2018 Annual Report

Onondaga Lake Ambient Monitoring Program

FINAL, September 2020

Onondaga County

J. Ryan McMahon, II, County Executive

Frank M. Mento, P.E., Commissioner

Save the Rain

Onondaga County Department of WATER ENVIRONMENT PROTECTION

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MISSION

To responsibly improve the water environments in our community

GUIDING PRINCIPLES

Infrastructure matters for our future

Our teams work together with TRUST and open

COMMUNICATIONS

Our planning and decision-making is data driven and fiscally responsible

Integrity to our mission is first with our partners

(staff, regulators, community)

Safety must always be top of mind

Onondaga County Department of WATER ENVIRONMENT PROTECTION

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Save the Rain

ONONDAGA LAKE AMBIENT MONITORING PROGRAM 2018 ANNUAL REPORT

ONONDAGA COUNTY, NEW YORK

Final September 2020

Prepared for

ONONDAGA COUNTY, NEW YORK

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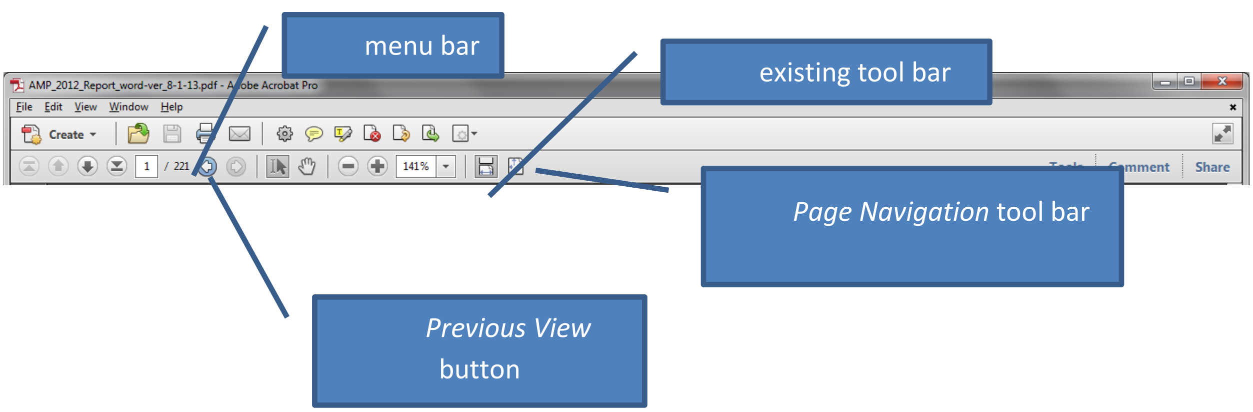

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View of Onondaga Lake from the Northeast Shore.

Introduction

Onondaga County has been monitoring Onondaga Lake and its tributary streams annually since 1970. In 1998, under the terms of an Amended Consent Judgment (ACJ) agreement, the long-term monitoring program was expanded to focus on the response of Onondaga Lake and its tributary streams to a planned series of improvements in wastewater collection and treatment infrastructure. The expanded program, known as the Ambient Monitoring Program (AMP), provides information to resource managers, elected officials, state and federal regulators, and the public regarding the state of the lake.

Onondaga County has successfully fulfilled its obligations to conduct the AMP, and this 2018 Annual Report is the final comprehensive reporting of this 20-year ACJ-mandated monitoring program. Over its history, the AMP has produced water quality data vital to the development of the Onondaga Lake Water Quality Model (OLWQM) and Total Maximum Daily Loads (TMDLs) for ammonia and phosphorus. Moreover, AMP data has served as the basis for tracking improvements in Onondaga Lake and the attainment of water quality goals. The County implemented an extensive biological monitoring program as part of the AMP to meet three goals: (1) evaluate aquatic habitat of the lake and tributary streams, (2) track primary production (trophic state), and (3) characterize the lake's biological community.

In 2019, Onondaga County transitioned to a simplified water quality monitoring program for Onondaga Lake modeled after the Citizen Statewide Lake Assessment Program (CLSAP). Future monitoring of Onondaga Lake tributaries will focus on CSO tributaries and will be guided by the County's Long-Term Control Plan (LTCP) for combined sewer overflows (CSOs).

This 2018 AMP Annual Report documents status and trends in water quality, external loading to Onondaga Lake, compliance with regulatory standards, habitat conditions, and the biological community. Additional details on all aspects of the AMP are provided in appendices to this report.

Many factors have contributed to a changing Onondaga Lake ecosystem; most factors relate directly or indirectly to the remedial efforts designed to bring the lake into compliance with regulatory requirements and community goals. Major remedial efforts include advanced treatment at the Syracuse Metropolitan Wastewater Treatment Plant (Metro), reduction in frequency and volume of Combined Sewer Overflows (CSOs), and removal and inactivation of legacy industrial wastes. Biological factors, such as invasive species and the fluctuations in abundance of alewives, also affect lake water quality. The AMP was designed to integrate the chemical and physical conditions of the waterways with implications for the biological community.

Highlights of 2018

Precipitation

Wetter than average conditions prevailed through much of 2018; total rainfall was 41.3 inches, above the long-term average of 39.3 inches. A relatively wet winter persisted through March and was followed by dry conditions in April, May and June. Wet weather returned in July with higher than average rainfall. Similar to 2017 conditions, August and September were dry. Above average rainfall returned in October and persisted though the end of December.

External Loading

In 2018, permitted construction took place at Metro to optimize phosphorus treatment. This caused temporary interruptions in the tertiary treatment process and increased loading of phosphorus and ammonia to Onondaga Lake. The percentage of the annual external phosphorus load from wastewater effluent was estimated at 50% in 2018, much greater than measured since 2005 when the advanced phosphorus removal system was installed. From 2005-2017, Metro effluent contributed around 25% of the external total phosphorus load. Metro effluent was also the largest source of fecal coliform bacteria input in 2018, estimated at 74%.

Trophic State

The AMP measures and reports several indicators of trophic state (level of primary productivity) in Onondaga Lake: water clarity and concentrations of total phosphorus and chlorophyll-*a*. Taken together, the 2018 indicator parameters confirm that the lake's trophic state has been stable over the past decade. Onondaga Lake has met the criteria for a mesotrophic (moderately productive) lake since 2008.

Regulatory Compliance

Similar to recent years, Onondaga Lake waters were generally in compliance with New York State ambient water quality standards (AWQS) and guidance values. Exceptions continued to include elevated total dissolved solids (TDS) concentrations, dissolved oxygen (DO) concentrations in the lower waters, and fecal coliform bacteria concentrations at the south end of the lake. Elevated TDS is primarily a result of watershed geochemistry, rather than human activities, and was not a target of the ACJ. Depletion of DO in the lower waters is common in moderately productive stratified lakes where the volume of the hypolimnion is relatively small. Although most of the lake meets water quality standards for fecal coliform bacteria, nearshore sites in the south end continue to exceed the standard during periods of wet weather. Ammonia, nitrite-N, and phosphorus have largely met applicable standards since completion of the advanced ammonia and phosphorus treatment at Metro.

The 2018 tributary data indicate that the major tributaries were generally in compliance with AWQS for most monitored parameters. The primary exceptions continued to be total dissolved solids, fecal coliform bacteria, and dissolved mercury. All of the monitored tributaries to Onondaga Lake regularly exceeded the AWQS for fecal coliform bacteria. Note that only Harbor Brook, Onondaga Creek, and Ley Creek receive CSOs.

The New York State Section 303(d) List identifies several additional pollutants causing impairments in Onondaga Lake and its tributaries that have no corresponding AWQS (see Appendix A-2). This report only addresses those impairments that can be evaluated relative to an AWQS using AMP data collected during 2018.

Stormwater Capture

Substantial progress has been made in abating CSOs to Onondaga Creek, Harbor Brook, and Ley Creek. At the start of the ACJ in 1998, 72 overflow points directed a mixture of stormwater and sanitary wastewater to the CSO-affected tributaries during wet weather. At present, 51 of the original 72 CSOs have been closed or abated. Through 2018, 221 green infrastructure projects have been completed as part of continuing efforts to reduce stormwater flows to tributaries.

The Fourth Stipulation to the ACJ identifies two specific metrics to determine compliance: CSO capture and compliance with AWQS. The 2018 annual update to the Storm Water Management Model (SWMM) indicates that the annual percent capture of combined sewage has surpassed 97%. Improvements to the sewerage system through green and gray infrastructure surpassed the ACJ-required target of 95% capture by December 2018.

Post Construction Compliance Monitoring: Recovery Time Monitoring

Onondaga County is required to sample CSO-affected streams during storms to evaluate the effectiveness of the gray and green infrastructure measures and to determine if CSOs are causing or contributing to exceedances of AWQS. Four years of stream monitoring during wet weather events (referred to as the Post Construction Compliance Monitoring program) have documented that CSOs and stormwater cause or contribute to exceedances of the AWQS for fecal coliform bacteria. In 2018, the monitoring focus shifted from the PCCM program to estimating the duration of the period of non-compliance with the AWQS (i.e., how long after storm events until water quality returns to baseline conditions?). In anticipation of requesting a regulatory variance from meeting bacteriological standards during wet weather, Onondaga County worked with NYSDEC and Atlantic States Legal Foundation (ASLF) to design a Recovery Time Monitoring (RTM) program to document the duration of elevated bacterial counts after CSO events.

Two storm events were monitored on Harbor Brook and Onondaga Creek for this assessment. The 2018 RTM results indicate that it may take up to 80 hours for bacterial cells to be transported, diluted, or die off following overflow events.

Biological Community

The major improvements in wastewater treatment at Metro have had a reverberating impact across the lake ecosystem. Lower phosphorus concentrations have reduced the biomass of phytoplankton (algae and cyanobacteria) and essentially eliminated the occurrence of nuisance algal blooms.

The reduction in phytoplankton has resulted in increased water clarity. This in turn has had a major influence on the physical structure of aquatic habitat in the lake by allowing rooted aquatic plants (macrophytes) to increase in both density and coverage. Aquatic macrophytes provide critical spawning and nursery habitat for many littoral zone fishes. Species such as largemouth bass, bluegill, and yellow perch have increased in Onondaga Lake as a result of this habitat enhancement. Less phytoplankton production has also resulted in lower rates of oxygen depletion in the deep waters, expanding habitat to support fish and benthic macroinvertebrates.

The same improvements to Onondaga Lake's water quality and habitat that have allowed the native fish community to thrive have also provided opportunities for invasive species to colonize and prosper in the lake. Invasive fishes that are becoming more prominent in the lake include alewife, round goby, green sunfish, and rudd. The impact of these and other invasive species on the Onondaga Lake ecosystem becomes more relevant as lake conditions continue to improve and become suitable for more species.

The aquatic macroinvertebrate communities of Onondaga Creek, Ley Creek, and Harbor Brook have been monitored periodically from 2000 to 2018 to evaluate response to CSO and non-point source control measures. The results of the 19-year macroinvertebrate program of three of Onondaga Lake's major tributaries (Onondaga Creek, Ley Creek, and Harbor Brook) have shown varying degrees of change over the course of the AMP. All sites sampled in 2018 showed some level of impact. Recovery of the most impaired sites does appear to be occurring gradually, but the recent invasion of some of these sites by New Zealand mud snails has confounded this assessment.

Section 1. Onondaga Lake and its Watershed

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 (Figure 1-1).

In addition to the natural tributaries, treated wastewater is discharged to the lake, as is storm runoff from developed areas. 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 1-2).

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. 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.

Land Use

Compared with other lakes in central New York, the watershed of Onondaga Lake is relatively urbanized; the National Land Cover Dataset classifies the watershed as 18% developed (urban/suburban), 34% forested or scrub/shrub, 9% developed open space, and 29% cultivated lands or pasture (Appendix B-1). 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.

Lower Harbor Brook Storage Facility.

Physical Characteristics of Onondaga Lake

Onondaga Lake is relatively small, with a surface area of 12 square kilometers and a maximum depth of 19.5 meters (Table 1-1). The lake basin is characterized by two minor depressions, referred to as the northern and southern basins, separated by a shallower region near the center of its longitudinal axis (Figure 1-3). The littoral zone, defined as the region of the lake where light reaches the sediment surface and can support growth of rooted plants, is narrow. Under current water clarity conditions, the littoral zone extends to a water depth of approximately 6 meters.

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 each year.

Section 1. Onondaga Lake and its Watershed

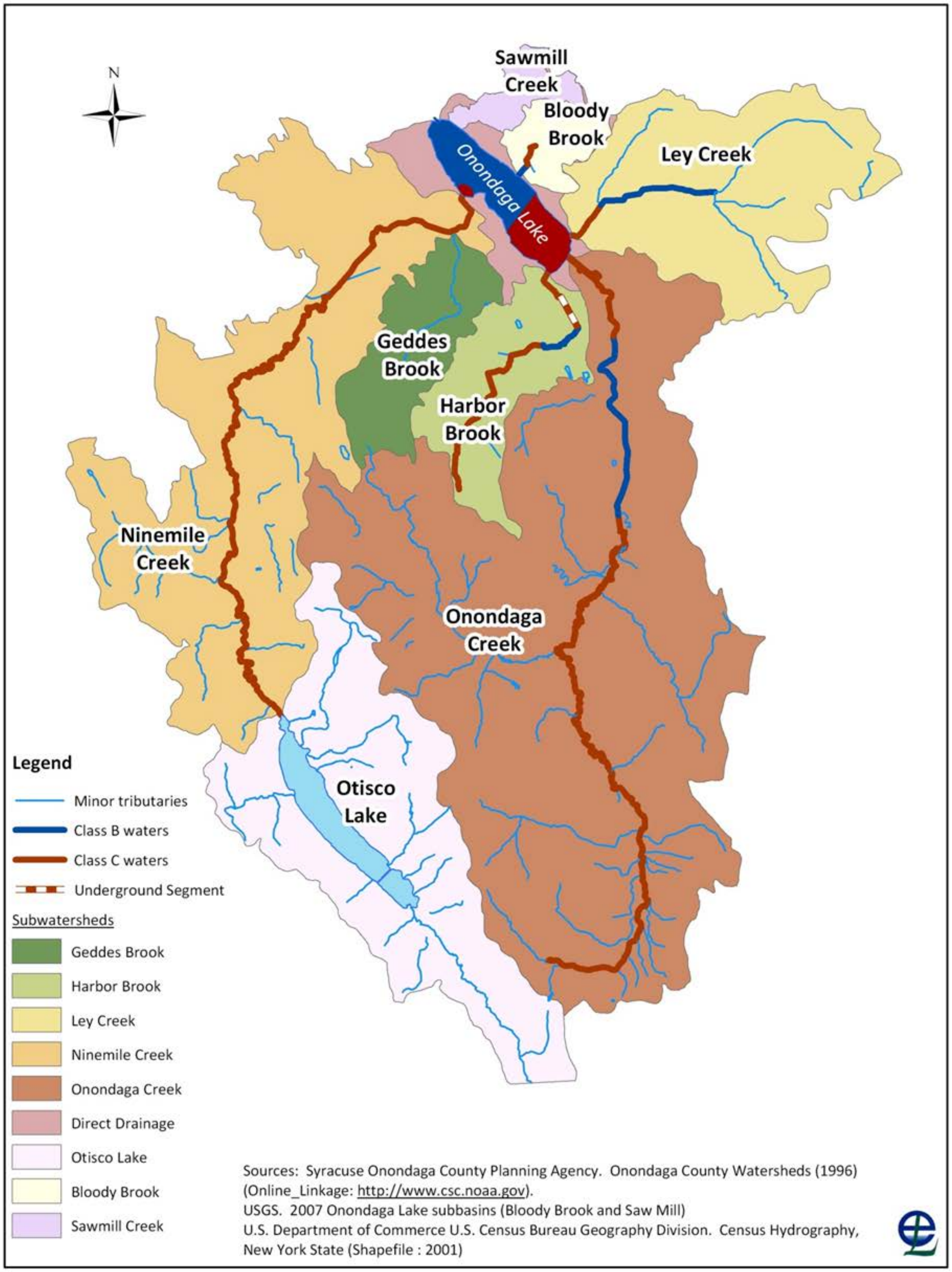


Figure 1-1. Tributary and lake regulatory classifications (6 NYCRR) and subwatershed boundaries.

Section 1. Onondaga Lake and its Watershed

Water residence (the average time water remains in the lake) 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. In Onondaga Lake the average water residence time is about three months.

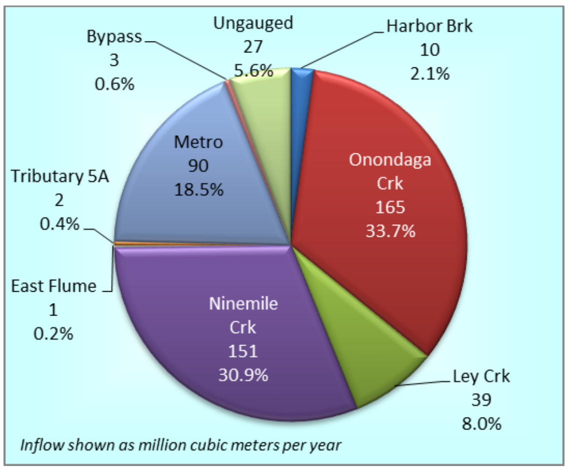


Figure 1-2. Annual average inflows (gauged and ungauged) to Onondaga Lake, 1990–2018.

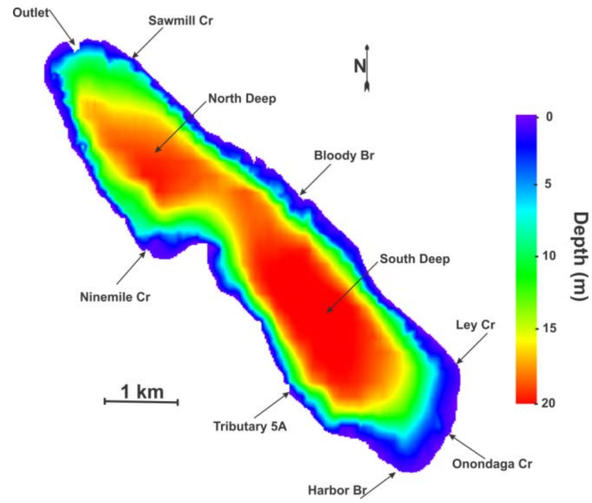


Figure 1-3. Bathymetric map of Onondaga Lake, with tributaries and primary sampling locations (South Deep, North Deep) identified.

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

Table 1-1. Physical characteristics of Onondaga Lake.

Characteristic	Metric	English
Surface area	12 km^2	4.6 square miles
Volume	131 x 10^6 m^3	35 billion gallons
Length	7.6 km	4.6 miles
Width	2 km	1.2 miles
Maximum depth	19.5 m	64 feet
Average depth	11 m	36 feet
Average elevation*	111 m	364 feet
Average flushing rate	4 times per year	4 times per year
Sources: http://www.upstatefreshwater.org/NRT-Data/System-Description/system-description.html *Elevation referenced to mean sea level.		

Section 1. Onondaga Lake and its Watershed

Sunset on Onondaga Lake.

Section 2. Regulatory Requirements

Classification and Best Use

NYSDEC classifies surface waters with respect to both human uses and ecosystem protection. Onondaga Lake and its tributaries are classified as Class B and Class C waters (Appendix A-1; Figure 1-1). The best uses of Class B waters are for primary and secondary water contact recreation and fishing (NYCRR Part 701.7). Class B and Class C waters shall also be suitable for fish, shellfish, and wildlife propagation and survival. The best usage of Class C waters is fishing and they shall be suitable for primary and secondary water contact recreation, although other factors may limit the use for these purposes.

NYSDEC Division of Water is responsible for evaluating whether water quality and habitat conditions fully support each resource's designated best use. Those waterbodies with water quality and/or habitat conditions that do not fully support the designated uses are compiled on a biennial listing and given priority for assessment and action. 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, is provided in Appendix A-2. The 2018 Section 303(d) List is currently in draft form as NYSDEC prepares responses to public comments.

History and Sources of Impairment

Onondaga Lake and several of its tributary streams have been included on the NYSDEC list of impaired waters since 1998. Among the cited water quality impairments were: elevated concentrations of ammonia-N that exceeded ambient water quality standards for protection of aquatic life; elevated concentrations of phosphorus resulting in overabundant algae that impaired recreational and aesthetic uses; and depletion of dissolved oxygen from the overabundant algae that impaired aquatic habitat. Several water quality issues (ammonia, phosphorus, dissolved oxygen, fecal coliform bacteria) were linked to municipal discharges from Metro and the CSOs.

Aerial View of the Metropolitan Syracuse Wastewater Treatment Plant.

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 rains and snowmelt, the capacity of the pipes to direct all flows to Metro can be exceeded. Relief points along creeks allow the mixture of stormwater and untreated sewage flows to overflow into Onondaga Creek, Harbor Brook, and Ley Creek, ultimately reaching Onondaga Lake. When these overflows occur, CSOs may carry bacteria, floatables, organic material, nutrients and solid materials to the waterways.

Amended Consent Judgment

In 1998, Onondaga County, New York State, and the Atlantic States Legal Foundation signed an agreement to mitigate the adverse impacts of municipal discharges on the waterways. The agreement, known as the Amended Consent

Judgment (ACJ), required Onondaga County to design and implement improvements to the County's wastewater collection and treatment infrastructure, and to measure and report on their effectiveness. The ACJ called for a phased program to be implemented over a 15-year period.

The ACJ has been modified four times since 1998, most recently by stipulation in 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.

Lakeview Amphitheater during Dave Matthews Band Concert, July 2016.

ACJ Milestones

The ACJ (1998) 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 (Appendix A-4). The Fourth Stipulation of the ACJ (2009) requires phased reductions of CSO volume and scheduled improvements to the wastewater collection and treatment infrastructure through 2018.

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 2-1. The 2018 annual stormwater management model (SWMM) update reflects green and gray infrastructure projects completed in 2018 and new or improved infrastructure data; this update of the model is referred to as the "2018 conditions model."

Table 2-1. 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]	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%	97.7%	December 31, 2018

[1] SWMM results based on the 1991 (selected as the typical year) precipitation record.

As documented in the 2018 ACJ Annual Report, SWMM results showed that the annual combined sewage percent capture for the 2018 system conditions was 97.7%. In November 2019, NYSDEC determined that Onondaga County had achieved compliance with the ACJ Stage IV Percent Capture Milestone Value.

A total maximum daily load (TMDL) allocation for phosphorus inputs to Onondaga Lake was developed by NYSDEC and approved by USEPA on in June 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. The TMDL also proposed a bubble permit for outfalls 001 and 002 of 27,212 pounds of phosphorus per year to allow for the natural variability inherent in combined sewer systems. Additionally, the TMDL targeted phosphorus loading reductions 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.

OCDWEP Technician sampling zooplankton from Onondaga Lake.

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 was designed to provide data and information required for this assessment. As a consequence, the annual report focuses on compliance and trends.

In 2018, trained field technicians collected representative samples from a network of permanent long-term sampling locations in nearshore and deep regions of Onondaga Lake (Appendix B-2) and along the lake tributaries (Appendix B-3). All analyses were completed by laboratories certified by the Environmental Laboratory Approval Program (ELAP). The OCDWEP Environmental Laboratory conducted analysis for all parameters, with the exception of methylmercury analyzed by Test America and Eurofins Frontier Global Sciences. Both contract laboratories are certified for analysis of the referenced parameters.

The AMP Five-Year Work Plan (2014–2018), a roadmap for monitoring and assessment of Onondaga Lake and its tributaries, was reviewed annually over the five-year period to address changing conditions and new information. The 2018 AMP Work Plan, representing the final year of the ACJ-mandated AMP, included monitoring programs to:

- Support evaluation of the trophic status of Onondaga Lake
- Determine whether designated best uses are supported in Onondaga Lake and its tributaries

- Assess species composition, abundance, and habitat conditions of key biological communities, including phytoplankton, macrophytes, zooplankton, macroinvertebrates, dreissenid mussels, and fish

- Evaluate effectiveness of improvements to the CSO network (Post Construction Compliance Monitoring (PCCM))

Parameters measured in the 2018 AMP are used to assess compliance, calculate loads, and examine lake ecology (Appendix A-3). The 2018 Onondaga Lake, Onondaga Lake Tributary, and Onondaga Lake Biological sampling programs remained largely unchanged from the 2017 programs. The 2018 PCCM program focused on documenting the time-course of recovery of fecal coliform concentrations in CSO tributaries following significant wet weather events. As part of the PCCM program, CSO facility influent chambers were monitored during storm events. Drone technology was used to conduct aerial photography of macrophytes in 2018.

Each year, Onondaga County reviews the laboratory data for quality assurance/quality control criteria (Appendix D-1) prior to uploading the annual data set to the long-term water quality database and use in the Annual AMP Report. This custom database archives the complete set of Onondaga Lake and tributary monitoring results collected since 1970. In addition, annual field audits of the tributary (Appendix D-2) and lake (Appendix D-3) water quality monitoring programs were conducted in 2018 by the AMP consultant UFI to ensure appropriate sampling protocols are followed by the sampling staff.

The Onondaga County Environmental Laboratory voluntarily participates in the Environment and Climate Change Canada Proficiency Testing Program for total phosphorus and total mercury analyses in natural waters (Appendix D-4). These biannual blind tests include multiple academic, government, and private laboratories. In 2018, the performance of the laboratory for total phosphorus was rated as “very good” and “fair” for the first and second proficiency tests, respectively. An extensive review of the total phosphorus results and potential causes for the “fair” rating is provided in (Appendix D-4). For low-level total mercury analysis both proficiency tests resulted in a laboratory rating of “very good”, which is the highest rating available.

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

Ronny Raindrop at the 2018 Clean Water Fair.

Section 2. Regulatory Requirements

Use of Metrics to Measure and Report Progress

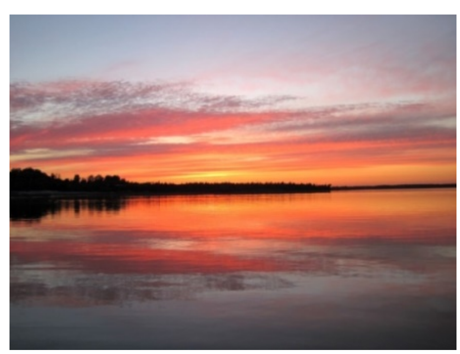
Onondaga County Department of Water Environment Protection, in consultation with NYSDEC and the Onondaga Lake Technical Advisory Committee (OLTAC), has developed a suite of metrics to help organize and report on the extensive AMP data set each year. These metrics relate to the lake's designated "best use" for water contact recreation, fishing, and protection of aquatic life. As summarized in Table 2-2 (see Appendix A-5 for additional details), the Class B segments of the 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 the lake's suitability 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

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

Metrics related to water contact recreation, aesthetic appeal, and aquatic life protection is 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.



Sunset on Onondaga Lake.

Table 2-2. Summary of metrics, Onondaga Lake 2018.

Metric	Target	2018 Results	Comments
Indicator bacteria	100% compliance with AWQS (April-October)	100% and 57-100% compliance in Class B and Class C waters, respectively	Class B segments of Onondaga Lake met the bacteria standard for water contact recreation
Water clarity	Secchi depth ≥ 1.2 m	100% and 75-100% compliance in Class B and Class C waters, respectively	Nearshore areas in the southern end of the lake (Class C) do not consistently meet the water clarity guidelines for swimming safety
Algal blooms	≤ 15% of Chl-a values > 15 µg/L and ≤ 10% of Chl-a values > 30 µg/L	3 of the 20 (15%) South Deep measurements exceeded 15 µg/L during summer; no values exceeded 30 µg/L	Chl-*a* exceeded 15 µg/L on three consecutive sampling dates in August
Algal community	Cyanobacteria represent ≤ 10% of algal biomass	Cyanobacteria represented 5.2% of the algal biomass at South Deep during summer	Cyanobacteria were a significant component of the algal community during September and October
Ammonia	100% compliance with AWQS (upper waters)	100% of South Deep measurements in compliance	The AWQS for ammonia was met in the upper waters
Nitrite	100% compliance with AWQS (upper waters)	88% of South Deep measurements in compliance	The AWQS for nitrite (0.1 mg/L) was exceeded on July 19 (15 m depth) and on November 14 and 27 (3, 15, 18 m depths). The July exceedance was likely caused by incomplete nitrification of ammonia within the lake. The November exceedances were likely due to suspension of tertiary treatment at Metro during construction.
Dissolved oxygen	100% compliance with AWQS (upper waters)	100% of South Deep measurements in compliance	The AWQS for dissolved oxygen was met in the upper waters
Habitat quality	40% macrophyte coverage	50%	Littoral zone macrophyte coverage provides high quality habitat for warm water fish community
Fish reproduction	Reproduction of target species	Evidence for all target species except black crappie, walleye, and northern pike	Rock Bass reproduction was first documented in 2017
Fish community	Species richness comparable to other regional lakes	Adults representing 27 species were identified during electrofishing, comparable to regional lakes	The lake's temperature and dissolved oxygen conditions limit habitat for cold water species

Note: summer defined as June 1 to September 30 and upper waters defined as 0-3 meters.

Section 3. Onondaga County Actions and Progress

Onondaga County Projects and Milestones

By signing the ACJ in 1998, Onondaga County agreed to design, construct, and maintain a series of engineering improvements to the wastewater collection and treatment infrastructure within the Metro service area. Improvements to Metro have reduced phosphorus concentrations and altered the speciation of nitrogen in the fully-treated effluent, associated with year-round nitrification treatment (Appendix A-6).

Abating the combined sewer overflows (CSOs) posed a significant challenge (Appendix B-4). 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. At the start of the ACJ, 72 overflow points were active during wet weather conditions, and directed a mix of untreated stormwater and sanitary wastewater to the CSO-affected tributaries and ultimately to the lake (Table 3-1). The ACJ included 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. By the end of the year, 52 of the original 72 CSOs were closed or abated (Table 3-1) and the ACJ-mandated discharge volume reduction had been met.

The County employed four strategies to reduce the frequency and volume of 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" (Appendix A-7, Appendix A-8). A fifth strategy, Green Infrastructure (GI) was subsequently added to this list with the 2009 agreement to amend the ACJ by stipulation.

Rain Barrel Installation.

In response to the stipulation adding GI to the strategy list, Onondaga County created the Save the Rain (STR) program in 2009. This national award-winning initiative encompasses both green and gray infrastructure improvements designed to keep stormwater from entering the combined sewer system. All five wet weather strategies are used. A total of 221 GI projects have been implemented in Onondaga County through the STR program; fifteen of these projects were completed in 2018. Results from the 2018 annual update to the Storm Water Management Model (SWMM) indicate that GI projects are reducing stormwater runoff by 170 million gallons per year. Results from the 2018 annual update to SWMM indicated that GI projects are reducing stormwater runoff by 170 million gallons per year. This volume translates to 81.6 million gallons of CSO volume reduction based on SWMM calculations and the average and system wide relationship for the combined sewer system estimated as 0.48 gallons of CSO reduction per 1 gallon of runoff reduction. For additional information on STR projects visit the Save the Rain website (savetherain.us).

Section 3. Onondaga County Actions and Progress

Table 3-1 Pre-ACJ and Current Number of CSOs (as of 12/31/2018).

Drainage Basin	Pre-ACJ Number of Operational CSOs (1998)	Current Number of CSOs		
		Abated [1]	Closed [2]	Operational [3]
Harbor Brook	20	6	4	10
Onondaga Creek	50	18	23	9
Ley Creek	2	1	0	1
Total	***72***	***25***	***27***	***20***

[1] Abated: CSO is zero or minimal for the 1-year, 2-hour design storm.
[2] Closed: CSO no longer discharges.
[3] Operational: CSO still discharges.

The ACJ required that an Optimization Analysis of Metro's current phosphorus treatment processes be completed followed by implementation under a schedule approved by NYSDEC. From notice to proceed (October 2017) to completion of construction and full commission (May 2019), this was a 20 month project. Much of the work was performed during two (2) winter shutdowns of the tertiary treatment system, October 16, 2017 through March 3, 2018, and October 16, 2018, thru February 28, 2019.

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.

Paddle boarder near the St. Joseph's Health Amphitheater at Lakeview.

Section 4. Tributary Water Quality

Tributary Monitoring Program

The primary objectives of the tributary monitoring program are: (1) assess compliance with ambient water quality standards (AWQS) in the tributary streams and (2) estimate loading of materials to the lake, including contributions from combined sewer overflows (CSOs). Tributary monitoring data are also used to support long-term trend analysis. Seven tributaries to the lake are monitored, as are Metro discharges and the Onondaga Lake outlet. Sampling is conducted over a range of streamflow conditions, including high flow events.

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 2018, recovery time monitoring (RTM) was conducted at the downstream compliance locations of Onondaga Creek and Harbor Brook to better understand the time-course of fecal coliform concentrations following wet weather events (see Appendix F-17 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.

Meteorological Drivers and Streamflow

Meteorological conditions in the Central New York region are subject to substantial seasonal and year-to-year variations. 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 41.3 inches in 2018, 2.0 inches more than the 32-year historic (1985–2017) average of 39.3 inches. Monthly precipitation totals were higher than the long-term averages during January through March, July, and October through December (Figure 4-1). November was a particularly wet month, receiving 6.3 inches of precipitation compared to the long-term average of 3.3 inches. The months of April through June, August, and September were dryer than the long-term average. Just 1.9 inches of rainfall was measured during May 2018 compared to the long-term average of 3.4 inches. Snowfall for the winter of 2017–2018 totaled 154 inches, well above the 1999–2016 average of 125 inches.

Bass fishing in Onondaga Lake.

Section 4. Tributary Water Quality

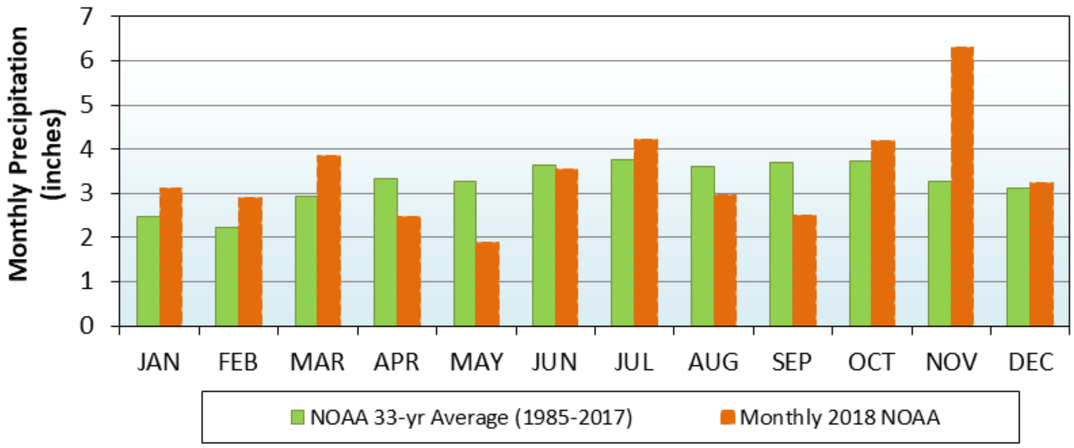


Figure 4-1. Monthly precipitation in 2018 compared to the long-term (1985–2017) average.

By the end of 2018, the higher rainfall caused the annual average discharge of Onondaga Creek to be 13% higher than the long-term mean (Appendix F-1). Rainfall and stream discharge patterns were tightly coupled during the January-April and October-December intervals (Figure 4-2). The streamflow response was moderated during the May to September period due to increased evapotranspiration. Daily measurements of streamflow in Onondaga Creek during 2018 depict a series of major runoff events from January through April, followed by a dry period that lasted through late October, and a return to higher flows during November and December (Figure 4-2a). Daily rainfall totals exceeded one inch on January 12, March 2, June 1, June 27, July 5, July 25, September 10, and November 16 (Figure 4-2b). Comparisons of 2018 streamflow conditions with earlier years are provided in Appendix F-1 and Appendix F-2.

Because concentrations and loading rates of many water quality constituents depend on stream flow conditions, the AMP targets a broad range of flow conditions to reduce uncertainty in annual loading estimates. Most loading occurs during high flows; the AMP is designed to target at least five sampling events 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 2018, Onondaga Creek was sampled during six (6) high flow events, Ninemile Creek during two (2), Ley Creek during nine (9), and Harbor Brook during five (5) (Appendix F-3).

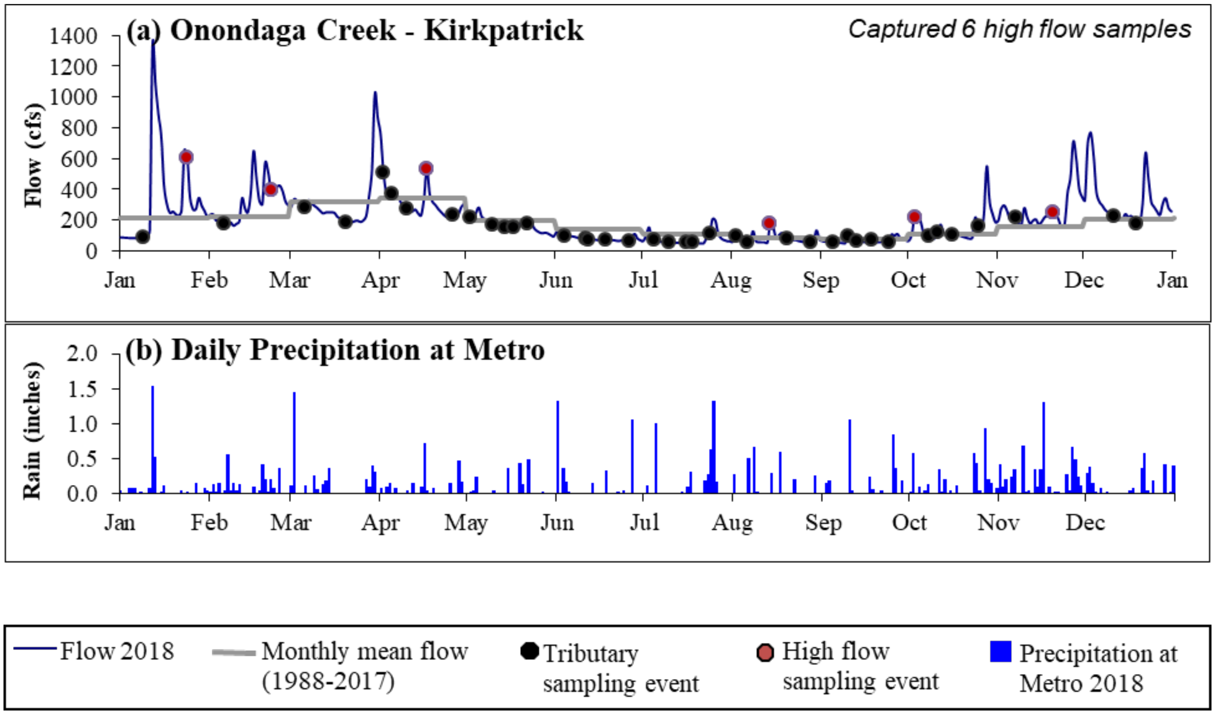


Figure 4-2. Hydrographs showing USGS tributary flows in 2018 compared with the 30-year average (1988–2017) flow for (a) Onondaga Creek, and (b) daily precipitation at Metro.

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

Loading Estimates

Methodology

Dr. William Walker developed customized software for WEP staff to calculate annual loads using the program AUTOFLUX. This software was used to compute all the loading estimates presented in this report. Annual loading estimates for selected parameters are presented in Appendix F-4. Loading estimates for additional constituents are provided in Appendix F-5 and relative standard errors of these estimates can be found in Appendix F-6. Tributary loading calculations were supported by at least 23 observations within the year, except for Honeywell Manhole 015 (n=4) and Tributary 5A (n=4), as per the 2018 AMP Work Plan. Fecal coliform samples were collected more frequently (5 samples per month during April-October) to evaluate compliance with the AWQS.

Results for Key Constituents

The largest total phosphorus (TP) loads to Onondaga Lake in 2018 were delivered by Metro 001+002 (21.2 metric tons), Onondaga Creek (9.8 metric tons), and Ninemile Creek (8.0 metric tons; Appendix F-4). Metro was the predominant source of TP, contributing 50% of the total load; Onondaga Creek, Ninemile Creek, and Ley Creek contributed 23%, 19%, and 7%, respectively (Table 4-1; Figure 4-3).

Tertiary treatment at Metro was taken offline for NYSDEC-approved construction twice during 2018, from January 1 to February 28 and

Table 4-1.. Percent contribution to total annual loading by gauged inflow in 2018.

Parameter	TP	NH_3-N	FC[1]	Water
Metro:				
Treated Effluent (001)	44.6%	85.1%	60.3%	18.3%
Bypass (002)	5.3%	3.1%	14.0%	0.4%
Watershed				
Harbor Brook	1.4%	0.2%	0.6%	2.2%
Ley Creek	6.5%	2.0%	2.0%	8.9%
Ninemile Creek	18.8%	6.7%	17.1%	32.7%
Onondaga Creek	23.2%	2.9%	5.8%	37.4%

[1] the annual loading contribution for the Treated Effluent (001) includes samples collected during months when disinfection is not required at the BAF Influent site from 1/1/18-2/28/18 and from 10/15/18-12/31/18, as the HRFS facility was off-line during this time period due to construction.

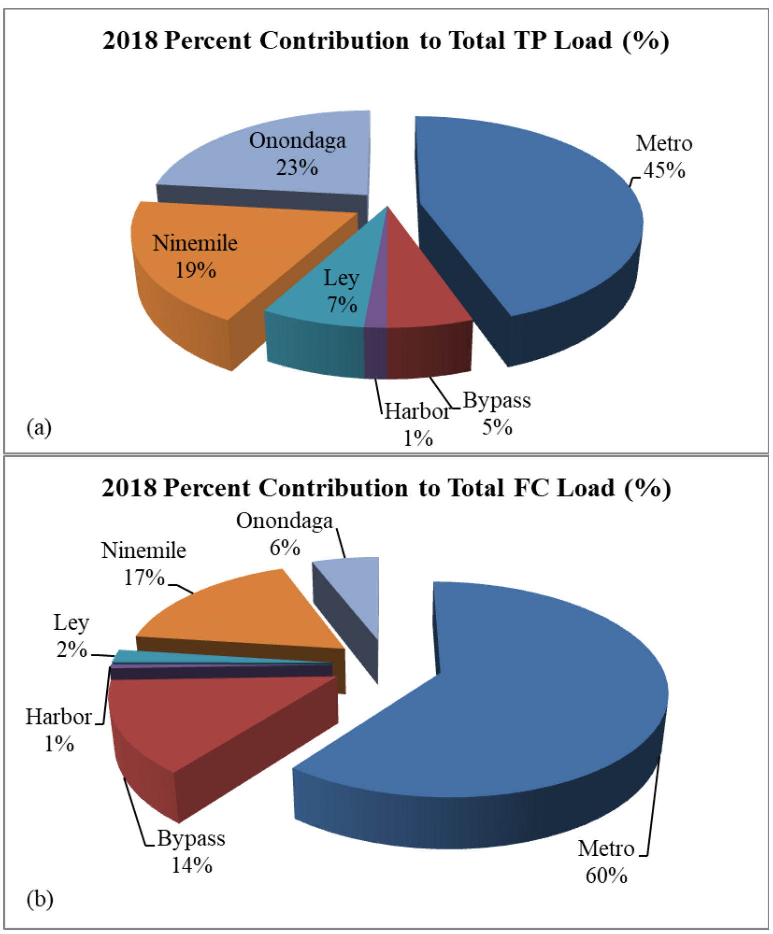


Figure 4-3. Percent contributions to 2018 total load to Onondaga Lake for (a) total phosphorus and (b) fecal coliform bacteria.

from October 16 to December 31. The sampling location was shifted to the BAF influent during construction, which may have affected results. Suspension of tertiary treatment for nearly five months of the year caused Metro's loading of TP, ammonia-nitrogen (NH_3-N), and fecal coliform bacteria (FC) to be unusually high in 2018. In contrast, loading of TP and FC from the lake's natural tributaries was somewhat lower than average in 2018.

Metro's contribution to TP loading decreased dramatically with implementation of the Actiflo® treatment in 2005 (Figure 4-4). Moreover, Metro's contribution to the total annual phosphorus load decreased from 61% over the 1990 to 2004 interval to 25% during 2007–2018 (Figure 4-5). Seasonal phosphorus loading information for Metro and the natural tributaries is provided in Appendix F-10 and Appendix F-11.

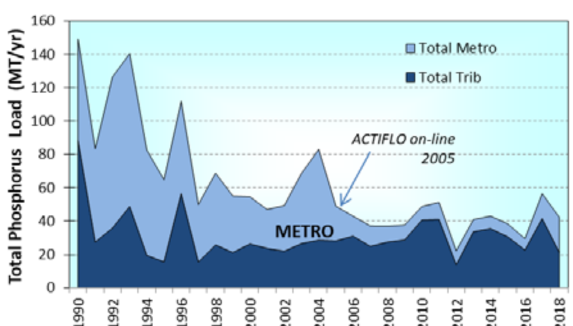


Figure 4-4. Time plot of the annual daily average Metro (outfalls 001+002) TP loading (metric tons per year) to Onondaga Lake, 1990–2018.

The phosphorus TMDL for Onondaga Lake established both an average TP load allocation (77,668 pounds per year) and a maximum TP load allocation (114,975 pounds per year). The lake model projections used to develop the eutrophication over time; the maximum

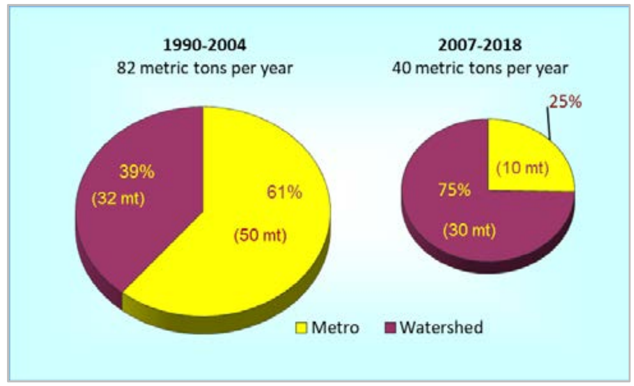


Figure 4-5. Contributions of Metro (outfalls 001+002) and the watershed to the annual input of TP to Onondaga Lake, average for 1990–2004 compared to the average of 2007–2018.

load reflects the reality of fluctuating TP load based on annual rainfall and streamflow conditions. The estimated total phosphorus load to the lake in 2018 was 93,476 pounds (42.4 metric tons; Figure 4-4). Certain elements of the lake phosphorus TMDL have not yet been fully implemented. Phosphorus loading reductions associated with CSOs and the Metro Bypass were fully implemented by 12/31/18 with completion of ACJ projects. However, implementation dates for agricultural lands and MS4s are 12/31/22 and 12/31/25, respectively.

The Metro effluent (outfalls 001+002) was the largest source of both total nitrogen (TN; 68%) and ammonia nitrogen (NH_3-N; 88%) to the lake in 2018 (Appendix F-4, Table 4-1). The second largest source of ammonia-N in 2018 was Ninemile Creek (7%). The ammonia concentration of the Metro effluent decreased by 98% with completion of the BAF treatment upgrade in 2004 (Figure 4-6). Note increases in 2017 and 2018 associated with construction-related shutdown of tertiary treatment. Efficient, year-round nitrification of ammonia reduced Metro's contribution to the total annual load (Metro + tributaries) from 91% to 56% (Figure 4-7).

The total suspended solids (TSS) load was dominated by inputs from Onondaga Creek (67%) and Ninemile Creek (21%), which combined to account for 89% of the total load to Onondaga Lake (Appendix F-4). The high TSS load in Onondaga Creek is attributed, at least in part, to inputs from the mud boils in upstream portions of its watershed.

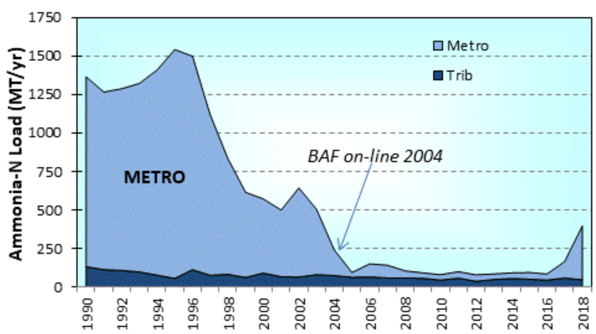


Figure 4-6. Time plot of the annual daily average Metro (outfalls 001+002) and tributary ammonia loading (metric tons per year) to Onondaga Lake, 1990–2018.

The primary sources of fecal coliform bacteria were Metro (74%), Ninemile Creek (17%), and Onondaga Creek (6%) (Table 4-1, Figure 4-3). The combined loading from these three sources accounted for 97% of the total fecal coliform bacterial load to the lake. Note that estimated fecal coliform loads are highly uncertain. For example, relative standard errors for Ley Creek, Ninemile Creek, and Metro (001) are 306%, 103% and 66%, respectively (Appendix F-6).

Total annual loads to Onondaga Lake for the 1996–2018 interval are presented in

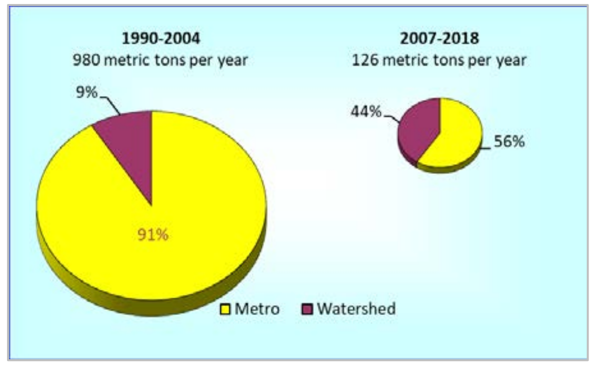


Figure 4-7. Contributions of Metro (outfalls 001+002) and the watershed to the total annual input of ammonia-N to Onondaga Lake, average for 1990–2004 compared to the average for 2007–2018.

Appendix F-7. Flow-weighted concentrations for 2018 are presented in Appendix F-8 and Appendix F-9.

Metro Performance

A schematic of the Metro treatment process, including the various outfalls, is available on page 32 of the Metro SPDES permit (Appendix E-1). 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 55 million gallons per day (mgd) in 2018, which was discharged to the lake through Outfall 001. On an annual basis, discharge from Outfall 001 was more than 20 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 E-2). There were 44 secondary bypasses in 2018, which had a combined duration of 450 hours and a total volume of 464 million gallons. Less frequently, the inflow receives secondary treatment and disinfection prior to discharge via Outfall 01A (tertiary bypass; Appendix E-3). In 2018 there were 4 tertiary bypasses that contributed a total of 0.62 million gallons over a period of 0.53 hours. Note that this total does not include permitted suspension of tertiary treatment during construction. Rarely, under particularly extreme runoff conditions or plant construction, influent flow volumes to Metro greater than 240 MGD receive no treatment but are to be disinfected prior to being discharged via Outfall 01B (headworks bypass volumes; Appendix E-4) as required by the Metro SPDES Permit (NY 0027081). Disinfection is performed on all flows between April 1 and October 15. There were 9 headworks bypasses in 2018 that lasted 13.82 hours and discharged a total volume of 15.52 million gallons. During six (6) of the nine (9) bypass events, the low lift pump station throttled as the plant was at reduced capacity associated with Metro Optimization Implementation Project and/or Metro 1978 Plant Evaluation inspections.

Metro's annual discharge volumes for 2010–2018 are summarized in Appendix E-5. The extent to which bypasses occur depends primarily on precipitation (both total volume and intensity) and construction projects at the plant.

Metro performance, relative to the requirements of the SPDES permit dated July 1, 2017, is summarized in Appendix E-6. No violations of permit limits were reported for Outfall 001 in 2018 for the following parameters: flow, CBOD5, suspended solids, fecal coliform bacteria, pH, ammonia, total phosphorus, cyanide, and total mercury. The SPDES permit limit for settleable solids was exceeded on five occasions due to high flows and exacerbated by the permitted shutdown of tertiary treatment.

The seasonal regulatory limits for ammonia concentrations in Metro effluent are 1.2 mg/L from June 1 to October 31 and 2.4 mg/L for November 1 to May 31. These limits were exceeded on a monthly average basis during periods of 2018 when tertiary treatment was suspended; 2017 conditions are included for reference (Appendix E-7). Note that an interim construction limit of 10 mg/L ammonia-N was requested on 10/23/17 and granted on 8/20/18.

Compliance with the effluent TP limit is calculated as a 12-month rolling average concentration; the current limit is 0.10 mg/L. (Appendix E-8). Metro's TP limit has been met since the Actiflo® treatment process came on line. In 2018, the average total phosphorus concentration in the Metro effluent was 0.188 mg/L. The higher TP values in 2018 were caused by the phosphorus optimization project, which required shutdown of tertiary treatment for nearly five months during 2018. The County requested an interim construction limit of "monitor only" for total phosphorus on 10/23/17, which was granted on 8/20/18.

Twenty-one SPDES limit violations were documented for Metro Outfall 01A, 002, and the aggregate outfall (calculated sum of Outfalls 001, 01A, 01B, and 002) during 2018 (Appendix

E-6). Ten violations were related to the TP limit for Outfall 002, which may have been the result of overestimated flows.

Prohibited Combined and Sanitary Sewer Overflows

OCDWEP tracks the occurrence and volumes of combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) within the Onondaga County service area each year. Certain overflows are prohibited; these include dry weather overflows and bypasses of the collection and treatment system, known as sanitary system overflows (SSOs). Documentation of the prohibited CSO and SSO events that occurred during 2018 is presented in Appendix E-9 and Appendix E-10. Annual summaries for the 2010–2018 period are presented in Appendix E-11.

Largemouth bass from Onondaga Lake on Display at the 2019 Clean Water Fair.

Compliance with Ambient Water Quality Standards

Several segments of Onondaga Lake's tributary streams are included on the 2016 NYSDEC compendium of impaired waters; these stream segments are also included on the draft 2018 list, which had not been finalized as of December 2019. NYSDEC places waterbodies on this list when there is evidence that water quality conditions do not meet applicable standards, and/or the water bodies do not support their designated use. The 2016 New York State Section 303(d) List identifies several additional pollutants causing impairments in Onondaga Lake and its tributaries that have no corresponding AWQS (see Appendix A-2). This report only addresses those impairments that can be evaluated relative to an AWQS using AMP data collected during 2018. Results of Onondaga County's AMP are among the primary data sets used to evaluate compliance with standards and use attainment.

The 2018 tributary data indicate that the major tributaries were generally in compliance with AWQS for most monitored parameters (Table 4-2, Appendix F-12). As in previous years, the primary exceptions continued to be total dissolved solids (TDS), fecal coliform bacteria (FC), and dissolved mercury. The AWQS for TDS (500 mg/L) was exceeded at all of the tributary monitoring sites, and often by a wide margin. Contravention of this standard is primarily associated with watershed hydrogeology, not anthropogenic effects. Compliance with the TDS standard was not among the goals of the remediation program.

The AWQS for fecal coliform bacteria is calculated as the geometric mean of a minimum of five observations per month; this value may not exceed 200 colony forming units (cfu) per 100 milliliters (mL). Fecal coliform bacteria counts in the tributaries are primarily affected by stormwater runoff and CSOs, although elevated counts are occasionally measured during dry conditions. CSO remedial measures and improved stormwater management measures remain underway.

Among the objectives of the AMP is to track changes in the input of bacteria to Onondaga Lake during wet weather. WEP also tracks bacterial abundance during non-storm periods; these observations can help identify potential illicit connections of sanitary waste to the stormwater collection system, or portions of the sewerage infrastructure in need of repair.

All the tributary monitoring sites regularly exceeded the AWQS for fecal coliform bacteria (Table 4-2, Appendix F-12), including the Tully Farms Road site located near the headwaters of Onondaga Creek. Note that only Harbor Brook, Onondaga Creek, and Ley Creek receive CSOs. In fact, volume-weighted fecal coliform concentrations in non-CSO Ninemile Creek exceeded those in Onondaga Creek, Ley Creek, and Harbor Brook by a wide margin (Appendix F-8, Appendix F-9), indicating that CSOs are not the only source of bacteria in this urban watershed.

Dissolved mercury concentrations were also out of compliance at Bloody Brook, Ley Creek, Sawmill Creek, and Trib. 5A during 2018 (Table 4-2, Appendix F-12). This parameter was monitored once each quarter. Past industrial activities may have caused elevated mercury levels in some areas. Several researchers have identified biogeochemical processes within wetlands as a potential source of mercury to downstream waters (Hall et al. 2008, Hurley et al. 1995, Rudd, 1995, St. Louis et al. 1994), and the wetland located near the mouth of Sawmill Creek likely contributes to elevated levels of dissolved mercury in this stream. Atmospheric deposition is a source of mercury as well.

Table 4-2. Summary of tributary compliance (percent of observations in compliance) with ambient water quality standards (AWQS), 2018.

Site	Field Data		Solids	Nitrogen	Metals	Bacteria[1]
	Dissolved Oxygen (4mg/L)	pH	TDS	Ammonia-N	Dissolved Mercury	Fecal Coliform
Bloody Brook at Onon. L. Parkway	100% (37)	100% (35)	0% (4)	100% (4)	50% (4)	14% (37)
Harbor Brook at Hiawatha Blvd.	100% (49)	96% (46)	4% (28)	96% (27)	100% (4)	0% (49)
Harbor Brook at Velasko Rd.	100% (45)	100% (41)	0% (24)	100% (21)	100% (4)	57% (47)
Ley Creek at Park St.	100% (44)	100% (42)	0% (23)	100% (23)	50% (4)	29% (44)
Ninemile Creek at Lakeland	98% (45)	100% (41)	0% (24)	100% (22)	100% (4)	43% (45)
Onondaga Creek at Kirkpatrick St.	100% (45)	100% (41)	0% (24)	100% (22)	100% (4)	14% (45)
Onondaga Creek at Dorwin Ave.	100% (45)	100% (41)	29% (24)	100% (22)	100% (4)	29% (45)
Sawmill Creek at Onon. L. Rec. Area	100% (37)	100% (35)	0% (4)	NS (0)	50% (4)	29% (37)
Trib. 5A at State Fair Blvd.	100% (37)	100% (35)	0% (4)	100% (4)	75% (4)	29% (37)

[1]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; the number of observations is shown in parentheses; NS is not sampled.

Occasional exceedances of AWQS for pH and ammonia at Harbor Brook-Hiawatha have been associated with a milky discharge observed in the vicinity of the bridge at Hiawatha Blvd. Single violations of the dissolved oxygen standard were documented at Ninemile Creek and the Onondaga Lake Outlet during 2018 (Table 4-2, Appendix F-12).

Long-Term Trends

The long-term AMP monitoring data set provides managers with the opportunity to assess water quality trends in tributaries to Onondaga Lake. The 2018 AMP report includes a series of graphs and tables of long-term trends in both concentrations and loads. Details are provided in Appendix F-7, Appendix F-13, Appendix F-14, Appendix F-15, Appendix F-16, and Appendix F-17.

The major findings related to **concentration trends in Metro effluent** include:

- The general long-term decreasing concentration of wastewater-related parameters (TP, ammonia-N) in Metro effluent since 1990 in response to the engineering improvements (Figure 4-4, Figure 4-6).
- Long-term improvements in the quality of the Metro effluent were interrupted in 2017 and 2018 due to construction projects (e.g., phosphorus optimization) that resulted in higher concentrations of phosphorus, ammonia, and nitrite (Appendix E-7, Appendix E-8, Appendix F-14).

The major findings related to concentration trends for the natural tributaries include:

- Decreasing counts of fecal coliform bacteria during 2009-2018 at the downstream Onondaga Creek site (Kirkpatrick; Appendix F-14, Appendix F-16).
- Decreasing ammonia, nitrate, and total Kjeldahl nitrogen concentrations in Ley Creek during 2009-2018 (Appendix F-14).
- Increasing nitrite concentrations in Onondaga Creek, Ninemile Creek and Harbor Brook during 2009-2018 (Appendix F-14). The reason for these increases is unknown.
- Decreasing TP and SRP concentrations at Harbor Brook – Hiawatha during 2009-2018 (Appendix F-14).

The major findings related to loading trends for Metro and the natural tributaries include:

- Long-term decreases in total P and total dissolved P loads since 1991 have been driven by reductions in the Metro contribution (Appendix F-13). Year-to-year variations in TP loading from the watershed reflect differences in the timing and magnitude of runoff.
- Long-term decreases in ammonia-N loading and increases in nitrate loading from the late 1990s through 2004 are associated with implementation of year-round nitrification at Metro (Appendix F-13).
- Noteworthy long-term reductions in Metro fecal coliform bacteria loads are evident from 1991 through 2015, with an increasing trend observed in recent years (2016 through 2018) due to construction (Appendix F-13). Increased loading of ammonia, nitrite, soluble reactive phosphorus, and fecal coliform in 2018 was the result of construction at Metro (Appendix F-15).

- Reductions in fecal coliform loading from Onondaga Creek and Harbor Brook during 2009-2018 (Appendix F-15).

Fecal coliform concentrations in the CSO-affected tributaries (Onondaga Creek, Harbor Brook, and Ley Creek) during 2018 are presented as annual geometric means for both wet and dry weather conditions (Figure 4-8). Wet weather samples are those collected following at least 0.1 inches of rain in the preceding 48 hours; all other samples were classified as dry weather samples. Both upstream and downstream results are reported for Onondaga Creek (at Dorwin Ave., Kirkpatrick St.) and Harbor Brook (at Velasko Rd., Hiawatha Blvd.). Only downstream samples are available for Ley Creek (Park St.).

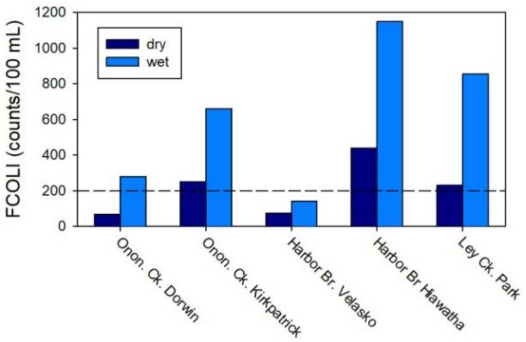


Figure 4-8. Comparisons of wet weather and dry weather fecal coliform concentrations (geometric means) in Onondaga Lake tributaries during 2018. The value of the AWQS for fecal coliform (200 counts/100 mL) is shown for reference.

Onondaga Lake Outlet.

Fecal coliform bacteria counts were higher at downstream sampling sites and during wet weather conditions (Figure 4-8). These increases were associated with bacterial inputs from CSOs and other urban sources. Note, however, that fecal coliform concentrations at the upstream sampling site in Onondaga Creek (Dorwin) were also elevated during wet weather.

Long-Term Trends in Tributary Fecal Coliform Bacteria

This section presents fecal coliform concentration trends in the CSO receiving streams for the period 1985 to 2018. Averaging techniques were used to smooth the fecal coliform time series and highlight the underlying temporal patterns in monthly (Figure 4-9) and annual (Figure 4-10) geometric means. Locally estimated scatterplot smoothing (LOESS) was used to assist with the visual interpretation of these time series (see red curves). The trend plots include routine monitoring data collected during both dry and wet weather conditions. High frequency data collected during storm events (e.g. post-construction compliance monitoring and recovery time monitoring programs) were not included in the long-term trend analysis to avoid potential bias associated with the uneven temporal coverage of these monitoring programs. Prior to April 2010, fecal coliform samples were collected at each tributary sampling site during the biweekly sampling events. Starting in April 2010, the frequency of bacterial sampling increased to five samples per month to support assessments of compliance with the AWQS for fecal coliform bacteria.

Note that the Dorwin Avenue monitoring site is located upstream of all Onondaga Creek CSOs and the Kirkpatrick Street site is located downstream of CSOs. For Harbor Brook, the Velasko Road monitoring site is located upstream of all CSOs and the Hiawatha Boulevard site is located downstream of CSOs.

The trends illustrated in Figure 4-9 and Figure 4-10 indicate:

- Modest increases in fecal coliform concentrations at both Onondaga Creek-Dorwin and Ley Creek in recent years.
- Fecal coliform concentrations at Onondaga Creek-Kirkpatrick have steadily decreased.
- Fecal coliform concentrations at both Harbor Brook-Velasko and Harbor Brook-Hiawatha have remained rather uniform in recent years.
- These results are consistent with the emphasis of phased improvements to Onondaga Creek due to the higher pre-ACJ number of operational CSOs (50), as compared to Harbor Brook (20) and Ley Creek (2). Since 1998, a combination of infrastructure projects has resulted in the closure or abatement of 41 of the 50 CSO relief points to Onondaga Creek.

A detailed analysis of long-term trends in fecal coliform concentrations is provided in Appendix F-16.

Post Construction Compliance Monitoring (PCCM)

Overview of the PCCM Program

Onondaga County is required by the ACJ Fourth Stipulation to conduct a PCCM program to evaluate the effectiveness of both green and

WEP Technician Sampling Onondaga Creek.

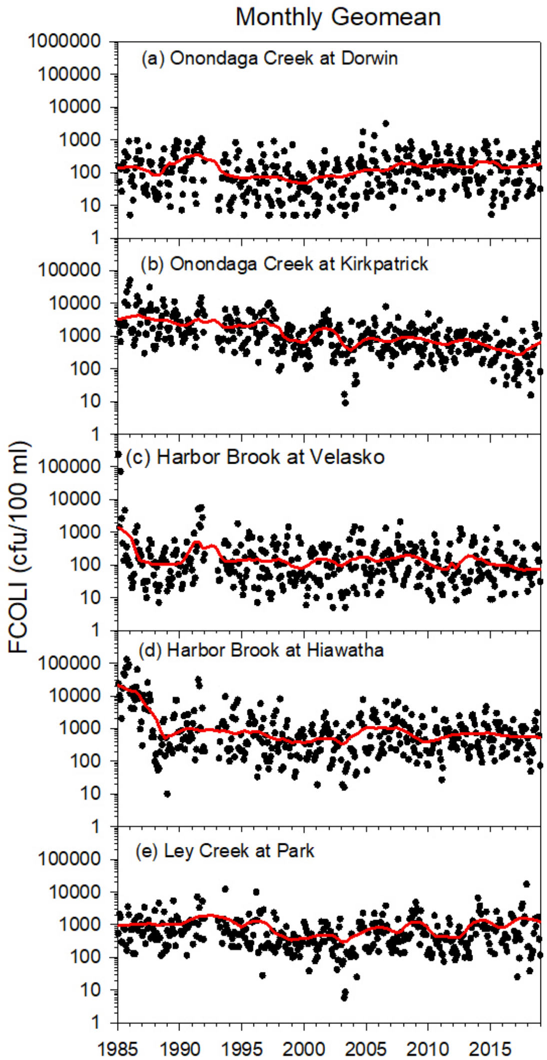


Figure 4-9. Monthly geometric mean fecal coliform (FCOLI) concentrations measured in Onondaga Creek, Harbor Brook and Ley Creek for 1985-2018.

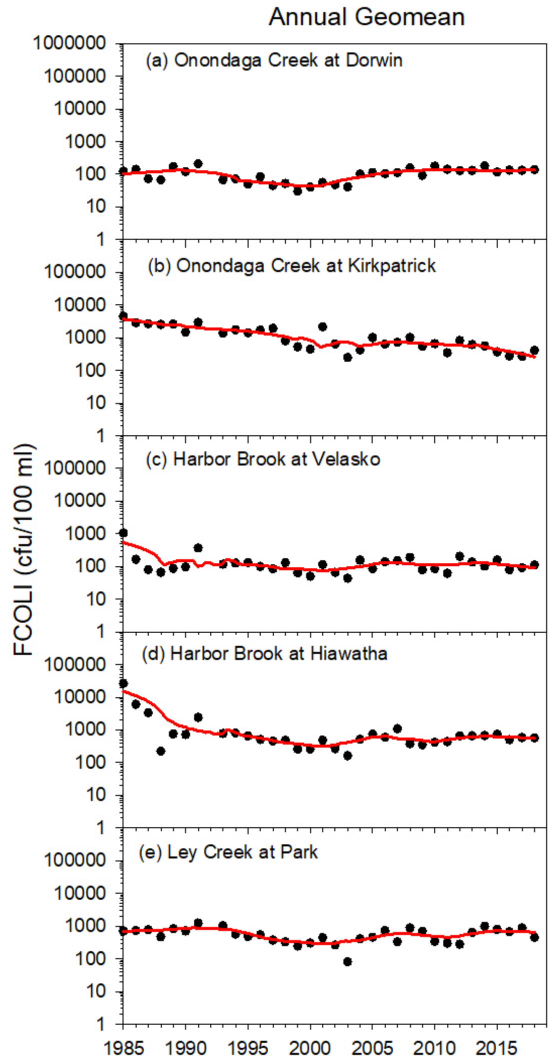


Figure 4-10. Annual geometric mean fecal coliform (FCOLI) concentrations measured in Onondaga Creek, Harbor Brook and Ley Creek for 1985-2018.

gray CSO controls, to assess whether ambient water quality standards (AWQS) are being met, and to determine whether the remaining CSOs cause or contribute to violations of AWQS. The PCCM program includes monitoring of water quantity and water quality of CSOs and the receiving streams (Onondaga Creek and Harbor Brook).

Since 2015, Onondaga County DWEP has completed 12 PCCM events, seven on Harbor Brook and five on Onondaga Creek. The monitoring targeted storms with rainfall intensities of at least 0.35 inches of rain per hour. Based on modeling and observations, most of the operational CSOs discharge when the rainfall intensity meets this threshold. Monitoring was conducted upstream and downstream of CSO discharges to evaluate water quality impacts during wet weather. Data analysis focused on patterns in fecal coliform concentrations and estimated loadings. Results from the 2015 and 2016 PCCM sampling indicated that CSO discharges contributed importantly to elevated fecal coliform levels in Onondaga Creek and Harbor Brook during monitored wet weather events (see the 2015 and 2016 Annual AMP reports for additional details).

The 2018 Recovery Time Monitoring (RTM) Program

Onondaga County WEP successfully completed two Recovery Time Monitoring (RTM) events on Harbor Brook and Onondaga Creek during 2018, one in August and one in October (Table 4-3). The primary objective of the 2018 RTM was to document the time-course of fecal coliform recovery following significant wet weather events. Rainfall totals were 0.61 to 1.12 inches for the August and October events, respectively. Rainfall intensity was 0.33 inches per hour for the August event and 0.31 inches per hour for the October event. Detailed summaries of the 2018 RTM events are provided in Appendix F-17.

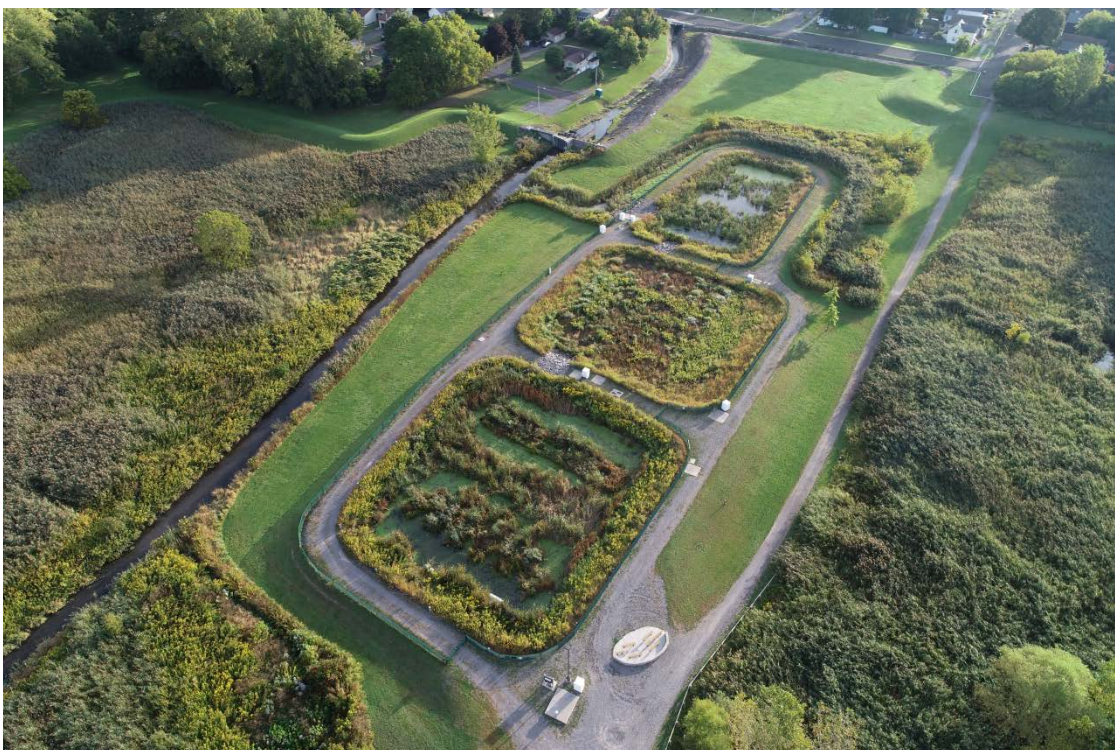
Salient findings from the two RTM events completed on Harbor Brook and Onondaga Creek include:

- Estimates of recovery times are complicated by the occurrence of multiple intervals of rainfall and multiple stream responses within a single event.
- Estimated recovery times for the August 17-22 event were 72 hours for Onondaga Creek and 59 hours for Harbor Brook. However, fecal coliform concentrations did not return to levels consistent with the AWQS in either stream following this event.
- Estimated recovery times for the October 2-7 event were 81 hours for Onondaga Creek and 80 hours for Harbor Brook. These estimates were based on single sample results from both streams that indicated fecal coliform concentrations similar to the value of the AWQS (200 cfu/100 mL). Fecal coliform concentrations subsequently increased in both streams in response to intermittent rainfall.

Table 4-3. Summary of monitoring results for 2018 RTM sampling events.

Stream	Date	Total Rainfall l (in)	Maximum Intensity[1] (in/hr)	Pre-Storm Fecal Coliform (cfu/100 mL)	Maximum Fecal Coliform (cfu/100 mL)	Post-Storm Fecal Coliform (cfu/100ml)	Approximate recovery time (hr)
Onondaga Creek	Aug. 17-22, 2018	0.61	0.33	--	>200,000	3,300	72
Onondaga Creek	Oct. 2-7, 2018	1.12	0.31	320	188,000	225	81
Harbor Brook	Aug. 17-22, 2018	0.61	0.33	--	>200,000	892	59
Harbor Brook	Oct. 2-7, 2018	1.12	0.31	350	49,000	210	80

[1]Maximum intensity (in/hr) represents the maximum amount of rainfall recorded at Metro during any one-hour period.



Harbor Brook CSO 018 Constructed Wetlands.

Connect the Drops ad campaign.

Section 5. Onondaga Lake Water Quality

Onondaga Lake Sampling Program

The Ambient Monitoring Program (AMP) encompasses multiple physical, chemical, and biological parameters of Onondaga Lake (Appendix A-3). 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.

WEP also tracks physical factors, such as the development and extent of ice cover (Appendix G-1). Since the winter of 1987-1988, the duration of lake-wide ice cover has averaged 34 days and ranged from a minimum of 0 days in the winter of 1997-1998 to a maximum of 95 days in 2013-2014. During the winter of 2017–2018, ice cover extended for 55 days in the north basin and 53 days lake wide. Ice cover was first reported on December 14, 2017 and last reported on February 23, 2018.

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. Results from North Deep and South Deep remained comparable in 2018 (Appendix G-2). The AMP also includes sampling of a network of ten near-shore locations for three parameters related to suitability for water contact recreation: Secchi disk transparency, turbidity, and fecal coliform bacteria.

Macroinvertebrate Sampling, 2018.

Trophic State

The trophic state of a lake refers to its level of primary production (production of organic matter through photosynthesis). 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 noxious blooms and harmful toxins, 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 aquatic organisms.

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. TP, Chl-*a*, and SD are all related to the amount of phytoplankton (microscopic algae) present in the water column.

Phosphorus

Total phosphorus (TP) concentrations in the upper waters of the lake remained near 20 µg/L for much of the 2018 monitoring period (Figure 5-1a). Only following major runoff events in April and November did TP concentrations exceed 30 µg/L. Note that the higher TP levels during November did not coincide with increases in algal biomass (Figure 5-1b). Total phosphorus concentrations in the upper waters of the lake averaged 20 µg/L during the summer (June–September) of 2018, matching the New York State guidance value.

Concentrations of total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) remained low during the summer months and increased during November (Figure 5-1a).

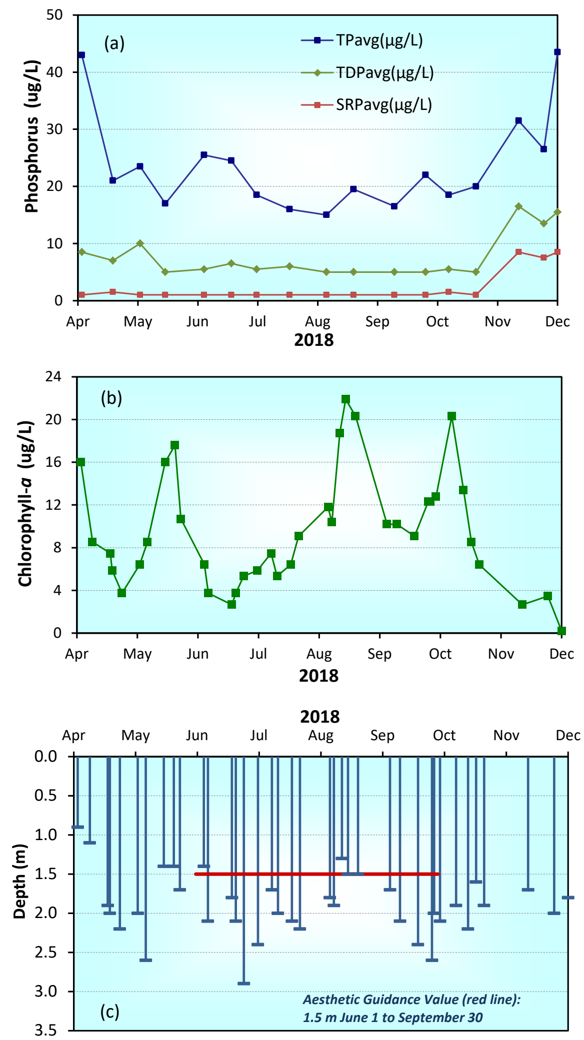


Figure 5-1. Time series of concentrations in the upper waters (0-3 meters) of Onondaga Lake during 2018 for (a) total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP), (b) chlorophyll-*a*, and (c) Secchi disk transparency.

Concentrations of TP in the upper waters have decreased substantially since the early 1990s (Figure 5-2a). 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 watershed loading, and food web structure. Summer average concentrations of both TDP and SRP have been consistently low since 2007.

Sailing on Onondaga Lake.

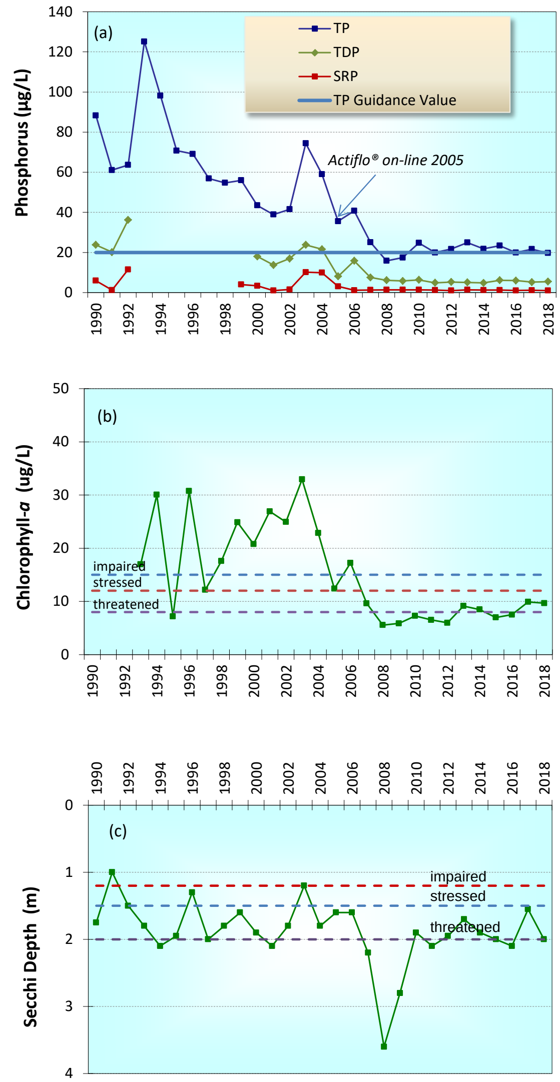


Figure 5-2. Summer (June to September) average concentrations in the upper waters (0-3 meters) of Onondaga Lake (South Deep), 1990–2018 for (a) total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP), (b) chlorophyll-*a*, and (c) Secchi disk transparency (median values).

Note: TDP data not collected during 1993-1999. SRP data not collected during 1993-1998. NYSDEC values corresponding to impaired, stressed, and threatened conditions are shown.

Section 5. Onondaga Lake Water Quality

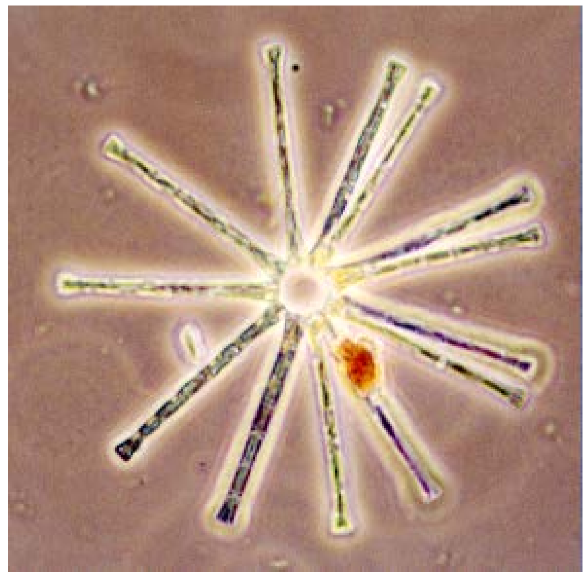
Chlorophyll-*a*

Chlorophyll-*a* (Chl-*a*) concentrations in the upper waters of the lake in 2018 ranged from <0.2 µg/L on December 4 to a peak of 21.9 µg/L on August 16 (Figure 5-1b). The summer average Chl-*a* concentration in 2018 was 9.7 µg/L, slightly lower than measured in 2017 but higher than observed in most recent years (Figure 5-2b).

Summer average concentrations of Chl-*a* in Onondaga Lake have declined substantially, particularly since the Actiflo® upgrade at Metro in 2005 (Figure 5-2b). Chl-*a* concentrations, which commonly exceeded a summer average of 15 µg/L during 1990–2004, have remained below 12 µg/L since 2007 (Figure 5-2b).

Summer data (June–September) are used to track suitability of the lake for recreational uses. NYSDEC (2009) defines Chl-*a* thresholds for suitability for recreational use as follows: above 8 µg/L recreational uses are stressed; above 12 µg/L they are threatened, and above 15 µg/L the uses are impaired.

Algal blooms are generally aesthetically undesirable and potentially harmful depending on the dominant taxa. In the absence of state or federal criteria, the AMP has relied upon the judgment of experts (OLTAC and consultants) to identify Chl-*a* thresholds that are consistent with the occurrence of "minor" and "major" algal blooms (i.e., impairments) in Onondaga Lake. Thresholds of 15 µg/L and 30 µg/L have been established and used to represent minor blooms (impaired conditions) and major blooms (noxious conditions), respectively. According to these criteria, and based on laboratory measurements of 20 samples, there were three minor algal blooms in Onondaga Lake during the summer of 2018 (Figure 5-1b; Figure 5-3). These minor blooms were documented on three consecutive sampling dates in August (8/13, 8/16, 8/21) (Figure 5-1b). The threshold for minor blooms was also exceeded on three occasions outside of the summer period, during early April, mid-May, and early October.



Two Diatom Species Found in Onondaga Lake.

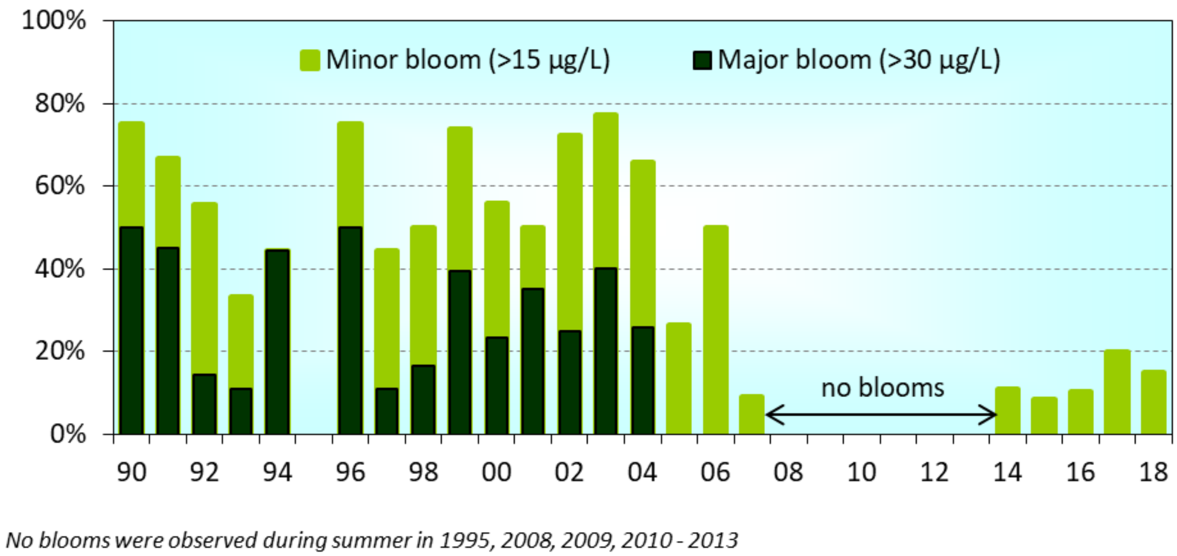


Figure 5-3. Percent occurrence of summer (June to September) algal blooms in Onondaga Lake evaluated annually for the 1990–2018 period, based on chlorophyll-*a* measurements taken at South Deep.

Secchi Disk Transparency

The Secchi disk, a 25 centimeter diameter disk with alternating black and white quadrants, is a standard tool for measuring lake clarity. 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 (Appendix A-5).

Based on South Deep measurements, the average water clarity of Onondaga Lake during the summer of 2018 was 2.0 meters and ranged from 1.3 to 2.9 meters (Figure 5-1c). Unusually low water clarity during the summer of 2017 (Figure 5-2c) was likely caused by elevated algal biomass and the influx of inorganic particles during storms. The unusually high water clarity observed in both 2008 and 2009 was the result of grazing by large *Daphnia* populations. The *Daphnia* were able to thrive due to low abundance of alewife, a planktivorous fish, during these years.

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 2018 and are displayed as color contour plots (Appendix G-4). 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 and the Upstate Freshwater Institute (UFI) (http://www.upstatefreshwater.org/NRT-Data/Data/data.html).

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 5-4) and contravention of the related AWQS. This goal has been achieved through reductions in Metro loading of both ammonia-N and total phosphorus.

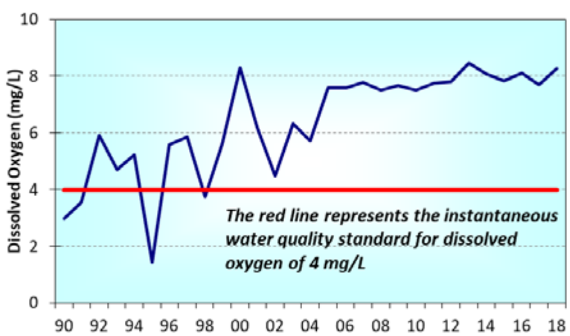


Figure 5-4. Minimum dissolved oxygen (DO) concentration in the upper waters (0-4 meter average) of Onondaga Lake during October, annually 1990–2018.

Biological monitoring of Onondaga Lake.

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 AWQS 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 5-5), enabling a more diverse biota. The lake is now in full compliance with the ambient water quality standards 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. Higher ammonia-N concentrations in 2018 were the result of suspension of tertiary treatment during project-related construction at Metro.

Efficient year-round nitrification treatment at Metro resulted in increased nitrate (NO_3-N) concentrations in Onondaga Lake (Figure 5-5b), which in turn caused diminished release of phosphorus and mercury from the sediments during intervals of anoxia (Matthews et al. 2013). To further abate sediment release of methylmercury, Honeywell has augmented nitrate levels in the hypolimnion through a program of targeted nitrate addition conducted annually during 2011-2017. Lower nitrate concentrations in 2018 were the result of suspension of tertiary treatment during construction at Metro.

Historically, nitrite (NO_2-N) concentrations commonly exceeded the AWQS of 0.1 mg/L intended to protect against possible toxicity effects. In-lake concentrations of nitrite, and exceedances of the AWQS, were greatly reduced following treatment upgrades to the biological aerated filter (BAF) at Metro.

Compliance with Ambient Water Quality Standards (AWQS)

The 2018 monitoring results indicate that the open waters of Onondaga Lake were in compliance with most ambient water quality standards (AWQS), with exceptions noted in Table 5-1. The concentration of total dissolved solids (TDS), which primarily reflects the concentration of the major ions, 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 its watershed.

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

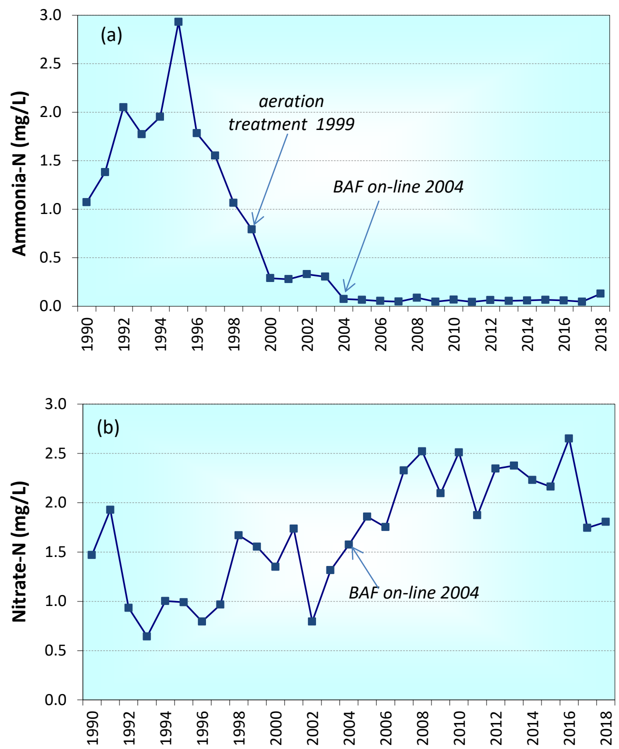


Figure 5-5. Summer average concentrations in the upper waters (0-3 meters) of Onondaga Lake, 1990–2018 for (a) ammonia-N, and (b) nitrate-N.

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 was approved by USEPA in 2012. The TMDL is intended to achieve the in-lake guidance value of 20 µg/L. The summer average total phosphorus (TP) concentration in 2018 was 20 µg/L, matching the state's guidance value.

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 2018.

Parameter	AWQS/Guidance Value	Upper Waters % compliance	Lower Waters % compliance
Dissolved Oxygen	≥ 4 mg/L instantaneous[1]	100%	*48%*
Dissolved Oxygen	≥ 5mg/L daily average[1]	100%	*45%*
pH	6.5-8.5	100%	100%
Total Phosphorus	≤ 20 µg/L summer average[2]	100% (20 µg/L)	--
Ammonia-N	Variable[3]	100%	100%
Nitrite	≤0.1 mg/L	88%	88%
Total Dissolved Solids	≤500 mg/L	0%	0%
Dissolved Mercury	≤0.7 ng/L	100%	100%
Fecal Coliform Bacteria	≤200 cfu/100 mL monthly geomean[4]	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 three 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 of at least 5 samples being less than or equal to 200 colony forming units (cfu) per 100 milliliters (mL) during the period of Metro disinfection (Apr 1-Oct 15).

The AWQS for nitrite (0.1 mg/L) was exceeded on July 19 (15 m depth) and on November 14 and 27 (3, 15, 18 m depths). Elevated nitrite concentrations in the lower waters during early summer are a recurring phenomenon associated with incomplete nitrification of ammonia-N during periods of hypoxia. The November exceedances were likely due to suspension of tertiary treatment at Metro during project related construction.

Throughout the April–October interval of 2018, fecal coliform levels were in compliance with the AWQS at both offshore sampling locations (South Deep and North Deep). In addition, eight of the ten nearshore sampling sites were in continuous compliance with the AWQS throughout the April–October period (Figure 5-6). Two nearshore sites, located within the Class C segment of the lake's southeastern shoreline (Figure 5-6), exceeded the standard for fecal coliform bacteria during the months of May and October. One of these sites also exceeded the AWQS in April. Note that Metro does not disinfect after October 15. Graphical results for 2008-2018 are provided in Appendix G-6.

Water clarity is measured five times per month during June–September with a Secchi disk 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). The NYSDOH guidance value was met for at least 90% of measurements at nine of the ten nearshore sites (Figure 5-7). The site near the mouth of Onondaga Creek failed to meet this guidance value on 25% of the monitored days (Figure 5-7). Graphical results for 2008-2018 are provided in Appendix G-7.

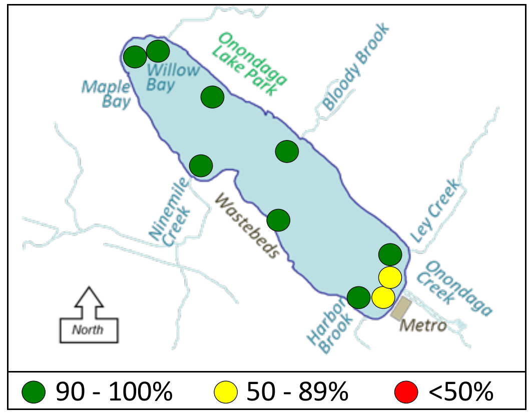


Figure 5-6. The percentage of months in compliance with the water quality standard for fecal coliform bacteria for nearshore stations in Onondaga Lake, April–October 2018.

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).

Canoe rental at Onondaga Lake.

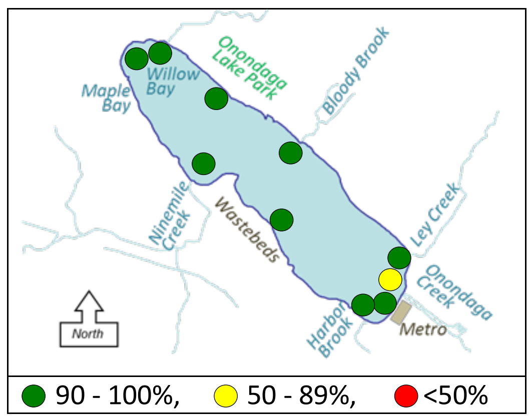


Figure 5-7. Percentage of nearshore Secchi disk transparency measurements greater than 1.2 meters (4 feet) during June–September 2018.

Section 5. Onondaga Lake Water Quality

OCDWEP technician collecting water samples from Onondaga Lake.

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 several key water quality parameters and restoration of impaired uses. In this section long-term trends are evaluated statistically.

10–Year Water Quality Trends: 2009–2018

The two-tailed seasonal Kendall test was applied to data from north and south deep sites (open waters) to evaluate whether trends in water quality conditions between 2009 and 2018 were statistically significant. (Appendix G-8). Note that long-term water quality improvements associated with the Metro upgrades of 2004-2005 predate this 10-year interval. Significant **decreasing** trends were identified for Secchi depth in the northern basin and total phosphorus, soluble reactive phosphorus, and temperature in the lower waters of the southern basin (Appendix G-8). Fecal coliform bacteria counts increased significantly in both the southern and northern basins, while total suspended solids increased only in the southern basin.

N to P Ratios and Cyanobacteria

The ratio of the major plant nutrients nitrogen and phosphorus is an important determinant of the composition of the phytoplankton community. The relative concentrations of bioavailable nutrients can have water quality management implications, particularly with respect to phytoplankton speciation and the risk of cyanobacterial blooms. Cyanobacteria (blue-green algae) 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 waters of Onondaga Lake has been a long-term management strategy to discourage cyanobacteria. As reported by Smith (1983), 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).

The time series of the summer average (June 1–September 30) TN:TP ratio for the lake's upper waters is presented for the 1998–2018 period (Figure 5-8). The TN:TP ratio has remained above the literature N:P threshold for increased risk of cyanobacteria dominance since 1998 (Figure 5-8). The higher values after 2007 reflect systematic decreases in total phosphorus loading from Metro, with mostly unchanging TN concentrations. 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. Although cyanobacteria have not been an important component of the phytoplankton community in recent years, there has been a modest increase in their relative abundance (Appendix H-1).

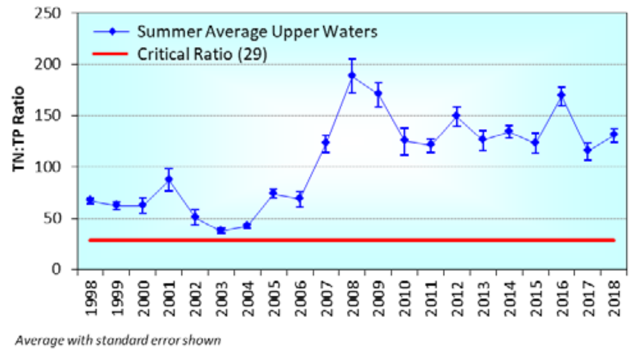


Figure 5-8. Summer average ratio of total nitrogen to total phosphorus (TN:TP, by weight) in the upper waters of Onondaga Lake, 1998–2018.

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

Section 5. Onondaga Lake Water Quality

Sunset at Onondaga Lake.

Section 6. Biological Conditions and Long-Term Trends

Phytoplankton

The average and peak biomass of phytoplankton (including algae and cyanobacteria) in Onondaga Lake has declined sharply over the last two decades. Following completion of the advanced phosphorus removal facilities at the Metro wastewater treatment plant, annual average algal biomass has remained below 2 mg/L (Figure 6-1). While phosphorus concentrations have remained relatively constant, since 2005, year-to-year variability in phytoplankton abundance is related to other ecosystem factors such as zooplankton.

Figure 6-1. Average annual phytoplankton biomass (April – October) in Onondaga Lake, 1998-2018.

In 2018, algal biomass peaked at 4.5 mg/L on July 2; the commuity was dominated by diatoms during the bloom (Figure 6.2). Diatom biomass was higher than in recent years and exceeded the average for 2007-2017. A spring diatom bloom was present in May 2018. Diatoms then declined in June but rebounded in July and remained relatively abundant through the summer. The most abundant algal genera in 2018 were the diatoms *Urosolenia*, *Fragilaria*, and *Diatoma*, followed by *Chrysochromulina* (haptophyte), *Cryptomonas* (cryptophyte), *Peridinium* (dinoflagellate), and *Pseudanabaena* (cyanobacterium). Cyanobacteria (bluegreen algae) were uncommon in 2018 and peaked in from the end of September to early October. Cyanobacteria are rare in Onondaga Lake compared to nearby Oneida Lake, which has phosphorus concentrations similar to those measured in Onondaga Lake (Idrisi et al. 2016). A detailed report of the 2018 phytoplankton community structure is in Appendix H-1.

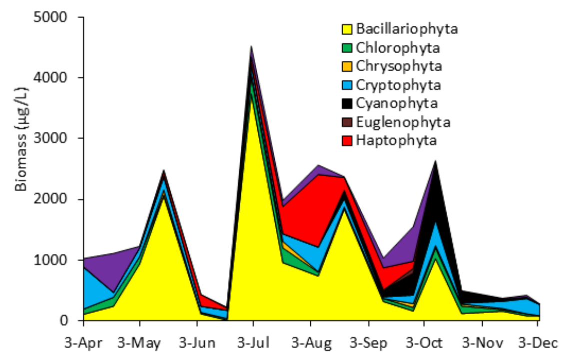


Figure 6-2. Temporal trends in biomass of phytoplankton divisions in Onondaga Lake, 2018.

Macrophytes

Macrophytes (defined as rooted aquatic plants and macroalgae) serve as breeding, feeding, and nursery grounds for many fish species and are an important food source for invertebrates and detritus-based organisims. Macrophytes also serve as a site for egg deposition by insects, zooplankton, and some fish species. Additionally, macrophytes help to stabilize bottom sediments by binding them and reducing wave action. Historically, Onondaga Lake's macrophyte community was extremely limited in areal extent and species richness; this was attributed to low water clarity from algal blooms and suboptimal sediment texture from calcium carbonate accretions (oncolites) resulting from legacy chemical waste disposal practices.

Surveys of the Onondaga Lake macrophyte community were included in the AMP to track progress toward recovery. Detailed field surveys were completed in 2000, 2005, and 2010. In addition, OCDWEP commissioned annual aerial imagery and ground truthing from 2001-2013 and in 2018 to monitor percent cover of macrophytes within the littoral zone. Extensive remedial dredging and capping activities precluded assessments between 2014-2017.

The annual surveys document a significant increase in macrophyte cover of the littoral zone in response to declining phosphorus concentrations and increased water clarity (Figure 6-3). The 2018 macrophyte survey report is included as Appendix H-2.

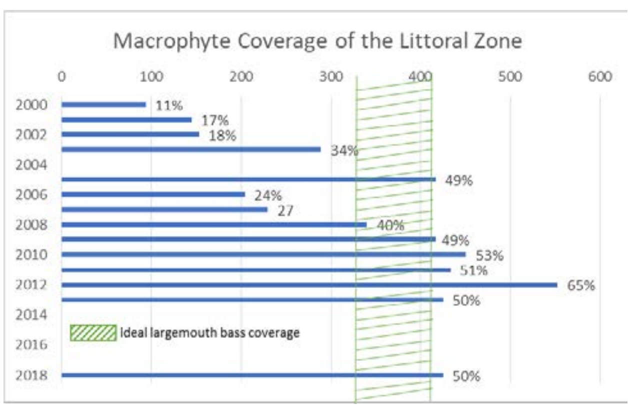


Figure 6-3. Macrophyte coverage of the littoral zone in Onondaga Lake, 2000-2013, 2018 (percent cover of the littoral zone noted in chart). 40% - 50% coverage is ideal for largemouth bass.

Zooplankton

Zooplankton play a key role in structuring the phytoplankton community and are in turn strongly affected by predation from planktivorous fishes. Zooplankton biomass in Onondaga Lake in 2018 was low but comparable to years 2010-2017 (Figure 6-4). *Daphnia* (large cladoceran zooplankton that effectively graze phytoplankton) again were not abundant in 2018. *Bosmina* (small cladocerans) and cyclopoid copepods (both *Diacyclops* and *Mesocyclops*) were the most abundant crustacean zooplankton. Density and biomass were highest in May and June and consisted mostly of *Bosmina* and cyclopoid copepods (Figure 6-5). *Daphnia* were present but rare in July. Zooplankton species and size composition in 2018 were similar to 2003-2007 and 2010-2017 when planktivorous alewife were abundant in the lake. A detailed report assessing the 2018 zooplankton community structure is included with the phytoplankton results in Appendix H-1.

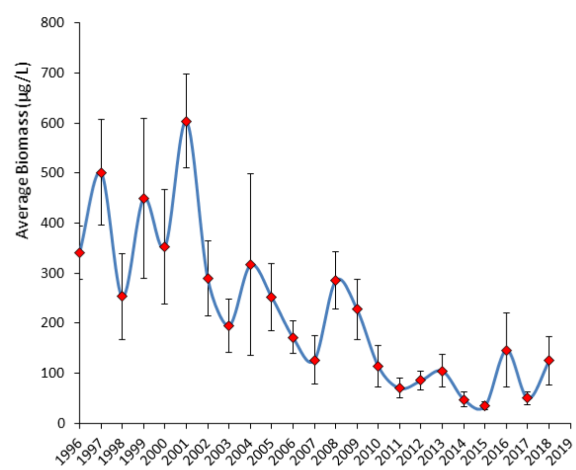


Figure 6-4. Average annual zooplankton biomass (April – October) in Onondaga Lake, 1996-2018.

Carp on display at the Clean Water Fair.

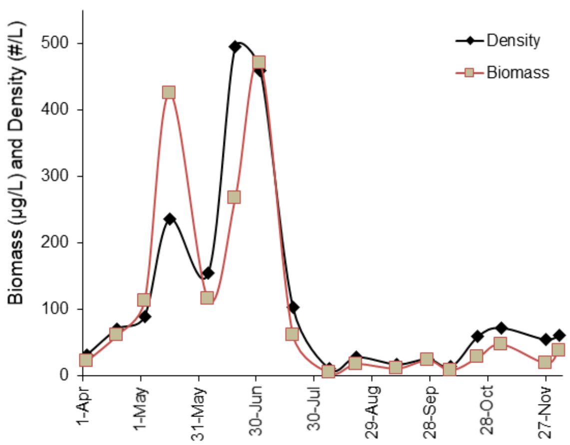


Figure 6-5. Density (#/L) and biomass (µg/L) of zooplankton in Onondaga Lake in 2018 from 15-m deep tows.

Dreissenid Mussels

Dreissenid mussels [zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*)] are invasive filter-feeding mussels. Both species were first found in Onondaga Lake in 1992, and their abundance and distribution in the lake have been monitored as part of the AMP since 2005. Because dreissenid mussels can reach high densities and are highly efficient filterers, they can significantly impact an ecosystem through filtering the water column and altering the benthic habitat.

Dreissenids were relatively rare in Onondaga Lake prior to 1998, but increased considerably in abundance by 1999, likely due to lower ammonia concentrations in the lake water in response to advanced wastewater treatment. Zebra mussels were initially the dominant dreissenid in the lake, but by 2009 they were surpassed by quagga mussels (Figure 6-6). Displacement of zebra mussels has been attributed to the quagga mussels' ability to grow faster at low food concentrations, adaptation to colder temperatures and ability to colonize soft substrates.

However, beginning in 2013, the proportion of dreissenid biomass composed of quagga mussels began to decline. In 2017 zebra mussel density was higher or similar to quagga mussel density in all depth zones sampled (0-9 m), and this continued to be the case in 2018. Shell-on biomass showed a similar relationship in the past two years (Figure 6-6). Such a decline in quagga mussels after the species became dominant has not been observed elsewhere (Strayer et al. 2018), making Onondaga Lake the first documented system in which zebra mussels returned to dominance after being largely displaced by quagga mussels. A detailed report of the 2018 dreissenid community is provided in Appendix H-3.

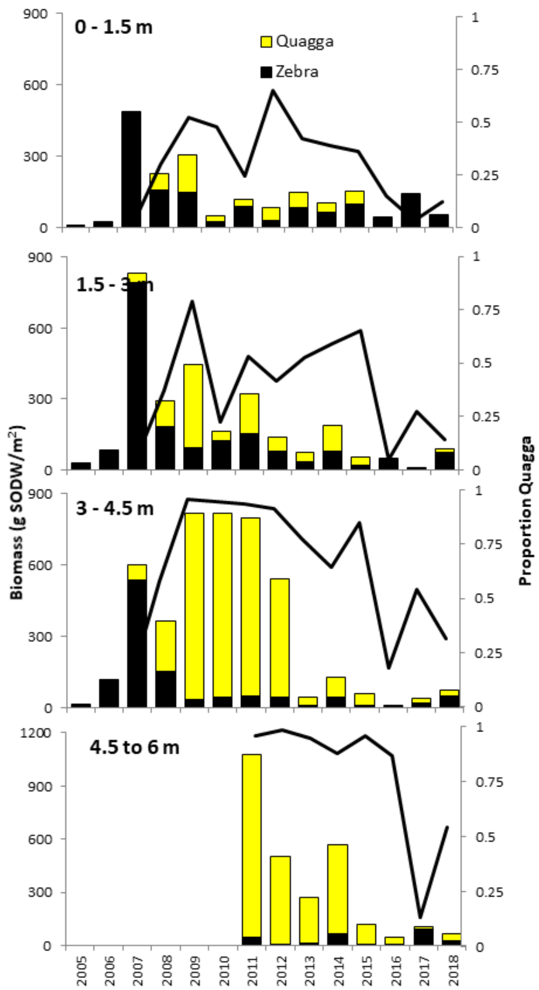


Figure 6-6. Shell-on dry weight of dreissenid mussels in four depth zones (0–1.5 m, 1.5–3 m, 3–4.5 m and 4.5–6 m) of Onondaga Lake, 2005–2018. Lines represent the proportion of quagga mussels.

Tributary Macroinvertebrates

The abundance and variety of aquatic macroinvertebrates (e.g., insects, worms, snails, mussels, leeches, and crustaceans) reflect the quality and health of a waterbody. The aquatic macroinvertebrate communities of three of Onondaga Lake's major tributaries (Onondaga Creek, Ley Creek, and Harbor Brook) have been monitored periodically since 2000 to evaluate response to implementation of combined sewer overflow (CSO) and non-point source control measures within the greater Onondaga Lake watershed. Macroinvertebrate communities of four sites on Onondaga Creek, three sites on Ley Creek, and two sites on Harbor Brook were monitored again in 2018 (Appendix H-4).

Macroinvertebrate sampling.

Results of the 19-year macroinvertebrate monitoring program indicate varying degrees of improvement in tributary macroinvertebrate communities over time. The two most upstream sites on Onondaga Creek (Tully Farms Road and Webster Avenue) have shown a slow, gradual decline in overall condition (Figure 6-7a), but this is not due to influences of the County's wastewater collection and treatment infrastructure. The Dorwin Avenue site has shown a generally stable level of impact (*slightly impacted*) throughout the monitoring period. The most downstream site on Onondaga Creek (Spencer Street) showed gradual but steady improvement from 2000 to 2015 (from *severely impacted* to *slightly impacted*) but declined to *severely impacted* in 2018 due to the invasion of New Zealand mud snails since 2015. See the macroinvertebrate monitoring report for additional details.

The level of impact at sites along Ley Creek has generally improved slightly over time (Figure 6-7b). The Townline Road site has remained essentially unchanged (between *severely* and *moderately impacted*), but the 7th North Street site has shown a gradual improvement from *severely impacted* to *moderately impacted* since 2000. The Park Street site in lower Ley Creek also has shown improvement over the long-term, particularly since 2008. This site was assessed as *moderately impacted* in two of the past three monitoring efforts.

Trends in condition of the two sites on Harbor Brook are difficult to assess. Prior to 2010 conditions of the sites was stable, both improved substantially by 2015. This improvement may have been in response to reduced CSO events after the Lower Harbor Brook storage facility came on line in 2013. The observed decline in 2018 may reflect the recent invasion of the sites by New Zealand mud snails. A detailed report of the 2018 tributary macroinvertebrate community monitoring is provided in Appendix H-4.

In 2018, the project team completed a complementary evaluation of additional habitat-related factors with the potential to affect the aquatic biota in these tributaries. The Stream Visual Assessment Protocol SVAP), designed by the Natural Resources Conservation Service evaluates physical conditions such as sedimentation, bank stability, overhanging vegetation, water temperature, barriers to fish passage, pool and riffle habitat and other factors. The SVAP was conducted four times over the period of the AMP: 2000, 2002, and 2008 and this final assessment in 2018.

The SVAP assessments are generally consistent over time for each of the monitored sites. Despite the improvements to the wastewater and stormwater collection system and incremental progress with reducing nonpoint sources of pollution, SVAP results are not measurably different at the end of the AMP. These three urban streams have experienced significant modification (rip rap, channelization, encroachment by invasive species, lost connection to riparian floodplain, etc.) that continue to affect habitat quality, even as water quality conditions improve. A detailed report of the 2018 SVAP results is included as Appendix H-5.

Round Goby.

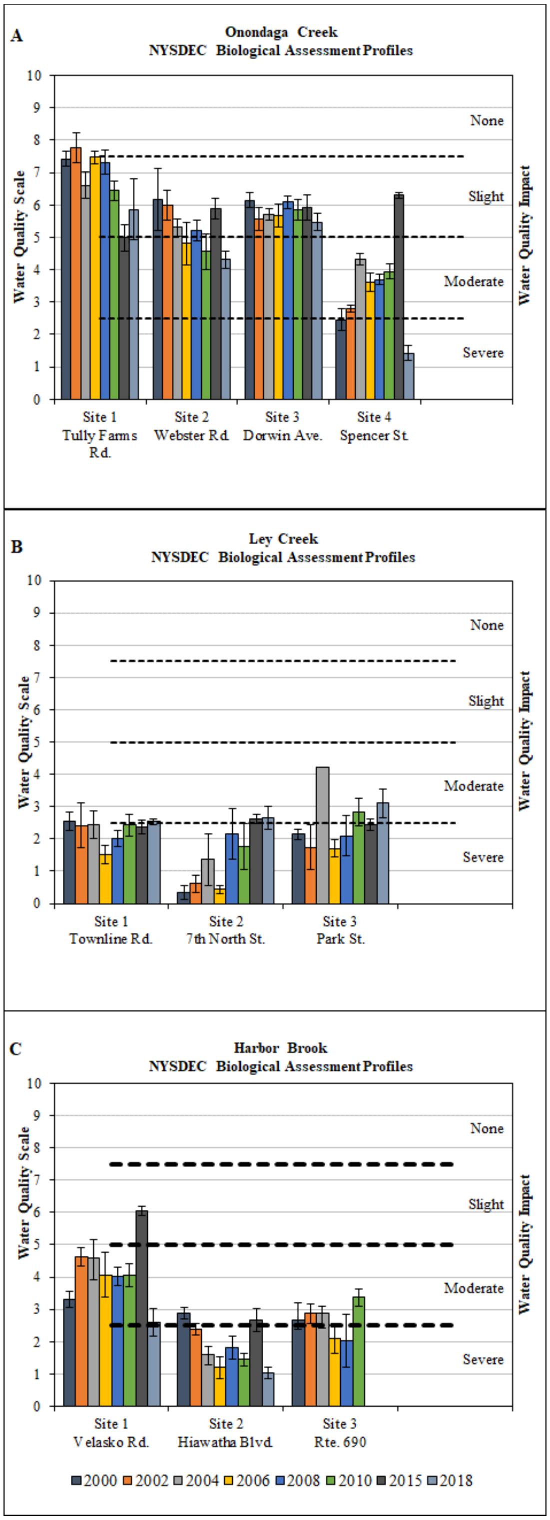


Figure 6-7. Biological assessment of lake tributary macroinvertebrate communities, 2000-2018.

Fish Community

The fish community of Onondaga Lake has undergone considerable change and improvement since inception of the AMP fish community sampling program in 2000. The number of fish species (species richness) recorded annually has increased over time (Figure 6-8). Altogether, 53 species of fish have been captured since 2000 (Table 6-1). Fish species richness in 2018 was 27, equaling the previously highest value in 2014. The increase in species richness is attributed to improved water quality (resulting from the higher level of wastewater treatment) and more diverse habitat (e.g., expansion of aquatic macrophytes).

Fish diversity (the number and relative abundance of species in the community) has shown only mild improvement over the long term and has been highly variable due primarily to large fluctuations in the abundance of alewife and gizzard shad. The swings in abundance of these species are influenced by occasional severe winter mortality and the periodic production of very strong year classes.

In the past, diversity declined sharply when one of these two clupeid species dominated the community; this tended to occur every 3-5 years. In 2018, alewife were nearly absent from the electrofishing catch, and gizzard shad was also relatively low, representing 14% of the community. Diversity in 2018 declined regardless of the low clupeid catch due to a high proportion of species (14 of 27 captured) being represented by fewer than 10 individuals. This contrasted with the capture of greater than 200 individuals of the four most abundant species.

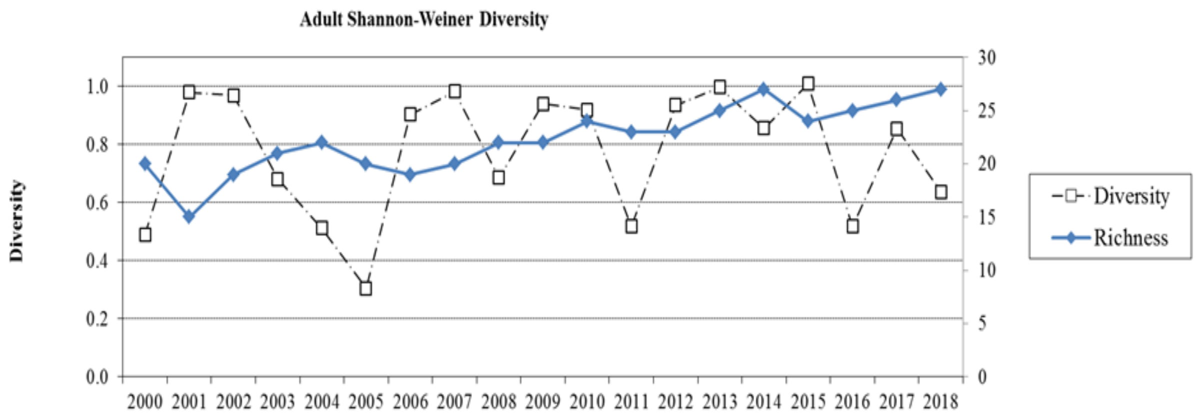


Figure 6-8. Trends in adult fish Shannon-Weiner diversity (H') and species richness for fish captured by electrofishing, Onondaga Lake, 2000–2018.

Table 6-1. Fish species identified in Onondaga Lake, 2000–2018 (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 Minnow	Northern Pike	Black Bullhead	Northern Hog Sucker
Banded Killifish	Largemouth Bass	Bowfin	Rock Bass	Black Crappie	Quillback
Bluegill	Pumpkinseed	Channel Catfish	Shorthead Redhorse	Brook Stickleback	Rainbow Smelt
Brown Bullhead	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 Silverside	Yellow Perch	Logperch	Yellow Bullhead	Goldfish	Spotfin Shiner
Round Goby		Longnose Gar	Green Sunfish	Greater Redhorse	Spottail Shiner
				Johnny Darter	Tadpole Madtom
				Lake Sturgeon	Trout Perch
				Longnose Dace	White Bass

The AMP fish community sampling targets four life stages: larval, young-of-year, juvenile, and adult. Nesting also is monitored for bass, sunfish, and bullhead. Monitoring across multiple life stages aids in interpreting population and community dynamics that may not be detected using a single life stage since not all species use the lake equally for all life stages. Data summaries for the various fish life stage sampling efforts in 2018 and for the entire fish community are provided in Appendix H-6.

Brown bullhead was the most abundant species in the electrofishing catch of adult fish in 2018, composing 23% of the catch (Figure 6-9). Yellow perch was second in abundance (20%), followed by largemouth bass (15%), and gizzard shad (14%). These were also the same four most abundant species in 2017. All remaining species individually composed less than 6% of the 2018 total catch.

Catch rates of individual species have been variable since the inception of the AMP.

Largemouth bass and brown bullhead have shown relatively consistent increases in catch rate since 2000. Pumpkinseed, yellow perch, and smallmouth bass showed relatively large increases in catch rate over the first several years of the AMP, but these rates have now declined to near their original levels. Still other species, such as bluegill, walleye, and white sucker have shown wide swings in catch rates between years, with no evident trend.

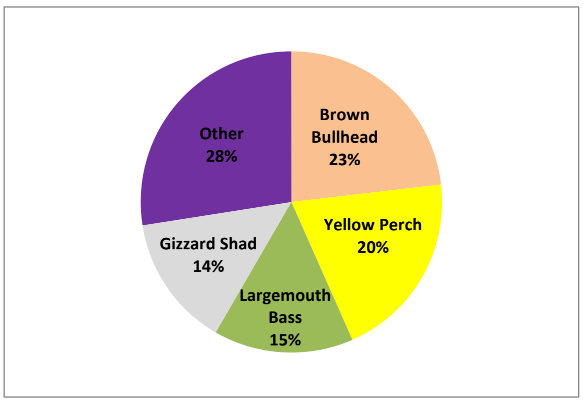


Figure 6-9. Lake-wide relative abundance of adult fish electrofished from Onondaga Lake, 2018.

Because of the challenges of sampling alewife using electrofishing or trap nets, the AMP has relied on a combination of hydroacoustics and gill netting to estimate alewife abundance since 2004. Lake-wide alewife density in the spring of 2018 (2268 fish/hectare) was slightly more than half of the record high value of 4119 fish/ha recorded in 2017 but was still the third highest value recorded since monitoring began (Figure 6-10). Gill net catch far exceeded any previous level and were likely due to spawning aggregations in the nearshore area where the nets were set. The proportion of age-1 alewife was low (10%) indicating poor recruitment of alewife in 2017.

Continued high alewife abundance is consistent with the zooplankton composition in the lake in 2018, as the zooplankton community was again dominated by small *Bosmina longirostris*. The estimated alewife biomass of 46 kg/ha was in the upper half of estimates since 2005. Alewives continued to be abundant in Onondaga Lake. A detailed report of the 2018 alewife monitoring program is provided in Appendix H-7.

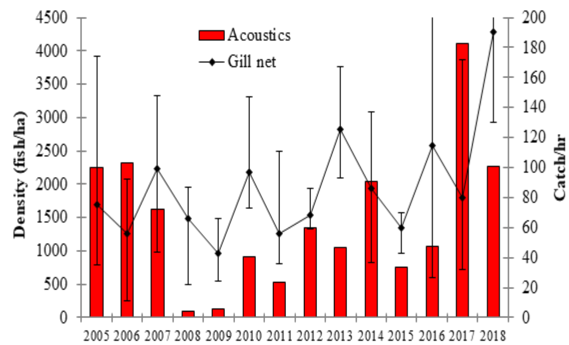


Figure 6-10. Alewife densities determined by gill net catch (catch/hour, right scale) and hydroacoustics (fish/ha, left scale) from May/June surveys of Onondaga Lake, 2005-2018.

Fish collected in Onondaga Lake as part of the AMP are examined for tumors and abnormalities using a standardized protocol known as DELT-FM. Data are used for trend analysis and to compare fish collected in the lake to those collected in other regional waters. Fish tumors and abnormalities can result from chemical contamination, biological agents such as bacteria, viruses, or fungi, or an interaction among multiple stressors.

Largemouth Bass Collected from Onondaga Lake, 2016.

Most abnormalities in the Onondaga Lake fish community are seen in the brown bullhead; eroded barbels are the most common. The percent of fish exhibiting abnormalities increased from 2000 to 2009, reaching a peak of 5.5%. This proportion has declined to and remained steady at approximately 2% since 2015. The relative abundance of bullhead in the fish community has also increased over this period. The incidence of lesions and tumors in brown bullhead captured in Onondaga Lake is now within the range associated with regional reference sites.

The ability of Onondaga Lake to support cold- and cool-water fishes has been modeled since 2009. A "fish space" metric was developed for Onondaga Lake as a useful tool for evaluating cool-water and cold-water fish habitat. The metric is based on dissolved oxygen (DO) and water temperature, two primary variables that determine the ability of fish species to maintain a viable population. This tool is a means to display changes in suitable habitat over both time and depth in the water column. As in past years, during most of summer 2018, high water temperatures at the surface and low DO conditions in deeper cooler zones rendered much of the lake unsuitable for cold-water species such as salmonids (Figure 6-11). In contrast, with the exception of two days, at least some suitable conditions for cool-water fish species such as walleye existed throughout the summer of 2018 (Figure 6-12).

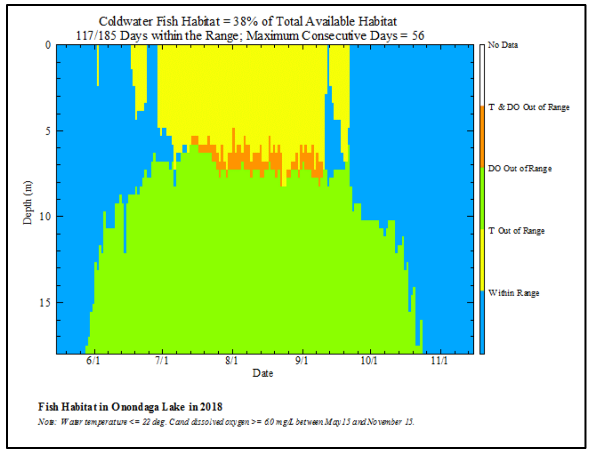


Figure 6-11. Available cold-water fish habitat in Onondaga Lake, May 15 through November 15, 2018.

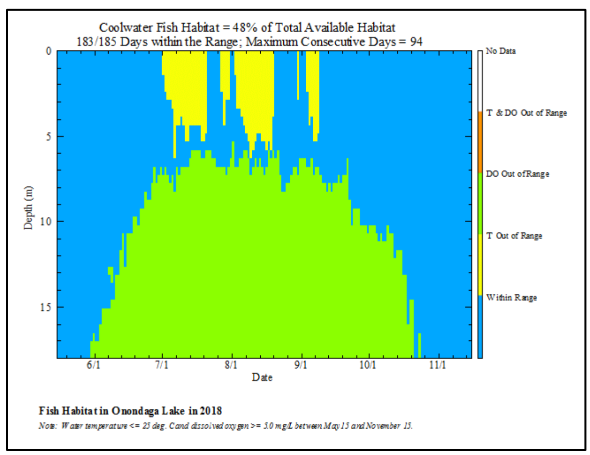


Figure 6-12. Available cool-water fish habitat in Onondaga Lake, May 15 through November 15, 2018.

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

The amount of suitable habitat for cold-water species was considerably lower in 2018 than in 2017, with the length of time conditions were unsuitable occurring from the first week of July to last week of September (compared to the second week of July to the last week of August in 2017). The abbreviated time frame in 2017 was due to sustained early cooling of surface water in late summer 2017. There was an abbreviated cooling period in early September 2018, but surface waters then warmed again to unsuitable levels.

Integrated Assessment of the Food Web

Onondaga Lake is a complex ecosystem influenced by a myriad of factors throughout its approximately 285 square-mile watershed. The lake is influenced not only by the physical, chemical, and biological characteristics of the basin, but by land-use and other anthropogenic factors as well. Some of these components have changed little since the inception of the AMP, but many have changed markedly. Understanding which of these factors changed, and to what extent, is one of the main goals of the AMP. The information gained through the AMP provides a means of evaluating the effectiveness of improvements to Onondaga County's wastewater collection and treatment infrastructure stemming from the Amended Consent Judgment.

Many of the largest changes seen in the Onondaga Lake ecosystem are directly or indirectly linked to improvements in wastewater treatment at Metro. The large and sustained reduction in phosphorus inputs since the early 2000s has reduced lake primary productivity significantly.

The lower production of phytoplankton has resulted in increased water clarity. This in turn has had a major influence on the physical structure of aquatic habitat in the lake by allowing aquatic macrophyte growth to increase in both density and area. Reduced phytoplankton production has also resulted in lower rates of oxygen depletion in the hypolimnion, resulting in declines in the degree and duration of anoxic conditions below the thermocline. This has expanded the volume of the lake that provides suitable habitat for fish, benthic macroinvertebrates, and more recently, zooplankton.

The major reduction in ammonia-N resulting from implementation of the biologically aerated filter (BAF) at Metro in 2004 brought the entire lake into compliance with the ammonia standard. The BAF converts ammonia to nitrate, a non-toxic form of nitrogen. The increased nitrate loading from Metro is supplemented by nitrate additions by Honeywell designed to reduce the formation of methyl mercury (Matthews et al. 2013). The elevated nitrate concentrations have also suppressed phosphorus release from the lake sediments. Biological repercussions of the reduction in ammonia-N and increased nitrogen: phosphorus ratio included elimination of the periodic, nuisance algal blooms that formerly plagued the lake and expansion of suitable habitat for ammonia-sensitive aquatic invertebrates and early life stages of fish.

Tiger Musky from Onondaga Lake.

Aside from nutrients, grazing pressure from zooplankton and benthic mussels can strongly influence phytoplankton abundance and water clarity. Observed reductions in phytoplankton abundance and increases in water clarity might have been even greater if not for intense predation of zooplankton by the invasive alewife. Zooplankton biomass and average size have declined over the course of the AMP and have remained relatively low for the last several years. This is due in large part to the abundance of alewife, which preferentially prey on the largest zooplankton. These large zooplankton (most commonly *Daphnia spp*.) are the most effective grazers of phytoplankton. This intensive predation reduces the overall abundance of zooplankton and increases the dominance of small-bodied species in the community. This is quite different from what was observed in 2008 and 2009 when the Onondaga Lake alewife population was low. During those years, *Daphnia* abundance was higher, chlorophyll-*a* concentrations were lower, and water clarity was higher than at any other time since the AMP began.

However, continued improvements to lake water quality may be leading to more favorable conditions for zooplankton. Zooplankton biomass in 2018 was higher in deeper water than in the upper mixed layer from mid-July through September. A similar observation was made for the first time in 2017, suggesting zooplankton are now concentrating in the lower epilimnion and metalimnion during much of the summer. This change is likely due to improved oxygen conditions in deeper waters in recent years allowing zooplankton to migrate deeper in the lake to avoid alewife predation. High abundance of zooplankton in the metalimnion during the day is found in lakes with clear waters and abundant planktivorous fish if oxygen concentrations in the hypolimnion are above ~1 mg/L (e.g. Klumb et al. 2004, Rudstam et al. 2015).

The macroinvertebrate community of three of Onondaga Lake's major tributaries (Onondaga Creek, Ley Creek, and Harbor Brook) have shown varying degrees of change over the course of the AMP. All sites sampled in 2018 showed some level of impact. Recovery of the most impaired sites does appear to be occurring gradually, but the recent invasion of some of these sites by New Zealand mud snails has confounded this assessment. Prior to the invasion of mud snails post-2015, those sites that began as the most impaired had shown notable improvement in condition over the course of the monitoring program and in response to the Clinton and Lower Harbor Brook CSO storage facilities coming online in 2013. The sites located farthest upstream and greatest distance from the storage facilities tended to show minimal change or a slight decline in condition.

Macroinvertebrate sampling.

The substantial increase in the density, biomass, and areal coverage of aquatic macrophytes in response to higher water clarity has resulted in increased habitat complexity. This complexity provides a wide range of microhabitats that can support a more diverse and abundant aquatic macroinvertebrate community. Expansion and diversification of the macrophyte community also has increased available habitat for many fish species. Aquatic macrophytes provide critical spawning and nursery habitat for many littoral zone fishes, and species such as largemouth bass have increased in abundance as a result of this habitat enhancement.

Improvements to water quality and the resultant changes in the lower trophic levels of Onondaga Lake have produced marked changes in the fish community at the top of the food web. Fish species richness has shown a consistent gradual increase. Several fish species have benefited from expansion and diversification of the aquatic macrophyte community. Others, such as walleye, and possibly smallmouth bass, have benefited from improvements in water quality in the hypolimnion and other open-water areas of the lake. Brown bullhead is an example of a species that has benefited in multiple ways, from habitat expansion and improvement to reduced incidence of tumors and abnormalities.

The same improvements to Onondaga Lake's water quality and habitats that have allowed the native fish community to thrive have also provided opportunities for invasive species to colonize and prosper in the lake. The influence of alewife was previously mentioned. Other invasive fishes that are becoming more prominent in the lake include round goby, green sunfish, and rudd. The potential influences of these species are poorly understood and could be negative, positive, or neutral. For instance, round goby is known to prey on the eggs of native species such as largemouth bass and sunfish, but it also can serve as an important prey item to bass, walleye, and other sportfishes. Round goby may also be contributing to the overall decline in invasive dreissenid mussels in the lake. The impact of these and other invasive species on the ecology of Onondaga Lake becomes more relevant as lake conditions continue to improve and become suitable for more species. The same can be said for the lake's tributaries, where improvements in water quality have benefitted the native community but may have also recently allowed the invasive New Zealand mud snail to prosper and alter macroinvertebrate community dynamics.

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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 in 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. The AMP was in place through December 31, 2018.
Amended Consent Judgment	**ACJ**	A legal finding or ruling. In 1998, an Amended Consent Judgment (ACJ) among 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 obligated the County to undertake a phased program of wastewater collection and treatment improvements, monitor water quality response, and report annually on 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 and can be toxic to sensitive aquatic animals at elevated concentrations.
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

Term	Abbreviation	Definition
		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.
Biological Aerated Filter	**BAF**	A combination standard filtration with biological treatment of wastewater. BAF usually includes a reactor filled with a filter media either in suspension or supported by a gravel layer. The dual purpose of this media is to support highly active microbes which remove dissolved nutrients from wastewater and to filter particulates.
Best Management Practices	**BMPs**	A combined group of activities designed minimize the amount of pollution that reaches a body of water. BMPs can be applied to agricultural, urban, and/or industrial areas as preventative measures to protect water quality.
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 biomass 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 carry an electrical charge (an indicator of dissolved ions present)
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**	Measure of oxygen dissolved in water, which is an important indicator of the ability of water to sustain fish and aquatic organisms.
ecosystem	**--**	An interrelated and interdependent community of plants,

Term	Abbreviation	Definition
		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 to pollutants such as chemicals, heat, and sediment. Used as a long-term indicator of water quality.
hypolimnion	**--**	Deep, cold waters of a stratified lake; portion of the lake volume that remains isolated from atmospheric exchange during periods of thermal stratification.
hypoxia	**--**	Low dissolved oxygen conditions of a water body which is detrimental to aerobic organisms.
indicator bacteria	**--**	Bacteria used to indicate the potential presence of pathogenic (disease-causing) microorganisms in water (see also fecal coliform bacteria).
interrelatedness	**--**	The degree to which organisms in an 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 respond to human disturbances; also, measurable attributes of the ecosystem that indicate whether a desired state has been achieved. Good metrics

Term	Abbreviation	Definition
		are cost-effective to measure, associated with low uncertainty, relevant to stakeholders, and sensitive to anticipated changes.
mercury	**Hg**	A heavy metal 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**	The state agency responsible for the protection and improvement of public health within New York.
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. The final stages of wastewater treatment at Metro produces large quantities of nitrate-N that is discharged to Onondaga Lake.
nitrite-N	**NO_2-N**	A form of nitrogen created in the intermediate step of nitrification. Accumulation of nitrite-N can be toxic to sensitive aquatic organisms.
nitrogen	**N**	A common element for all forms of life. In aquatic ecosystems, nitrogen is usually present 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**	A group of technical experts in lake ecology and water quality modeling appointed to advise Onondaga County DWEP on issues related to Onondaga Lake, including AMP design and data interpretation.
organic nitrogen	**--**	The total amount of nitrogen in a water sample, including dissolved and particulate forms of organic and inorganic N.
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.

Term	Abbreviation	Definition
particulate phosphorus	**PP**	The non-dissolved fraction of total phosphorus.
pelagic zone	**--**	Open waters of a lake (not nearshore or near the lake bottom).
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 all life. In freshwater aquatic ecosystems, phosphorus is usually the nutrient that limits phytoplankton production. Increases in phosphorus can result in accelerated eutrophication.
photic zone	**--**	Upper layer of the water column where light penetration is sufficient for photosynthesis (algal growth).
phytoplankton	**--**	The community of algae and cyanobacteria present in a water body.
percent model affinity	**PMA**	A measure of similarity of a sampled community to a model non-impacted community. PMA uses 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 disk 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, notably diatoms, for construction of cellular structures.
soluble reactive phosphorus	**SRP**	A dissolved form of phosphorus that is most readily used by algae for growth.
sodium	**Na**	A common metallic element in aquatic ecosystems usually associated with chloride, NaCl a common form of salt.
sonde	**--**	A compact monitoring device that includes one or more sensors or probes to measure water quality parameters, such as temperature, pH, salinity, oxygen content, and turbidity directly, eliminating the need to collect samples and transport them to a laboratory for analysis.

Term	Abbreviation	Definition
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 algae 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.
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. Summer average TP in the upper waters of lakes is a common metric of water quality.
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	**VSS**	The total amount of organic particulate matter in a water

Term	Abbreviation	Definition
suspended solids		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. Thus, the year ending September 30, 2010 is referred to as the 2010 water year.
watershed	--	An area of land that drains rainfall and streams to a common outlet.
Water Environment Protection	**WEP**	The agency in Onondaga County, NY responsible for permit compliance for those wastewater treatment plants located within the Onondaga County Consolidated Sanitary District