2016 Annual Report

Onondaga Lake Ambient Monitoring Program

Final, April 2018

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

http://www.savetherain.us

ONONDAGA LAKE AMBIENT MONITORING PROGRAM
2016 ANNUAL REPORT

ONONDAGA COUNTY, NEW YORK

Final, April 2018

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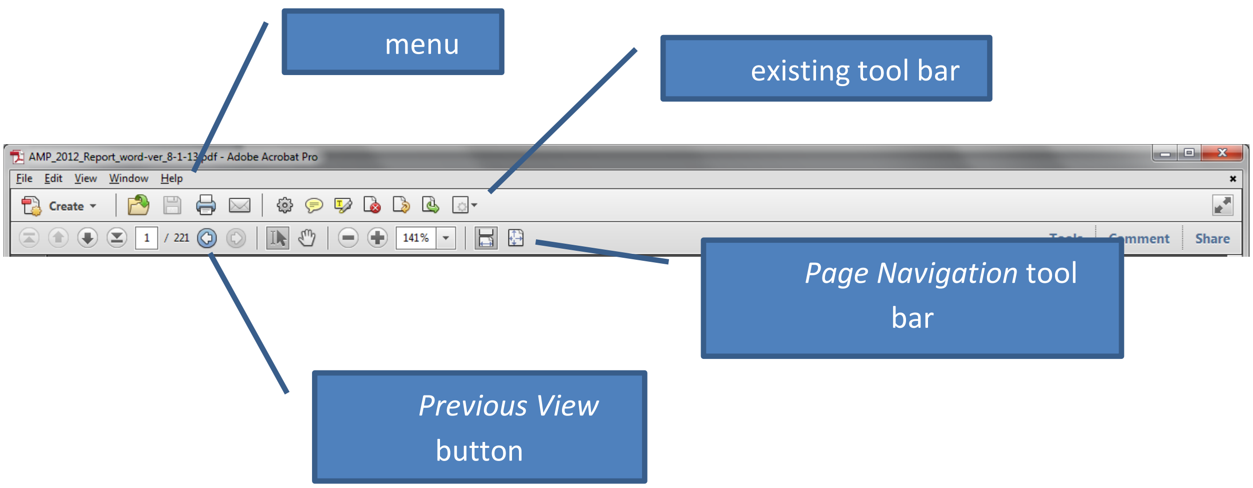

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Executive Summary

Introduction

Onondaga County has conducted the Onondaga Lake monitoring program annually since 1970 and the Ambient Monitoring Program (AMP) annually since 1998, providing water resource managers, public officials, state and federal regulators, and the entire community with a detailed evaluation of the state of Onondaga Lake and its tributaries. The 2016 AMP Annual Report documents water quality conditions, the status of the biological community during 2016, and the substantial improvements achieved in Onondaga Lake over the long term.

A variety of factors have contributed to recent changes observed in the Onondaga Lake ecosystem. Some of these factors are directly related to lake cleanup efforts, including the significant investment in state-of-the-art wastewater treatment technology and the ongoing efforts to remediate legacy industrial wastes. Biological factors, such as the fluctuating population of the Alewife and its cascading effects on the food web, have also affected water quality in Onondaga Lake. The 2016 Annual Report provides estimated inputs of water and materials (bacteria, sediment, nutrients, and salts) to the lake from its watershed and the Metropolitan Syracuse Wastewater Treatment Plant (Metro). Documenting the response of the lake to changing inputs is a primary focus of the AMP. In addition, the AMP evaluates water quality conditions, compliance with New York State ambient water quality standards (AWQS), and long-term trends. The AMP also tracks 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 2016, 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.

Regulatory Framework

The 2016 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 amendments are posted on the Onondaga County web site http://www.ongov.net/wep/we15.html.

The 2016 AMP results should be considered in the context of two important regulatory milestones reached in 2012. 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. A modification to Metro's SPDES permit (No. NY 002 7081) became effective on June 4, 2014. Second, a total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake was approved by U.S. Environmental Protection Agency (EPA) 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's primary 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 are referred to as the Post Construction Compliance Monitoring (PCCM) Program. The primary objective of PCCM, in the context of the recently constructed gray project milestones, is to demonstrate that the abated CSOs are not causing or contributing to violations of water quality standards in receiving waters. The ultimate goal of the PCCM program is to determine whether Onondaga Creek and Harbor Brook are meeting the NYS AWQS and their designated best uses. Results of the 2016 PCCM program are summarized in Section 4.8 of this report.

Onondaga County Actions and Progress with Related Initiatives

The County completed a number of "gray" and "green" infrastructure projects in recent years designed to 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 2016, 51 of the County's 72 pre-ACJ CSOs have been closed or abated as a result of ACJ projects. Abated CSOs have zero or minimal discharge for the 1-year, 2-hour design storm, based on Storm Water Management Model (SWMM) results. In addition, green infrastructure projects captured an estimated 131 million of gallons of stormwater runoff in 2016 before it could enter the combined sewer system. Results from the County's recently SWMM indicate that the annual capture percentage for the 2016 system conditions exceeds 97 percent and is ahead of schedule with respect to the mandated compliance milestones. NYSDEC will make the determination of compliance with the ACJ Stage IV Percent Capture Milestone Value as part of the 2018 ACJ Annual Report review.

The County has completed construction of all gray infrastructure projects required in the ACJ, including milestone projects such as the Clinton and Lower Harbor Brook Storage Facilities. The gray infrastructure projects are enhanced by the County's use of green infrastructure. Indeed, the combination of the two technologies has succeeded in exceeding the CSO program's volume capture goals. Going forward, the County will focus on optimizing the performance of its CSO control facilities, while continuing to implement green infrastructure in priority areas, perform maintenance on both gray and green facilities, implement best management practices (BMPs) and floatables control measures, and monitor system performance. 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, 189 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 131 million gallons annually and providing CSO reduction of approximately 63 million gallons per year according to SWMM simulations. Nine green infrastructure projects were completed as part of the "Save the Rain" program in 2016. In 2016 the County initiated the "Connect the Drops" education and outreach campaign, which focuses on street litter because approximately 98 percent of trash reaching Onondaga Lake and its tributaries is street-borne litter. The Connect the Drops campaign highlights the connection between "drops" of litter and rain "drops" that can carry litter downstream, entering catch basins and tributaries. A new joint initiative between Save the Rain and the Onondaga County Resource Recovery Agency (OCRRA) encourages local residents and businesses to help "Block Litter" where they live and work through regular neighborhood cleanups. The "Block Litter" program aims to educate community members about the importance of litter-free neighborhoods and cleaning the community one block at a time.

Honeywell International, with oversight by NYSDEC and the federal Environmental Protection Agency, is proceeding with a number of projects to address industrial contamination issues in and around Onondaga Lake. By the end of 2014, about 2.2 million cubic yards of contaminated Onondaga Lake sediments had been removed from the lake by hydraulic dredging. The dredging effort was completed a year ahead of schedule. The capping phase of the sediment restoration effort was completed in December 2016. About 475 acres of the lake bottom have been capped to provide a new habitat layer, prevent erosion, and isolate remaining contaminants. To date, 74 acres of wetlands have been created or enhanced at Geddes Brook, Harbor Brook, Ninemile Creek, the former LCP Chemicals site, and along the western shoreline of Onondaga Lake. These wetlands provide habitat for more than 230 wildlife species. About 1.1 million plants, shrubs, and trees are being planted to enhance habitat for fish and wildlife in the Onondaga Lake watershed. Following a successful three year pilot test during 2011–2013, nitrate is being applied to the deep waters of Onondaga Lake annually with the objective of limiting release of methylmercury from the profundal sediments to the hypolimnion. Additional information on Honeywell's remediation activities is available on their project website (http://www.lakecleanup.com).

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 40.6 inches in 2016, 1.2 inches more than the 31-year historic (1985–2015) average of 38.9 inches and 1.3 inches less than the 41.9 inches received in 2015. Despite above average precipitation during 2016, the annual average flow for Onondaga Creek was 18% lower than the 1971–2015 average. The timing of precipitation may have contributed to the apparent contradiction of above average rainfall and below average streamflow.

The largest total phosphorus (TP) loads to Onondaga Lake were delivered by Onondaga Creek (35%), Ninemile Creek (29%), and the fully treated Metro effluent (17%). Ley Creek (11%) and the Metro Bypass (6%) were estimated to be the fourth and fifth largest sources of TP, respectively. Ninemile Creek (33%), Onondaga Creek (24%), and the Metro effluent (20%) also had the highest total dissolved phosphorus (TDP) loads in 2016.

The Metro effluent was the leading source of both total nitrogen (TN) and ammonia nitrogen (NH_3-N) to Onondaga Lake in 2016. The total suspended solids (TSS) load was dominated by inputs from Onondaga Creek and Ninemile Creek, which combined to account for

89% 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. The primary sources of fecal coliform bacteria were the Metro Bypass (69%) and Ninemile Creek (15%). However, Onondaga Creek (7%), Ley Creek (4%) and the treated Metro effluent (5%) also made noteworthy contributions.

Metro continued to perform at a high level in 2016, meeting permit limits for total phosphorus 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. The 12-month rolling average total phosphorus concentration has remained below 0.08 mg/L since May 2013. The average total phosphorus concentration in the Metro effluent during 2016 was 0.060 mg/L. In 2016, monthly average ammonia concentrations continued to meet permit limits by wide margins.

Headworks bypasses of the full Metro treatment process, which are sometimes required during intense runoff events, receive little treatment prior to discharge. There were 23 headworks bypasses in 2016 that discharged 93 million gallons. An additional 540 million gallons were discharged as a result of 35 secondary bypasses and another 207 million gallons were discharged as a result of 38 tertiary bypasses. As a result of the Secondary Bypass Disinfection Improvements project, the plant capacity was reduced for periods contributing to an increased number and volume of bypasses during 2016. A detailed description of headworks, secondary, and tertiary bypasses is provided in Section 4.4.

The 2016 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 2016 was the Metro Bypass. However, Ninemile Creek, Onondaga Creek, and Ley Creek made noteworthy contributions as well. Compliance with the AWQS for fecal coliform bacteria, which is calculated as the monthly geometric mean of a minimum of five samples, was met less than half of the time at Bloody Brook (29%), Harbor Brook-Hiawatha (0%), Ley Creek (14%), and Onondaga Creek-Kirkpatrick (14%).

The County's Post Construction Compliance Monitoring (PCCM) program includes monitoring of water quality and water quantity to demonstrate that abated and separated CSOs are not causing or contributing to violations of water quality standards in receiving waters. In 2016, Onondaga County conducted a total of three PCCM events, all in Onondaga Creek. Each of these sampling events included high frequency monitoring of storms targeting rainfall intensities of at least 0.35 inches of rain per hour. Results of the 2016 PCCM events indicate that CSO discharges were an important contributor to elevated fecal coliform levels in Onondaga Creek during wet weather.

Onondaga Lake Water Quality

Trained Water Environment Protection (WEP) technicians collect samples from various locations and depths within Onondaga Lake to characterize physical, chemical, and biological conditions. Most sampling occurs between April and November, when the lake is free of ice. The data are used to track seasonal and long-term trends and to assess status with respect to ambient water quality standards.

The lake was included on state and federal list of impaired waters, due to elevated phosphorus concentrations; this impairment has been addressed by the approved phosphorus TMDL. Long-term trends in total phosphorus (TP) concentrations in the upper waters of Onondaga Lake continue to depict major decreases since the early 1990s. The 2016 summer (June-September) average TP concentration in the upper waters of the lake was 20 micrograms per liter (µg/L), equal to the NYSDEC guidance value of 20 µg/L. Dissolved oxygen (DO) concentrations met the AWQS in the upper waters of Onondaga Lake throughout the 2016 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 7.5 µg/L in 2016, somewhat higher than the 2015 average of 7.0 µg/L. The average and peak concentrations of this measure of algal biomass have declined substantially since completion of the phosphorus treatment upgrade at Metro in 2005. According to the criteria adopted by the AMP (15 µg/L and 30 µg/L for minor and major blooms, respectively), and based on weekly laboratory measurements, there were two minor algal blooms identified in Onondaga Lake during the summer recreational period (June–September) of 2016. The infrequent occurrence of algal blooms in Onondaga Lake stands in contrast to the widespread occurrence of blue-green (cyanobacterial) harmful algal blooms in lakes across many 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 2016, Secchi disk values ranged from 1.8 to 3.1 meters and averaged 2.2 meters, well above the target minimum.

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 has been augmented by Honeywell since 2011 to control sediment release of mercury. Release of both phosphorus and mercury 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 2011–2016 clearly demonstrates the positive effect of nitrate on phosphorus cycling.

The 2016 monitoring results indicate that the open waters of Onondaga Lake were in compliance with most ambient water quality standards. The lake is now in full compliance with the AWQS for ammonia-N, 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 hypoxic conditions prevail. These conditions reflect incomplete nitrification of ammonia-N within those lower lake depths rather than excessive external loading of nitrite.

The southern end of Onondaga Lake is listed on NYSDEC's 2016 303(d) list as impaired for pathogens. Fecal coliform bacteria levels in Class B areas of Onondaga Lake did not exceed the standard established for contact recreation during the April to October interval of 2016. Bacteria levels at three nearshore sites, located within the Class C segment in the southeastern portion of the lake, exceeded the standard during the month of October. With the exception of a single low Secchi disk measurement near the mouth of Bloody Brook on June 9, the New York State Department of Health (NYSDOH) swimming safety guidance value for water clarity was met in Class B waters throughout the summer recreational period of 2016. Sampling locations in the southern end of the lake, near the mouths of Onondaga Creek and Harbor Brook, failed to meet this guidance value on 10-20% of the monitored days due to inputs of turbid water from tributaries.

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 natural hydrogeology of the lake 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. The dramatic decline in phosphorus concentrations has led to lower phytoplankton biomass and greater water clarity. Light penetration deeper into the water column resulted in expansion of macrophyte beds, which has improved habitat and shelter for fish and other aquatic organisms.

The algal biomass in Onondaga Lake has remained below 2 mg/L (April through October averages) since 2007, and 2016 was among the lower values recorded (0.9 mg/L) (Figure 6-1). This is lower than expected from meso-eutrophic systems (3-5 mg/L, Wetzel 2001). Peak algal biomass in 2016 reached 3.7 mg/L during a mixed species increase in the late summer (9/13). Concentrations of diatoms were low compared to previous years, and a spring diatom bloom was not detected. The most abundant algal genera in 2016 were a cryptophyte and a haptophyte. Cryptophytes as a group had the highest average biomass followed by diatoms and haptophytes. Cryptophytes had higher biomass than diatoms for the first time since 2001. There was no evidence of the harmful algal blooms in Onondaga Lake which have been reported in other regional lakes in 2016.

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. In 2016 zooplankton biomass was dominated by small zooplankton such as bosminids and cyclopoids. There were also some *Daphnia mendotae* present in the summer. The species and size composition were similar to 2003-2007 and 2010-2015 and quite different from what was observed in 2008 and 2009 when the Alewife population was low. The available long-term data shows that zooplankton biomass has been low since 2010 and there has been an overall long-term decline. Variability among years reflects changes in the abundance of planktivorous Alewife. The temporal changes in the zooplankton community are linked to changes in predation by Alewife, the dominant planktivorous fish in the lake

Dreissenid mussel density and biomass was low in 2016 compared to previous years. This was especially true for quagga mussels for which the 2016 values were the lowest on record since the species became abundant in the lake in 2008. This decline occurred at all depths, but was more dramatic in shallower depths were the population of quagga mussels declined an order of magnitude. Quagga mussels are displacing zebra mussels in many lakes, and several hypotheses have been proposed for the mechanisms behind this process. This was also observed in Onondaga Lake up until 2015. Although the initial increase in dreissenid mussels were due to zebra mussels, quagga mussels started to increase in 2007 and was the dominant species by biomass in the lake from 2009 through 2012, particularly in depths deeper than 4.5 m. The most commonly proposed hypothesis for this replacement is that quagga mussels grow faster at lower food concentrations. Quagga mussels did grow faster than zebra mussels in Onondaga Lake, but this growth advantage is also present in more productive lakes where food concentrations are high. Naddafi and Rudstam (2014) found lower growth rates of zebra mussels only when the animals were reared with predator cues and not when reared without predators. With predator cues present, zebra mussels invest more energy in shell growth and byssal thread production and reduce their filtering rates resulting in lower overall growth rates. These morphological and behavioral responses to predators result in lower vulnerability to predation and higher attachment strength of zebra mussels compared to quagga mussels. Higher attachment strength should allow zebra mussels to be better adapted to persist in high predation environments as well as in high wave-energy environments of shallow water in large lakes. Elsewhere, the two species coexist in larger shallow lakes and in some rivers.

Changes in the fish community of Onondaga Lake have occurred as water quality and habitat conditions improved. In 2016, OCDWEP field technicians sampled the larval, juvenile, and adult fish communities. Researchers from SUNY-ESF continued their fishery research programs on the lake as well. In 2016, 2177 larval fish representing 14 species were collected. Banded Killifish (*Fundulus diaphanus*) was the most common larval fish collected in the seines, and comprised 34% of the lakewide catch, followed by Brook Silverside (*Labidesthes sicculus*) at 20%.

In 2016, 481 young-of-year fish were captured representing seven species: Bluegill (*Lepomsis macrochirus*), Pumpkinseed (*Lepomis gibbosus*), Rock Bass (*Ambloplites rupestris*), Largemouth Bass (*Micropterus salmoides*), Brown Bullhead (*Ameiurus nebulosus*), Longnose Gar (*Lepisosteus osseus*), and Golden Shiner (*Notemigonus crysoleucas*). Largemouth Bass constituted the largest proportion (87.5%) of the total catch followed by Bluegill and Pumpkinseed (*Lepomis spp*) which comprised 6.4% of the total catch. Juvenile fish collected during the seining event totaled 83 individuals representing eight species. Largemouth Bass and Brown Bullhead were the most common species collected, comprising 49% and 13% of the total catch. Rock Bass, Bluegill, Pumpkinseed, Golden Shiner (*Notemigonus crysoleucas*), Carp (*Cyprinus carpio*), and Green Sunfish (*Lepomis cyanellus*), were also captured.

Adult fish are sampled by boat electrofishing in the littoral zone. In 2016, 1187 fish representing 25 species were collected during the fall boat electrofishing event. More fish were captured during the 2016 sampling event than in 2015. There was also one more fish species encountered in 2016 than in 2015. Alewife comprised (16.5%) of the total catch, followed by Largemouth Bass (16.2%), Yellow Perch (*Perca flavescens*; 13.7%), Brown Bullhead (11.5%), Gizzard Shad (10%), and Pumpkinseed (10%). Together, these six species comprised 77.9% of the adult fish community. Overall the adult fish community did not change much between

2015 and 2016. The same species that dominated the total catch in 2016 also dominated in 2015 and comprised 82.1% of the total catch.

Overall trends in catch rates have varied by species since 2000. Smallmouth Bass, White Perch (*Morone americana*), and Channel Catfish (*Ictalurus punctatus*) have had reduced catch rates over the past several years, while catch rates for other species such as Bluegill, Carp, and Walleye fluctuated considerably but have not shown any clear trend. However, catch rates of some species, including Largemouth Bass, Brown Bullhead, and Yellow Perch, have generally increased since 2000. More recently species including Bowfin and Chain Pickeral appear to be increasing in abundance also. These patterns are thought to reflect responses to increased macrophyte coverage, improved water quality, increased dreissenid mussel abundance, variation in climatic conditions, and influences of boom and bust cycles of Alewife and Gizzard Shad abundance. Changes in the abundance of Alewife and Gizzard Shad can have a cascading effect across multiple trophic levels.

The occurrence of physical abnormalities in adult fish captured during AMP sampling is monitored using a standardized protocol to identify Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies (DELTFM). Data are used for trend analysis and to compare fish from Onondaga Lake to those from other waterbodies. Fish abnormalities can result from chemical contamination, biological agents such as bacteria, viruses, or fungi, or interactions among multiple stressors, and are an overall tool to evaluate recovery or degradation of the aquatic ecosystem.

The percentage of fish with observed DELTFM abnormalities increased from 2% in 2003 to nearly 8% in 2009, but has decreased since then. DELTFM abnormalities began declining in 2010 and decreased steadily to 2.1% by 2015 and 2% in 2016. The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake in 2016 was 0.25% and is within the range associated with regional reference sites.

Spectators Enjoying the Onondaga Cup and Lakefest, July 16, 2016.

Section 1. Introduction to the AMP

1.1 Regulatory Requirements

The 2016 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 ACJ requires Onondaga County to design and implement various improvements to the County's wastewater collection and treatment infrastructure. Moreover, the County is required to conduct an extensive monitoring program to document the effectiveness of these improvements on Onondaga Lake and its tributary streams. Onondaga County Department of Water Environment Protection (WEP) is responsible for implementing the AMP and reporting its findings each year in this technical report.

The three signatories have modified the ACJ four times since 1998, most recently by stipulation in November 2009. Modifications to the 1998 document incorporate emerging information regarding appropriate technologies to mitigate the impacts of Metro and the CSOs on local waterways. Links to the ACJ and the Fourth Stipulation are posted on the Onondaga County web site at http://www.ongov.net/wep/we15.html.

1.2 Classification and Designated Best Use

NYSDEC classifies surface waters and groundwater with respect to both human uses and ecosystem protection. The AMP is designed to provide the data and information required to assess whether Onondaga Lake and its tributary streams meet water quality standards and guidelines appropriate for the designated best use of the waterways. A recent report (Attainment of Designated Uses in Onondaga Lake) presents an evaluation of the extent to which Onondaga Lake is presently meeting its designated uses, including public bathing and recreation, aquatic life support, fish consumption, natural resources habitat/hydrology, and aesthetics.

Onondaga Lake and its tributaries are classified as Class B and Class C waters (Table 1-1; Figure 1-1). The best uses of Class B waters are for 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).

The NYSDEC Division of Water is responsible for evaluating whether water quality and habitat conditions fully support each resource's designated best use. Periodically, the Division of Water issues a Priority Waterbodies List (PWL) for each of the state's major river basins to report on the findings of the evaluation. Data from NYSDEC as well as other sources (including County Water Quality Committees, lake associations, Departments of Health, Soil & Water Conservation Districts, and others) are used to determine whether water bodies should be categorized as "stressed, threatened, impaired, or precluded" with respect to supporting human uses and a healthy aquatic biota. The specific criteria used by NYSDEC in their evaluation are described in the Consolidated Assessment and Listing Methodology (http://www.dec.ny.gov/docs/water_pdf/asmtmeth09.pdf). The most recent PWL for the Seneca-Oneida-Oswego Basin, which encompasses Onondaga Lake and its watershed, was published in 2007 (http://www.dec.ny.gov/docs/water_pdf/wioswegoonondaga.pdf). However, the listing for Onondaga Lake was updated in 2014. Segments of several tributary streams within the Onondaga Lake watershed, as well as the lake itself, were included in the 2007 document. An update to the PWL that reflects more recent data is pending.

In addition to the PWL, the NYSDEC Division of Water publishes a List of Impaired Waterbodies-the 303(d) List-every two years. The 303(d) list, which is divided into three parts, includes waterbodies where use attainment is considered to be "impaired" or "precluded", the two most severe categories reported in the PWL. Part 1 includes waters with verified impairment which is expected to be addressed by a segment/pollutant specific Total Maximum Daily Load (TMDL) allocation. Part 2 waters are groups of waters affected by similar causes or sources where a single TMDL may be able to address multiple waters with the same issue. Waters impaired by atmospheric deposition (acid rain), fish consumption advisories, and shellfishing restrictions are covered in Part 2. Part 3 waters include those where the suspected impairment requires verification, and a TMDL may be deferred. A listing of water quality impairments in Onondaga Lake and its watershed, based on the Final New York State 2016 Section 303(d) List of Impaired Waters Requiring a TMDL/Other Strategy (Part 1), is provided in Table 1-2. The water quality impairments listed for cyanide in Ley Creek and ammonia-N in Ley Creek and Onondaga Creek (Table 1-2) should be revisited based on recent AMP data.

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 the Hiawatha Regional Treatment Facility	C	C
	from the Hiawatha Regional Treatment Facility 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			

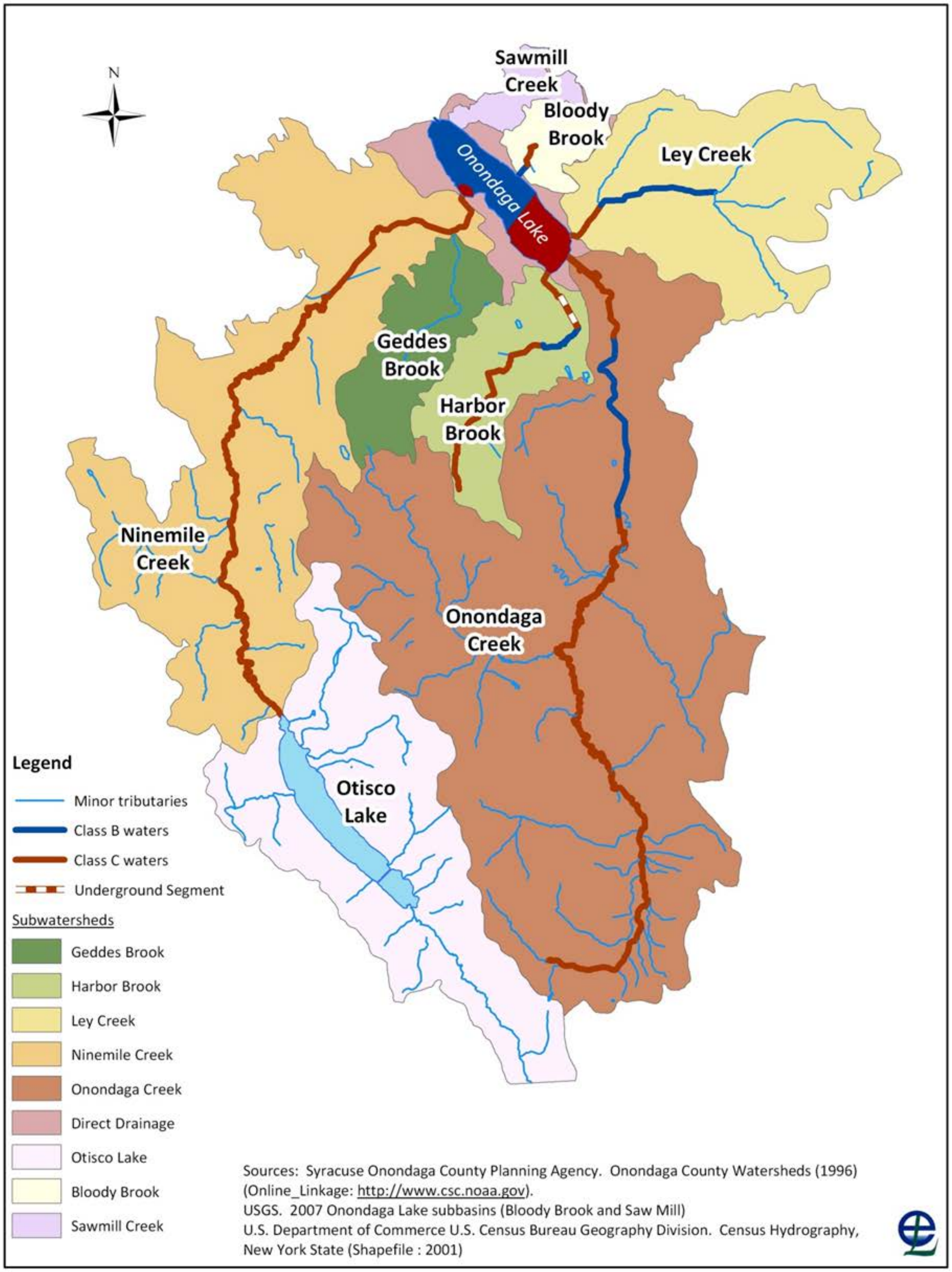

Figure 1-1. Tributary and lake regulatory classifications (6 NYCRR) and subwatershed boundaries.

Table 1-2. Listing of water quality impairments in Onondaga Lake, its tributaries, and Seneca River.

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

Table 1-2. Listing of water quality impairments in Onondaga Lake, its tributaries, and Seneca River.

Waterbody Name	Category of Impairment	Cause/Pollutant	Source	Year Listed
Ley Creek and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	ammonia-N	CSOs, municipal, urban runoff	1998
Ley Creek and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	cyanide	municipal, urban runoff	2008
Minor tribs to Onondaga Lake	TMDL is deferred pending development/implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	TMDL is deferred pending development/implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	TMDL is deferred pending development/implementation/evaluation of other restoration measures	nitrogen (ammonia, nitrite)	CSOs, municipal, urban runoff	2008
Minor tribs to Onondaga Lake	TMDL is deferred pending development/implementation/evaluation of other restoration measures	cyanide	CSOs, municipal, urban runoff	2008
Ninemile Creek, lower, and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	pathogens	municipal, urban runoff	2008
Ninemile Creek, lower, and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	nutrients (phosphorus)	municipal, urban runoff	1998
Onondaga Creek, lower, and tribs	requires verification of impairment	turbidity	streambank erosion (mudboils)	2010
Onondaga Creek, lower	TMDL is deferred pending development/implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Onondaga Creek, lower	TMDL is deferred pending development/implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	1998
Onondaga Creek, lower	TMDL is deferred pending development/implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	1998
Onondaga Creek, middle, and tribs	requires verification of impairment	turbidity	streambank erosion (mudboils)	2008

Table 1-2. Listing of water quality impairments in Onondaga Lake, its tributaries, and Seneca River.

Waterbody Name	Category of Impairment	Cause/Pollutant	Source	Year Listed
Onondaga Creek, middle, and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	pathogens	CSOs, municipal, urban runoff	2008
Onondaga Creek, middle, and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	nutrients (phosphorus)	CSOs, municipal, urban runoff	2008
Onondaga Creek, middle, and tribs	TMDL is deferred pending development/implementation/evaluation of other restoration measures	ammonia	CSOs, municipal, urban runoff	2008
Onondaga Creek, upper, and tribs	requires verification of impairment	turbidity	streambank erosion (mudbiols)	2008
Seneca River, lower, main stem	fish consumption advisory	PCBs, other toxics	contaminated sediments	2014
Seneca River, lower, main stem	requires verification of impairment	pathogens	onsite WTS	1998
Seneca River, lower, main stem	requires verification of cause/pollutant/source	oxygen demand	invasive species, agriculture	1998
Source: ***The Final New York State 2016 Section 303(d) List of Impaired Waters Requiring a TMDL/Other Strategy***, on-line at http://www.dec.ny.gov/docs/water_pdf/303dListfinal2016.pdf				

1.3 AMP Objectives and Design

The primary objectives of the AMP are to evaluate the effectiveness of improvements to the wastewater collection and treatment infrastructure, and to assess the need for additional measures to bring the waters into compliance. The AMP is designed to provide data and information required for this assessment. As a consequence, the annual report focuses on compliance and trends.

In 2016, trained field technicians collected representative samples from a network of permanent long-term sampling locations in nearshore and deep regions of Onondaga Lake (Figure 1-2) and along the lake tributaries (Figure 1-3). In 2016, all analyses were completed by fully-certified laboratories participating in the Environmental Laboratory Approval Program (ELAP). The OCDWEP Environmental Laboratory conducted analysis for all parameters, with the exception of methyl mercury analyzed by Test America and free-cyanide analyzed by Eurofins Spectrum Analytical.

In addition to the overall assessment of compliance and trends in water quality, the 2016 program incorporated monitoring efforts designed to:

- Identify sources of materials (nutrients, sediment, bacteria, and chemicals) entering the lake
- Track the species composition and diversity of the biological community
- Support evaluation of whether designated uses are fully supported

The design of the AMP is presented in the AMP Five-Year Work Plan (2014–2018), dated October 2014. The current AMP work plan, which serves as a roadmap for monitoring and assessment of Onondaga Lake and its tributaries between 2014 and 2018, 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 is intended to comply with the requirements of the Fourth Stipulation to the ACJ and the SPDES permit for Metro. The monitoring program continues to remain flexible to respond to new information and emerging issues. In addition to approving the annual workplan and AMP report, NYSDEC participates in technical discussions of the AMP results and their implications.

The Five-Year Work Plan may be amended annually to address the changing needs of the AMP and new information. The following elements were included in the 2016 AMP Work Plan:

- Monitoring to support evaluation of the trophic status of Onondaga Lake
- Monitoring to determine whether designated best uses are supported in Onondaga Lake and its tributaries
- Monitoring of various biological communities, including phytoplankton, zooplankton, dreissenid mussels, and fish
- Post Construction Compliance Monitoring (PCCM) of Onondaga Creek to assess CSO impacts

Parameters measured in the 2016 AMP are used to support compliance assessment, loading calculations, and analysis of lake ecology (Table 1-3). The 2016 Onondaga Lake, Onondaga Lake Tributary, and Onondaga Lake Biological sampling programs remained unchanged from the 2015 programs. The 2016 PCCM program included the following:

- Samples continued to be collected from CSO facility influent chambers rather than from individual CSO outfalls. The number of fecal coliform samples collected from the influent chambers during a storm event was increased in 2016 from single grabs to hourly, as feasible.
- The 2016 PCCM sampling program focused on Onondaga Creek and targeted four wet weather events. No PCCM events were planned for Harbor Brook in 2016 because no new gray or green projects were scheduled for completion.
- Quarterly sampling to evaluate the effectiveness of the CSO 061 Sewer Separation Project.

Admiring a Largemouth Bass from Onondaga Lake
at the 2015 Clean Water Fair, September 12, 2015 at Metro.

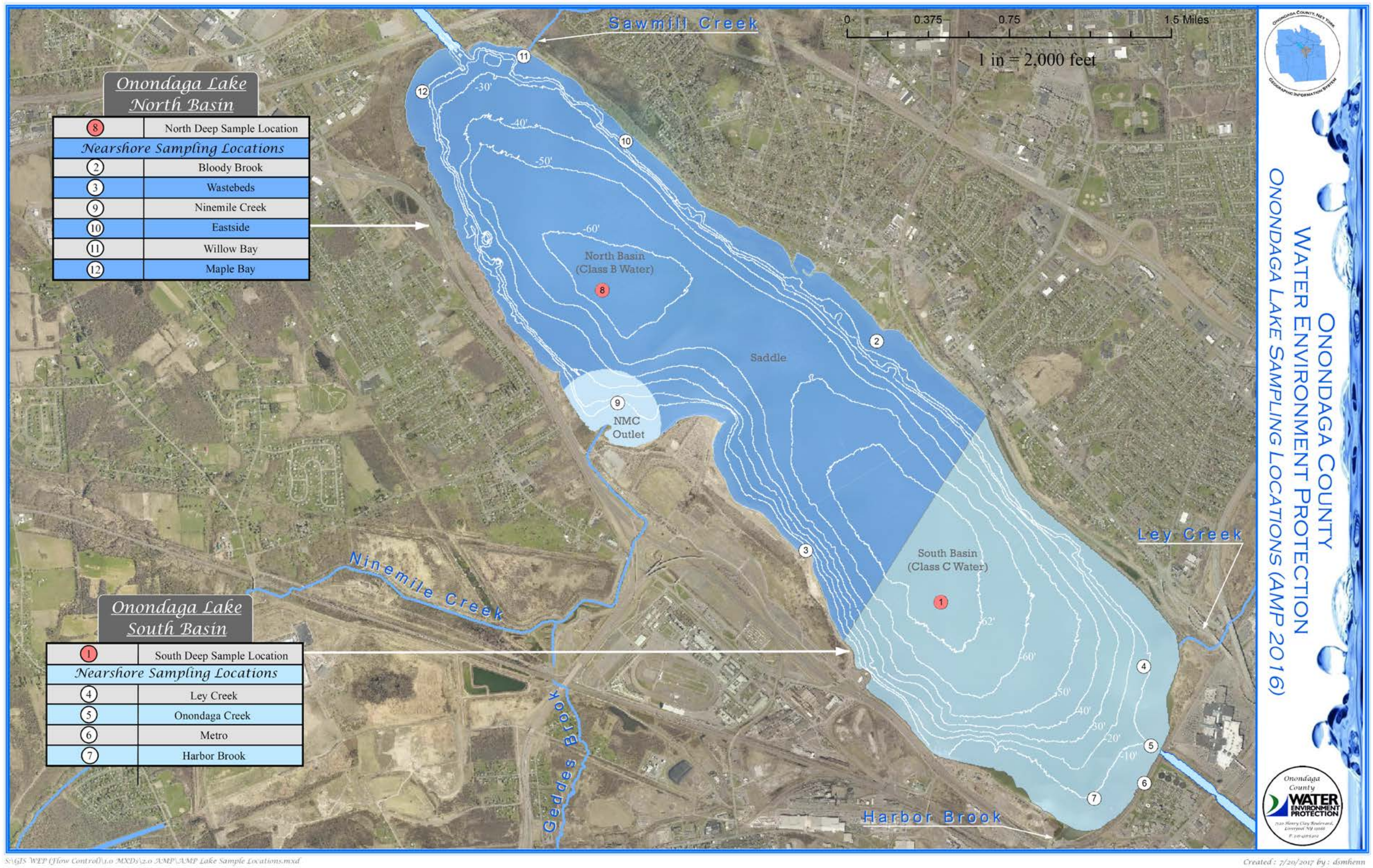

Figure 1-2. Map of AMP monitoring locations in Onondaga Lake.

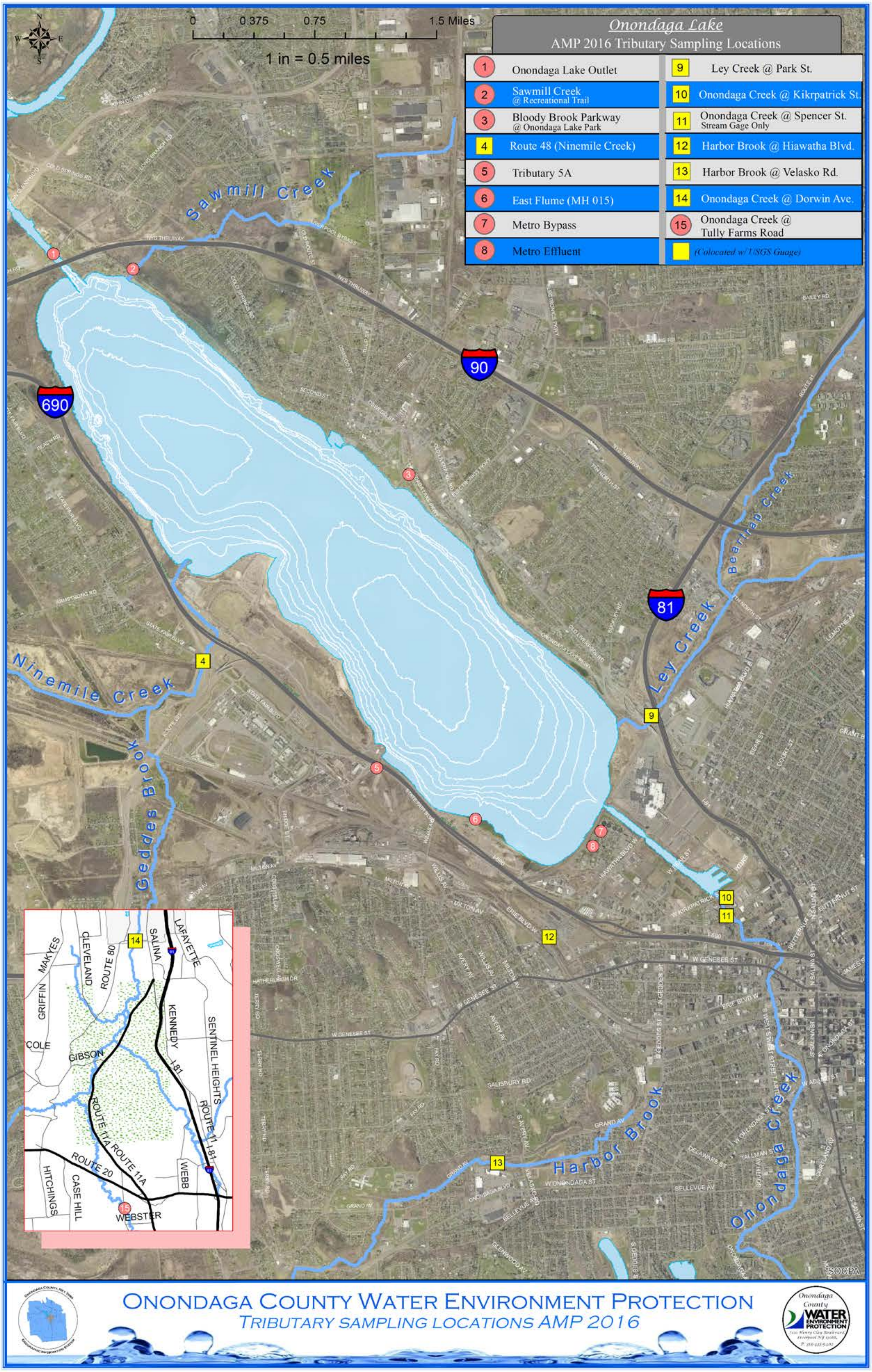

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Figure 1-3. Map of AMP tributary monitoring locations.

Table 1-3. Overview of the 2016 AMP parameters and their uses.

Parameters	Sampling Program	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			✓								
Bacteria	L,T	✓		✓		✓	✓	✓				
BOD-5	T			✓		✓						
Carbon	L,T			✓	✓	✓						
Dissolved oxygen	L,T	✓		✓	✓		✓					✓
Mercury	L,T	✓		✓								
Metals/Salts	L,T	✓		✓		✓						
Nitrogen	L,T	✓	✓	✓	✓	✓	✓			✓	✓	✓
Phosphorus	L,T	✓	✓	✓	✓	✓				✓		✓
Salinity	L,T			✓			✓					
Silica-dissolved	L,T				✓							✓
Solids	L,T	✓		✓								
Specific conductance	L,T			✓								
Optical												
Secchi Disk transparency	L	✓		✓	✓		✓		✓			✓
Turbidity	L,T			✓					✓			
Biological												
Chlorophyll-*a*/ algae	L			✓	✓		✓					✓
Zooplankton	L			✓								✓
Dreissenid mussels	L			✓								✓
Fish	L			✓							✓	✓
Visual Observation												
Floatables	L,T							✓				

Locations: L = Lake; T = Tributaries

Each year, Onondaga County reviews the laboratory data for quality assurance/quality control criteria (Appendix B-1) prior to uploading the annual data set to the long-term database. This custom database archives the complete set of Onondaga Lake and tributary monitoring results collected since 1970. In addition, annual field audits associated with tributary (Appendix B-2) and lake (Appendix B-3) water quality monitoring programs were conducted 2016 in accordance with the approved work plan.

The Onondaga County Laboratory voluntarily participates in a program of Environment Canada documenting proficiency of low-level total phosphorus and low-level total mercury analyses in natural waters (Appendix B-4). These annual blind tests include multiple academic, government, and private laboratories. In 2016, the Onondaga County Environmental Laboratory participated in PT Study 0107 (December 2015 to March 2016) and PT Study 0108 (June 2016 to August 2016) for total phosphorus analysis. Although the total phosphorus (TP) results of PT Study 0107 were within the acceptance criteria established by Environment Canada, the results were flagged as having a "High Bias" of 2% and the Onondaga County Environmental Laboratory was given an overall performance rating of "poor". A review of analyses was conducted by the Onondaga County Environmental Laboratory to determine the possible reason(s) for the results being biased high. Based on the results of this review, the exact reason for the bias could not be identified. The performance of the laboratory for TP and low-level total mercury analyses was rated as "very good" for PT Study 0108, which is the highest laboratory rating.

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.

Lakeview Amphitheater during Dave Matthews Band Concert, July 2016.

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 stormwater in a single pipe. During heavy rain and snowmelt, the pipes can overflow, and a mixture of stormwater and untreated sewage flows into Onondaga Creek, Harbor Brook, and Ley Creek 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 Fourth Stipulation of the ACJ requires phased reductions of CSO volume.

Table 1-4. Metro compliance schedule for ammonia and total phosphorus.
(lbs/d = pounds per day; mg/L = milligrams per liter; WLA = waste load allocation)

Parameter	SPDES Limit	Effective Date	Achieved Date
Ammonia-N	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 15, 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) Final loading limit Outfall 001 – 21,511 lbs/yr	July 1, 2012 through December 31, 2018	November 2010
	Final limit: 0.10 mg/L (12-month rolling average) Final loading limit – 27,212 lbs/yr	January 1, 2019	Pending
	WLA for 002 is 7,602 lbs/yr WLA for bubble permit is 27,212 lbs/yr	January 1, 2019	Pending

* This is the final limit determination based on lake/watershed models and subsequent TMDL analysis and allocation process, approved by the USEPA, June 29, 2012.

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. The 2016 annual stormwater management model (SWMM) update reflects projects completed by December 31, 2016. The model was calibrated using flow monitoring data collected in 2016; this update of the model is referred to as the "2016 conditions model." SWMM results showed that the annual combined sewage percent capture for the "2016 system conditions" exceeded 97%, and continues to be ahead of schedule with respect to the mandated Stage IV compliance milestone. NYSDEC will make the determination of compliance with the ACJ Stage IV Percent Capture Milestone Value as part of the 2018 ACJ Annual Report review.

Table 1-5. CSO capture compliance schedule.

ACJ Compliance Stage	ACJ Percent CSO Capture by Volume	Onondaga County Save the Rain Program Status Percent CSO Capture by Volume[1,2]	ACJ Compliance Deadline
Stage I	89.5%	92.9%	December 31, 2013
Stage II	91.4%	96.2%	December 31, 2015
Stage III	93.0%	97.4%	December 31, 2016
Stage IV	95%	TBD	December 31, 2018

[1] SWMM results based on the 1991 precipitation record.
[2] TBD = To Be Determined

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) developed by AnchorQEA was a key component of this modeling ensemble. OLWQM was developed and calibrated using data from the AMP, and was 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. As summarized in Table 1-6, the Class B segments of Onondaga Lake demonstrate water quality conditions that support the lake's designated best uses. Major reductions in loading of ammonia-N 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

Sailing in Onondaga Lake, 2016.

Table 1-6. Summary of metrics, Onondaga Lake 2016.

Metrics	Measured By	Target[1]	2016 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% On. Lake Park: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: 86% Metro: 86% Ley Creek: 100% Onondaga Creek: 86%	Three sites within Class C segments of Onondaga Lake met the bacteria standard for water contact recreation in all months. Three nearshore sites exceeded the standard only during the month of October: Harbor Brook nearshore, Onondaga Creek nearshore, and Metro nearshore, following runoff events (refer to plot in Appendix E-3 - Onondaga Lake Fecal Coliform and Metro Daily Precipitation, 2016).

Table 1-6. Summary of metrics, Onondaga Lake 2016.

Metrics	Measured By	Target[1]	2016 Results[2]	Comments
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: 95% North Deep: 100% Eastside:100% Willow Bay: 100% Maple Bay:100% Westside Wastebeds:100%	With the exception of a single measurements of low transparency at the Bloody Brook nearshore station in June 2016, Class B segments of Onondaga Lake met the designated use for water contact recreation.
	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: 95% Harbor Brook: 80% Metro: 80% Ley Creek: 90% Onondaga Creek: 90%	Nearshore areas of the lake's southern basins (Class C) do not consistently meet water clarity guidelines for swimming safety. Transparency is reduced near tributary mouths after storm events.

Table 1-6. Summary of metrics, Onondaga Lake 2016.

Metrics	Measured By	Target[1]	2016 Results[2]	Comments
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 2.2 m)	By these metrics, the lake met its designated use as an aesthetic resource.
Algal blooms[4]	Reduction in average and peak algal biomass and absence of noxious 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	2 of 19 (11%) measurements exceeded 15 µg/L No measurements exceeded 30 µg/L	
Algal community structure	Low abundance of cyanobacteria (blue-green algae)	Cyanobacteria represent no more than 10% of the algal biomass	Cyanobacteria represented 6.1% of the algal biomass during summer (June – September)	

Table 1-6. Summary of metrics, Onondaga Lake 2016.

Metrics	Measured By	Target[1]	2016 Results[2]	Comments
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	Based on these metrics, the designated use for aquatic life protection (warm water fishery) was met in the upper waters
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	7.96 mg/L[5] 7.76 mg/L	

Table 1-6. Summary of metrics, Onondaga Lake 2016.

Metrics	Measured By	Target[1]	2016 Results[2]	Comments
Improving Sustainable Recreational Fishery				
Habitat quality	Percent of the littoral zone that is covered by macrophytes	40%	50% (2013)	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 four 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	Species richness of the adult fish community – warm water and cool water species	Comparable to other regional lakes with similar habitat and connectivity	Adults representing 25 species were identified during electrofishing, comparable to regional lakes.	The lake's natural temperaure and dissolved oxygen conditions limit habitat for cold water species (see discussion of habitat in Section 6.5).

[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/2485.html)*
- *ammonia-N and nitrite 6 NYCRR Part **703.5** (http://www.dec.ny.gov/regs/2485.html)*
- *dissolved oxygen 6 NYCRR Part **703.3** (http://www.dec.ny.gov/regs/2485.html)*

[2]2016 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 "noxious" at >30 µg/L

[5]Daily average based on average of all measurements taken within a day from the Honeywell-UFI *in-situ* water quality monitoring buoy, 2 meter depth.

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, including:

- total phosphorus (Appendix A-1)
- chlorophyll-*a* (Appendix A-2)
- Secchi disk transparency (Appendix A-3)
- dissolved oxygen (Appendix A-4)
- ammonia-N (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)

Metrics related to water contact recreation, aesthetic appeal, and aquatic life protection are also tracked in the tributaries to Onondaga Lake as part of the AMP. Tributaries are monitored for fecal coliform bacteria and compared to standards developed for contact recreation, although other factors limit recreational access and use of these urban streams. Bacteria data are also used to identify potential sources and track the effectiveness of stormwater management efforts. The occurrence of floatables is documented to demonstrate effectiveness of floatable control measures and support assessment of aesthetic conditions in the streams affected by CSOs. Many water quality parameters measured in the tributaries are indicators of suitability for aquatic life, e.g., dissolved oxygen, pH, and ammonia-N.

Section 2. Onondaga Lake and its 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 former East Flume, now manhole HW MH 015, 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. Lake Ontario and Otisco Lake are source waters for suburban towns and villages. 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.

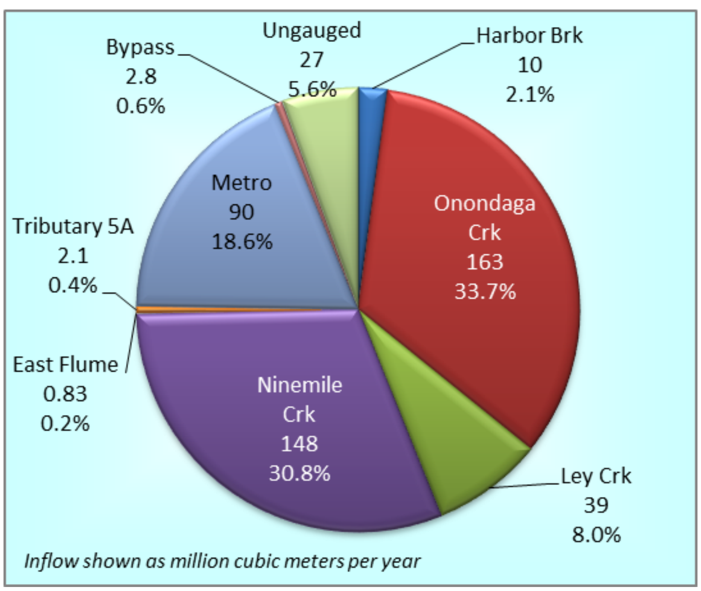


Figure 2-1. Annual average inflows (gauged and ungauged) to Onondaga Lake, 1990–2016.

The tributaries convey surface runoff and groundwater seepage from the watershed to 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 (daily flows that exceed one standard deviation above the long-term monthly average flow are designated as high flows). 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 in 2011. The National Land Cover Dataset classified approximately 18% of the watershed as developed (urban/suburban), 34% as forested or scrub/shrub, 9% as developed open space, and 29% as cultivated lands or pasture. The remaining 10% is comprised of wetlands, lakes and barren land. Urban areas of the City of Syracuse, two towns (Geddes and Salina) and two villages (Liverpool and Solvay) border the lake.

OCDWEP Technicians sampling zooplankton from Onondaga Lake.

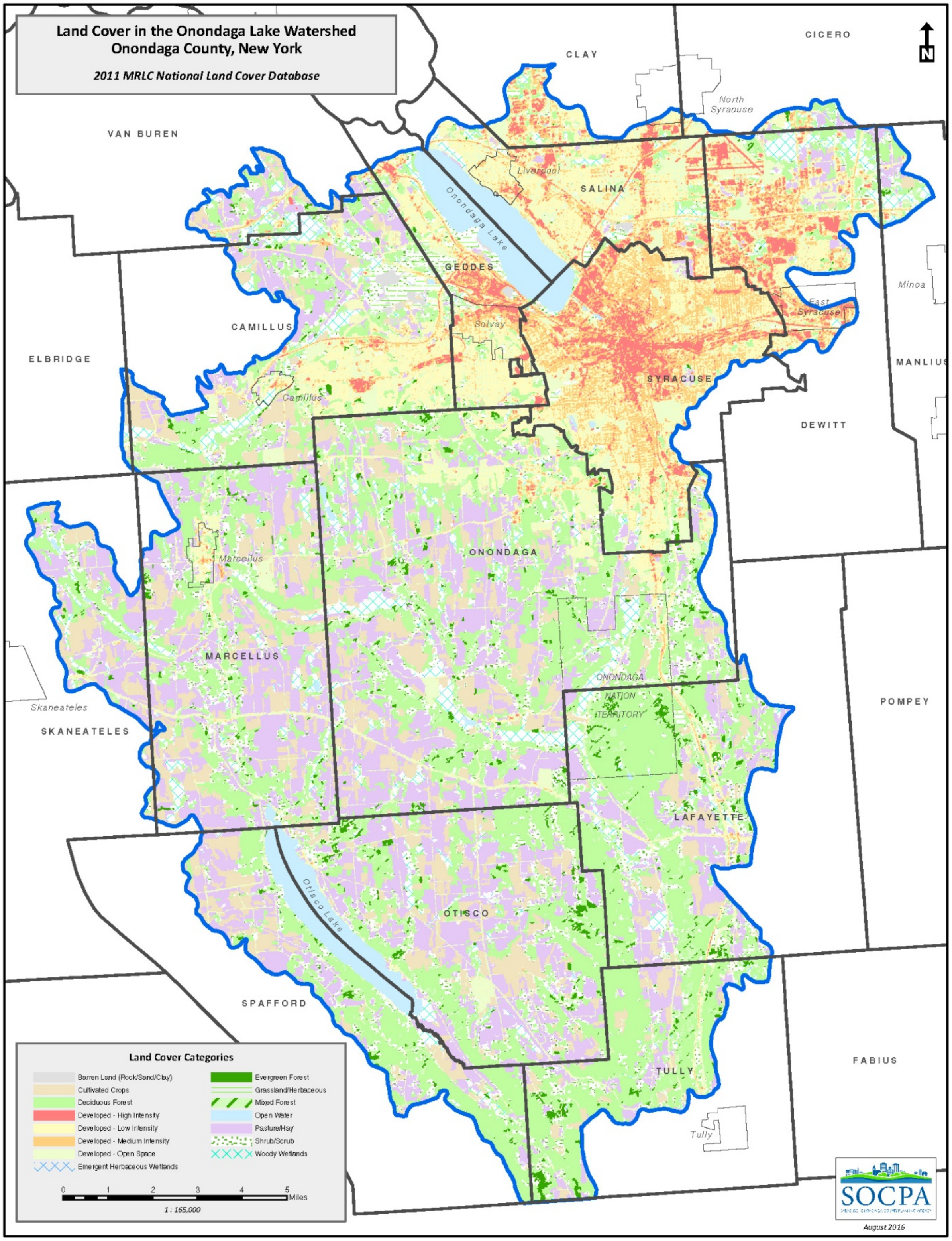


Figure 2-2. Land cover classification map.

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 frequently referred to as North and South Deep), 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 volume, such as Onondaga Lake, will result in a relatively short water residence time. 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	131×10^6 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 the City of Syracuse and Onondaga Lake.

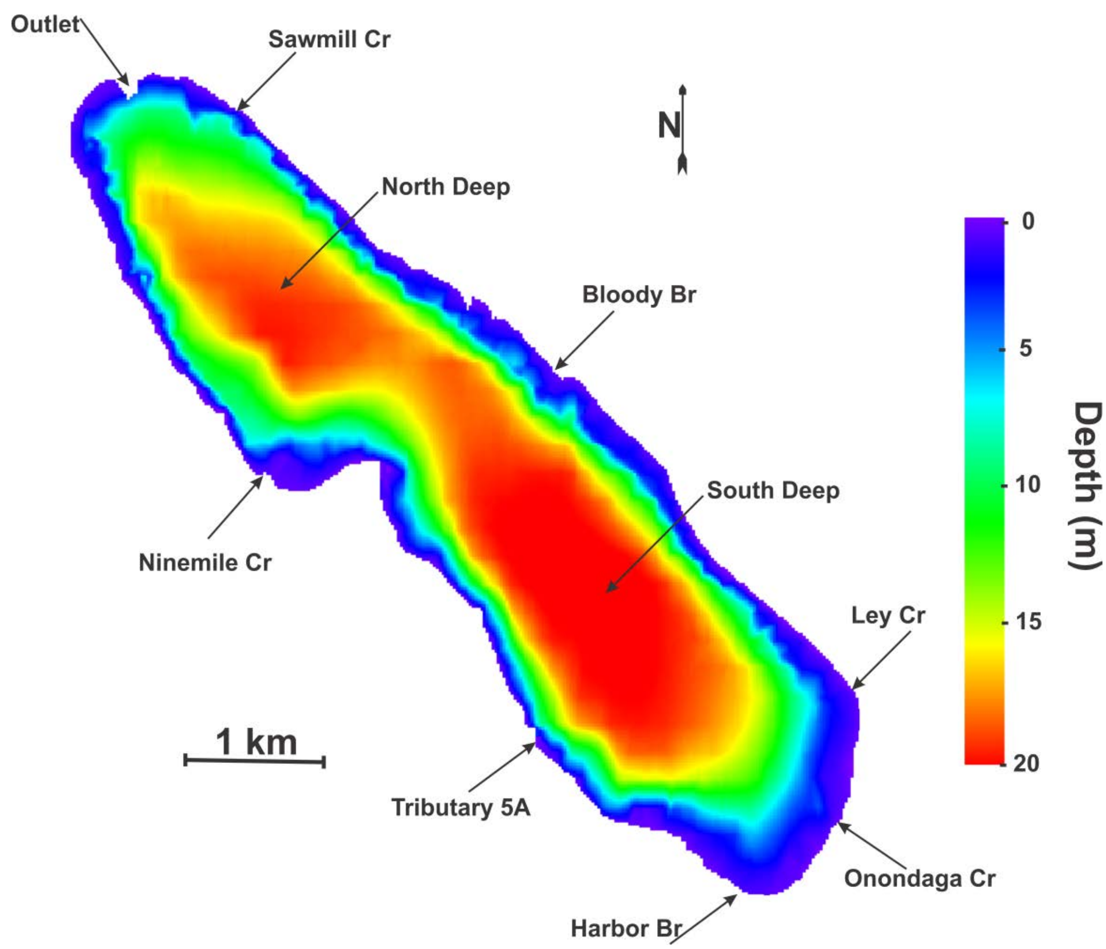


Figure 2-3. Bathymetric map of Onondaga Lake, with tributaries and primary sampling locations (South Deep, North Deep) identified.

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

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 wastewater collection and treatment infrastructure within 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 (Table 3-1).

Abating the combined sewer overflows (CSOs) is a significant challenge (Figure 3-1). The Combined Sewer System tributary to Metro includes an area of 7,337 acres or approximately 11 square miles. CSOs are tributary to three receiving waters, Onondaga Creek, Harbor Brook, and Ley Creek. The County has employed four strategies to reduce wet weather discharges from the combined sewer system to the Metro treatment plant: (1) sewer separation, (2) construction of regional treatment facilities, (3) capture of floatable materials, and (4) maximization of system storage capacity, or "gray infrastructure" (Table 3-2, Table 3-3). Since 1998, the County has closed or abated 51 of the 72 CSO locations that were active prior to the ACJ.

Onondaga County's Save the Rain (STR) Program was created in response to the 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 for combined sewer overflow control. GI is the County's fifth strategy to significantly reduce or eliminate the discharge of untreated combined sewage into Onondaga Lake and its tributaries.

The ACJ includes a phased schedule for CSO compliance, with the goal of capturing, for treatment or elimination, no less than 95 percent by volume of CSO by 2018. This is within the meaning of the Environmental Protection Agency's (EPA) National CSO Policy. To meet this goal the County initiated the "Save the Rain" Program in 2009, which is implementing 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 Metro, and elimination of CSO discharge points. Nine GI projects were completed in 2016 as part of the STR program. To date, a total of 189 GI projects have been implemented in Onondaga County through the STR program. Results from the County's recently calibrated Storm Water Management Model (SWMM) indicate that GI projects are reducing stormwater runoff by 131 million gallons per year and providing CSO reduction of approximately 63 million gallons per year.

The County has completed construction on all gray infrastructure projects required in the ACJ. Going forward, the County will focus on optimizing the performance of its CSO control facilities, while continuing to implement green infrastructure in priority areas, perform maintenance on both gray and green facilities, implement best management practices (BMPs) and floatables control measures, and monitor system performance.

Two new projects will contribute importantly to upgraded treatment at Metro in the coming years. The Metro Secondary Bypass Treatment Improvements Project, which was completed in April 2017, will reduce the occurrence of secondary and tertiary bypass events and loading of fecal coliform bacteria to Onondaga Lake. This project includes modification of the existing chlorine tank, upgrade of the chemical feed system, addition of a new de-chlorination tank, and improved flow monitoring and facility operation. The Metro Phosphorus Optimization project will ensure consistent high-level phosphorus treatment into the future, helping to achieve water quality goals in Onondaga Lake. This project is scheduled for completion in June 2019.

Crew Practice on Onondaga Lake.

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-N and phosphorus load to the lake • began selection and design of improvements	evaluation and implementation of nine minimum control measures	summer TP 55 µg/L in lake's upper waters	county began design of integrated biological monitoring program
1999	--	completed upgrade of aeration system for biological treatment of ammonia 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	--

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
2004	--	• year-round nitrification of ammonia-N at Metro using BAF • Stage III SPDES limit for ammonia-N met 8 years ahead of schedule	progress with sewer separations (refer to 2009)	compliance with AWQS: • Ammonia-N in lake upper waters • for fecal coliform bacteria in lake Class B segments during Metro disinfection period	--
2005	--	Actiflo® system on-line to meet Metro Stage II SPDES limit for TP (0.12 mg/L 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/calibrat ion review (Phase 2).	progress with sewer separations (refer to 2009)	• compliance with AWQS for ammonia-N 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

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
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 16.7 acres of impervious surfaces	summer average TP of 25 µg/L in lake's upper waters	resurgence of Alewife; loss of larger zooplankton
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

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
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 • 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.	summer average TP of 25 µg/L in lake's upper waters	continued high densities of Alewife and absence of larger zooplankton

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

Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
2014	On June 4, 2014, the NYSDEC issued a modification to Metro's SPDES permit. The modified permit determined Metro's permit effluent total phosphorus concentration limits not exceed 0.10 mg/L as a 12-month rolling average and a monitoring requirement for the operation of the CSO 018 pilot constructed wetland.	compliance with TP limit of 0.10 mg/L as a 12-month rolling average	• 22 GI projects completed in 2014 • 95.3% of CSO volume is captured	summer average TP of 22 µg/L in lake's upper waters	continued high densities of Alewife and absence of larger zooplankton

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

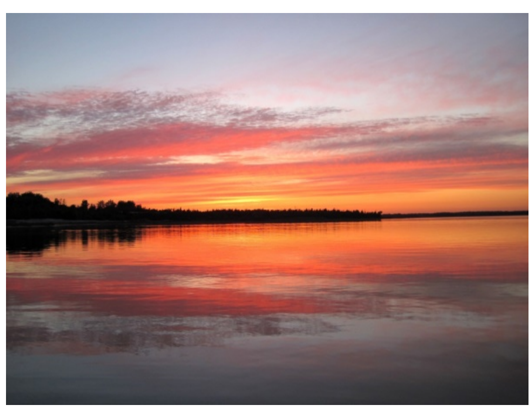
Year	Regulatory/ Management Actions	Metro Actions	CSO Abatement Actions	Water Quality Status	Biological Status
2015	--	compliance with TP limit of 0.10 mg/L as a 12-month rolling average	• 11 GI projects completed • In August 2015 the CSO 063 Conveyances Project was completed, including 3,100 linear feet of new pipe to convey flow to the LHBSF. • Construction of the Harbor Brook CSO 018 Constructed Wetlands Pilot Treatment System was completed and placed into operation in April 2015. • The typical year model results show that the annual CSO capture percentage for the 2015 system conditions is 96.2%, exceeding the 95% final capture milestone mandated for 2018. • Since 2011, over 5,000 trees have been planted as part of the STR street tree planting program.	summer average TP 23 µg/L in lake's upper waters	Alewife population reduced by cold winter of 2014-2015

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
			• The County introduced the "Connect the Drops" campaign, which focuses on preventing street litter from entering our waters and builds on the STR Program		
2016	--	compliance with TP limit of 0.10 mg/L as a 12-month rolling average	• 9 GI projects were completed in 2016, which brings the total number of GI projects completed to 189. • The "Connect the Drops" campaign, which focuses on preventing street litter from entering our waters, was launched. • "Block Litter", a joint initiative between Save the Rain and the Onondaga County Resource Recovery Agency encourages local residents and businesses to help "Block Litter" where they live and work.	summer average TP was 20 µg/L in lake's upper waters	Alewife remained abundant, influencing the zooplankton community and water clarity

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
			• Construction of the CSO 061 Sewer Separation Project was completed in December 2016. This project separates sanitary and stormwater flow along Crehange Street within CSO 061. • The typical year model results show that the annual CSO capture percentage for the 2016 system conditions is 97.4%, exceeding the 95% final capture milestone mandated for 2018.		



Sunset on Onondaga Lake.

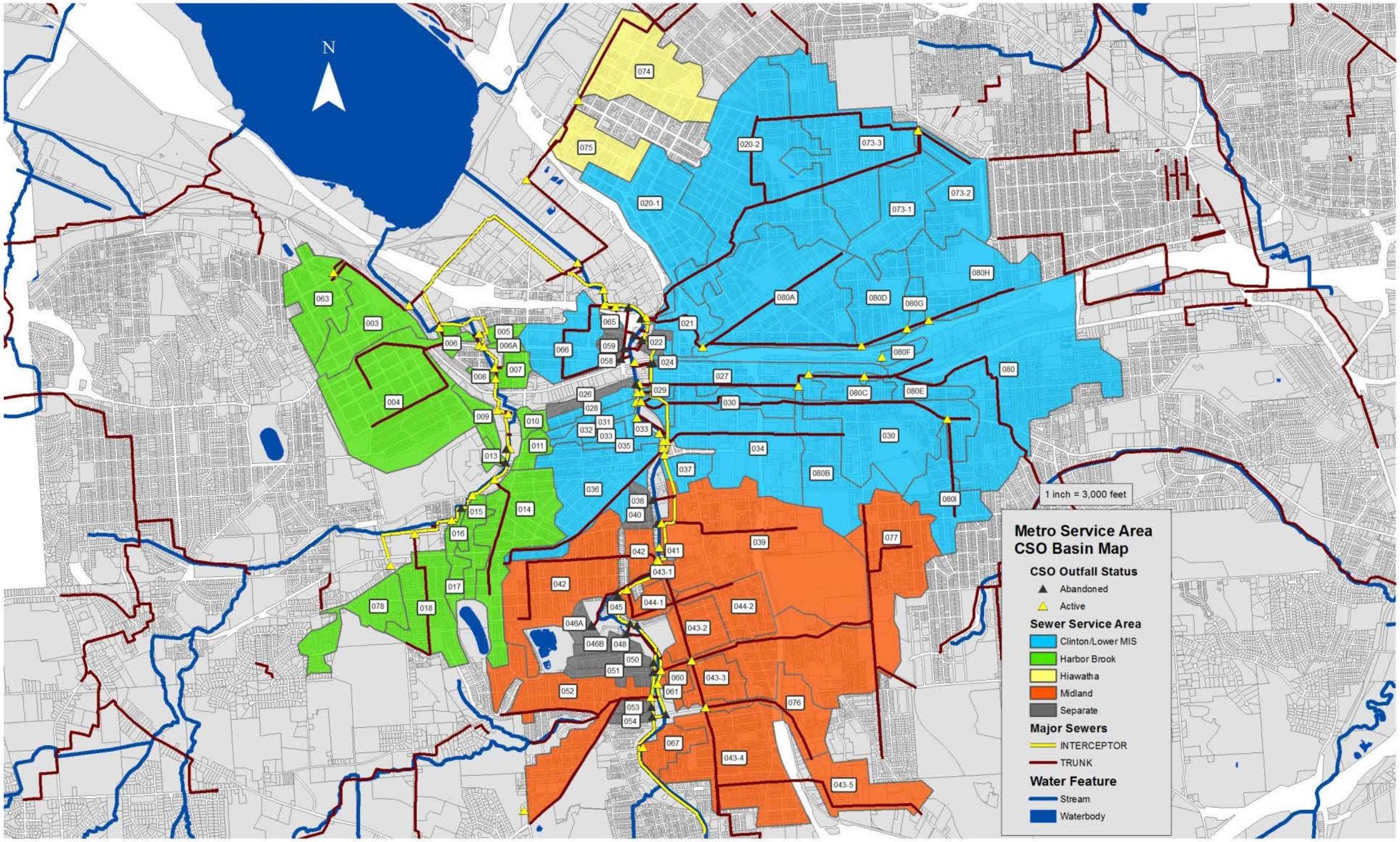


Figure 3-1. Map of CSO areas.

Table 3-2. ACJ and additional gray infrastructure milestones, schedules, 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	3,100 linear feet of new pipe was installed to convey flow to the LHBSF	Completed August 2015
Hiawatha Trunk Sewer	Rehabilitation Project (relined)	Completed November 2015
Harbor Brook pilot wetlands and Hiawatha Trunk Sewer monitoring	Sewage flow monitoring to calibrate CSO 018 and CSO 075 sewersheds	Completed 2015
Model validation – Harbor Brook Interceptor	Install flow monitoring devices to compare predicted and measured flow volumes	Completed 2015
CSO 061 Sewer Separation	Separate sanitary and stormwater flow along Crehange Street and convey all wastewater to the MIS for treatment at Metro	Construction completed December 2016

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.

Fishing from the Pier at Onondaga Lake Park.

The County began final design of the CSO 061 Sewer Separation Project in early 2016 and completed construction in December 2016. The purpose of the CSO 061 Sewer Separation Project was to separate sanitary and stormwater flow along Crehange Street within CSO 061. With the completion of the project, wastewater in the former 061 is now conveyed to the MIS for treatment at Metro via a new sanitary sewer. Stormwater is conveyed to Onondaga Creek via the repurposed existing combined sewer. The former CSO 061 outfall is now utilized for stormwater discharge. CSO discharge at this location is now eliminated. Inspection and confirmation of closure by NYSDEC is pending.

Since 2011, over 5,000 trees have been planted as part of the STR street tree planting program. In 2016 the County initiated the "Connect the Drops" education and outreach campaign, which builds off the successful STR Program. The campaign is focused on street litter because the previous assessment has demonstrated that approximately 98 percent of trash reaching the water of Onondaga Lake and its tributaries is street-borne litter. The Connect the Drops campaign was launched in Spring 2016 and was very active in the second and third quarter of the year. The campaign is focused on making that connection between "drops" of litter and rain "drops" that can carry litter downstream, entering catch basins and/or tributaries. A new joint initiative between Save the Rain and the Onondaga County Resource Recovery Agency (OCRRA) encourages local residents and businesses to help "Block Litter" where they live and work through regular neighborhood cleanups. The "Block Litter" program aims to educate community members about the importance of litter-free neighborhoods and cleaning the community one block at a time. "Block Litter" is about small acts that can play a big role in keeping our community clean. For additional information on these and other projects please visit the Save the Rain website (savetherain.us).

County Executive Joanne Mahoney continues to champion the Save the Rain (STR) initiative to educate residents about stormwater 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. The STR program 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. Additionally, the STR initiative continued a comprehensive public education and outreach program to engage the local community while providing continued support for program activities. For additional information on STR projects please visit the Save the Rain website (savetherain.us).

Rain Barrel Installation.

3.2 Progress with Related Initiatives

Honeywell International is proceeding with a number of projects to address industrial contamination issues, with oversight by EPA and NYSDEC. About 2.2 million cubic yards of contaminated Onondaga Lake sediments were removed from the lake bottom by hydraulic dredging. The dredging effort was completed by the end of 2014, a year ahead of schedule. The capping phase of the sediment restoration effort was completed in December 2016. Approximately 475 acres of the lake bottom have been capped to provide a new habitat layer, prevent erosion, and isolate remaining contaminants. The cap consists of more than 3 million cubic yards of material consisting primarily of sand, activated carbon, and stone. To date, 74 acres of wetlands have been created or enhanced at Geddes Brook, Harbor Brook, Ninemile Creek, the former LCP Chemicals site, and along the western shoreline of Onondaga Lake. These wetlands provide habitat for more than 230 wildlife species. About 1.1 million plants, shrubs, and trees will be planted within the watershed to enhance fish and wildlife habitat. Additional details can be found on Honeywell's project website (http://www.lakecleanup.com).

Following the success of a three-year pilot test from 2011 to 2013, nitrate additions to the deep waters of Onondaga Lake have continued annually. The nitrate applications are designed to limit the release of methylmercury from the sediments under the deep portions of the lake by altering the chemical oxidation status of the overlying lake water. A liquid calcium-nitrate solution is injected into the deep waters of the lake several times each week during the summer stratification interval, when oxygen concentrations fall below critical levels in the deep waters. The nitrate additions have reduced the flux of methylmercury and soluble reactive phosphorus out of the sediments by over 90%. Detailed descriptions of Honeywell's planned remedial projects, designed to reduce the adverse impacts of legacy pollutants 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 and provides the public with access to information on the lake cleanup. Thousands of people have visited the Center to learn more about Onondaga Lake and the cleanup project. Additional information on Honeywell's remediation activities is available on their project website http://www.lakecleanup.com.

For decades, scientists at Onondaga County Department of Water Environment Protection (OCDWEP) and the State University of New York College of Environmental Science and Forestry (SUNY-ESF) have been monitoring Onondaga Lake to evaluate how biological communities are changing as pollution levels decline. A formal collaboration was launched in 2011. Researchers from Cornell University with interests in the lower trophic levels (phytoplankton, macrophytes, zooplankton, and Dreissenid mussels) have also been part of the collaborative monitoring and data interpretation efforts. The significance of the Alewife in structuring the lake's food web is another area of active research. Taken together, the findings of both academic and agency programs offer a unique window into the ecological changes taking place in this valuable community asset.

Onondaga Lake Dredging Operations.

Section 4. Tributary Water Quality: 2016 Results and Long-Term Trends

4.1 Tributary Monitoring Program

The primary objectives of the tributary monitoring program are to assess compliance with ambient water quality standards in the tributary streams and to estimate loading of materials to the lake, including the volume and loading of materials from combined sewer overflows (CSOs). In addition, results from the annual tributary monitoring data, conducted on a biweekly basis, are used to support long-term trend analysis. To support these objectives, seven tributaries to the lake are monitored, as are the Metro effluent and the Onondaga Lake outlet. The tributary monitoring program targets sample collection over a range of streamflow conditions, including a minimum number of high flow events as defined by statistical analysis of long-term flow records.

The post construction monitoring program (PCCM) supports evaluation of green and gray CSO controls through monitoring of receiving waters and the influent chambers of CSO facilities. High frequency monitoring during storm events is an important component of the PCCM efforts. In 2015, Harbor Brook was monitored during four storm events and Onondaga Creek was monitored during two events. Because no new green or gray infrastructure projects were scheduled for Harbor Brook during 2016, the PCCM focused on Onondaga Creek. High frequency event monitoring will be resumed in Harbor Brook following the remediation of an upstream community septic system. In 2016, high frequency monitoring of Onondaga Creek was conducted during three storm events (see Section 4.8.2 for details).

Additional information on the tributary monitoring program can be found in the Five-Year (2014–2018) AMP Work Plan. Results for key parameters and tributary sampling locations are presented in this section. Long-term time series covering 2007–2016 are provided for all AMP parameters and tributary sampling locations in Appendix D-1.

4.2 Meteorological Drivers and Streamflow

Meteorological conditions in the Central New York region are subject to substantial seasonal variations. These conditions typically vary day-to-day, and noteworthy differences are commonly observed between years. Air temperature is the primary determinant of 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 40.6 inches in 2016, 1.2 inches more than the 31-year historic (1985–2015) average of 39.4 inches and 1.3 inches less than the 41.9 inches received in 2015. Monthly precipitation totals were higher than the long-term averages in February, May, August, October, and December (Figure 4-1). Precipitation was particularly high during February and October. In fact, 2016 had the wettest months of February and October in the 1985–2015 record. The months of January, March, April, June, July, and November, were dryer than the long-term average. June and July were particularly dry months, with just 4.6 inches of rainfall compared to the long-term average of 7.5 inches. Snowfall for the winter of 2015–2016 totaled just 80.3 inches, well below the 1951–2014 average of 119 inches.

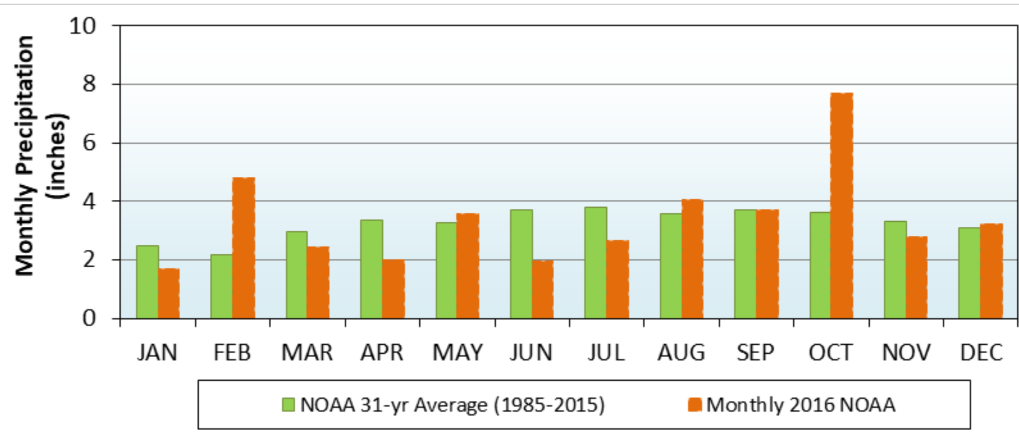


Figure 4-1. Monthly precipitation in 2016 compared to the long-term (1985–2015) average.

Substantial year-to-year variations in precipitation are reflected in the wide range of annual average flows carried by Onondaga Creek during the 1971–2016 interval (Figure 4-2). Despite slightly above average precipitation during 2016, the annual average flow for Onondaga Creek was 18% lower than the long-term mean (Figure 4-2). The apparent contradiction of near average precipitation and low streamflow may be related to the timing of precipitation or changes in runoff patterns. Plotting the long-term annual average flows in a cumulative probability format shows that 80% of the annual average flows were higher than the average flow measured in 2016 (Figure 4-3).

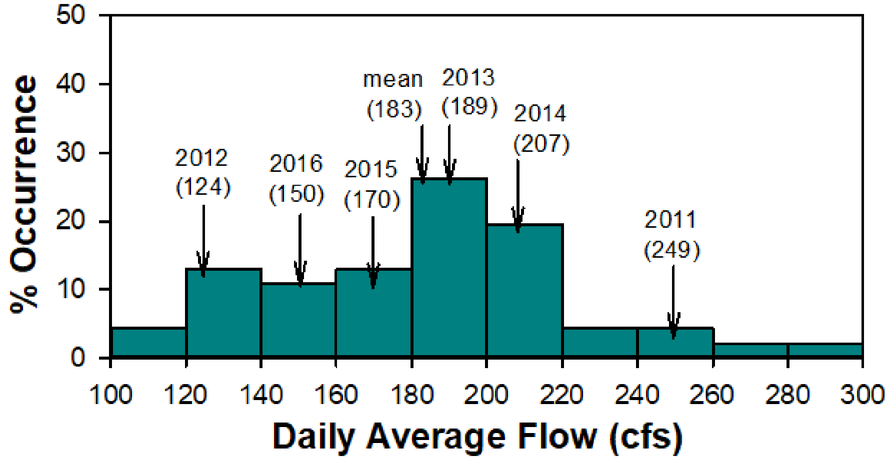


Figure 4-2. Distribution of the annual average of daily average flows for Onondaga Creek at Spencer Street, 1971–2016.

Note: Annual average values for 2011-2016 and the mean for the entire 46-year record are identified.

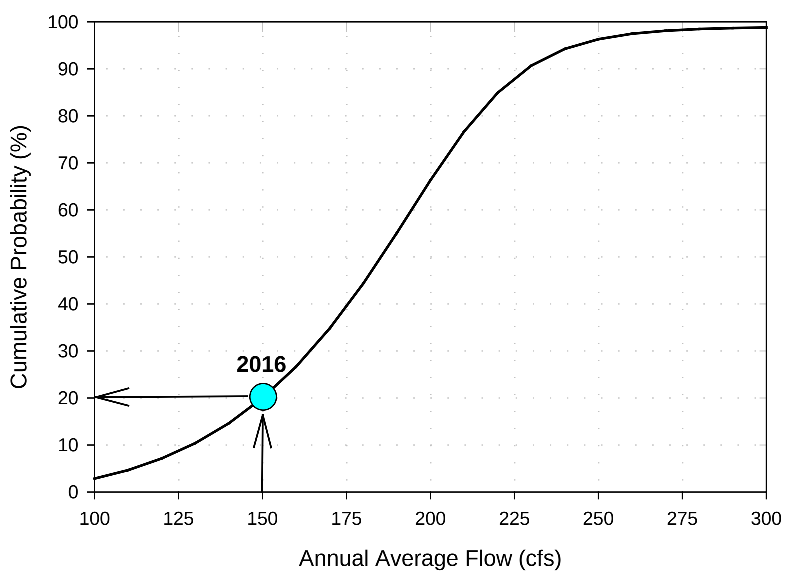


Figure 4-3. Cumulative probability plot of annual average flows for Onondaga Creek at Spencer Street, 1971–2016.

Daily streamflow measurements for the major tributaries in 2016 depict major runoff events in late February, late October, late November, and early December (Figure 4-4). The wettest day of 2016 was May 29, when the Metro rain gauge reported 2.42 inches of rain. Interestingly, this event resulted in only modest increases in streamflow because it occurred subsequent to an extremely dry interval (0.39 inches of rain in the preceding 26 days) and during a period of high evapotranspiration. The March to July interval was characterized by unusually dry conditions, which was reflected in below average streamflow during the spring and summer months (Figure 4-4). The daily average flow in Onondaga Creek at Spencer St. during June–September 2016 was less than one-half of the 30-year (1986–2015) average for this period.

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 were 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 2016, this goal was met for Ley Creek and Harbor Brook (Figure 4-4). Only three and four high flow samples were collected at Onondaga Creek and Ninemile Creek, respectively, due to the unusually dry conditions that prevailed during most of 2016. The percentage of samples collected during high flow conditions ranged from 6% at Onondaga Creek to 14% at Ley Creek.

Harbor Brook Wetland.

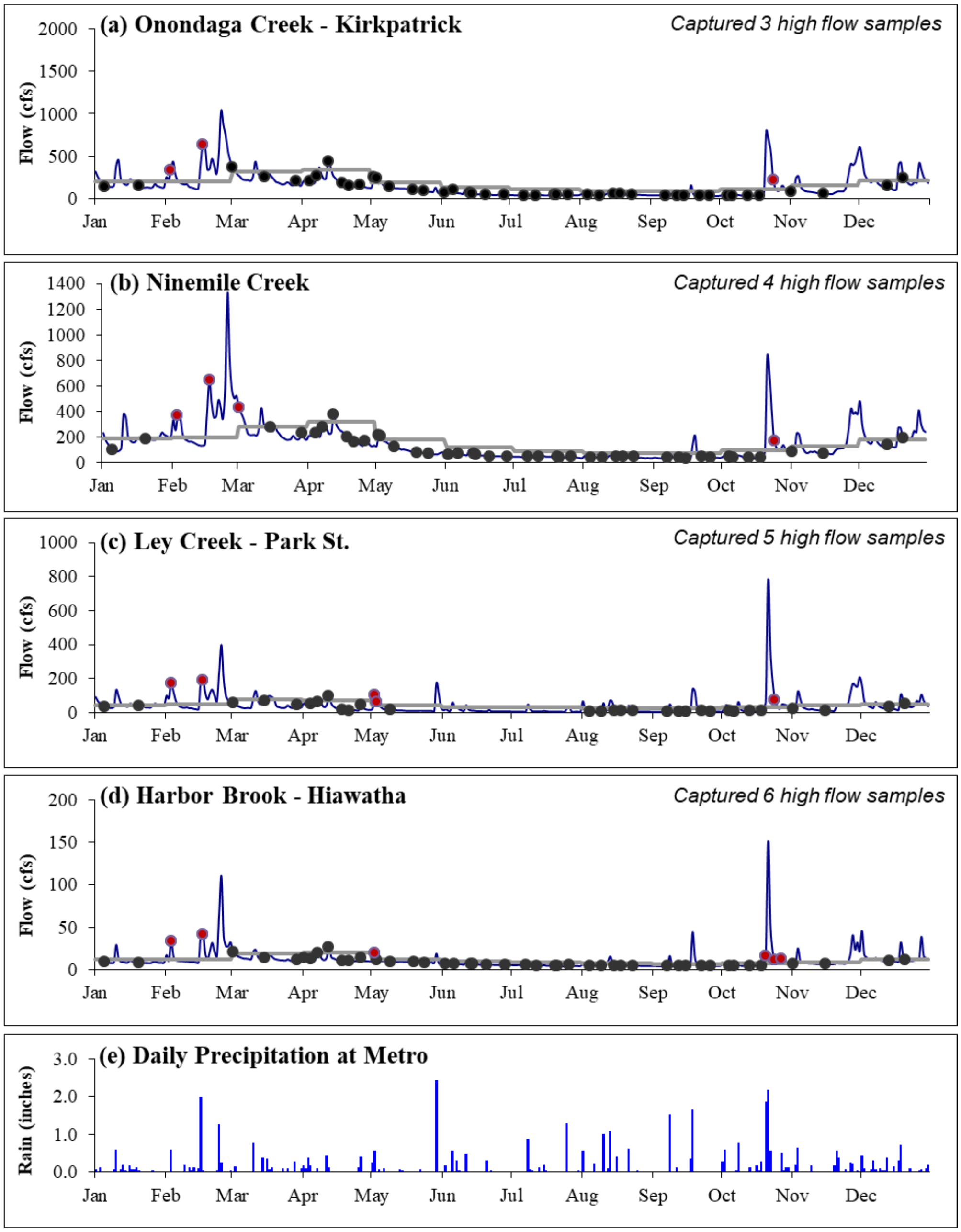


Figure 4-4. Hydrographs showing USGS tributary flows in 2016 compared with the 30-year average (1986–2015) flow for (a) Onondaga Creek, (b) Ninemile Creek, (c) Ley Creek, (d) Harbor Brook, and (e) daily precipitation at Metro.

Note: high flow samples are indicated by red circles and other samples are indicated by black circles.

4.3 Loading Estimates

4.3.1 Methodology

Dr. William Walker (http://www.wwwalker.net/onondaga) developed customized software for WEP staff to calculate annual loads using the program AUTOFLUX, method 5. This software was designed to support load estimates from detailed (e.g., continuous) flow measurements and less frequent (often biweekly) analyses of tributary water quality samples. Concentrations from the tributary monitoring program are stratified by flow regime and by season using a multiple regression technique. High-frequency measurements collected during storm events (PCCM) are incorporated into the calculations. Conditions during unmonitored periods are estimated using a residual interpolation method that includes a flow derivative term. This term was included to account for the potential effect of differences in the flow and concentration relationship depending on whether samples were collected during periods of increasing or decreasing flows. This software was used to compute all of the loading estimates presented in this report. Annual loading estimates for selected parameters are presented for 2016 (Table 4-1), 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 24 observations within the year, except for HW MH 015 (n=4) and Tributary 5A (n=4), as per the 2016 AMP Work Plan. Fecal coliform samples were collected more frequently (5 samples per month) to allow for determination of compliance with the AWQS. Note that estimated daily discharges for Harbor Brook are rated as poor by USGS and thus contribute to greater uncertainty in loading estimates at this site.

4.3.2 Results for Key Constituents

The largest total phosphorus (TP) loads to Onondaga Lake in 2016 were delivered by Onondaga Creek (10.4 metric tons), Ninemile Creek (8.5 metric tons), and the Metro effluent (6.8 metric tons; Table 4-1). Onondaga Creek was the predominant source of TP, contributing 35% of the total load. Ninemile Creek, Metro Bypass (002), and Ley Creek contributed 29%, 23%, and 11%, respectively (Table 4-2). Metro's contribution to TP loading was substantially greater before the Actiflo® upgrade in 2005. Total phosphorus loads in 2016 were 30% lower than in 2015, consistent with lower stream flow in 2016. TP loading from Onondaga Creek decreased by 14% from 2015 to 2016, while loads from Ninemile Creek and Metro (001+002) decreased by 36% and 12%, respectively. Reduced TP loading from Onondaga Creek was primarily associated with a 16% decrease in loading at Dorwin Ave. Decreased loading from Ninemile Creek was caused by a 34% decrease in the average TP concentration, potentially related to ongoing cleanup activities in the stream. Ninemile Creek, the Metro effluent (001+002), and Onondaga Creek were also the largest contributors of total dissolved phosphorus (TDP) loads in 2016. The TDP fraction is a better representation of bioavailable forms than is TP, as a large portion of particulate phosphorus is typically unavailable to support algal growth.

The phosphorus TMDL for Onondaga Lake established both an average pollutant load allocation (77,668 pounds per year) and a maximum pollutant load allocation (114,975 pounds per year) and is based upon TP. The former is intended to protect the lake in the long run, while the latter was used to develop SPDES permit limits, recognizing interannual variability in loads. The estimated total phosphorus load in 2016 was 65,050 pounds per year (converted from 29.5 metric tons in Table 4-1). 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 phosphorus TMDL for Onondaga Lake has not yet been fully implemented. Phosphorus loading reductions associated with CSOs and the Metro Bypass are scheduled to be fully implemented by 12/31/18. Implementation dates for agricultural lands and MS4s are 12/31/22 and 12/31/25, respectively.

The Metro effluent (001+002) was the leading source of both total nitrogen (TN; 70%) and ammonia nitrogen (NH_3-N; 47%) to the lake in 2016 (Table 4-1, Table 4-2). The second largest source of ammonia-N in 2016 was Ninemile Creek (30%), followed by Onondaga Creek (13%). The total suspended solids (TSS) load was dominated by inputs from Onondaga Creek (59%) and Ninemile Creek (31%), which combined to account for 90% 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.

Table 4-1. Annual loading estimates for selected water quality constituents, 2016.

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]	5.1	(362)	1.5	(244)	1,168	(365)	28.4	(365)	458	(365)	87,844	(211)
Bypass (002)[6]	1.7	(18)	0.8	(9)	19	(18)	10.6	(18)	85	(18)	1,227,801	(7)
Watershed:												
HW MH 015[4]	0.0	(4)	0.0	(4)	4	(4)	0.2	(4)	6	(4)	435	(4)
Harbor Brook-Velasko[4]	0.2	(25)	0.1	(26)	15	(26)	0.3	(26)	152	(26)	2,119	(48)
Harbor Brook-Hiawatha[4]	0.5	(29)	0.2	(26)	18	(29)	0.8	(29)	212	(29)	18,103	(51)
Ley Creek[4]	3.2	(24)	0.9	(24)	39	(24)	8.3	(24)	703	(24)	74,321	(46)
Ninemile Creek[4]	8.5	(26)	2.5	(26)	216	(26)	24.7	(26)	4,125	(26)	261,163	(48)
Onondaga Creek-Dorwin[4]	7.7	(32)	1.0	(26)	182	(32)	4.4	(32)	6,011	(26)	55,393	(53)
Onondaga Creek-Kirkpatrick[4]	10.4	(26)	1.8	(26)	225	(26)	10.6	(26)	7,877	(26)	116,653	(48)
Tributary 5A[4]	0.0	(4)	0.0	(4)	1	(4)	0.1	(4)	5.8	(4)	43	(39)
Total	**29.5**	--	**7.5**	--	**1,690**	--	**83.7**	--	**13,473**	--	**1,786,364**	--

Notes:

[1]Parameters are: TP (total phosphorus), TDP (total dissolved phosphorus), 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, soluble reactive phosphorus (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 2016 measurements and concentration-flow relationships for the 2006-2016, processed through AutoFlux Method 5.

[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 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]TN loads were calculated by summing the annual NH_3-N, NO_3-N, NO_2-N, and ORG-N loads; Honeywell's nitrate addition program has contributed approximately 67 metric tons of nitrate to the hypolimnion annually since 2011.

Table 4-2. Percent annual loading contribution by gauged inflow in 2016.

Parameter	TP	TDP	TN	NH_3-N	TSS	FC	Water
Metro:							
Treated Effluent (001)	17.2%	19.9%	69.1%	34.0	3.4%	4.9%	21.1%
Bypass (002)	5.8%	8.0%	1.1%	12.7%	0.6%	68.7%	0.4%
Harbor Brook	1.7%	2.4%	1.1%	1.0%	1.6%	1.0%	2.4%
Ley Creek	10.8%	11.6%	2.3%	9.9%	5.2%	4.2%	9.0%
Ninemile Creek	29.0%	33.1%	12.8%	29.6%	30.6%	14.6%	33.5%
Onondaga Creek	35.4%	24.4%	13.3%	12.7%	58.5%	6.5%	33.4%
Tributary 5A	0.1%	0.2%	0.0%	0.1%	0.0%	0.0%	0.1%

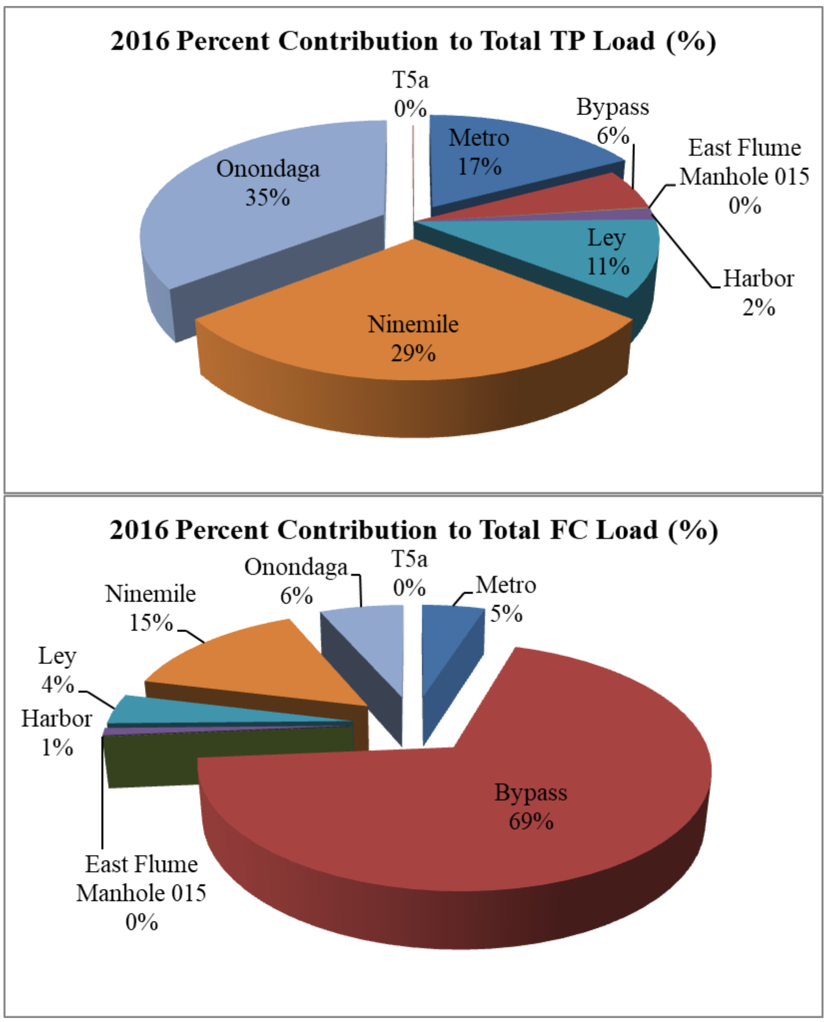


Figure 4-5. Percent contributions to 2016 total load to Onondaga Lake for (a) total phosphorus and (b) fecal coliform bacteria.

The primary sources of fecal coliform bacteria were the Metro Bypass (69%), Ninemile Creek (15%), and Onondaga Creek (7%). Note that estimated fecal coliform loads for the Metro Bypass and Ninemile Creek are highly uncertain, with relative standard errors of 88% and 92%, respectively (Appendix D-6). The combined loading from these three sources accounted for 91% of the total fecal coliform load to Onondaga Lake. The Metro (001+002) contribution to total fecal coliform loading increased from 20% in 2014 to 42% in 2015 to 73.6% in 2016. Fifty-three percent of the total fecal coliform load in Onondaga Creek entered between Dorwin and Kirkpatrick, while 88% of the total fecal coliform load in Harbor Brook entered between Velasko and Hiawatha. Loading contributions of gauged inputs for selected constituents in 2016 are presented here in both tabular (Table 4-2) and graphical (Figure 4-5) formats. Loading estimates for additional constituents are provided in Appendix D-2 and relative standard errors of these estimates can be found in Appendix D-6. Total annual loads (tributaries and Metro) to Onondaga Lake for the 1997–2016 interval are presented in Appendix D-3.

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 2016 are presented in Table 4-3 for selected constituents. The flow-weighted concentrations of total phosphorus ranged from 50 µg/L in Harbor Brook to 87 µg/L in Ley Creek, but were much higher for the partially treated Metro bypass (1,158 µg/L). Concentrations of total dissolved phosphorus were lowest in Onondaga Creek (10 µg/L) and highest in the bypass (409 µg/L). The Metro effluent, Metro bypass, and HW MH 015 were enriched in total nitrogen relative to the other inputs. Concentrations of TSS were highest in Onondaga Creek and the bypass and lowest in the fully treated Metro effluent. The bypass had the highest fecal coliform concentrations, followed by Ley Creek, Ninemile Creek, and Harbor Brook. The complete list of flow-weighted average concentrations and relative standard errors is provided in tabular format (Appendix D-4).

Fish from Onondaga Lake on Display at the 2014 Clean Water Fair
September 6, 2014 at Metro.

Table 4-3. Average annual flow and flow-weighted average concentrations for selected constituents in Onondaga Lake tributaries, 2016.

Parameters[1]	Flow	TP		TDP		TN[7]		NH_3-N		TSS		FC[2]	
units	(ft^3/s)	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]	95	60	(362)	18	(244)	13.8	(365)	0.33	(365)	5.4	(365)	1,034	(211)
Bypass (002)[6]	2	1,158	(18)	409	(1)	13.2	(18)	7.24	(18)	58.1	(18)	839,558	(7)
Tributaries:													
Harbor Brook-Velasko[4]	10	25	(25)	12	(26)	1.8	(26)	0.04	(26)	17.8	(26)	247	(48)
Harbor Brook-Hiawatha[4]	11	50	(29)	18	(26)	1.8	(29)	0.08	(29)	21.5	(29)	1,835	(51)
Ley Creek[4]	41	87	(24)	24	(24)	1.1	(24)	0.23	(24)	19.4	(24)	2,044	(46)
Ninemile Creek[4]	151	63	(26)	18	(26)	1.6	(26)	0.18	(26)	30.6	(26)	1,934	(48)
Onondaga Creek-Dorwin[4]	118	73	(32)	10	(26)	1.7	(32)	0.04	(32)	57.1	(26)	526	(53)
Onondaga Creek-Kirkpatrick[4]	150	77	(26)	14	(26)	1.7	(26)	0.08	(26)	58.5	(26)	867	(48)
Tributary 5A[4]	1	62	(4)	29	(4)	1.6	(4)	0.13	(4)	11.4	(4)	84	(39)
HW MH 015[4]	1	71	(4)	66	(4)	7.8	(4)	0.38	(4)	13.3	(4)	944	(4)
All Inflows[8]	**577**	**69**	--	**17**	--	**3.9**	--	**0.19**	--	**31**	--	**4,160**	--

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 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 with 2016 observations (n = number of samples for 2016) processed through AutoFlux Method 5.
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 the capacity of Metro is exceeded.
7 All TN flow-weighted concentrations were calculated by dividing the total TN load (see Table 4-1) by the total flow volume for each site.
8 Flow-weighted average concentrations for the sum of all inflows (Metro+tributaries).

4.3.3 Phosphorus Loading and Bioavailability

Estimates of total phosphorus loads for the tributaries have generally been greater in higher runoff years (Figure 4-6). Annual rainfall for the 1990–2016 period explained 44% of the year-to-year variation 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 because of natural variations in rainfall. Clearly, variations in runoff need to be considered when evaluating year-to-year dynamics in lake water quality.

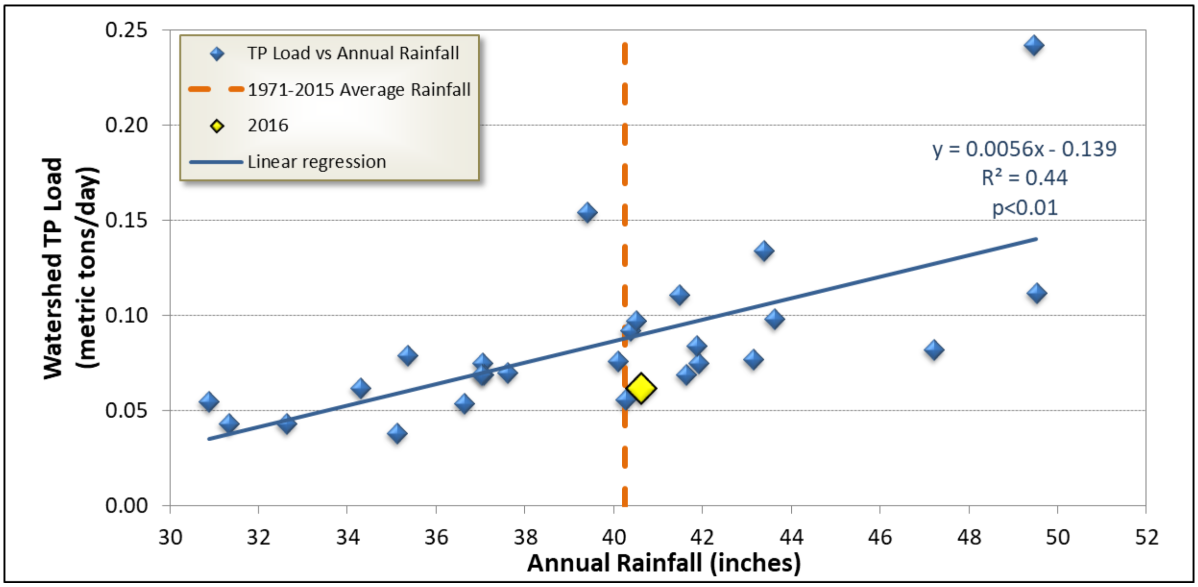


Figure 4-6. Daily average total phosphorus (TP) loading from the watershed versus annual precipitation for the 1990–2016 period.

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

The timing of phosphorus loads within a year is an important factor influencing 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 particularly important drivers of algal growth for Onondaga Lake. Monthly loads of total phosphorus (TP) and total dissolved phosphorus (TDP) are presented for 2016 (Figure 4-7). Compared to recent years (Appendix D-5), watershed loading of total phosphorus in 2016 was high during February and October and quite low during the spring and summer months. Monthly total phosphorus loads are also presented for the years 2012–2015 for comparison (Appendix D-5). There has been a recurring seasonal pattern 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 in loading have occurred because of the dependency on the timing of runoff.

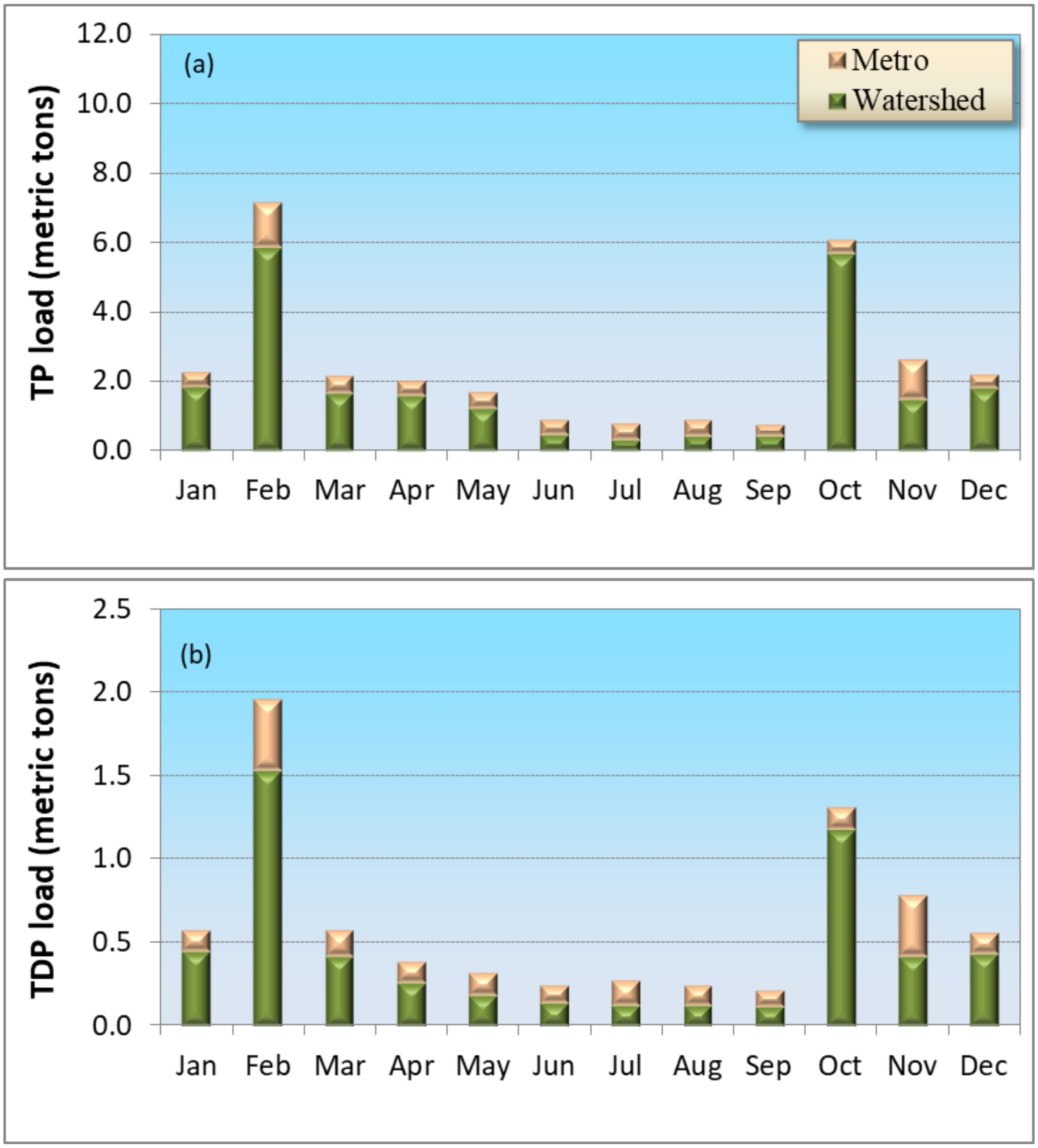


Figure 4-7. Monthly phosphorus loading to Onondaga Lake from Metro and watershed sources in 2016: (a) total phosphorus (TP) and (b) total dissolved phosphorus TDP).

Increasingly, lake management programs acknowledge that only a portion of the total phosphorus loading to a lake is available to support algal growth. It is important to note that 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 is 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: (1) settling of PP before it can be transformed and (2) the plunging of dense inputs that are colder or more saline than the upper waters 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 was available to support algal growth. Moreover, the PP from Metro had an unusually high settling rate and a portion plunged below layers where algae grow. Further reductions in PP are unlikely to contribute importantly to decreased algal growth. 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 loading from Metro and the tributaries from the 1990–1998 interval (before the ACJ) to after implementation of Actiflo® (2007–2016) are presented here for total phosphorus (Table 4-4), total dissolved phosphorus (Table 4-5), and soluble reactive phosphorus (Table 4-6). Loading of total phosphorus was reduced by 87% for the fully treated Metro effluent (Table 4-4). The 76% decrease in the total phosphorus load from the bypass is also noteworthy. The changes for the tributaries over this period have been relatively modest, including 42% and 23% decreases for Ley Creek and Onondaga Creek, respectively. In recent years (post-Actiflo®), Metro (effluent plus bypass) has represented about 23% of the total phosphorus load, the third largest source, after Onondaga and Ninemile Creeks.

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 2007–2016 interval (post-Actiflo® upgrade) are presented in Table 4-5. Metro's average contribution to TDP loading over this interval was 29%, approximately equivalent to loadings from Ninemile Creek (29%) and Onondaga Creek (27%). Flow-weighted concentrations of total dissolved phosphorus for the three smallest tributaries considered (Harbor Brook, Tributary 5A, and HW MH 015) were higher than for the treated Metro effluent (0.023 mg/L). The Actiflo® upgrade resulted in a 98% reduction in SRP loading from the treated Metro effluent (Table 4-6).

The SRP fraction is particularly 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 (34%) or Ninemile Creek (32%).

Table 4-4. A comparison of total phosphorus (TP) loading and flow-weighted concentrations for pre-ACJ (1990–1998) and post-Actiflo® (2007–2016) periods.

Note: mt = metric tons; concentrations flow-weighted

Site	1990-1998 (pre ACJ)				2007- 2016 (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 (001)	21%	52	57%	0.56	19%	6.7	18%	0.08
Bypass (002)	1%	8.5	8%	1.83	0%	2.0	5%	1.18
Tributaries:								
HW MH 015	0%	0.2	0%	0.20	0%	0.1	0%	0.13
Harbor Brook	2%	0.7	1%	0.07	2%	0.8	2%	0.07
Ley Creek	9%	5.7	6%	0.14	8%	3.3	9%	0.09
Ninemile Creek	32%	10.2	10%	0.07	33%	10.7	28%	0.07
Onondaga Creek	34%	20.1	19%	0.12	36%	15.0	38%	0.09
Tributary 5A	1%	0.2	0%	0.05	0%	0.1	0%	0.10
Total	--	**97.4**	--	--	--	**38.6**	--	--

Table 4-5. Total dissolved phosphorus (TDP) loading and flow-weighted concentrations for the post-Actiflo® (2007–2016) period.

Note: mt = metric tons; concentrations flow-weighted; TDP wasn't measured during the pre-ACJ period.

Site	2007- 2016 (post-Actiflo®)			
	Flow (%)	TDP (mt P/yr)	TDP (% load)	TDP (mg P/L)
Metro:				
fully treated	19%	2.0	22%	0.02
Bypass	0%	0.6	7%	0.37
Tributaries:				
HW MH 015	0%	0.1	1%	0.10
Harbor Brook	2%	0.3	4%	0.03
Ley Creek	8%	0.9	10%	0.02
Ninemile Creek	33%	2.7	29%	0.02
Onondaga Creek	36%	2.5	27%	0.02
Tributary 5A	0%	0.1	1%	0.04
Total	--	**9.1**	--	--

Table 4-6. A comparison of soluble reactive phosphorus (SRP) loading and flow-weighted concentrations for pre-ACJ (1990–1998) and post-Actiflo® (2007–2016) periods.

Note: mt = metric tons; concentrations flow-weighted

Site	1990-1998 (pre ACJ)				2007- 2016 (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%	0.13	19%	0.26	5%	0.003
Bypass	1%	2.5	10%	0.50	0%	0.53	11%	0.313
Tributaries:								
HW MH 015	0%	0.1	0%	0.09	0%	0.06	1%	0.089
Harbor Brook	2%	0.3	1%	0.02	2%	0.28	6%	0.025
Ley Creek	9%	1.4	6%	0.03	8%	0.52	11%	0.014
Ninemile Creek	32%	1.7	8%	0.01	33%	1.63	32%	0.011
Onondaga Creek	34%	3.3	16%	0.02	36%	1.65	33%	0.010
Tributary 5A	1%	0.0	0%	0.01	0%	0.03	1%	0.028
Total	--	**21.2**	--	--	--	**5.0**	--	--

4.4 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 46% (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 met these limits by wide margins in 2016; 2015 conditions are included for reference (Figure 4-10). Seasonality in the performance of the nitrification treatment is commonly 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.

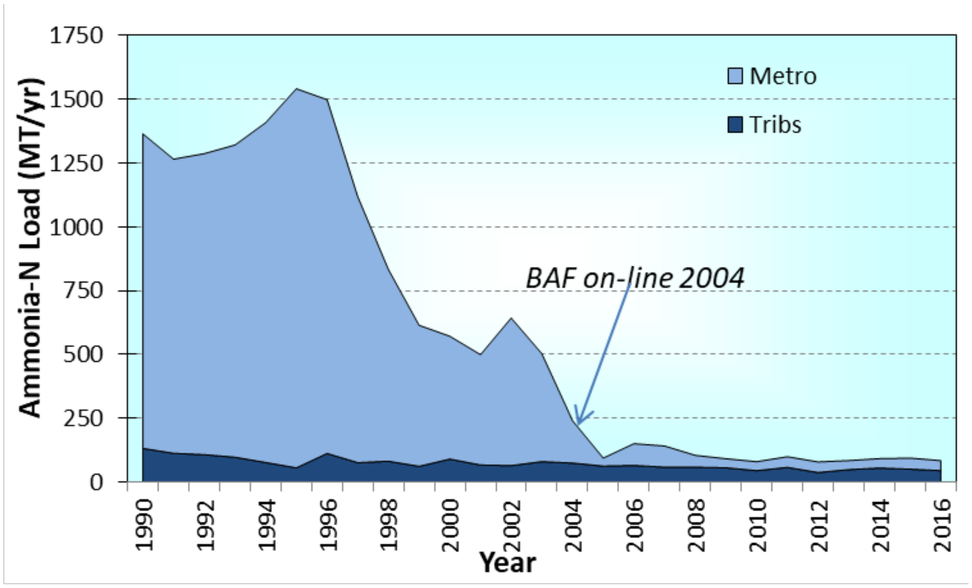


Figure 4-8. Time plot of the annual daily average Metro (outfalls 001+002) and tributary ammonia loading (metric tons per year) to Onondaga Lake, 1990–2016.

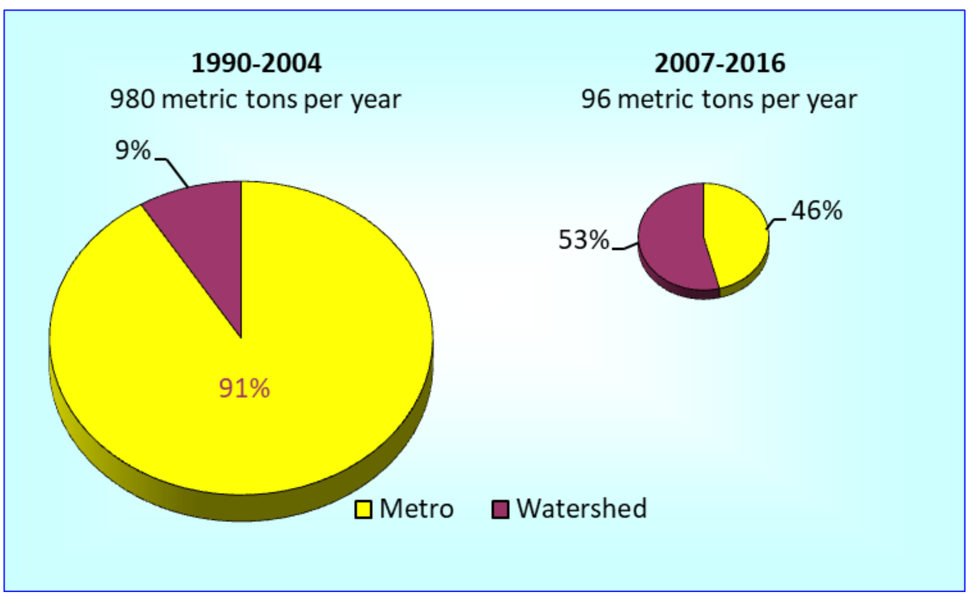


Figure 4-9. Contributions of Metro (outfalls 001+002) and the watershed to the total annual input of ammonia-N to Onondaga Lake, average for 1990–2004 compared to the average for 2007–2016.

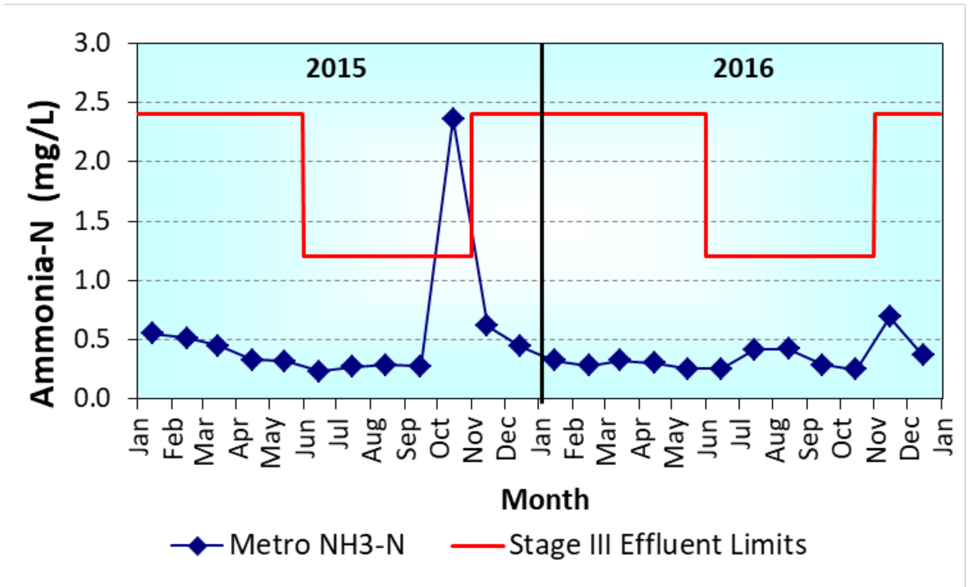


Figure 4-10. Metro effluent monthly average ammonia concentrations compared to permit limits for 2015 and 2016.

The total phosphorus concentration of Metro's effluent and associated loading (Figure 4-11) decreased dramatically with the implementation of the Actiflo® treatment upgrade in 2005. Moreover, Metro's contribution to the total annual phosphorus load decreased from 61% over the 1990 to 2004 interval to 22% during 2007–2016 (Figure 4-12). Total phosphorus concentrations for the 2006–2017 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. The rolling average total phosphorus concentration in the Metro effluent has remained below 0.10 mg/L since mid-2008 and below 0.07 mg/L since May 2013 (Figure 4-13). During 2016, the average total phosphorus concentration in the Metro effluent was 0.060 mg/L.

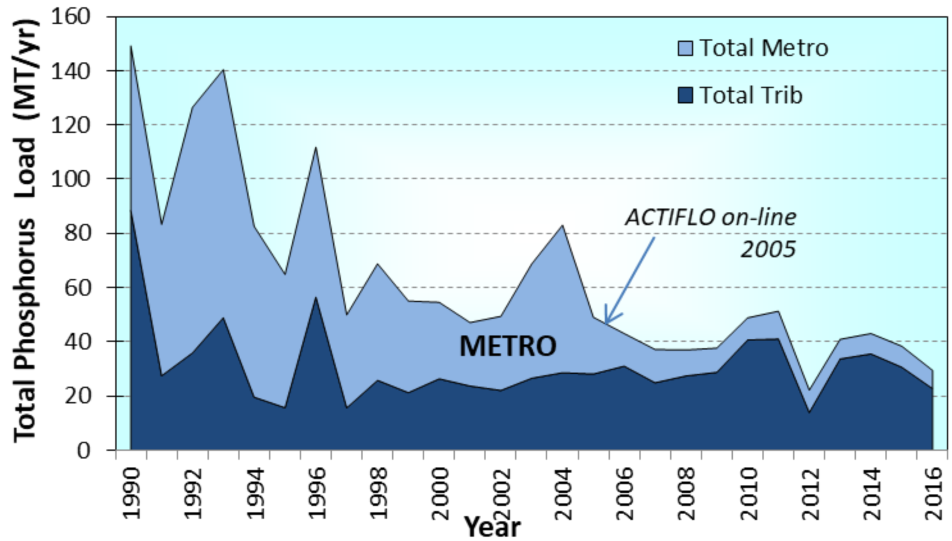


Figure 4-11. Time plot of the annual daily average Metro (outfalls 001+002) total phosphorus (TP) loading (metric tons per year) to Onondaga Lake, 1990–2016.

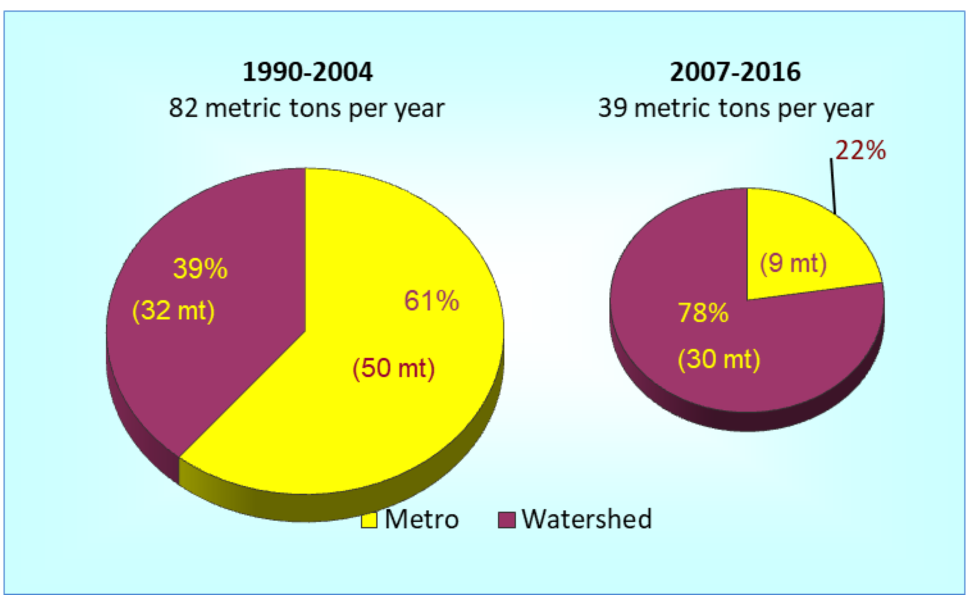


Figure 4-12. Contributions of Metro (outfalls 001+002) and the watershed to the annual input of total phosphorus to Onondaga Lake, average for 1990–2004 compared to the average of 2007–2016.

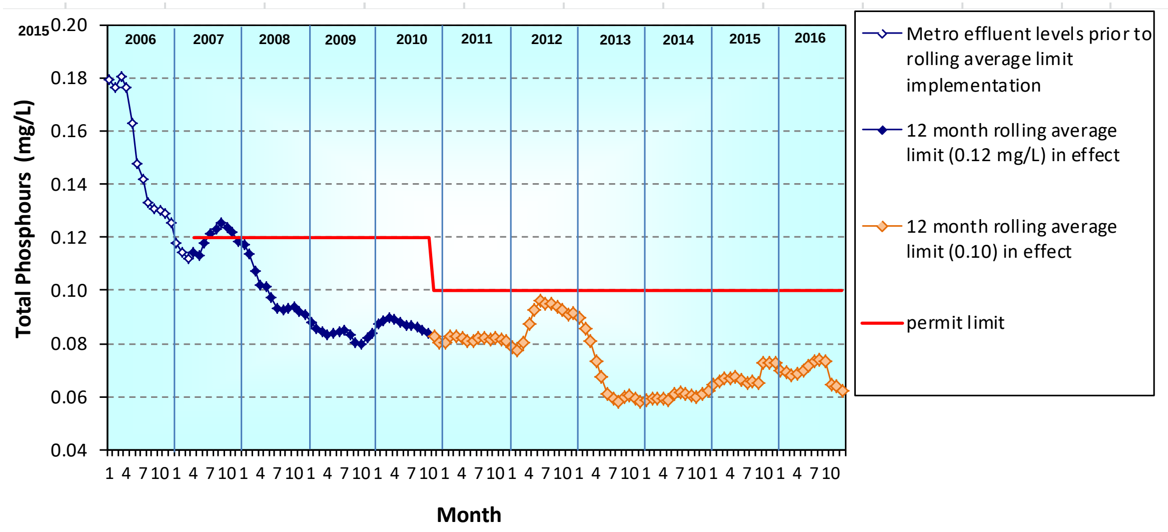


Figure 4-13. Metro effluent total phosphorus concentrations compared to permit limits for the 2006–2016 interval.

Note: Concentrations are monthly rolling average values for 12-month intervals. Interim limits were in place through June 30, 2012. The final limit of 0.10 mg/L as a 12-month rolling average has been in place since June 30, 2012.

The major reductions in ammonia-N and total phosphorus loading from treatment upgrades at Metro (BAF and Actiflo®, respectively) were identified and graphically supported (Figure 4-8 for ammonia-N, Figure 4-11 for total phosphorus). The BAF upgrade resulted in a 98% decrease in ammonia-N 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 was achieved. Implementation of the BAF treatment reduced the Metro loading of ammonia-N and nitrite, forms of nitrogen that raise water quality concerns. The BAF also increased the input of nitrate, a form of nitrogen that 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 performance, relative to the requirements of the SPDES permit dated June 4, 2014, is summarized in Appendix C-4. There were no violations of permit limits reported for Outfall 001 in 2016 for the following parameters: flow, suspended solids, pH, settleable solids, ammonia-N, total phosphorus, cyanide, and total mercury. The SPDES permit limit for CBOD5 was violated due a sample being designated as "invalid" due to a laboratory error. The SPDES limit for fecal coliform bacteria (7-day geometric mean) was exceeded on two occasions. Nine violations of the daily average permit limit for total phenols were recorded. Whole effluent toxicity testing (WET) of the Metro effluent in 2016 indicated no chronic toxicity to invertebrates. The action level limit for tetrachloroethene, a chemical used for dry cleaning and degreasing, was exceeded on a single occasion. Three SPDES limit violations were documented for daily maximum settleable solids in Metro Outfall 01 A during 2016.

A schematic of the Metro treatment process, including the various outfalls, is available on page 32 of the Metro SPDES permit (Appendix C-7). Flow exits Metro through four outfalls, depending on the level of wastewater treatment:

- headworks bypass – Outfall 01B
- secondary bypass – Outfall 002
- tertiary bypass – Outfall 01A
- fully treated – Outfall 001

Metro provided full treatment to an average flow of 61.3 million gallons per day (mgd) in 2016, which was discharged to the lake through Outfall 001. On an annual basis, discharge from Outfall 001 was more than 22.4 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 35 secondary bypasses in 2016, which had a combined duration of 325 hours and a total volume of 540 million gallons. Typically less frequently, the inflow receives secondary treatment and disinfection prior to discharge via Outfall 01A (tertiary bypass; Appendix C-2). In 2016 there were 38 tertiary bypasses that contributed a total of 207 million gallons over a period of 241 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 or plant construction, 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 23 headworks bypasses in 2016 that lasted 66 hours and discharged a total volume of 93 million gallons.

Metro's annual discharge volumes for 2010–2016 are summarized in Table 4-7. The extent to which bypasses occur depends critically on precipitation and runoff, both of which are subject to substantial variability. During 2016, Metro was undergoing construction of the Secondary Bypass Disinfection Improvements project. As a result, plant capacity was often reduced as different phases of construction advanced. The planned reduced capacity periods contributed to the increased number and volume of bypasses during 2016. Construction was completed in April 2017.

Table 4-7. Annual Metro discharge volumes for the fully treated effluent and bypasses, 2010–2016.

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
2014	24,400	19	442	33
2015	22,600	41	462	0.65
2016	22,400	207	540	93

4.5 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, bypasses of the collection and treatment system without treatment (i.e., SSOs) are prohibited. Detailed documentation of the prohibited CSO and SSO events that occurred during 2016 is presented in Appendix C-5 and Appendix C-6, respectively. Annual summaries of the prohibited CSOs and SSOs within the Onondaga Lake watershed for the 2010–2016 period are presented in Table 4-8. Approximately 281,900 gallons of prohibited CSO volume discharged to Onondaga Creek was associated with rocks and grit from 2.4 inches of rain restricting a regulator at CSO 066 between May 29 and June 1, 2016. Nearly one-half of the SSO volume during 2016 was attributable to deterioration of a 42-inch force main, resulting in 10,800,000 gallons of sanitary sewer overflow entering Onondaga Lake during October 21-22. An additional 6,996,000 gallons of SSO entered Ley Creek on October 29 as the bad section of the Ley Creek force main was repaired.

Table 4-8. Number and volume of prohibited combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) within the Onondaga Lake watershed during 2010–2016.

Year	CSO		SSO	
	Number	Volume (gallons)	Number	Volume (gallons)
2010	7	98,000	37	23,614,535
2011	4	2,700	66	12,390,818
2012	7	20,450	40	69,940
2013	5	800	35	31,105
2014	1	1,000	31	1,694,150
2015	3	51,600	29	11,165,794
2016	3	481,900	27	23,185,450

4.6 Compliance with Ambient Water Quality Standards

Several segments of Onondaga Lake's tributary streams are included on the 2016 NYSDEC compendium of impaired waters. NYSDEC places waterbodies on this list when there is evidence that water quality conditions do not meet applicable standards, and/or the water bodies do not support their designated use. Results of Onondaga County's AMP are among the primary data sets used to evaluate compliance with standards and use attainment. The 2016 tributary data indicate that the major tributaries were generally in compliance with ambient water quality standards (AWQS) for most parameters addressed (Table 4-9). The primary exceptions in meeting AWQS in the tributaries were total dissolved solids (TDS), fecal coliform bacteria (FC), and dissolved mercury. 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 was not established as 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 monthly 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

Table 4-9. Summary of tributary and outflow compliance (percent of observations in compliance) with ambient water quality standards (AWQS), 2016.

Site	Field Data		Solids	Nitrogen		Metals[1]				Bacteria
	Dissolved Oxygen (4mg/L)	pH	TDS	Ammonia-N	Nitrite	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Mercury[2]	Fecal[3] Coliform
Bloody Brook at Onon. L. Parkway	100% (39)	100% (38)	0% (6)	100% (3)	100% (6)	NS (0)	NS (0)	NS (0)	75% (4)	29% (39)
Harbor Brook at Hiawatha Blvd..	100% (51)	98% (51)	0% (29)	97% (29)	100% (26)	NS (0)	NS (0)	NS (0)	75% (4)	0% (51)
Harbor Brook at Velasko Rd.	100% (48)	100% (48)	0% (26)	100% (25)	100% (26)	NS (0)	NS (0)	NS (0)	100% (4)	100% (48)
Ley Creek at Park St.	100% (46)	100% (46)	4% (26)	100% (24)	100% (24)	NS (0)	NS (0)	NS (0)	50% (4)	14% (46)
Ninemile Creek at Lakeland	100% (48)	100% (48)	0% (26)	100% (25)	100% (25)	NS (0)	NS (0)	NS (0)	100% (4)	57% (48)
Onondaga Creek at Kirkpatrick St.	100% (48)	100% (48)	0% (26)	100% (25)	100% (26)	100% (4)	100% (4)	100% (4)	100% (4)	14% (48)
Onondaga Creek at Dorwin Ave.	100% (68)	100% (68)	22% (46)	100% (38)	100% (26)	100% (4)	100% (4)	100% (4)	100% (4)	29% (69)
Sawmill Creek at Onon. L. Rec. Area	100% (39)	100% (39)	0% (4)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	75% (4)	57% (39)
Trib. 5A at State Fair Blvd.	100% (39)	100% (39)	0% (4)	100% (4)	100% (4)	NS (0)	100% (4)	100% (4)	25% (4)	100% (39)
Onondaga Lake Outlet (12ft)	100% (22)	100% (22)	0% (26)	88% (24)	100% (23)	NS (0)	NS (0)	NS (0)	100% (4)	NS (0)
Onondaga Creek at Elmhurst (Upstream)	100% (3)	100% (3)	0% (3)	100% (2)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)
Harbor Brook at Culvert(NrOnonLake)	100% (3)	100% (3)	0% (3)	100% (2)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)
Onondaga Creek at Rich St. Bridge Center	100% (61)	100% (61)	0% (23)	100% (19)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	14% (61)
Onondaga Creek at South Ave. Downstream	100% (4)	100% (4)	0% (3)	100% (4)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)
Onondaga Creek at South Ave. Upstream	100% (3)	100% (3)	0% (3)	100% (3)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)
Onondaga Creek at Spencer St.	100% (59)	100% (59)	5% (22)	100% (22)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	14% (61)
Onondaga Creek at Tully Farms Rd.	100% (48)	100% (48)	19% (26)	100% (26)	100% (26)	NS (0)	NS (0)	NS (0)	100% (4)	29% (48)
Onondaga Creek at West Genesee St. mid transect	100% (63)	100% (63)	0% (25)	100% (26)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	0% (65)
Onondaga Creek at Water St.	100% (4)	100% (4)	0% (3)	100% (4)	NS (0)	NS (0)	NS (0)	NS (0)	NS (0)	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 mean of at least 5 samples; *Note: occurrences of less than 100% compliance are highlighted in red text; dissolved oxygen, ammonia-N, nitrite, and fecal coliform are specified in the ACJ; the number of observations is shown in parentheses; NS is not sampled.*

input of bacteria to Onondaga Lake during wet weather. 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. Compliance with the AWQS for fecal coliform bacteria was achieved for less than 50% of the monthly means at Bloody Brook (29%), Harbor Brook at Hiawatha (0%), Ley Creek (14%), and all monitored sites on Onondaga Creek at Kirkpatrick (0-29%). Fecal coliform conditions were somewhat better at Ninemile and Sawmill Creeks where 57% of the monthly means were in compliance. Note that Bloody Brook, Ninemile Creek, and Sawmill Creek do not have CSOs.

Another parameter with noteworthy exceptions to 100% compliance was dissolved mercury, which was monitored on a quarterly basis. Compliance with the AWQS for dissolved mercury was documented for all four samples collected at Onondaga Creek-Tully Farms, Onondaga Creek-Dorwin, Onondaga Creek-Kirkpatrick, Ninemile Creek, and Harbor Brook-Velasko, three of the four samples from Bloody Brook, Harbor Brook-Hiawatha, and Sawmill Creek, two of the four samples from Ley Creek, and one of the four samples at Tributary 5A. The wetland located near the mouth of Sawmill Creek likely contributes importantly to elevated levels of dissolved mercury in this stream. Inputs from atmospheric deposition result in regional increases in mercury levels. Occasional exceedances of AWQS for pH and ammonia at Harbor Brook-Hiawatha are associated with a milky discharge in the vicinity of the Hiawatha Ave. bridge.

Harbor Brook.

Time series of fecal coliform concentrations in Onondaga Creek, Harbor Brook, and Ley Creek during 2016 are presented for both wet and dry weather conditions (Figure 4-14). Wet weather samples are those collected following at least 0.1 inches of rain in the preceding 48 hours; all other samples were 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 4-14a) and Harbor Brook (Velasko Rd., Figure 4-14c) routinely exceeded the AWQS of 200 counts/100 mL during both wet and during dry weather conditions in the summer months. A distinct seasonality in fecal coliform concentrations was apparent at all sampling locations, with generally 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).

Fecal coliform time series data for Onondaga Creek (Figure 4-15), Harbor Brook (Figure 4-16), and Ley Creek (Figure 4-17) are presented for the April–October interval of 2010–2016. The frequency of bacterial sampling increased to five samples per month starting in April 2010 to support assessments of compliance with the AWQS for fecal coliform bacteria. These figures include a reference line at 200 cfu/100 mL, which is the NYS AWQS for fecal coliform bacteria. Because this standard strictly applies to a monthly geometric mean based on a minimum of five samples, it is only included for numerical perspective. Although the upstream concentrations of fecal coliform were generally lower than the downstream concentrations, the upstream concentrations were frequently above 200 cfu/100 mL. Thus compliance is likely affected by issues upstream of urban sources. The long-term record continues to show higher fecal coliform concentrations during the summer months.

WEP Technician Sampling Ninemile Creek 2016

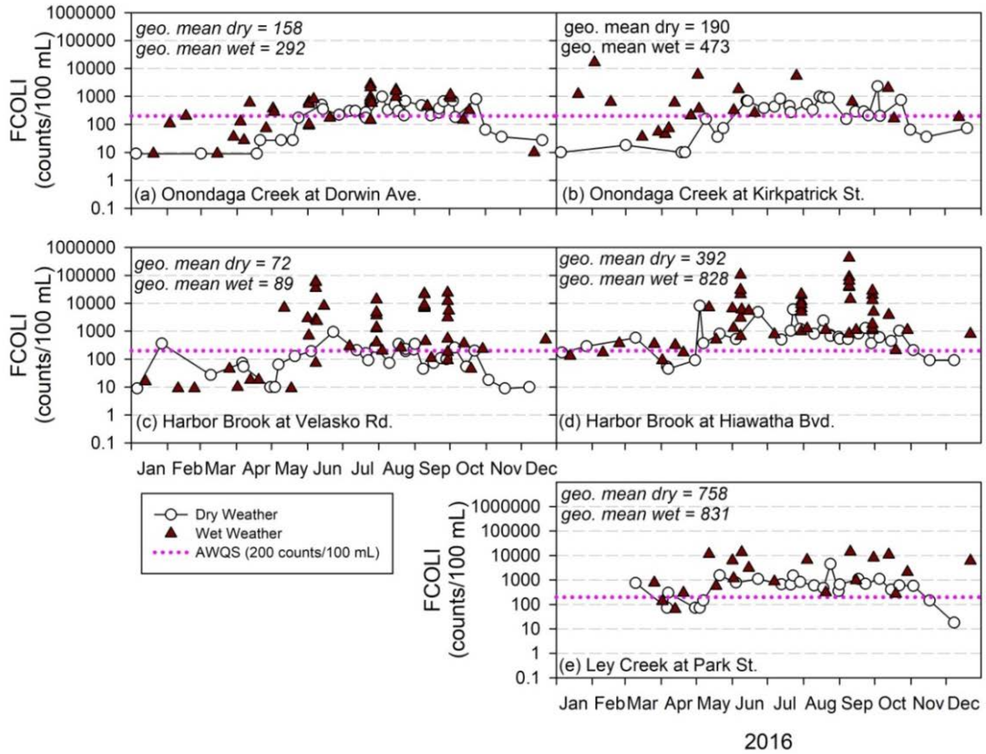


Figure 4-14. Time series of fecal coliform concentrations during wet weather and dry weather during 2016: (a) Onondaga Creek at Dorwin Ave., (b) Onondaga Creek at Kirkpatrick St., (c) Harbor Brook at Velasko Rd., (d) Harbor Brook at Hiawatha Blvd., and (e) Ley Creek at Park St.

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

Sturgeon Onondaga Lake 2016

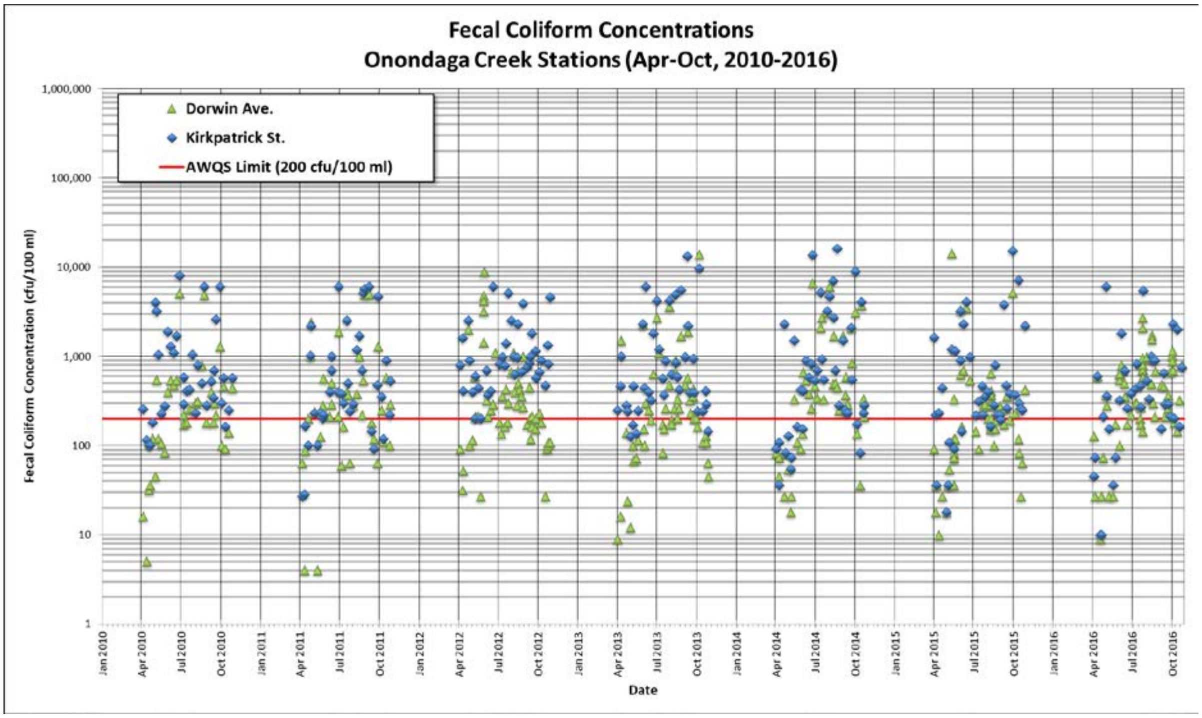


Figure 4-15. Fecal coliform concentrations measured at Onondaga Creek stations (April–October 2010–2016).

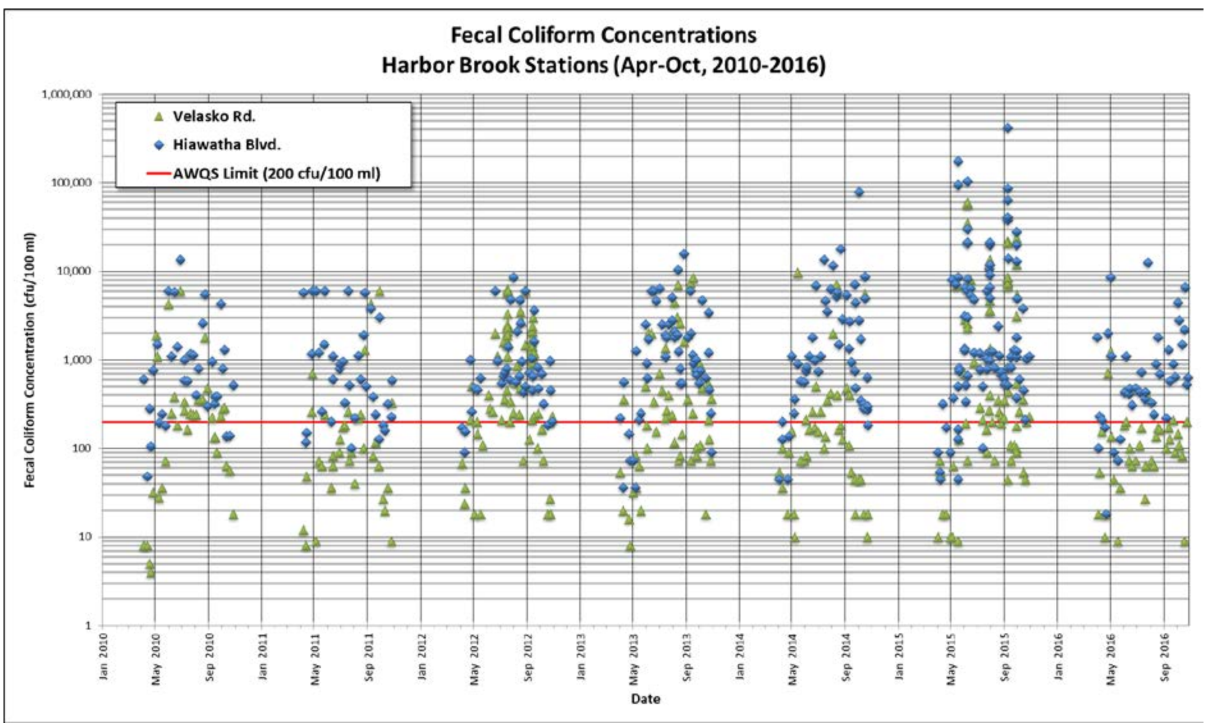


Figure 4-16. Fecal coliform concentrations measured at Harbor Brook stations (April–October, 2010–2016).

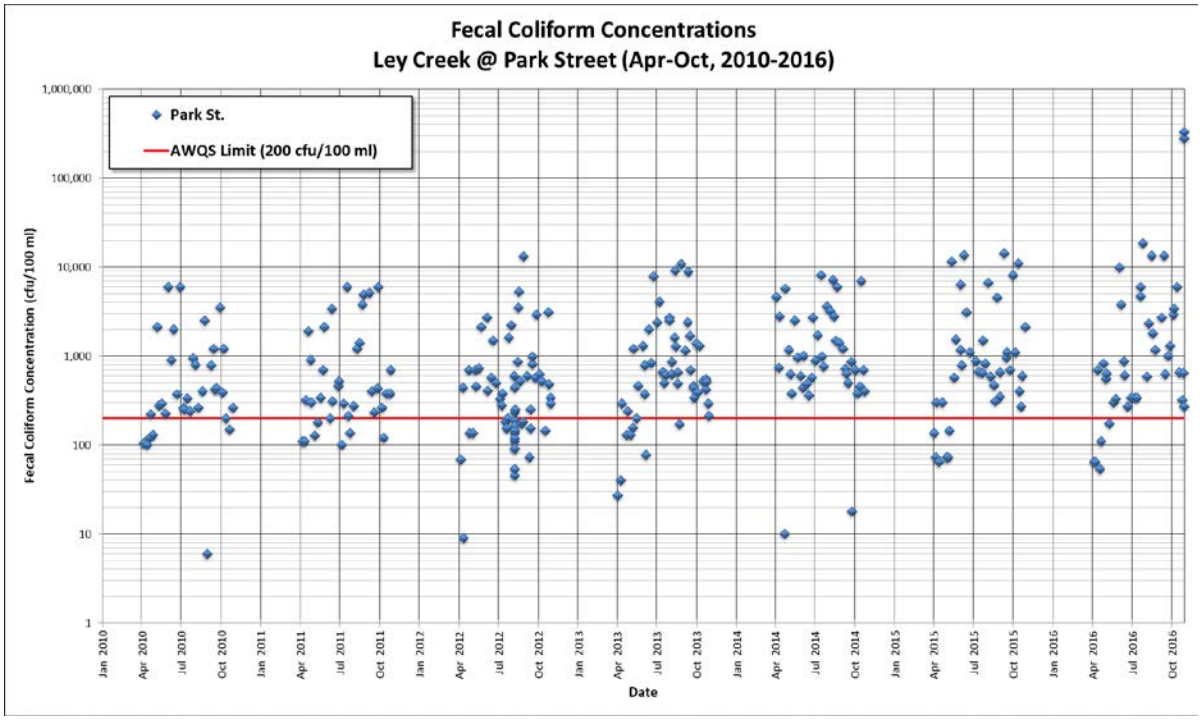


Figure 4-17. Fecal coliform concentrations measured at Ley Creek, (April–October, 2010–2016).

4.7 Long-Term Trends

Loading trends for Metro and the tributaries over the 1991–2016 interval are presented graphically for selected constituents (Figure 4-18). Annual loads for additional constituents are presented in tabular format in Appendix D-3. 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. For example, the particularly low runoff conditions of 2012 are reflected in major reductions in constituent loading from the tributaries. Long-term decreases in ammonia-N loading and increases in nitrate loading are associated with implementation of efficient, year-round nitrification treatment at Metro. Variations in ammonia-N 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.

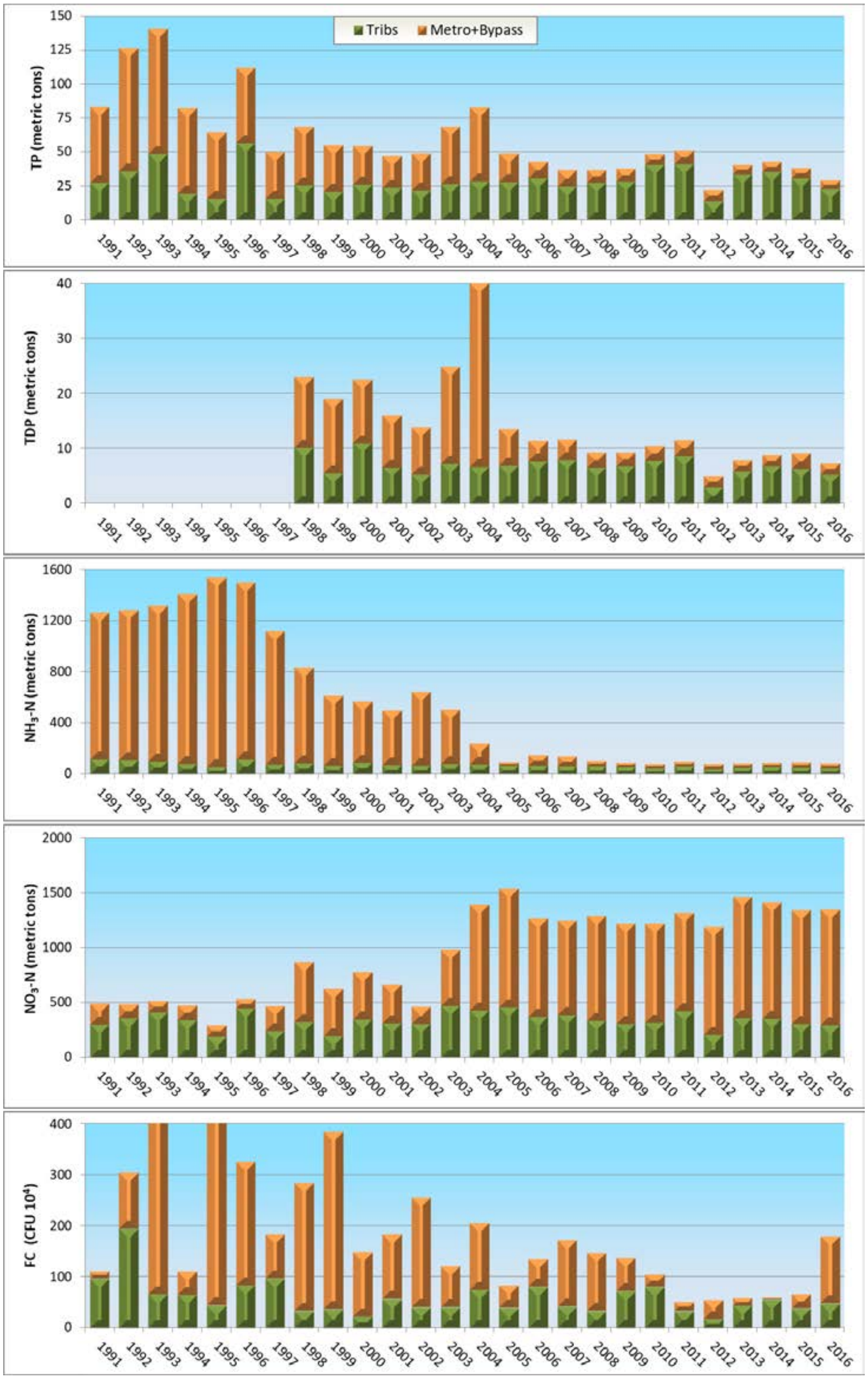


Figure 4-18. Annual loading of selected constituents to Onondaga Lake from Metro and watershed sources, 1991–2016: (a) total phosphorus (TP), (b) total dissolved phosphorus (TDP), (c) ammonia-N (NH_3-N), (d) nitrate (NO_3-N), and (e) fecal coliform (FC) bacteria.

Seasonal Kendall tests were conducted for the 10-year period 2007–2016 to identify statistically significant ($p<0.1$) trends in tributary concentrations (Table 4-10). Statistically significant decreases were evident for concentrations of total phosphorus and soluble reactive phosphorus in the Metro effluent. However, this 10-year analysis doesn't capture the effects of major upgrades to ammonia-N and phosphorus treatment that occurred in 2004 and 2005, respectively. Increased concentrations in the treated Metro effluent were indicated for organic nitrogen, calcium, and total dissolved solids. Fecal coliform bacteria decreased in the treated Metro effluent, in the Bypass, at the downstream site on Onondaga Creek (Kirkpatrick St.), and at the upstream site on Harbor Brook (Velasko). The decrease in fecal coliform concentrations was particularly noteworthy for the Metro Bypass (002), where levels have dropped at the rate of 37.6% per year.

Significant decreases in concentrations of ammonia and nitrate are indicated since 2006 for Ley Creek (Table 4-10). In contrast, concentrations of organic nitrogen and total Kjeldahl nitrogen have increased at the upstream sampling locations on Onondaga Creek and Harbor Brook. A cause for these changes in concentrations of nitrogen species is not apparent at this time. Both total phosphorus and soluble reactive phosphorus concentrations decreased at the downstream site on Harbor Brook (Hiawatha Blvd.).

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. However, the magnitude of the reductions decreased because the pre-upgrade years were no longer included in the 10-year period covered by this analysis. However, further reductions in both total phosphorus and soluble reactive phosphorus continue to be observed. Harbor Brook-Hiawatha has experienced significant loading reductions for total phosphorus, soluble reactive phosphorus, and fecal coliform bacteria.

Table 4-10. Ten-year (2007–2016) statistically significant trends in tributary concentrations, from application of two-tailed Seasonal Kendall tests adjusted for serial correlation.

Variable		Metro		Onondaga Creek		Harbor Brook		Ley Creek	Ninemile Creek
		Treated Effluent	Bypass	Dorwin	Kirkpatrick	Velasko	Hiawatha	Park	Route 48
Nitrogen	Ammonia-N (NH_3-N)	○	○	3.1%	○	○	○	-2.9%	○
	Nitrite (NO_2-N)	○	8.4%	○	○	○	○	○	○
	Nitrate (NO_3-N)	○	○	○	○	-1.8%	○	-3.4%	○
	Organic Nitrogen	4.2%	○	5.4%	○	3.3%	○	2.6%	○
	Total Kjeldahl Nitrogen (TKN)	○	○	5.3%	○	3.0%	○	○	○
Phosphorus	Total Phosphorus (TP)	-6.3%	-2.2%	○	○	○	-8.8%	○	○
	Soluble Reactive Phosphorus (SRP)	-7.8%	6.1%	○	○	○	-14.1%	○	○
Solids	Total Suspended Solids (TSS)	○	-4.0%	○	○	○	○	○	○
	Total Dissolved Solids (TDS)	2.1%	○	○	○	-1.7%	○	-1.6%	○
Carbon	Total Organic Carbon (TOC)	○	○	○	○	○	○	○	○
Other	Calcium (Ca)	2.9%	--	○	○	-1.8%	○	○	○
	Chloride (Cl)	○	○	○	○	○	1.0%	○	○
	Specific Conductance	○	○	○	○	○	0.9%	○	○
	Dissolved Oxygen (DO)	0.7%	○	○	○	0.6%	1.3%	1.2%	○
	Fecal Coliform Bacteria	-5.0%	-37.6%	○	-8.9%	-10.5%	○	○	○
	pH	○	○	○	○	○	○	○	○
	Temperature (°C)	○	○	○	○	○	○	○	○

Table 4-10. Ten-year (2007–2016) statistically significant trends in tributary concentrations, from application of two-tailed Seasonal Kendall tests adjusted for serial correlation.

Variable	Metro		Onondaga Creek		Harbor Brook		Ley Creek	Ninemile Creek
	Treated Effluent	Bypass	Dorwin	Kirkpatrick	Velasko	Hiawatha	Park	Route 48

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

Table 4-11. Ten-year (2007–2016) 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-N (NH_3-N)	o	o	o	o	o	o	o	-3%
	Nitrite (NO_2-N)	2%	o	o	o	o	o	o	o
	Nitrate (NO_3-N)	o	o	o	o	o	o	-4%	o
	Total Kjeldahl Nitrogen (TKN)	o	o	o	o	o	o	o	o
Phosphorus	Total Phosphorus (TP)	-6%	o	o	o	o	-10%	o	o
	Soluble Reactive Phosphorus (SRP)	-5%	o	o	o	o	-16%	o	o
Solids	Total Suspended Solids (TSS)	o	o	o	o	-14%	o	o	o
Carbon	Total Organic Carbon (TOC)	o	o	o	o	o	o	o	o
Other	Calcium (Ca)	2%	o	o	o	-3%	o	o	o
	Chloride (Cl)	o	o	o	o	o	o	o	-3%
	Fecal Coliform Bacteria	o	o	o	o	o	-13%	o	o

Notes:
Significance level, least squares linear regression of annual loads ($p < 0.1$).
Blue value (%) indicates decreasing trend, percent per year
Red value (%) indicates increasing trend, percent per year
o 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.

4.8 Post Construction Compliance Monitoring Program (PCCM)

4.8.1 Overview of the PCCM Program

Onondaga County is required to conduct a post construction compliance monitoring (PCCM) program to evaluate the effectiveness of both green and gray CSO controls and to assess whether ambient water quality standards (AWQS) are being met. The PCCM program includes monitoring of water quantity and water quality of CSOs and the receiving streams (Onondaga Creek and Harbor Brook. The PCCM is designed to provide the data necessary to determine whether or not the remaining operational CSOs are causing or contributing to violations of AWQS.

A total of six PCCM events were completed in 2015, four on Harbor Brook and two on Onondaga Creek. The monitoring targeted storm rainfall intensities of at least 0.35 inches of rain/hour because most of the operational CSOs trigger at a rainfall intensity of 0.3 inches per hour or less. Monitoring was conducted upstream and downstream of CSO discharges to Onondaga Creek and Harbor Brook to evaluate water quality impacts during wet weather. Data analysis focused on patterns in fecal coliform concentrations and loadings. Results from the 2015 PCCM events suggested that CSO discharges contributed importantly to elevated fecal coliform levels in Onondaga Creek and Harbor Brook during the wet weather sampling events.

4.8.2 The 2016 PCCM Program

The 2016 PCCM was designed to accomplish the objectives of the Fourth Stipulation of the ACJ and includes water quality monitoring in CSO-impacted tributaries to specifically assess the effectiveness of the gray and green infrastructure projects designed to mitigate the impacts of CSOs. Onondaga Creek was the focus of the 2016 in-stream PCCM sampling program. Monitoring was conducted at four sites along Onondaga Creek: Dorwin Ave., Rich St., West Genesee St., and Spencer St. (see Figure 4-19). Dorwin Ave. is located upstream of all CSOs and Spencer St. is located downstream of the CSOs. Sites at Rich St. and West Genesee St. were included to support evaluation of intervening CSO inputs. All samples were collected as grabs from mid-channel and mid-depth of the stream except for fecal coliform samples, which were collected just below the water surface.

The goal was to collect samples during all stages of the runoff event, from baseflow to baseflow. Pre-Storm (Cycle 0) samples were collected during dry weather, prior to each sampling event, to evaluate baseline concentrations at each of the in-stream sampling locations. The timing and duration of the sampling event was based on the information from the Metro rainfall gage and USGS flow data. Storm samples were collected for the duration of storm event to capture the hydrograph peak. A post-storm sample was collected after stream flow decreased to pre-storm levels. The in-stream sampling program focused on the pollutants causing impairments of designated uses in Onondaga Creek, including ammonia-N (NH_3-N), total phosphorus (TP), fecal coliform bacteria, turbidity, and floatables. In-situ measurements of dissolved oxygen (DO), pH, temperature, and specific conductance were made with each round of sampling.

Measuring Water Quality at Sawmill Creek.

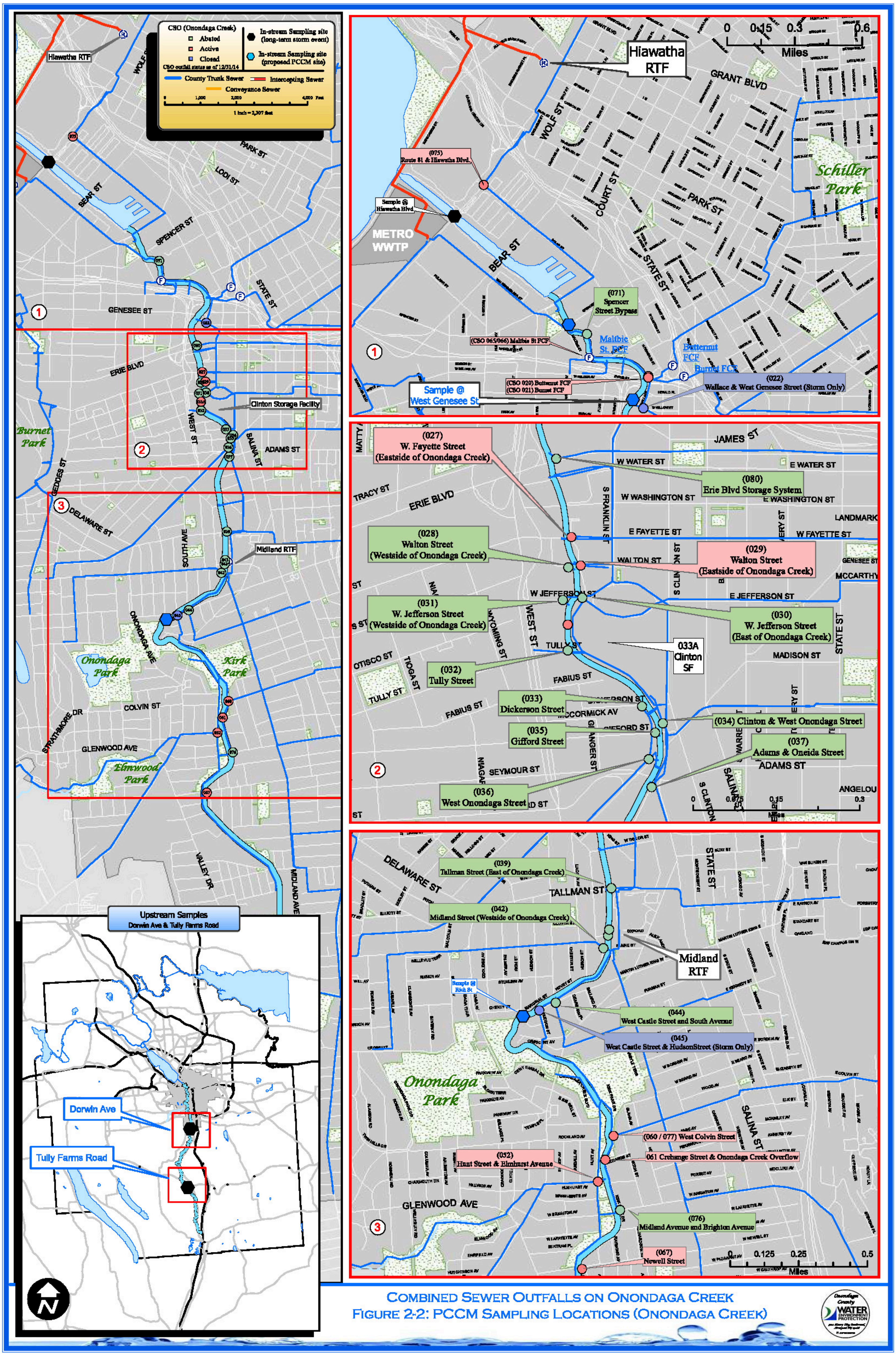


Figure 4-19. PCCM sampling locations and combined sewer outfalls on Onondaga Creek.

4.8.3 2016 PCCM Results

A total of three PCCM events were conducted for Onondaga Creek in 2016. PCCM events were conducted on June 2, July 25 and October 1-2, 2016. An additional PCCM event was initiated on August 16, 2016, in response to rainfall of 0.54 inches/hour. However, rising limb samples were missed due to short event notification time and sampling was suspended after three cycles. Table 4-12 provides a summary of the three Onondaga Creek PCCM events completed in Onondaga Creek in 2016. This section of the report provides a summary of the PCCM event conducted on July 25, 2016, the most complete PCCM event for Onondaga Creek to-date. Detailed summaries of all three PCCM events are presented in Appendix D-7.

Storm cycle samples were collected each half-hour (Cycle 0.5, 1.0, 1.5, 2, 2.5, 3.0), more frequently than outlined in the 2016 PCCM Sampling Work Plan. The goal of these additional half-hour samples was to better represent the rising limb of the hydrograph and capture the peak flow concentrations. This sampling program modification allowed all four phases (base flow, rising limb, peak flow, and falling limb) of the July 25, 2016 PCCM event to be well-characterized.

Table 4-12. Summary of the 2016 PCCM events.

Event	Date	Stream	Total Rainfall (in)	Maximum Intensity[1] (in/hr)	Peak Stream Flow (cfs)	EMC[2] (cfu/100mL)	Floatables
1	June 2	Onondaga Creek	0.26	0.25	66	26,279	N
2	July 25	Onondaga Creek	0.49	0.44	252	443,271	Y[3]
3	October 1-2	Onondaga Creek	0.44	0.42	67	97,648	N

[1]Maximum intensity (in/hr) represents the maximum amount of rainfall recorded at Metro during any one-hour period.
[2]Event Mean Concentration - EMC (cfu/100 ml) is calculated as the total event load divided by the total event flow volume for the results at the Spencer Street sampling location.
[3]The observed floatables were not sanitary related.

4.8.3.1 PCCM Event 2 Onondaga Creek – July 25, 2016

Rainfall, Streamflow, and Monitoring

- Fecal coliform concentrations varied among the four sampling sites during baseflow conditions (Cycle 0), ranging from 145 cfu/100 mL at Dorwin Avenue to 450 cfu/100 mL at Spencer Street. Dorwin Avenue and W. Genesee Street were the two monitoring locations with FCOLI concentrations less than the AWQS of 200 cfu/100mL, which is applied as a monthly geometric mean based on a minimum of five samples. Reference to the AWQS is included only for numerical perspective (Figure 4-20).

- Fecal coliform concentrations increased at each of the four sampling sites during the event. The peak FCOLI concentration at Dorwin Avenue was 2,700 cfu/100mL at 10:23. The peak concentration at Rich Street was >60,000 cfu/100 mL, more than 22-times higher than at Dorwin Avenue. The peak concentration at W. Genesee Street was 500,000 cfu/100 mL at 11:50, more than 185-times higher than at Dorwin Avenue. The peak fecal coliform concentration at Spencer Street was 840,000 cfu/100 mL at 10:40, more than 200-times higher than concentrations measured at Dorwin Avenue and only slightly higher than the value at W. Genesee Street.
- Bacteria concentrations decreased on the falling limb of the hydrograph. At Dorwin Avenue, FCOLI concentrations were less than 1,000 cfu/100mL at 11:55 and decreased further to 580 cfu/100mL at 14:26. At Rich Street, the concentration decreased to 3,800 cfu/100mL by 14:10. FCOLI concentrations remained elevated at the conclusion of sampling at W. Genesee and Spencer Street (38,000 and 320,000 cfu/100mL, respectively).
- FCOLI results for two samples collected on July 25 were qualified as estimates: Spencer Street at 11:40 (>600,000 cfu/100mL) and the 11:00 sample at Rich Street (>60,000 cfu/100mL). The values 600,000 cfu/100 mL and 60,000 cfu/100mL were used in subsequent analysis.

AMP Sampling Crew at Onondaga Creek.

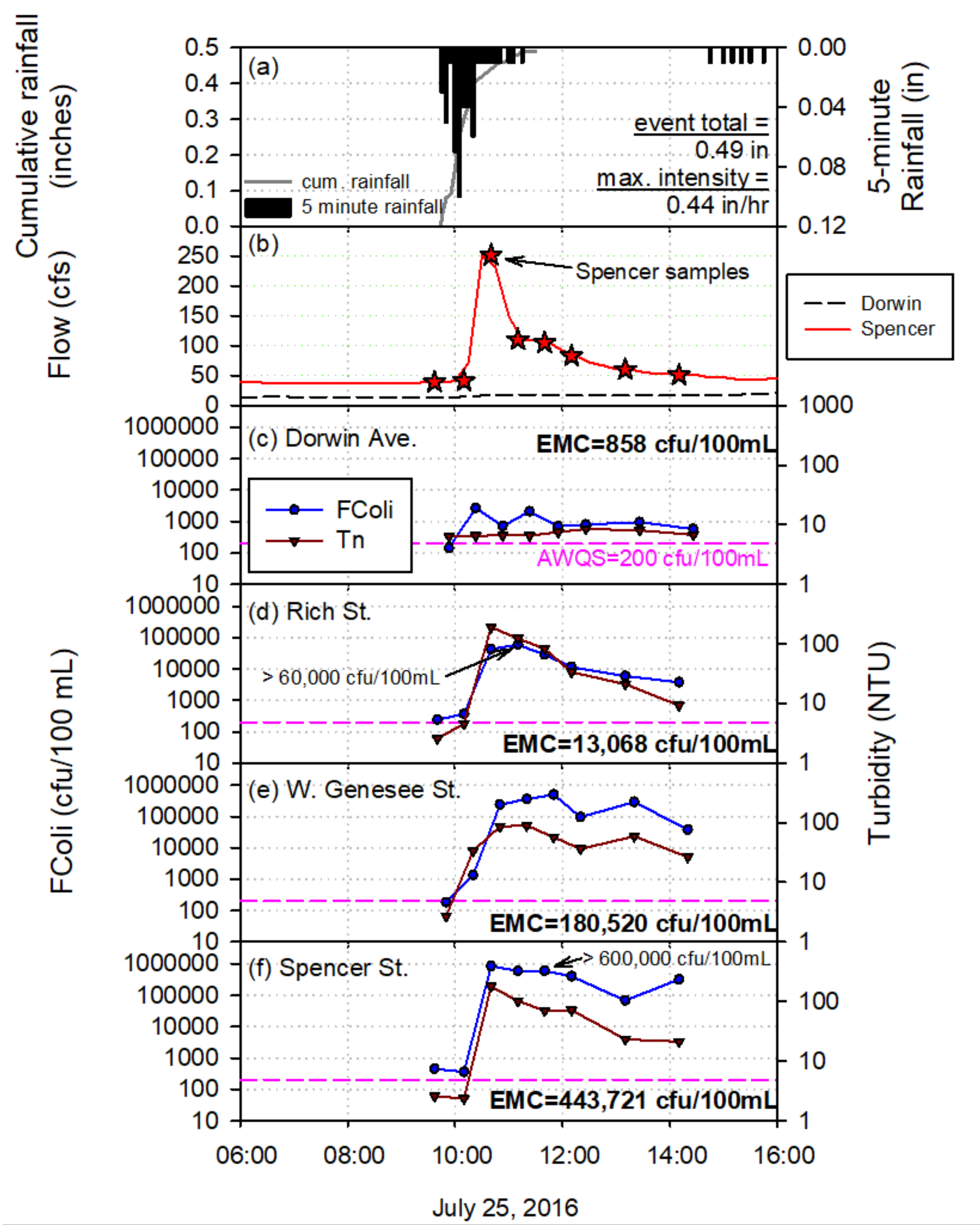


Figure 4-20. Cumulative and hourly rainfall data from the Metro rain gauge, 15-minute flow data from Onondaga Creek at Dorwin Ave. and Spencer St., and fecal coliform and turbidity results for the July 25, 2016 PCCM storm event.

Note: The value of the AWQS for fecal coliform (200 counts/100 mL) is represented by dashed lines.

CSO Flow Volumes

Measured flows were available for 10 CSOs for this event (Figure 4-21, Table 4-13). No flow was recorded at three of these CSOs during this event. The measured discharge from CSO 021 was 2.33 MG, which was the largest contribution from a CSO. Model output from SWMM was used to estimate CSO discharge volumes in cases where flow measurements were not available. Measured CSO volumes and SWMM output volumes (based on a rainfall intensity of 0.39 inches/hour - 5/17/1991 event) compared closely for most CSOs. For CSO 021, the SWMM volume estimate was 1.70 MG (measured volume = 2.33 MG). Other notable CSO volume contributions were from CSO 020, 027, 066, and 060/077. Measured and estimated volumes for all CSOs to Onondaga Creek are included in Table 4-13. The best estimate of total CSO discharge volume to Onondaga Creek during this event was 6.31 MG. This estimate was derived from a combination of measured CSO volumes and SWMM estimates.

CSO Water Quality

The median fecal coliform concentration of combined sewage, based on CSO facility Influent data collected as part of the Onondaga Creek and Harbor Brook PCCM is 495,000 cfu/100mL. Figure 4-22 is a graphical representation of fecal coliform concentrations measured in the influent to the Clinton and Lower Harbor Brook Storage Facilities, Midland RTF, and Maltbie FCF during 2015 and 2016. The 10th and 90th percentiles are represented by error bars, the 25th and 75th percentiles are represented as the lower and upper bounds of the box, and the median is the line within the box. Outliers are shown as circles. The mean is biased slightly high because of one unusually high concentration measured in the Clinton Storage Facility influent (2,700,000 cfu/100mL).

Mermaid at 2016 Onondaga Cup and Lakefest.

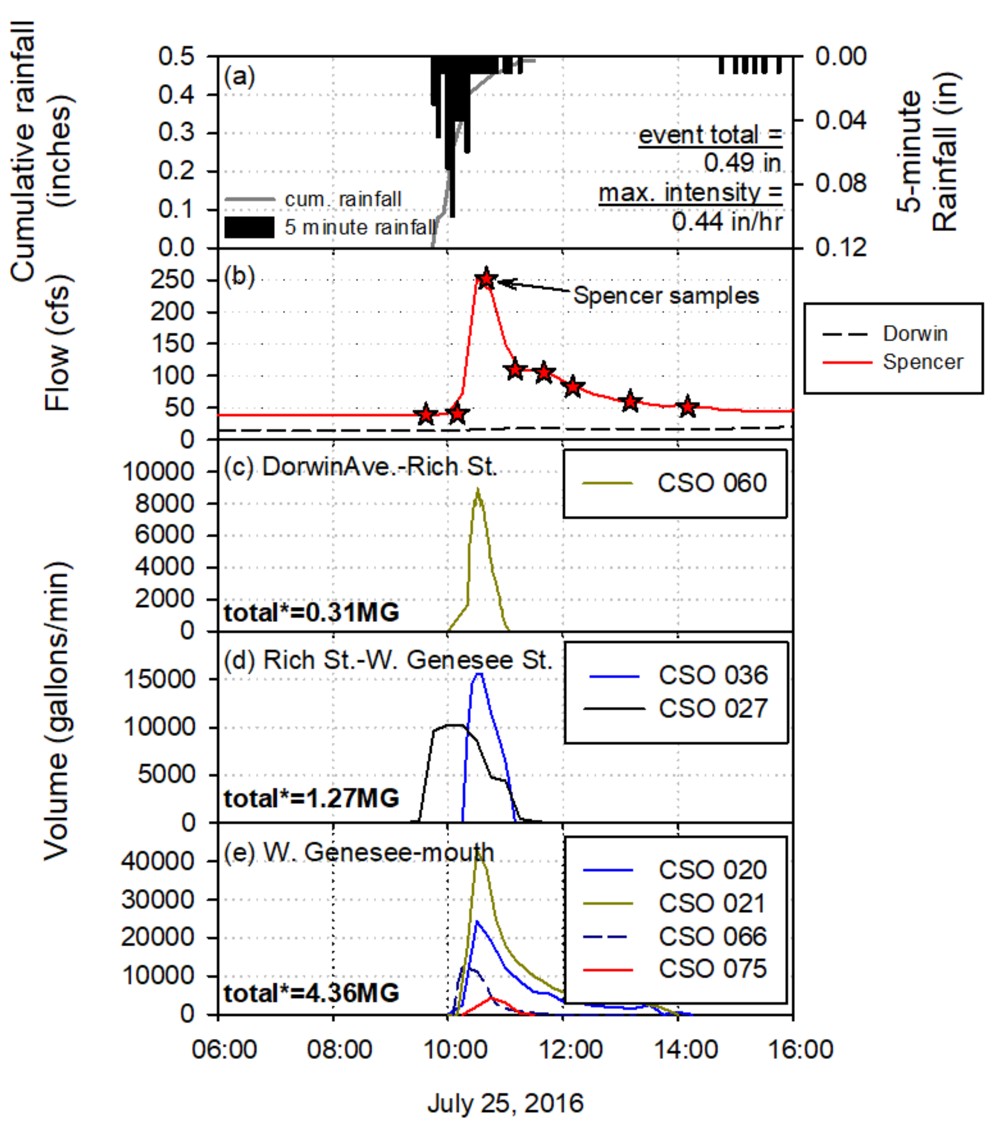


Figure 4-21. Cumulative and hourly rainfall data from the Metro rain gauge, 15-minute flow data from Onondaga Creek at Dorwin Ave. and Spencer St., and measured CSO discharges for the July 25, 2016 PCCM storm event.

Table 4-13. Measured and predicted CSO flows for the July 25, 2016 PCCM event with peak intensity of 0.44 inches/hour and total precipitation of 0.49 inches.

Reach	CSO Number	CSO Description	Measured Flow (MGD)[1]	SWMM Predicted Flow (MGD)[2]
Dorwin Ave. – Rich Street	CSO-052	Hunt St.-Elmhurst Ave.	0.00	0.18
	CSO-060/077	W. Colvin St.	0.31	0.48
		Reach Total	**0.31**	**0.66**
Rich Street – W. Genesee Street	CSO-027	W. Fayette St.	0.73	0.89
	CSO-030	W. Jefferson St.	0.00	0.00
	CSO-036	W. Onondaga St.	0.54	0.00
	CSO-080	EBSS	0.00	0.00
		Reach Total	**1.27**	**0.89**
W. Genesee Street – Spencer Street	CSO-020	Butternut St.	1.44	1.24
	CSO-021	Burnet Ave.	2.33	1.70
	CSO-066	Maltbie St.	0.44	0.44
	CSO-075	Rt. 81-Hiaw. Blvd.	0.15	0.15
		Reach Total	**4.36**	**3.53**

[1]Only those CSOs with measured flow data are included in this table.
[2]SWMM CSO volume discharge based on SWMM output results for a 0.39 inch per hour rainfall (5/17/91 storm).

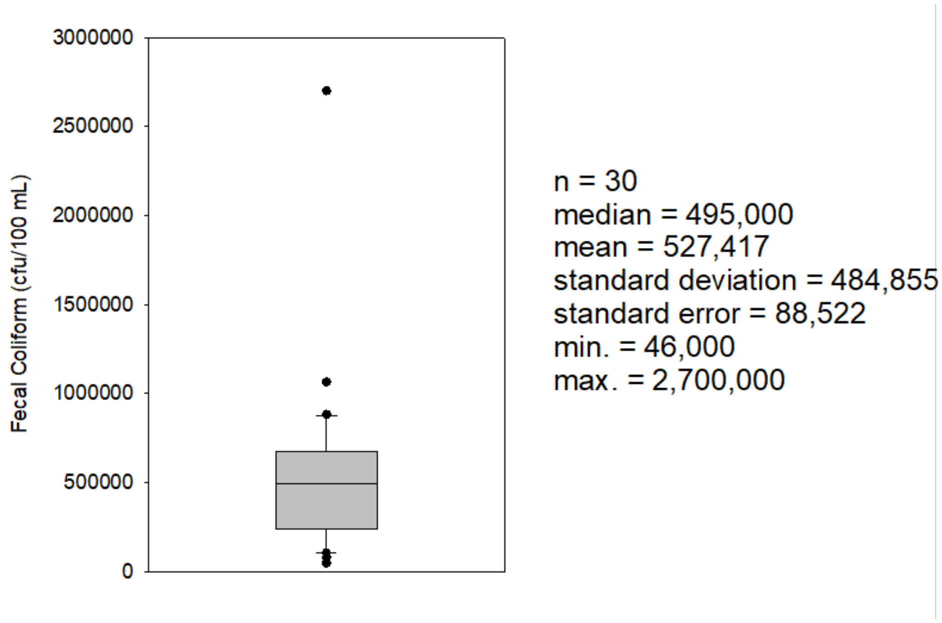


Figure 4-22. Box plot of 2015 and 2016 fecal coliform concentrations measured in the influent to the Clinton and Lower Harbor Brook Storage Facilities, Midland RTF, and Maltbie FCF.

In-Stream FCOLI Loading and CSO Contributions

- Streamflow at Dorwin Avenue (USGS No. 04239000) was used for loading estimates at both Dorwin Avenue and Rich Street, and the flow at the Spencer Street (USGS No. 04240010) was used for loading estimates at Spencer Street and W. Genesee Street. This approach is consistent with the protocols adopted for the 2015 PCCM analyses. This simplification likely represents a relatively small source of error in the loading estimates; however, this approach could be refined by adjusting flows for the contributing watershed areas between sites. Fecal coliform samples were paired with flow (at the nearest 15-minute interval). Linear interpolation was used to develop 15-minute fecal coliform concentration estimates for periods intervening measurements. 15-minute loads were calculated as the product of these concentrations/estimates and 15-minute flows from the appropriate USGS gauges.
- Fecal coliform loading estimates (as cfu) for CSOs were estimated as the product of CSO volume and a fecal coliform concentration of 495,000 cfu/100mL (Figure 4-23). An estimated 69 percent of the CSO load entered between W. Genesee Street and Spencer Street and 26 percent entered between Rich Street and W. Genesee Street (Figure 4-23).
- Fecal coliform loading was 15-times higher at Rich Street ($1.9 \cdot 10^{12}$ cfu; Figure 4-23) compared to Dorwin Avenue ($1.2 \cdot 10^{11}$ cfu). FCOLI load at W. Genesee St was $1.1 \cdot 10^{14}$ cfu, 56-times higher than Rich Street The fecal coliform load at Spencer Street was $2.6 \cdot 10^{14}$ cfu, 2.5-times higher than W. Genesee Street and more than 2,000-times higher than Dorwin Avenue. Event mean concentrations (EMC) were calculated at all four locations as the total event load divided by the total event flow volume. Moving from upstream to downstream, EMCs were 858 cfu/100 mL, 13,068 cfu/100 mL, 180,520 cfu/100 mL, and 443,721 cfu/100 mL for Dorwin Avenue, Rich Street, W. Genesee Street, and Spencer Street, respectively.

Figure 4-23. Estimated fecal coliform loads for the PCCM storm event on July 25, 2016: (a) linear and (b) log-10 scales.

Aerial View of the Harbor Brook Wetland Pilot Treatment System at CSO 018.

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Summary of July 25, 2016, PCCM Event

- The AWQS for fecal coliform bacteria was exceeded in pre-storm samples at several sites, suggesting dry weather sources of bacteria to Onondaga Creek. Data collected during the event suggest that both upstream sources and CSO discharges contribute to elevated fecal coliform levels in Onondaga Creek, but the contributions from upstream were minor relative to urban inputs for this event.
- The dissolved oxygen (DO) data collected from all sites with the exception of Dorwin Avenue demonstrated a conspicuous DO sag in response to this event (see Appendix D-7). This is supporting evidence of sewage inputs to Onondaga Creek from CSOs.
- The results of this PCCM event suggest that CSOs contribute the majority of FCOLI load to Onondaga Creek. However, we caution against over-interpreting the results of this single storm. A number of factors contribute to uncertainties in these analyses, including (1) uncertainties in measured and estimated CSO flow volumes and (2) the fecal coliform concentration assumed for CSOs was a best estimate based on the median of 30 samples.

4.9 Microbial Trackdown Study (PCCM)

4.9.1 Phase 1 and Phase 2

The Microbial Trackdown Study (MTS) identified potential bacteria inputs into Onondaga Creek and Harbor Brook during dry weather in 2008 and 2009 (Phase 1). The results from Phase 1 and Phase 2 (conducted from June 2012 through July 2014) of the study have effectively documented the effects of dryweather 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:

- Explain patterns in stream water quality related to land use, and detect relationships between measured parameters.
- Identify and prioritize point source trackdown work.
- Measure effects of remedial activities on bacteria levels.
- Assess long-term changes in bacteria levels since Phase 1.

Through the combined efforts of the Phase 1 and Phase 2 Microbial Trackdown Studies, 12 point sources were successfully corrected (7 during and after Phase 1, and 5 during and after Phase 2). However, at the conclusion of Phase 2 sampling there remained problematic point source discharges in Harbor Brook and Onondaga Creek that, at constant flows, could have significantly deleterious effects on water quality. Results have also identified several locations where bacteria levels have significantly worsened since Phase 1, suggesting that remedial efforts have failed and/or new problems have emerged in the system. The results are presented in the “Identification of the Primary Sources of Bacteria Loading in Selected Tributaries of Onondaga Lake: Phase 2 Microbial Trackdown Study,” Final Report (Rev. 2 dated April 8, 2015), approved by the NYSDEC in November 2015.

White Library Rain Garden.

The funds remaining from the Phase 2 efforts were allocated to further trackdown work in the watershed; targeting specific point sources and tracking sources upstream and/or up the sewershed to identify and remediate source(s). The Phase 2 sampling efforts resulted in four locations (three point sources and one in-stream location) in the Harbor Brook Watershed and nine point sources in the Onondaga Creek Watershed being recommended for further sewershed trackdown work in an effort to isolate the bacterial source(s). Through the efforts of Phase 2 follow-up sampling, areas of concern in several sewersheds and watersheds in Harbor Brook and Onondaga Creek were identified. Results from sampling efforts also showed the effects of seasonal changes in temperature on in-stream and point source water quality and bacteria levels.

Trackdown led to the identification of collapsed pipes, illicit discharges, and cross-connections. Positive effects of these corrections on in-stream bacteria levels were especially evident in Onondaga Creek; where several routine sampling locations showed significant declines in fecal coliform levels between Phase 1 and Phase 2 that could be attributed to point source corrective work.

4.9.2 Phase 3

The Microbial Trackdown Study Phase 3 work, which began in June 2014, included the following sampling events:

- **Routine sampling** events for fecal coliform (FC) analysis up to two times per month during dry weather conditions for Onondaga Creek, Harbor Brook, and Ley Creek. Routine sampling provides a long-term dataset of temporal changes in bacteria throughout the watershed and helps to interpret trends in bacteria levels that are not CSO driven discharges. Two additional routine events in Upper Onondaga Creek per month were conducted, irrespective of weather conditions (i.e., dry or wet weather) for the parameters fecal coliforms, ammonia-N (NH3-N), Total Phosphorus (TP), Total Kjeldahl-Nitrogen (TKN), and Total Suspended Solids (TSS). The wet weather sampling was performed in an attempt to better understand the effects of rain events on in-stream bacteria and nutrient levels that may be caused by surrounding land-use practices (e.g., agriculture) in upper Onondaga Creek.
- **Priority point source** sampling for FC and total suspended solids (TSS) was performed at a maximum of four locations in Harbor Brook and ten locations in Onondaga Creek during dry weather conditions. The sampling program was designed to focus on point sources of concern that were previously identified (during Phase 1 and Phase 2 of the study), which: (1) continue to discharge high levels of bacteria at persistent rates (i.e., high flow) and the source(s) remains unknown, or (2) where corrective actions have been taken and follow-up sampling is needed to verify that those corrections have been successful.
- **Tributary trackdown** involved dry weather sampling of all natural, urban tributaries to Onondaga Creek and included a total of 22 sampling locations.
- **Point source trackdown** focused on identifying the sources of bacterial discharge in the urban sewersheds upstream of the actual point sources in Onondaga Creek and Harbor Brook during dry weather conditions. This effort involved coordination between the City of Syracuse and Onondaga County to develop and implement a strategized sampling program at select manholes, as well as potentially performing dye testing and TV camera-scoping when necessary. Numerous point sources have been identified as

discharging persistently high levels of bacteria during the Phase 1 and Phase 2 Microbial Trackdown studies, and the source(s) of these discharges remain unknown. Tracking up the sewershed is necessary in order to pin point the source(s) of the discharge and effectively eliminate the discharge at its source.

Petit Library Porous Pavement Parking Lot.

In 2015, significant fecal bacteria concentrations continued to be detected in these urban tributaries during dry weather where sources have not been able to be identified, in spite of significant trackdown sampling, TV scoping, and dye testing work. In addition, in spite of considerable effort, bacterial levels appear to be increasing at some sites. Although the watershed of each site differs, most include multiple land uses and therefore potential fecal sources, including human, canine, avian (waterfowl) and bovine.

Project collaborators of Phase 3 included NYS Department of Environmental Conservation Region 7, NYS Department of Health (Wadsworth Center), OCDWEP, City of Syracuse Engineering Department, and OEI; collectively referred to as the "Working Group." As part of Phase 3, Microbial Trackdown Study was used at problematic sites on Onondaga Creek and Harbor Brook to better identify and characterize the source(s) of fecal contamination. Strategies were developed in 2016 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. A subset of point sources was selected for Bacteroides analysis in an effort to identify the predominant source (i.e., animal vs. human) of bacteria.

Source identification enhances the ability to identify responsible parties and ultimately, to remediate and reduction of levels of fecal coliform in Onondaga Lake and its tributaries. MTS can be used to distinguish whether the bacterial contamination originated from ruminants (cows), canines (dogs), avian (primarily waterfowl), and/or humans. Correctly identifying the source(s) is a critical first step toward remediating these sources of bacterial contamination.

Barker Park Rain Garden in Autumn During a Rain Event.

Goals of this project have been to:

1. Apply MTS techniques to samples for which bacterial trackdown has been unsuccessful and source(s) remain significant and unknown;
2. Differentiate human from other sources of bacterial contamination to clarify the role of Onondaga County contributions to dry weather tributary fecal contamination;
3. Improve understanding of the contributions of a) agriculture and other nonpoint sources, and b) in-channel storage to dry weather tributary fecal contamination.

The data from the MTS will aid in tracking and remediating non-CSO discharges of bacteria in Onondaga Creek, Harbor Brook and Ley Creek. The AMP data will be integrated with the data from the MTS to evaluate the efficacy of remedial measures and support compliance evaluations.

Results from the 2016 MTS continue to highlight pervasive and problematic discharges, from unknown sources at select point source and tributary locations in Harbor Brook and Onondaga Creek during dry weather. A total of 14 locations in Harbor Brook and Onondaga Creek were sampled between July and August 2016 to assess fecal coliform levels during dry weather. Fecal coliform levels were found to be moderate (100-1000 cfu/100mL) to very high (10,000-50,000 cfu/100mL) from nearly all of the sampled locations. As a result, ten locations in Onondaga Creek and two locations in Harbor Brook were selected for Bacteroides analysis in July and August of 2016, in an effort to elucidate bacteria sources in both of these tributaries. Bacteroides analysis determined the predominant source of bacteria to come from human sources for all 12 sampling locations. Results have highlighted the need for the continuation and expansion of trackdown sampling efforts in both the Harbor Brook and Onondaga Creek watersheds to more accurately isolate the physical source of human-caused bacterial discharges during dry weather. As a result, the 2017 MTS sampling plan will incorporate a strategized sampling plan that includes sites previously sampled in 2016, as well as new locations that will isolate the potential source(s) of bacteria in Harbor Brook and Onondaga Creek. The Phase 3 report (2014-2016) will also be compiled in 2017.

Fishing on Onondaga Lake.

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Section 5. Onondaga Lake Water Quality: 2016 Results and Trends

5.1 Onondaga Lake Sampling Program

The Ambient Monitoring Program (AMP) includes a sampling program for Onondaga Lake that encompasses multiple physical, chemical, and biological parameters (Table 1-2). Trained Water Environment Protection (WEP) technicians collect samples from various locations and depths within Onondaga Lake to characterize water quality and biological conditions. Most sampling occurs between April and November when the lake is free of ice. The lake monitoring program focuses on evaluation of compliance with ambient water quality standards (AWQS) and assessment of progress toward attainment of designated uses. Results for key parameters and lake sampling locations are presented in this section. Long-term time series covering 2007–2016 are provided for all AMP parameters and lake sampling locations in Appendix E-1. Detailed results from the biological monitoring program are presented in Section 6.

WEP also tracks physical factors, such as the development and extent of ice cover. During the winter of 2015–2016, ice cover extended for 25 days in the north basin and 24 days lake wide. Ice cover was first reported on January 5, 2016 and last reported on March 8, 2016. This was a major decrease in the duration of ice cover compared to the winters of 2014-2015 (89 days) and 2013-2014 (95 days). Since the winter of 1987-1988, the duration of ice cover lake wide has averaged 35 days and ranged from a minimum of 0 days in the winter of 1997-1998 to a maximum of 95 days in 2013-2014.

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 for a reduced number of parameters 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 2016 (Appendix E-2). 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. The in-lake sampling program for 2016 was unchanged from the program conducted in 2015.

5.2 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 implications for water quality. 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 particular uses, such as water supply or contact 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, especially cyanobacteria (blue-green algae), which can have deleterious effects on water quality. Certain cyanobacteria are capable of producing harmful toxins. Blooms of toxin-producing cyanobacteria are referred to as harmful algal blooms (HABs). Additional information on HABs is available on NYSDEC's website.

Decay of settled algae contributes to the depletion of dissolved oxygen in the lower stratified layers of lakes. 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, soluble phosphorus, methylmercury, 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 effectiveness of this program has been tracked by monitoring multiple measures of the trophic state of the lake, including 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 commonly monitored parameters of trophic state – TP, Chl-*a*, and SD – 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 various measures 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 may confound relationships between phosphorus loading and common metrics of trophic state.

5.2.1 Phosphorus

Total phosphorus (TP) concentrations in the upper waters of the lake remained near 20 µg/L for much of the 2016 monitoring period (Figure 5-1). Only in late October and November, following fall turnover, did TP concentrations exceed 25 µg/L. The highest TP concentration of 31 µg/L was measured on both October 26 and November 8, a period of slow algal growth, senescence of macrophytes, and increased sediment resuspension. Note that these higher TP levels did not coincide with increases in algal biomass (Figure 5-3a). Total phosphorus concentrations in the upper waters of the lake averaged 20 µg/L during the summer (June–September) of 2016, somewhat lower than the summer average of 23 µg/L measured in 2015. Total dissolved phosphorus (TDP) concentrations averaged 6.0 µg/L and accounted for 24% to 34% (average of 30%) of TP (Figure 5-1). Soluble reactive phosphorus (SRP) levels were consistently low during summer, with a maximum concentration of 1.5 µg/L. Concentrations of both TDP and SRP increased during October and November.

The concentration of TP in the upper waters has exhibited a substantial decrease since the early 1990s (Figure 5-2). Beginning in 2007, summer average total phosphorus concentrations in the upper waters of Onondaga Lake have been close to the guidance value of 20 µg/L. With the advanced treatment system at Metro producing consistently low effluent total phosphorus, the year-to-year variability in lake phosphorus levels largely reflects changes in precipitation, resultant watershed loading, and food web structure (see Section 5.8.3). At times, a substantial portion of the total phosphorus in Onondaga Lake may be associated with inorganic particles rather than phytoplankton. Total phosphorus is a flawed metric of trophic state during these periods, which are usually associated with major runoff events and the resulting influx of inorganic particles to the lake. Summer average concentrations of both TDP and SRP have been consistently low since 2007.

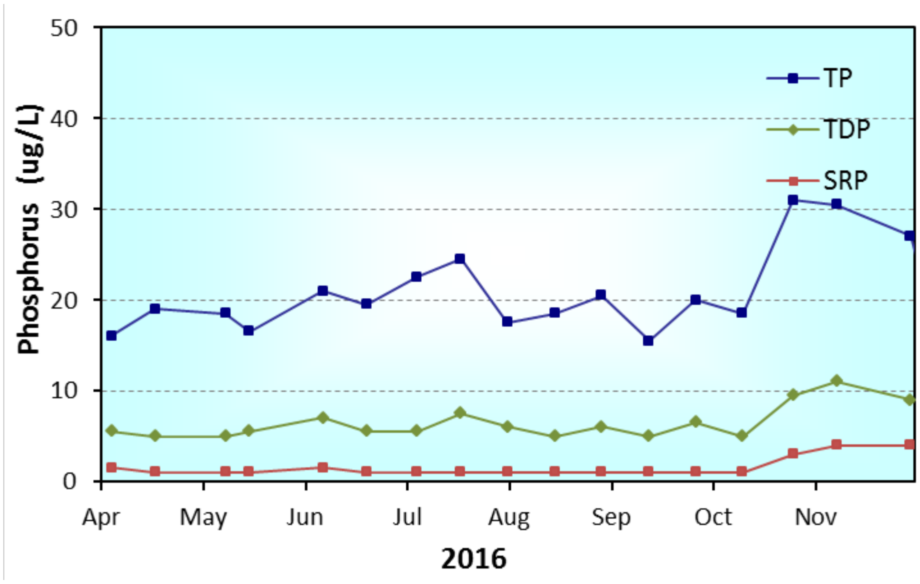


Figure 5-1. Time series of total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) concentrations in the upper waters (0-3 meters) of Onondaga Lake during 2016.

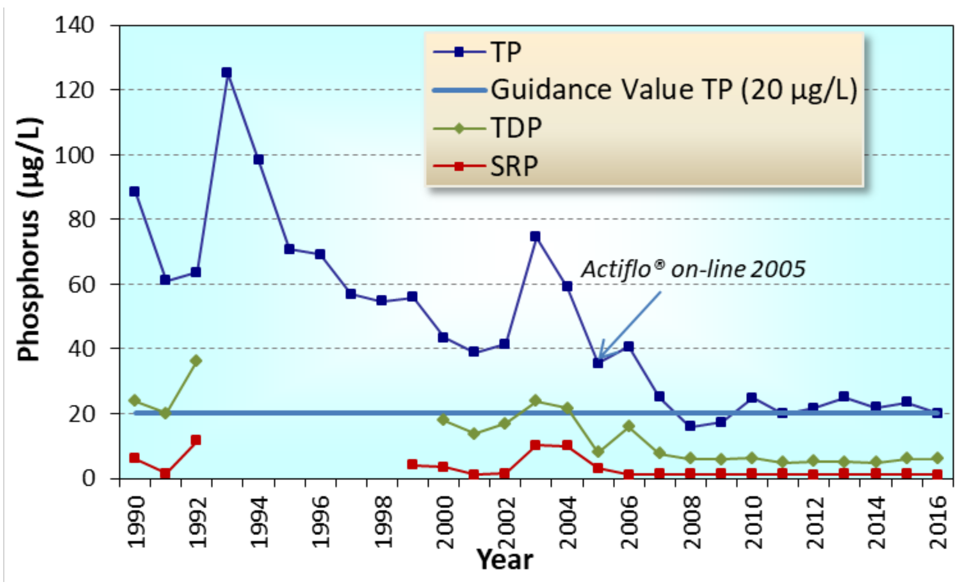


Figure 5-2. Summer (June to September) average total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990–2016.

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

5.2.2 Chlorophyll-*a*

Chlorophyll-*a* (Chl-*a*) concentrations in the upper waters of the lake in 2016 ranged from 0.5 µg/L on April 14 to a peak of 19.2 µg/L on September 29 (Figure 5-3a). The decreasing silica concentrations during April–July suggest uptake by a major group of phytoplankton known as diatoms (Figure 5-3b), which use silica to form their cell walls, known as frustules. Diatoms are a particularly important component of the phytoplankton during spring and early summer and this pattern of silica depletion is a recurring feature in Onondaga Lake. The summer average Chl-*a* concentration in 2016 was 7.5 µg/L, only slightly higher than the 2015 average of 7.0 µg/L (Figure 5-4). The average and peak concentrations of Chl-*a* have declined substantially, particularly since the Actiflo® upgrade at Metro (Figure 5-4). Summer data (June–September) are used to track suitability of the lake for recreational uses. NYSDEC (2009) lists three levels of chlorophyll-*a* that serve as recreation use assessment criteria. Chlorophyll-*a* concentrations greater than 15 µg/L, 12 µg/L, and 8 µg/L correspond to impaired, stressed, and threatened conditions, respectively. Summer average Chl-*a* concentrations, which commonly exceeded 15 µg/L during 1990–2004, have remained below 12 µg/L since 2007 (Figure 5-4).

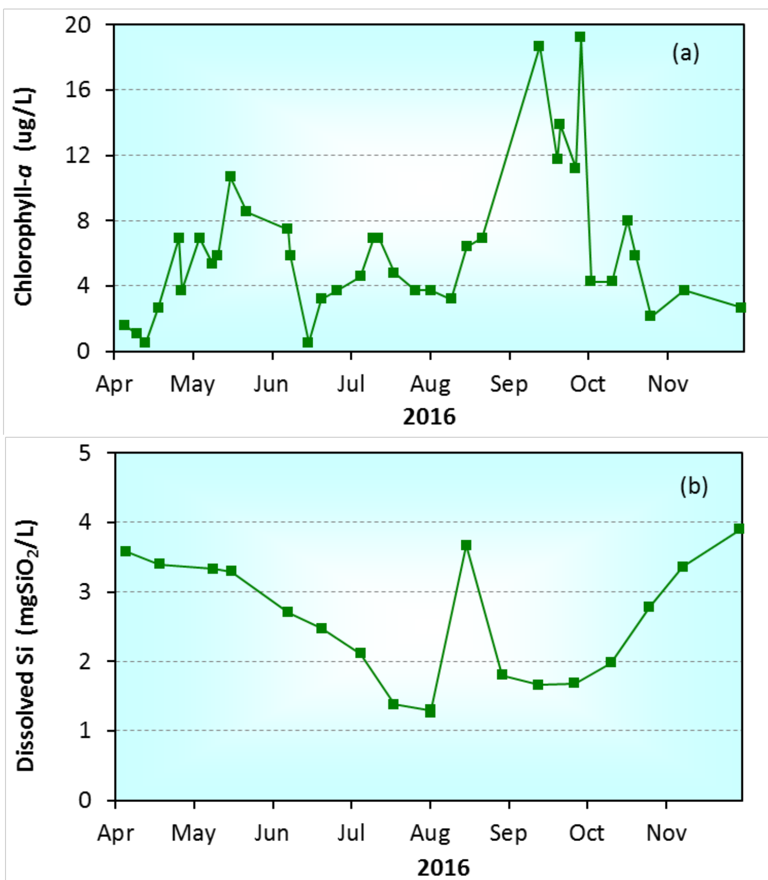


Figure 5-3. Seasonal time plot of average upper water (0-3 meters) concentrations in Onondaga Lake, 2016: (a) chlorophyll-*a*, and (b) dissolved silica.

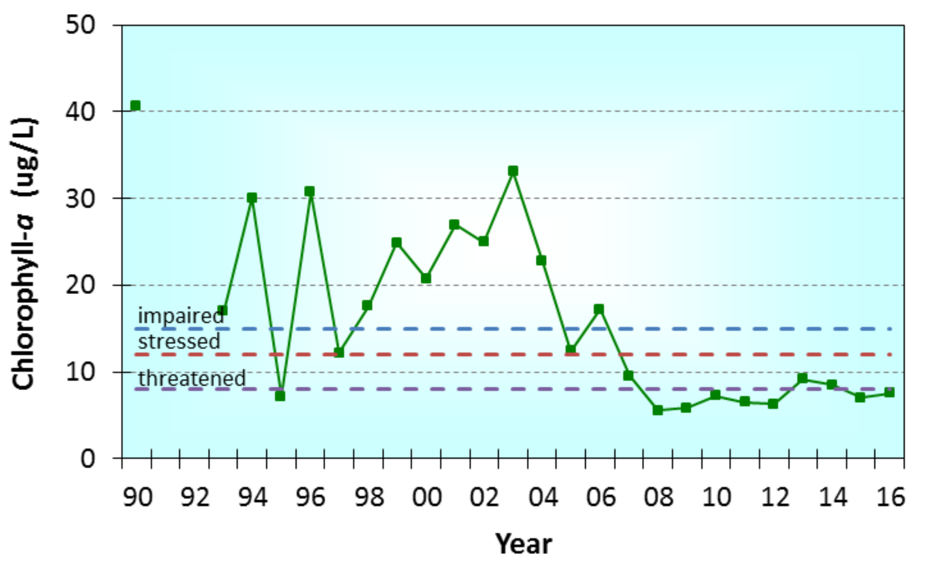
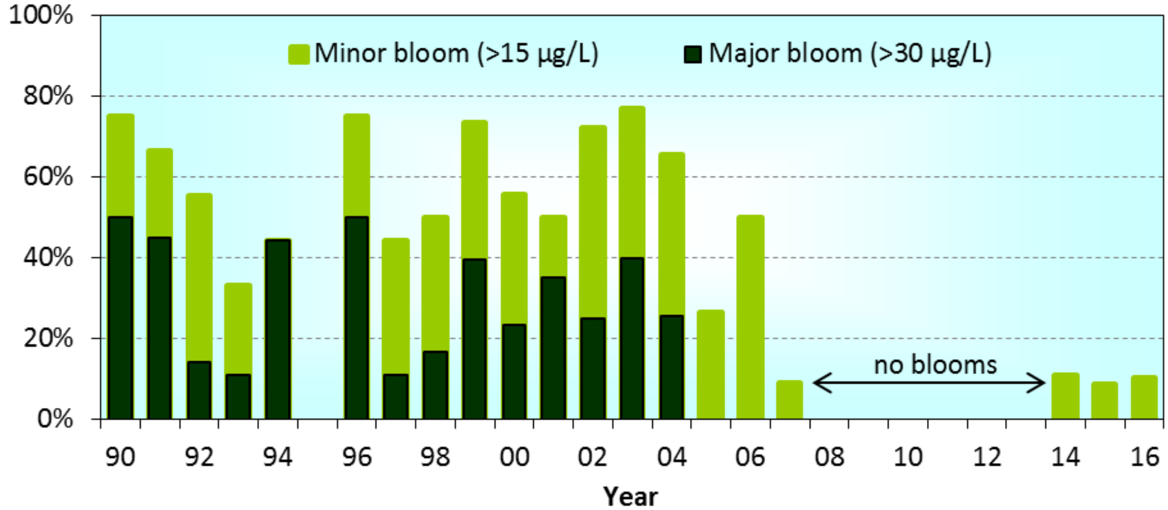


Figure 5-4. Summer average (June–September) chlorophyll-*a* concentrations in the upper waters of Onondaga Lake (South Deep), 1990–2016.

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 aesthetically undesirable and often 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 (noxious conditions), respectively. According to the criteria adopted here, and based on biweekly laboratory measurements, there were two minor algal blooms in Onondaga Lake during the summer recreational period (June–September) of 2016, when chlorophyll-*a* concentrations of 18.7 µg/L and 19.2 µg/L were measured on September 13 and September 29, respectively (Figure 5-3, Figure 5-5).

Detailed vertical patterns of chlorophyll-*a* are depicted in Figure 5-13d 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 do 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. Although the paired laboratory and *in-situ* chlorophyll-*a* measurements from 2016 were significantly correlated (p = 0.05), the relationship was rather weak (R^2 = 0.33). Accordingly, with the exception of Figure 5-13d, laboratory results are used exclusively in this report.



No blooms were observed during summer in 1995, 2008, 2009, 2010 - 2013

Figure 5-5. Percent occurrence of summer (June to September) algal blooms in Onondaga Lake evaluated annually for the 1990–2016 period, based on chlorophyll-*a* measurements taken at South Deep.

Note: Percent occurrence is calculated as the number of sampling events with blooms divided by the total number of sampling events multiplied by 100.

The total phosphorus concentration in spring has been a good predictor of the occurrence of major summertime algal blooms (Figure 5-6), 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 chlorophyll-*a* concentration of the upper waters. Note the decreases in chlorophyll-*a* observed as the total phosphorus load has been reduced (Figure 5-7). This analysis uses total phosphorus loads from the full water year (e.g., October 2015–September 2016) to account for loading that may influence algal growth during summer.

Two Diatom Species Found in Onondaga Lake.

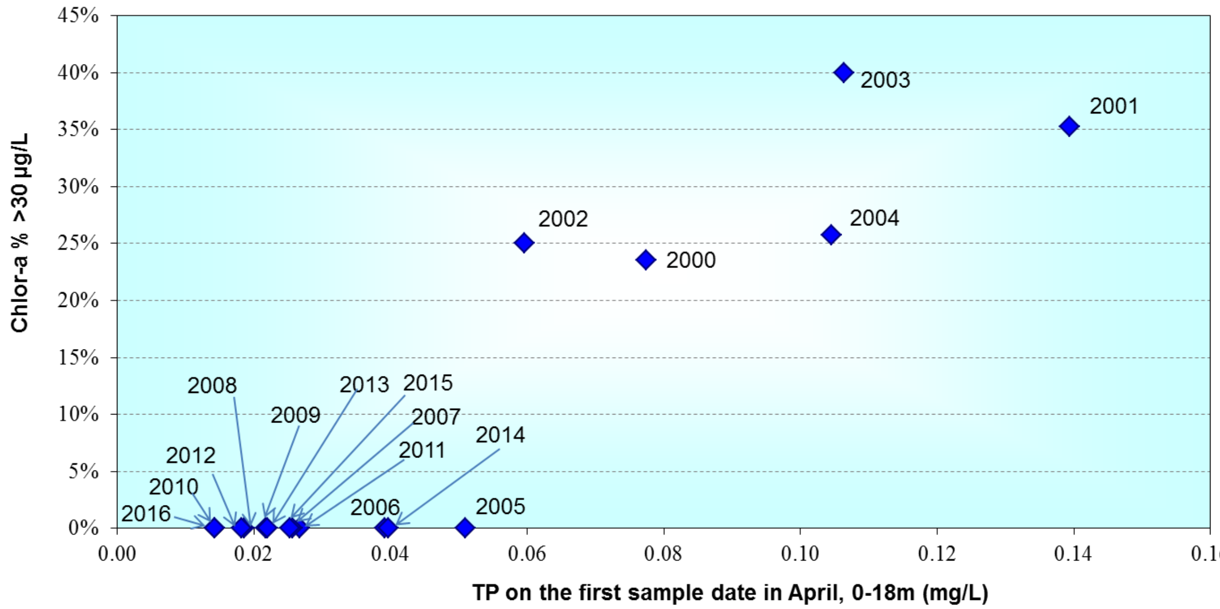


Figure 5-6. Relationship between the frequency of major summertime algal blooms at South Deep and the total phosphorus concentration in spring, 2000–2016.

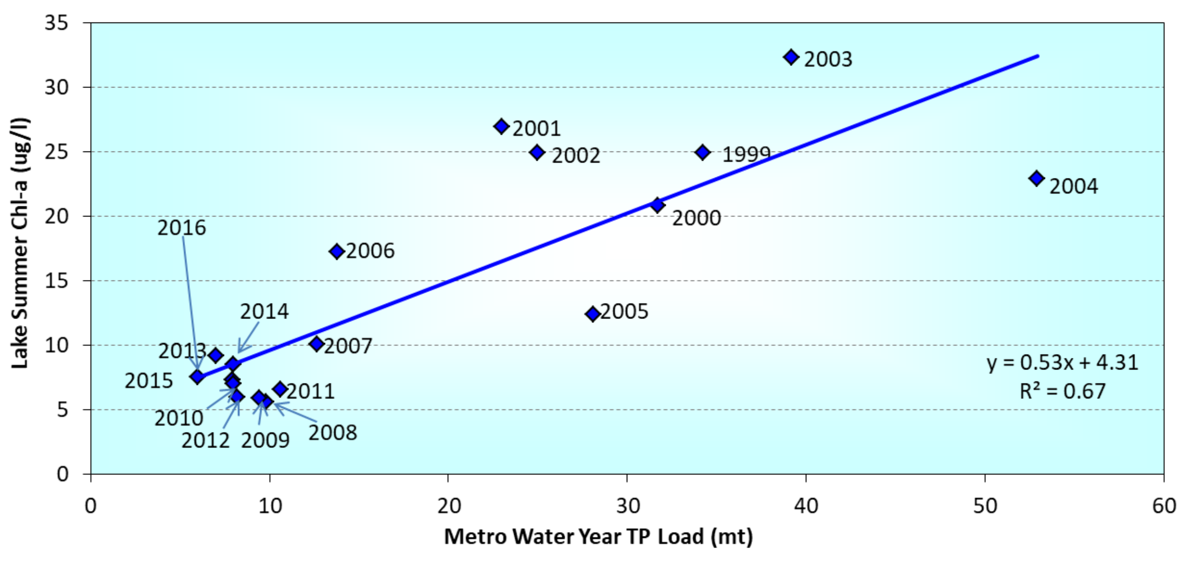


Figure 5-7. Relationship between summer (June–September) average chlorophyll-*a* concentrations in the upper waters at South Deep and total phosphorus loading from Metro over the full water year (October–September) for 1999–2016.

Note: Loads are presented on a water year (October 1–September 30) basis for (a) Metro (including secondary bypass only).

5.2.3 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 in the water 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 1-6). The Citizens Statewide Lake Assessment Program (CSLAP), a joint effort of NYSDEC and the NYS Federation of Lake Associations, considers summer average Secchi disk transparencies greater than 2 meters as indicative of mesotrophic conditions (Kishbaugh 2009). Based on South Deep measurements, the average water clarity of Onondaga Lake during the summer of 2016 was 2.2 meters and ranged from 1.8 to 3.1 meters (Figure 5-8). Summer median water clarity during summer has been consistent since 2010, remaining in the narrow range of 1.7-2.1 meters (Figure 5-9a). There have been no Secchi disk measurements less than 1.2 meters in the past three years (Figure 5-9b). The unusually high transparencies observed in both 2008 and 2009 were the result of grazing by large *Daphnia* populations. The *Daphnia* were enabled by low abundance of Alewife, a planktivorous fish, during these years.

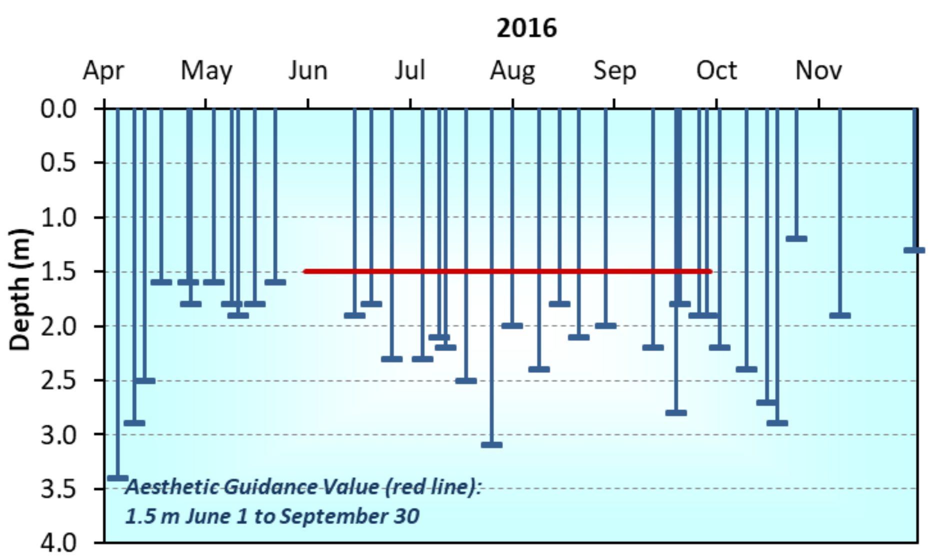


Figure 5-8. Secchi disk transparency, Onondaga Lake South Deep, 2016.

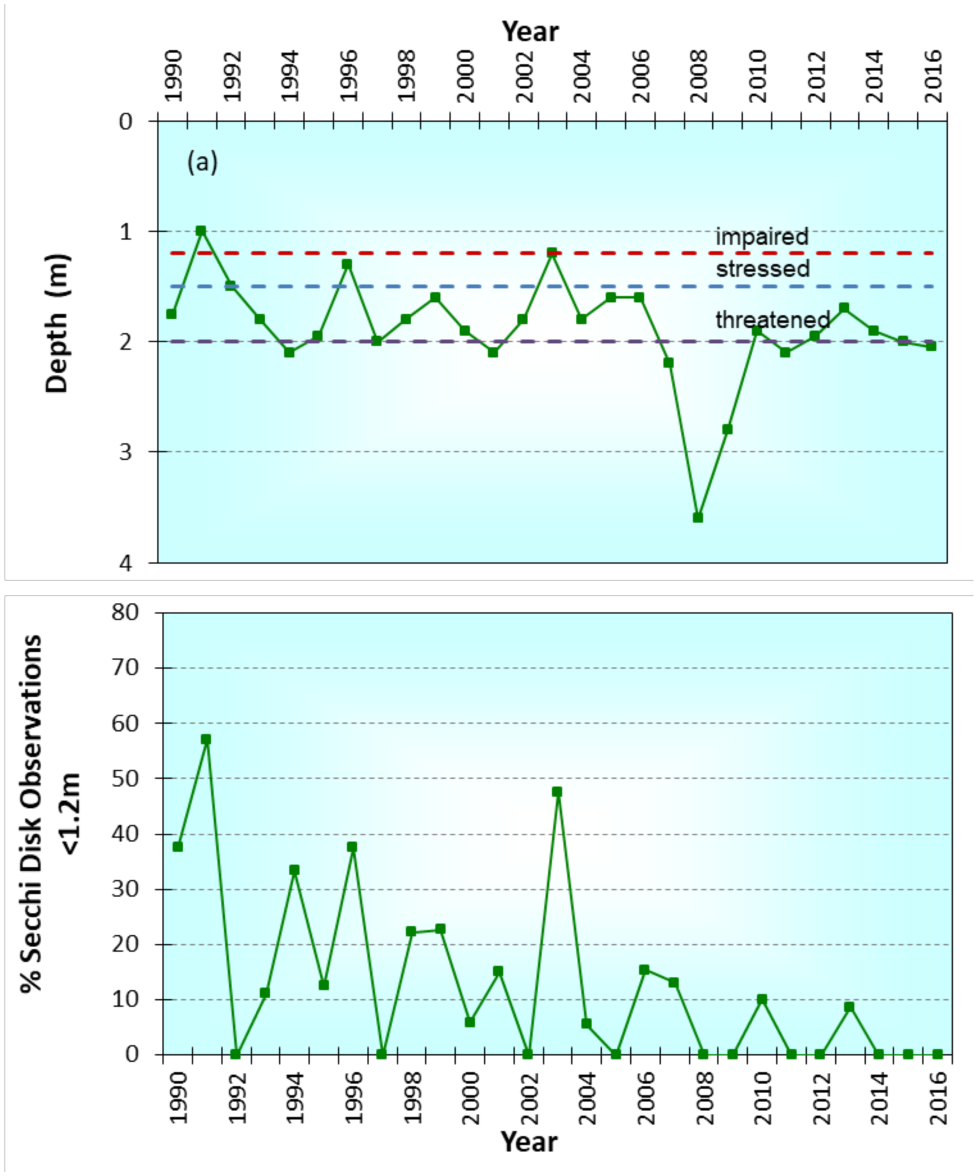


Figure 5-9. Long-term summer median Secchi disk transparency, Onondaga Lake South Deep, 1990–2016 for (a) the summer median value, and (b) the percent Secchi disk observations less than 1.2 meters.

Note: The points in panel (a) represent summer median values. NYSDEC values for impaired (1.2 m), stressed (1.5 m), and threatened conditions (2.0 m) are shown.

5.2.4 Trends in Trophic State

Summer (June–September) average values of the three trophic state indicator parameters (total phosphorus, chlorophyll-*a*, Secchi disk transparency) are presented for the 1998–2016 interval (Figure 5-10). 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 these parameters, trophic conditions have varied only modestly since 2010. Concentrations of total phosphorus and chlorophyll-*a* indicate a shift in the trophic state of Onondaga Lake 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, despite the significant decline in the frequency of Secchi depths < 1.2 m, 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 during 2010–2015, efficient grazers of phytoplankton (i.e., *Daphnia*) continued to be mostly absent in 2016, consistent with the continuing large population of the Alewife (*Alosa pseudoharengus*). See Section 6 for a detailed discussion of food web dynamics. With the exception of the increased water clarity in 2008 and 2009, the trophic status of Onondaga Lake has been remarkably consistent over the past decade.

Save the Rain Tree Planting.

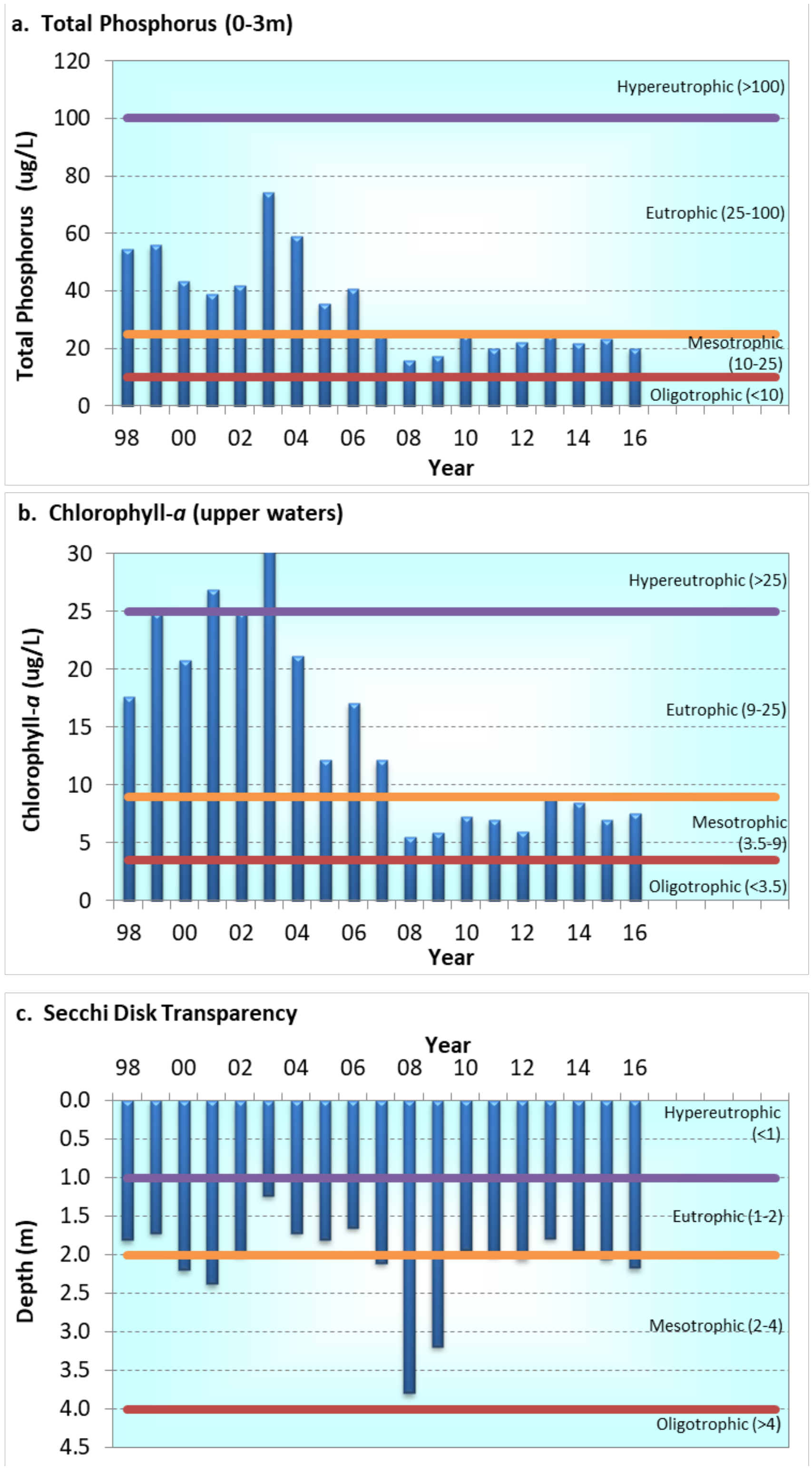
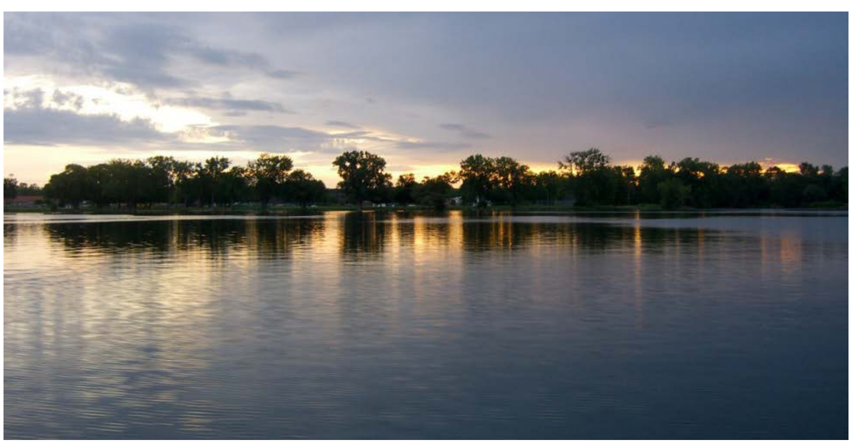


Figure 5-10. Time series of common trophic state indicators based on summer average (June–September) data, 1998–2016.

5.2.5 Comparisons to Other Regional Lakes

In lakes where phytoplankton production is limited by phosphorus, total phosphorus and chlorophyll-*a* are highly correlated. Data from regional lakes, including Onondaga, illustrate this relationship and provide a valuable regional context (Figure 5-11). 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 2015, Rudstam et al. 2016b). 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 5-12). Since 2007, levels of these important water quality indicators have been similar to those measured in Otisco Lake and Oneida Lake. The absence of cyanobacteria (blue-green algae) blooms in Onondaga Lake stands in contrast to the widespread occurrence of harmful algal blooms in lakes across New York State (see http://www.dec.ny.gov/chemical/77118.html for more information).



Onondaga Lake.

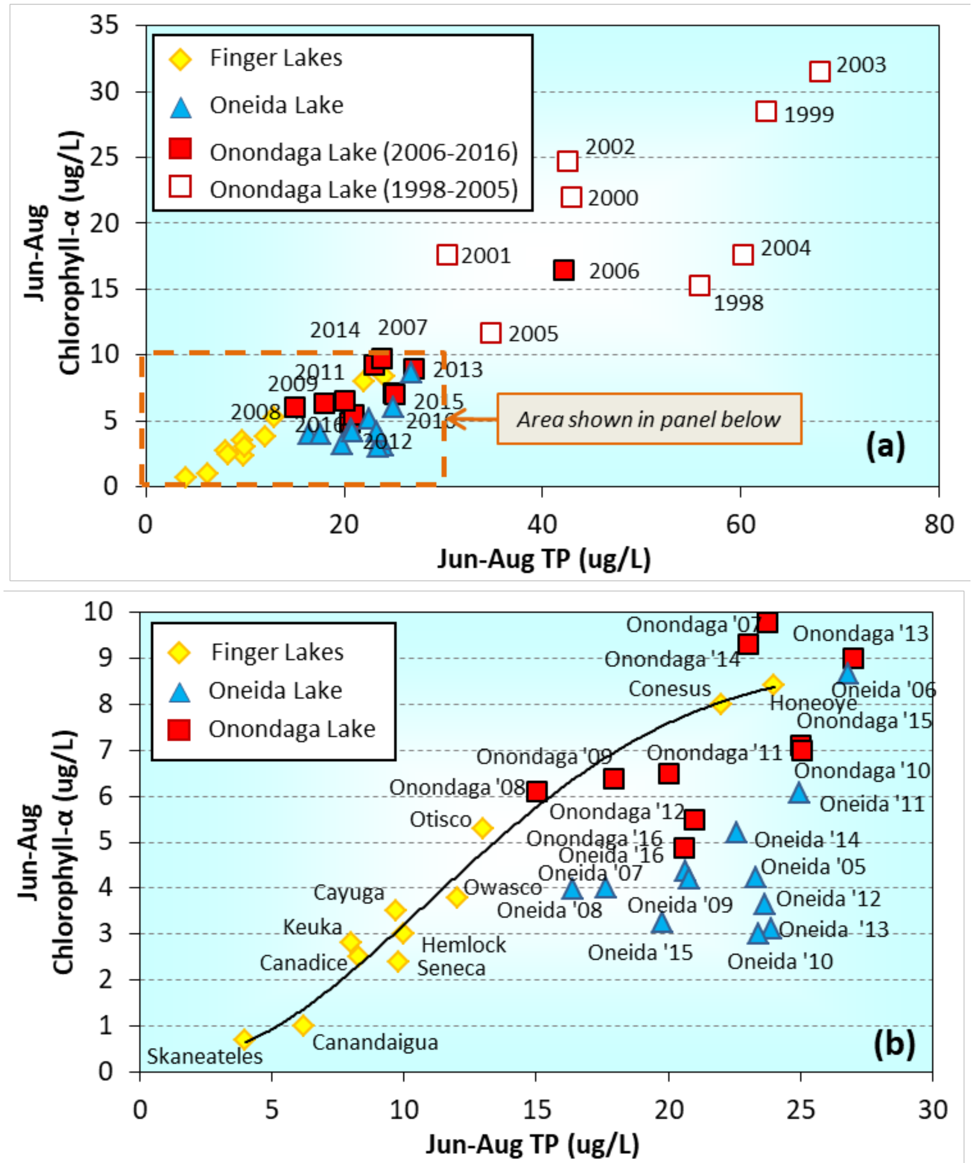


Figure 5-11. June to August average total phosphorus (TP) and chlorophyll-*a* concentrations in Onondaga Lake compared with selected regional lakes.

Note: (a) The top panel shows Onondaga Lake concentrations pre-Actiflo® (1998-2005) and post-Actiflo® (2006-2016). (b) The bottom panel represents the same data, scaled to show the 2007-2016 Onondaga Lake data and a best-fit trendline (R^2 = 0.97) of the Finger Lakes concentrations (1996-1999), and Oneida Lake concentrations (2005-2016; Rudstam 2015, Rudstam et al. 2016b).

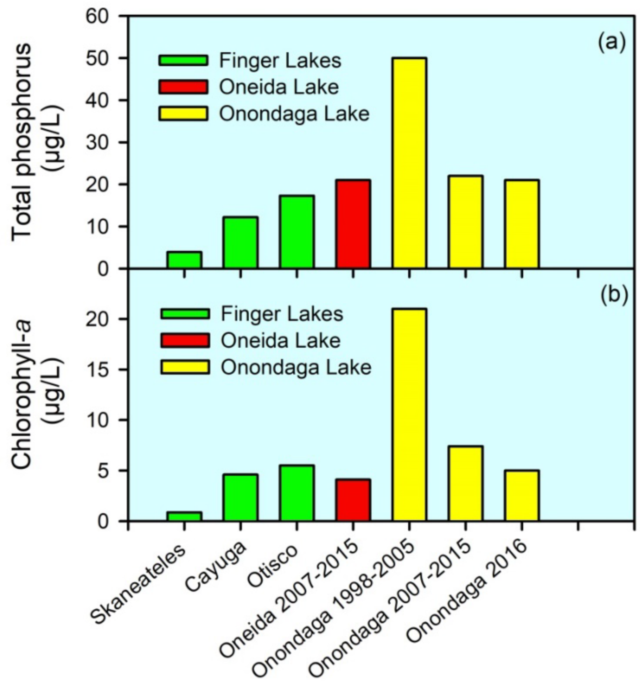


Figure 5-12. A comparison of summer average (May – September) trophic state metrics in Onondaga Lake and selected regional lakes: (a) total phosphorus concentrations and (b) chlorophyll-*a* concentrations.

Note: Skaneateles Lake data from 2011 and 2014, courtesy of the Town of Skaneateles. Cayuga Lake data from 2013, courtesy of Cornell University. Otisco Lake data from 2011-2012, courtesy of NYSDEC. Oneida Lake 2007-2015 data from Rudstam et al. 2017.

5.3 Dissolved Oxygen

Adequate dissolved oxygen (DO) content is critical for aquatic life and a common focus of water quality monitoring programs. Vertically detailed in-situ profiles of DO, temperature, specific conductance, and chlorophyll-*a* were collected at South Deep during 2016 and are presented here as color contour plots (Figure 5-13). These daily measurements were made at 1 meter depth increments over the spring to fall interval at South Deep with a monitoring buoy courtesy of Honeywell (http://www.upstatefreshwater.org/NRT-Data/Data/data.html). Dissolved oxygen concentrations were uniformly high throughout the water column during April and early May (Figure 5-13b). Depletion of DO from the lower layers began with the onset of thermal stratification in mid-May and by mid-July the lake was largely anoxic below a depth of 10 meters (Figure 5-13b). The lower waters were replenished with DO in late October, following the occurrence of fall turnover. There was no noteworthy depletion of DO in the upper waters during the fall of 2016, and the minimum concentration remained well above the AWQS of 4 mg/L (Figure 5-13b).

AMP Sampling for Zooplankton Onondaga Lake, 2016.

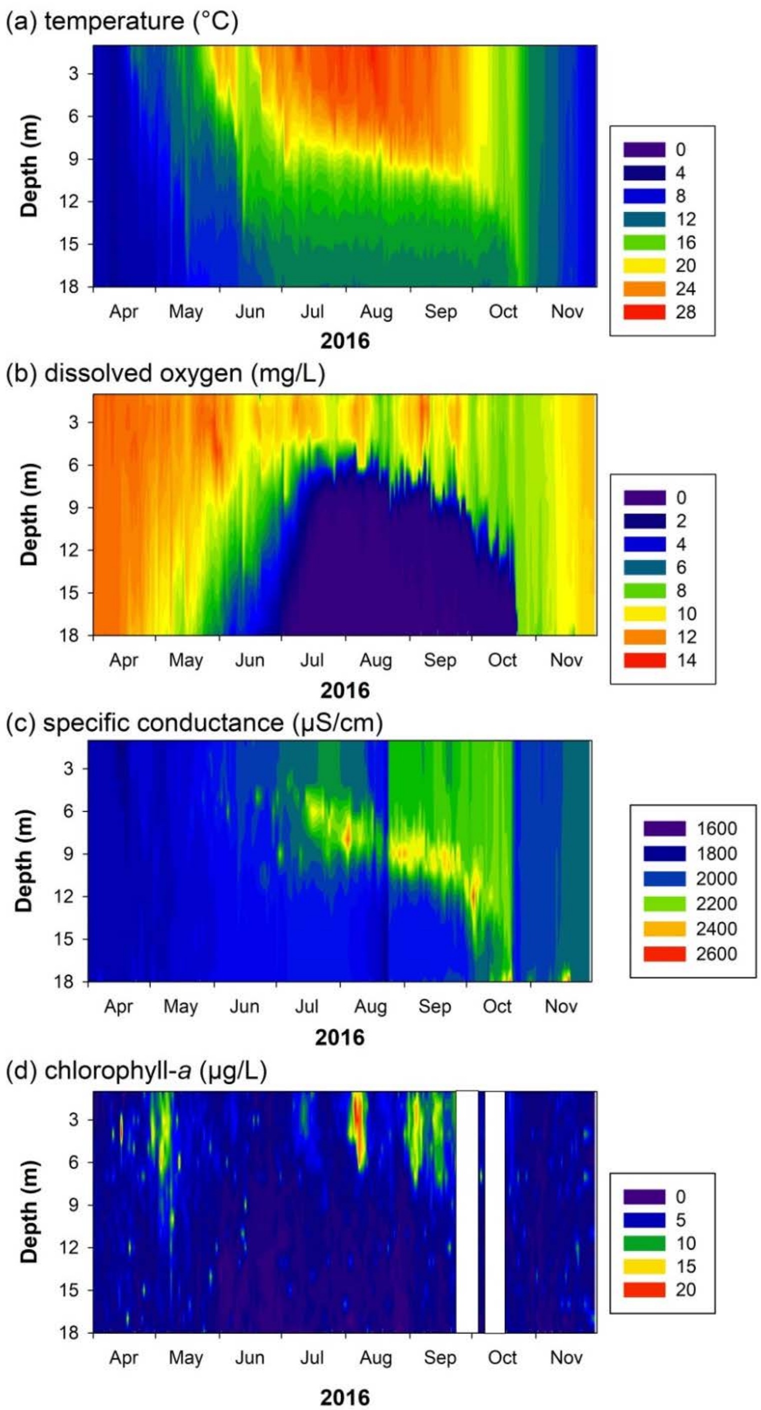


Figure 5-13. Color contour plots of Onondaga Lake in 2016, based on daily sensor profiles conducted at South Deep: (a) temperature (°C), (b) dissolved oxygen (mg/L), (c) specific conductance (µS/cm), and (d) chlorophyll-*a* (µg/L).

A high priority goal for rehabilitation of the lake was the elimination of severe DO depletion in the upper waters during the approach to fall turnover in October (Figure 5-14) and contravention of the related AWQS. This goal has been achieved through reductions in Metro loading of both ammonia-N (Figure 4-8) and total phosphorus (Figure 4-11). 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 resulted in lower rates of DO depletion, as manifested by a delay in the onset of anoxic conditions and decreases in "volume-days of anoxia" (Figure 5-15). Linear regression analysis indicates significant decreases in both volume days of anoxia (R^2=0.53, p<0.01) and volume days of anoxia + hypoxia (R^2=0.45, p<0.01) over the 1992–2016 interval. When evaluated over the 2004–2016 period, the decreasing trends for anoxic conditions (R^2=0.44, p=0.01) and anoxia + hypoxia (R^2=0.38, p=0.02) remained statistically significant. 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 6.5.

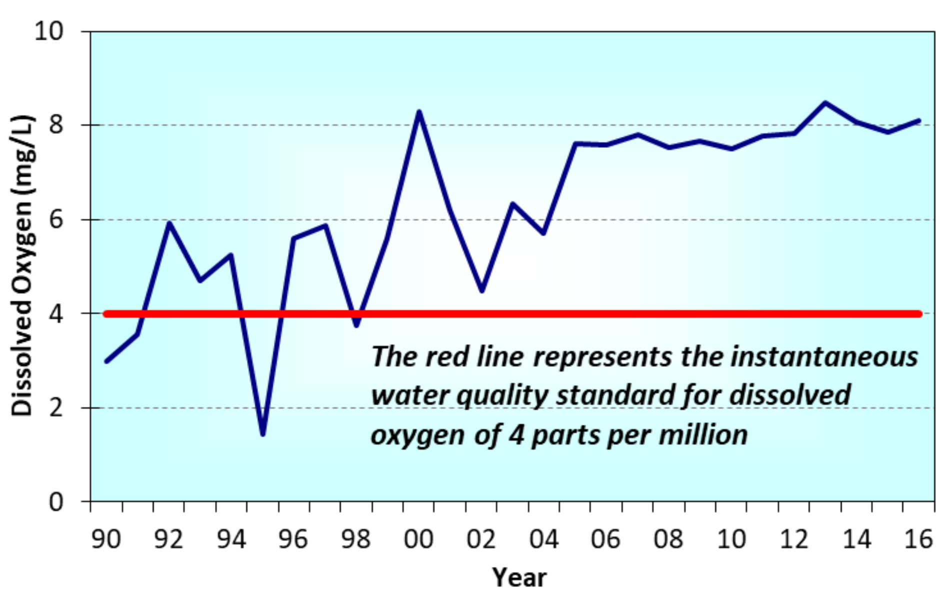


Figure 5-14. Minimum dissolved oxygen (DO) concentration in the upper waters (0-4 meter average) of Onondaga Lake during October, annually 1990–2016.

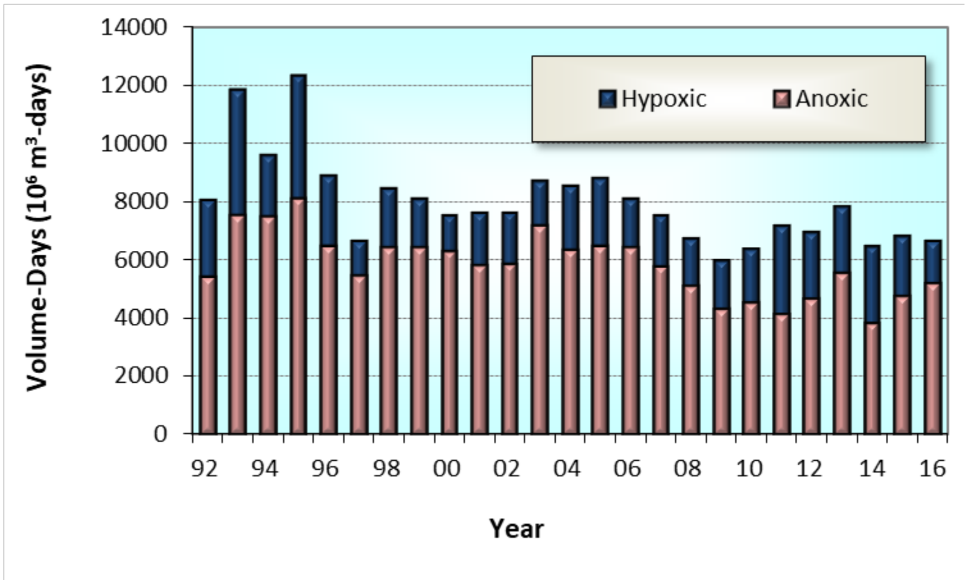


Figure 5-15. Volume-days of anoxia (dissolved oxygen less than 1 mg/L) and hypoxia (dissolved oxygen less than 4 mg/L), in Onondaga Lake, 1992–2016.

5.4 Ammonia, Nitrite, and Nitrate

Onondaga Lake was impaired by elevated concentrations of ammonia-N (NH_3-N) prior to the treatment upgrades at Metro designed to achieve efficient year-round nitrification of wastewater. 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 biologically aerated filter (BAF) technology in 2004 significantly reduced ammonia-N concentrations in the upper waters of the lake (Figure 5-16, Figure 5-17a), enabling a more diverse biota. The lake is now in full compliance with the ambient water quality standards for ammonia-N (Table 5-1), and in 2008 was officially removed from the New York State's 303(d) list of impaired waterbodies for this water quality parameter.

Efficient year-round nitrification treatment resulted in increased nitrate (NO_3-N) loading to the lake and increased in-lake concentrations (Figure 5-17b). These changes 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 calcium nitrate solution was added to the hypolimnion during 2014, 2015, and 2016. Since 2011, the nitrate addition program has applied an average of 67 metric tons of nitrate-N to the hypolimnion annually. In comparison, annual nitrate-N loading from Metro averaged 940 metric tons per year over the 2004–2013 interval. During the stratified period, Metro effluent tends to remain in the lake's upper waters; consequently, the hypolimnetic nitrate injection program has a disproportionately large beneficial impact.

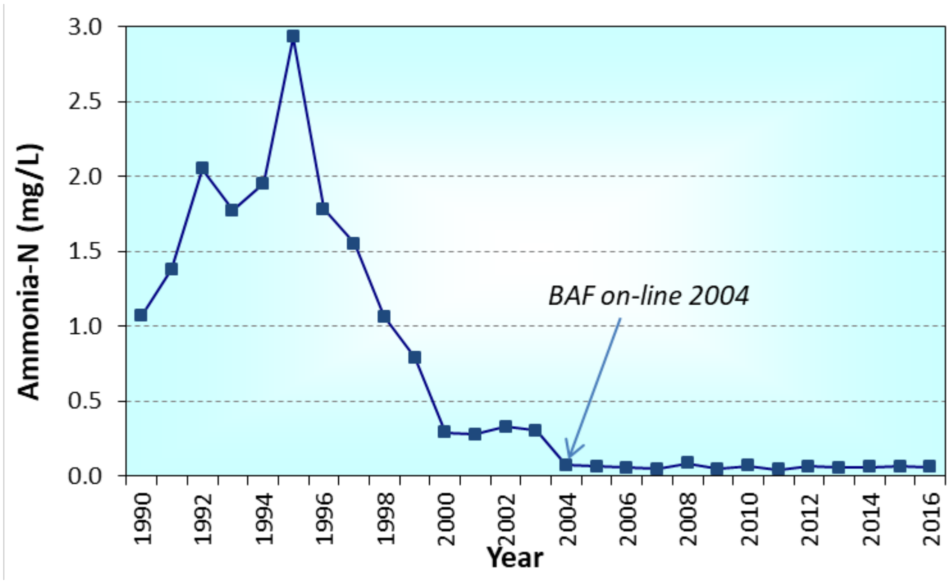


Figure 5-16. Summer average ammonia-N (NH_3-N) concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990–2016.

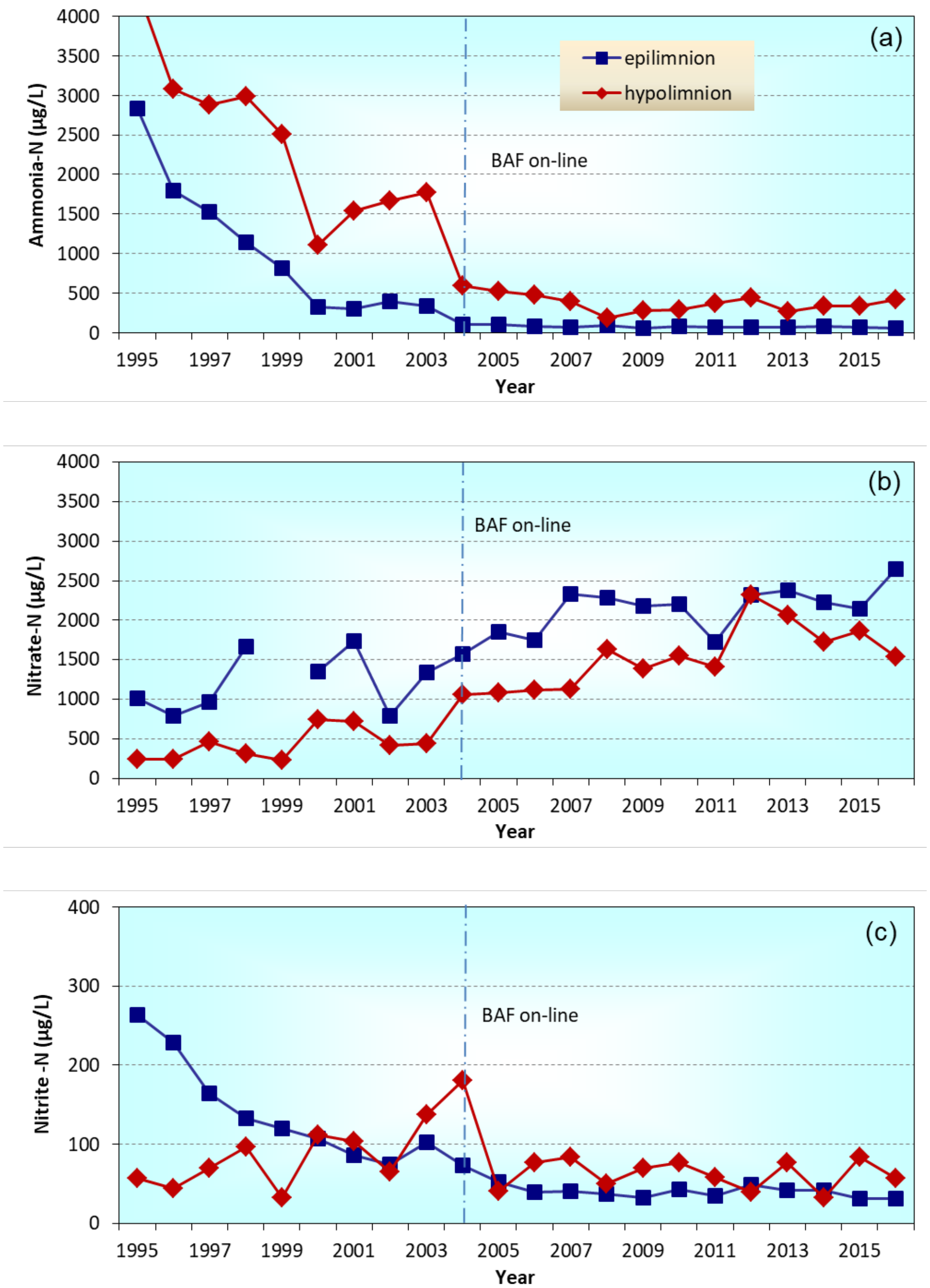


Figure 5-17. Summer average concentrations of nitrogen species in the epilimnion and hypolimnion of Onondaga Lake, 1995–2016: (a) ammonia-N, (b) nitrate-N, and (c) nitrite-N.

Note: 2015 ammonia-N and 2013-2015 nitrate-N and nitrite-N data based on discrete depths (epilimnion = 3m; hypolimnion = average of 15 and 18m.

Table 5-1.Percent of Onondaga Lake ammonia-N measurements in compliance with ambient water quality standards, 1998–2016.

Depth (m)	Percent measurements in compliance, NYS Standards																		
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015[1]	2016[1]
0	64	62	86	95	68	96	100	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	100	100	100
6	50	86	90	95	73	100	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	100	-	-
12	18	52	90	81	50	80	100	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	100	100	100
18	23	48	52	38	32	48	75	95	95	100	100	100	100	100	100	100	100	-	-

[1] only 3 and 15 meter depths were sampled in 2015 and 2016

Kayak Rentals at Willow Bay, 2016.

Nitrite (NO_2-N) concentrations also commonly 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. In-lake concentrations of nitrite and exceedances of the AWQS were greatly reduced following the treatment upgrade (Figure 5-17c). Exceedances of the AWQS now only occur in the lower layers of the lake when dissolved oxygen concentrations are less than 2 mg/L. These conditions reflect incomplete nitrification of ammonia-N 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.

5.5 Deep Water Conditions

The treatment plant upgrades at Metro resulted in profound changes in the lower waters of the lake. These were in addition to those described previously, associated with both the decreased loading of phosphorus and the increased inputs of nitrate (instead of ammonia-N). 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 of organic matter, 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 (Figure 5-18b) resulted in release of soluble reactive phosphorus from the profundal sediments (Figure 5-18c). The complete absence of sediment phosphorus release under the high nitrate concentrations of 2016 (Figure 5-18f) clearly demonstrates the positive effect of nitrate, even under anoxic conditions (Figure 5-18d). 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 5-19).

The mass of phosphorus accumulated in the hypolimnion during the summer stratification interval has decreased by 90% since the 1990s (Figure 5-19). 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, both associated with natural variations in meteorological conditions. Additionally, 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. Rates of sediment phosphorus release have been particularly low since the initiation of nitrate addition in 2011 (Figure 5-19).

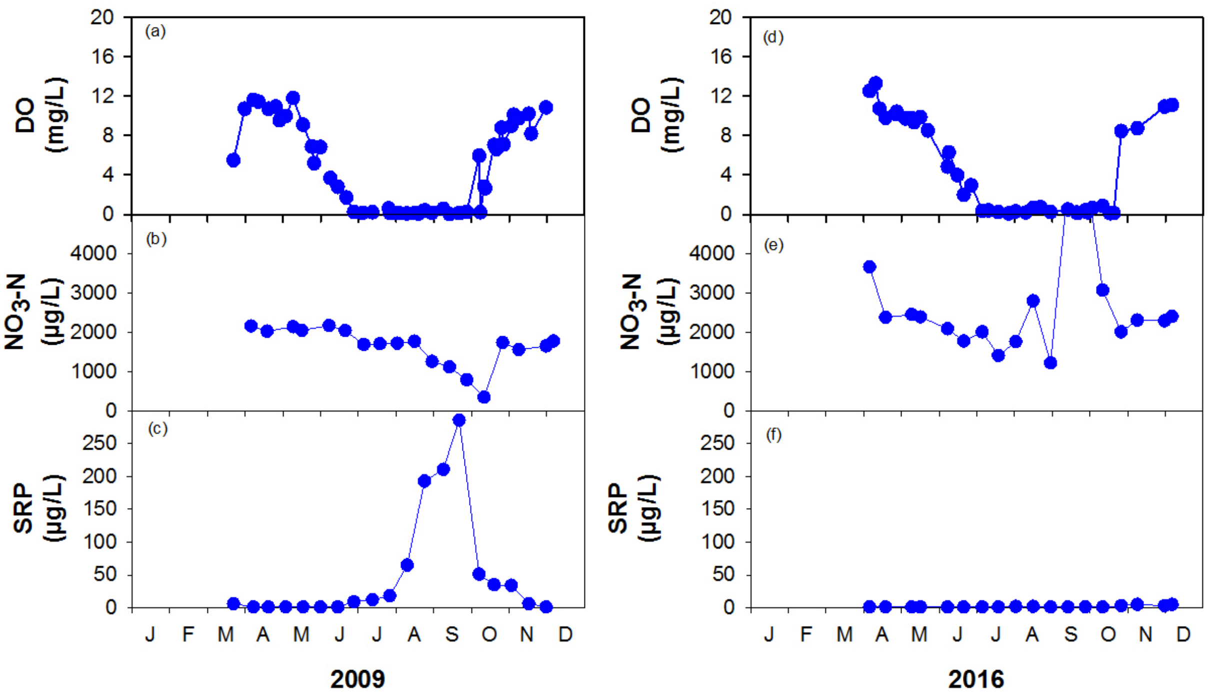


Figure 5-18. Time-series of concentration values in the deep waters of Onondaga Lake: (a) 2009 (18 meters) dissolved oxygen (DO), (b) 2009 (hypolimnion composite) nitrate (NO_3-N), (c) 2009 (18 meters) soluble reactive phosphorus (SRP), (d) 2016 (18 meters) dissolved oxygen (DO), (e) 2016 (18 meters) nitrate (NO_3-N), (f) 2016 (18 meters) soluble reactive phosphorus (SRP).

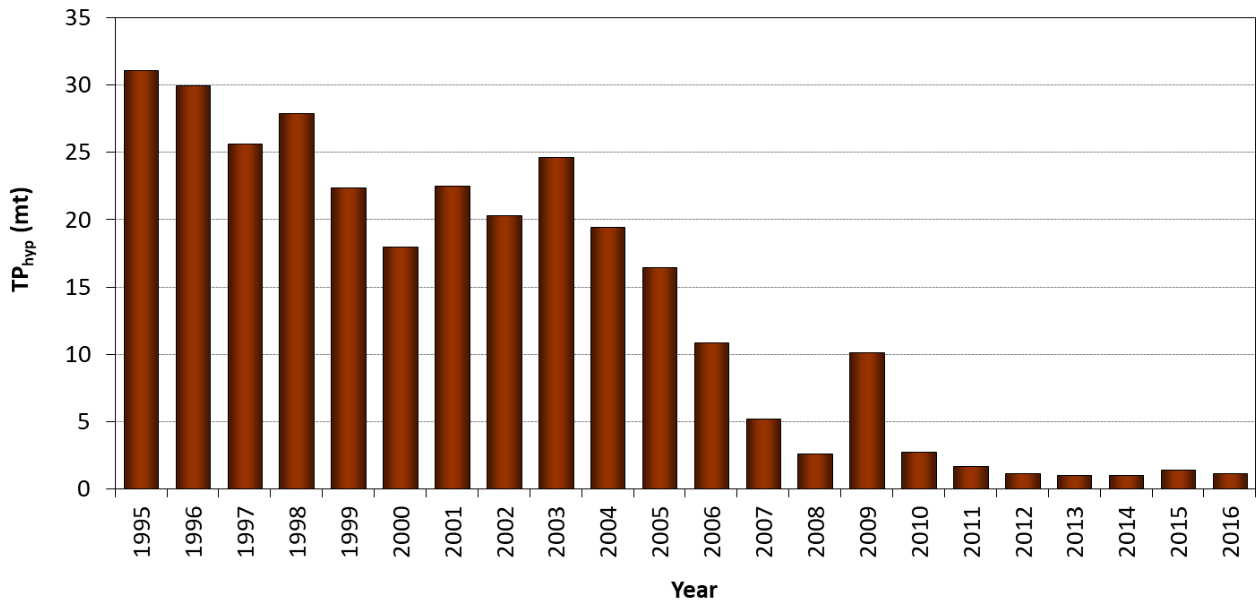


Figure 5-19. The maximum mass of total phosphorus (TP) accumulated in the hypolimnion during summer stratification, 1995–2016.

5.6 Compliance with AWQS

The 2016 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 5-2. The concentration of total dissolved solids (TDS), which primarily reflects the concentrations of the major cations (calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+})), and anions (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 natural hydrogeology of the lake 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.

Table 5-2. 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 2016.

Parameter	AWQS/Guidance Value	Upper Waters		Lower Waters	
		Depths	%	Depths	%
Dissolved Oxygen (n=464, 462)[5]	≥ 4 mg/L instantaneous[1]	2m	100%	12m	*60%*
Dissolved Oxygen (n=237, 220)	≥ 5mg/L daily average[1]	2m	100%	12m	*53%*
pH (n=51)	6.5-8.5	0-6m	100%	12-18m	100%
Total Phosphorus (n=9)	≤ 20 µg/L summer average[2]	0, 3m	100% (20 µg/L)	--	--
Ammonia-N (n=17)	variable[3]	3m	100%	15m	100%
Nitrite (n=18, 36)	≤0.1 mg/L	3m	100%	15m	*89%*
Total Dissolved Solids (n=18)	≤500 mg/L	3m	*0%*	15m	*0%*
Dissolved Mercury (n=3)	≤0.7 ng/L	3m	100%	18m	100%
Fecal Coliform Bacteria (n=7)	≤200 cfu/100 mL monthly geomean[4]	0m	100%	--	--

Notes:

Dashed lines indicate that compliance was not evaluated; occurrences of less than 100% compliance are highlighted in italic red text.

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

[2]Total phosphorus compliance based on the 0-3m average for the June 1-September 30 period.

[3]The AWQS for ammonia-N varies as a function of pH and temperature.

[4]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).

[5]n refers to the number of measurements for the upper and lower waters individually. For example, compliance for dissolved oxygen was based on 237 measurements from 2 m and 220 measurements from 12 m.

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 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 2016 summer average total phosphorus (TP) concentration in the lake's upper waters was 20 µg/L, matching the state's guidance value of 20 µg/L. Four of the nine TP values measured during the June–September period exceeded 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 November of 2016. Sampling for mercury was not conducted at North Deep in 2016. Methylmercury is of particular concern because this form bioaccumulates strongly in aquatic food webs, resulting in toxic effects at upper trophic levels when concentrations are high. 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 5-20). The AWQS for dissolved mercury in Class B and C waters is 0.7 nanograms per liter (ng/L) and applies to the health fish consumption standard. This standard was not exceeded in any of the samples collected during 2016 (data not shown).

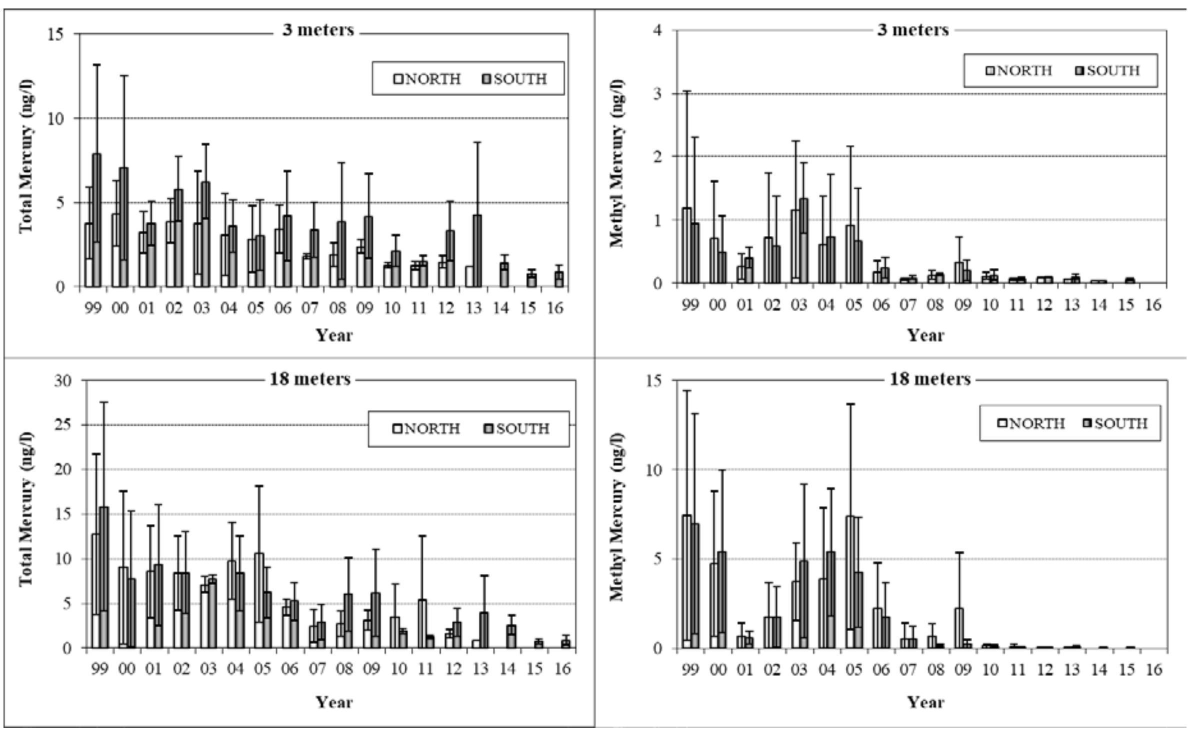


Figure 5-20. Time series of annual average mercury (Hg) concentrations at the North and South Deep stations of Onondaga Lake, 1999–2016 (a) total Hg at 3 meters, (b) methyl Hg at 3 meters, (c) total Hg at 18 meters, and (d) methyl Hg at 18 meters.

Note: The error bars depict one standard deviation of the annual mean concentration. Error bars are not included for the North Deep station in 2013 because only one useable sample was available for total and methyl Hg. Sampling at the North Deep station was discontinued in 2014. Please note that scaling of the Y-axis varies from plot to plot.

Dissolved oxygen (DO) concentrations met the AWQS (Table 5-3) in the upper waters of Onondaga Lake throughout the 2016 sampling period. DO concentrations in the lower waters were below the minimum 4 mg/L 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. NYSDEC recognizes that low dissolved oxygen concentrations are likely to occur at lower depths of stratified lakes as the result of natural conditions (NYSDEC Consolidated Assessment and Listing Methodology, March 2015). 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 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 a 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 5-3. 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 2016, 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. Three sites, located within the Class C segment of the lake's southeastern shoreline, exceeded the standard for fecal coliform bacteria during the month of October (see Section 5.7). The other locations within the Class C water segment met the ambient water quality standard for all monitored months.

5.7 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 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 cfu per 100 mL for a single sample and ≤ 200 cfu per 100 mL for a 30 day geometric mean. Presently, there is no public bathing beach located on Onondaga Lake.

The 30-day standard is applied on a monthly basis to assess bacterial contamination at nearshore locations (Figure 5-21) as well as at the two 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 2016, bacteria levels in Class B areas of Onondaga Lake did not exceed the standard established for contact recreation. Three sites (LS_HARB, LS_METRO, LS_OUT), located within the Class C segment of the lake's southeastern shoreline (Figure 5-21), exceeded the bacteria standard during the month of October. LS_METRO and LS_OUT are located near the outlets of Metro and Onondaga Creek, respectively. LS_HARB is located near the mouth of Harbor Brook. Bacterial counts at the offshore monitoring location, South Deep, were below the AWQS for fecal coliform bacteria throughout the 2016 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 Secchi disk measurement near the mouth of Bloody Brook on June 9, the NYSDOH swimming safety guidance value for water clarity was met in Class B waters throughout the summer recreational period of 2016 (Figure 5-22). Sampling locations in the southern end of the lake, near the mouths of Onondaga Creek and Harbor Brook, failed to meet this guidance value on 10-20% of the monitored days. Sediment inputs from the mud boils on upper Onondaga Creek likely contributed to the diminished water clarity in nearshore areas of the Class C segment in the southern portion of the lake. The guidance value for clarity was met in the Class C segment near the mouth of Ninemile Creek on 19 of the 20 monitored dates (95%). 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.

Sunset at Onondaga Lake.

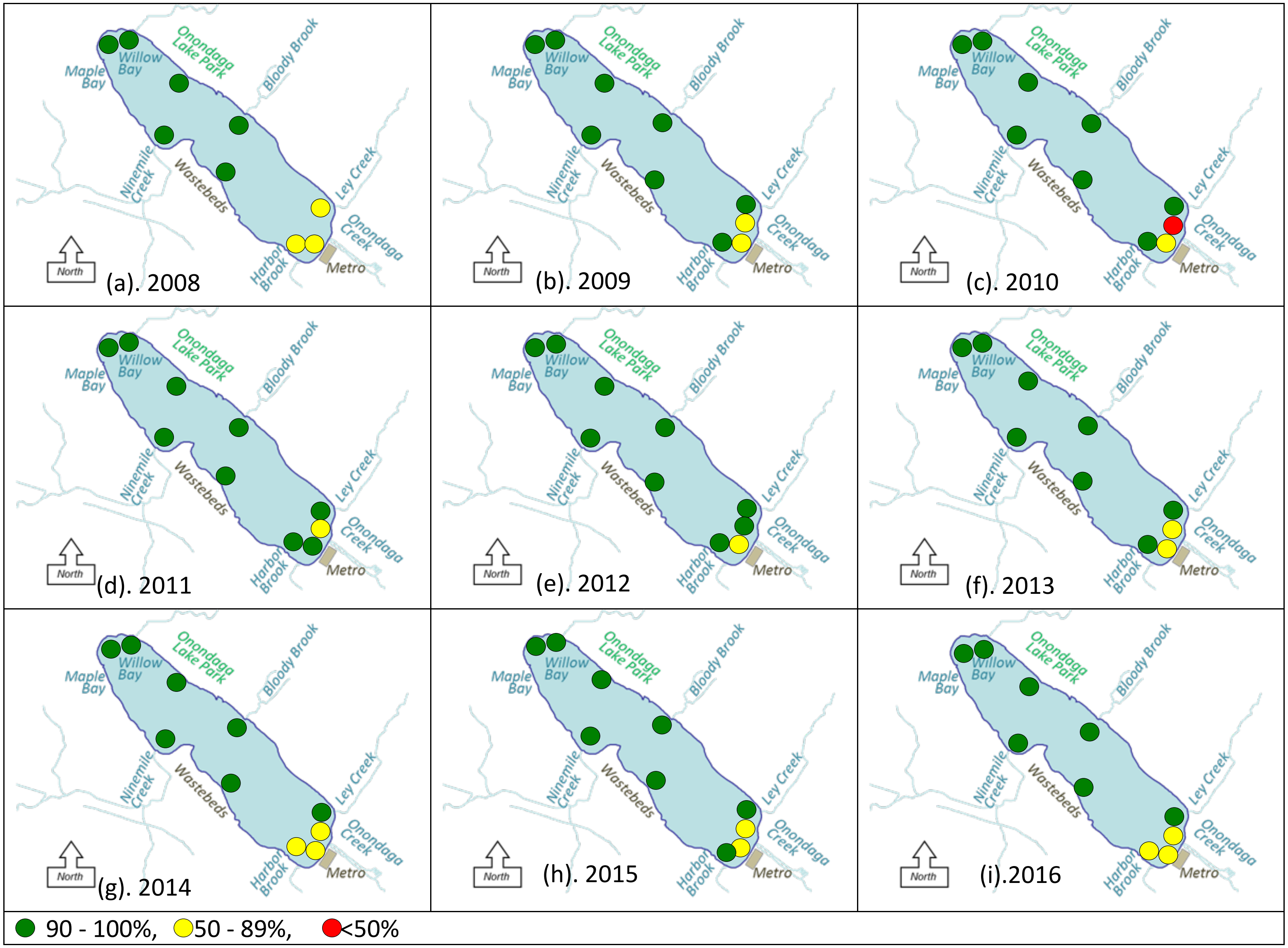


Figure 5-21. The percentage of months in compliance with the water quality standard for fecal coliform bacteria for nearshore stations in Onondaga Lake, April–October: (a) 2008, (b) 2009, (c) 2010, (d) 2011, (e) 2012, (f) 2013, (g) 2014, (h) 2015, and (i) 2016.

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).

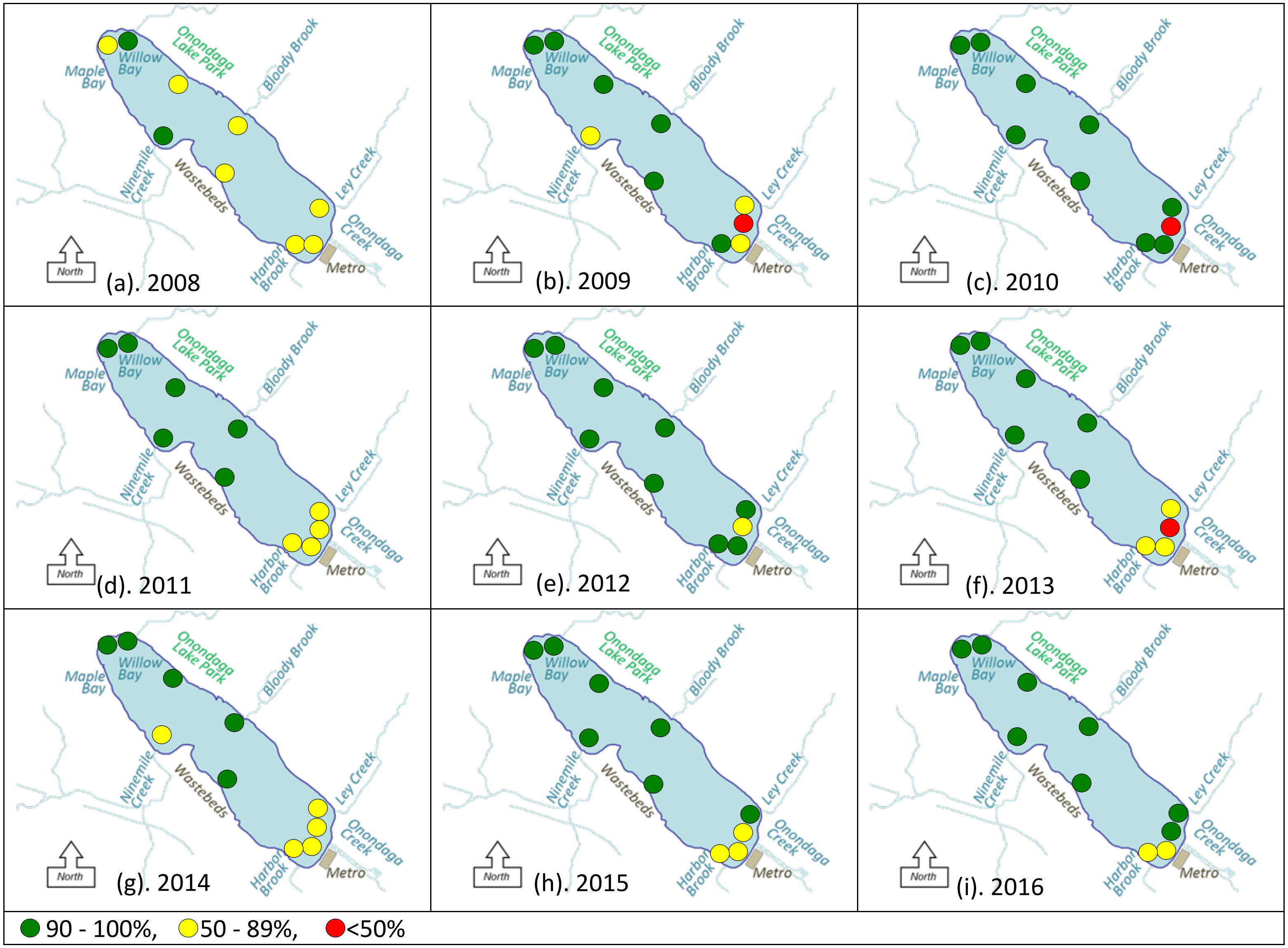


Figure 5-22. Percentage of nearshore Secchi disk transparency measurements greater than 1.2 meters (4 feet) during June–September: (a) 2008, (b) 2009, (c) 2010, (d) 2011, (e) 2012, (f) 2013, (g) 2014, (h) 2015, and (i) 2016.

5.8 Long-Term Trends in Water Quality

Advanced wastewater treatment at Metro has resulted in major reductions in loading of total phosphorus, ammonia-N, and nitrite to Onondaga Lake. The lake responded positively to these loading reductions, with major improvements documented for a number of key water quality parameters and recovery of lost uses. In this section long-term trends are identified using various statistical approaches, including seasonal Kendall tests and least squares linear regression models.

5.8.1 10–Year Water Quality Trends: 2007–2016

Water quality trends for the last 10 years (2007–2016) were 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 (2007–2016) reflects conditions following the major treatment upgrades at Metro in 2004 and 2005. The number of trends identified as significant and the strength of these trends has diminished as the 10-year analysis period has shifted further in time from the Metro upgrades. Nevertheless, significant decreasing trends continued to be identified for ammonia-N, total phosphorus, and soluble reactive phosphorus (Table 5-4). Nitrate addition has contributed to increased nitrate levels and decreased concentrations of soluble reactive phosphorus in the hypolimnion since 2011. Increases in total suspended solids were noted at South Deep and decreases in Secchi disk transparency were identified at both South Deep and North Deep.

Table 5-4. Summary of statistically significant trends in lake concentrations during the 2007 to 2016 period, according to two-tailed Seasonal Kendall tests that account for serial correlation.

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	**-2.0%**	--	**-3.1%**	--	--	--
Bacteria	Fecal coliform	o	--	**6.0%**	--	o	--
Nitrogen	Ammonia-N (NH_3-N)	**-3.8%**	o	o	o	**-9.4%**	o
	Nitrite (NO_2-N)	o	o	o	o	o	o
	Nitrate (NO_3-N)	o	**3.9%**	o	**5.6%**	**5.0%**	o
	Organic nitrogen as N	o	o	o	o	**3.4%**	**2.7%**

Table 5-4. Summary of statistically significant trends in lake concentrations during the 2007 to 2016 period, according to two-tailed Seasonal Kendall tests that account for serial correlation.

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 upper waters	South Basin lower waters	North Basin upper waters	North Basin lower waters	Lake Outlet 0.6m	Lake Outlet 3.7m
	Total Kjeldahl nitrogen as N (TKN)	o	o	o	o	o	o
Phosphorus	Total phosphorus (TP)	o	**-3.1%**	o	o	**-7.8%**	**-3.1%**
	Soluble reactive phosphorus (SRP)	o	**-5.6%**	o	o	**-19.3%**	**-12.7%**
Solids	Total suspended solids (TSS)	**6.6%**	**10.0%**	o	o	o	o
	Tota l dissolved solids (TDS)	o	o	o	o	o	o
Chlorophyll	Chlorophyll-*a*	o	--	o	--	--	--
	Phaeophytin-*a*	o	--	o	--	o	o
Carbon	Total organic carbon (TOC)	o	o	o	o	o	o
	Total inorganic carbon (TIC)	**-1.5%**	o	**-2.7%**	o	**-1.8%**	o
Other	Alkalinity as $CaCO_3$	o	o	o	o	o	o
	Calcium (Ca)	o	o	o	o	o	o
	Chloride (Cl)	o	o	o	o	o	o
	Specific conductance	o	o	o	o	o	o
	Dissolved oxygen (DO)	o	o	o	o	o	o
	Magnesium (Mg)	o	o	o	o	o	o
	Manganese (Mn)	o	o	o	o	**-4.4%**	**-1.2%**
	Sodium (Na)	o	o	o	**-4.0%**	o	o
	pH	o	o	o	o	o	o
	Dissolved Silica (SiO_2)	o	o	o	o	o	o
	Sulfate (SO_4)	o	o	o	o	o	o
	Temperature	o	o	o	o	o	o

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
o indicates no trend
- dash indicates parameter not measured at this location.

5.8.2 Drivers of Long-term Phosphorus Trends

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 2016 period depict systematic decreases in both loading and in-lake concentrations achieved by the upgrades in treatment at Metro (Figure 5-23). The water year time segmentation is used to be more consistent with the summer interval of the in-lake total phosphorus guidance value. Empirical analysis according to linear least-squares regression demonstrates that changes in Metro loads explained 80% (R^2 = 0.80) of the observed variations in the summer average total phosphorus concentration of the upper waters (Figures 5-23a). This relationship becomes substantially weaker (R^2 = 0.46) when tributary contributions are included in the independent variable (Figure 5-23b). 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.

Onondaga Lake Marina.

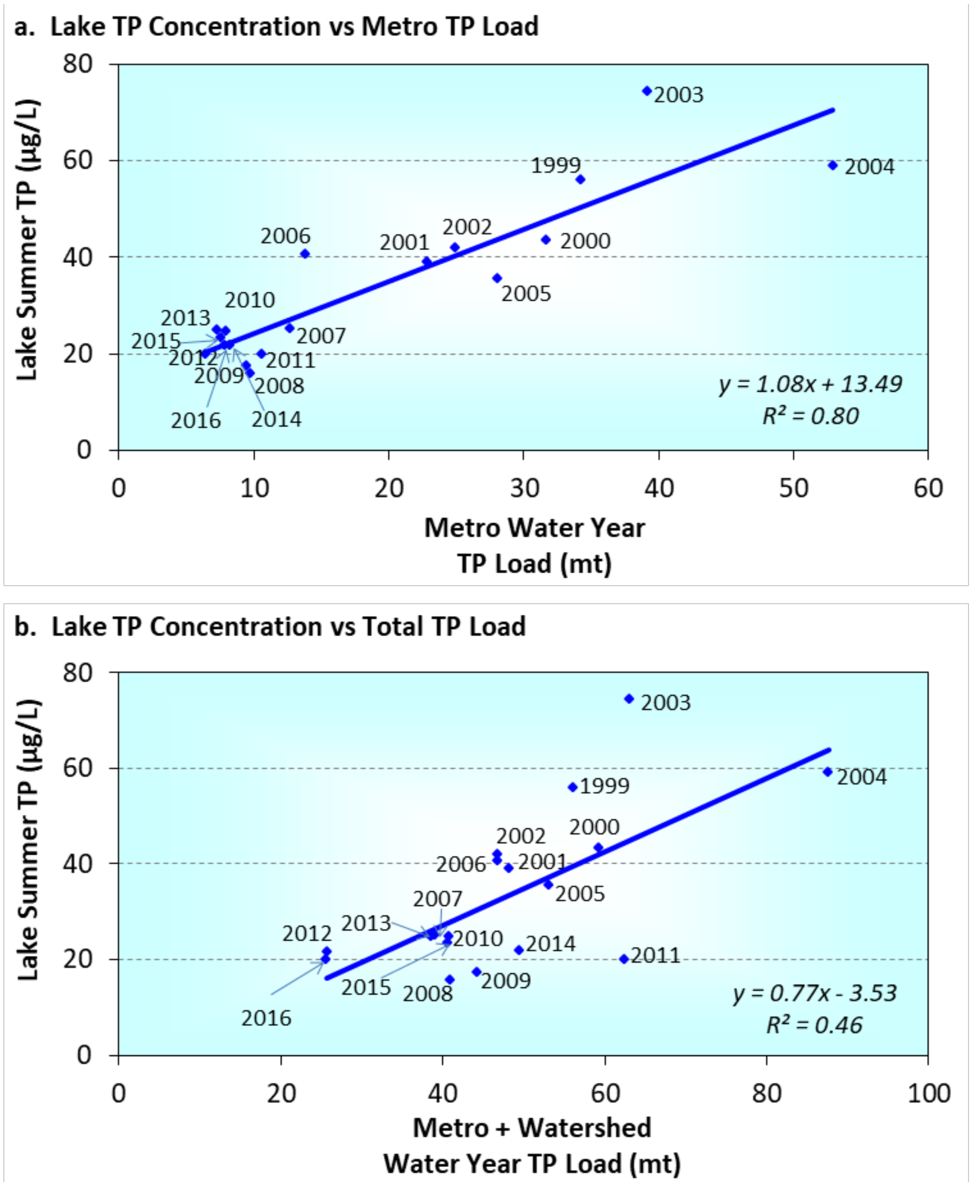


Figure 5-23. Evaluation of the relationship between summer (June–September) average total phosphorus (TP) concentration in the upper waters (0–3 meters) of Onondaga Lake and TP loading for the 1999–2016 period.

Note: Loads are presented on a water year (October 1–September 30) basis for (a) Metro (including secondary bypass only), and (b) the sum of Metro (including secondary bypass only) 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 11 year interval (2006–2016) following implementation of Actiflo® treatment at Metro. The regulatory goal of 20 µg/L has been met in four (2008, 2009, 2011, 2016) 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* ($Chl\text{-}a_{epi}$) were developed and tested by Matthews et al. (2015) for the post-Actiflo® interval of 2006–2011, 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). We have extended the original analysis to include the 2006–2016 interval.

The updated best-fit multiple regression relationships were

$$TP_{epi} = 241.57\ (TP_{Metro}) + 4.37\ (Q_{ON}) - 9.09\ (D) - 10.18 \quad (1)$$

$$Chl\text{-}a_{epi} = 157.76\ (TP_{Metro}) + 2.41\ (Q_{ON}) - 3.39\ (D) - 12.99 \quad (2)$$

These relationships explained 88% and 87% of the observed variations in TP_{epi} and $Chl\text{-}a_{epi}$, respectively. Despite the small sample size (n = 11 years), *p* values for both expressions were highly significant ($p<0.01$). The *p* values for the TP_{Metro}, Q_{ON}, and D components of the TP_{epi} model were 0.016, 0.003, and 0.010, respectively, and for the $Chl\text{-}a_{epi}$ model these were 0.036, 0.011 and 0.063. Scatter plots of predicted versus observed TP_{epi} and $Chl\text{-}a_{epi}$ demonstrate the ability of these simple empirical models to predict summer average conditions with high confidence (Figure 5-24). The models substantially underpredicted summer average values of TP_{epi} and $Chl\text{-}a_{epi}$ based on the conditions of 2016. The relatively poor performance for 2016 may be related to the unusually low flows observed during the summer. The models also underpredicted for 2008 and 2012, two summers that were nearly as dry as 2016.

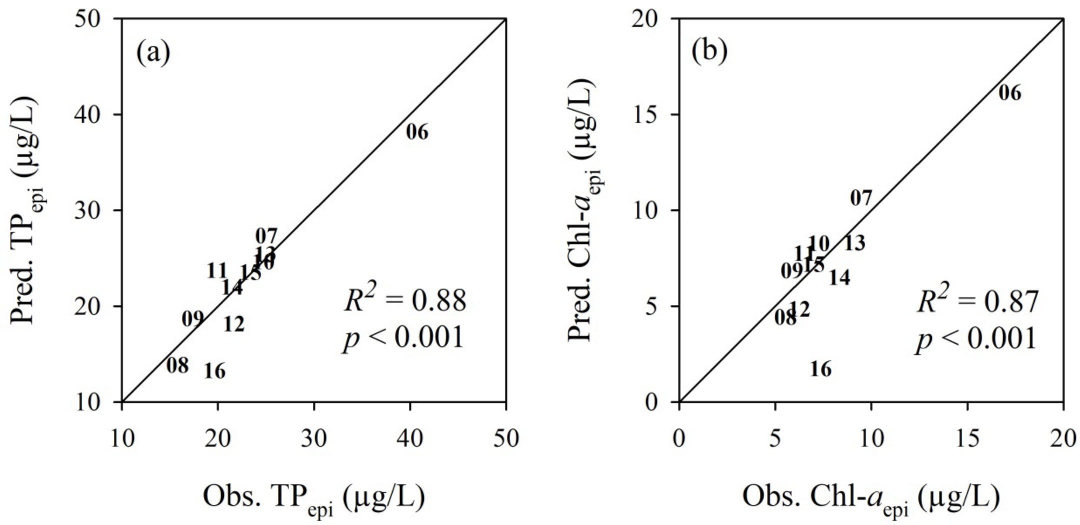


Figure 5-24. Performance of multiple linear regression models in describing contemporary (2006–2016) interannual variations in trophic state metrics: (a) TP_{epi}, and (b) Chl-a_{epi}.

The major improvements in trophic state metrics in Onondaga Lake over the last 30 years were 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 noxious 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 noxious conditions. Data from a wide range of temperate lakes suggest 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 1998–2016 period (Figure 5-25). Total nitrogen (TN) was calculated as the sum of Total Kjeldahl N (TKN; organic nitrogen plus ammonia-N), nitrite, and nitrate.

The TN:TP ratio remained above the literature N:P threshold for cyanobacteria dominance for the entire 1998 to 2016 period (Figure 5-25). The higher values from 2007 to 2016 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 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 immediately 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 much 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. The continued occurrence of harmful algal blooms (HABs) in nearby Oneida Lake and increased occurrence in the New York Finger Lakes motivated preparation of the attached white paper, "Analysis of Phytoplankton Community Dynamics: Is Onondaga Lake at Risk for Cyanobacterial Blooms?", which investigates the likelihood of HABs returning to a recovering Onondaga Lake.

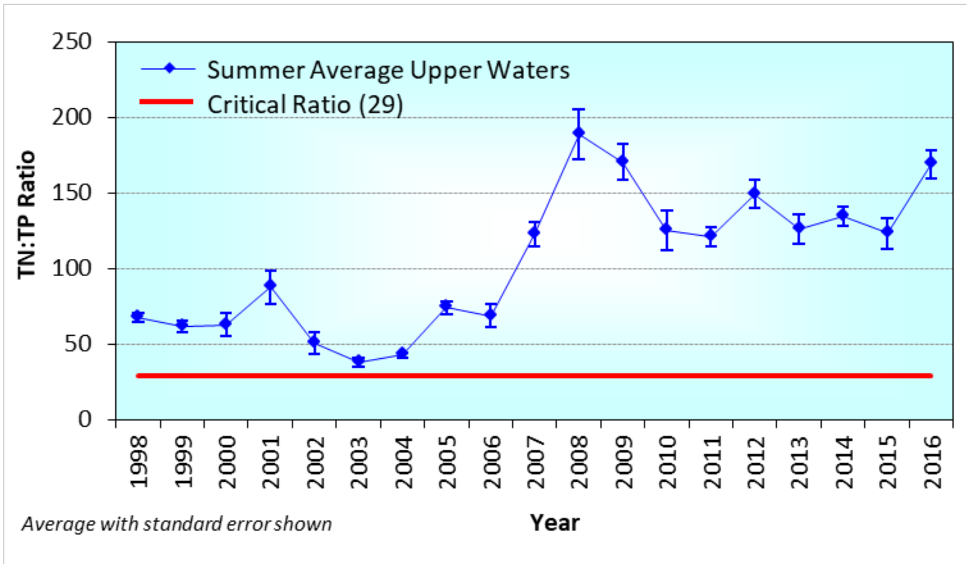


Figure 5-25. Summer average ratio of total nitrogen to total phosphorus (TN:TP, by weight) in the upper waters of Onondaga Lake, 1998–2016.

Note: Error bars represent plus and minus 1 standard error.

Section 6. Biology and Food Web: 2016 Results and Trends

6.1 Introduction

This section of the Annual Report reviews the extensive AMP data describing the phytoplankton, macrophyte, zooplankton, dreissenid mussel, and fish communities that form the Onondaga Lake food web. As phosphorus concentrations in Onondaga Lake have declined to mesotrophic levels, biological conditions have responded. The dramatic decline in phosphorus concentrations has led to lower phytoplankton biomass and greater water clarity. Light penetration deeper into the water column resulted in expansion of macrophyte beds, which has improved habitat and shelter for fish and other aquatic organisms. The assemblage of plants and animals in the lake has changed over the last decade as well, and some invasive species have become established. The immense database developed over the course of the AMP supports a detailed analysis of ecosystem condition and change.

6.2 Primary Producers

6.2.1 Phytoplankton

The algal biomass (April through October wet mass averages) in Onondaga Lake has been below 2 mg/L since 2007, and 2016 had among the lower values recorded (0.9 mg/L) (Figure 6-1). This is lower than expected from meso-eutrophic systems (3-5 mg/L, Wetzel 2001). Peak biomass in 2016 reached 3.7 mg/L during a mixed-species increase in late summer (9/13). Diatom concentrations were low compared to previous years, and a spring diatom bloom was not detected. The most abundant algal genera in 2016 were a cryptophyte and a haptophyte. Cryptophytes as a group had the highest average biomass followed by diatoms and haptophytes. Cryptophytes had higher biomass than diatoms for the first time since 2001 (Figure 6-2).

Algal biomass (wet mass) declined significantly from 1998 to 2008 but has remained relatively stable since then.The phytoplankton community of Onondaga Lake consists mainly of diatoms (Bacillariophyta), Chlorophyta, Chrysophyta, Cryptophyta, dinoflagellates (Pyrrhophyta), bluegreens (Cyanophyta), Haptophytes, and a miscellaneous group (Figure 6-3). Chrysophytes are the only group that has increased over time ($P=0.006$). All other groups declined; diatoms ($P<0.04$), bluegreens ($P<0.001$) and dinoflagellates ($P<0.001$) declined significantly. The lower panel shows the proportional distribution of the seven groups. Chrysophytes (P<0.0002) and diatoms (P<0.04) increased significantly in proportional biomass over this period, while dinoflagellates and bluegreens decreased (P<0.002). Note that these significant changes are due to the shifts in community composition between 1998 and 2004. Since 2005, community composition has been more stable, although there have been significant increases in the proportion of cyanophytes (P=0.038) and of "other" (mainly haptophytes, P=0.022) from 2005 to 2016 (Figure 6-3).

Cyanobacteria biomass was low throughout the year, except for, a large biomass of Pseudanabaena (reaching 302 µg/L) on 9/27 (Figure 6-4). Bluegreen algae (cyanobacteria)

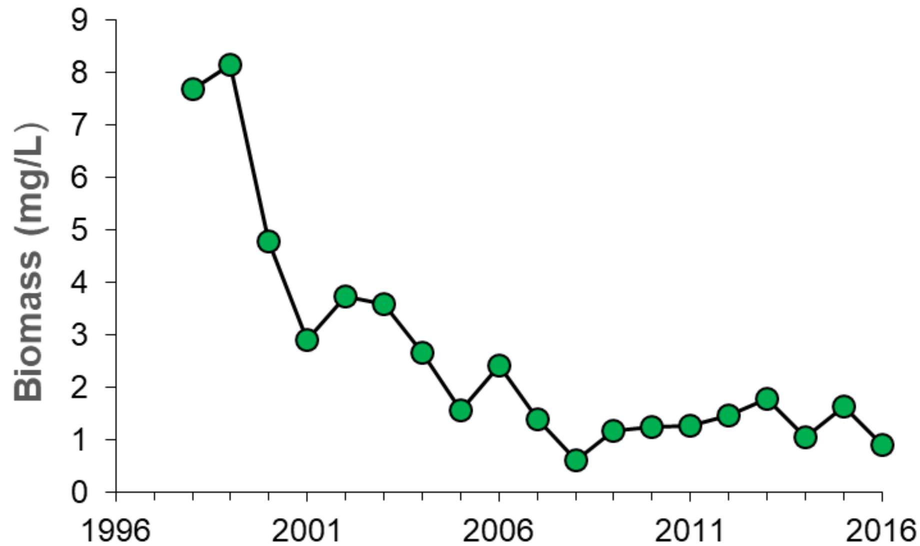


Figure 6-1. Temporal trend of average annual phytoplankton biomass (April – October) in Onondaga Lake from 1998-2016.

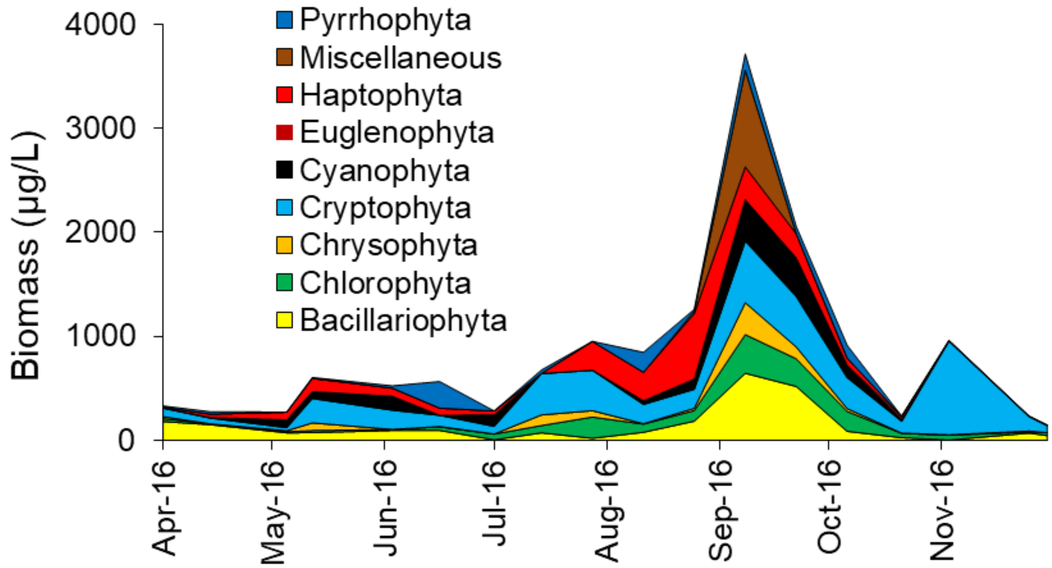


Figure 6-2. Temporal trend of average annual phytoplankton biomass (April – October) in Onondaga Lake during 2016.

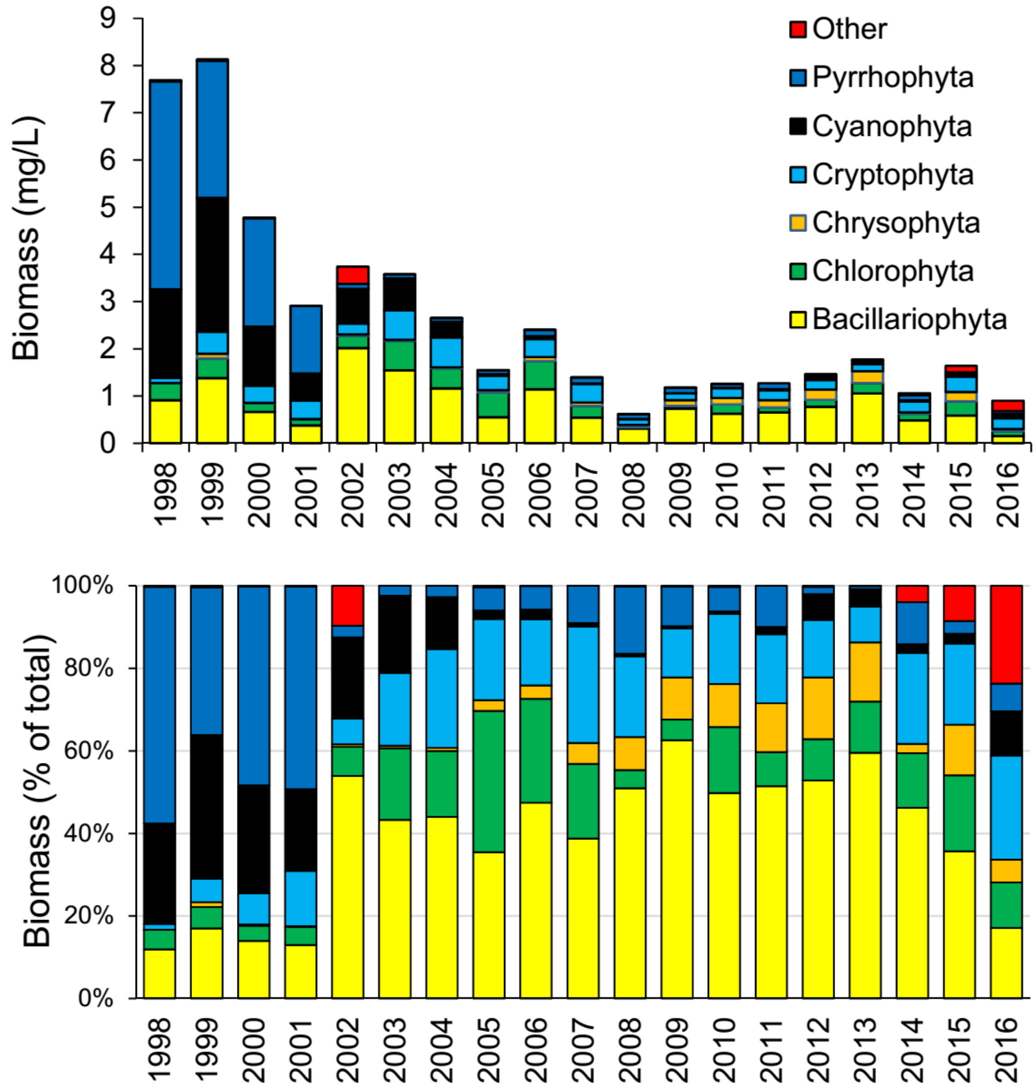


Figure 6-3. Temporal trend of average biomass (April-October) of phytoplankton divisions in Onondaga Lake from 1998-2016. Haptophytes and miscellaneous taxa are grouped as Other for this figure.

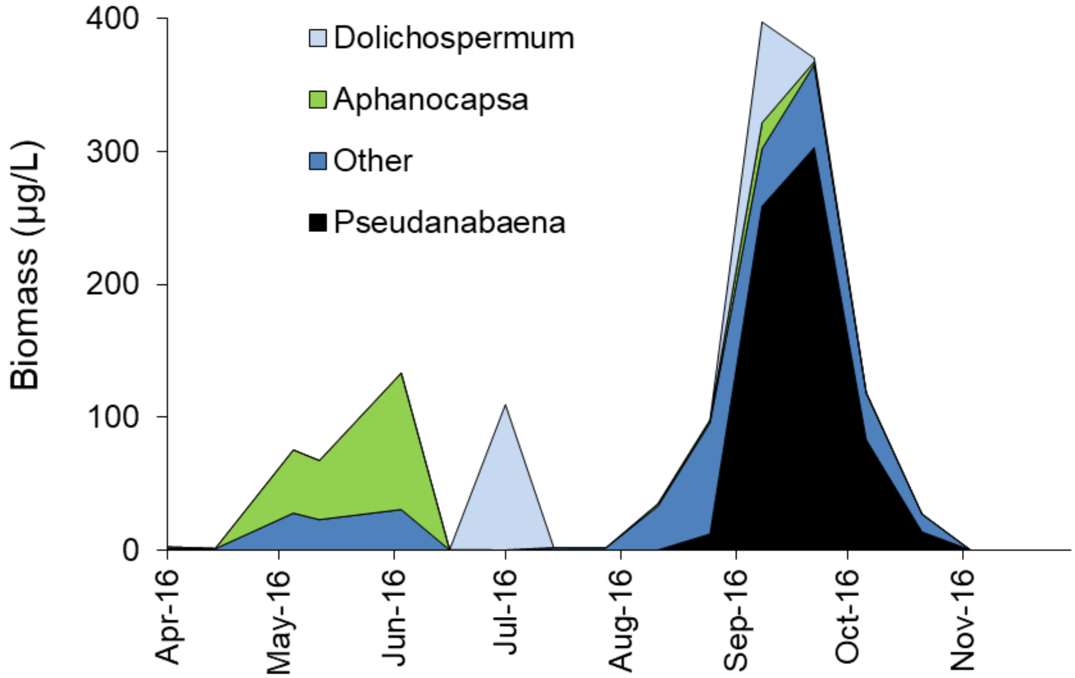


Figure 6-4. Temporal trend of biomass of cyanobacteria genera in Onondaga Lake (South station) in 2016.

Note: Cyanobacterial biomass was low throughout the year. The Other group includes the genera Anabaena, Aphanizomenon, Aphanotheca, Chroococcus, Cuspidothrix, Cylindrospermopsis, Dactylococcopsis, Glaucospira, Jaaginema, Merismopedia, Microcystis, Planktolyngbya, Planktothrix, Synechococcus, Synechocystis, and Woronichinia. Note that most, but not all, Anabaena species have been reclassified in the genus Dolichospermum.

have almost disappeared from the lake. Bluegreen algae are now rare in Onondaga Lake compared to nearby Oneida Lake, which has similar phosphorus concentrations as Onondaga Lake (Idrisi et al. 2016). A detailed report on Onondaga Lake phytoplankton results can be found in Appendix F-1.

6.2.2 Macrophytes

Macrophytes play a critical role in lake ecosystems by providing food for waterfowl and other wildlife, providing cover and foraging substrate for juvenile and adult fish, creating spawning habitats, providing refuges for zooplankton, and oxygenating the water. They help stabilize bottom sediments and prevent their resuspension in response to waves. Macrophytes can also play a crucial role in nutrient transport from the sediments because most macrophyte species acquire nutrients via root uptake from the sediment pore water rather than from the overlying water (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, OCDWEP acquired aerial photographs of the littoral zone annually (2000–2013), when water clarity conditions allowed.

The area of the littoral zone covered with macrophytes more than doubled from 2006-2013, after the reduced phosphorus load from Metro led to the decline in phytoplankton biomass and increased depth of light penetration through the water column. Macrophyte coverage in 2013 was at desirable levels for supporting spawning and nursery habitat for the warmwater fish community. Because of dredging and capping operations macrophyte surveys were not conducted in 2014 through 2016. A final aerial survey is scheduled to occur in 2018 to complete the ACJ required monitoring.

6.3 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.

Zooplankton data from 2015 and 2016 should be interpreted with caution. Typically, samples are collected from April into October, but an error in mesh size of the sample cup made samples collected in 2015 and through May 2016 unusable. Because spring peaks in zooplankton were not sampled, the densities from 2016 are likely biased low. Even so, the data suggest an increase in zooplankton biomass dominated by small zooplankton such as bosminids and cyclopoids (Figure 6-5). There were also some *Daphnia mendotae* present in the summer. The species and size composition were similar to 2003-2007 and 2010-2015 and quite different from what was observed in 2008 and 2009 when the Alewife population was low. In the available long-term data, zooplankton biomass has been low since 2010, and there has been an overall long-term decline (Figure 6-5). Variability among years reflects changes in the abundance of planktivorous Alewife. The temporal changes in the zooplankton community are linked to changes in predation by Alewife, the dominant fish planktivore in the lake (Wang et al. 2010).

Cercopagis pengoi was measured at similar densities in 2016 as in recent years. This exotic predatory zooplankton species is more likely to negatively affect small-bodied zooplankton like Bosmina than large-bodied forms like Daphnia (Warner et al. 2006) (Figure 6-6).

Populations of Daphnia can exert strong influence on the phytoplankton (Sommer et al. 2012). High water clarity and low phytoplankton biomass were observed in 2008 and 2009 and associated with the combination of high grazing pressure from large zooplankton, decreased phosphorus loading, and possibly increased grazing by dreissenids (Figure 6-7). Algal biomass was relatively low in 2016, which is not consistent with the low Daphnia abundance in 2016 (Figure 6-7). This may be due to the low spring diatom abundance in 2016. Reasons for this atypically low spring biomass of diatoms are unknown. The chlorophyll data from May 17 showed more of an increase than the biomass data. However, the silica data show only a limited decline in the late spring, and values are over 1.3 mg/L during the whole year. This is consistent with the low diatom abundance in the phytoplankton counts, as high diatom abundance will deplete silica from the water column.

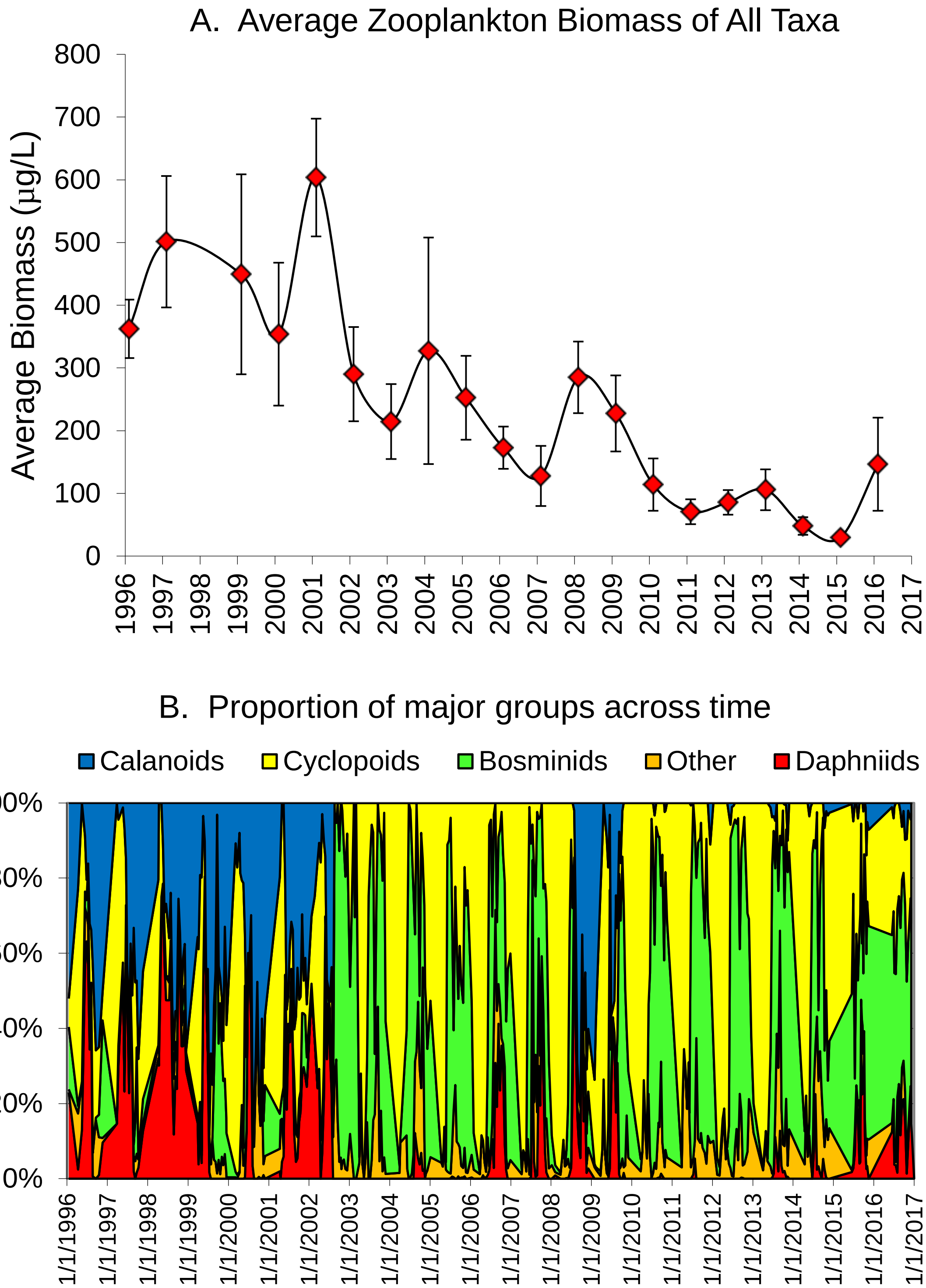


Figure 6-5. Average biomass of zooplankton (all taxa combined) and the proportion of major taxa in Onondaga Lake from April through October in 1996-2016 (June through October, 2016).

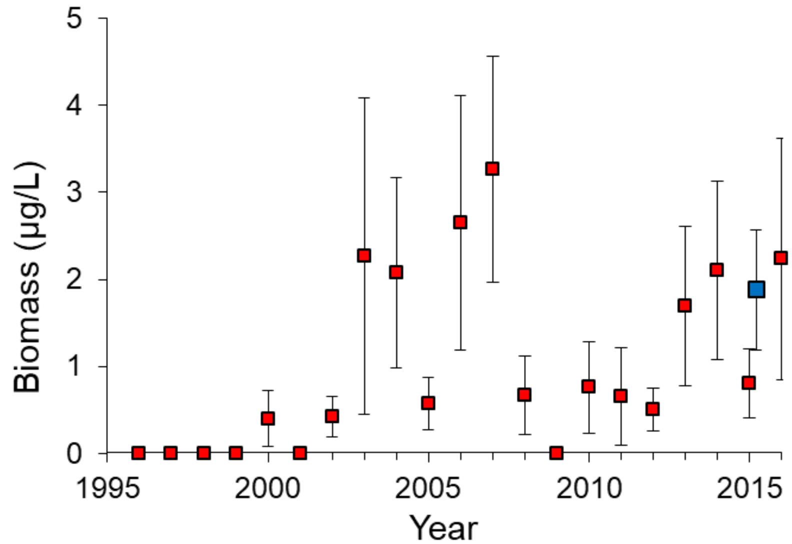


Figure 6-6. Time series of *Cercopagis pengoi* in Onondaga Lake, 1996 to 2016. Data represent the average biomass from standard samples collected at South Deep station from April through October.

Note: Bars represent one SE. For 2015, both the average for April – October standard samples using the 500-µm mesh cup (blue square) and the average for June-October samples using a 64-µm net (red square) are shown. The first individual caught in Onondaga Lake was on November 3, 1999.

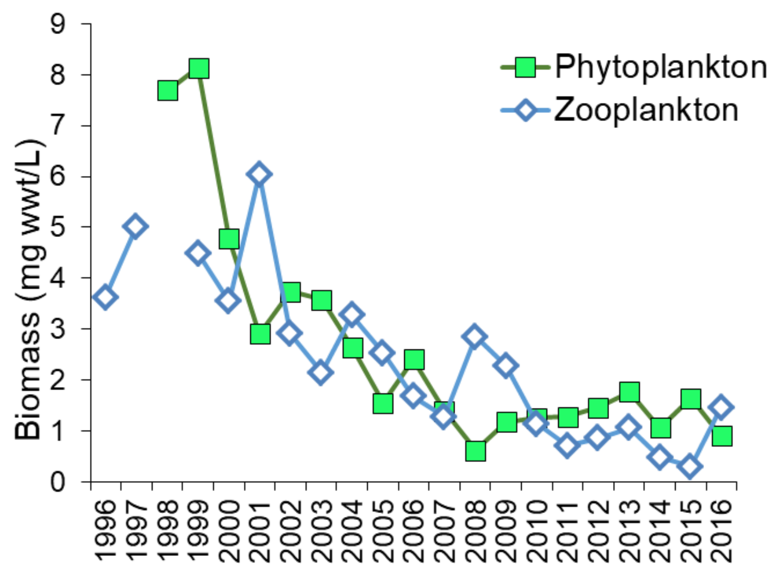


Figure 6-7. Time trend of zooplankton and phytoplankton wet biomass in Onondaga Lake 1996 to 2016 (April-October; June-October for 2015 and 2016 zooplankton).

Dreissenid Mussel Sample from Onondaga Lake, 2014.

6.4 Dreissenid Mussels

Since 2005, the dreissenid mussel population in Onondaga Lake has been surveyed annually as part of the AMP. Dreissenid mussels, both zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena rostriformis bugensis*), are invasive ecosystem engineers that can have large effects on the ecosystem through filtering and alteration of the benthic habitat (reviews in Karatayev et al. 1997, 2002, Higgins and VanderZanden 2010, Mayer et al. 2014). Both species arrived to North America and Lake Erie in the mid-1980s (Carlton 2008, Mills et al. 1993, 1996). Zebra mussels then spread rapidly and by 1993 were common across the Great Lakes and in many inland lakes. Its congener, the quagga mussel, spread more slowly (Karatayev et al. 2011, Benson 2014). After arrival, quagga mussels have displaced zebra mussels in many waterbodies, especially in deeper lakes where quagga mussels are found both in shallow and deep, cold water (Mills et al. 1996, Nalepa et al. 2010, Watkins et al. 2007, 2012). A similar range expansion of quagga mussels and displacement of zebra mussels has occurred in Europe (Orlova 2014, Matthews et al. 2014). The displacement of zebra mussels by quagga mussels may increase the ecosystem effects of dreissenid mussels (Karatayev et al. 2014a, Rudstam et al. 2016a).

In Onondaga Lake, dreissenids are largely limited to water depth shallower than 7.5 m. This is most likely due to low oxygen levels in deeper water during the summer stratified period. In 2016, oxygen levels at the 9-m depth were below 1.0 mg/L from the third week of July to the third week of September, which is not unusual for Onondaga Lake. Low oxygen levels are known to restrict mussel distributions elsewhere (Karatayev et al. 2017).

Dreissenid density and biomass were low in 2016 compared with previous years (Figure 6-8). This was especially true for quagga mussels for which the 2016 values were the lowest on record since the species became abundant in the lake in 2008. This decline occurred at all depths, but was more dramatic in shallower depths, where the population of quagga mussels declined an order of magnitude. Although invasive species population often decreases after an initial biomass peak (Karatayev et al. 2014a), the decline in Onondaga Lake is unusually large. Even so, densities and biomass of mussels in Onondaga Lake (0–6 m depth) are comparable to observations elsewhere in North America (1,000 to 100,000/m^2) but higher than typically found in Europe (100–1,000/m^2, Ramcharan et al. 1992, Naddafi et al. 2010). Mussel density was positively related to surface area and calcium content and negatively related to total phosphorus content in a comparative study of 55 European and 13 North American lakes (Naddafi et al. 2010). Given the size, calcium content, and phosphorus concentrations in Onondaga Lake, densities of 1,000 to 10,000 individuals/m2 would be expected, and the densities observed from 2005 to 2016 were in this range.

Quagga mussels are displacing zebra mussels in many lakes, and this was also observed in Onondaga Lake up until 2015. Although the initial increase in dreissenid mussels in Onondaga Lake was due to zebra mussels, quagga mussels started to increase in 2007 and was the dominant species by biomass in the lake from 2009 through 2012, particularly in depths greater than 4.5 m. The most commonly proposed hypothesis for this replacement is that quagga mussels grow faster at lower food concentrations (Karatayev et al. 2014b, Garton et al. 2014). However, Naddafi and Rudstam (2014) found lower growth rates of zebra mussels only when the animals were reared with predator cues and not when reared without predators. With predator cues present, zebra mussels invested more energy in shell growth and byssal thread production and reduced their filtering rates, resulting in lower overall growth rates (Naddafi and Rudstam 2013, 2014). These morphological and behavioral responses to predators result in lower vulnerability to predation and higher attachment strength of zebra mussels compared to quagga mussels. Higher attachment strength should allow zebra mussels to be better adapted to persist in high predation environments as well as in high wave-energy environments in shallow waters of large lakes. Elsewhere, the two species coexist in larger shallow lakes and in some rivers (Dnieper River – Zhulidov et al. (2010), Mississippi River – Grigorovich et al. (2008), the western basin of Lake Erie – Karatayev et al. (2014c) and Oneida Lake – Karatayev et al. (2014a)).

If the higher anti-predation investments and associated reduced growth rates of zebra mussels compared to quagga mussels explain the increased dominance of quagga mussels in Onondaga Lake observed after 2007, the competitive advantage of quagga mussels should decrease with the invasion of a dreissenid-specialist predator, the Round Goby. The presence of Round Goby should give zebra mussels, the species with the stronger anti-predation behavior, an advantage. Round Goby were first reported in Onondaga Lake in 2010 and have subsequently increased in abundance (UFI et al. 2014). The density of both mussel species declined significantly from 2011 to 2016, but the decline was greater for quagga mussels. Both the observed timing of the decline and the larger decline for quagga mussels are consistent with a predation effect from Round Goby. Declines in dreissenids have been observed after Round Goby invasions elsewhere (Lederer et al. 2008, Barton et al. 2005, Wilson et al. 2006), and fish predation is considered an important determinant of dreissenid abundance in both Europe (Stanczykowska 1977, Naddafi et al. 2010) and North America (Thorp et al. 1998, Magoulick and Lewis 2002, Watzin et al. 2008, Ruetz e al. 2012). However, others suggest that Round Goby will only have minor effects on the abundance or size structure of mussels (Kipp et al. 2012, Foley et al. 2017). In Onondaga Lake, Round Goby appear to be decreasing the abundance of dreissenid mussels overall and decreasing the proportion of quagga mussels.

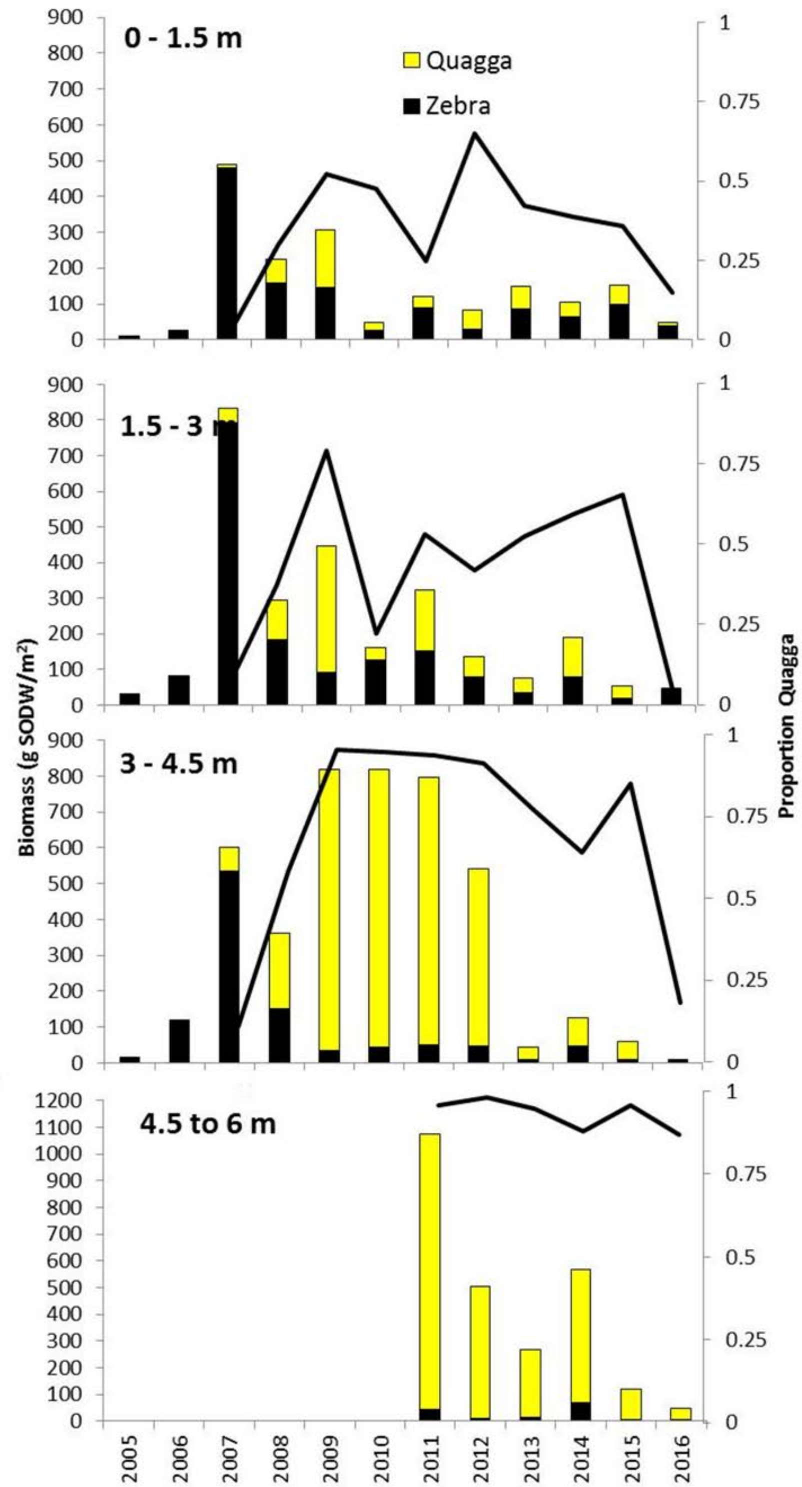


Figure 6-8. Biomass (shell-on dry weight) of zebra and quagga mussels in depth zones of Onondaga Lake, 2002-2016. The black lines represent the proportion of quagga mussel in each depth zone.

6.5 Fish

6.5.1 Introduction

The improvements in water quality and habitat conditions have altered the fish community of Onondaga Lake. The significant reduction in ammonia-N and phosphorus loading from Metro brought about a shift from eutrophic to mesotrophic conditions, which improved the fish habitat in both the littoral and pelagic zones. Since 2000, the AMP included an extensive fisheries monitoring program using multiple types of sampling gear to assess nesting, larval, juvenile, and adult stages of several species of the fish community. Over 177,000 individual fish representing fifty-three species have been captured or observed in Onondaga Lake through the Onondaga County's sampling efforts (Table 6-1). Species richness and catch per unit effort (CPUE) are metrics commonly used by fisheries biologists to describe the fish community. Species richness is the number of different species represented in an ecological community and CPUE is the number of a given species captured with a standard measure of sampling effort (e.g., a seine sweep or an hour of electrofishing). CPUE is not a measure of abundance, but trends in CPUE may reflect trends in abundance.

The many biotic and abiotic environmental factors affecting the fish community in Onondaga Lake present challenges for analyzing and interpreting the available fisheries data. The following sections provide an overview of the lake's fish community in 2016, 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 Honeywell from 2008 to 2016. Additionally, an analysis of growth and survival of Largemouth Bass (Micropterus salmoides) conducted by Onondaga County in 2016 is summarized in Appendix F-3.

Largemouth Bass Collected from Onondaga Lake, 2016.

Table 6-1. Fish species identified in Onondaga Lake, 2000–2016 (total catch, all gear types, and all life stages).

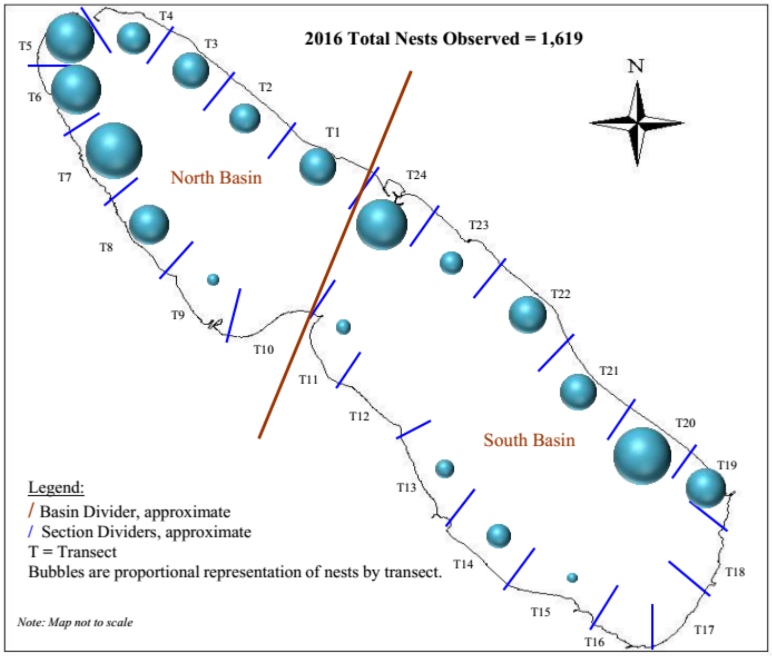
Abundant Species (>1000 individuals)		Common Species (50-1000 individuals)		Uncommon Species (<50 individuals)	
Alewife	Golden Shiner	Bluntnose Minnov	Northern Pike	Black Bullhead	Northern Hog Sucker
Banded Killifish	Largemouth Bass	Bowfin	Rock Bass	Black Crappie	Quillback
Bluegill	Pumpkinseed	Channel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

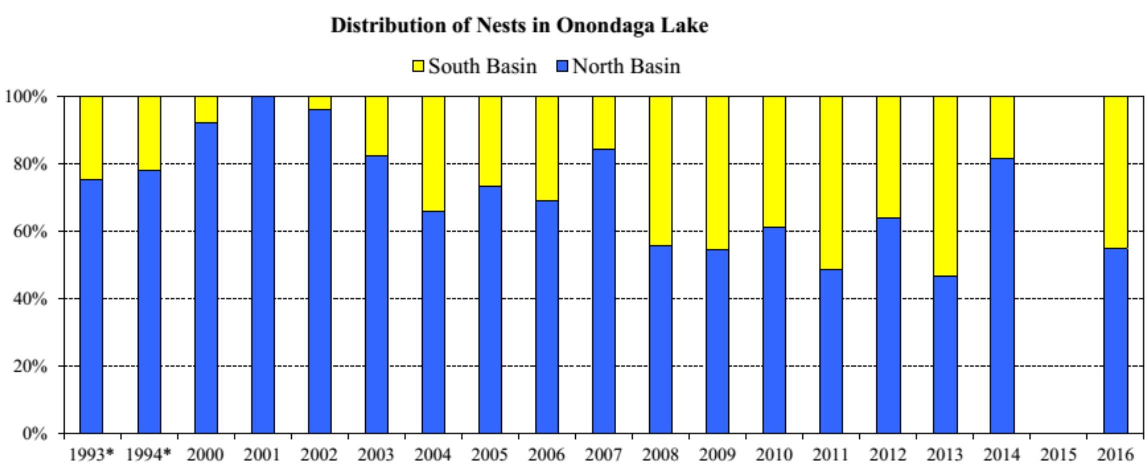
6.5.2 Early Life Stages

The AMP employs several methods to assess fish reproduction and recruitment (i.e., juvenile survival to the adult life stage). 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. Both abiotic and biotic factors can affect the reproductive success of many species. In theory, comparing the relative abundances of different age classes of young fish can elucidate the net effects of reproductive success and environmental factors. This analysis is complicated due to differences in gear and sampling efficiencies. In addition, environmental factors affect the AMP team's ability to evaluate the various life stages.

6.5.2.1 Nesting

Centrarchid species [Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieu*), Pumpkinseed (*Lepomis gibbosus*), Bluegill (*Lepomis macrochirus*), and Rock Bass (*Ambloplites rupestris*)] and Brown Bullhead (Ameiurus nebulosus) 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. Since 2000, most fish nests in Onondaga Lake have been documented in the north basin (average 70%, range 46% to 100%), presumably because of better habitat conditions there. This is consistent with the spatial pattern documented by Arrigo (1998) in the early 1990s when approximately 75% of nests documented in that study were found in the north basin. More recently (2008–2013) nests have been more evenly distributed between the north and south basins. The increased nesting activity observed in the southern basin of the lake was likely 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. However, 81% of the 1,619 nests observed in 2014 were in the north basin (Figure 6-9). The lack of nesting in the south basin in 2014 was likely due to Honeywell's dredging and capping activities in that area of the lake. In 2016, the distribution returned toward a more uniform distribution, with 55% in the north and 45% in the south (Figure 6-8). Sunfish (Pumpkinseed, Bluegill, Rock Bass) accounted for 40% of the total nests identified (Table 6-2). A few Largemouth Bass and Brown Bullhead nests were also observed. Almost 60% of nests counted in 2016 were not attributed to a species (i.e., without an adult fish present).





	1993*	1994*	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015*	2016
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%	81.3%	NA	54.9%
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%	18.7%	NA	45.1%
Nest count by basin																			
North Basin	958	1291	3301	1887	2042	1430	1409	739	848	1759	3941	1085	1250	1159	1537	1620	1316	NA	671
South Basin	319	364	287	0	85	307	737	273	383	332	3170	910	800	1231	879	1872	303	NA	548
Total	1277	1655	3588	1887	2127	1737	2146	1012	1231	2091	7111	1995	2050	2390	2416	3492	1619	NA	1219

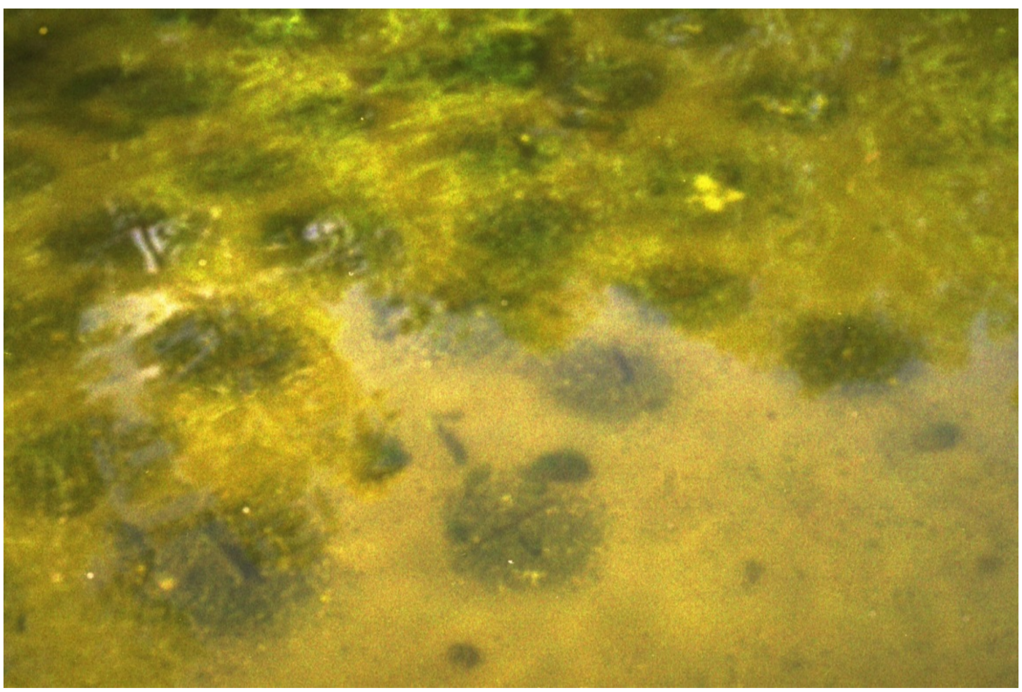
**Historic nest distribution. 1993 and 1994 data from Arrigo 1998.*
**Nesting Survey not completed in 2015 due to extended periods of low water clarity.*

Figure 6-9. Fish nesting survey map (a) and comparison of north vs. south 1993–2016 (b).

Table 6-2. Fish species nesting in Onondaga Lake, 2016.

Species	Total Number of Nests	Percent of Total
Bullhead (species unknown)	7	.6%
Bluegill	88	7.2%
Rock Bass	3	0.3%
Pumpkinseed	259	21.3%
Lepomis spp.	132	10.8%
Largemouth Bass	8	.7%
Unknown	722	59.2%

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

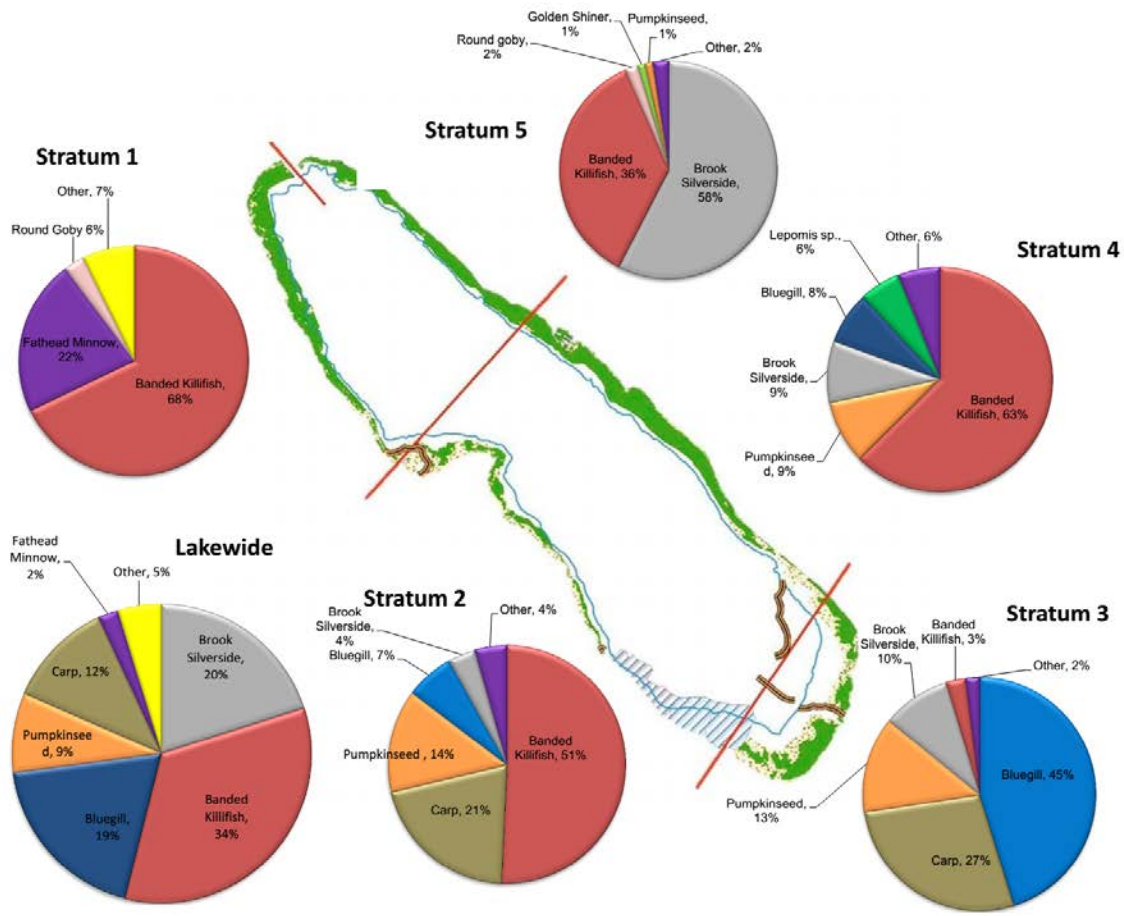


Nesting Colony of *Lepomis* spp. (Bluegill and Pumpkinseed) observed in Onondaga Lake.

6.5.2.2 Larval, young-of-year, juvenile assessment

Larval seines are used to enumerate and identify this early life stage. In 2016, 2,177 larval fish representing 14 species were collected. Banded Killifish (*Fundulus diaphanus*) was the most common larval fish collected and comprised 34% of the lakewide catch, followed by Brook Silverside (Labidesthes sicculus) at 20%. (Figure 6-10). The proportion of Brook Silverside decreased from 2015 to 2016 (57% to 20%). Carp (*Cyprinus carpio*) were not collected in 2015; however, in 2016 they comprised 12% of the catch. CPUE in 2016 was 48.4 fish captured per seine, the lowest value reported since 2013.

OCDWEP Technicians Conducting Larval Seining, 2016.



Year	2000	2002	2003	2012	2013	2014	2015	2016
Overall CPUE	38.64	47.33	47.7	35.7	66.1	60.9	67.9	48.4
Richness	20	12	9	9	12	10	14	14

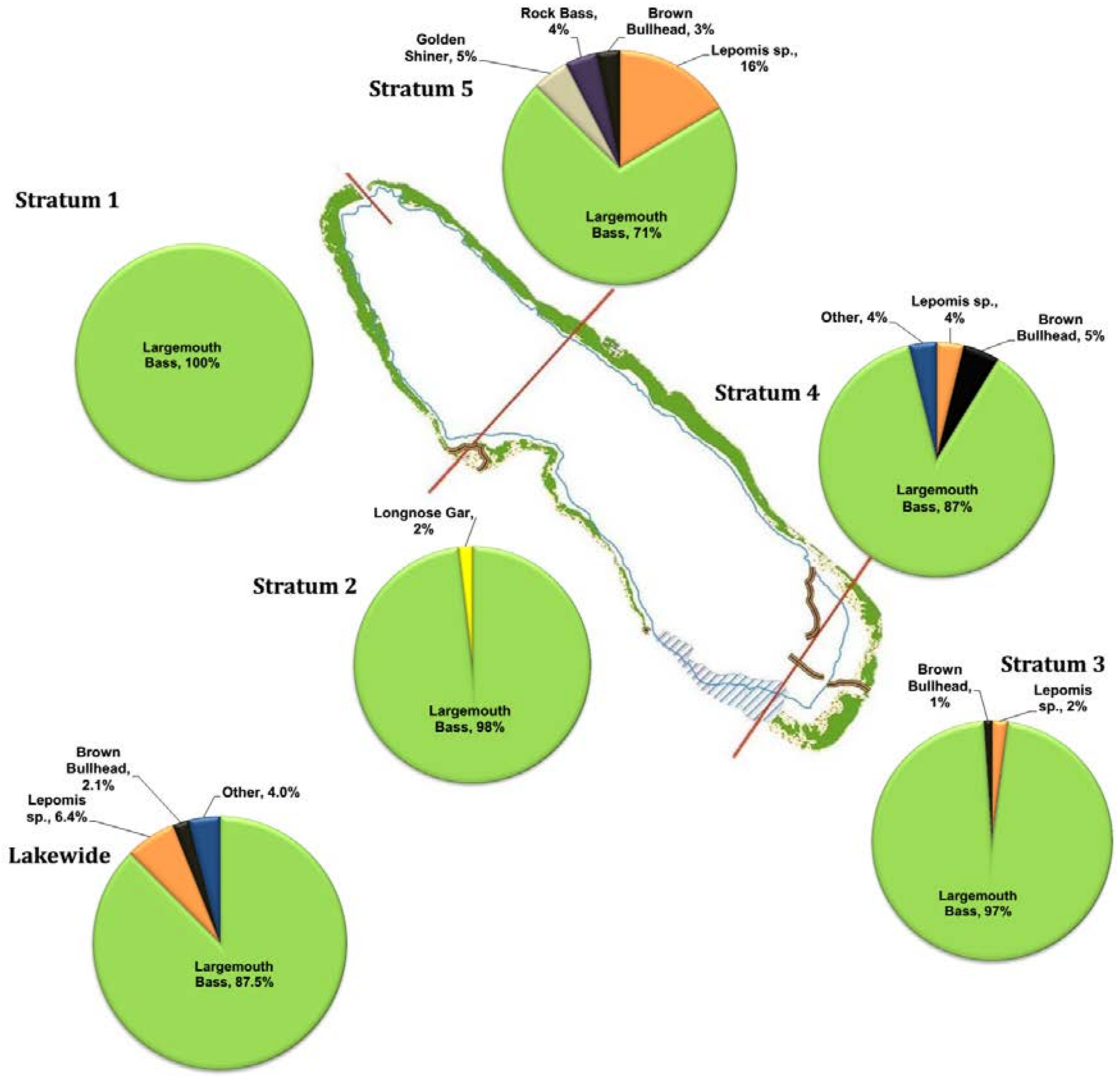
Figure 6-10. Relative abundance and catch per unit effort (number of fish per seine sweep) of larval fish in 2016 by stratum and species (fish collection by larval seining).

Note: Brown lines at the south end of the lake and near Ninemile Creek identify the location of silt curtains associated with dredging and capping activities. The blue hashing represents the area impacted by dredging in 2012 -2016. The area of each pie is not proportional to its total count.

Later in the summer, another round of littoral zone seining was conducted to enumerate and identify older fishes. These events were conducted twice during the summer and early fall of 2016 to assess abundance and diversity of young-of-year (YOY) and juvenile (age 1+ or greater, not yet mature) fishes. In 2016, 481 YOY fish were captured representing seven species: Bluegill, Pumpkinseed, Rock Bass, Largemouth Bass, Brown Bullhead, Longnose Gar (*Lepisosteus osseus*), and Golden Shiner (*Notemigonus crysoleucas*). Largemouth Bass constituted the largest proportion (87.5%) of the total catch followed by Bluegill and Pumkinseed (*Lepomis spp.*), which comprised 6.4% of the total catch (Figure 6-11).

A total of 83 juvenile fish were collected during the seining event representing eight species. Largemouth Bass and Brown Bullhead were the most common species collected, comprising 49% and 13% of the total catch. Rock Bass, Bluegill, Pumpkinseed, Golden Shiner, Carp, and Green Sunfish (*Lepomis cyanellus*), were also captured. (Figure 6-12). The percent contribution of Largemouth Bass in the total juvenile catch between 2015 and 2016 was unchanged at 49%. The incidental capture of juvenile species such as Walleye (*Sander vitreus*), Longnose Gar, Northern Pike (*Esox lucius*) and Freshwater Drum (*Aplodinotus grunniens*) in previous years did not occur in 2016. These species likely migrate into the lake through the Seneca River and when present in early life stages are likely represented by a few individuals that are only sporadically captured.

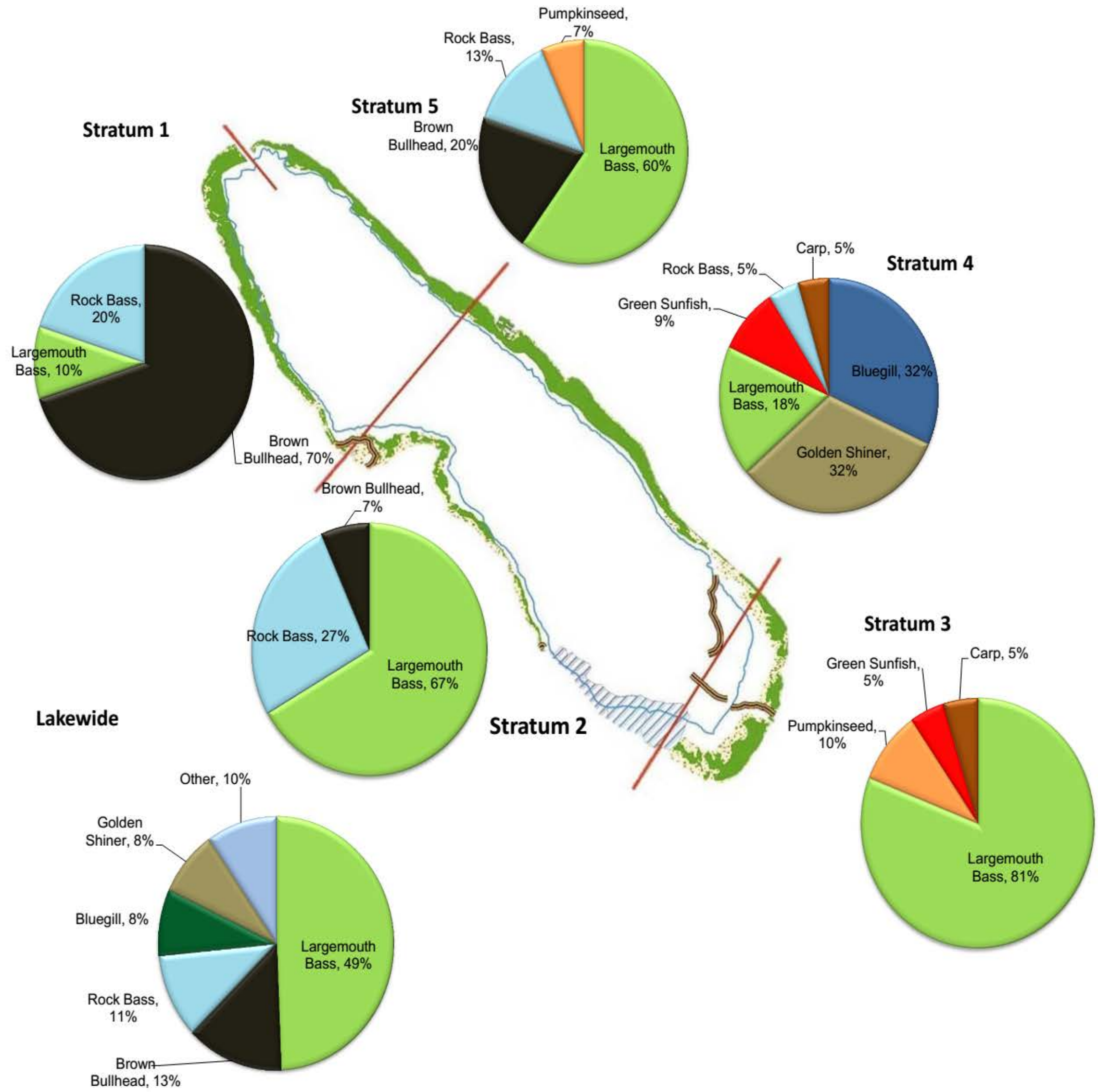
OCDWEP Technicians Demonstrating Juvenile Seining
(Honeywell Summer Science Week, 2016).



Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
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	12.3	11.0	12.3
Richness	14	13	14	9	9	12	5	8	13	10	9	9	7	10	7	8	7

Figure 6-11. Relative abundance and catch per unit effort (number of fish per seine sweep) of young-of-year fish in 2016 by stratum and species.

Note: Brown lines at the south end of the lake and near Ninemile Creek identify the location of silt curtains associated with dredging and capping activities. The blue hashing represents the area impacted by dredging in 2012 -2016. The area of each pie is not proportional to its total count.



Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Overall CPUE (#/seine sweep)	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	2.60	1.90	2.76
Richness	18	20	16	14	11	14	13	11	14	15	14	16	15	8	10	8	8

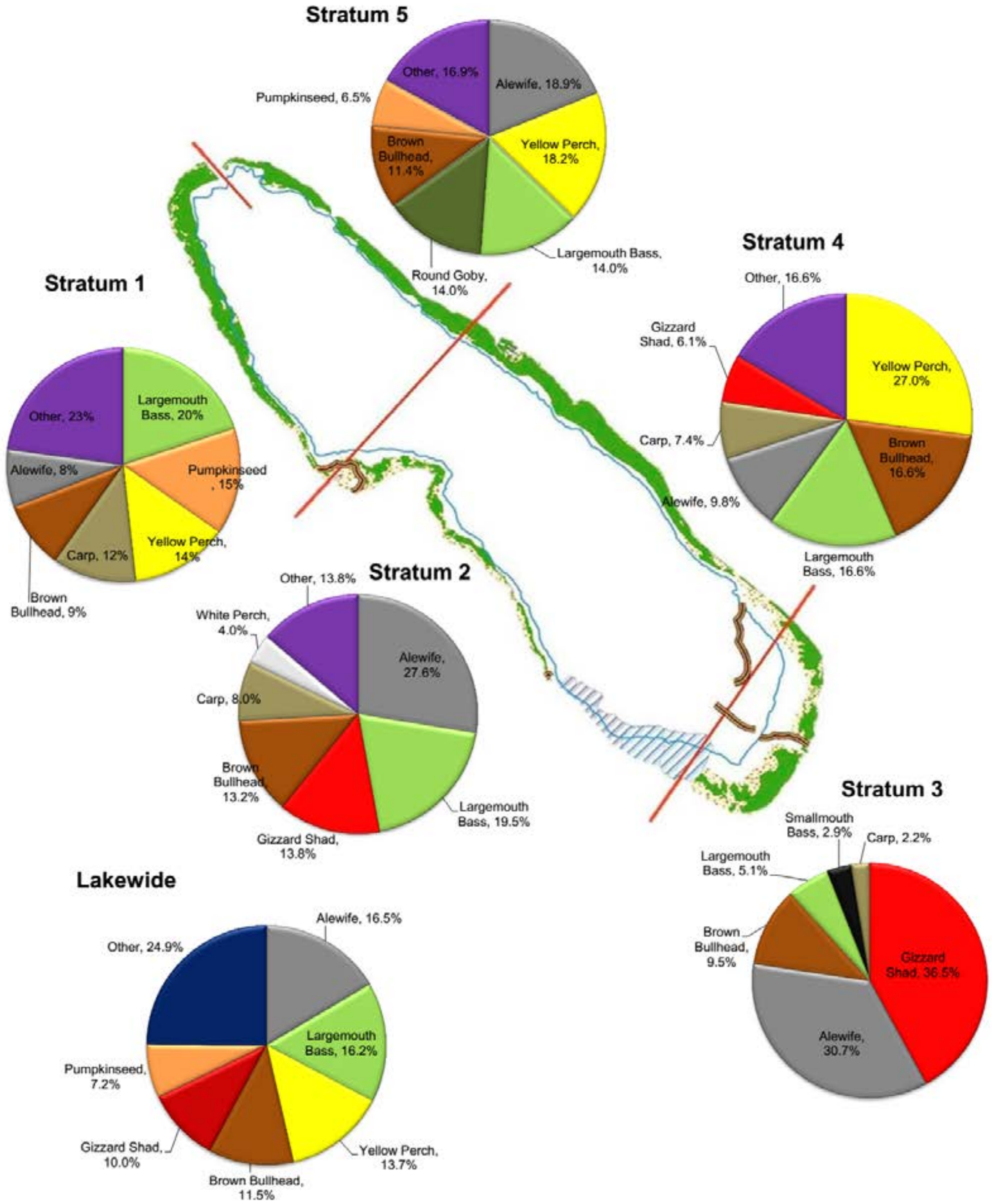
Figure 6-12. Relative abundance and catch per unit effort of juvenile fish in 2016 by stratum and species. Life stage indicated as juvenile during seining (young-of-year and adult excluded).

Note: Brown lines at the south end of the lake and near Ninemile Creek identify the location of silt curtains associated with dredging and capping activities. The blue hashing represents the area impacted by dredging in 2012 -2016. The area of each pie is not proportional to its total count.

6.5.3 The Adult Fish Community

Adult fish 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 2016, 1,187 fish representing 25 species were collected during the fall boat electrofishing event. Alewife comprised 16.5% of the total catch, followed by Largemouth Bass (16.2%), Yellow Perch (*Perca flavescens*; 13.7%), Brown Bullhead (11.5%), Gizzard Shad (10%), and Pumpkinseed (10%). Together, these six species comprise 78% of the adult fish community (Figure 6-13). Overall the adult fish community remained stable between 2015 and 2016.

Alewife sampling gill net set June 2016.

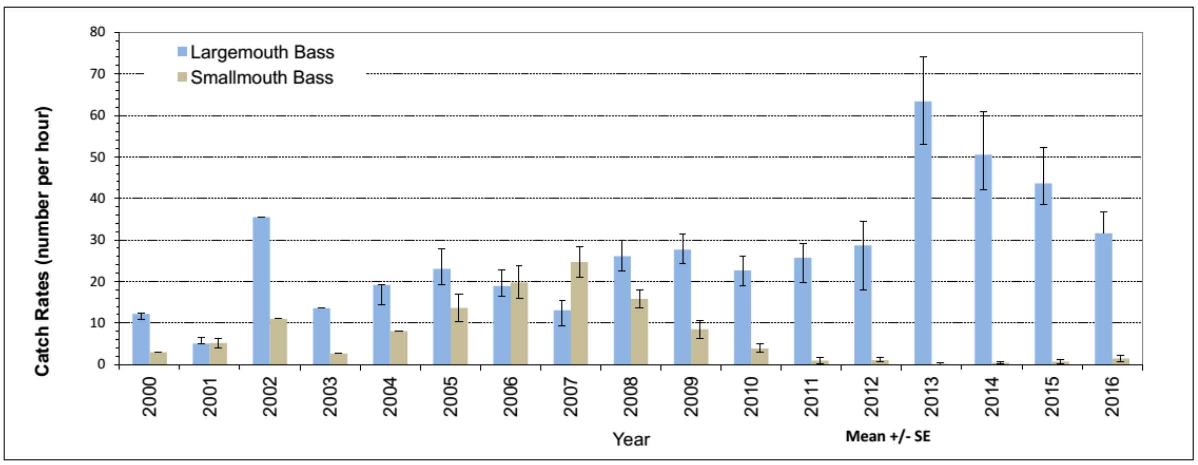


Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Overall CPUE	254.2	196.47	634.23	519.93	2098.24	1158.47	371.19	471.3	802.03	814.06	1297.65	2344.99	1668.34	1019.43	1016.5	470.87	1374.1
Richness	23	21	25	21	26	25	25	21	24	28	28	25	28	23	26	24	25

Figure 6-13. Relative abundance and catch per unit effort (fish collected per hour of electrofishing) of littoral adult fish in 2016 by species and stratum.

Note: Brown lines at the south end of the lake and near Ninemile Creek identify the location of silt curtains associated with dredging and capping activities. The blue hashing represents the area impacted by dredging in 2012 -2016. The area of each pie is not proportional to its total count.

Largemouth and Smallmouth Bass are two of the principal warm water predators in Onondaga Lake. However, since 2002 Largemouth Bass have been the more prevalent of the two species (Figure 6-14). The declining catch rates observed for the Smallmouth Bass are likely indicative of the changing conditions in the littoral zone; increased macrophyte coverage is more suitable habitat for Largemouth Bass (Stuber et al. 1982, Edwards et al. 1983). Smallmouth Bass prefer clear-water lakes and cool streams with moderate current, and rock and gravel substrate (Robbins and MacCrimmon 1974). Increases in the relative abundance of Largemouth Bass over Smallmouth Bass also occurred in Oneida Lake and Canadarago Lake, two other New York lakes with increasing macrophyte coverage (Jackson et al. 2012, Brooking et al. 2012). Honeywell International is in the final stages of a lake bottom restoration project. In 2016 a habitat layer of gravel/cobble was placed over approximately 234 hectares of the littoral zone in the south basin, additionally in 2017 habitat improvements including cribs and rock piles will be placed in the southern end of the lake, likely enhancing Smallmouth Bass habitat.



Mean CPUE, entire year

Sample Period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Largemouth Bass	12.2	5.1	35.5	13.6	19.2	23.1	19.0	13.1	26.1	27.7	22.7	25.7	28.7	63.4	50.6	43.6	31.7
Smallmouth Bass	3.0	5.2	11.0	2.7	8.1	13.6	19.8	24.7	15.8	8.5	3.9	0.9	1.1	0.2	0.5	0.1	1.5

Figure 6-14. Annual average catch rates (number per hour) from fall electrofishing events of Largemouth and Smallmouth Bass combined in Onondaga Lake from 2000 to 2016.

Overall trends in catch rates have varied by species since 2000. Smallmouth Bass, White Perch (*Morone americana*), and Channel Catfish (*Ictalurus punctatus)* have had reduced catch rates over the past several years, while catch rates for other species such as White Sucker (*Catostomus commersoni*) and Walleye have fluctuated with no clear trend. However, catch rates of some species, including Largemouth Bass, Brown Bullhead, and Yellow Perch, have generally increased since 2000 (Figure 6-15). These patterns are thought to reflect responses to increased macrophyte coverage, improved water quality, increased dreissenid mussel abundance, and variation in climatic conditions. In addition, the large fluctuations in abundance of Alewife and Gizzard Shad can have a cascading effect across multiple trophic levels.

Freshwater Drum Collected from Onondaga Lake.

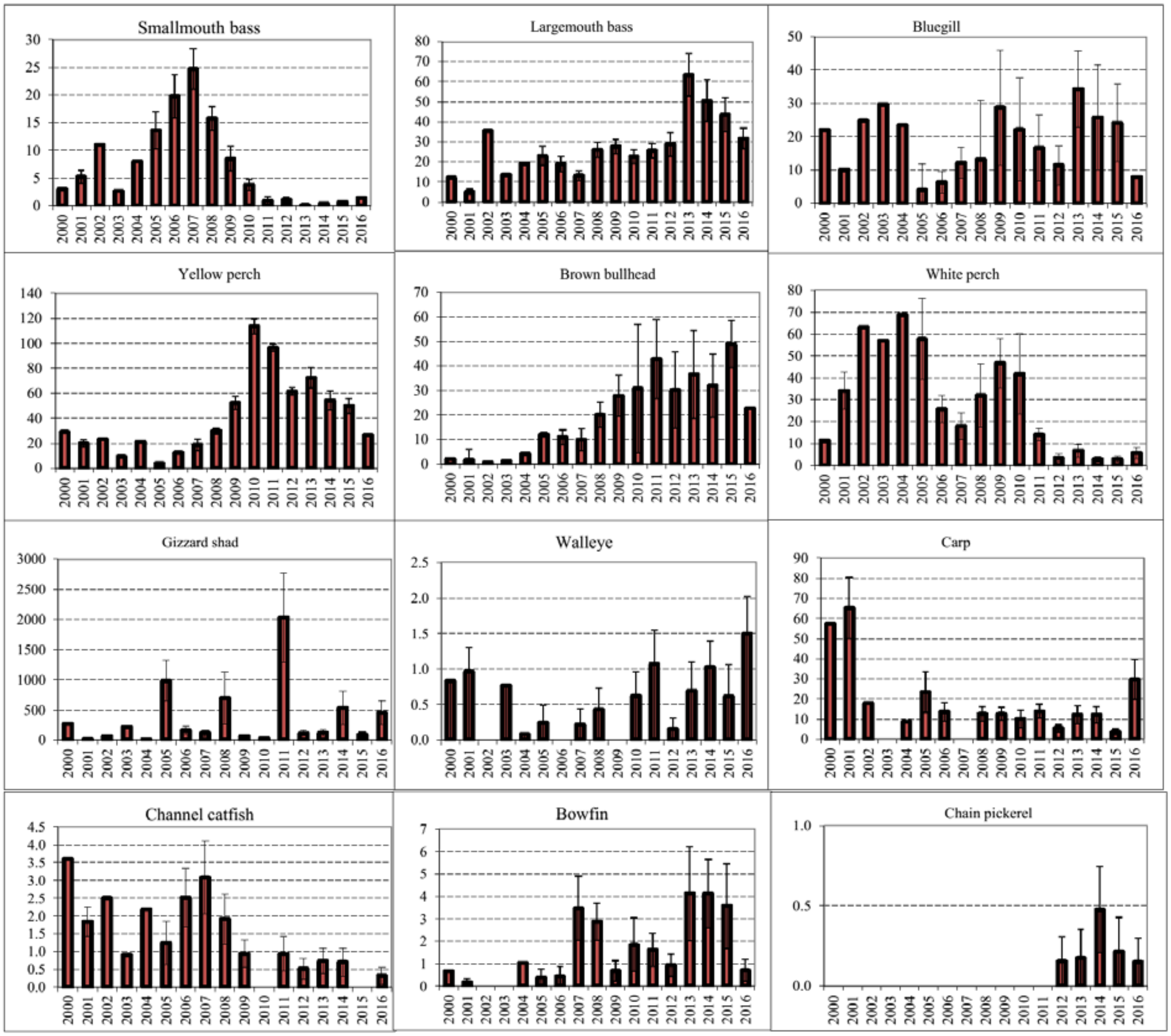


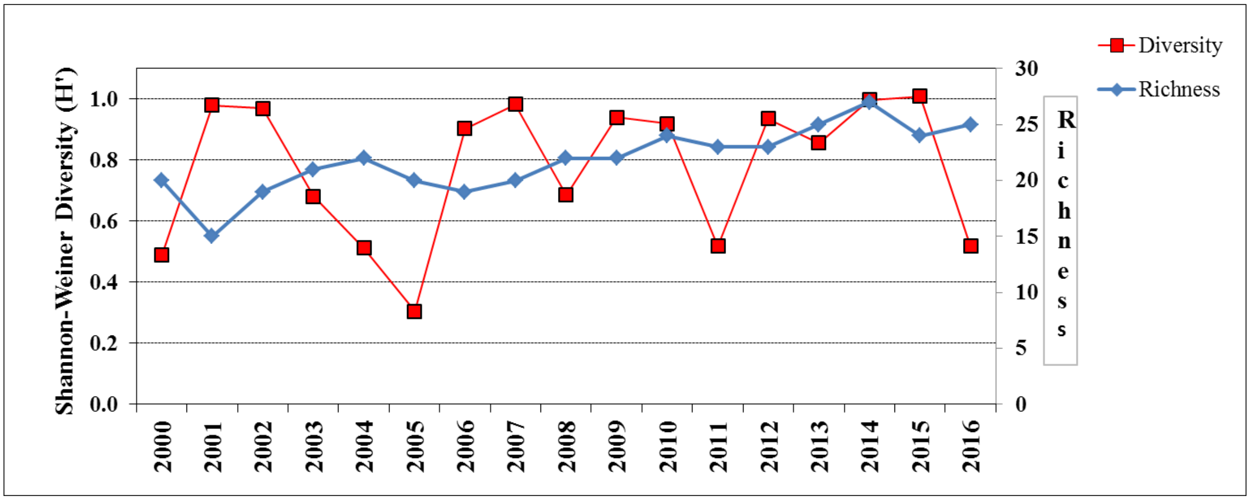
Figure 6-15. Trends in catch per unit effort (CPUE) of select fish species captured by electrofishing, 2000–2016. CPUE is based upon number of fish captured per hour.

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) is calculated from only 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 seen but not netted. Note: Y-axis differs for each species.

In Onondaga Lake, adult fish species richness (i.e., number of species) collected during electrofishing events has gradually increased since 2000. A total of 25 adult species were captured during the electrofishing survey in 2016. This is the third highest value since 2000 and comparable to the 26 species collected during 2013 and 2014 (Figure 6-16). Minor fluctuations in species richness over the past six years are due primarily to the incidental catches of uncommon species such as Black Bullhead (*Ameiurus melas)*, White Bass (*Morone chrysops*), Goldfish (*Carassius auratus*), and Quillback (*Carpiodes cyprinus*) and the introduction of invasive species such as Round Goby. 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 by tagged fish returns since 1987 (Gandino 1996, Siniscal 2009, Hurley 2013). Species tagged in Onondaga Lake, including Channel Catfish, Pumpkinseed, Bluegill, Largemouth and Smallmouth Bass, and Walleye, have been recaptured in the Seneca River system. Walleye have been recaptured as far away as Oneida Lake. Since the monitoring program started in 2000, 53 species have been identified in Onondaga Lake.

Changes in diversity of the Onondaga Lake fish community 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.

The adult electrofishing data were used to calculate Shannon-Weiner diversity (H'), an index that considers richness and relative abundance. This index has fluctuated over the 16-year AMP due primarily to shifts in abundance of clupeids. The highest diversity (H' = 1.01) was calculated from the 2015 data, and the lowest value (H' = 0.30) from the 2005 data (Figure 6-16). A detailed report on Alewife abundance in Onondaga Lake in 2016 can be found in Appendix F-4.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shannon Weiner Diversity (H')	0.49	0.98	0.97	0.68	0.51	0.30	0.90	0.98	0.69	0.94	0.92	0.52	0.94	0.86	1.00	1.01	0.52
Richness	20	15	19	21	22	20	19	20	22	22	24	23	23	26	26	24	25

Figure 6-16. Trends in adult fish Shannon-Weiner diversity (H') and richness, fish captured electrofishing, Onondaga Lake, 2000–2016.

Trap nets are a passive gear used to sample littoral zone fish and have been used by SUNY-ESF since 1987 on Onondaga Lake. Because fish are not equally vulnerable to different gear types, trap net catches and electrofishing catches cannot be directly compared. However, examining both data sets in combination allows for a more complete assessment of the overall fish community in Onondaga Lake.

Results of the SUNY-ESF trap net program from the 1990s indicated that the catch was dominated by Gizzard Shad and White Perch (Arrigo 1998; Gandino 1996; Tango 1999). By 2005, the Alewife had become firmly established and dominated trap-net catches (Siniscal 2009). As part of the Honeywell monitoring program that began in 2008, SUNY-ESF students conduct monthly trap net sampling from May through October at ten locations around the lake. Overall catches in trap nets varied from year to year (Table 6-3).

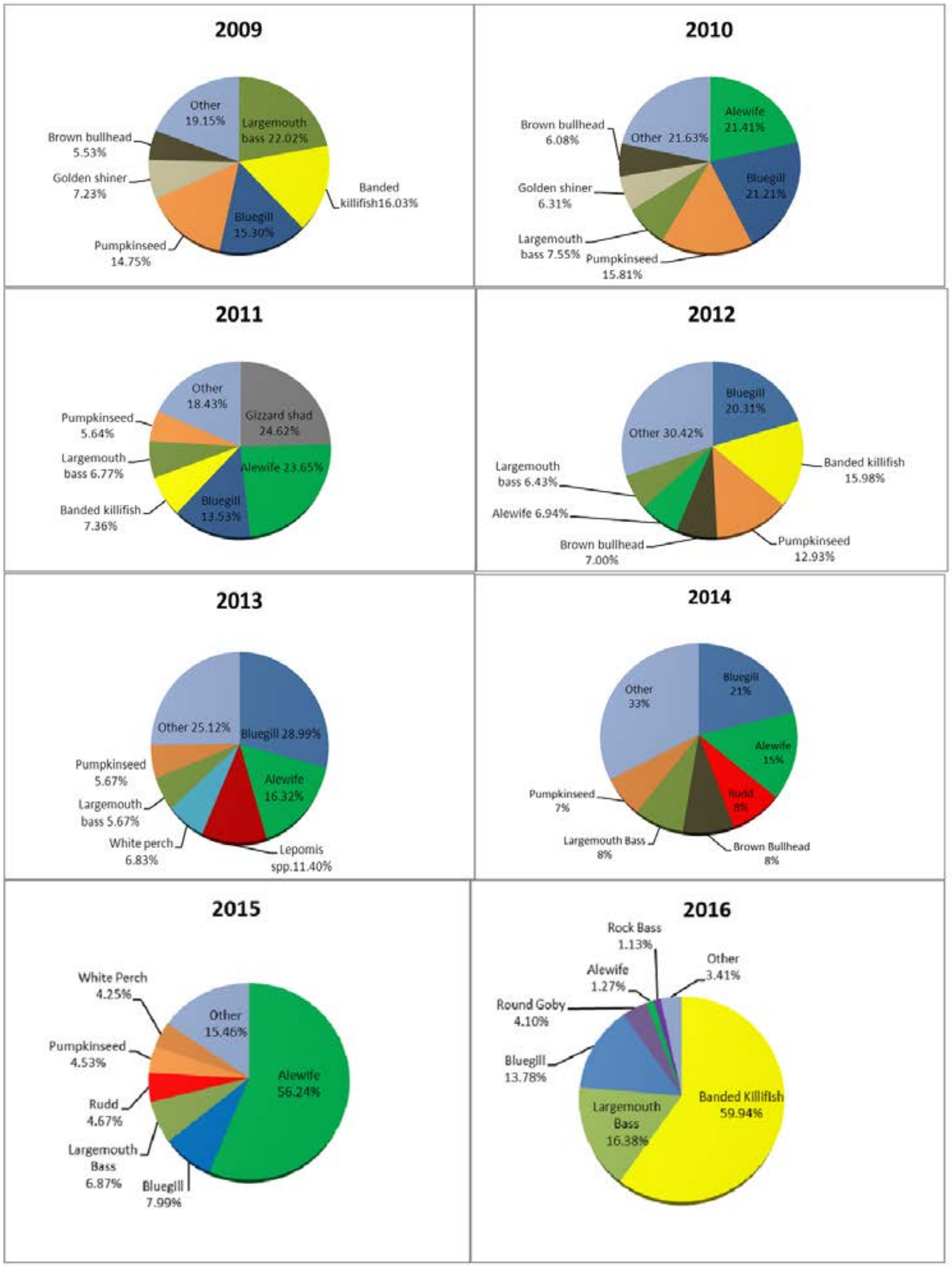
Lepomis (Pumpkinseed and Bluegill) were the most frequently collected species in trap net samples in all years with the exception of 2011, 2015 and 2016 when Alewife, Gizzard Shad, and Banded Killifish were the most frequent species collected (Figure 6-17). Additionally, species richness, total catch, and species evenness observed in 2016 were the lowest observed since 2009, likely a result of the large number of Banded Killifish captured in 2016.

Alewife is currently the dominant pelagic planktivore in Onondaga Lake, displacing White Perch and Gizzard Shad which were dominant prior to the establishment of the Alewife in 2004. These patterns likely reflect the changing environmental factors in the lake, including increased macrophyte coverage, increased mussel abundance, changes in the fish community associated with water quality improvements, and variability in year-class strength of competing planktivores. It is likely that occasional shifts in the dominance of planktivores will continue to occur and have cascading effects on other trophic levels within the lake community.

Table 6-3. Total number of fish collected in trap nets from Onondaga Lake by SUNY-ESF 2008-2016. Includes all life stages.

Year	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Captures	8011	8857	6134	6295	3373	5589	3806	2041	29806

Chain Pickerel (*Esox niger*) Captured from Onondaga Lake in 2016.



	2009	2010	2011	2012	2013	2014	2015	2016	Overall
Total Fish Captured	8857	6134	6295	3373	5589	3806	2141	29806	66001
Richness	33	37	36	35	35	31	22	28	45
Shannon Diversity	2.35	2.34	2.26	2.56	2.39	2.59	1.79	1.31	2.20
Evenness	0.67	0.65	0.63	0.72	0.67	0.75	0.52	0.39	0.63

Figure 6-17. Relative abundance of fish collected in trap nets from Onondaga Lake by SUNY-ESF, 2009–2016.

6.5.4 Physical 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. Changes in the occurrence of physical abnormalities are an indicator of recovery or degradation of the aquatic ecosystem.

Examining a Brown Bullhead collected in Onondaga Lake for the Occurrence of Physical Abnormalities.

The percentage of fish with observed DELTFM abnormalities increased from 2% in 2003 to nearly 8% in 2009, when they began to decline (Figure 6-18). The increases in recent years (2008-2012) were mostly due to an increase in the Brown Bullhead catch, a species with a comparatively high level of anomolies. Brown Bullhead from the lake were analyzed by the Cornell University College of Veterinary Medicine's Diagnositc Laboratory in 2008. A variety of pathogens were confirmed, including *Trichodina*, *Saprolegnia*, *Digenean* infestations, *Micrococcus luteus*, and *Aeromonas sobria*. The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake declined since 2008, suggesting a gradual recovery of the population. The incidence of lesions and tumors in Brown Bullhead in Onondaga Lake in 2016 was 0.25% and is within the range associated with regional reference sites (Figure 6-19).

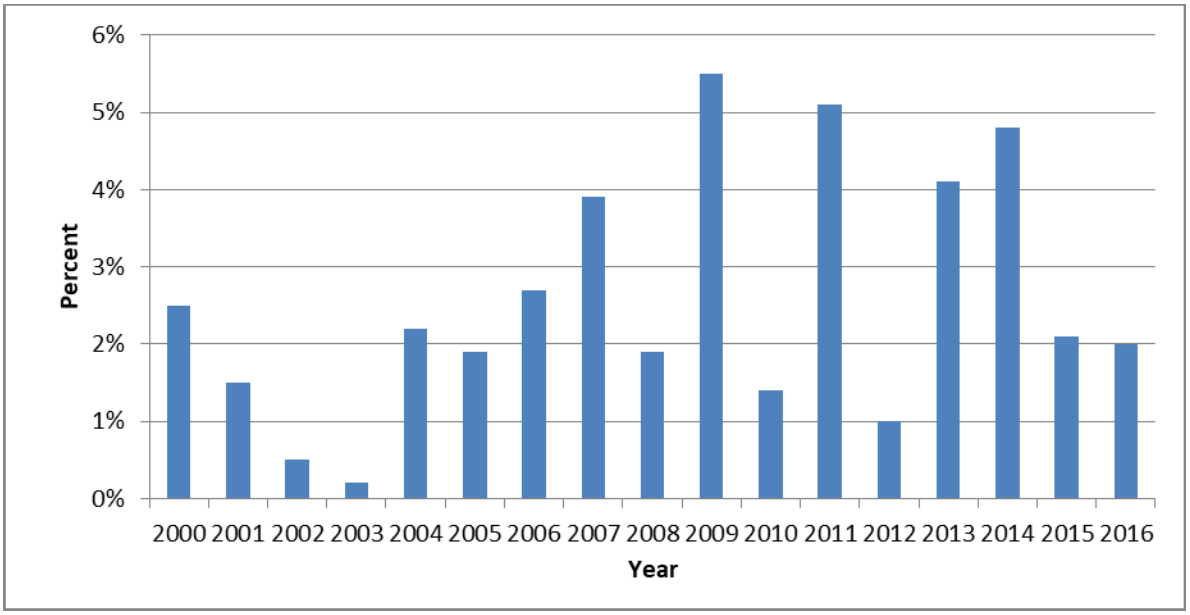


Figure 6-18. Percent of adult fish captured during AMP sampling with DELTFM abnormalities.

Note: DELTFM are defined as Deformities, Erosions, Lesions, Tumors, Fungus, and/or Malignancies.

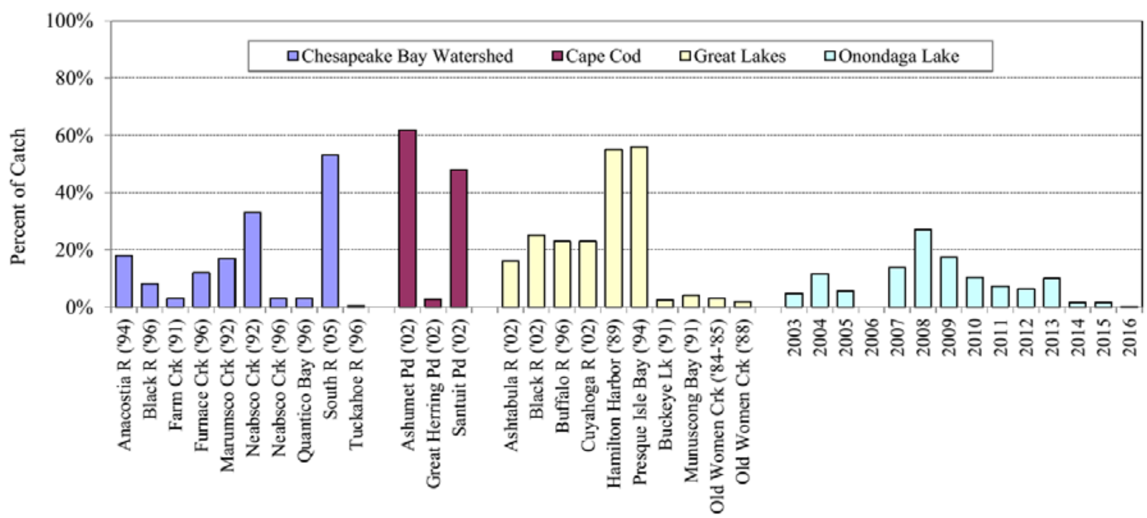


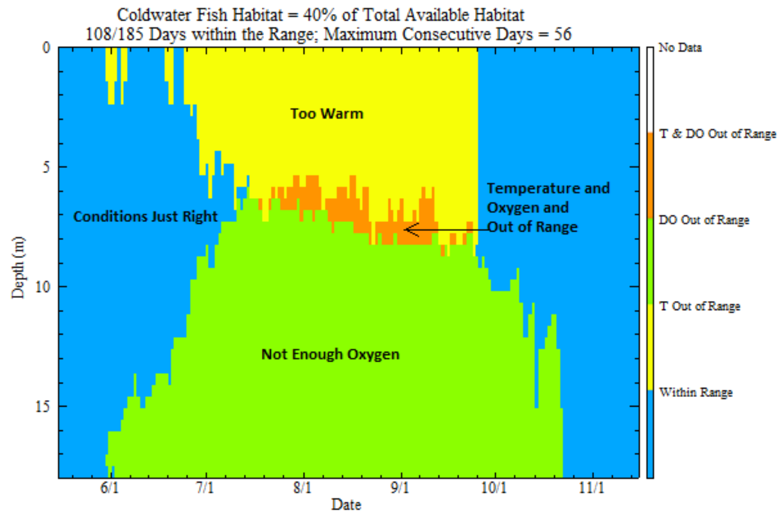
Figure 6-19. Occurrence of lesions and tumors in Brown Bullhead from Onondaga Lake and other regional waters.

Note: Onondaga Lake Brown Bullhead data include Lesions, Tumors and Malignancies, but 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 (Baumann et al. 2008, Pinkney et al. 2004).

6.5.5 Cool-water and Cold-water Fish Habitat

There is broad interest, among scientists working on Onondaga Lake as well as stakeholders throughout the community, regarding the desired future of the Onondaga Lake fish community. Both habitat and water quality conditions inform the discussion of a sustainable fish community. In addition to factors such as spawning habitat and predator/prey relationships, two physical and chemical variables are central to determining whether certain species can thrive in a lake. These factors are dissolved oxygen (DO) concentration and water temperature.

Complicating an analysis of whether DO and temperature conditions are optimal for various fish species is the fact that these parameters vary over the course of the year, as well as by depth. In an effort to quantify the effect of DO and water temperature conditions and track changes over time and depth, the AMP project team developed the "fish space" metric for Onondaga Lake. During most of summer, high water temperatures at the surface and low oxygen conditions in deeper cooler zones, render much of the lake unsuitable for cold-water species such as salmonids (Figure 6-20). Note, however, that the habitat for cold-water species increased after 2007. In contrast, the habitat for cool-water fish species such as walleye exists throughout most of the year, and the temporal data exhibit no trend toward expansion (Figure 6-21). The summer of 2016 was warm, and Onondaga Lake's surface water exceeded preferred conditions for cold-water species for most of the summer. However, the habitat for cool-water species was less affected, as surface water temperatures exceeded the preferred temperature range only sporadically from late July through mid-September.



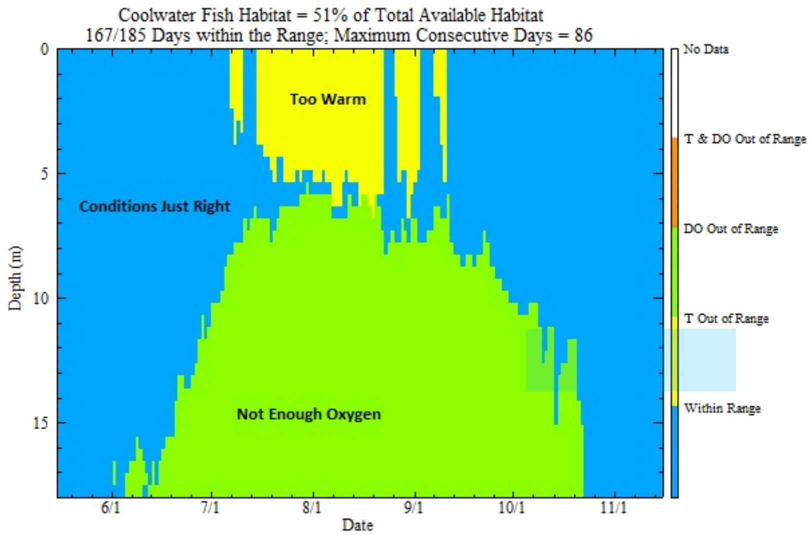
Year	% Avail. Habitat[2]	Total # Days in Range[3]	# Consec. Days in Range[3]	Year	% Avail. Habitat[2]	Total # Days in Range[3]	# Consec. Days in Range[3]
2001	33	140	72	**2009**	47	156	80
2002	30	95	49	**2010**	45	142	71
2003	31	125	47	**2011**	37	131	77
2004	32	161	67	**2012**	40	119	68
2005	34	115	59	**2013**	43	153	70
2006	39	131	80	**2014**	45	142	68
2007	36	138	65	**2015**	40	133	66
2008	40	124	67	**2016**	40	108	56

[1] Default 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 (185 Day Max).

Figure 6-20. Cold-water fish habitat in Onondaga Lake in 2016 and trends in cold-water habitat availability, 2000–2016.



Fish Habitat in Onondaga Lake in 2016
Note: Water temperature <= 25 deg. C and dissolved oxygen >= 5.0 mg/L between May 15 and November 15.

Year	% Avail. Habitat[2]	Total # Days in Range[3]	# Consec. Days in Range[3]	Year	% Avail. Habitat[2]	Total # Days in Range[3]	# Consec. Days in Range[3]
2001	46	185	185	**2009**	56	185	185
2002	40	153	67	**2010**	55	180	95
2003	39	172	87	**2011**	46	172	106
2004	45	185	185	**2012**	46	155	94
2005	43	162	89	**2013**	48	180	115
2006	47	179	101	**2014**	57	185	185
2007	49	184	102	**2015**	52	185	185
2008	53	185	185	**2016**	51	167	86

[1] Default 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 (185 Day Max).

Figure 6-21. Cool-water fish habitat in Onondaga Lake in 2016 and trends in cool-water habitat availability, 2000–2016.

6.6 Integrated Assessment of the Food Web

6.6.1 Introduction

The Onondaga Lake ecosystem continues to change, although the overall nutrient status has stabilized over the past few years (i.e., ammonia-N and phosphorus concentrations have remained relatively consistent since 2006). The reduced phosphorus and ammonia-N concentrations have resulted in a decrease in algal productivity and virtual elimination of nuisance cyanobacterial blooms. However, other less desirable species including Alewife, dreissenid mussels, Rudd (*Scardinius erythrophthalmus*) and recently, Round Goby are now present in Onondaga Lake and in other regional lakes. Several successful year classes of Alewife have reduced the abundance of large Daphnia. This resulted 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 2016 can be found in Appendix F-4. Zebra mussels and quagga mussels have continued to expand deeper into the lake. Increased macrophyte coverage, last measured in 2013, has expanded nearshore habitat for many fish and presumably other aquatic animal species.

6.6.2 Influence of Alewives, Dreissenid Mussels, and Invasive Fish

Phytoplankton biomass in the lake has declined in response to reduced phosphorus loading from Metro. Despite the relatively consistent external TP loading since 2005, there are annual fluctuations in phytoplankton biomass; these are attributed to the abundance and efficiency of grazing organisms. While the species present in Onondaga Lake affect the food web in various ways, the Alewife has the most pronounced influence through its impact on the size, structure of the zooplankton community. Years with abundant Alewife result in a zooplankton community dominated by small *Bosmina longirostris* (Appendix F-1). The small zooplankton are far less efficient grazers of phytoplankton than are larger species such as *Daphnia*, preferred prey of Alewife. Consequently, years with larger zooplankton, reduced phytoplankton and higher water clarity are those when the Alewife is not abundant (Wang et al. 2010, Appendix F-1).

Alewives are preyed on by larger, fish species such as Largemouth Bass, Smallmouth Bass, Northern Pike, and Walleye. Studies of the fish community of Onondaga Lake conducted from 1987 to 1996 concluded that the lake Walleye population was low (Ringler et al. 1996); however, surveys conducted by ESF from 2009-2016 documented a substantial increase in Walleye abundance. Alewife abundance increased dramatically in Onondaga County's electrofishing samples in 2003 following a strong year class in 2002. Alewife abundance remained high during 2004–2007 and continued to dominate in offshore samples from 2005 to 2017 (Appendix F-4), providing a food source for Walleye and Bass.

Collecting dreissenid mussel sample from Onondaga Lake.

The project scientists have also evaluated the extent to which another grazing organism dreissenid mussels, affect the Onondaga lake ecosystem. In nearby Oneida Lake, the arrival of zebra mussels led to increased water clarity as phytoplankton abundance decreased, especially in the spring, early summer and fall (Rudstam et al. 2016a). This in turn led to increases in macrophytes, benthic invertebrates other than unionids mussels, and littoral fish (Zhu et al. 2006, Mayer et al. 2016, Irwin et al. 2016), a process known as benthification (Mayer et al. 2014, 2016). Water clarity in Onondaga Lake has been variable over time, as it is affected by amount of rainfall, improvements to the Metro plants, and the food web changes associated with Alewife described above (UFI et al. 2016, Wang et al. 2010). After Alewife abundance rebounded in the fall of 2009, Daphnia declined and water clarity decreased. In Onondaga Lake, the timing of changes in dreissenid mussel biomass do not correspond to changes in water clarity. Mussels peaked in 2007, remained abundant through 2012 and have subsequently declined. This suggests that the dreissenid mussels are not as important as *Daphnia* as the cause of clarity changes in Onondaga Lake.

This difference between the two lakes is likely due to their bathymetry and mixing regimes. Oneida Lake is shallow and polymictic (i.e., does not undergo stable thermal stratification during the summer) with a largely oxygenated bottom. Consequently, mussel habitat extends throughout 100% of the lake bottom. Because Onondaga Lake is stratified in the summer and oxygen is depleted from the hypolimnion, mussels are restricted to the littoral zone and extend only to an overlying water depth of 7.5m. Thus, mussel habitat comprises about 28% of the lake bottom. In 2016, the mussel biomass in Oneida Lake was 455 g shell on dry weight (SODW)/m^2 or almost 40 times higher than in Onondaga Lake. This difference in biomass likely explains the lower ecosystem impact of dreissenid mussels in Onondaga Lake compared to Oneida Lake.

The presence of zebra and quagga mussels in Onondaga Lake may be helping to support the increased abundance of several fish species by providing an additional food source. Pumpkinseed, Freshwater Drum, Yellow Perch, Common Carp, Lake Sturgeon (*Acipenser fulvescens*), and Round Goby feed on mussels and are likely benefiting from the presence of these mussels. Predation pressure from fish may be driving the overall decline in dreissenid abundance observed over the last several years. Siniscal (2009) reported that the dominant *Lepomis* species shifted from Bluegill in the 1990s to Pumpkinseed in 2005 and 2006, and hypothesized that the switch in the littoral sunfish community could be a result of the introduction of dreissenid mussels. Adult Pumpkinseed feed on mollusks, while Bluegill tend to feed preferentially on zooplankton (Werner 2004). 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. 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 their aggressive defense of nesting sites, predation on native fish and their eggs, and competition for food resources (Werner 2004). Additionally, Round Gobies are capable of spawning every 18-20 days and may potentially do so up to six times during a breeding season. This reproductive pattern gives them an ecological advantage over native species, which usually spawn only once (Dubs and Corkum 1996). Impacts of the Round Goby invasion of Onondaga Lake are uncertain. However, in the Great Lakes and other areas where the Round Goby has become established, they have had a severely negative impact on native benthic fish populations, such as the Mottled Sculpin (*Cottus bairdi*) and Logperch (*Percina caprodes*).

Rudd.

The first documented occurrence of Rudd in Onondaga Lake was in 1994 when Arrigo (1998) captured three individuals. Every year since 2008, ESF, as part of the Honeywell monitoring program, has captured Rudd in trap nets with increasing frequency. The number of Rudd collected increased from 12 in 2008 to a high of 315 in 2014. In 2016 the total catch decreased to 32 Rudd. Hybridization between Rudd and Golden Shiner is probable, and such hybridization could threaten the genetic integrity of Golden Shiner (Burkhead and Williams 1991). Impacts on other native fishes are also a possibility. Small Rudd are vulnerable to predatory fish. Eklöv and Hamrin (1989) reported that Northern Pike selected Rudd over Eurasian Perch (*Perca fluviatilis*) in laboratory and field enclosure experiments, suggesting the potential to disrupt natural predator-prey relationships. This disruption may not necessarily be entirely negative since a preference for Rudd over other prey species by one predator may reduce competition among predators for other prey species. The other prey species may also benefit from reduced predation pressure if one or more predators shift their diets to include more Rudd. Competition with native fishes for food is also a concern. In New Zealand, young-of-year Rudd fed on zooplankton and chironomids and larger Rudd fed on benthic invertebrates but became increasingly herbivorous with increasing size (Hicks 2003). Feeding on zooplankton and chironomids could lead to competition between Rudd and many native fishes during the fishes' early life stages.

6.6.3 Macrophyte Coverage and Implications for the Fishery

In lakes, the structure and stability of the fish community are associated with the presence, abundance, species composition, and structural heterogeneity of macrophytes (Weaver et al., 1996). Research indicates that there is a positive relationship between macrophyte coverage and Largemouth Bass production, up to a point. For Largemouth Bass, the optimum macrophyte coverage is between 36 and 60 percent of the littoral zone (Stuber et al. 1982, Wiley et al. 1987). It appears that macrophyte coverage in Onondaga Lake in 2013 (reported at 50%) was within this optimal range for Largemouth Bass. The increasing catch rates of Largemouth Bass since 2013 possibly reflect this relationship.

Section 7. Recommendations

Onondaga Lake and its tributaries have undergone remarkable water quality improvements since the AMP was first implemented in 1998. Improved treatment of phosphorus and ammonia-N at Metro has resulted in a healthier lake with greatly diminished algal blooms. With improved water quality, the lake now provides habitat for robust warm and cool water fish communities. Major investments in gray and green infrastructure have substantially reduced CSO inputs to Onondaga Creek and Harbor Brook. Additionally, the Honeywell cleanup has removed industrial contaminants from the lake and improved habitat for aquatic biota and birds. The cumulative effect of these achievements is the transformation of Onondaga Lake from a local embarrassment to a community resource. For nearly two decades the AMP has monitored these changes and reported critical findings to regulators and community stakeholders.

In light of the upcoming compliance deadline for the Fourth Stipulation of the ACJ, the County has begun to plan out the path forward to meet the requirements of the ACJ. A Water Quality Compliance Conference was convened by Atlantic States Legal Foundation (ASLF) on January 25, 2017 to discuss the challenges of meeting water quality standards during wet weather. A follow-up meeting was held on July 17, 2017 with the ACJ parties (NYSDEC, ASLF, Onondaga County) to discuss development of a variance of SPDES permit limits for fecal coliform bacteria during wet weather.

After ACJ closure, the County's obligation to conduct an AMP under the requirements of the ACJ will be concluded. The County's related activities going forward would then be regulated by the SPDES permit. Although the County would continue to advance water quality improvements and additional CSO controls after the ACJ, the extensive monitoring and reporting requirements would be scaled back. The County's vision is to devote the majority of its available financial resources to continued green project implementation rather than extensive monitoring programs and annual report preparation. Investments in projects to reduce CSO volume and frequency will maximize the County's ability to achieve water quality improvements.

The County envisions a focused post-ACJ monitoring program that supports assessment of impacts of the remaining CSOs, evaluation of compliance with AWQS, tracking of progress toward designated use attainment, and future management decisions. Monitoring activities outside of this scope should be transferred to local research institutions. In the coming months, the County looks forward to working with NYSDEC and ASLF to develop a plan for the post-ACJ monitoring program that achieves these objectives.

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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
CFU	Colony Forming Units
CPUE	Catch Per Unit Effort
CSO	Combined Sewer Overflow
DO	Dissolved Oxygen
DVT	Data Visualization Tool
EPA	Environmental Protection Agency
GIS	Geographic Information System
HBI	Hilsenhoff Biotic Index
HRFS	High Rate Flocculated Settling
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
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

Term	Abbreviation	Definition
		progress towards compliance.
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	**BMPs**	A combined group of activities designed

Term	Abbreviation	Definition
Practices		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.
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.
catch per unit effort	**CPUE**	An indirect measure of the abundance of a target species
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
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

Term	Abbreviation	Definition
		community of plants, animals, and the physical environment in which they live
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.

Term	Abbreviation	Definition
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 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

Term	Abbreviation	Definition
		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.
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**	
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.
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

Term	Abbreviation	Definition
		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
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

Term	Abbreviation	Definition
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.
species evenness	**--**	A measure of the relative abundance of different species in an ecological community.
species richness	**--**	The number of different species represented in an ecological community
stoichiometric	**--**	The ratio of required elements needed for a chemical reaction; in this context, refers to 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-N 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.

Term	Abbreviation	Definition
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 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.

Term	Abbreviation	Definition
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 stormwater treatment as well as the monitoring and protection of all water resources in the county.