Onondaga County Department of
WATER
ENVIRONMENT
PROTECTION

# Onondaga Lake

# Ambient Monitoring Program: 2011

**2011 Annual Report**
**Final, February 2013**

Onondaga County, New York
Joanne M. Mahoney, County Executive

# ONONDAGA COUNTY DEPARTMENT OF WATER ENVIRONMENT PROTECTION

## VISION

*To be a respected leader in wastewater treatment, stormwater management, and the protection of our environment using state of-the-art, innovative technologies and sound scientific principles as our guide.*

## MISSION

*To protect and improve the water environment of Onondaga County in a cost-effective manner ensuring the health and sustainability of our community and economy.*

## CORE VALUES

**Excellence**
**Teamwork**
**Honesty**
**Innovation**
**Cost-Effectiveness**
**Safety**

http://www.savetherain.us

**Cover photo by C. Strait**

# ONONDAGA 2011 LAKE AMBIENT MONITORING PROGRAM

# 2011 ANNUAL REPORT

**ONONDAGA COUNTY, NEW YORK**

***Final, February 2013***

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ONONDAGA COUNTY, NEW YORK

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## Key Features of this Report

This report presents the findings of Onondaga County's Ambient Monitoring Program (AMP) for 2011. The County's annual monitoring program is designed to evaluate compliance with water quality standards and trends as improvements to the wastewater collection and treatment infrastructure are completed. Each year, the Onondaga County Department of Water Environment Protection collects extensive water quality and biological data to characterize Onondaga Lake and its watershed. This summary report of 2011 conditions provides a synopsis of the extensive data to the many stakeholders interested in Onondaga Lake.

The 2011 report was prepared and distributed as an electronic document. Key results and supporting tables and graphics are included in the main document, with links to supporting tables, technical reports and graphics in an electronic library. The report and supporting files are available on CD upon request and on the Onondaga County web site www.ongov.net/wep. Throughout the document, the reader will find hyperlinks to additional detailed tables, graphs and related reports. These hyperlinks appear as blue underlined words in the print copy. Simple definitions of many of the technical terms are included. These words and phrases will appear as grey shaded in the print copy with blue underlined words. They are hyperlinks to a glossary list. These words are marked once in each chapter of the report. If the user follows these links in the web browser, simply use the back arrow key in your web browser to return to the section of the report you are reading.

Once in the library of supporting documents, the reader can navigate back to the main report using browser navigation tools such as the back arrow. There are more than 200 supporting tables and graphics in the library of supporting materials. While each hyperlink has been checked, it is possible that some features will not be enabled on every computer's operating system. Feedback on the functionality of the electronic features of the document is welcome. Please contact JeannePowers@ongov.net with comments.

## *Table of Contents- AMP 2011*

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## LIST OF TABLES

## LIST OF FIGURES

# Executive Summary

## Introduction

This Annual Report of Onondaga County's Ambient Monitoring Program (AMP) describes the state of Onondaga Lake in 2011. Conducted annually since 1970, the County's monitoring program provides water resource managers, public officials, state and federal regulators, and the entire community a window into the significant changes evident in Onondaga Lake – both in the lake's water quality conditions and in its biological community.

Changes in the lake ecosystem are the result of multiple factors. Some of these factors reflect human intervention, notably, the significant investment in improved wastewater treatment technology and the ongoing efforts to remediate legacy industrial wastes. Other changes in the Onondaga Lake ecosystem reflect biological factors such as the fluctuating population of the alewife and its cascading effects on the lake's food web. The 2011 Annual Report documents the input of water and materials (bacteria, sediment, nutrients, salts) to Onondaga Lake from the watershed and the Metropolitan Syracuse Wastewater Treatment Plant (Metro). The lake's response to these inputs is a focus of the annual program; the AMP examines water quality conditions, compliance with ambient water quality standards (AWQS), and long-term trends. The AMP also examines the species composition and abundance of fish, phytoplankton, zooplankton, benthic invertebrates, aquatic plants, and dreissenid (zebra and quagga) mussels.

The Executive Summary highlights selected measures of the lake's current water quality and biological conditions, and reports on long-term changes brought about by rehabilitation efforts. Following this brief summary is the main body of the 2011 Annual AMP Report, where the results are discussed in more detail and supporting documentation is provided.

## Report Format

The 2011 AMP annual report is a concise summary of major findings with hyperlinks to a library of related materials, including tables and graphs of historic data, and reports of biological sampling. This paperless format was developed to advance two objectives: first, to reach a broader audience, and second, to continue to find ways to reduce our environmental footprint, through a commitment to green initiatives (for more information on Onondaga County's green initiatives visit http://www.savetherain.us). This format was envisioned as a means to enable Onondaga County leaders and citizens to learn about the condition of Onondaga Lake and its watershed. Additional program information is available on the County web site http://www.ongov.net/wep/we15.html. Annual reports from prior years are posted at http://www.ongov.net/wep/we1510.html.

## *Dramatic Reductions in Ammonia and Phosphorus Loading to Onondaga Lake from Improved Wastewater Treatment*

Major reductions in the loading of ammonia ($NH_3$-N) and phosphorus (P) to Onondaga Lake from Metro have been achieved through implementation of state-of-the-art wastewater treatment technologies. Progressive improvements in treatment have been made since the 1970s. The most recent Metro upgrades were designed to meet specific water quality goals in Onondaga Lake. Total Maximum Daily Load (TMDL) analyses established the loading reductions required to meet these water quality goals.

The Biological Aerated Filter (BAF) system, which came on line in January 2004, provides year-round nitrification of ammonia, a potentially toxic form of nitrogen (N). This treatment resulted in a 98% decrease in the ammonia loading to the lake from Metro since the mid-1990s (Figure EX-1) and reduced Metro's contribution to the total annual load (Metro + tributaries) from 91% to 42% (Figure EX-2). Implementation of BAF treatment also reduced the loading of nitrite ($NO_2$-N), another form of nitrogen that is a potentially toxic to aquatic organisms. Loading of nitrate ($NO_3$-N), yet another form of nitrogen, has increased as a result of the BAF treatment process. However, this form of nitrogen is not a water quality concern in Onondaga Lake. In fact, the increases in nitrate are having beneficial effects on the lake by diminishing the cycling of phosphorus and mercury in the lower waters and bottom sediments.

A physical-chemical High-Rate Flocculated Settling (HRFS) treatment technology, known as Actiflo®, came on line in February 2005 to provide additional phosphorus removal. This treatment resulted in an 85% decrease in total phosphorus (TP) loading since the early 1990s (Figure EX-3) and a 99% reduction since the early 1970s. Metro's contribution to Onondaga Lake's total annual phosphorus load decreased from 61% prior to implementation of Actiflo® (1990-2004) to 20% in 2011 (Figure EX-4).

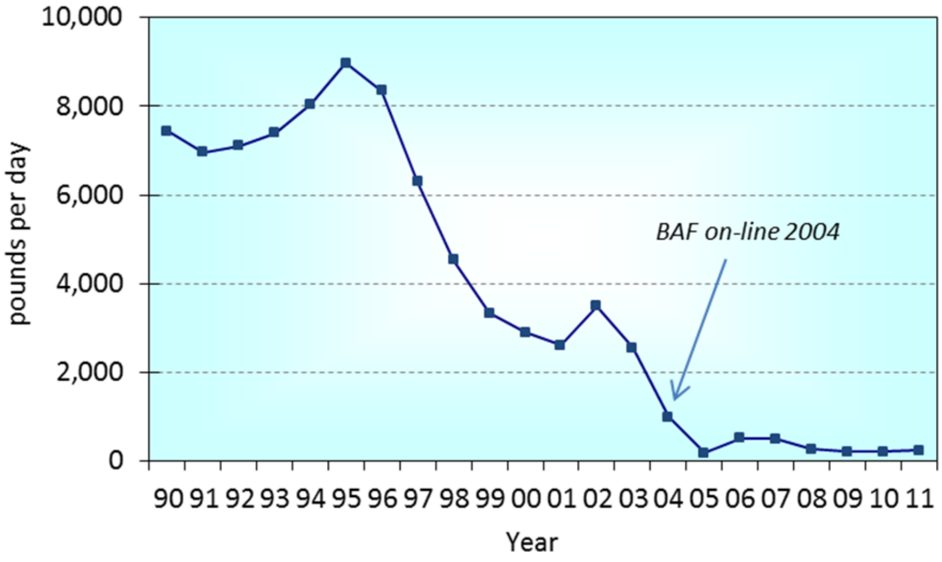


**Figure EX-1.** Annual time plot of the daily average Metro ammonia ($NH_3$-N) loading to Onondaga Lake, 1990-2011.

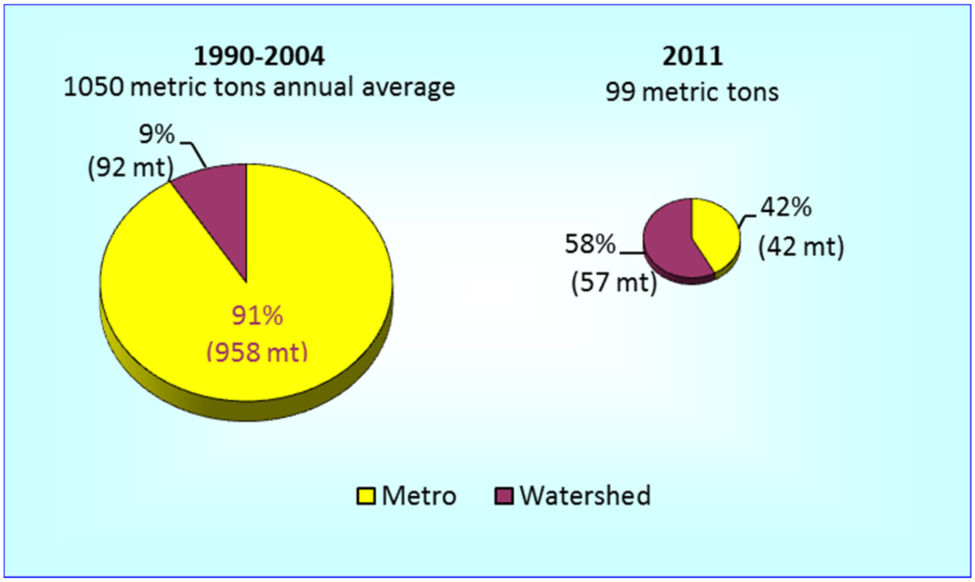


**Figure EX-2.** Contributions of Metro and the watershed to the total annual input of ammonia to Onondaga Lake, average for 1990-2004 compared to 2011.

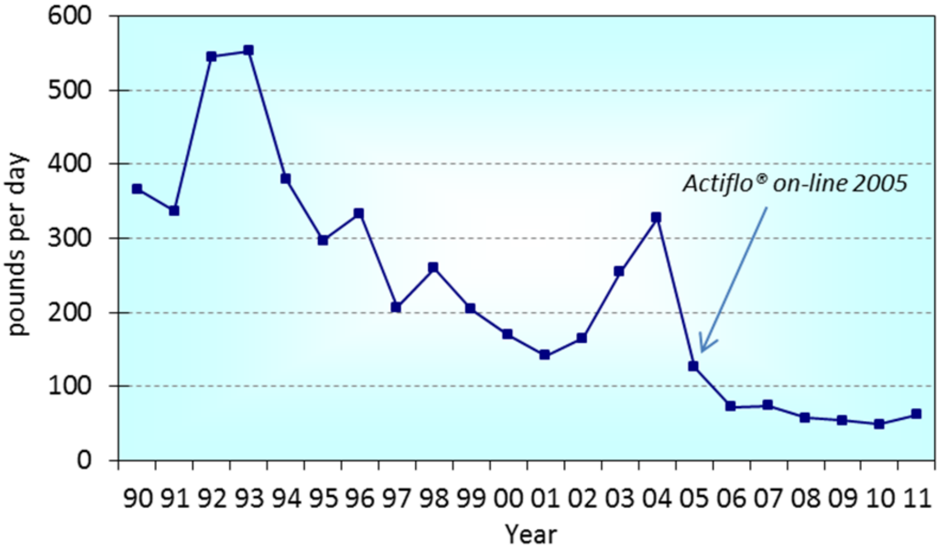


**Figure EX-3.** Annual time plot of the daily average Metro total phosphorus (TP) loading to Onondaga Lake, 1990-2011.

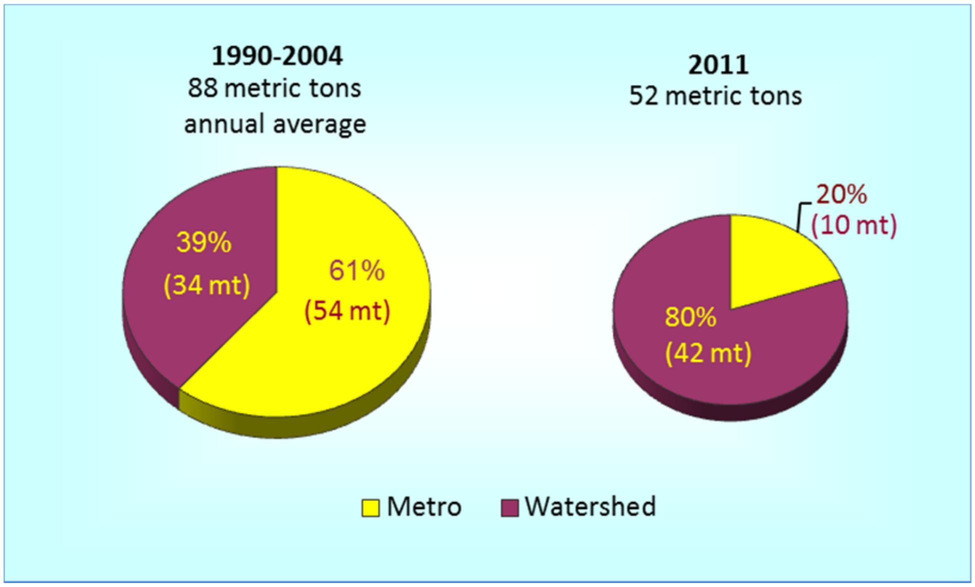


**Figure EX-4.** Contributions of Metro and the watershed to the annual input of total phosphorus to Onondaga Lake, average for 1990-2004 compared to 2011.

## *Remarkable Improvements in Onondaga Lake from Metro Upgrades*

The inputs of ammonia, nitrite, and phosphorus from Metro caused severely degraded conditions in Onondaga Lake during earlier portions of the monitored record. Violations of water quality standards to protect against the toxic effects of ammonia and nitrite occurred frequently in the upper waters of the lake. The high phosphorus loads caused a severe case of cultural eutrophication (major increases in the production of microscopic plants – phytoplankton). Associated features of degraded water quality included: (1) high concentrations of phytoplankton, including nuisance conditions described as blooms; (2) low water clarity, as measured by a Secchi disk (SD); (3) high rates of deposition of oxygen-demanding organic material into the lower layers of the lake; (4) rapid loss of oxygen from the lower layers of the lake; and (5) depletion of oxygen in the upper layers of the lake during the fall mixing period.

In the context of lake rehabilitation examples from North America and beyond, the water quality improvements in Onondaga Lake have been extraordinary. While lakes usually respond to reductions in nutrient inputs, the response is often slow and the degree of improvement less than expected (Cooke et al. 2005). In contrast, water quality improvements in Onondaga Lake were both substantial and rapid following Metro upgrades. Violations of the ammonia and nitrite standards were eliminated by implementation of the BAF treatment process. The reductions in ammonia concentrations in the upper waters of the lake (Figure EX-5) have enabled a more diverse biota. In 2008, New York State Department of Environmental Conservation (NYSDEC) removed Onondaga Lake from the state's 303(d) list for impairment by excessive ammonia concentrations.

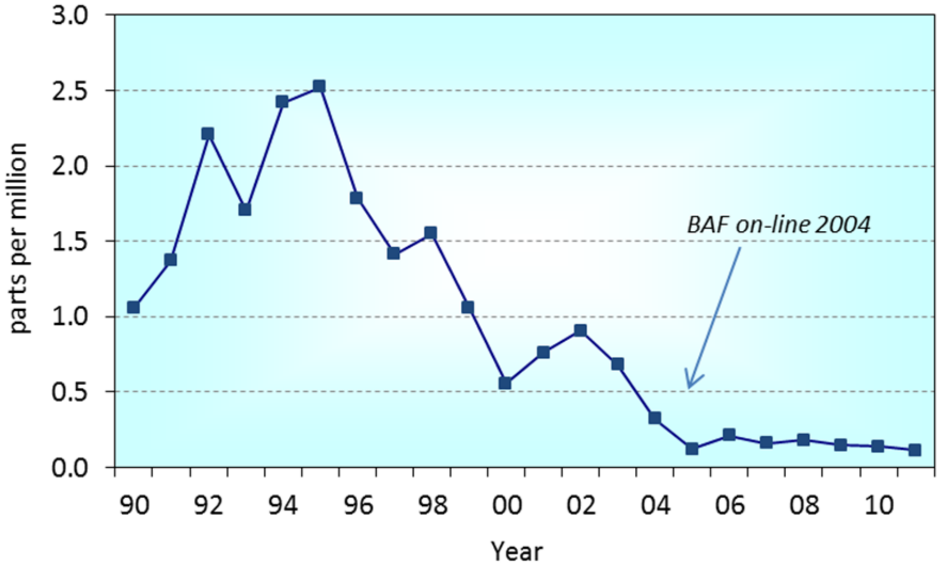


**Figure EX-5.** Annual average ammonia concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990-2011.

Substantial decreases in the summer average (June to September) concentration of total phosphorus in the upper waters of the lake have been achieved from the Actiflo® upgrade (Figure EX-6). The summer average concentration in 2011 matched the guidance value of 20 micrograms per liter (µg/L) established by New York State. Values of less than 20 µg/L were observed in 2008 and 2009. Similar total phosphorus concentrations are observed in several nearby lakes with intermediate levels of phytoplankton production. Loading of soluble reactive phosphorus (SRP), a form of phosphorus immediately available to support algal growth, was also reduced significantly as a result of Actiflo® treatment. Occurrences of phytoplankton blooms, subjectively defined as chlorophyll-a concentrations of 15 µg/L and 30 µg/L for minor (impaired conditions) and major blooms (nuisance conditions), respectively, have decreased dramatically since implementation of Actiflo® (Figure EX-7). No major blooms have occurred since the upgrade, and no minor blooms have occurred during summer since 2008. A minor bloom was observed in May of 2011, prior to the summer averaging period. Water clarity has also improved, though biological (food web) effects also cause noteworthy variations in this water quality metric.

The reductions in phytoplankton from decreases in phosphorus loading have led to less deposition of organic matter (settling phytoplankton) and thereby reduced oxygen demand in the lower layers of the lake. As a result, the oxygen resources of the lower layers have improved, according to a metric termed "volume-days of anoxia" (Figure EX-8), which takes into account both the volume of the lake affected by low dissolved oxygen concentrations and the duration of these conditions. Two different low oxygen thresholds are presented (Figure EX-8), corresponding to hypoxia (less than 2 milligrams per liter (mg/L) and anoxia (less than 0.5 mg/L). Decreasing (improving) trends are shown for both thresholds. The oxygen status of the upper waters through the fall mixing period has also improved substantially, as indicated by the recent higher annual minima in oxygen concentration (Figure EX-9). Oxygen concentrations in the upper waters have remained well above the standard to protect aquatic organisms since Actiflo® was implemented.

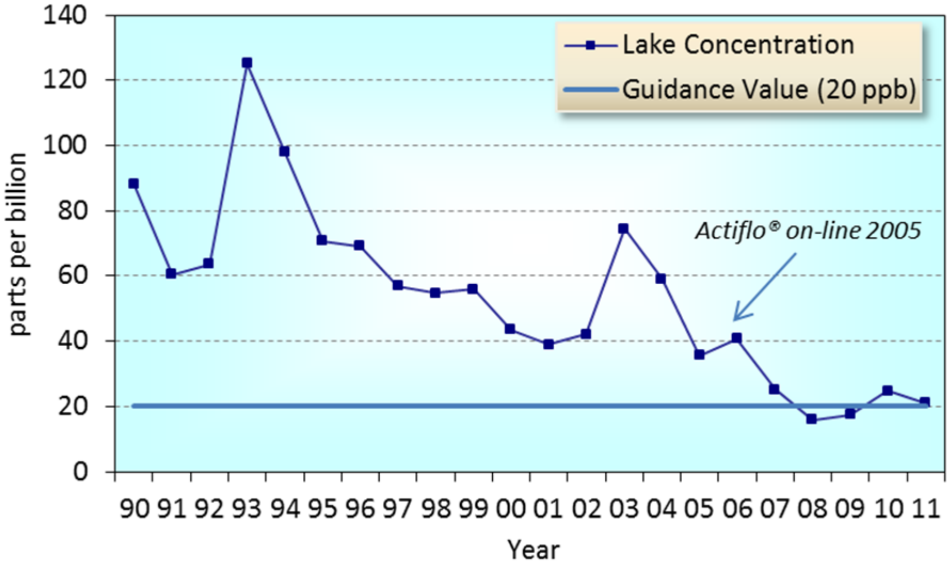
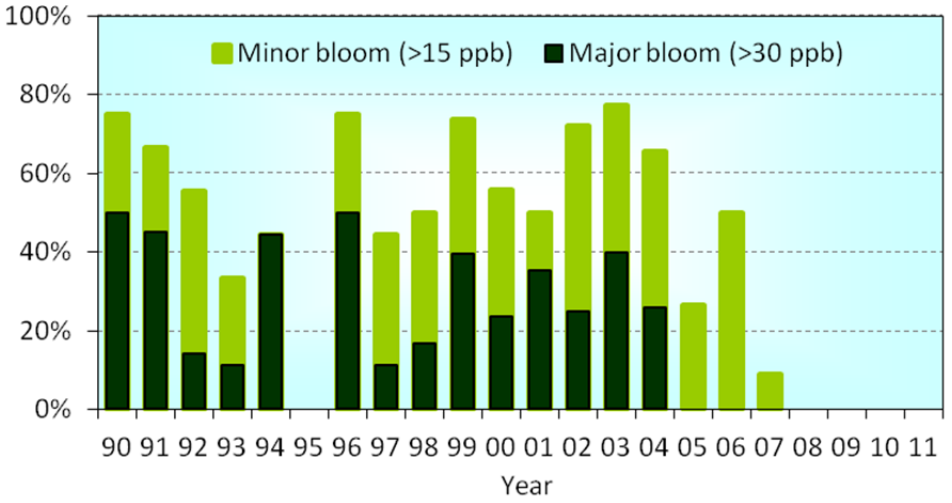


**Figure EX-6.** Summer (June to September) average total phosphorus concentration in the upper waters (0-3 meters) of Onondaga Lake, 1990-2011.



*No blooms were observed during summer in 1995, 2008, 2009, 2010 or 2011*

**Figure EX-7.** Summer (June to September) algal bloom percent occurrences in Onondaga Lake evaluated annually for the 1990 - 2011 period, based on chlorophyll-a measurements.

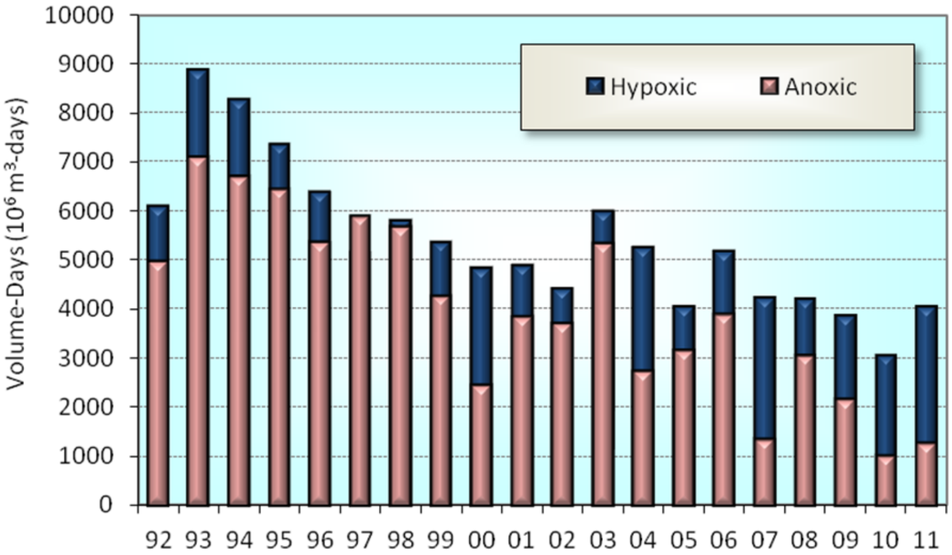


**Figure EX-8.** Volume-days of anoxia (dissolved oxygen less than 0.5 mg/L) and hypoxia (dissolved oxygen less than 2 mg/L), in Onondaga Lake during the summer, 1992-2011.

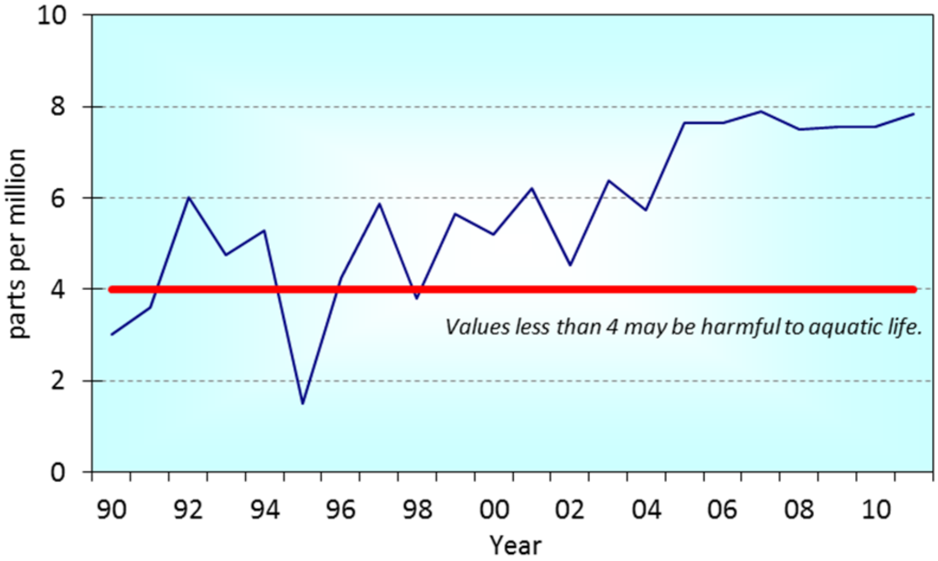


**Figure EX-9.** Minimum dissolved oxygen (DO) concentration in the upper waters (0-3 meters) of Onondaga Lake during fall turnover (October), annually 1990 – 2011.

## *Improved Water Quality Reflected in a Changed Biological Community*

The reduction in phosphorus and algae has resulted in clearer water throughout the lake. Light penetrates deeper into the lake, and supports the growth of macrophytes (rooted aquatic plants and bottom-dwelling algae) in nearshore shallow waters (littoral zone). Macrophytes are an important component of the lake's ecology; they produce food for other organisms, provide habitat for aquatic invertebrates, fish, and wildlife, and help stabilize sediments. The percent of the littoral zone with macrophytes has increased greater than four-fold since 2000 (Figure EX-10). The increasing macrophytes provide spawning and nursery habitat, shelter and food for the fish community. Electrofishing catch rates of gamefish such as largemouth bass have generally increased since 2000, while the catch of smallmouth bass is declining (Figure EX-11).

Several important metrics of the fish community consider the diversity and richness of the adult fish community, both littoral (near-shore) and pelagic (open water). Richness is a count of the number of species within a community, while diversity considers both the number of species present and their relative abundance. In Onondaga Lake, richness has fluctuated annually since the start of the AMP with 25 species captured during spring and fall electrofishing surveys in 2011. Surveys conducted since 1987 have identified a total of 64 fish species in the lake, making the species richness of Onondaga Lake comparable to that of regional waters. The lake is an open system, with easy migration into and from connected waterways through the Seneca River system.

Diversity of the fish community fluctuates in response to the periodic peaks and crashes of two species of clupeid: the alewife (*Alosa pseudoharengus*) and gizzard shad (*Dorosoma cepedianum*). Abundance of these two species of the herring family is highly variable, as Onondaga Lake is near the northern edge of their range, and both species periodically exhibit significant winter mortality. Extremes in recruitment are common; both species periodically produce very strong year classes that dominate the catch for years, as individual fish can live 10 years or longer. In 2011, clupeids dominated the lake fish community, with alewife and gizzard shad combined representing 90% of the fish observed (boated and estimated number of fish combined), and 52% of the netted catch (fish boated and counted); yellow perch and pumpkinseed sunfish were the next dominant species.

Onondaga Lake's aquatic food web continues to include new species, both native and exotic, with increasingly complex pathways of material and energy transfer among the different life stages. This increasing complexity with regard to energy sources and energy flow results in an ecosystem that may be more resilient to environmental stress. The results of the 2011 AMP indicate that this is an ongoing process and that more changes are likely to occur. As lake water quality continues to improve, resulting in more diverse and higher quality habitat conditions, increases in aquatic species diversity, abundance, and interrelatedness can also be expected.

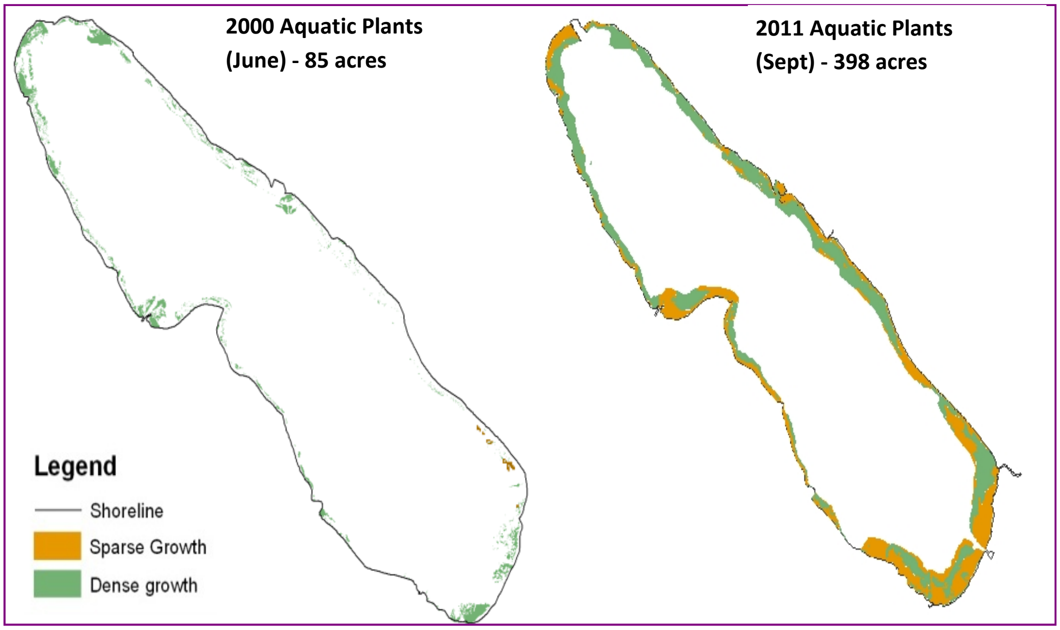


**Figure EX-10**. Aquatic plant coverage, 2000 and 2011.

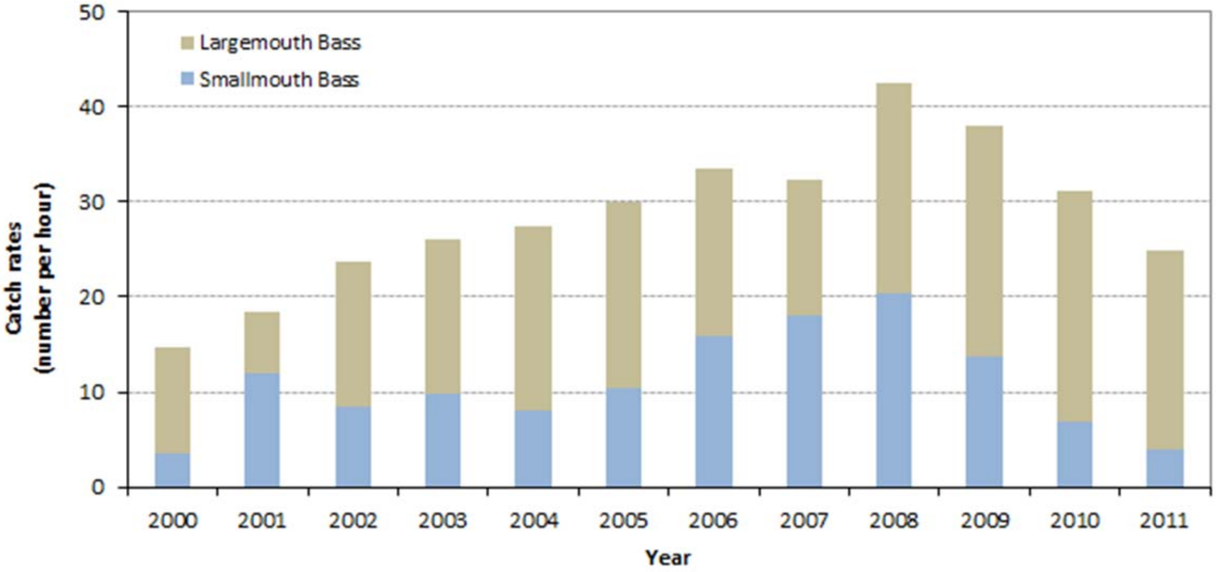


**Figure EX-11.** Bass (smallmouth and largemouth adults) captured by electrofishing in Onondaga Lake, 2000 – 2011.

## Food Web Effects and Impacts on Water Clarity

Because the AMP includes monitoring water quality and biological parameters, it is possible to analyze the relative effects of “bottom-up” (nutrient management) controls and “top-down” (food web) controls on the lake’s trophic state. Clearly, nutrient reductions at Metro have affected the lake’s algal abundance, water clarity, and DO concentrations. Food web effects are also important, however, and now that Onondaga Lake is in the mesotrophic range (i.e., total phosphorus between 10 and 35 ug/L and algal biomass 3 to 5 mg/L), the impact of fluctuations in the abundance of three key species – alewife and dreissenid (zebra, quagga) mussels – has become increasingly apparent.

Alewife and dreissenid mussels have a major impact on food web dynamics in Onondaga Lake. Analysis of the 2011 data has indicated that the 2009 and 2010 alewife year classes dominated the clupeids. This fish is a selective grazer of the larger zooplankton species; heavy predation by the alewife in 2010 and 2011 virtually eliminated large zooplankton in the lake. The average zooplankton size in 2011 declined to the lowest value measured during the AMP (Figure EX-12).

The absence of large zooplankton was reflected in the 2011 algal community. Larger zooplankton are more efficient grazers of phytoplankton than smaller zooplankton. Without the larger zooplankton to graze on phytoplankton, the 2011 standing crop increased and water clarity diminished. The grazing on phytoplankton by dreissenid mussels may have reduced this overall impact (Figure EX-13).

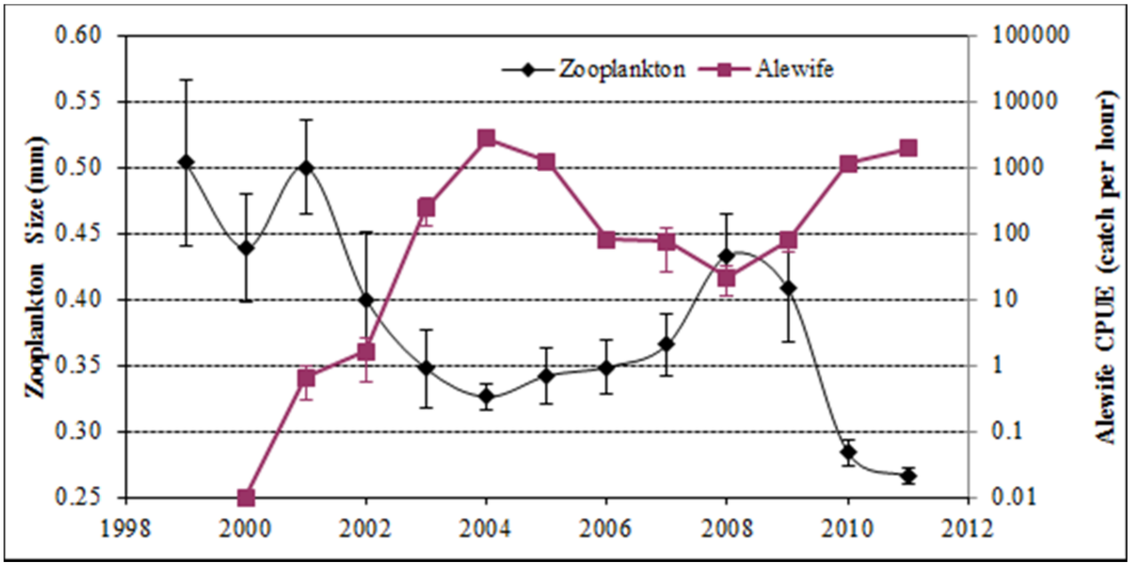


**Figure EX-12**. Average zooplankton size (all taxa combined) and alewife catch rates from electrofishing, 2000-2011, Onondaga Lake. *Note: error bars are standard error of the mean.*

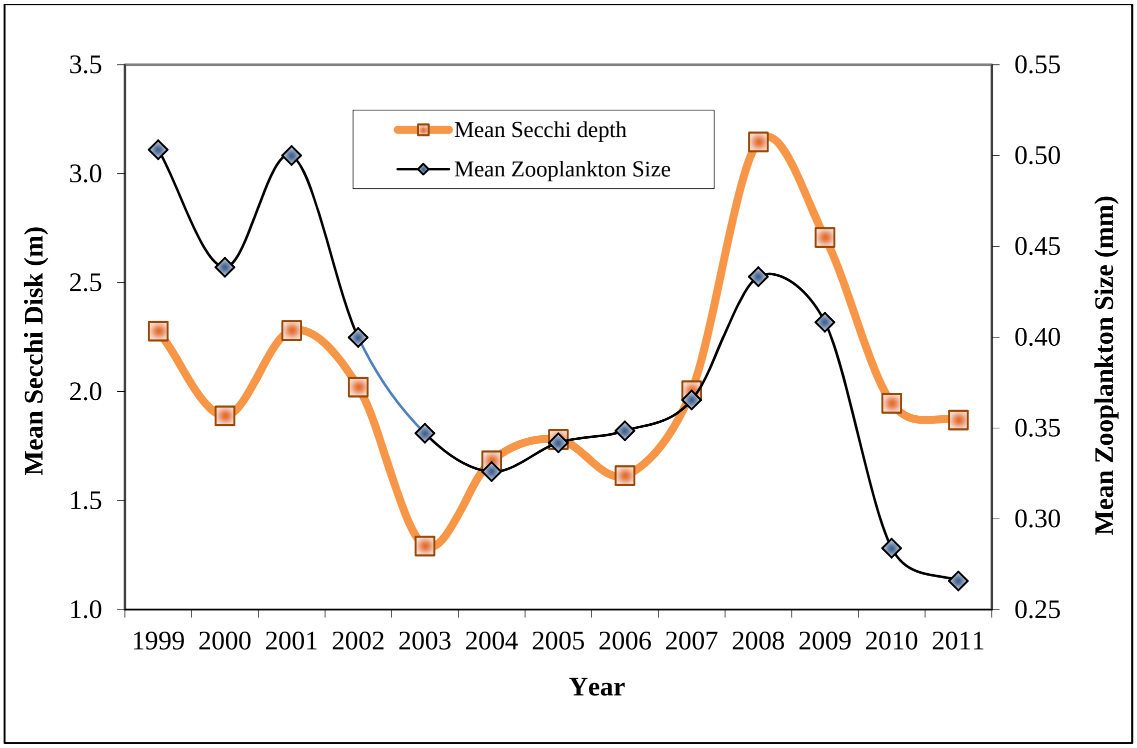


**Figure EX-13.** Mean Secchi disk depth measurements and mean zooplankton size, Onondaga Lake, 1999 – 2011.

## *Suitability of Nearshore Areas for Contact Recreation*

Two parameters are used to assess the suitability of a waterbody for contact recreation: fecal coliform bacteria (FC) and water clarity. The fecal coliform bacteria standard is used by NYSDEC to evaluate water quality and by NYS Department of Health (DOH) to evaluate suitability for swimming at designated beaches. During the April to October interval of 2011, bacteria levels in Class B nearshore areas of Onondaga Lake were less than the standard established for contact recreation. One site, located within the Class C segment at the lake's southeastern shoreline, exceeded the bacteria standard during 29% of the monitored months. While there is no NYSDEC standard for water clarity, DOH has a swimming safety guidance value for designated bathing beaches of 4 ft. The DOH swimming safety guidance value was met in Class B waters throughout the summer recreational period of 2011 at all but one monitoring location. This single location, near the mouth of Bloody Brook, met the swimming safety guidance value 95% of the time. Sediment inputs from the mud boils on upper Onondaga Creek likely contributed to the diminished water clarity in nearshore areas of the Class C segment in the southern portion of the lake. Presently, Onondaga Lake has no designated bathing beaches.

## *Measuring Attainment of Designated Best Uses*

Onondaga County Department of Water Environment Protection, in consultation with NYSDEC and the Onondaga Lake Technical Advisory Committee (OLTAC), has developed a suite of metrics to help organize and report on the extensive AMP data set each year. These metrics relate to the lake's designated "best use" for water contact recreation, fishing, and protection of aquatic life. Table EX-1 documents the extent to which water quality conditions support the lake's designated best uses. Major reductions in loading of ammonia (Figure EX-1) and phosphorus (Figure EX-3) from Metro to Onondaga Lake have resulted in marked improvements in suitability of the lake for water contact recreation, aesthetic appeal, aquatic habitat, and recreational fishing (Table EX-1).

## *Onondaga County Initiatives and AMP Modifications*

In 2011, the County continued work on both "gray" and "green" infrastructure projects to reduce wet weather discharges from combined sewer overflows (CSOs). Gray infrastructure projects include sewer separation, capture of floatable materials, and maximization of system storage capacity. In 1998, there were 70 active CSOs in the collection system. Through 2011 the ACJ projects have closed or minimized 32 of these collection system overflow points by separating combined sewers where feasible, maximizing the capacity of the sewerage system, building the Hiawatha and Midland regional treatment facilities, and installing six floatable control facilities.

Substantial progress was made on a number of gray infrastructure projects in 2011. Construction of the CSO 044 Conveyances Project was 90% complete by the end of 2011, which met an ACJ deadline of substantial completion of CSO modifications by 12/31/11. This project is designed to capture 6 million gallons of CSO volume that was discharged to Onondaga Creek annually. The Harbor Brook Interceptor Sewer Replacement Project will capture a CSO volume of 36 million gallons through upgrades to the existing Harbor Brook Interceptor. By the end of 2011, this project was 95% complete. Work on three CSO storage facilities advanced in 2011. Modifications to the Erie Boulevard Storage System were completed in October 2011, providing an estimated CSO capture of 8 million gallons per year. In 2011, construction began on the Clinton and Harbor Brook Storage Facilities, which will provide 55 and 92 million gallons of annual CSO capture, respectively. Green infrastructure components have been incorporated in many of these gray infrastructure projects, including bioretention basins, tree plantings, green roofs, and rain gardens.

Green infrastructure projects increase infiltration, capture, and reuse of storm runoff before it enters the sewer system. County facilities and other urban areas are implementing "green infrastructure" solutions to help manage urban storm runoff before it enters the CSO system. By the end of 2011, construction was completed on 74 green infrastructure projects. These projects included replacement of traditional pavement with porous pavement, construction of vegetated roofs, installation of rain barrels and infiltration trenches, removal of pavement from some areas, and other techniques to reduce storm water runoff. By preventing storm water runoff from entering the combined sewers, more capacity is available for sanitary sewage flow to reach Metro for treatment. A "Save the Rain" initiative is underway to educate watershed residents about ways to capture and use rainwater. An informational website (http://savetherain.us/) describes current initiatives and incentive programs for watershed residents to reduce impervious areas.

Onondaga County continued working with NYSDEC and ASLF during 2011 to modify the tributary monitoring program to address the requirements of the Fourth Stipulation Amending the Amended Consent Judgment (ACJ), which directs the County to evaluate the effectiveness of the green and gray infrastructure improvements. Enhanced tributary monitoring includes additional storm event sampling on Onondaga Creek and Harbor Brook, following completion of the Clinton and lower Harbor Brook storage facilities. The enhanced tributary monitoring program also includes limited testing for the presence and concentration of priority pollutants, such as heavy metals, pesticides, and other compounds. The additional monitoring was implemented following NYSDEC approval of the work plan in 2011.

Although the 2011 monitoring results indicate that Onondaga Lake tributaries were generally in compliance with ambient water quality standards, contraventions of the standard for fecal coliform bacteria were widespread. The highest concentrations of fecal coliform bacteria were measured near the mouths of Onondaga Creek, Ley Creek, and Harbor Brook. The enhanced tributary monitoring program will support further evaluation of fecal coliform levels, including assessment of long-term trends and potential improvements related to both gray and green infrastructure projects.

**Table EX-1.** Summary of metrics, Onondaga Lake 2011.

| Metrics | Measured By | Target | 2011 Results | Significance |
|---|---|---|---|---|
| ***Improved Suitability for Water Contact Recreation*** | | | | |
| Indicator bacteria | Percent of months in compliance with AWQS[1] for fecal colilform bacteria, April – October (disinfection period). Measured at nearshore sites, Class B segment | 100%<br>(both indicators) | 100%<br>(both indicators) | Class B segments of Onondaga Lake met the designated use for water contact recreation, with the exception of one measurement near the mouth of Bloody Brook<br>Class C segments in the southern end of the lake occasionally fail to meet standards for water contact recreation, particularly following runoff events. |
| Water clarity | Percent of observations with Secchi disk transparency at least 1.2 m (4 ft.) to meet swimming safety guidance[2], June – Sept (recreational period). Measured at nearshore sites, Class B segment | 100% | 99.99% | |
| ***Improved Aesthetic Appeal*** | | | | |
| Water clarity | Summer average Secchi disk transparency at least 1.5 m<br>Measured at South Deep during the summer recreational period (June- Sept.). | Summer average 1.5 m | Summer average 2.0 m | By these metrics, the lake met its designated use as an aesthetic resource |
| Algal blooms | Algal abundance low in summer and the lake is free of nuisance algal blooms[3]. Measured by the magnitude, frequency and duration of elevated chlorophyll-a during the summer recreational period (June- Sept). | No more than 15% of chlorophyll-a measurements above 15 µg/L; no more than 10% of observations above 30 µg/L | 100% of observations less than 15 µg/L | |
| Algal community structure | Low abundance of cyanobacteria (blue-green algae) | Cyanobacteria represent no more than 10% of the algal biomass | Cyanobacteria were less than 1% of the algal biomass | |

**Table EX-1.** Summary of metrics, Onondaga Lake 2011.

| **Metrics** | **Measured By** | **Target** | **2011 Results** | **Significance** |
|---|---|---|---|---|
| ***Improved Aquatic Life Protection*** | | | | |
| Ammonia | In-lake Ammonia concentrations compared to AWQS[1] | 100% of measurements in compliance, all depths and all times | 100% of measurements in compliance, all depths and all times | By these metrics, the lake met its designated use for aquatic life protection (warm water fishery) |
| Nitrite | In-lake Nitrite concentrations[1] (upper waters) | 100% | 100% | |
| Dissolved oxygen | minimum of the daily average in October[1]<br>Instantaneous minimum in October[1] | >5 mg/L<br>>4 mg/L | 7.6 mg/L<br>7.4 mg/L | |
| ***Improving Sustainable Recreational Fishery*** | | | | |
| Habitat quality | Percent of the littoral zone that is covered by macrophytes | 40% | 51% | Littoral zone macrophyte coverage provides high quality habitat for warm water fish community |
| Fish reproduction | Reproduction of target species:<br>• Bass and sunfish<br>• yellow perch<br>• black crappie<br>• rock bass<br>• walleye and northern pike | <br>Occurring<br>Occurring<br>Occurring<br>Occurring<br>Occurring | <br>Occurring<br>Occurring<br>No evidence<br>No evidence<br>No evidence | Fish reproduction for several target species has not been observed; reproduction of sunfish has been limited in the last 3 years. Adult population of these species are stable and, in some cases, increasing. |
| | *The lack of suitable spawning habitat, not water quality, is the limiting factor for the reproduction of some fish species in the lake. Habitat restoration and enhancement are included in the Honeywell lake restoration efforts.* | | | |

**Table EX-1.** Summary of metrics, Onondaga Lake 2011.

| Metrics | Measured By | Target | 2011 Results | Significance |
|---|---|---|---|---|
| Fish community structure | Percent of fish species intolerant or moderately intolerant of pollution | Increasing presence of fish species in the overall community (based on all sampling methods) that are intolerant or moderately intolerant of pollution. | 0% (100% of community is considered pollution tolerant) | The Onondaga Lake fish community includes mostly warmwater species. Most warmwater fish species are classified as relatively tolerant of pollution. |

[1] Ambient water quality standards (AWQS), criteria and guidance regulatory citations are as follows:

- *FC- fecal coliform bacteria* Ambient Water Quality Criteria for Bacteria 1986 - EPA440/5-84-002, (http://water.epa.gov/type/oceb/beaches/upload/2009_04_13_beaches_1986crit.pdf)
- fecal coliform bacteria 6 NYCRR Part 703.4 (http://www.dec.ny.gov/regs/4590.html#16133)
- ammonia and nitrite 6 NYCRR Part 703.5 (http://www.dec.ny.gov/regs/4590.html#16130)
- dissolved oxygen 6 NYCRR Part 703.3 (http://www.dec.ny.gov/regs/4590.html#16132)

[2] Secchi depth water clarity swimming safety guidance of 4 ft. NYSDOH Title 10, Section 7-2.11

[3] Algal blooms subjectively defined as “impaired” at >15 ug/L and “nuisance” at >30 ug/L

Biological metrics were developed in consultation with members of the Onondaga Lake Technical Advisory Committee and other stakeholders participating in the annual meetings and reviews.

# ONONDAGA LAKE AMBIENT MONITORING PROGRAM
# 2011 ANNUAL REPORT

## Section 1. Introduction to the AMP

### 1.1 Regulatory Requirements

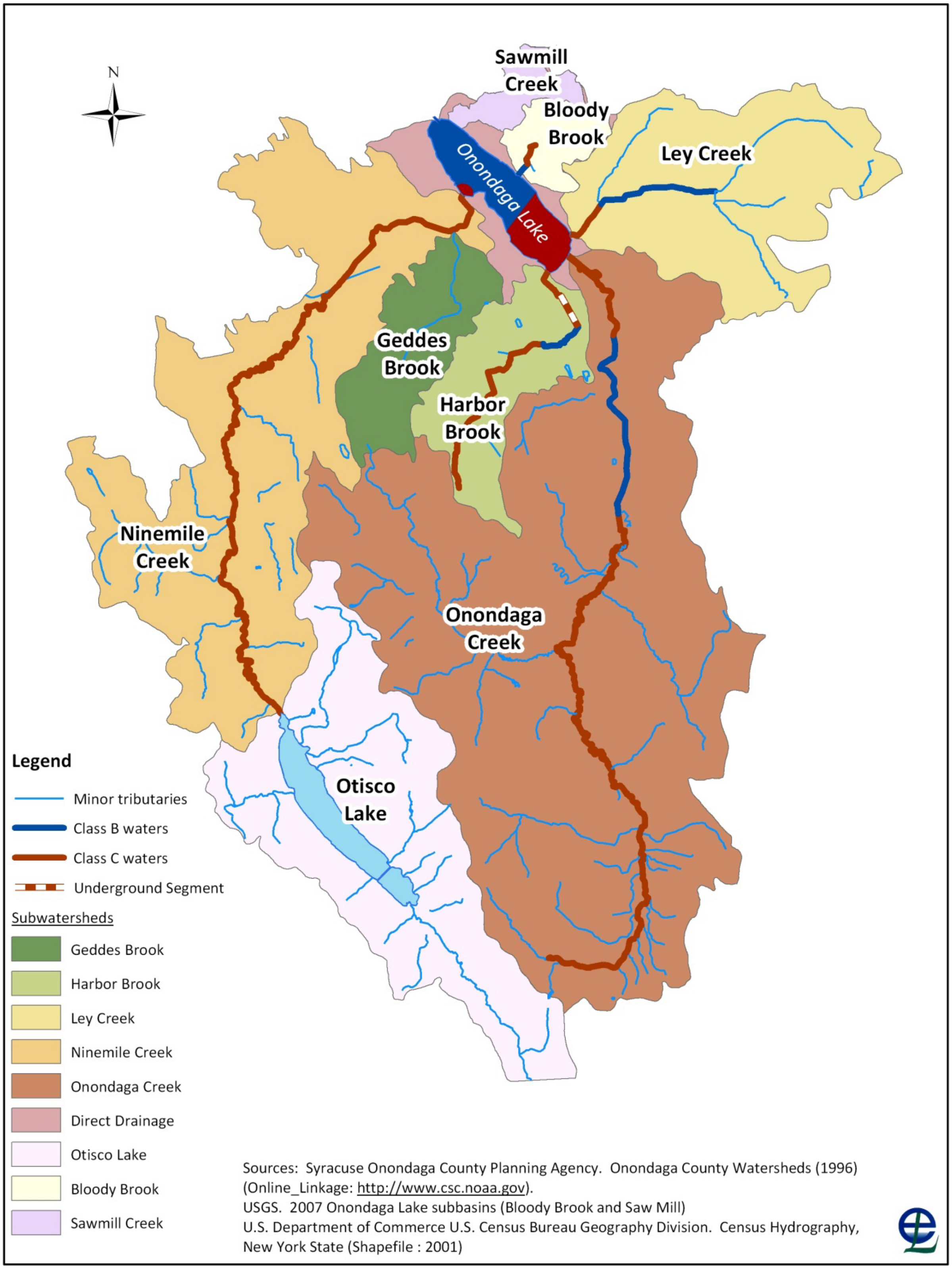
The 2011 Annual Ambient Monitoring Program (AMP) report has been prepared and submitted to the New York State Department of Environmental Conservation (NYSDEC) to comply with a judicial requirement set forth in the 1998 Amended Consent Judgment (ACJ) between Onondaga County, New York State, and the Atlantic States Legal Foundation. The parties have modified the ACJ four times since 1998, most recently by stipulation in November 2009. The ACJ requires a series of improvements to the County's wastewater collection and treatment infrastructure, and an extensive monitoring program (the AMP) to document the improvements achieved by these measures. Onondaga County Department of Water Environment Protection (WEP) is responsible for implementing the AMP and reporting its findings. Links to the ACJ and the Fourth Stipulation are posted on the Onondaga County web site http://www.ongov.net/wep/we15.html.

### 1.2 Classification and Best Use

NYSDEC classifies surface waters, including lakes, rivers, streams, embayments, estuaries and groundwater with respect to their best use. Onondaga Lake and its tributaries are currently classified as Class B and Class C waters (Figure 1-1). The best usages of Class B waters are primary and secondary water contact recreation and fishing (New York Codes, Rules and Regulations (NYCRR) Part 701.7). Primary water contact recreation includes activities that immerse the body in the water, such as swimming; secondary water contact recreation includes activities without full immersion, such as boating. In addition, Class B waters shall be suitable for fish, shellfish, and wildlife propagation and survival (NYCRR Part 701.7). The best usage of Class C waters is fishing. These waters shall also be suitable for fish, shellfish and wildlife propagation and survival. Class C waters shall be suitable for primary and secondary water contact recreation, although other factors may limit the use for these purposes (NYCRR Part 701.8).

### 1.3 AMP Objectives and Design

Onondaga County WEP designed the AMP to meet several specific objectives related to the effectiveness of the required improvements to the wastewater collection and treatment infrastructure. Trained field technicians collect representative samples from a network of permanent sampling locations along the lake tributaries, nearshore and deep stations in Onondaga Lake (Figure 1-2), and along the Three Rivers System (see Figure 7-1, in Section 7), and evaluate water quality conditions and the nature of the biological community. These data are interpreted to determine whether designated uses are, in fact, supported in the waterways.



Sources: Syracuse Onondaga County Planning Agency. Onondaga County Watersheds (1996) (Online_Linkage: http://www.csc.noaa.gov).
USGS. 2007 Onondaga Lake subbasins (Bloody Brook and Saw Mill)
U.S. Department of Commerce U.S. Census Bureau Geography Division. Census Hydrography, New York State (Shapefile : 2001)

**Figure 1-1.** Tributary and lake regulatory classifications (6 NYCRR) and subwatershed boundaries.

In addition to the overall assessment of use attainment, Onondaga County personnel rely on the AMP data for several related objectives:

- to identify and quantify sources of materials (nutrients, sediment, bacteria and chemicals) entering the lake,
- to evaluate stream and lake water quality conditions with respect to compliance with ambient water quality standards (AWQS) and guidance values,
- to understand the interactions between Onondaga Lake and the Seneca River,
- to track the nature of the biological community, and
- to support development of mechanistic models for managing water quality conditions.

A Data Analysis and Interpretation Plan (DAIP) (Table 1-1) guides program design and is a component of the annual workplan, and thus subject to NYSDEC review and approval. In addition to approving the annual workplan and AMP report, NYSDEC participates in technical discussions of the AMP results and their implications.

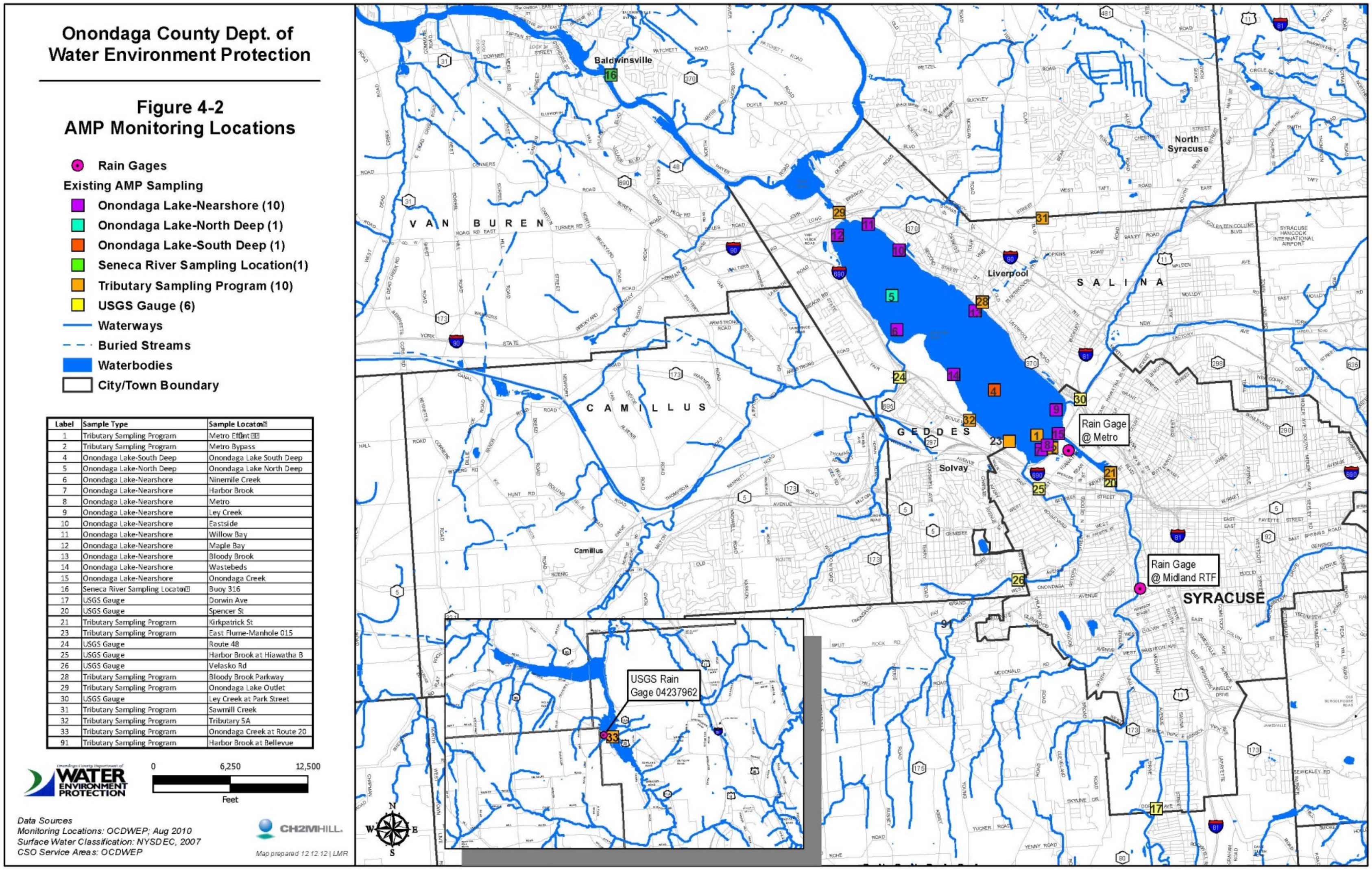
Each year, Onondaga County reviews the laboratory data for quality assurance/quality control criteria prior to uploading the analytical data set to the long-term water quality database. This custom database archives the complete set of Onondaga Lake and tributary monitoring results since 1970. In addition, field activities of both the water quality and biological monitoring programs are audited annually to ensure that they are carried out in accordance with the approved workplan. The Onondaga County Laboratory participates in a program of Environment Canada documenting proficiency of low-level phosphorus and mercury analyses in natural waters.

The ACJ directs Onondaga County to consider results of other investigators in framing a conceptual model of how the lake functions. To this end, the County maintains a bibliography of published materials related to Onondaga Lake. The bibliography serves the AMP team and the community at large by compiling references to investigations by agencies of local government, regulatory agencies, university researchers, and private companies working on various aspects of the Onondaga Lake restoration effort. The findings of these investigations help inform the AMP team in data analysis and interpretation.

## 1.4 Amended Consent Judgment Milestones

The ACJ stipulates a series of specific engineering improvements to the County's wastewater collection and treatment infrastructure. Onondaga County has agreed to undertake a phased program of Metro improvements (Table 1-2).

Other remedial programs abate the impacts of combined sewer overflows (Table 1-3). Combined sewer overflows (CSOs) serve older portions of the City of Syracuse. These utilities carry both sewage and storm water in a single pipe. During heavy rain and snowmelt, the pipes can overflow, and a mixture of stormwater and untreated sewage flows into creeks and ultimately reaches Onondaga Lake.



| Label | Sample Type | Sample Location |
|---|---|---|
| 1 | Tributary Sampling Program | Metro Effluent |
| 2 | Tributary Sampling Program | Metro Bypass |
| 4 | Onondaga Lake-South Deep | Onondaga Lake South Deep |
| 5 | Onondaga Lake-North Deep | Onondaga Lake North Deep |
| 6 | Onondaga Lake-Nearshore | Ninemile Creek |
| 7 | Onondaga Lake-Nearshore | Harbor Brook |
| 8 | Onondaga Lake-Nearshore | Metro |
| 9 | Onondaga Lake-Nearshore | Ley Creek |
| 10 | Onondaga Lake-Nearshore | Eastside |
| 11 | Onondaga Lake-Nearshore | Willow Bay |
| 12 | Onondaga Lake-Nearshore | Maple Bay |
| 13 | Onondaga Lake-Nearshore | Bloody Brook |
| 14 | Onondaga Lake-Nearshore | Wastebeds |
| 15 | Onondaga Lake-Nearshore | Onondaga Creek |
| 16 | Seneca River Sampling Location | Buoy 316 |
| 17 | USGS Gauge | Dorwin Ave |
| 20 | USGS Gauge | Spencer St |
| 21 | Tributary Sampling Program | Kirkpatrick St |
| 23 | Tributary Sampling Program | East Flume-Manhole 015 |
| 24 | USGS Gauge | Route 48 |
| 25 | USGS Gauge | Harbor Brook at Hiawatha B |
| 26 | USGS Gauge | Velasko Rd |
| 28 | Tributary Sampling Program | Bloody Brook Parkway |
| 29 | Tributary Sampling Program | Onondaga Lake Outlet |
| 30 | USGS Gauge | Ley Creek at Park Street |
| 31 | Tributary Sampling Program | Sawmill Creek |
| 32 | Tributary Sampling Program | Tributary 5A |
| 33 | Tributary Sampling Program | Onondaga Creek at Route 20 |
| 91 | Tributary Sampling Program | Harbor Brook at Bellevue |

**Figure 1-2.** Map of routine AMP monitoring locations, Onondaga Lake and tributaries.

**Table 1-1.** Overview of AMP data analysis and interpretation plan.

| Parameters | Sampling Locations | Compliance | TMDL Analysis | Trend Analysis | Trophic Status | Load Analysis | Model Support | Use Attainment | Effectiveness of CSO control measures | Indicator of Water Clarity | Nutrient Cycling | Habitat Conditions | Lake Ecology |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Chemical*** | | | | | | | | | | | | | |
| Alkalinity | L, T | | | ✓ | | | | | | | | | |
| Bacteria | L, T | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ | | | | |
| BOD-5 | L, T, R | | | ✓ | | ✓ | ✓ | | | | | | |
| Carbon | L, T, R | | | ✓ | ✓ | ✓ | ✓ | | | | | | |
| Mercury | L, T | ✓ | | ✓ | | | | | | | | | |
| Metals/Salts | L, T, R | ✓ | | ✓ | | ✓ | ✓ | | | | | | |
| Nitrogen | L, T, R | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ |
| Phosphorus | L, T, R | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | | ✓ | | ✓ |
| Silica-dissolved | L, T | | | | ✓ | | | | | | | | ✓ |
| Solids | L, T, R | ✓ | | ✓ | | | ✓ | | | | | | |
| Sulfides | L | | | | | | ✓ | | | | | | |
| ***Physical*** | | | | | | | | | | | | | |
| Conductivity | L, T, R | ✓ | | ✓ | | | ✓ | ✓ | | | | | |
| Dissolved oxygen | L, T, R | ✓ | | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ |
| LiCor irradiance | L, R | | | ✓ | ✓ | | | ✓ | | ✓ | | | ✓ |
| Salinity | L, T, R | ✓ | | ✓ | | | ✓ | ✓ | | | | | |
| Secchi transparency | L, R | ✓ | | ✓ | ✓ | | ✓ | ✓ | | ✓ | | | ✓ |
| Turbidity | L, T, R | ✓ | | ✓ | | | ✓ | | | ✓ | | | |
| ***Biological*** | | | | | | | | | | | | | |
| Chlorophyll-a/algae | L, T, R | | | ✓ | ✓ | | ✓ | ✓ | | | | | ✓ |
| Zooplankton | L | | | ✓ | | | | | | | | | ✓ |
| Macrophytes | L | | | ✓ | | | ✓ | | | | | ✓ | ✓ |
| Macroinvertebrates | L, T | | | ✓ | | | | | | | | ✓ | ✓ |
| Fish | L | | | ✓ | | | | | | | | ✓ | ✓ |

*Locations:*
*L = Lake; T = Tributaries; R = Seneca River.*

**Table 1-2.** Metro compliance schedule.
*(lb/d = pounds per day; mg/L = milligrams per liter)*

| Parameter | SPDES Limit | Effective Date | Achieved Date |
|---|---|---|---|
| Ammonia | *Interim limit:*<br>8,700 lb/d (7/1-9/30)<br>13,100 lb/d (10/1-6/30) | January 1998 | January 1998 |
| | *Interim limit:*<br>2 mg/L (6/1-10/31)<br>4 mg/L (11/1-5/31) | May 2004 | February 2004 |
| | *Final limit:*<br>1.2 mg/L (6/1-10/31)<br>2.4 mg/L (11/1-5/31) | March 21, 2012 to March 20, 2017 | February 2004 |
| Total Phosphorus | *Interim limit:*<br>400 lbs/day<br>(12-month rolling average) | May 1, 2004 to March 31, 2006 | January 1998 |
| | *Interim limit:*<br>0.12 mg/L<br>(12-month rolling average) | April 1, 2006 to November 5, 2010 | April 2006 |
| | *Interim limit:*<br>0.10 mg/L<br>(12-month rolling average) | November 16, 2010 to June 30, 2012 | November 2010 |
| | *Final limit*:*<br>0.10 mg/L (12-month rolling average pursuant to the TMDL approved by the USEPA on June 29, 2012) | June 30, 2012 | November 2010 |

* The permit for Metro 001 will be modified to reflect the phosphorus waste load allocation (WLA) on a 12 month rolling average basis for Metro outfall 001 set at 21,511 pounds per year and 7,602 pounds per year set for Metro outfall 002 (Bypass) to meet the TMDL allocation endpoint.

A bubble permit limit of 27,212 pounds per year to be applied on a 12 month rolling average basis calculated from the monthly total loads from the two outfalls is proposed in the TMDL as an option for implementation by December 31, 2018.

When these overflows occur, the mixture of stormwater and untreated sewage carries bacteria, floating trash, organic material, nutrients and solid materials through the CSOs to the waterways. Together, the improvements to the wastewater collection and treatment infrastructure are scheduled through 2018.

## 1.5 Projects to Address Legacy Industrial Pollution

Honeywell International is proceeding with a number of projects to address industrial contamination issues, with oversight by the federal Environmental Protection Agency (EPA) and NYSDEC. Projects include intercepting and treating contaminated groundwater, removing contaminated sediments, and restoring shoreline and littoral habitats. In 2011, a restoration project was initiated on Ninemile Creek and a whole-lake nitrate addition pilot test was conducted with the objective of limiting sediment release of methylmercury. In 2012, the focus shifted toward addressing contaminated lake sediments with dredging and capping operations. Detailed descriptions of Honeywell's planned remedial projects, designed to prevent the flux of contamination into the lake and restore aquatic habitat, are on the NYSDEC web site http://www.dec.ny.gov/chemical/48828.html.

**Table 1-3.** CSO compliance schedule.

| Project Phase | Goal | Effective Date |
|---|---|---|
| Stage I | Capture for treatment or eliminate 89.5% of combined sewage* during precipitation, within the meaning of EPA's National CSO Control Policy | Dec 31, 2013 |
| Stage II | Capture for treatment or eliminate 91.4% of combined sewage during precipitation, within the meaning of EPA's National CSO Control Policy | Dec 31, 2015 |
| Stage III | Capture for treatment or eliminate 93% of combined sewage during precipitation within the meaning of EPA's National CSO Control Policy | Dec 31, 2016 |
| Stage IV | Capture for treatment or eliminate 95% of combined sewage during precipitation within the meaning of EPA's National CSO Control Policy | Dec 31, 2018 |

**on a system-wide annual average basis*
(per Fourth Stipulation to ACJ, Nov. 2009)

## 1.6 Use of Metrics to Measure and Report Progress

Onondaga County, in consultation with members of the Onondaga Lake Technical Advisory Committee (OLTAC), has selected a suite of metrics to organize and report on the extensive AMP data collected each year. The metrics focus on key indicators of the lake's water quality and ecologic status and are used to track progress toward compliance and attainment of designated uses (refer to Table EX-1). Metrics selected for Onondaga Lake address both human uses and ecosystem function:

- water contact recreation;
- aesthetics;
- aquatic life protection; and
- sustainable recreational fishery.

In addition to the annual snapshot provided in the table of metrics, a series of more detailed tables are presented to describe progress toward improvement with respect to specific water quality and biological attributes of Onondaga Lake. Library references 2.2.1-2.2.11 provide an overview of the monitoring program design, criteria used to evaluate progress, and a summary of temporal trends.

## Section 2. Onondaga Lake and Watershed

### 2.1 Watershed Size and Hydrology

The Onondaga Lake watershed encompasses approximately 285 square miles (740 $km^2$), almost entirely within Onondaga County, including six natural sub-basins: Onondaga Creek, Ninemile Creek, Ley Creek, Harbor Brook, Bloody Brook and Sawmill Creek (refer to Figure 1-1). Tributary 5A and the East Flume direct runoff and industrial discharges into the lake. Onondaga County's Metro treatment plant discharges to Onondaga Lake. Onondaga Creek is the largest water source to the lake, followed by Ninemile Creek, Metro, Ley Creek, Harbor Brook, minor tributaries and direct runoff (Figure 2-1). Much of the annual volume of water flowing to Onondaga Lake through the Metro treatment plant originates outside of the watershed. Water supply for the City of Syracuse is drawn from Skaneateles Lake, and for suburban towns and villages, Lake Ontario and Otisco Lake. Onondaga Lake discharges into the Seneca River, which flows in a northerly direction and joins the Oneida River to form the Oswego River, ultimately discharging into Lake Ontario.

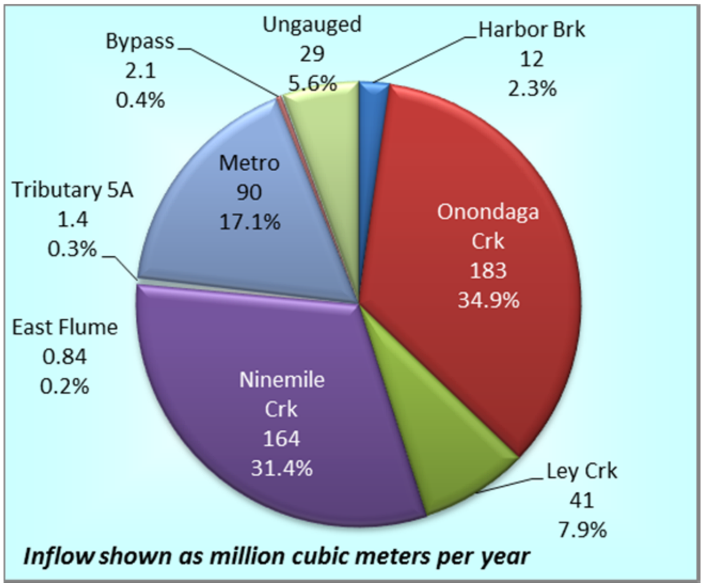
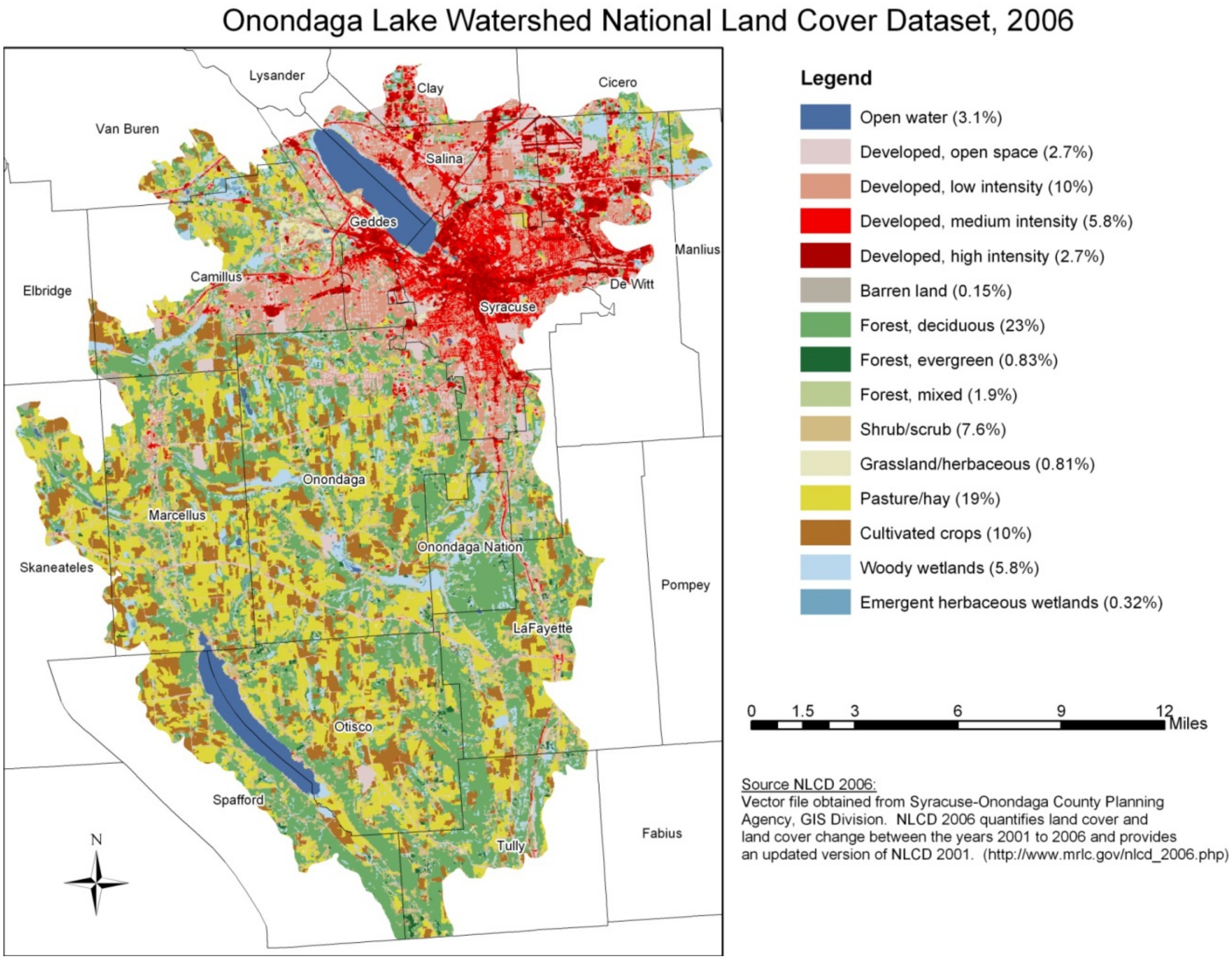


**Figure 2-1.** Annual average inflows (gauged and ungauged) to Onondaga Lake, 2001-2011.

The tributaries convey surface runoff and groundwater seepage from the watershed toward Onondaga Lake. The volume of runoff, and consequently streamflow varies each year depending on the amount of rainfall and snow cover. Overflows from the combined sewer system also vary in response to the intensity and timing of rainfall events, and, to a lesser degree, snowmelt. The Metro effluent volume exhibits less annual variation, although the effects of extreme wet or dry years can be detected due to the portion of the service area served by combined sewers.



Source NLCD 2006:
Vector file obtained from Syracuse-Onondaga County Planning Agency, GIS Division. NLCD 2006 quantifies land cover and land cover change between the years 2001 to 2006 and provides an updated version of NLCD 2001. (http://www.mrlc.gov/nlcd_2006.php)

**Figure 2-2.** Land cover classification map.

## 2.2 Land Use

Compared with other lakes in the Seneca-Oneida-Oswego river basin, the watershed of Onondaga Lake is relatively urbanized, as displayed in Figure 2-2, a map of land cover updated in 2006. The National Land Cover Dataset classified approximately 21% of the watershed as developed (urban/suburban), 33% as forested or scrub/shrub, and 30% as cultivated lands or pasture. The remaining 9% is comprised of wetlands, lakes and barren land. Urban areas of the City of Syracuse, two towns and two villages border the lake.

## 2.3 Morphometry

Onondaga Lake is relatively small, with a surface area of 12 km$^2$. The lake's depth averages 10.9 meters (m), with a maximum of 19.5 m. Its bathymetry is characterized by two minor depressions, referred to as the northern and southern basins (also referred to as North and South Deep in much of the literature), separated by a shallower region near the center of its longitudinal axis (Figure 2-3). The littoral zone, defined as the region of the lake where 1% of the incident light reaches the sediment surface, and consequently supports the growth of rooted plants, is narrow as illustrated by the proximity of the depth contours on the bathymetric map. Under current water clarity conditions, macrophyte growth extends to a water depth of approximately 6 meters; this is a more extensive littoral zone than existed in the late 1990s.

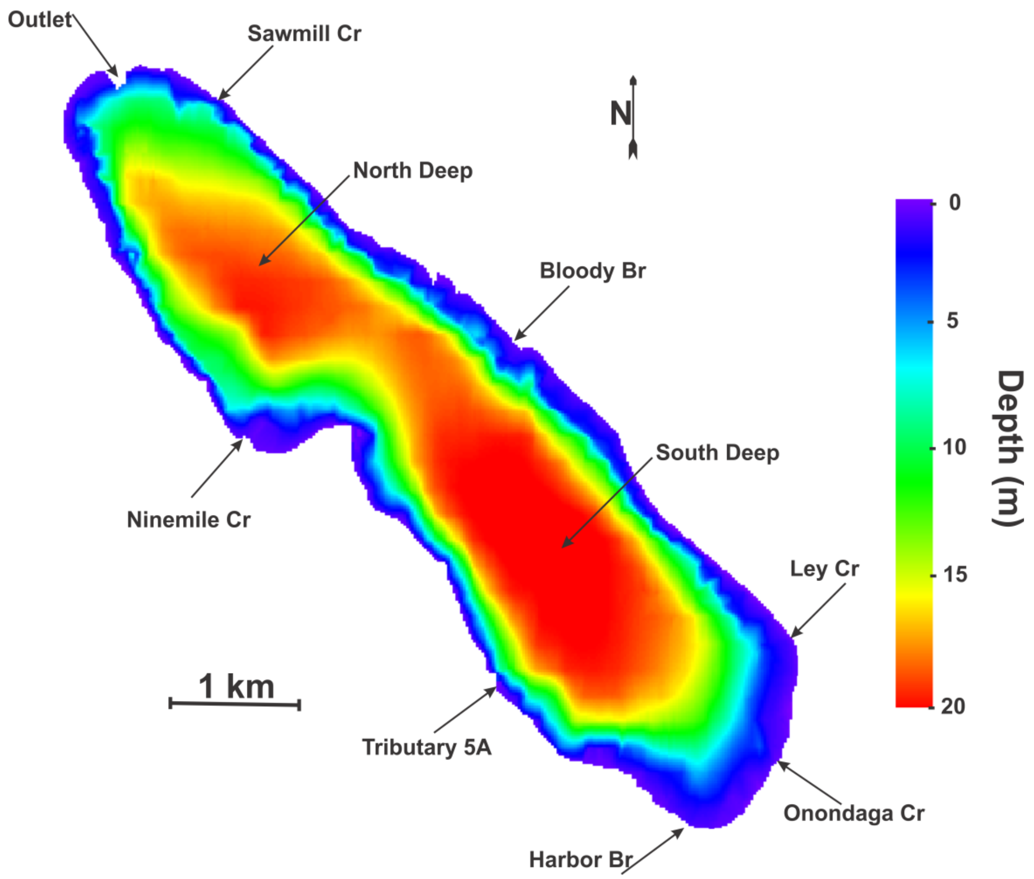


**Figure 2-3.** Bathymetric map of Onondaga Lake, with tributaries and sampling locations (South Deep, North Deep) identified.

The Onondaga Lake shoreline is highly regular with few embayments. Onondaga County owns most of the shoreline, and maintains a popular park and trail system. Syracuse residents and visitors use the parklands for varied recreational activities and cultural entertainment. The lake is increasingly popular for boating; sailboats, motorboats, kayaks and canoes are familiar sights on summer days. Local and regional fishing tournaments attract anglers to the lake and shoreline each year.

Water residence time is defined as the average time water remains in the lake, and is dependent on the ratio of inflow volume to lake volume. A large watershed with a small lake will have a shorter water residence time. Because Onondaga Lake has a relatively small volume, and receives drainage from a large watershed, the water residence time is short. For Onondaga Lake, there are 62 km$^2$ of watershed area for each km$^2$ of lake surface area. Because of the relatively large watershed and abundant rainfall, the inflowing water is sufficient to replace the entire lake volume about four times each year; the average water residence time is about three months on a completely mixed basis. Lakes with smaller contributing watersheds and larger volumes have a longer water residence time. For example, Skaneateles Lake has a watershed area to lake area ratio of 4.3 and a water residence time of 18 years. Oneida Lake provides another example; this large, shallow lake has a watershed area to lake area ratio of 17 and a water residence time of one-half year.

## Section 3. Onondaga County Actions

By signing the ACJ in 1998, Onondaga County agreed to design and construct a series of engineering improvements to the Metro service area. The County has now completed many improvements to the Metro wastewater treatment plant and the wastewater collection system, including the combined sewers (Table 3-1). The improvements to Metro have altered the speciation of nitrogen in the fully-treated effluent, associated with year-round nitrification treatment.

Abating the CSOs is a significant challenge. The County has employed four strategies to reduce wet weather discharges from the combined sewer system to the Metro treatment plant: sewer separation, construction of regional treatment facilities, capturing of floatable materials and maximization of system storage capacity (Figure 3-1), or "gray infrastructure" (Table 3-2). In 1998, there were 70 active CSOs in the collection system. The ACJ projects have closed or minimized 32 of these collection system overflow points through a combination of these approaches.

County facilities and other urban areas have begun to implement "green infrastructure" solutions to help manage urban storm runoff before it enters the CSO system. Green infrastructure encourages infiltration, capture, and reuse of storm runoff before it enters the sewer system. By the end of 2011, construction was completed on 74 green infrastructure projects; these projects included replacement of traditional pavement with porous pavement in parking lots, construction of vegetated roofs, installation of rain barrels and infiltration trenches, removal of pavement from some areas, and other techniques to reduce storm water runoff. By preventing storm water runoff from entering the combined sewers, more capacity is available for sanitary sewage flow to reach Metro for treatment. A "Save the Rain" initiative is underway to educate watershed residents about ways to capture and use rainwater. An informational website describes current initiatives and incentive programs for watershed residents to reduce impervious areas http://savetherain.us/.

**Table 3-1.** Summary (timeline) of significant milestones and pollution abatement actions and lake water quality conditions

| Year | Regulatory/ Management Actions | Metro Actions | CSO Abatement Actions | Water Quality Achievements | Biological Response |
|---|---|---|---|---|---|
| 1998 | Amended Consent Judgment (ACJ) signed | cap on annual ammonia and phosphorus load to the lake, begin selection and design of improvements | Evaluation and implementation of nine minimum control measures | summer TP 55 µg/L in lake's upper waters | County begins design of integrated biological monitoring program |
| 1999 | | completed upgrade of aeration system for secondary clarifiers at Metro | Maltbie Floatables Control Facility (FCF) | | |
| 2000 | | | Franklin FCF<br>Harbor Brook Interim FCF | | Biological AMP begins<br>littoral zone plant coverage in June: 11%. |
| 2001 | | | Teall FCF<br>Hiawatha Regional Treatment Facility (RTF) | | |
| 2002 | | | Erie Blvd Storage System repairs completed<br>Kirkpatrick St. Pump Station Upgrade | | strong alewife year class followed by declines in large zooplankton |
| 2003 | Three Rivers Water Quality Model peer review completed | | progress with sewer separation<br>*(refer to 2009)* | compliance with AWQS for DO in lake upper waters during fall | |

**Table 3-1.** Summary (timeline) of significant milestones and pollution abatement actions and lake water quality conditions

| Year | Regulatory/ Management Actions | Metro Actions | CSO Abatement Actions | Water Quality Achievements | Biological Response |
|---|---|---|---|---|---|
| 2004 | | year-round nitrification of ammonia at Metro using BAF; Stage III SPDES limit for ammonia met. | progress with sewer separations<br>*(refer to 2009)* | compliance with AWQS for ammonia in lake upper waters, and for fecal coliform bacteria in lake Class B segments during Metro disinfection period. | |
| 2005 | | Actiflo® system on-line to meet Metro Stage II SPDES limit for TP (0.12 mg/L) | progress with sewer separations<br>*(refer to 2009)* | | no summer algal blooms<br>littoral zone plant coverage in June: 49%. |
| 2006 | ACJ Amendment motion filed by NYS Attorney General's Office | | progress with sewer separations<br>*(refer to 2009)* | compliance with AWQS for nitrite in the lake's upper waters | |
| 2007 | | Metro meets Stage 2 SPDES limit for TP on schedule.<br>Onondaga Lake Water Quality Model development/calibration review (Phase 2). | progress with sewer separations<br>*(refer to 2009)* | compliance with AWQS for ammonia in the lake, all depths<br>Summer TP 25 µg/L in lake's upper waters | mesotrophic conditions achieved |
| 2008 | | | Midland Ave. Phase I and II conveyance, storage and RTF | Onondaga Lake declared restored for ammonia.<br>summer TP 15 µg/L in lake's upper waters | alewife population decline followed by resurgence of large zooplankton |

**Table 3-1.** Summary (timeline) of significant milestones and pollution abatement actions and lake water quality conditions

| Year | Regulatory/ Management Actions | Metro Actions | CSO Abatement Actions | Water Quality Achievements | Biological Response |
|---|---|---|---|---|---|
| 2009 | ACJ amended by Stipulation #4. | | Clinton St. conveyance<br>Green Infrastructure (GI) program begins<br>13 sewer separation projects completed 1999-2009 | summer TP 17 µg/L in lake's upper waters | strong alewife year class |
| 2010 | | compliance with interim Stage II TP limit of 0.10 mg/L | Harbor Brook Interceptor replacement initiated<br>close to 40 GI projects complete by 2010, converting approx. 16.7 acres of impervious surfaces | summer TP 25 µg/L in lake's upper waters | resurgence of alewife; loss of larger zooplankton |
| 2011 | AMP modifications to evaluate effectiveness of GI projects approved by NYSDEC | compliance with interim TP limit of 0.10 mg/L | 57 GI projects completed in 2011<br>Modifications to Erie Blvd. Storage System completed<br>Harbor Brook Interceptor Sewer 95% complete<br>CSO-044 Conveyance 90% complete | summer TP 20 µg/L in lake's upper waters | continued high densities of alewife and absence of larger zooplankton |

**Table 3-1.** Summary (timeline) of significant milestones and pollution abatement actions and lake water quality conditions

| Year | Regulatory/ Management Actions | Metro Actions | CSO Abatement Actions | Water Quality Achievements | Biological Response |
|---|---|---|---|---|---|
| 2012 | TMDL for phosphorus approved by USEPA on June 29, 2012; established a concentration limit for total phosphorus of 0.10 mg/L for Metro outfall 001 | - | - | - | - |

**Table 3-2.** CSO remedial projects (gray infrastructure) planned.

| Project | Project Type | ACJ Deadline | Estimated Completion Date |
|---|---|---|---|
| Harbor Brook Intercepting Sewer | Sewer replacement | 12/21/2013 | 12/31/2012 |
|  | Wetlands treatment with floatables control | 12/21/2013 | 12/31/2013 |
| Lower Harbor Brook | 4.9 million gallon storage | 12/21/2013 | 12/13/2013 |
| Clinton Storage | 6.5 million gallon storage | 12/21/2013 | 12/31/2013 |
| CSO 045 Separation | Sewer separation | NA | 12/31/2012 |
| CSO 022 | Sewer separation | NA | 12/31/2012 |
| CSO 044 | Conveyance pipeline to Midland RTF | 12/31/2011 | 12/31/2011 |
| CSO 063 | Conveyance pipeline to Lower Harbor Brook Storage | 10/2014 | 10/2014 |

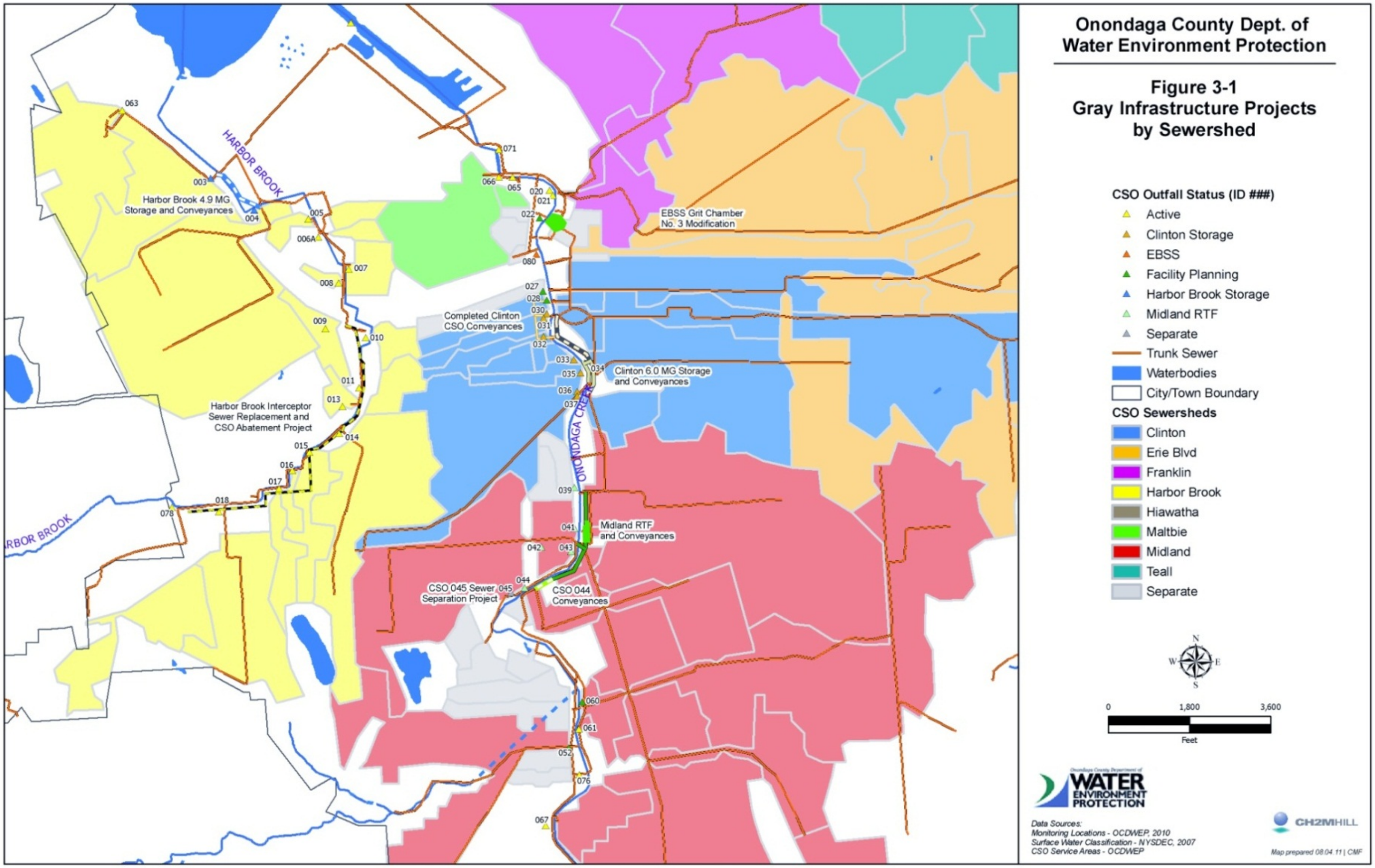


Figure 3-1. Map of CSO areas.

## Section 4. Tributary Water Quality: 2011 Results and Long-Term Trends

### 4.1 Meteorological Drivers and Stream Flow

Meteorological conditions are subject to substantial seasonal variations in this region. These conditions typically vary day-to-day, and noteworthy differences are commonly observed between years. Air temperature influences stream temperatures, which can affect the fate and transport of these inflows in the lake. However, precipitation, as the primary driver of stream flow, is the single most important meteorological attribute affecting material loading from the tributaries. Precipitation was particularly high in April, August and September of 2011, relative to the 30-year historic (1981-2010) average (Figure 4-1). Precipitation in April was nearly three times the long-term average for that month. Total annual precipitation in 2011 was 49.5 inches, exceeding the long-term average by 11.3 inches.

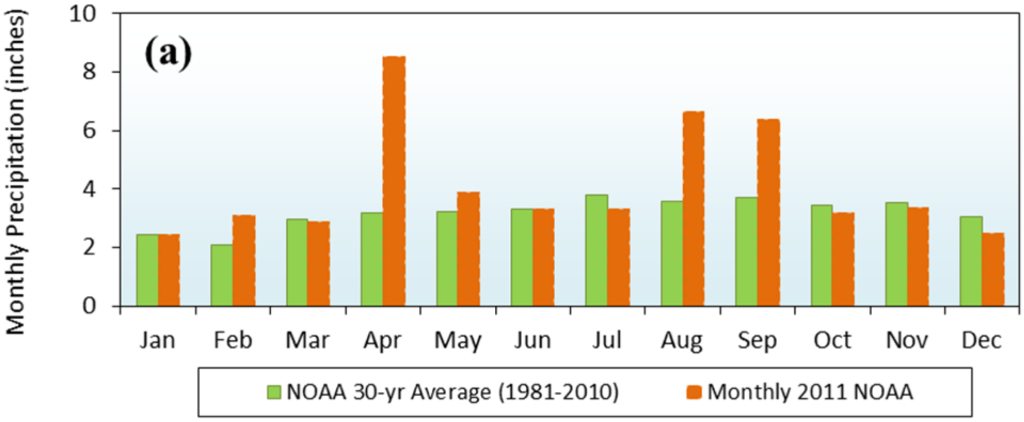


**Figure 4-1.** Monthly precipitation in 2011 compared to the long-term (1981-2010) average.

Stream flow patterns in the major tributaries in 2011 were particularly noteworthy for the very high magnitudes in March and April. The March conditions were driven primarily by snowmelt, while high flow in April reflected the elevated precipitation. Flows over most of the March to mid-May interval were above the 30-year average, and often by a wide margin. Spring flows and coupled material loadings are considered particularly important in influencing early summer water quality in receiving lakes.

Concentrations, and thereby loading rates, of many constituents of water quality interest are known to depend importantly on the magnitude of stream flow. In recognition of this, the AMP targets a broad range of flow conditions to support robust loading rate estimates; specifically, a minimum of five sampling events are targeted during high flow conditions (defined as stream flow at the Onondaga Creek-Spencer St. gauge of at least one standard deviation above the long-term monthly average). This goal was met by a wide margin for the primary tributaries in the 2011 sampling program.

The 2011 sampling program included modifications for two of the smallest tributaries to Onondaga Lake. The monitoring location for Allied East Flume was relocated to a manhole, designated as Allied East Flume-Manhole 015. Tributary 5A was not sampled after 8/23/11 due to a remediation project that pumped flows around this stream.

## 4.2 Compliance with Ambient Water Quality Standards

Several segments of Onondaga Lake's tributary streams are included on the 2010 NYSDEC compendium of impaired waters. NYSDEC places waterbodies on this list when there is evidence that water quality conditions do not meet applicable standards, and/or the water bodies do not support their designated use. Results of Onondaga County's AMP are among the primary data sets used to evaluate compliance with standards and use attainment. The 2011 tributary data indicate that the major tributaries were generally in compliance (Table 4-1) with ambient water quality standards (AWQS) for most parameters addressed. Exceptions to 100% compliance included the parameters (1) pH – Allied East Flume-Manhole 015 (75%), Ley Creek (98%), Tributary 5A (95%), (2) nitrite ($NO_2$) – Allied East Flume-Manhole 015 (0%; no days in compliance), (3) dissolved oxygen (≥ 4 mg/L) – Harbor Brook at Hiawatha (98%), Ley Creek (98%), Sawmill (90%), (4) cyanide – Allied East Flume-Manhole 015 (50%), Ley Creek (50%), and (5) ammonia ($NH_3$-N) – Allied East Flume-Manhole 015 (80%). In addition, total mercury was measured at detectable levels – ranging from 0.024 to 0.11 µg/L – in each sample from the East Flume-Manhole 015 in 2011.

The primary exception in meeting AWQS was fecal coliform bacteria (FC). The only tributary with 100% compliance of the related standard was Tributary 5A (Table 4-1). Compliance with the AWQS for fecal coliform bacteria is specified by NYSDEC as the geometric mean of a minimum of five observations per month being less than or equal to 200 colony forming units (cfu) per 100 milliliters (ml). Onondaga County increased the frequency of bacterial sampling (starting in April 2010) at each tributary sampling location to support these assessments of compliance. The abundance of fecal coliform bacteria in the tributaries during wet weather is affected by stormwater runoff and functioning of the combined sewer system. CSO remedial measures and improved stormwater management measures are underway. Among the objectives of the AMP is the tracking of changes in the input of bacteria to Onondaga Lake during wet weather (Table EX-1). WEP also tracks bacterial abundance during non-storm periods; these observations provide a means of identifying potential illicit connections of sanitary waste to the stormwater collection system, or portions of the sewerage infrastructure in need of repair.

Time series of fecal coliform bacteria concentrations in Onondaga Lake tributaries during 2011 (Figure 4-2 a-d) depict wide temporal variations (note log scale) that were generally coupled to variations in rainfall (Figure 4-2 f) and runoff (Figure 4-2 e). For example, runoff events in late February, late April, and early September resulted in major increases in fecal coliform concentrations in Harbor Brook (Figure 4-2 a), Ley Creek (Figure 4-2 b), Ninemile Creek (Figure 4-2 c), and Onondaga Creek (Figure 4-2 d). While the highest fecal coliform concentrations were generally observed to coincide with increases in rainfall and runoff, there was also evidence of somewhat higher concentrations during the

**Table 4-1.** Summary of tributary compliance (percent of observations in compliance) with ambient water quality standards AWQS, 2011 (underlined parameters are specified in the ACJ).

| Site | Ammonia | Arsenic* | Cadmium* | Chromium* | Copper* | Cyanide* | Dissolved Oxygen | Fecal Coliform | Lead* | Mercury* | Nickel* | Nitrite | pH | Zinc* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Allied East Flume-Manhole 015† | 80% | 100% | 100% | 100% | 100% | NA (50%) | 100% >4; 98% >5 | 75% | 100% | NA | 100% | 0% | 75% | 100% |
| Bloody Brook at Onondaga Lake Parkway | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 63% | 100% | NA | 100% | 100% | 100% | 100% |
| Harbor Brook at Hiawatha | 100% | 100% | 100% | 100% | 100% | 100% | 98% >4; 98% >5 | 18% | 100% | NA | 100% | 100% | 100% | 100% |
| Harbor Brook at Bellevue | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 83% | 100% | NA | 100% | 100% | 100% | 100% |
| Harbor Brook at Velasko | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 90% | 100% | NA | 100% | 100% | 100% | 100% |
| Ley Creek at Park | 100% | 100% | 100% | 100% | 100% | NA (50%) | 98% >4; 98% >5 | 36% | 100% | NA | 100% | 100% | 98% | 100% |
| Ninemile Creek at Lakeland | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 70% | 100% | NA | 100% | 100% | 100% | 100% |
| Onondaga Creek at Dorwin | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 58% | 100% | NA | 100% | 100% | 100% | 100% |
| Onondaga Creek at Kirkpatrick | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 36% | 100% | NA | 100% | 100% | 100% | 100% |
| Onondaga Lake Outlet (12ft) | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 89% >5 | -- | 100% | NA | 100% | 100% | 100% | 100% |
| Onondaga Lake Outlet (2ft) | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 100% | 100% | NA | 100% | 100% | 100% | 100% |
| Sawmill at Onondaga Lake Recreation Area | 100% | 100% | 100% | 100% | 100% | 100% | 90% >4; 90% >5 | 50% | 100% | NA | 100% | 100% | 100% | 100% |
| Tributary 5A at State Fair Blvd. | 100% | 100% | 100% | 100% | 100% | 100% | 100% >4; 100% >5 | 100% | 100% | NA | 100% | 100% | 95% | 100% |

** AWQS for metals apply to the total dissolved fraction; the AMP reports total recoverable metals concentrations; if result < MRL and ≤ AWQS, compliance is assumed; if result > MRL and > AWQS, compliance cannot be assessed (designated as NA; percent samples where total exceeded compliance in parentheses after NA). † Data collected from Allied East Flume – Manhole 015 are compared with the AWQS for streams, although this is a manhole sampling location.*

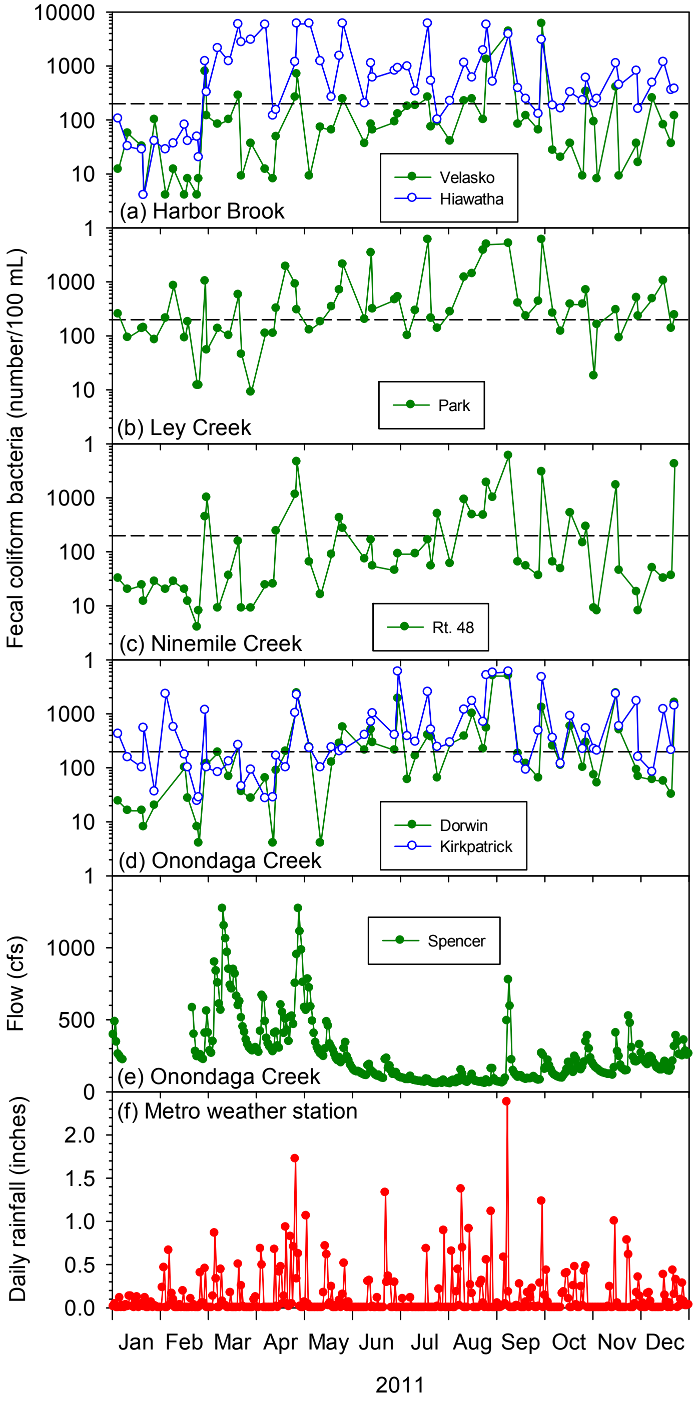


**Figure 4-2.** Time series of fecal coliform bacteria counts for tributaries to Onondaga Lake, 2011. Harbor Brook at Velasko and Hiawatha (a); Ley Creek at Park (b); Ninemile Creek at Rt. 48 (c); Onondaga Creek at Dorwin and Kirkpatrick (d); Onondaga Creek discharge at Spencer (e); and daily rainfall at Metro weather station (f).

May to September period when tributary flow was low. The highest bacteria concentrations were measured at sites near the mouths of Harbor Brook (Hiawatha Blvd.), Onondaga Creek (Kirkpatrick St.), and Ley Creek (Park St.). These streams drain urbanized areas of Syracuse and receive combined sewer overflows (CSO) inputs during significant runoff events. Bacteria levels at nearshore sites in the south end of Onondaga Lake have been distinctly higher following wet weather, demonstrating that these streams are important sources of bacteria to the lake (see related report). Bacteria levels were relatively low in Ninemile Creek, which drains a less urbanized watershed.

Both Harbor Brook and Onondaga Creek were sampled upstream and downstream of urban areas containing CSOs. Marked increases in fecal coliform bacteria were observed at the downstream sites of both Harbor Brook (Hiawatha Blvd.) and Onondaga Creek (Kirkpatrick St.). During wet weather, bacteria counts increased almost 9-fold in the urban corridor of Harbor Brook and nearly 2-fold in the urban reach of Onondaga Creek (Table 4-2). Inputs from CSOs undoubtedly contributed to higher bacteria levels at the downstream sites during runoff events. However, large increases in fecal coliform counts between these sites persisted under dry conditions, indicating the potential for seepage from sewer lines and illicit connections of sanitary waste to the stormwater collection system (Table 4-2).

**Table 4-2.** Fecal coliform bacteria concentrations at selected tributary sampling sites in 2011. Sample counts (N) and geometric means are presented for dry weather and wet weather conditions.

Note: Dry weather samples are defined as those preceded by less than 0.08 inches of rainfall over the 60 hour period extending back from noon on the day of sampling. All other samples are defined as wet weather. Rainfall data was obtained from the Metro weather station in Syracuse.

| | Dry Weather Conditions | | Wet Weather Conditions | |
|---|---|---|---|---|
| Site | N | Geometric Mean (counts/100 mL) | N | Geometric Mean (counts/100 mL) |
| Harbor Brook – Velasko | 28 | 34 | 34 | 100 |
| Harbor Brook – Hiawatha | 28 | 172 | 36 | 890 |
| Ley Creek – Park | 28 | 120 | 36 | 587 |
| Ninemile – Rt. 48 | 27 | 30 | 36 | 197 |
| Onondaga Creek – Dorwin | 28 | 49 | 35 | 323 |
| Onondaga Creek – Kirkpatrick | 28 | 169 | 37 | 601 |

## 4.3 Loads

### *4.3.1 Calculations and Multi-format Results for 2011*

Dr. William Walker developed customized software for WEP staff to calculate annual loads using the program AUTOFLUX, method 5. This software is designed to support load estimates from detailed (e.g., continuous) flow measurements and the results of analyses of less frequent (often biweekly) tributary water quality samples. This software was used to compute all of the loading estimates presented in this report. Annual loading estimates for selected parameters are presented for 2011 (Table 4-3), mostly in units of metric tons (mt). Forms of phosphorus and nitrogen are measured frequently in the Metro effluent. Tributary monitoring was supported by ≥ 25 observations within the year, except for Tributary 5A. Fecal coliform samples were collected more frequently (≥ 40 observations, Table 4-3) to meet AWQS criteria for determining compliance. The sampling to support secondary bypass and headworks bypass loads is driven by the number of intense runoff events that require bypass. In 2011, 750.5 million gallons were discharged through Bypass Outfall 002, and another 41 million gallons were discharged through Outfall 001 as a result of tertiary bypasses.

The Metro total phosphorus (TP) load was the third highest, following the two largest tributaries, Onondaga and Ninemile Creeks (Table 4-3). This represents an improvement since the implementation of the Actiflo® upgrade. The Metro bypass load was estimated to be the fifth highest, following Ley Creek. This load was higher than in 2010 because of the increase in extremely high flow events. The soluble reactive phosphorus (SRP) loads from the four largest tributaries were all greater than the Metro effluent. The bypass SRP load was only exceeded by the two largest tributaries.

The ammonia and total Kjehldahl nitrogen (TKN) loads for Ninemile Creek were the highest, followed by the Metro effluent. The total suspended solids (TSS) load from Onondaga Creek exceeded the next largest source, Ninemile Creek (with similar flow), by nearly a factor of three, and the Metro input by a factor of thirty. The particularly high load of TSS in Onondaga Creek is at least in part attributable to inputs from the mud boils in upstream portions of its watershed. Annual loading of TSS from the tributaries increased 13% from 2010 to 2011, most likely due to unusually high runoff in April, August, and September.Onondaga Creek was also the largest source of chloride (Cl), with Ninemile Creek second and Metro effluent third. The Cl load from Metro is primarily associated with the coagulant used in the Actiflo® treatment – ferric chloride.

The primary source of fecal coliforms was Onondaga Creek. However, the other primary tributaries and Metro made noteworthy contributions (Table 4-3). Individual tributary and Metro loading estimates for 2011 and total annual loads (sum of tributaries and Metro) to Onondaga Lake for the 1992-2011 interval are provided as library references. The 2011 loading estimates for selected constituents are also presented in a percent contribution (according to gauged inputs) format (Table 4-4).

Representation of the inputs as an annual flow-weighted average concentration (total annual loads (mass) ÷ total flow (volume)) for each input is valuable to describe their relative potency. These are presented here for the same selected constituents for 2011 (Table 4-5). Flow-weighted concentrations for total phosphorus were generally similar for the Metro effluent and the primary tributaries, but of course much higher for the Metro bypass (only partially treated). Concentrations in Harbor Brook of SRP and ammonia were the highest except for the bypass. The concentrations of TSS were the highest in Onondaga Creek and the bypass, the lowest in fully treated Metro effluent. Of the tributaries, the highest fecal coliform concentrations were in Harbor Brook. The complete list of constituent flow-weighted average concentrations, along with the relative error of the means, is presented in tabular format.

**Table 4-3.** Annual loading of selected water quality constituents to Onondaga Lake, 2011, Onondaga Lake tributaries with number of samples in parentheses

*Notes: mt = metric tons. N represents the number of water quality samples included in the annual load calculation.*

| **Parameters*** | **TP** | **SRP** | **$NH_3$-N** | **TKN** | **TSS** | **Cl** | **FC**** |
|---|---|---|---|---|---|---|---|
| **Units** | **mt (N)** | **mt (N)** | **mt (N)** | **mt (N)** | **mt (N)** | **mt (N)** | **$10^{10}$ cfu (N)** |
| Metro: | | | | | | | |
| Treated Effluent(1) | 7.2 (364) | 0.29 (234) | 28 (364) | 106 (364) | 448 (364) | 38,820 (61) | 53,849 (209) |
| Bypass(2) | 3.0 (62) | 0.9 (30) | 14 (62) | 26 (62) | 175 (62) | 762 (2) | 120,874 (46) |
| Watershed: | | | | | | | |
| Onondaga Creek | 21 (28) | 1.8 (26) | 11.4 (28) | 116 (28) | 13,442 (28) | 82,225 (28) | 162,952 (65) |
| Ninemile Creek | 15 (27) | 2.7 (27) | 34 (27) | 134 (27) | 5,456 (27) | 45,890 (27) | 79,149 (63) |
| Ley Creek | 3.9 (27) | 0.61 (27) | 10.4 (27) | 37 (27) | 733 (27) | 15,186 (27) | 43,656 (64) |
| Harbor Brook | 1.09 (28) | 0.39 (28) | 0.92 (28) | 8.6 (28) | 272 (28) | 3,907 (28) | 38,249 (64) |
| Tributary 5A | 0.044 (17) | 0.013 (16) | 0.12 (17) | 0.29 (17) | 5 (17) | 229 (17) | 25 (40) |
| Allied East Flume-Manhole 015 | 0.15 (25) | 0.09 (25) | 0.6 (25) | 1.1 (25) | 15 (25) | 596 (25) | 459 (55) |

*Notes:*

*. Parameters are: TP (total phosphorus), soluble reactive P (SRP), $NH_3$-N (ammonia), TKN (total Kjeldahl N), TSS (total suspended solids), Cl (chloride), and F.Coli (Fecal coliforms).

**. FC- fecal coliform bacteria loads have a very high standard error due to the episodic nature of the FC inputs.

1. Tributary loading results are calculated using 2011 observations (N = number of samples for 2011) and processed through AutoFlux Method 5 and are reported here for the sampling locations closest to Onondaga Lake.

2. Metro Effluent Outfall 001 loads for TP, TSS, $NH_3$-N and TKN are calculated using daily observations, SRP is collected 5d/wk, Cl is collected 1d/wk, and F.Coli are collected biweekly as part of the long-term tributary program and daily April through mid-October.

3. Metro Bypass Outfall 002 loads are calculated using periodic grab samples when Outfall 002 is active (high flow events when the capacity of Metro is exceeded).

**Table 4-4.** Percent annual loading contribution by gauged inflow, 2011.

| Parameter | TP | SRP | $NH_3$-N | TKN | TSS | Cl | FC | Water |
|---|---|---|---|---|---|---|---|---|
| Metro: | | | | | | | | |
| Treated Effluent | 14% | 4.3% | 28% | 25% | 2.2% | 21% | 10.7% | 16% |
| Bypass | 5.9% | 13.3% | 14% | 6.0% | 0.85% | 0.41% | 24% | 0.49% |
| Watershed: | | | | | | | | |
| Onondaga Creek | 41% | 27% | 11% | 27% | 65% | 44% | 33% | 39% |
| Ninemile Creek | 29% | 40% | 34% | 31% | 27% | 24% | 16% | 34% |
| Ley Creek | 7.6% | 9.1% | 11% | 8.7% | 3.6% | 8.1% | 8.7% | 8.5% |
| Harbor Brook | 2.1% | 5.7% | 0.93% | 2.0% | 1.32% | 2.1% | 7.7% | 2.5% |
| Tributary 5A | 0.09% | 0.19% | 0.12% | 0.07% | 0.03% | 0.21% | 0.005% | 0.09% |
| Allied East Flume-Manhole 015 | 0.30% | 1.33% | 0.6% | 0.27% | 0.074% | 0.32% | 0.092% | 0.17% |

### *4.3.2 Selected Phosphorus Topics*

Estimates of total phosphorus loads for the tributaries have generally been greater in higher runoff years (Figure 4-3). Variations in rainfall for the 1990-2011 period explained 44% of the differences in total phosphorus loading according to linear least-squares regression (p = 0.001). Accordingly, two- to three-fold differences in total phosphorus loads from the watershed can be expected due to natural variations in rainfall. Variations in runoff need to be considered in evaluating year-to-year dynamics in-lake water quality.

The timing of phosphorus loads within a year is a potentially important factor relative to their potency to support algae growth during the critical summer months, particularly in the context of the rapid flushing rate of the lake (~ 4 times/yr). For example, loads received in the fall to winter interval are mostly flushed through the lake, or particulate forms are deposited, by the following late spring. Late spring and summer loads are expected to be the most important. Monthly total phosphorus loads are presented for the years 2008, 2009, 2010 and 2011 for comparison. There is a recurring seasonality driven by the seasonality of runoff, with the lowest loads generally prevailing in the summer and the highest in spring. Substantial interannual differences have occurred because of the dependency on runoff. In 2011, watershed loading of total phosphorus was relatively high in spring and low during the June-August interval.

Contemporary lake management programs are increasingly considering the processes that diminish the effectiveness of total phosphorus loads to support algae growth. First, only dissolved forms of phosphorus can be utilized by algae. Much of the total phosphorus loading from the primary tributaries and Metro is in the form of particulate phosphorus (PP). Only a fraction of this PP can be converted to dissolved forms that are available to support algae growth. At least two other processes act to diminish

**Table 4-5.** Flow-weighted average concentration of selected constituents in Onondaga Lake tributaries, 2011.

| Parameter* | TP | SRP | $NH_3$-N | TKN | TSS | Cl | FC*** |
|---|---|---|---|---|---|---|---|
| Units | µg/L (N) | µg/L (N) | mg/L (N) | mg/L (N) | mg/L (N) | mg/L (N) | cells/100ml (N) |
| Metro**: | | | | | | | |
| Treated Effluent | 78 (364) | 3.2 (234) | 0.30 (364) | 1.1 (364) | 4.9 (364) | 421 (61) | 584 (209) |
| Bypass | 1070 (62) | 315 (30) | 4.9 (62) | 9 (62) | 61 (62) | 268 (2) | 42,478 (46) |
| Watershed: | | | | | | | |
| Onondaga Creek | 95 (28) | 8 (26) | 0.051 (28) | 0.52 (28) | 60 (28) | 369 (28) | 732 (66) |
| Ninemile Creek | 75 (27) | 14 (27) | 0.17 (27) | 0.68 (27) | 28 (27) | 235 (27) | 405 (63) |
| Ley Creek | 80 (27) | 13 (27) | 0.21 (27) | 0.76 (27) | 15 (27) | 311 (27) | 893 (64) |
| Harbor Brook | 75 (28) | 27 (28) | 0.063 (28) | 0.59 (28) | 19 (28) | 268 (28) | 2,627 (64) |
| Tributary 5A | 90 (17) | 25 (16) | 0.24 (17) | 0.58 (17) | 10 (17) | 462 (17) | 50 (40) |
| Allied East Flume-Manhole 015 | 160 (25) | 93 (25) | 0.6 (25) | 1.2 (25) | 16 (25) | 616 (25) | 474 (55) |

*Notes:*

*. Parameters are: TP (total phosphorus), soluble reactive P (SRP), $NH_3$-N (ammonia), TKN (total Kjeldahl N), TSS (total suspended solids), Cl (chloride), and F.Coli (Fecal coliforms).

**. FC- fecal coliform bacteria concentrations have a very high standard error due to the episodic nature of the FC inputs.

1. Flow weighted concentrations are calculated dividing total annual load estimates from AutoFlux Method 5 (mass) by the total volume of flow at the site (volume).
2. see Table 4-3 for a summary of observations and datasets used in annual loading estimation.

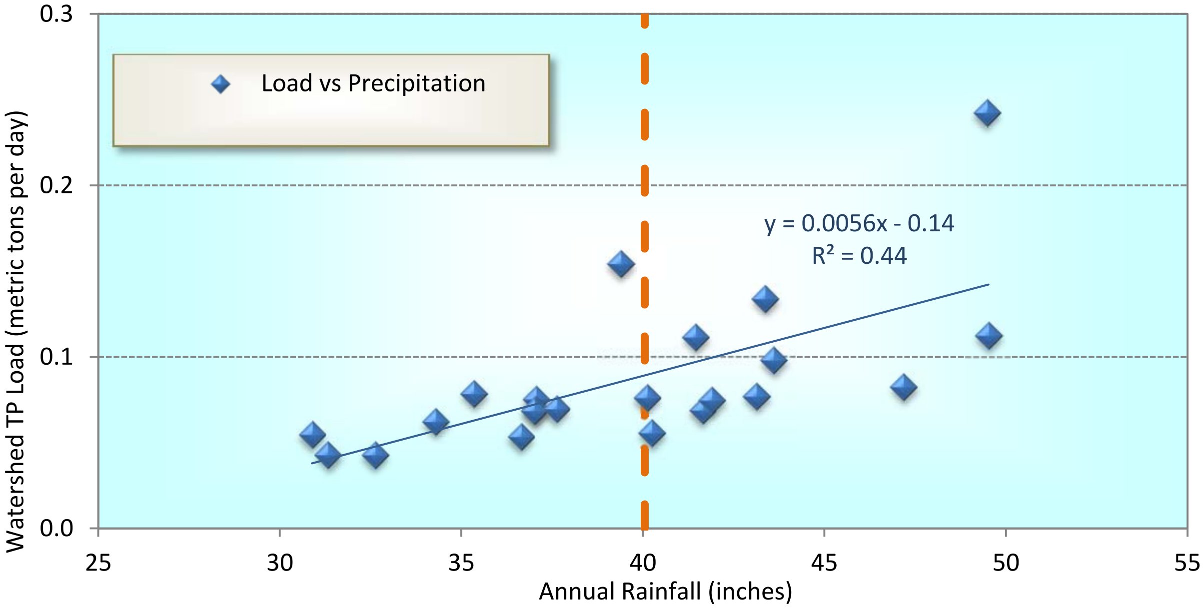


**Figure 4-3.** Evaluation of the dependence of the daily average total phosphorus load from the watershed (non-Metro), annually, on the annual precipitation for the 1990-2011 period. Note: (precipitation data from: http://www.nws.noaa.gov/climate/emacis.php?wfo=bgm)

the effectiveness of external total phosphorus loads, settling of PP before it can be transformed, and the plunging of dense inputs (e.g., those that are colder or more saline than the upper layers of the lake). Experiments conducted with the Metro effluent in 2009 established the limited bioavailability of this phosphorus load (Effler et al. 2012). Only about 30% of the total phosphorus load from Metro is in a dissolved form, while the remaining 70% is in particulate form. Bioavailability assays established that only 1% of the particle bound phosphorus is available to support algae growth. Moreover, the PP from Metro had an unusually high settling rate and a portion plunged below layers where algae grow. These findings indicate that pursuit of further optimization of phosphorus treatment at Metro should focus on the dissolved fraction. Further reductions in PP would not contribute importantly to achievement of water quality goals. In contrast, the bioavailability of PP from the primary tributaries ranged from 22% to 52% (Effler et al. 2002).

Bioavailability considerations make the loading rates of total dissolved phosphorus (TDP) particularly important, as these forms of phosphorus are generally available to algae. The contributions of Metro versus those of the tributaries to annual TDP loading for the 2007-2011 interval (post-Actiflo® upgrade) are presented in Table 4-6. Metro's average contribution to the TDP load over this interval was 21%, the third highest, following Ninemile Creek (33%) and Onondaga Creek (26%). The Metro bypass was the fifth largest contributor. Flow-weighted total dissolved phosphorus concentrations for the three smallest tributaries considered (Harbor Brook, Tributary 5A, and East Flume-Manhole 015) were higher than for the Metro effluent (0.027 mg/L).

**Table 4-6.** Tributary and Metro total dissolved phosphorus (TDP) loading and flow-weighted concentrations to Onondaga Lake for post-ActiFlo implementation.
(mt = metric tons; concentrations flow-weighted)

| | **2007-2011 (post-Actiflo®)** | | | |
|---|---|---|---|---|
| **SITE** | **Flow (%)** | **TDP (mt)** | **TDP (% load)** | **TDP (mg/L)** |
| Metro: | | | | |
| fully treated | 18% | 2.3 | 22% | 0.027 |
| bypass | 0.39% | 0.64 | 6.0% | 0.35 |
| Watershed: | | | | |
| Onondaga Creek | 37% | 2.8 | 27% | 0.016 |
| Ninemile Creek | 34% | 3.2 | 31% | 0.020 |
| Ley Creek | 8.3% | 0.96 | 9.3% | 0.024 |
| Harbor Brook | 2.5% | 0.46 | 4.4% | 0.039 |
| Tributary 5A | 0.23% | 0.046 | 0.46% | 0.042 |
| Allied East Flume-Manhole 015 | 0.20% | 0.067 | 0.63% | 0.069 |
| **Total** | | **10.5** | | |
| **no TDP data prior to Actiflo ® implementation** | | | | |

### *4.3.3 Recent Metro Performance*

Metro's effluent ammonia concentration decreased dramatically with the implementation of the BAF treatment upgrade in 2004. The seasonal regulatory limits presently are 1.2 mg/L for the June to October 31 interval and 2.4 mg/L for November 1 to May 31. Metro effluent monthly average concentrations continued to meet the limits by a wide margin in 2011; 2010 conditions are included for reference (Figure 4-4). Seasonality in the performance of the nitrification treatment is observed, with the lowest ammonia concentrations reported in summer. This seasonality is consistent with the timing of the limits, as well as the known dependence of nitrification treatment performance on temperature. Implementation of this treatment resulted in a 98% decrease in the ammonia loading to the lake from Metro (Figure 4-5). Efficient, year-round nitrification of ammonia reduced Metro's contribution to the total annual load (Metro + tributaries) from 91% to 42% (Figure 4-6).

Metro's effluent total phosphorus concentration and loading (Figure 4-7) decreased dramatically with the implementation of the Actiflo® treatment upgrade. Total phosphorus concentrations for the 2006-2011 interval are presented in a format consistent with the regulatory limit as a rolling average monthly concentration (Figure 4-8). Accordingly, each monthly value on the plot corresponds to the average total phosphorus concentration of that month combined with the 11 preceding months. Initially, the limit was 0.12 mg/L (or 120 µg/L), starting in the spring of 2007. As part of the November

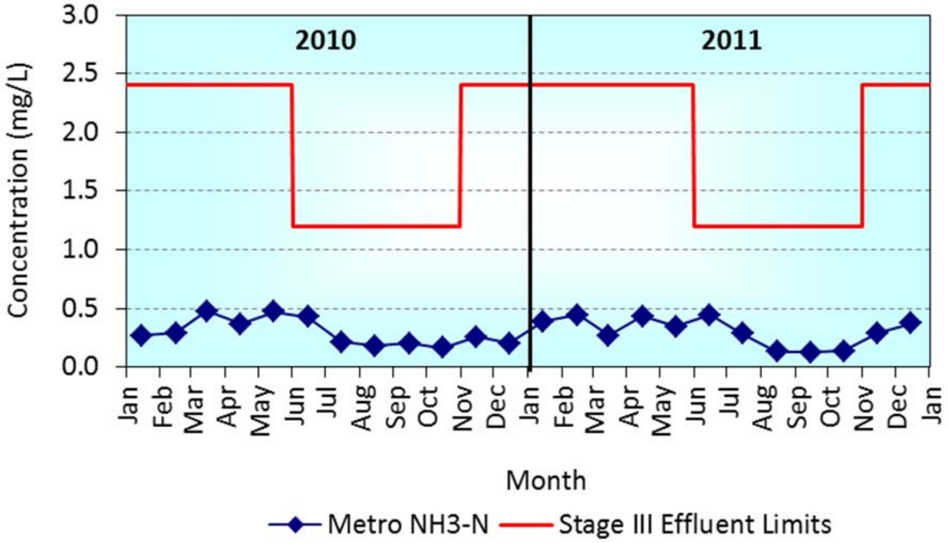


**Figure 4-4.** Metro effluent monthly average ammonia concentrations compared to permit limits for 2010 and 2011.

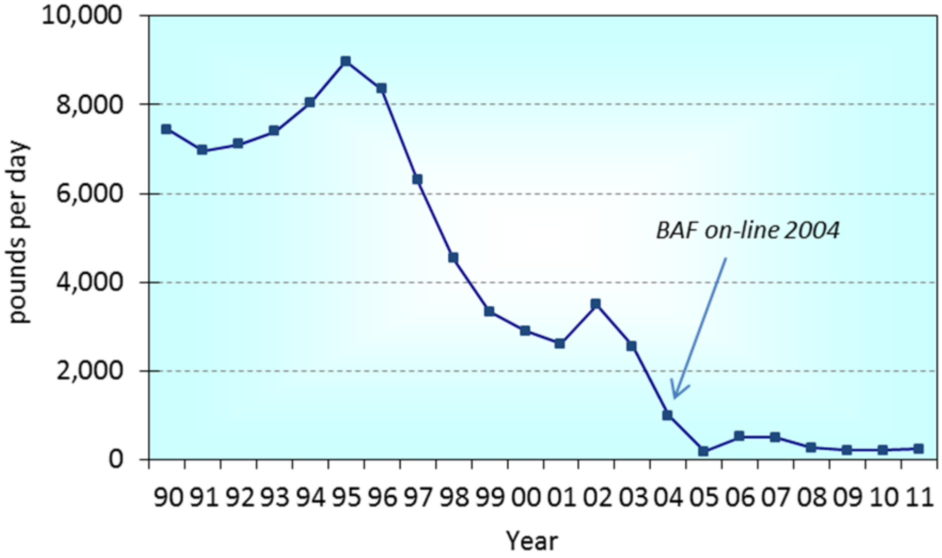


**Figure 4-5.** Annual time plot of the daily average Metro ammonia ($NH_3$-N) loading to Onondaga Lake, 1990-2011.

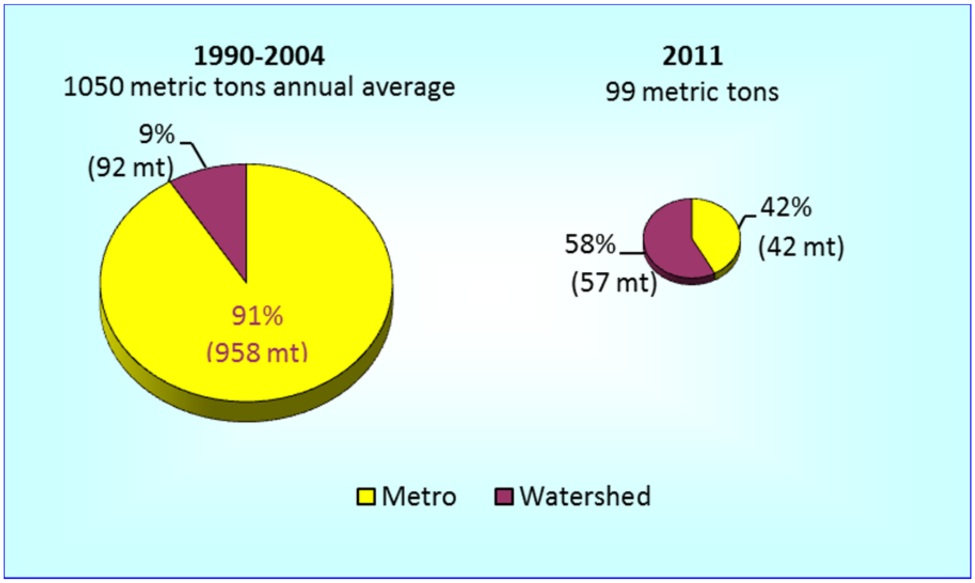


**Figure 4-6.** Contributions of Metro and the watershed to the total annual input of ammonia to Onondaga Lake, average for 1990-2004 compared to 2011.

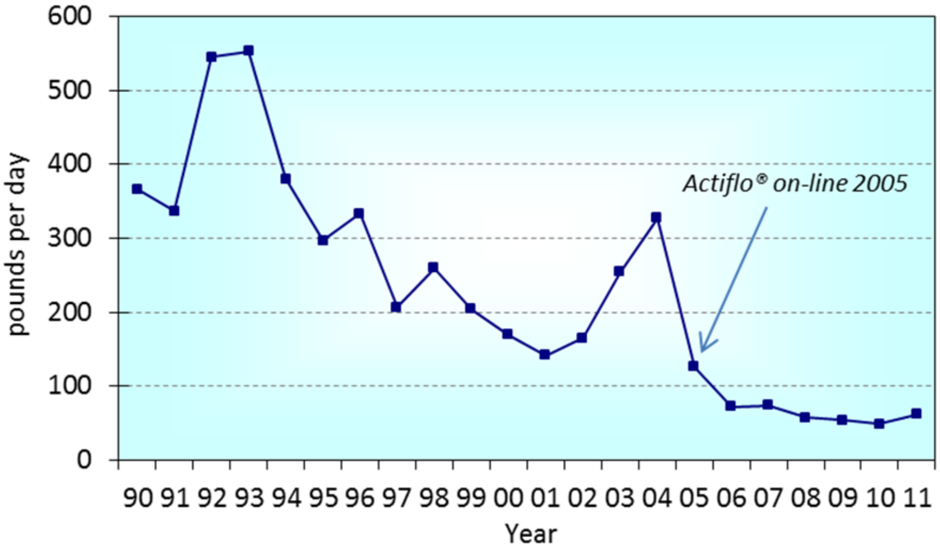


**Figure 4-7.** Annual time plot of the daily average Metro total phosphorus (TP) loading to Onondaga Lake, 1990-2011.

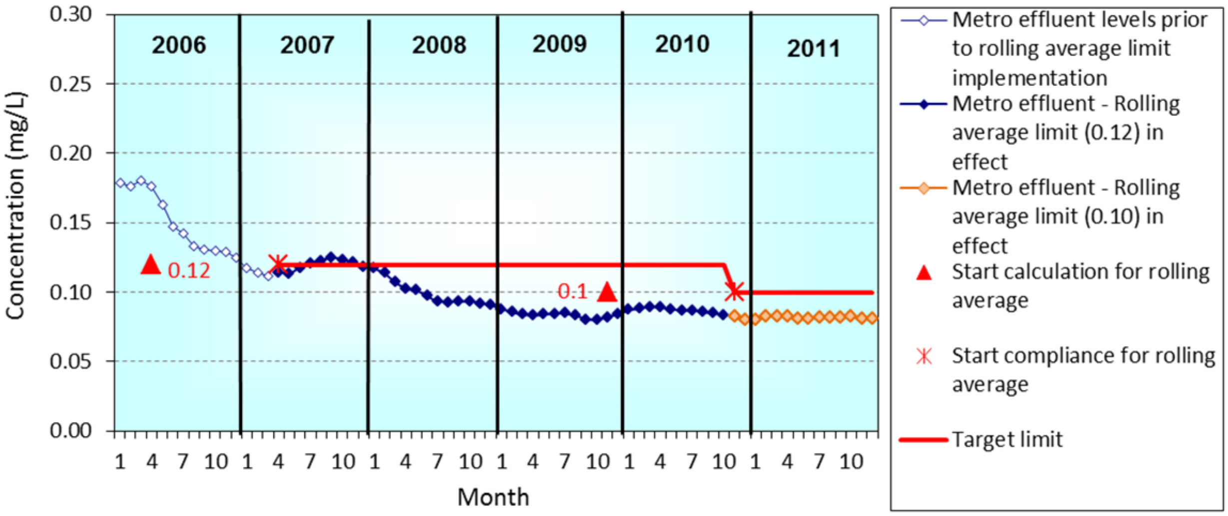


**Figure 4-8.** Metro effluent total phosphorus concentrations compared to permit limits for the 2006-2011 interval. Concentrations are monthly rolling average values for 12 months intervals.

2009 Fourth Stipulation Amending the ACJ, the interim Stage II total phosphorus effluent limit became 0.10 mg/L (Figure 4-8). These limits have been successfully met with the Actiflo® upgrade in treatment. Since mid-2008 the rolling average total phosphorus concentration in the Metro effluent has remained below 0.10 mg/L (Figure 4-8). Moreover, Metro's contribution to the total annual phosphorus load has decreased from about 60% over the 1990 to 2004 interval to approximately 20% in 2011 (Figure 4-9).

During particularly high runoff intervals, inflows to Metro can exceed the capacity of the facility to provide full treatment. Portions of this inflow receive partial treatment, usually primary treatment and disinfection, and are discharged via outfall 002. These inputs are of concern because concentrations of various constituents are higher compared to the fully treated effluent, as described above. Rarely, under particularly extreme runoff conditions, a small portion of the inflow to the facility receives no treatment (plant headworks are bypassed). The extent to which bypasses occur depends critically on runoff, and therefore precipitation, that is subject to substantial variability. Discharges via outfall 002 occurred on 71 days in 2011, for a cumulative duration of 771 hours. A total of 750 million gallons were discharged via that outfall in 2011. Approximately 35% of this input occurred during the high runoff interval of the second half of April. It should be noted that although disinfection of this discharge occurs seasonally as required by the Metro SPDES Permit, fecal coliform limits of 200 #/100ml were not in effect in 2011, and will not be effective until April 1, 2016, for this outfall. The total duration of bypass of the headworks in 2011 was 24 hours. Documentation of combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) throughout the Onondaga County service area is presented in the library.

### *4.3.4 Trends*

The major reductions in ammonia and total phosphorus loading from treatment upgrades at Metro (BAF and Actiflo®, respectively) were identified and graphically supported (Figure 4-5 for ammonia, Figure 4.7

for total phosphorus). The BAF upgrade resulted in a 98% decrease in ammonia loading to the lake from Metro. Implementation of the Actiflo® upgrade achieved an 85% decrease in total phosphorus loading from Metro compared to the early 1990s. These decreases were clearly statistically significant.

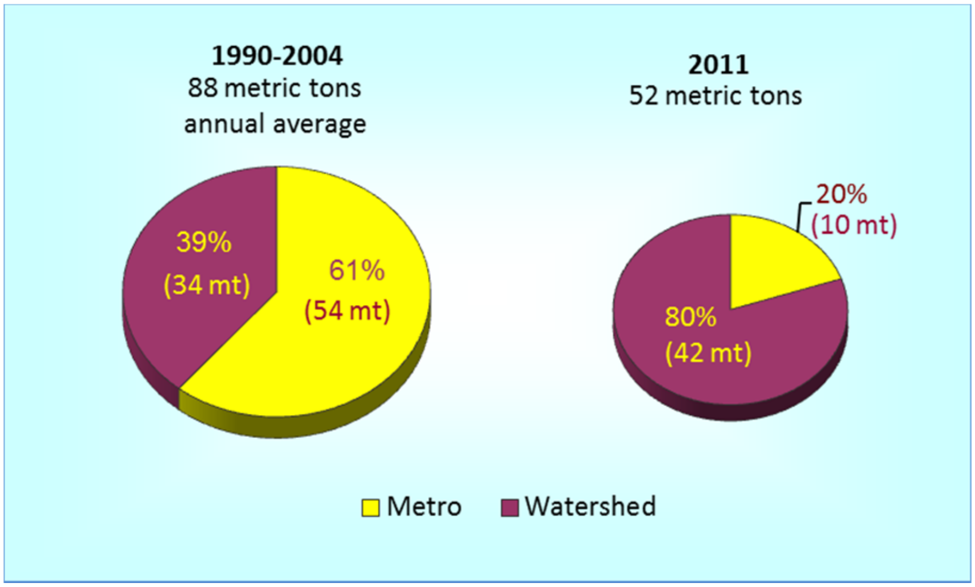


**Figure 4-9.** Contributions of Metro and the watershed to the annual input of total phosphorus to Onondaga Lake, average for 1990-2004 compared to 2011.

The changes in total phosphorus (Table 4-7) and soluble reactive phosphorus (Table 4-8) loading from Metro and the tributaries from the 1990-1998 interval (before the ACJ) to after implementation of Actiflo® (2007-2011) are presented here. Loading of total phosphorus was reduced by nearly a factor of 7 for the fully treated Metro effluent (Table 4-7). The nearly 4-fold decrease in the bypass load is also noteworthy. The changes for the tributaries over this period have been smaller, including 40 and 15% decreases for Ley Creek and Onondaga Creek, respectively. Metro (effluent plus bypass) in recent years (post-Actiflo®) has represented about 25% of the total phosphorus load, the third largest source, after Onondaga Creek and Ninemile Creek. The Actiflo ® upgrade resulted in and even greater decrease in SRP loading, a 40-fold reduction (Table 4-8). This phosphorus fraction is noteworthy because it is generally available to support algae growth. The decrease in the bypass SRP load was nearly 5-fold. Metro's combined SRP load represents about 15% of the contemporary total, and substantially (more than 2-fold) less than the inputs from Onondaga Creek or Ninemile Creek.

Implementation of the BAF treatment also reduced the Metro loading of nitrite, another form of nitrogen that is a water quality concern, but increased the input of nitrate. Nitrate is not a water quality concern for Onondaga Lake. Moreover, the increased nitrate loading from Metro is having beneficial effects on the lake by diminishing the cycling of phosphorus and mercury. The total loading of the total nitrogen from Metro has not changed substantially from the BAF upgrade, but a highly desirable shift in the contribution of the various forms has been achieved.

**Table 4-7.** Tributary and Metro total phosphorus (TP) Loading to Onondaga Lake and flow-weighted concentration, pre-ACJ and post-Actiflo® implementation.
(mt = metric tons; concentrations flow-weighted)

| | **1990-1998 (pre-ACJ)** | | | | **2007-2011 (post-Actiflo®)** | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE** | **Flow (%)** | **TP (mt)** | **TP (% load)** | **TP (mg/L)** | **Flow (%)** | **TP (mt)** | **TP (% load)** | **TP (mg/L)** |
| Metro: | | | | | | | | |
| fully treated | 21% | 52 | 57% | 0.56 | 18% | 7.6 | 19% | 0.089 |
| Bypass | 0.94% | 8.5 | 7.5% | 1.8 | 0.39% | 2.2 | 5.2% | 1.2 |
| Watershed: | | | | | | | | |
| Onondaga Creek | 34% | 20 | 19% | 0.12 | 37% | 17 | 39% | 0.095 |
| Ninemile Creek | 32% | 10 | 10% | 0.065 | 34% | 11 | 26% | 0.067 |
| Ley Creek | 8.7% | 5.7 | 5.8% | 0.14 | 8.3% | 3.3 | 8.0% | 0.082 |
| Harbor Brook | 2.1% | 0.71 | 0.71% | 0.070 | 2.5% | 1.0 | 2.4% | 0.084 |
| Tributary 5A | 0.72% | 0.17 | 0.19% | 0.054 | 0.23% | 0.12 | 0.30% | 0.11 |
| Allied East Flume-Manhole 015 | 0.23% | 0.19 | 0.18% | 0.20 | 0.20% | 0.11 | 0.27% | 0.12 |
| **Total** | | **97** | | | | **42** | | |

**Table 4-8.** Tributary and Metro soluble reactive phosphorus (SRP) loading to Onondaga Lake, and flow-weighted concentrations, pre-ACJ and post-Actiflo® implementation
(mt = metric tons; concentrations flow-weighted)

| | **1990-1998 (pre-ACJ)** | | | | **2007-2011 (post-Actiflo®)** | | | |
|---|---|---|---|---|---|---|---|---|
| **SITE** | **Flow (%)** | **SRP (mt)** | **SRP (% load)** | **SRP (mg/L)** | **Flow (%)** | **SRP (mt)** | **SRP (% load)** | **SRP (mg/L)** |
| Metro: | | | | | | | | |
| fully treated | 21% | 12 | 59% | 0.13 | 18% | 0.30 | 5.5% | 0.003 |
| Bypass | 0.94% | 2.5 | 9.7% | 0.50 | 0.39% | 0.51 | 9.0% | 0.27 |
| Watershed: | | | | | | | | |
| Onondaga Creek | 34% | 3.3 | 16% | 0.021 | 37% | 1.8 | 33% | 0.010 |
| Ninemile Creek | 32% | 1.7 | 7.9% | 0.011 | 34% | 1.9 | 33% | 0.011 |
| Ley Creek | 8.7% | 1.4 | 6.1% | 0.033 | 8.3% | 0.55 | 10% | 0.014 |
| Harbor Brook | 2.1% | 0.25 | 1.1% | 0.024 | 2.5% | 0.41 | 7.6% | 0.034 |
| Tributary 5A | 0.72% | 0.030 | 0.17% | 0.010 | 0.23% | 0.034 | 0.69% | 0.031 |
| Allied East Flume-Manhole 015 | 0.23% | 0.065 | 0.29% | 0.092 | 0.20% | 0.042 | 0.75% | 0.045 |
| **Summary** | | **21** | | | | **5.2** | | |

Seasonal Kendall tests were conducted for the 10 year period 2002-2011 to identify significant ($p < 0.1$) trends in tributary concentrations (Table 4-9) and loads (Table 4-10). Significant changes for constituents involved in the Metro treatment upgrades were evident, including decreases in forms of phosphorus and nitrogen (except the increase in nitrate), organic carbon (and $BOD_5$), and an increase in chloride. Ammonia loading from the watershed has decreased markedly since the early 1990s (Figure 4-6). Significant decreases in ammonia loading have occurred since 2002 for all of the tributaries to Onondaga Lake, except for Allied East Flume (Table 4-10). Ninemile Creek is the largest tributary source of ammonia and has contributed most to the overall decrease. Increases in total phosphorus, soluble reactive phosphorus, and total suspended solids were observed for both the upstream (Dorwin Ave.) and downstream (Kirkpatrick St.) sites on Onondaga Creek. Decreasing trends were identified for dissolved oxygen (DO) for those same sites. Increases in chloride have occurred in Harbor Brook and Ley Creek. The increase in suspended solids loading in Onondaga Creek has been linked to the resurgence of mud boil activity in the Tully Valley, which likely also contributed to increased total phosphorus loading. The increasing trends in total phosphorus loading in Onondaga Creek and Ninemile Creek may be linked to changes in runoff conditions over this 10-year period.

Application of the seasonal Kendall test for the 2002-2011 interval indicated one statistically significant trend, increases in concentrations of fecal coliform bacteria in Onondaga Creek at the Dorwin Ave. site. Long-term time series of annual geometric mean concentrations for the 1998-2011 period depict a general trend of decreasing fecal coliform levels for Harbor Brook at Velasko Rd. (Figure 4-10a), Onondaga Creek at Kirkpatrick St. (Figure 4-10d), and Ley Creek at Park St. (Figure 4-10e). These decreasing trends are not statistically significant according to a simple linear least squares regression analysis (i.e., $p > 0.10$). However, the magnitude of these decreases – approximately 3% to 4% per year (note log scale) – is noteworthy, and consistent with long-term reductions in fecal coliform levels documented in the south end of Onondaga Lake (see Section 5.6). It is also noteworthy that the annual geometric mean concentrations at these three sites for 2011 were the lowest of the 13-year record.

Concentrations of fecal coliform bacteria in tributaries to Onondaga Lake have been observed to vary widely in both time and space, which poses difficult challenges for the design of sampling programs and statistical models targeting assessment of trends. Characterization of the temporally irregular CSO inputs that occur in response to runoff events requires intensive sampling during wet weather intervals, while inputs from leaky sewer pipes are best identified during dry weather. All of the fecal coliform data from Onondaga Creek at Kirkpatrick St. (Figure 4-11a) were identified as being collected during either dry weather (Figure 4-11b) or wet weather (Figure 4-11c) conditions according to measurements of antecedent precipitation. Although decreasing trends are evident for both dry and wet conditions, they are not statistically significant. The analysis of long-term trends is complicated by the uneven intensity of sampling over the 13 year record, particularly during runoff events, and the extremely high temporal variability observed during both dry and wet weather conditions. A more rigorous analysis will be included in the 2012 annual report that will consider (1) Onondaga Creek, Harbor Brook, Ley Creek, and Ninemile Creek; (2) data collected during the 1998 to 2012 interval; (3) trends other than monotonic trends (e.g., step changes); (4) seasonal variations; (5) alternate thresholds for dry and wet weather conditions; and (6) potential covariates, such as flow, temperature, and phosphorus concentrations.

**Table 4-9.** Ten-year trends in tributary concentrations (2002-2011) – summary, from application of seasonal Kendall test.

| | | Metro | | Onondaga Creek | | Harbor Brook | | Ley Creek | Ninemile Creek | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | | **Treated Effluent** | **Bypass** | **Dorwin** | **Kirkpatrick** | **Velasko** | **Hiawatha** | **Park** | **Route 48** | **Tributary 5A** | **Allied East Flume-Manhole 015** |
| Nitrogen | Ammonia ($NH_3$-N) | ↓ | ○ | ↓ | ↓ | ↓ | ↓ | ○ | ↓ | ○ | ○ |
| | Nitrite ($NO_2$-N) | ↓ | ○ | ↑ | ○ | ↑ | ○ | ○ | ○ | ○ | ↑ |
| | Nitrate ($NO_3$-N) | ↑ | ○ | ○ | ↓ | ↓ | ○ | ↓ | ↓ | ○ | ○ |
| | Organic Nitrogen | ↓ | ○ | ↑ | ↑ | ↑ | ↑ | ↓ | ↑ | ○ | ↓ |
| | Total Kjeldahl Nitrogen (TKN) | ↓ | ○ | ○ | ↑ | ○ | ↑ | ○ | ○ | ○ | ○ |
| Phosphorus | Total Phosphorus (TP) | ↓ | ○ | ↑ | ↑ | ○ | ○ | ○ | ○ | ○ | ↓ |
| | Soluble Reactive Phosphorus (SRP) | ↓ | ○ | ↑ | ↑ | ○ | ↑ | ↓ | ○ | ↓ | ○ |
| Solids | Total Suspended Solids (TSS) | ↓ | ○ | ↑ | ↑ | ○ | ○ | ○ | ○ | ○ | ↓ |
| | Total Dissolved Solids (TDS) | ○ | ↓ | ○ | ○ | ↑ | ○ | ○ | ↓ | ○ | ○ |
| | Volatile Suspended Solids (VSS) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Carbon | Total Inorganic Carbon (TIC) | ↓ | ○ | ○ | ○ | ○ | ↓ | ○ | ○ | ○ | ○ |
| | Total Organic Carbon (TOC) | ↓ | ○ | ○ | ○ | ↓ | ○ | ○ | ○ | ○ | ↓ |
| | Total Organic Carbon, filtered (TOC_F) | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ |
| Other | Alkalinity | ↓ | ○ | ○ | ○ | ↑ | ○ | ↑ | ↑ | ○ | ○ |
| | $BOD_5$* | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Calcium (Ca) | ↑ | ○ | ↑ | ○ | ↑ | ↑ | ↑ | ↓ | ○ | ↑ |

**Table 4-9.** Ten-year trends in tributary concentrations (2002-2011) – summary, from application of seasonal Kendall test.

| Variable | | Metro | | Onondaga Creek | | Harbor Brook | | Ley Creek | Ninemile Creek | Tributary 5A | Allied East Flume-Manhole 015 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Treated Effluent | Bypass | Dorwin | Kirkpatrick | Velasko | Hiawatha | Park | Route 48 | | |
| | Chloride (Cl) | ↑ | ○ | ○ | ○ | ↑ | ↑ | ↑ | ↓ | ○ | ↑ |
| | Conductivity | ○ | ○ | ○ | ○ | ↑ | ○ | ↑ | ↓ | ○ | ○ |
| | Dissolved Oxygen (DO) | ○ | ○ | ↓ | ↓ | ○ | ↑ | ○ | ○ | ↑ | ○ |
| | Fecal Coliform Bacteria | ○ | ○ | ↑ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Hardness | ↑ | ○ | ↑ | ○ | ↑ | ↑ | ○ | ↓ | ○ | ○ |
| | Magnesium (Mg) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↓ | ○ |
| | Sodium (Na) | ○ | ○ | ○ | ○ | ↑ | ↑ | ↑ | ↓ | ○ | ○ |
| | pH | ○ | ○ | ○ | ↑ | ○ | ↑ | ○ | ↑ | ↑ | ↓ |
| | Silica ($SiO_2$) | ○ | ○ | ○ | ○ | ○ | ○ | ↑ | ○ | ↑ | ○ |
| | Sulfates ($SO_4$) | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↓ |
| | Temperature | ○ | ○ | ○ | ○ | ↓ | ○ | ○ | ○ | ↓ | ○ |

*Notes:*

Significance level, two-tailed, seasonal Kendall test accounting for serial correlation.

↓ indicates decreasing trend ($p < 0.1$)

↑ indicates increasing trend ($p < 0.1$)

○ indicates no trend ($p > 0.1$)

- Dash indicates parameter is not measured at this location.

*$BOD_5$ (Biochemical Oxygen Demand (5-day)) trend analysis results are accurate only for METRO & BYPASS because of the preponderance of data less than the MRL (PQL) in other inputs.

**Table 4-10.** Ten-year trends in tributary loading (2002-2011) – summary, from application of the seasonal Kendall test.

| Variable | | Metro | | Onondaga Creek | | Harbor Brook | | Ley Creek | Ninemile Creek | Tributary 5A | Allied East Flume-Manhole 015 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Treated Effluent* | *Bypass* | *Dorwin* | *Kirkpatrick* | *Velasko* | *Hiawatha* | *Park* | *Route 48* | | |
| Nitrogen | Ammonia ($NH_3$-N) | ↓ | ○ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↑ |
| | Nitrite ($NO_2$-N) | ↓ | ↓ | ↑ | ↑ | ○ | ○ | ○ | ○ | ↓ | ↑ |
| | Nitrate ($NO_3$-N) | ↑ | ○ | ○ | ○ | ○ | ○ | ↓ | ○ | ↓ | ↑ |
| | Total Kjeldahl Nitrogen (TKN) | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ○ |
| Phosphorus | Total Phosphorus (TP) | ↓ | ○ | ↑ | ↑ | ○ | ○ | ○ | ↑ | ↓ | ○ |
| | Soluble Reactive Phosphorus (SRP) | ○ | ○ | ↑ | ↑ | ○ | ○ | ○ | ↑ | ↓ | ○ |
| Solids | Total Suspended Solids (TSS) | ↓ | ○ | ↑ | ↑ | ○ | ○ | ○ | ↑ | ○ | ○ |
| Carbon | Total Inorganic Carbon (TIC) | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↑ |
| | Total Organic Carbon (TOC) | ↓ | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ○ |
| | Total Organic Carbon, filtered (TOC_F) | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ○ |
| Other | Alkalinity | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↑ |
| | BOD5* | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ↑ | ↓ | ↑ |
| | Calcium (Ca) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↑ |
| | Chloride (Cl) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↓ | ↑ |
| | Fecal Coliforms | ↓ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ○ |
| | Sodium (Na) | ○ | ○ | ○ | ○ | ↑ | ○ | ○ | ○ | ↓ | ↑ |
| | Silica (SIO2) | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ↓ | ↑ |

**Table 4-10.** Ten-year trends in tributary loading (2002-2011) – summary, from application of the seasonal Kendall test.

| | Metro | | Onondaga Creek | | Harbor Brook | | Ley Creek | Ninemile Creek | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Variable** | *Treated Effluent* | *Bypass* | *Dorwin* | *Kirkpatrick* | *Velasko* | *Hiawatha* | *Park* | *Route 48* | **Tributary 5A** | **Allied East Flume-Manhole 015** |

*Notes:*

Significance level, two-tailed, seasonal Kendall test accounting for serial correlation.

↓ indicates decreasing trend ($p < 0.1$)

↑ indicates increasing trend ($p < 0.1$)

○ indicates no trend ($p > 0.1$)

*BOD5 (Biological Oxygen Demand (5-day)) test reliable only for METRO & BYPASS because of variations in detection limits.

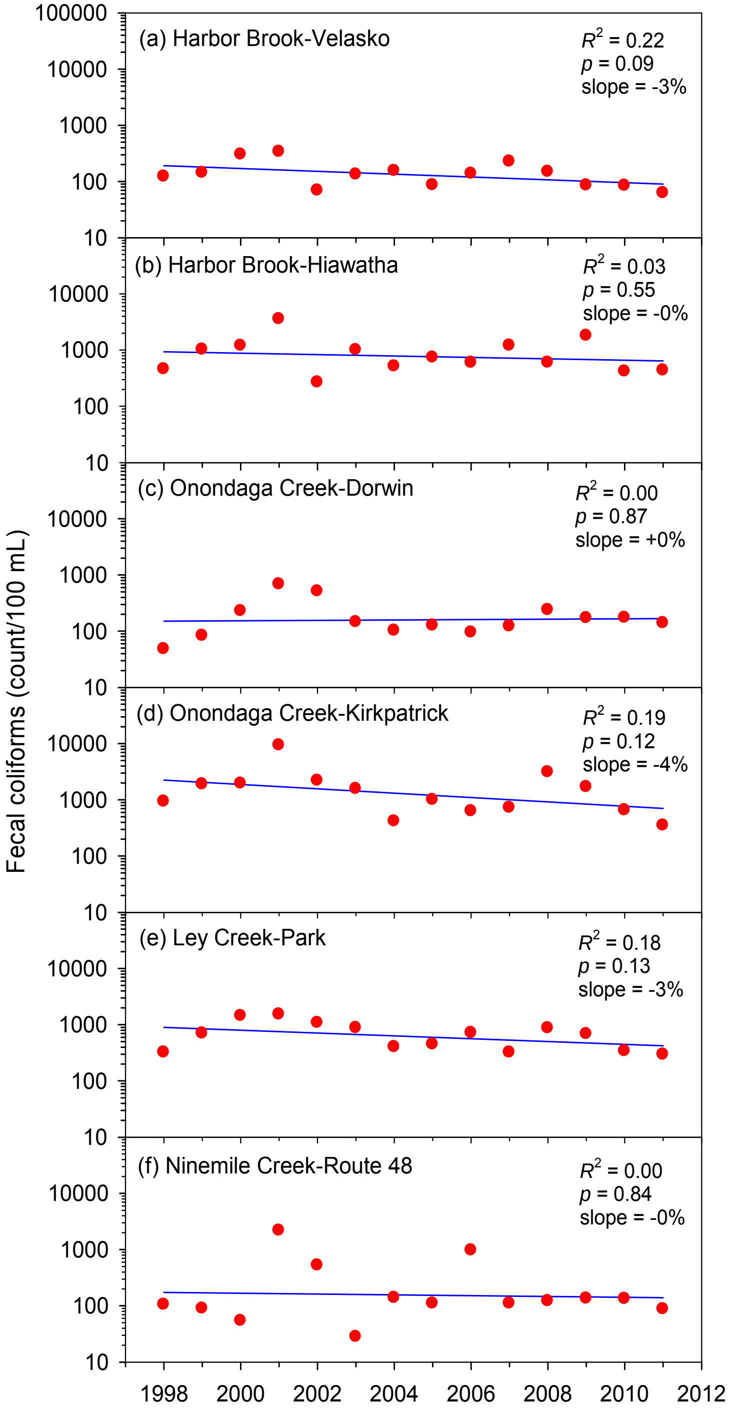


**Figure 4-10.** Time series of fecal coliform bacteria counts for tributaries to Onondaga Lake, 1998-2011. Annual geometric mean values are presented for six sampling sites: (a) Harbor Brook-Velasko, (b) Harbor Brook-Hiawatha, (c) Onondaga Creek-Dorwin, (d) Onondaga Creek-Kirkpatrick, (e) Ley Creek-Park, and (f) Ninemile-Route 48.

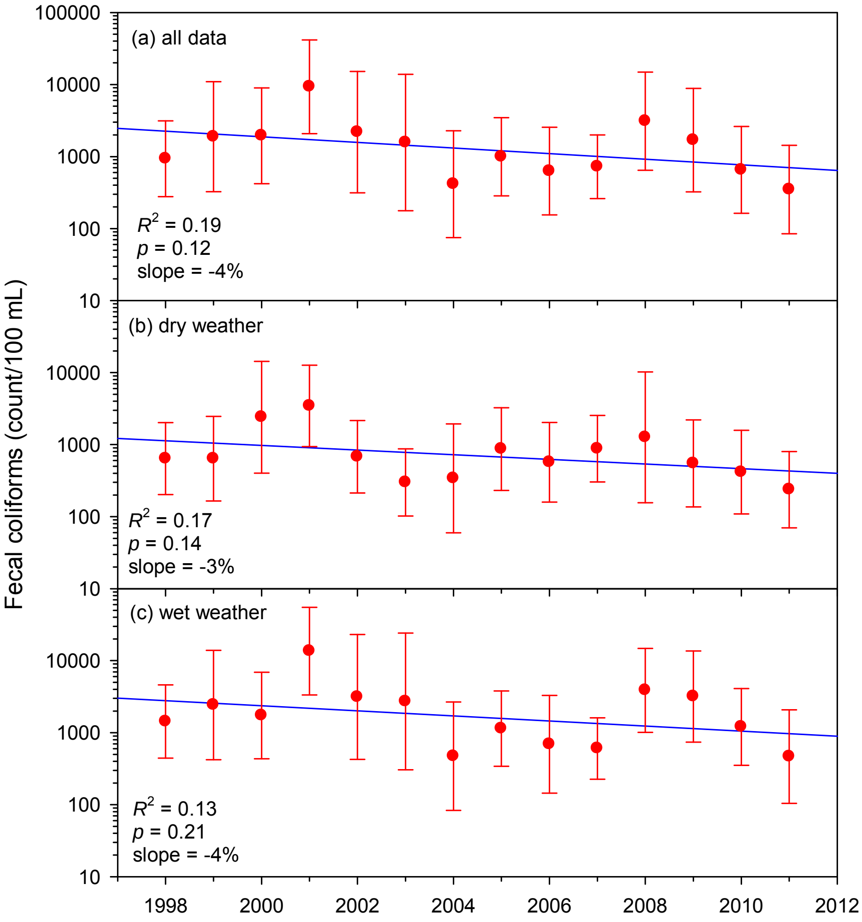


**Figure 4-11.** Time series of fecal coliform bacteria counts for Onondaga Creek at Kirkpatrick Street, 1998-2011. Annual geometric mean values are presented for three data sets: (a) all data, (b) dry weather data, and (c) wet weather data.

Note: Dry weather samples are defined as those preceded by less than 0.08 inches of rainfall over the 60 hour period extending back from noon on the day of sampling. All other samples are defined as wet weather. Rainfall data for 1998 was obtained from Hancock International Airport. Rainfall data for 1999-2011 was collected at the Metro weather station in Syracuse. Error bars represent on standard deviation of the geometric mean concentration.

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## Section 5. Onondaga Lake Water Quality: 2011 Results and Trends

### 5.1 Sampling Locations

Trained Water Environment Protection (WEP) technicians collect samples from Onondaga Lake throughout the year to characterize water quality and biological conditions. Most sampling occurs between April and November when the lake is free of ice. Winter sampling is conducted as conditions allow. The ambient monitoring program (AMP) encompasses multiple parameters (Table 1-1) with a focus on compliance with ambient water quality standards (AWQS) and assessment of trends toward attainment of designated uses. WEP also tracks physical factors, such as the development and extent of ice cover.

The lake's main sampling station, referred to as South Deep, is the deepest point in the southern basin. South Deep has been the long-term reference monitoring location on Onondaga Lake since the County initiated monitoring in 1970. In addition to the routine biweekly sampling at South Deep, WEP technicians collect samples from the deepest point of the lake's northern basin (North Deep) four times each year to confirm that water quality conditions measured at the South Deep station adequately characterize open water conditions. Results from North Deep and South Deep remained comparable in 2011.

During the summer, the AMP additionally includes sampling of a network of ten near-shore locations for parameters indicative of the lake's suitability for water contact recreation. These parameters include Secchi disk transparency, turbidity, and fecal coliform bacteria.

### 5.2 Compliance with AWQS

The 2011 monitoring results indicate that the open waters of Onondaga Lake were in compliance with most ambient water quality standards (AWQS), with exceptions noted in Table 5-1. The concentration of total dissolved solids (TDS), which primarily reflect the concentrations of the major cations and anions (calcium (Ca), sodium (Na), magnesium (Mg), bicarbonate, potassium (K), chloride (Cl), sulfate ($SO_4$)), was above the AWQS of 500 mg/L. TDS concentrations consistently exceed this standard in Onondaga Lake. However, these conditions are primarily associated with the lake's natural hydrogeology, rather than from anthropogenic effects.

The 2011 summer average total phosphorus (TP) concentration in the lake's upper waters was 20 µg/L, equal to the state's guidance value. NYS has promulgated a narrative standard for phosphorus in water: "None in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages" (NYSCRR §703.2). For ponded waters, such as Onondaga Lake, the narrative standard is interpreted using a guidance value of 20 µg/L, which is calculated as the average total phosphorus concentration in the lake's upper waters, at South Deep, between June 1 and September 30. A total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake has been developed to meet this water quality goal. The phosphorus TMDL was approved by USEPA on June 29, 2012.

**Table 5-1.** Percentage of measurements in compliance with ambient water quality standards (AWQS) and guidance values in the upper mixed and lower water layers of Onondaga Lake in 2011.

Note: All measurements were made at South Deep and are generally representative of conditions in the open waters of the lake. Dashed lines indicate that compliance was not evaluated at this location. Parameters listed in **bold** are cited in the ACJ.

| **Parameter** | **South Deep** | |
|---|---|---|
| | **Upper Mixed Layer (0-6m)** | **Lower Water Layer (9-18m)** |
| **Ammonia** | 100% | 100% |
| Arsenic | 100% | 100% |
| Cadmium | 100% | 100% |
| Chromium | 100% | 100% |
| Copper | 100% | 100% |
| **Dissolved Oxygen** | 100% >5 mg/L;<br>100% >4 mg/L | 40% >5 mg/L;<br>44% >4 mg/L |
| Total Dissolved Solids | 0% | 0% |
| **Fecal Coliform** | 100% | -- |
| Lead | 100% | 100% |
| Mercury | -- | -- |
| Nickel | 100% | 100% |
| **Nitrite** | 100% | 90% |
| pH | 100% | 100% |
| **Total Phosphorus (*guidance value*)** | 100% | -- |
| Zinc | 100% | 100% |

Notes:

Ammonia compliance represented as average of discrete depth percent compliance

Dissolved oxygen compliance based on 15-min. buoy data at 2 m and 12 m depths

The AWQS for fecal coliform bacteria is specified as the monthly geometric mean (GM) being less than or equal to 200 colony forming units (cfu) per 100 milliliters (mL) during the period of Metro disinfection (April 1 – October 15).

Mercury samples collected at 3 m and 18 m depths

Total phosphorus compliance based on 0-3m average biweekly samples averaged for June 1 – Sept 30

AWQS for arsenic, cadmium, copper, lead, and mercury, nickel and zinc apply to the dissolved forms. Total recoverable concentrations of these metals are measured by the AMP.

Onondaga County WEP collected (EPA sampling method 1669) water samples for analysis of ultra-low level total mercury (Hg; EPA method 1631) and methyl mercury (MeHg; EPA method 1630). Samples were collected at two depths (3 m and 18 m) on three dates in 2011. The April and August samples were submitted to Frontier Global Sciences Inc. and the October samples were submitted to Test America.

The AWQS for total dissolved mercury in Class B and C waters is 0.7 ng/L. The 2011 AMP did not include analysis of samples for total dissolved mercury. However, all six of the 2011 Onondaga Lake total Hg results exceeded the 0.7 ng/L value. The time series of total Hg and methyl Hg data measured in both the upper and lower waters of Onondaga Lake since 1999 indicate a decline in the concentration of this heavy metal.

Dissolved oxygen (DO) concentrations met the AWQS (Table 5-2) in the upper waters of Onondaga Lake during the 2011 fall mixing period. The AMP further documented that dissolved oxygen (DO) concentrations were not in 100% compliance with AWQS in 2011; DO in the lower waters was below the minimum 4 mg/L during a portion of the summer stratified period. However, this situation is not uncommon in stratified lakes where the volume of the lower stratum (the hypolimnion) is relatively small. In New York, an estimated 70% of assessed lakes do not meet the minimum DO standards in the deep waters (NYSDEC Consolidated Assessment and Listing Methodology, May 2009). NYSDEC has not classified Onondaga Lake as trout water (T) or trout spawning water (TS). The onset of anoxia in the lake's lower waters is occurring later, suggesting improved water quality and habitat conditions.

**Table 5-2.** New York State water quality standards for dissolved oxygen.

| | |
|---|---|
| AA, A, B, C, AA-Special | For trout spawning waters (TS), the DO concentration shall not be less than 7.0 mg/L from other than natural conditions. For trout waters (T), the minimum daily average shall not be less than 6.0 mg/L, and at no time shall the concentration be less than 5.0 mg/L. For non-trout waters, the minimum daily average shall not be less than 5.0 mg/L, and at no time shall the DO concentration be less than 4.0 mg/L. |

In 2011, the measured fecal coliform bacteria counts at the Onondaga Lake monitoring stations did not exceed the ambient water quality standard (200 cfu/100 mL) at offshore locations or at nearshore locations within the Class B portion of the lake. For nearshore locations within the Class C water segment, monthly geometric mean concentrations of fecal coliform bacteria met the ambient water quality standard for all monitored months at 9 of the 10 sampling locations. Fecal coliform counts exceeded the standard at one site adjacent to the mouth of Onondaga Creek in two months (April and May) of the seven-month assessment period (Section 5.6).

## 5.3 Trophic State

The trophic state of a lake refers to its level of primary production (production of organic matter through photosynthesis). This is a fundamental feature of the ecology of lakes that also has important water quality implications. Highly productive systems are termed **eutrophic**, while systems with low levels of productivity are termed **oligotrophic**. Those in between are described as **mesotrophic**. Excessive productivity can result in conditions that impair a waterbody for a particular use, such as water supply or recreation.

Primary production in Onondaga Lake, like most lakes in the Northeast, is limited by the availability of phosphorus. Addition of phosphorus to lakes causes increased primary production, described as eutrophication. This is generally accompanied by higher concentrations of algae and often cyanobacteria (blue-green algae), which can have deleterious effects on water quality. Certain cyanobacteria can produce harmful toxins.

Decay of settled algae contributes to the depletion of dissolved oxygen in the lower stratified layers. Where this decay is substantial, oxygen can be depleted to levels that make these layers uninhabitable for fish and other oxygen-requiring biota. The complete absence of dissolved oxygen (anoxia) enables the release of a number of undesirable substances from the sediments, including ammonia, soluble phosphorus, and various oxygen-demanding constituents, such as hydrogen sulfide and methane.

Much effort has been directed at decreasing primary production in Onondaga Lake through reductions in phosphorus loading. The progress of this program has been tracked by monitoring multiple measures of the lake's trophic state. This has included measurements of the three common trophic state parameters, total phosphorus (TP), chlorophyll-a, and Secchi disk (SD) transparency, as well as related chemical metrics of the deep waters, and the composition and abundance of the algal community (see section 6). Each of these parameters has shortcomings, but together they represent a robust representation of trophic state conditions. The three most often monitored parameters are all related to the amount of phytoplankton (microscopic algae) present in the water column. Much of the phosphorus and all of the chlorophyll-a (the dominant pigment of algae) is associated with phytoplankton. The Secchi disk measurement is more indirectly related to trophic state and controlled primarily by the concentration of particles in the water. The common case of dominance of the overall particle population by phytoplankton makes Secchi disk a valuable trophic state metric. These metrics of trophic state can all be influenced by both bottom-up (e.g., phosphorus supply) and top-down (food web) effects. Top-down effects associated with large zooplankton that effectively feed on (graze) phytoplankton can confound the relationship between phosphorus loading and common metrics of trophic state.

### *5.3.1 Total Phosphorus*

Total phosphorus (TP) concentrations in the lake's upper waters have decreased four-fold since 1990 (Figure 5-1). Phosphorus concentrations in the lake's upper waters averaged 20 µg/L over the summer of 2011. Since 2007, summer total phosphorus concentrations in the upper waters of Onondaga Lake have been under 30 µg/L. With the advanced treatment system at Metro producing consistently low effluent total phosphorus, the year-to-year variability in lake phosphorus levels probably reflects changes in precipitation patterns and the resultant watershed loading as well as changes in the food web structure. A substantial portion of the total phosphorus in certain lakes may be associated with inorganic particles rather than phytoplankton, making it a conservative metric of trophic state.

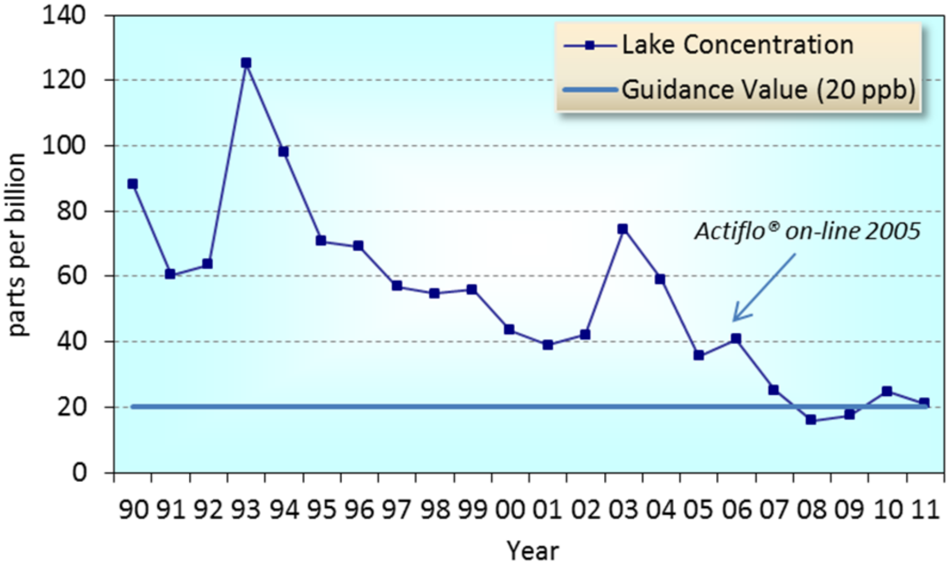


**Figure 5-1.** Summer (June to September) average total phosphorus concentration in the upper waters (0-3 meters) of Onondaga Lake, 1990-2011.

### *5.3.2 Chlorophyll-a*

The EPA and NYSDEC are developing nutrient criteria for lakes to protect aquatic life, water supply and recreational use, as well as deriving numerical limits on response variables such as chlorophyll-a. Algal blooms are generally esthetically undesirable, accompanied by a turbid green appearance in Onondaga Lake. In the absence of state or federal criteria, the AMP has used subjective thresholds of 15 µg/L and 30 µg/L to represent minor blooms (impaired conditions) and major blooms (nuisance conditions), respectively.

According to the criteria adopted here, there were no algal blooms in Onondaga Lake during the summer recreational period (June 1 – September 30) of 2011 (Figure 5-2). However, a minor bloom was observed in May, prior to the summer averaging period. The average and peak concentrations of this plant pigment have declined substantially, particularly since the Actiflo® upgrade at Metro (Figure 5-2). Summer data (June-September) are used to track suitability of the lake for recreational uses. The annual data (Figure 5-3) provide additional information regarding peak concentrations of chlorophyll-a during spring and fall.

Spring total phosphorus concentration has been a good predictor of the occurrence of severe summertime blooms, which have not been observed when the total phosphorus concentration is less than 50 µg/L. The Metro total phosphorus load has been a good predictor of summer average chlorophyll-a concentration of the upper waters, with decreases in chlorophyll-a observed as the phosphorus load has been reduced.

In lakes where phytoplankton production is limited by phosphorus, total phosphorus and chlorophyll-a are highly correlated. Data from regional lakes, including Onondaga, (Figure 5-4) illustrate this relationship and provide a valuable regional context. Data for the Finger Lakes represent results of a NYSDEC survey conducted between 1996 and 1999. The NYSDEC study design called for sampling each Finger Lake monthly between June and August at a single mid-lake station, with the exception of Cayuga Lake, which was sampled at three locations (Callinan 2001). Data for Onondaga and Oneida Lakes have been averaged over these same summer months in this presentation, for data comparability. Oneida Lake data were provided by the Cornell Biological Field Station (Lars Rudstam, personal communication, June 2011). Oneida Lake is notably shallower than the Finger Lakes, has a larger proportion of the bottom suitable for zebra mussels, and does not develop stable thermal stratification during the summer, features that may contribute to the observed deviations from the other lakes.

### *5.3.3 Secchi Disk Transparency*

A Secchi disk is a 25 cemtimeter diameter disk with alternating black and white quadrants. The depth at which it can no longer be seen is known as the Secchi disk transparency. Greater depth indicates clearer waters with lower concentrations of particles, often in the form of phytoplankton.

To meet swimming safety guidance, Secchi disk transparency greater than 1.2 meters (4 feet) is required at designated beaches. There is no New York State standard or guidance value for Secchi disk transparency for off-shore waters. Most lake monitoring programs in the state make Secchi disk measurements at a mid-lake station overlying the deepest water, comparable to the Onondaga Lake South Deep station. An improved aesthetic appeal target of a summer average Secchi disk transparency of 1.5 meters at South Deep (Table EX-1) was met in 2011 (Figure 5-3) . The Citizens Statewide Lake Assessment Program (CSLAP),a joint effort of NYSDEC and the NYS Federation of Lake Associations,

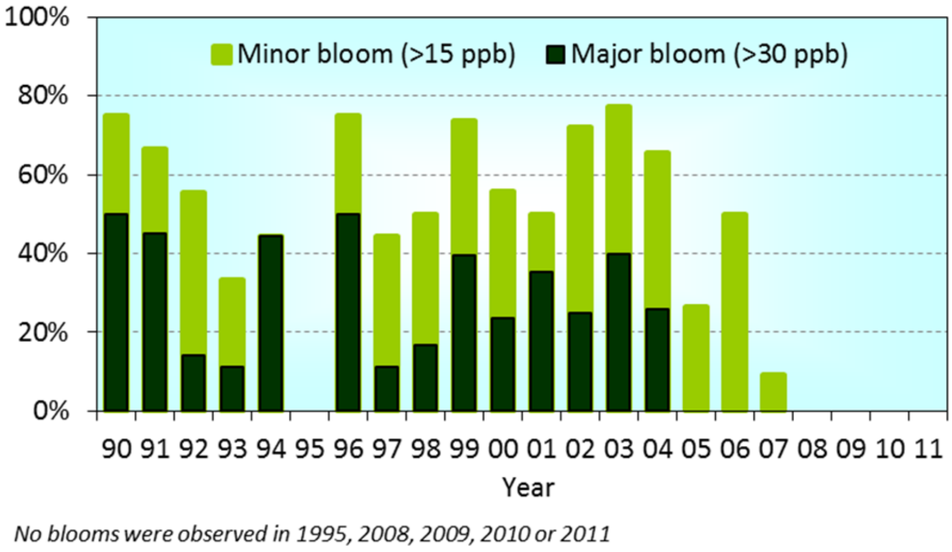


**Figure 5-2.** Summer (June to September) algal bloom percent occurrences in Onondaga Lake evaluated annually for the 1990 - 2011 period, based on chlorophyll-a measurements.

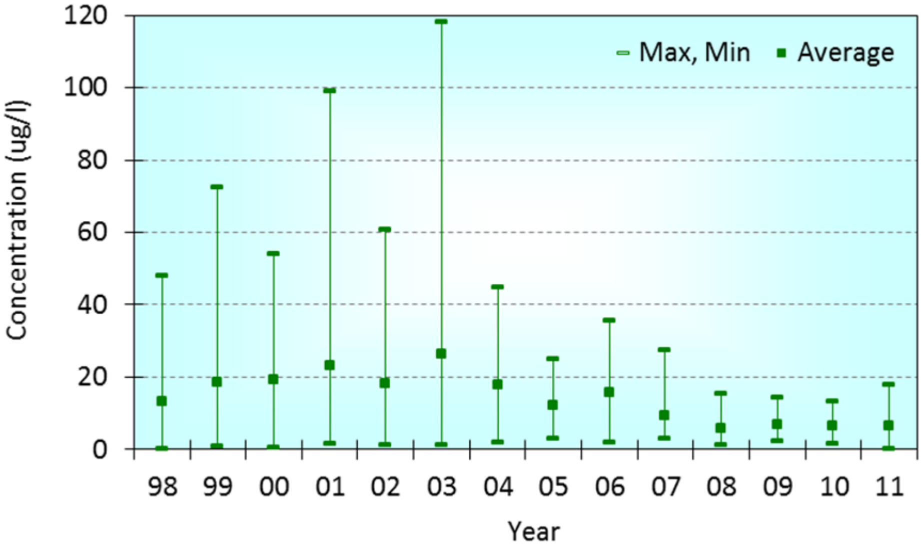


**Figure 5-3.** Chlorophyll-a concentration, January to December, 1998-2011.

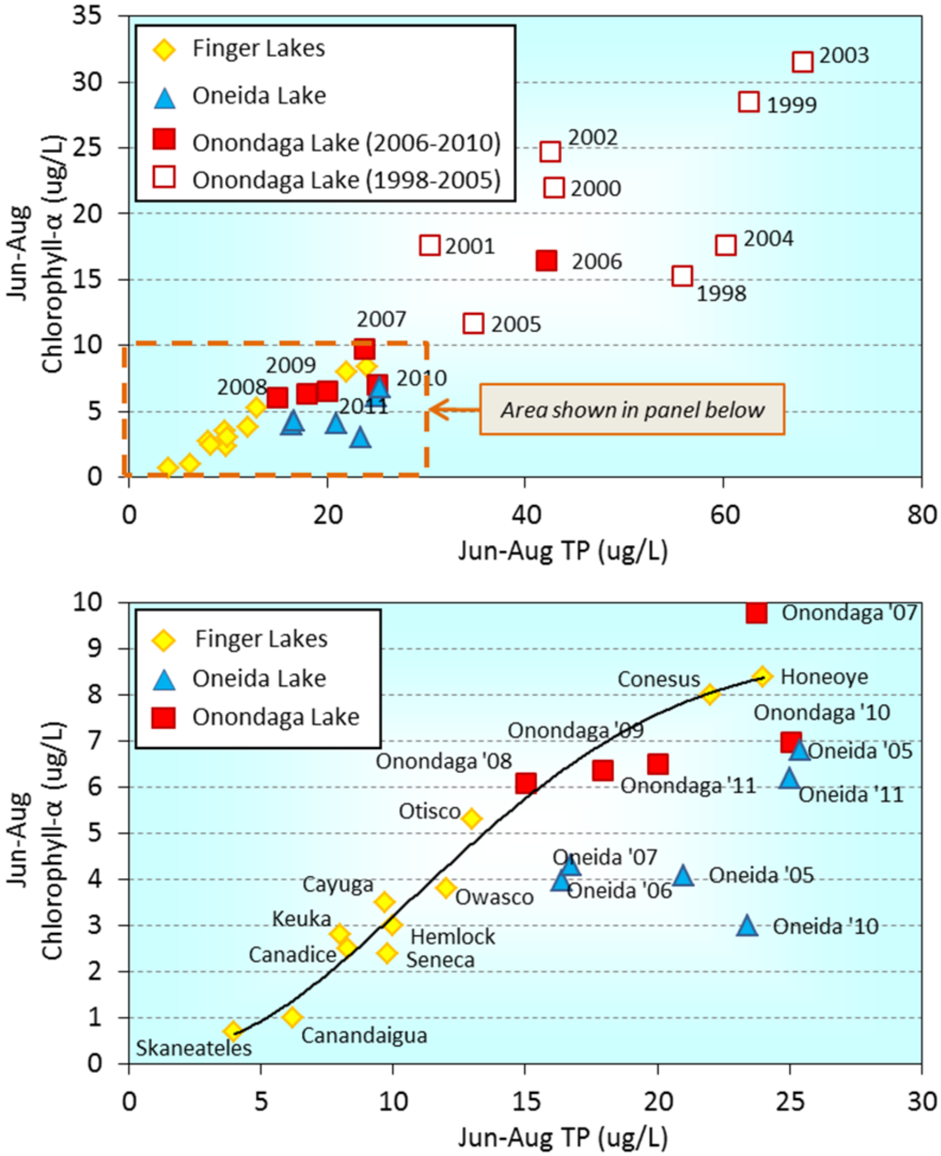


**Figure 5-4.** Summer (June to August) average total phosphorus (TP) and chlorophyll-a concentrations in Onondaga Lake compared with selected regional lakes.

Note: (a) The top panel shows Onondaga Lake concentrations pre-Actiflo® (1998-2005) and post-Actiflo® (2006-2011). (b) The bottom panel represents the same data, scaled to show the 2007-2011 Onondaga Lake data and a best-fit trendline ($R^2$ = 0.97) of the Finger Lakes concentrations (1996-1999), and Oneida Lake concentrations (2005-2011; Rudstam, 2012).

considers summer average Secchi disk transparency greater than 2 meters as indicative of mesotrophic conditions (Kishbaugh 2009). The average water clarity of Onondaga Lake was at this threshold for the summer of 2011, averaging 2.0 meters and ranging from 1.4 to 2.5 meters over the June to September interval (Figure 5.5). Results in 2011 were comparable to the water clarity conditions observed from 2007 to 2010.

In addition to Secchi disk transparency, the AMP includes measurements of light extinction that quantify light penetration using a *LiCor instrument and data logger*. These measurements correlate reasonably well with Secchi disk transparency measurements.

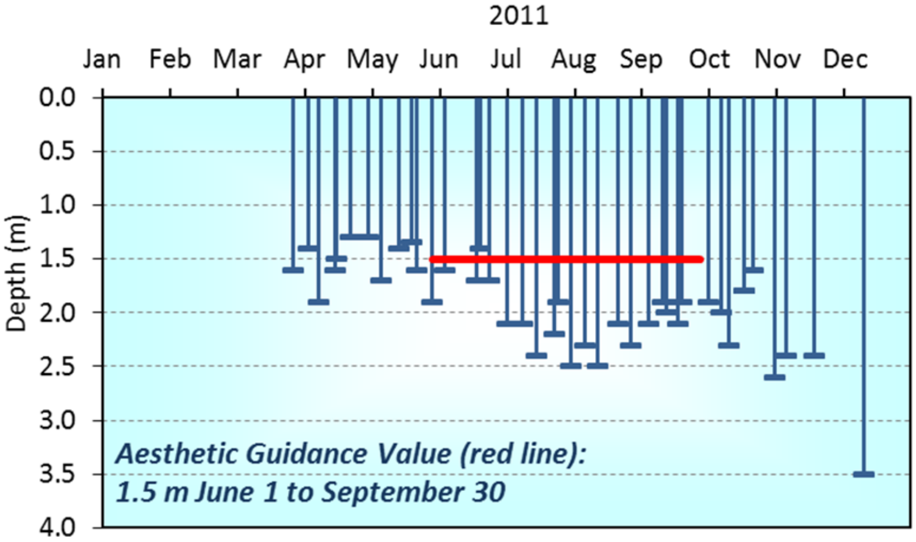
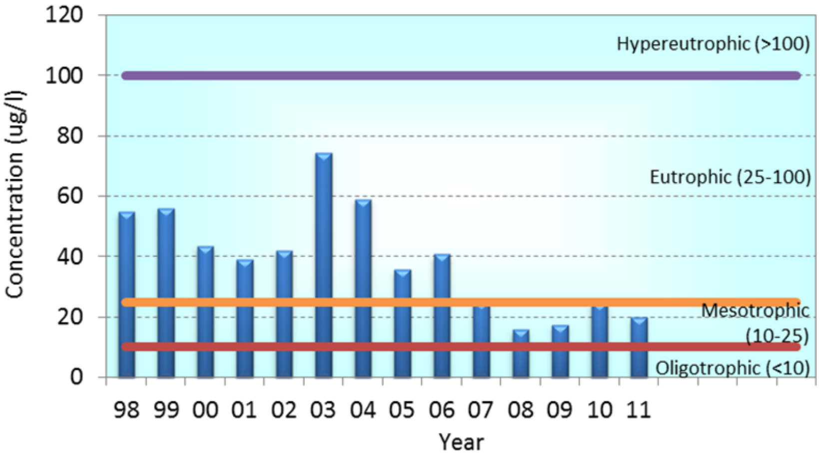


**Figure 5-5.** Secchi disk transparency, Onondaga Lake South Deep, 2011.

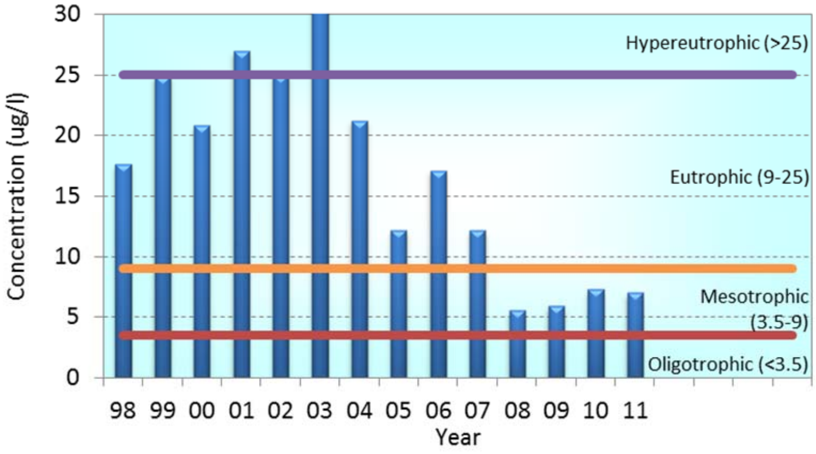
### 5.3.4 Trophic State Indicators

Summer (June 1 through September 30) average values of the three trophic state indicator parameters (total phosphorus, chlorophyll-a, Secchi disk transparency) are presented for the 1998-2011 interval (Figure 5-6). The 2011 results varied little from the 2010 observations. These trophic indicators are expressed relative to the trophic state boundary values presented by Cooke et al. (2005). Although the specific values of these trophic boundaries are somewhat subjective, they do serve as convenient general indicators of lake productivity. According to total phosphorus and chlorophyll-a, the trophic state of Onondaga Lake has shifted from eutrophy to mesotrophy since 2008. Secchi disk transparency was higher in 2008 and 2009 due grazing of particles by large *Daphnia.* However, no systematic improvement in Secchi disk transparency has been observed since 1998. This apparent inconsistency suggests that non-phytoplankton particles contributed to the relatively low Secchi disk transparency. Two factors likely contribute to this anomaly for Secchi disk versus total phosphorus and chlorophyll-a (Effler et al. 2008): (1) large inputs of inorganic particles, that also decrease clarity; and (2) the absence

a. Total Phosphorus (0-3m)



b. Chlorophyll-a (upper waters)



c. Secchi Disk Transparency

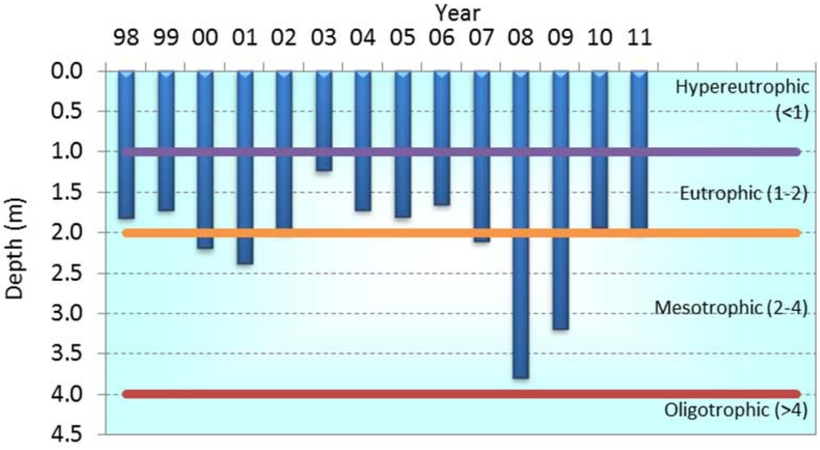


**Figure 5-6.** Time series of common trophic state indicators based on summer average (June 1 - September 30) data, 1998-2011.

of the grazing effects of larger zooplankton that efficiently consume/remove phytoplankton as well as non-phytoplankton particles. The mud boils on upper Onondaga Creek have contributed to the diminished water clarity of the lake, and therefore to the disparity in trophic state index (TSI) values calculated based on SD versus the other two metrics. As observed in 2010, efficient grazers of phytoplankton (i.e., *Daphnia*) continued to be essentially absent in 2011, consistent with the continuing large population of the alewife (see Section 6 for further discussion of these top-down effects).

## 5.4 Dissolved Oxygen

Adequate dissolved oxygen (DO) content is critical for aquatic life and a common focus of water quality monitoring. Frequent measurements of DO were made at depths of 2 meters and 12 meters at South Deep with a monitoring buoy over the spring to fall interval. A high priority goal for rehabilitation of the lake was elimination of severe depletion of DO in the upper waters during the approach to fall turnover in October (Figure 5-7), and contravention of the related AWQS. This was achieved through reductions in Metro loading of both ammonia (Figure 4-5) and total phosphorus (Figure 4-7). Other improvements in the lake's oxygen resources, particularly within the lower stratified layers (hypolimnion), have also been observed. Following the onset of summer stratification, these layers are subject to oxygen depletion, from decay of depositing constituents and demand from the underlying sediments. Decreases in deposition of phytoplankton from reductions in Metro phosphorus loading have resulted in lower rates of DO depletion, that has been manifested in delayed onset of anoxic conditions (Figure 5-8), and decreases in volume-days of anoxia (Figure 5-9). Since the Actiflo® process came on line in 2005, anoxia has been delayed for a period of several weeks in the lower waters. Some interannual variability is to be expected in this metric due to variations in the onset of stratification from natural meteorological variability. The implications of these improved conditions for the lake's fish community are discussed in Section 6.6.

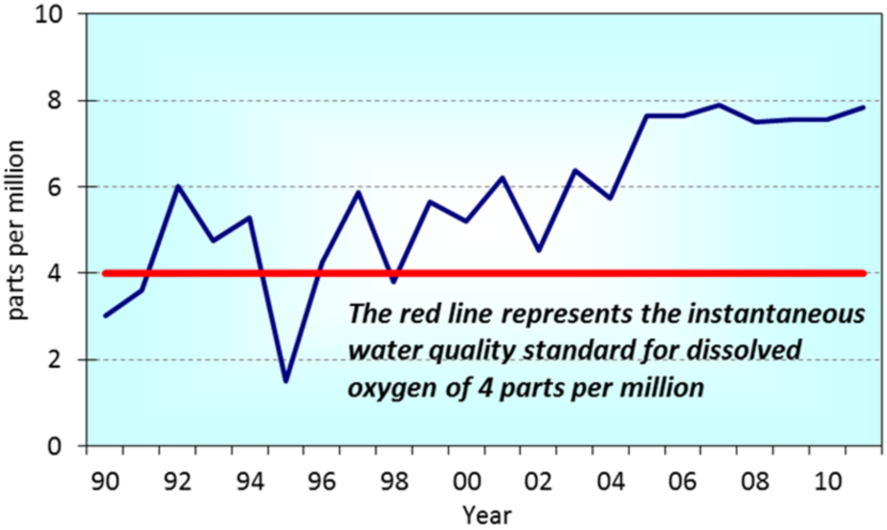


**Figure 5-7.** Minimum dissolved oxygen (DO) concentration in the upper waters (0-3 meters) of Onondaga Lake during October, annually 1990 – 2011.

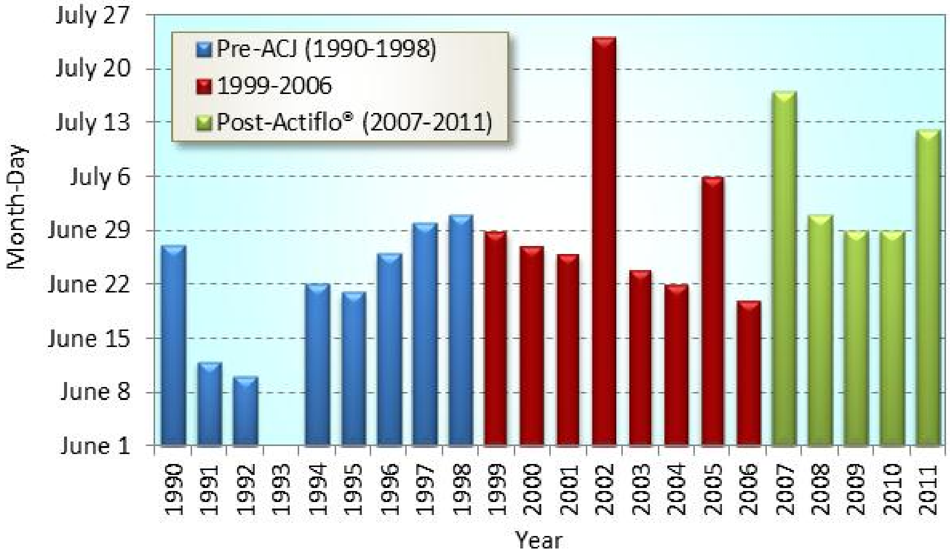


**Figure 5-8.** First date of measured anoxic conditions at 15m depth, Onondaga Lake, 1990 – 2011. No observation for 1993 because the lake failed to turnover in spring of that year.

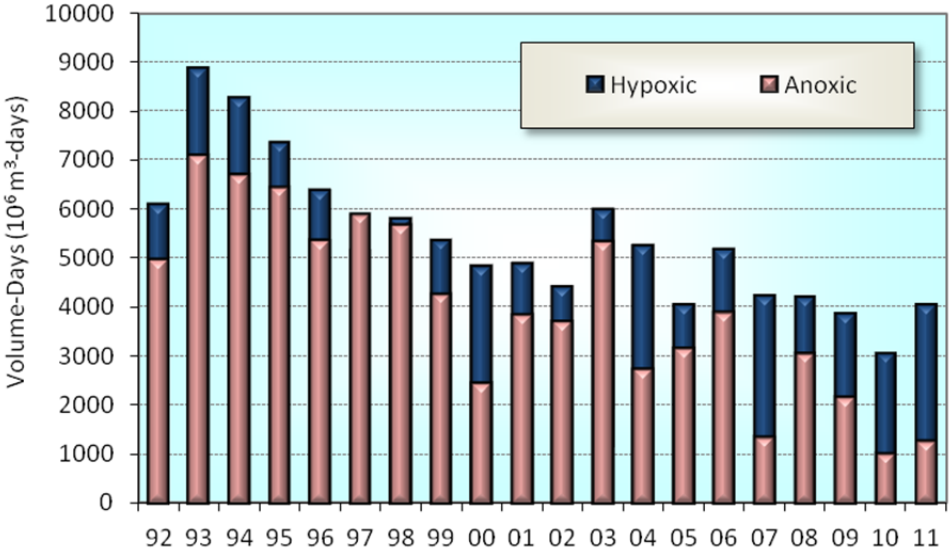


**Figure 5-9.** Volume-days of anoxia (dissolved oxygen less than 0.5 mg/L) and hypoxia (dissolved oxygen less than 2 mg/L), in Onondaga Lake during the summer, 1992-2011.

## 5.5 Ammonia, Nitrite, and Nitrate

Prior to the engineering improvements at Metro to bring about efficient year-round nitrification of wastewater, Onondaga Lake was impaired by elevated concentrations of ammonia ($NH_3$-N). Concentrations of this potentially harmful form of nitrogen exceeded the state ambient water quality standard for protection of aquatic life. Implementation of the BAF technology in 2004 reduced ammonia concentrations in the upper waters of the lake (Figure 5-10), enabling a more diverse biota. The lake is now in full compliance with the ambient water quality standards for ammonia (Table 5-3), and in 2008 was officially removed from the State's 303(d) list of impaired waterbodies for this water quality parameter.

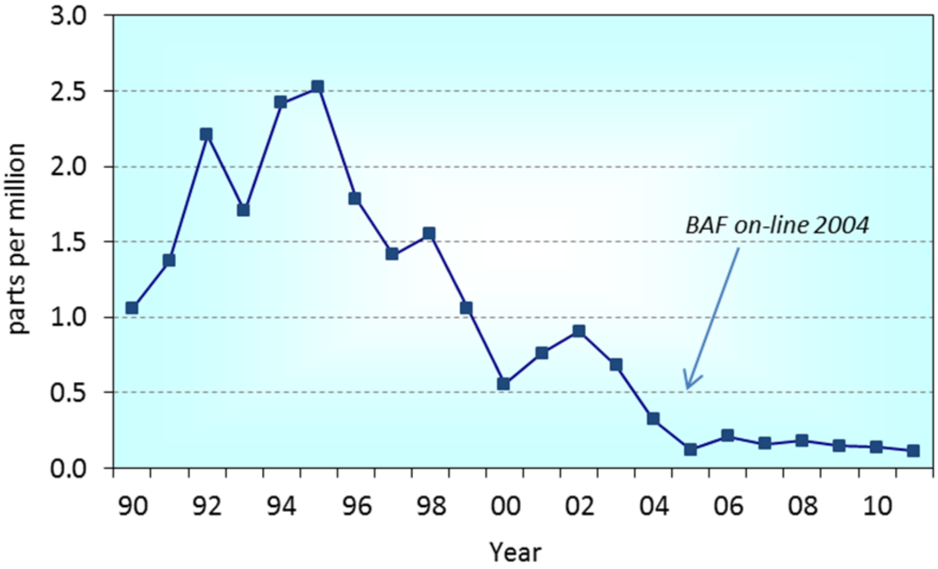


**Figure 5-10.** Annual average ammonia concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990-2011.

**Table 5-3.** Percent of ammonia measurements in compliance with ambient water quality standards, Onondaga Lake, 1998-2011.

| ***Depth (m)*** | ***Percent measurements in compliance, NYS standard*** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***1998*** | ***1999*** | ***2000*** | ***2001*** | ***2002*** | ***2003*** | ***2004*** | ***2005*** | ***2006*** | ***2007*** | ***2008*** | ***2009*** | ***2010*** | ***2011*** |
| 0 | 64 | 62 | 86 | 95 | 68 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 3 | 45 | 67 | 90 | 90 | 68 | 96 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 6 | 50 | 86 | 90 | 95 | 73 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 9 | 41 | 76 | 90 | 95 | 73 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 12 | 18 | 52 | 90 | 81 | 50 | 80 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 15 | 23 | 52 | 57 | 52 | 41 | 56 | 80 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 18 | 23 | 48 | 52 | 38 | 32 | 48 | 75 | 95 | 95 | 100 | 100 | 100 | 100 | 100 |

*6 NYCRR §703.5 Water quality standards for taste-, color- and odor-producing, toxic and other deleterious substances (http://www.dec.ny.gov/regs/4590.html#16130)

Nitrite ($NO_2$-N) concentrations also often exceeded the limit to protect against possible toxicity effects within the upper waters of the lake before the BAF upgrade at Metro. These exceedances were also eliminated with that treatment upgrade. Exceedances of the AWQS now only occur in the lower layers of the lake when hypoxia prevails (dissolved oxygen concentrations less than 2 mg/L). These conditions reflect incomplete nitrification within those lower lake depths. However, these exceedances are not limiting to fish habitat. Rather, the limiting condition is the low oxygen concentration in these lower layers during summer stratification. At oxygen levels required to support fish, these higher nitrite levels would likely not be observed because complete nitrification would occur.

Nitrate concentrations have increased in the lake since implementation of the biologically aerated filter that resulted in increased nitrate ($NO_3$-N) loading to the lake, associated with the year-round nitrification treatment. These changes have had some unintended benefits for the lake rehabilitation initiatives, including diminished release of phosphorus and mercury from the sediments during intervals of anoxia. In 2011, a whole-lake nitrate addition pilot test was conducted on behalf of Honeywell with the objective of limiting release of mercury from the deep-water sediments through maintenance of nitrate concentrations > 1 mg/L. This pilot test is scheduled to continue during the summers of 2012 and 2013.

## 5.6 Recreational Quality

The suitability of Onondaga Lake for water contact recreation is assessed using two parameters: fecal coliform bacteria (FC) and water clarity. Substantial increases in the input of bacteria and turbidity (causing reductions in clarity) often occur in both urban and agricultural areas during runoff events from the wash-off of pollutants from land surfaces and overflow of combined sewers. In New York, fecal coliform bacteria are used to indicate the potential presence of raw or partially treated sewage in water. Although most strains of fecal coliform bacteria are not harmful, this class of bacteria is present in the intestinal tract of all mammals; the presence and abundance of fecal coliform bacteria in water is correlated with the risk of encountering pathogenic (disease-causing) microorganisms, including bacteria, viruses, and parasites.

The applicable New York State ambient water quality standard for fecal coliform bacteria in surface water, as set forth in 6NYCRR Part 703.4, is as follows: for classes A, B, C, D, SB, SC - the monthly geometric mean concentration of fecal coliform bacteria (colony forming units, cfu, per 100 mL), from a minimum of five examinations, shall not exceed 200 cfu per 100 mL. The fecal coliform standard for classes B, C, D, and SB shall be met during all periods: (1) when disinfection is required for SPDES permitted discharges directly into, or affecting the best usage of, the water; or (2) when NYSDEC determines it necessary to protect human health.

This standard is used to assess bacterial contamination at nearshore locations (Figure 5-11) as well as at the open water sites North Deep and South Deep (refer to Figure 1-2). Bacteria levels in portions of the lake typically increase following significant rainfall, and concentrations often vary by orders of

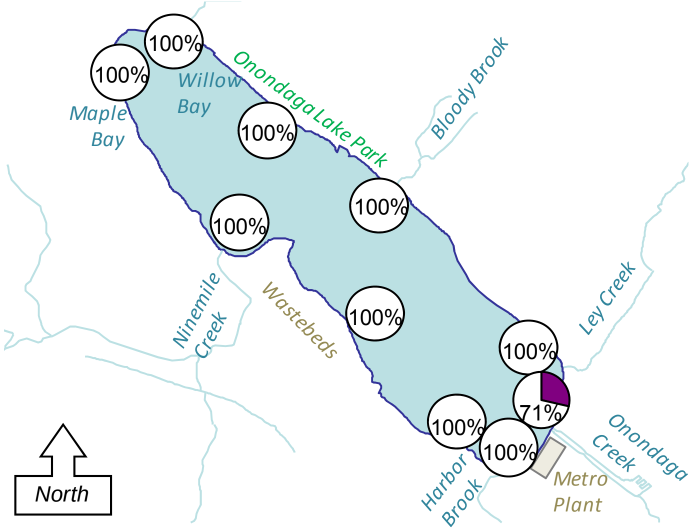


**Figure 5-11.** Fecal coliform bacteria results for nearshore stations in Onondaga Lake, April – October 2011.

*Note: Compliance is calculated for each location by comparing the monthly geometric mean of a minimum of five samples with the AWQS (200 cfu/100 mL).*

magnitude due to the event-driven nature of the sources. Consequently, geometric means are appropriate for examining spatial and temporal trends. In 2011, bacteria counts at the monitoring stations were less than the fecal coliform bacteria standard at all but one nearshore monitoring location within the Class C segment at the lake's southeastern shoreline (Figure 5-11). In addition, bacterial counts at the two offshore monitoring locations, North Deep and South Deep, were below the AWQS for fecal coliform bacteria during the 2011 assessment period. Water clarity is measured at the same network of near shore stations. While there is no NYSDEC standard for water clarity, the NYS Department of Health (DOH) has a swimming safety guidance value for designated bathing beaches of 4 ft. (1.2 m). The 2011 results demonstrate that the DOH swimming safety guidance value was met throughout the summer recreational period (June 1 to September 30) at all but one monitoring location in the Class B segment of the lake. This location, near the mouth of Bloody Brook, met the swimming safety guidance value on 19 of the 20 monitored days. Sediment inputs from the mud boils on upper Onondaga Creek likely contributed to the diminished water clarity in nearshore areas of the Class C segment in the southern portion of the lake.

## 5.7 Nearshore Trends

Onondaga County WEP has monitored near shore water quality conditions as part of the AMP since 2000. The monitoring program includes both routine sampling and sampling following storm events. Dr. William Walker completed a trend analysis of the water clarity and bacteria data through 2010. Both a full report of the analysis and a summary of the findings appeared in the annual report for 2010, in the form of a library and as a sub-section (5.7) of the main body of the 2010 report, respectively.

The data were segmented in that analysis according to runoff (wet versus dry) and portions in the lake. Noteworthy trends over the period that emerged from the analysis were (1) clarity increased in the near shore area (but more robustly represented by turbidity decreases), (2) fecal coliform levels were distinctly higher during wet weather, (3) decreases occurred in wet-weather fecal coliform levels at the southern stations and adjacent to Bloody Brook inflow, and (4) an increasing dry weather trend in bacteria levels prevailed in the southern nearshore areas adjacent to Harbor Brook and the Metro outfall. Metro outfall 001 consistently meets its SPDES limit for fecal coliform bacteria (ultraviolet disinfection system since 2004). These observations were generally supported by the 2011 program results. Outside of the two sites adjoining the Metro outfall (001) and the mouth of Onondaga Creek, summer monthly geometric means have not exceeded the regulatory limit over the 2003 – 2011 (nine-year) period.

## 5.8 Selected Lake Trends Coupled to Metro Improvements

The improvements to the Metro treatment plant have resulted in major reductions in ammonia and phosphorus loads to Onondaga Lake, and consistent decreases in the concentrations of these nutrients in the lake water (Table 5-3; Figure 4-9). Ammonia in 2011 met the AWQS at all depths (Table 5-3).

### *5.8.1 Indicators of Primary Production*

Primary production and concentrations of algal biomass have declined in response to the increased limitation to growth from the decreases in phosphorus loading from Metro. These changes are also manifested in the results of application of the two tailed seasonal Kendall test for the last 10 years (2002 – 2011) for a number of related parameters (Table 5-4). Significant decreasing trends in ammonia, TKN, total phosphorus, and soluble reactive P (SRP) were identified for both the upper and lower layers. Significant nitrite decreases have occurred in the upper waters. Decreases in metrics associated with algal biomass, including chlorophyll-a, total organic carbon and organic nitrogen, were identified for the upper waters (Table 5-4). The significant increase in nitrate over the same period, is a manifestation of the intentional increased discharge of this constituent associated with the Metro upgrade in treatment to year-round nitrification. Improvements in oxygen levels of the lower waters, associated with decreases in primary production, have also been identified through these statistical analyses. For example, the Seasonal Kendell test indicated increased lower waters dissolved oxygen levels at North Deep druing the 2002 – 2011 period (Table 5-4).

### *5.8.2 Phosphorus*

The paired time-series of the water year (October 1 to September 30) total phosphorus (TP) load estimates and summer average (June 1 to September 30) total phosphorus concentrations for the 1990 to 2011 period depict systematic decreases in loading (Figure 4-7) and in-lake concentrations (Figure 5-1) achieved by the upgrades in treatment at Metro (Figure 4-9). The water year time segmentation is more consistent with the specified summer interval of the in-lake total phosphorus guidance value than

**Table 5-4.** Summary of trends in lake concentrations during the 2002 to 2011 period, according to two-tailed Seasonal Kendall test.
See table footnotes for specifications of significance levels associated with the various symbols.

| Variable | | South Basin | | North Basin | | Lake Outlet | |
|---|---|---|---|---|---|---|---|
| | | *Upper Waters* | *Lower Waters* | *Upper Waters* | *Lower Waters* | *3.7 m* | *0.6 m* |
| Clarity | Secchi disk transparency | ↑ | -- | ○ | -- | -- | -- |
| Bacteria | Fecal coliforms | ↓ | ○ | ○ | ○ | ○ | ○ |
| Nitrogen | Ammonia ($NH_3$-N) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| | Nitrite ($NO_2$-N) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| | Nitrate ($NO_3$-N) | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Organic nitrogen as N | ↓ | ○ | ↓ | ○ | ↓ | ↓ |
| | Total Kjeldahl nitrogen as N (TKN) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| Phosphorus | Total phosphorus (TP) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| | Soluble reactive phosphorus (SRP) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| Solids | Total solids (TS) | ○ | ○ | ○ | ○ | ○ | ○ |
| | Total suspended solids (TSS) | ↓ | ○ | ○ | ○ | ○ | ○ |
| | Total dissolved solids (TDS) | ○ | ○ | ↓ | ○ | ↓ | ↓ |
| | Volatile suspended solids (VSS) | ○ | ○ | ○ | ○ | ○ | ○ |
| Chlorophyll | Chlorophyll-a | ↓ | ○ | ↓ | ○ | -- | -- |
| | Phaeophytin-a | ↓ | ○ | ○ | ○ | -- | -- |
| Carbon | Total organic carbon (TOC) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| | Total organic carbon, filtered (TOC-F) | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ |
| | Total inorganic carbon (TIC) | ↓ | ↓ | ○ | ○ | ○ | ○ |
| Other | Alkalinity as $CaCO_3$ | ○ | ○ | ○ | ○ | ○ | ○ |
| | Calcium (Ca) | ○ | ○ | ○ | ○ | ○ | ○ |
| | Chloride (Cl) | ○ | ○ | ○ | ○ | ○ | ↓ |
| | Conductivity | ○ | ○ | ○ | ○ | ○ | ↓ |
| | Dissolved oxygen (DO) | ○ | ○ | ○ | ↑ | ↑ | ○ |
| | Hardness | ○ | ○ | ○ | ○ | ○ | ○ |

**Table 5-4.** Summary of trends in lake concentrations during the 2002 to 2011 period, according to two-tailed Seasonal Kendall test.
See table footnotes for specifications of significance levels associated with the various symbols.

| Variable | South Basin | | North Basin | | Lake Outlet | |
|---|---|---|---|---|---|---|
| | *Upper Waters* | *Lower Waters* | *Upper Waters* | *Lower Waters* | *3.7 m* | *0.6 m* |
| Magnesium (Mg) | ↓ | ○ | ↓ | ○ | ↓ | ↓ |
| Sodium (Na) | ○ | ○ | ○ | ○ | ○ | ○ |
| pH | ○ | ○ | ○ | ○ | ↑ | ↑ |
| Silica ($SiO_2$) | ↑ | ○ | ○ | ○ | ○ | ○ |
| Sulfate ($SO_4$) | ↓ | ↓ | ○ | ↓ | ↓ | ↓ |
| Temperature | ○ | ○ | ○ | ○ | ○ | ○ |

*Notes:*
Significance level of two-tailed Seasonal Kendall test accounting for serial correlation.
↓ indicates decreasing trend ($p < 0.1$)
↑ indicates increasing trend ($p < 0.1$)
○ indicates no trend ($p > 0.1$)

an annual load. The external loads have been partitioned between the contributions of Metro and the tributaries in this presentation (Figure 4-9). Dominance of the external total phosphorus load has shifted from Metro to the tributaries over this period.

Empirical analysis according to linear least-squares regression demonstrates that changes in Metro loads explained 75% ($R^2 = 0.75$) of the observed variations in the summer average total phosphorus concentration of the upper waters (Figures 5-12a). The relationship becomes substantially weaker ($R^2 = 0.37$) when tributary contributions are included in the independent variable (Figure 5-12b). Multiple factors contribute to the weaker empirical model from inclusion of tributary contributions, including (1) disproportionately large inputs of total phosphorus from tributaries during intervals of the year that do not contribute substantively to in-lake total phosphorus concentrations during summer, (2) large interannual variations in tributary total phosphorus loading associated with natural variations in runoff, and (3) differences in the in-lake behavior of tributary phosphorus inputs compared to those from Metro. The relationship based on total phosphorus loads (includes tributaries) deteriorated substantially from the 2010 report ($R^2 = 0.53$) because of the particularly high tributary total phosphorus load associated with high runoff in 2011.

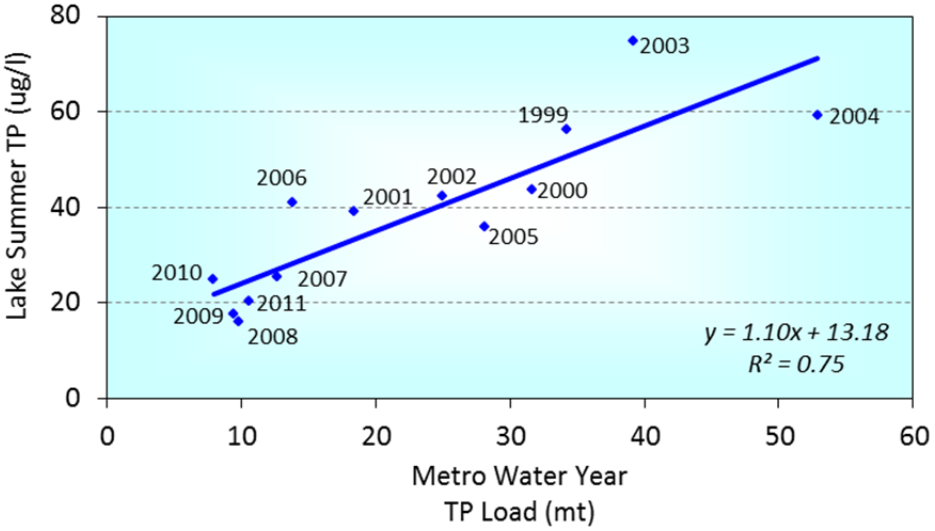
### *5.8.3 N to P Ratio*

The relative concentration of various nutrients is ecologically important in influencing the composition of the phytoplankton community. Such considerations have water quality management implications, particularly with respect to achieving the goal to avoid proliferation of cyanobacteria, that can cause nuisance, and potentially toxic, conditions when present in high concentrations. The maintenance of high nitrogen to phosphorus ratios (N:P) in the upper productive layers of Onondaga Lake has been a long-term management strategy to discourage such nuisance conditions. Data from a wide range of temperate lakes suggests that a total N:P ratio (TN:TP) of 29:1 (by mass) differentiates between lakes with cyanobacteria dominance (TN:TP<29:1) and lakes without such dominance (TN:TP>29:1; Smith 1983). The time series of the summer average (June 1-September 30) N:P ratio, represented as the ratio of total N to total P (TN:TP), for the upper waters is presented for the 1998-2011 period (Figure 5-13). Total nitrogen (TN) was calculated as the sum of total Kjeldahl N (TKN; organic nitrogen plus ammonia), nitrite and nitrate.

The TN:TP ratio has remained above the literature N:P threshold for cyanobacteria dominance for the entire 1988 to 2011 period. The major increases since 2007 reflect the effects of systematic decreases in total phosphorus from the Metro Actiflo upgrade, with mostly unchanging TN concentrations. This representation of the N:P ratio conditions is in fact quite conservative, as the TN pool is dominated by dissolved forms while most of the total phosphorus pool in the upper waters of the lake is usually in particulate form and not available to support algae growth. The common occurrence of dense populations of filamentous cyanobacteria in summer from the late 1980s to early 2000s was likely due to a combination of lower N:P ratios and higher levels of P pre-2000. Large cyanobacteria are better competitors when P levels are high both because they can get large enough to be inedible to grazers like

*Daphnia*, and because they can regulate their buoyancy and better compete for light that can be limiting at high nutrient concentrations.

**a. Lake TP Concentration vs Metro TP Load**



**b. Lake TP Concentration vs Total TP Load**

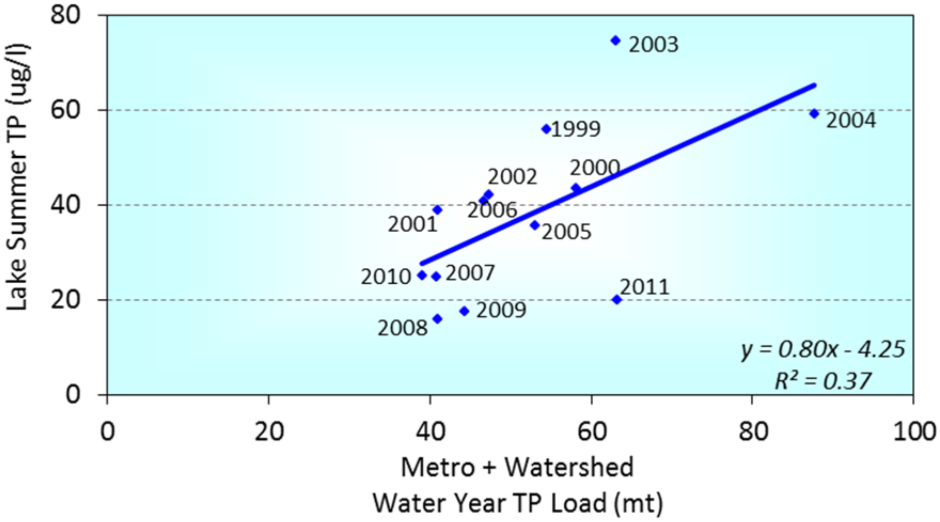


**Figure 5-12.** Relationship between summer average lake total phosphorus (TP) concentrations (0-3 meters, June to September) for the 1999 to 2011 period.

Note: (a) Metro total phosphorus loading (based on water year) and (b) total (Metro + tributary) total phosphorus loading (based on water year).

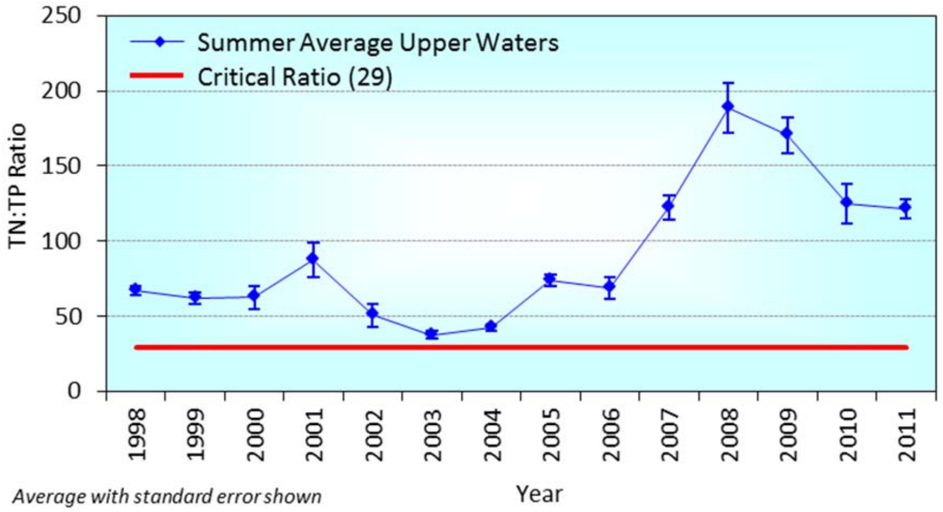


**Figure 5-13.** Summer average ratio of total nitrogen to total phosphorus (N:P, by weight) in the upper waters of Onondaga Lake, 1998-2011. Error bars represent plus and minus 1 standard error.

### *5.8.4 Deep Waters*

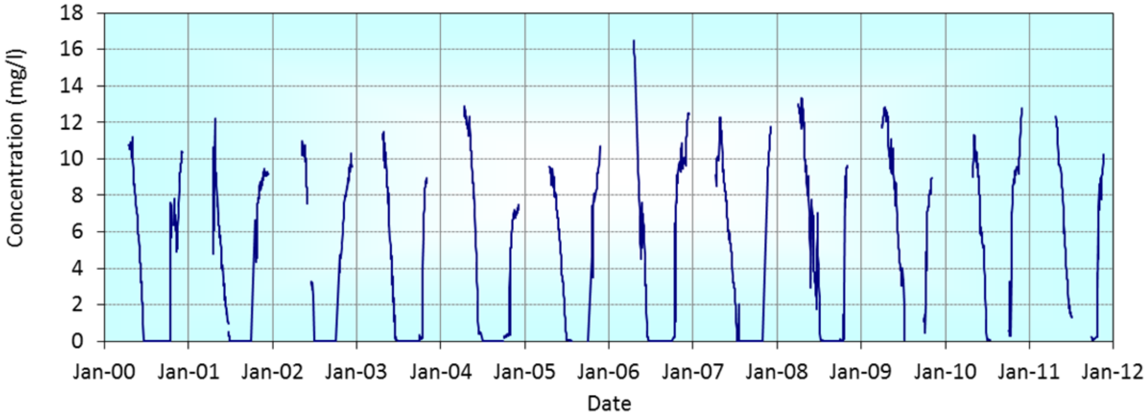
The upgrades in treatment at Metro have resulted in profound changes in the lower waters of the lake, in addition to those described previously, associated with both the decreased loading of phosphorus and the increased inputs of nitrate (instead of ammonia). The improvements from reduced phosphorus loading were anticipated, following a well-established logic pattern for rehabilitation of culturally eutrophic lakes. Accordingly, reductions in phosphorus loading are expected to decrease algae production and its associated deposition into the lower stratified layers, and thereby decrease the oxygen demand associated with its decay. This has been manifested in the delayed onset of anoxia to later in summer, described previously. This would be expected to translate to some reduction in the subsequent release of soluble reactive phosphorus (SRP) from the sediments, which can act to augment phytoplankton growth in the upper waters (mediated by mixing processes). The operation of this sediment release process for phosphorus in the lake following the onset of anoxia is clearly depicted through the paired time series of dissolved oxygen (Figure 5-14a, 15 meter depth) and soluble reactive phosphorus (Figure 5-14b, 15 meter depth) for the lower waters.

The increased in-lake concentrations of nitrate have further diminished phosphorus release from the sediments, because this constituent serves as an effective electron acceptor (redox status) to support the decay of organic material. This constituent is favored, after depletion of oxygen, over other redox species, including iron, with which phosphorus release is associated. Thus maintenance of nitrate in the hypolimnion serves to effectively block the release of phosphorus from the sediments. The addition of nitrate to the time-series (Figure 5-14b) demonstrates the temporal coupling of nitrate depletion and sediment phosphorus release. The extent of temporal coupling would likely be enhanced if nitrate concentrations were available from the 15 m depth rather than the lower water layer (LWL). Note that the decrease in sediment P release has been in response to both the decrease in primary production from the Metro phosphorus treatment upgrade and the increase in nitrate from the facility's year-round nitrification. Some interannual variations are to be expected due to differences in the duration of stratification and ambient mixing associated with natural meteorological variations. Moreover, the supply of nitrate to the lower waters in summer is now being augmented by Honeywell as a test of a strategy to control sediment release of mercury. Low sediment release rates of phosphorus during this three year (2011 to 2013) pilot test are a reasonable expectation (Figure 5-14b).

## 5.9 All Other Parameters

The summary of findings for all monitored parameters monitored in the lake in 2011 appears in the library.

**(a). Dissolved Oxygen, 15m (daily average)**



**(b). Nitrate and SRP, lower waters**

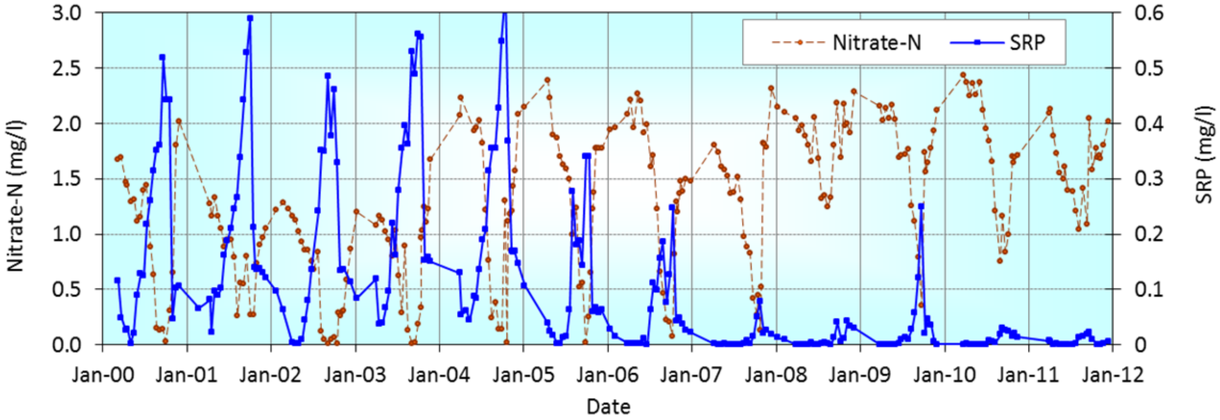


**Figure 5-14.** Time-series of concentration values in the deep waters of Onondaga Lake, 2000 to 2011:

Note: (a) daily average dissolved oxygen concentrations at 15 meters depth, and (b) lower water layer (LWL) nitrate concentrations and soluble reactive phosphorus concentrations from 15 meters depth.

## Section 6. Biology and Food Web: 2011 Results and Trends

In this section of the Annual Report the extensive AMP data describing the phytoplankton**,** macrophyte, zooplankton, dreissenid mussel and fish communities that form the Onondaga Lake food web are reviewed.

As phosphorus concentrations in Onondaga Lake have declined to mesotrophic levels, biological conditions have responded. Improved light penetration, a consequence of lower algal abundance, has contributed to expansion of macrophyte beds. This expanded coverage of macrophytes throughout the littoral zone has improved habitat and shelter for fish and other aquatic organisms.

### 6.1 Primary Producers- Algae and Macrophytes

Since the late 1990s, the biomass of phytoplankton, which includes algae and cyanobacteria, in Onondaga Lake has declined rapidly, from a standing crop around 8 mg/L in 1998-99 to less than 1.5 mg/L after 2007. Algal biomass has increased slightly from 2008 levels, although the results for 2011 (April-October) are similar to the previous two years at 1.27 mg/L (Figure 6-1). These results are consistent with the discussion of trends in chlorophyll-a and water clarity presented in Section 5. There is a strong correlation between spring total P and algal abundance (as measured by chlorophyll-a) in the summer months that follow.

Phytoplankton abundance in 2011 was similar to that measured in 2009 and the average algal biomass for April-October remained well below that expected for a meso-eutrophic lake (3-5 mg/L, Wetzel 2001) (Figure 6-1). Peak algal biomass did not exceed 3.0 mg/L again in 2011, confirming the lake's mesotrophic status. Over the last decade, phytoplankton biomass has declined significantly, and the years from 2007 to 2011 were the five lowest years on record. This decline is likely due to the reduced phosphorus loading from Metro. In 2008 and 2009, algal biovolume was also affected by grazing from large zooplankton and likely mussels. Large zooplankton were rare in 2011 and algal biomass increased marginally compared to 2009.

The composition of the phytoplankton community has changed from one dominated by undesirable cyanobacteria (blue-greens) and pyrrhophytes (dinoflagellates) to one dominated by more desirable diatoms and chlorophytes (green algae) (Figure 6-2). Diatoms (Bacillariophyta) continued to dominate the phytoplankton community and showed two peaks, a spring peak in May-early June and a fall peak in October (Figure 6-2 and Figure 6-3). *Diatoma* and *Synedra* were common genera in June and *Cyclotella* in the fall. The other genera of phytoplankton dominant in 2010 remained common in the 2011 assemblage.

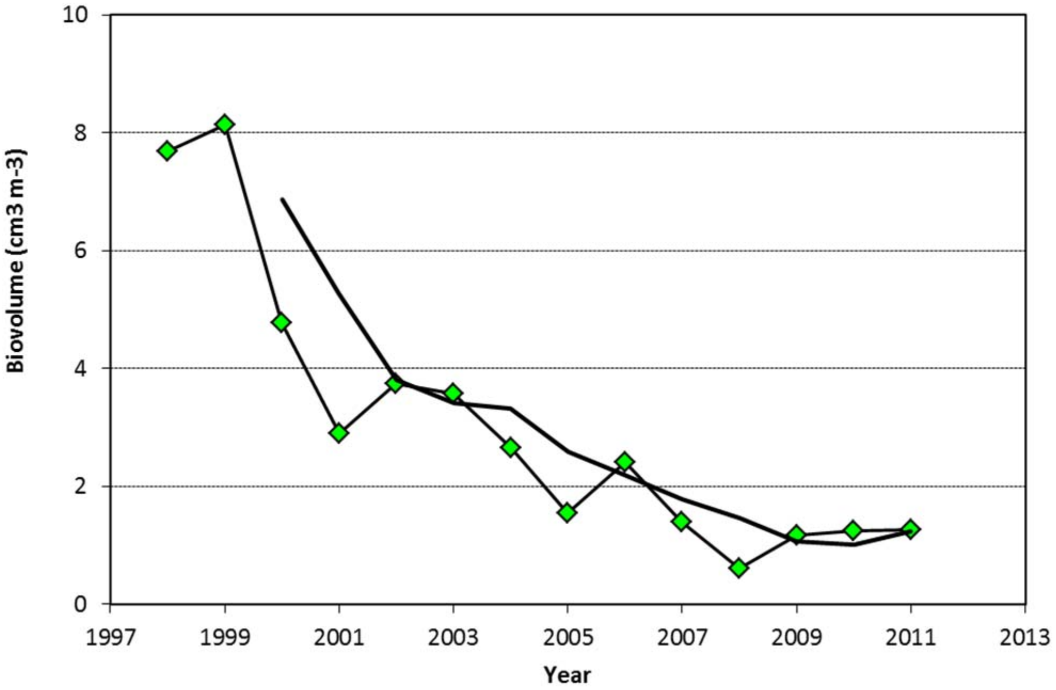


**Figure 6-1**. Onondaga Lake phytoplankton standing crop, 1998-2011. The heavy line is a 3 point moving average.

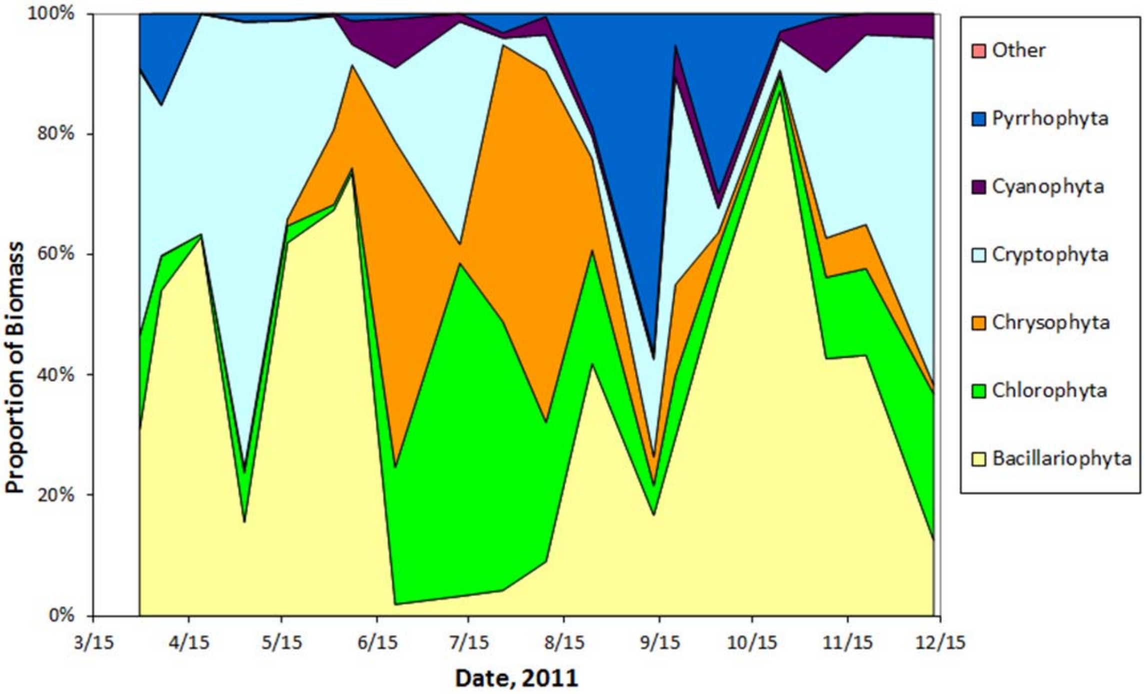


**Figure 6-2**. Proportional biomass of phytoplankton divisions, 2011.

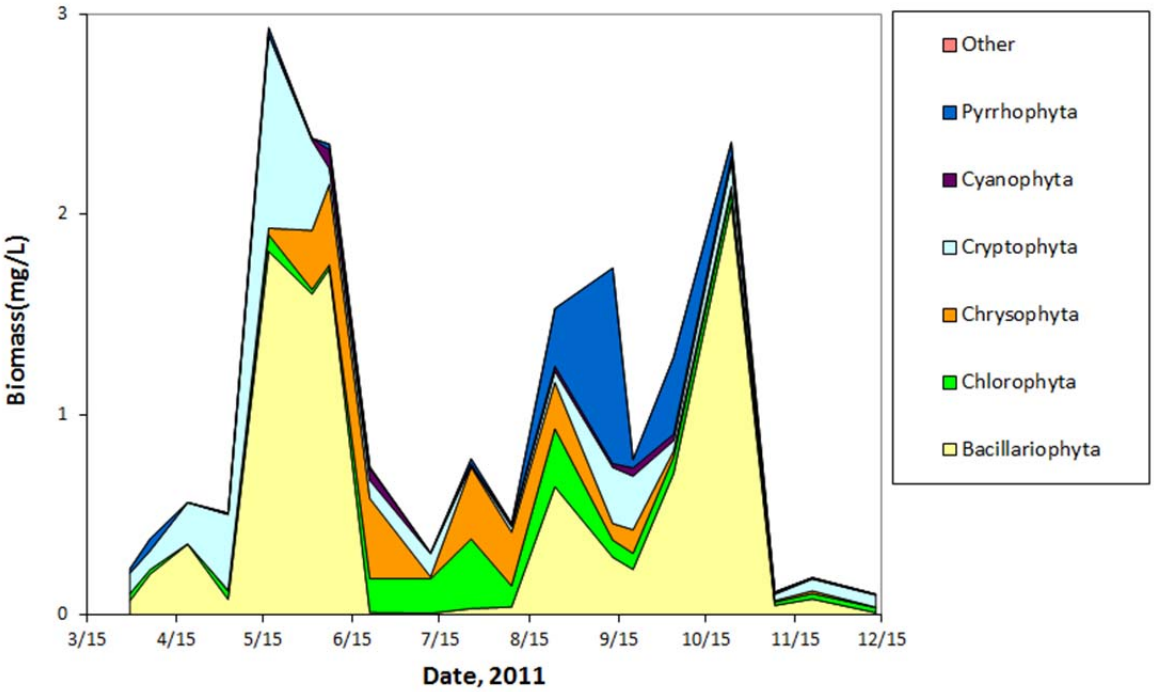


**Figure 6-3**. Phytoplankton community structure and biomass, 2011.

Cyanobacteria and dinoflagellates, which dominated the phytoplankton community in Onondaga Lake until 2001, have now nearly disappeared from the lake, and nuisance blooms of Aphanizomenon (*A. gracile* and *A. flos-aquae*), which were typical of summers before 2000, no longer occur. The species of cyanobacteria remaining in the lake are smaller in size, and peak cyanobacteria abundance reached only 0.09 mg/L in 2011, slightly higher than in 2010 but still quite low.

Along with phytoplankton, aquatic macrophytes (plants) also are an important component of lake ecology; the rooted plants and algae have major effects on productivity and biogeochemical cycles. Macrophytes produce food for other organisms and provide habitat for aquatic invertebrates, fish, and wildlife, and help to stabilize sediments. As part of the ACJ, the AMP includes extensive sampling of the macrophyte community every five years (2000, 2005, and 2010) to complete a species list and document changes in biomass. Aerial photographs of the littoral zone are collected annually (when water clarity allows) to determine plant distribution.

The macrophyte community within the littoral zone in 2011 was similar in coverage as the previous two years with approximately half of the littoral zone covered (Figure 6-4). The improved water clarity, allowing more light to penetrate to the bottom in inshore areas, has led to a trend of increasing colonization by macrophytes (Figure 6-5). Throughout the past decade macrophyte coverage has expanded to cover approximately five times more of the littoral zone based on annual aerial photographs providing more complex habitat for many aquatic organisms.

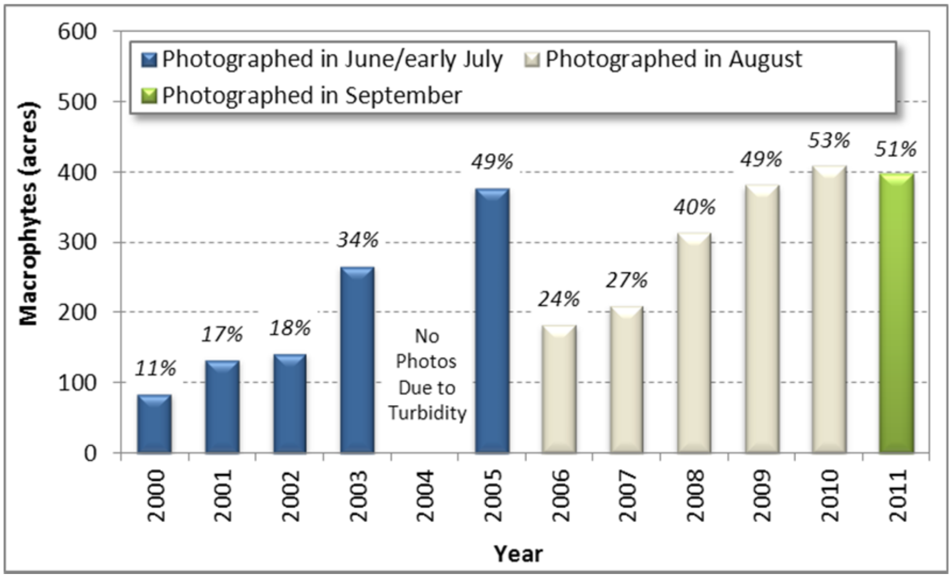


**Figure 6-4**. Macrophyte distribution, 2000 – 2011.

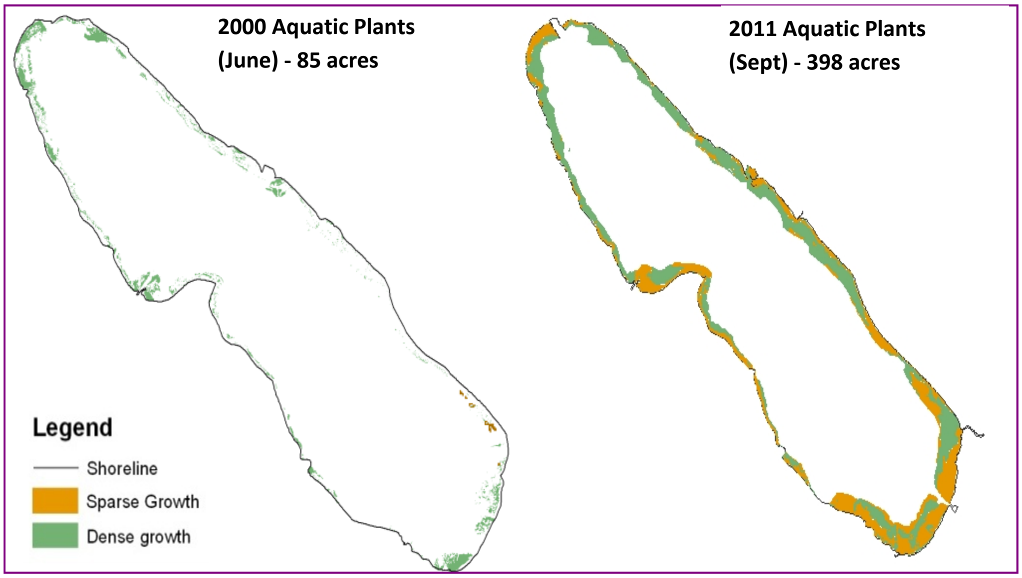


**Figure 6-5**. Aquatic plant coverage, 2000 and 2011.

The aerial photos do not enable species identification, only percent cover. The AMP team completes limited field surveys of the macrophyte community the week of the aerial flights; this field program is used to verify the estimates of relative abundance and assess the species composition.

## 6.2 Zooplankton and Dreissenid Mussels

The zooplankton community is a pivotal component of the lake ecosystem; these grazing aquatic animals affect the abundance and species composition of the phytoplankton community, and are, in turn, affected by the fish community. The size structure and abundance of the Onondaga Lake zooplankton community is tracked annually as part of the AMP. In Onondaga Lake, zooplankton and benthic mussels are the most important grazers of phytoplankton.

The size structure of the zooplankton community (*i.e.*, the relative abundance of small and large species), is a consequence of the grazing pressure exerted on zooplankton by fish. The temporal changes in the zooplankton community are linked to changes in predation by the dominant fish planktivore in the lake, alewife (*Alosa pseudoharengus*) (Wang et al. 2010). In general, alewife tend to feed on larger zooplankton species leaving smaller zooplankton alone. When alewife populations are high, the population of larger zooplankton species declines. In the absence of alewife predation, the population of larger zooplankton species increases, as illustrated in Figure 6-6. This in turn affects the phytoplankton community, as larger zooplankton are far more efficient grazers than the smaller zooplankton; the presence of larger organisms results in less algae and clearer waters (Figure 6-7).

The average biomass of zooplankton samples collected in Onondaga Lake (as measured in dry weight) was the lowest recorded in the time series during April-October 2011 (60 µg/L). The peak zooplankton biomass, evident in early July 2011, was 227 µg/L. During this period of peak biomass, the zooplankton community was dominated by taxa in the family Bosminidae, which are small crustacean species (Figure 6-8). The low biomass of the larger zooplankton, *Daphnia*, between 2003 and 2007 and then again in 2010 and 2011 (Figure 6-9) is attributed to the presence of abundant alewife during these time periods.

The data from Onondaga Lake clearly indicate that selective predation of larger zooplankton by fish has a direct effect on the species composition and size structure of the zooplankton community. The significance of alewife on this process is striking. The average size of the total zooplankton community in Onondaga Lake during periods of higher alewife abundance (2003-2007) was 0.33 mm (Figure 6-10). In 2011, another year with high alewife abundance, the average size of the zooplankton community was 0.27 mm, which is the smallest average size in the dataset (Figure 6-10). In the spring of 2011, the alewife community was dominated by age 1 and 2 year old fish (2009 and 2010 year classes). Spring biomass in 2010 and 2011 was substantially higher than in the spring of 2008 and 2009 when *Daphnia* were still abundant. The 2009 and 2010 year classes affected the zooplankton community resulting in the small sized zooplankton observed throughout 2010 and 2011 (Figure 6-11).

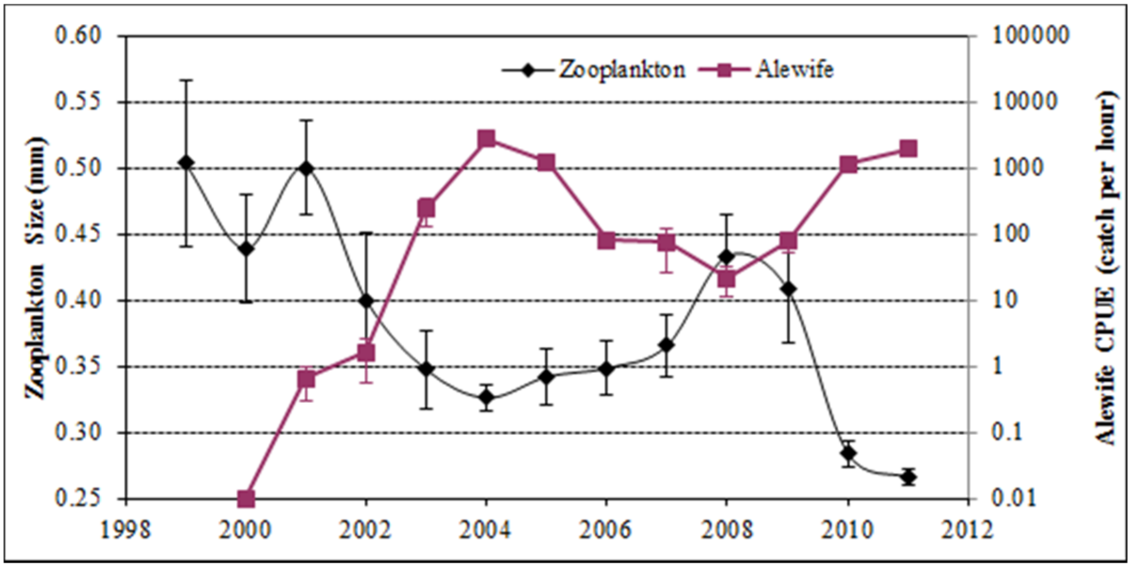


**Figure 6-6**. Average zooplankton size (all taxa combined) and alewife catch rates from electrofishing, growing season 2000-2011, Onondaga Lake.
*Note: error bars are standard error of the mean.*

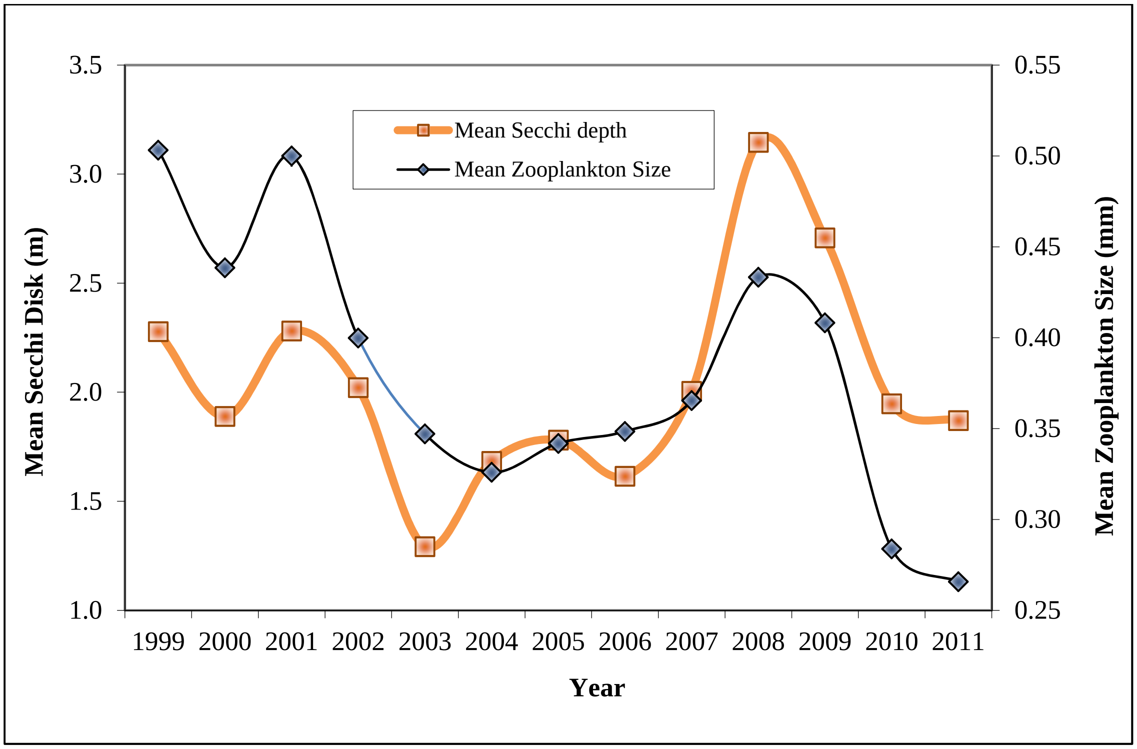


**Figure 6-7.** Mean Secchi disk depth measurements and mean zooplankton size, Onondaga Lake, growing season 1999 – 2011.

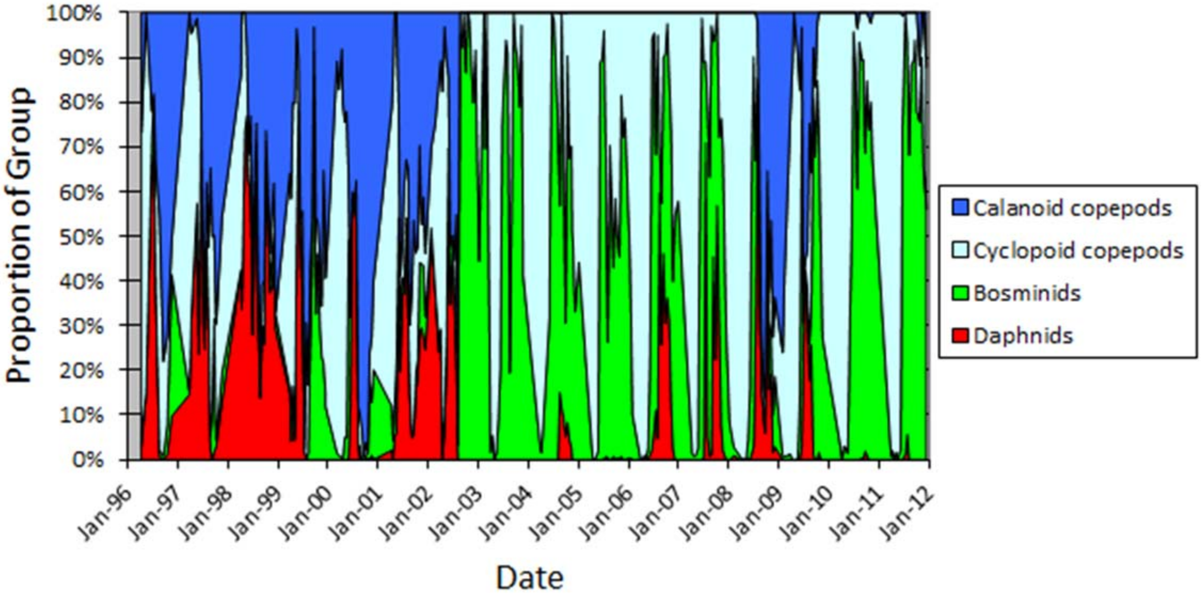


**Figure 6-8**. Average biomass of zooplankton, proportion of major groups. Calanoid copepods and Daphnids are large taxa and Cyclopoid copepods and Bosminids are relatively small.

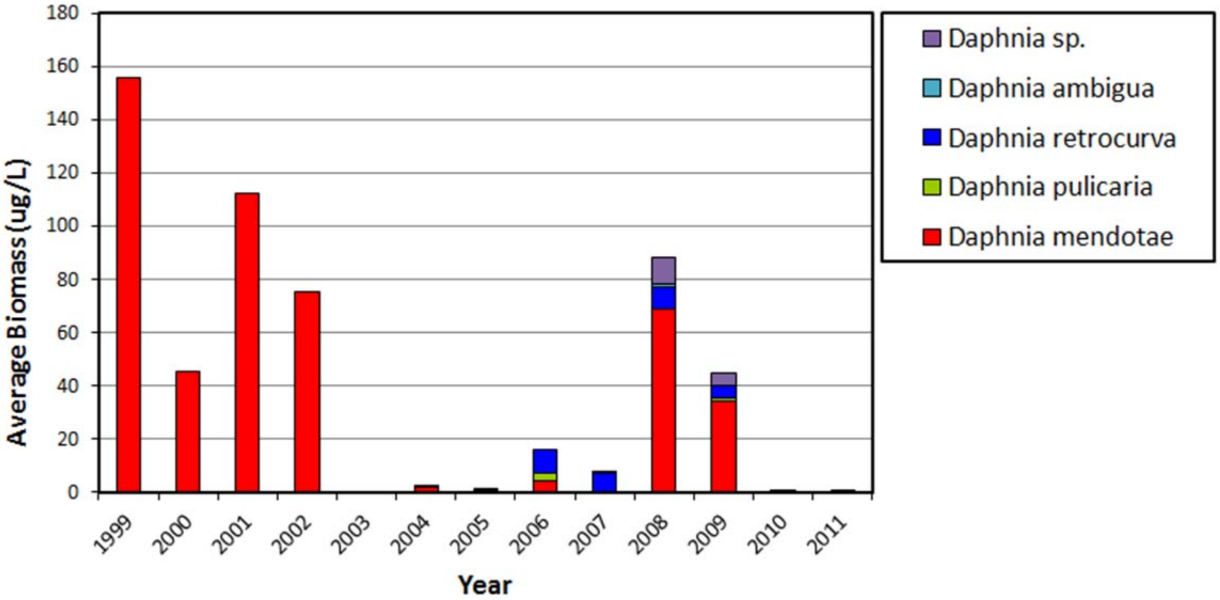


**Figure 6-9**. Biomass of various *Daphnia* species during the growing season in Onondaga Lake.

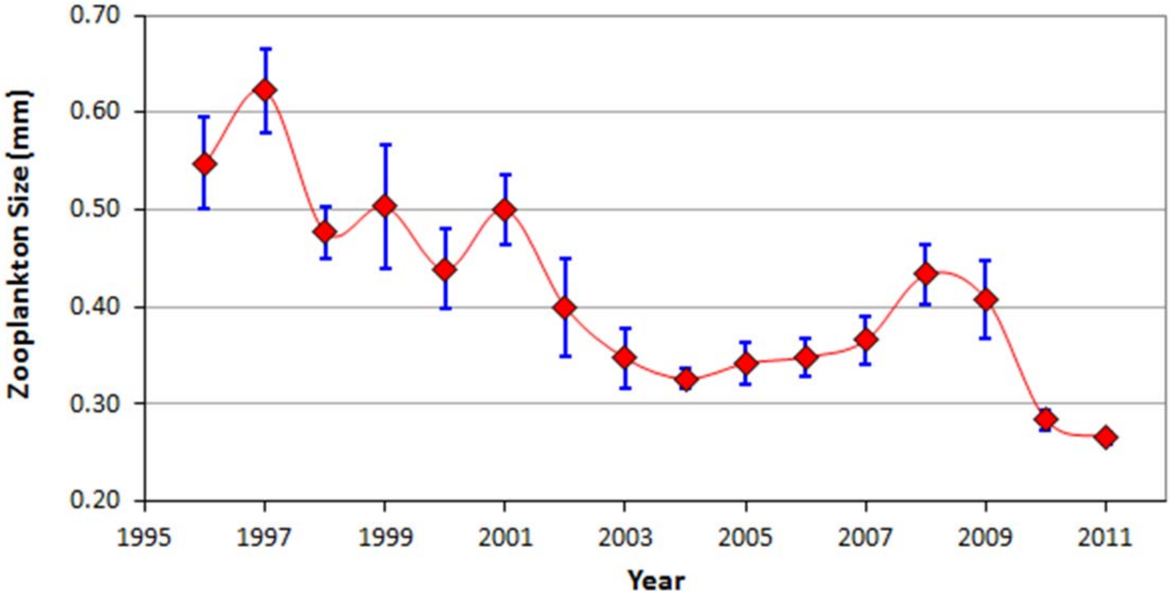


**Figure 6-10**. Average size of all crustacean zooplankton in Onondaga Lake during the growing season, 1996 – 2011. Error bars represent standard error.

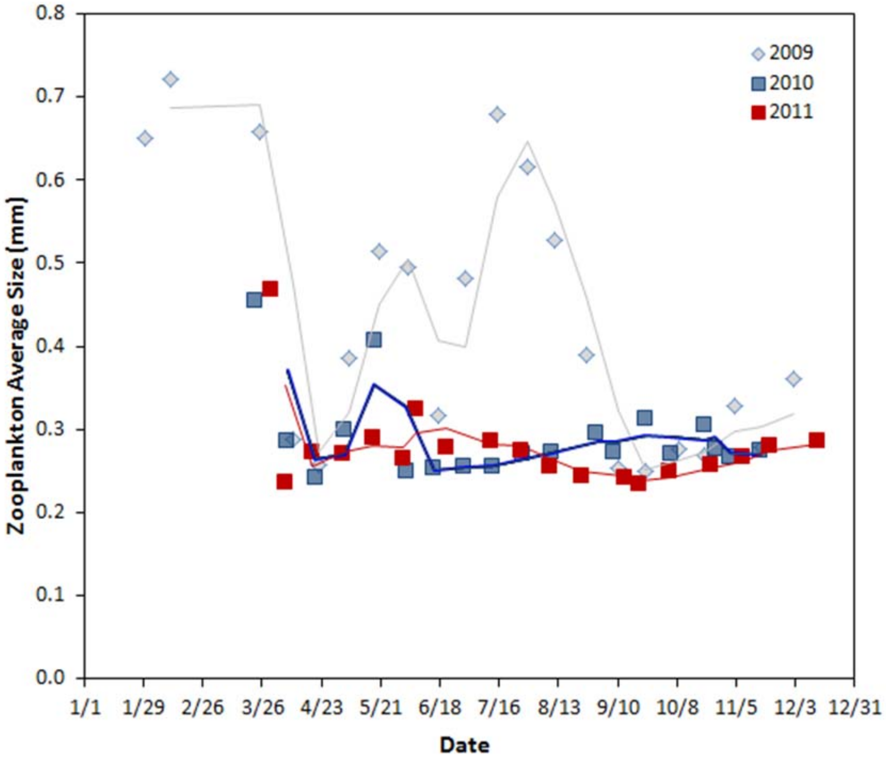


**Figure 6-11**. Average crustacean zooplankton length (mm), 2009 through 2011. Lines are the 2 point moving average for each year.

Continued high alewife abundance had an important cascading effect on lower levels of the food web in 2011. At the level of the zooplankton, alewife feeding selectively on larger zooplankton leads to lower biomass and smaller average size of the crustacean zooplankton (Figure 6-11). Smaller zooplankton are less efficient grazers of phytoplankton than larger ones, and phytoplankton abundance increases as a result. More abundant phytoplankton results in increased primary production and decreased water clarity, typically measured as Secchi disk transparency. The relationship between zooplankton size and water clarity was illustrated in Figure 6-7. These top-down effects are often referred to as a "trophic cascade", with alternating increases and decreases between adjacent levels of the food web. High water clarity and low phytoplankton biovolume was observed in 2008 and 2009 reflecting this top-down effect, as alewife abundance was lower resulting in higher abundance of large zooplankton. In 2010 and 2011, with the large zooplankton absent, water clarity was lower than the previous two years and algal biovolume was slightly higher. This trend is indicative of the grazing pressure by alewife, but does not account for potential grazing pressure on algae by mussels (i.e., resulting in lower algal biovolume and increased water clarity). It appears that the cascading effect from alewife in 2011 was a larger factor in the trophic cascade than the mussels.

Zebra mussels (*Dreissena polymorpha*) were introduced into the Great Lakes from Eurasia in ballast water from international shipping. They were first recorded in Onondaga Lake in 1992, although they did not become abundant until 2000 (Spada et al. 2002). A second related species, the quagga mussel (*Dreissena bugensis*), appeared in Onondaga Lake in 2005. Their abundance and distribution has been tracked as part of the Annual Monitoring Program using consistent methods since 2005. One modification was made in 2011 with the maximum depth sampled increased from 4.5 m to 6.0 m to assess if quagga mussels had colonized deeper. Assessments in 2011 included both the 0 to 4.5 m range and 0 to 6.0 m range for comparison among years. The relative abundance of quagga mussels increased in 2008 and reached higher abundances than zebra mussels by 2009. Abundance of quagga mussels was similar to abundance of zebra mussels in 2010 and 2011 (Figure 6-13). The average density of dreissenid mussels more than doubled in 2011 with the highest average recorded (in the 0 to 4.5 m depth average in 2010 was 5952 mussels/m2 and in 2011 was 12,777 mussels/m$^2$), although average biomass declined slightly (Figure 6-12). Including the entire range sampled in 2011 (0 to 6.0 m) average density was even higher with 13,614 mussels per m$^2$. Including the 4.5 to 6.0 m depth range, average annual mussel biomass increased to 589 g/m2 from 544 g/m2 in 2010 (Figure 6-12). Quagga mussels dominated mussel biomass again in 2011 (79%) due to their larger average size.

These benthic mussels are filter feeders, and, as such, exercise a top-down effect on phytoplankton abundance similar to that of the zooplankton. However, this effect from dreissenid mussels does not appear to be as strong of a control on phytoplankton as the effect of alewife grazing controlling the larger zooplankton that allows algal abundance to increase, although the mussel grazing likely keeps algal abundance from increasing more in the absence of heavy zooplankton grazing.

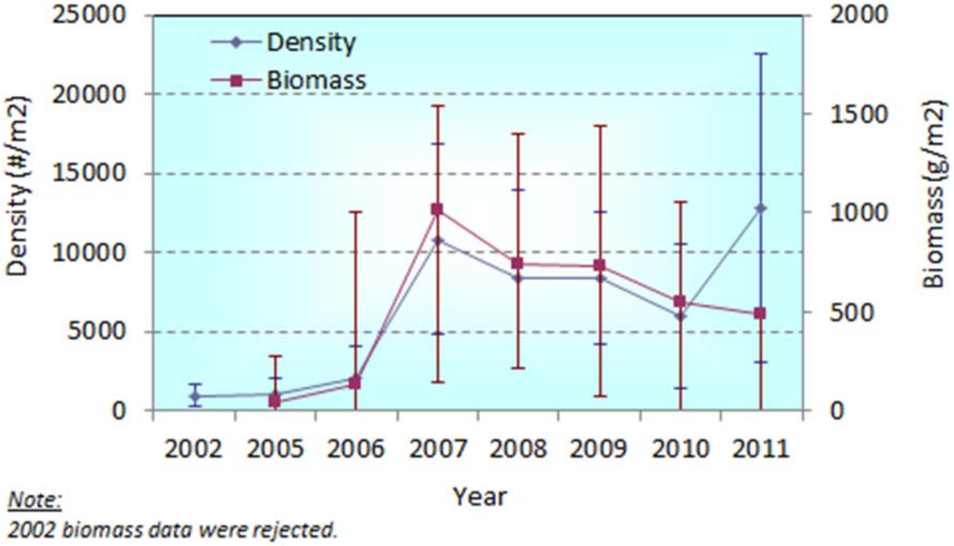


**Figure 6-12**. Dreissenid mussel average density and biomass with standard deviation, 2002-2011.

*(Note: where average quagga and zebra mussel biomass by zone were reported separately (2009 - 2011), the biomass of each species in each zone was averaged to obtain total average mussel biomass by zone. Average zone biomasses were then averaged, and standard deviation calculated, for the lake biomass as presented in this graphic. In 2011, an additional depth was sampled [4.5 to 6.0 m]; these data are not included here for consistency of comparison among years.)*

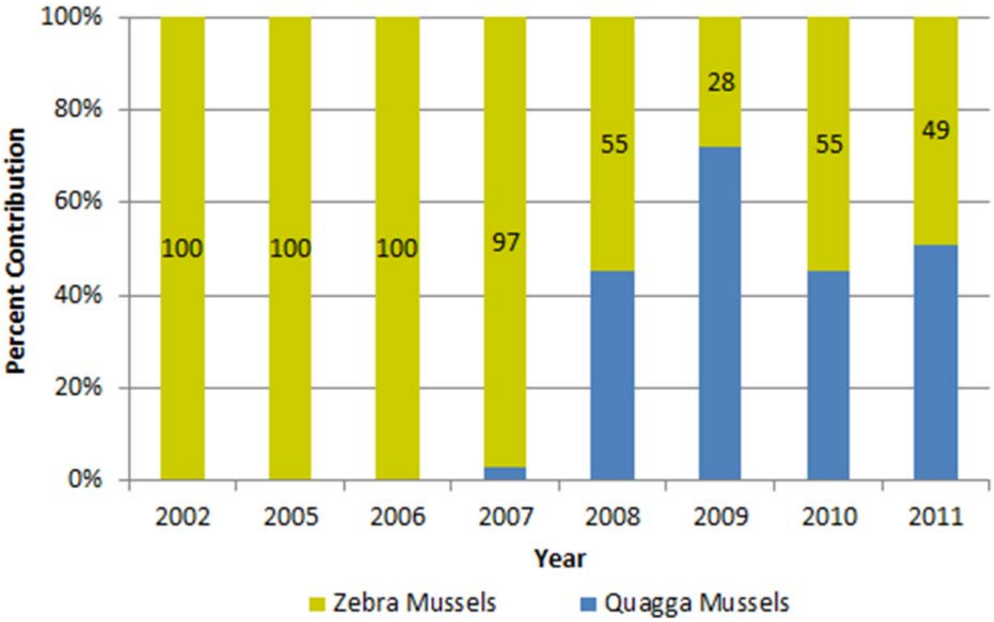


**Figure 6-13.** Relative abundance of dreissenid mussels, 2002-2011.

## 6.3 Fish

Changes in the fish community of Onondaga Lake have occurred as water quality and habitat conditions have improved. The significant reduction in ammonia and phosphorus input, and the consequent shift from eutrophic to mesotrophic conditions over the past several years have expanded available fish habitat within both the littoral zone and the pelagic zone. Since 2000, an extensive fisheries monitoring program has been included in the AMP, incorporating different types of sampling gear to assess nesting, larval, juvenile, and adult stages of the fish community. The challenge in data analysis and interpretation lies with the multitude of abiotic and biotic factors affecting the fish community, including weather and climate, interactions among species, food web effects, and invasive species. The following section provides an overview of the lake's fish community in 2011 and includes an assessment of trends observed since the AMP biological program began in 2000. The species identified in Onondaga Lake from 2000 through 2011 are listed in Table 6-1.

**Table 6-1.** Fish species identified in Onondaga Lake, 2000-2011.

| **Abundant Species** | | **Common Species** | | **Uncommon Species** | |
|---|---|---|---|---|---|
| Alewife | Largemouth bass | Black crappie | Fathead minnow | Black bullhead | Rainbow smelt |
| Banded killifish | Pumpkinseed | Bluntnose minnow | Freshwater drum | Chain pickerel | Rainbow trout |
| Bluegill | Smallmouth bass | Bowfin | Longnose gar | Goldfish | Round goby |
| Brown bullhead | Walleye | Brook silverside | Logperch | Greater redhorse | Rudd |
| Carp | White perch | Brook stickleback | Northern pike | Green sunfish | Silver redhorse |
| Gizzard shad | White sucker | Brown trout* | Rock bass | Johnny darter | Spotfin shiner |
| Golden shiner | Yellow perch | Channel catfish | Tessellated darter | Lake sturgeon | Spottail shiner |
| | | Emerald shiner | Shorthead redhorse | Longnose dace | Tiger muskie |
| | | | | Northern hogsucker | Trout perch |
| | | | | Quillback | White bass |
| | | *in spring and fall | | | Yellow bullhead |

### 6.3.1 *Richness and Diversity*

Several important metrics of the fish community are based on measured diversity and richness of the adult fish community, both littoral (near-shore) and pelagic (open water). Richness is a count of the number of species within a community, while diversity considers both the number of species present and their relative abundance. In Onondaga Lake, richness has fluctuated annually since the start of monitoring with 25 species captured during spring and fall electrofishing surveys in 2011. Onondaga Lake is part of the Seneca River system, which provides a corridor for fish movement between the lake and the waterways connected to the Seneca River. Surveys conducted since 1987 have identified a total of 64 species in the lake, comparable to regional waters.

The diversity of fish communities fluctuates in response to changes in seasonal and environmental variables, and inter-species competition. In Onondaga Lake, changes in diversity are highly influenced by the periodic peaks and crashes of two species of clupeid, alewife *(Alosa pseudoharengus*) and gizzard shad (*Dorosoma cepedianum*). Abundance of these two species of the herring family is highly variable, as Onondaga Lake is near the northern edge of their range, and both species periodically exhibit significant winter mortality. Extremes in recruitment are seen as well; both species periodically produce very strong year classes that dominate the catch for years, as individual fish can live 10 years or longer. Shannon-Wiener diversity (an index that considers richness and relative abundance) has fluctuated over the past 10 years; however, when calculating this index without clupeids there is a much more consistent trend. In 2011, abundance was dominated by clupeids with alewife and gizzard shad comprising 90% of the entire catch; yellow perch and pumpkinseed sunfish were the next dominant species.

### *6.3.2 Reproductive Success*

Several methods are used in the AMP to assess fish reproduction, including nesting surveys and separate sampling of larval and juvenile fish. Evaluation of larval and juvenile fish provides information on the overall health of the fish community within the lake and the success of reproduction from year to year. Recruitment varies annually in most lakes and may be affected by several variables. Environmental factors including water quality, habitat, wind, water level, and temperature during and following spawning have been suggested as factors affecting reproductive success. Other factors including predation and competition have also been attributed to adversely affecting the reproductive success of many species.

The centrarchid species in the lake (largemouth and smallmouth bass, pumpkinseed and bluegill sunfish, rock bass) and bullhead construct nests in the littoral zone. Each year, the AMP team conducts nesting surveys to estimate the number and spatial distribution of the nests. In 2011, 2,390 nests were observed (Figure 6-14), with a fairly even distribution between the north and south basins (49% and 51%, respectively). The distribution of nests between the north and south basins has been more evenly distributed during the past several years, and 2011 was the first year in which nest counts were higher in the south basin compared to the north. More than half of the nests supported pumpkinseed sunfish. The increased nesting activity observed in the southern basin of the lake may be influenced by the increased macrophyte coverage of the littoral zone over the last decade. Dense beds of macrophytes may reduce the effects of waves induced by wind that can cover eggs with sediment and dislodge eggs from nesting areas.

During sampling in 2011, only larval stages of alewife were collected in Onondaga Lake, documenting successful reproduction of this species. In addition, the 2011 field effort captured young-of-the-year smallmouth and largemouth bass, brown and yellow bullhead, common carp, gizzard shad, white sucker, and *Lepomis spp* (bluegill and pumpkinseed sunfish; Figure 6-15). The lack of other larval species in 2011, as well as lower numbers of *Lepomis spp* young-of-the-year, may indicate strong predation on these species and may warrant further evaluation. In response to these observed decreases in larval and juvenile fish, OCDWEP modified its sampling program in 2012 to include larval seines, extra juvenile seine locations, and an electrofishing event intended to sample juvenile fish.

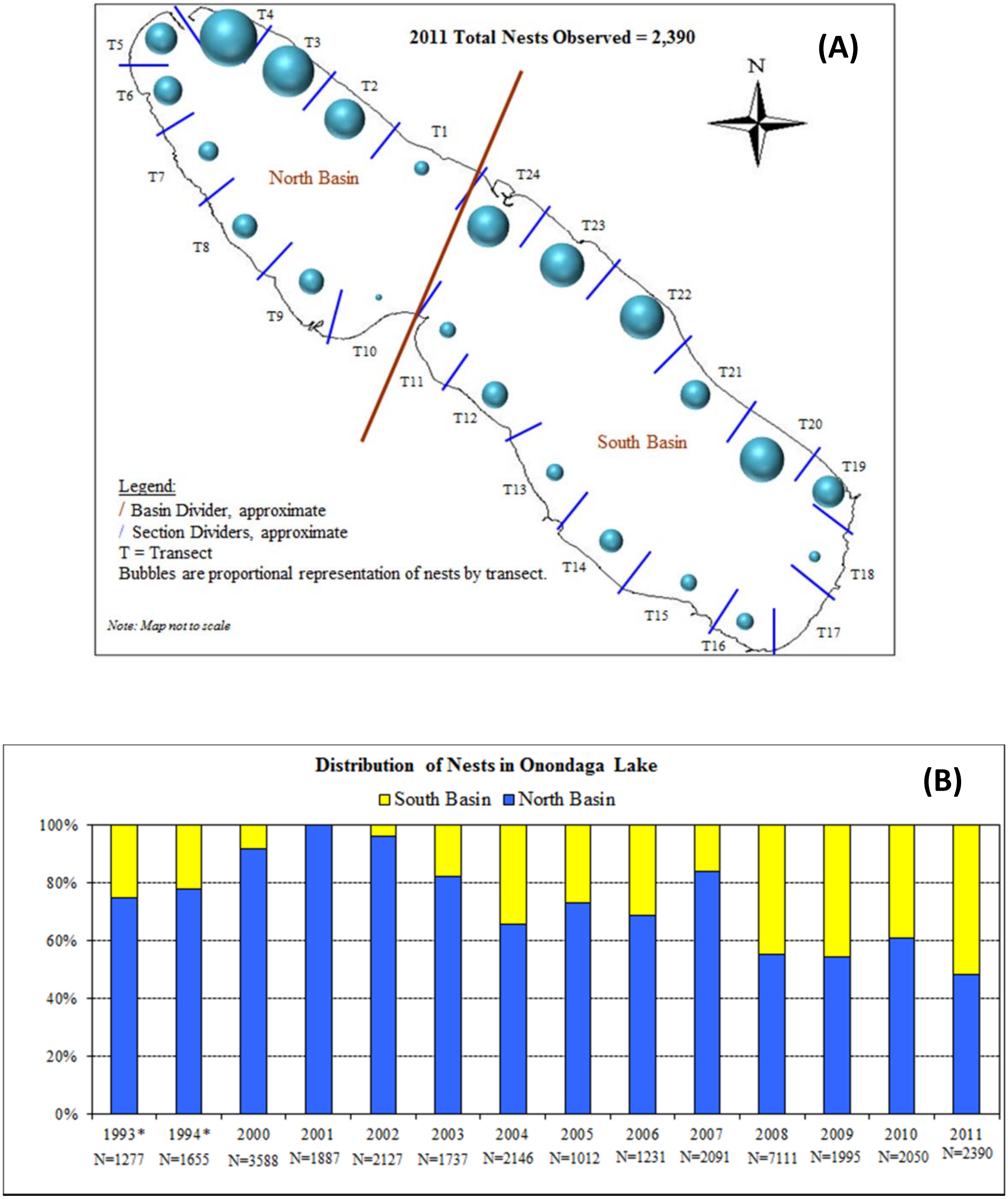


**Figure 6-14**. Nesting survey map (A) and comparison of north vs. south 1993-2011 (B).

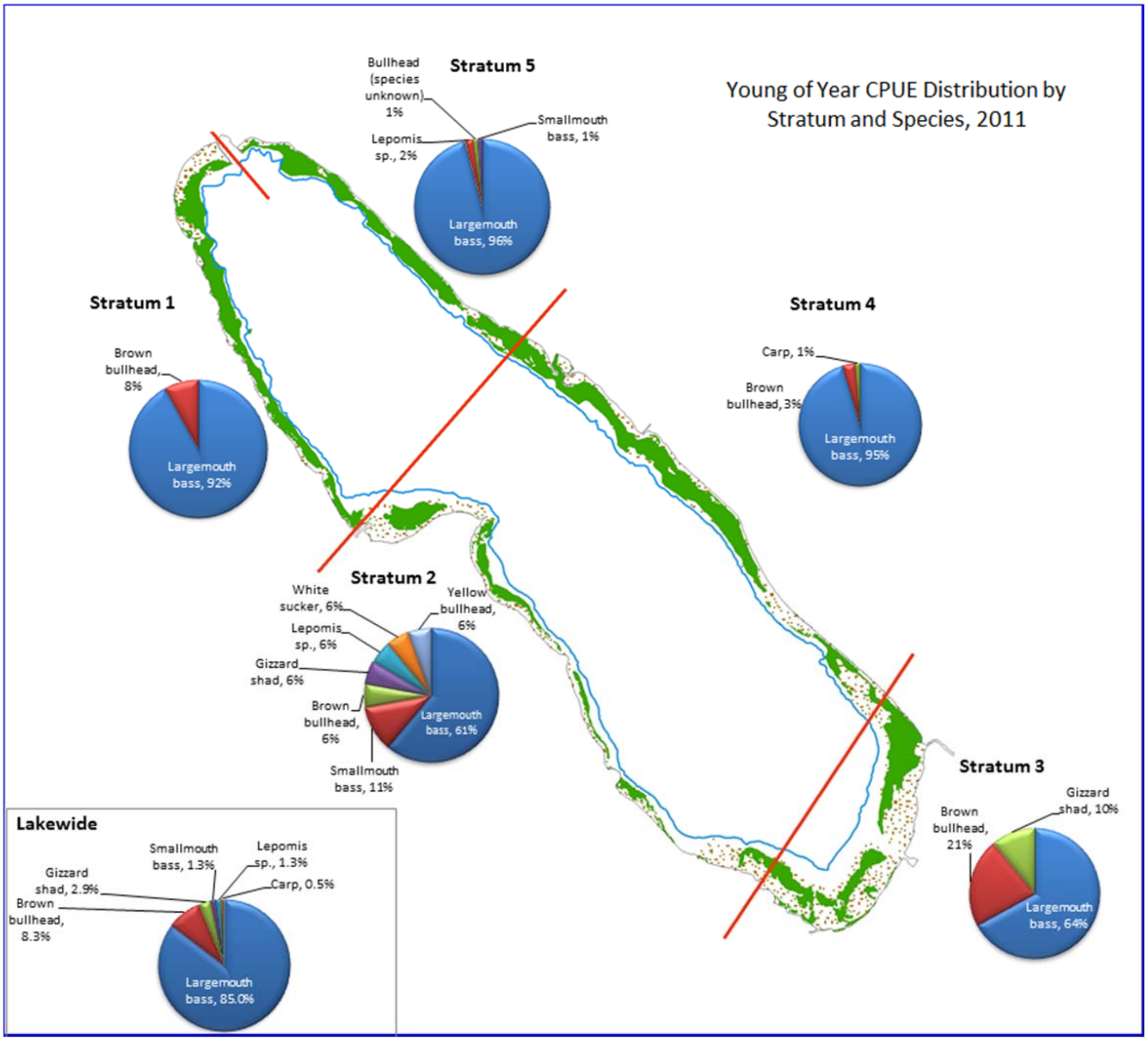


**Figure 6-15**. 2011 Young-of-year Catch per Unit Effort (CPUE) distribution by stratum and species. Data indicate where young-of-year fish were caught in the lake during 2011, as well as the percentage of species captured in each stratum.

The blue line is the extent of the littoral zone (6 meter depth contour) and vegetation is indicated green areas.

### *6.3.3 Recreational Fishery*

Onondaga Lake supports a varied recreational fishery, with largemouth bass, smallmouth bass, bluegill and pumpkinseed (Lepomis or sunfish species), yellow perch, and brown bullhead examples of the more common sport fish. Population characteristics of these species are monitored to assess changes in the quality of the lake's sport fishery. Specifically, the relative abundance of fish in various size classes available to anglers, the general condition of fish with regard to the relative weight of individuals of each species, and angler catch rates for largemouth and smallmouth bass are analyzed to determine the quality of the fishery and identify any changes that may be occurring. During 2011, the angler diary program was suspended due to lack of reports; therefore, angler catch rates were not determined for 2011. The estimated abundance of two important gamefish, largemouth and smallmouth bass, over the last decade of the AMP is illustrated in Figure 6-16.

### *6.3.4 Fish Size – Largemouth Bass*

Electrofishing and gill net catches of largemouth bass in fall 2011 indicated that slightly less than half (45%) of the angling-size largemouth bass in the lake are 8-15 inches (200 to 380 mm) in length, with approximately 39% of the catch of legal size (12 inches (305 mm)or greater). The proportion of the population greater than 12 inches in 2011 represents 39% of the angling-size population. Largemouth bass exceeding 20 inches (508 mm) are rarely collected during AMP sampling efforts. This suggests that fish of this size are rare in Onondaga Lake, since they would be susceptible to capture by electrofishing. The current size structure of the largemouth bass population in the lake provides anglers with a large proportion of catchable-size largemouth bass of small to moderate length (8-15 inches, 200-380 mm) and a moderate proportion of fish of legal size. Analysis of largemouth bass weight by size class in 2011 indicates that fish continue to be relatively heavy for their length and suggests that forage is not limiting.

### *6.3.5 Fish Size – Smallmouth Bass*

The size distribution of smallmouth bass in the fall 2011 electrofishing and gill net catches was similar to that of largemouth bass, with 42% of fish being at least legal size (12 inches, 305 mm) or greater in length. However, overall numbers of smallmouth bass (26) were much less than largemouth bass (162). The overall number of smallmouth bass captured during fall sampling efforts has shown a steady decline since 2007, with the fewest fish captured in 2010 and 2011 since reaching a high of 122 in fall 2007. The proportion of smallmouth bass that were legal size or greater in fall 2011 was the highest it has been since 2003. This increase was due primarily to an increase in the number of 12 inch(305 mm) fish. The current abundance and size structure of the smallmouth bass population in Onondaga Lake provides somewhat limited availability of smallmouth bass to anglers, but those fish that are available provide relatively high angling quality. Analysis of smallmouth bass weight by size class in 2011 indicates that smallmouth bass are in generally good condition and above average in weight for their length. Though not as abundant as largemouth bass, Onondaga Lake provides anglers the opportunity to catch smallmouth bass that are of desirable weight for their length*)*.

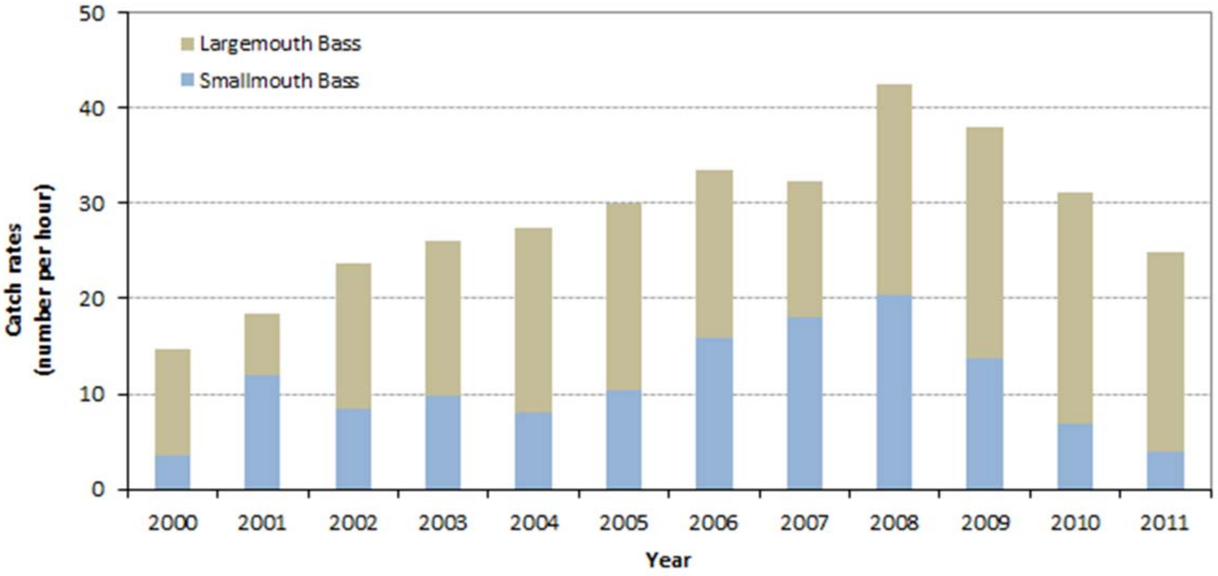


**Figure 6-16.** Bass (smallmouth and largemouth adults) captured by electrofishing in Onondaga Lake, 2000 – 2011.

### *6.3.6 Fish Size – Sunfish*

The fall 2011 electrofishing and gill net catches of sunfish (bluegill and pumpkinseed) indicated that the population is dominated (85%) by fish of 4-6 inches (102-152 mm) in length. This has been the case since the AMP began in 2000. The proportion of sunfish 6-8 inches (152-203 mm) increased from 13% in fall 2009 to 22% in fall 2010 and 27% in fall 2011. This means that currently a greater proportion of quality-size sunfish are available to anglers than in the previous two years. This proportion may continue to increase in 2012 as the large proportion (73%) of angling-size sunfish less than 6 inches (152 mm) grow to quality size.

Sunfish greater than 8 inches (203 mm) in the catch have been scarce throughout the AMP. Several factors may be contributing to this. It is possible that the selected gear does not capture larger sunfish in proportion to their abundance. Larger adult sunfish tend to be more pelagic than juveniles and smaller adults and may be captured disproportionately less than these other groups when electrofishing littoral habitats. Slow growth of fish after reaching reproductive age and competition for food with other species such as alewife and gizzard shad may also be contributing to low abundance of larger sunfish in Onondaga Lake. Weight analysis of adult-size fish indicates that forage is not limiting for sunfish in Onondaga Lake and energy reserves of individual fish are relatively high, so it is possible that this energy goes to reproduction rather than growth. Despite the scarcity of sunfish longer than 8 inches (203 mm), sunfish up to that size are readily available to anglers and are increasing in abundance in recent years.

### *6.3.7 Fish Size – Yellow Perch and Brown Bullhead*

Size distribution of yellow perch in the fall 2011 electrofishing and gill net catch indicated that the angling-size population is dominated (87%) by fish 5-8 inches (127-203 mm) long. Yellow perch from 8-10 inches (203-254 mm) long make up 18% of the angling-size population, and fish larger than 10 inches (254 mm) are rare, but slightly more common than in previous years (6% in 2011; 1% in 2010). Increases in the proportion of yellow perch larger than 10 inches (254 mm) in 2012 can be expected as the abundant year-class representing fish 5-8 inches (127-203 mm) ages. The overall abundance of yellow perch has been increasing since 2006; this coupled with a strong year-class that is approaching quality size should translate to more and larger yellow perch being available to anglers in the near future.

Electrofishing and gill net catches of brown bullhead in fall 2011 indicated that there is an increasing distribution of larger fish, with the 11 to 14 inch size class representing 50% of the catch; and the 9 to 11 and 6 to 9 inch (152-229 mm) size classes representing 27% and 20% of the catch, respectively. Over 75% of the angling-size fish are of quality size (9 inches, 229 mm) or greater. This offers anglers an opportunity to catch relatively large brown bullhead. The increasing overall number of brown bullhead and increasing size trend in recent years has created the potential for a high-quality brown bullhead fishery in Onondaga Lake.

## 6.4 Fish Abnormalities

The occurrence of physical abnormalities in fish captured during AMP sampling is monitored using a standardized protocol known as DELTFM. DELTFM abnormalities are defined as Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies. Data are used for trend analysis and to compare fish collected from Onondaga Lake to those collected in other areas. Fish abnormalities can result from chemical contamination; biological agents such as bacteria, viruses, or fungi; or interactions among multiple stressors.

DELTFM abnormalities showed an overall increase from 2003 to 2009, but decreased in frequency in 2010 and 2011. DELTFM abnormalities were found in 0.6% of adult fish from Onondaga Lake in 2003, increased to 4.1% in 2005, decreased slightly to approximately 3% in 2006 and 2007, and then increased steadily to 7.7% in 2009. DELTFM abnormalities declined in 2011, occurring in 5.9% of adult fish. The majority of abnormalities in the Onondaga Lake fish community in 2011 were lesions (64%), followed by deformities (25%), and erosions (7%). Tumors, malignancies, and fungal infections were rare (<3% combined).

Nineteen species of adult fish were found with DELTFM abnormalities in 2011, similar to 2010. The species contributing the most to the DELTFM total in 2011 were brown bullhead (41% of total), gizzard shad (25%), largemouth bass (11%), northern pike (5%), and white sucker (4%). The slight increase in DELTFM abnormalities observed in 2011 is due primarily to an increase in brown bullhead abundance in

2011 (Figure 6-17). However, overall occurrence of DELTFM in brown bullhead was not as high as that seen in 2009 when similar numbers of brown bullhead were evaluated.

The incidence of lesions and tumors in brown bullhead in Onondaga Lake from 2000 to 2011 was compared with similar data from waters in the Chesapeake Bay watershed, Great Lakes, and Cape Cod area (see Library Reference 9.15). Prior to 2007, occurrences of lesions and tumors in Onondaga Lake brown bullhead were within the range associated with reference sites (typically <5% incidence) from this larger regional set of waters. Data from 2007-2009 indicated a shift in occurrence to levels associated with contaminated sites from regional waters. The cause of this shift is not known, but may have been due to several recently identified pathogens affecting brown bullhead in Onondaga Lake. The incidence of lesions and tumors in brown bullhead in Onondaga Lake has declined the past three years, suggesting a recovery of the population from these pathogens. The incidence of lesions and tumors in brown bullhead in Onondaga Lake in 2011 fell to 7% and is again approaching the range associated with regional reference sites.

## 6.5 Additional Information Regarding the Fish Community

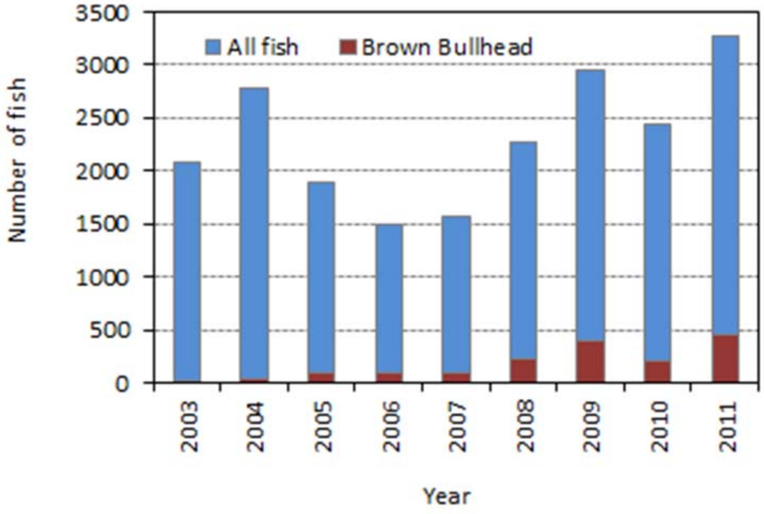
Each year large amounts of data related to the lake's fish community are collected; lake managers, local scientists, university professors and others use these data for teaching and research purposes. Onondaga County maintains a custom database to manage these extensive data sets and facilitate their retrieval. In addition to the topics discussed in the 2011 Annual AMP report, the Library includes an additional 20 figures and tables of data related to the lake's fish community. Interested parties are encouraged to explore the additional resources archived in Library Section L09.

## 6.6 Integrated Assessment of the Food Web

The Onondaga Lake ecosystem is continuing to change. The improvements made at the Metro wastewater treatment facility reduced the input of phosphorus and ammonia, resulting in decreased algal productivity and biomass in Onondaga Lake. Along with this shift toward mesotrophic conditions, the zebra mussel and quagga mussel have been able to thrive in the lake. Rooted aquatic plants have returned to the littoral zone, providing expanded nearshore habitat for fish and other aquatic animals. However, the successful reproduction of alewife and the impacts of grazing on large zooplankton has shifted Secchi disk transparency values to more typical of eutrophic conditions.

The story of Onondaga Lake's recovery is complex and reductions in nutrients do not account for all of the changes observed in recent years. The AMP long-term data set allows scientists to document the details of the water quality changes and to integrate the role of food-web dynamics in an understanding of water quality changes. Clearly, phytoplankton biomass in the lake has declined as a result of reduced phosphorus loading from Metro, but differences between years are also affected by changes in the lake's trophic conditions, primarily the abundance and efficiency of grazing organisms. The trophic cascade from alewives has altered the zooplankton community which affects phytoplankton abundance and dreissenid mussels may also play a role in moderating summer phytoplankton biomass and water clarity when large zooplankton are absent.

**A. Adult Fish Captured**



**B. Percent of Fish with DELTFM**

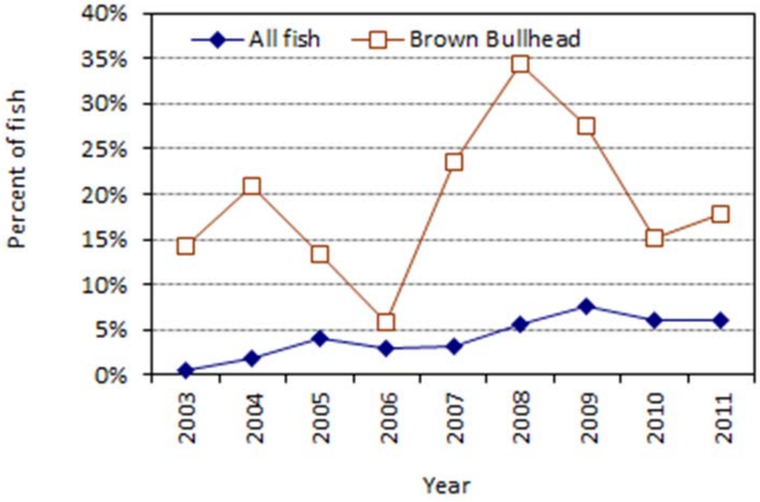


**Figure 6-17**. Relative importance of brown bullhead in characterizing DELTFM abnormalities in Onondaga Lake fishes, 2003-2011.

The size structure of the zooplankton community is directly affected by the alewife. Analysis of the 2011 data has indicated alewife abundance is still high and large zooplankton have been virtually eliminated. The average size zooplankton in Onondaga Lake in 2011 was the lowest measured since monitoring of lower trophic levels began. Water clarity was lower in 2011 compared to 2008 and 2009; total phosphorus was down slightly, although loading from Metro was unchanged, and chlorophyll-a was unchanged from 2010. This is consistent with a cascading effect of alewife on phytoplankton through the elimination of large zooplankton. However, there are confounding patterns in nutrient and sediment loading in 2011 that also need to be considered. Mussel populations remain high in the littoral zone and may impact algal abundance, although algal numbers have increased slightly in the absence of large zooplankton suggesting the role of mussels is minor in comparison.

Macrophyte coverage and abundance in Onondaga Lake was slightly lower in 2011 compared to 2010, although this may be due to the slightly later flight and some plant senescence. Increased macrophyte abundance presumably has resulted in a substantial increase in production of macroinvertebrates in the littoral zone. The increased macrophytes should result in increases in the littoral zone fish community that use these areas for foraging, including largemouth bass, pumpkinseed, yellow perch, and brown bullhead among others. Abundance of largemouth bass, yellow perch, and brown bullhead adults have been increasing the past several years; however, pumpkinseed sunfish abundance has declined since 2009, which suggests other factors may be limiting this species. The impact of the increased coverage of macrophytes needs to be more fully considered on the overall trophic dynamics in the lake.

In years of high alewife abundance, including 2011, fish with pelagic larvae (such as pumpkinseed, bluegill, yellow perch, and white perch) have shown reduced recruitment, which is likely due to predation of larvae by alewife. Analysis of larval trawl data indicates that alewife was the only larval species collected in 2011, with no evidence of pumpkinseed or bluegill larvae throughout the entire season. The potential effects of alewife abundance and the lack of recruitment of these species over the last couple years should be further evaluated to understand how this may impact abundance of adults in the next several years.

In addition, alewife are forage for larger, fish-eating species such as smallmouth and largemouth bass, yellow perch, white perch, and walleye. For smallmouth bass, the availability of alewife as forage in pelagic habitats, as well as the increased macrophyte coverage in the littoral zone (less preferred habitat), may be facilitating a shift to deeper, offshore habitat from shallower, littoral habitat resulting in the lower abundance observed over the past couple years. If such a shift has occurred, this would reflect a change in adult smallmouth bass foraging from a littoral-based food web to a pelagic-based food web.

The proliferation of zebra and quagga mussels in the lake following reductions in ammonia levels may be helping to support the increased abundance of several species by providing an abundant food source. While pumpkinseed also are known to feed on mussels, abundance has declined over the past few years with virtually no evidence of reproduction, suggesting some other factor influencing this species that should be evaluated. Freshwater drum, yellow perch, and common carp also feed on mussels and are likely benefitting from the increasing abundance of these mussels. All three species utilize both littoral and pelagic areas with all three species captured by electroshocking in the littoral zone as well as by gill netting in the pelagic zone. Consumption of mussels by multiple fish species provides another connection between the littoral-based food web and the pelagic-based food web. The increasing complexity of the overall food web in Onondaga Lake is an important sign that the lake is recovering from past environmental perturbations.

In addition to the food web effects, dissolved oxygen (DO) and temperature affect habitat availability for different species of fish, which shapes the fish community structure of Onondaga Lake. The Data Visualization Tool (DVT) provides insight into the habitat available for coolwater and coldwater fish communities, or "fish space". The fish space metric is useful for tracking changes in habitat based on DO and temperature, two variables that are necessary, but not sufficient to maintain a population. Optimal DO and temperature requirements differ for coolwater and coldwater fish species. Two metrics illustrate this approach: (1) coldwater fish habitat (Figure 6-18(a)), and (2) coolwater fish habitat (Figure 6-18(b)).

In both graphics, the blue color represents depth and temporal location of water temperatures and dissolved oxygen concentrations suitable for cold- and coolwater fish habitat, respectively. Yellow shows where and when temperatures are out of range, while green shows where and when dissolved oxygen is out of range. Orange represents conditions where both temperature and dissolved oxygen are out of the range suitable for fish habitat.

Overall, there has been an increase in the quantity and quality of habitat available to fish species in Onondaga Lake in the past 10 years. This has resulted in a slight increase in fish species richness with a more even distribution of fish throughout the lake. However, additional changes are occurring that still are not completely understood and should be evaluated over the next couple years of monitoring. Specific analysis should include the influence of the increased macrophyte coverage on trophic structure and nutrient dynamics and the factors potentially responsible for the lack of recruitment observed for several species over the past 3 years. While water quality improvements have resulted in establishment of more diverse and higher quality habitats, a more thorough understanding of the shifts in trophic structure are necessary for continued improvements in the lake.

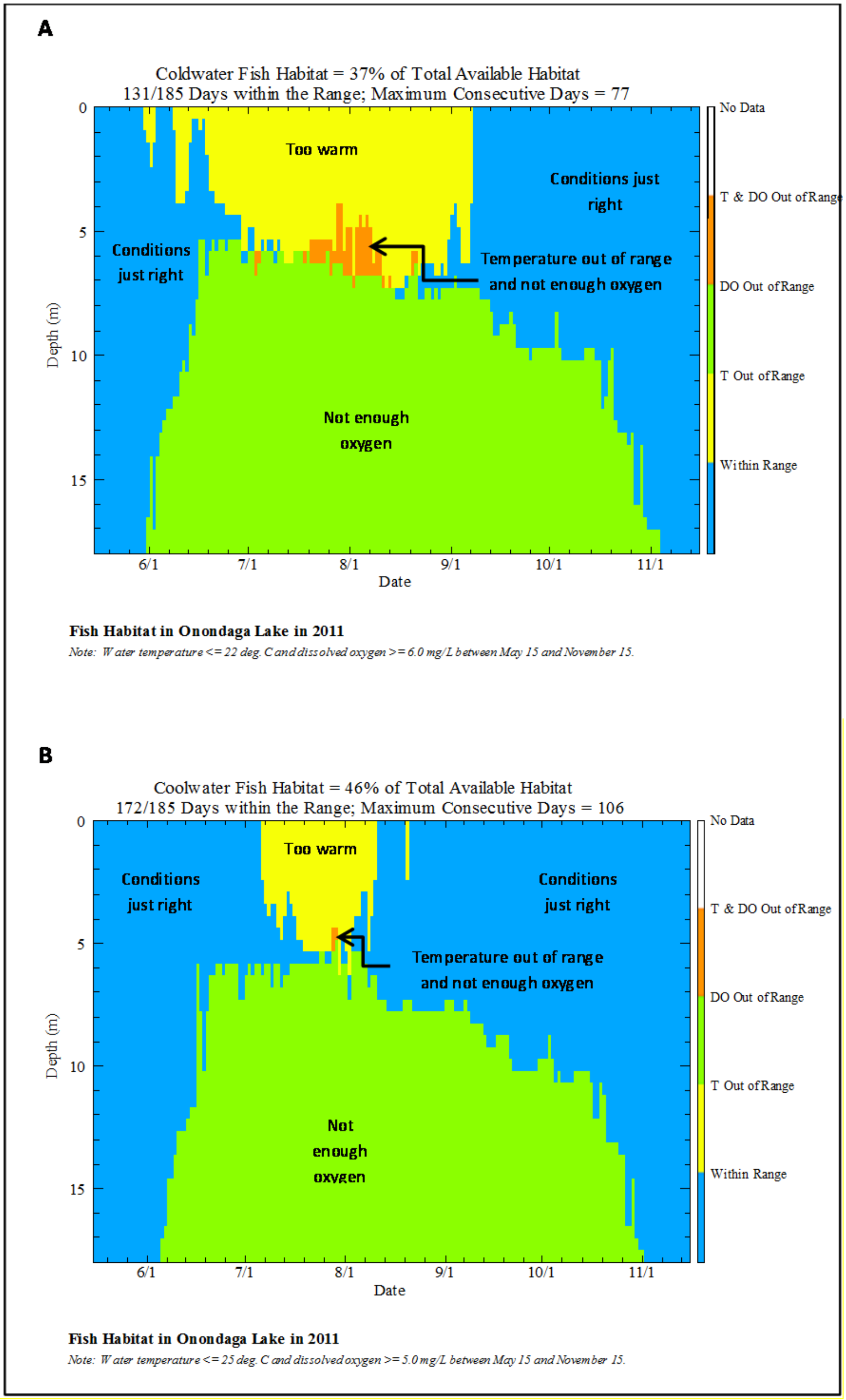


**Figure 6-18**. Fish space metric, 2011, for coldwater and coolwater species. Data from South Deep monitoring buoy.

## Section 7. Water Quality in the Three Rivers System

The Three Rivers System consists of the Seneca, Oneida, and Oswego rivers, which connect Cross Lake, Onondaga Lake, and Oneida Lake with Lake Ontario (Figure 7-1). The Seneca River, which drains the Finger Lakes region and Onondaga Lake, joins the Oneida River, which drains Oneida Lake, to form the Oswego River, the second largest inflow to Lake Ontario. The rivers are used for recreation, navigation, and waste discharge. They receive nutrient inputs from agricultural activities and wastewater treatment plants (WWTP), including four operated by Onondaga County (Baldwinsville-Seneca Knolls, Brewerton, Oak Orchard, Wetzel Road). The Metro WWTP effluent enters Onondaga Lake, which flows to Seneca River via its outlet (Figure 7-1). The Seneca River is listed as an impaired water body by NYSDEC because of low dissolved oxygen concentrations during summer low flow periods. The metabolism of invasive dreissenid mussels (zebra and quagga mussels) contributes importantly to this oxygen depletion. Physical alterations of the rivers to support navigation, including locks and dams, channelization, and maintenance of a minimum depth of 4.5 meters have eliminated much of the natural turbulence and associated reaeration capacity, further compromising oxygen resources. Water quality conditions of the Three Rivers System are of concern to protect the multiple uses of the rivers and downstream Lake Ontario.

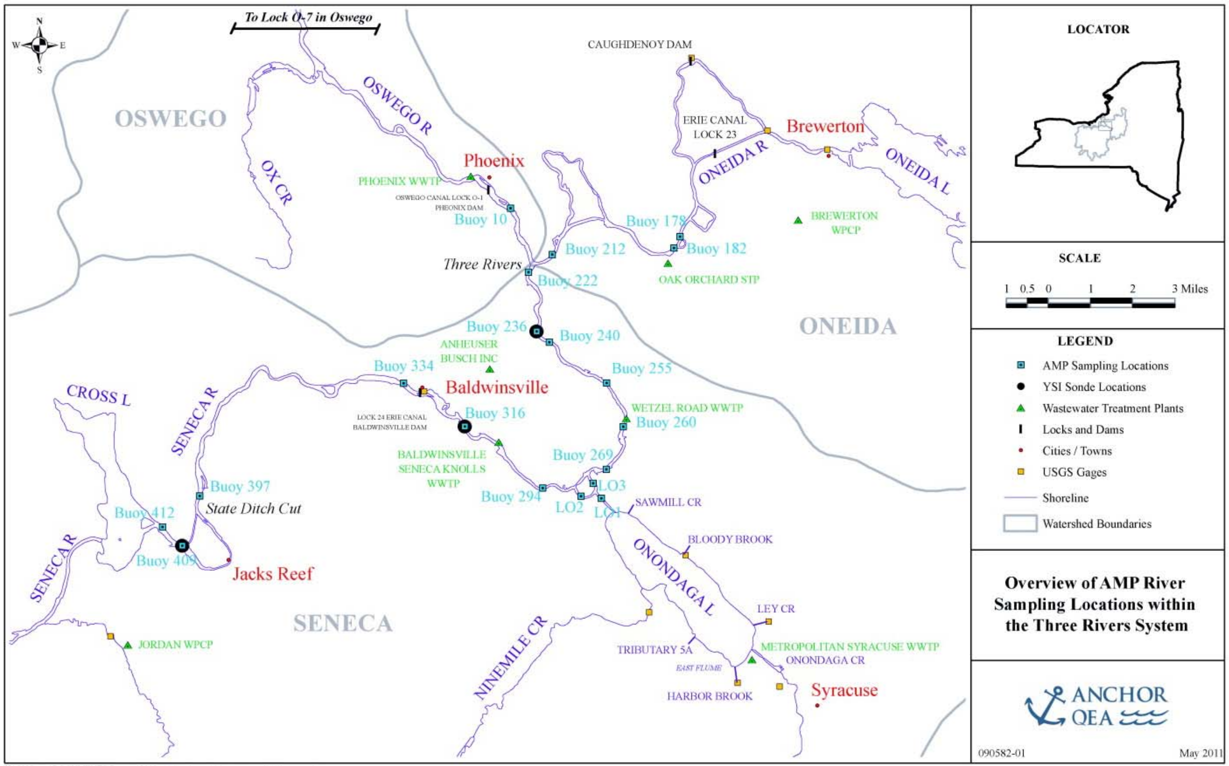


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**Figure 7-1.** The Three Rivers System, with AMP sampling locations and wastewater treatment plants identified.

In 2011, spatially detailed water quality surveys of the Three Rivers System were conducted by OCDWEP on July 13, August 31, and September 28. During these surveys, which targeted critical low flow conditions, samples were collected from 1 meter below the water surface and 1 meter above the sediments at 18 locations and analyzed for a suite of water quality parameters, including forms of phosphorus (P), nitrogen and carbon, chlorophyll-a, dissolved oxygen, and turbidity. In addition, measurements of temperature, dissolved oxygen, pH, and salinity were made at 15-minute intervals using YSI sondes deployed at three locations in the Seneca River from mid-June to late October. The sondes were located at Buoy 409 (downstream of Cross Lake and upstream of the State Ditch Cut), Buoy 316 (upstream of the Baldwinsville-Seneca Knolls WWTP and the outlet of Onondaga Lake), and Buoy 236 (downstream of the Onondaga Lake outlet and Wetzel Road WWTP). Graphical representations of the 2011 Three Rivers data set are provided as Library Reference 10.1 of this report.

Flow rates in the Seneca and Oneida rivers were extremely high during the spring months of 2011 due to snowmelt and heavy rainfall (Figure 7-2). The average summer (July-September) flow in the Seneca River was 2,528 cfs, substantially higher than the long-term summer average of 1,740 cfs. Flows were relatively low during July and early August and higher in late August. Summer average flow in the Oneida River was 1,237 cfs in 2011, slightly lower than the long-term summer average of 1,262 cfs. Compared to the long-term record, July flows were low, August flows were normal, and September flows were high. The surveys of July 13 and August 31 were conducted under low flow conditions, while the September 28 survey occurred during elevated flow on the rising limb of the hydrograph. The lowest 7-day average flow that occurs on average once every 10 years (7Q10) is a commonly used statistic for identifying critical low flow conditions in rivers and streams. Flow in the Seneca River remained above the 7Q10 of 350 cfs throughout the summer of 2011. Only on September 15 did flow in the Oneida River fall below the 7Q10 of 210 cfs.

The outlet of Onondaga Lake and nearby portions of the Seneca River experience density stratification, particularly during periods when flow in the river is low. This unusual phenomenon is caused by the more saline and therefore denser waters of the lake flowing beneath the comparatively less dense waters of the river. During the July and August surveys of 2011, vertical gradients in the Seneca River were measured for various water quality parameters, including salinity, temperature, dissolved oxygen, and nitrate. A number of factors likely contributed to these observations, including influx of Onondaga Lake water to the river, limited vertical mixing, and possibly inflow of groundwater downstream of the lake outlet. Distinct vertical gradients were not observed during the September survey, when flow in the Seneca River was elevated.

Zebra mussels were first observed in the Seneca River in 1991, and dense populations had developed by 1993. These invasive, filter-feeding bivalves have had a considerable impact on water quality in the Three Rivers System since their introduction in the early 1990s. Water quality changes have been particularly well-documented for the Seneca River near Baldwinsville (Effler et al. 2004). The dreissenid mussel invasion has converted the Seneca River at Baldwinsville from a low clarity, phytoplankton rich,

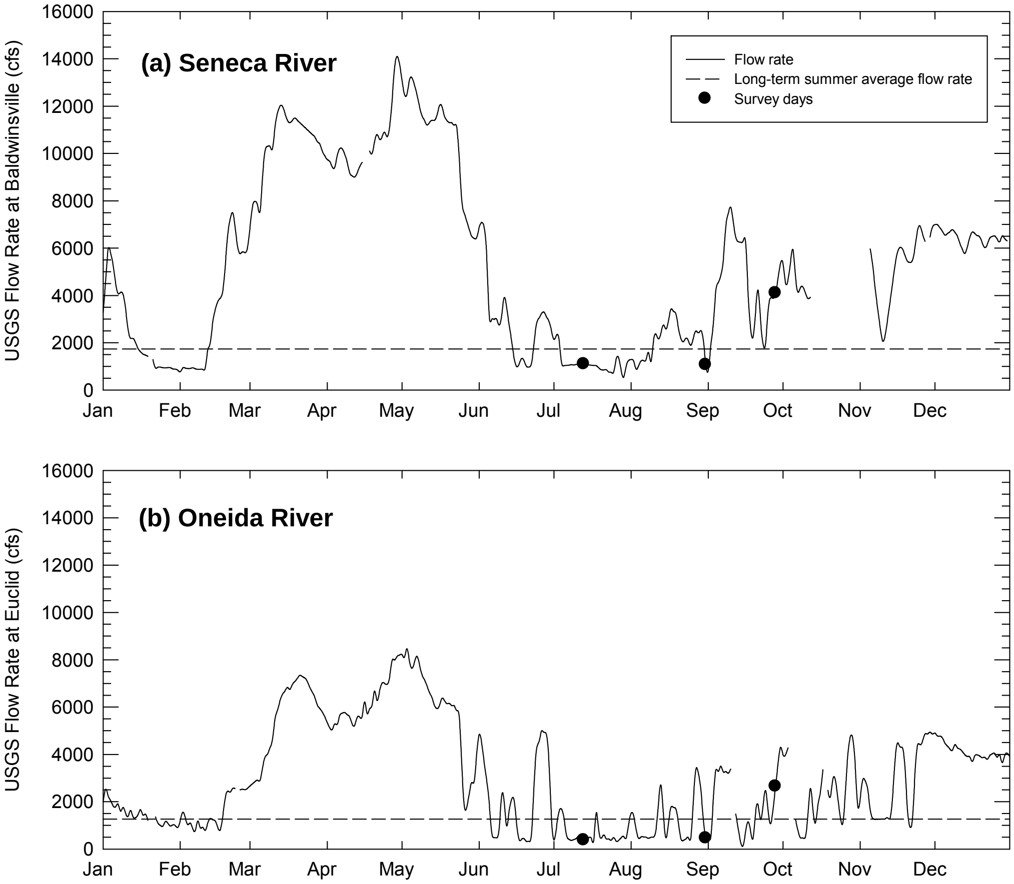

**Figure 7-2.** 2011 hydrographs for Seneca River at Baldwinsville and Oneida River at Euclid, with survey dates identified.

nutrient depleted system, with nearly saturated oxygen concentrations, to a system with increased clarity, low phytoplankton levels, highly enriched in dissolved nutrients, with substantially undersaturated oxygen concentrations. These changes reflect at least three features of the metabolism of the invader, including respiration (decreases in dissolved oxygen and pH), filter feeding (decreases in chlorophyll-a and increases in Secchi disk), and excretion (increases in soluble reactive phosphorus and ammonia). Increased water clarity has led to a major expansion in macrophyte coverage in many areas of the Three Rivers System. Conspicuous signatures of dreissenid mussel metabolism were observed in the 2011 survey data, including decreases in dissolved oxygen concentrations from Cross Lake to the Onondaga Lake outlet (Figure 7-3).

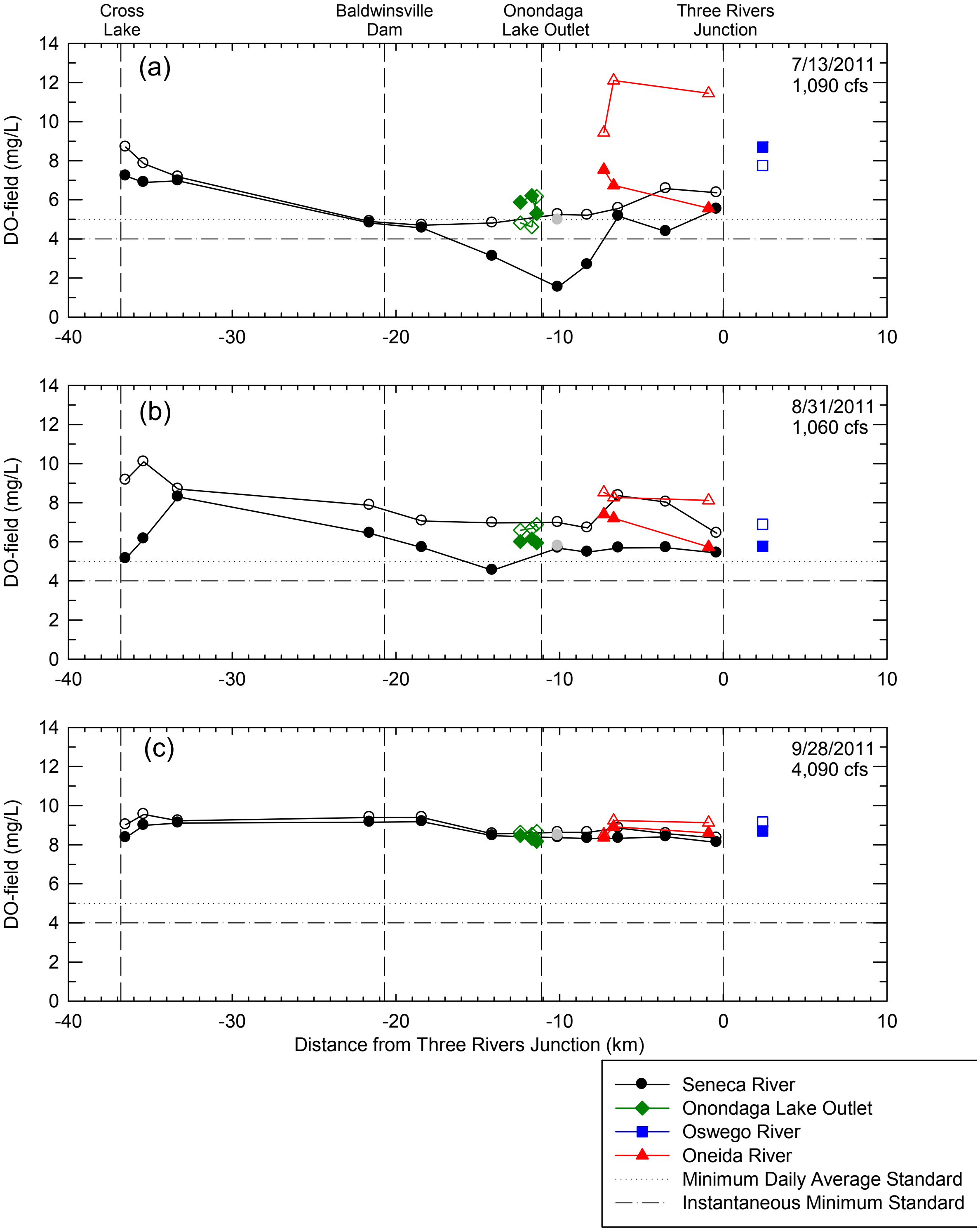

**Figure 7-3.** Dissolved oxygen patterns in the Three Rivers System on (a) 7/13/11, (b) 8/31/11, 9/28/11.

Notes: (1) River km measured from Three Rivers Junction, upstream (-) for Seneca River and Oneida River and downstream (+) for Oswego; (2)Open symbols represent surface samples, filled symbols represent bottom samples, gray circles represent mid-depth samples; (3) Dailey average flow at Baldwinsville are shown in each panel.

Violations of the NYSDEC instantaneous minimum dissolved oxygen standard of 4 mg/L were documented at three locations on the Seneca River during the July 13 survey (Table 7-1). Extremely low dissolved oxygen concentrations of 1.5 to 3.1 mg/L were measured at locations immediately upstream and downstream of the Onondaga Lake outlet. Dissolved oxygen concentrations were higher than the instantaneous minimum standard at all sampling locations during the August 31 and September 28 surveys. There were no measured violations of the ambient water quality standards for nitrite or ammonia during the 2011 field program.

**Table 7-1.** Summary of non-compliance with ambient water quality standards for dissolved oxygen, nitrite, and total ammonia in Three Rivers System on discrete sampling dates of 7/13/2011, 8/31/2011, and 9/28/2011.

| Parameter | Sampling Date | Location | Depth | Values Out of Compliance (mg/L) |
|---|---|---|---|---|
| Dissolved Oxygen (Instantaneous Compliance Criteria = 4 mg/L) | 7/13/2011 | Buoy #269 | Bottom | 1.53 |
| | 7/13/2011 | Buoy #260 | Bottom | 2.68 |
| | 7/13/2011 | Buoy #294 | Bottom | 3.11 |
| Nitrite (Compliance Criteria = 0.1 mg/L) | None | None | None | -- |
| Total ammonia (NYSDEC Criteria Calculated from pH and Temperature) | None | None | None | -- |

*Note: Bottom measurements taken 1 meter above sediments*

High frequency measurements of dissolved oxygen made during the mid-June to early November period of 2011 provide information on the frequency and duration of low dissolved oxygen conditions in the Seneca River. Violations of minimum dissolved oxygen standards (less than 5 mg/L as a daily average and less than 4 mg/L for instantaneous measurements) were documented at the three locations where in-situ sondes were deployed (Table 7-2). The most severe dissolved oxygen depletion was measured in the bottom waters at Buoy 236, located between the Onondaga Lake outlet and Three Rivers junction. Violations of the 5 mg/L standard occurred on 46 of the 144 days for which measurements are available. Daily average dissolved oxygen concentrations of less than 5 mg/L were measured on 27 and 25 days at Buoy 409 (downstream of Cross Lake) and Buoy 316 (downstream of Baldwinsville), respectively. These data indicate a small improvement in dissolved oxygen conditions at Buoys 409 and 316 relative to recent years. This improvement is likely related to relatively high flows during 2011, particularly during the spring and fall.

**Table 7-2.** Summary of 15-minute dissolved oxygen (DO) data[1] collected by the YSI sondes in 2011.

| **Sonde Location** | **Deployment Dates[2]** | | **Operation (days)[3]** | **DO < 5 mg/L (days)[4]** | **DO < 4 mg/L (days)[5]** |
|---|---|---|---|---|---|
| | **Start** | **End** | | | |
| Buoy 409 (TOP) | 6/17/11 | 11/7/11 | 143 | 15 | 14 |
| Buoy 409 (Bottom) | 6/17/11 | 10/3/11 | 107 | 12 | 4 |
| Buoy 409 (TOP or BOTTOM) | 6/17/11 | 11/7/11 | 143 | 27 | 18 |
| | | | | | |
| Buoy 316 (TOP) | 6/20/11 | 11/2/11 | 135 | 7 | 4 |
| Buoy 316 (Bottom) | 6/20/11 | 11/2/11 | 132 | 23 | 10 |
| Buoy 316 (TOP or BOTTOM) | 6/20/11 | 11/2/11 | 135 | 25 | 13 |
| | | | | | |
| Buoy 236 (TOP) | 6/17/11 | 11/9/11 | 144 | 3 | 1 |
| Buoy 236 (Bottom) | 6/17/11 | 11/9/11 | 144 | 46 | 40 |
| Buoy 236 (TOP or BOTTOM) | 6/17/11 | 11/9/11 | 144 | 46 | 40 |

*Notes:*

[1] *Blank and negative DO values were excluded from analysis.*

[2] *Not all parameters may have been measured during the deployment dates.*

[3] *DO measured at least half of the time within one day.*

[4] *NYSDEC minimum daily average DO standard. Reported value represents number of days in which the daily average calculated from the 15-minute data was below the standard.*

[5] *NYSDEC instantaneous minimum DO standard. Reported value represents the number of days in which one or more of the 15-minute readings was below the standard.*

## Section 8. Progress with Related Initiatives

The restoration of Onondaga Lake continues to progress along a number of fronts. Multiple projects have been completed to restore water quality and habitat conditions, and the lake has responded positively. The County wastewater collection and treatment systems have received major upgrades and industrial wastes are being remediated. More than 70 green infrastructure projects have been completed as part of the "Save the Rain" initiative, reducing the amount of stormwater runoff that reaches the lake. For example, a 60,000 square ft. green roof, one of the largest in the northeast, has been installed on the OnCenter Convention Center, capturing more than 1 million gallons of runoff annually. The Connective Corridor, which links Syracuse University to the downtown business districts, has incorporated a variety of green infrastructure features in its design, including tree trenches, porous pavement, and landscape buffers. These improvements have reduced runoff by an estimated 5.7 million gallons per year. Onondaga County's "Save the Rain" program continues efforts to educate the watershed community on effective measures to reduce runoff from the urban landscape. Information on porous pavement, tree planting, rain gardens, rain barrels and more are available at http://savetherain.us/.

The ACJ requires the County to construct and operate a number of gray infrastructure projects designed to capture CSO flows and improve water quality in Onondaga Lake and its tributaries. Substantial progress was made on a number of these projects in 2011. Construction of the CSO 044 Conveyances Project, designed to capture 6 million gallons of CSO volume that was discharged to Onondaga Creek annually, was 90% complete by the end of 2011. The Harbor Brook Interceptor Sewer Replacement Project will capture a CSO volume of 36 million gallons through upgrades to the existing Harbor Brook Interceptor, which has fallen into disrepair since its construction in the 1920s. By the end of 2011, this project was 95% complete. In addition, work on three CSO storage facilities advanced in 2011. Modifications to the Erie Boulevard Storage System, completed in October 2011, will provide an estimated CSO capture of 8 million gallons per year. In 2011, construction began on the Clinton and Harbor Brook Storage Facilities, which will provide 55 and 92 million gallons of annual CSO capture, respectively. Many of these gray infrastructure projects have been enhanced by green infrastructure components, such as bioretention basins, tree plantings, green roofs, and rain gardens. Additional, project-specific information is available at http://savetherain.us/.

Honeywell International, Inc. is proceeding with remediation of legacy industrial pollution under regulatory oversight. Through 2011, efforts focused on identification and removal of sources to prevent additional contamination from reaching the lake. Beginning in 2012 the focus of this remedial project will shift toward addressing contaminated lake sediments. Plans for sediment dredging and capping in certain areas, mostly in the southern littoral zone, are complete and dredging and capping operations began in 2012 and will continue through 2016. In 2011, a whole-lake nitrate addition pilot test was conducted with the objective of limiting release of methylmercury from the pelagic sediments to the hypolimnion through maintenance of adequate nitrate concentrations. A liquid calcium-nitrate solution was added to the hypolimnion as a neutrally buoyant plume approximately three times per week during the summer stratification interval. Maximum hypolimnetic concentrations of methylmercury and soluble reactive phosphorus decreased 94% and 95% from 2009 levels. This project is scheduled to continue in 2012 and 2013. Information on Honeywell project submittals is available online at the NYSDEC website www.dec.ny.gov/chemical/37558.html.

The Onondaga Creekwalk is now complete from the historic Armory Square district in Downtown Syracuse to the southern shore of Onondaga Lake. The Creekwalk extends both north and south from the Syracuse Inner Harbor. Heading north toward Onondaga Lake, a paved pathway follows the western shoreline of the Inner Harbor and Barge Canal for almost 0.75 mile. The trail is 2.6 miles long and averages 13 feet wide. It will eventually connect to the Loop the Lake Trail, as well as to the Erie Canalway Trail, scheduled to connect Canal communities from Albany to Buffalo along the 524-mile New York State Canal System.

The engineering improvements to the wastewater collection and treatment infrastructure continue to be the subject of professional and trade publications and presentations. In addition, scientists and academics continue to analyze this remarkable example of lake rehabilitation and publish their findings in the peer-reviewed literature. The human health impacts and ecological analysis of the contaminant issues are of interest to academic and agency scientists, public policy specialists, economists, and engineers. The Onondaga Lake Scientific Forum is convened each year by Upstate Freshwater Institute as a means of disseminating critical scientific information to stakeholders (http://www.upstatefreshwater.org/html/annual_olsf.html). The next meeting is scheduled for March 2013 on the campus of SUNY-ESF in Syracuse.

## Section 9. Emerging Issues and Recommendations

The AMP continues to evolve in response to new information and emerging issues affecting Onondaga Lake, its tributaries, and the Three Rivers System. Each year, Onondaga County, NYSDEC, ASLF, and members of OLTAC review the monitoring program design and recommend modifications in light of changing objectives. Maintaining the integrity of the long-term monitoring program is important for trend analysis; consequently, most program changes build on the current monitoring framework.

During 2011, Onondaga County continued working with NYSDEC and ASLF to modify the tributary monitoring program to address the requirements of the Fourth Stipulation Amending the ACJ, which directs the County to evaluate the effectiveness of the green and gray infrastructure improvements. Enhanced tributary monitoring, as approved by NYSDEC in 2011, includes additional storm event sampling on Onondaga Creek and Harbor Brook, following completion of the storage facilities planned for Clinton and lower Harbor Brook. The enhanced tributary monitoring program also includes limited testing for the presence and concentration of priority pollutants, such as heavy metals, pesticides, and other compounds. The additional monitoring was implemented following NYSDEC approval of the work plan in 2011.

The 2011 monitoring results indicate that Onondaga Lake tributaries were generally in compliance with ambient water quality standards, with the noteworthy exception of the standard for fecal coliform bacteria (Table 4-1). Contraventions of this standard were documented at all monitored sites except for Tributary 5A and the Onondaga Lake Outlet. Fecal coliform concentrations increased in urban portions of Onondaga Creek and Harbor Brook under both wet and dry weather conditions. Although long-term data suggests decreases in fecal coliform levels in Onondaga Creek, Harbor Brook, and Ley Creek, these trends are not statistically significant. A more rigorous statistical analysis is recommended that will consider: (1) Onondaga Creek, Harbor Brook, Ley Creek, and Ninemile Creek; (2) data collected during the 1998 to 2012 interval; (3) trends other than monotonic trends (e.g., step changes); (4) seasonal variations; (5) alternate thresholds for dry and wet weather conditions; and (6) potential covariates, such as flow, temperature, and phosphorus concentrations.

A resurgence of mud boil activity in upstream portions of the Onondaga Creek watershed (Tully Valley) has been reported by USGS that may be responsible for increased suspended solids loading from the creek to Onondaga Lake. Landslide activity in Rattlesnake and Rainbow Creek valleys has diminished. However, periodic slumps into Rattlesnake Creek continue to cause short-term turbidity and sediment loading pulses. These changes may impact water clarity in both the creek and the lake, and should be considered in assessment of long-term trends.

As noted in Section 6.3.2 the catch rates of juvenile bluegill and pumpkinseed have shown a marked decline since 2006 when the average CPUE reported was 4.64 fish captured per seine haul. This decline has become more apparent – recently with reported catch rates of 0.16, 0.03, and 0.04 fish captured per seine haul in 2009, 2010, and 2011, respectively. Initial observations from 2012 suggest that catch rates will still be very low. Recruitment varies annually in most lakes and may be affected by several variables. Environmental factors including water quality, habitat, wind, water level, and temperature during and following spawning have been suggested as factors affecting reproductive success. Other factors including predation and competition also have been attributed to decreased reproductive success of many species. Which factor or factors are causing the decline of bluegill and pumpkinseed young of the year in Onondaga Lake is unclear. In 2012 Onondaga County expanded its larval and juvenile fish sampling program in an attempt to understand the role of some of these variables. With the establishment of alewife in Onondaga Lake, predation on larval bluegill and pumpkinseed is a strong possibility and should be evaluated. Stomach samples of alewife should be collected from late June through early July following the peak of larval bluegill and pumpkinseed emergence. In addition, further analysis of environmental factors should be conducted to assess the potential impact that water level, temperature, and wind may have had on reproductive success in 2009 through 2012.

Remedial measures to mitigate legacy pollutants are underway. Addition of nitrate to the lake's lower waters during summer began in 2011, in an effort to prevent release of methylmercury from the lake's deep sediments. Plans to dredge and cap contaminated sediments and restore nearshore aquatic habitat are proceeding, and related activities began in 2012. The restoration efforts will inevitably affect analysis and interpretation of the AMP biological and habitat data. The County will consider remedial activities conducted on behalf of Honeywell in evaluation of trends in lake water quality and biology. Any change to the County's approach to data evaluation brought about by the Honeywell program will be documented in the Data Analysis and Interpretation Plan, which is part of the annual work plan submittal and included in the library of the Annual Report.

The Onondaga Lake Water Quality Model (OLWQM) was developed and calibrated using data from the AMP, and has been subject to outside expert peer review. This model will serve the community by defining the water quality and aquatic habitat benefits, if any, realized by further reducing nutrient and sediment inputs from point and nonpoint sources. NYSDEC used an ensemble modeling approach to evaluate the environmental benefits associated with additional phosphorus removal from Metro and other sources. This analysis supported a total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake, which was approved by USEPA on June 29, 2012. A total phosphorus concentration limit of 0.10 mg/L on a 12-month rolling average basis was established for Metro outfall 001, and became effective upon TMDL approval. In addition, phosphorus loading reductions are to be implemented for other SPDES permits by 1/1/2016, CSOs and Metro outfall 002 by 12/31/2018, agricultural lands by 12/31/2022, and for MS4 areas by 12/31/2025.

## Section 10. Acknowledgements

In addition to the authors of the Annual Report, several other individuals and professional service firms contribute their expertise to the data collection and interpretation effort. We wish to acknowledge the contribution of the following specialists for their ongoing commitment to investigating the Onondaga Lake ecosystem.

(1) AirPhotographics Inc. of Martinsburg WV. This firm obtains the aerial photographs of the lake's nearshore zone each summer and provides high-quality images for interpretation of the amount of the littoral zone covered with macrophytes. They have been working with the AMP team since 2000.

(2) PhycoTech Inc. of St. Josephs MI. Dr. Ann L. St. Amand has been identifying the Onondaga Lake phytoplankton community since 1990. Each year, Dr. St. Amand and her staff at PhycoTech provide the detailed taxonomic information needed to characterize this ecosystem in flux.

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