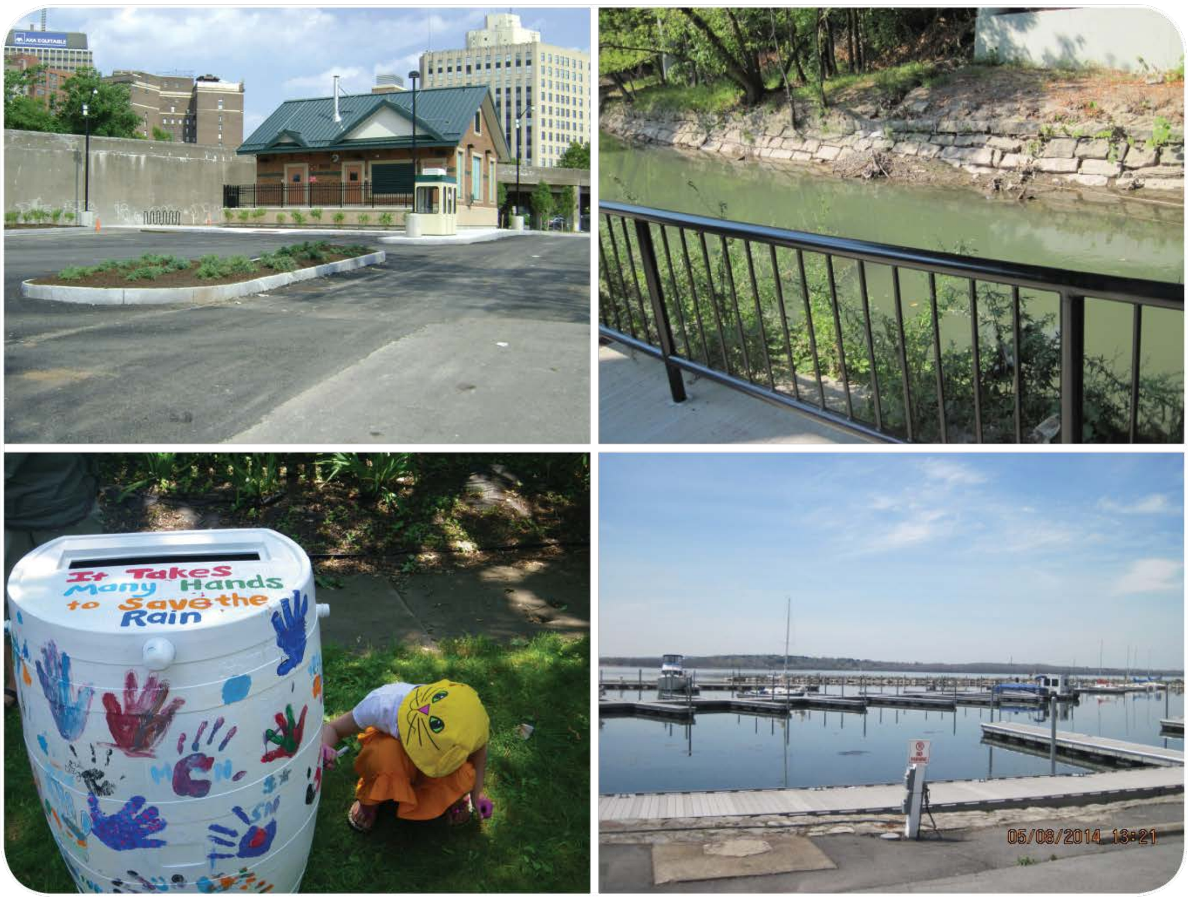
2013 Annual Report

ONONDAGA LAKE AMBIENT MONITORING PROGRAM

Final, March 2015



Onondaga County

Joanne M. Mahoney, County Executive • Tom Rhoads, P.E., Commissioner

Save the Rain

Onondaga County Department of WATER ENVIRONMENT PROTECTION

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

Onondaga County Department of WATER ENVIRONMENT PROTECTION

Save the Rain

http://www.savetherain.us

ONONDAGA LAKE AMBIENT MONITORING PROGRAM
2013 ANNUAL REPORT

ONONDAGA COUNTY, NEW YORK

Final, March, 2015

Prepared for

ONONDAGA COUNTY, NEW YORK

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Key Features of this Report

The 2013 report is distributed as an electronic file in portable document format (PDF), which can be opened using Adobe Reader. Key results and supporting tables and graphics are included in the main document, with links to additional tables, technical reports, and graphics in electronic appendices. The report and supporting files are available on CD upon request and on the Onondaga County web site http://www.ongov.net/wep. Throughout the document the reader will find hyperlinks marked in bright blue, which provide easy access to other sections of the report (e.g., figures, tables) as well as external links to web pages and email addresses.

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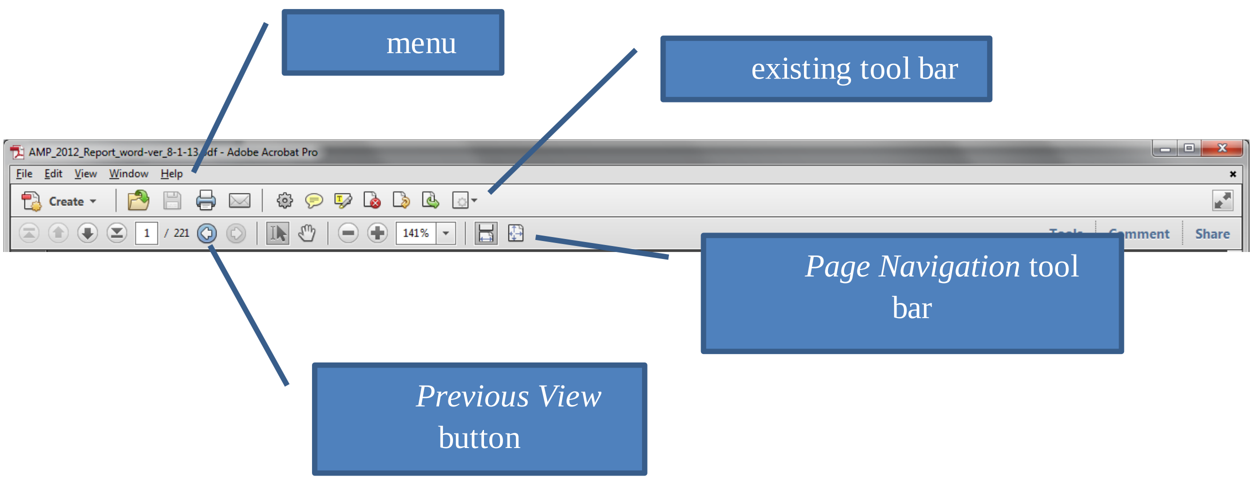

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While each hyperlink has been checked, it is possible that some features will not be enabled on every computer's operating system. Feedback on the functionality of the electronic features of the document is welcome. Please contact JeannePowers@ongov.net with comments.

Acknowledgements

In addition to the authors of the Annual Report, several other individuals and professional service firms contributed 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.

3. Ecologic, LLC digitized the aerial photographs of macrophytes in the littoral zone.

Table of Contents

Appendices

Crew Team at the Onondaga Lake Outlet

LIST OF TABLES

LIST OF FIGURES

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Executive Summary

Introduction

This Annual Report of Onondaga County's Ambient Monitoring Program (AMP) describes the state of Onondaga Lake, its tributaries, and adjoining portions of the Three Rivers System in 2013. 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, most 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 2013 Annual Report documents the input of water and materials (bacteria, sediment, nutrients, and salts) to Onondaga Lake from the watershed and the Metropolitan Syracuse Wastewater Treatment Plant (Metro). The response of the lake to these inputs is a focus of the annual program. The AMP evaluates water quality conditions, compliance with New York State ambient water quality standards (AWQS), and long-term trends. The AMP also tracks the species composition and abundance of fish, phytoplankton, zooplankton, benthic invertebrates, aquatic macrophytes, and dreissenid (zebra and quagga) mussels.

Report Format

This report is a scientific summary of the major findings of the AMP in 2013, supported by graphs and tables of current and historic data. 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. While the *Executive Summary* focuses on noteworthy features of the 2013 AMP results, the following section (*Highlighting Improvements in Onondaga Lake*) reports on the long-term water quality and biological improvements that have been achieved in Onondaga Lake.

Regulatory Framework

The 2013 AMP annual report has been prepared 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 (ASLF). The ACJ requires upgrades to the County's wastewater collection and treatment infrastructure and an extensive monitoring program (the AMP) to document related environmental improvements. Onondaga County Department of Water Environment Protection (WEP) is responsible for implementing the AMP and reporting its findings. Links to the ACJ and its modifications are posted on the Onondaga County web site http://www.ongov.net/wep/we15.html.

Two important regulatory milestones were reached in 2012 that provide important context for the 2013 AMP results. First, New York State Department of Environmental Conservation (NYSDEC) issued a new State Pollution Discharge Elimination System (SPDES) Permit for Metro on March 21, 2012. Second, a total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake was approved by USEPA on June 29, 2012. Upon TMDL approval, a total phosphorus concentration limit of 0.10 mg/L on a 12-month rolling average basis became effective for Metro outfall 001. 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 municipal separate storm sewer systems (MS4) areas by 12/31/2025. Phosphorus loading reductions from small farms are voluntary and incentive based.

The Fourth Stipulation of the ACJ required the County to submit a plan, with a schedule for implementation, for proposed modifications to the tributary component of the County's established AMP. These modifications, referred to as the Post-Construction Compliance Monitoring (PCCM) Program, include additional wet weather monitoring within the CSO-affected stream reaches to evaluate completion of the planned improvements to the wastewater and stormwater collection infrastructure and compliance with the AWQS for bacteria and floatables. The scope and schedule of the PCCM Program is summarized in Section 4.3.7 of this report.

Onondaga County Actions and Progress with Related Initiatives

The County completed a number of "gray" and "green" infrastructure projects in 2013 that will reduce wet weather discharges from combined sewer overflows (CSOs) into Onondaga Lake and its tributaries. Gray infrastructure projects include sewer separation, capture of floatable materials, and maximization of system storage capacity. In 1998, there were 72 active CSOs (outfall points with the potential to discharge combined sewage) in the collection system discharging to Onondaga Creek, Harbor Brook, and Ley Creek. Through 2013, 44 CSOs have been abandoned (completely eliminated or converted to a storm discharge point only) as a result of ACJ projects. In addition, green infrastructure projects are capturing hundreds of millions of gallons of stormwater runoff before it can enter the combined sewer system.

Construction was completed on multiple gray infrastructure projects in 2013 that will significantly reduce CSO discharge. Harbor Brook Interceptor Sewer (HBIS) Replacement was completed in December 2013, including upsizing of approximately 7,500 linear feet of interceptor sewer. The capacity of HBIS was expanded by 500,000 gallons and the flow increased by 400,000 gallons per day. This project included a two-acre green infrastructure site that provides an additional 467,000 gallons of stormwater capture. The Clinton and Lower Harbor Brook Storage Facilities were placed into operation and capable of receiving wet weather flow on December 31, 2013. The Clinton and Lower Harbor Brook facilities provide 6.5 million gallons and 4.9 million gallons of CSO storage, respectively, which is routed to Metro for treatment. These facilities will provide a combined 147 million gallons of CSO capture annually.

Green infrastructure solutions are being implemented at County facilities and in other urban areas to help capture and reuse urban storm runoff before it enters the CSO system. To-date, over 175 green infrastructure projects have been completed as part of the "Save the Rain" initiative (http://savetherain.us/), reducing inputs of stormwater runoff and pollution to Onondaga Lake and its tributaries by 100 million gallons annually. The "Save the Rain" program experienced another impressive year in 2013 with 50 green infrastructure projects completed. 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 stormwater runoff.

The updated version of the Microbial Trackdown Phase 2 workplan, dated April 5, 2012, outlined a comprehensive study implemented in 2012 and 2013 to monitor presence of fecal coliform bacteria in Harbor Brook and Onondaga Creek, as a follow-up to the findings of the Phase I study conducted in 2008 and 2009. Funding for the Phase 2 project was provided by USEPA and administered by NYSDEC (Region 7). The entire study was undertaken as a joint project of the Onondaga Environmental Institute (OEI) and Onondaga County Department of Water Environment Protection (OCDWEP), with OEI as the principal partner and OCDWEP providing analytical and sampling support. Results from the study helped to elucidate spatial and temporal trends in bacteria and water quality, identify areas of concern, and make physical improvements to the system. Based on the findings of the 2013 sampling program, OEI identified eight point sources of concern in Onondaga Creek and three into Harbor Brook. Strategies are being developed to perform targeted sampling and analysis of each point source in an effort to isolate the source (i.e., animal vs. human) and location (cross-connection, illicit discharge, etc.) of the discharge. Results from this study effectively documented the effects of dry-weather inputs on bacteria levels and water quality in Harbor Brook, Onondaga Creek, and Ley Creek. In addition, spatial and temporal trends in bacteria levels were identified that helped to: (1) explain patterns of stream water quality related to land use, (2) detect relationships between measured parameters, (3) identify and prioritize point source trackdown work, (4) measure the effects of remedial activities on bacteria levels, and (5) assess long-term changes in bacteria levels since Phase 1.

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. Dredging and capping of Onondaga Lake sediments began in summer 2012 and continued in 2013. About 2 million cubic yards of contaminated sediment will be removed from the lake by hydraulic dredging, which is expected to be completed in 2014, a year ahead of schedule. About 450 acres of the lake bottom are being capped to provide a new habitat layer, prevent erosion, and isolate remaining contaminants. Additional work is under way to improve up to 50 acres of wetlands on the shores of Onondaga Lake and along the lake's tributaries. About 1.1 million plants, shrubs, and trees are being planted to enhance habitat for fish and wildlife in the Onondaga Lake watershed. In 2013, the third year of a three year pilot test, nitrate was added to the deep waters of Onondaga Lake with the objective of limiting release of methylmercury from the profundal sediments to the hypolimnion. Based on the success of this pilot test, a long-term program of nitrate addition will begin in 2014.

Tributary Water Quality

Precipitation is the primary driver of stream flow and the single most important meteorological attribute affecting material loading from the tributaries to Onondaga Lake. Annual precipitation totaled 40.4 inches in 2013, 4% higher than the 30-year historic (1983–2012) average of 38.7 inches and 15% higher than the 35.1 inches received in 2012. Approximately average precipitation during most of 2013 resulted in an annual average flow for Onondaga Creek that was only slightly higher than the 1971–2012 average. Precipitation was particularly high during the month of June when 6.8 inches of rain was reported. It was the wettest June since 1976 and the 5^{th} wettest since 1902.

The 2013 tributary data continued to indicate that the major tributaries were generally in compliance with New York State ambient water quality standards (AWQS). The primary exceptions in meeting AWQS in the tributaries were total dissolved solids (TDS) and fecal coliform bacteria (FC). Contravention of the AWQS for TDS is primarily associated with the natural hydrogeology of the watershed and not with anthropogenic effects. The largest source of fecal coliform bacteria to Onondaga Lake in 2013 was Onondaga Creek. However, the Metro bypass (002) and the other primary tributaries made noteworthy contributions as well. The following tributaries were 100% compliant with the fecal coliform standard: Tributary 5A and the Onondaga Lake Outlet-2ft. Compliance with the AWQS for fecal coliform bacteria was achieved for less than 50% of the monthly geometric means at Harbor Brook at Hiawatha (17%), Ley Creek (22%), Onondaga Creek at Kirkpatrick (0%), and Sawmill Creek (43%).

Results from a detailed analysis of runoff event data collected from Onondaga Creek over the 1999–2003 and 2008–2009 intervals highlight the importance of considering fecal coliform concentrations in relation to short-term (e.g., hours) changes in precipitation and stream flow. Urban contributions to stream flow, including contributions from CSOs, are typically short-lived, averaging only four to five hours in duration. However, fecal coliform levels during these urban flow peaks are 50-fold higher than during other wet weather intervals and 150-fold higher than during dry weather periods. The most conspicuous improvements from completed green and gray infrastructure projects may be reductions in the magnitude of urban flow peaks and fecal coliform concentrations during these peaks. Accordingly, short-term dynamics in stream flow and fecal coliform levels should be analyzed as part of post-construction monitoring and assessment.

The largest total phosphorus (TP) loads to Onondaga Lake were delivered by the two largest tributaries, Onondaga and Ninemile Creeks, and the Metro effluent. The Metro bypass (002) load was estimated to be the fifth highest, following Ley Creek. Annual total phosphorus loads in 2013 were nearly two-fold higher than in 2012, consistent with unusually low precipitation and stream flow in 2012. Onondaga Creek, Ninemile Creek, and the Metro effluent also had the highest total dissolved phosphorus (TDP) loads in 2013. In an effort to reduce phosphorus levels in stormwater runoff, New York State restricted the use of phosphorus fertilizer on lawns and non-agricultural turf beginning January 1, 2012.

The Metro effluent was the leading source of total nitrogen (TN) and an important source of ammonia nitrogen (NH_3-N) to the lake in 2013. The largest source of ammonia in 2013 was Ninemile Creek. The total suspended solids (TSS) load was dominated by inputs from Onondaga Creek and Ninemile Creek, which combined to account for 94% of the total load to Onondaga Lake. Inputs of clay particles from the mud boils in upstream portions of the watershed contribute substantially to the high TSS contribution from Onondaga Creek.

Metro continued to perform at a high level in 2013, meeting permit limits for total phosphorus and ammonia throughout the year, and often by a wide margin. Since mid-2008 the 12-month rolling average total phosphorus concentration in the Metro effluent has remained below 0.10 mg/L. Phosphorus treatment took another step forward in 2013, as the annual average total phosphorus concentration in the effluent decreased to 0.059 mg/L. Headworks bypasses of the full treatment process, which are sometimes required during intense runoff events, receive little or no treatment prior to discharge. In 2013, 11 headworks bypasses summed to 71 million gallons. All of the headworks bypasses during 2013 were associated with reduced capacity due to the Grit Improvement Project. An additional 446 million gallons were discharged through Outfall 002 as a result of 73 secondary bypasses and another 26 million gallons were discharged through Outfall 001 as a result of tertiary bypasses.

Onondaga Lake Water Quality

Trained County 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. The 2013 monitoring results indicate that the open waters of Onondaga Lake were in compliance with most AWQS. The lake is now in full compliance with the AWQS for ammonia, and in 2008 was officially removed from the New York State's 303(d) list of impaired waterbodies for this water quality parameter. Exceedances of the AWQS for nitrite now only occur in the lower layers of the lake when hypoxia prevails. These conditions reflect incomplete nitrification of ammonia within those lower lake depths.

Long-term trends in total phosphorus (TP) concentrations in the lake's upper waters continue to depict major decreases since the early 1990s. The 2013 summer (June-September) average TP concentration in the lake's upper waters was 25 (micrograms per liter) µg/L, somewhat higher than the state's guidance value of 20 µg/L. Dissolved oxygen (DO) concentrations met the AWQS in the upper waters of Onondaga Lake throughout the 2013 sampling period. Anoxic conditions prevailed in the lower waters during most 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 AWQS for DO in the deep waters.

The summer average chlorophyll-*a* (Chl-*a*) concentration in the upper waters of the lake was 9.1 µg/L in 2013, higher than it has been since 2007. The average and peak concentrations of this measure of algal biomass have declined substantially since the phosphorus treatment upgrade at Metro in 2005. According to the Chl-*a* thresholds of 15 µg/L to represent minor blooms (impaired conditions) and 30 µg/L to represent major blooms (nuisance conditions), there were no algal blooms in Onondaga Lake during the summer recreational period (June–September) of 2013. The absence of algal blooms in Onondaga Lake stands in contrast to the widespread occurrence of blue-green harmful algal blooms in lakes across New York State (see http://www.dec.ny.gov/chemical/77118.html for more information). The AMP has established a minimum summer average Secchi disk transparency of 1.5 meters at South Deep as a target for improved aesthetic appeal. During the summer of 2013, Secchi disk values ranged from 1.1 to 2.8 meters and averaged 1.8 meters. Water clarity in 2013 was lower than it has been since 2006. The unusually large phosphorus loads received during June and July likely contributed to the relatively low clarity and high total phosphorus and Chl-*a* concentrations observed during the summer of 2013.

During the April to October interval of 2013, bacteria levels in Class B areas of Onondaga Lake did not exceed the standard established for contact recreation. Two sites, located within the Class C segment of the lake's southeastern shoreline, exceeded the bacteria standard during the month of October, and one of these sites also exceeded the standard in April. With the exception of a single measurement made near the mouth of Bloody Brook in June following a runoff event, the NYSDOH swimming safety guidance value for water clarity was met in Class B waters throughout the summer recreational period of 2013. Monitoring locations in the southern end of the lake, near the mouths of Onondaga Creek, Harbor Brook, and Ley Creek, regularly failed to meet this guidance value.

The mass of phosphorus accumulated in the hypolimnion during the summer stratification interval has decreased by 90% since the 1990s as a result of lower primary production following the Metro phosphorus treatment upgrade and the increase in nitrate from year-round nitrification. The supply of nitrate to the lower waters in summer was augmented by Honeywell during a three year (2011–2013) pilot test intended to control sediment release of mercury. This also affects phosphorus accumulation because phosphorus release from the sediments is blocked by maintenance of high nitrate concentrations in the hypolimnion. The absence of noteworthy sediment phosphorus release under the high nitrate concentrations of 2013 clearly demonstrates the positive effect of nitrate.

The concentration of total dissolved solids (TDS) in Onondaga Lake routinely exceeds the AWQS of 500 mg/L by a wide margin. Exceedance of this standard is associated with the lake's natural hydrogeology and not with anthropogenic effects. The bedrock in Onondaga County is comprised of sedimentary rocks with high concentrations of calcium and sulfate, which contribute to the high TDS levels in Onondaga Lake and its tributaries.

Biology and Food Web

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 resulted in expansion of macrophyte beds. This expanded coverage of macrophytes throughout the littoral zone has improved habitat and shelter for many fish and other aquatic organisms.

The biomass of phytoplankton in Onondaga Lake has declined rapidly since the 1990s, from a standing crop around 8 mg/L in 1998–99 to less than 1.5 mg/L from 2007-2012. Phytoplankton biomass in 2013 was 1.6 mg/L, the highest value since 2006 but substantially lower than in 1998–99. Both biovolume and chlorophyll levels are measures of phytoplankton abundance and in 2013 both were within the range expected from a meso-eutrophic lake (biovolume 3-5 mg/L; Chl-*a* of 3.5-9.0 µg/L). The composition of the phytoplankton community has changed from one dominated by undesirable blue-green algae (cyanobacteria) and dinoflagellates to one dominated by more desirable diatoms and green algae.

The overall coverage of macrophytes in 2013 (387 acres) was less than that observed in 2012 (505 acres), a drop in percent coverage of the littoral zone of approximately 15%. Remedial activities occurring in the southern end of the lake may account for the reduced area of vegetation coverage in 2013 as compared with 2012. However, the estimated percent coverage of 50% in 2013 was consistent with that reported from 2009 through 2011. Water stargrass had the highest overall (lakewide) relative abundance (32%), with stonewort (23%) and coontail (21%) as second and third in overall relative abundance. The expansion of macrophyte coverage since 2001 has provided more complex habitat for many aquatic organisms and has played a major role in structuring the biological communities of the lake.

The size structure of the zooplankton community is regulated by the selective feeding of fish on zooplankton. The average biomass of zooplankton samples collected in Onondaga Lake in 2013 was slightly higher than in 2011 and 2012, the lowest recorded in the AMP. Zooplankton biomass has been low since 2010, and there is an overall long-term decline. Zooplankton species and size composition indicate high fish planktivory continued in 2013, similar to 2010–2012. The low biomass of *Daphnia* from 2003 through 2007 and 2010 through 2013 is attributed to predation pressure by abundant Alewife during these periods.

Zebra mussels were first recorded in Onondaga Lake in 1992, although they were not abundant until 1999. A related species, the quagga mussel, that was noted as present in the lake in both 1992 and 2002 increased greatly from 2006 through 2009 and became the dominant mussel in water deeper than 3 m by 2009. Quagga mussels contributed more than 75% of the lake-wide mussel biomass and approximately 50% of the lake-wide mussel density from 2009 to 2012. Biomass and density of both mussels declined in 2013, with a larger decline in quagga mussels. In 2013 dreissenid biomass in water depths of 0-6 meters averaged 139 g wet weight/m^2 with quagga mussels contributing 73% of the biomass. This represents a nearly 5-fold decline since peak biomass in 2011 (619 g ww/m^2) and may be associated with dredging by Honeywell, predation by an increasing number of Round Goby, and lower food availability as water quality continues to improve.

Changes in the fish community of Onondaga Lake have occurred as water quality and habitat conditions have improved. Centrarchid species (Largemouth and Smallmouth Bass, Pumpkinseed, Bluegill, and Rock Bass) and Brown Bullhead construct nests in the littoral zone of the lake. In 2013, 3,492 nests were observed, with 54% in the South basin and 46% in the North basin. The occurrence of nests in the North and South basins has been more evenly distributed during the past several years, primarily due to increased numbers of nests in the South basin since 2008. The majority of the nests observed in 2013 were sunfish (Pumpkinseed, Bluegill, and Rock Bass) accounting for 66% of the total nests identified. Lesser amounts of Largemouth Bass (1.4%) and Brown Bullhead (0.60%) were also observed. The remaining 32% of the nests were without adult fish present.

Twelve fish species were identified during the 2013 larval seine events, including Pumpkinseed, Bluegill, Banded Killifish, Brook Silverside, Bluntnose Minnow, Golden Shiner, Round Goby, Alewife, Yellow Perch, Common Carp, Fathead Minnow, and Largemouth Bass.

Overall catch per unit effort (CPUE) was higher in 2013 compared to other years when larval seines were used (2000 through 2003 and 2012), and the number of species collected in 2013 was the highest since 2000. Young-of-year Bluegill and Pumpkinseed, Common Carp, Largemouth and Smallmouth Bass, Gizzard Shad, Round Goby, Tadpole Madtom, Golden Shiner, Brown Bullhead, and Channel Catfish were captured by littoral zone seining in 2013. Largemouth Bass accounted for 52% of the overall catch followed by Bluegill and Pumpkinseed together accounting for 43% of the overall catch.

A total of 746 fish representing 23 species was collected during the two gill net sampling events during late spring and fall of 2013. White Perch was the most abundant species collected, making up 34% of the total catch. Other relatively abundant species included Yellow Perch (24%), Gizzard Shad (8%), Longnose Gar (6%), and Brown Bullhead (5%). Eighteen of the 23 species together constituted 24% of the total catch. Overall catch per unit effort (CPUE) for pelagic adults was higher than rates seen in previous years.

A total of 23 species was collected in 2013 during the two (spring and fall) boat electrofishing sampling events. Gizzard Shad and Alewife were the most abundant species collected, making up 32% and 26% of the total catch, respectfully. Other relatively abundant species included Yellow Perch (11%), Brown Bullhead (7%), Pumpkinseed (7%), and Largemouth Bass (7%). Seventeen of the 23 species collected each constituted less than 4% of the overall catch. The black bass population is increasingly dominated by Largemouth Bass in both adult and young-of-year life stages. Smallmouth Bass catch rates continue to decline, likely indicative of the changing conditions in the littoral zone with increased macrophyte coverage more suitable for Largemouth Bass.

Overall trends in catch rates have varied by fish species since 2000. Several species have increased recently, including Largemouth Bass, Gizzard Shad, Brown Bullhead, and Yellow Perch; while catch rates of Smallmouth Bass, Pumpkinseed, White Perch, and Common Carp have declined. These patterns likely reflect the changing habitats in the lake including increased macrophyte coverage, increased mussel abundance, and changes in the fish community associated with Alewife. In Onondaga Lake, fish species richness has gradually increased since 2000. In 2013, a total of 35 species were captured during electrofishing, gill netting, and seining surveys. Since the monitoring program started in 2000, fifty two fish species have been identified in the lake.

DELTFM (Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies) abnormalities in adult fish showed an overall increase from 2003 to 2009, but have decreased since then. DELTFM abnormalities began declining in 2010 and have steadily decreased to 2% in 2013. The majority of abnormalities in the Onondaga Lake fish community in 2013 were lesions (64%), followed by deformities (35%) and tumors (1%). Fifteen species of adult fish were found with DELTFM abnormalities in 2013, similar to 2012 and recent previous years.

Water Quality in the Three Rivers System

Water quality conditions in lotic ecosystems are highly dependent on the magnitude and timing of flow. Flow rates in the Seneca and Oneida Rivers exceeded long-term median flows for much of 2013. The summer average (June–September) flow in the Seneca River was 2,925 cubic feet per second (cfs) in 2013, more than 50% higher than the long-term summer average of 1,907 cfs. Summer average flow in the Oneida River was 2,416 cfs in 2013, 69% higher than the long-term summer average of 1,428 cfs. 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. Flows in the Seneca and Oneida Rivers remained above the respective 7Q10 flows of 400 cfs and 298 cfs throughout the summer of 2013. The 2013 survey of the Three Rivers System was conducted on September 17, 2013 when flows in the Seneca and Oneida Rivers were 1020 cfs and 349 cfs, respectively.

Dreissenid 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. The dreissenid mussel invasion has converted the Seneca River at Baldwinsville from a low clarity, phytoplankton rich, 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. Increased water clarity has led to a major expansion in macrophyte coverage in many areas of the Three Rivers System. Conspicuous signatures of dreissenid mussels have been observed in the survey data from previous years, including decreases in turbidity, dissolved oxygen, and chlorophyll-*a*, and increases in ammonia and soluble reactive phosphorus concentrations from Cross Lake to the Onondaga Lake outlet. These signatures were not as conspicuous in 2013 as they have been in previous years, likely because the 2013 survey was conducted during relatively high flows and later in the year.

Contraventions of the NYSDEC instantaneous minimum dissolved oxygen standard of 4 mg/L were documented at one of the six locations monitored during the September 17, 2013 survey. This is in stark contrast to 2012, when the dissolved oxygen standard was contravened at all six sampling locations. This difference is likely a result of the higher flow conditions present during the 2013 survey rather than an indication of systematic improvements in dissolved oxygen concentrations. There were no documented exceedances of AWQS for ammonia or nitrite at any of the six sampling locations. As per the County's Five-Year AMP Workplan, water quality monitoring of the Three Rivers System will be discontinued in 2014. This component of the AMP is being discontinued because Metro effluent diversion to the river system is no longer a management option under consideration and the Three Rivers Water Quality Model (TRWQM) efforts are complete.

Future AMP Modifications

Onondaga County submitted an Ambient Monitoring Program (AMP) work plan to NYSDEC and ASLF annually from 1999 to 2013, as required by the ACJ. These work plans provided detailed descriptions of the sampling programs proposed for Onondaga Lake, its tributaries, and the Three Rivers System. In light of the notable water quality improvements in Onondaga Lake, recently completed major gray infrastructure project milestones to remediate CSOs, and on-going green infrastructure projects, Onondaga County conducted a thorough review of the AMP and developed a five-year work plan to guide monitoring and assessment of Onondaga Lake and its tributaries from 2014 to 2018. The proposed five-year work plan builds on revisions to the AMP instituted as part of the 2013 program. Program modifications implemented in 2013 included the following:

- Based on long-term, consistent compliance with ambient water quality standards measurements of arsenic, cadmium, chromium, copper, nickel, lead, and zinc in the tributaries were discontinued except as follows: dissolved forms of cadmium, copper, and lead were analyzed on a quarterly basis from routine sampling sites on Onondaga Creek; dissolved forms of copper and lead were analyzed on a quarterly basis from the routine sampling site on Tributary 5a; Analysis of dissolved total mercury was added to the program to support assessment of compliance with the applicable AWQS.
- Revised the sampling program for North Deep to comply with the phosphorus TMDL follow-up monitoring requirements and discontinued other parameters at this site.
- Replaced composite sampling of the upper mixed layer (UML) and lower water layer (LWL) with discrete samples collected from depths of 3 and 15 meters.
- Discontinued measurements of arsenic, cadmium, chromium, copper, nickel, lead, and zinc in Onondaga Lake because long-term, consistent compliance with ambient water quality standards has been established. Analysis of dissolved total mercury was added to the program to support assessment of compliance with the applicable AWQS.
- Utilized data from the Honeywell funded monitoring buoy at South Deep and discontinued deployment of the Onondaga County buoy.
- Discontinued LiCor Underwater Illumination profiles in the lake and river. Secchi disk transparency is used to assess compliance, trophic status, aesthetics, and use attainment.
- Discontinued special Fall Turnover sampling because dissolved oxygen concentrations during fall have met New York State ambient water quality standards consistently for more than a decade.

Onondaga County's proposed five-year AMP work plan, which serves as a roadmap for monitoring and assessment of Onondaga Lake and its tributaries during the 2014–2018 period, was developed in consultation with members of the County's Onondaga Lake Technical Advisory Committee (OLTAC), representatives of NYSDEC (Region 7), ASLF, Onondaga Environmental Institute (OEI), and Parsons (Honeywell's project consultant). The work plan, which is intended to comply with the requirements of the Fourth Stipulation to the ACJ and the SPDES permit for Metro, was submitted to NYSDEC and ASLF for review on February 6, 2014.

It is the County's goal to supplement this Five-Year AMP Workplan annually, with updates submitted to NYSDEC and ASLF by January 31 of each year. These updates will reflect findings from the previous year's sampling efforts and any changes in the NYS AWQS or guidance values. The sampling program will continue to incorporate the flexibility necessary to respond to new data and information. It is the County's goal to ensure all elements of the AMP provide meaningful data in a scientifically defensible and cost-effective manner.

The County has developed a Post-Construction Compliance Monitoring Program (PCCMP) to meet the requirements of the ACJ, the 4^{th} Stipulation of the ACJ, and the Metro SPDES permit. The PCCMP includes three elements: in-stream monitoring, CSO monitoring, and verification of sewer separation projects. The in-stream monitoring data is reviewed annually in the AMP Report (see Section 4.3.7). The purpose of the CSO discharge monitoring effort is to increase the veracity of the Stormwater Management Model (SWMM) used for planning, design, and determination of compliance with the volume capture requirements. Flow meters are installed at 13 representative CSO locations. Additional information on the CSO monitoring and verification of sewer separation components can be found in the ACJ Fourth Stipulation 2013 Annual Report dated April 1, 2014 (http://savetherain.us/acj-annual-report-2013/).

Pavilion at Onondaga Lake Park

Highlighting Improvements in Onondaga Lake

Introduction

This section highlights selected water quality and biological improvements that have been documented in the lake, and reports on long-term changes brought about by rehabilitation efforts. Following this brief summary is the main body of the 2013 Annual AMP Report, where the results are discussed in more detail and supporting documentation is provided.

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 HI-1) and reduced Metro's contribution to the total annual load (Metro + tributaries) from 91% to 47% (Figure HI-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 HI-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 24% during 2007–2013 (Figure HI-4).

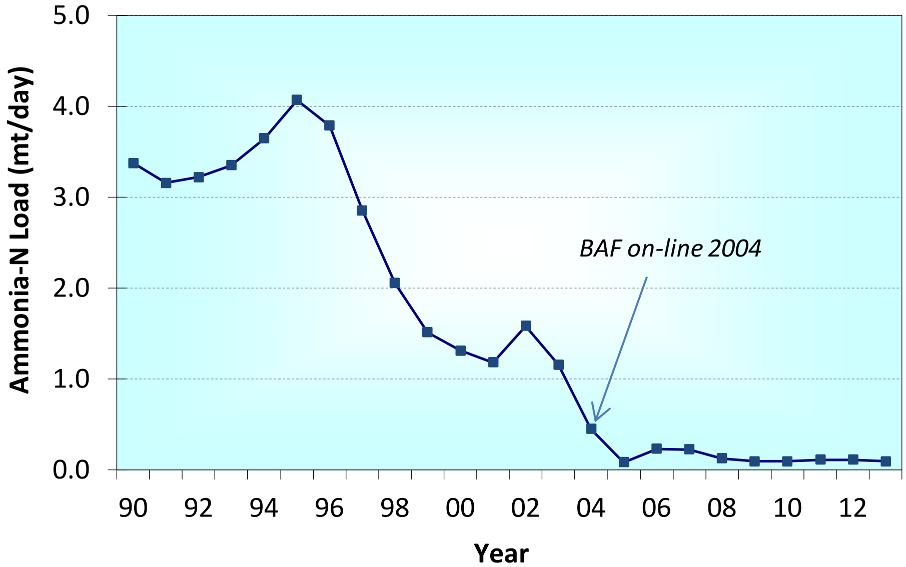


Figure HI-1. Time plot of the annual daily average Metro (outfalls 001+002) ammonia-N loading (metric tons/day) to Onondaga Lake, 1990–2013. BAF refers to biological aerated filter.

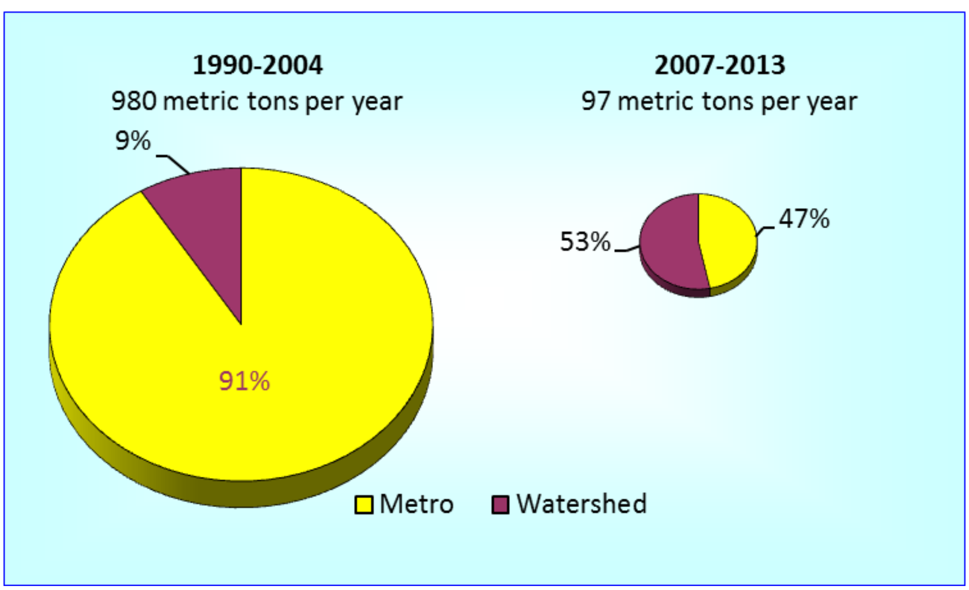


Figure HI-2. Contributions of Metro (outfalls 001+002) and the watershed to the total annual input of ammonia to Onondaga Lake, average for the time periods 1990–2004 and 2007–2013.

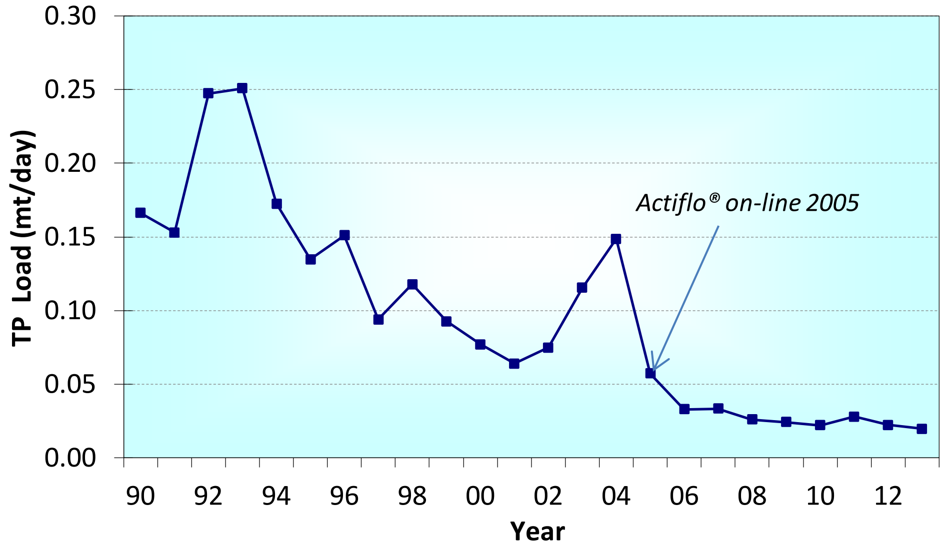


Figure HI-3. Time plot of the annual daily average Metro (outfalls 001+002) total phosphorus (TP) loading (metric tons/day) to Onondaga Lake, 1990–2013.

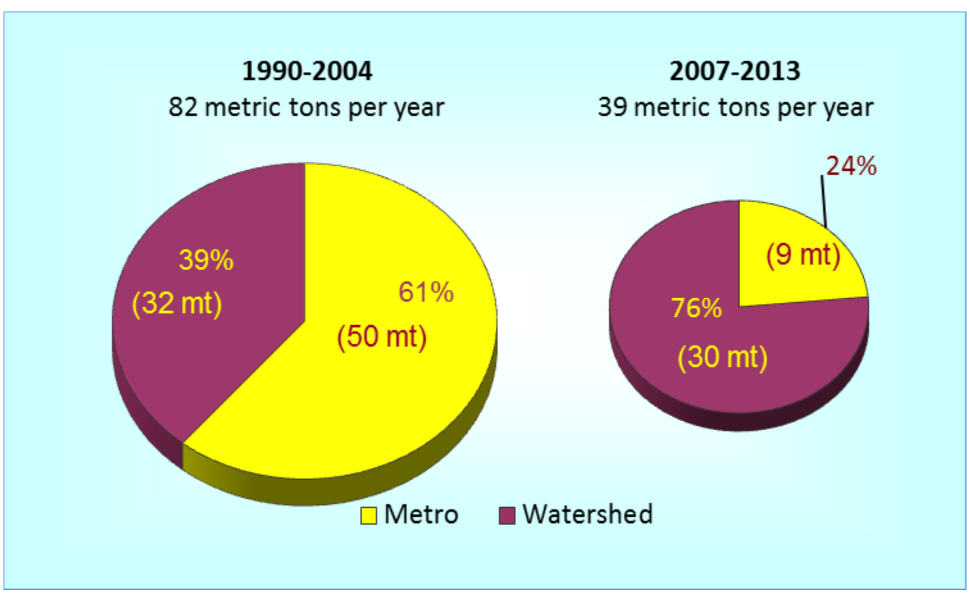


Figure HI-4. Contributions of Metro (outfalls 001+002) and the watershed to the annual input of total phosphorus to Onondaga Lake, average for the time periods 1990–2004 and 2007–2013.

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. Exceedences 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 (increases in algal production caused by human activities). 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. Exceedances 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 HI-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.

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 HI-6). The summer average concentration in 2013 was 25 micrograms per liter (µg/L), somewhat higher than the guidance value of 20 µg/L established by New York State. This is a modest increase from the 2012 value of 22 µg/L. The summer average total phosphorus concentration was less than 20 µg/L 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, 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 HI-7). According to laboratory measurements, no major blooms have occurred since the upgrade and no minor blooms have occurred during summer since 2007. Chlorophyll-*a* concentrations approached the 15 µg/L threshold in early August of 2013. Water clarity has also improved, though biological (food web) effects have contributed to noteworthy variations in this water quality metric.

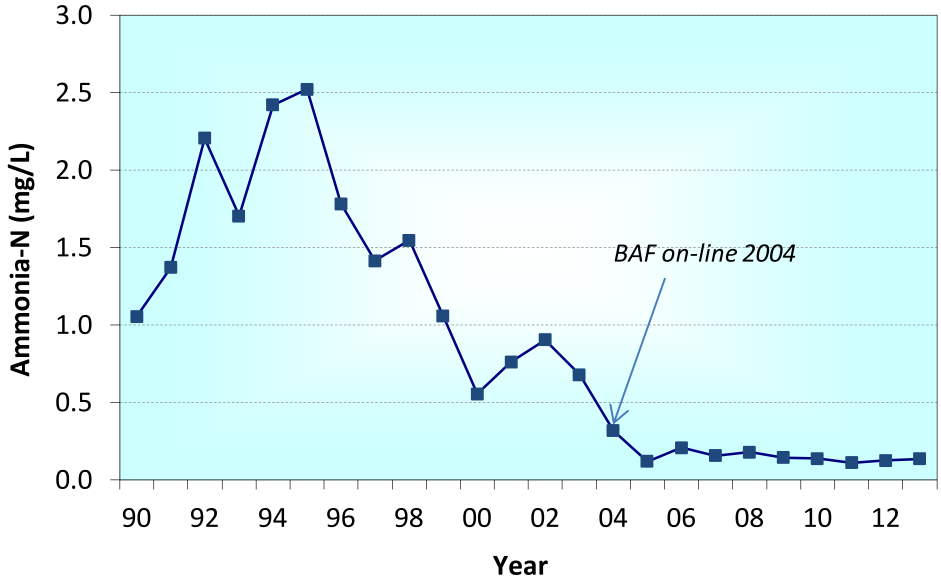


Figure HI-5. Annual average ammonia-N concentrations in the upper waters (0-6 meters) of Onondaga Lake, 1990–2013.

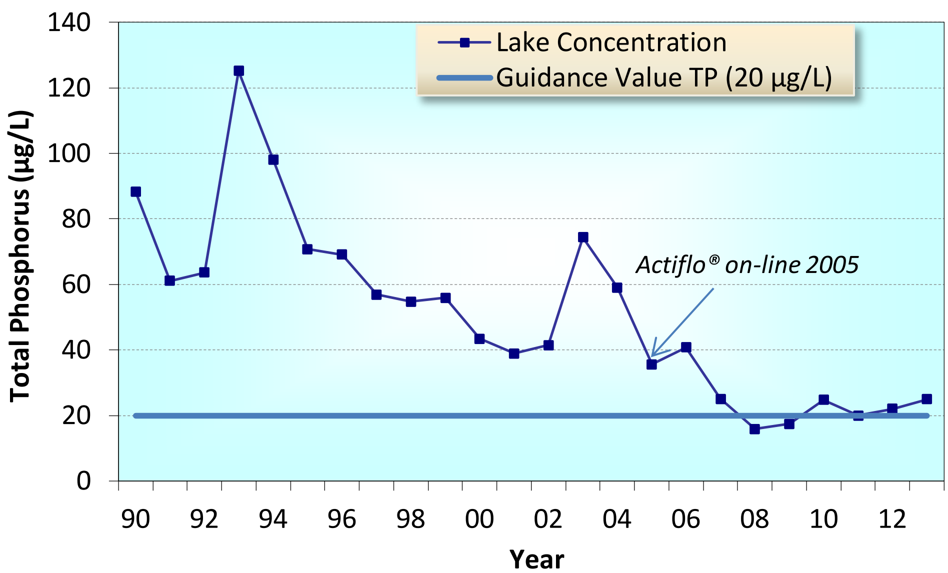


Figure HI-6. Summer (June to September) average total phosphorus concentration in the upper waters (0-3 meters) of Onondaga Lake, 1990–2013.

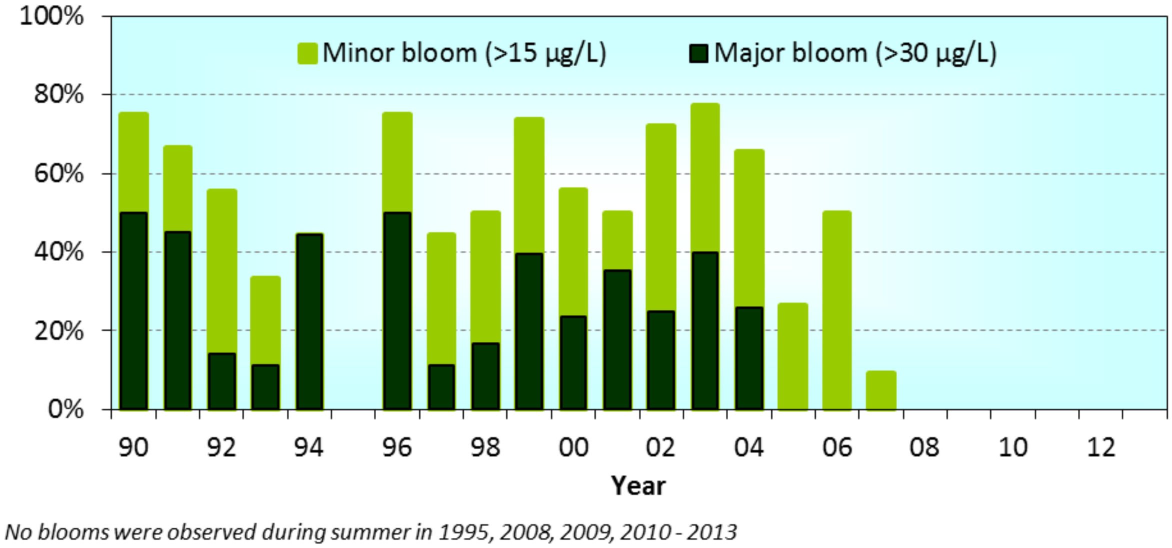


Figure HI-7. Percent occurrence of summer (June to September) algal blooms in Onondaga Lake evaluated annually for the 1990–2013 period, based on laboratory chlorophyll-*a* measurements.

Reductions in phytoplankton growth have led to decreased 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 HI-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 HI-8), less than 4 milligrams per liter (mg/L) to represent hypoxia and less than 1 mg/L to indicate anoxia. Reduced oxygen demand has resulted in decreasing (improving) trends for both thresholds. The oxygen status of the upper waters through the fall mixing period has also improved substantially, as indicated by consistently higher annual minima in oxygen concentration since 2005 (Figure HI-9). Oxygen concentrations in the upper waters have remained well above the standard to protect aquatic organisms since Actiflo® was implemented.

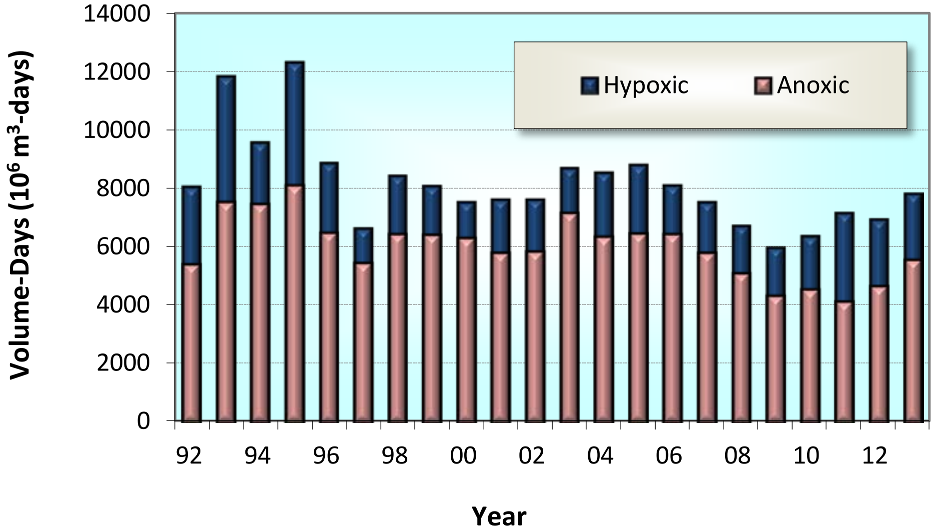


Figure HI-8. Volume-days of anoxia (dissolved oxygen less than 1 mg/L) and hypoxia (dissolved oxygen less than 4 mg/L), in Onondaga Lake, 1992–2013.

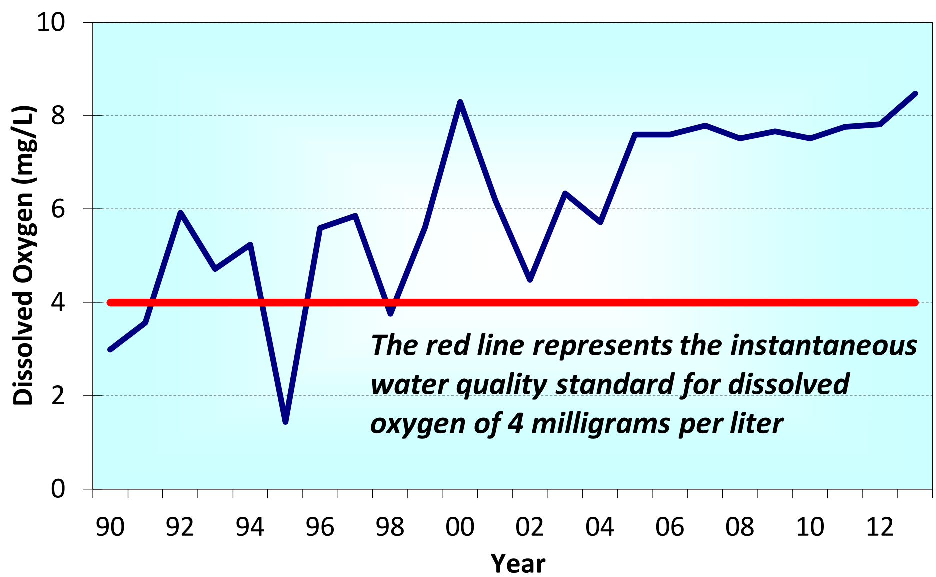


Figure HI-9. Minimum dissolved oxygen (DO) concentration in the upper waters (0-4 meters) of Onondaga Lake during fall turnover (October), annually 1990–2013.

Food Web Effects and Impacts on Water Clarity

Because the AMP includes monitoring of water quality and biological parameters, it is possible to analyze the relative effects of "bottom-up" (nutrient management) and "top-down" (food web) controls on the lake's trophic state. Clearly, treatment upgrades at Metro have affected the lake's algal abundance, water clarity, DO concentrations, and ammonia-N concentrations. Food web effects also are important, however, and now that Onondaga Lake is in the mesotrophic range (i.e., total phosphorus between 10 and 35 µg/L and algal biomass 3 to 5 mg/L), the impact of fluctuations in the abundance of 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. In 2013, Alewife dominated the open water region of Onondaga Lake. Densities in the spring of 2013 were similar to observations made since 2010 and higher than densities during the low Alewife years of 2008 and 2009, but lower than estimates from 2005–2007 (Appendix F-05). Alewife abundance was high enough to continue to impact the larger zooplankton, with *Daphnia* essentially non-existent since the fall of 2009. The average size of the total zooplankton community in Onondaga Lake in 2013 was higher than in 2010–2012, but still indicative of high planktivory rates. The species and size composition is similar to 2003–2007 and 2010–2012 and quite different from what was observed in 2008 and 2009 when the Alewife population was low (Figure HI-10). Phytoplankon biomass has declined as a result of reduced phosphorus loading by Metro and is dominated by diatoms; however, annual variation also is affected by the changes in the zooplankton body size structure. Smaller zooplankton are less efficient grazers of phytoplankton than larger ones, and phytoplankton abundance typically increases as a result. More abundant phytoplankton results in decreased water clarity, typically measured as Secchi disk transparency. The relationship between zooplankton size and water clarity is illustrated in Figure HI-11.

The impact of zebra and quagga mussel populations on Onondaga Lake currently is not fully understood, but likely plays a role in the food web dynamics. Both quagga and zebra mussels filter large amounts of water (up to two liters per day as an adult) in order to draw in phytoplankton, small zooplankton, and bacteria they use as food. The removal of phytoplankton through this filtering action potentially could increase water clarity and reduce food availability for fish and other organisms. Additionally, waste produced by mussels could potentially affect the nitrogen and phosphorous budgets of Onondaga Lake.

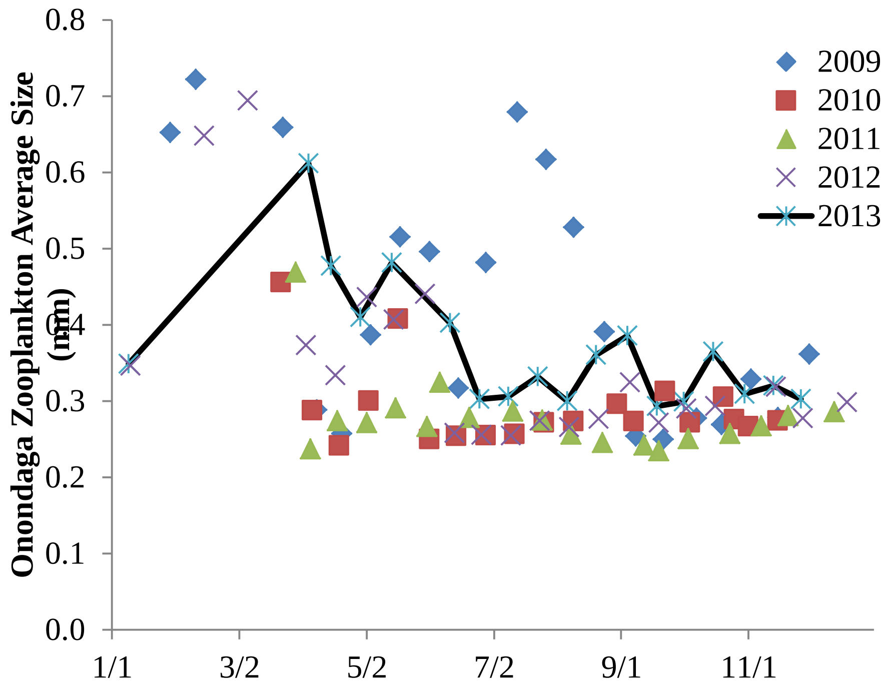


Figure HI-10. Seasonal development of average crustacean zooplankton length (mm), 2009 through 2013. Lines connect the values from 2013.

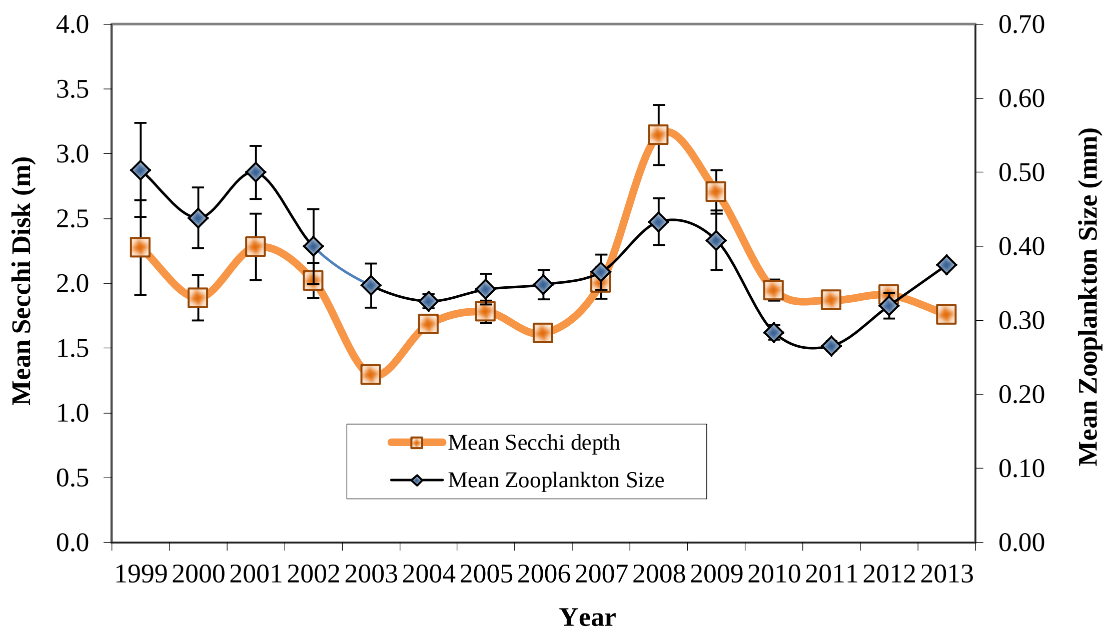


Figure HI-11. Growing season (April-October) mean (± standard error) Secchi disk depth and zooplankton size for Onondaga Lake, 1999–2013.

Improved Water Quality Reflected in a Changed Biological Community

The reduction in phosphorus also has led to changes in the phytoplankton community with no undesirable blue-green algal blooms reported again in 2013 and diatoms dominating the community. Aquatic plants have continued to persist within Onondaga Lake, with over 380 acres covering 50 percent of the littoral zone in 2013. This increased coverage has notably improved Largemouth Bass habitat with catch rates in 2013 the highest reported since the start of the program.

The black bass population is increasingly dominated by Largemouth Bass (Figure HI-12). A marked increase in catch rates for Largemouth Bass was observed in 2013 with 44 fish captured per hour, the highest observed since the start of the AMP in 2000. Conversely, the observed catch rate for Smallmouth Bass of 1 fish caught per hour was the lowest reported since 2000. The declining catch rates observed for the Smallmouth Bass are likely indicative of the changing conditions in the littoral zone with increased macrophyte coverage more suitable for Largemouth Bass. (Figure HI-12). In Onondaga Lake, fish species richness (number of species) has fluctuated annually since the start of the AMP. Thirty-five species of fish were collected during the 2013 field season. Since the start of the AMP fisheries program in 2000, 53 species have been captured and identified from Onondaga Lake. The lake is an open system, allowing migration of fish between the Lake, its tributaries, and the adjoining Seneca River. These community interactions are largely responsible for the fish diversity of Onondaga Lake.

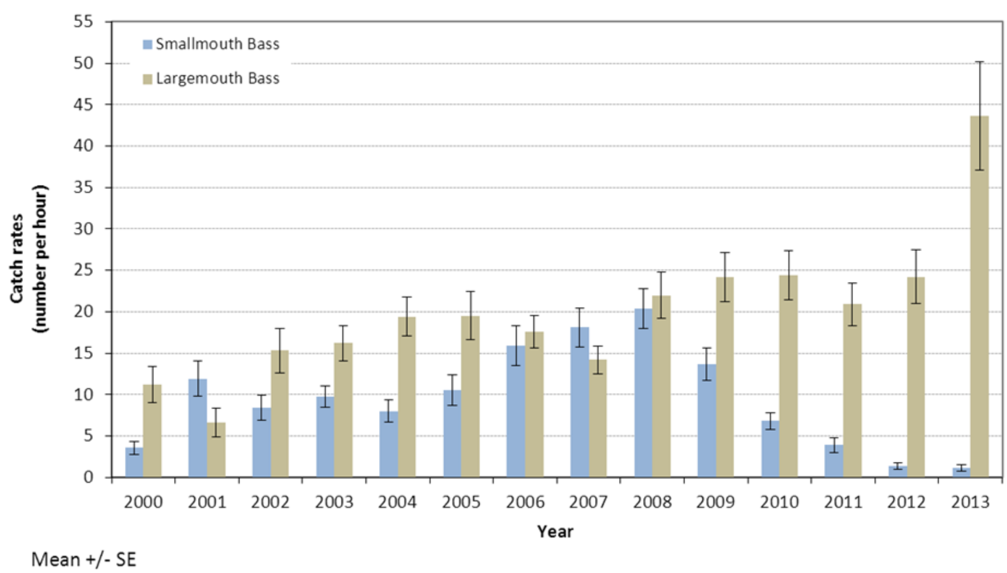


Figure HI-12. Trend in annual average catch rates (number per hour) from two electrofishing events (spring and fall) of Largemouth and Smallmouth Bass combined in Onondaga Lake from 2000 to 2013.

Diversity of the fish community also fluctuates in response to the periodic peaks and crashes of two species of clupeid: Alewife and Gizzard Shad. Abundance of these two species of the herring family is highly variable, as 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 Alewife can live to 10 years and Gizzard Shad even longer. In 2013, Alewife catch per hour boat electrofishing was lower than in 2012 (328 versus 589, respectively), while Gizzard Shad catch per hour boat electrofishing was also lower in 2013 in (382) than in 2012 (2,005).

Sport fishing has become increasing popular over the past 15 years and continues to expand. A modest tournament fishery has developed in addition to non-competitive angling. Local bass organizations compete several weekends throughout the summer, and several large-scale fishing tournaments have been held on Onondaga Lake including the Bassmasters Memorial in 2007 and the BASS Junior World Championship in 2008. The improved water quality, increased plant coverage, changing plankton community, and the invasion by dreissenid mussels have altered the trophic dynamics within the lake. This increasing complexity with regard to energy sources and energy flow results in an ecosystem that may be more resilient to environmental stress. As lake water quality continues to improve, resulting in more diverse and higher quality habitat conditions, increases in aquatic species diversity, abundance, and interrelatedness also can be expected.

Suitability of Nearshore Areas for Contact Recreation

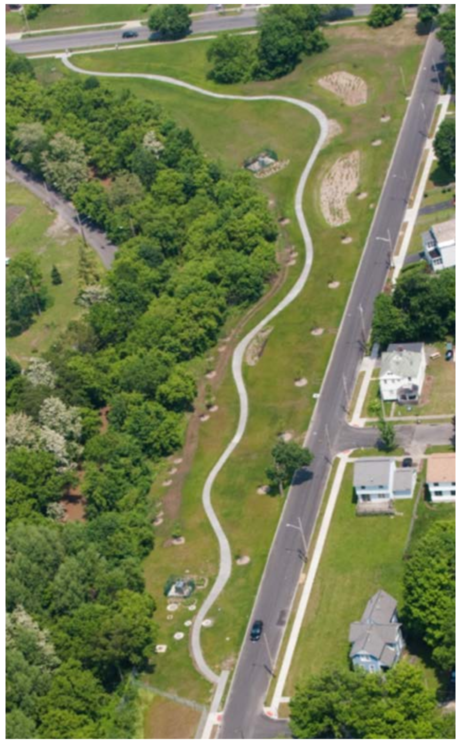
Two parameters are used to assess the suitability of a waterbody for contact recreation: fecal coliform bacteria (FC) and water clarity. The fecal coliform bacteria standard is used by NYSDEC to evaluate water quality and by New York State Department of Health (NYSDOH) to evaluate suitability for swimming at designated beaches. During the April to October interval of 2013, bacteria levels in Class B areas of Onondaga Lake did not exceed the standard established for contact recreation. Two sites, located within the Class C segment of the lake's southeastern shoreline, exceeded the bacteria standard during the month of October, and one of these sites also exceeded the standard in April. While there is no NYSDEC standard for water clarity, NYSDOH has a swimming safety guidance value for designated bathing beaches of 4 feet or 1.2 meters. With the exception of a single measurement made near the mouth of Bloody Brook in June following a runoff event, the NYSDOH swimming safety guidance value was met in Class B waters throughout the summer recreational period of 2013. Monitoring locations in the southern end of the lake, near the mouths of Onondaga Creek, Harbor Brook, and Ley Creek, regularly failed to meet this guidance value. 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. The guidance value for clarity was not met in the Class C segment at the mouth of Ninemile Creek on two monitoring dates following major runoff events. Presently, Onondaga Lake has no designated bathing beaches.

Onondaga County Initiatives

In 2013, Onondaga 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 72 active CSOs in the collection system (outfall points with the potential to discharge combined sewage). These CSOs discharged to three tributaries to Onondaga Lake: Onondaga Creek, Harbor Brook, and Ley Creek. Through 2013, the Amended Consent Judgment (ACJ) projects have closed or captured for storage 44 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 constructing the Clinton and Harbor Brook Storage Facilities.

Substantial progress was made on a number of gray infrastructure projects in 2013. The Harbor Brook Interceptor Sewer (HBIS) Replacement project was completed in December 2013. Approximately 7,500 linear feet of interceptor sewer was upsized, expanding the capacity of HBIS by 500,000 gallons and increasing the flow by 400,000 gallons per day. In addition, the County completed a two-acre green infrastructure site that provides an additional 467,000 gallons of stormwater capture. The 6.5 million gallon Clinton Storage Facility and 4.9 million gallon Lower Harbor Brook Storage Facility were placed into operation and were capable of receiving wet weather flow on December 31, 2013, a major ACJ compliance date. The facilities collect millions of gallons of wastewater during storms and route it to Metro for state-of-the-art treatment. 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. To-date, more than 175 green infrastructure projects have been completed as part of the “Save the Rain” (STR) initiative, reducing inputs of stormwater runoff and pollution to Onondaga Lake and its tributaries. The STR program had another impressive year in 2013 with 50 GI projects completed. 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. A number of these green infrastructure solutions were implemented at the Rosamond Gifford Zoo. The Greening the Zoo project will capture nearly 6 million gallons of stormwater annually through implementation of various green infrastructure elements. By preventing storm water runoff from entering the combined sewers, more capacity is available for sanitary sewage flow to reach Metro for treatment. The STR program educates 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.



Restored CSO 044 Project Area between Midland Avenue,
West Castle Street and Onondaga Creek
Includes two bioretention cells, a butterfly garden and porous concrete path.

The Save the Rain Program received a considerable amount of recognition during 2013. In addition to receiving the prestigious U.S. Water Prize for "Best Public Sector," Onondaga County received the following awards from local, regional, state, and national levels for its continued efforts to restore Onondaga Lake: U.S. Water Prize, NYS Environmental Excellence Award, APWA Environmental Project of the Year, International Association of Fairs and Expositions Best Solution-Based Communication, StormWater Solutions Magazine Top Stormwater Project, and American Academy of Environmental Engineers Honor Award.

Green Infrastructure at Rosamond Gifford Zoo

Section 1. Introduction to the AMP

1.1 Regulatory Requirements

The 2013 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 (Table 1-1; 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). A listing of water quality impairments in Onondaga Lake and its watershed is provided in Table 1-2.

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 in nearshore and deep regions of Onondaga Lake (Figure 1-2), along the lake tributaries (Figure 1-3), and along the Three Rivers System (see Figure 7-1, in Section 7). These samples are used to evaluate water quality conditions and the nature of the biological community. In addition, these data are interpreted to determine whether designated uses are, in fact, supported in these waters.

Table 1-1. Summary of regulatory classification of Onondaga Lake and streams within the Onondaga Lake watershed.

Lake/Stream	Description of Lake/Stream segment	Regulatory Classification	Standards
Onondaga Lake	northern 2/3 of lake, excluding the area adjacent to Ninemile Creek	B	B
	southern 1/3 of lake and waters adjacent to the mouth of Ninemile Creek	C	C
Onondaga Creek	enters Onondaga Lake at southeastern end. Mouth to upper end of Barge Canal terminal (0.85 miles)	C	C
	upper end of Barge Canal terminal to Temple Street (1.7 miles)	C	C
	from Temple Street, Syracuse to Tributary 5B (4.4 miles)	B	B
	from Tributary 5B to Commissary Creek (1.9 miles)	C	C
	from Commissary Creek to source	C	C(T)
Ninemile Creek	enters Onondaga Lake from south approximately 2.25 miles from lake outlet along west shore of lake. From mouth to Allied Chemical Corp. water intake located on creek 0.6 mile upstream of Airport Rd and 0.6 mile downstream of Rt. 173 bridge at Amboy	C	C
	from water intake between Airport Rd and Rt. 173 to outlet of Otisco Lake	C	C(T)
Harbor Brook	enters Onondaga Lake at the southernmost point of the lake and within the City of Syracuse. From mouth to upper end of underground section, at Gifford Street (approx. 1.9 miles)	C	C
	from upper end of underground section to City of Syracuse line (1.3 miles)	B	B
	from City of Syracuse City line to source	C	C(T)
Ley Creek	enters Onondaga Lake 0.2 mile southeast of point where City of Syracuse line intersects east shore of lake. From mouth to Ley Creek sewage treatment plant outfall sewer	C	C
	from Ley Creek sewage treatment plant outfall sewer to South Branch. Tribs. 3-1A and 3-1B enter from north approximately 3.0 and 3.1 miles above mouth respectively	B	B
Bloody Brook	enters Onondaga Lake 2.25 miles southeast of outlet. From mouth to trib. 1 of Bloody Brook (approximately 0.37 miles from mouth)	B	B
	from trib. 1 of Bloody Brook to source	C	C
Source: 6 NYCRR Part 895 Onondaga Lake Drainage Basin, on-line at http://www.dec.ny.gov/regs/4539.html			

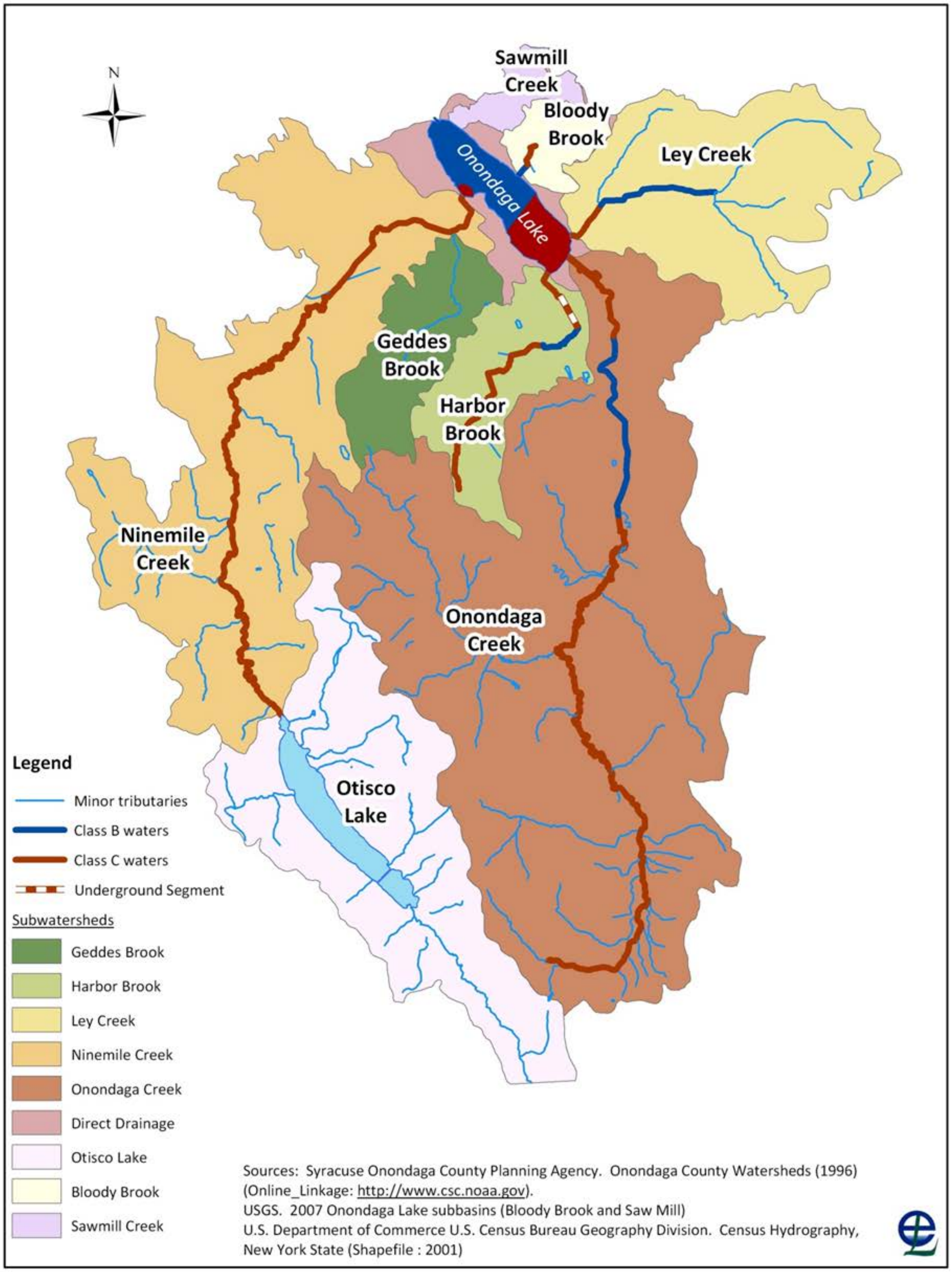


Figure 1-1. Tributary and lake regulatory classifications (6 NYCRR) and subwatershed boundaries.

Table 1-2. Listing of water quality impairments in Onondaga Lake and its watershed.

Waterbody Name	Category of Impairment	Cause/Pollutant	Source	Year Listed
Onondaga Lake, northern end	fish consumption advisory	PCBs, dioxin, mercury, other toxics	contaminated sediments	1998
Onondaga Lake, southern end (including Ley Creek)	fish consumption advisory	PCBs, dioxin, mercury, other toxics	contaminated sediments	1998
Onondaga Lake, southern end	pending implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Onondaga Lake, northern end	pending verification of use impairments/pollutants/sources	dissolved oxygen	–	2012
Onondaga Lake, southern end	pending verification of use impairments/pollutants/sources	dissolved oxygen	–	2012
Bloody Brook and tribs	requires verification of cause/pollutant	aquatic toxicity	unknown	2010
Bloody Brook and tribs	pending implementation/evaluation of other restoration measures	pathogens	municipal, urban runoff	2008
Geddes Brook and tribs	pending implementation/evaluation of other restoration measures	ammonia	municipal, urban runoff	1998
Harbor Brook, lower, and tribs	pending implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Harbor Brook, lower, and tribs	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	1998
Harbor Brook, lower, and tribs	pending implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	1998
Ley Creek and tribs	pending implementation/evaluation of other restoration measures	pathogens	municipal, urban runoff	2008
Ley Creek and tribs	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	1998
Ley Creek and tribs	pending implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	1998
Ley Creek and tribs	pending implementation/evaluation of other restoration measures	cyanide	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	pending implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	pending implementation/evaluation of other restoration measures	nitrogen (ammonia, nitrite)	CSOs, municipal, urban runoff	2008

Table 1-2. Listing of water quality impairments in Onondaga Lake and its watershed.

Waterbody Name	Category of Impairment	Cause/Pollutant	Source	Year Listed
Minor tribs to Onondaga Lake	pending implementation/evaluation of other restoration measures	cyanide	CSOs, municipal, urban runoff	2008
Ninemile Creek	pending implementation/evaluation of other restoration measures	pathogens	municipal, urban runoff	2008
Ninemile Creek	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	municipal, urban runoff	1998
Onondaga Creek, lower, and tribs	requires verification of impairment	turbidity	streambank erosion	2010
Onondaga Creek, lower	pending implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Onondaga Creek, lower	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	1998
Onondaga Creek, lower	pending implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	1998
Onondaga Creek, middle, and tribs	requires verification of impairment	turbidity	streambank erosion	2008
Onondaga Creek, middle, and tribs	pending implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Onondaga Creek, middle, and tribs	pending implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	2008
Onondaga Creek, middle, and tribs	pending implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	2008
Onondaga Creek, upper, and tribs	requires verification of impairment	turbidity	streambank erosion	2008
Seneca River, lower, main stem	requires verification of impairment	pathogens	onsite WTS	1998
Seneca River, lower, main stem	requires verification of cause/pollutant	oxygen demand	invasive species, agriculture	1998

Source:
The Final New York State 2012 Section 303(d) List of Impaired Waters Requiring a TMDL/Other Strategy, on-line at http://www.dec.ny.gov/chemical/31290.html

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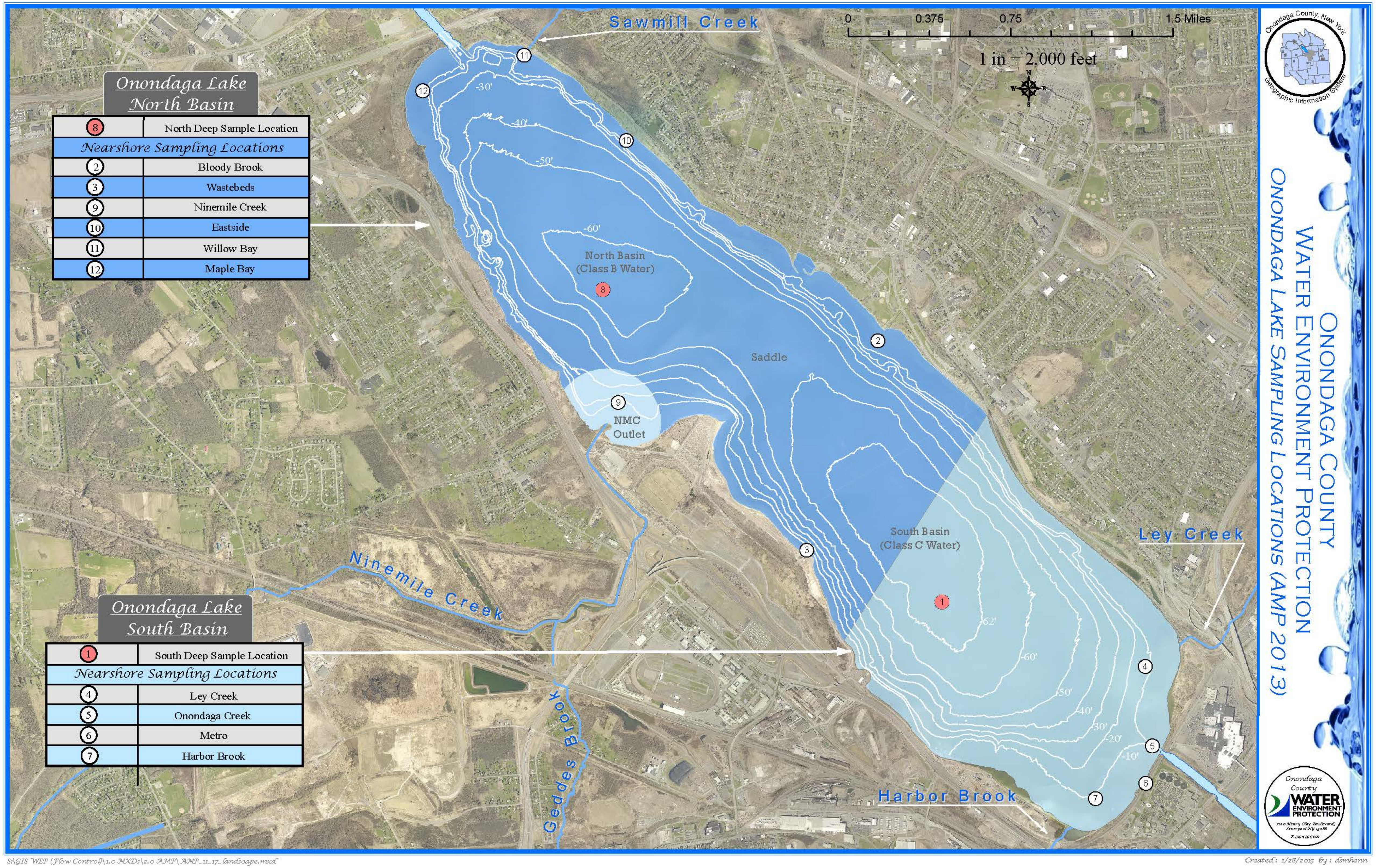

Figure 1-2. Map of AMP monitoring locations in Onondaga Lake.

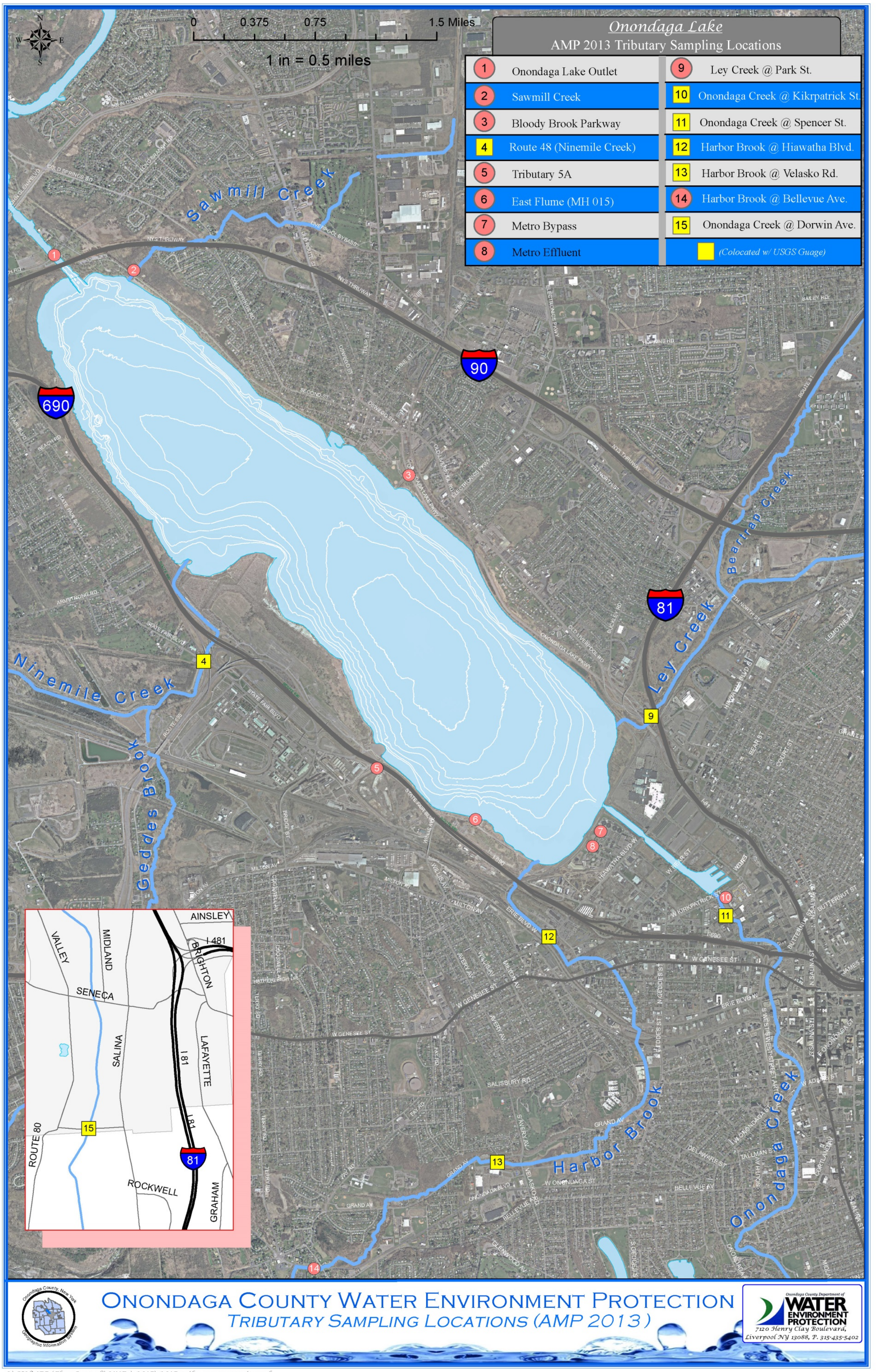

Figure 1-3. Map of AMP tributary monitoring locations.

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
- to support development of mechanistic models for managing water quality conditions

A Data Analysis and Interpretation Plan (DAIP) (Table 1-3) guides program design and is a component of the annual work plan and thus subject to NYSDEC review and approval.

Each year, Onondaga County reviews the laboratory data for quality assurance/quality control criteria (Appendix B-1) 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 associated with tributary (Appendix B-2) and lake (Appendix B-3) water quality and biological (Appendix B-4) monitoring programs are audited annually to ensure that they are carried out in accordance with the approved work plan. The Onondaga County Laboratory participates in a program of Environment Canada documenting proficiency of low-level total phosphorus and low-level total mercury analyses (Appendix B-5) in natural waters. Based on proficiency testing studies conducted by Environment Canada, the Onondaga County Laboratory was rated as "very good", the highest laboratory performance rating available.

The County maintains a bibliography of published materials related to Onondaga Lake (Appendix G-1). 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.

The 2013 AMP sampling workplan included several revisions to the Onondaga Lake, Tributary, and River sampling programs. With the completion of the advanced wastewater treatment at Metro, which became operational in 2005, several notable water quality improvements have been realized in the lake. In addition, several major milestones have recently been achieved, including successful completion of the Onondaga Lake Water Quality Model Project related efforts in 2012 and the NYSDEC's issuance of the Final Onondaga Lake TMDL for Phosphorus, dated May 2012. These important accomplishments are reflected in revisions to the scope of the AMP for 2013.

A detailed re-evaluation of the sampling program was undertaken, based on defining program objectives in relation to the collection of meaningful data. This evaluation was completed taking into consideration future data collection needs, effort to reduce data redundancy, and completion of additional data analysis used in supporting these modifications. An AMP Technical Workgroup was convened on February 5, 2013, with participation by several members of the Department's Onondaga Lake Technical Advisory Committee, who have extensive knowledge of the AMP. Program modifications were based on input and feedback received during this session from members of the workgroup (including Drs Ed Mills, Liz Moran, Jim Rhea, Lars Rudstam, and Bill Walker) relating to sampling program locations, parameters, protocols, and depths. Program modifications implemented in 2013 included the following:

- Based on long-term, consistent compliance with ambient water quality standards measurements of arsenic, cadmium, chromium, copper, nickel, lead, and zinc in the tributaries were discontinued except as follows: dissolved forms of cadmium, copper, and lead were analyzed on a quarterly basis from routine sampling sites on Onondaga Creek; dissolved forms of copper and lead were analyzed on a quarterly basis from the routine sampling site on Tributary 5a; Analysis of dissolved total mercury was added to the program to support assessment of compliance with the applicable AWQS.

- Revised the sampling program for North Deep to comply with the phosphorus TMDL follow-up monitoring requirements and discontinued other parameters at this site.
- Replaced composite sampling of the upper mixed layer (UML) and lower water layer (LWL) with discrete samples collected from depths of 3 and 15 meters.
- Discontinued measurements of arsenic, cadmium, chromium, copper, nickel, lead, and zinc in Onondaga Lake because long-term, consistent compliance with ambient water quality standards has been established. Analysis of dissolved total mercury was added to the program to support assessment of compliance with the applicable AWQS.
- Utilized data from the Honeywell funded monitoring buoy at South Deep and discontinued deployment of the Onondaga County buoy.
- Discontinued LiCor Underwater Illumination profiles in the lake and river. Secchi disk transparency is used to assess compliance, trophic status, aesthetics, and use attainment.

- Discontinued special Fall Turnover sampling because dissolved oxygen concentrations during fall have met New York State ambient water quality standards consistently for more than a decade.

Table 1-3. Overview of the 2013 AMP data analysis and interpretation plan.

Parameters	Sampling Locations	Compliance	TMDL Analysis	Trend Analysis	Trophic Status	Load Analysis	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	T,R			✓		✓						
Carbon	L,T,R			✓	✓	✓						
Dissolved oxygen	L,T,R	✓		✓	✓		✓					✓
Mercury	L,T	✓		✓								
Metals/Salts	L,T,R	✓		✓		✓						
Nitrogen	L,T,R	✓	✓	✓	✓	✓	✓			✓	✓	✓
Phosphorus	L,T,R	✓	✓	✓	✓	✓				✓		✓
Salinity	L,T,R	✓		✓			✓					
Silica-dissolved	L,T				✓							✓
Solids	L,T,R	✓		✓								
Specific conductance	L,T,R	✓		✓			✓					
Optical												
Secchi Disk transparency	L	✓		✓	✓		✓		✓			✓
Turbidity	L,T,R			✓					✓			
Biological												
Chlorophyll-*a*/ algae	L,R			✓	✓		✓					✓
Zooplankton	L			✓								✓
Macrophytes	L			✓							✓	✓
Fish	L			✓							✓	
Locations: L = Lake; T = Tributaries; R = Seneca and Oneida Rivers												

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 1-4). 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 storm water and untreated sewage flows into creeks and ultimately reaches Onondaga Lake. When these overflows occur, CSOs carry bacteria, floating trash, organic material, nutrients and solid materials through the CSOs to the waterways. Improvements to the wastewater collection and treatment infrastructure are scheduled through 2018. The 4th Stipulation of the ACJ requires phased reductions of CSO volume. The schedule of the percentage of CSO volume that must be captured or eliminated on a system-wide annual average basis is provided in Table 1-5. According to simulations from the stormwater management model (SWMM) the annual combined sewage percent capture in 2013 was 92.9%, greater than the Stage I goal of 89.5%.

Table 1-4. Metro compliance schedule.
(lb/d = pounds per day; mg/L = milligrams per liter)

Parameter	SPDES Limit	Effective Date	Achieved Date
Ammonia	Interim limit: 8,700 lb/d (7/1-9/30) 13,100 lb/d (10/1-6/30)	January 1998	January 1998
	Interim limit: 2 mg/L (6/1-10/31) 4 mg/L (11/1-5/31)	May 2004	February 2004
	Final limit: 1.2 mg/L (6/1-10/31) 2.4 mg/L (11/1-5/31)	March 21, 2012 to March 20, 2017	February 2004
Total Phosphorus	Interim limit: 400 lbs/day (12-month rolling average)	May 1, 2004 to March 31, 2006	January 1998
	Interim limit: 0.12 mg/L (12-month rolling average)	April 1, 2006 to November 5, 2010	April 2006
	Interim limit: 0.10 mg/L (12-month rolling average)	November 16, 2010 to June 30, 2012	November 2010
	Final limit*: 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. The bubble permit allows for the natural variability inherent of combined sewer systems.

Table 1-5. 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)		

A total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake was developed by NYSDEC and 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. Phosphorus loading reductions from small farms are voluntary and incentive based. NYSDEC used an ensemble modeling approach to evaluate the environmental benefits associated with additional phosphorus removal from Metro and other sources. The Onondaga Lake Water Quality Model (OLWQM) was a key component of this modeling ensemble. OLWQM was developed and calibrated using data from the AMP, and has been subject to outside expert peer review.

1.5 Use of Metrics to Measure and Report Progress

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 1-6 documents the extent to which water quality conditions support the lake's designated best uses. Major reductions in loading of ammonia and phosphorus 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. Metrics selected for Onondaga Lake address both human uses and ecosystem function:

- water contact recreation
- aesthetics
- aquatic life protection
- sustainable recreational fishery

Fishing on Onondaga Lake

Table 1-6. Summary of metrics, Onondaga Lake 2013.

Metrics	Measured By	Target[1]	2013 Results[2]	Comments
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% NOTE: The best usages of Class B waters are primary and secondary contact recreation and fishing (NYCRR Part 701.7).	Percent in compliance, Lake Class B locations: Bloody Brook: 100% North Deep: 100% Eastside:100% Willow Bay: 100% Maple Bay:100% Westside Wastebeds:100%	Class B segments of Onondaga Lake met the bacteria standard for water contact recreation.
	Percent of months in compliance with AWQS[1] for fecal coliform bacteria, April–October (disinfection period). Measured at nearshore sites, Class C segment.	NOTE: The best usage classification of Class C waters is fishing; water quality shall be suitable for primary contact and secondary contact recreation, although other factors may limit the use for these purposes (NYCRR Part 701.8).	Percent in compliance, Lake Class C locations: South Deep: 100% Ninemile Creek: 100% Harbor Brook: 100% Metro: 86% Ley Creek: 100% Onondaga Creek: 71%	Class C segments of Onondaga Lake also met the bacteria standard for water contact recreation, except for two nearshore sites: Onondaga Creek nearshore (during the months of April and October) and Metro nearshore (during the month of October), following runoff events (refer to plot in Appendix E-2 - Onondaga Lake Fecal Coliform and Metro Daily Precipitation, 2013).
Water clarity	Percent of observations with Secchi disk transparency at least 1.2 m (4 ft.) to meet swimming safety guidance[3], June–September (recreational period). Measured at nearshore sites, Class B segment.	100%	Percent in compliance, Lake Class B locations: Bloody Brook: 96% North Deep: 100% Eastside:100% Willow Bay: 100%	• With the exception of a single observation near the mouth of Bloody Brook, Class B segments of Onondaga Lake met the designated use for water contact recreation.

Table 1-6. Summary of metrics, Onondaga Lake 2013.

Metrics	Measured By	Target[1]	2013 Results[2]	Comments
			Maple Bay:100% Westside Wastebeds:100%	
	Percent of observations with Secchi disk transparency at least 1.2 m (4 ft.) to meet swimming safety guidance[3], June–September (recreational period). Measured at nearshore sites, Class C segment.	NOTE: The best usage classification of Class C waters is fishing; water quality shall be suitable for primary contact and secondary contact recreation, although other factors may limit the use for these purposes (NYCRR Part 701.8).	Percent in compliance, Lake Class C locations: South Deep: 100% Ninemile Creek: 91% Harbor Brook: 61% Metro: 61% Ley Creek: 61% Onondaga Creek: 17%	• Class C segments in the southern end of the lake often fail to meet the clarity standard for water contact recreation, particularly following runoff events.
Improved Aesthetic Appeal				
Water clarity	Summer average Secchi disk transparency at least 1.5 m at South Deep during the summer recreational period (June–September).	Summer average at least 1.5 m	100% (summer average 1.8 m)	By these metrics, the lake met its designated use as an aesthetic resource.
Algal blooms[3]	Reduction in average and peak algal biomass and absence of nuisance algal blooms[4]. Measured by the magnitude, frequency and duration of elevated chlorophyll-*a* (Chl-*a*) during the summer recreational period (June–September). Based on laboratory measurements of Chl-*a* at South Deep.	• No more than 15% of Chl-*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	Cyanobacteria was 5.7% of the algal	

Table 1-6. Summary of metrics, Onondaga Lake 2013.

Metrics	Measured By	Target[1]	2013 Results[2]	Comments
		than 10% of the algal biomass	biomass	
Improved Aquatic Life Protection				
Ammonia	South Deep ammonia concentrations compared to AWQS[1] (upper waters)	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	South Deep nitrite concentrations[1] (upper waters)	100%	100%	
Dissolved oxygen	Minimum daily average[1] at South Deep Instantaneous minimum[1] at South Deep (upper waters)	>5 mg/L >4 mg/L	7.23 mg/L[5] 6.98 mg/L	
Improving Sustainable Recreational Fishery				
Habitat quality	Percent of the littoral zone that is covered by macrophytes	40%	50%	Littoral zone macrophyte coverage provides high quality habitat for warm water fish community
Fish reproduction	Reproduction of target species: • bass and sunfish • yellow perch • black crappie • rock bass • walleye and northern pike	 occurring occurring occurring occurring occurring	 occurring occurring no evidence no evidence 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				
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	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

Table 1-6. Summary of metrics, Onondaga Lake 2013.

Metrics	Measured By	Target[1]	2013 Results[2]	Comments
		intolerant 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)*
- *ammonia and nitrite 6 NYCRR Part **703.5** (http://www.dec.ny.gov/regs/4590.html)*
- *dissolved oxygen 6 NYCRR Part **703.3** (http://www.dec.ny.gov/regs/4590.html)*

[2]2013 Results are shaded green, yellow, or red to qualitatively represent the results as positive, mixed, or negative.
[3]Secchi depth water clarity swimming safety guidance of 4 ft. NYSDOH Title 10, Section 7-2.11
[4]Algal blooms subjectively defined as "impaired" at >15 µg/L and "nuisance" at >30 µg/L
[5]daily average based on average of all measurements taken within a day (1 to 4 profiles were collected daily from the water quality monitoring buoy).

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 (Appendix A). This appendix provides an overview of the monitoring program design, criteria used to evaluate progress, and a summary of temporal trends. The parameters covered are:

- total phosphorus (Appendix A-1)
- chlorophyll-*a* (Appendix A-2)
- Secchi disk transparency (Appendix A-3)
- dissolved oxygen (Appendix A-4)
- ammonia (Appendix A-5)
- nitrite (Appendix A-6)
- bacteria (Appendix A-7)
- phytoplankton (Appendix A-8)
- macrophytes (Appendix A-9)
- zooplankton (Appendix A-10)
- fish (Appendix A-11)

OCDWEP Technicians Sampling Onondaga Lake

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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.

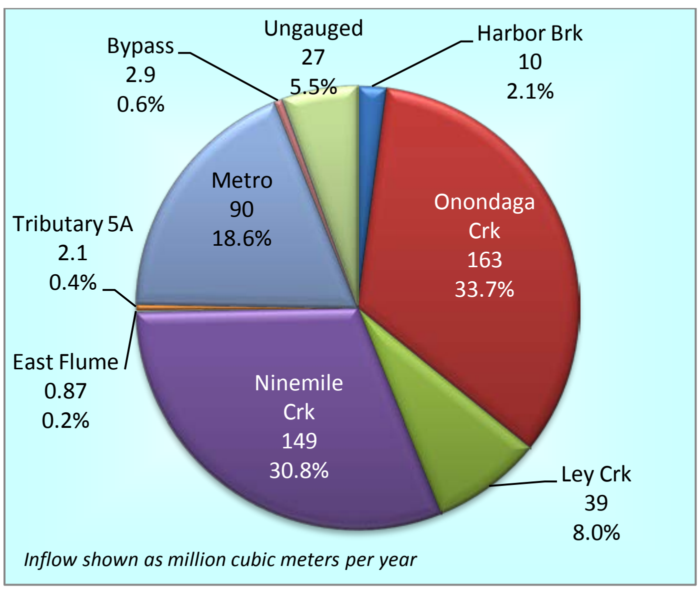

Figure 2-1. Annual average inflows (gauged and ungauged) to Onondaga Lake, 1990–2013.

The tributaries convey surface runoff and groundwater seepage from the watershed toward Onondaga Lake. The volume of runoff, and consequently stream flow varies each year depending on the amount of rainfall and snow cover. Overflows from combined sewer systems 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. The goal of the AMP is to sample the tributaries over a range of representative flow conditions, targeting a minimum of five samples collected during high flow (*High flow* is defined as one standard deviation above the long-term monthly average flow). OCDWEP targets high flow sampling events based on real-time provisional data from the USGS flow gage at Onondaga Creek-Spencer Street.

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

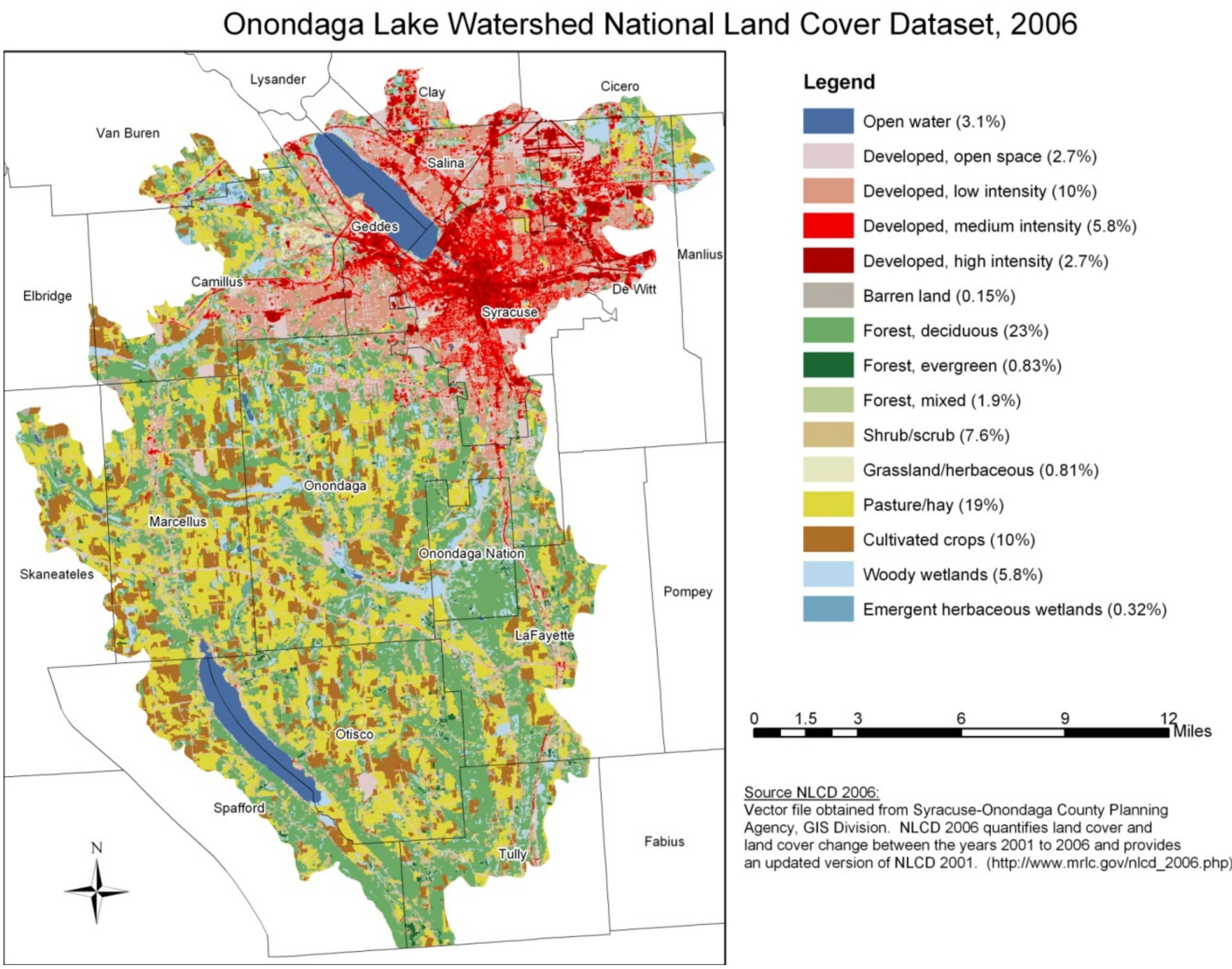

Figure 2-2. Land cover classification map.

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. Morphologic characteristics of Onondaga Lake are summarized in Table 2.1. 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.

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.

Table 2-1. Morphologic characteristics of Onondaga Lake.

Characteristic	Metric	English
Watershed area	738 km^2	285 square miles
Lake:		
Surface area	12 km^2	4.6 square miles
Volume	131 x 10^6 m^3	35 billion gallons
Length	7.6 km	4.6 miles
Width	2 km	1.2 miles
Maximum depth	19.5 m	64 feet
Average depth	11 m	36 feet
Average elevation*	111 m	364 feet
Average flushing rate	~4 times per year	~4 times per year

Sources:
http://www.upstatefreshwater.org/NRT-Data/System-Description/system-description.html
http://www.dec.ny.gov/chemical/8668.html
*Elevation references to mean sea level.

Aerial View of Onondaga Lake

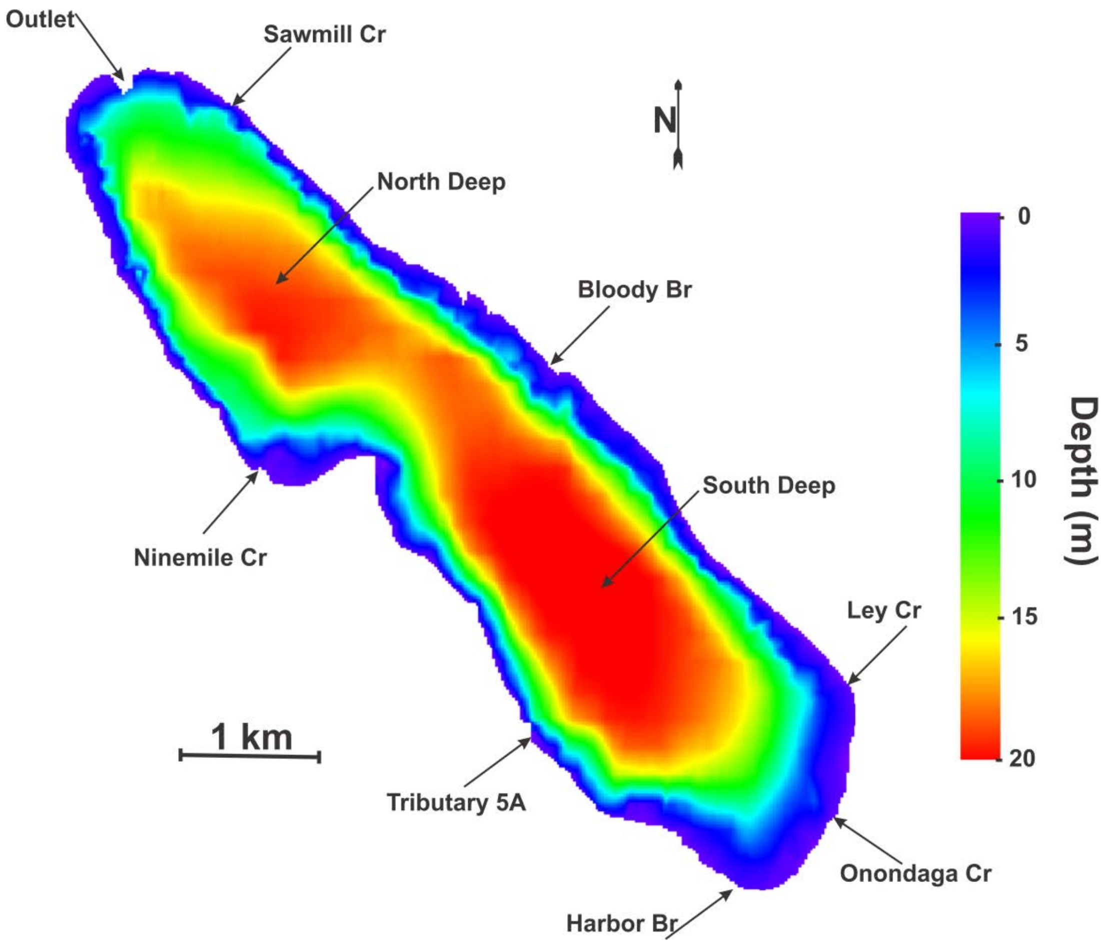

Figure 2-3. Bathymetric map of Onondaga Lake, with tributaries and primary sampling locations (South Deep, North Deep) identified.

Note: bathymetry based on data from CR Environmental Inc. 2007.

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Section 3. Onondaga County Actions and Progress with Related Initiatives

3.1 Onondaga County Projects and Milestones

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 reduced phosphorus concentrations and 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, Table 3.3). Since 1998, the County has closed or abated 44 of the 72 CSO locations that were active prior to the ACJ. In addition to the CSO abatement projects, Metro upgrades are planned that will achieve compliance with disinfection/dechlorination requirements and contribute to compliance with the P TMDL waste load allocation, specifically the aggregate limit for Metro discharges (001, 001A and 002).

Onondaga County's Save the Rain (STR) Program was created in response to Fourth Stipulation of the Amended Consent Judgment (ACJ), entered into by Onondaga County, New York State and Atlantic States Legal Foundation (ASLF) on November 16, 2009. The ACJ specifically identified Green Infrastructure (GI) as an acceptable technology to significantly reduce or eliminate the discharge of untreated combined sewage into Onondaga Lake and its tributaries, and bring the County's effluent discharges into compliance with the applicable water quality standards for the receiving waters.

The ACJ includes a phased schedule for Combined Sewer Overflow (CSO) compliance that uses an incremental approach to meeting the new goal of capture for treatment or elimination of, within the meaning of the Environmental Protection Agency's (EPA) National CSO Policy, no less than 95 percent by volume of CSO by 2018. To meet this goal the County initiated the "Save the Rain" program which will implement a combination of green and gray infrastructure that focuses on the removal of stormwater from the combined sewer system through GI, CSO storage with conveyance to the Metropolitan Syracuse Wastewater Treatment Plant (Metro), and elimination of CSO discharge points. Fifty GI projects were completed in 2013 as part of the STR program. To date, a total of more than 175 GI projects have been implemented in Onondaga County through the STR program. The completed GI projects are reducing stormwater runoff by over 100 million gallons per year and providing CSO reduction of approximately 50 million gallons per year.

Table 3-1. Summary (timeline) of significant milestones, pollution abatement actions, lake water quality status, and biological status.

Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
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 • Harbor Brook Interim FCF	--	• Biological AMP begins • littoral zone plant coverage 11% in June
2001	--	--	• Teall FCF • Hiawatha Regional Treatment Facility (RTF)	--	--
2002	--	--	• Erie Blvd Storage System repairs completed • 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 (refer to 2009)	compliance with AWQS for DO in lake upper waters during fall	--
2004	--	• year-round nitrification of ammonia at Metro using BAF • Stage III SPDES limit for ammonia met 8 years ahead of schedule	progress with sewer separations (refer to 2009)	compliance with AWQS: • ammonia in lake upper waters • for fecal coliform bacteria in lake Class B segments during Metro	--

Table 3-1. Summary (timeline) of significant milestones, pollution abatement actions, lake water quality status, and biological status.

Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
				disinfection period	
2005	--	Actiflo® system on-line to meet Metro Stage II SPDES limit for TP (0.12 mg/L as a 12-month rolling average)	progress with sewer separations (refer to 2009)	--	• no summer algal blooms • littoral zone plant coverage in June: 49%.
2006	ACJ 2nd Amendment motion filed by NYS Attorney General's Office	--	progress with sewer separations (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. • Onondaga Lake Water Quality Model development/calibration review (Phase 2).	progress with sewer separations (refer to 2009)	• compliance with AWQS for ammonia in the lake at all depths • Summer TP 25 µg/L in lake's upper waters	mesotrophic conditions achieved
2008	ACJ amended by Stipulation #3	--	Midland Ave. Phase I and II conveyance, storage and RTF	• Onondaga Lake delisted for ammonia. • summer TP 15 µg/L in lake's upper waters	Alewife population decline followed by resurgence of large zooplankton
2009	ACJ amended by Stipulation #4	Interim Stage II TP limit of 0.10 mg/L	• Clinton St. conveyance • Green Infrastructure (GI) program begins • 13 sewer separation projects completed 1999–2009	summer average TP of 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 • 40 GI projects completed , eliminating	summer average TP of 25 µg/L in lake's upper waters	resurgence of Alewife; loss of larger zooplankton

Table 3-1. Summary (timeline) of significant milestones, pollution abatement actions, lake water quality status, and biological status.

Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
			16.7 acres of impervious surfaces		
2011	NYSDEC approved AMP modifications to determine whether CSOs are causing or contributing to violations of the NYS AWQS	compliance with interim TP limit of 0.10 mg/L	• 57 GI projects completed in 2011 • Gate chamber modifications to Erie Blvd. Storage System completed • Harbor Brook Interceptor Sewer 95% complete • CSO-044 Conveyance 90% complete	summer average TP of 20 µg/L in lake's upper waters	continued high densities of Alewife and absence of larger zooplankton
2012	• Metro SPDES permit issued on March 21, 2012 • Onondaga Lake Water Quality Model completed and applied to TMDL for phosphorus • TMDL for phosphorus approved by USEPA on June 29, 2012 (in-lake TP concentration of 20 µg/L established as a target)	compliance with TP limit of 0.10 mg/L as a 12-month rolling average	• 35 GI projects completed in 2012 • CSO-044 Conveyance completed • CSO-022/045 sewer separation constructed • Construction of Harbor Brook Interceptor Sewer completed • Construction of Clinton and Harbor Brook Storage Facilities 50% complete	summer average TP of 22 µg/L in lake's upper waters	continued high densities of Alewife and absence of larger zooplankton
2013	--	compliance with TP limit of 0.10 mg/L as a 12-month rolling average	• 50 GI projects completed in 2013	summer average TP of 25 µg/L in lake's upper waters	continued high densities of Alewife and absence of larger

Table 3-1. Summary (timeline) of significant milestones, pollution abatement actions, lake water quality status, and biological status.

Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
			• Harbor Brook Interceptor Sewer (HBIS) replacement completed • Clinton Storage Facility - completed and placed into operation. • Lower Harbor Brook Storage Facility - completed and placed into operation.		zooplankton

View of Onondaga Lake from the West Shore Trail

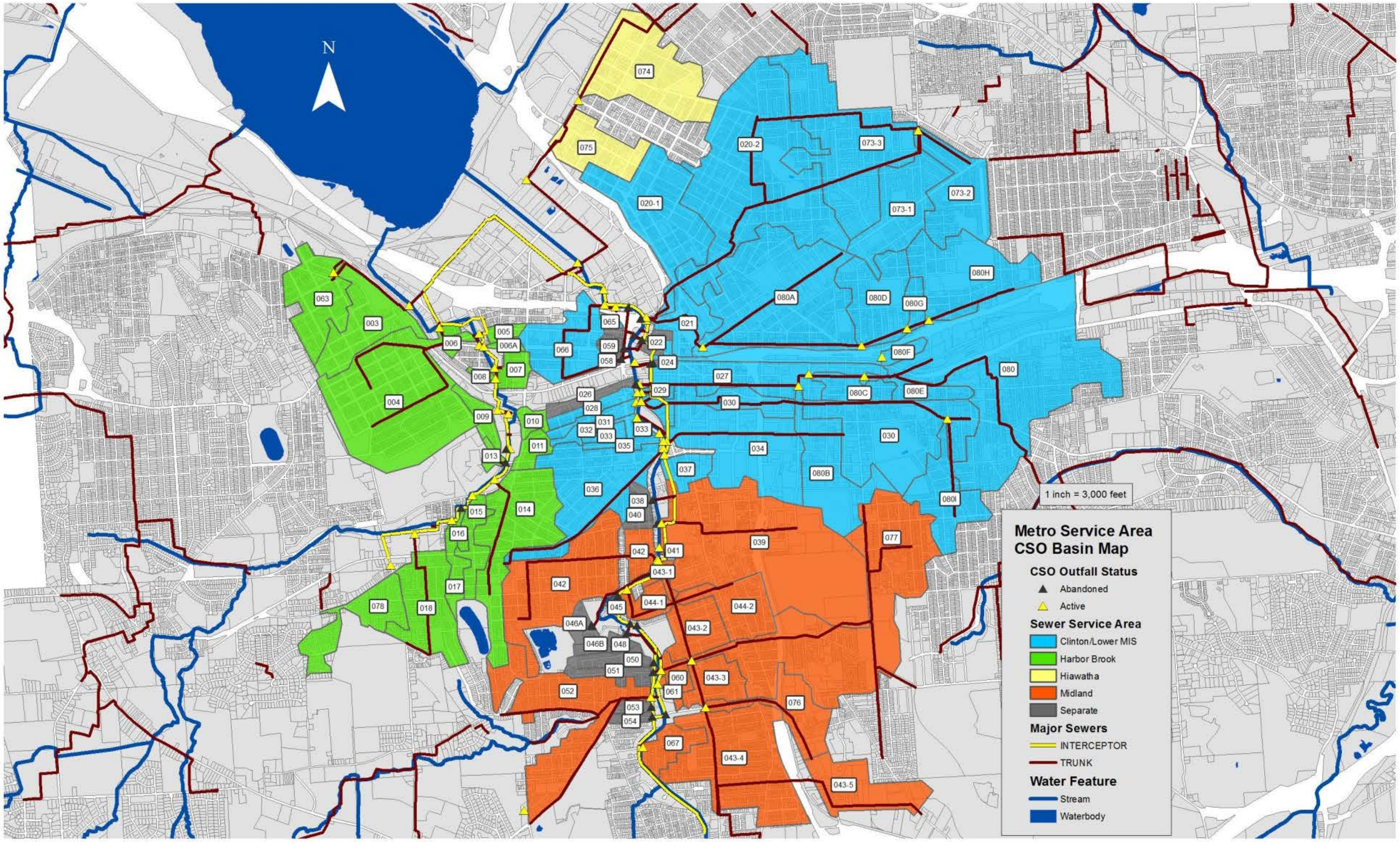


Figure 3-1. Map of CSO areas.

Table 3-2. ACJ and additional gray infrastructure milestone, schedule and compliance status.

Projects	Milestone Description	Milestone Type	Milestone Date	Compliance Status
CSO 044 Conveyances	Plans and specs to NYSDEC for review and approval	Minor	06/01/2010	Achieved
	Commence construction	Minor	12/31/2010	Achieved
	Complete construction and commence operation	Major	12/31/2011	Achieved
Harbor Brook Interceptor Sewer Replacement	Plans and specs to NYSDEC for review and approval	Minor	08/17/2009	Achieved
	Commence construction	Minor	01/01/2010	Achieved
	Complete construction and commence operation	Major	12/31/2013	Achieved
Erie Boulevard Storage System Modifications	Plans and specs to NYSDEC for review and approval	Minor	09/01/2010	Achieved
	Complete required modifications	Major	12/31/2011	Achieved
Clinton Storage Facility	Plans and specs to NYSDEC for review and approval	Minor	02/01/2011[1]	Achieved
	Commence construction	Minor	10/01/2011[1]	Achieved
	Complete construction and commence operation	Major	12/31/2013	Achieved
Lower Harbor Brook Storage Facility	Plans and specs to NYSDEC for review and approval	Minor	04/29/2011[1]	Achieved
	Commence construction	Minor	12/31/2011[1]	Achieved
	Complete construction and commence operation	Major	12/31/2013	Achieved

[1] Date reflects ACJ Milestone extension approved by the NYSDEC on November 4, 2010

Table 3-3. Additional gray infrastructure projects and implementation schedules.

Projects	Task	Compliance Status
CSO 063 Conveyances	Plans and specifications to NYSDEC for review and approval	5/23/2013
	Construction bid opening	4/28/2014
	Notice to proceed	8/8/2014
	Complete construction	9/1/2015

Green infrastructure facility installed on a two acre parcel of land at the intersection of Amy Street, Delaware Avenue and Grand Avenue

Green infrastructure features include two bio-retention areas, a rain garden, porous gravel interior paths, and porous concrete sidewalks.

A number of significant gray infrastructure milestones were achieved in 2013, including the following major projects. Harbor Brook Interceptor Sewer (HBIS) Replacement was completed, including upsizing of approximately 7,500 linear feet of interceptor sewer. The capacity of HBIS expanded by 500,000 gallons and the flow increased by 400,000 gallons per day. The County also completed a two-acre green infrastructure site, providing an additional estimated 467,000 gallons of stormwater capture and significantly improving aesthetics. The Clinton and Lower Harbor Brook Storage Facilities were placed into operation and capable of receiving wet weather flow on December 31, 2013. The Clinton and Lower Harbor Brook facilities provide 6.5 million gallons and 4.9 million gallons of CSO storage, respectively, which is routed to Metro for treatment.

In 2013 the STR Program included several signature GI projects that showcase the use of GI and build general awareness in the community through impressive transformations of neighborhoods across Syracuse. A variety of GI elements were incorporated in the West Onondaga Street Green Gateway Project, including an underground infiltration system, enhanced tree plantings, and vegetated swales. This project will capture approximately 5.5 million gallons of stormwater annually while providing improved pedestrian access to the business district and dedicated bike lanes in the roadway. Nearly 1,400 tree plantings were installed as part of the Save the Rain Street Tree Program in 2013. Since 2011, over 2,640 trees have been planted as part of this program. The Westcott Street porous pavement project incorporates enhanced street tree plantings, porous asphalt parking lanes, infiltration trenches with vegetated planters, and additional landscaping.

Student Volunteers at the 2013 Clean Water Fair

The Greening the Zoo project includes an impressive assortment of green infrastructure spread across the entire footprint of the Rosamond Gifford Zoo. This project will capture nearly 6 million gallons of stormwater annually through implementation of the following GI elements: rain garden systems; a combination of porous pavement, underground infiltration trenches, and vegetated bioretention areas installed in the zoo parking lot; a "Courtyard" project that includes the construction of a 75-foot porous pavement path, 100-gallon rain barrel to capture stormwater from the roof of the main building, and a 1,000 square foot rain garden system adjacent to the primate exhibit; an 11,000-square foot vegetated green roof on the zoo's elephant barn; a stormwater wetland recirculation system connecting the waterfowl exhibits; and a 5,000-gallon cistern installed at the bear exhibit to collect stormwater. For additional information on these and other projects please visit the Save the Rain website (savetherain.us).

Hands on Science at the 2013 Clean Water Fair
held at Metro on September 7, 2013

County Executive Joanne Mahoney is championing a Save the Rain (STR) initiative to educate residents about storm water management. The campaign raises awareness of effective ways to improve the environment by using rain barrels, rain gardens, porous pavement, green roofs, cisterns, and vegetated swales. STR continued its approach to rebuilding neighborhoods, developing strong community relationships, and advancing signature projects to solidify its place as a national leader in stormwater management. In addition, STR continued a comprehensive public education and outreach program to engage the local community and provide continued support for program activities. The Save the Rain Program received a considerable amount of recognition during 2013. In addition to receiving the prestigious U.S. Water Prize for “Best Public Sector,” Onondaga County received awards from local, regional, state, and national levels for its continued efforts to restore Onondaga Lake.

In 2013, the STR Public Education and Outreach Team continued to engage the general public to raise awareness of the benefits of green infrastructure and the County’s efforts to implement the program. Public outreach activities in 2013 included 15 rain barrel workshops and distribution of 255 rain barrels, 35 Workshop Training Sessions, and participation of more than 1500 K-12 students in STR educational programming.

Clinton Storage Facility during construction

The updated version of the Microbial Trackdown Phase 2 workplan, dated April 5, 2012, outlined a comprehensive study implemented in 2012 and 2013 to monitor presence of fecal coliform bacteria in Harbor Brook and Onondaga Creek, as a follow-up to the findings of the Phase I study conducted in 2008 and 2009. Funding for the Phase 2 project was provided by USEPA and administered by NYSDEC (Region 7). The entire study was undertaken as a joint project of OEI and Onondaga County Department of Water Environment Protection (OCDWEP), with Onondaga Environmental Institute (OEI) as the principal partner and OCDWEP providing analytical and sampling support.

The microbial trackdown working group continued to provide technical guidance, comment on action items and deliverables, and project oversight and includes representatives from, ASLF, City of Syracuse Department of Public Works, NYSDEC Region 7, NYS Department of Law, OEI, Onondaga County, Onondaga Nation, US Army Corps of Engineers Buffalo District, and USEPA Region 2.

Phase 2 of the Microbial Trackdown Study began in an effort to: (A) monitor spatial trends in bacteria levels in tributaries to Onondaga Lake, (B) monitor problematic point sources identified during Phase 1, (C) monitor newly discovered point sources, and (D) track down and remediate problematic bacterial discharges. All activities were performed during dry weather conditions, defined as a maximum of 0.08" (2 mm) in the preceding 48 hours of a sampling event. Five tasks were completed as part of this study, including: (1) in-stream routine sampling, (2) 12-hr temporal sampling, (3) priority point source sampling, (4) point source identification, and (5) tributary trackdown sampling. Field efforts were performed in the summer and fall of 2012 (June-November) and 2013 (June-October). The results are presented in **Identification of the Primary Sources of Bacteria Loading in Selected Tributaries of Onondaga Lake: Phase 2 Microbial Trackdown Study**, Final Draft Report, August 2014 (to be finalized in 2015).

Results from the study helped to elucidate spatial and temporal trends in bacteria and water quality, identify areas of concern, and make physical improvements to the system, most notably:

- In-stream bacteria levels were significantly different between rural and urban locations, with urban locations consistently having higher bacteria levels.
- Routine and temporal sampling events identified several drivers that explained patterns in bacteria levels.
- Decreased water quality, including elevated turbidity, temperature, and conductivity levels, was evident at several routine locations in Harbor Brook, Onondaga Creek, and Ley Creek, and was consistent with impacts caused by increased urban runoff, stream channelization, reduced riparian vegetative protection, the Tully Valley mudboils, and the infiltration of natural salt springs. However, collectively, water quality at most in-stream locations were generally not at levels considered detrimental to aquatic life or human health.
- Priority point source sampling found several point sources in Onondaga Creek and Harbor Brook to be continuously discharging high levels of bacteria. These sampling efforts helped to identify point sources identified during Phase 1 that were remediated under Phase 2 as a result of Phase 1 efforts, as well as those that remained problematic.

Routine sampling of these persistently problematic point sources (high bacterial loads) allowed Working Group members to prioritize sampling efforts and develop strategies for investigating and remediating the discharge.

- Five new point sources were identified in Onondaga Creek since Phase 1, illustrating the dynamic nature of an aging infrastructure.
- The addition of Ley Creek to field efforts resulted in the identification of 52 point sources throughout the watershed, including one point source discharging fecal coliform bacteria levels >50,000 cfu/100mL caused by a failed, improper connection to the storm system.
- The analysis of trihalomethanes (THMs) from samples collected during point source identification sampling identified a number of point sources discharging detectable levels of THMs; suggestive of potable water discharges. Ten point sources in Onondaga Creek and four in Ley Creek had high THM levels indicative of water system leaks. In Onondaga Creek, the collective contribution of potable water from these point sources is estimated to be as much as 6.5 million gallons, annually. Despite high levels at some point sources (maximimum of 27 ppb), none of the THM concentrations observed exceeded the EPA's limit of 80 ppb.
- Two urban tributaries to Onondaga Creek, City Line Brook and Hopper Brook (N), had high levels of bacteria at several locations during the 2013 trackdown event.
- Site-specific bacteria levels in Onondaga Creek varied between Phase 1 and Phase 2, with two upstream locations showing significant increases in bacteria levels and three downstream locations showing significant decreases in bacteria levels between study phases. In 2012, OEI conducted an extensive ecological study of the Upper Onondaga Creek Watershed (OEI, 2013). Results found water quality impacts at several sites associated with agricultural and residential practices. Decreases in bacteria at several locations downstream were attributed to physical improvements to the system made during and shortly after the completion of Phase 1.
- Despite several physical improvements made in Harbor Brook during and after Phase 1, in-stream bacteria levels for nearly all sampling locations showed a significant increase in bacteria levels. Results suggest that issues at and just upstream of Velasko Rd are the source of the high bacteria levels.
- Through the collective efforts of Phase 1 and Phase 2, a total of 12 physical improvements to the system have been made in Harbor Brook, Onondaga Creek, and Ley Creek, and follow-up work is currently being conducted on several other point sources. With the exception of one point source in Harbor Brook, subsequent sampling events showed that the corrective work was successful.

Based on the findings of the 2013 sampling program, OEI identified eight point sources of concern in Onondaga Creek and three into Harbor Brook. Strategies are being developed to perform targeted sampling and analysis of each point source in an effort to isolate the source (i.e., animal vs. human) and location (cross-connection, illicit discharge, etc.) of the discharge. Results from this study effectively documented the effects of dry-weather inputs on bacteria levels and water quality in Harbor Brook, Onondaga Creek, and Ley Creek. In addition, spatial and temporal trends in bacteria levels were identified that helped to: (1) explain patterns of stream water quality related to land use, (2) detect relationships between measured parameters, (3) identify and prioritize point source trackdown work, (4) measure the effects of remedial activities on bacteria levels, and (5) assess long-term changes in bacteria levels since Phase 1. The collaborative and adaptive management-based approach to this study has allowed decision-makers and Working Group members to redirect resources and focus to areas in the watershed that have had, or continue to require further trackdown work. Remaining funds from Phase 2 efforts have been allocated to further trackdown work in the watershed, which began in May 2014, targeting specific point sources and tracking sources upstream and/or up the sewershed to locate and remediate the source. This work is currently being conducted as a coordinated effort of Onondaga County, the City of Syracuse, and OEI.

3.2 Progress with Related Initiatives

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. Dredging and capping of Onondaga Lake sediments continued in 2013. About 2 million cubic yards of contaminated sediment will be removed from the lake by hydraulic dredging, which is expected to be completed in 2014, a year ahead of schedule. About 450 acres of the lake bottom are being capped to provide a new habitat layer, prevent erosion, and isolate remaining contaminants. Capping and habitat restoration are on schedule to be completed in 2016. Additional work is under way to improve up to 50 acres of wetlands on the shores of Onondaga Lake and along the lake's tributaries. About 1.1 million plants, shrubs, and trees are being planted to enhance habitat for fish and wildlife in the Onondaga Lake watershed. By the end of 2013, 32 acres of wetlands had been restored. Honeywell has documented the return of more than 110 species of fish, birds, and mammals to the restored wetlands and nearby areas. Additional details can be found on Honeywell's website (http://www.lakecleanup.com/about-the-cleanup/cleanup-areas/geddes-brook-wetlands/).

Geddes Brook Wetlands

In 2013, the third year of a three year pilot test, nitrate was added to the deep waters of Onondaga Lake with the objective of limiting release of methylmercury from the profundal sediments to the hypolimnion. 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. 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. The Onondaga Lake Visitors Center opened on the southwest shoreline of the lake in 2012 to provide the public with access to information on the lake cleanup. Nearly 5,000 people have visited the center. Additional information on Honeywell's remediation activities is available on their project website http://www.lakecleanup.com.

Dredging Operations in November 2013

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 important 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.

Section 4. Tributary Water Quality: 2013 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. Annual precipitation totaled 40.4 inches in 2013, 4% higher than the 30-year historic (1983–2012) average of 38.7 inches and 15% higher than the 35.1 inches received in 2012. Monthly precipitation totals were higher than the long-term averages in February, April, May, June, October, and November (Figure 4-1). Precipitation was particularly high during the month of June when 6.8 inches of rain was reported. It was the wettest June since 1976 and the 5th wettest since 1902. The months of January, March, July, August, September, and December were dryer than the long-term average.

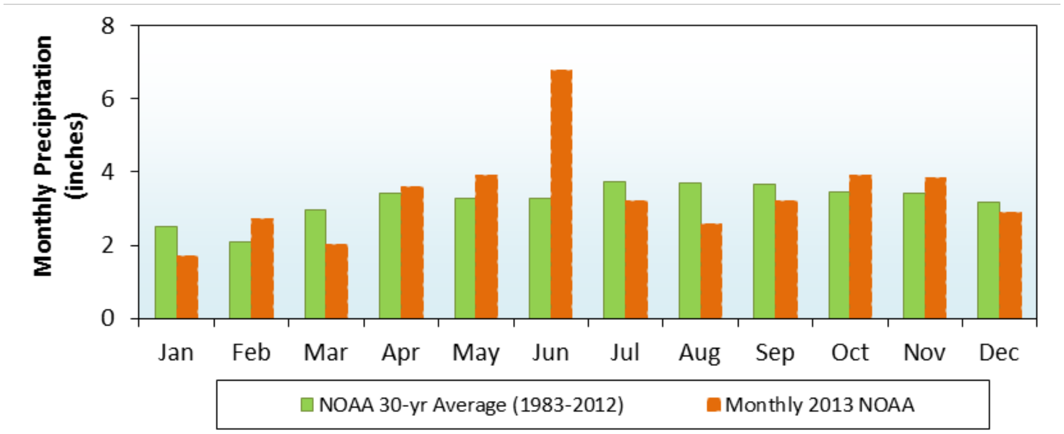


Figure 4-1. Monthly precipitation in 2013 compared to the long-term (1983–2012) average.

Substantial year-to-year variations in precipitation are reflected in the wide range of annual average flows carried by Onondaga Creek during the 1971–2013 interval (Figure 4-2). Approximately average precipitation during most of 2013 resulted in an annual average flow for Onondaga Creek that was only slightly higher than the average for the 43-year record (Figure 4-2). Average precipitation in 2013 was in stark contrast to the unusually dry conditions of 2012 and the very wet conditions of 2011.

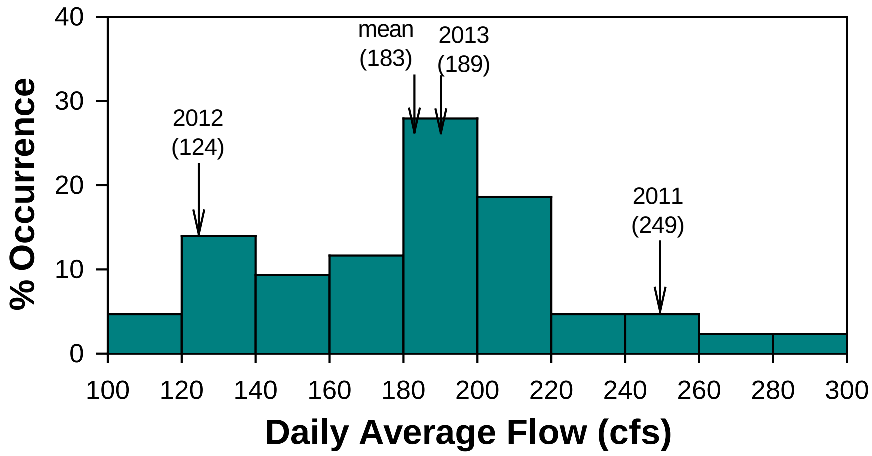


Figure 4-2. Distribution of the annual average of daily average flows for Onondaga Creek at Spencer Street, 1971–2013.

Note: Annual average values for 2011, 2012, 2013, and the entire 43-year record are identified.

Temporally detailed stream flow patterns for the major tributaries in 2013 depict major runoff events in mid-January, early February, mid-March, and mid-April (Figure 4-3). Snowfall for the 2012–2013 winter season totaled 115.4 inches, just below the 1951–2012 average of 119 inches. Snowmelt contributed to elevated tributary flows in January, February, and March. Following a dry interval that began in mid-April, the late May to early July period was characterized by a series of significant runoff events and elevated flows in the tributaries. The wettest day of the year was June 6, when 2.55 inches of rain fell. This was preceded by 1.13 inches of rain on May 29 and followed by 0.7 inches on June 10-11 and 1.23 inches on June 13. An additional 1.91 inches of rain fell during the June 25-29 interval. The flows and coupled material loadings received during late spring and early summer are considered particularly important in influencing summer water quality in receiving lakes. Accordingly, the elevated flows of June and early July would be expected to have significant impacts on lake water quality during the summer months. Tributary flows were mostly low from early July to late November, with the exception of modest runoff events in late July, early September, early October, and early November. Major runoff events occurred following the growing season in late November and late December. Relative to runoff events that occur during summer, these events have a diminished impact on lake water quality during the following summer season.

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). In 2013 this goal was exceeded by a wide margin at Onondaga Creek, Ninemile Creek, Ley Creek, and Harbor Brook (Figure 4-3).

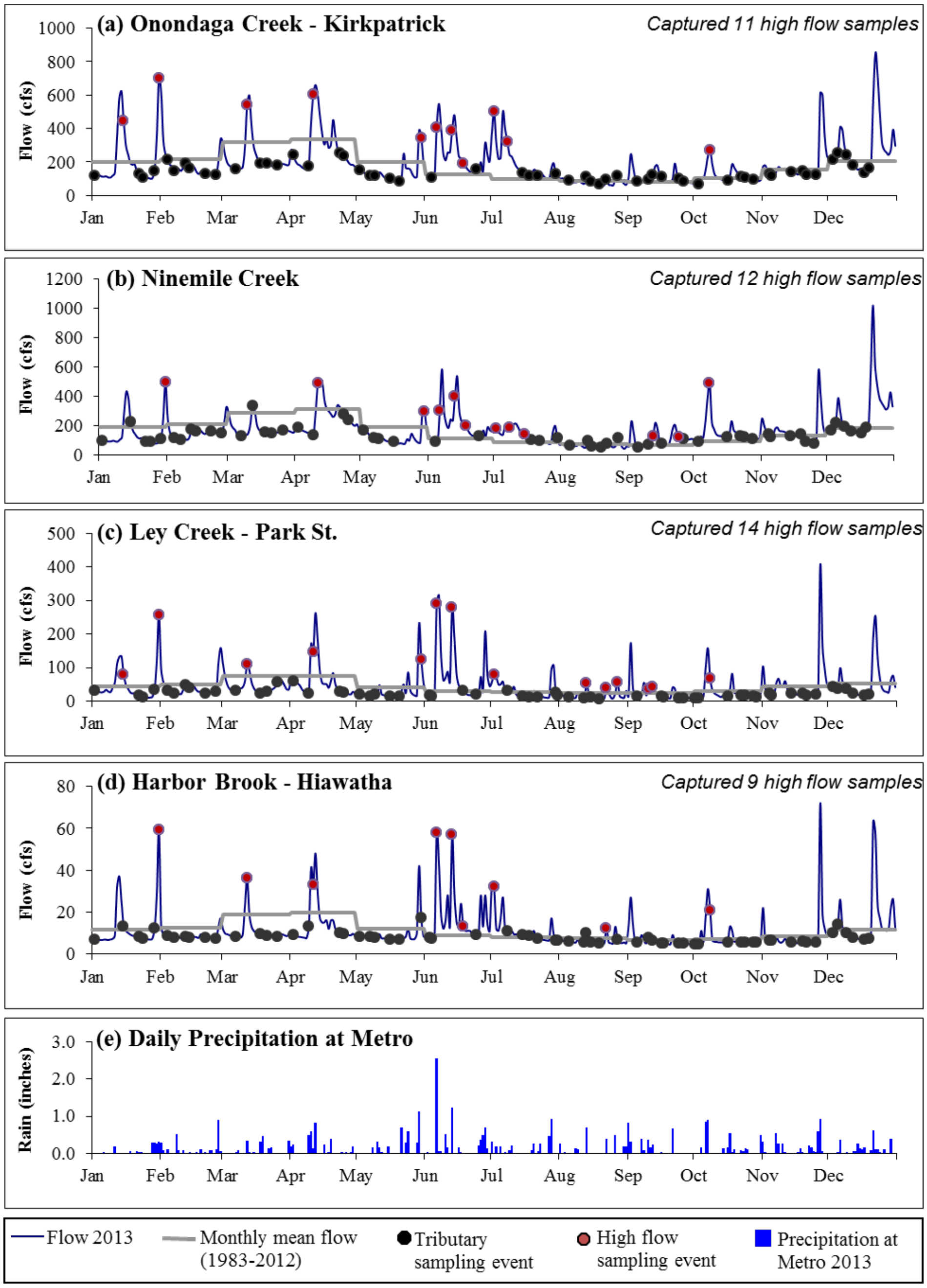


Figure 4-3. Hydrographs showing tributary flows in 2013 compared with the 30-year average (1983–2012) USGS average flow for (a) Onondaga Creek, (b) Ninemile Creek, (c) Ley Creek, (d) Harbor Brook, and (e) daily precipitation at Metro.

Note: points indicate days of sampling.

4.2 Compliance with Ambient Water Quality Standards

Several segments of Onondaga Lake's tributary streams are included on the 2012 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. The **Final New York State 2014 Section 303(d) List of Impaired/TMDL Waters** was "partially approved and partially disapproved" by USEPA on January 13, 2015. Results of Onondaga County's AMP are among the primary data sets used to evaluate compliance with standards and use attainment. The 2013 tributary data indicate that the major tributaries were generally in compliance with ambient water quality standards (AWQS) for most parameters addressed (Table 4-1). The primary exceptions in meeting AWQS in the tributaries were total dissolved solids (TDS) and fecal coliform bacteria (FC). The AWQS for TDS (500 mg/L) was contravened at all of the tributary monitoring sites, and often by a wide margin. Contravention of this standard is primarily associated with the natural hydrogeology of the watershed and not with anthropogenic effects. Achieving compliance with this water quality standard is not a goal of the remediation program.

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). In April 2010 Onondaga County increased the frequency of bacterial sampling at each tributary sampling location to support assessments of compliance with this AWQS. 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 1-5). 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. The following tributaries were 100% compliant with the related standard (Table 4-1): Tributary 5A and the Onondaga Lake Outlet-2ft. Compliance with the AWQS for fecal coliform bacteria was achieved for less than 50% of the monthly means at Harbor Brook at Hiawatha (17%), Ley Creek (22%), Onondaga Creek at Kirkpatrick (0%), and Sawmill Creek (43%).

Additional exceptions to 100% compliance included the parameters: (1) dissolved oxygen – Onondaga Lake Outlet-12ft. (92%), (2) pH – Harbor Brook at Hiawatha (98%) and Ley Creek (99%), and (3) dissolved mercury – Bloody Brook (75%), Ley Creek (50%), Sawmill Creek (50%), Tributary 5A (25%), and Onondaga Lake Outlet-12ft. (33%). Samples were collected from Ley Creek for analysis of weak acid dissociable cyanide (WAD-CN) in September and November. The concentration of WAD-CN in the September sample exceeded the AWQS established for free cyanide. The concentration of WAD-CN in the November sample was lower than the standard.

Table 4-1. Summary of tributary and outflow compliance (percent of observations in compliance) with ambient water quality standards (AWQS), 2013.

Note: occurrences of less than 100% compliance are highlighted in red text; dissolved oxygen, ammonia, nitrite, and fecal coliform are specified in the ACJ; the number of observations is shown in parentheses; NS is not sampled.

	Field Data		Solids	Nitrogen		Metals[1]				Bacteria
Site	Dissolved Oxygen (4 mg/L)	pH	TDS	Ammonia	Nitrite	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved[2] Mercury	Fecal[3] Coliform
Bloody Brook at Onon. L. Parkway	100% (69)	100% (69)	**11% (28)**	100% (28)	100% (27)	NS (0)	NS (0)	NS (0)	**75% (4)**	**50% (69)**
Harbor Brook at Hiawatha Bvd.	100% (80)	**98% (80)**	**4% (28)**	100% (28)	100% (27)	NS (0)	NS (0)	NS (0)	100% (3)	**17% (78)**
Harbor Brook at Bellevue Ave.	100% (78)	100% (78)	**33% (6)**	100% (6)	100% (6)	NS (0)	NS (0)	NS (0)	100% (1)	**91% (75)**
Harbor Brook at Velasko Rd.	100% (80)	100% (80)	**0% (28)**	100% (28)	100% (27)	NS (0)	NS (0)	NS (0)	100% (3)	**64% (77)**
Ley Creek at Park St.	100% (72)	**99% (72)**	**7% (27)**	100% (27)	100% (26)	NS (0)	NS (0)	NS (0)	**50% (4)**	**22% (72)**
Ninemile Creek at Lakeland	100% (69)	100% (69)	**4% (28)**	100% (28)	100% (27)	NS (0)	NS (0)	NS (0)	100% (4)	**55% (65)**
Onondaga Creek at Kirkpatrick St.	100% (69)	100% (69)	**4% (28)**	100% (28)	100% (27)	100% (2)	100% (2)	100% (2)	100% (4)	**0% (65)**
Onondaga Creek at Dorwin Ave.	100% (78)	100% (78)	**32% (28)**	100% (28)	100% (27)	100% (2)	100% (2)	100% (2)	100% (3)	**64% (75)**
Sawmill Creek at Onon. L. Rec. Area	100% (40)	100% (40)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	**50% (2)**	**43% (40)**
Trib. 5A at State Fair Blvd.	100% (67)	100% (67)	**0% (27)**	100% (27)	100% (26)	100% (2)	100% (2)	100% (2)	**25% (4)**	100% (65)
Onondaga Lake Outlet (2ft)	100% (11)	100% (11)	**8% (5)**	100% (5)	100% (5)	NS (0)	NS (0)	NS (0)	100% (1)	100% (9)
Onondaga Lake Outlet (12ft)	**92% (25)**	100% (26)	**7% (26)**	100% (26)	100% (25)	NS (0)	NS (0)	NS (0)	**33% (3)**	NS (0)

[1] AWQS for metals apply to the total dissolved form

[2] Dissolved mercury standard applies to health fish consumption standard (H(FC))

[3] Fecal coliform compliance is assessed monthly, based on the geometric means of at least 5 samples.

Time series of fecal coliform concentrations in Onondaga Creek, Harbor Brook, and Ley Creek during 2013 are presented for both wet and dry weather conditions (Figure 4-4). Wet weather samples are those collected following at least 0.1 inches of rain in the preceding 48 hours; all other samples are considered to be representative of dry weather conditions. Both upstream and downstream values are shown for Onondaga Creek (Dorwin Ave., Kirkpatrick St.) and Harbor Brook (Velasko Rd., Hiawatha Blvd.). Only downstream samples are available for Ley Creek (Park St.). Fecal coliform levels were generally higher at downstream sampling sites and during wet weather. However, fecal coliform concentrations at the upstream sampling locations of Onondaga Creek (Dorwin Ave., Figure 4-4a) and Harbor Brook (Velasko Rd., Figure 4-4c) routinely exceeded the AWQS of 200 counts/100 mL during wet weather and during dry weather in the summer months. A distinct seasonality in fecal coliform concentrations was apparent at all sampling locations, with higher values observed during the warmer summer months of June–September. This temporal pattern, which suggests that fecal coliform abundance is strongly dependent on ambient temperatures, was also observed in an analysis of historic data (see Section 4.3.5 of the 2012 AMP Report). This seasonality was least apparent at the Kirkpatrick St. site on Onondaga Creek (Figure 4-4b).

Aerial view of the H-14 Harbor Brook Wetland Pilot Treatment System at CSO 018
(construction nearly completed)

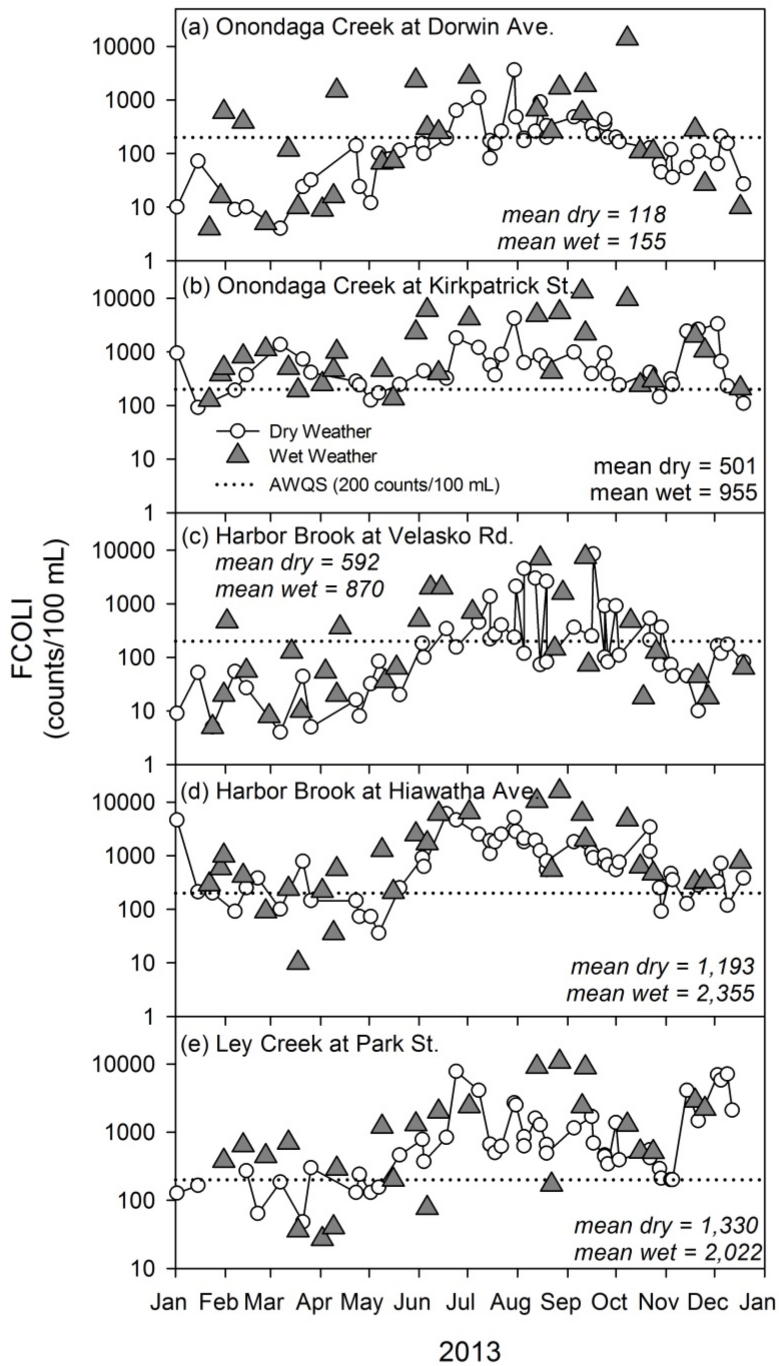


Figure 4-4. Time series of fecal coliform concentrations during wet weather and dry weather during 2013: (a) Onondaga Creek at Dorwin Ave., (b) Onondaga Creek at Kirkpatrick St., (c) Harbor Brook at Velasko Rd., (d) Harbor Brook at Hiawatha Blvd., and (e) Ley Creek at Park St.

Note: value of the AWQS for fecal coliform shown for reference (200 counts/100 mL).

4.3 Loading Estimates

4.3.1 Calculations and Results for Key Constituents

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 2013 (Table 4-2), mostly in units of metric tons (mt). Forms of phosphorus and nitrogen are measured frequently in the Metro effluent. Tributary loading calculations were supported by at least 27 observations within the year, except for Allied East Flume Manhole 015 (n=8). Fecal coliform samples were collected more frequently (5 samples per month) to allow for determination of compliance with the AWQS.

The largest total phosphorus (TP) loads to Onondaga Lake were delivered by the two largest tributaries, Onondaga and Ninemile Creeks, and the Metro effluent (Table 4-2). The Metro bypass (002) load was estimated to be the fifth highest, following Ley Creek. Metro's contribution was substantially greater before the Actiflo® upgrade in 2005. Total phosphorus loads in 2013 were nearly 2-fold higher than in 2012, consistent with unusually low precipitation and stream flow in 2012. The total Metro load (001+002) increased 12% from 2012 to 2013 while loads from Onondaga and Ninemile Creeks decreased by 128% and 192%, respectively. Increased total phosphorus loading from Ninemile Creek may be associated with in-stream remediation activities conducted by Honeywell in 2013. Onondaga Creek, Ninemile Creek, and the Metro effluent also had the highest total dissolved phosphorus (TDP) loads in 2013. In an effort to reduce phosphorus levels in stormwater runoff, New York State restricted the use of phosphorus fertilizer on lawns and non-agricultural turf beginning January 1, 2012.

Sawmill Creek entering Onondaga Lake

Table 4-2. Annual loading estimates for selected water quality constituents to Onondaga Lake, 2013. Loads calculated at downstream sampling locations.

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

Parameters[1]	TP		TDP		TN[7]		NH_3-N		TSS		FC[2]	
units	**mt**	**n**	**mt**	**n**	**mt**	**n[3]**	**mt**	**n**	**mt**	**n**	**10^{10} cfu**	**n**
Metro:												
Treated Effluent (001)[5]	5.3	363	1.6	249	1,199.4	363	23.2	363	465	363	21,319	210
Bypass (002)[6]	1.9	56	0.6	--	21.8	56	12.2	56	105	56	117,799	46
Watershed:												
Allied East Flume[4] Manhole 015	0.1	8	0.1	8	4.7	8	0.2	8	7	8	57	18
Harbor Brook[4]	0.7	28	0.2	28	19.6	28	0.9	28	210	28	18,538	73
Ley Creek[4]	3.3	27	0.9	26	42.6	27	8.9	27	868	27	94,294	67
Ninemile Creek[4]	14.0	28	2.3	28	268.8	28	27.0	28	13,146	28	110,793	65
Onondaga Creek[4]	15.5	28	2.3	28	310.1	28	11.6	28	14,304	28	208,771	65
Tributary 5A[4]	0.0	27	0.0	27	0.6	27	0.1	27	4	27	21	65
Total	41	--	8	--	1,868	--	84	--	29,109	--	571,593	--

Notes:

[1]Parameters are: TP (total phosphorus), TDP (total dissolved P), TN (total nitrogen), NH_3-N (ammonia-N), TSS (total suspended solids), and FC (Fecal coliform bacteria). Because TDP was not measured on the Bypass, SRP loads are reported rather than TDP loads.

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

[3]Not measured directly, counts reflect NH_3-N counts.

[4]Tributary loading results are calculated using 2013 observations (n = number of samples for 2013) and processed through AutoFlux Method 5 and are reported here for the sampling locations closest to Onondaga Lake.

[5]Metro Effluent Outfall 001 loads for TP, TSS, and NH_3-N are calculated using daily observations, and FC are collected biweekly as part of the long-term tributary program and daily from April 1 to October 15 (per SPDES permit during disinfection season).

[6]Metro Bypass Outfall 002 loads are calculated using periodic grab samples when Outfall 002 is active (secondary bypass events when the capacity of Metro is exceeded).

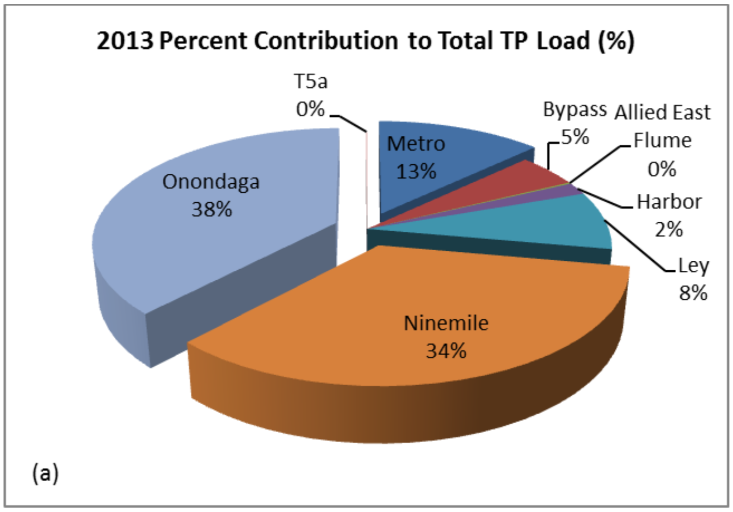
[7]All TN loads were calculated by summing the annual NH_3-N, NO_3-N, NO_2-N, and ORG-N loads

The Metro effluent was the leading source of total nitrogen (TN) and an important source of ammonia nitrogen (NH_3-N) to the lake in 2013 (Table 4-2). The largest source of ammonia in 2013 was Ninemile Creek. The total suspended solids (TSS) load was dominated by inputs from Onondaga Creek and Ninemile Creek, which combined to account for 94% of the total load to Onondaga Lake. The high TSS load in Onondaga Creek is at least in part attributable to inputs from the mud boils in upstream portions of its watershed. The contribution from Ninemile Creek in 2013 (45%) was much higher than in 2011 (27%) or 2012 (21%). This is attributable to a period of elevated TSS concentrations (mean=388 mg/L) from June 13, 2013 to July 30, 2013. Outside of this period the mean TSS concentration for Ninemile Creek was 28 mg/L. This short-term increase in TSS was likely caused by in-stream remediation activities conducted as part of the Honeywell cleanup. Silt curtains were deployed at the mouth of Ninemile Creek to control transport of TSS to Onondaga Lake.

The primary source of fecal coliform bacteria was Onondaga Creek. However, the Metro bypass (002), Ninemile Creek, and Ley Creek made noteworthy contributions as well (Table 4-2). The combined loading from these four sources accounted for approximately 93% of the total fecal coliform load to Onondaga Lake. Loading contributions of gauged inputs for selected constituents in 2013 are presented here in both tabular (Table 4-3) and graphical (Figure 4-5) formats. Loading estimates for additional constituents are provided in Appendix D-1. Total annual loads (sum of tributaries and Metro) to Onondaga Lake for the 1994–2013 interval are presented in Appendix D-2.

Table 4-3. Percent annual loading contribution by gauged inflow in 2013.

Parameter	TP	TDP	TN	NH_3-N	TSS	FC	Water
Metro:							
Treated Effluent (001)	13%	20%	64%	28%	2%	4%	20%
Bypass (002)	5%	7%	1%	15%	0%	21%	0%
Harbor Brook	2%	3%	1%	1%	1%	3%	2%
Ley Creek	8%	11%	2%	11%	3%	17%	8%
Ninemile Creek	34%	29%	14%	32%	45%	19%	32%
Onondaga Creek	38%	29%	17%	14%	49%	37%	37%
Tributary 5A	0%	0%	0%	0%	0%	0%	0%



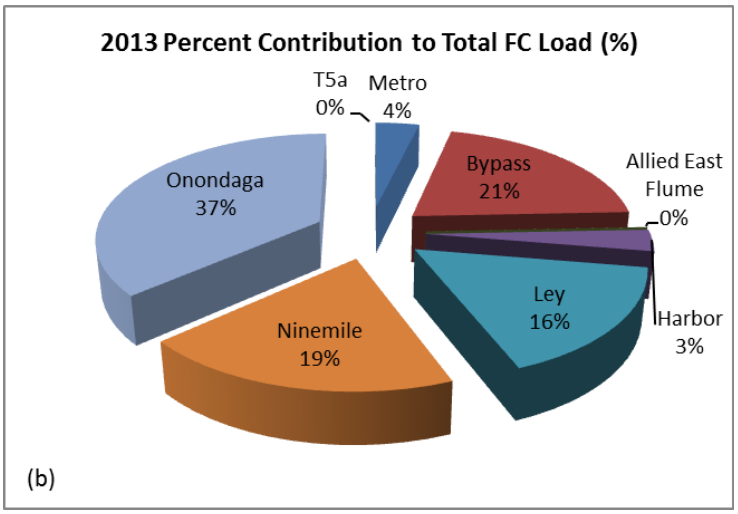


Figure 4-5. Percent contributions to 2013 total load to Onondaga Lake for (a) total phosphorus and (b) fecal coliform bacteria.

The relative potency of the various inflows can be represented by comparisons of annual flow-weighted average concentrations (total annual loads (mass) ÷ total flow (volume)) calculated for each input. Flow-weighted concentrations for 2013 are presented for the same selected constituents (Table 4-4). Total phosphorus concentrations ranged from 57 µg/L in the Metro effluent to 166 µg/L in Allied East Flume, but were of course much higher for the partially treated Metro bypass (1,142 µg/L). Concentrations of TDP were lowest in Ninemile Creek, Onondaga Creek, and the fully-treated Metro effluent and highest in the bypass. The Metro effluent and bypass were enriched in TN and ammonia relative to the other inputs. Concentrations of TSS were highest in Ninemile Creek, Onondaga Creek, and the bypass and lowest in fully treated Metro effluent. The highest fecal coliform concentrations were in the

Table 4-4. Flow-weighted average concentrations for selected constituents in Onondaga Lake tributaries, 2013.

Parameters[1]	TP		TDP		TN[7]		NH_3-N		TSS		FC[2]	
units	µg/L	n	µg/L	n	mg/L	n[3]	mg/L	n	mg/L	n	10^{10} cfu	n
Metro:												
Treated Effluent (001)[5]	57	363	17	249	15.8	363	0.25	363	5.0	363	231	210
Bypass (002)[6]	1142	56	331	6	21.8	56	7.20	56	62.2	56	69,526	46
Watershed:												
Allied East Flume[4] Manhole 015	166	8	138	8	7.9	8	0.40	8	15.9	8	122	18
Harbor Brook[4]	74	28	24	28	2.8	28	0.10	28	21.6	28	1,902	73
Ley Creek[4]	87	27	24	26	1.6	27	0.23	27	22.5	27	2,449	67
Ninemile Creek[4]	94	28	16	28	2.8	28	0.18	28	88.1	28	742	65
Onondaga Creek[4]	92	28	14	28	2.8	28	0.07	28	84.6	28	1,235	65
Tributary 5A[4]	87	27	29	27	1.9	27	0.16	27	10.7	27	61	65

Notes:

[1] Parameters are TP (total phosphorus), TDP (total dissolved P), TN (total nitrogen), NH_3-N (ammonia), TSS (total suspended solids), and FC (fecal coliforms). Because TDP was not measured on the Bypass, SRP loads are reported rather than TDP loads.

[2] FC loads have a very high standard error due to the episodic nature of the FC inputs.

[3] Not measured directly, sample counts reflect NH_3-N counts.

[4] Tributary flow-weighted concentrations are calculated using 2013 observations (n = number of samples for 2013) processed through AutoFlux Method 5 and reported here for the sampling locations closest to Onondaga Lake.

[5] Metro Effluent Outfall 001 loads for TP, TSS, and NH_3-N are calculated using daily observations; FC are collected biweekly as part of the long-term tributary program and daily during the Metro disinfection period of April 1 –October 15.

[6] 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).

[7] All TN flow-weighted concentrations were calculated by dividing the total TN load (see Table 4-3) by the total flow volume for each site.

bypass, followed by Ley Creek, Harbor Brook, and Onondaga Creek. The complete list of constituent flow-weighted average concentrations, along with the relative error of the means, is presented in tabular format (Appendix D-3).

4.3.2 Selected Phosphorus Topics

Estimates of total phosphorus loads for the tributaries have generally been greater in higher runoff years (Figure 4-6). Variations in rainfall for the 1990–2013 period explained 45% of the differences in total phosphorus loading according to linear least-squares regression ($p<0.01$). Two- to three-fold differences in total phosphorus loads from the watershed can be expected due to natural variations in rainfall. Clearly, variations in runoff need to be considered when evaluating year-to-year dynamics in lake water quality.

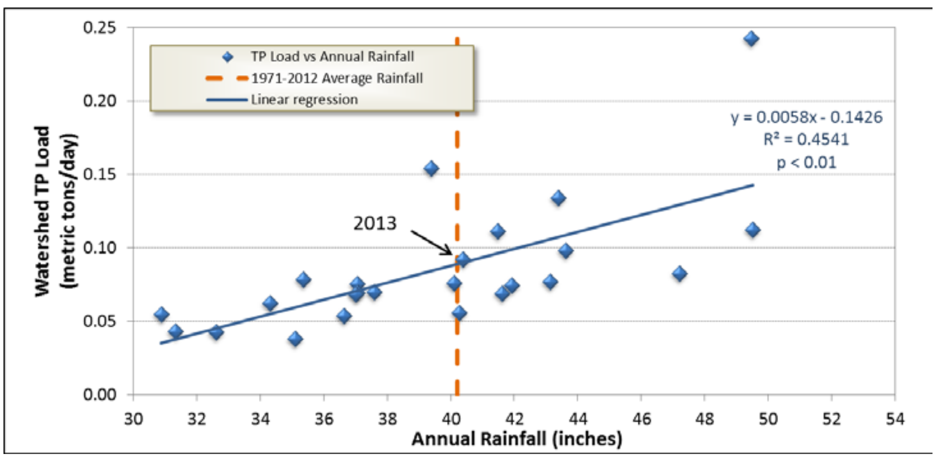


Figure 4-6. Daily average total phosphorus (TP) loading from the watershed versus annual precipitation for the 1990–2013 period.

Note: precipitation data from: http://www.nws.noaa.gov/climate/xmacis.php?wfo=bgm

The timing of phosphorus loads within a year is a potentially important factor relative to algal growth during the critical summer months, particularly in the context of the rapid flushing rate of Onondaga Lake (~ 4 times per year). Although a portion of the phosphorus load received in the fall to winter interval can contribute through various recycle pathways (e.g., sediment diagenesis), it is largely flushed through the lake, or particulate forms are deposited, by the following spring. Accordingly, late spring and summer loads are expected to be the most important for this lake. Monthly loads of total phosphorus (TP) and total dissolved phosphorus (TDP) are presented for 2013 (Figure 4-7). Monthly total phosphorus loads are presented for the years 2008–2013 for comparison (Appendix D-4). There is a recurring seasonality driven by the seasonality of runoff, with the lowest loads generally prevailing in the summer and the highest in winter and spring. Substantial interannual differences have occurred because of the dependency on runoff. In 2013, watershed loading of total phosphorus was unusually high in June and July and rather low during August. The high loading of total dissolved phosphorus in June is particularly noteworthy with respect to summertime algal growth.

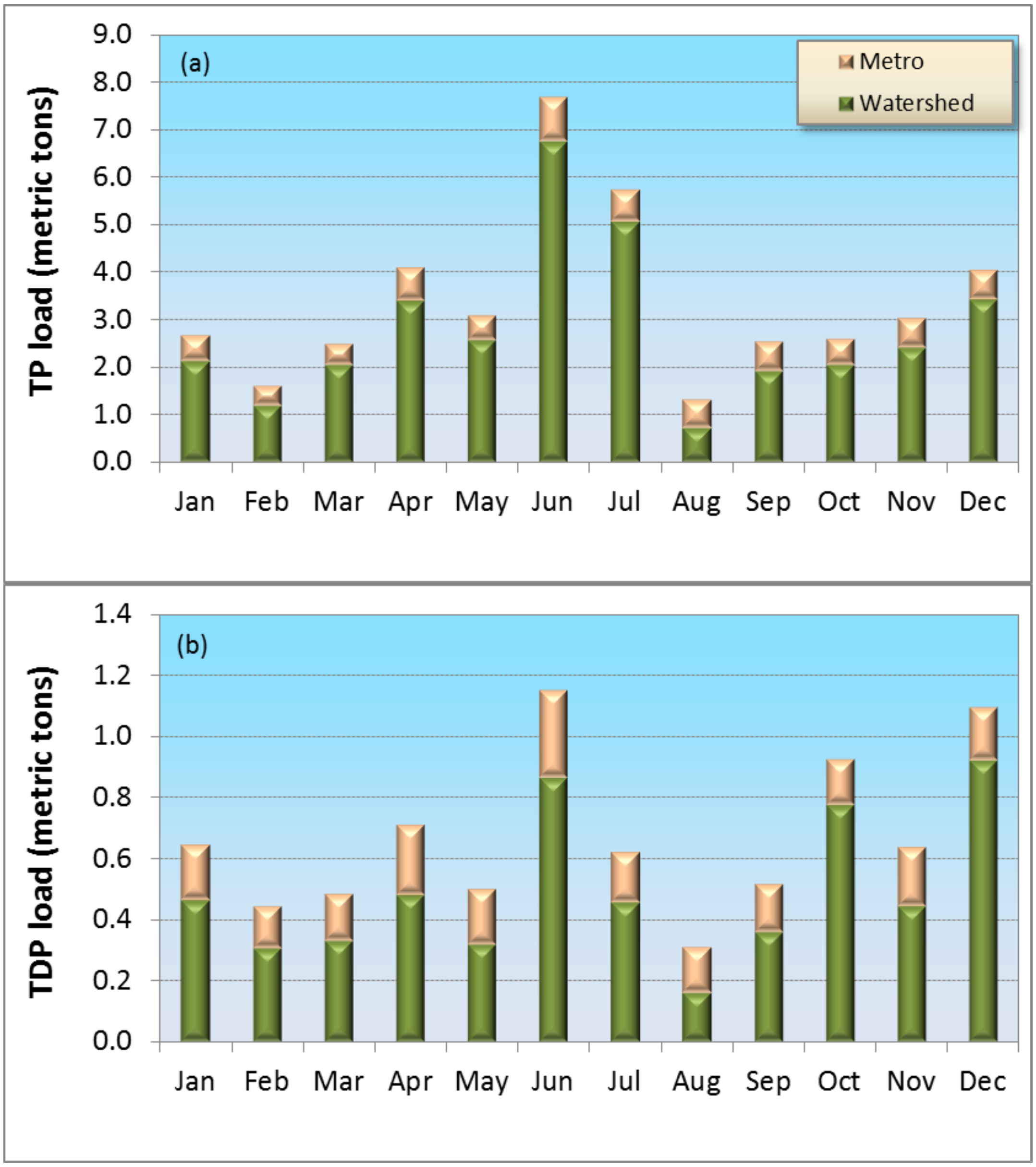


Figure 4-7. Monthly phosphorus loading to Onondaga Lake from Metro and watershed sources in 2013: (a) total phosphorus (TP) and (b) total dissolved phosphorus (TDP).

Increasingly, lake management programs are accounting for the fact that only a portion of the total phosphorus loading to a lake is available to support algal growth. It is important to note than 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 algal growth. At least two other processes further limit the potential for external total phosphorus loads to support algal growth, 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 highlight the importance of assessing loading rates for the major forms of phosphorus. The changes in total phosphorus (Table 4-5), total dissolved phosphorus (Table 4-6) and soluble reactive phosphorus (Table 4-7) loading from Metro and the tributaries from the 1990–1998 interval (before the ACJ) to after implementation of Actiflo® (2007–2013) are presented here. Loading of total phosphorus was reduced by 87% for the fully treated Metro effluent (Table 4-5). The 76% decrease in the total phosphorus load from the bypass is also noteworthy. The changes for the tributaries over this period have been smaller, including 46% and 24% decreases for Ley Creek and Onondaga Creek, respectively. In recent years (post-Actiflo®), Metro (effluent plus bypass) has represented about 25% of the total phosphorus load, the third largest source, after Onondaga Creek and Ninemile Creek.

Loading rates of total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) are particularly important, as these forms of phosphorus are generally available to support algal growth. The contributions of Metro versus those of the tributaries to annual TDP loading for the 2007–2013 interval (post-Actiflo® upgrade) are presented in Table 4-6. Metro's average contribution to the TDP load over this interval was 23%, the third highest, following Ninemile Creek (29%) and Onondaga Creek (27%). The Metro bypass was the fifth largest contributor at 6%. 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 (0.025 mg/L). The Actiflo® upgrade resulted in a 98% reduction in SRP loading from the treated effluent (Table 4-7). The SRP fraction is noteworthy because it is immediately available to support algal growth. Loading of SRP from the Metro bypass declined by 80%

during this period. Metro's combined SRP load represents about 15% of the contemporary total, less than one-half of the inputs from Onondaga Creek or Ninemile Creek.

Table 4-5. A comparison of total phosphorus (TP) loading and flow-weighted concentrations for pre-ACJ (1990–1998) and post-Actiflo® (2007–2013) periods.

Note: (mt = metric tons; concentrations flow-weighted)

Site	1990-1998 (pre ACJ)				2007- 2013 (post-Actiflo®)			
	Flow (%)	TP (mt P/yr)	TP (% load)	TP (mg P/L)	Flow (%)	TP (mt P/yr)	TP (% load)	TP (mg P/L)
Metro:								
fully treated	21%	51.9	57%	0.559	19%	7.2	20%	0.085
Bypass	1%	8.5	7%	1.832	0%	2.0	5%	1.199
Allied East Flume Manhole 015	0%	0.2	0%	0.203	0%	0.1	0%	0.135
Harbor Brook	2%	0.7	1%	0.070	2%	0.9	2%	0.077
Ley Creek	9%	5.7	6%	0.139	8%	3.1	8%	0.082
Ninemile Creek	32%	10.2	10%	0.065	33%	10.5	26%	0.068
Onondaga Creek	34%	20.1	19%	0.119	37%	15.3	38%	0.090
Tributary 5A	1%	0.2	0%	0.054	0%	0.1	0%	0.106
Total		**97.4**				**39.3**		

Table 4-6. A comparison of total dissolved phosphorus (TDP) loading and flow-weighted concentrations for pre-ACJ (1990–1998) and post-Actiflo® (2007–2013) periods.

Note: (mt = metric tons; concentrations flow-weighted)

Site	1990-1998 (pre ACJ)				2007- 2013 (post-Actiflo®)			
	Flow (%)	TDP (mt P/yr)	TDP (% load)	TDP (mg P/L)	Flow (%)	TDP (mt P/yr)	TDP (% load)	TDP (mg P/L)
Metro:								
fully treated	21%	-	-	-	19%	2.1	23%	0.025
Bypass	1%	-	-	-	0%	0.6	6%	0.339
Allied East Flume Manhole 015	0%	-	-	-	0%	0.1	1%	0.091
Harbor Brook	2%	-	-	-	2%	0.4	4%	0.034
Ley Creek	9%	-	-	-	8%	0.9	9%	0.023
Ninemile Creek	32%	-	-	-	33%	2.8	29%	0.018
Onondaga Creek	34%	-	-	-	37%	2.5	27%	0.015
Tributary 5A	1%	-	-	-	0%	0.0	0%	0.041
Total						**9.4**		

Table 4-7. A comparison of soluble reactive phosphorus (SRP) loading and flow-weighted concentrations for pre-ACJ (1990–1998) and post-Actiflo® (2007–2013) periods.

Note: (mt = metric tons; concentrations flow-weighted)

Site	1990-1998 (pre ACJ)				2007- 2013 (post-Actiflo®)			
	Flow (%)	SRP (mt P/yr)	SRP (% load)	SRP (mg P/L)	Flow (%)	SRP (mt P/yr)	SRP (% load)	SRP (mg P/L)
Metro:								
fully treated	21%	12.0	59%	0.130	19%	0.3	6%	0.003
Bypass	1%	2.5	10%	0.500	0%	0.5	9%	0.21
Allied East Flume Manhole 015	0%	0.1	0%	0.092	0%	0.0	1%	0.065
Harbor Brook	2%	0.3	1%	0.024	2%	0.3	7%	0.030
Ley Creek	9%	1.4	6%	0.033	8%	0.5	11%	0.013
Ninemile Creek	32%	1.7	8%	0.011	33%	1.6	32%	0.010
Onondaga Creek	34%	3.3	16%	0.021	37%	1.6	34%	0.010
Tributary 5A	1%	0.0	0%	0.010	0%	0.0	1%	0.031
Total		**20.9**				**4.9**		

4.3.3 Metro Performance

The ammonia concentration of the Metro effluent decreased dramatically with the implementation of the BAF treatment upgrade in 2004 (Figure 4-8). Upgraded treatment resulted in a 98% decrease in ammonia loading to the lake from Metro (Figure 4-8). Efficient, year-round nitrification of ammonia reduced Metro's contribution to the total annual load (Metro + tributaries) from 91% to 47% (Figure 4-9). The seasonal regulatory limits for ammonia concentrations in the Metro effluent are presently 1.2 mg/L for the June 1 to October 31 interval and 2.4 mg/L for November 1 to May 31. Monthly average concentrations continued to meet these limits by a wide margin in 2013; 2012 conditions are included for reference (Figure 4-10). 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.

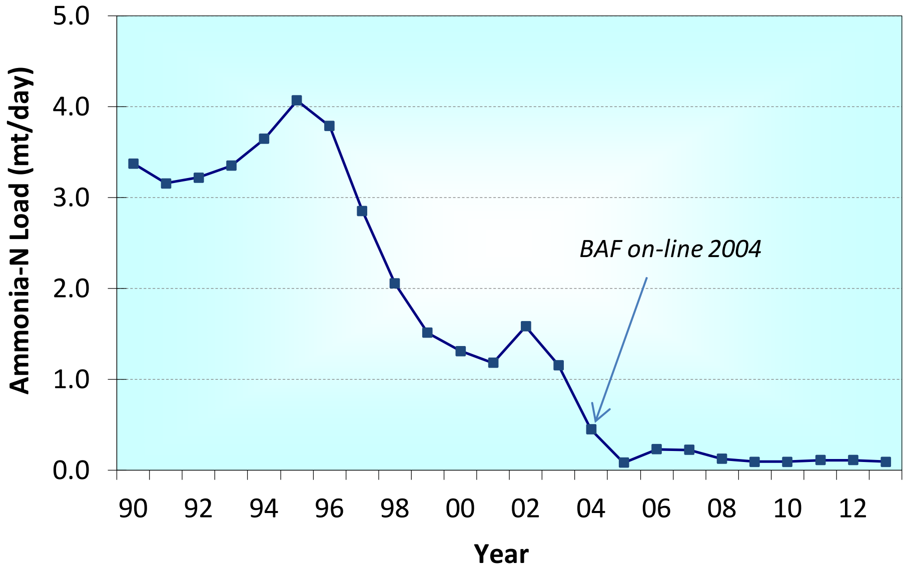


Figure 4-8. Time plot of the annual daily average Metro (outfalls 001+002) ammonia-N loading (metric tons/d) to Onondaga Lake, 1990–2013.

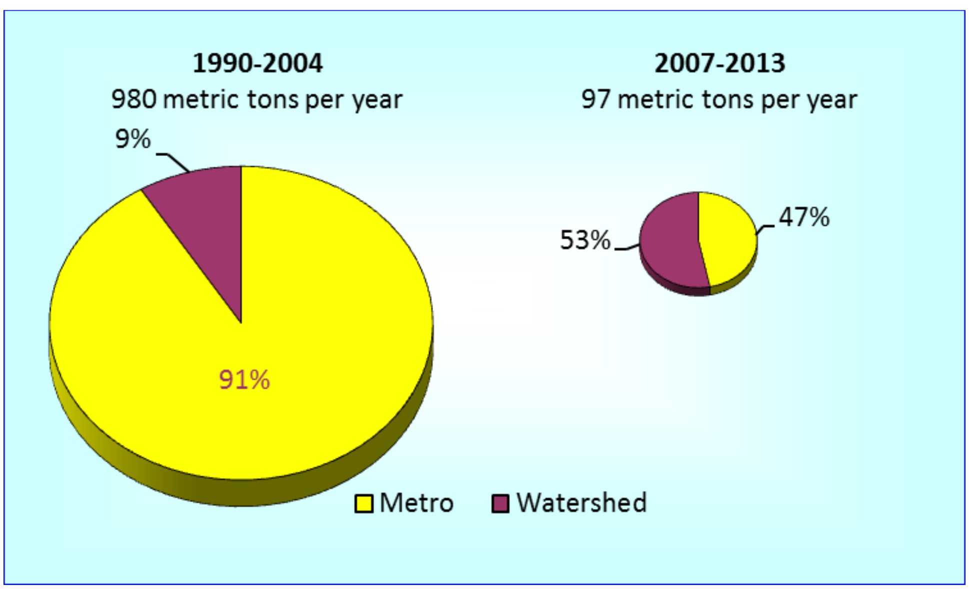


Figure 4-9. Contributions of Metro (outfalls 001+002) and the watershed to the total annual input of ammonia-N to Onondaga Lake, average for 1990–2004 compared to the average for 2007–2013.

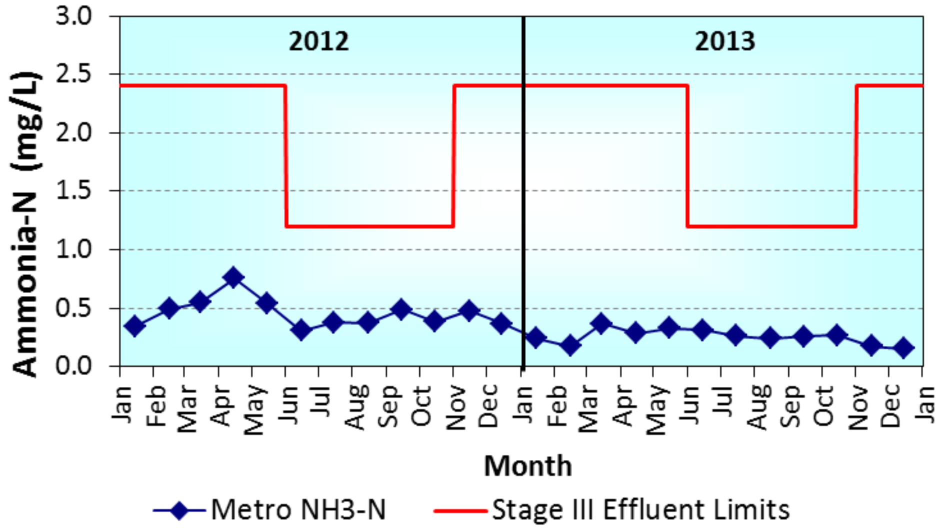


Figure 4-10. Metro effluent monthly average ammonia-N concentrations compared to permit limits for 2012 and 2013.

The total phosphorus concentration of Metro's effluent and associated loading (Figure 4-11) decreased dramatically with the implementation of the Actiflo® treatment upgrade. Moreover, Metro's contribution to the total annual phosphorus load has decreased from 61% over the 1990 to 2004 interval to 24% during 2007–2013 (Figure 4-12). Total phosphorus concentrations for the 2006–2013 interval are presented as a 12-month rolling average concentration, calculated monthly, consistent with the format of the regulatory limit (Figure 4-13). 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 2009 Fourth Stipulation Amending the ACJ, the interim Stage II total phosphorus effluent limit became 0.10 mg/L (Figure 4-13). These limits have been successfully met with the Actiflo® treatment upgrade. Since mid-2008 the rolling average total phosphorus concentration in the Metro effluent has remained below 0.10 mg/L (Figure 4-13). Phosphorus treatment took another step forward in 2013, as the annual average total phosphorus concentration in the effluent decreased to 0.059 mg/L.

Metro performance relative to SPDES permit requirements is provided in Appendix C-4. There were no violations of permit limits reported in 2013 for the following parameters: flow, $CBOD_5$, suspended solids, fecal coliform bacteria, pH, settleable solids, ammonia-N, total phosphorus, and total mercury. The SPDES permit limit for total cyanide was exceeded twice during 2013 and the limit for total phenols was exceeded on five occasions. The bypass (Outfall 002) exceeded the limit for chlorine residual once and the limit for settleable solids four times.

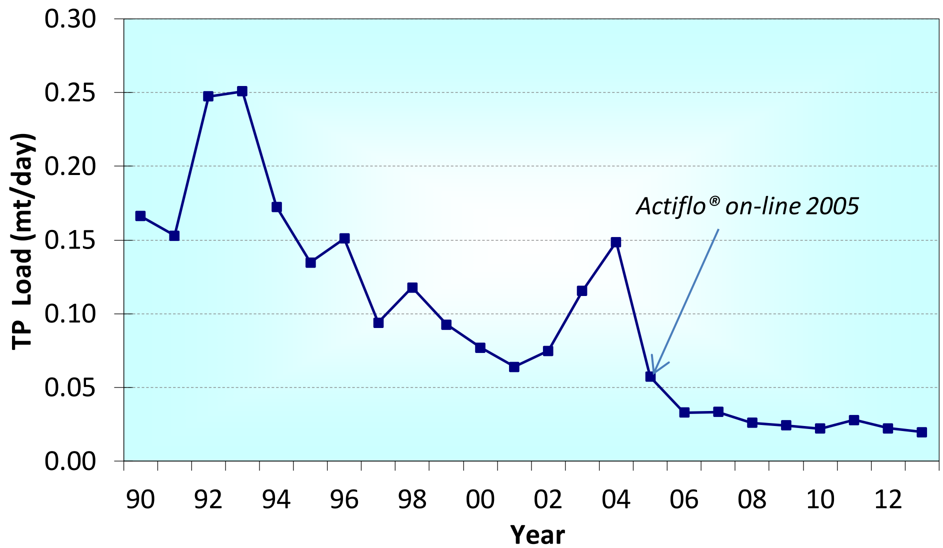


Figure 4-11. Time plot of the annual daily average Metro (outfalls 001+002) total phosphorus (TP) loading (metric tons/day) to Onondaga Lake, 1990–2013.

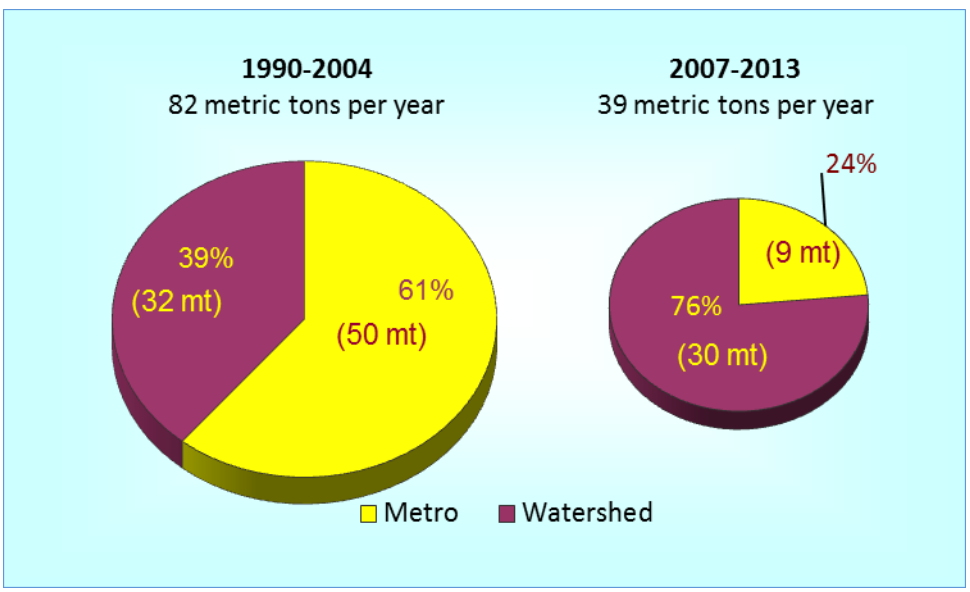


Figure 4-12. Contributions of Metro (outfalls 001+002) and the watershed to the annual input of total phosphorus to Onondaga Lake, average for 1990–2004 compared to the average of 2007–2013.

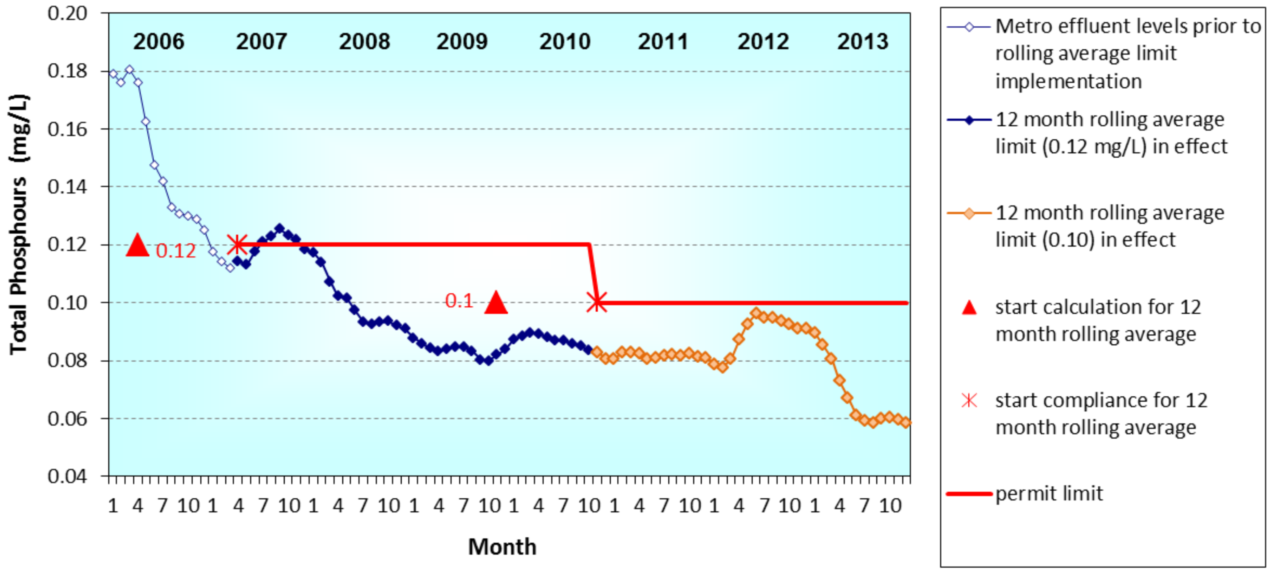


Figure 4-13. Metro effluent total phosphorus concentrations compared to permit limits for the 2006–2013 interval. Concentrations are monthly rolling average values for 12-month intervals.

The major reductions in ammonia and total phosphorus loading from treatment upgrades at Metro (BAF and Actiflo®, respectively) were identified and graphically supported (Figure 4-8 for ammonia, Figure 4-11 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. Loading of 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. Implementation of the BAF treatment 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 (Matthews et al. 2013).

Metro provided full treatment to an average flow of 66.6 million gallons per day (mgd) in 2013, which was discharged to the lake through Outfall 001. On an annual basis, this discharge summed to more than 24.3 billion gallons. During particularly high runoff intervals, inflows to Metro can exceed the capacity of the facility to provide full treatment of wastewater. Portions of this inflow receive partial treatment, usually primary treatment and disinfection, and are discharged via Outfall 002 (secondary bypass; Appendix C-1). There were 73 secondary bypasses in 2013, which had a combined duration of 379 hours and a total volume of 446 million gallons. Less frequently, the inflow receives secondary treatment and disinfection prior to discharge via Outfall 01A (tertiary bypass; Appendix C-2). In 2013 there were 14 tertiary bypasses that contributed a total of 26 million gallons over a period of 69 hours. 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 and is discharged via Outfall 01B (plant headworks are bypassed; Appendix C-3). There were 11 headworks bypasses in 2013, which had a combined duration of 28 hours and a total volume of 71 million gallons. All of the headworks bypasses during 2013 were associated with reduced capacity due to the Grit Improvement Project. A total of 446 million gallons were discharged via outfall 002 in 2013, compared to 214 million gallons in 2012 and 750 million gallons in 2011. The extent to which bypasses occur depends critically on runoff, and therefore precipitation, both of which are subject to substantial variability. Metro's annual discharge volumes for 2010–2013 are summarized in Table 4-8.

Table 4-8. Annual Metro discharge volumes for the fully treated effluent and bypasses, 2010–2013.

Year	Fully Treated Outfall 001 (million gallons)	Tertiary Bypass Outfall 01A (million gallons)	Secondary Bypass Outfall 002 (million gallons)	Headworks Bypass Outfall 01B (million gallons)
2010	22,000	22	374	43
2011	24,300	41	751	5
2012	20,200	12	214	0
2013	24,300	26	446	71

Saline groundwater from dewatering of the Clinton and Harbor Brook Storage facilities during construction was conveyed to Metro from June 2012 to May 2013, resulting in elevated ionic content in the Metro effluent. Specific conductance and other measures of the ionic content (e.g., chloride, TDS) of the Metro effluent decreased abruptly when dewatering ceased in May of 2013 (Figure 4-14). Whole effluent toxicity testing (WET) of the Metro effluent in the third and fourth quarters of 2012 and in the first quarter of 2013 indicated the effluent was both acutely and chronically toxic. Toxicity was likely the result of temporarily elevated salinity levels from dewatering activities. The specific conductance values measured during this period were in the range that has been associated with toxic effects to aquatic biota (Corsi et al. 2010, Kimmel and Argent 2009). A year of monthly WET testing of the Metro effluent was initiated in September 2013, as requested by NYSDEC. Monthly WET testing during the September-December interval of 2013 indicated a reduced level of toxicity in the Metro effluent. There was no indication of chronic toxicity during this period and acute toxicity was only noted in the November sample.

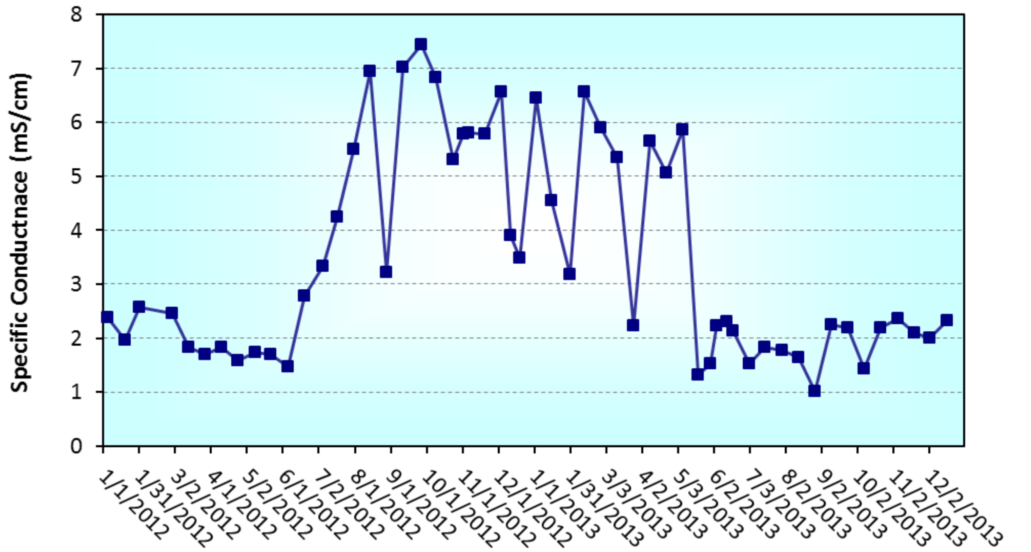


Figure 4-14. Time series of specific conductance in the Metro effluent (outfall 001), 2012–2013.

4.3.4 Prohibited Combined and Sanitary Sewer Overflows

The occurrence and volumes of prohibited combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) within the Onondaga County service area are tracked by OCDWEP each year. As per the Metro SPDES permit CSO best management practices (BMP) requirements, dry weather overflows from the combined sewer system are prohibited. In accordance with 6NYCRR Part 750-2.8(b) and 40CFR 122.41, bypass of the collection and treatment system without treatment (i.e., SSOs) are prohibited except as noted in the Metro SPDES Permit. Detailed documentation of the prohibited CSO and SSO events that occurred during 2013 is presented in Appendix C-5 and Appendix C-6, respectively. Annual summaries of prohibited CSOs and SSOs within the Onondaga Lake watershed for the 2010–2013 period show a marked reduction in overflow volumes in 2013 compared to the preceding three years (Table 4-9). Other CSO discharges are summarized in the 2013 ACJ Annual Report (dated April 2014).

Table 4-9. Number and volume of prohibited combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) within the Onondaga Lake watershed during 2010–2013.

Year	CSO		SSO	
	Number	Volume (gallons)	Number	Volume (gallons)
2010	7	98,000	30	22,620,055
2011	4	2,700	46	9,743,317
2012	7	20,450	20	23,275
2013	5	800	35	34,105

4.3.5 Trends

Loading trends for Metro and the tributaries over the 1991–2013 interval are presented graphically for selected constituents (Figure 4-15). Annual loads for additional constituents are presented in tabular format in Appendix D-2. Long-term decreases in loading of total phosphorus and total dissolved phosphorus have been driven mostly by reductions in the Metro contribution. Year-to-year variations in phosphorus loading from the watershed are regulated to a large extent by differences in the timing and magnitude of runoff. The increase in phosphorus inputs from the tributaries in 2013 was caused by particularly low runoff in 2012 and average runoff conditions in 2013. Long-term decreases in ammonia loading and increases in nitrate loading are associated with implementation of efficient, year-round nitrification treatment at Metro. Variations in ammonia and nitrate loading from the tributaries have been modest in comparison. Noteworthy reductions in loading of fecal coliform bacteria have occurred since the 1990s, led by decreasing inputs from the Metro bypass.

Seasonal Kendall tests were conducted for the 10 year period 2004–2013 to identify significant ($p<0.1$) trends in tributary concentrations (Table 4-10). Statistically significant changes for constituents related to the Metro treatment upgrades were evident, including decreases in phosphorus, nitrite, organic carbon, total suspended solids, and BOD_5, and increases in nitrate and chloride. Significant decreases in ammonia concentrations are indicated since 2004 for Ninemile Creek and at the upstream sampling locations of Onondaga Creek and Harbor Brook (Table 4-10). Nitrate concentrations in Harbor Brook, Ley Creek, and Ninemile Creek have decreased since 2004 (Table 4-10). In contrast, concentrations of organic nitrogen and total Kjeldahl nitrogen have increased in Onondaga Creek, Ninemile Creek, and at the upstream sampling location on Harbor Brook. A cause for these changes in concentrations of nitrogen species is not apparent at this time. Increases in chloride and specific conductance have occurred in Harbor Brook. Increases in total phosphorus, soluble reactive phosphorus, iron, and total suspended solids concentrations were observed for both the upstream (Dorwin Ave.) and downstream (Kirkpatrick St.) sites on Onondaga 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.

Tributary loading trends were analyzed and tested using a linear regression analysis of annual load in metric tons (mt) versus time (Table 4-11). Annual loading trend slopes with *p*-values less than 0.1 were considered statistically significant. Treatment upgrades at Metro have resulted in decreasing loading trends for most constituents. Increased loading of chloride and sodium is related to the temporary routing of saline groundwater to Metro associated with dewatering activities. Reductions in ammonia loading were indicated for Onondaga Creek, Ley Creek, Ninemile Creek, and the upstream site on Harbor Brook. Ninemile Creek is the largest tributary source of ammonia to the lake and has contributed most to the overall decrease. Harbor

Brook has experienced significant loading reductions for most of the constituents measured, particularly at the upstream sampling location (Velasko Rd.).

WEP staff technician samples water from a tributary to Onondaga Lake

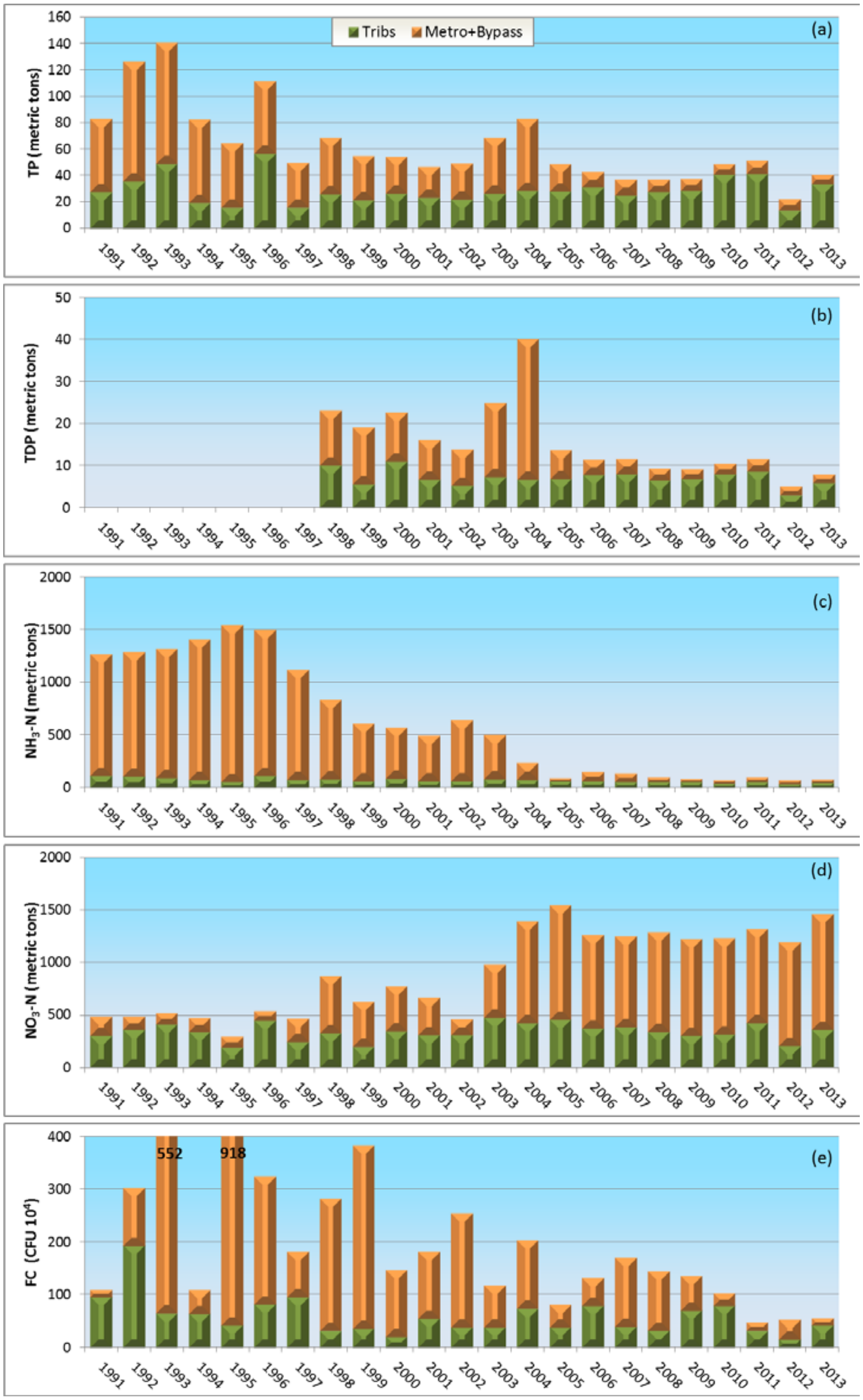


Figure 4-15. Annual loading of selected constituents to Onondaga Lake from Metro and watershed sources, 1991–2013: (a) total phosphorus (TP), (b) total dissolved phosphorus (TDP), (c) ammonia-N (NH_3-N), (d) nitrate (NO_3-N), and (e) fecal coliform (FC) bacteria.

Table 4-10. Ten-year (2004–2013) trends in tributary concentrations, from application of seasonal Kendall test.

Variable		Metro		Onondaga Creek		Harbor Brook		Ley Creek	Ninemile Creek
		Treated Effluent	Bypass	Dorwin	Kirkpatrick	Velasko	Hiawatha	Park	Route 48
Nitrogen	Ammonia (NH_3-N)	○	○	-5.7%	○	-11.9%	○	○	-3.2%
	Nitrite (NO_2-N)	-11.6%	○	5.3%	0.7%	○	○	○	○
	Nitrate (NO_3-N)	1.3%	-8.9%	○	○	-2.1%	-2.2%	-4.4%	-2.4%
	Organic Nitrogen	○	○	7.4%	9.1%	4.6%	○	○	8.1%
	Total Kjeldahl Nitrogen (TKN)	○	○	6.2%	7.1%	1.9%	○	○	2.6%
Phosphorus	Total Phosphorus (TP)	-12.0%	○	8.8%	7.4%	○	○	○	3.0%
	Soluble Reactive Phosphorus (SRP)	-18.4%	○	3.2%	8.2%	-5.1%	○	○	○
Solids	Total Suspended Solids (TSS)	-1.6%	○	11.9%	8.5%	○	○	○	○
	Total Dissolved Solids (TDS)	1.9%	○	○	○	○	0.9%	○	○
	Volatile Suspended Solids (VSS)	○	○	○	○	○	○	○	○
Carbon	Total Inorganic Carbon (TIC)	-3.2%	○	-1.2%	-1.2%	-1.2%	-1.1%	○	-1.1%
	Total Organic Carbon (TOC)	-4.3%	○	○	○	○	-3.6%	-2.0%	○
	Total Organic Carbon, filtered (TOC_F)	-3.8%	○	○	○	○	-2.4%	-4.3%	○
Other	Alkalinity	○	○	○	○	○	○	○	○
	BOD_5*	-8.3%	4.7%	○	○	○	○	○	○
	Calcium (Ca)	2%	○	0.9%	○	○	1.3%	○	○
	Chloride (Cl)	3.7%	○	○	○	2.3%	1.4%	○	-2.9%
	Specific Conductance	2.4%	○	○	○	2.0%	1.4%	1.3%	○
	Dissolved Oxygen (DO)	○	○	-0.6%	○	○	○	1.0%	○
	Fecal Coliform Bacteria	○	○	○	○	○	○	○	○

Table 4-10. Ten-year (2004–2013) trends in tributary concentrations, from application of seasonal Kendall test.

Variable	Metro		Onondaga Creek		Harbor Brook		Ley Creek	Ninemile Creek
	Treated Effluent	Bypass	Dorwin	Kirkpatrick	Velasko	Hiawatha	Park	Route 48
pH	○	○	○	○	○	○	○	○
Silica (SiO_2) dissolved	○	○	○	○	○	○	○	○
Sulfate (SO_4)	○	○	○	○	○	○	○	○
Temperature (°C)	○	○	○	○	-1.5%	○	○	○

Notes:
Significance level, two-tailed, seasonal Kendall test accounting for serial correlation ($p < 0.1$).
Blue value (%) indicates decreasing trend
Red value (%) indicates increasing trend
○ indicates no trend
- dash indicates parameter is not measured at this location.

Table 4-11. Ten-year (2004–2013) trends in tributary loading, from linear regression of annual load versus time.

Variable		Metro		Onondaga Creek		Harbor Brook		Ley Creek	Ninemile Creek
		Treated Effluent	Bypass	Dorwin	Kirkpatrick	Velasko	Hiawatha	Park	Route 48
Nitrogen	Ammonia (NH_3-N)	-18.1%	○	-9.1%	-5.0%	-12.3%	○	-4.5%	-5.7%
	Nitrite (NO_2-N)	-23.4%	○	○	○	-5.8%	○	○	○
	Nitrate (NO_3-N)	○	○	○	○	-5.6%	-5.8%	-6.7%	-4.9%
	Total Kjeldahl Nitrogen (TKN)	-9.3%	○	○	○	○	○	○	○
Phosphorus	Total Phosphorus (TP)	-24.5%	○	○	○	-10.6%	-5.8%	○	○
	Soluble Reactive Phosphorus (SRP)	-49.1%	○	○	○	-9.7%	-6.9%	○	○
Solids	Total Suspended Solids (TSS)	-6.3%	○	○	○	-20.9%	-10.7%	-7.2%	○
Carbon	Total Inorganic Carbon (TIC)	-6.3%	○	-4.6%	-3.9%	-4.9%	-4.7%	-3.3%	-3.9%
	Total Organic Carbon (TOC)	-6.4%	○	-5.9%	-6.9%	-10.3%	-10.3%	○	-5.2%
	Total Organic Carbon, filtered (TOC_F)	-5.6%	○	-5.1%	-5.8%	-8.8%	-9.4%	○	○
Other	Alkalinity	-4.9%	○	-3.2%	○	-3.6%	○	○	○
	BOD_5*	-14.5%	○	○	○	-4.5%	○	○	○
	Calcium (Ca)	○	○	○	○	-3.0%	○	○	-3.2%
	Chloride (Cl)	8.6%	○	○	-4.6%	○	○	○	-4.8%
	Fecal Coliform Bacteria	-18.7%	-15.3%	○	○	-31.2%	-9.9%	○	○
	Sodium (Na)	8.0%	○	-2.7%	-4.5%	○	○	○	-3.7%
	Silica (SiO_2)	-2.1%	○	-3.5%	○	○	○	○	-3.0%

Notes:
Significance level, two-tailed, seasonal Kendall test accounting for serial correlation ($p < 0.1$).
Blue value (%) indicates decreasing trend
Red value (%) indicates increasing trend
○ indicates no trend
- 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.

4.3.6 Insights from Pre-Construction Storm Monitoring for Fecal Coliform Bacteria

OCDWEP conducted high-frequency sampling of storm events during 1999–2003 and 2008–2009 to establish baseline conditions prior to the completion of green and gray infrastructure projects targeting abatement of CSOs. A number of major CSO projects have recently been completed and post-construction monitoring is beginning. In this section we analyze the pre-construction fecal coliform data collected from Onondaga Creek at Kirkpatrick St. during runoff events to provide insights related to the collection and analysis of post-construction data. CSOs are typically short-lived and caused by infrequent and sometimes brief precipitation events. Therefore, it is important to consider fecal coliform concentrations in relation to short-term (e.g., hours) changes in precipitation and stream flow. For this analysis, the 15-minute flow record at Spencer St. (USGS Site No. 04240010) and hourly precipitation data (Hancock International Airport) were used to analyze short-term dynamics in fecal coliform concentrations during storm events for Onondaga Creek at Kirkpatrick St. over the 1999–2003 and 2008–2009 periods. The Spencer St. stream flow gauge is located immediately upstream of the Kirkpatrick St. monitoring site.

Runoff hydrology can be quite different in urban compared to rural watersheds. During precipitation-driven runoff events, urban hydrographs tend to be more flashy (shorter time to peak flow) with larger peaks and shorter durations compared to rural hydrographs. This is mostly due to rapid surface runoff in urban watersheds associated with more impervious surface area compared to rural areas. It is during these periods of intense rainfall and urban runoff when CSO release and elevated fecal coliform loading is of particular concern. The availability of high frequency (15-minute) stream flow data for sites bounding urban areas provides an opportunity to isolate fecal coliform dynamics in response to changes in the urban portion of the hydrograph.

Visual and quantitative comparisons of the flow records at upstream and downstream locations allow for detailed hydrograph analysis and determination of base flow and surface runoff contributions. This analysis technique is known as hydrograph separation. Hydrograph separation can also be used to delineate the urban runoff component of the hydrograph (Figure 4-16). There was a conspicuous rapid increase in flow observed at Kirkpatrick St. on November 26, 2000 at 1100 (urban peak) that was absent at the Dorwin Ave. gage located upstream of Syracuse (Figure 4-16). This abrupt increase in flow at the downstream site before clear responses occurred at the upstream site is a recurring manifestation of CSOs (Effler et al. 2009, Onondaga County 2009), although direct inputs from stormwater runoff doubtless also contribute. The abruptness of the response reflects the relatively large area of impervious surfaces within contributing portions of the city. Hydrograph separation allows for targeted analysis of fecal coliform levels during the brief periods of CSO contributions.

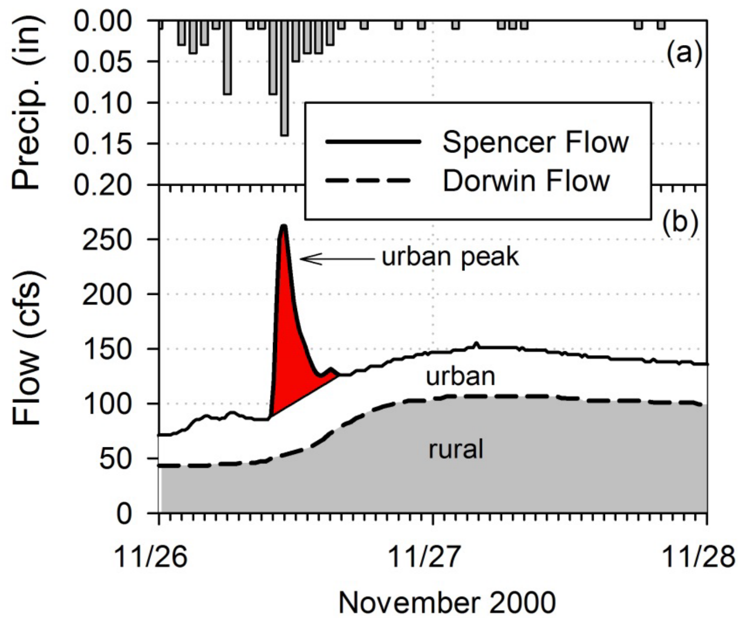


Figure 4-16. Time series of precipitation and flow data for a November 2000 runoff event at Onondaga Creek: (a) hourly precipitation and (b) 15-minute stream flow. Shaded areas in panel (b) represent flow sources (gray-rural, white-urban, and red-urban peak).

We were unable to use the USGS HYSEP software (Sloto and Crouse 1996) for hydrograph separation because it will not accept the 15-minute flow data that is necessary for this analysis. Therefore, hydrograph separation was performed manually. The urban peaks were identified through review of the 15-minute USGS flow data from the downstream gauge at Onondaga Creek as abrupt increases, usually of brief duration. The beginning and end of each event was determined by visual inspection of the hydrograph. The total volume delivered for each of these events was estimated as the area under the hydrograph, above the antecedent flow. The use of a computer program would remove inconsistencies inherent in manual methods and substantially reduce the time required for the analysis. However, computer methods are based on a mathematical technique that mimics the way that humans have been separating hydrographs, rather than on the physics of the process. Although computer programs consistently apply algorithms that are commonly used for hydrograph separation, hydrograph separation remains a subjective process (Sloto and Crouse 1996). Fortunately, the signature of urban flow peaks in Onondaga Creek is quite conspicuous and difficult to misinterpret.

A precipitation event started on June 14, 2002 at 0500 and continued for approximately 10 hours (Figure 4-17a). During the initial phase of this event, 2.9 inches of rain fell with average and maximum intensities of 0.29 in/hr and 0.52 in/hr, respectively. A rapid increase in stream flow at Kirkpatrick St. (solid line) occurred in response to the precipitation (Figure 4-17). The urban component of the hydrograph peaked at 1,200 cfs at 1100 on June 14, an increase of 1,100 cfs from pre-storm conditions. The flow at Dorwin Ave. increased as well, but the initial peak occurred about 3 hours after the urban peak, indicating that the peak at Kirkpatrick St. was due to urban runoff only. Sampling for fecal coliform bacteria began at 1300 on June 14 with the initial count of 32,000 counts/100 mL just after the urban flow peak at Kirkpatrick St. Fecal coliform levels decreased progressively following the urban flow peak. Following a rain-free period of approximately 12 hours, lower intensity precipitation fell during the day of June 15. Three smaller urban flow peaks were observed at 0240, 1150, and 1730 on June 15. Fecal coliform increased to the highest level observed for this event (140,000 counts/100mL) immediately following the small flow peak at 1150, suggesting additional CSO contributions. Fecal coliform levels decreased progressively for the remainder of the event.

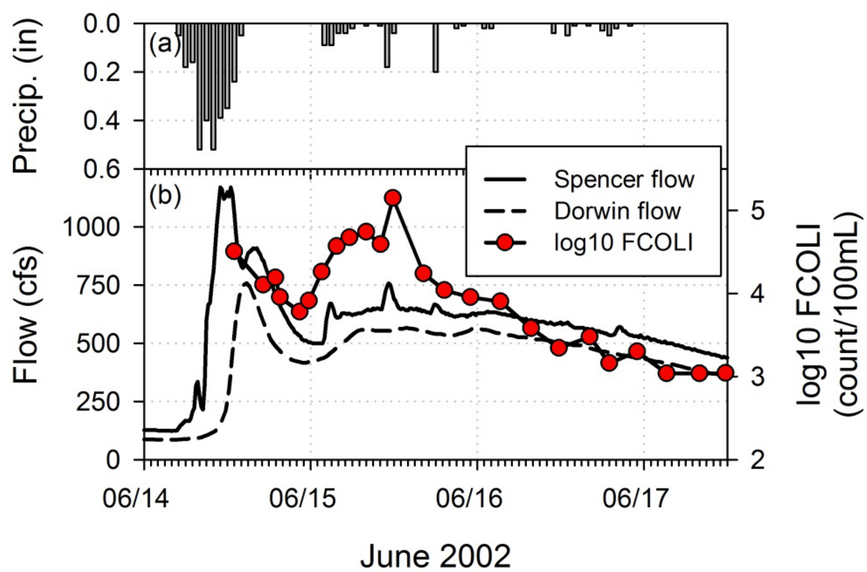


Figure 4-17. Time series of precipitation and flow data for a June 2002 runoff event at Onondaga Creek: (a) hourly precipitation and (b) stream flow at Dorwin Ave. and Spencer St. and log fecal coliform concentrations at Kirkpatrick St.

Back-to-back runoff events at Onondaga Creek were sampled during September 12-15, 2008 (Figure 4-18). The first precipitation event began on September 12 at 1100 and continued for about 9 hours (Figure 4-18a). On September 12, a total of 0.59 inches fell with average and maximum intensities of 0.07 in/hr and 0.22 in/hr, respectively. A rapid increase in stream flow at Kirkpatrick St. occurred in response to the precipitation. The urban portion of the hydrograph peaked at 400 cfs at 1600, an increase of 350 cfs from pre-storm conditions only 3 hours previously (Figure 4-18b). There was very little change in flow upstream at Dorwin Ave. during any portion of this event, indicating that the changes in flow and fecal coliform levels at Kirkpatrick St. were due almost entirely to urban influences. Fecal coliform sampling began coincident with the urban flow peak at 1530 with an initial concentration of >60,000 counts/100 mL. Fecal coliform levels decreased rapidly following the urban flow peak on September 12.

A second runoff event began at 0100 on September 14 and lasted for approximately 5 hours (Figure 4-18). The total precipitation for this shorter event was only 0.42 inches, but it occurred at a higher average rate of 0.084 in/hr. The flow peak was approximately 25% of the peak on September 12. However, fecal coliform concentrations increased dramatically during this event from 3,700 to a peak of > 60,000 counts/100 mL at 0330 on September 14. Fecal coliform levels dropped precipitously to pre-event conditions (3,330 counts/100 mL) at 1440 on September 14 and continued to decrease for the remainder of the event.

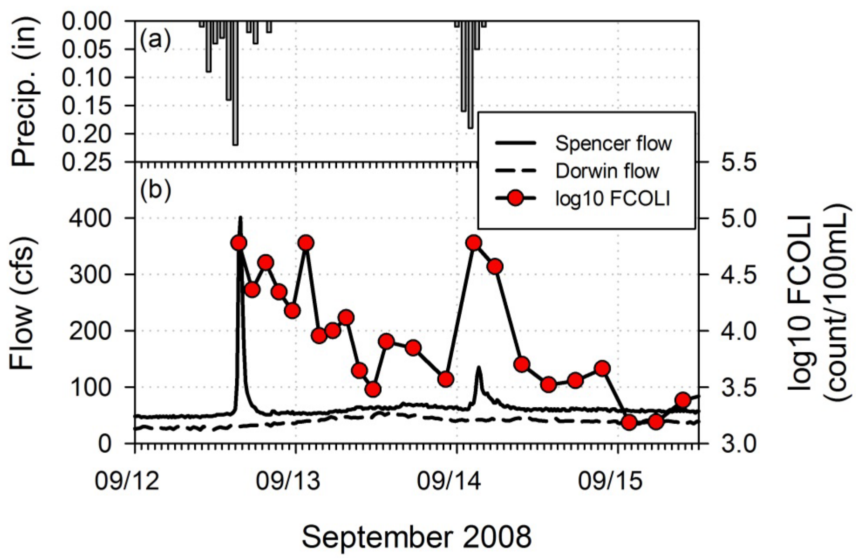


Figure 4-18. Time series of: (a) precipitation and (b) stream flow (Dorwin and Spencer St.) and log FCOLI concentrations and Kirkpatrick St. for a September 2008 event for Onondaga Creek.

The two events depicted here are generally representative of the 16 events included in this analysis. All 16 monitored runoff events were characterized by (1) well-defined urban runoff signatures driven by precipitation events characterized by large increases in flow at Kirkpatrick St. that were absent from Dorwin Ave.; (2) urban runoff peaks that were generally short-lived

(90% less than 8 hours in duration); (3) fecal coliform concentrations that were substantially higher during the urban peak compared with other intervals; and (4) short periods of greatly elevated fecal coliform concentrations.

There was a strong (r^2=0.68 and p<0.001) positive relationship between urban runoff volume and the total precipitation received during an event (Figure 4-19a). For the 16 events analyzed over the 1999–2003 and 2008–2009 periods, no urban peaks were observed for events totaling less than 0.2 inches of precipitation. The relationship between urban runoff volume and the average precipitation rate (Figure 4-19b) was also statistically significant (r^2=0.27, p=0.039), but weaker than the relationship between total precipitation and urban runoff volume. For the 16 events analyzed, no urban peaks were observed for events with precipitation rates less than 0.05 in/hr.

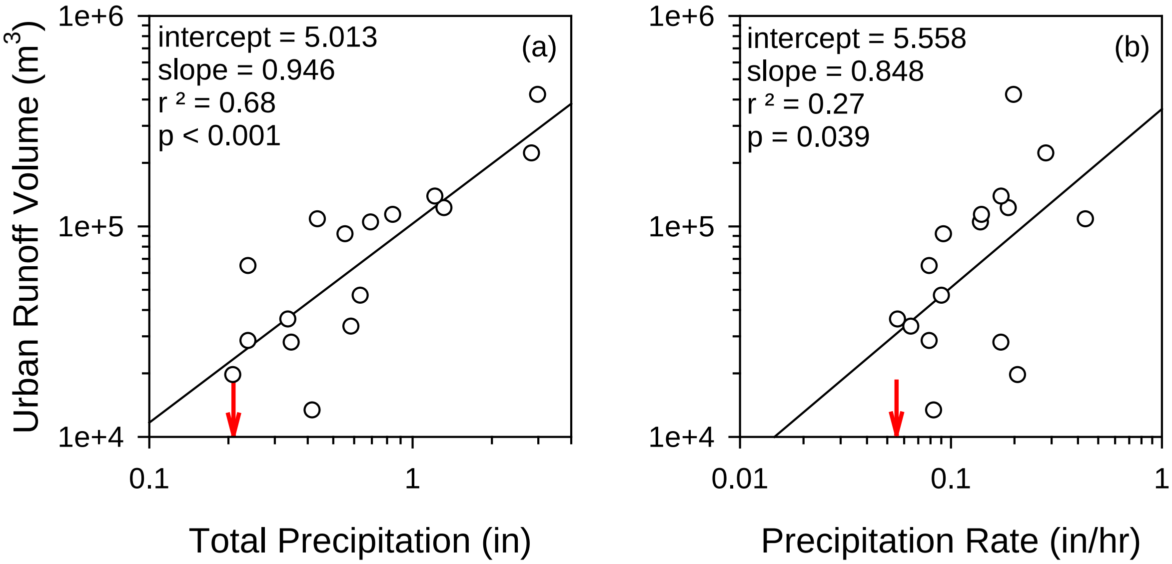


Figure 4-19. Evaluation of drivers of urban runoff volume for Onondaga Creek: (a) urban runoff volume versus total event precipitation, and (b) urban runoff volume versus the average event precipitation rate. The red arrows represent the minimum precipitation and precipitation intensity that resulted in an urban peak.

Fecal coliform samples were grouped according to flow condition at the time of collection. If a sample was collected during the urban peak it was labeled as “urban”. All other samples collected during runoff event sampling were labeled as “other event”. Fecal coliform concentrations were observed to be highly variable during runoff events. For example, the range between the 10th and 90th percentile of the urban runoff samples was nearly 300,000 counts/100mL (Figure 4-20). Fecal coliform concentrations are depicted as geometric means for four flow conditions (Figure 4-20): (1) during the urban runoff peak, (2) runoff event samples outside of the urban peak, (3) during wet weather (48 hour average precipitation greater than 0.1 inches), and (4) during dry weather (48 hour average precipitation less than 0.1 inches). The geometric mean for fecal coliform samples collected during the urban peak was 63,000 counts/100mL, which was significantly greater ($p<0.001$, t-test on log-transformed data) than the geometric mean for other event samples (4,200 counts/100 mL). Also, the low range of the urban peak samples is only slightly overlapped by the high range of the other event samples, which highlights the differences in fecal coliform levels during the urban peak (including CSOs) compared to the rest of the event. The overall ranking of geometric mean fecal coliform concentrations is urban event samples (63,000), other event samples (4,200), wet weather samples (1,202), and dry weather samples (407). It is noteworthy that the mean dry weather fecal coliform concentration is twice as high as the AWQS of 200 cfu/100 mL.

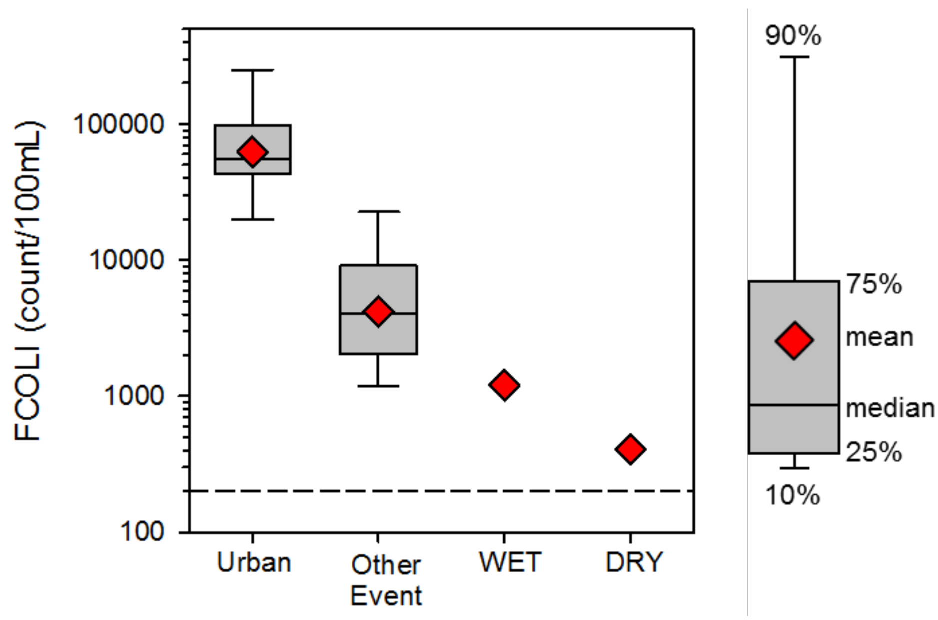


Figure 4-20. Comparison of fecal coliform concentrations (counts/100 mL) from Onondaga Creek at Kirkpatrick St. during 1999–2012 for four runoff conditions: during urban runoff, other event samples, during wet weather, and during dry weather. Red diamonds are the geometric means. The AWQS for fecal coliform bacteria (200 counts/100 mL) is shown for reference.

Over the 1999–2012 period, 451 urban runoff events for Onondaga Creek were identified and analyzed for volume and duration. The duration of the urban peak is typically short, with 90% of the urban runoff events lasting less than 8 hours (Figure 4-21a). The median and average durations were 4.5 and 5 hours, respectively. For the 16 urban runoff events sampled by OCDWEP, variations in total precipitation explained 69% of the variations in event duration (Figure 4-21b). Completed green and gray infrastructure projects may be expected to reduce the magnitude of the urban peak as well as fecal coliform concentrations during the urban peak. Accordingly, post-construction monitoring and assessment should give particular attention to short-term dynamics in stream flow and fecal coliform levels. Given their short duration, it is extremely difficult to effectively monitor urban runoff peaks (rising and falling limbs) using manual sampling techniques. Fecal coliform dynamics during the rising limb of the urban peak may be particularly informative, but it is a challenge to sample this portion of the hydrograph effectively using manual techniques. Finally, despite the focus on assessment of individual CSO projects it is critical that storm event sampling continues at long-term downstream sampling sites (e.g., Kirkpatrick St.) in order to capture the cumulative effects of gray and green infrastructure improvements.

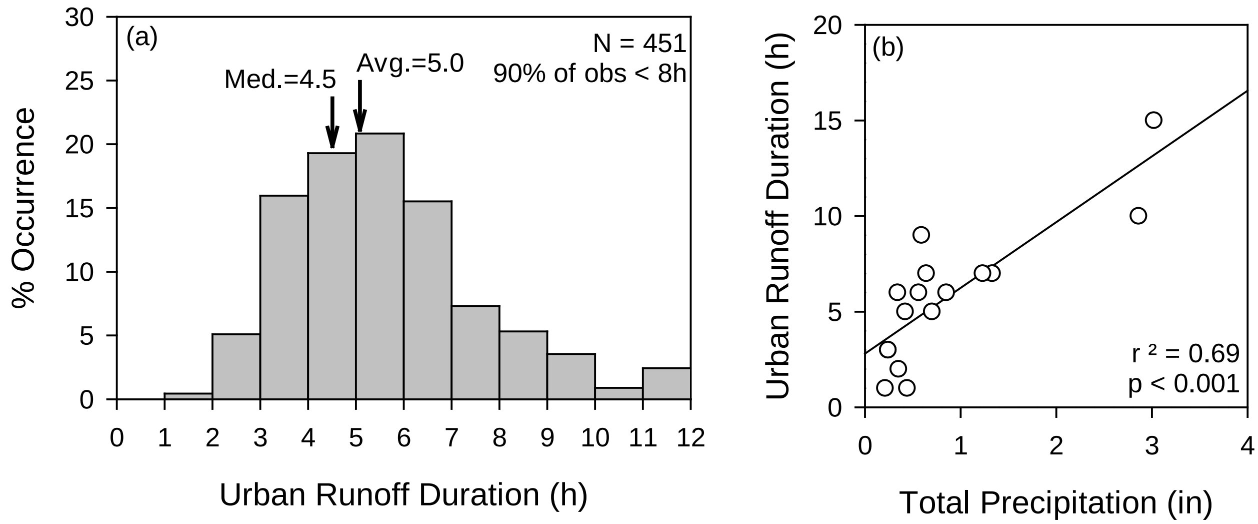


Figure 4-21. Analysis of urban runoff events for Onondaga Creek at Kirkpatrick St.: (a) distribution of urban peak durations for 451 storm events analyzed over the 1999–2012 period and (b) the relationship between the duration of the urban peak and total precipitation for the 16 storm events monitored by OCDWEP over the 1999–2003 and 2008–2009 intervals.

4.3.7 Post-Construction Compliance Monitoring Program (2011–2018)

The ACJ Fourth Stipulation required the County to submit a plan, with a schedule for implementation, for proposed modifications to the tributary component of the County's established AMP. The NYSDEC approved AMP Modifications Work Plan Final, dated December 2011, outlines proposed modifications designed to enhance monitoring of tributary water quality in those tributaries impacted by CSOs to determine the effectiveness of the gray and green infrastructure projects. These modifications, which include additional wet weather monitoring within the CSO-affected stream reaches to evaluate whether completion of the planned improvements to the wastewater (and stormwater) collection infrastructure results in compliance with the AWQS for bacteria and floatables in the CSO-affected tributaries, are an element of the PCCM.

The PCCM is intended to provide data that can be used to:

- Verify the effectiveness of CSO controls; and
- Demonstrate compliance with WQS and protection of designated uses and sensitive areas

Evaluation of CSO control measures, CSO volumes, loadings of conventional and toxic pollutants, and receiving water quality environmental indicators are to be used to measure compliance and are all elements of the proposed PCCM plan. The goal of the PCCM sampling plan is to time sample collection (to capture first flush) during storms which have sufficient magnitude and intensity to trigger CSO/storage facility overflows to the receiving water.

The PCCM includes a monitoring plan for demonstrating compliance with AWQS associated with specific CSO controls and includes the following CSO/Facility outfalls:

- **(10) Representative CSOs**: Includes the NYSDEC-recommended list of ten (10) representative CSOs to serve as the basis for sampling (previously developed for the AMP Modifications, required by the ACJ Fourth Stipulation) refer to "Proposed Modifications to the AMP", Final Revised Work Plan, dated December 2011 and includes the following CSO service areas:
    - Harbor Brook CSO Service Area - CSO 003, 004, 014, 018
    - Clinton CSO Service Area - CSO 027, 030, 034, 080 (EBSS)
    - Midland CSO Service Area - CSO 052, 060/077
- **(2) Storage Facilities** - Clinton and Lower Harbor Brook Storage Facilities: Includes the new discharge outfalls and sampling in the creeks immediately adjacent to these outfalls.
- **(3) Sewer Separation Projects** - CSO 022, 045, and 061: Consistent with the requirements of the Metro SPDES Permit Number NY 002 7081, these outfalls are to be monitored for a three (3) year period.

- **<u>(1) CSO Conveyances Project</u>** (CSO 063): Consistent with the requirements of the Metro SPDES Permit Number NY 002 7081 and NYSDEC letter dated November 22, 2013.

4.3.7.1 PCCM (2011–2013)

Monitoring CSO Flow Quantity

CSO monitoring is an essential component of the PCCMP and includes monitoring of flow quantity and quality. In accordance with the ACJ Fourth Stipulation and Order, Paragraph 14I, Determination of Compliance, and the AMP Work Plan, the County installed flow meters at the manhole of each of the NYSDEC recommended list of 13 representative CSOs, which serve as the basis for the CSO flow monitoring program, and received data from the installed flow metering. The majority of monitoring devices were installed in 2011 and 2012. The purpose of the CSO discharge monitoring effort is to increase the veracity of the Stormwater Management Model (SWMM) used for planning, design, and determination of compliance with the volume capture requirements.

PCCM Sampling Program

The enhanced in-stream water quality (PCCM) sampling program was implemented on December 16, 2011. Two sampling events were conducted in May 2012, following the completion of the Gate Chamber (GC) modifications for the Erie Boulevard Storage System (EBSS) (CSO 080) completed in October 2011, as required by the ACJ Fourth Stipulation. Based on the evaluation of data collected from these two (2) sampling events, several sampling program recommendations were proposed to NYSDEC and ASLF, consistent with the approach outlined in EPA's "CSO Post Construction Compliance Monitoring Guidance," dated May 2012.

In February 2013, NYSDEC transmitted review comments on the County's 2012 sampling summary submittal with recommendations for the sampling program. The five-year AMP work plan incorporates the changes to the sampling protocol for the Tributary monitoring program, as approved by the NYSDEC in 2013.

Verification of Sewer Separation – CSOs 022 and 045

Consistent with the requirements of SPDES Permit Number NY 002 7081, a PCCM program was also implemented in 2013 to verify that CSOs 022 and 045 are not causing or contributing to violations of water quality standards in the receiving waters. This monitoring program was specifically designed to verify the separation of sanitary and storm flow performed under two sewer separation projects completed in 2012 to improve the water quality of Onondaga Creek and to reduce system-wide overflows from the combined sewer outfalls. These outfalls included CSO 022, located in the vicinity of Wallace and West Genesee streets, and CSO 045 located in the vicinity of West Castle and Hudson streets, as required by the Fourth Stipulation of the ACJ. During significant wet weather events, CSOs 022 and 045 would overflow to Onondaga Creek. The lateral sanitary sewers tributary to the combined sewers connected within the regulator manholes were separated in 2012 to eliminate sanitary connections to CSOs 022 and 045, allowing these CSOs to be converted to stormwater outfalls to the creek.

The PCCM Program was designed to include monitoring of fecal coliform, total suspended solids (TSS), turbidity, dissolved oxygen, and a visual observation of floatables at CSOs 022 and 045 and at the Onondaga Creek sites downstream of each of these two outfalls (Onondaga Creek at West Genesee Street and Onondaga Creek at South Avenue). In-stream sampling results indicating non-compliance with the AWQS could lead to a trackdown program to determine sources. As required by the Metro SPDES permit, these outfalls will be monitored for 3 years (2013, 2014, and 2015), with a minimum of four samples per location per year during storm events to confirm the effectiveness of the sewer separation. Once the monitoring period ends, the NYSDEC will perform an inspection to confirm that these outfalls have been permanently sealed or eliminated. Once confirmed by NYSDEC, these outfalls would be removed from the County's SPDES Permit. The ACJ 2013 Annual Report (http://savetherain.us/acj-annual-report-2013/), submitted to NYSDEC on March 31, 2014, summarizes the results of the two (2) sampling events conducted during wet weather at the CSO outfalls and receiving water. Due to the fact that street runoff can mobilize many contaminants, including bacteria, it can be expected that storm drains will be affected by runoff from precipitation.

4.3.7.2 PCCM (2014–2018)

The five-year AMP work plan submitted to the NYSDEC in July 2014, and conditionally approved in September 2014, incorporates a proposed schedule for sampling in the context of the recently constructed gray project milestones and post construction compliance monitoring program to ensure that the captured (up to the 1-year, 2-hour storm) and separated CSOs are not causing or contributing to violations of water quality standards in the receiving water. Monitoring parameters and/or locations may be modified based on evaluation of the data. The work plan is intended to comply with the requirements of the Fourth Stipulation to the Amended Consent Judgment (ACJ) and the State Pollution Discharge Elimination System (SPDES) permit for the Metropolitan Syracuse Wastewater Treatment Plant (Metro).

Monitoring of CSO Outfalls (Quality and Quantity):

Water quality sampling of each of the ten (10) representative CSO discharges and the two (2) storage facility outfalls is planned, in conjunction with the flow monitoring data, to evaluate the impacts of the CSO outfalls to the receiving water. The majority of the sampling program parameters of interest are to be collected as "grabs". These samples will be collected at the CSO manholes (regulator structures) during overflows. This sampling program may be subsequently modified based on the nature of the overflow conditions and list of analytes.

In-stream Tributary Sampling Program of CSO Outfalls:

The primary objective of the in-stream component of the PCCM tributary sampling program is to evaluate whether completion of the planned improvements to the wastewater (and stormwater) collection infrastructure results in compliance with the AWQS and Guidance Values. Figure 4-22 provides a map of the CSO sewersheds, CSO outfalls, and the CSO Gray Infrastructure Projects. As conditions allow, four (4) overflow events are targeted per representative CSO outfall over a two-year period. The selection of the in-stream sites needs to take into consideration distances from and between outfalls for a mixing zone and estimated time-of-travel analysis.

Sampling Schedule (2014-2018):

The sampling schedule proposed from 2014 through 2018 is designed to coincide with the completion of major gray or green Infrastructure projects in a particular CSO basin. The majority of the sampling is targeted following the completion of the Harbor Brook and Clinton Storage Facilities. Sampling is targeted in 2014-2015 for CSO overflows 003, 004, 030, and 034, to determine the impact of the overflow relief upon water in Onondaga Creek and in assessing AWQS.

The sampling schedule for CSO discharges from the 014, 027, 052, and 060/077 service areas will be determined based on the approved facility plans. Monitoring and evaluation are required through 2018 and will address all CSO abatement projects. Design of the future years sampling program may be modified based on information obtained from previous efforts. Table 4-12 presents the targeted sampling schedule for the PCCM and the associated gray infrastructure projects.

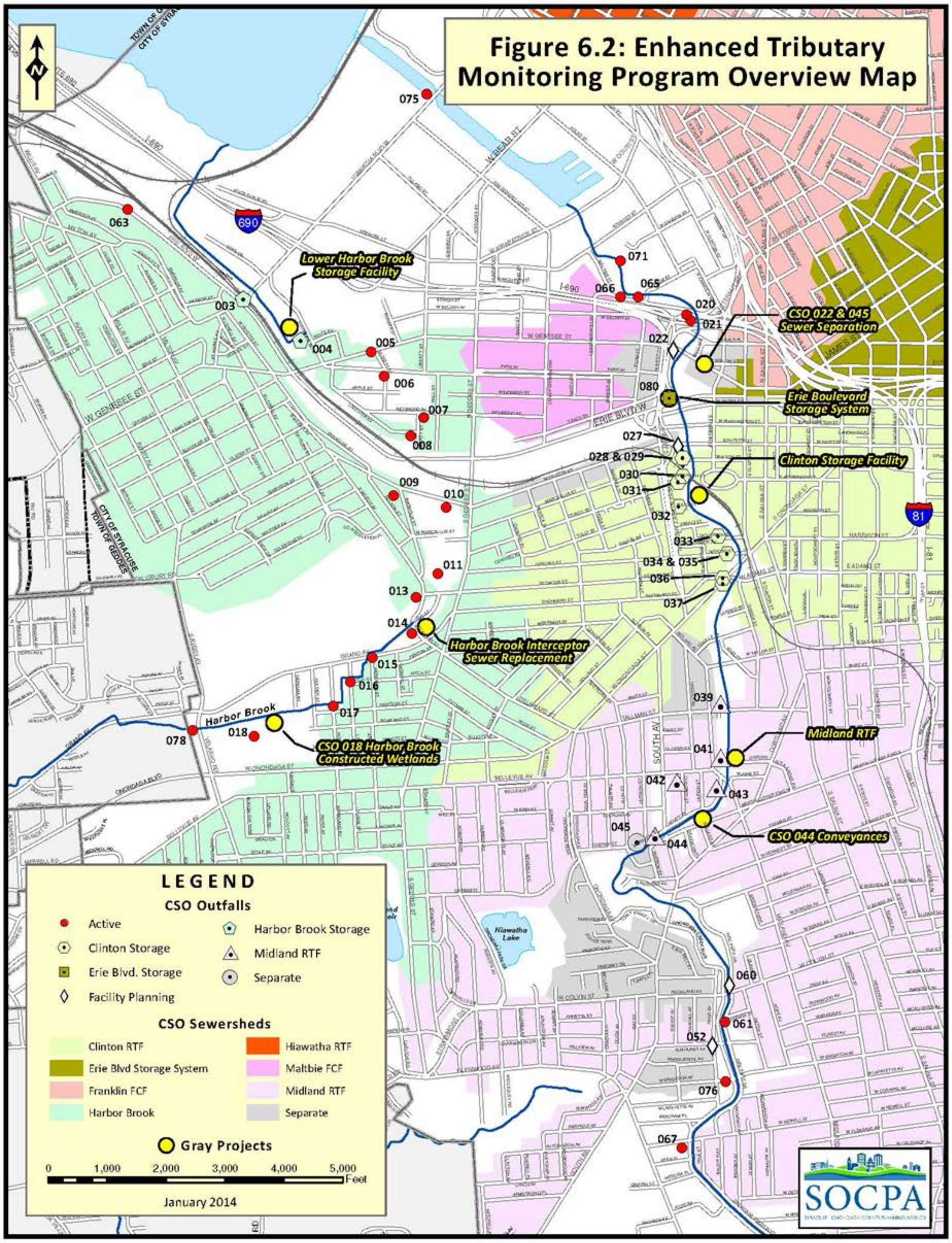


Figure 4-22. Map of sewersheds, CSO outfalls, and the gray infrastructure projects.

Table 4-12. Post Construction Compliance Monitoring (Tentative Sampling Schedule 2014–2018).

CSO Service Area	CSO Outfall	CSO Abatement Strategy	Construction Date	Sampling Event Targeted Schedule	NOTES
Harbor Brook	OO3	Lower Harbor Brook Storage Facility (LHBSF) & GI	12/31/2013 & GI by 2018	2014-2015	CSO 003 captured by this storage facility for up to the 1-year, 2-hour design storm.
Harbor Brook	OO4	LHBSF & GI	12/31/2013& GI by 2018	2014-2015	CSO 004 captured by this storage facility for up to the 1-year, 2-hour design storm.
Harbor Brook	LHBSF Outfall[1]	Lower Harbor Brook Storage Facility	12/31/2013	2014-2015	CSO 003 and 004 captured by this storage facility for up to the 1-year, 2-hour design storm.
Harbor Brook	O14	Floatables Control Plan (FCF Plan Amendment re-submittal 3/12/13) & GI	TBD	TBD	The sampling schedule of this CSO overflow will be conducted no later than 2018, as required by the ACJ Fourth Stipulation.
Harbor Brook	O18	GI - Wetland Treatment with Floatables Control	12/31/2013	2016-2017	Sampling is targeted when the facility comes on-line and operational; could be conducted during the facility performance testing period.
Clinton	022	Sewer Separation	12/31/2011	2013-2015	Quarterly sampling scheduled during wet weather for a 3-year period.
Clinton	O27	Facility Plan & GI	TBD & GI by 2018	TBD	The sampling schedule of this CSO overflow will be conducted no later than 2018, as required by the ACJ Fourth Stipulation.
Clinton	O30	Clinton Street Storage Facility (CSF) & GI	12/31/2013 & GI by 2018	2014-2015	Sampling is targeted when the facility comes on-line and operational; could be conducted during the facility performance testing period.
Clinton	O34	CSF & GI	12/31/2013 & GI by 2018	2014-2015	
Clinton	CSF Outfall[1]	Clinton Storage Facility (CSOs 028, 030, 031, 032, 033, 034, 035, 036 and 037 captured for up to the 1-year, 2-hour design storm).	12/31/13	2014-2015	
Clinton	CSO 045	Sewer Separation	12/31/2011	2013-2015	Quarterly sampling scheduled during wet weather for a 3-year period.
Clinton	080 (a-i)	Erie Boulevard Storage System (EBSS) (Gate Chamber Modifications and GI)	GC Modifications completed 2011 & GI by 2018	2016-2017	2 sampling events completed in 2012.

Table 4-12. Post Construction Compliance Monitoring (Tentative Sampling Schedule 2014–2018).

CSO Service Area	CSO Outfall	CSO Abatement Strategy	Construction Date	Sampling Event Targeted Schedule	NOTES
Midland	O52	Facility Plan & GI	TBD & GI by 2018	TBD	The sampling schedule of this CSO overflow will be conducted no later than 2018, as required by the ACJ Fourth Stipulation.
Midland	O60/O77	Facility Plan	TBD	TBD	The sampling schedule of this CSO overflow will be conducted no later than 2018, as required by the ACJ Fourth Stipulation.
Clinton	CSO 061	Sewer Separation	TBD	TBD	Quarterly sampling scheduled during wet weather for a 3-year period.
Clinton	CSO 063	CSO Conveyance Project/LHBS Facility	TBD	TBD	Quarterly sampling scheduled during wet weather for a 3-year period.

[1] Operation commenced following the construction of the two (2) storage facilities (completed on 12/31/13). Storage Facility performance testing/optimization has no impact on the operation and PCCM planned for these facilities.

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Section 5. Onondaga Lake Water Quality: 2013 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. The ambient monitoring program (AMP) encompasses multiple parameters (Table 1-2) with a focus on evaluating 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. During the winter of 2012–2013, ice covered the north basin of the lake on 53 days and the entire lake on 46 days. In 2013–2014, ice cover extended for 107 days in the north basin and 95 days lake wide. This was the most extensive ice cover documented during the 1987–2014 record.

The main sampling station in the lake, referred to as South Deep, is located near 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 generally comparable in 2013 (Appendix E-1).

The AMP also includes sampling of a network of ten near-shore locations for parameters related to suitability for water contact recreation. These parameters include Secchi disk transparency, turbidity, and fecal coliform bacteria.

5.2 Compliance with AWQS

The 2013 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 reflects the concentrations of the major cations and anions (calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulfate (SO_4^{2-})), exceeded the AWQS of 500 mg/L by a wide margin. Exceedance of this standard is associated with the lake's natural hydrogeology and not with anthropogenic effects. The bedrock in Onondaga County is comprised of Paleozoic sedimentary rocks with high concentrations of calcium and sulfate, which contribute to the high TDS levels in Onondaga Lake and its tributaries.

New York State 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

Table 5-1. Percentage of measurements in compliance with ambient water quality standards (AWQS) and guidance values in the upper and lower waters of Onondaga Lake at South Deep in 2013.

Parameter	Upper Waters		Lower Waters	
	Depths	%	Depths	%
Dissolved Oxygen (>4 mg/L)	2m	100%	12m	*51%*
Dissolved Oxygen (>5 mg/L)[1]	2m	100%	12m	*49%*
pH	0 - 6m	100%	12 - 18m	100%
Total Phosphorus[2]	0, 3m	*0% (25 µg/L)*	--	--
Ammonia	0, 3, 6m	100%	12, 15, 18m	100%
Nitrite	3m	100%	15, 18m	*77%*
Total Dissolved Solids	3m	*0%*	15m	*0%*
Dissolved Mercury	3m	*67%*	18m	*67%*
Fecal Coliform Bacteria[3]	0m	100%	--	--

Notes:
Dashed lines indicate that compliance was not evaluated; parameters listed in bold are cited in the ACJ; occurrences of less than 100% compliance are highlighted in italic red text.

[1] Dissolved oxygen compliance based on buoy data from 2 m and 12 m depths (between 1 and four profiles per day).

[2] Total phosphorus compliance based on the average for the June 1–September 30 period.

[3] The AWQS for fecal coliform bacteria is specified as the monthly geometric mean 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).

their best usages" (NYSCRR §703.2). For ponded waters the narrative standard is interpreted using a guidance value of 20 µg/L, calculated as the average total phosphorus concentration in the lake's upper waters 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. The 2013 summer average total phosphorus (TP) concentration in the lake's upper waters was 25 µg/L, somewhat higher than the state's guidance value of 20 µg/L.

Based on long-term consistent compliance with AWQS, quarterly sampling of metals in the lake was discontinued in 2013. Samples for analysis of total mercury, dissolved mercury, and methylmercury were collected from South Deep at two depths (3 meters and 18 meters) in April, August, and October of 2013. Sampling for mercury at North Deep was conducted only during April. Methylmercury is of particular concern because it bioaccumulates strongly in aquatic food webs, resulting in toxic effects at upper trophic levels when concentrations are high. The AWQS for dissolved mercury in Class B and C waters is 0.7 nanograms per liter (ng/L). This standard was exceeded in April in the lower waters and in October in the upper waters. The time series of total mercury and methylmercury concentrations measured in both the upper and lower waters of Onondaga Lake since 1999 indicate a substantial reduction in the concentration of this heavy metal (Figure 5-1).

Dissolved oxygen (DO) concentrations met the AWQS (Table 5-2) in the upper waters of Onondaga Lake throughout the 2013 sampling period. DO concentrations in the lower waters were 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). In the ***TMDL for Phosphorus in Onondaga Lake***, NYSDEC concluded that the Lake is unable to meet the existing statewide DO water quality standard at all

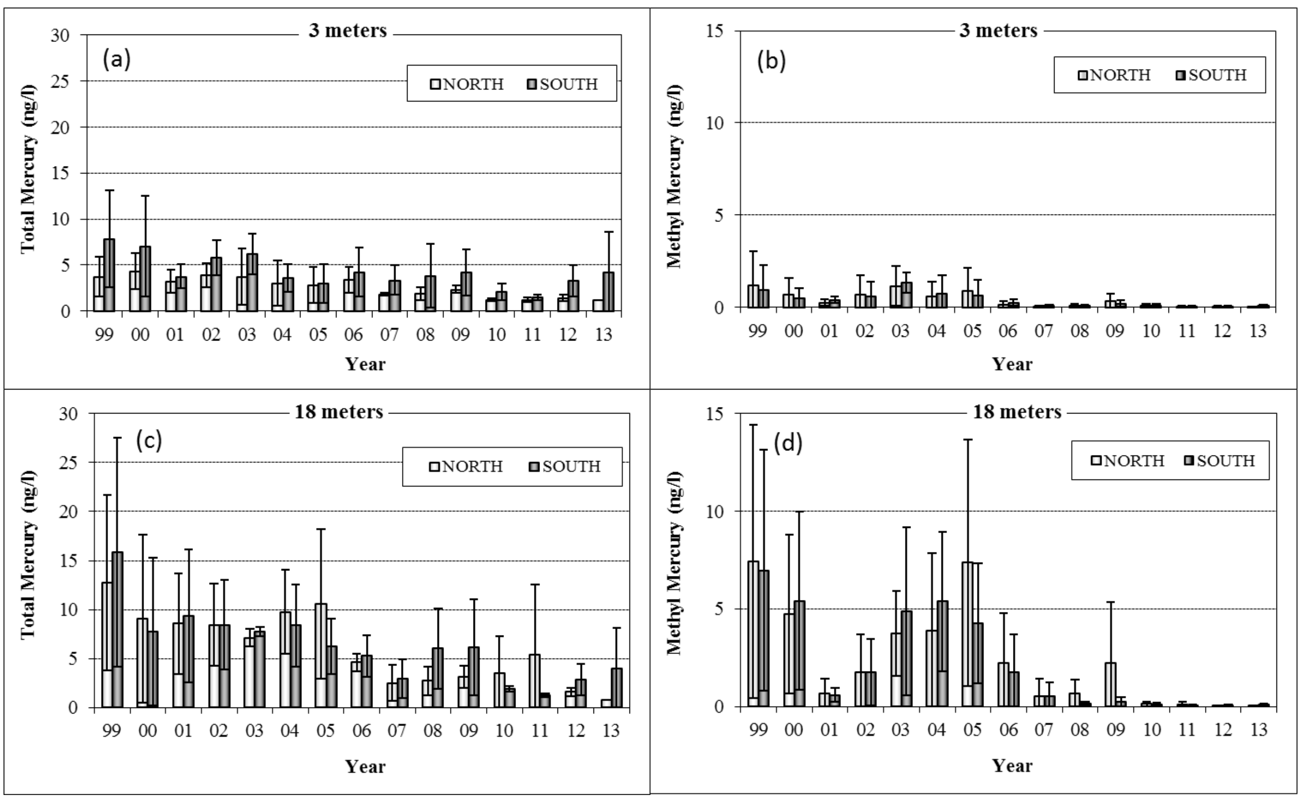


Figure 5-1. Time series of annual average mercury concentrations at the North and South Deep stations of Onondaga Lake, 1999–2013 (a) total mercury at 3 m, (b) methylmercury at 3 m, (c) total mercury at 18 m, and (d) methylmercury at 18 m.

Note: The error bars depict one standard deviation of the annual mean concentration.

times during the year in the lower depths of the Lake because natural conditions contribute to the depletion of oxygen in the hypolimnion. 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 2013, the measured fecal coliform bacteria counts at the Onondaga Lake monitoring stations were in compliance with the ambient water quality standard (monthly geometric mean concentration from at least five samples less than or equal to 200 cfu/100 mL) at offshore and nearshore locations within the Class B portion of the lake. Two sites, located within the Class C segment of the lake's southeastern shoreline, exceeded the bacteria standard during the month of October, and one of these sites also exceeded the standard in April (see Section 5.6). All other locations within the Class C water segment met the ambient water quality standard for all monitored months.

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 lakes are termed eutrophic, while lakes with low levels of productivity are termed oligotrophic. Those with intermediate levels of productivity 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 the nutrient 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* (Chl-*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 relationships between phosphorus loading and common metrics of trophic state.

5.3.1 Phosphorus

Total phosphorus (TP) concentrations in the upper waters of the lake remained above 20 µg/L during most of the 2013 monitoring period (Figure 5-2). The highest TP concentrations were measured in early July, early August, and in mid-November. The peak of 36 µg/L on July 9 followed a period of elevated stream flow. On August 6 a TP concentration of 30 µg/L coincided with a peak in algal biomass (Figure 5-4). The final peak on November 13 followed fall turnover. Total phosphorus concentrations in the lake's upper waters averaged 25 µg/L over the summer (June–September) of 2013. Total dissolved phosphorus (TDP) concentrations averaged 6 µg/L and accounted for 14% to 67% (average of 27%) of TP. Soluble reactive phosphorus (SRP) levels were consistently low, with a maximum concentration of 4 µg/L. Long-term trends in TP concentrations in the upper waters of the lake depict major decreases since the early 1990s (Figure 5-3). Since 2007, summer total phosphorus concentrations in the upper waters of Onondaga Lake have been close to the guidance value of 20 µg/L. The summer average TP concentration was below the guidance value in 2008 and 2009. With the advanced treatment system at Metro producing consistently low effluent total phosphorus, the year-to-year variability in lake phosphorus levels reflects changes in precipitation patterns and the resultant watershed loading as well as changes in the food web structure (see Section 5.8.3). A substantial portion of the total phosphorus in certain lakes may be associated with inorganic particles rather than phytoplankton, making it a flawed metric of trophic state in these systems. Summer average concentrations of both TDP and SRP have been consistently low since 2007.

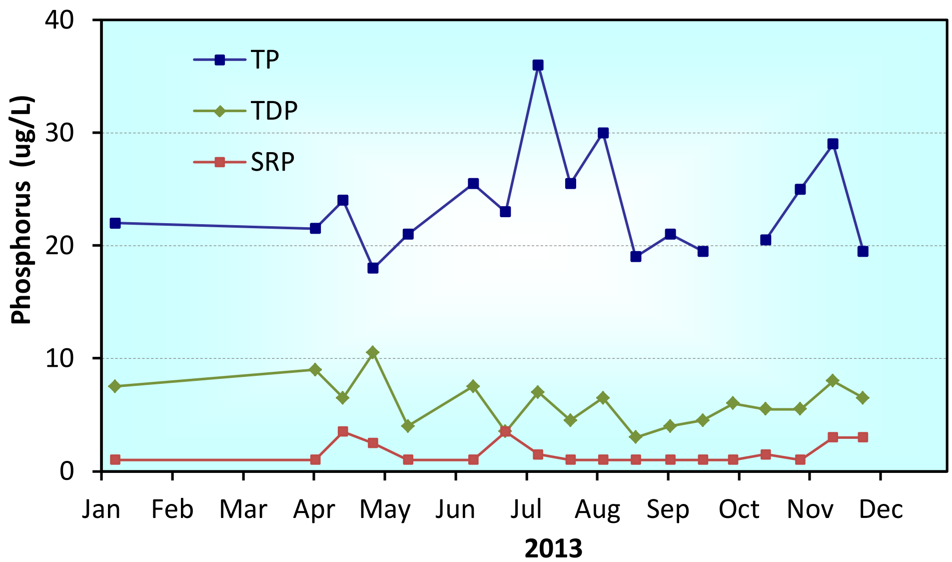


Figure 5-2. Time series of total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) concentrations in the upper waters (0-3 meters) of Onondaga Lake during 2013.

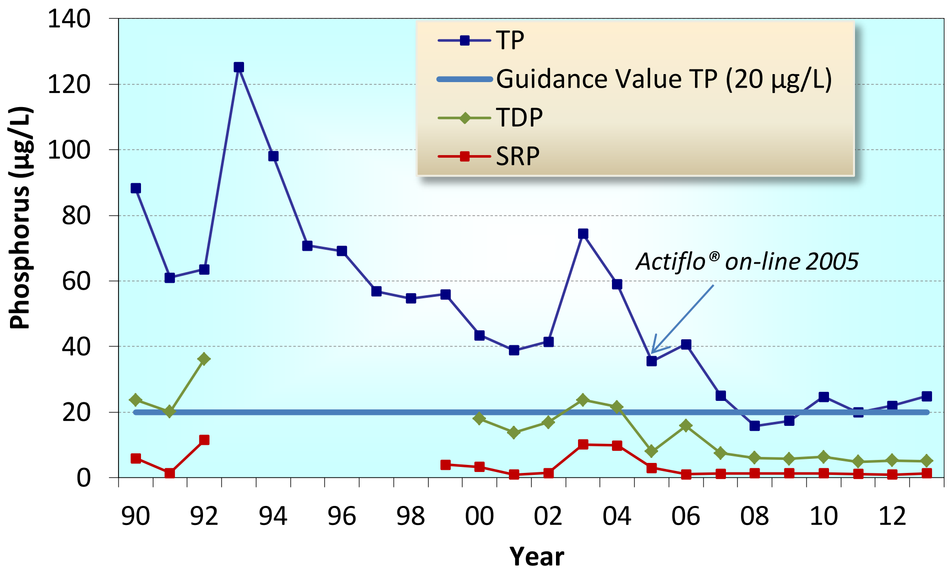


Figure 5-3. Summer (June to September) average total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990–2013.

Note: TDP and SRP data not collected during 1993-1998.

5.3.2 Chlorophyll-a

Chlorophyll-*a* (Chl-*a*) concentrations in the upper waters of the lake in 2013 ranged from 2 µg/L in late November to a peak of 14 µg/L in early August (Figure 5-4). The summer average Chl-*a* concentration was 9.1 µg/L, higher than it has been since 2007 (Figure 5-5). The average and peak concentrations of this indicator of algal biomass have declined substantially, particularly since the Actiflo® upgrade at Metro (Figure 5-5). Summer data (June–September) are used to track suitability of the lake for recreational uses.

The EPA and NYSDEC are developing nutrient criteria for lakes to protect aquatic life, water supply and recreational uses, 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, and based on weekly laboratory measurements, there were no algal blooms in Onondaga Lake during the summer recreational period (June–September) of 2013 (Figure 5-6). Detailed vertical patterns of chlorophyll-*a* are depicted in Figure 5-14d as a color contour plot. It is important to note that the results of the in-situ chlorophyll-*a* analysis are not as accurate as results from the certified extractive analysis procedure performed in the laboratory. The in-situ high frequency measurements are not intended to replace the standard procedure, but are intended to complement the more accurate, but less frequent laboratory results. The laboratory results are best suited for tracking and reporting long-term patterns in the occurrence of summer algal blooms because they are more accurate and there is a long-term record of these measurements.

The total phosphorus concentration in spring has been a good predictor of the occurrence of severe summertime blooms (Figure 5-7), 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 the summer average Chl-*a* (Figure 5-8) concentration of the upper waters, with decreases in Chl-*a* observed as the TP load has been reduced. This analysis uses TP loads from the full water year (October–September) to account for loading that may influence algal growth during summer.

Diatoms – A Major Group of Algae in Onondaga Lake

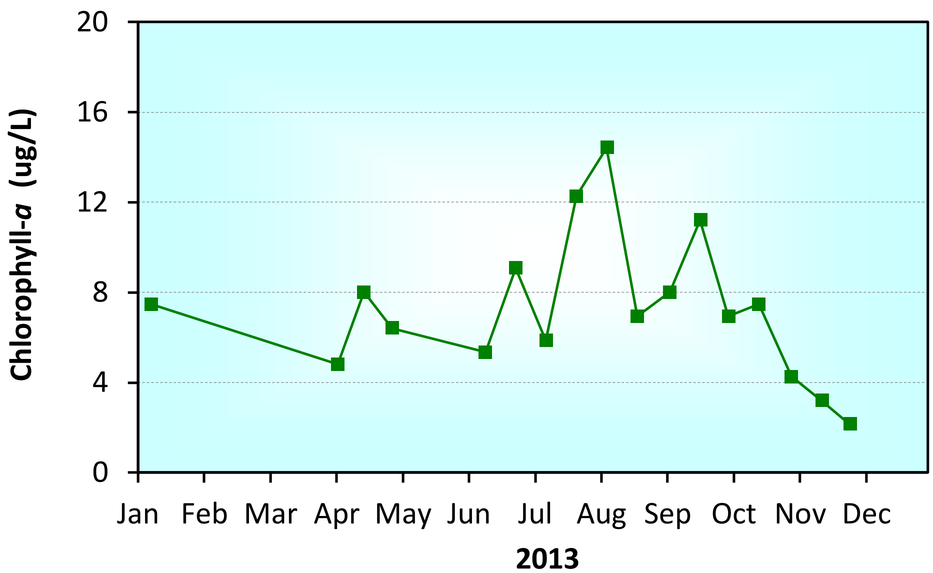


Figure 5-4. Seasonal time plot of average chlorophyll-*a* concentration in the upper waters (0-3 meters) of Onondaga Lake, 2013.

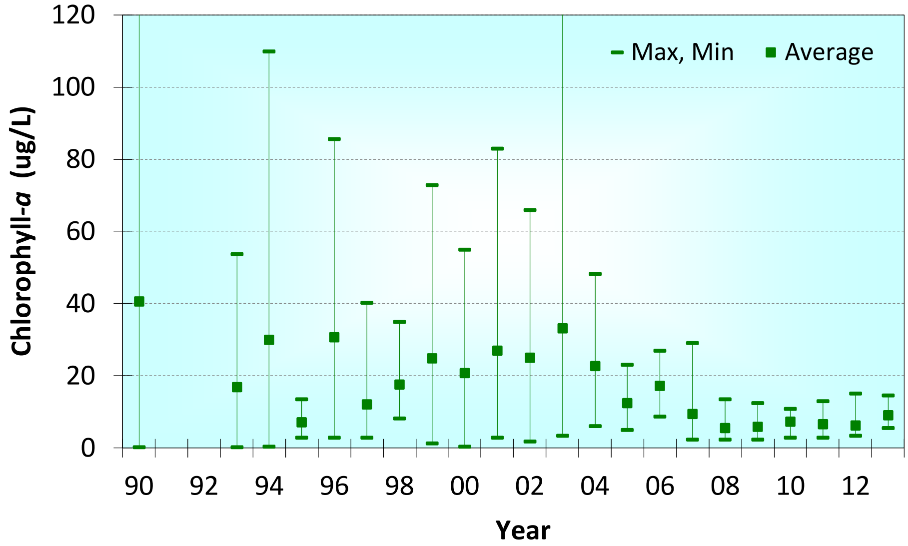


Figure 5-5. Summer average (June–September) chlorophyll-*a* concentrations in the upper waters of Onondaga Lake (South Deep), 1990–2013.

Note: points represent summer average; bars represent the min and max in summer.

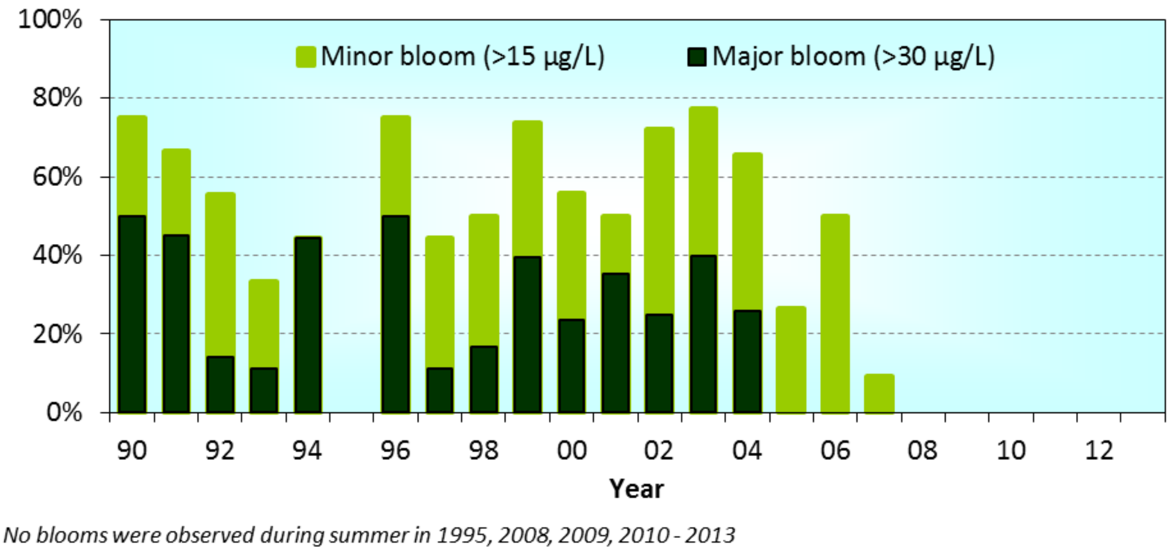


Figure 5-6. Percent occurrence of summer (June to September) algal blooms in Onondaga Lake evaluated annually for the 1990–2013 period, based on chlorophyll-*a* measurements.

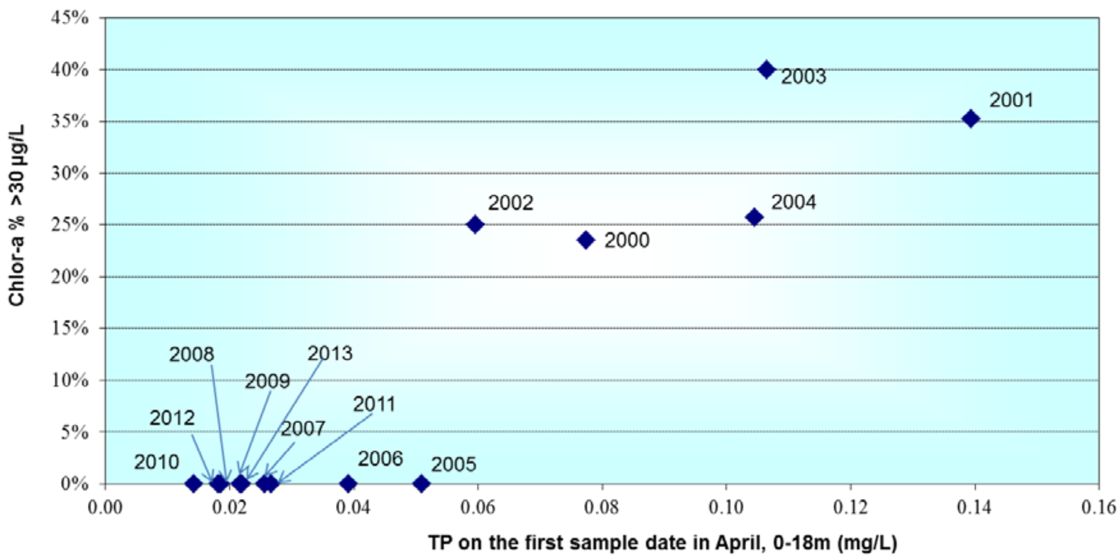


Figure 5-7. Relationship between the frequency of summertime nuisance algal blooms and the total phosphorus concentration in spring, 2000–2013.

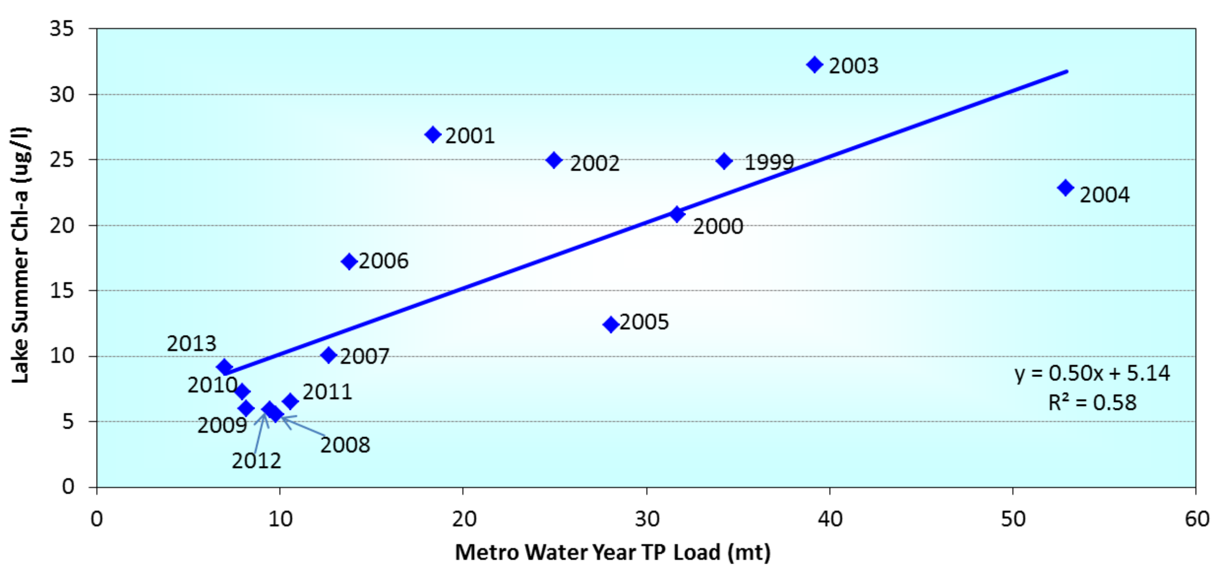


Figure 5-8. Relationship between summer (June–September) average chlorophyll-*a* concentrations in the upper waters and total phosphorus loading from Metro over the full water year (October–September).

In lakes where phytoplankton production is limited by phosphorus, total phosphorus and chlorophyll-*a* are highly correlated. Data from regional lakes, including Onondaga, (Figure 5-9) 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 (Rudstam 2013). Oneida Lake is notably shallower than the Finger Lakes, has a larger proportion of the bottom suitable for dreissenid mussels, and does not develop stable thermal stratification during the summer, features that may contribute to the observed deviations from the other lakes.

Advanced wastewater treatment has resulted in major decreases in total phosphorus and chlorophyll-*a* levels in Onondaga Lake. A comparison of total phosphorus and chlorophyll-*a* conditions in Onondaga Lake to other regional lakes provides context for the magnitude of the water quality improvements that have been achieved. During the 1998–2005 interval total phosphorus and chlorophyll-*a* levels in Onondaga Lake far exceeded those measured in some of the eastern Finger Lakes and Oneida Lake (Figure 5-10). Since 2007, levels of these important water quality indicators have been similar to those measured in Otisco Lake and Oneida Lake. The absence of algal blooms in Onondaga Lake stands in contrast to the widespread occurrence of blue-green harmful algal blooms in lakes across New York State (see http://www.dec.ny.gov/chemical/77118.html for more information).

5.3.3 Secchi Disk Transparency

A Secchi disk is a 25 centimeter 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. Secchi disk transparency greater than 1.2 meters (4 feet) is required to meet swimming safety guidance 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. A summer average Secchi disk transparency of at least 1.5 meters at South Deep has been established for Onondaga Lake as a target for improved aesthetic appeal (Table 1-5). The Citizens Statewide Lake Assessment Program (CSLAP), a joint effort of NYSDEC and the NYS Federation of Lake Associations, considers summer average Secchi disk transparency greater than 2 meters as indicative of mesotrophic conditions (Kishbaugh 2009). The average water clarity of Onondaga Lake during the summer of 2013 was 1.8 meters and ranged from 1.1 to 2.8 meters (Figure 5-11). Water clarity in 2013 was lower than it has been since 2006 (Figure 5-12).

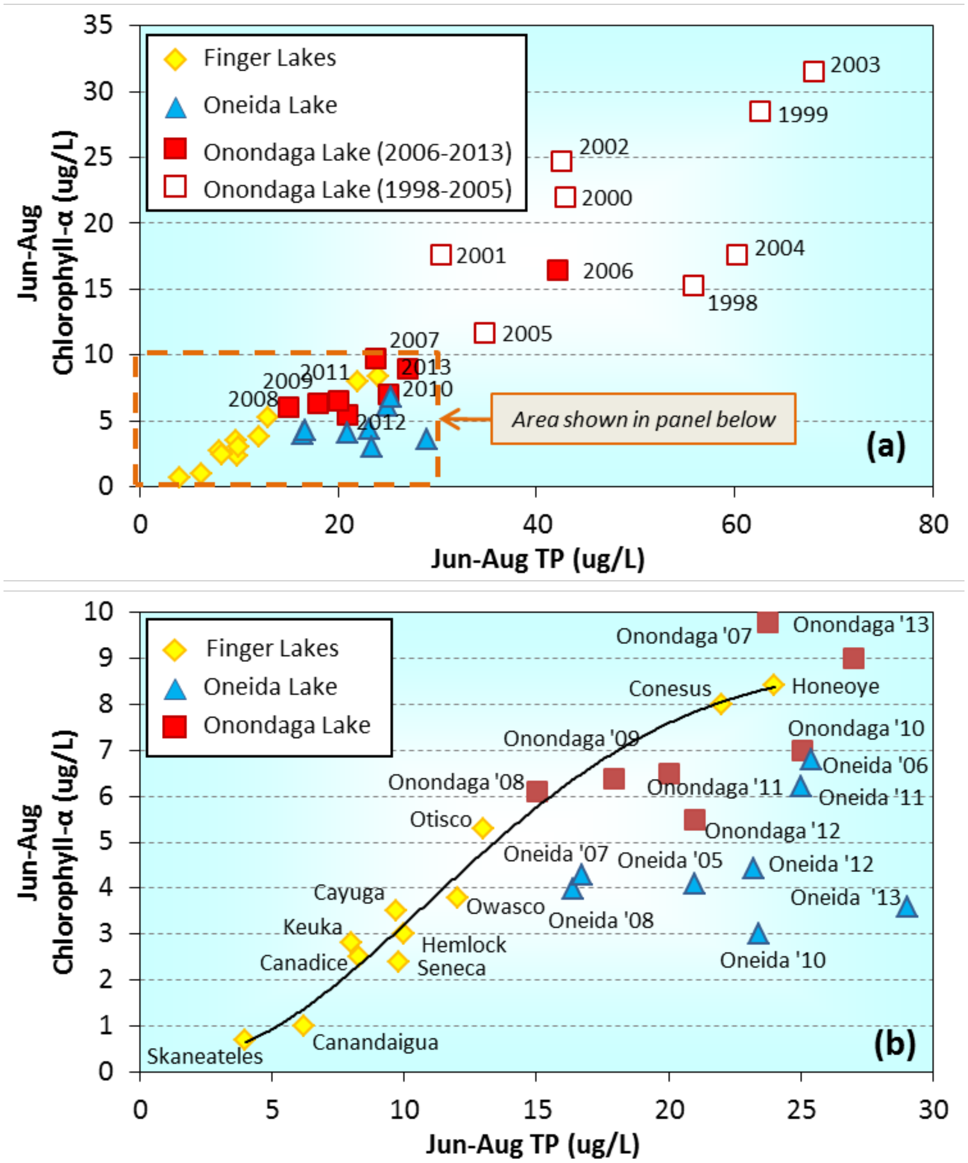


Figure 5-9. June to August average total phosphorus (TP) and chlorophyll-*a* concentrations in Onondaga Lake compared with selected regional lakes.

Note: (a) The top panel shows Onondaga Lake concentrations pre-Actiflo® (1998-2005) and post-Actiflo® (2006-2013. (b) The bottom panel represents the same data, scaled to show the 2007-2013 Onondaga Lake data and a best-fit trendline (R^2 = 0.97) of the Finger Lakes concentrations (1996-1999), and Oneida Lake concentrations (2005-2012; Rudstam 2013).

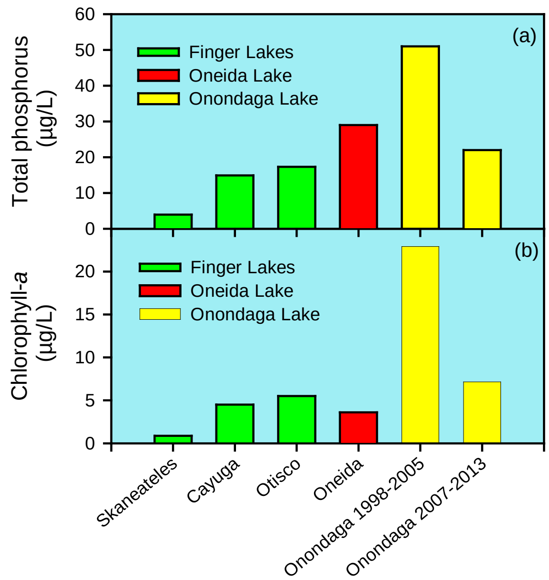


Figure 5-10. A comparison of trophic state metrics in Onondaga Lake and selected regional lakes: (a) summer average (June to September) total phosphorus concentrations and (b) summer average (June to September) chlorophyll-*a* concentrations.

Note: Skaneateles Lake data from 2011, courtesy of the Town of Skaneateles. Cayuga Lake data from 2013, courtesy of Cornell University. Otisco Lake data from 2010-2011, courtesy of NYSDEC. Oneida Lake data from 2013, courtesy of Dr. Lars Rudstam.

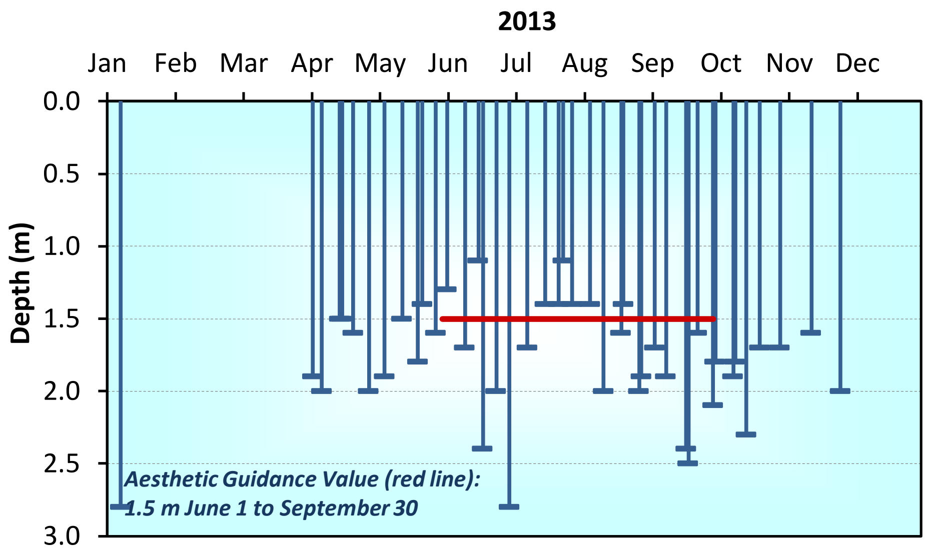


Figure 5-11. Secchi disk transparency, Onondaga Lake South Deep, 2013.

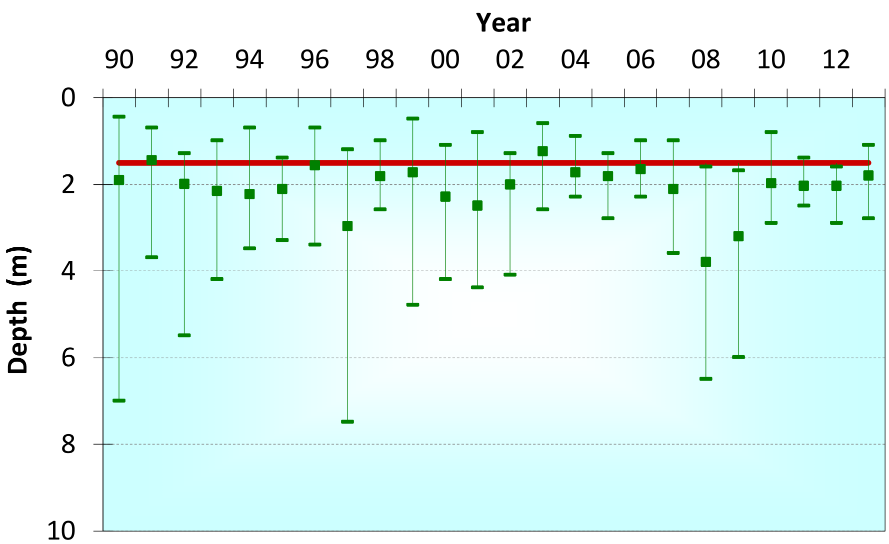


Figure 5-12. Long-term summer average Secchi disk transparency, Onondaga Lake South Deep, 1990–2013.

Note: points represent summer average; bars represent the min and max in summer. The aesthetic guidance value of 1.5 m is shown in red.

5.3.4 Trophic State Indicators

Summer (June–September) average values of the three trophic state indicator parameters (total phosphorus, chlorophyll-*a*, Secchi disk transparency) are presented for the 1998–2013 interval (Figure 5-13). According to these parameters, trophic conditions have varied only modestly since 2010. 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 to grazing of particles by *Daphnia*, a large, filter feeding zooplankter. However, no systematic improvement in summer average Secchi disk transparency has been observed since 1998. Two factors likely contribute to this inconsistency for Secchi disk versus total phosphorus and chlorophyll-*a* (Effler et al. 2008): (1) inputs of inorganic particles that decrease clarity; and (2) the recent absence 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 based on Secchi disk versus the other two metrics. As observed in 2010, 2011, and 2012, efficient grazers of phytoplankton (i.e., *Daphnia*) continued to be essentially absent in 2013, consistent with the continuing large population of the alewife (*Alosa pseudoharengus*). See Section 6 for a detailed discussion of food web dynamics. The observed decreases in total phosphorus and chlorophyll-*a* and the decrease in Secchi disk transparency in 2013 were likely related to high runoff and material loading that occurred in early summer.

Enjoying the View at Onondaga Lake Park

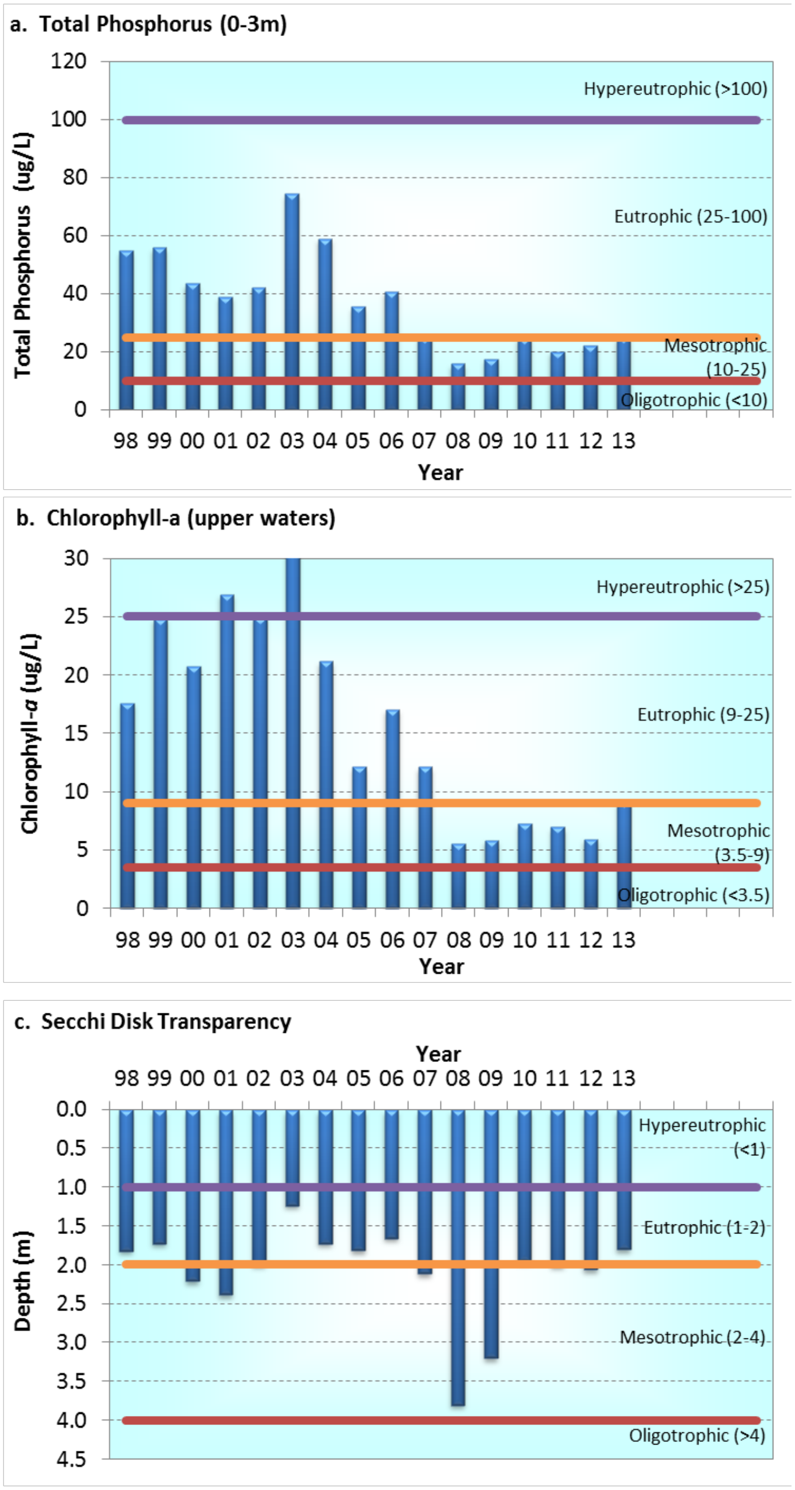


Figure 5-13. Time series of common trophic state indicators based on summer average (June–September) data, 1998–2013.

5.4 Dissolved Oxygen

Adequate dissolved oxygen (DO) content is critical for aquatic life and a common focus of water quality monitoring programs. Vertically detailed profiles of DO, temperature, specific conductance, and chlorophyll-*a* were collected at South Deep during 2013 and are presented here as color contour plots (Figure 5-14). These measurements were made at 1 meter depth increments at South Deep with a monitoring buoy over the spring to fall interval courtesy of Honeywell (http://www.upstatefreshwater.org/NRT-Data/Data/data.html). DO concentrations were uniformly high throughout the water column during the January to early April interval. Depletion of DO from the lower layers began during May with the onset of thermal stratification, and by mid-July the lake was largely anoxic below a depth of 6 meters (Figure 5-14). The lower waters were replenished with DO in early November following the occurrence of fall turnover. There was no noteworthy depletion of DO in the upper waters during the fall of 2013, and the minimum concentration remained well above the AWQS of 4 mg/L (Figure 5-15).

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 5-15), and contravention of the related AWQS. This goal has been achieved through reductions in Metro loading of both ammonia (Figure 4-7) and total phosphorus (Figure 4-10). Other improvements in the lake's oxygen resources have been observed, particularly within the lower stratified layers (hypolimnion). Following the onset of summer stratification, these layers are subject to oxygen depletion from decay of depositing organic 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, manifested as a delay in the onset of anoxic conditions and decreases in "volume-days of anoxia" (Figure 5-16). Linear regression analysis indicates significant decreases in both volume days of anoxia (R^2=0.46, p<0.01) and volume days of anoxia + hypoxia (R^2=0.39, p<0.01) over the 1992–2013 interval. When evaluated over the 2000–2013 period the decreasing trend for anoxic conditions remained significant (R^2=0.50, p<0.01) while the trend for anoxia + hypoxia did not (R^2=0.23, p<0.08). 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 6.4.

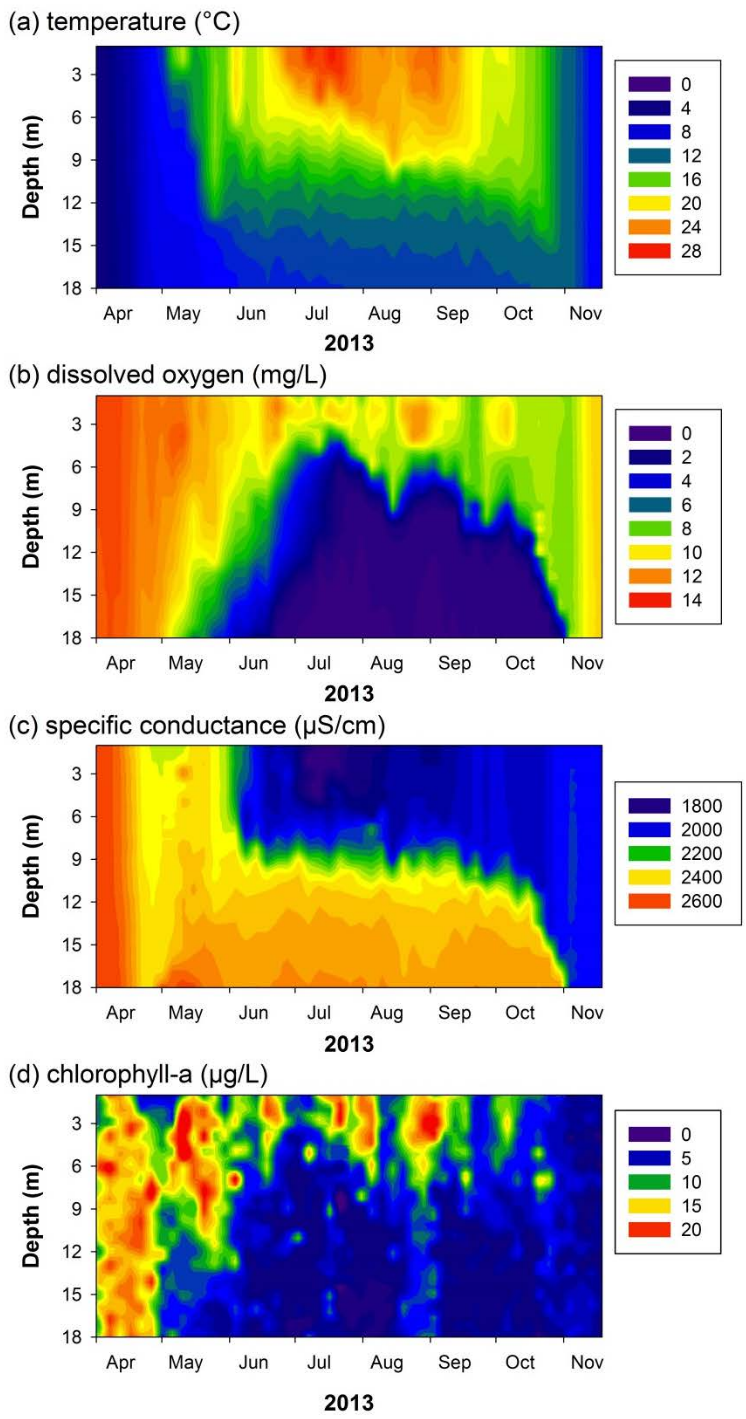


Figure 5-14. Color contour plots of Onondaga Lake in 2013, based on biweekly sensor profiles conducted at South Deep: (a) temperature (°C), (b) dissolved oxygen (mg/L), and (c) specific conductance (µS/cm), (d) chlorophyll-*a* (µg/L).

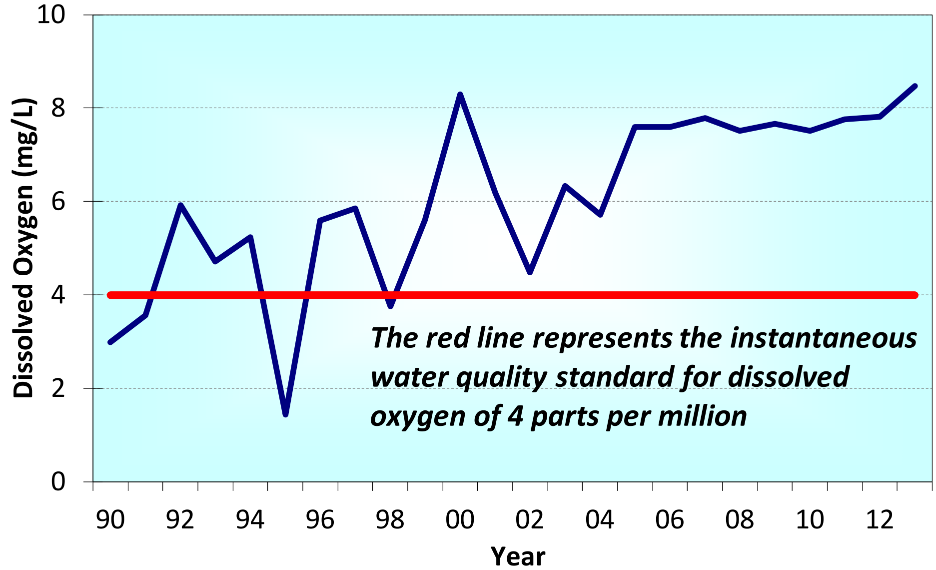


Figure 5-15. Minimum dissolved oxygen (DO) concentration in the upper waters (0-4 meters average) of Onondaga Lake during October, annually 1990–2013.

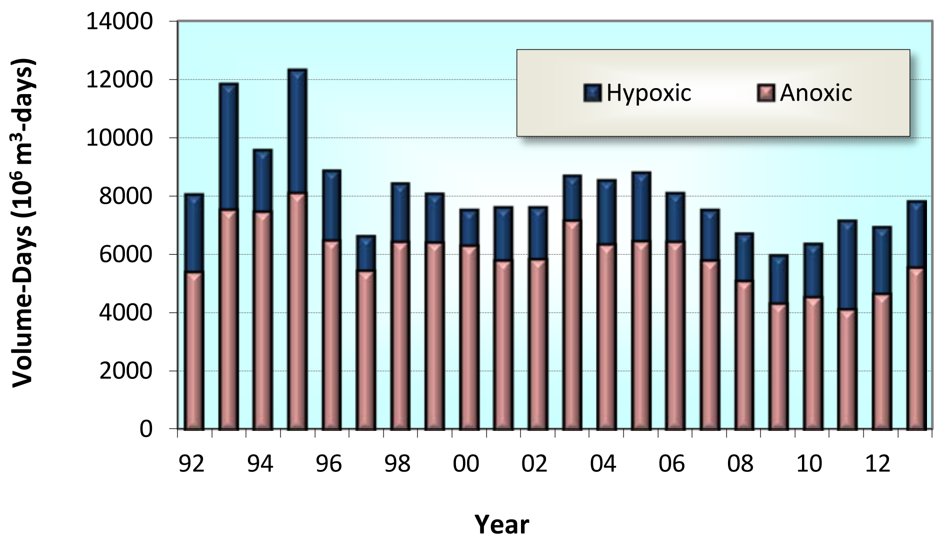


Figure 5-16. Volume-days of anoxia (dissolved oxygen less than 1 mg/L) and hypoxia (dissolved oxygen less than 4 mg/L), in Onondaga Lake, 1992–2013.

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. Upgraded aeration treatment at Metro in the late 1990s and implementation of the BAF technology in 2004 significantly reduced ammonia concentrations in the upper waters of the lake (Figure 5-17, Figure 5-18a), 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 New York State's 303(d) list of impaired waterbodies for this water quality parameter.

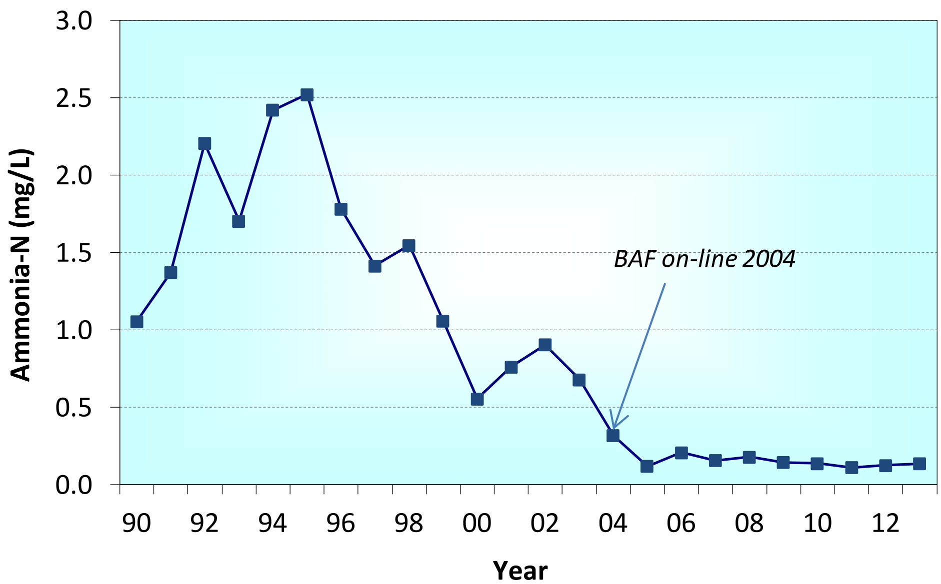


Figure 5-17. Annual average ammonia-N (NH_3-N) concentrations in the upper waters (0-6 meters) of Onondaga Lake, 1990–2013.

Table 5-3. Percent of Onondaga Lake ammonia measurements in compliance with ambient water quality standards, 1998–2013.

Depth (m)	Percent measurements in compliance, NYS Standards															
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
0	64	62	86	95	68	96	100	100	100	100	100	100	100	100	100	100
3	45	67	90	90	68	96	100	100	100	100	100	100	100	100	100	100
6	50	86	90	95	73	100	100	100	100	100	100	100	100	100	100	100
9	41	76	90	95	73	100	100	100	100	100	100	100	100	100	100	100
12	18	52	90	81	50	80	100	100	100	100	100	100	100	100	100	100
15	23	52	57	52	41	56	80	100	100	100	100	100	100	100	100	100
18	23	48	52	38	32	48	75	95	95	100	100	100	100	100	100	100

Efficient year-round nitrification treatment from implementation of the biologically aerated filter (BAF) resulted in increased nitrate (NO_3-N) loading to the lake and increased in-lake concentrations (Figure 5-18b). 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 (Matthews et al. 2013). A 3-year (2011–2013) whole-lake nitrate addition pilot test was conducted as part of the Honeywell cleanup with the objective of limiting release of methylmercury from the deep-water sediments through maintenance of nitrate concentrations > 1 mg/L. Based on the success of this pilot test, a long-term program of nitrate addition will begin in 2014. During the 2011-2013 nitrate addition pilot test an average of 73 metric tons of nitrate-N was added to the hypolimnion annually. In contrast, annual nitrate loading from Metro averaged 940 metric tons per year over the 2004-2013 interval.

Acceptance of saline groundwater at Metro during the summer of 2012 caused the effluent to be unusually dense and to plunge to the metalimnion and hypolimnion during the July–October interval. The plunging Metro effluent was an important source of nitrate to the hypolimnion in 2012, supplementing inputs from the nitrate addition pilot project. The higher salinity of the Metro effluent contributed to elevated specific conductance values in the lake that persisted into April 2013 (Figure 5-14c). Dewatering activities were discontinued in May of 2013 and the propensity of the effluent to plunge was greatly reduced. Elevated runoff in June caused specific conductance values in the upper waters to decrease abruptly (Figure 5-14c).

Nitrite (NO_2-N) concentrations also often exceeded the limit (0.1 mg/L) 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 the lower in-lake nitrite concentrations that accompanied the treatment upgrade (Figure 5-18c). Exceedances of the AWQS now only occur in the lower layers of the lake when dissolved oxygen concentrations less than 2 mg/L. These conditions reflect incomplete nitrification of ammonia 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.

5.6 Recreational Water Quality

The suitability of Onondaga Lake for water contact recreation is assessed using two parameters: fecal coliform bacteria and water clarity. Substantial inputs 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 State, fecal coliform bacteria (a class of bacteria present in the intestinal tract of all mammals) 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, the abundance of fecal coliform

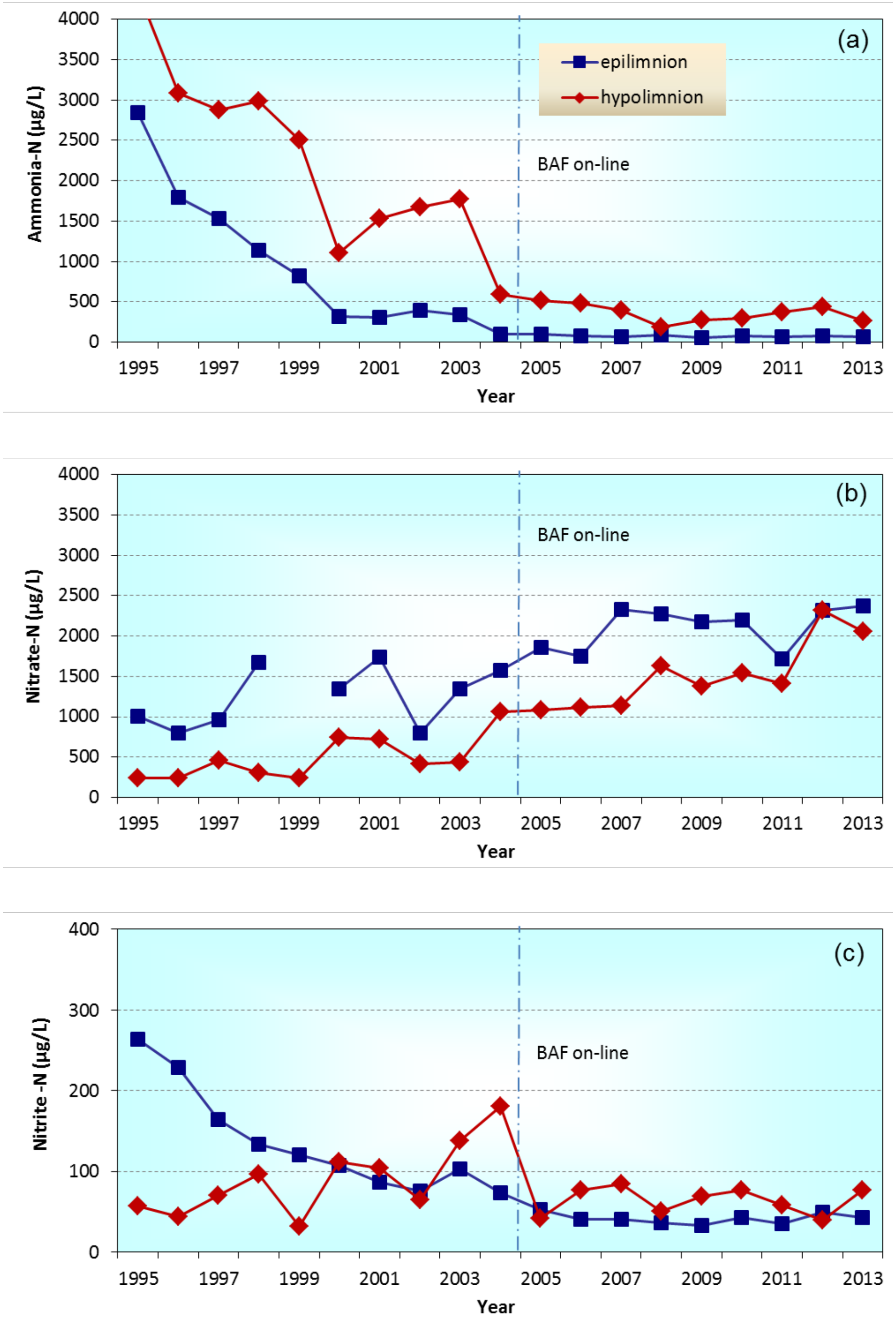


Figure 5-18. Summer average concentrations of nitrogen species in the epilimnion and hypolimnion of Onondaga Lake, 1995–2013: (a) ammonia-N, (b) nitrate-N, and (c) nitrite-N.

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. The NYS Department of Health (NYSDOH) criterion for fecal coliform in bathing beaches are ≤ 1,000 per 100 mL for a single sample and ≤ 200 per 100 mL for a 30 day geometric mean.

The 30-day standard is applied on a monthly basis to assess bacterial contamination at nearshore locations (Figure 5-19) as well as at the open water sites North Deep and South Deep (refer to Figure 1-2). Bacteria levels in southern portions of the lake often increase following significant rainfall, and concentrations can vary by orders of magnitude due to the event-driven nature of the sources. Consequently, geometric means are appropriate for examining spatial and temporal trends. During the April to October interval of 2013, bacteria levels in Class B areas of Onondaga Lake did not exceed the standard established for contact recreation. Two sites, located within the Class C segment of the lake's southeastern shoreline, exceeded the bacteria standard during the month of October, and one of these sites also exceeded the standard in April (Figure 5-19). In addition, bacterial counts at the two offshore monitoring locations, North Deep and South Deep, were below the AWQS for fecal coliform bacteria throughout the 2013 assessment period.

Water clarity is measured at the same network of ten near shore stations. While there is no NYSDEC standard for water clarity, the NYSDOH has a swimming safety guidance value for designated bathing beaches of 4 feet (1.2 meters). With the exception of a single measurement made near the mouth of Bloody Brook in June following a runoff event, the NYSDOH swimming safety guidance value was met in Class B waters throughout the summer recreational period of 2013 (Figure 5-20). Monitoring locations in the southern end of the lake, near the mouths of Onondaga Creek, Harbor Brook, and Ley Creek, regularly failed to meet this guidance value. 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. The guidance value for clarity was not met in the Class C segment at the mouth of Ninemile Creek on two monitoring dates following major runoff events. Dreissenid (zebra, quagga) mussels likely have a significant positive impact on water clarity in the nearshore, while zooplankton have a greater effect on clarity in offshore regions.

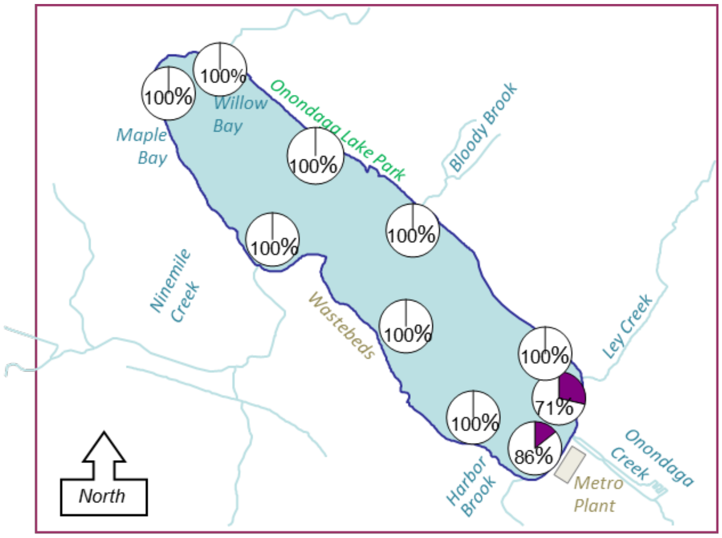


Figure 5-19. The percentage of months in compliance with the water quality standard for fecal coliform bacteria for nearshore stations in Onondaga Lake, April–October 2013.

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).

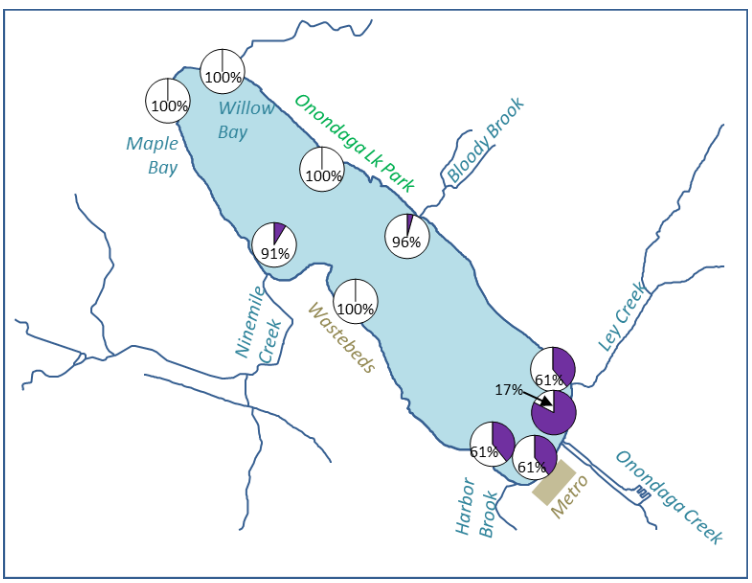


Figure 5-20. Percentage of nearshore Secchi disk transparency measurements greater than 1.2 meters (4 feet) during June–September 2013.

Note: The percent shown in figure indicates compliance with swimming safety guidance value (1.2 m), and the shaded area of pie charts indicates percent of samples where Secchi depth was below the guidance value for the period June 1 through September 30.

5.7 Nearshore Trends

Onondaga County WEP has monitored near shore water quality conditions as part of the AMP since 2000. The monitoring program has included 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 are included in the annual AMP report for 2010.

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 nearshore area (but more robustly represented by turbidity decreases), (2) fecal coliform levels were distinctly higher during wet weather (especially at nearshore stations in the southern end of the lake), (3) decreases over time occurred in wet-weather fecal coliform levels at the southern stations and adjacent to the 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. Other than the two sites adjoining the Metro outfall and the mouth of Onondaga Creek, summer monthly geometric means have not exceeded the regulatory limit over the 2003–2013 (11-year) period.

5.8 Long-Term Trends in Water Quality

Advanced wastewater treatment at Metro has resulted in major reductions in loading of total phosphorus, ammonia, and nitrite to Onondaga Lake. The lake has responded positively to these loading reductions, with major improvements documented for a number of key water quality parameters. In this section, long-term trends for the last 10 years (2004–2013) are evaluated statistically using the two-tailed seasonal Kendall test (Table 5-4). It is important to note that the 10-year period covered by this analysis (2004–2013) primarily reflects conditions following the major treatment upgrades in 2004 and 2005. We expect both the number of trends identified and the strength of these trends to diminish as the 10-year analysis period is shifted further in time from these major reductions in phosphorus, ammonia, and nitrite loading.

Table 5-4. Summary of statistically significant trends in lake concentrations during the 2004 to 2013 period, according to two-tailed Seasonal Kendall tests.

Note: See table footnotes for color code. "Upper waters" refers to the 0-3m depth interval and "lower waters" refers to the 12-18m interval.

Variables		South Basin		North Basin		Lake Outlet	
		upper waters	lower waters	upper waters	lower waters	0.6m	3.7m
Clarity	Secchi disk transparency	○	--	○	--	--	--
Bacteria	Fecal coliforms	○	--	○	--	○	--
Nitrogen	Ammonia (NH_3-N)	**-5.8%**	**-8.0%**	○	**-7.7%**	**-7.5%**	**-5.7%**
	Nitrite (NO_2-N)	○	○	**-3.8%**	**-5.5%**	○	**-3.9%**
	Nitrate (NO_3-N)	**2.7%**	**4.8%**	○	**3.0%**	○	**2.1%**
	Organic nitrogen as N	○	**1.2%**	○	○	○	○
	Total Kjeldahl nitrogen as N (TKN)	**-2.0%**	**-3.0%**	**-2.7%**	○	○	○
Phosphorus	Total phosphorus (TP)	**-12.1%**	**-17.2%**	**-13.0%**	**-17.3%**	**-11.4%**	**-10.6%**
	Soluble reactive phosphorus (SRP)	**-16.0%**	**-35.0%**	**-16.7%**	**-33.3%**	**-23.9%**	**-22.9%**
Solids	Total solids (TS)	○	○	○	○	○	○
	Total suspended solids (TSS)	○	○	○	○	○	○
	Total dissolved solids (TDS)	○	○	○	○	○	○
	Volatile suspended solids (VSS)	○	○	○	○	○	○
Chlorophyll	Chlorophyll-*a*	**-8.6%**	--	**-7.5%**	--	--	--
	Phaeophytin-*a*	**-8.3%**	--	**-5.8%**	--	--	--
Carbon	Total organic carbon (TOC)	**-2.0%**	**-2.6%**	**-2.8%**	**-2.3%**	**-2.1%**	**-1.7%**
	Total organic carbon, filtered (TOC-F)	**-3.6%**	**-3.2%**	**-4.6%**	**-4.1%**	**-1.7%**	**-1.3%**
	Total inorganic carbon (TIC)	**-1.9%**	**-2.3%**	**-1.7%**	**-2.3%**	**-2.2%**	**-2.2%**
Other	Alkalinity as $CaCO_3$	○	○	○	○	○	○
	Calcium (Ca)	○	○	○	○	○	○
	Chloride (Cl)	○	○	○	○	○	○
	Specific conductance	○	○	○	○	○	○
	Dissolved oxygen (DO)	○	○	**1.3%**	○	○	○

Table 5-4. Summary of statistically significant trends in lake concentrations during the 2004 to 2013 period, according to two-tailed Seasonal Kendall tests.

Note: See table footnotes for color code. "Upper waters" refers to the 0-3m depth interval and "lower waters" refers to the 12-18m interval.

Variables		South Basin		North Basin		Lake Outlet	
		upper waters	lower waters	upper waters	lower waters	0.6m	3.7m
	Hardness	○	○	○	○	○	○
	Magnesium (Mg)	○	○	○	○	○	○
	Sodium (Na)	○	○	○	○	○	○
	pH	**-0.1%**	○	○	○	**0.2%**	○
	Dissolved Silica (SiO_2)	○	○	○	○	○	○
	Sulfate (SO_4)	○	○	○	○	**-2.3%**	○
	Temperature	○	○	○	○	○	○

Notes:
Two-tailed Seasonal Kendall test accounting for serial correlation, evaluated at the 10% significance level.
Blue value (%) indicates decreasing trend
Red value (%) indicates increasing trend
○ indicates no trend
- dash indicates parameter not measured at this location.

5.8.1 Indicators of Primary Production

Primary production, algal biomass, and related parameters have declined in response to increased limitation to growth from decreases in phosphorus loading from Metro. Significant decreasing trends in ammonia, total Kjeldahl nitrogen, total phosphorus, soluble reactive phosphorus, organic carbon (total and filtered), and total inorganic carbon were identified for both the upper and lower layers (Table 5-4). Decreases in chlorophyll-*a* were identified for the upper waters. The significant increase in nitrate over the same period is primarily a manifestation of year-round nitrification at Metro. Honeywell's nitrate addition pilot project also increased nitrate levels in the hypolimnion during 2011–2013.

5.8.2 Phosphorus

Scatterplots of water year (October 1 to September 30) total phosphorus (TP) loading estimates and summer average (June 1 to September 30) TP concentrations for the 1999 to 2013 period depict systematic decreases in both loading and in-lake concentrations achieved by the upgrades in treatment at Metro (Figure 5-21). The water year time segmentation is more consistent with the specified summer interval of the in-lake total phosphorus guidance value than an annual load. Empirical analysis according to linear least-squares regression demonstrates that changes in Metro loads explained 78% (R^2 = 0.78) of the observed variations in the summer average total phosphorus concentration of the upper waters (Figures 5-21a). The relationship becomes substantially weaker (R^2 = 0.42) when tributary contributions are included in the independent variable (Figure 5-21b). The weaker empirical model from inclusion of tributary contributions is attributable to multiple factors, 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.

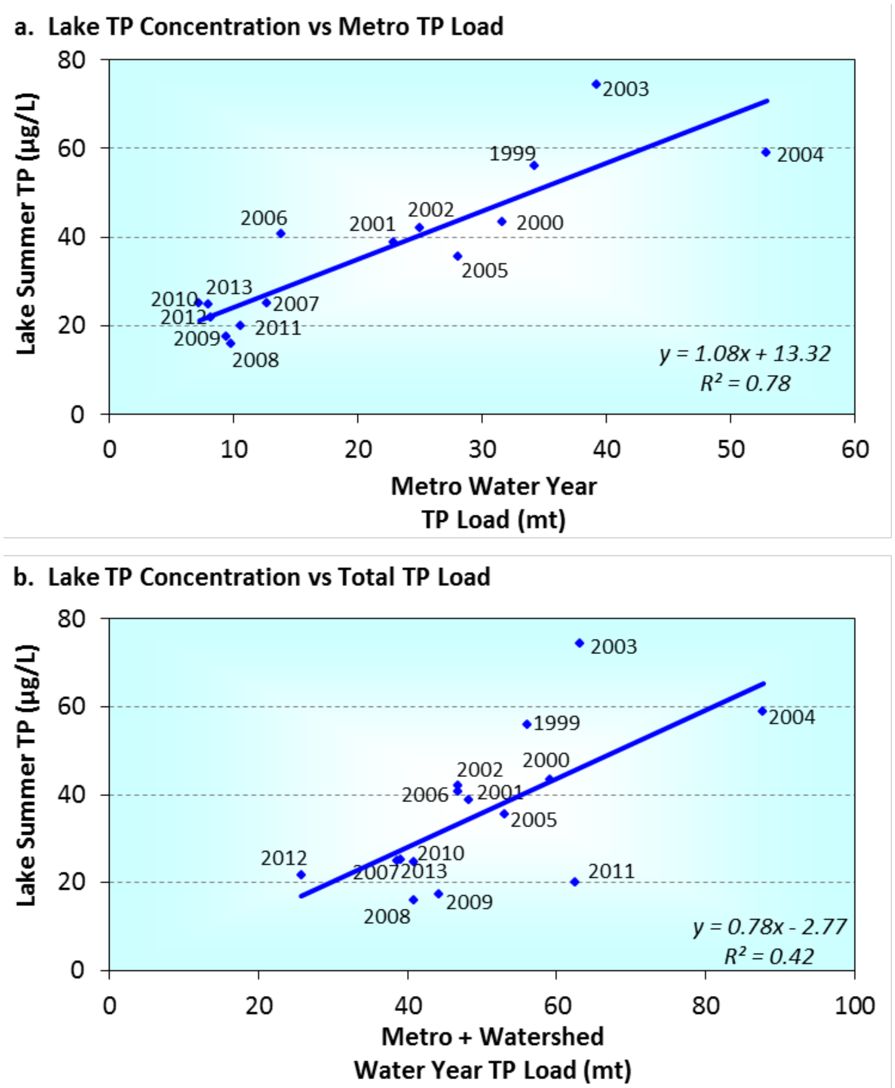


Figure 5-21. Evaluation of the relationship between summer (June–September) average total phosphorus (TP) concentration in the upper waters (0–3 meters) of Onondaga Lake and TP loading for the 1999–2013 period.

Note: Loads are presented on a water year (October 1–September 30) basis for (a) Metro, and (b) the sum of Metro and the tributaries.

5.8.3 Application of Empirical Models to Explain Contemporary Dynamics in Total Phosphorus and Chlorophyll-a

Summer average total phosphorus concentrations in the upper waters have varied from 15 (2008) to 41 µg/L (2006) over the eight year interval (2006–2013) following implementation of Actiflo® treatment. The regulatory goal of 20 µg L/ has been met in three (2008, 2009, 2011) of these years. The drivers of the contemporary dynamics of trophic state metrics and their relative effects are of water quality and management interest, particularly given the year-to-year differences in the status of the lake related to the goal. Multiple linear regression models for summer average total phosphorus (TP_{epi}) and chlorophyll-*a* (Chl-a_{epi}) were developed and tested for the post-Actiflo® interval (2006–2013), considering three potential drivers of year-to-year variations: the total phosphorus concentration of the Metro effluent (TP_{Metro}), tributary flow (Q_{ON}), and the presence of *Daphnia* (D). The models considered these drivers for the summer (June–September) interval, consistent with the specification for the total phosphorus goal. Tributary flow, a surrogate for phosphorus loading from the watershed, was represented as the summer average for Onondaga Creek (Q_{ON}, m^3/s). Flows for the other tributaries have been found to be strongly correlated to Q_{ON} (Effler 1996). The effect of *Daphnia* grazing (D) was represented as a categorical variable, either present (D = 1) or absent (D = 0).

The best-fit multiple regression relationships were

$$TP_{epi} = 241.6\ (TP_{Metro}) + 4.37\ (Q_{ON}) - 9.09\ (D) - 10.18 \qquad (1)$$

$$Chl\text{-}a_{epi} = 157.8\ (TP_{Metro}) + 2.41\ (Q_{ON}) - 3.39\ (D) - 12.99 \qquad (2)$$

These relationships explained 90% and 91% of the observed variations in TP_{epi} and Chl-a_{epi}, respectively (Figure 5-22). Despite the small sample size (n = 8 years), *p* values for both expressions were highly significant ($p<0.001$). The *p* values for the TP_{Metro}, Q_{ON}, and D components of the TP_{epi} model were 0.050, 0.011, and 0.031, respectively; for the Chl-a_{epi} model these were 0.020, 0.007 and 0.066.

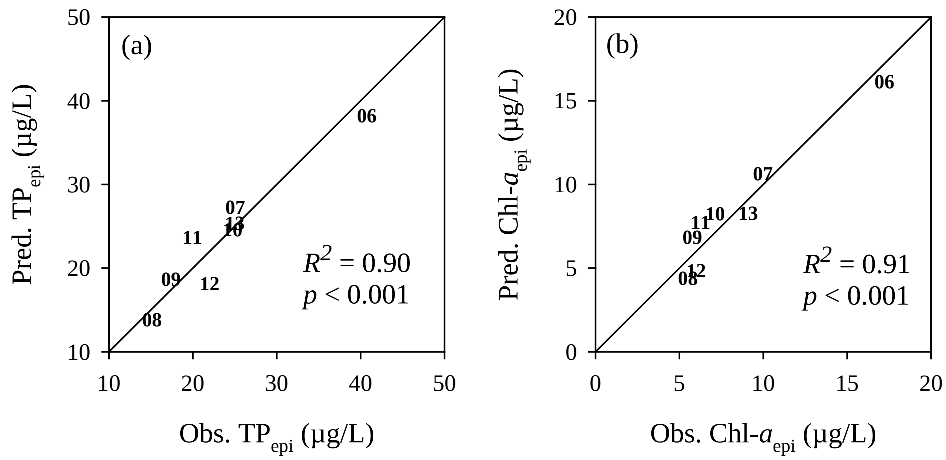


Figure 5-22. Performance of multiple linear regression models in describing contemporary (2006–2013) interannual variations in trophic state metrics: (a) TP_{epi}, and (b) Chl-a_{epi}.

The major improvements in trophic state metrics in Onondaga Lake over the last 30 years have been driven by decreases in the total phosphorus concentration of the Metro effluent, consistent with the historic dominance of the Metro load. With the decrease in the Metro load, other factors now contribute importantly to contemporary variability in trophic state. Inclusion of tributary flow and *Daphnia* as predictor variables in the empirical models for contemporary conditions reflects this change. Tributary phosphorus loading rates to Onondaga Lake have been observed to increase as runoff increases (Effler et al. 2009), supporting Q_{ON} as an appropriate independent variable. Lake total phosphorus concentrations have been reported to decrease as *Daphnia* populations increase (Shapiro and Wright 1984), reflecting efficient removal of phosphorus containing particles. Indeed, the lowest TP_{epi} values (15 and 17 µg/L) were observed in 2008 and 2009 when *Daphnia* were abundant. The inverse dependence of *Daphnia* abundance on planktivorous fish populations, as reported for Onondaga Lake (Wang et al. 2010), has been observed widely (Brooks and Dodson 1965, Carpenter et al. 1987, Rudstam et al. 1993, Lathrop et al. 1999).

5.8.4 N to P Ratio

The relative concentration of nutrients is an important determinant of the composition of the phytoplankton community. The effects of nutrient concentrations on phytoplankton speciation can have water quality management implications, particularly with respect to avoiding proliferation of cyanobacteria (blue-green algae). Cyanobacteria 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 to total 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) TN:TP ratio for the upper waters is presented for the 1998–2013 period (Figure 5-23). 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 1998 to 2013 period (Figure 5-23). The higher values from 2007 to 2013 reflect the effects of systematic decreases in total phosphorus loading from Metro, with mostly unchanging TN concentrations. This representation of the N:P ratio is in fact quite conservative, as the TN pool is dominated by dissolved forms while most of the TP pool in the upper waters of the lake is in particulate form and not available to support algal 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. 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. Cyanobacteria have not been an important component of the algal community in recent years.

5.8.5 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 algal growth and associated deposition, thereby decreasing the oxygen demand associated with its decay. This has been manifested as a delay in the onset of anoxia, described previously, which would be expected to translate to some reduction in the release of soluble reactive phosphorus (SRP) from the sediments. When transported to the upper waters by vertical mixing processes, SRP released from the sediments can act to augment phytoplankton growth.

Phosphorus release from the sediments has been greatly diminished by increased in-lake concentrations of nitrate (Matthews et al. 2013). In the presence of dissolved oxygen or nitrate, sediment phosphorus remains in particulate phase, tightly bound to ferric iron. When oxygen and nitrate are depleted from the surface sediments, iron is converted to the reduced ferrous form and soluble reactive phosphorus is released. Thus maintenance of high nitrate concentrations in the hypolimnion serves to effectively block the release of phosphorus from the sediments. In 2009, depletion of nitrate in the lower waters during August and September resulted in release of soluble reactive phosphorus from the profundal sediments (Figure 5-24). The complete absence of sediment phosphorus release under the high nitrate concentrations of 2013 clearly demonstrates the positive effect of nitrate, even under anoxic conditions (Figure 5-24). This is in stark contrast to the high rates of phosphorus release that prevailed in years when both dissolved oxygen and nitrate were depleted from the hypolimnion (Figure 5-25).

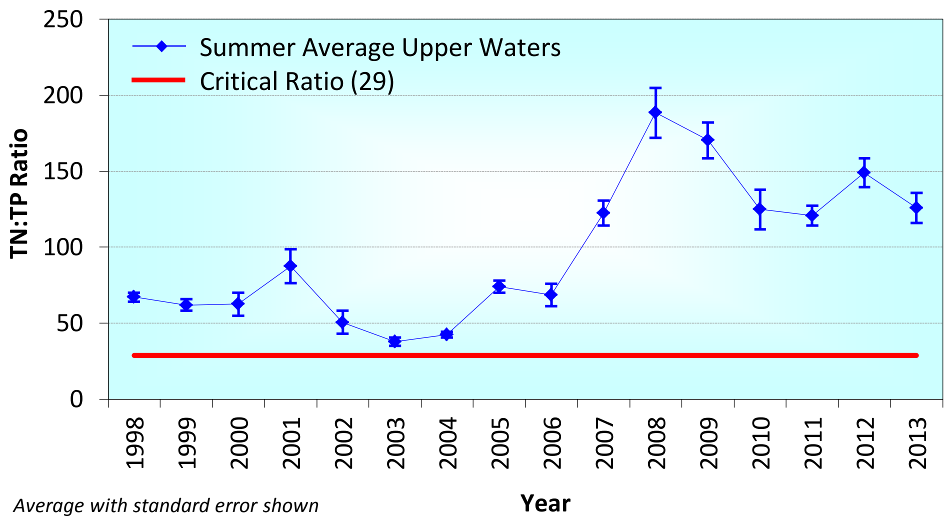


Figure 5-23. Summer average ratio of total nitrogen to total phosphorus (TN:TP, by weight) in the upper waters of Onondaga Lake, 1998–2013. Error bars represent plus and minus 1 standard error.

The mass of phosphorus accumulated in the hypolimnion during the summer stratification interval has decreased by 90% since the 1990s (Figure 5-25). 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 strategy to control sediment release of mercury. Sediment release rates of phosphorus were particularly low during the three year (2011–2013) pilot test of nitrate addition (Figure 5-25).

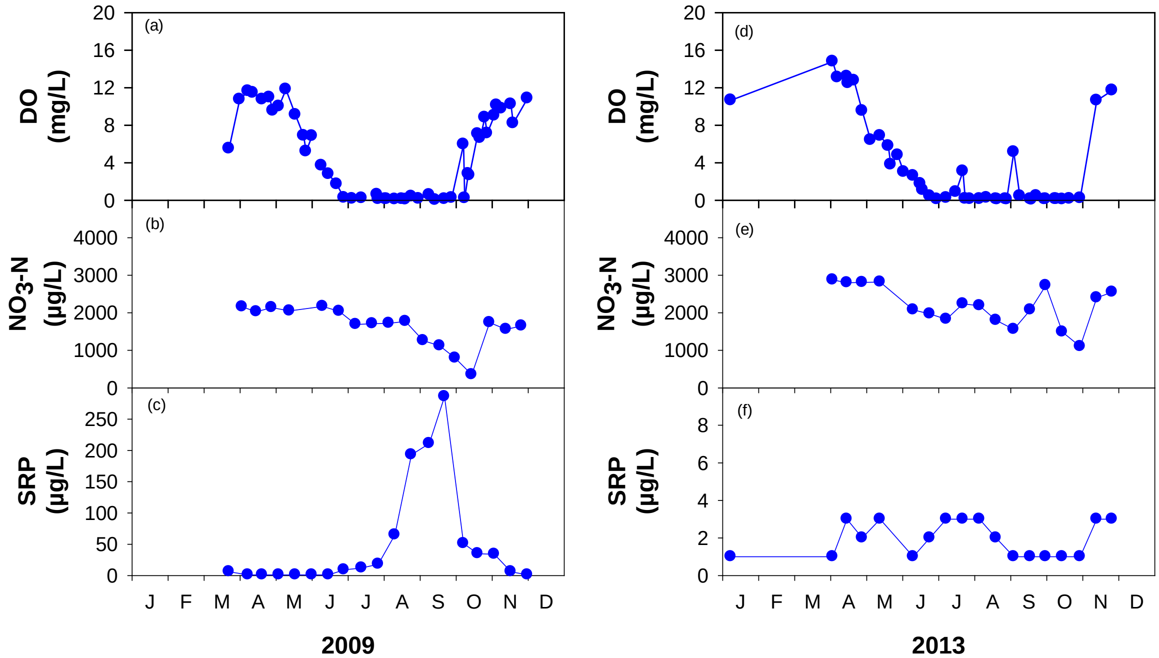


Figure 5-24. Time-series of concentration values in the deep waters of Onondaga Lake: (a) 2009 (18m) dissolved oxygen (DO), (b) 2009 (hypolimnion composite) nitrate (NO_3-N), (c) 2009 (18 m) soluble reactive phosphorus (SRP), (d) 2013 (18 m) dissolved oxygen (DO), (b) 2013 (18m) nitrate (NO_3-N), (c) 2013 (18m) soluble reactive phosphorus (SRP).

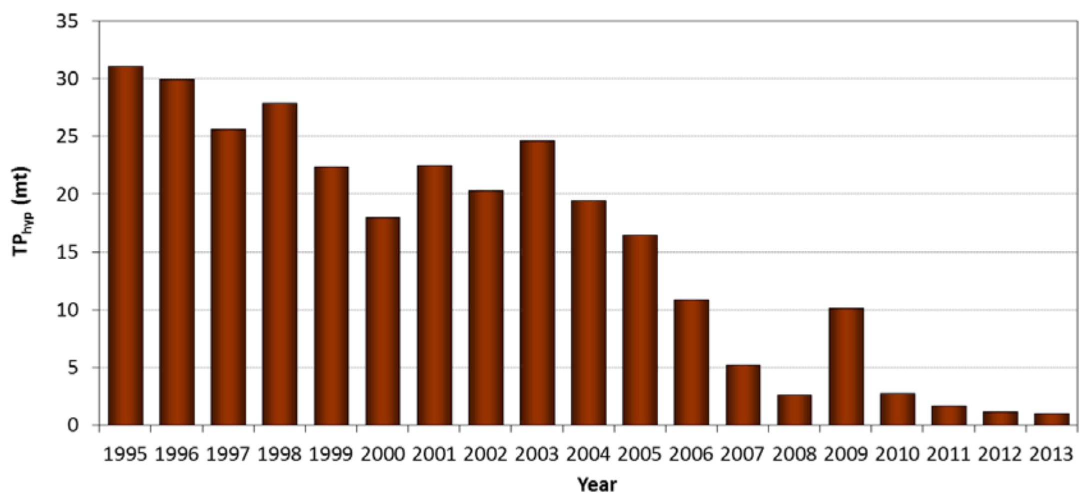


Figure 5-25. The maximum mass of total phosphorus (TP) accumulated in the hypolimnion during summer stratification, 1995–2013.

Section 6. Biology and Food Web: 2013 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. The goals for the biological monitoring program are summarized according to program component: phytoplankton (Appendix A-8), macrophytes (Appendix A-9), zooplankton (Appendix A-10), and fish (Appendix A-11).

As phosphorus concentrations in Onondaga Lake have declined to mesotrophic levels (see Section 5.3.4) biological conditions have responded. Improved light penetration, a consequence of lower algal abundance resulting from the reduced phosphorus concentrations, has resulted in expansion of macrophyte beds. This expanded coverage of macrophytes throughout the littoral zone has improved habitat and shelter for many fish and other aquatic organisms.

6.1 Primary Producers

6.1.1 Phytoplankton

Since 2007 algal biomass in Onondaga Lake has been below 2 mg/L (April through October averages), a level lower than expected in meso-eutrophic systems (3-5 mg/L, Wetzel 2001). However, average biomass in 2013 was slightly higher than in 2012 and about three times the value from 2008 (Figure 6-1). Peak biomass exceeded 5 mg/L (Figure 6-2), as it did in 2012. Peak biomass did not exceed 4.1 mg/L from 2007 to 2011. An unusually wet June and early July may have contributed to increased nutrient inputs to the lake and higher phytoplankton biomass compared to recent years. In nearby Oneida Lake, bluegreen blooms started earlier in 2013 than typical for that lake and this was associated with high nutrient input from the tributaries. The dominant alga in July in Onondaga Lake was the diatom *Uroselenia sp*. This genus had only been observed in two previous years, 2007 and 2011.

The longer term time trend shows a continuous decline in algal biomass since 1998 that is highly significant (Figure 6-1). However, algal biomass has not declined further since low values in 2008. We attribute the low algal biomass to lower phosphorus loading since implementation of enhanced phosphorus removal at the Metro wastewater treatment plant. In 2008 and 2009, algal biovolume was also affected by grazing from large zooplankton. Large zooplankton were rare in 2013. A detailed report on lower trophic levels of Onondaga Lake can be found in Appendix F-1.

The composition of the phytoplankton community has changed from one dominated by undesirable blue-green algae (Cyanobacteria) and dinoflagellates (Pyrrhophyta) to one dominated by more desirable diatoms (Bacillariophyta) and green algae (Chlorophyta; Table 6-1; Figure 6-2). Phytoplankton biomass peaked in May during the diatom-dominated spring bloom and again in July and August (Figure 6-2). Biomass was low from the end of June through the beginning of August. The summer phytoplankton consisted of diverse assemblage including diatoms, chlorophytes, chrysophytes, and cryptophytes although the peaks in July and August were again dominated by diatoms. A small peak in cyanophytes occurred in the end of September (Figure 6-3)

Figure 6-1. The mean April–October standing crop of phytoplankton in Onondaga Lake, 1998–2013.

Table 6-1. Phytoplankton scientific and common names.

Scientific Division	Common Name
Cyanophyta (Cyanobacteria)	Blue-green algae
Pyrrhophyta	Dinoflagellates
Bacillariophyta	Diatoms
Chlorophyta	Green algae
Cryptophyta	Brown algae
Chrysophyta	Golden algae

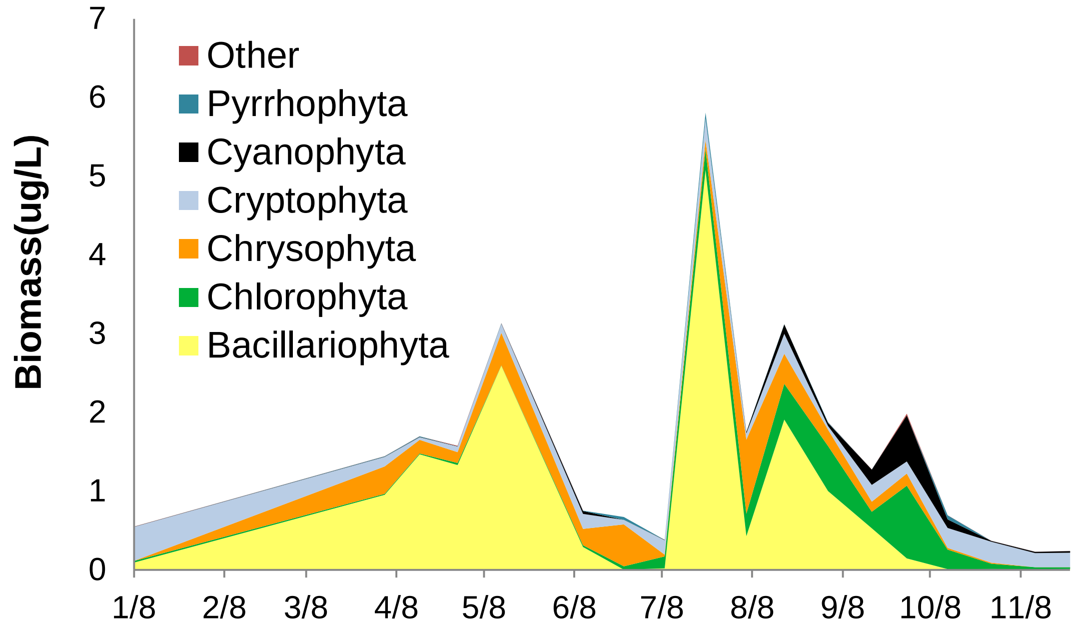


Figure 6-2. Phytoplankton community structure and biomass, 2013.

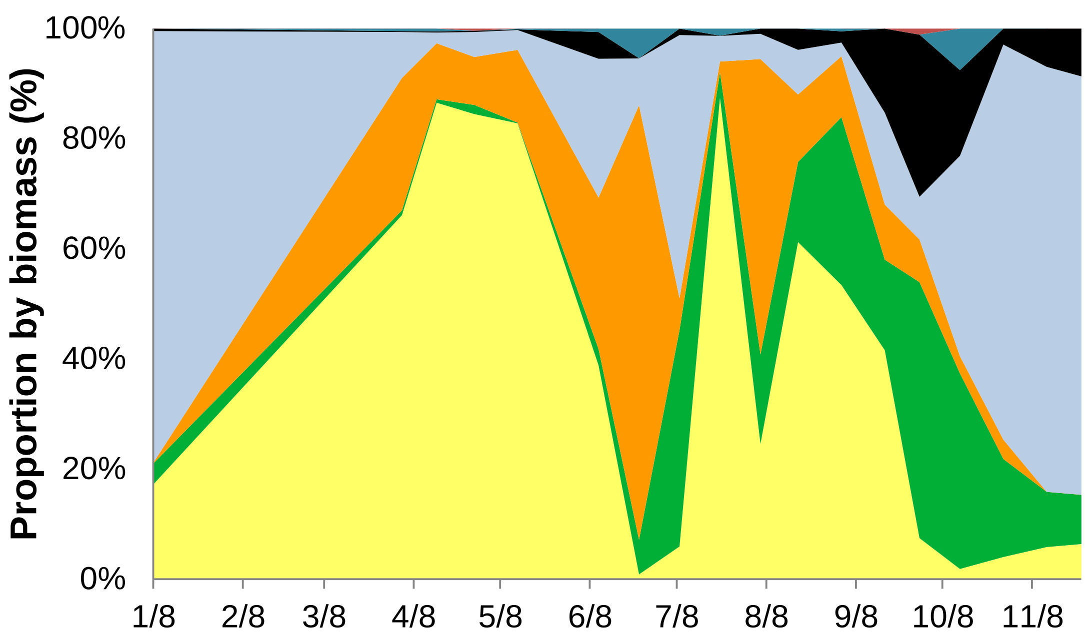


Figure 6-3. Proportional biomass of phytoplankton divisions, 2013.

6.1.2 Macrophytes

Macrophytes in Onondaga Lake

Macrophytes play a critical role in lake ecosystems. Macrophytes provide food for waterfowl and wildlife, protect small fish, create spawning habitats, act as refuges for zooplankton, and oxygenate water. They reduce erosion by providing bottom stability and diminishing wave action. Macrophytes also play a crucial role in nutrient transport from the sediments (James et al. 2001). As part of the ACJ, the AMP included extensive sampling of the macrophyte community every five years (2000, 2005, and 2010) to document species occurrence and biomass. In addition, aerial photographs of the littoral zone (i.e., depths 6 m or less) were collected annually, when water clarity allowed, to determine plant distribution. A detailed report on 2013 Onondaga Lake macrophyte monitoring can be found in Appendix F-2.

The overall coverage of macrophytes in 2013 (387 acres) was less than observed in 2012 (505 acres), an approximately 15% reduction in percent coverage of the littoral zone. However, the estimated percent coverage of 50% in 2013 was similar to the three years prior to 2012 (2009 through 2011; Figure 6-4). Remedial activities occurring in the southern end of the lake may account for the reduced vegetation observed in 2013 compared to 2012. Areas within the dredging zone in 2012 (64 acres) and 2013 (129 acres) were not assessed due to the disturbance caused by dredging activities. The percent cover values in Figure 6-4 reflect the calculated plant coverage area, excluding the dredged areas, divided by the total littoral zone of 777 acres. Therefore, these percent cover values include the assumption that the dredging area is absent of plants. Macrophyte coverage increases to 66% in 2013 if the 129 acres dredged are excluded from the calculation. Macrophytes have expanded to cover approximately five times more of the littoral zone in 2013 compared to 2000, increasing habitat for many aquatic organisms (Figure 6-5).

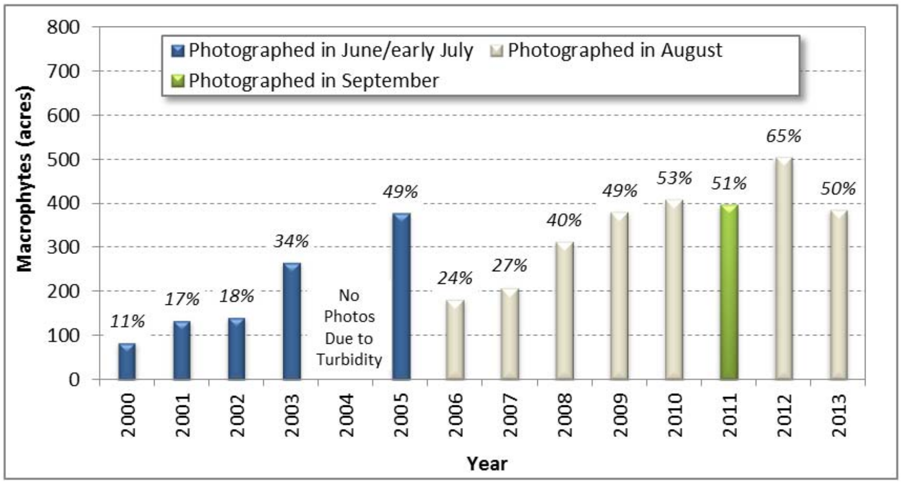


Figure 6-4. Macrophyte distribution, 2000–2013. Percentage represents coverage of the littoral zone (to depth of 6 m).

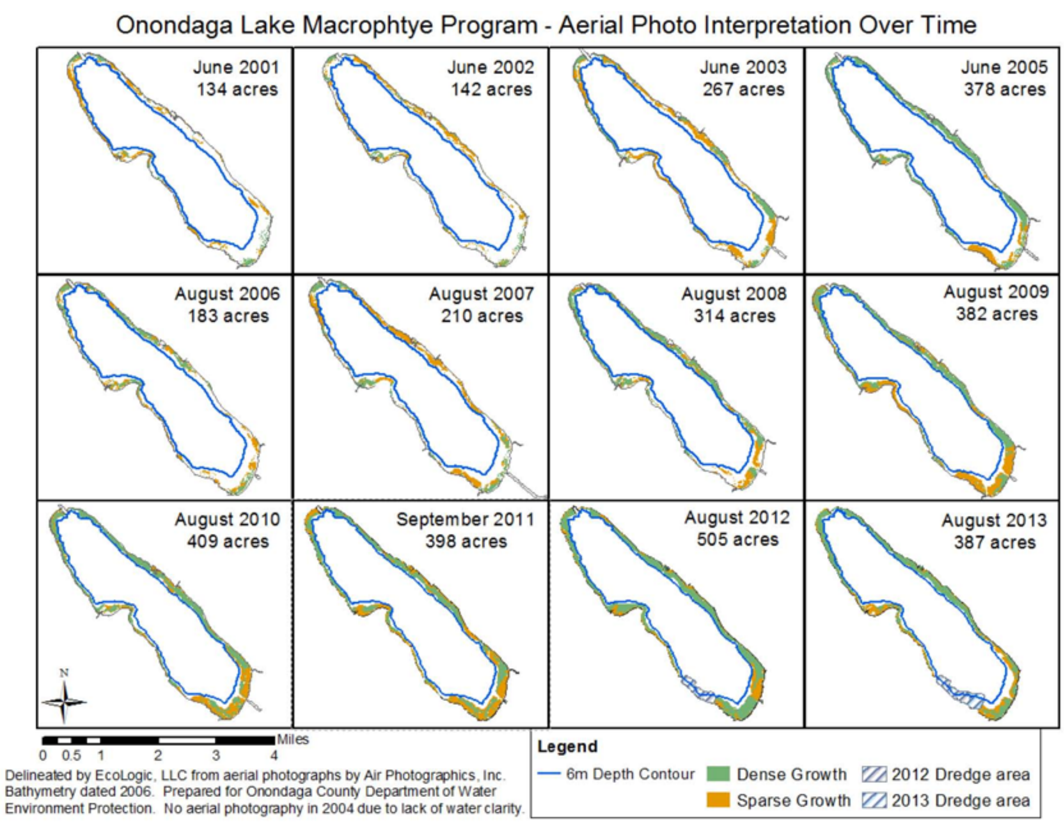


Figure 6-5. Macrophyte coverage, 2001–2013.

The annual aerial photos do not allow for species identification, only percent cover. The AMP team completes limited field surveys of the macrophyte community during the week of the aerial flights to verify the estimates of relative abundance and assess species composition. During the ground truthing effort eight taxa were identified at ten sites. Coontail *(Ceratophyllum demersum)*, and water stargrass *(Zosterella dubia)* were the most widely distributed species, found at 80% of the sites. Species found at 50% to 60% of the sites were Eurasian water milfoil *(Myriophyllum spicatum),* southern naiad *(Najas guadalupensis)* and common waterweed *(Elodea canadensis);* Sago pondweed *(Stuckenia pectinata)* and stonewort *(Chara vulgaris)* were found at 40% and 30% of sites, respectively. Water crowfoot (*Ranunculus* species) was found at one site. Water stargrass had the highest overall (lakewide) relative abundance (32%), with stonewort (23%) and coontail (21%) second and third in overall relative abundance; the remaining species were present at 10% or less. The spread of Eurasian water milfoil in Onondaga Lake has slowed considerably since 2005. The expanding number of macrophytes species and improved growing conditions now found in the lake may be providing strong enough competition to keep Eurasian water milfoil from becoming overly dominant. It is also possible the presence in the lake of the milfoil-grazing moth *Acentria ephemerella* could be limiting expansion of this invasive species.

6.2 Zooplankton

The zooplankton community is a central component of the lake ecosystem; these grazing aquatic animals affect the abundance and species composition of the phytoplankton community. Zooplankton, in turn, are a critical food for many species of fish, particularly in early stages of development. The size structure and abundance of the Onondaga Lake zooplankton community is tracked annually as part of the AMP. A detailed report on Onondaga Lake zooplankton monitoring results can be found in Appendix F-1. 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 community composition changed dramatically during several time periods; in late summer 2002 as alewife increased in abundance, in summer 2008 following alewife declines, and again during summer 2009 when alewife abundance rebounded (Figure 6-6, Figure 6-7). Alewife preferentially feed on larger zooplankton species. When alewife populations are high, the population of larger zooplankton species declines. With reduced alewife predation, the population of larger zooplankton species increases (Figure 6-6, Figure 6-7).

The average dry weight biomass of zooplankton samples collected in Onondaga Lake in 2013 was 104 µg/L; an increase from 2011 and 2012. Zooplankton biomass has been low since 2010 and there is an overall long-term decline. Variability among years, such as the increase in 2008 and 2009, is due to the low abundance of planktivorous alewife in those two years. The changes over time suggest that the decline in nutrient concentrations caused a 3-5 fold decline in zooplankton and increased planktivory caused a 2-3 fold decline. The average size of the total zooplankton community in Onondaga Lake in 2013 was higher than in 2010–2012, but still indicative of high planktivory rates. The species and size composition is similar to 2003–2007 and 2010–2012 and quite different from what was observed in 2008 and 2009 when the alewife population was low (Figure 6-7).

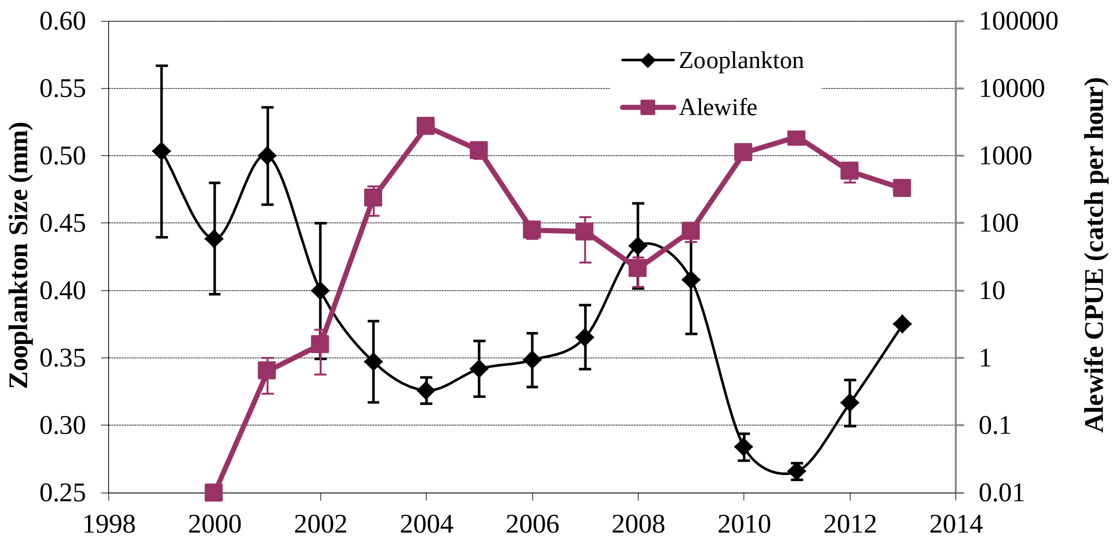


Figure 6-6. Average zooplankton size (all taxa combined) and alewife catch rates from electrofishing, growing season 2000–2013, Onondaga Lake.

Note: error bars are standard error of the mean.

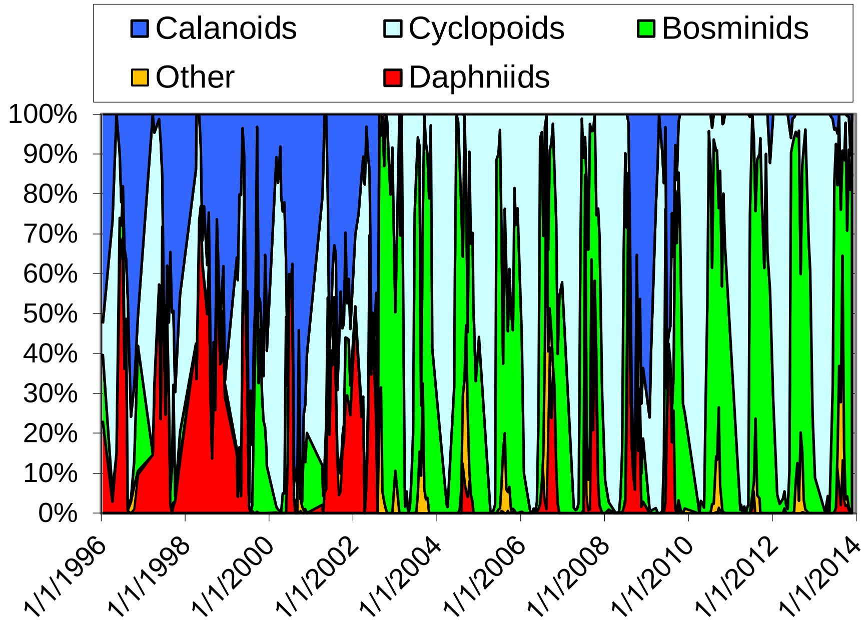


Figure 6-7. Proportion by biomass of major zooplankton groups. Calanoid copepods and daphnids are large taxa and cyclopoid copepods and bosminids are small.

The low biomass of *Daphnia* from 2003 through 2007 and 2010 through 2013 is attributed to the presence of abundant alewife during these periods. *Daphnia* was abundant in 2008 and 2009, and primarily consisted of *D. mendotae* with limited biomass of *D. retrocurva* (Figure 6-8). *D. mendotae* was present from mid-July to early December 2008, and from mid-June through August 2009. All *Daphnia* species have been virtually absent in the lake since fall 2009.

Continued high alewife abundance had an important cascading effect on lower levels of the food web in 2013. Alewife feeding selectively on larger zooplankton leads to lower biomass and smaller average size of the crustacean zooplankton (Figure 6-9). Smaller zooplankton are less efficient grazers of phytoplankton than larger ones, and phytoplankton abundance increases as a result. More abundant phytoplankton results in decreased water clarity, typically measured as Secchi disk transparency. The relationship between zooplankton size and water clarity is illustrated in Figure 6-10. 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 to 2013, with alewife again abundant and the large zooplankton absent, water clarity was lower than in 2008-2009 and algal biovolume was approximately three times as high as in 2008.

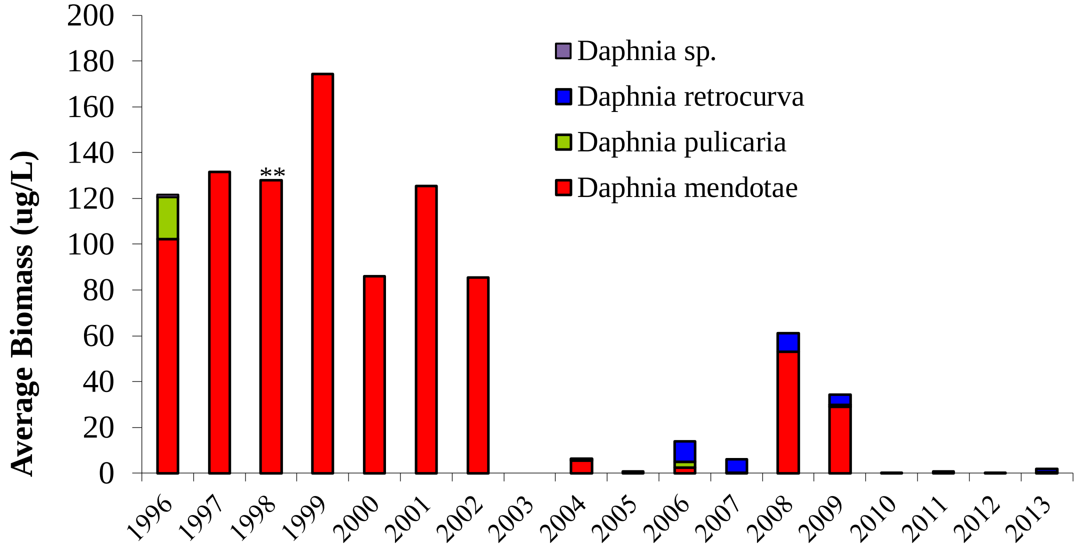


Figure 6-8. Biomass of various *Daphnia* species during the growing season in Onondaga Lake. Daphnids were almost non-existent in 2013. No Data for 1998, ** average biomass for 1998 is chosen as 125 µg/L only to show the species composition for that year.

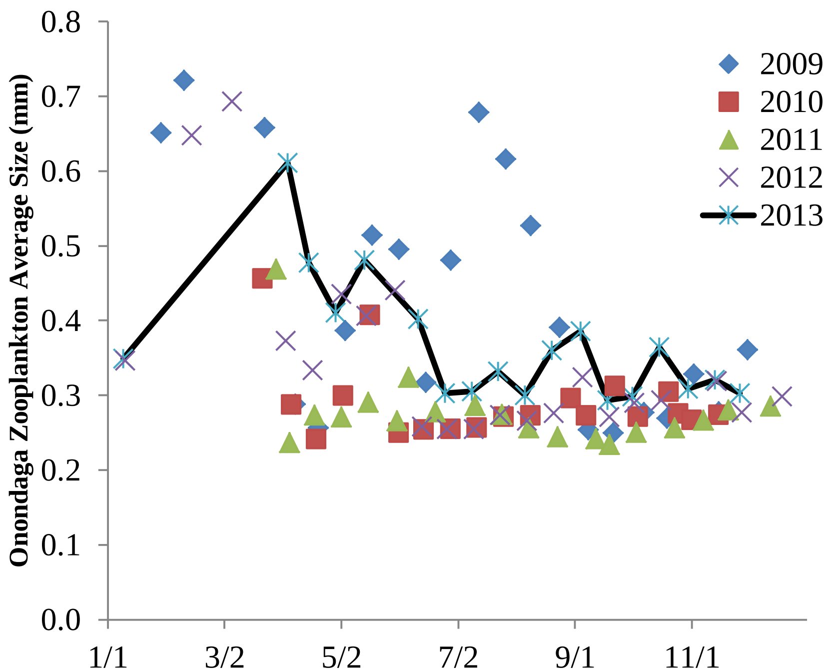


Figure 6-9. Seasonal development of average crustacean zooplankton length (mm), 2009 through 2013. Lines connect the values from 2013.

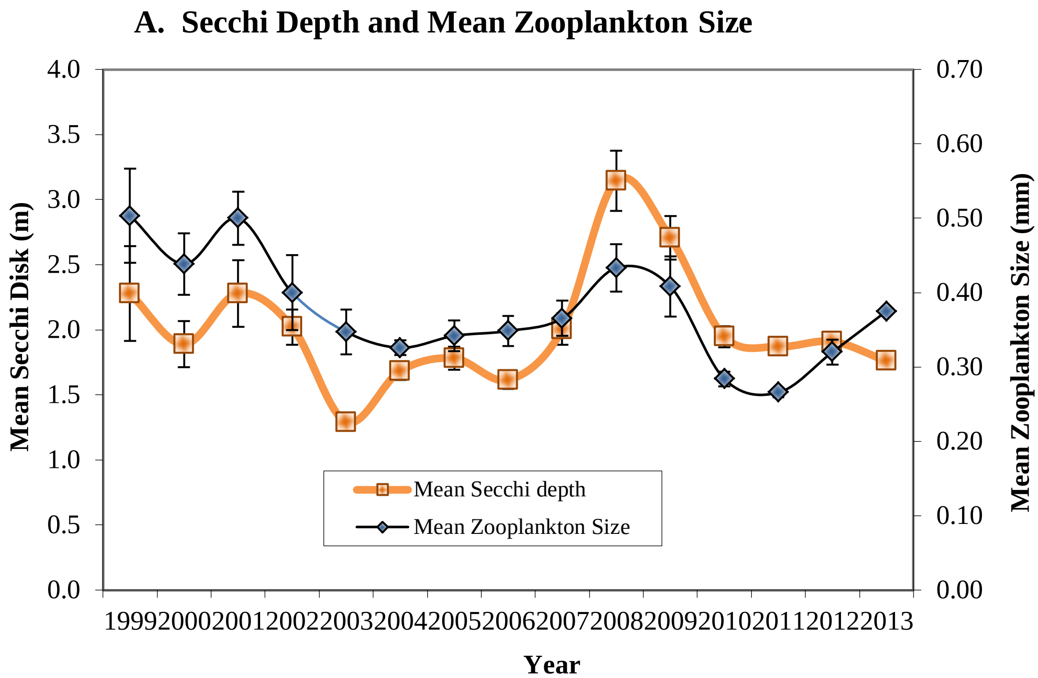
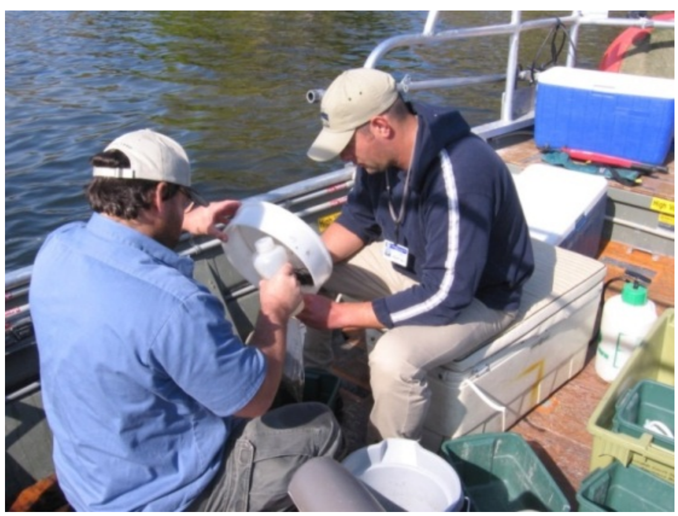


Figure 6-10. Growing season (April-October) mean (± standard error) Secchi disk depth and zooplankton size for Onondaga Lake, 1999–2013.



OCDWEP Technicians Sampling Dreissenid Mussels

6.3 Dreissenid 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 (Mills et al. 1993, Spada et al. 2002). A second related species, the quagga mussel (*Dreissena bugensis*), was also detected in Onondaga Lake in 1992 and again in 2002 (Mills et al. 1993, Onondaga County 2003). Their abundance and distribution has been tracked as part of the AMP using consistent methods since 2005. One modification was made in 2011 when the maximum depth sampled increased from 4.5 m to 6.0 m to determine if quagga mussels had colonized deeper areas of the lake. Assessments in 2013 also included the depths 6.0-7.5 m. Analyses of the time trends are in Appendix F-3. Biomass of quagga mussels increased from 2006 through 2009 when the biomass of quagga mussels lake-wide exceeded that of zebra mussels (Figure 6-11). Biomass of quagga mussels was over 75% of the total mussel biomass in 2010–2012 (water depths shallower than 4.5 m, Figure 6-11) although this declined to 50% in 2013. Quagga mussels dominate in water below 3 m since 2009 whereas both species coexist in water depth 0-3 m (Figure 6-12). In many systems, quagga mussels have displaced zebra mussels over time in many systems but both species tend to coexist in shallow areas were the stronger attachment strength of zebra mussels is an advantage (Karatayev et al. 2013). The biomass of dreissenid mussels declined in 2012 and declined further in 2013 (Figure 6-11). This decline is partly due to declines in the areas dredged by Honeywell but also occurred at other sites. It is possible this decline is also due to an increase in round goby. Declines in dreissenids have been reported elsewhere after the invasion of Round Goby, and quagga mussels are more vulnerable to round goby predation than zebra mussels (Naddafi and Rudstam 2014).

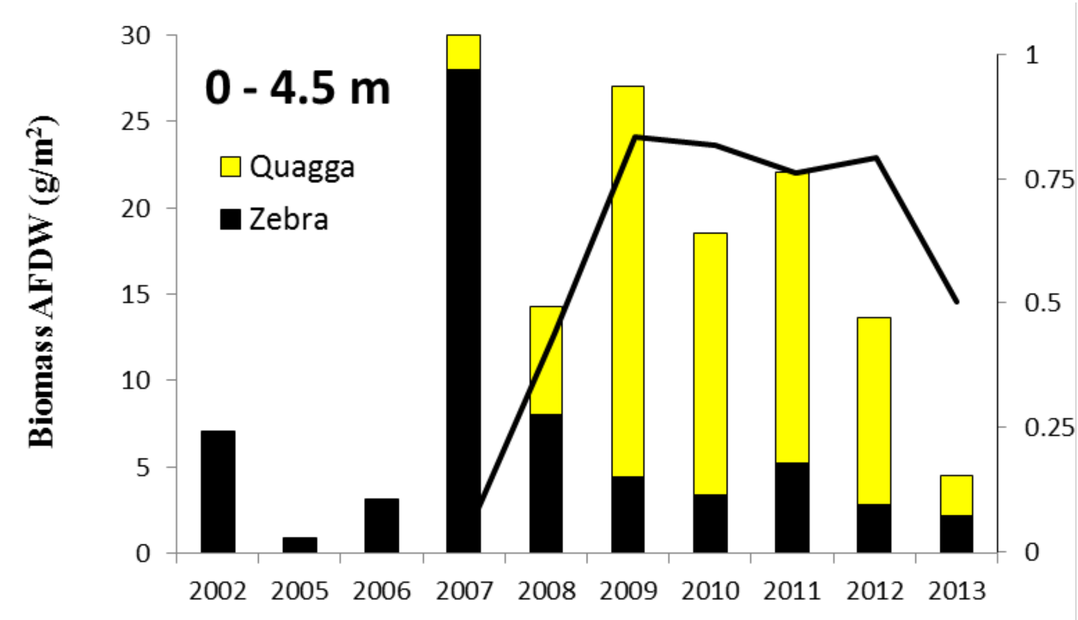


Figure 6-11. Annual time series of dreissenid biomass (ash-free dry weight) in the 0 to 4.5 meter water depth, 2002 to 2013. The line represents the proportion of total dreissenid biomass contributed by quagga mussels.

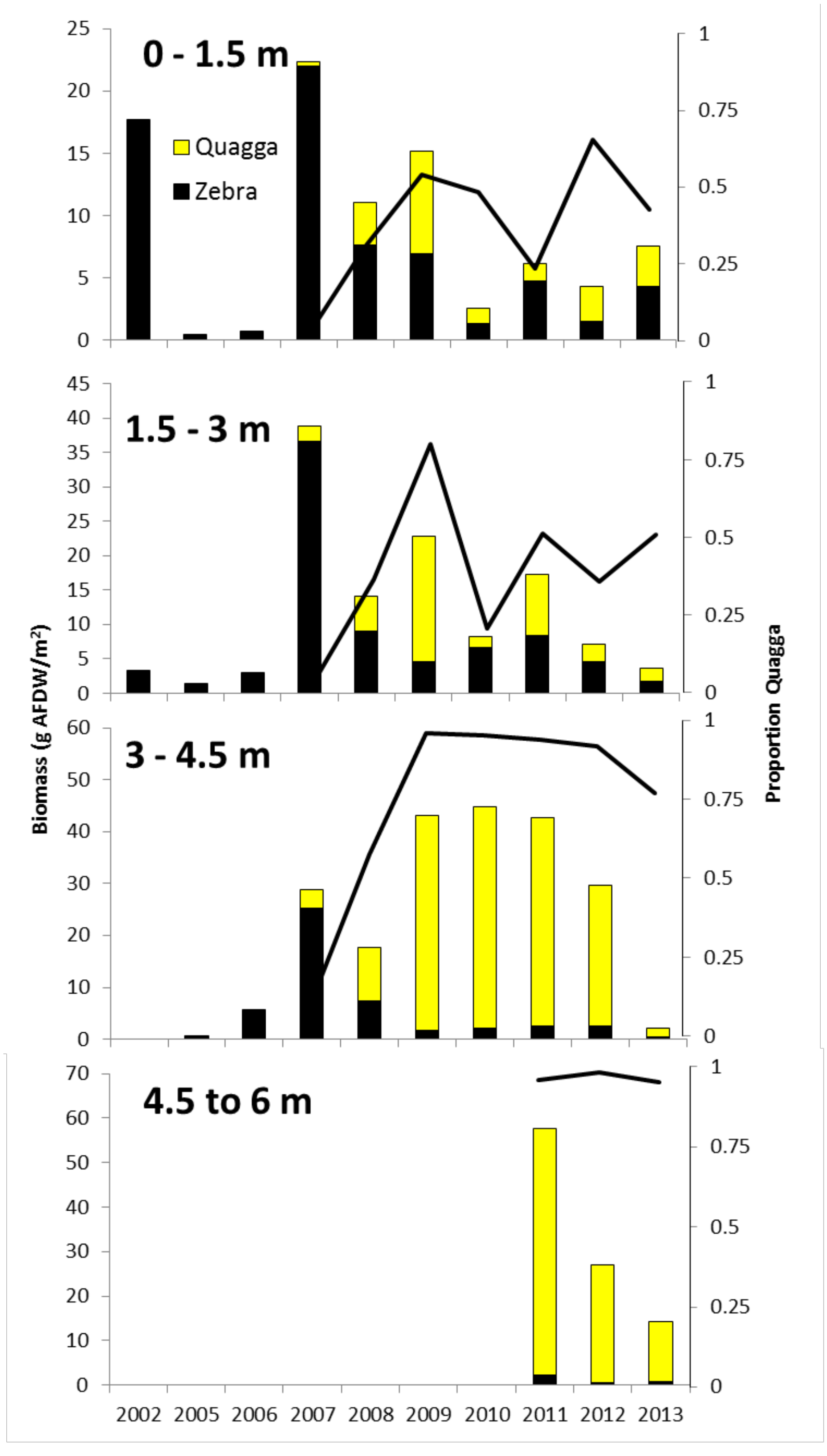


Figure 6-12. Dreissenid mussel average biomass in four depth regions of Onondaga Lake. The proportion of quagga mussels by biomass is indicated by the line. Depths 3–4.5 m were not sampled in 2002 but were reported to have low mussel abundance. Depths 4.5–6m were sampled from 2011–2013.

6.4 Fish

Tiger Muskie collected from Onondaga Lake

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, resulting in the shift from eutrophic to mesotrophic conditions over the past several years, has expanded available fish habitat in both the littoral and pelagic zones. Fish communities are good indicators of aquatic ecosystem conditions because they integrate physical, chemical, and biological conditions and express them in terms of species composition, age and growth characteristics, and reproductive success. Since 2000, an extensive fisheries monitoring program has been included in the AMP, incorporating multiple types of sampling gear to assess nesting, larval, juvenile, and adult stages of the fish community. Since 2000, more than 166,000 individual fish have been captured or observed from Onondaga Lake by Onondaga County's sampling efforts, representing fifty-three species (Table 6-2). Growth and survival of Largemouth Bass are summarized in a separate report (Appendix F-4).

Honeywell implemented an annual biological monitoring program in 2008 to assess mercury concentration in fish tissue. As part of that program, State University of New York College of Environmental Science and Forestry (SUNY-ESF) students conduct sampling to assess the fish community and to calculate population estimates of several sport fish species. During development of Honeywell's monitoring program, project scientists conferred with County employees working on the biological programs to reduce duplication and provide complementary information to the AMP. Some of the SUNY-ESF data are incorporated into this report to provide a more holistic assessment of the overall fish community in Onondaga Lake.

The challenge in fishery data analysis and interpretation lies with the multitude of abiotic and biotic factors affecting the fish community, including annual variability in 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 2013, an assessment of trends observed since the onset of the AMP biological program in 2000, and an assessment of changes in the fish community that integrates data from the Honeywell program from 2008 to 2013.

Table 6-2. Fish species identified in Onondaga Lake, 2000–2013 (all gear types).

Abundant Species (>1000 individuals)		Common Species (50-1000 individuals)		Uncommon Species (<50 individuals)	
Alewife	Golden Shiner	Bluntnose Minnow	Longnose Gar	Black Bullhead	Quillback
Banded Killifish	Largemouth Bass	Bowfin	Northern Pike	Black Crappie	Rainbow Smelt
Bluegill	Pumpkinseed	Channel Catfish	Rock Bass	Brook Stickleback	Rainbow Trout
Brown Bullhead	Smallmouth Bass	Emerald Shiner	Round Goby	Brown Trout	Rudd
CommonCarp	White Perch	Fathead Minnow	Shorthead Redhorse	Chain Pickerel	Silver Redhorse
Gizzard Shad	White Sucker	Freshwater Drum	Tessellated Darter	Creek Chub	Spotfin Shiner
Brook Silverside	Yellow Perch	Logperch	Walleye	Goldfish	Spottail Shiner
				Greater Redhorse	Tadpole Madtom
				Green Sunfish	Tiger Muskie
				Johnny Darter	Trout Perch
				Lake Sturgeon	White Bass
				Longnose Dace	Yellow Bullhead
				Northern Hogsucker	

6.4.1 Reproduction and Recruitment

OCDWEP Technicians Larval Seining

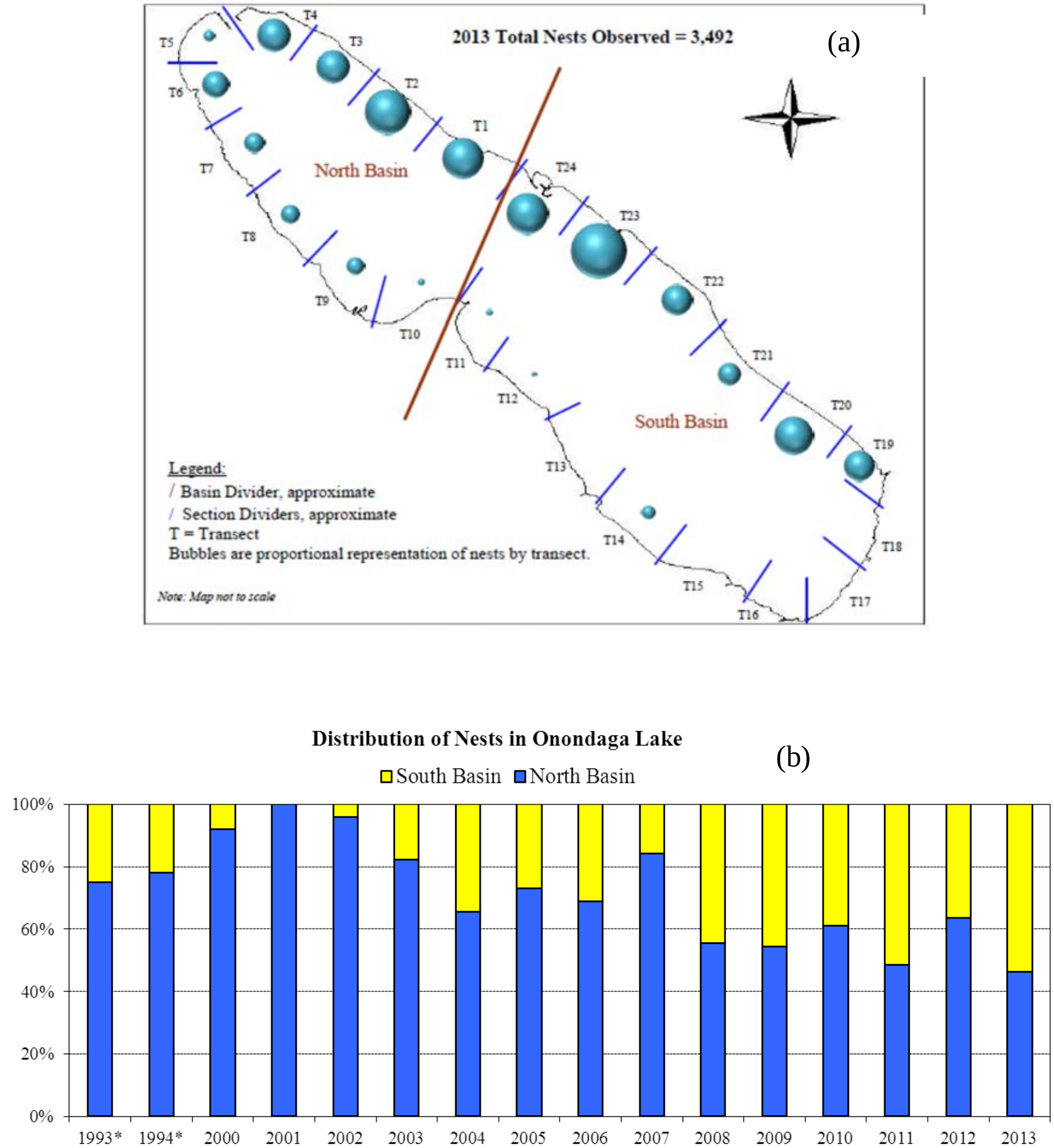
Several methods are used in the AMP to assess fish reproduction and recruitment (i.e., juvenile survival to the adult life stage), including nesting surveys and separate sampling of larval, juvenile, and adult fish. Evaluation of larval and juvenile fish provides information on the overall health of the fish community within the lake and the success of annual reproduction. Additionally, younger life stages often are less tolerant of water quality conditions such as elevated ammonia or low DO than are adults. Fish are known to have variable recruitment from year to year; environmental factors including water quality, habitat availability, wind, water level, and water temperature during and following spawning affect reproductive success. In addition, predation, disease, and competition can affect the reproductive success of many species.

6.4.1.1 Nesting

Centrarchid species (Largemouth Bass *(Micropterus salmoides)*, Smallmouth Bass *(Micropterus dolomieu)*, Pumpkinseed *(Lepomis gibbosus)*, Bluegill *(Lepomis macrochirus)*, Rock Bass *(Ambloplites rupestris)*, and Brown Bullhead construct nests in the littoral zone of the lake. Each year, the AMP team conducts nesting surveys to estimate the number and spatial distribution of the nests of these species. In 2013, 3,492 nests were observed (Figure 6-13), with a fairly even distribution between the north and south basins (46% and 54%, respectively). The distribution of nests between the north and south basins has been more evenly distributed during the past several years, primarily due to increased numbers of nests in the south basin since 2008 (Figure 6-13). 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 wind-induced waves that can cover eggs with sediment and dislodge eggs from nesting areas. The lack of nesting along the southwest shoreline over the past two years is likely due to the Honeywell's dredging and capping activities in that area of the lake. The majority of the nests observed in 2013 were sunfish (Pumpkinseed, Bluegill, and three Rock Bass) accounting for 66% of the total nests identified (Table 6-3). Lesser amounts of Largemouth Bass (1%) and Brown Bullhead (1%) were also observed. The remaining 32% of the nests were described as unknown (nest observed without an adult fish present).

6.4.1.2 Larval, young-of-year, juvenile assessment

A total of 2,975 larval fish representing 12 species was collected during the 2013 larval seine events. Lepomis species (Bluegill and Pumpkinseed) were the most common fish collected composing over 61% of the lakewide catch followed by Banded Killifish *(Fundulus diaphanus)* 23%, Brook Silverside *(Labidesthes sicculus)* 7%, and Golden Shiner *(Notemigonus crysoleucas)* 6%. Smaller numbers of Bluntnose Minnow *(Pimephales notatus)*, Fathead Minnow *(Pimephales promelas)*, Common Carp *(Cyprinus carpio*), Round Goby *(Neogobius melanostomus)*, Alewife, Yellow Perch *(Perca flavescens)*, and Largemouth Bass were also collected. Overall catch per unit effort (CPUE) was higher in 2013, compared to other years when larval seines were used (2000 through 2003 and 2012), and the number of species collected in 2013 was the highest since 2000 (Figure 6-14).



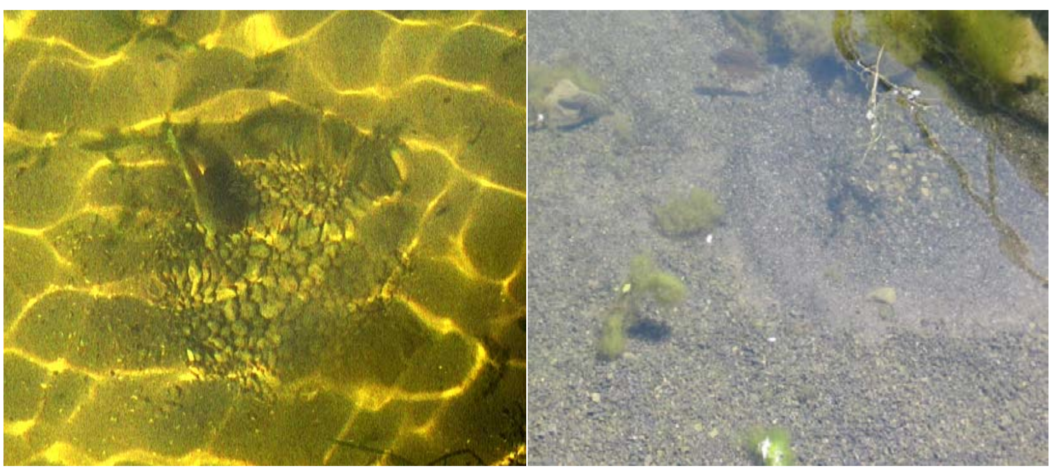
	1993*	1994*	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
North Basin	75%	78%	92%	100%	96%	82%	66%	73%	68.9%	84.1%	55.4%	54.4%	61.0%	48.5%	63.6%	46.4%
South Basin	25%	22%	8%	0%	4%	18%	34%	27%	31.1%	15.9%	44.6%	45.6%	39.0%	51.5%	36.4%	53.6%
Nest count by basin																
North Basin	958	1291	3301	1887	2042	1430	1409	739	848	1759	3941	1085	1250	1159	1537	1620
South Basin	319	364	287	0	85	307	737	273	383	332	3170	910	800	1231	879	1872
Total	1277	1655	3588	1887	2127	1737	2146	1012	1231	2091	7111	1995	2050	2390	2416	3492

Figure 6-13. Fish nesting survey map (a) and comparison of north vs. south 1993–2013 (b).

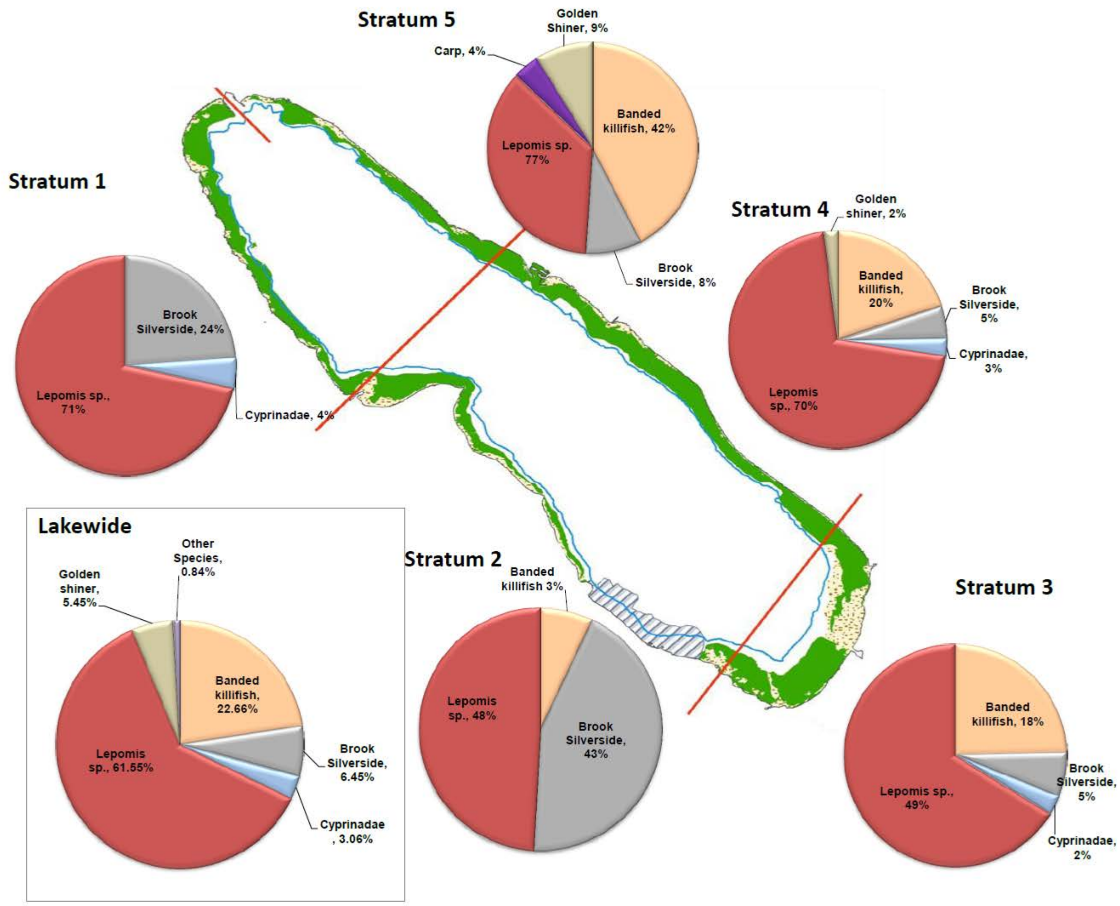
Table 6-3. Fish species nesting in Onondaga Lake, 2013.

Species	Total Number of Nests	Percent of Total
Bullhead (species unknown)	22	1%
Bluegill	43	1%
Rock Bass	3	0%
Pumpkinseed	1322	38%
Lepomis spp.	944	27%
Largemouth Bass	47	1%
Other	1111	32%

Note: Lepomis spp.refers to Bluegill and Pumpkinseed when unable to differentiate species in the field.



Centrarchid Nests



Year	2000	2002	2003	2012	2013
Overall CPUE	38.64	47.33	47.7	194.73	462.67
Richness	20	12	9	9	12

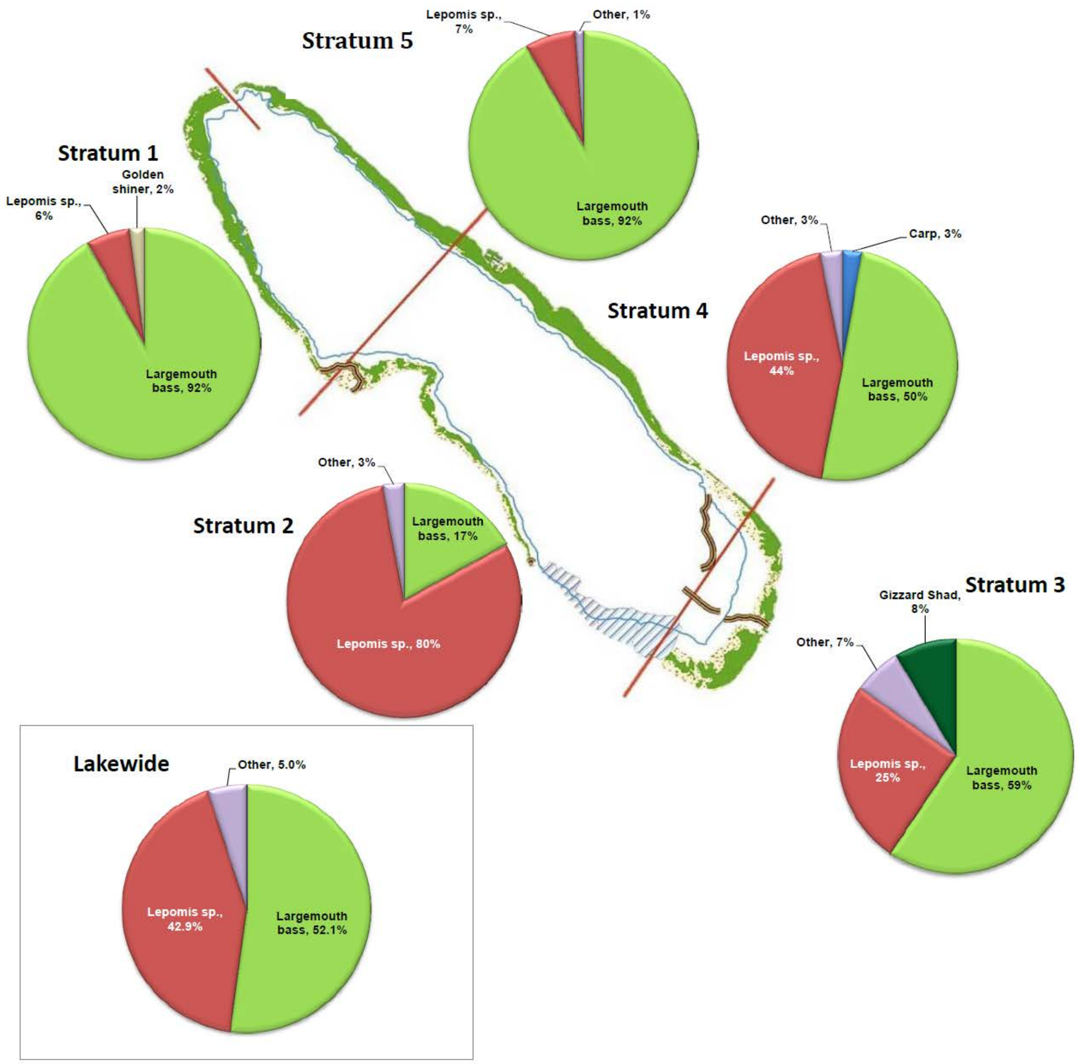
Figure 6-14. Relative abundance of larval fish in 2013 by stratum and species (fish collection by larval seining).

Note: The area of each pie is not proportional to its total.

Littoral zone seining is conducted every three weeks during the summer and early fall to assess young-of-year (YOY) and juvenile (age 1+ or greater, not yet mature) abundance and diversity. Young-of-year Bluegill, Pumpkinseed, Common Carp, Largemouth Bass, Smallmouth Bass, Brown Bullhead *(Ameiurus nebulosus)*, Channel Catfish *(Ictalurus punctatus)*, Gizzard Shad *(Dorosoma cepedianum)*, Golden Shiner, Tadpole Madtom *(Noturus gyrinus)*, and Round Goby were captured in 2013. During all the events combined (total of 75), 1,118 young-of-year fish representing 11 species were captured. Largemouth Bass and Lepomis species (Pumpkinseed and Bluegill) young-of-year were the most abundant species collected composing 52% and 43% of the total catch, respectively. The remaining species together accounted for 5% of the lakewide catch (Figure 6-15). Largemouth Bass was the most abundant species collected in each of the individual strata with the exception of stratum 2 in which Lepomis was the most prevalent species. A marked increase in overall YOY catch per unit effort was greater in 2013 compared to the previous four years (2009 to 2012). The most apparent change was the increase in young Lepomis catch rates from less than 0.16 (2009–2012) to 6.3 in 2013.

Juvenile abundance was evaluated based on the life stage description of "juvenile" in the seining events with 8 species and 445 individuals identified. Lepomis species (Pumpkinseed and Bluegill), Largemouth Bass, and Gizzard Shad were the most common species collected composing 80%, 11%, and 6% of the total catch respectively. The remaining four species (Rock Bass, Brown Bullhead, Green Sunfish *(Lepomis cyanellus)*, and Common Carp) composed less than 3% of the total catch (Figure 6-16). Compared to previous years, the number of juvenile fish species collected in 2013 was lower. The incidental capture of species such as Walleye, Longnose Gar, Northern Pike and Freshwater Drum in previous did not occur in 2013. These species likely immigrate into the lake through the Seneca River and when present in early life history stages are only represented by few individuals that are sporadically captured.

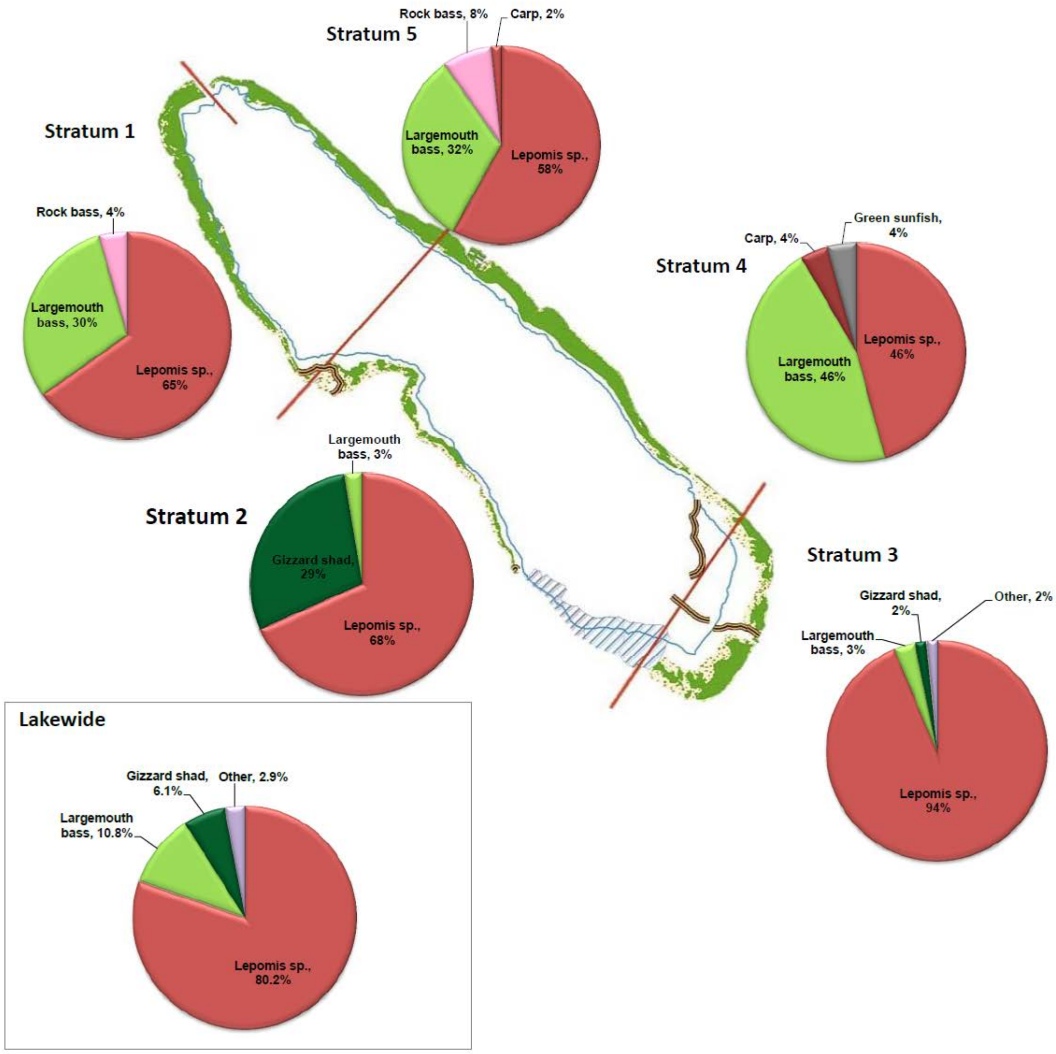
OCDWEP Technicians Juvenile seining



Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Overall CPUE	17.4	127.0	23.1	36.3	27.6	57.5	9.9	16.4	16.9	2.5	5.8	4.2	6.5	14.9
Richness	14	13	14	9	9	12	5	8	13	10	9	9	7	11

Figure 6-15. Relative abundance of young-of-year fish in 2013 by stratum and species. Sampled by seining.

Note: The area of each pie is not proportional to its total.



Note: The area of each pie is not proportional to its total.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Overall CPUE	1.75	9.15	53.54	3.16	0.49	21.36	3.06	4.74	3.69	1.71	3.01	0.94	2.61	5.93
Richness	18	20	16	14	11	14	13	11	14	15	14	16	15	8

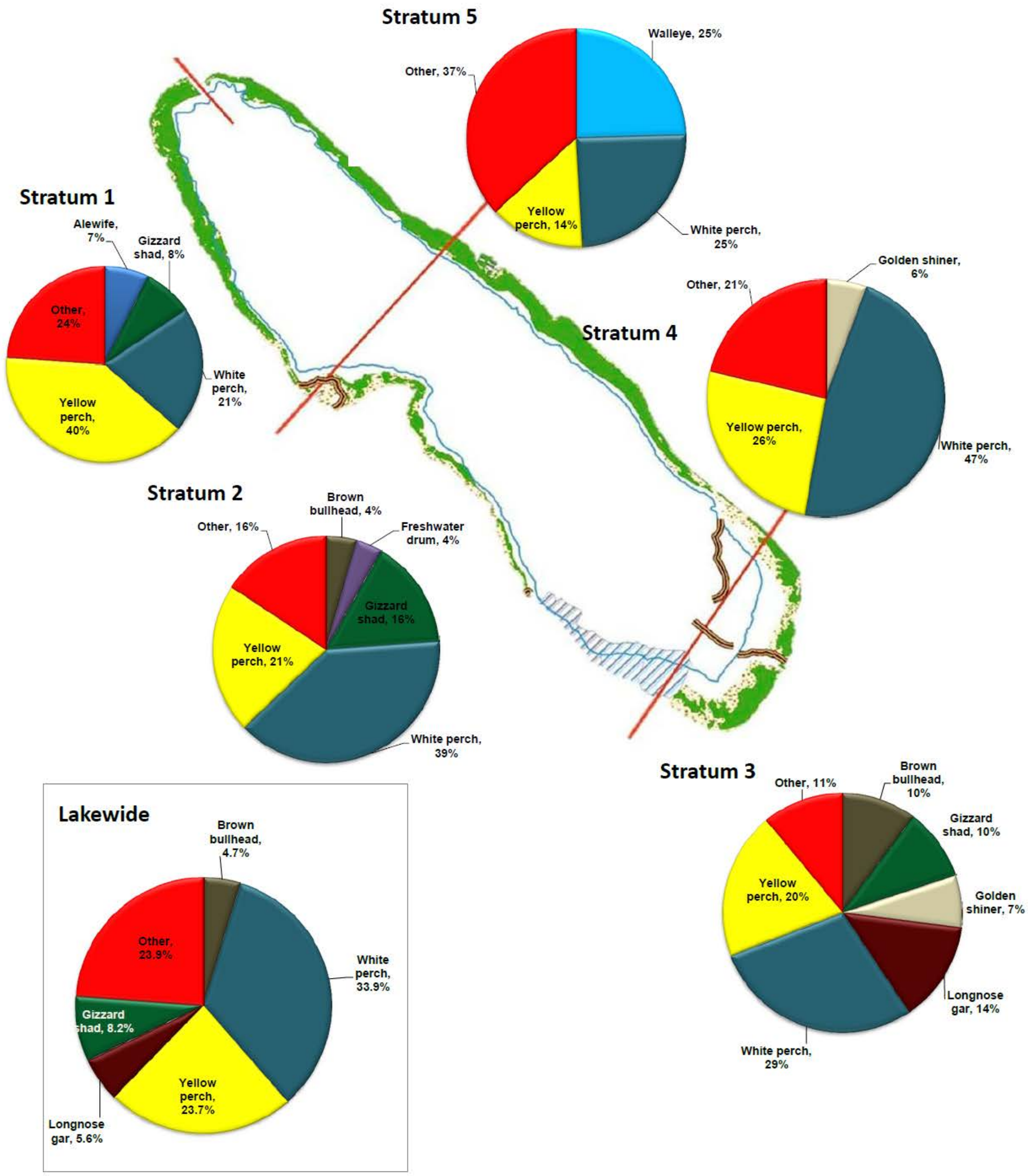
Figure 6-16. Relative abundance of juvenile fish in 2013 by stratum and species. Life stage indicated as juvenile during seining and electroshocking (young-of-year excluded).

6.4.2 Fish Community

6.4.2.1 Abundance

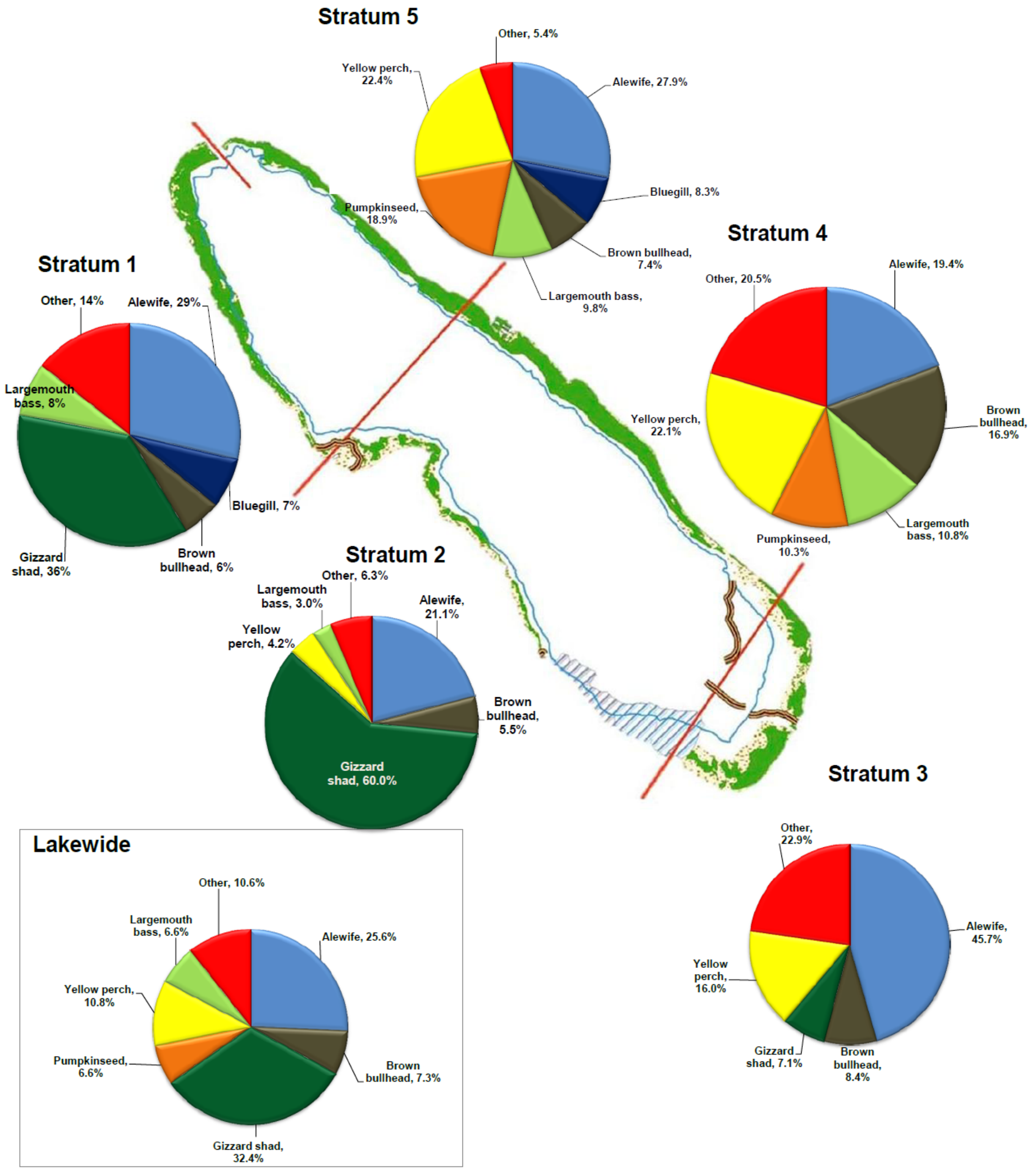
The relative abundance of the adult fish community has been assessed by two sampling programs. Pelagic adults are sampled using experimental gillnets in the deeper littoral zone and pelagic zone, while littoral adults are sampled by boat electrofishing in the littoral zone. Some adults, particularly the smaller species (minnows and killifishes) are captured during the littoral juvenile seining as well. In 2013, 746 fish were collected in gillnets comprising 23 species. White Perch (*Morone americana*) were the most abundant species collected comprising 34% of the total catch. Lesser amounts of Yellow Perch (24%), Gizzard Shad (8%), Longnose Gar (*Lepisosteus osseus; 6%*), and Brown Bullhead (5%), were collected (Figure 6-17). Overall catch per unit effort (CPUE) was higher than rates seen in previous years (Figure 6-17). However, the increased catch rates observed in 2013 may be a function of changes made to the pelagic adult fish community sampling program (change from day to night set). A total of 7,918 fish representing 23 species was collected during the two boat electrofishing events. Six of the 23 species accounted for 89% of the catch. Gizzard Shad was the most abundant species collected making up 32% of the catch, followed by Alewife (26% of catch), Yellow Perch (11%), Brown Bullhead (7%), Pumpkinseed (7%), and Largemouth Bass (7%). Seventeen of the 23 species collected together constituted 11% of the catch. Overall CPUE was 1,019 fish per hour (Figure 6-18).

OCDWEP Technicians Electrofishing



Year	2000	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Overall CPUE	0.31	4.7	7.6	12.53	13.25	7.26	6.09	3.72	2.74	5.69	6.05	12.62	13.64
Richnes	9	10	12	11	16	11	16	12	11	15	16	21	23

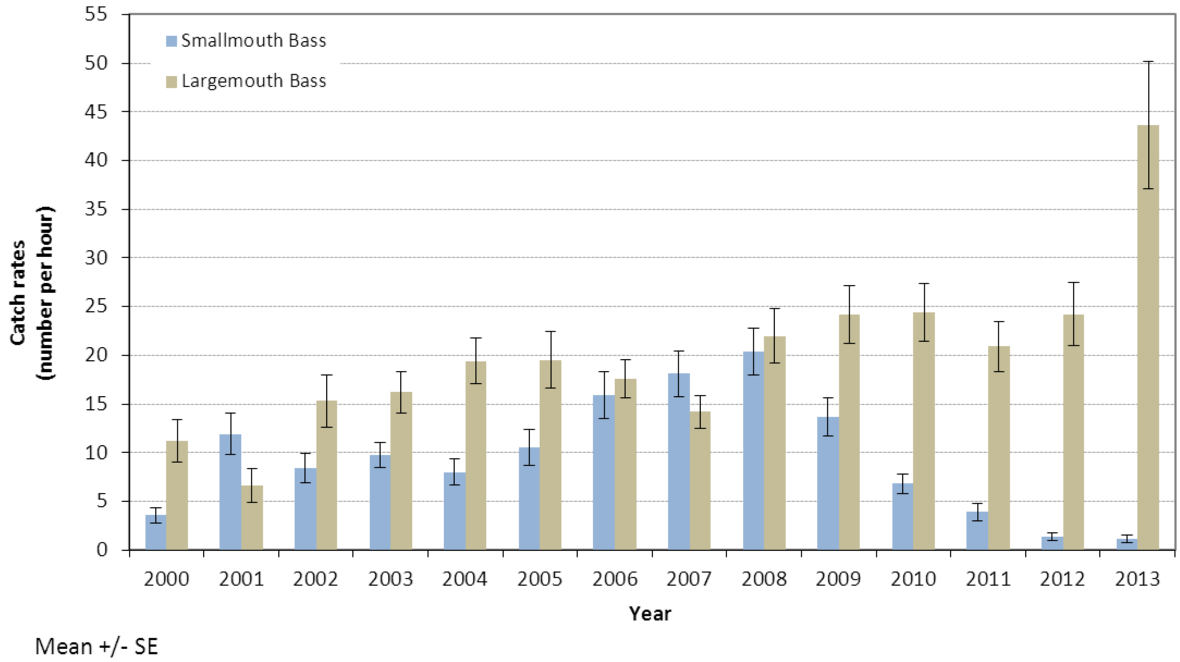
Figure 6-17. Relative abundance of pelagic adult fish in 2013 by species and stratum. Sampled by gill net.



Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Overall CPUE	254.2	196.47	634.23	519.93	2098.24	1158.47	371.19	471.3	802.03	814.06	1297.65	2344.99	1668.34	1019.43
Richness	23	21	25	21	26	25	25	21	24	28	28	25	28	23

Figure 6-18. Relative abundance of littoral adult fish in 2013 by species and stratum (based on "counts" only; counts and estimates for Gizzard Shad and Alewife only).

The black bass population is increasingly dominated by Largemouth Bass (Figure 6-19). A marked increase in littoral zone catch rates for Largemouth Bass was observed in 2013 with 44 fish captured per hour, the highest observed since the start of the AMP in 2000. Conversely, the observed catch rate for Smallmouth Bass of 1 fish caught per hour was the lowest reported since 2000. The declining catch rates observed for the Smallmouth Bass are likely indicative of the changing conditions in the littoral zone with increased macrophyte coverage more suitable for Largemouth Bass (Stuber et al. 1982, Edwards et al. 1983). Increases in the relative abundance of Largemouth Bass over Smallmouth Bass also have occurred in Oneida Lake and Canadarago Lake, two other New York lakes with increasing macrophyte coverage (Jackson et al. 2012, Brooking et al. 2012).



Mean CPUE, entire year

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Smallmouth Bass	3.57	11.9	8.41	9.75	7.99	10.5	15.9	18.1	20.4	13.7	6.8	3.9	1.39	1.15
Largemouth Bass	11.2	6.61	15.3	16.21	19.4	19.5	17.6	14.2	22	24.2	24.4	20.9	24.2	43.6

Figure 6-19. Trend in annual average catch rates (number per hour) from two electrofishing events (spring and fall) of Largemouth and Smallmouth Bass combined in Onondaga Lake from 2000 to 2013.

Overall trends in catch rates have varied by species since 2000 (Figure 6-20). Several species including Smallmouth Bass, Bluegill, White Perch, and Channel Catfish have had reduced catch rates since 2000, while other species such as White Sucker and Walleye had less variation in catch rates. However, catch rates of several species including Largemouth Bass, Brown Bullhead, and Yellow Perch have had a marked increase in recent years (Figure 6-20). These patterns likely reflect the changing habitats in the lake including increased macrophyte coverage, increased mussel abundance, and changes in the fish community associated with alewife. Species such as Gizzard Shad are susceptible to winter induced mortality and commonly show variations in yearly catch rates at the periphery of their geographic range, most notably during long, harsh winters. It is likely that the reasons for changes in abundance are more complex and species-specific and reflect changes in overall lake productivity as well as increased littoral zone habitat diversity.

Winter kill Gizzard Shad along the shoreline of Onondaga Lake in the spring of 2014.

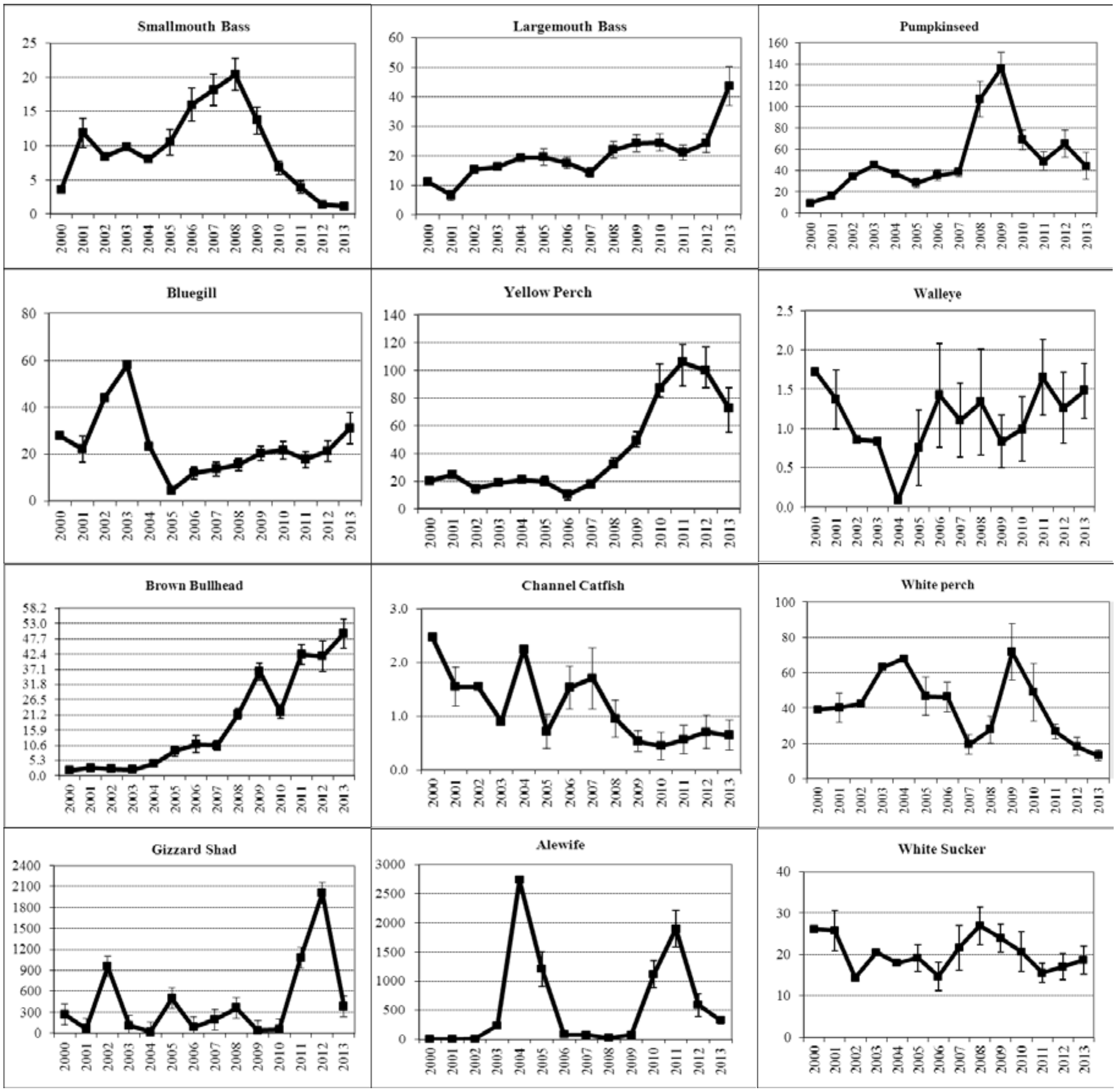


Figure 6-20. Trends in catch per unit effort (CPUE) of select fish species captured by electrofishing 2000–2013.

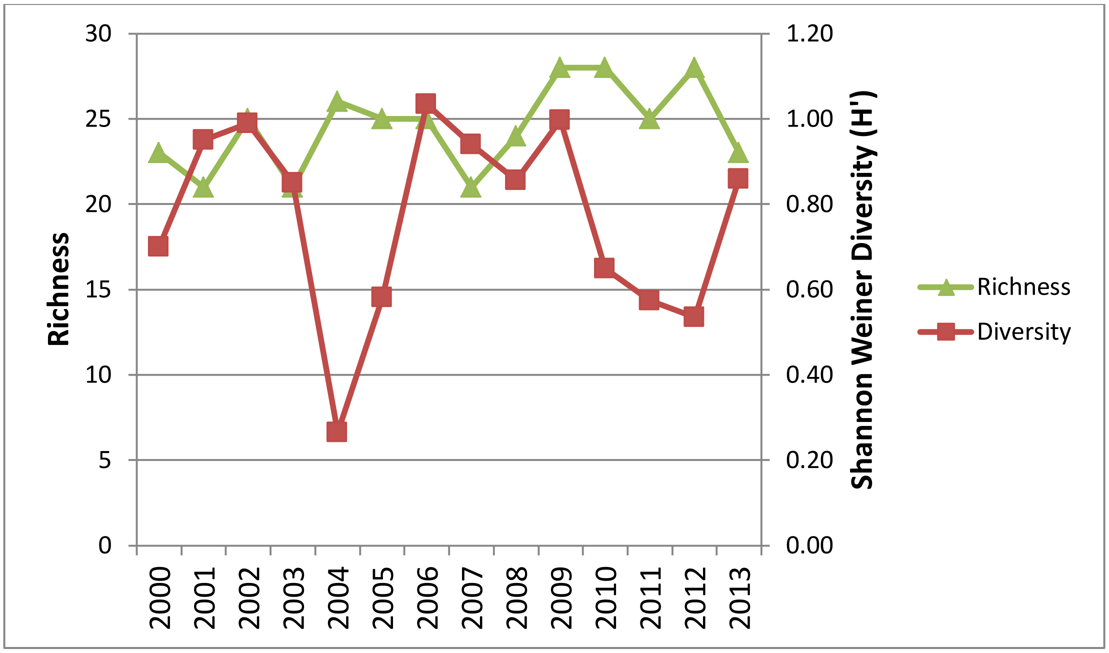
Note: CPUE for gamefish (Smallmouth Bass, Largemouth Bass, Pumpkinseed, Bluegill, Yellow Perch, Walleye, Brown Bullhead, and Channel Catfish) is calculated from all 24 transects. CPUE for non-gamefish (White Sucker, Gizzard Shad, Alewife, and White Perch) are calculated from only the one-half of the transects where all fish are collected (every other transect). Because of the difficulty in netting clupeids (shad and alewives), the CPUE for these species is calculated from a combination of fish that are boated and estimates of the number of fish missed. Because of their large size carp are not boated, instead carp within netting distance are counted while still in the water. Note: Y-axis differs for each species.

6.4.2.2 Richness and Diversity

In Onondaga Lake, adult species richness (i.e., number of species) collected during electrofishing events has fluctuated since 2000 with slight increases in 2009, 2010, and 2012. A total of 23 adult species were captured during electrofishing surveys in 2013, less than the previous five years (Figure 6-21). Minor fluctuations in species richness over the past five years is primarily due to the incidental catches of uncommon species such as Black Bullhead *(Ameiurus melas)*, White Bass *(Morone chrysops)*, and Quillback *(Carpiodes cyprinus)*. 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 as evident based on tag returns since 1987 (Gandino 1996, Siniscal 2009). Since the monitoring program started in 2000, 53 species have been identified in the lake.

Fish community diversity fluctuates in response to changes in seasonal and environmental variables and inter-species competition, among other factors. In Onondaga Lake, changes in diversity are highly influenced by periodic peaks and crashes of two species of clupeid (herring family), Alewife and Gizzard Shad. Abundance of these two species is highly variable because both species periodically exhibit significant winter mortality. Extremes in recruitment are seen as well; both fish periodically produce very strong year classes that dominate the catch for years, as alewife can live to ten years and Gizzard Shad even longer. Shannon-Weiner diversity (H'), an index that considers richness and relative abundance, has fluctuated over the past 14 years due largely to shifts in abundance of clupeids, with the highest value (1.04) observed in 2006 and the lowest value (0.27) observed in 2004. The 2013 value was 0.86 (Figure 6-21).

Sunset on Onondaga Lake



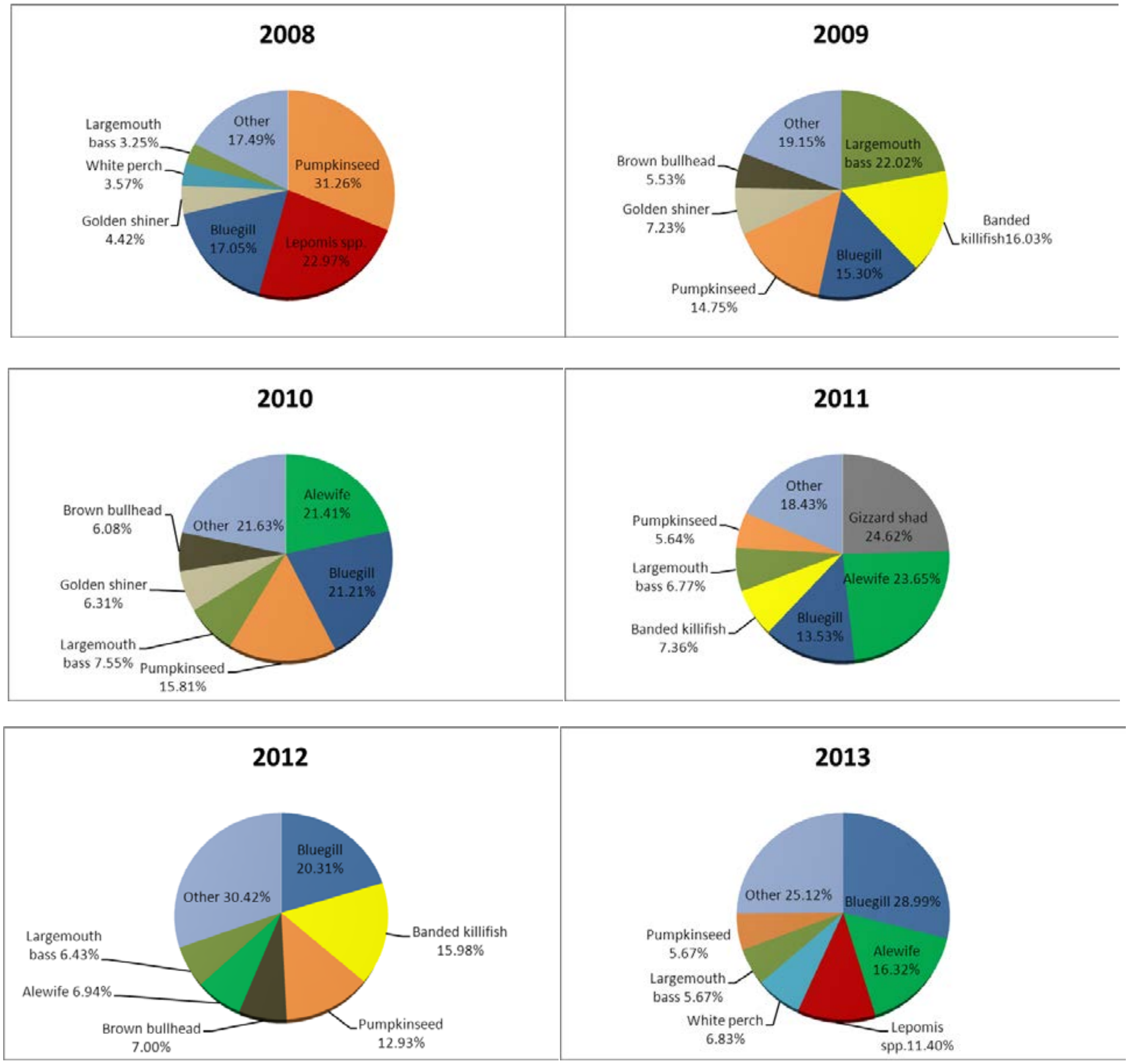
Electrofishing (Adult fish only)														
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Richness	23	21	25	21	26	25	25	21	24	28	28	25	28	23
Diversity	0.70	0.95	0.99	0.85	0.27	0.58	1.04	0.94	0.86	1.00	0.65	0.57	0.54	0.86

Figure 6-21. Trends in adult fish Shannon-Weiner diversity (H') and richness 2000–2013.

6.4.3 ESF Trapnet Catches

As part of the Honeywell monitoring program, monthly trapnet sampling is conducted by SUNY-ESF students from May through October at ten locations around the lake. Trap-nets are passive gear, which are used to sample littoral zone fish and have been used by ESF since 1987 on Onondaga Lake. Because vulnerability to different gear types is not the same for all species of fish, direct comparisons to electrofishing will not be made, however, the combination of the two data sets allows for a more complete assessment of the overall fish community in Onondaga Lake.

Overall catches in trapnets were 8,011, 8,857, 6,134, 6,295, 3,373, and 5,589 from 2008–2013 respectively. Lepomis (Pumpkinseed and Bluegill) were the most frequently collected species in all years with the exception of 2011 when Alewife and Gizzard Shad were the most frequent species collected (Figure 6-22). Although the total catches in 2008 and 2009 were the highest reported, species richness for the two years was the lowest compared to 2010–2013. Additionally, the total catch in 2012 was the lowest compared to all years, yet species diversity and evenness was the highest that year.



	2008	2009	2010	2011	2012	2013	Overall
Total Fish Captured	8011	8857	6134	6295	3373	5589	38259
Richness	28	33	37	36	35	35	45
Shannon Diversity	2.11	2.35	2.34	2.26	2.56	2.39	2.34
Evenness	0.63	0.67	0.65	0.63	0.72	0.67	0.66

Figure 6-22. Relative abundance of fish collected in trapnets from Onondaga Lake by SUNY-ESF, 2008–2013.

(*Note: For each analysis the top 6 most abundant were used and all others combined into "other" category*).

Trapnet catches from 1987–2006 were dominated by a planktivorous fish including, Gizzard Shad and Alewife (Arrigo 1998; Gandino 1996; Tango 1999, Siniscal 2009). 2008 was the first year since SUNY-ESF students began sampling that the trapnet catch was not dominated by a planktivorous fish. However, Alewife dominated the catch in 2010 and by 2011 with Gizzard Shad accounted for over 48% of the catch. Numbers of Alewife and Gizzard Shad again declined in 2012 and 2013 composing 13% and 18% of the total catch respectively. These pelagic planktivore successions have occurred many times over the years (Gandino 1996; Tango 1999, Siniscal 2009). Kirby (2009), suggested that the decrease in planktivore dominance is a typical sign of a lake moving out of hypereutrophy and entering a clear water state. This may or may not happen in Onondaga Lake. Onondaga has moved to a lower productivity state without much decrease in planktivore dominance. These patterns likely reflect the changing habitats in the lake including increased macrophyte coverage, increased mussel abundance, and changes in the fish community associated with water quality improvements.

6.4.4 Fish Abnormalities

The occurrence of physical abnormalities in adult fish captured during AMP sampling is monitored using a standardized protocol of identifying Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies (DELTFM). 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.

Channel Catfish with no eyes.

Overall, DELTFM abnormalities increased from 2003 to 2009, but have decreased since then. DELTFM abnormalities began declining in 2010 and have steadily decreased to 2% in 2013 (Figure 6-23). The majority of abnormalities in the Onondaga Lake fish community in 2013 were lesions (64%), followed by deformities (35%). Fifteen species of adult fish were identified with DELTFM abnormalities in 2013, similar to 2012 and recent years. The species contributing the most to the DELTFM total in 2013 were Brown Bullhead (34% of total), Gizzard Shad (15%), Northern Pike (15%), White Sucker (13%), Largemouth Bass (10%), Pumpkinseed (9%), and Bluegill (5%). The frequency of DELTFM occurrences by species compared to proportion of those species in the total fish community is generally less than 1% with the exception of Bluegill (2%).and Brown Bullhead (10%).

The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake from 2000 to 2013 was compared with similar data from the Chesapeake Bay watershed, Great Lakes, and Cape Cod (Baumann et al. 2008, Pinkney et al. 2004; Figure 6-24). 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 2007–2009 a shift in occurrence was observed to levels more similar to contaminated sites from regional waters. The cause of this shift is not known, but may have been due to several identified pathogens affecting Brown Bullhead in 2008. The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake has continued to decline since 2008, suggesting a recovery of the population from these pathogens. The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake in 2013 was 10% and is again approaching the range associated with regional reference sites (Figure 6-24).

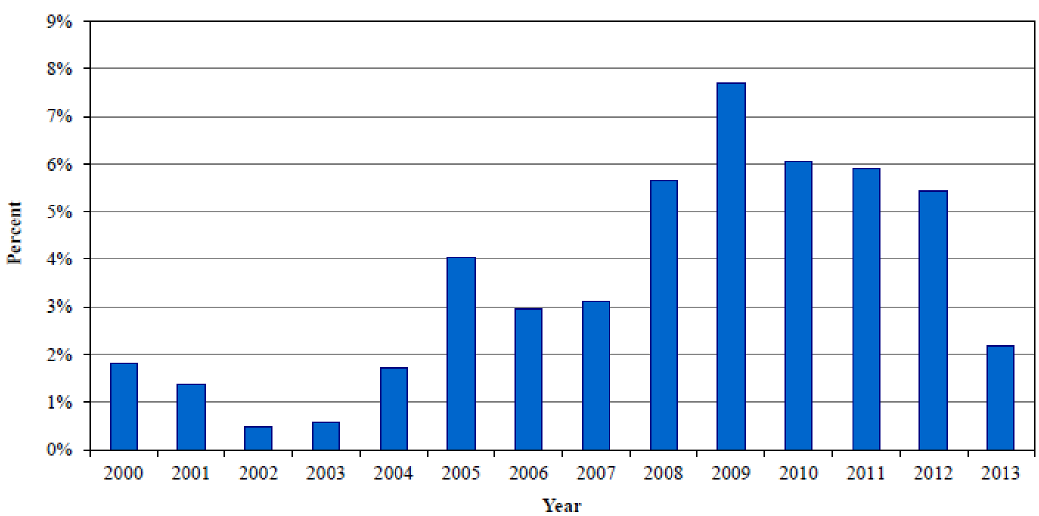


Figure 6-23. Percent of adult fish captured during AMP sampling with DELTFM abnormalities.

Note: DELTFM are defined as Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies. The increase in recent years is mostly due to an increase in the brown bullhead catch and a higher proportion of those Brown

Bullhead having skin lesions. Analysis by Cornell University of Onondaga Lake Brown Bullhead in 2008 found a variety of pathogens including: Trichodina, Saprolegnia, Digenean infestations, Micrococcus luteus, and Aeromonas sobria

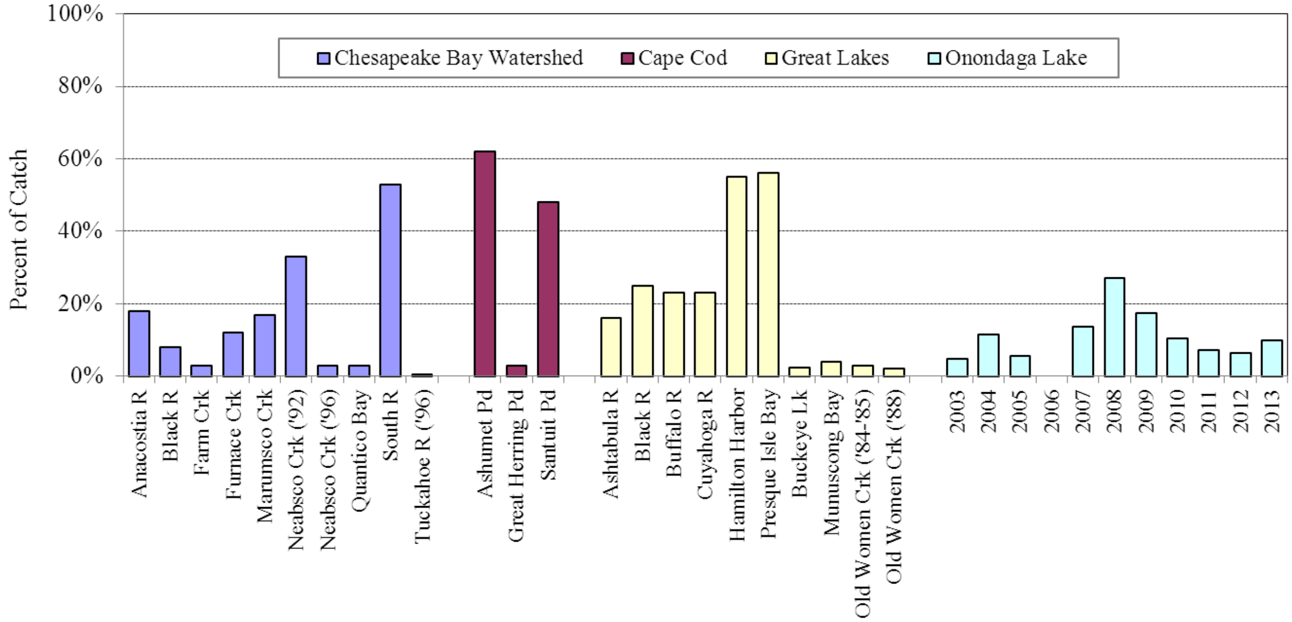


Figure 6-24. Occurrence of lesions and tumors in Brown Bullhead from Onondaga Lake and other regional waters.

Note: Onondaga Lake Brown Bullhead data includes Lesions, Tumors and Malignancies, and does not include Deformities, Erosions or Fungal Infections. The following locations were identified as reference sites in the cited reports: Cape Cod – Great Herring Pond and Santuit Pond; Great Lakes: Buckeye Lake, Munuscong Bay, and Old Women Creek.

Sources:

1. *Baumann, P.C., LeBlanc, D.R., Blazer, V.S., Meier, J.R., Hurley, S.T., and Kiryu, Yasu, 2008, Prevalence of tumors in Brown Bullhead from three lakes in southeastern Massachusetts, 2002: U.S. Geological Survey Scientific Investigations, Report 2008–5198, 43 p., available online at http://pubs.usgs.gov/sir/2008/5198.*

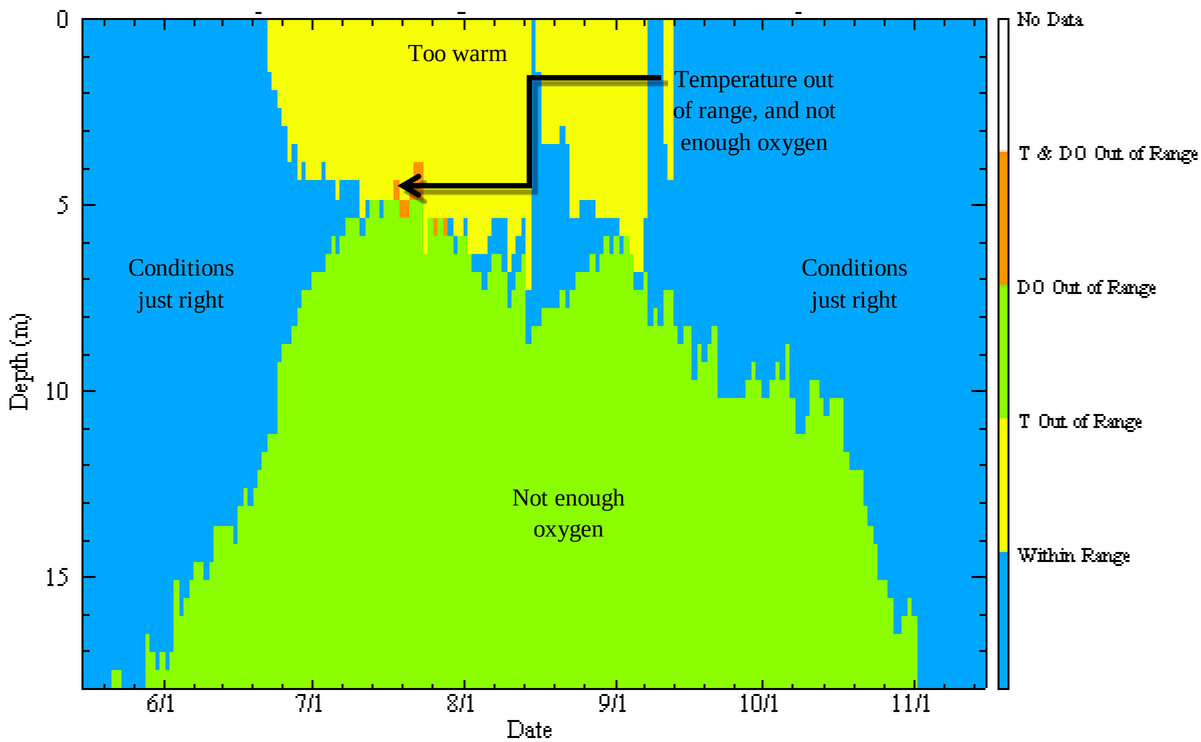
2. *Pinkney, A.E.; Harshbarger, J.C.; May, E.B.; Melancon,M.J. ,2004 Tumor prevalence and biomarkers of exposure in Brown Bullhead (Ameiurus nebulosus) from Black River, Furnace Creek, and Tuckahoe River, Maryland. Archives of Environmental Contamination and Toxicology 46 (issue 4) : 492-501*

6.4.5 Coolwater and Coldwater Habitat

Dissolved oxygen and water temperature largely determine the amount of habitat available for the different species that make up the Onondaga Lake fish community. 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 water temperature, two variables that determine the ability of coolwater and coldwater species to maintain a population. Optimal DO and water temperature requirements differ for coldwater and coolwater fish species as shown on Figures 6-25 and 6-26, respectively.

Available habitat for the coldwater fish community is calculated as a percent of the theoretical total, using volume-days as the measurement. For example, if half the lake's water volume had suitable DO and temperature conditions for half of the selected time period, the percent available habitat is 25% for a given year. The 6-month period from May 15 through November 15 (185 days) is used because it encompasses the summer season when the upper waters of the lake can reach temperatures that are potentially stressful to the coldwater fish community. Moreover, the water quality monitoring buoy is deployed over this period and high frequency data are available. In Figures 6-25 and 6-26, the blue color represents the depth and timing of water temperatures and DO concentrations that are suitable for coldwater and coolwater fish habitat, respectively. Yellow represents where and when temperatures are out of range, and green represents where and when DO is out of range. Orange represents conditions where and when both temperature and DO are out of the range.

Overall, there has been a general lack of trends in coldwater and coolwater habitat in the past few years. The summer of 2013 was warm and surface water temperatures within the lake exceeded preferred conditions for coldwater species for a majority of the summer. (Figure 6-25). This effect was less pronounced for coolwater species with surface water temperatures exceeding preferred conditions for most of July and again briefly in early September (Figure 6-26).



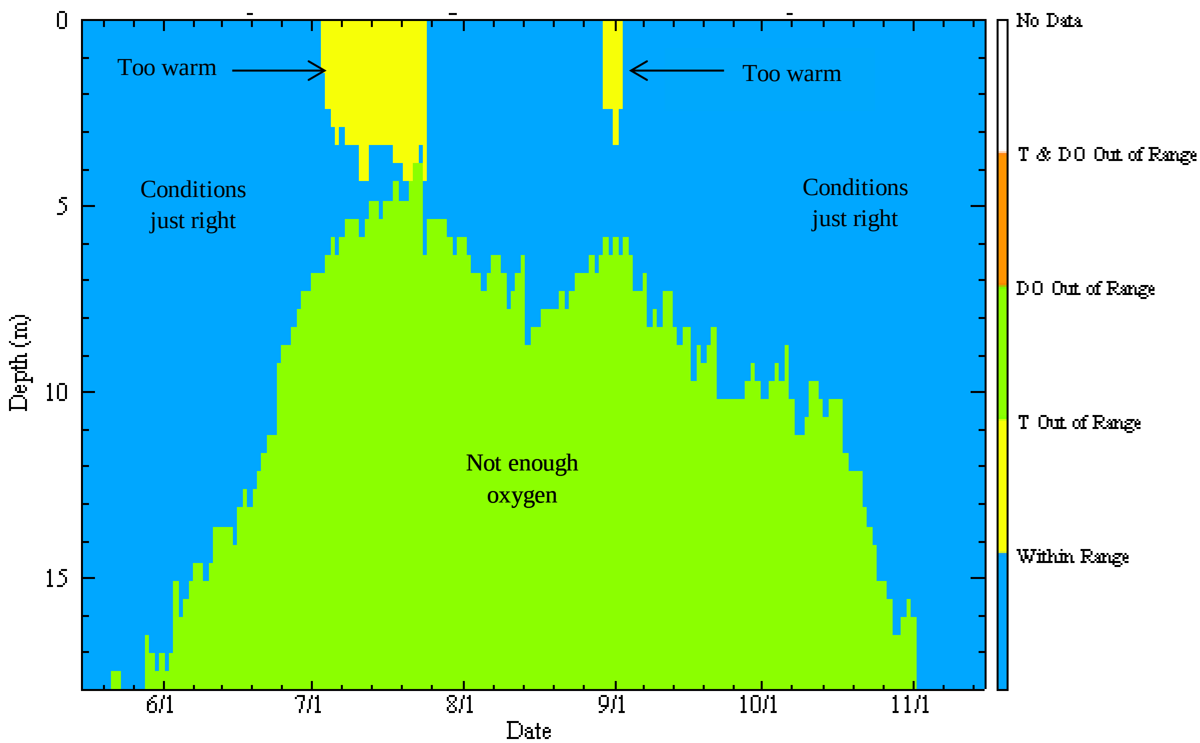
Year	% Avail. Habitat[2]	Total # Days in Range (max 185)[3]	# Consec. Days in Range (max 185)[3]	Year	% Avail. Habitat[2]	Total # Days in Range (max 185)[3]	# Consec. Days in Range (max 185)[3]
2000	33	145	50	**2007**	36	138	65
2001	33	140	72	**2008**	40	124	67
2002	30	95	49	**2009**	47	156	80
2003	31	125	47	**2010**	45	142	71
2004	32	161	67	**2011**	37	131	77
2005	34	115	59	**2012**	40	119	68
2006	39	131	80	**2013**	43	153	70

[1] Default DVT criteria: temperature ≤ 22ºC and DO ≥ 6 mg/L between May 15 and November 15.

[2] Assumes entire volume of the lake (May 15 to November 15) is available.

[3] Number of days where temperature and DO are within range in at least a 1 meter vertical section of the lake.

Figure 6-25. Coldwater fish habitat in Onondaga Lake in 2013 and trends in coldwater habitat availability 2000–2013.



Year	% Avail. Habitat[2]	Total # Days in Range (max 185)[3]	# Consec. Days in Range (max 185)[3]	Year	% Avail. Habitat[2]	Total # Days in Range (max 185)[3]	# Consec. Days in Range (max 185)[3]
2000	46	185	185	**2007**	49	184	102
2001	46	185	185	**2008**	53	185	185
2002	40	153	67	**2009**	56	185	185
2003	39	172	87	**2010**	55	180	95
2004	45	185	185	**2011**	46	172	106
2005	43	162	89	**2012**	46	155	94
2006	47	179	101	**2013**	48	180	115

[1] Default DVT criteria: temperature ≤ 25ºC and DO ≥ 5 mg/L between May 15 and November 15.

[2] Assumes entire volume of the lake (May 15 to November 15) is available.

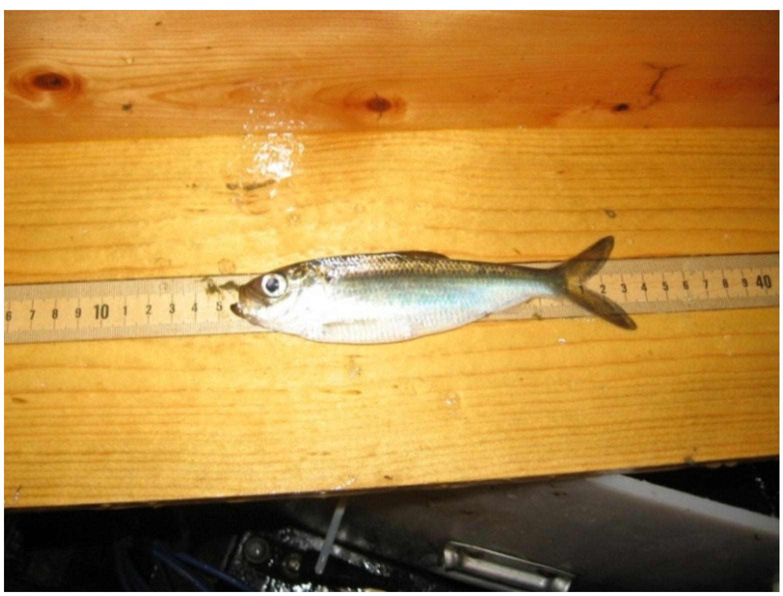
[3] Number of days where temperature and DO are within range in at least a 1 meter vertical section of the lake.

Figure 6-26. Coolwater fish habitat in Onondaga Lake in 2013 and trends in coolwater habitat availability 2000–2013.

6.5 Integrated Assessment of the Food Web

The Onondaga Lake ecosystem is continuing to change, although overall nutrient status and indicators have stabilized over the past few years (i.e., ammonia and phosphorus concentrations have remained relatively consistent since 2006). The reduced phosphorus and ammonia concentrations have resulted in a decrease in algal productivity and virtual elimination of nuisance blue-green algal blooms. However, other less desirable species including Alewife, dreissenid mussels, and recently, round goby apparently have benefited from the water quality improvements. Alewife have had several successful year classes which have reduced the abundance of large *Daphnia*, resulting in less grazing on phytoplankton thereby decreasing Secchi disk transparency values to those more typical of eutrophic conditions. A detailed report on alewife abundance in Onondaga Lake in 2013 can be found in Appendix F-5. Zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis*) have continued to expand deeper into the lake and Round Goby populations have continued to increase each year. Increased macrophyte coverage has expanded nearshore habitat for many fish and presumably other aquatic animal species.

6.5.1 Influence of Alewife, Dreissenid Mussels, and Round Gobies



Alewife

Understanding Onondaga Lake's recovery is complex and reductions in nutrients do not account for all of the changes observed in recent years. Phytoplankton biomass in the lake has declined as a result of reduced phosphorus loading from Metro, but differences between years are affected by the abundance and efficiency of grazing organisms. New species of fish have entered Onondaga Lake have had varying degrees of influence on the biota. However, the influence of Alewife may be the most pronounced because the size structure of the zooplankton community is directly affected by Alewife. Alewife densities in the spring of 2013 were similar to observations made since 2010 and higher than densities during the low Alewife years of 2008 and 2009, but lower than estimates from 2005-2007. This general pattern is consistent with the zooplankton composition. Large *Daphnia*, which are correlated with higher water transparency, were only present in high abundance in years prior to 2002 and in 2008-2009; years with low Alewife abundance (Wang et al. 2010).

Like most lakes the community structure of young-of-year fish populations in Onondaga Lake varies annually and has been well documented in this and previous studies (Gandino 1996, Arrigo 1998, Siniscal 2009). Reproductive success of any species is a complex process controlled by many biotic and abiotic variables. Abundance of food resources, predation, climatic condition, habitat quality, and anthropogenic influences all play a role in the level of reproductive success. Young-of-year Bluegill and Pumpkinseed in Onondaga Lake have experienced sustained reductions in recruitment since 2006, possibly as a result of increased mortality during the pelagic larval phase from Alewife predation. Nesting surveys and the subsequent capture of larvae indicate centrarchids are reproducing in the lake; however, the reduced abundance of Pumpkinseed and Bluegill young-of-year indicates high mortality between the egg stage and the juvenile stage. Largemouth Bass dominated the young-of-year catch; this species defends the nest and young for several weeks, and the young remain in the littoral zone after leaving the nest, potentially providing some protection from predation by Alewife and other species.

Alewife are preyed on by larger, fish-eating species such as Smallmouth Bass, Northern Pike (*Esox lucius*), and Walleye (*Sander vitreus*) and have been frequently observed being regurgitated by Largemouth Bass during electrofishing sampling events during this study. Studies conducted from 1987 to 1996 described Walleye populations as being low (Ringler et al.1996), however studies conducted in 2005 and 2006 (Siniscal 2009) documented substantial increases in Walleye abundance compared to earlier studies. Alewife increased dramatically in Onondaga County's electrofishing samples in 2003 and remained high in 2004 to 2007, possibly providing a food source for Walleye that was absent before their establishment in Onondaga Lake.

The invasion of the both zebra and quagga mussels in Onondaga Lake was first documented in 1992 (Mills et al. 1993). These mussels remained at low abundance through 1998 and then zebra mussels increased and dominated in a survey completed in 2000 (Spada et al. 2002). A similar survey in 2002 reported few mussels in water deeper than 3 m and high abundance of zebra mussels in 0-3m depth (Onondaga County 2003). Zebra mussel abundance and biomass peaked in 2007. Quagga mussels were observed in 2002, but rare. Between 2006 and 2009, quagga mussels increased and became the dominant species by biomass on a lake-wide basis by 2009. By depth, quagga mussels dominate in water deeper than 3 m and both mussel species coexist in water 0-3m depth. Mussels have the highest biomass in water 3-6m depth and biomass decline in deeper water. (Appendix F-3) These mussels are filter feeders and have a top-down effect on phytoplankton abundance, similar to that of zooplankton. We estimate that these mussels can filter 10-20 % of the lake volume per day (5% in 2013), although this filtering activity is limited to the nearshore areas of the lake (Appendix F-3). Even so, dreissenid mussels remove substantial amounts of phytoplankton, zooplankton, and suspended particulates from the water, which reduces the food sources for zooplankton and small fish, altering the food web (Higgins and VanderZanden 2010, Mayer et al. 2014). With the filtering out of suspended particulates and phytoplankton, water clarity increases allowing sunlight to penetrate the water deeper triggering increased vegetation growth possibility damping the effects from declines in Daphnia due to Alewife predation. Both mussel species declined in 2013 due at least partly to dredging in areas with previous high density of mussels. Predation by Round Goby may also have contributed to the decline.

Zebra Mussel (Left side) and a Quagga Mussel (Right side)

The proliferation of zebra and quagga mussels in the lake may be helping to support the increased abundance of several species by providing an abundant food source. Pumpkinseed, Freshwater Drum, Yellow Perch, Common Carp, Lake Sturgeon, and Round Goby feed on mussels and are likely benefiting from the increasing abundance of these mussels. Siniscal (2009) reported that the dominant Lepomis species shifted from Bluegill in the 1990's (Gandino 1996) to Pumpkinseed in 2005 and 2006. He speculated that the switch in the littoral sunfish community from Bluegill dominance in 1993 to Pumpkinseed dominance in 2005 and 2006 could be a result of the introduction of dreissenid mussels. Adult Pumpkinseed are known to feed on mollusks, while Bluegill tend to feed preferentially on zooplankton (Werner 2004). He postulated that the shift in the dominant species of Lepomis captured in trapnets may be a combined effect of Pumpkinseed concentration in near shore areas and successful feeding on zebra mussels, and Bluegill utilization of zooplankton resources away from the littoral zone. Consumption of mussels by multiple fish species provides a connection between the benthic-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.


Round Goby

Round Gobies were first collected in Onondaga Lake in 2010 and have continued to increase in abundance to date. Like Alewife they are preyed on by larger, fish-eating species and have been frequently observed being regurgitated by Largemouth Bass during electrofishing sampling events in Onondaga Lake. Hurley (2013) reported that Round Gobies were the most common food source of Largemouth Bass in Onondaga Lake based on the analysis of 137 stomach samples collected between May and July 2013. Where abundant, Round Goby can cause declines in native fish populations through its aggressive defense of nesting sites, predation on native fish and their eggs, and competition for food resources (Werner 2004), but whether their long-term effect on the fish communities in Onondaga Lake will be positive or negative is still unknown.

6.5.2 Macrophyte Coverage and Implications for Fishery

Macrophytes can contribute to increased fish abundance compared to areas or water bodies low or devoid of macrophytes (Valley et al. 2004); however, aquatic vegetation can have both positive and negative effects on warm-water fisheries. Excessive plant growth can monopolize light and nutrients in a lake and prevent stored energy from ascending the food chain. At high densities, aquatic plants reduce the ability of predatory species to find and capture forage species (Colle and Shireman 1980). This condition often results in overcrowding and stunting of panfish species as well as reduced growth rates of predatory fish. On the positive side, aquatic plants provide habitat for invertebrates and positively affects sportfish densities by increasing production at the lower end of the food chain (Wiley et al. 1984). In addition, vegetation provides escape cover for the young of most warm-water fish species and spawning habitat for many.

Fish behavior related to macrophytes also has been described as an important factor influencing fish communities. Many fish associate with either the water surface immediately above the plants, the edge of the dense stands, “pockets” formed in the plant beds, or the bottom directly below dense canopy formations for foraging and predator avoidance (Killgore et al., 1989). Research suggests that, up to a certain point, there is a positive relationship between macrophyte coverage and Largemouth Bass production. A review of the literature estimates optimum macrophyte coverage for Largemouth Bass between 36 percent and 60 percent of the littoral zone (Stuber et al. 1982, Wiley et al. 1987). Based upon these relationships it appears that macrophyte coverage in Onondaga Lake (50%) is currently in the ideal range for Largemouth Bass. Catch rates of Largemouth Bass in 2013 were the highest observed since the start of the AMP possibly reflecting this relationship. Other species such as Pumpkinseed, Yellow Perch, and Brown Bullhead have increased markedly since 2008, likely benefiting from the increasing macrophyte distribution. Other species have not responded as favorably to the increase in macrophytes; Smallmouth Bass catch rates began declining in 2008 and reported catch rates in 2013 were the lowest observed since 2000. Smallmouth Bass occupies a variety of habitats throughout its native and introduced range. For the most part, the species prefers rocky and sandy areas of lakes (Werner 2004); with the increased depth and distribution of macrophytes in Onondaga Lake these areas are largely covered by macrophytes by early June.

6.5.3 Fish Community Dynamics

Changes in the biological and chemical characteristics of Onondaga Lake have been particularly marked over the past ten years. Overall, there has been an increase in the quantity and quality of habitat available to fish species in Onondaga Lake as a result of decreases in nutrient loading. The fishes of Onondaga Lake are primarily a mixture of warm-water and cool-water forms with less abundant seasonal cold-water species composed mainly of Brown Trout. At least 66 species of fish have been reported from Onondaga Lake since 1987. Thirty five fish species were documented in Onondaga Lake in 2013. Since 2000, 53 species have been documented in the lake by Onondaga County.

Channel Catfish

Alewife and Gizzard Shad continue to dominate the total catch but have yearly variations in catch rates. Abundance of these two species is highly variable because Onondaga Lake is near the northern edge of their range, and both populations periodically exhibit significant winter mortality. Largemouth Bass and Brown Bullhead adults continue to steadily increase, and Smallmouth Bass have continued to decline. This pattern is consistent with the increasing macrophyte coverage, which is not a preferred habitat for Smallmouth Bass. Additionally, Onondaga Lake lacks extensive gravel and rock shoals characteristic of ideal Smallmouth Bass waters. The limited abundance of young-of-year Bluegill and Pumpkinseed is not completely understood, but predation on the larval stage is likely a factor. The increase in Yellow Perch adults may be attributed to movement into the lake from the Seneca River. The connection to the Seneca River has served as a source of diversity to Onondaga Lake (Gandino 1996, Tango 1999, Siniscal 2009). This is supported by the documented instances of migration and the recurring presence of adult fish populations that lack juvenile year classes in Onondaga Lake.

Sport fishing has become increasing popular over the past 15 years and continues to expand. A modest tournament fishery has developed in addition to non-competitive angling. Local bass organizations compete several weekends throughout the summer, and several large-scale fishing tournaments have been held on Onondaga Lake including the Bassmasters Memorial in 2007 and the BASS Junior World Championship in 2008. The improved water quality, increased plant coverage, changing plankton community, and the invasion by dreissenid mussels have altered the trophic dynamics within the lake. The fish community is still adapting to the various changes and will need to be monitored to more fully understand the trophic structure of the lake and how this may affect sportfishing opportunities in the future.

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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.

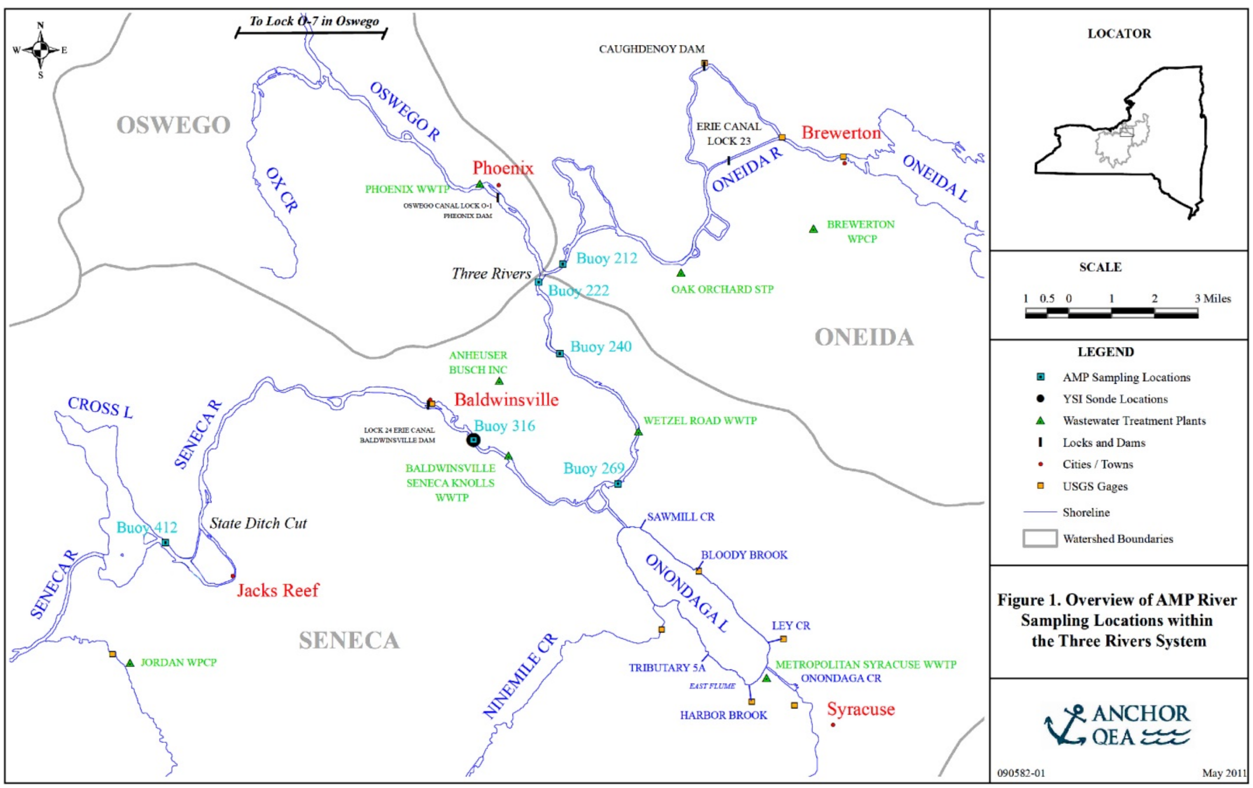

Figure 7-1. The Three Rivers System, with AMP sampling locations and wastewater treatment plants identified.

The Three Rivers monitoring program was developed and implemented to support the detailed mathematical modeling study of the system. These modeling efforts were conducted by Anchor QEA and finalized in May 2012 with the issuance of the *Final Phase 3 Model Validation and Application Report, Onondaga Lake Water Quality Modeling Project*. In a memorandum dated February 26, 2013, Anchor QEA recommended discontinuing the annual diurnal monitoring at Buoy 316 within the Seneca River. Annual low-flow surveys have been deemed sufficient to: (1) provide the data needed to monitor the water quality trends within the Three Rivers System; and (2) update the modeling framework in the future, if deemed necessary. As per the County's Five-Year AMP Workplan, water quality monitoring of the Three Rivers System will be discontinued in 2014. This component of the AMP is being discontinued because Metro effluent diversion to the river system is no longer a management option under consideration and the Three Rivers Water Quality Model (TRWQM) efforts are complete.

On September 17, 2013 a synoptic survey of water quality conditions in the Three Rivers System was conducted by OCDWEP. During this survey, which targeted critical low flow conditions, samples were collected from 1 meter below the water surface and 1 meter above the sediments at six locations (Buoys #212, 222, 240, 269, 316, 412; Figure 7-1) and analyzed for a suite of water quality parameters, including forms of phosphorus, nitrogen and carbon, chlorophyll-*a*, dissolved oxygen (DO), and turbidity.

Flow rates in the Seneca and Oneida Rivers exceeded long-term median flows for much of 2013 (Figure 7-2). Median flows for Seneca River at Baldwinsville are based on 36 years of measurements (1978–2013) and median flows for Oneida River at Euclid are based on 17 years of measurements (1997–2013). In general, flows in the Seneca and Oneida Rivers were high in 2013 compared to historic conditions. Flows were particularly high during the June–September period. Flows were distinctly lower than the long-term median in March and May. The summer average (June–September) flow in the Seneca River was 2925 cubic feet per second (cfs) in 2013, more than 50% higher than long-term summer average of 1907 cfs. Summer average flow in the Oneida River was 2416 cfs in 2013, 69% higher than the long-term summer average of 1,428 cfs. 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. Flows in the Seneca River remained above the 7Q10 of 400 cfs throughout the summer (June–September) of 2013. In contrast, flows were less than the 7Q10 on 13 days during the summer of 2012. Flows in the Oneida River never fell below the 7Q10 of 298 cfs during the summer 2013. In 2012, flows were below the 7Q10 for 17 days during the summer. During the September 17, 2013 survey flows were 1020 cfs for the Seneca River and 349 cfs for the Oneida River, both well above critical low flow conditions.

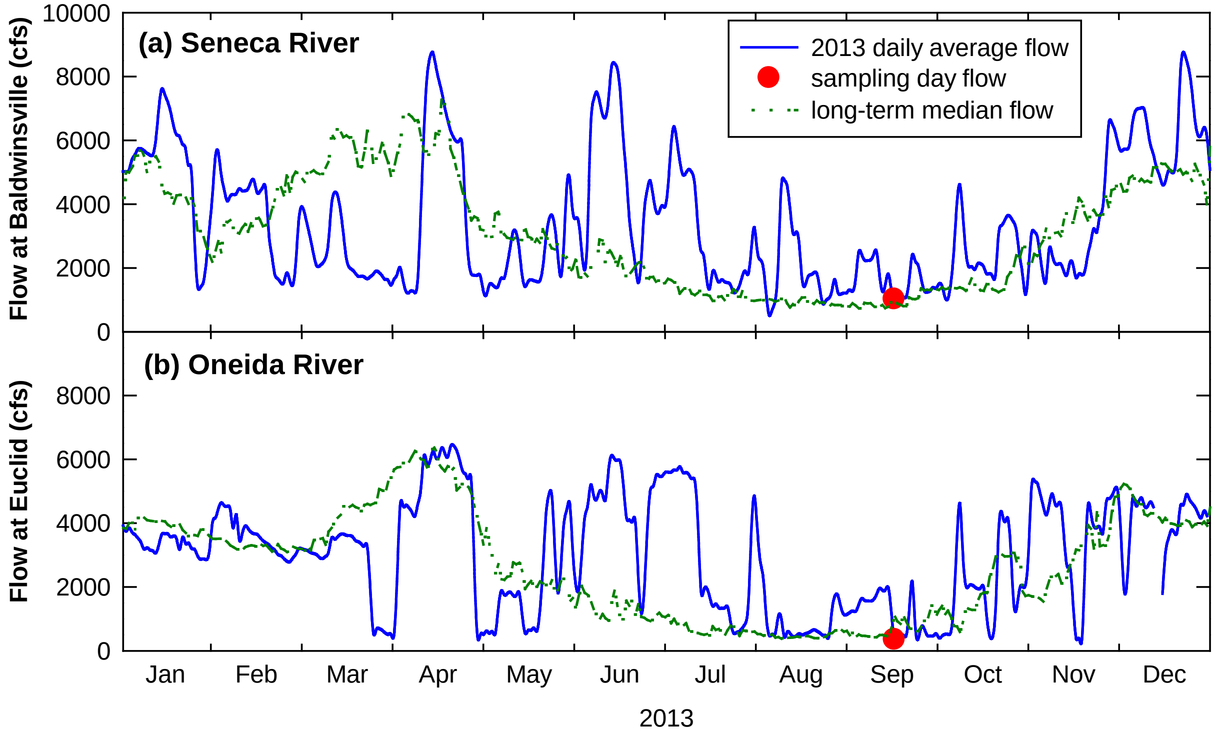

Figure 7-2. Daily average flows for 2013 compared to long-term median flows: (a) Seneca River at Baldwinsville and (b) Oneida River at Euclid.

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 phenomenon is unusual for rivers and 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 Sept. 17, 2013 survey, conspicuous vertical gradients in the Seneca River were apparent for various water quality parameters, including specific conductance, dissolved oxygen, nitrate, ammonia, and chlorophyll-*a* (Figure 7-3, Figure 7-4, and Figure 7-5). 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 are not observed during high flow conditions when levels of turbulence and vertical mixing are sufficient to overcome stratification.

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, nutrient depleted system, with nearly saturated oxygen concentrations, to a system with increased clarity, low phytoplankton levels, high nutrient levels, 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 mussels have been observed in the survey data from previous years, including decreases in turbidity dissolved oxygen, and chlorophyll-*a*, and increases in ammonia and soluble reactive phosphorus concentrations from Cross Lake to the Onondaga Lake outlet. These signatures were not as conspicuous in 2013 as they have been in previous years (Figure 7-3, Figure 7-4, Figure 7-5), likely because the 2013 survey was conducted during relatively high flows and later in the year.

Onondaga Lake Outlet

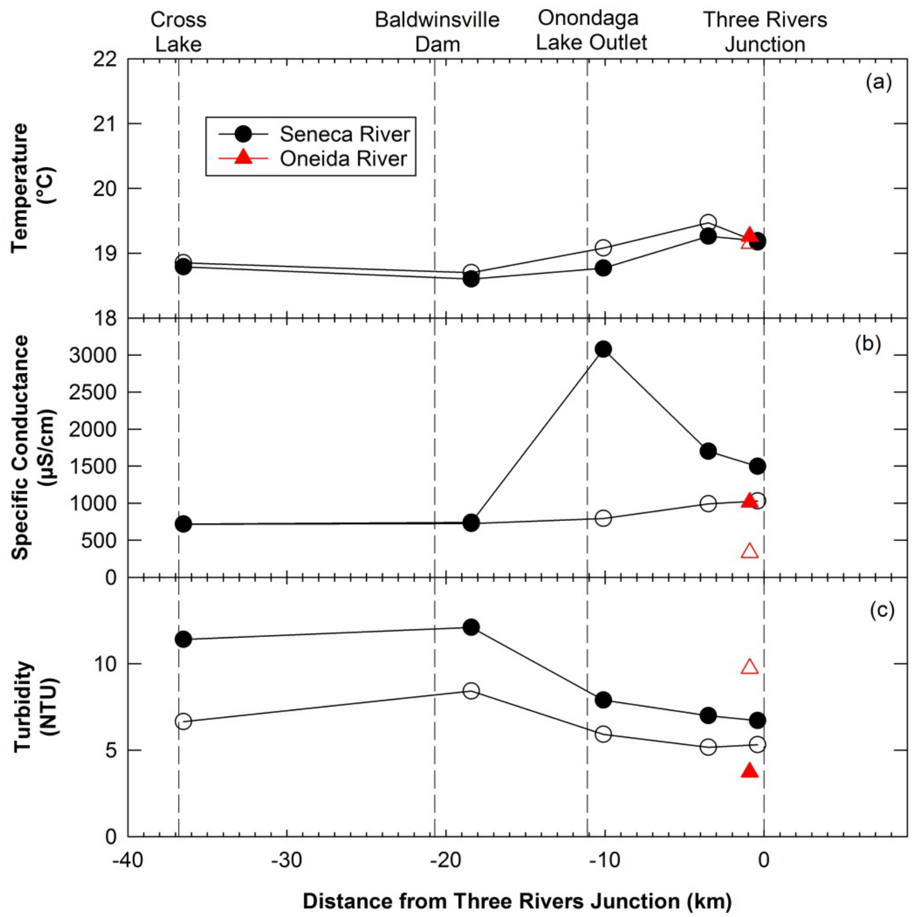

Figure 7-3. Longitudinal profiles of water quality parameters in the Three Rivers System on 9/17/2013: (a) temperature, (b) specific conductance, and (c) turbidity.

Note: Surface samples are represented by open symbols and bottom samples are represented by closed symbols.

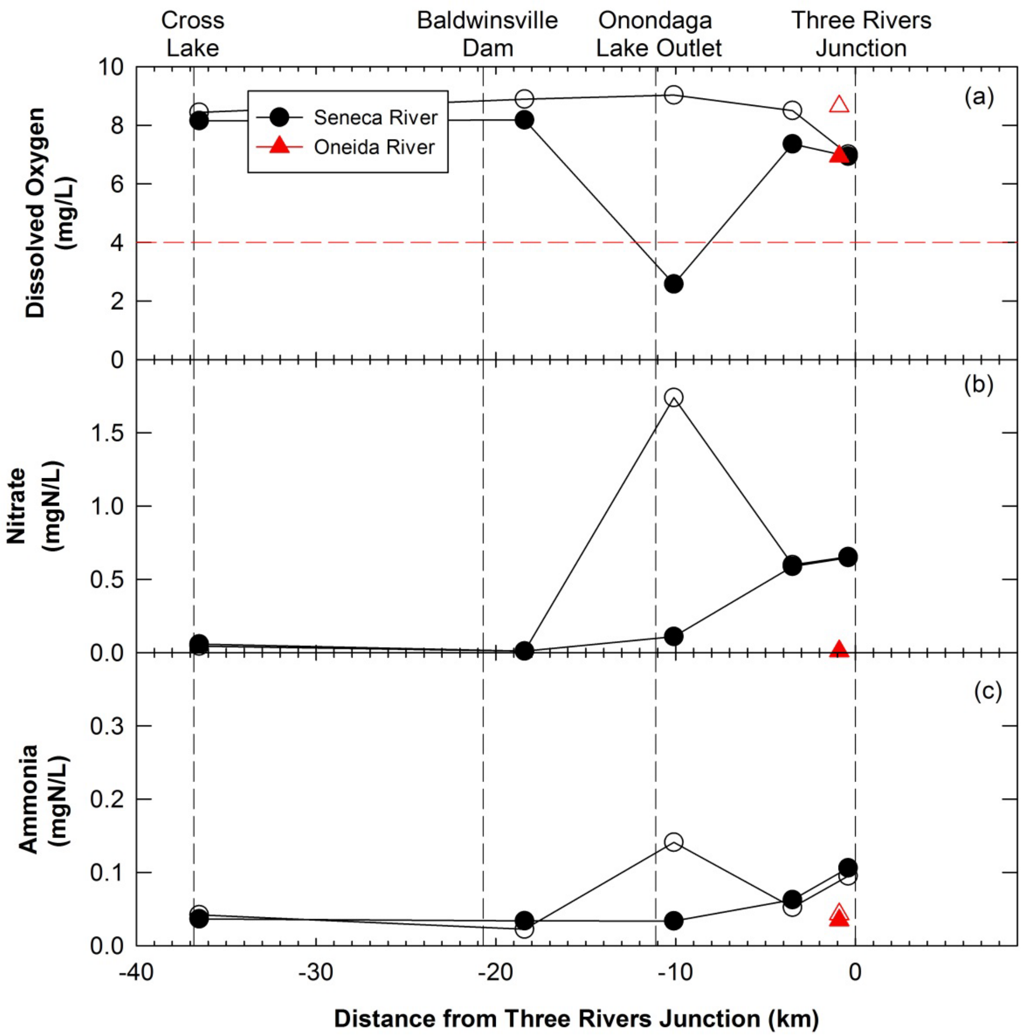

Figure 7-4. Longitudinal profiles of water quality parameters in the Three Rivers System on 9/17/2013: (a) dissolved oxygen, (b) nitrate, and (c) ammonia.

Note: Surface samples are represented by open symbols and bottom samples are represented by closed symbols. Red dashed line on panel (a) represents the NYS instantaneous DO standard.

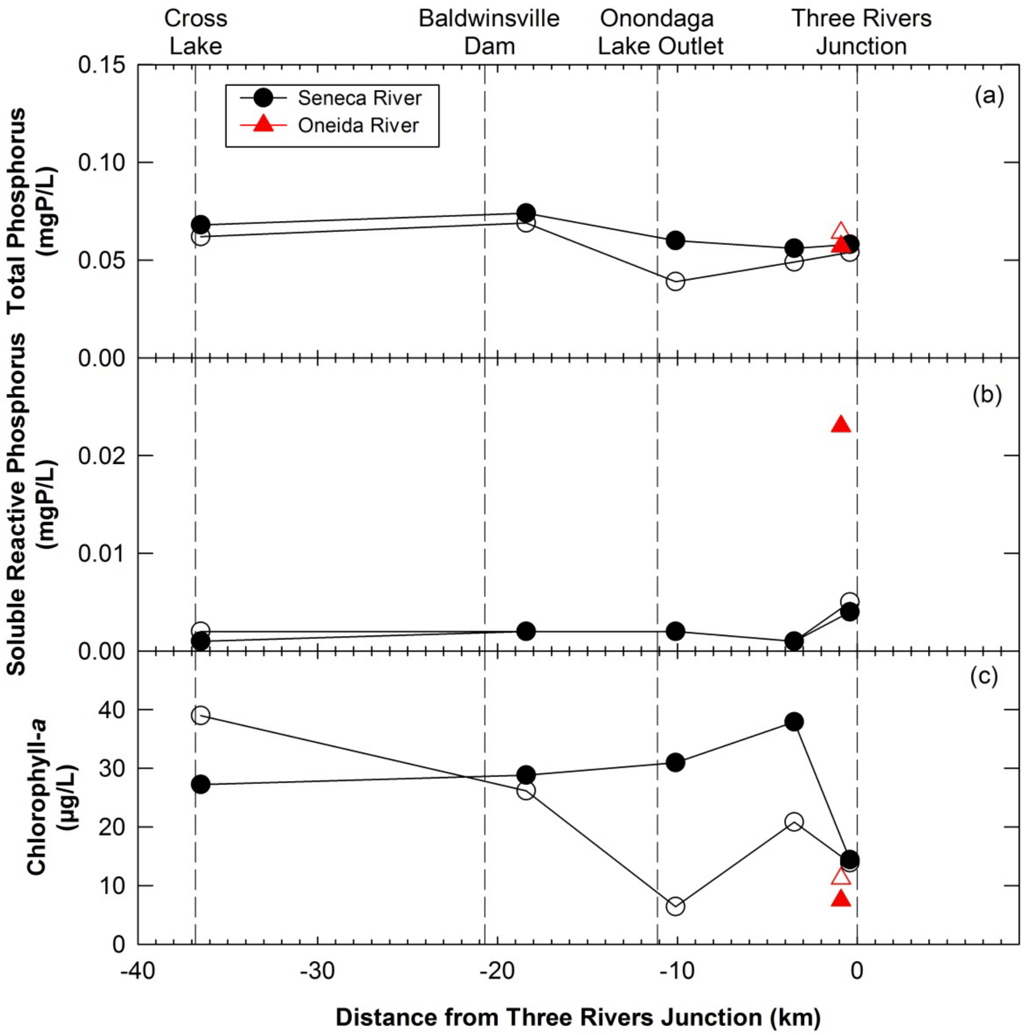

Figure 7-5. Longitudinal profiles of water quality parameters in the Three Rivers System on 9/17/2013: (a) total phosphorus, (b) soluble reactive phosphorus, and (c) chlorophyll-*a*.

Note: Surface samples are represented by open symbols and bottom samples are represented by closed symbols.

Contraventions of the NYSDEC instantaneous minimum dissolved oxygen standard of 4 mg/L were documented at one of the six locations monitored during the Sept. 17 survey (Table 7-1). Only at Buoy #269 in waters greater than 8 meters in depth were dissolved oxygen concentrations less than 4 mg/L observed. This is in stark contrast to 2012, when the dissolved oxygen standard was contravened at all six sampling locations. This difference is likely a result of the higher flow conditions present during the 2013 survey rather than an indication of systematic improvements in dissolved oxygen concentrations. There were no documented exceedances of the ambient water quality standards for nitrite or ammonia during the 2013 field program.

Table 7-1. Summary of compliance with the ambient water quality standard for dissolved oxygen in the Three Rivers System on 9/17/2013.

Parameter	Location	Depths Out of Compliance (m)	Values Out of Compliance (mg/L)
Dissolved Oxygen (Instantaneous Compliance Criteria = 4 mg/L)	Buoy #412	none	none
	Buoy #316	none	none
	Buoy #269	8-9.6	0.49-3.98
	Buoy #240	none	none
	Buoy #222	none	none
	Buoy #212	none	none

Section 8. Future AMP Modifications

Onondaga County submitted an Ambient Monitoring Program (AMP) work plan to NYSDEC and ASLF annually from 1999 to 2013. These work plans provided detailed descriptions of the sampling programs proposed for Onondaga Lake, its tributaries, and the Three Rivers System. In light of the notable water quality improvements in Onondaga Lake, recently completed major gray infrastructure project milestones to remediate CSOs, and on-going green infrastructure projects, Onondaga County has conducted a thorough review of the AMP and developed a five-year work plan to guide monitoring and assessment of Onondaga Lake and its tributaries from 2014 to 2018.

Onondaga County's proposed five-year AMP work plan, which serves as a roadmap for monitoring and assessment of Onondaga Lake and its tributaries during the 2014–2018 period, was developed in consultation with members of the County's Onondaga Lake Technical Advisory Committee (OLTAC), representatives of NYSDEC (Region 7), ASLF, Onondaga Environmental Institute (OEI), and Parsons (Honeywell's project consultant). The work plan, which is intended to comply with the requirements of the Fourth Stipulation to the ACJ and the SPDES permit for Metro, was submitted to NYSDEC and ASLF for review on February 6, 2014. The five-year work plan includes the following elements:

- AMP sampling program changes for Onondaga Lake and its tributaries, as accepted by the NYSDEC in 2013 as part of the 2013 AMP Work Plan review.
- Proposed sampling program changes, with supporting justifications, based on recommendations of the AMP Technical Workgroups convened in November and December of 2013.
- Modifications to the Enhanced Tributary sampling program to support assessment of the effectiveness of green and gray infrastructure projects, consistent with the Final Workplan, dated December 2011, with changes as approved by NYSDEC in 2013.
- A tentative sampling program schedule over the five-year period and sampling plans related to Post-Construction Compliance Monitoring Program (PCCMP).
- Coordination efforts with Honeywell and their sediment remediation program, to increase synergies and reduce data redundancy.

It is the County's goal to supplement this Five-Year AMP Workplan annually, with updates submitted to NYSDEC and ASLF each year. These updates will reflect findings from the previous year's sampling efforts and any changes in the NYS AWQS or guidance values. The sampling program will continue to incorporate the flexibility necessary to respond to new data and information. It is the County's goal to ensure all elements of the AMP provide meaningful data in a scientifically defensible and cost-effective manner.

The County has developed a Post-Construction Compliance Monitoring Program (PCCMP) to meet the requirements of the ACJ, the 4th Stipulation of the ACJ, and the Metro SPDES permit. The PCCMP includes three elements: in-stream monitoring, CSO monitoring, and verification of sewer separation projects. The in-stream monitoring data is reviewed annually in the AMP Report (see Section 4.3.7). The purpose of the CSO discharge monitoring effort is to increase the veracity of the Stormwater Management Model (SWMM) used for planning, design, and determination of compliance with the volume capture requirements. Flow meters are installed at 13 representative CSO locations. Additional information on the CSO monitoring and verification of sewer separation components can be found in the ACJ Fourth Stipulation 2013 Annual Report dated April 1, 2014 (http://savetherain.us/acj-annual-report-2013/).

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List of Acronyms

AMP	Ambient Monitoring Program
ACJ	Amended Consent Judgment
ASLF	Atlantic States Legal Foundation
AWQS	Ambient Water Quality Standards
BAF	Biological Aerated Filter
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFU	Colony Forming Units
CPUE	Catch Per Unit Effort
CSO	Combined Sewer Overflow
DAIP	Data Analysis and Interpretation Plan
DO	Dissolved Oxygen
DVT	Data Visualization Tool
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
GIS	Geographic Information System
HBI	Hilsenhoff Biotic Index
HRFS	High Rate Flocculated Settling
ISD	Impact Source Determination
METRO	Metropolitan Syracuse Wastewater Treatment Plant
MRL	Method Reporting Limit
N	Nitrogen

NYCRR	Official Compilation of the Rules and Regulations of the State of New York
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priority List
NYSDEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
OCDWEP	Onondaga County Department of Water Environment Protection
OLP	Onondaga Lake Partnership
OLTAC	Onondaga Lake Technical Advisory Committee
OLWQM	Onondaga Lake Water Quality Model
PWL	Priority Waterbodies List
RSE	Relative Standard Error
SPDES	State Pollution Discharge Elimination System
SRP	Soluble Reactive Phosphorus
SSO	Sanitary Sewer Overflow
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TRWQM	Three Rivers Water Quality Model
TSS	Total Suspended Solids
UFI	Upstate Freshwater Institute
USGS	United States Geological Survey

GLOSSARY OF TERMS

Term	Abbreviation	Definition
303(d List)	**--**	the list of impaired and threatened waters (stream/river segments, lakes) that the Clean Water Act requires all states to submit for EPA approval every two years on even-numbered years. The states identify all waters where required pollution controls are not sufficient to attain or maintain applicable water quality standards, and establish priorities for development of TMDLs based on the severity of the pollution and the sensitivity of the uses to be made of the waters, among other factors (40C.F.R. §130.7(b)(4)).
Ambient Monitoring Program	**AMP**	Onondaga County's comprehensive program to evaluate the quality of the waterways [in Onondaga County] and track changes brought about by the improvements to the wastewater collection and treatment infrastructure and reductions in watershed sources of nutrients.
Amended Consent Judgment	**ACJ**	A legal finding or ruling. In this case, in 1998, an Amended Consent Judgment (ACJ) between Onondaga County, New York State and Atlantic States Legal Foundation was signed to resolve a lawsuit filed against Onondaga County for violations of the Clean Water Act. The lawsuit alleged that discharges from the Metropolitan Syracuse Wastewater Treatment Plant (Metro) and overflows from the combined sewer system (CSOs) precluded Onondaga Lake from meeting its designated best use. The ACJ obligates the County to undertake a phased program of wastewater collection and treatment improvements that will extend though the year 2012, monitor water quality response, and report annually on progress towards compliance.

Term	Abbreviation	Definition
Ambient Water Quality Standard	**AWQS**	Enforceable limits on the concentration of pollutants designed to protect a designated use of the waterbody. Standards are promulgated by NY State and approved by the U.S. Environmental Protection Agency.
ammonia-N	**NH_3-N**	An important form of nitrogen that is the end product of the decomposition of organic material; it is used by phytoplankton for growth.
assimilative capacity	**--**	The capacity of a natural body of water to receive wastewaters or toxic materials without deleterious effects to its designated use (e.g., without damage to aquatic life or humans who consume the water).
AUTOFLUX	**AUTOFLUX**	A customized software package developed by Dr. William Walker and used by Onondaga County WEP staff to estimate loading of water quality constituents (nutrients) to Onondaga Lake. The program uses continuous flow data and less frequent (often biweekly) tributary water quality samples to estimate annual loading rates.
biochemical oxygen demand 5 day	**BOD_5**	The amount of oxygen a water sample's chemical and biological composition will consume over a 5 day incubation period. The higher the BOD_5, the more oxygen used by the sample. Generally, the higher BOD_5 means lower water quality
Biological Aerated Filter	**BAF**	A combination standard filtration with biological treatment of wastewater. BAF usually includes a reactor filled with a filter media either in suspension or supported by a gravel layer. The dual purpose of this media is to support highly active microbes which remove dissolved nutrients from wastewater and to filter particulates.
Best Management Practices	**BMPs**	A combined group of activities designed minimize the amount of pollution that reaches a body of water. BMPs can be applied to agricultural, urban, and/or industrial areas as preventative measures to protect water quality.

Term	Abbreviation	Definition
bicarbonate	**HCO_3^-**	Serves a crucial biochemical role in the physiological pH buffering water in natural systems and thereby minimize the disturbance of biological activities in these systems
calcium	**Ca**	A nutrient required by aquatic plants and some algae for proper metabolism and growth. Calcium, normally as calcium carbonate, is also a common contributor to water hardness.
chloride	**Cl**	A halogen element usually associated with metallic elements in the form of salts.
chlorophyll-*a*	**Chl-*a***	A pigment used by plants and algae for photosynthesis. Chlorophyll concentration in lakes is used as a surrogate for estimating the amount of algae present.
combined sewer overflows	**CSOs**	A discharge of untreated sewage and stormwater to a water body; CSOs occur when the capacity of a combined storm/sanitary sewer system is exceeded by storm runoff.
conductivity	**--**	The measure of the ability of water to conduct electricity
cultural eutrophication	**--**	An increase in a water body's biological production due to human activities. Cultural eutrophication usually results in negative water quality impacts such as loss of clarity, increased algal blooms, decreased oxygen resources, and accumulation of reduced species
Data Analysis and Interpretation Plan (DAIP)	**DAIP**	A document created to guide managers and advisors on how numerous environmental and biological measurements, specific to Onondaga Lake, will be analyzed and interpreted in order to assess biological and water quality status and changes from remediation effort.
dissolved oxygen	**DO**	Dissolved form of oxygen, (dissolved in water) an indicator of the quality of water to support fish and aquatic organisms.
ecosystem	**--**	An interrelated and interdependent community of plants, animals, and the physical environment in which they live

Term	Abbreviation	Definition
Environmental Protection Agency	**EPA**	The federal agency responsible for the conservation, improvement, and protection of natural resources within the US.
eutrophic	**--**	Systems with high levels of productivity
fecal coliform bacteria	**FC**	Microscopic single-celled organisms found in the wastes of warm-blooded animals. Their presence in water is used to assess the sanitary quality of water for body-contact recreation or for consumption. Their presence indicates contamination by the wastes of warm-blooded animals and the possible presence of pathogenic (disease producing) organisms.
frustules	**--**	Silica-rich external cell walls of diatoms.
guidance value	**--**	Best professional judgment of the maximum concentration of certain pollutants that will protect a designated use.
High-Rate Flocculated Settling	**HRFS or Actiflo®,**	An advanced process used in the treatment of municipal wastewater. Actiflo™ is a compact process that operates with microsand (Actisand™) as a seed for floc formation. Actisand™ provides surface area that enhances flocculation and also acts as a ballast or weight to aid a rapid settlement.
Hilsenhoff Biological Index	**HBI**	An index that uses species-defined pollution tolerance levels to assess the overall tolerance level of a community of organisms, and is an indicator of water quality.
hypolimnion	**--**	Deep, cold waters of a stratified lake; portion of the lake volume that remains isolated from atmospheric exchange during periods of thermal stratification
hypoxia	**--**	Low dissolved oxygen conditions of a water body which is detrimental to aerobic organisms.
indicator bacteria	**--**	Bacteria used to indicate the potential presence of pathogenic (disease-causing) microorganisms in water (see also fecal coliform bacteria).
interrelatedness	**--**	The degree to which organisms in an

Term	Abbreviation	Definition
		ecosystem interact and are influenced by other organisms. Pathways of interaction between species in an ecosystem
littoral zone	**--**	Shallow water zone at the edges of lakes, where light reaches the sediment surface
magnesium	**Mg**	A metallic element required by algae for the production of chlorophyll.
metrics	**--**	Quantifiable physical, chemical and/or biological attributes of an ecosystem that responds to human disturbances; also, measurable attributes of the ecosystem that indicate whether a desired state has been achieved. Good metrics are cost-effective to measure, associated with low uncertainty, relevant to stakeholders and sensitive to anticipated changes.
mercury	**Hg**	A trace metal element that is toxic to aquatic life and humans.
mesotrophic	**--**	Systems with mid-levels of productivity; between eutrophic and oligotrophic
Metropolitan Syracuse Wastewater Treatment Plant	**Metro**	The wastewater treatment plant that treats the municipal waste from the City of Syracuse and large portions of Onondaga County, located in Syracuse, NY near Onondaga Lake.
New York State Department of Environmental Conservation	**NYSDEC**	The state agency responsible for the conservation, improvement, and protection of natural resources within the state of New York.
New York State Department of Health	**NYSDOH**	
nanograms per liter	**ng/L**	A concentration unit. One billionth of a gram per liter or 10^{-9} g per liter
nitrate-N	**NO_3-N**	A form of nitrogen used by phytoplankton for growth; the end product of nitrification. In addition, the final stages of wastewater treatment at Metro produces large quantities of nitrate-N that is discharged to Onondaga Lake.
nitrite-N	**NO_2-N**	A form of nitrogen formed in the intermediate step of nitrification. Accumulation of nitrite-N can be toxic to aquatic organisms.

Term	Abbreviation	Definition
nitrogen	**N**	A common element required by algae for growth. In aquatic ecosystems, nitrogen is usually in abundance and does not limit algal growth in most freshwater systems.
oligotrophic	**--**	Systems with low levels of productivity
Onondaga Lake Technical Advisory Committee	**OLTAC**	
particulate phosphorus	**PP**	The non-dissolved fraction of total phosphorus.
pelagic zone	**--**	Any water in the sea of a lake that is not near the bottom or the shore.
pH	**pH**	The negative log of the hydrogen ion concentration commonly used to quantify the acidity of a waterbody. pH is an important regulator of chemical reactions in ecosystems.
phosphorus	**P**	A common element required by algae for growth. In freshwater aquatic ecosystems, phosphorus is usually the nutrient limiting phytoplankton production. Increases in phosphorus can result in accelerated eutrophication.
photic zone	**--**	Upper layer of the water column where light penetration is sufficient for photosynthesis (algal growth).
phytoplankton	**--**	The community of algae and cyanobacteria present a water body.
percent model affinity	**PMA**	A measure of similarity of a sampled community to a model non-impacted community, using percent abundance of 7 major groups to quantify the community structure. The closer the similarity of the sampled community structure is to the model non-impacted community structure, the more likely that the sampled community is non-impacted.
potassium	**K**	A common alkali metal element necessary for proper growth and functioning of aquatic organisms.
profundal	**--**	The deep zone in an inland lake below the range of effective light penetration, typically below the thermocline

Term	Abbreviation	Definition
organic nitrogen	**--**	The total amount of nitrogen in a water sample, associated with total (particulate and dissolved) organic matter.
oxidation-reduction potential	**Redox or ORP**	A measure (in volts) of the affinity of a substance for electrons. The value is compared to that for hydrogen, which is set at zero. Substances that are more strongly oxidizing than hydrogen have positive redox potentials (oxidizing agents); substances more reducing than hydrogen have negative redox potentials (reducing agents). In Onondaga Lake's hypolimnion, ORP declines as organic material is decomposed.
Secchi disk	**SD**	A round disk, 25 cm in diameter, with alternating quadrants of black and white commonly used in limnology to quantify the clarity of surface waters. The disc is lowered through the water column on a calibrated line, and the depth at which it is no longer visible is recorded; thus indicating water clarity.
silica	**Si**	A metallic element used by phytoplankton for construction of cellular structures
soluble reactive phosphorus	**SRP**	A dissolved form of phosphorus that is most readily used by algae for growth.
sodium	**Na**	A common metallic element in aquatic ecosystems usually associated with chloride, NaCl a common form of salt
sonde	**--**	A compact monitoring device that includes one or more sensors or probes to measure water quality parameters, such as temperature, pH, salinity, oxygen content, and turbidity directly, eliminating the need to collect samples and transport them to a laboratory for analysis.
specific conductance	**SC**	Conductivity normalized to 25°C.
species diversity	**--**	A common ecological measure of the abundance and relative frequency of species in an ecosystem.
stoichiometric	**--**	The ratio of required elements needed for a chemical reaction; in this context, refers to

Term	Abbreviation	Definition
		the ratio of N and P required by phytoplankton for metabolism.
sulfate	**SO_4^{2-}**	A compound in abundance in Onondaga Lake due to the large quantities of gypsum (naturally occurring geological formation) in the lake's watershed. SO_4^{2-} can be converted to hydrogen sulfide when oxygen is depleted.
total dissolved phosphorus	**TDP**	A dissolved form of phosphorus that is used by algal for growth. TDP is not as readily available as SRP.
total dissolved solids	**TDS**	A common measure of the amount of salts in a water body.
total inorganic carbon	**TIC**	The total amount of carbon in a water sample, not associated with organic matter.
total Kjehldahl nitrogen	**TKN**	A measure of the concentration of organic nitrogen and ammonia in a water sample.
Total Maximum Daily Load	**TMDL**	An allocation of the mass of a pollutant that can be added to a water body without deleterious effects to its designated use.
total organic carbon	**TOC**	The total amount of carbon in a water sample, associated with total (particulate and dissolved) organic matter
total nitrogen	**TN**	The total amount of nitrogen in a water sample, associated with particulate and dissolved organic and inorganic matter.
total organic carbon filtered	**TOC_f**	The total amount of carbon in a water sample, associated with dissolved organic matter.
total phosphorus	**TP**	The total amount (dissolved plus particulate) of phosphorus in a water sample. TP is a common metric of water quality of aquatic ecosystems and an important water quality standard in Onondaga Lake is determined using surface water TP concentration during the summer months.
total suspended solids	**TSS**	The amount of particulate material in a water sample.
trophic state	**--**	The status of a water body with regard to its level of primary production (production of organic matter through photosynthesis)
micrograms per liter	**µg/L**	A concentration unit. One millionth of a

Term	Abbreviation	Definition
		gram per liter or 10^{-6} g per liter
milligram per liter	**mg/L**	A concentration unit. One thousandths of a gram per liter or 10^{-3} g per liter
volatile suspended solids	**VSS**	The total amount of organic particulate matter in a water sample (a fraction of TSS).
volume days of anoxia	**--**	A metric that integrates the volume of the lake water affected by low dissolved oxygen (DO) conditions over the duration of the low DO.
water year	**--**	The continuous 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2010, is referred to as the 2010 water year.
watershed	**--**	The area of land that drains into a body of water
Water Environment Protection	**WEP**	The agency in Onondaga County, NY responsible for wastewater and storm water treatment as well as the monitoring and protection of all water resources in the county.