 2003. Williams and Beck, Inc. (Contact AWRI for report).

Appendix 6.1. Map Atlas of Mona Lake watershed (list of figures).

Appendix 6.2. Chemical data for inflows and outflow (channel only), Mona Lake: June 2002 through August 2003.

	Cl mg/L	SO$_4$ mg/L	NO$_3$ mg/L	NH$_3$-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
6/19/02											
BC	28	45	0.7	0.03	0.35	0.005	0.06	8.13	108	14	325
LBC	94	36	0.88	0.15	0.41	0.005	0.05	7.64	163	4	650
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	39	31	0.04	0.19	0.81	0.005	0.05	8.98	113	8	16
ND3	70	40	3.2	0.02	0.24	0.03	0.04	7.75	177	1	175
NT1	63	360	1.7	0.05	0.59	0.04	0.15	8.23	126	8	175
NT2	-	-	-	-	-	-	-	-	-	-	-
NT3	67	21	2.2	0.09	0.33	0.02	0.04	7.87	123	5	175
ST1	37	17	1.3	0.02	0.29	0.005	0.04	7.87	98	16	175
ST2	81	23	1.8	0.05	0.42	0.03	0.08	7.59	89	26	175
ST4	41	13	0.88	0.18	1.00	0.005	0.13	8.20	125	26	725
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	83	18	1.4	0.04	0.24	0.005	0.04	7.94	119	11	100
CH	34	30	0.04	0.18	0.78	0.005	0.05	8.98	119	7	33

7/22/02	Cl mg/L	SO$_4$ mg/L	NO$_3$ mg/L	NH$_3$-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	19	26	0.55	0.03	0.63	0.02	0.07	8.01	106	12	330
LBC	79	20	0.78	0.09	0.50	0.03	0.04	7.70	173	5	430
ND1	70	25	0.80	0.34	0.63	0.04	0.10	7.66	203	3	680
ND2	150	21	2.1	0.08	0.09	0.01	0.01	7.75	147	5	50
ND3	220	26	2.8	0.03	0.25	0.02	0.02	7.83	191	9	820
NT1	49	42	1.5	0.03	0.15	0.02	0.02	7.96	107	7	340
NT2	30	17	1.2	0.04	0.79	0.02	0.06	7.79	123	8	200
NT3	54	13	1.9	0.06	0.24	0.03	0.03	7.89	125	4	82
ST1	34	11	1.3	0.05	0.31	0.03	0.03	7.89	101	12	440
ST2	38	14	1.4	0.07	0.22	0.04	0.10	7.60	89	18	1000
ST4	34	9	0.78	0.08	0.86	0.03	0.09	7.60	136	12	390
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	77	13	1.4	0.05	0.27	0.02	0.03	7.94	121	8	400
CH	76	36	0.87	0.01	0.68	0.02	0.07	8.69	113	6	16

8/27/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	100	60	0.76	0.04	0.53	0.01	0.06	8.14	139	8	420
LBC	31	43	1.2	0.14	0.24	0.005	0.03	7.72	163	1	340
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	200	45	3	0.16	0.26	0.005	0.01	7.85	167	2	16
ND3	280	50	3.6	0.04	0.16	0.02	0.04	7.95	219	1	1700
NT1	56	31	1.6	0.06	0.21	0.005	0.03	7.90	119	5	500
NT2	36	19	1.2	0.05	0.35	0.005	0.04	7.76	123	15	290
NT3	57	21	2	0.08	0.22	0.005	0.03	7.64	127	2	260
ST1	54	17	0.99	0.07	0.19	0.005	0.02	7.75	119	11	320
ST2	57	23	1.9	0.06	0.62	0.05	0.11	7.65	87	14	910
ST4	32	9	0.34	0.22	0.89	0.07	0.11	7.41	143	36	130
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	81	21	1.5	0.05	0.17	0.005	0.02	7.82	119	3	170
CH	33	23	0.005	0.03	0.66	0.005	0.05	9.13	115	4	16

9/17/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	46	64	0.70	0.005	0.59	0.02	0.07	8.31	129	9	200
LBC	120	52	1.5	0.07	0.35	0.02	0.04	7.80	153	3	400
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	200	47	3.2	0.06	0.16	0.005	0.01	7.98	163	2	100
ND3	310	55	3.9	0.005	0.22	0.005	0.03	7.93	224	2	2300
NT1	61	34	1.7	0.005	0.21	0.02	0.03	8.03	121	6	1500
NT2	30	23	1.1	0.005	0.46	0.005	0.06	7.82	127	35	1400
NT3	64	22	2.1	0.02	0.27	0.005	0.04	7.86	123	2	300
ST1	47	18	1.0	0.01	0.32	0.02	0.04	8.44	103	6	600
ST2	66	28	2.5	0.005	0.10	0.03	0.05	7.74	87	24	300
ST4	40	15	0.65	0.005	0.62	0.005	0.09	7.59	139	46	2800
ST5	-	-	-	-	-	-	-	-	-	-	-

10/29/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	34	50	0.41	0.05	0.42	0.01	0.06	8.11	129	3	33
LBC	110	44	1.4	0.21	0.17	0.005	0.06	7.69	173	3	1400
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	120	29	1.8	0.12	0.98	0.005	0.01	8.02	165	0	16
ND3	180	34	2.1	0.04	0.44	0.01	0.02	7.98	211	1	130
NT1	49	32	1.3	0.03	0.53	0.005	0.04	7.85	115	2	550
NT2	26	22	1.1	0.03	0.63	0.005	0.05	7.73	117	23	230
NT3	42	19	1.8	0.04	0.18	0.02	0.05	7.83	123	5	390
ST1	30	14	1.0	0.06	0.54	0.005	0.06	7.61	101	6	67
ST2	37	18	1.7	0.04	0.77	0.01	0.05	7.56	85	22	550
ST4	23	10	0.32	0.14	0.66	0.005	0.07	7.36	135	22	490
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	60	18	1.2	0.05	0.29	0.005	0.06	7.82	119	9	200
CH	41	37	0.27	0.20	0.62	0.005	0.09	8.22	115	6	16

11/25/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	22	37	0.62	0.02	0.43	0.005	0.03	7.90	133	3	33
LBC	57	24	0.47	0.18	0.05	0.005	0.03	7.51	159	1	860
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	110	27	2	0.1	0.78	0.005	0.01	7.80	155	0	16
ND3	150	23	1.8	0.005	0.62	0.005	0.02	7.81	199	1	620
NT1	50	28	1.3	0.01	0.34	0.005	0.02	7.45	99	2	130
NT2	33	30	0.21	0.01	0.38	0.005	0.03	7.52	111	5	100
NT3	66	18	1.8	0.03	0.43	0.005	0.03	7.56	117	6	320
ST1	23	10	0.59	0.06	0.52	0.005	0.04	7.34	103	18	190
ST2	59	25	1.8	0.01	0.58	0.005	0.02	7.28	81	2	16
ST4	20	8	0.36	0.16	0.38	0.005	0.07	7.39	129	38	190
ST5	-	-	-	-	-	-	-	-	-	-	-

12/19/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	38	40	0.83	0.005	0.29	0.005	0.04	7.88	117	4	-
LBC	130	38	1.0	0.06	0.17	0.005	0.005	7.58	129	3	-
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	-	-	-	-	-	-	-	-	-	-	-
ND3	200	38	0.31	0.44	2.12	0.02	0.26	7.55	137	4	-
NT1	-	-	-	-	-	-	-	-	-	-	-
NT2	31	25	0.94	0.005	0.92	0.005	0.04	7.48	97	21	-
NT3	-	-	-	-	-	-	-	-	-	-	-
ST1	75	24	1.0	0.005	2.12	0.005	0.20	7.36	87	140	-
ST2	-	-	-	-	-	-	-	-	-	-	-
ST4	-	-	-	-	-	-	-	-	-	-	-
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	100	21	1.8	0.005	0.26	0.005	0.03	7.85	111	1	-
CH	-	-	-	-	-	-	-	-	-	-	-

1/14/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	64	42	0.88	0.14	0.33	0.02	0.04	7.95	131	4	16
LBC	140	48	1.4	0.21	0.44	0.02	0.10	7.73	161	11	410
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	340	40	2.9	0.11	0.74	0.01	0.005	7.90	162	1	16
ND3	410	52	4.8	0.08	0.56	0.03	0.03	7.86	217	1	120
NT1	160	38	1.6	0.02	0.42	0.01	0.005	7.75	118	3	390
NT2	59	25	1.2	0.03	0.56	0.01	0.05	7.46	121	34	50
NT3	85	23	2.8	0.03	0.45	0.02	0.04	8.00	122	8	16
ST1	64	26	2.5	0.005	0.73	0.02	0.06	7.62	88	34	17
ST2	150	23	2.1	0.02	2.02	0.03	0.33	7.45	102	191	-
ST4	44	19	1	0.17	0.40	0.03	0.06	7.45	130	25	50
ST5	-	-	-	-	-	-	-	-	-	-	-

2/11/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	87	42	0.89	0.43	0.71	0.04	0.09	7.62	148	3	16
LBC	270	53	1.5	0.08	0.60	0.005	0.08	7.85	163	13	100
ND1	120	35	1.4	0.005	0.36	0.03	0.04	7.57	199	13	17
ND2	270	39	2.8	0.09	0.83	0.005	0.03	8.01	149	1	16
ND3	1300	58	4.3	0.06	0.52	0.005	0.03	7.90	199	3	330
NT1	74	37	1.5	0.005	0.33	0.005	0.02	7.75	108	4	450
NT2	33	25	1.1	0.005	0.55	0.005	0.05	7.62	120	27	33
NT3	100	24	2.8	0.005	0.30	0.02	0.03	7.81	119	3	16
ST1	64	20	1.6	0.005	0.41	0.005	0.02	7.52	102	5	17
ST2	70	27	2.4	0.005	1.10	0.005	0.14	7.50	83	98	16
ST4	-	-	-	-	-	-	-	-	-	-	-
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	110	22	2.1	0.005	0.49	0.005	0.05	7.98	125	19	200
CH	48	36	0.61	0.31	0.51	0.005	0.07	7.83	138	1	16

3/17/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	74	36	0.67	0.12	0.40	0.01	0.05	8.02	118	9	17
LBC	180	42	1	0.14	0.44	0.01	0.04	7.86	159	3	58
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	-	-	-	-	-	-	-	-	-	-	-
ND3	260	25	0.54	0.17	0.29	0.01	0.05	7.61	45	22	160
NT1	-	-	-	-	-	-	-	-	-	-	-
NT2	-	-	-	-	-	-	-	-	-	-	-
NT3	-	-	-	-	-	-	-	-	-	-	-
ST1	-	-	-	-	-	-	-	-	-	-	-
ST2	-	-	-	-	-	-	-	-	-	-	-
ST4	71	24	1.2	0.19	1.05	0.01	0.09	7.31	76	40	170
ST5	210	32	0.27	0.24	2.29	0.06	0.82	7.82	54	528	16

3/18/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	34	32	0.8	0.13	0.70	0.02	0.05	8.19	105	14	100
LBC	84	34	0.63	0.08	0.31	0.01	0.11	7.76	123	21	16
ND1	140	36	1.9	0.24	0.74	0.03	0.08	7.58	230	3	510
ND2	270	37	2.6	0.19	0.98	0.02	0.02	7.65	161	2	16
ND3	370	36	1.8	0.16	0.40	0.01	0.02	7.55	89	2	16
NT1	88	41	1.1	0.05	0.26	0.02	0.02	7.69	87	1	16
NT2	34	24	0.98	0.07	1.20	0.02	0.08	7.51	71	51	300
NT3	61	24	2	0.06	1.20	0.03	0.08	7.79	101	37	160
ST1	57	23	1.1	0.10	0.80	0.02	0.06	7.34	74	23	16
ST2	72	29	1.3	0.03	0.18	0.02	0.02	7.40	54	3	-
ST4	63	24	1.2	0.20	1.05	0.01	0.05	7.28	82	20	2200
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	120	21	1.7	0.03	0.40	0.02	0.02	8.14	117	5	180
CH	61	37	0.78	0.13	0.31	0.02	0.03	7.98	125	4	17

4/22/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	54	45	0.52	0.05	0.53	0.005	0.05	8.10	133	10	280
LBC	133	37	0.7	0.12	0.23	0.005	0.04	7.84	151	2	100
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	323	47	3.5	0.13	0.83	0.005	0.02	7.78	147	1	16
ND3	521	50	4.7	0.04	0.99	0.005	0.03	7.87	178	1	2500
NT1	126	42	1.6	0.01	0.68	0.005	0.03	7.89	103	1	370
NT2	92	27	0.91	0.01	1.81	0.005	0.06	7.91	117	29	950
NT3	127	25	2.6	0.02	1.22	0.02	0.10	8.05	120	47	82
ST1	86	20	0.84	0.04	0.28	0.005	0.04	7.74	97	3	58
ST2	76	26	1.4	0.02	0.63	0.005	0.03	7.61	73	5	82
ST4	94	23	0.62	0.05	0.31	0.005	0.03	7.65	117	7	590
ST5	-	-	-	-	-	-	-	-	-	-	-

5/13/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	77	44	1.41	0.04	1.25	0.01	0.10	7.89	114	22	2600
LBC	151	36	0.56	0.12	0.35	0.005	0.05	7.81	147	1	33
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	357	47	3.12	0.09	0.67	0.005	0.05	7.74	174	0	10
ND3	516	42	3.81	0.005	0.43	0.005	0.02	7.88	178	1	17
NT1	141	40	1.73	0.02	0.43	0.005	0.01	7.87	125	1	1500
NT2	78	26	1.07	0.005	0.74	0.005	0.03	7.93	115	13	82
NT3	116	22	1.98	0.02	0.41	0.005	0.03	8.09	119	11	37
ST1	90	21	0.83	0.03	0.34	0.005	0.02	7.86	97	7	37
ST2	82	30	1.24	0.01	0.36	0.005	0.02	7.59	70	3	33
ST4	68	19	0.46	0.02	0.39	0.005	0.03	7.66	115	5	140
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	110	19	0.85	0.02	0.38	0.005	0.03	8.03	105	1	120
CH	50	38	0.13	0.07	0.69	0.005	0.06	8.86	125	10	17

6/4/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	62	49	0.58	0.005	0.96	0.005	0.07	8.01	132	17	330
LBC	134	40	0.84	0.09	0.43	0.005	0.04	7.79	159	3	860
ND1	107	30	1.11	0.29	0.57	0.005	0.04	7.56	230	1	400
ND2	227	44	3.43	0.10	1.05	0.005	0.01	7.77	153	1	17
ND3	482	50	4.94	0.06	0.62	0.02	0.03	7.80	190	1	16
NT1	74	29	1.41	0.03	0.86	0.005	0.02	7.86	106	4	140
NT2	28	17	0.86	0.02	0.71	0.005	0.03	7.82	125	13	170
NT3	96	22	2.12	0.02	0.57	0.02	0.03	7.86	121	5	200
ST1	51	16	1.09	0.03	0.85	0.005	0.05	7.73	102	20	240
ST2	60	25	2.31	0.01	0.62	0.02	0.03	7.56	76	9	170
ST4	46	16	0.58	0.06	0.75	0.005	0.06	7.51	125	19	3200
ST5	-	-	-	-	-	-	-	-	-	-	-

7/15/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	45	55	0.57	0.02	0.71	0.005	0.05	8.17	127	13	890
LBC	136	40	0.79	0.10	0.32	0.01	0.06	7.86	163	4	1400
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	219	48	2.9	0.08	0.88	0.005	0.005	7.94	160	4	83
ND3	163	22	1.24	0.04	0.61	0.06	0.08	7.85	177	2	870
NT1	94	37	1.98	0.06	0.80	0.005	0.03	8.05	144	10	1500
NT2	54	26	1.11	0.03	1.71	0.005	0.10	7.76	127	65	2100
NT3	75	24	2.28	0.03	0.53	0.03	0.05	8.02	128	9	610
ST1	58	17	1.16	0.04	0.55	0.02	0.03	7.81	106	7	900
ST2	79	24	2.75	0.04	0.93	0.04	0.06	7.75	84	28	140
ST4	56	12	0.15	0.04	0.84	0.005	0.06	7.58	154	18	50
ST5	-	-	-	-	-	-	-	-	-	-	-
ST6	105	17	1.15	0.04	0.48	0.01	0.04	7.98	123	8	150
CH	26	32	0.19	0.01	0.64	0.005	0.03	8.69	119	10	67

8/12/03	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L	TSS mg/L	Fecals #/100 ml
BC	38	43	0.54	0.02	0.77	0.02	0.07	8.13	121	12	460
LBC	119	34	0.64	0.03	0.55	0.03	0.07	7.64	148	8	5800
ND1	-	-	-	-	-	-	-	-	-	-	-
ND2	191	39	2.49	0.07	1.10	0.005	0.01	7.96	152	1	2200
ND3	335	56	2.75	0.02	2.53	0.02	0.49	8.31	300	304	-
NT1	96	33	1.41	0.05	0.80	0.005	0.03	7.91	111	12	2400
NT2	51	23	0.99	0.04	0.90	0.005	0.04	8.02	131	18	930
NT3	90	22	2.27	0.02	0.64	0.02	0.03	8.00	127	3	1400
ST1	67	16	1.2	0.03	0.66	0.005	0.03	7.88	109	9	980
ST2	73	23	2.83	0.03	1.05	0.03	0.08	7.75	84	34	450
ST4	53	9	0.15	0.02	0.51	0.005	0.03	7.69	150	11	120
ST5	-	-	-	-	-	-	-	-	-	-	-

Appendix 6.3. Chemical and physical data for 4 sampling sites in Mona Lake: May 2002 through August 2003.

Chemical Data

	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L
5/10/02									
Site 1 Top Avg	46	43	0.04	0.02	0.77	0.01	0.09	9.04	124
Site 1 Bottom 2	44	41	0.03	0.05	0.79	0.005	0.06	8.93	126
Site 2 Top Avg	46	44	0.04	0.005	0.86	0.005	0.06	9.02	126
Site 2 Bottom Avg	46	44	0.04	0.005	0.74	0.005	0.07	9.04	127
Site 3 Top Avg	47	45	0.04	0.005	0.81	0.005	0.08	8.99	128
Site 3 Bottom Avg	47	46	0.04	0.005	0.77	0.005	0.08	9.01	130
Site 4 Top Avg	46	47	0.03	0.04	0.64	0.005	0.08	8.82	127
Site 4 Bottom Avg	45	46	0.03	0.02	0.63	0.005	0.09	8.78	128
6/5/02									
Site 1 Top Avg	34	31	0.03	0.005	0.48	0.005	0.05	8.97	122
Site 1 Bottom Avg	32	27	0.04	0.26	0.72	0.005	0.07	7.94	128
Site 2 Top Avg	34	31	0.02	0.01	0.56	0.005	0.06	8.95	122
Site 2 Bottom Avg	33	30	0.02	0.17	0.62	0.005	0.06	8.28	126
Site 3 Top Avg	34	31	0.02	0.05	0.63	0.005	0.07	8.79	124
Site 3 Bottom Avg	34	32	0.03	0.12	0.64	0.005	0.06	8.31	126
Site 4 Top Avg	34	32	0.02	0.04	0.72	0.005	0.07	8.88	124
Site 4 Bottom Avg	34	31	0.03	0.05	0.79	0.005	0.07	8.84	125
7/9/02									
Site 1 Top Avg	29	26	0.04	0.03	0.35	0.01	0.06	8.53	116
Site 1 Bottom	27	17	0.02	3.01	4.18	0.21	0.29	7.46	142
Site 2 Top	30	27	0.05	0.01	0.22	0.01	0.06	8.70	117
Site 2 Bottom	29	17	0.02	2.56	3.80	0.21	0.38	7.59	144
Site 3 Top	32	28	0.26	0.04	0.54	0.02	0.08	8.85	115
Site 3 Bottom	31	22	0.02	1.52	2.15	0.15	0.18	7.58	133
Site 4 Top	32	29	0.03	0.05	0.56	0.01	0.08	8.98	116
Site 4 Bottom	33	28	0.02	0.32	1.24	0.10	0.20	7.89	115

8/2/02	**Cl mg/L**	**SO_4 mg/L**	**NO_3 mg/L**	**NH_3-N mg/L**	**TKN-N mg/L**	**SRP-P mg/L**	**TP-P mg/L**	**pH**	**Total Alk. mg/L**
Site 1 Top	31	25	0.07	0.06	0.63	0.005	0.08	8.50	113
Site 1 Bottom	32	25	0.08	0.09	0.61	0.005	0.07	8.44	113
Site 2 Top	34	26	0.07	0.005	0.84	0.005	0.09	8.85	109
Site 2 Bottom	35	27	0.08	0.005	0.73	0.005	0.08	8.93	111
Site 3 Top	34	27	0.22	0.005	0.77	0.005	0.09	9.09	107
Site 3 Bottom	36	28	0.09	0.07	0.92	0.005	0.10	8.75	113
Site 3B Top	*37*	*29*	*0.09*	*0.01*	*0.95*	*0.005*	*0.10*	*9.20*	*107*
Site 3B Bot	*34*	*25*	*0.15*	*0.01*	*1.3*	*0.01*	*0.10*	*8.80*	*95*
LBC	*33*	*19*	*0.49*	*0.09*	*1.3*	*0.04*	*0.10*	*7.21*	*71*

8/6/02

Site 1 Top	31	36	0.08	0.02	0.13	0.01	0.08	9.02	113
Site 1 Bottom	35	20	0.08	0.43	2.56	0.22	0.42	7.36	151
Site 2 Top	40	33	0.07	0.02	0.18	0.04	0.08	8.92	109
Site 2 Bottom	44	67	0.07	0.47	2.04	0.22	0.40	7.45	145
Site 3 Top	40	31	0.08	0.02	0.29	0.01	0.09	8.89	107
Site 3 Bottom	37	19	0.07	0.41	3.02	0.22	0.38	7.37	147
Site 4 Top	38	30	0.11	0.10	0.67	0.02	0.10	8.62	107
Site 4 Bottom	39	33	0.08	0.41	0.69	0.03	0.23	7.88	111

9/11/02

Site 1 Top	36	27	0.03	0.13	0.37	0.005	0.04	8.21	111
Site 1 Bottom	30	22	0.25	1.06	1.20	0.07	0.15	7.45	125
Site 2 Top	35	28	0.005	0.18	0.50	0.005	0.07	8.46	109
Site 2 Bottom	33	25	0.39	1.20	1.51	0.13	0.26	7.44	125
Site 3 Top	37	31	0.005	0.10	0.62	0.005	0.06	8.93	105
Site 3 Bottom	39	33	0.23	0.50	0.76	0.03	0.14	7.88	113
Site 4 Top	33	32	0.15	0.18	0.79	0.02	0.11	8.65	105
Site 4 Bottom	33	31	0.28	0.38	0.77	0.01	0.11	7.95	111

10/9/02	Cl mg/L	SO_4 mg/L	NO_3 mg/L	NH_3-N mg/L	TKN-N mg/L	SRP-P mg/L	TP-P mg/L	pH	Total Alk. mg/L
Site 1 Top	31	28	0.09	0.08	0.43	0.005	0.09	8.02	115
Site 1 Bottom	21	25	0.12	0.06	0.20	0.005	0.06	8.09	113
Site 2 Top	36	31	0.04	0.25	0.49	0.005	0.11	8.22	113
Site 2 Bottom	37	31	0.11	0.24	0.56	0.005	0.11	8.12	115
Site 3 Top	40	34	0.005	0.33	0.53	0.005	0.11	8.43	115
Site 3 Bottom	38	33	0.10	0.33	0.48	0.005	0.12	8.37	115
Site 4 Top	39	35	0.005	0.35	0.52	0.005	0.11	8.70	117
Site 4 Bottom	39	36	0.03	0.25	0.53	0.005	0.10	8.60	155
2/17/03									
Site 1 Top	94	44	0.78	0.35	0.54	0.005	0.04	7.95	143
Site 1 Bottom	120	44	0.67	0.54	0.70	0.01	0.05	7.58	143
Site 2 Top	82	45	0.82	0.35	0.82	0.005	0.06	8.06	143
Site 2 Bottom	110	43	0.66	0.50	0.84	0.01	0.04	7.66	143
Site 3 Top	100	43	0.93	0.29	0.71	0.005	0.03	7.86	143
Site 3 Bottom	86	45	0.72	0.37	0.54	0.005	0.03	7.73	141
Site 4 Top	80	42	0.87	0.29	0.43	0.005	0.03	7.83	139
Site 4 Bottom	84	46	0.78	0.37	0.50	0.005	0.03	7.76	141
4/13/03									
Site 1 Top	80	33	0.63	0.16	0.67	0.005	0.04	8.42	127
Site 1 Bottom	86	33	0.58	0.23	0.63	0.005	0.04	8.25	127
Site 2 Top	83	38	0.64	0.10	0.65	0.005	0.03	8.48	126
Site 2 Bottom	88	34	0.56	0.10	0.51	0.005	0.04	8.49	126
Site 3 Top	84	41	0.62	0.07	0.86	0.005	0.04	8.42	127
Site 3 Bottom	81	41	0.62	0.05	0.53	0.005	0.04	8.44	129
Site 4 Top	76	44	0.58	0.05	1.44	0.005	0.05	8.42	131
Site 4 Bottom	92	44	0.60	0.04	0.69	0.005	0.05	8.43	131

5/20/03	**Cl mg/L**	**SO_4 mg/L**	**NO_3 mg/L**	**NH_3-N mg/L**	**TKN-N mg/L**	**SRP-P mg/L**	**TP-P mg/L**	**pH**	**Total Alk. mg/L**
Site 1 Top	82	42	0.02	0.12	0.97	0.005	0.04	9.04	129
Site 1 Bottom	83	37	0.07	0.38	0.51	0.005	0.05	8.00	131
Site 2 Top	45	41	0.02	0.09	1.03	0.005	0.05	9.03	124
Site 2 Bottom	49	38	0.05	0.23	0.78	0.005	0.03	8.42	131
Site 3 Top	66	43	0.06	0.08	0.93	0.005	0.03	8.90	129
Site 3 Bottom	52	43	0.06	0.08	0.98	0.005	0.04	8.85	129
Site 4 Top	46	44	0.10	0.06	1.00	0.005	0.03	8.78	129
Site 4 Bottom	45	44	0.10	0.07	1.20	0.005	0.03	8.82	131

6/17/03

Site 1 Top	46	42	0.02	0.09	1.08	0.005	0.06	8.64	121
Site 1 Bottom	43	37	0.02	0.37	1.69	0.07	0.17	7.68	127
Site 2 Top	46	42	0.03	0.16	1.69	0.005	0.07	8.67	144
Site 2 Bottom	46	40	0.02	0.39	1.72	0.08	0.12	7.78	127
Site 3 Top	47	43	0.03	0.05	1.39	0.005	0.07	8.77	125
Site 3 Bottom	46	40	0.02	0.32	1.48	0.07	0.11	7.84	130
Site 4 Top	46	43	0.03	0.14	1.68	0.005	0.08	8.33	124
Site 4 Bottom	46	43	0.02	0.10	1.56	0.005	0.06	8.13	128

7/22/03

Site 1 Top	73	40	0.03	0.005	0.95	0.005	0.04	9.02	116
Site 1 Bottom	58	35	0.02	0.6	1.67	0.16	0.22	7.66	133
Site 2 Top	63	41	0.005	0.005	1.11	0.005	0.06	9.08	115
Site 2 Bottom	64	37	0.02	0.39	1.4	0.13	0.19	7.7	132
Site 3 Top	68	41	0.005	0.005	1.4	0.005	0.07	9.12	112
Site 3 Bottom	122	39	0.005	0.005	1.28	0.005	0.09	8.09	117
Site 4 Top	63	41	0.005	0.005	1.32	0.005	0.07	9.12	111
Site 4 Bottom	63	38	0.04	0.03	1.23	0.005	0.11	8.2	110

8/19/03	**Cl** **mg/L**	**SO$_4$** **mg/L**	**NO$_3$** **mg/L**	**NH$_3$-N** **mg/L**	**TKN-N** **mg/L**	**SRP-P** **mg/L**	**TP-P** **mg/L**	**pH**	**Total Alk.** **mg/L**
Site 1 Top	47	35	0.005	0.33	1.11	0.005	0.07	9.06	94
Site 1 Bottom	57	31	0.005	0.59	0.98	0.11	0.13	7.60	118
Site 2 Top	70	34	0.005	0.31	0.83	0.005	0.07	9.01	92
Site 2 Bottom	50	27	0.005	0.82	1.52	0.30	0.35	7.54	125
Site 3 Top	60	35	0.005	0.38	1.12	0.005	0.09	9.15	111
Site 3 Bottom	50	31	0.005	0.86	2.16	0.19	0.27	7.78	111
Site 4 Top	52	32	0.005	0.49	1.91	0.005	0.13	9.23	88
Site 4 Bottom	65	36	0.005	0.38	1.07	0.005	0.08	8.89	91

Averages

Site 1 Top	51	35	0.14	0.11	0.65	0.01	0.06	8.65	119
Site 1 Bottom	51	30	0.15	0.59	1.26	0.07	0.14	7.88	129
Site 2 Top	50	35	0.14	0.12	0.75	0.01	0.07	8.73	119
Site 2 Bottom	51	35	0.16	0.54	1.29	0.09	0.16	8.03	129
Site 3 Top	53	36	0.18	0.11	0.82	0.01	0.07	8.78	119
Site 3 Bottom	54	35	0.15	0.36	1.21	0.05	0.13	8.15	126
Site 4 Top	49	38	0.16	0.15	0.97	0.01	0.08	8.70	118
Site 4 Bottom	52	38	0.17	0.20	0.91	0.02	0.10	8.35	123

Site 1	51	33	0.15	0.35	0.96	0.04	0.10	8.26	124
Site 2	50	35	0.15	0.33	1.02	0.05	0.12	8.38	124
Site 3	53	36	0.17	0.23	1.01	0.03	0.10	8.47	122
Site 4	50	38	0.16	0.18	0.94	0.01	0.09	8.52	121

All Sites	51	35	0.16	0.27	0.98	0.03	0.10	8.41	123

Physical Data

	Site 1	Site 2	Site 3	Site 4
Lake Depth - m				
5/10/02	8.3	7.0	6.0	5.0
6/5/02	8.0	5.5	5.0	4.0
7/9/02	7.7	7.0	5.9	4.4
8/2/02	6.5	7.3	6.0	
8/6/02	7.9	7.6	6.0	4.5
9/11/02	8.0	7.2	5.7	4.2
10/9/02	8.2	7.2	5.8	4.2
2/17/03	7.5	6.5	5.0	3.5
4/14/03	7.9	6.5	5.1	3.6
5/20/03	7.7	6.7	5.5	3.9
6/17/03	8.2	7.5	5.7	4.0
7/22/03	8.2	7.3	5.7	4.1
8/19/03	8.2	6.8	5.7	4.0
Min	**6.5**	**5.5**	**5.0**	**3.5**
Max	**8.3**	**7.6**	**6.0**	**5.0**
Avg	**7.9**	**6.9**	**5.6**	**4.1**
Secchi Depth - m				
5/10/02	0.57	0.55	0.51	0.44
6/5/02	0.50	0.48		0.48
7/9/02	0.55	0.57	0.48	0.40
8/2/02	0.45	0.40	0.35	
8/6/02	0.40	0.52	0.47	0.54
9/11/02	1.00	0.75	0.70	0.45
10/9/02	0.95	0.90	0.85	0.75
2/17/03				
4/14/03	1.20	0.25	1.20	1.00
5/20/03	0.77	0.80	0.82	0.80
6/17/03	1.10	0.95	0.85	0.65
7/22/03	0.90	0.80	0.70	0.65
8/19/03	0.65	0.55	0.55	0.45
Min	**0.40**	**0.25**	**0.35**	**0.40**
Max	**1.20**	**0.95**	**1.20**	**1.00**
Avg	**0.75**	**0.63**	**0.68**	**0.60**

Appendix 6.4. Organic analytical results for Little Black Creek, Cress Creek, and Mona Lake.

SEPTEMBER 2002 RESULTS

	EVANSTON AVE MG/KG	SHERMAN & GETTY DOWNSTREAM MG/KG	SHERMAN & GETTY UPSTREAM MG/KG	MONA VIEW WETLAND MG/KG	LBC SUMMIT MG/KG	LBC SEAWAY MG/KG	LBC MOUTH MG/KG
PNA Compounds							
Naphthalene	<0.10	0.2	0.1	0.2	0.1	0.1	0.0
2-Chloronaphthalene	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Acenaphthylene	<0.10	0.1	0.1	0.2	0.1	0.0	0.0
Acenaphthene	0.1	0.2	0.2	0.1	0.1	0.3	0.0
Fluorene	<0.10	0.4	0.3	0.3	0.2	0.3	0.0
Phenanthrene	0.0	5.7	3.8	3.0	3.4	3.4	0.1
Anthracene	<0.10	0.8	0.5	0.5	0.4	0.5	0.0
Fluoranthene	<0.10	12.0	9.5	8.0	6.5	5.3	0.3
Pyrene	0.0	9.6	7.4	6.5	5.0	4.2	0.2
Benz(a)anthracene	<0.10	3.6	2.8	2.3	1.8	1.6	0.2
Chrysene	0.1	7.5	5.4	5.8	4.0	2.7	0.3
Benzo(b)fluoranthene	<0.10	8.5	7.2	7.9	5.0	3.0	0.3
Benzo(k)fluoranthene	<0.10	5.7	3.9	4.2	2.9	1.7	0.2
Benzo(a)pyrene	<0.10	4.6	5.6	3.0	4.4	2.0	0.3
Indeno(1,2,3-cd)pyrene	<0.10	5.9	5.2	5.0	3.0	2.1	0.2
Dibenz(a,h)anthracene	<0.10	0.6	0.5	0.4	0.2	0.3	0.1
Benzo(g,h,i)perylene	<0.10	4.8	4.6	4.2	2.6	1.9	0.3
TOTAL PNA'S (MG/KG)	0.2	63.3	82.5	43.3	56.1	29.3	2.5
PHTHALATES							
Dimethyl phthalate	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diethyl phthalate	0.0	0.02	0.0	0.0	0.20	0.0	0.0
Di-n-butyl phthalate	0.02	1.0	1.2	1.7	1.4	0.27	0.22
Butyl benzyl phthalate	0.01	0.98	0.45	1.9	0.75	0.23	0.02
Bis(2-ethylhexyl)phthalate	0.02	7.9	4.0	29.0	6.3	1.3	0.20
Di-n-octyl phthalate(CCC)	0.0	0.59	0.27	0.58	0.31	0.08	0.0
TOTAL PHTHALATES MG/KG)	0.05	10	5.9	33.2	9.0	1.9	0.44
PCBs							
AROCLOR 1254	0.34	1.9	0.8	8.9	6.3	1.0	0.48

JULY 2003 RESULTS

	Black Creek Basin 9'	Little Black Creek Basin-10'	Mid Basin 19'	CRESS CREEK QUARTERLINE RD	CRESS CREEK TOWNER STREET	CRESS CREEK TOWNER WETLAND	CRESS CREEK SOUTH BRANCH	CRESS CREEK OLD GRAND HAVEN RD	CRESS CREEK HIDDEN CREEK
	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG	MG/KG
PNA Compounds									
Naphthalene	0.005	0.093	0.069	<0.10	<0.10	<0.10	<0.10	0.0	0.007
2-Chloronaphthalene	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.0	0.0
Acenaphthylene	0.018	0.070	0.055	<0.10	<0.10	<0.10	<0.10	0.009	0.006
Acenaphthene	0.015	0.12	0.009	<0.10	<0.10	<0.10	<0.10	0.0	0.004
Fluorene	0.017	0.16	0.062	<0.10	<0.10	<0.10	<0.10	0.0	0.006
Phenanthrene	0.21	2.1	0.73	0.022	<0.10	0.020	0.024	0.043	0.077
Anthracene	0.045	0.40	0.19	0.0035	<0.10	0.003	0.0	0.0	0.088
Fluoranthene	0.54	5.4	1.6	0.040	<0.10	0.046	0.047	0.16	0.16
Pyrene	0.46	4.2	1.6	<0.10	0.007	0.037	0.037	0.12	0.12
Benz(a)anthracene	0.26	1.8	0.59	0.018	0.020	0.012	0.009	0.082	0.079
Chrysene	0.33	3.1	1.1	0.020	0.006	0.027	0.031	0.090	0.21
Benzo(b)fluoranthene	0.26	2.2	0.85	0.014	<0.10	0.017	0.033	0.063	0.064
Benzo(k)fluoranthene	0.25	2.1	0.50	0.012	<0.10	0.013	0.028	0.073	0.066
Benzo(a)pyrene	0.34	2.1	0.72	0.017	<0.10	0.014	0.027	0.069	0.069
Indeno(1,2,3-cd)pyrene	0.22	0.48	0.82	<0.10	<0.10	<0.10	<0.10	0.056	0.0
Dibenz(a,h)anthracene	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.0	0.0
Benzo(g,h,i)perylene	0.17	1.8	0.68	<0.10	<0.10	<0.10	<0.10	0.051	0.051
TOTAL PNA'S (MG/KG)	3.1	26	9.6	0.15	0.03	0.19	0.24	0.82	1.01
PHTHALATES									
Dimethyl phthalate	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.0	0.0
Diethyl phthalate	<0.10	<0.10	<0.10	<0.10	0.0	0.026	0.013	0.014	0.015
Di-n-butyl phthalate	0.087	0.41	1.8	0.013	0.35	0.48	0.31	0.41	0.40
Butyl benzyl phthalate	0.0	0.60	0.48	<0.10	<0.10	<0.10	<0.10	0.0	0.0
Bis(2-ethylhexyl)phthalate	2.7	4.6	2.2	0.17	0.15	0.098	0.13	0.30	0.59
Di-n-octyl phthalate(CCC)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.0	0.0
TOTAL PHTHALATES (MG/KG)	2.8	5.6	4.5	0.18	0.50	0.60	0.45	0.72	1.0
PCBs									
AROCLOR 1254 (MG/KG)	0.70	1.1	3	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PESTICIDES									
4,4'-DDE	0.022	0.006	0.033	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
4,4'-DDD	0.017	0.007	0.088	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
4,4'-DDT	0.003	0.003	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005

Appendix 6.5. Potential Pollution Sources to Little Black Creek, Muskegon County, Michigan. October 28, 2003. Williams and Beck, Inc.

(Contact AWRI for Report).