Appendix 2.1

ATTACHMENT 4

Data Analysis and Interpretation Plan
Onondaga Lake and Watershed
Ambient Monitoring Program

REVISED April 2011

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1. OBJECTIVES OF THE DAIP

Each year Onondaga County Department of Water Environment Protection (OCDWEP) collects and analyzes more than 20,000 water quality samples and hundreds of biological samples collected from Onondaga Lake and its watershed. Results are used to evaluate water quality conditions and assess whether the waters are in compliance with applicable standards, criteria, and guidance values. The biological samples are used to evaluate the nature of the biological community and assess change.

This Data Analysis and Interpretation Plan (DAIP) was prepared to guide program managers and advisors regarding how these thousands of measurements will be analyzed and interpreted. It is a roadmap of how data become information (**Figure 1).** This document will be revised and updated as new information becomes available, new issues emerge, or new tools are developed to help with data analysis and interpretation.

2. REGULATORY BACKGROUND – AMENDED CONSENT JUDGMENT

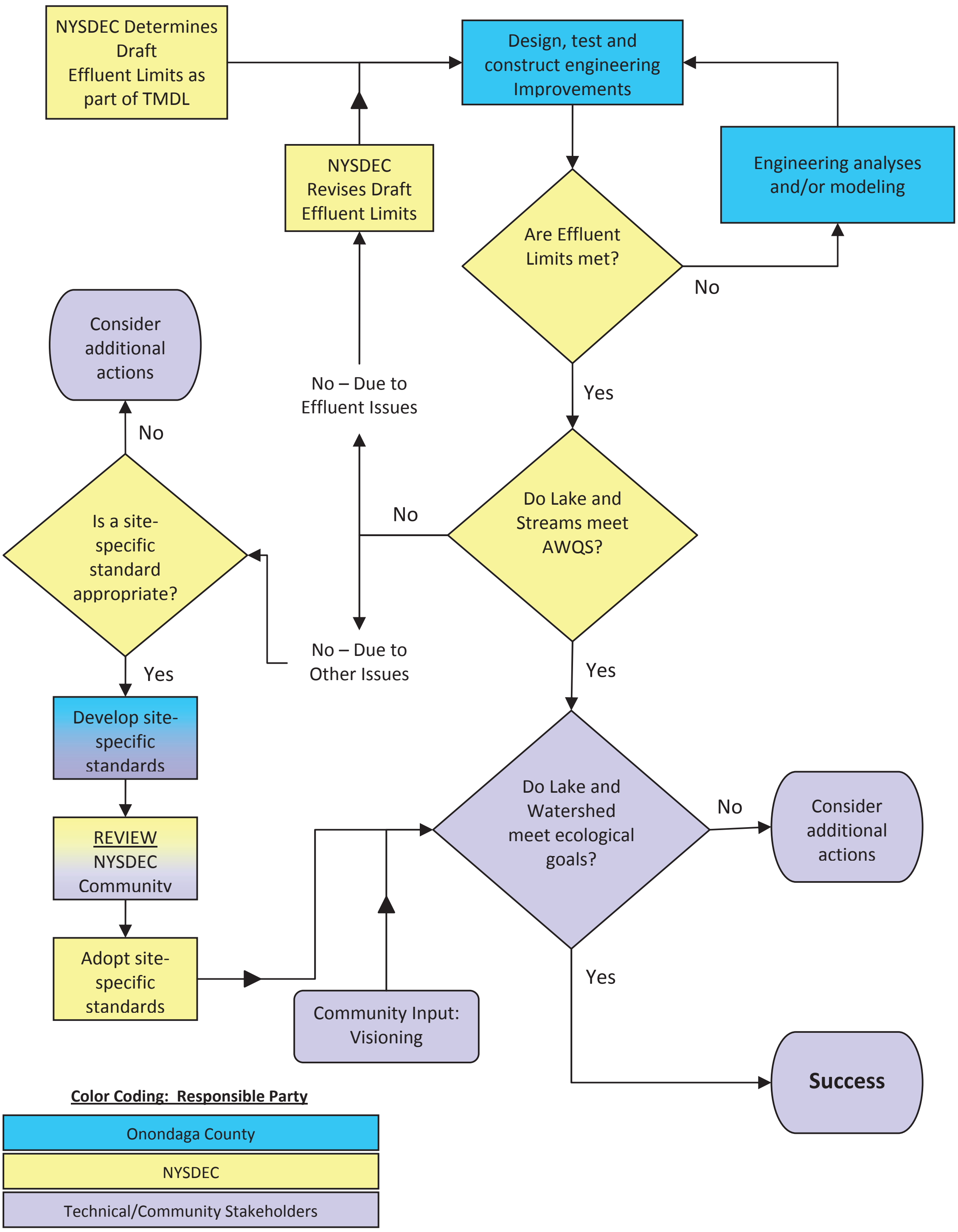
In January 1998, Onondaga County signed an Amended Consent Judgment (ACJ) committing to a phased program of upgrades and improvements to the County's wastewater collection and treatment system. The ACJ includes three major elements:

- Improvements to the wastewater and stormwater collection systems to abate Combined Sewer Overflows (CSOs);
- Improvements to the Metropolitan Syracuse Wastewater Treatment Plant (Metro) to reduce the concentration of ammonia N, phosphorus, BOD, solids, and bacteria in treated effluent prior to discharge; and
- Monitoring Onondaga Lake, the lake tributaries, and the Seneca River to track their response to the pollution abatement actions.

Improvements to Metro and the CSOs will be implemented over a time period extending more than 15 years. One of the factors considered in developing the phasing plan was uncertainty regarding how Onondaga Lake would respond to reductions in the loading of wastewater-related contaminants. Onondaga County was required to design, fund and implement a monitoring program to provide the data and information needed to support key decisions regarding adequacy of the pollution abatement measures and the need for additional actions. These key decisions relate to the level of treatment and the location of the Metro discharge; results will provide the foundation for the Metro SPDES permit, which will include the CSOs.

The November 2009 fourth stipulation to the Amended Consent Judgment calls for modifications to the AMP designed to "enhance monitoring of the tributary water quality in the tributaries impacted by CSOs, to determine the effectiveness of the gray and green infrastructure projects…". These projects have been designed to mitigate the impacts of the Combined Sewer Overflows (CSOs).

Figure 1. Flow Chart of Decisions and Responsibilities: Onondaga Lake



2.1 Water Quality Classification and Designated Use

Lakes and streams are classified according to their designated use (for example, water supply, swimming, fish propagation, aesthetic enjoyment, and fish survival). Onondaga Lake is classified as B and C (**Figure 2** and **Table 1**) The Class B segment encompasses the northern basin; the Class C segments include much of the southern basin and a small area around the mouth of Ninemile Creek. Both B and C waters must exhibit water quality conditions suitable for fish survival and propagation. Class B waters are to be suitable for primary water contact recreation (e.g. swimming) and secondary water contact recreation (e.g. boating). Class C waters shall be suitable for primary and secondary water contact recreation, although other factors may limit the use for these purposes.

The main stems of the lake tributaries are primarily classified as C waters (suitable for fish propagation and secondary water contact recreation) but several small segments are Class B. The Seneca River segment in the vicinity of the Onondaga Lake outflow and downstream is Class B. As summarized in **Table 1**, several Class C stream segments within the subwatersheds are required to comply with Class C(T) water quality standards, meaning that dissolved oxygen and ammonia levels shall be suitable for salmonids.

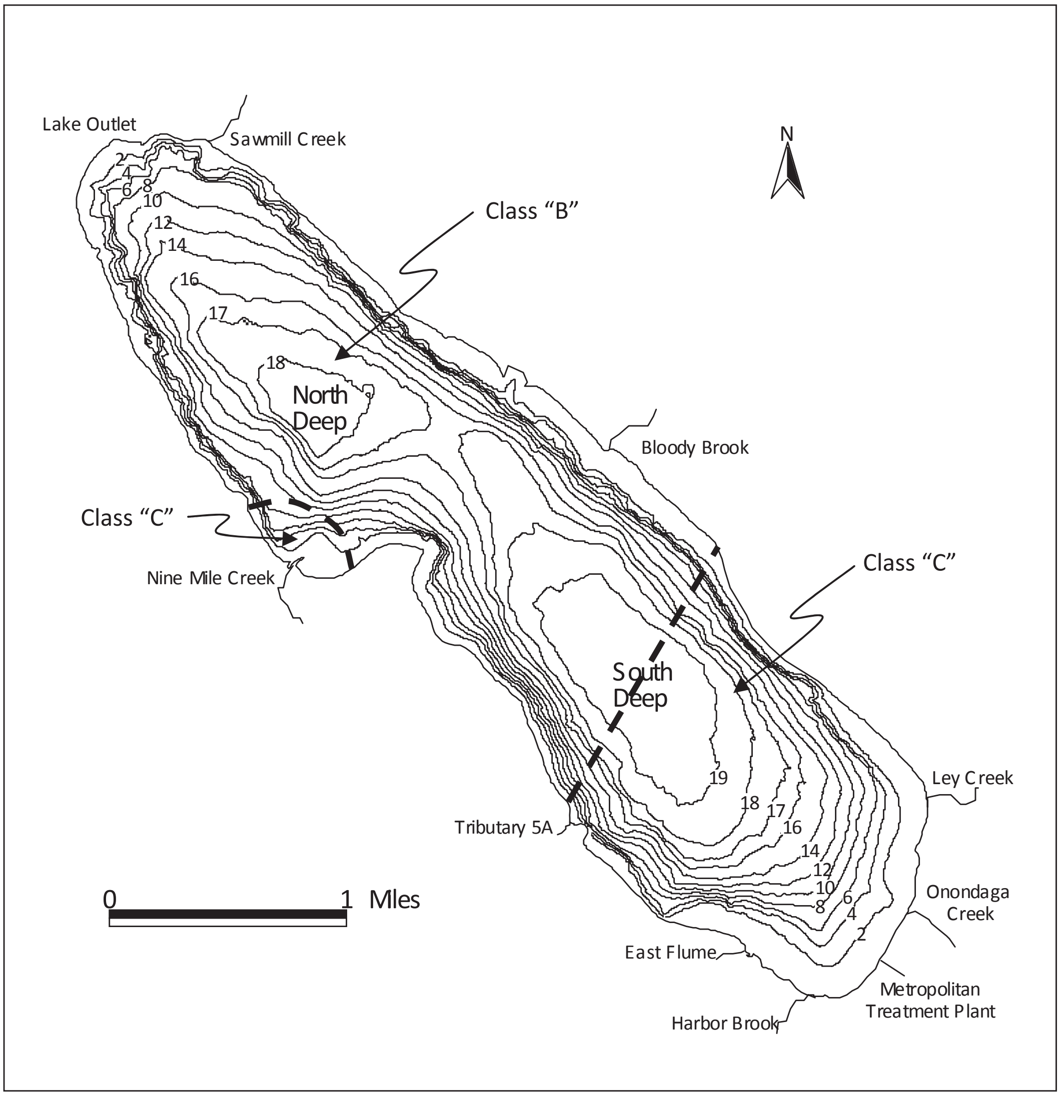


Figure 2. Regulatory Classifications and Bathymetry of Onondaga Lake (Note: Contour lines are in meters)

Table 1. Summary of Regulatory Classification of Onondaga Lake and Tributary Streams.

Water body	Description of Segment	Regulatory Classification	Standards
Onondaga Creek	Enters Onondaga Lake at southeastern end. Mouth to upper end of Barge Canal terminal (0.85 miles)	C	C
	Upper end of Barge Canal terminal to Temple Street (1.7 miles)	C	C
	From Temple Street, Syracuse to Tributary 5B (4.4 miles)	B	B
	From Tributary 5B to Commissary Creek (1.9 miles)	C	C
	From Commissary Creek to source	C	C(T)
Ninemile Creek	Enters Onondaga Lake from south. From mouth to Allied Chemical Corp. water intake located on creek to point mid-way between Airport Rd and Rt. 173 bridge at Amboy (3.4 miles).	C	C
	From point mid-way between Airport Rd and Rt. 173 to outlet of Otisco Lake	C	C(T)
Harbor Brook	Enters Onondaga Lake at the southern most point of the lake and within the City of Syracuse. From mouth to upper end of underground section, at Gifford Street (approx. 1.9 miles)	C	C
	From upper end of underground section to City of Syracuse line (1.3 miles)	B	B
	From City of Syracuse City line to source	C	C(T)
Ley Creek	Enters Onondaga Lake 0.2 mile southeast of point where City of Syracuse line intersects east shore of lake. From mouth to Ley Creek sewage treatment plant outfall sewer.	C	C
	From Ley Creek sewage treatment plant outfall sewer to South Branch. Tribs. 3-1A and 3-lB enter from north approximately 3.0 and 3.1 miles above mouth respectively.	B	B
Bloody Brook	Enters Onondaga Lake 2.25 miles southeast of outlet. From mouth to trib. 1 of Bloody Brook (approximately 0.37 miles from mouth)	B	B
	From trib. 1 of Bloody Brook to source.	C	C
Onondaga Lake (1)	Northwest of a line extending from a point located on the west shore 0.25 miles northwest of the mouth of trib. 5A to a point on the east shore located at a point 0.6 miles southeast of the mouth of Bloody Brook, except portions of the lake designated as items no. 2 and 3.	B	B
Onondaga Lake (2)	Southeast of a line extending from a point located on the west shore 0.25 miles northwest of the mouth of trib. 5A to a point on the east shore located at a point 0.6 miles southeast of the mouth of Bloody Brook, except portions of the lake designated as items numbered 1 and 3.	C	C
Onondaga Lake (3)	Area within 0.25 mile radius of the mouth of Ninemile Creek, except portions designated as items numbered 1 and 2.	C	C

Source: NYSDEC (classifications as of February 2010); on-line linkage http://www.dec.ny.gov/regs/4539.html#17588

2.2 Compliance Assessment

The regulatory goal of the ACJ is to bring Onondaga Lake and its tributaries into compliance with best usage designated for Class B and C waters pursuant to 6 NYCRR Parts 701 and 703. Applicable NY State Water Quality Standards and Guidance that will be used to assess the extent to which these actions are successful include the following:

- Dissolved Oxygen: 6NYCRR Sec. 703.3
- Ammonia: 6 NYCRR Sec. 703.5
- Turbidity: 6 NYCRR Sec. 703.2
- Floatable Solids in CSO Discharges: 6 NYCRR Sec. 703.2
- Phosphorus: 6 NYCRR Sec. 703.2
- Water Quality Standards & Guidelines (NYSDEC TOGS 1.1.1)
- Nitrogen: 6 NYCRR Sec. 703.2
- Bacteria: 6 NYCRR Sec. 703.4

3. SUMMARY OF THE ONONDAGA COUNTY AMBIENT MONITORING PROGRAM (AMP)

Onondaga County is required by the ACJ to design and implement an annual monitoring program of the lake, the lake tributaries, and portions of the Seneca River adjacent to the Onondaga Lake Outlet. The objective of the Ambient Monitoring Program (AMP) is to provide the data and information needed to assess the effectiveness of the controls at Metro and the CSOs and determine if additional remedial measures are required to bring the waters into compliance with applicable state standards and guidelines and federal criteria.

Onondaga County and its partners rely on an integrated program of monitoring and modeling to determine whether the planned improvements to the Onondaga County wastewater collection and treatment infrastructure are effective in bringing the surface water system into compliance with state and federal requirements. Monitoring is used to measure conditions over the 15-year period of phased improvements to the wastewater collection and treatment system. Modeling is used to describe the interrelationships between physical, chemical, and biological characteristics of the lake and watershed. Models are also valuable tools for interpreting data and understanding underlying mechanisms. Once verified, models can be used to predict future conditions under a range of management scenarios and environmental conditions.

The interrelationship between the management questions, monitoring and modeling, and the spatial and temporal designation of compliance is summarized in **Table 2**.

Table 2. Summary of management questions and decision analysis.

Management Question:	Decision Analysis Components and Regulatory References	Spatial and Temporal Scale of Assessment	Tools for Assessment
Can ambient water quality standards be achieved with continued Metro discharge to Onondaga Lake?	Dissolved Oxygen: 6NYCRR Sec. 703.3 Ammonia: 6 NYCRR Sec. 703.5 Turbidity: 6 NYCRR Sec. 703.2 Floatables: 6 NYCRR Sec. 703.2 Phosphorus: 6 NYCRR Sec. 703.2 TOG 1.1.1 Nitrogen: 6 NYCRR Sec. 703.2 Bacteria: 6 NYCRR Sec. 703.4	Dissolved Oxygen: Upper waters, fall mixing, South Deep Ammonia and nitrite: Upper waters; South Deep, year-round Bacteria: Class B portions of lake	Monitoring: AMP data Modeling CSOs: Use SWMM to confirm: system-wide annual average capture of 85% of combined sewage volume. Modeling Lake: Onondaga Lake model (development began in 2005)
Must Metro effluent meet the Stage III phosphorus and ammonia limits for discharge to Onondaga Lake or the Seneca River in order for the receiving water to achieve compliance with ambient water quality standards?	Phosphorus: 6 NYCRR Sec. 703.2 (*possibly modified by site-specific guidance value)* Trophic state indicators: frequency, intensity and duration of algal blooms Ammonia: TOG 1.1.1 NYSDEC revised TMDL for phosphorus: **December 31, 2011**	Phosphorus and other trophic state parameters: Summer average, upper waters, South Deep Dissolved Oxygen: Upper waters, fall mixing, South Deep Ammonia: Upper waters; South Deep, year-round	For lake discharge: • AMP data: Ammonia: effects of Stage 3 limits, met in 2004 TP: effects of Stage 2 limits, met in 2006 For Seneca River discharge: TRWQM

Are additional measures needed to ensure compliance with dissolved oxygen standards during fall mixing?	Feasibility analysis of hypolimnetic oxygenation (ENSR 2004). *Status: removed from ACJ by stipulation*	Focus of compliance for dissolved oxygen: fall mixing, upper waters	• AMP data: profiles and buoy • Mass-balance model • Onondaga Lake model

3.1 History of Onondaga County Monitoring Efforts

The AMP is not Onondaga County's first monitoring effort. Following completion of a baseline State of the Lake Report in 1970, Onondaga County conducted an annual program from 1970–1997 to monitor tributaries, quantify external loading, and track lake water quality conditions and trends in response to pollution abatement efforts. When the ACJ was signed in 1998, Onondaga County modified its historical monitoring program to ensure that the data collected would be adequate to evaluate the response of the lake, streams, and river to the planned improvements to the CSOs and Metro. This process of evaluation and modification was a collaborative effort of Onondaga County, Onondaga Lake Technical Advisory Committee (OLTAC), U.S. Geological Survey (USGS), New York State Department of Environmental Conservation (NYSDEC), Environmental Protection Agency (EPA) and Atlantic States Legal Foundation (ASLF). The AMP began in August 1998 and is scheduled to continue through 2012.

The AMP differs from the historical program in several important ways:

- Storm Event Monitoring: The AMP incorporated a storm event program on the CSO-affected tributaries (Onondaga Creek, Harbor Brook, Ley Creek), plus Ninemile Creek. Storm event data are used to evaluate the effectiveness of the CSO remedial measures.

- Stream Mapping: A stream mapping component was added to the AMP to document habitat quality along the CSO-affected tributaries; this program will support evaluation of the effectiveness of CSO controls and has provided additional information regarding nonpoint sources of pollution (particularly sediment).

- Recreational Indices: The AMP was expanded to include monitoring for indices of recreational quality (bacteria and water transparency) at a network of eight nearshore stations (a ninth station was added in 2006).

- In-Situ Buoy: A monitoring buoy has been placed at the South Deep station to provide high-frequency measurements of water temperature, dissolved oxygen and related parameters.

- Precipitation Stations: Onondaga County has expanded its network of precipitation gauging stations.

- Biological Monitoring: With the AMP, Onondaga County undertook an extensive biological monitoring program.

3.2 Design of the AMP: Required Elements

The AMP was designed to provide data and information needed to guide management decisions regarding the level of treatment of municipal wastewater (including CSOs) and the location of the Metro discharge.

The AMP includes Onondaga Lake, the lake's tributaries, and the Seneca River in the region of the Onondaga Lake outlet. The program includes measures to evaluate physical and habitat conditions, chemical water quality, and the nature of the biota as summarized in the language from the ACJ listing the required elements of the AMP.

These required elements from Appendix D of the ACJ include measures to:

- Assess compliance with ambient water quality standards in the lake and tributary streams
- Estimate loading of materials to the lake, including the volume and loading of materials from the combined sewer overflows
- Evaluate physical habitat conditions in the lake and tributaries
- Evaluate the lake's trophic state (level of productivity)
- Model the assimilative capacity of the Seneca River in the region of the Onondaga Lake outlet to support a decision regarding diversion of Metro effluent
- Characterize the lake's biological community.

In addition to these specific measures, Appendix D of the ACJ (abstracted below) includes requirements to document data integrity (for example, preparation of a detailed Quality Assurance Project Plan). Onondaga County is required to consult with technical experts to ensure that the AMP is designed and implemented in a defensible manner. Data interpretation and reporting is to be open and subject to rigorous technical review. Finally, Appendix D includes specific requirements to ensure that Onondaga County's monitoring program collects data related to habitat quality. The addition of attributes to measure habitat quality highlights the expansion of the program from a traditional water quality monitoring program to one that aims at a more holistic assessment of ecological integrity.

OCDWEP also has an expanded monitoring program on the Seneca River that is not part of the AMP; this program extends into the Oneida River and is used to evaluate performance of other Onondaga County wastewater treatment plants.

An overview of how the AMP is designed to meet ACJ requirements is provided in **Table 3**. While the AMP is designed to assure compliance with the specific requirements in the ACJ, Onondaga County collects and analyzes additional data to meet related program objectives. In many cases, additional data are collected that enable a more integrated analysis of water quality conditions and the response of the biota. Details of how data collected through the AMP are used and interpreted is included in **Table 4.** Onondaga Lake Chemical/Water Quality Monitoring Program

AMBIENT MONITORING PROGRAM REQUIREMENTS
(Appendix D of the ACJ)

Abstracted from the Amended Consent Judgment, January 1998

I. Tributaries and Lake Water Quality Monitoring Program

1. Assess compliance with ambient water quality standards and progress toward use attainment.
2. Assess physical habitat for stream and lake biota, and indicators of the biotic response.
3. Incorporate flexibility to assess additional chemicals or potential sources as needed
4. Concentrate data collection during critical ecological periods (e.g. spring spawning of dominant lake fishes, onset of thermal stratification, fall mixing).
5. Define monitoring as a priority at the Department and commit adequate resources
6. Increase participation of outside technical experts, e.g., Onondaga Lake Technical Advisory Committee in design and implementation of AMP and interpretation of results.
7. Incorporate appropriate QA/QC.
8. Maintain data in an electronic format that facilitates summarizing data, reporting results, and depicting results (including graphical depiction)

II. Tributary Monitoring Program

1. Quantify external loadings of phosphorus, nitrogen, suspended solids, indicator bacteria, heavy metals, and salts. Utilize FLUX.
2. High flow monitoring to partition point and nonpoint sources of phosphorus (minimum of 5 events).
3. Sample upstream and downstream of CSO discharges: Onondaga Cr, Harbor Br and Ley Cr, during storms
4. Assess compliance with water quality standards in Onondaga Cr, Harbor Br, and Ley Cr.
5. Measure attributes of the physical environment in tributaries: (a) velocity; (b) cross-sectional area to map erosional and depositional sections; (c) survey for presence and character of sludge deposits in depositional areas and map; (d) map physical characteristics of the stream bed that could affect spawning habitat from mouth to first barrier; (e) sample macroinvertebrate communities and calculate NYSDEC rapid field biotic index throughout tributaries' length.
6. Continue cooperative arrangements with USGS to gauge discharge of the major tributaries.
7. Continue data collection, analysis and reporting consistent with historical database (1970 to 1997) to enable statistical trend analysis.

III. Onondaga Lake Monitoring Program

1. Assess compliance with ambient water quality standards including bacteria in nearshore areas.
2. Assess trophic status of the Lake.
3. Continue data collection, analysis, and reporting consistent with the long-term lake database (1970 – 1997) to enable statistical trend analysis.
4. Complement chemical program with a biological monitoring effort to assess the densities and species composition of phytoplankton, zooplankton, macrophytes, macroinvertebrate, and fish.
5. Evaluate success of walleye, bass, and sunfish propagation (quantitative lake-wide nest surveys,

recruitment estimates, and juvenile community structure). Coordinate with NYSDEC fisheries management activities on the lake.

6. Establish data sharing protocols with NYSDEC for County to track contaminants in fish flesh.
7. Acquire and track data by others regarding nature of littoral sediments in Onondaga Lake.

IV. Seneca River Program

1. Evaluate current water quality of the Seneca River and compliance with water quality standards upstream and downstream of the Onondaga Lake outlet.
2. Evaluate and quantify the assimilative capacity of the Seneca River and quantify effects of zebra mussels.
3. Monitor critical conditions of warm weather and low flows.
4. Test temporal and spatial variability (e.g., diurnal variations in river water quality, and the extent of chemical stratification).

Table 3. Elements of the AMP in relation to ACJ-Required Monitoring Objectives

ACJ Statement of Required Program Objective	Ambient Monitoring Program Elements	Data Used To
Quantify external loading of phosphorus, nitrogen, suspended solids, indicator bacteria, and salts. Assess the reduction in loading achieved by the CSO improvements. Design program to evaluate the relative contribution of point and nonpoint sources of pollution to the lake.	Tributary monitoring (Annual Program): biweekly and high flow events – includes locations upstream and downstream of CSOs, urban and rural segments of subwatersheds. Storm event program (Periodic): higher frequency sampling on CSO-affected streams during storms.	Estimate annual external loading to the lake Calculate loading from CSO-affected tributaries and compare pre-and post-remedial load of phosphorus, suspended sediment and bacteria
Assess the tributaries' physical habitat and macroinvertebrate community	Periodic stream mapping using NRCS Visual Stream Assessment Protocol in CSO-subwatersheds- Macroinvertebrate surveys CSO-affected subwatersheds every 2 years.	Quantify baseline conditions and provide basis to measure change. Calculate standard indices to indicate status of water quality and habitat conditions. Evaluate changes over time.
Gather data on an adequate temporal and spatial scale to assess compliance with ambient water quality standards	Lake monitoring program (Annual): South Deep Station and nine nearshore stations Tributary monitoring program (Annual) Seneca River monitoring program (Annual)	Assess compliance with numerical and narrative standards for substances per TOGS 1.1.1 Calibrate and verify models
Evaluate changes in the water quality and trophic state of Onondaga Lake in response to reductions in external loading achieved by the improvements to Metro and the CSOs.	Lake monitoring program (Annual): phosphorus, chlorophyll-a, water clarity, DO status of lower waters Tributary and Metro effluent monitoring (Annual): loads (esp. nutrients) Seneca River monitoring (Annual)	Assess inputs and trends Calibrate USGS watershed model using AMP data Construct conceptual and mass-balance models Calculate "fish space metrics" to track changes in fish habitat Develop and calibrate Onondaga Lake model
Coordinate data collection and analysis to provide data at an adequate spatial and temporal scale to use in existing or revised lake models	Annual program and supplemental investigations, NYSDEC review and approvals Meetings with OLTAC and work groups	Support conceptual and empirical (mass-balance) model; AMP data will be used to calibrate and verify new lake model (begun in 2005)
Assess Seneca River water quality between Cross Lake and the Three Rivers junction.	Annual surveys during low flow conditions at Seneca River Buoy 316.	Assess current conditions and compliance provide data for model verification
Evaluate the assimilative capacity of the Seneca River and quantify effects of dreissenid mussels.	River modeling work group and peer review Surveys during low flow conditions	Assess current conditions, data set for model verification

Table 4. Detailed Reporting of AMP Program, Data Analysis and Interpretation Strategy. ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Alkalinity, Total	Concentration	• Charge Balance • Trends • Compute Hardness	South Deep North Deep	UML composite LWL composite	South Deep: Biweekly (April- Dec) North Deep: Quarterly Winter as possible	Wildco Beta horizontal sampler/ Churn
Bacteria Fecal Coliform, E. Coli	• Abundance of indicator organisms • Compliance with standards	• Potential presence of pathogens • Compliance with standards • Use attainment. • Trend analysis • Effectiveness of CSO control measures.	South Deep North Deep Nearshore sites	0m	South Deep: 5 samples/month (April - October) North Deep: As above, plus winter as possible Nearshore: 5 samples/month (April -October)	Grab sample into sterile bottle
Carbon: TOC, TIC	Concentration	• Trends • Trophic Status. • Indicator of oxygen demanding material. • Support models	South Deep North Deep	Discrete depths (0m, 6m, 12m, 18m)	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Submersible Pump
Low level Mercury: Total and Methyl Mercury	Concentration	• Compliance • Trends	South Deep North Deep	3m & 18m	April, August, October	Teflon Dunker Modified USEPA 1669

Table 4 Detailed Reporting of AMP Program. (continued) ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Metals: Cd, Cr, Cu, Ni, Pb, Zn, As, K, Se	Concentration	• Compliance • Charge balance computations (K)	South Deep North Deep	UML composite LWL composite	Quarterly	Wildco Beta horizontal sampler/ Churn
Metals/Salts: Ca, Na, Mg, Mn, Fe, Cl, SO_4	Concentration	• Charge Balance (data quality) • Trends • Geochemical analysis • Electrochemical (redox) • Density stratification	South Deep North Deep	UML composite LWL composite	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Wildco Beta horizontal sampler/ Churn
Nitrogen: NO_3, NO_2	• Concentration • Compliance	• Compliance. • Nitrogen cycling • Use attainment	South Deep North Deep	UML composite LWL composite	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Wildco Beta horizontal sampler/ Churn
Nitrogen: TKN, NH3-N, Org-N, TKN-Filtered	Concentration	• Compliance • Nitrogen cycling • N:P ratios • Habitat for biota • Trend analysis • Model support	South Deep North Deep	Discrete Depths (0m, 3m, 6m, 9m, 12m, 15m, 18m)	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Submersible Pump

Table 4 Detailed Reporting of AMP Program. (continued) ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Phosphorus: TP, SRP, TDP	Concentration	• Trophic status • Trends • Compliance with NYS guidance value • TMDL analysis • Model support • Bioavailability	South Deep North Deep	Discrete Depths (0m, 3m, 6m, 9m, 12m, 15m, 18m)	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Submersible Pump
Silica-diss	Concentration	Trophic levels interaction	South Deep North Deep	Discrete depths (0m, 6m, 12m, 18m)	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Submersible Pump
Solids: TS, TSS, TDS	Concentration	• Compliance • Trend analysis • Chemical stratification • Correlation with turbidity	South Deep North Deep	Discrete depths (0m, 6m, 12m, 18m)	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	Submersible Pump
Sulfides	Concentration	• Anoxia • Model support (diagenesis)	South Deep North Deep	Discrete depths (12m, 15m, 18m)	When anoxia is present South Deep: Biweekly North Deep: Quarterly	Wildo Beta horizontal sampler

Turbidity	Light scattering (NTU)	• Trend analysis • Correlation with indices affecting water clarity	South Deep	Discrete depths (2m, 6m)	Daily at 15 minute intervals (Apr-Dec)	YSI Buoy
			South Deep North Deep	UML composites, plus 0m at S Deep	South Deep UML: Biweekly(Apr-Dec) North Deep: Quarterly, winter as possible	Wildco Beta horizontal sampler/ Churn

Table 4. Detailed Reporting of AMP Program. (continued) . ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Field data: pH, Temperature, Salinity, Conductivity, Dissolved Oxygen, ORP	• Volume-days of Anoxia • Rate of hypolimnetic oxygen depletion • DO during fall mixing • Volume-days of anoxia • Fish-space metrics	• Compliance • Stratification (thermal and chemical) • Model support • Trend analysis • Ammonia toxicity. • Use attainment.(habitat) • Concentration of reduced substances and oxidation status of lake (ORP data) • pH indicator of CO2 production and decomposition.	South Deep North Deep	0.5 m intervals through water column	South Deep: Biweekly (Apr-Dec) North Deep: Quarterly Winter as possible	YSI (In-situ)
		• Compliance with DO and pH standards. • Evidence of mixing processes (seiche)	South Deep	Discrete depths (2m, 6m, 12m, 15m)	Daily at 15 minute intervals (Apr-Dec)	YSI Buoy

Secchi Disk Transparency	• Average Secchi, percent of measurements meeting 1.2 m (nearshore), 1.5 m (South Deep)	• Secchi disk transparency: Compliance swimming safety guidance • Trends • Trophic Status • Indicator of water clarity • Aesthetics • Use attainment	South Deep North Deep Nearshore sites	Depth at which the disk is no longer visible from the surface	South Deep: Weekly (May-Sep) Biweekly (Apr, Oct-Dec) North Deep: Quarterly Winter as possible Nearshore: Weekly (May–Sep)	

Table 4. Detailed Reporting of AMP Program. (continued) ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
LiCor Underwater Illumination Profile	• Extinction coefficient	• Trends • Trophic Status • Indicator of water clarity • Aesthetics • Use attainment	South Deep North Deep	From lake surface to depth at which light is 1% of surface illumination	Biweekly (Apr-Dec)	LiCor Datalogger
Chlorophyll-*a* & Phaeophytin-*a*	• Concentration • Magnitude and frequency of bloom conditions	• Use attainment. • Aesthetic quality • Assess trophic Trends • Food web • Lake model calibration and validation	South Deep North Deep	UML composite and Photic Zone[1]	South Deep: In duplicate weekly (May-Sept) and biweekly (April; Oct –Dec) North Deep: Quarterly	¾" Tygon tube sampler (Depth-integrated tube samples)
Phytoplankton	• Biovolume • Abundance • Species composition	• Assess community structure, importance of cyanobacteria • Trends in abundance and biomass	South Deep North Deep	UML composite	South Deep: Biweekly (Apr–Nov) and monthly in winter, as conditions allow	¾" Tygon tube sampler (Depth-

1 The Photic Zone is defined as two times the Secchi disk transparency depth measured the day of sampling.

	• Annual succession • Percent blue green	• Aesthetic quality • Correlation with chlorophyll • Relationship to light penetration			North Deep: Quarterly	integrated tube samples)

Table 4 Detailed Reporting of AMP Program. (continued) ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Zooplankton	• Count • Dry weight biomass • Identification • Abundance • Species composition • Annual succession • Size	• Trends in abundance and biomass • Assess community structure • Size structure • Correlate data with other regional lakes (Oneida Lake) • Test relationship to fish community • Infer food web impacts	South Deep North Deep	6m (during stratified period) and 15 m tow	South Deep: Biweekly (Apr–Nov) North Deep: Quarterly	Vertical Haul 0.5 m diameter net, 80 μm mesh
Macrophytes	Plant distribution	Used to track percent cover during years without field surveys	Entire Lake	To maximum depth of plant growth	Annual	Digitize beds from aerial photographs using GIS
	Lakewide and by strata: • Species richness • Biomass • Percent cover	• Percent cover compared with optimal levels for warmwater fish community (bass) nursery and cover • Biomass to support lake model • Richness compared with regional lakes Trends	Transects in littoral strata	From shoreline to depth where plant growth stops (6 m contour standard)	2000, 2005, 2010 (August surveys)	Field surveys

Table 4. Detailed Reporting of AMP Program. (continued*)* . ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Fish Nesting survey	Count Where possible, identify species	Change over time: lakewide and at five strata used for biological programs	Entire Lake divided into 24 sections	1 m	June	Visual Count around littoral zone (along depth contour)
Fish Pelagic Larvae	• Species identification • Length frequency	• Community Structure • Growth rate, compared to regional lakes and to historical data • Condition factor • Species Richness • Pollution tolerance	South basin North basin	5.5 meter double oblique tow	Biweekly (April-August)	Miller Trawl
Fish Littoral Juvenile	• Number and species of juveniles • Catch per unit effort	• Community Structure • Size/length distribution • Species Richness • Evidence of recruitment • Pollution tolerance	15 sites lakewide	~ 1m	Every three weeks (July-October)	¼” mesh bag seine sweep

Table 4. Detailed Reporting of AMP Program. (continued) ***Lake Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Fish Littoral Adults	• Number and species captured • Catch per unit effort	• Community Structure • Size/length distribution • Species Richness • Evidence of recruitment • Pollution tolerance • Index of Biological Integrity	24 sections	< 1m	May, September, October	Night Electrofishing Angler diary program
Fish Pelagic Adults	• Number and species captured • Catch per unit effort	• Community Structure • Size/length distribution • Species Richness • Evidence of recruitment • Pollution tolerance	5 sites (1 per station)	4-5 m water (2 hour set)	May, October	Littoral - Profundal Gill Nets Experimental: hydroacoustics Angler diary program
Fish Deformities, Erosions, Lesions, Tumors, Fungal and Multiple Anomalies (DELT-FM)	Number and types of anomalies	Change over time	Lakewide	All (most are adults captured by electrofishing)	Screening on all captured fish	Visual analysis by trained field teams

Table 4. Detailed Reporting of AMP Program. (continued) ***Tributary Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Frequency Sampling Interval	Method
Alkalinity	Concentration	• Calculate bicarbonate (charge balance) • Trends	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF- Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Bacteria: Fecal Coliform	Abundance Compliance	• Potential presence of pathogens • Trends • Compliance with standards • Effectiveness of CSO control measures	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Grabs
BOD-5	Concentration	• Load • Indicator of oxygen-demanding material	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Wildco Beta horizontal sampler/churn

Table 4. Detailed Reporting of AMP Program. (continued) ***Tributary Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Frequency Sampling Interval	Method
Carbon: TOC, TOC-F, TIC	Concentration	• Trends • Trophic status • Oxygen demand • Load	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Cyanide	Concentration	Compliance	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Quarterly	Depth Integrated Sampling Techniques
Metals: Cd, Cr, Cu, Ni, Pb, Hg, Zn, As, K	Concentration	• Compliance (if AWQS) • Load • Data quality (K used in charge balance)	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Quarterly	Depth Integrated Sampling Techniques

Table 4. Detailed Reporting of AMP Program. (continued) ***Tributary Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Frequency Sampling Interval	Method
Metals/Salts: Ca, Na, Mg, Mn, Fe, Cl, SO4, SiO2-diss	Concentration	• Compliance (if AWQS) • Load • Data quality (major ions used in charge balance) • Geochemical analysis	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December) High flow events as occur	Depth Integrated Sampling Techniques
Nitrogen: TKN, NH_3-N, Org-N, TKN-Filtered	Concentration	• Trends • Support TMDL • Load	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Nitrogen: NO_3, NO_2	Concentration	• Compliance with standards • Load • Trends	Routine: Ninemile; Hiawatha; Velasko; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Phosphorus: TP, SRP, TDP	Concentration	• Trends • Support TMDL • Load • Bioavailability	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March)	Biweekly (January-December)	Depth Integrated Sampling Techniques

			biweekly and Sawmill Creek: biweekly, June – Sept		

Table 4. Detailed Reporting of AMP Program. (continued) ***Tributary Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Frequency Sampling Interval	Method
Solids: TSS, TDS	Concentration	Loading	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Turbidity	Concentration	Transport dynamics	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	Depth Integrated Sampling Techniques
Field data: pH, Temperature, Salinity, Specific conductance, Redox potential, dissolved oxygen	Average, maximum and minimum values	• Compliance • Model support • Trend analysis. • Use attainment.(habitat) • pH indicator of production and decomposition.	Routine: Ninemile; Hiawatha; Velasko; Bellevue; Kirkpatrick; Dorwin; ; Ley; Trib5A; Metro; EF-Manhole#015; Outlet; Bloody Brook (April – March) biweekly and Sawmill Creek: biweekly, June – Sept	Biweekly (January-December)	In-situ

Table 4. Detailed Reporting of AMP Program. (continued) ***Seneca River Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
BOD-5	Concentration	• Indicator of oxygen-demanding material • Model support	Buoy 316	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler
Carbon: TOC, TDC	Concentration	• Trends • Trophic status • Indicator of oxygen-demanding material • Model support	Buoy 316	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler Tube sampler "Depth Integrated Tube samples"
Chlorophyll-*a*	Concentration	• Trophic status • Trends • Model support	Buoy 316	Through the water column. Tube composite through the photic zone and a grab at 1-meter above the river sediments.	Monthly (July – September)	

Table 4. Detailed Reporting of AMP Program. (continued) ***Seneca River Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Metals/Salts: Cl	Concentration	• Trends • Geochemical analysis • Model support	Buoy 316 (Seneca River	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler
Nitrogen: TKN, NH3-N, TKN-Filtered, NO3, NO2	Concentration	• Compliance • N dynamics • N:P ratios • Trends • Model support	Buoy 316 (Seneca River)	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler
Phosphorus: TP, SRP, TDP	Concentration	• Trophic status and algal productivity • Trends • Model support	Buoy 316 (Seneca River)	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler
Solids: TSS, VSS	Concentration	• Trends • Model support • Indicator of water clarity	Buoy 316 (Seneca River)	1 meter below water surface 1 meter above the river sediments	Monthly (July –September)	Wildco Beta horizontal sampler

Table 4. Detailed Reporting of AMP Program (continued) ***Seneca River Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
Turbidity	Light scattering (NTU)	• Trends • Model support • Indicator of water clarity	Buoy 316 (Seneca River)	1 meter below water surface 1 meter above the river sediments	Monthly (July – September)	Wildco Beta horizontal sampler
				Upper waters: 0.86m Lower waters: 3.80 m	Daily at 15 minute intervals (April- Nov)	YSI Buoy
Field data: pH, Temperature, Salinity, Conductivity, Dissolved Oxygen, ORP	Concentration	• Compliance • Stratification regime. • Trends • Ammonia toxicity. • Redox status • pH indicator of CO2 production/decomposition • DO indicator of suitability of aquatic biota/zebra mussel activity. • Support river model and evaluate assimilative capacity		0.5 m increments	Monthly (July – September)	YSI (in-situ)
			Buoy 316 (Seneca River)	Upper waters: 0.86m Lower waters: 3.80 m	Daily at 15 minute intervals (April- Nov)	YSI Buoy
Secchi Disk Transparency		• Model support • Indicator of water clarity • Use attainment	Buoy 316 (Seneca River)	Depth at which the disk is no longer visible from the surface		Secchi Disk

Table 4. Detailed Reporting of AMP Program (continued) ***Seneca River Program Summary***

Parameter	Data Analysis and Reporting	Data Interpretation Strategy	Sites	Depths	Frequency Sampling Interval	Method
LiCor Underwater Illumination Profile		• Trends • Model support • Indicator of water clarity	Buoy 316 (Seneca River)	Licor data – 20 cm intervals from river surface to depth at which light is 1% of surface illumination	Monthly (July – September) & with diurnal cycles	LiCor Datalogger

3.3 Design of the AMP: Underlying Assumptions

Design of the AMP builds on decades of monitoring within the lake and its watershed. Several important assumptions underlie the monitoring program; these assumptions are based on analysis of the historical data and mass-balance calculations. Among the assumptions are:

- South Deep is representative of lake-wide conditions.

  This assumption has been evaluated by comparing data collected at North Deep on a quarterly frequency with the South Deep data. A t-test of paired samples was used to compare data from 1999-2007, and resulted in no systematic difference in trophic status indicator parameters (chlorophyll-a, phytoplankton biomass, and Secchi disk transparency) measured at North and South Deep. Of the other parameters, the N species and Fe are higher at South Deep, which is likely due to the Metro discharge. Fecal coliform bacteria are higher at South Deep; this is attributed to the proximity of major sources (storm water and CSO discharges). Specific conductance and pH were higher at North Deep, likely reflecting the influence of Ninemile Creek.

- External loading to the lake is assessed by monitoring discharge and concentration of six tributaries plus Metro effluent. In total, approximately 95% of the water flow into the lake is gauged and sampled. It is assumed that this monitoring is sufficient to provide a robust estimate of external loading.

  This assumption was tested in 2003, when storm event samples were obtained from two small streams draining the nearshore (ungauged) portion of the watershed. The concentrations of monitored parameters in the two streams, Bloody Brook and Sawmill Creek, were less than or comparable to concentrations measured in the gauged streams. With the very low flow contribution, it was determined that the loading from the nearshore (ungauged) portion of the lake watershed was minimal. That is, the ungauged areas do not contribute a disproportionate load given their drainage area.

- Deposition onto the lake surface (including precipitation and dry fall) accounts for a small fraction of the total external nutrient load and can be adequately characterized from regional data.

  The mass balance framework developed by Dr. William Walker provides a basis for evaluating the magnitude and importance of precipitation within the lake's phosphorus budget. The lake surface area comprises a very small fraction of the overall drainage basin, and precipitation onto the lake surface represents about 2% of *the total water inflow. The concentration of phosphorus in rainwater is variable, but typically well below the concentrations measured in the tributary streams, and an order of magnitude less than the concentration in the Metro effluent. Again looking to Dr. Walker's mass balance framework, precipitation represents < 1% of the total P loading to the lake assuming the regional average TP concentration in precipitation of 30 µg/l. Doubling this estimated concentration still represents less than 1% of the current total annual TOP load; for this reason site-specific sampling has not been recommended. The magnitude and importance of atmospheric loading of mercury has not been quantified as part of the AMP.*

- Groundwater does not represent a significant component of the lake's hydrologic budget.

  This assumption can be examined by evaluating the extent to which water and chloride models show reasonable agreement between inputs, outputs, and retention in the lake. Onondaga Creek is influenced by groundwater seepage into the downstream reaches just above the Inner Harbor. Likewise, groundwater flux into Ninemile Creek has been documented. A chloride model of the lake, assuming no groundwater contribution, was constructed (Doerr et al. 1994) and predicted measured concentrations within about 5%. This implies that groundwater input to the lake is likely a minor component (<5%) of the hydrologic budget.

- Water quality of the lake may be adequately characterized by examining the lake as a two-layer system during the period of thermal stratification, which typically extends from late May through late October. Furthermore, the photic zone does not extend into the lower water layer.

  This assumption is tested as part of the Onondaga Lake water quality model development and peer review process, which began in 2005.

3.4 Design of the AMP: Hypothesis Testing and Statistical Power

The elements of the monitoring program were distilled into a series of testable hypotheses. This work product was used as a basis for evaluating the AMP design, allowing the project team and the advisors to determine whether the correct parameters were being measured. A summary of the hypotheses for elements of the monitoring program is presented in **Table 5**. There are three types of hypotheses to be tested using data generated by the AMP:

- Is Onondaga County in compliance with the effluent limits required by the State Pollution Discharge Elimination System (SPDES) permit?

- Have ambient water quality standards or guidance values in the receiving water been met?

- Is there a trend or shift in the monitoring data, in both water quality and biological programs?

It is evident from the list of hypotheses that a major focus of the AMP is to differentiate actual trends from natural variability. OLTAC member Dr. William W. Walker Jr. examined the historical monitoring data to characterize the variability of the parameters used to assess progress (for example, concentrations of ammonia-N, bacteria, chlorophyll-a at the lake's South Deep station). The AMP design was then evaluated to determine what magnitude of "true" change in concentration could be detected at a given level of statistical certainty. The AMP was modified to increase the monitoring frequency for certain parameters that are highly variable (e.g. chlorophyll-a). For the majority of lake water quality parameters the biweekly sampling program was found to be adequate. Dr. Walker summarized his analysis of the power of the water quality monitoring program in the Phase 1 Statistical Framework (January 1999) and an updated Phase 1 Statistical Framework (January 2002). His report evaluating the design of the biological programs and their power to detect change was issued as the Phase 2 Statistical Framework (February 2000) and an update to the Phase 2 Statistical Framework (August 2002).

Dr. Walker has updated the statistical framework for both the water quality and biological programs using recent data. The update was structured to reference these specific hypotheses.

Table 5. Summary of Hypotheses Underlying the AMP.

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment
		Compliance with SPDES permit	Compliance with AWQS or guidance value	Significant Trend or Shift in Data	
Ammonia-N	Improvements at Metro enable the County to meet Stage III effluent limits for ammonia N	*			Outfall 001 effluent concentrations, calculated for summer and winter (seasonal limits apply)
	Reduced ammonia load results in compliance with ambient water quality standards and federal criteria for ammonia in Onondaga Lake		*	*	South Deep station, biweekly monitoring, discrete samples collected at 3-m intervals, with temperature and pH
Nitrite-N	Achievement of Stage III effluent limits for ammonia results in compliance with the NYS ambient water quality standard for nitrite (warm water fish community)		*	*	UML, LWL composite samples, biweekly at South Deep
Phosphorus	Improvements at Metro enable the County to meet final SPDES effluent limits (as set forth in a revised TMDL on or before Jan 1 2009)	*			Outfall 001 effluent concentrations
	Reduced phosphorus load from Metro reduces concentration of phosphorus in Onondaga Lake		*	*	South Deep station Biweekly monitoring TP, SRP and TDP, discrete samples collected at 3-m intervals
	Reduced phosphorus load from Metro brings the lake into compliance with guidance value (or site-specific guidance Value)		*	*	TP at South Deep, 1-m depth (biweekly measurements, June –Sept)

Table 5. Summary of Hypotheses Underlying the AMP (continued)

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment
		Compliance with SPDES permit	Compliance with AWQS or guidance value	Significant Trend or Shift in Data	
Dissolved Oxygen	Improvements at Metro enable the County to meet interim effluent limits for BOD	*			Outfall 001 effluent concentrations
	Improvements at Metro and related nonpoint source phosphorus load reductions bring the lake into compliance with NYS AWQS for DO during fall mixing.		*	*	Weekly or biweekly profiles and high-frequency measurements at buoy at South Deep station
	Improvements at Metro and related nonpoint source phosphorus load reductions reduce the volume-days of anoxia and hypoxia.			*	Weekly or biweekly profiles and high-frequency measurements at buoy at South Deep station
	Improvements at Metro and related nonpoint source phosphorus load reductions reduce the areal hypolimnetic oxygen depletion rate.			*	Weekly or biweekly profiles and high-frequency measurements at buoy at South Deep station
Indicator bacteria	CSO remedial measures and improved stormwater management reduce the loading of fecal coliform bacteria entering the lake from tributaries during high flow conditions.	*	*	*	Storm event data: baseline and post-improvement rating curves for fecal coliform bacteria
	Implementation of improvements (including CSO projects) and progress with stormwater management will reduce concentration of indicator organisms	*	*	*	Indicator bacteria abundance at nearshore stations during summer and following storms.

Table 5. Summary of Hypotheses Underlying the AMP (continued)

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment
		Compliance with SPDES permit	Compliance with AWQS or guidance value	Significant Trend or Shift in Data	
Chlorophyll-*a*	Metro improvements and watershed phosphorus load reductions result in lower chlorophyll-a concentrations in the lake.			*	Weekly or biweekly measurements at South Deep, photic zone and UML
Secchi disk transparency	Metro improvements and related nutrient load reductions result in improved water clarity (as measured by Secchi disk transparency) in Onondaga Lake			*	Weekly or Biweekly measurements at South Deep and nearshore stations.
Phytoplankton community	Metro improvements and watershed phosphorus load reductions result in lower biomass of phytoplankton in the lake			*	Biweekly samples of UML phytoplankton community, numbers, size and identifications (PhycoTech)
	Metro improvements and watershed load reductions result in reduced relative abundance of cyanobacteria to the lake's phytoplankton community (measured by percent of total biomass)			*	Biweekly composite samples of UML phytoplankton abundance, biomass, and ID (PhycoTech)
Zooplankton community	Metro improvements and watershed phosphorus load reductions reduce the biomass of zooplankton in Onondaga Lake by reducing the algal food supply			*	Biweekly composite samples of UML and tow (0-15 m), zooplankton abundance, size, biomass, ID (Cornell)

Table 5. Summary of Hypotheses Underlying the AMP (continued)

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment
		Compliance with SPDES permit	Compliance with AWSQ or guidance value	Significant Trend or Shift in Data	
Macrophytes	Metro improvements and watershed phosphorus load reductions indirectly result in increased areal coverage of macrophytes in lake's littoral zone			*	Percent cover, biomass, and maximum depth of growth. Surveys: 2000, 2005, 2010 plus annual aerial photo evaluation
	Metro improvements and watershed phosphorus load reductions result in increased number of macrophyte species			*	Macrophyte species richness Detailed surveys: 2000, 2005, 2010

Table 5. Summary of Hypotheses Underlying the AMP (continued)

Monitoring Parameter	Hypothesis	Type of Hypothesis			Data Used for Assessment
		Compliance with SPDES permit	Compliance with AWQS or guidance value	Significant Trend or Shift in Monitoring Data	
Fish community	Implementation of nutrient load reductions at Metro and nonpoint sources, including CSO remediation, will indirectly increase the number of fish species present in Onondaga Lake			*	Annual monitoring program: Species richness, electrofishing, gill nets, seines
	Implementation of point and nonpoint nutrient load reductions will indirectly increase the number of fish species that are sensitive to pollution in Onondaga Lake			*	Annual monitoring program: Electrofishing, pollution tolerance index (Whittier and Hughes 1998)
	Implementation of point and nonpoint nutrient load reductions will increase the reproductive success of fish in Onondaga Lake			*	Annual monitoring program: Nesting survey, larval tows, larval light traps, littoral seines
	Implementation of point and nonpoint nutrient load reductions will improve the lake's IBI. Note effects may be more evident in Strata 2,3, and 4.			*	Annual monitoring program: Electrofishing
	Implementation of point and nonpoint nutrient load reductions will increase the habitat available for the coolwater fish community			*	Fish space metrics: dissolved oxygen and temperature profiles at South Deep station

3.5 Design of the AMP: Data Management

The AMP produces an extensive dataset; more than 20,000 water quality measurements are obtained each year in Onondaga Lake, its tributary streams, and the Seneca River. Dr. Walker has developed an integrated database to manage the data. This effort has resulted in a powerful tool for the County and other stakeholders to evaluate specific results by parameter, depth, and date. The database is also used to screen for outliers and test for trends; it generates plots for data exploration and reporting.

3.6 Design of the AMP: Metrics to Measure and Report Progress

Analytical and field data are submitted on a quarterly basis to the NYSDEC. Screened and validated data are provided annually and are included in the OCDWEP Annual AMP Report. The process of turning data into information occurs continually through the year and is formalized in the Annual AMP report. Results and findings of the complete monitoring effort are documented in this report is reviewed by OLTAC members and NYSDEC. The County is required to submit an approvable annual AMP report to NYSDEC by December 1 each year.

A series of metrics have been developed to organize and report the extensive AMP dataset. As defined by EPA, metrics are attributes of the physical, chemical and/or biological ecosystem that respond to human disturbance. For the Onondaga Lake watershed, metrics are designed to indicate progress toward compliance with applicable standards and guidelines, and progress toward attaining a desired use.

Selected metrics may relate directly to an impairment of the lake or watershed; relate to a resource of interest; or correspond to a published standard that, in turn, reflects the requirements of public health or the aquatic biota. Candidate metrics can be measured and interpreted with relative ease to answer basic questions, such as, "is the lake getting better?" and "is it safe for my family to swim here?".

Metrics selected to interpret and report on the AMP data are listed in **Table 6**. Note that the metrics are grouped into categories addressing human uses and ecosystem function: (1) water contact recreation; (2) aesthetics; (3) aquatic life protection; and (4) sustainable recreational fishery Metrics for water contact recreation are straightforward: New York State Department of Health and EPA have standards and guidance values for indicator bacteria and water clarity that are designed to be protective of human health and safety. Selecting metrics for aesthetics is slightly more judgmental, as they relate to perceived attributes such as water color and clarity, odors, and the visible extent of weed and algal growth. Water quality conditions needed to support aquatic life are fairly well defined in federal criteria and state standards. Onondaga County AMP metrics are designed to track water quality and habitat conditions during critical periods for reproduction and survival of young animals.

Table 6 Summary of Metrics

Desired Use	Metrics	Measured By
Water contact recreation	Indicator Bacteria	Fecal coliform bacteria abundance measured at stations within the Class B segment of Onondaga Lake (includes nearshore and North Deep station)
	Water Clarity	Secchi disk transparency at nearshore stations.
Aesthetics	Water Clarity	Secchi disk transparency at South Deep.
	Bloom frequency and magnitude	Percent of chlorophyll-*a* measurements greater than 15 µg/l (USEPA threshold for public perception as impaired for recreational use)
		Percent of chlorophyll-*a* measurements greater than 30 µg/l (threshold for public perception of nuisance bloom).
	Algal community structure	Percent of algal community represented by cyanobacteria (blue-green taxa)
	Macroalgae proliferation	Percent cover of littoral zone, measured at nine nearshore stations June 1 – August 31 annually
Aquatic Life Protection	Ammonia N	Percent of measurements in compliance
	Nitrite N	Percent of measurements in compliance
	Dissolved Oxygen	DO at fall mixing.
		Duration of DO concentrations < 4 mg/l (buoy data)
	Integrated metrics	"Fish space" metrics, volume-days with suitable conditions of DO and temperature for cold water and cool water fish communities *(Note: this metric does not account for other requirements such as habitat and forage base)*
	Species assemblage	Percent intolerant or moderately intolerant of pollution
Fish Reproduction	Number of species with documented reproduction and recruitment[2]	Nesting surveys, larval sampling (Miller tows), young-of-year sampling (littoral and pelagic) adult survey (electrofishing, gill netting), hydroacoustical survey.
	Habitat quality	Percent cover of macrophytes: scaled to optimal level for largemouth bass (40 - 60% cover is target).

[2] Sampling captures young-of-the-year (YOY) fish in the lake. It is assumed that the majority of these small fish originated in the lake, given their size and limited mobility of the early life stages. However, the presence of YOY fish that originated in the Seneca River or tributaries to Onondaga Lake cannot be ruled out.

4. DATA INTERPRETATION FOR THE BIOLOGICAL PROGRAMS

Analysis and interpretation of the biological components of the AMP is challenging. There are no equivalent promulgated standards as cited for the water quality parameters. The plan for analysis and interpretation of the biological data is primarily focused on changes over time. There are also limited comparisons with reference systems such as Oneida Lake, and comparisons to benchmark conditions considered desirable for various functions and values of the aquatic ecosystem.

One way to interpret the fish data is to compare the current community to the fish community present in Onondaga Lake at two critical periods: (1) during the early years of European settlement, and (2) during the early 1960s. The nature of the early fish community can provide insight into the natural condition, while the community during the 1960s likely represents the worst conditions of water quality and habitat degradation.

However, the biological data, including fish, must be evaluated with respect to the rest of the ecosystem. For example, the reproductive success of some fish species is influenced by macrophyte coverage, planktivorous fish can alter zooplankton community assemblages, and zebra mussels can alter trophic interactions. In order to fully understand and interpret changes to one aspect of the biological community it is necessary to describe the biological components that interact and influence the community in question. This important effort will continue as the AMP progresses through 2012.

4.1 Sampling design

Biological sampling in Onondaga Lake occurs both nearshore (fish, macroinvertebrates, macrophytes) and offshore (larval fish, zooplankton, phytoplankton). Because of the variability of the lake's nearshore habitat conditions, the littoral habitat was divided into five strata based on a combination of substrate type and wave energy, both of which influence aquatic macrophytes and macroinvertebrates and, in turn, fish distribution. These five strata are displayed in **Figure 3**:

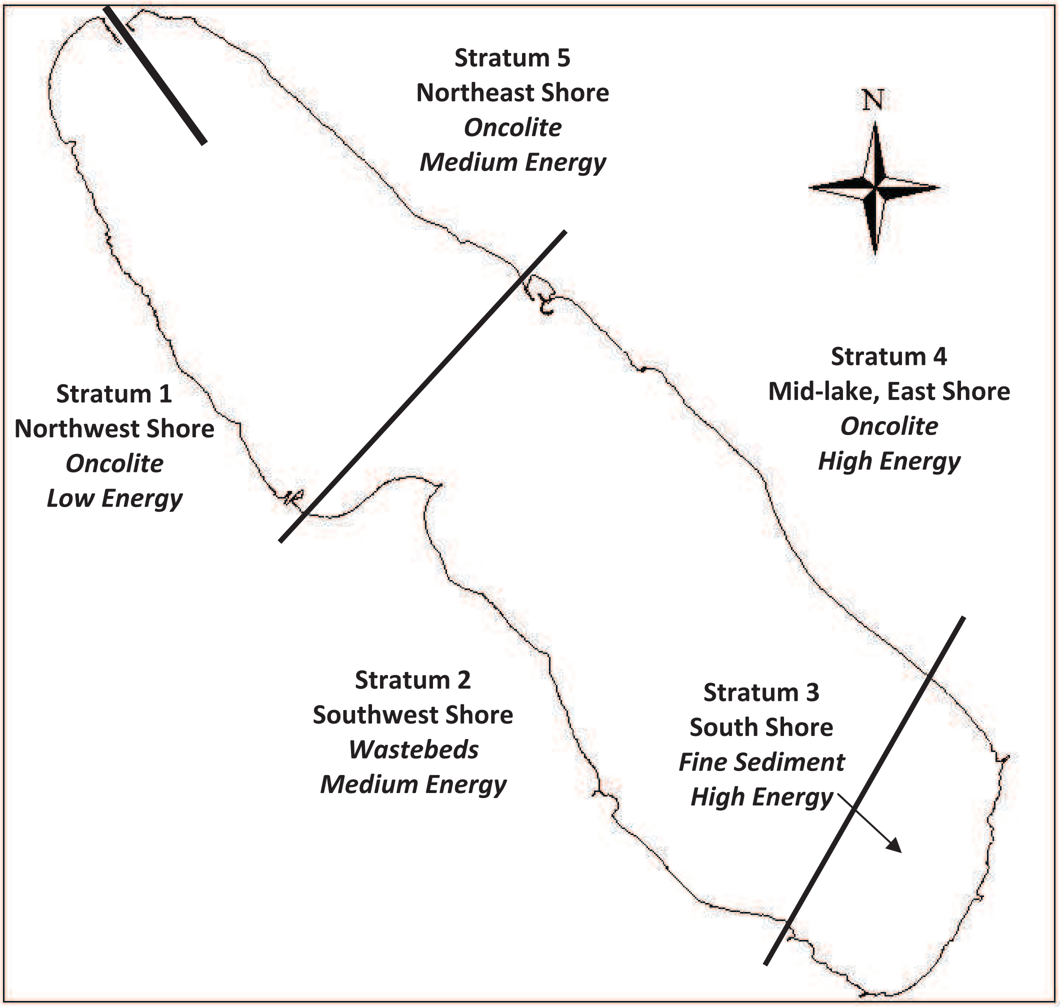
Stratum 1. Oncolite substrate with low wave energy (NW portion of the lake).

Stratum 2. Wastebed substrate with moderate wave energy (SW shore)

Stratum 3. Soft substrate with high wave energy (South end)

Stratum 4. Oncolite substrate with high wave energy (SE shore)

Stratum 5. Oncolite substrate with medium wave energy (NE shore)



Strata Boundaries

Figure 3. Shoreline and Littoral Zone Strata used in the AMP Biological Programs

4.2 Species Data

Species data collected during the biological monitoring programs are used to evaluate pollution tolerance of the biological community, the presence of exotic or invasive species, nuisance species that affect best usage of the lake, and evaluate the status of those species highlighted in the ACJ.

- Pollution tolerance. Organisms have varying degrees of sensitivity to disturbances in their environment. Those most sensitive to disturbance are the first to be extirpated and the last to re-colonize. Dominance and distribution of pollution-tolerant or pollution-sensitive organisms can indicate relative degree of impact between locations. Changes in the distribution of these communities can be tracked over time. The AMP utilizes several ways of examining pollution tolerance, including metrics specifically derived to quantify this property of the community (**Table 7**).

- Exotic/invasive species. Onondaga Lake is directly connected to the Barge Canal system, therefore it is highly susceptible to invasion by exotic species. Invasive species often take advantage of disturbance to establish populations. Once established they can dramatically alter habitat, water quality, and trophic structure. The AMP has detected the early stages of invasion of several important species. For example, the exotic zooplankton *Cercopagis pengoi* was first detected in Onondaga Lake during routine sampling in 2000. Once exotic species are detected, the program can be tailored to track their progress and effects on the ecosystem.

- Associated with nuisance conditions. Some species can be considered to be a nuisance to humans. Some of these obvious, such as blue-green algal blooms; others become apparent to lake users through indirect effects in the food web. For example, the 2002 increase in alewife (*Alosa pseudoharengus*) numbers reduced the population of larger zooplankton (their preferred food source) in the lake; this reduction in larger zooplankton decreased the effective grazing pressure on algae. As a result, water clarity declined. Larger zooplankton species are returning to the lake, and water clarity has improved, as alewife abundance has declined.

- Included in management/rehabilitation plan. Some species have special meaning within the context of the ACJ and/or future management plans. This is most common with the fish program. For example, the ACJ states the County should “evaluate the success of walleye, bass and sunfish propagation (quantitative lakewide nest surveys, survival and recruitment estimates, and juvenile community structure) in the lake” (ACJ Appendix D, IV.5). These species are given special consideration within the biological monitoring program.

Table 7. Summary of Pollution Tolerance Metrics Used for the Biological Monitoring Program

Program	Component	Pollution Tolerance Metric	Comments
Fish	Adult	Pollution Tolerance Index	Based on the Index published by Whittier and Hughes (1998). Tolerance categories include: intolerant, moderately intolerant, moderate, moderately tolerant, and tolerant.
		Indicator Species	Indicator species are used to assess environmental condition, using organisms with documented tolerance or sensitivity to environmental degradation
	Young-of-the-Year	Indicator Species	Young-of-the-year organisms are good indicators of environmental change, as they are highly susceptible to disturbance and pollution.
Macrophytes	Field Survey	Non specific	Some species have known tolerances to water quality variables. For example *Potamogeton pectinatus* (common in Onondaga Lake since at least the early 1990s) is more tolerant of salinity than many other macrophytes. Knowledge of these types of tolerances can help in understanding the current lake community as well as the changes that occur.

4.3 Population Data

Population data collected during the biological monitoring programs are used to evaluate individual size, abundance and reproductive success in Onondaga Lake and the tributaries.

- Average size of individuals. Size of individuals is monitored for fish and zooplankton in the AMP. The size that animals attain is a function of both the genetics of the organism as well as the environmental conditions the organism has been subjected to throughout its life. Changes in the ecosystem are often reflected by changes in growth, thus making analysis of size of certain organisms a potential valuable monitoring tool. For example, growth may be density dependant, so populations with poor recruitment may be characterized by fast-growing individuals. In addition, the size structure of some organisms can have dramatic cascading effects throughout the trophic structure of the lake. Average size of some organisms can also be compared to other regional lakes.

- Abundance. Abundance measures are difficult to quantify in biological populations due to their inherent spatial and temporal variability. However, changes in abundance can provide useful information in the AMP because change in population size is the mechanism underlying changes in many community metrics. Expected changes in abundance due to improving water quality or habitat may not always be positive. Some species exploit disturbed conditions and their abundance can be expected to decrease with improving conditions. As the dynamics of the lake community change, the lake will become more hospitable to some species and less to others, gradually abundance of species will change to reflect the new lake condition.

- Reproductive success. Monitoring reproduction and recruitment of the fish community is particularly useful because the early life history stages are often very sensitive to disturbance. Reproductive success is affected by both biotic and abiotic factors. For example, reduction in ammonia concentration in the water column during the spring is likely to increase survival of sensitive early life stages (abiotic factor). Any effects of improved water quality on the fish community will likely first be reflected in the early life history stages. However, the food web effects must also be considered. Predation by fish such as alewife will reduce survival of larval fishes (biotic factor). The AMP monitors nesting of fish, larval fish, and juveniles.

4.4 Community Data

Community data collected during the biological monitoring programs are used to evaluate richness, diversity, and relative abundance of indicator species in Onondaga Lake and the tributaries.

- Richness. Richness, the number of different taxa (usually species) found in a community, is calculated for all components of the biological monitoring program. Richness may not be correlated with water or habitat quality. In fact, richness can increase with disturbance; for example, invasive species may become established without eliminating native species. Richness measurements can be used to detect substantial changes in community structure, if the sampling effort is held relatively constant. If changes in richness are detected, the underlying mechanism will be investigated to analyze the potential significance.

- Diversity. The distribution and abundance of different organisms, and how these attributes vary both spatially and temporally, play a major role in determining how an ecosystem functions to process energy and materials (Hooper et al. 2005). The numbers and types of organisms present (sometimes referred to as biodiversity) act together with the effects of climate, resource availability, and disturbance regimes to influence ecosystem properties (Hooper et al. 2005). Species composition, richness, evenness, and interactions respond to and influence ecosystem properties (Hooper et al. 2005). A high biodiversity can be interpreted as indicating functional stability (Karr 1968, Margalef 1968, Odum 1969). Biodiversity can be expressed in terms of numbers of entities (how many genotypes, species, or ecosystems), the evenness of their distribution, the differences in their functional traits, and their interactions (Hooper et al. 2005).

  The Onondaga Lake biological monitoring program utilizes the Shannon-Weiner diversity index as a measure of biodiversity. Shannon-Weiner diversity is a function of both the number of species present (richness) and the equitability of distribution of individuals within these species (evenness) (Washington 1984). Shannon-Weiner diversity is greatest when large numbers of taxa are represented in equal proportions. Shannon-Weiner diversity can help determine if disparity occurs between different sites within the same waterbody or over time. However, care should be taken to not compare Shannon-Weiner diversity values between waterbodies as this metric is expected to differ depending on size and connectedness of the waterbody. Shannon-Weiner diversity is usually utilized with other more descriptive indices that, taken together, can yield a more complete view of the community. This group of metrics is used to document change at the community level. If changes are observed, species-level information is examined to determine the source of those changes and whether they might be attributed to changes in habitat or water quality.

- Presence and relative abundance of indicator organisms. One important characteristic of macroinvertebrates is their differential tolerance to various types of pollution; these different tolerances can influence the species composition and relative abundance of organisms in stream segments affected by various types of pollution. Several indices have been developed to examine the macroinvertebrate community and infer water quality and habitat conditions. Benthic macroinvertebrates are good indicators of localized conditions due to their limited migration patterns and sessile mode of life.

The tolerance of benthic macroinvertebrates to various types of pollution has been investigated, including organic (oxygen-demanding) waste, nutrients, sediment, salts, metals, and temperature. Both point sources and nonpoint sources (runoff) can cause these types of pollution to reach streams and rivers.

The AMP includes two macroinvertebrate sampling efforts to evaluate if the stream biota changes as CSO improvements are brought on line. The first is the biennial tributary macroinvertebrate program; macroinvertebrates are collected and identified to the lowest possible taxon (ideally, the species level) at three or four sites on the CSO-affected streams (Onondaga Creek, Ley Creek, and Harbor Brook). The second effort is associated with the periodic stream mapping program; macroinvertebrates are collected and identified to family at one site per stream mile on the three CSO-affected streams. Results are used to calculate standard indices that assess whether a stream segment is impaired, and what type of pollution is most likely responsible.

5. MODELING

An integrated program of monitoring and modeling will provide the information needed to determine whether the improvements to Metro and the CSOs are sufficient to bring the surface waters (Onondaga Lake, the tributary streams, and a segment of the Seneca River) into compliance with state and federal requirements. Data from the AMP are used to construct and verify models. There are conceptual models of the lake and its watershed that describe how energy and materials cycle. Mathematical models, which are quantitative formulations of mechanisms and interactions that affect water quality, are under development.

5.1. Conceptual Model

A conceptual model describes the interrelationships between physical, chemical, and biological characteristics of the lake and watershed; it provides a tool for interpreting data and understanding underlying mechanisms. The conceptual model also provides a valuable tool to evaluate the adequacy of the monitoring program itself and determine whether the appropriate questions are being asked of the ecosystem and the data set. Finally, the conceptual model provides the foundation for development of a predictive mathematical model.

5.2. Mass-balance Model

The development and structure of a mass-balance modeling framework for Onondaga Lake is described in the Onondaga County AMP Annual Reports. The framework facilitates computation and analysis of mass balances for nutrients and other water quality components using hydrologic and water quality data collected in the Lake and its tributaries since 1986. Lake water and mass balances are formulated on yearly and seasonal (May-September) time scales. Results provide a basis for:

- Estimating the magnitude and precision of loads from each source;
- Assessing long-term trends in load and inflow concentration from each source and source category (point, nonpoint, total);
- Evaluating the adequacy of the monitoring program, based on the precision of loads computed from concentration and flow data;
- Developing and updating an empirical nutrient loading model that predicts eutrophication-related water quality conditions (as measured by nutrient concentrations, chlorophyll-a, algal bloom frequency, transparency, and hypolimnetic oxygen depletion) as a function of yearly nutrient loads, inflows, and lake morphometry;
- Developing simple input/output models for other constituents; and
- Developing data summaries to support integration and interpretation of monitoring results in the County's annual AMP reports.

5.3. NYSDEC Total Maximum Daily Load (TMDL) Allocation

The ACJ requires that NYSDEC issue a revised Total Maximum Daily Load (TMDL) allocation for phosphorus inputs to Onondaga Lake by December 31, 2011. The TMDL will define the total loading of phosphorus that can be assimilated by the lake while maintaining compliance with water quality standards. The total required reductions in point and nonpoint source loading will be defined. To complete this task, NYSDEC requires a reliable model of how the lake responds to loading, plus an accurate allocation of the sources of phosphorus.

5.4. USGS Onondaga Lake Watershed Model

One of the projects funded by the Onondaga Lake Partnership is a watershed model of the lake. USGS is developing this model which will be used to estimate nonpoint source loads of materials to Onondaga Lake under various hydrologic conditions and land use practices. The tributary loading estimates developed through the AMP are the basis for model calibration.

5.5. Three Rivers Water Quality Model (TRWQM)

A water quality model of the Three Rivers system was developed by QEA, LLC to assess the waste load assimilative capacity of the Seneca River. The model quantifies the River's assimilative capacity and accommodates respiration of zebra mussels, as set forth in the AMP Requirements (ACJ Appendix D, item IV.2). The model will serve as the basis for a TMDL allocation for oxygen-demanding materials and will be used to determine if diversion of Metro effluent to the Seneca River is a viable alternative.

Onondaga County funded development of the TRWQM. The model domain extends from Cross Lake to the Phoenix Dam. A peer review of the TRWQM has been completed.

The model simulates water quality conditions in the river in response to various environmental conditions, including upstream water quality conditions, point source discharges, water temperature, and zebra mussel growth.

5.6. Onondaga Lake Water Quality Model

In 2005, Onondaga County completed a Request for Proposals and selection process for development of a water quality/eutrophication model of Onondaga Lake. Anchor QEA, LLC is developing complete the lake model that will be used for the NYSDEC TMDL allocation and final effluent limits. This water quality model will link the watershed model and the TRWQM. The model will be developed using data from the AMP and will be the primary means of determining the level of treatment and location of the Metro discharge. Model development is a collaborative effort including Onondaga Lake Partnership as well as expert peer reviewers. While the primary focus is on water quality, the model will incorporate biological influences on the lake ecosystem. The overall goal will be to develop a tool that can help assess water quality improvements from both the bottom-up effects (i.e. reduced loading of nutrients and organic material) and the top-down effects (i.e. food web interactions).

6. LITERATURE CITED

Doerr, S.M., S.W. Effler, K.A. Whitehead, M.T. Auer, M.G. Perkins and T.M. Heidke. 1994. Chloride model for polluted Onondaga Lake. Water Res. 28:849-861.

Hooper, D.U., F.S. Chapin III, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J.H. Lawton, D.M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setala, A.J. Symstad, J. Vandermeer, and D.A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecol. Mono. 75(1) 3-35.

Karr, J. R. 1968. Habitat and Avian Diversity on Strip-mined Land in East Central Illinois. Condor 70(4): 348-57.

Klemm, D.J., P. A. Lewis, F. Fulk, J. M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. United States Environmental Protection Agency. EPA/600/4-90/030.

Novak, M.A., and R.W. Bode. 1992. Percent model affinity: a new measure of macroinvertebrate community composition. N. Am. Benthol. Soc. 11(1): 80-85).

MacArthur, R.H. 1955. Fluctuations of Animal Populations, and a Measure of Community Stability. Ecology 36: 522-36.

Margalef, D. R. 1968. Perspectives in Ecological Theory. Univ. Chicago Press, Chicago.

Odum, E. P. 1969. The Strategy of Ecosystem Development. Science 164: 262-70.

Walker, William W. Jr. 2002 – 2003 Phase 1 and Phase 2 Statistical Framework. Reports prepared for Onondaga County Department of Water Environment Protection, Syracuse NY.

Washington, H.G. 1984. Diversity, biotic and similarity indices. A review with special relevance to aquatic systems. Water Res. 18(6):653-694.

Whittier, T.R. and R. M. Hughes. 1998. Evaluation of fish species tolerance to environmental stressors in lakes in the northeastern United States. N.A. J. Fish. Mngt. 18:236-25.