Appendix A. Numeric Nutrient Criteria (NNC) Development for Potable Water Use

The development of a TMDL requires a scientifically defensible numeric endpoint which will ensure that the best uses of the water body are met. For the purpose of TMDL development in this watershed, a link between phosphorus concentrations and protection of the best use of the water body as a source of drinking water must be established. New York State's current guidance value for phosphorus is 20 µg/L (NYSDEC 1993) but was derived to protect primary and secondary contact recreational uses from impairment due to aesthetic effects. The current guidance value was not specifically derived to protect the drinking water use of water bodies, such as Cayuga Lake. The link is best made through a site-specific interpretation of New York State's existing narrative ambient water quality standard for phosphorus (6NYCRR 703.2): "none in amounts that will result in growths of algae, weeds and slimes that will impair the waters for their best usages"(NYSDEC 2008), because an appropriate numeric translator for drinking water use has not been adopted.

In 2000, NYSDEC incorporated such a site-specific interpretation of the narrative criterion protective of drinking water use into TMDLs for the New York City Reservoirs (NYSDEC 2000). The USEPA, NYSDEC and the New York City Department of Environmental Protection (NYCDEP) worked toward the development of water supply-based phosphorus criteria for the New York City Reservoir Watershed, as part of the Phase II TMDL process. A weight-of-evidence approach utilized all available NYC reservoir-specific data to develop a relationship between phosphorus and Chl-a levels, and a selected set of water quality variables which have been demonstrated to negatively affect the water quality of the drinking water supplied by the reservoirs in the Watershed. Five water quality variables that are important concerns to water supply and are associated with excessive nutrient loading and reservoir water quality were selected, including THM precursor concentrations for certain reservoirs (Stepczyk 1998, NYCDEP 1999). Using the weight-of evidence approach, the EPA-approved TMDL used a site-specific phosphorus guidance value of 15 µg/L as the ambient phosphorus level to protect NYC source water reservoirs used directly for public water supply.

Eutrophication-related water quality impairments adversely affect a broad spectrum of water uses, including water supply and recreation, and also adversely affect aquatic life. Concerns about cultural eutrophication (human induced enhancement of primary productivity) are not unique to New York, and the issue is widely recognized as a significant water quality concern at the national and international levels. These concerns lead the USEPA (USEPA 1998) to initiate a National Nutrient Strategy in 1998 with the goal of assisting all states in the development of numeric nutrient criteria.

To further the process of developing numeric nutrient criteria protective of potable water use, the NYSDEC, in collaboration with investigators from NYSDOH, Upstate Freshwater Institute (UFI), State University of New York College of Environmental Science and Forestry (SUNY-ESF), and Morgan State University, conducted a study to investigate the relationship between nutrient-related indices and certain human health related indices. The study was funded by the USEPA as part of that agency's National Nutrient Criteria Strategy (USEPA, 1998). The study involved the monthly collection of paired water column samples from 21 lakes and reservoirs during the growing season (May to October 2004 and/or 2007). The study systems were distributed throughout New York

State, and spanned a relatively broad range of trophic conditions ranging from oligotrophic systems (low primary productivity) to eutrophic systems (high primary productivity).

From that study, DEC has developed a process for determining Ambient Water Quality Values for ponded sources of potable waters in New York State, (NYSDEC 2010) which has undergone USEPA and peer-review. That research for that process, as described in a peer-review journal (Callinan et al 2013), is used as the basis to evaluate the degree to which the TMDL target is adequately protective for the Cayuga Lake TMDL, and to provide a correlation between Chl-a and TP that is more protective for drinking water given the site-specific data available.

USEPA recently issued guiding principles "to offer clarity to states about an optional approach for developing a numeric nutrient criterion {Editor's Note: Herein referred to as target concentration} that integrates causal (nitrogen and phosphorus) and response parameters into one water quality standard (WQS)… These guiding principles apply when states wish to rely on response parameters to indicate that a designated use is protected… A criterion must protect the designated use of the water, and states should clearly identify the use(s) they are seeking to protect. Where a criterion is intended to protect multiple designated uses, states must ensure that it protects the most sensitive one (40 CFR 131.11(a))… Documentation supporting the criterion should identify all applicable nutrient pathways, addressing all potential direct and indirect effects (e.g., as identified in a conceptual model that outlines the effects of nutrient pollution)" (USEPA 2013).

A.1 Conceptual Model

Nutrient enrichment of lakes and reservoirs used for potable water supply (PWS) can cause adverse effects, ranging from operational problems to increases in health-related risks such as disinfection by-products (DBPs), cyanotoxins, and arsenic.

The linkages between eutrophication and PWS concerns are shown in Figure A1. As illustrated by the red arrows in the figure, the primary route of concern is: (1) nutrient (P) enrichment leads to (2) increases in algae (measured as Chl-a), which results in (3) increases in natural organic matter (NOM), which (4) combines with chlorination (Cl_2) to form disinfection by-products.

Additional phosphorus inputs may further accelerate eutrophication, which may lead to oxygen depletion, which may cause reductive release of sediment-bound arsenic and phosphorus, which can provide a positive feedback to further nutrient enrichment, and production of cyanotoxins. Although an increase in arsenic levels and production of cyanotoxins are health concerns for PWS, the NYSDEC study found that formation of DBPs was likely to be the most sensitive endpoint for developing a phosphorus criterion for PWS, and it is the relationship to formation of DBPs that is the focus of the site-specific phosphorus target in this TMDL.

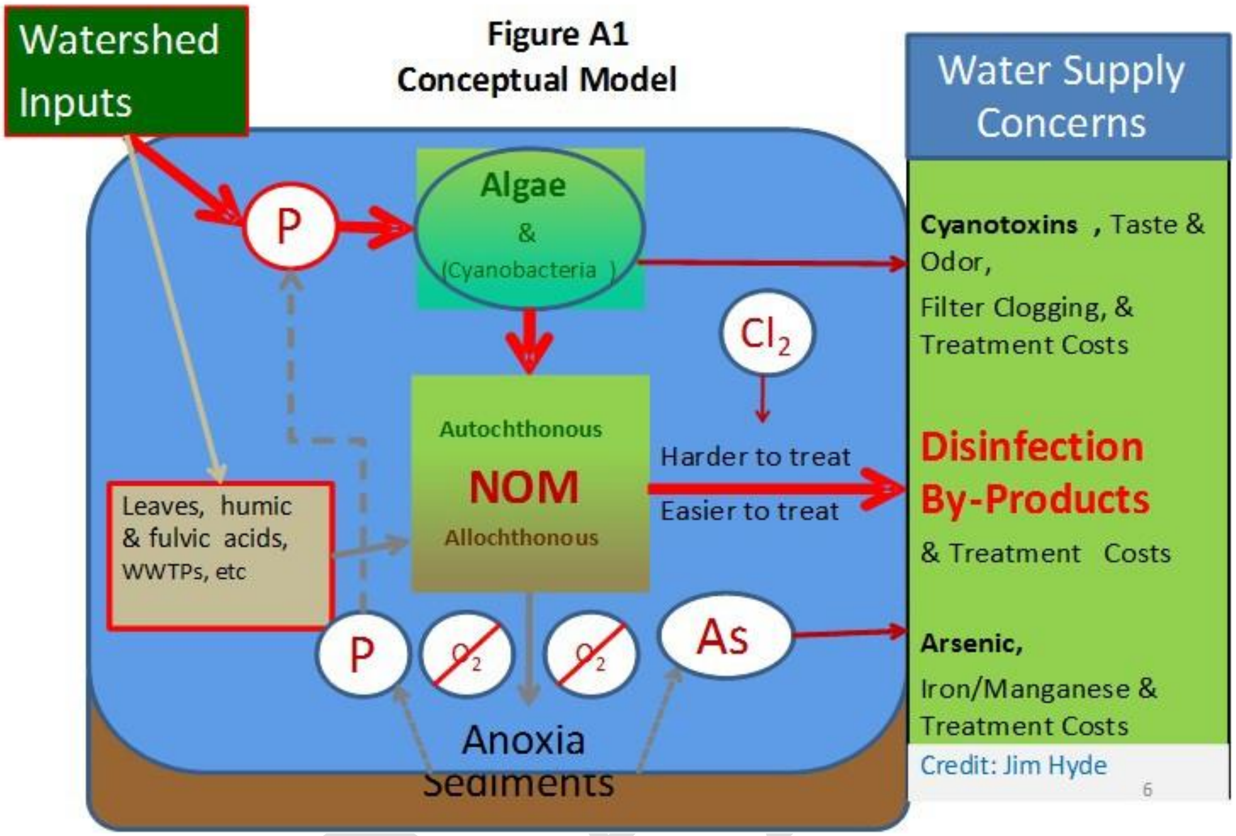


Figure A1. Conceptual model of eutrophication and Public Water Supply concerns.

Disinfection By-Products

Disinfection by-products (DBPs) are a group of compounds formed as a result of chemical reactions between natural organic matter (NOM) and certain disinfection agents (e.g., chlorine). The two major classes of DBPs are trihalomethanes (THMs) and haloacetic acids (HAAs). Several of these compounds (e.g., bromodichloromethane, trichloroacetic acid) are considered to be carcinogenic (ATSDR 1997, USEPA 2006). There is also some evidence linking DBPs to adverse reproductive effects (USEPA 2006).

The link between nutrient enrichment and increased production of DBPs occurs because in many temperate freshwater systems, phosphorus acts as the limiting growth factor for primary production. This increase in primary production leads to: (a) an increase in the level of NOM, and (b) a change in the nature of NOM within the system, which heightens the risk for DBP production when the water is subjected to disinfection. The NYSDEC study discussed above was limited to THMs (TTHMs). The USEPA (2006) defines TTHMS as the sum of four chlorinated compounds: chloroform, bromodichloromethane, dibromochloromethane, and bromoform.

Research on DBPs initially focused on the allochthonous (watershed, e.g., leaves and wastewater) precursor pool; however, subsequent studies also identified the autochthonous (in-lake; e.g., algae) precursor pool as important (Figure A1). There are important distinctions between allochthonous and autochthonous precursors that are relevant to PWS management. For example, autochthonous precursors are both more amenable to mitigation through nutrient management and more difficult to remove through water treatment. Furthermore, autochthonous precursors may produce greater quantities of unregulated DBPs.

A.2 Derivation of Site-specific Ambient Water Quality Values (Criteria)

The approach taken in the NYSDEC study to derive appropriate site-specific ambient water quality values (AWQVs) is based upon findings from NYSDEC's Disinfection By-Product/Algal Toxins Project (DBP-AT Project), as well as pertinent material from other independent investigations (both peer reviewed literature and technical reports). The toxicological basis for the criteria in the DBP-AT Project was based upon previous drinking- water related toxicological findings for disinfection by-products (specifically total trihalomethanes) derived to meet the current MCLs as summarized and presented in the Code of Federal Regulations (40 CFR January 4, 2006).

Several assumptions were made in the derivation of nutrient thresholds THMs:

1. The target nutrient thresholds are designed to attain the current maximum contaminant level (MCL) for TTHMs, presently set at 80 µg/L per the USEPA Stage 2 Disinfectants and Disinfection Byproducts Rule (USEPA 2006).
2. The applicable toxicological evidence as presented in the USEPA Stage 2 Rule in support of the current MCL is adequate for the protection of human health. The current MCL for TTHMs is deemed the appropriate target value given that the criteria are directed toward protection of public water supply use which, in all instances for ponded surface waters, involves disinfection.
3. The nutrient thresholds defined for THMs are sufficient to protect for HAAs. Some studies suggest that algae are equally important in the generation of HAAs and TTHMs (Nguyen, et al., 2005), thus, it is assumed that limiting algae production will have comparable effects of both major classes of DBPs.

The NYSDEC's DBP-AT Study involved the collection of paired ambient water samples that were analyzed for Trihalomethane Formation Potential (THMFP) and nutrient-related indices. THMFP is commonly used in research investigations to normalize results for the purpose of system comparisons.

The study developed relationships for each step in the conceptual model. For the first step, the regression relationship between mean Chl-a and TP indicates that approximately 78% of the variability in phytoplankton biomass (based on Chl-a) is accounted for by changes in TP, which supports the idea that phytoplankton biomass is controlled by phosphorus during the growing season. Study findings also offer several lines of evidence in support of the hypothesis that increased primary productivity (or cultural eutrophication) leads to an increase in the generation of THMFP:

- The relationship between mean Dissolved Organic Carbon (DOC) (a measure of NOM) and Chl-a indicates a trend of increasing DOC concentrations with increasing Chl-a.

- THMFP levels are substantially influenced by algal biomass. (The importance of the autochthonous precursor pool is supported by observed increases in THMFP concentrations with increases in trophic state, observed correlations between mean concentrations of THMFP and trophic indexes, and observed increases in THMFP concentrations during the growing season in most study systems).
- The relationship between mean THMFP and DOC, shows that approximately 80% of the variation in mean THMFP is attributable to mean DOC.

The observed relationships between THMFP and trophic indexes in the DEC's DBP-AT Project provide a sound basis for the derivation of nutrient-related thresholds protective of PWS. These findings are also consistent with a significant body of literature demonstrating a qualitative relationship between nutrient enrichment and the risk of increased THMFP production (Palmstrom, et al 1988, Wardlaw, et al. 1991, Cooke and Kennedy 2001) and showed similar quantitative relationships to research by Arruda and Fromm (1989) and the Colorado Department of Public Health and Environment (2011).

Building upon the relationships discussed above, the next step in the criteria development process is to identify potential AWQVs for the nutrient indices that are protective of potable waters with respect to DBPs. This required associating the measured THMFP to the TTHM drinking water standard. THMFP represents something of a "worst case" scenario in that the analytical protocol is designed to fully exploit the reaction between the available natural organic matter (NOM) and the disinfectant agent. In contrast, water treatment plant (WTP) operators attempt to minimize the generation of TTHMs, and other DBPs, while providing adequate disinfection.

This THMFP to TTHM translation, involved fitting observed THMFP data to a TTHM simulation model, and running the model using representative treatment/distribution system conditions coupled with the TTHM maximum contaminant level (MCL) of 80 µg/l. Using the relationships among Chl-a, DOC and THMs established in the DEC's DBP-AT Project, a threshold of Chl-a = 4.0 µg/L was derived, where values apply as growing season (May-October) means within the photic zone of the lake or reservoir.

Target Chl-a Concentrations (TMDL Target)

NYSDEC's DBP-AT Project derived threshold for Chl-a is 4.0 µg/L as an AWQV to protect Class AA waters, given that these systems are required to meet applicable drinking water standards following only disinfection (without coagulation, sedimentation and/or filtration treatments).

For ponded waters, it is appropriate to derive distinct target concentrations for different water use classes of ponded surface waters carrying best usage of source of potable water supply, because of the differing level of expected treatment inherent in the specific use classes. Classes AA will be subject to the more stringent target concentrations given that these waters are expected to meet applicable drinking water standards after only disinfection, whereas, ponded water supply source waters carrying water use Classes A will be subject to a somewhat less stringent target concentrations given that they are expected to meet applicable drinking water standards following "conventional" water treatment.

Conventional water treatment processes (coagulation, sedimentation and, filtration) can reduce levels of DOC in raw source water, however, removal efficiency diminishes as trophic level increases. Thus, the draft fact sheet assumed a somewhat conservative DOC removal efficiency of 10% - note, this is a reduction in DOC, not in phosphorus or Chl-a. Thus, using the relationships among Chl-a, DOC and THMs established in the NYSDEC DBP-AT Project, the draft fact sheet proposed a Chl-a concentration of 6.0 μg/L for Class A waters, where values apply as growing season (May-October) means within the photic zone of the lake or reservoir.

Although water use classes listed above include a caveat relating to "naturally present impurities", this was not deemed applicable for situations of cultural eutrophication, which, by definition are driven by anthropogenic-driven processes.

The NYSDEC findings compare well with other independent investigations. Arruda and Fromm (1989) investigated the relationship between trophic indexes and THMs in 180 Kansas lakes and arrived at a recommended Chl-a threshold of 5 μg/L to attain a TTHM limit of 100 μg/L (MCL in place at that time). Colorado (Colorado DPHE, 2011) conducted a study patterned on New York's study, although with enhancements including use of the Uniform Formation Conditions method (Summers 1996) that also targeted HAA formation and alternative methods of interpretation, and determined that a mean Chl-a concentration of 5 μg/L would be an appropriate threshold for direct use public water supply reservoirs.

An endpoint for phosphorus is premised on an extensive body of literature indicating that phosphorus is the limiting nutrient (or causal variable) for primary productivity in most temperate, freshwater, ponded waters, including Cayuga Lake. The rationale behind setting criteria for Chl-a is that it provides the most widely accepted measure of primary productivity (response variable) within freshwater ponded systems.

NYSDEC has focused on the response variable, Chl-a as the more appropriate ambient target because of its closer relationship to NOM and DBPs which directly affect the drinking water use. Thus, demonstration of the achievement of the water quality standard for Total Phosphorus, including for the purpose of a TMDL, would be informed by site-specific biomass response. This approach is consistent with the EPA guiding principles about an optional approach for developing a numeric nutrient criterion that apply when states wish to rely on response parameters to indicate that a designated use is protected (USEPA 2013). The EPA recognized that developing numeric values for phosphorus may present challenges associated with the temporal and spatial variability, as well as the ability to tie them directly to environmental outcome. Therefore, the USEPA guiding principles allow a State approach that integrates causal (nitrogen and phosphorus) and response parameters into one water quality standard.

NYSDEC's subsequent study, River Disinfection By-Product/Algal Toxin Study, prepared for the USEPA recommended that the primary metric for the establishment of numerical nutrient criteria be Chl-a (response variable) because it is the parameter most closely linked to autochthonous DBP precursors (NYSDEC 2010). While consideration was given to establishing a single numerical stressor (total phosphorus) criteria for flowing potable waters, the study concluded that the available dataset could not support the establishment of a single criteria value due to the variability in the relationships between both total phosphorus and Chl-a as well as between total phosphorus and THMFP. Such variability is to be expected in natural systems including ponded water as the relationship between stressor and response variables has inherent variability.

Given findings from the NYSDEC ponded and flowing water studies, as well as findings from other comparable studies, the more appropriate approach for establishing the stressor target (total phosphorus) is to establish a criteria "band" delineated by the prediction bands for the regression relationships. USEPA has proposed such an approach for the derivation of nutrient criteria in the state of Florida (USEPA, 2010). Ideally such an approach would use site-specific information regarding the response variable to fine-tune the stressor target but would also be informed by general relationships demonstrated in robust datasets of multiple water bodies. Site-specific information, even where collected over several years with a variety of hydrological conditions is limited to the empirical range of the measurements. In the case of impaired waters, observations generally would not include Chl-a levels that meet the target threshold, so the relationship would need to be extrapolated. Therefore, a broader database of lakes, covering a broad band of trophic conditions including those which meet the target threshold Chl-a level, provides additional context to a stressor-response model.

A.3 Model Development

The general approach for establishing the water quality target for Cayuga Lake Class AA and A segments was to:

- Select a criterion for the response variable (Chl-a = 4 µg/l) appropriate for protection of a drinking water use in a Class AA water based on the NYSDEC's DBP-AT Project.
- Select a criterion for the response variable (Chl-a = 6 µg/l) appropriate for protection of a drinking water use in a Class A water based on the NYSDEC's DBP-AT Project.
- Use the (slope of the regression) relationship between mean Chl-a and mean TP in combination with the 50% prediction interval to establish possible stressor criteria based on best-fit: and,
- Define the upper and lower prediction bands in which the criteria relationship would be used.
- Determine the practicality and usefulness between the options of using Chl-a or TP as the target-based purpose, modeling to be used, and the specific goals of the waterbody.

The process to establish a best fit and prediction bands for the total phosphorus to Chl-a relationship considered available NYSDEC and other quality assured data for lakes in New York State.

A.4 Application

Application of the stressor-response model developed in the previous section requires specification of how and when the model will be applied. The rationale used to make decisions on how to account for assessed conditions within the model framework and how the target values will be expressed are described in the following sections.

Accounting for Site-specific Information

To incorporate site-specific context into the stressor-response relationship, the actual measured mean Chl-a concentration is used as a starting point for the analysis. Next, the slope of the general stressor-response relationship is used to determine an appropriate mean Total Phosphorus concentration target, by solving for the response threshold of 6 µg/L Chl-a. The relative improvement in the Chl-a at each site is accomplished through changes in the Total Phosphorus concentration, weighted by the pre-factor from the regression equation.

For Cayuga Lake, upper water total phosphorus and chlorophyll-a monitoring data was available from 1998 through 2013 (16 years), both in the Southern End (Class A) and in the Mid-South (Class AA) segments. The entire dataset was collected by experienced technicians under the guidance of approved Quality Assurance Project Plans (QAPPs) and samples were processed by the same ELAP certified laboratory (Upstate Freshwater Institute, NY Laboratory ID No. 11462, EPA Laboratory Code NY01276) for all years. This consistent approach allows for a high level of assurance in data quality.

Site Specific Sampling Data as Target Basis for Cayuga Lake, Southern End and Mid-South Segments

Section 5 and Appendix B provides the Cayuga Lake monitoring data available from 1998 to 2013. Values are presented as the summer mean concentration per year for TP and Chl-a.

Application of the Target Concentrations

The response model was developed using summer average phosphorus concentrations (June through September). This was done because this was the identified critical period when phosphorus concentrations were measured and sunlight and temperature are favorable, creating the best condition for the production of algae. The associated NOM from production of algae is available for formation of DBPs. The applicability of the response model is therefore the same: an average TP concentration calculated over the June through September period.

Appendix B. Cayuga Lake Model (CLM-2D) Setup and Calibration for Cayuga Lake

The information presented in this Appendix is a summary of previously published reports: (1) Phase I: Monitoring and Modeling Support for a Phosphorus/Eutrophication Model for Cayuga Lake (288p; UFI 2014) and (2) Phase 2 Final Report: A Phosphorus/Eutrophication Water Quality Model for Cayuga Lake, New York (227p; UFI 2017). For more information, please see the aforementioned reports.

B1. Introduction

This Appendix describes the setup, calibration, and performance of the Cayuga Lake Model (CLM-2D), a hydrodynamic and water quality model developed for Cayuga Lake, New York. CLM-2D is a hybrid model developed using the CE-QUAL-W2 hydrothermal transport model (Cole and Wells 2015) and water quality sub-models developed for Cayuga Lake by the Upstate Freshwater Institute, Syracuse, New York.

B2. Description of CLM-2D

Sub-models of CLM-2D

A model is a theoretical construct that assigns numerical values to parameters and relates external inputs or forcing conditions to system variable responses (Thomann and Mueller 1987, Chapra 1997). CLM-2D is a two-dimensional model composed of a hydrothermal/transport model and water quality sub-models. The two-dimensional hydrothermal/transport sub-model used in CLM-2D is the hydrothermal/transport sub-model in CE-QUAL-W2, a public access model developed by the U.S. Army Corps of Engineers (Cole and Wells 2015). The hydrothermal/transport sub-model was setup and tested during Phase 1 (version 3.70; UFI 2014; Gelda et al. 2015) and subsequently upgraded to version 3.72 for the final CLM-2D model. The two-dimensional transport model simulates the thermal stratification regime and mixing/transport processes in the vertical and longitudinal dimensions for Cayuga Lake. The hydrothermal/transport sub-model was calibrated using 2013 observations and validated with observations from the 1998-2012 period (UFI 2014; Gelda et al. 2015).

Hydrothermal/Transport Sub-model

CE-QUAL-W2 is a public domain two-dimensional (longitudinal and vertical) hydrodynamic and water quality model (Cole and Wells 2015, http://www.cee.pdx.edu/w2). The model assumes lateral homogeneity within a segment of a waterbody and is therefore ideally suited for long and narrow waterbodies such as rivers or narrow lakes (Cole and Wells 2015). CE-QUAL-W2 is capable of predicting water surface elevations, velocities, temperature, and several water quality constituents. The model represents a waterbody using multiple longitudinal segments and multiple vertical layers within each segment. Resolution for Cayuga Lake was 25 longitudinal segments (~ 2,450m) and 1 m vertical layers from the water surface to the lake bottom (UFI 2017).

Nutrient-Phytoplankton Water Quality Model (CLM-2D)

The inflow concentrations for the water quality model follow the same formatting and daily input frequency of CE-QUAL-W2. However, the model structure and state variables used in CLM-2D differ from those used in CE-QUAL-W2. The water quality model is described in Section B5. CLM-2D includes sub-models representing algae and Chlorophyll-a, zooplankton, the effects of dreissenid mussels, and four major algal constituents: (1) carbon (C), (2) phosphorus (P), (3) nitrogen (N), and (4) silica (Si). Sub-models are also included for dissolved oxygen, minerogenic particles and optics (e.g., Secchi depth). For a more detailed description of this model please see UFI 2017.

B3. Overview of Model Setup and Data Requirements

Overview of Model Setup and Data Requirements

The general data requirements of the hydrothermal/transport model are: (1) geometric data (lake bathymetry, model cell dimensions, elevation, area, volume); (2) meteorological data (air and dew point temperature, wind velocity and direction, cloud cover or solar radiation); (3) hydrologic data (tributary inflows, outflows, and water surface elevation); (4) nutrient concentrations and temperatures of the lake and its tributaries; (5) hydrodynamic and kinetic coefficients; and (6) other data such as water withdrawals or discharges (Table B1). CE-QUAL-W2 uses laterally averaged two-dimensional (vertical and longitudinal) equations of fluid motion (Edinger and Buchak 1975). Inherent to this framework is the assumption of uniform lateral mixing in the cross-channel direction. The basic equations that describe water movement and the movement of materials (such as nutrients) are described in detail in UFI 2017.

The primary drivers for CLM-2D fall into one of three types: (1) meteorological, (2) hydrologic, and (3) constituent loading. Meteorological measurements are critical to drive the hydrothermal/transport sub-model and incident light is utilized in the phytoplankton growth sub-model. These measurements are available from a proximate location on Cornell campus (hourly since 1987), and from a site on the lake at its southern end (15 min. intervals) since 2011 (Table B2). Several of the major tributaries that enter the lake as well as lake water surface elevation are presently continuously gaged by the United States Geological Survey (USGS; Table B3). Estimates of overall tributary inflow and lake level are embedded in the hydrologic budget maintained within the model. Descriptions of constituent loading are presented in Section B3.

Table B1. Data needs for CE-QUAL-W2 and CLM-2D lake modeling.

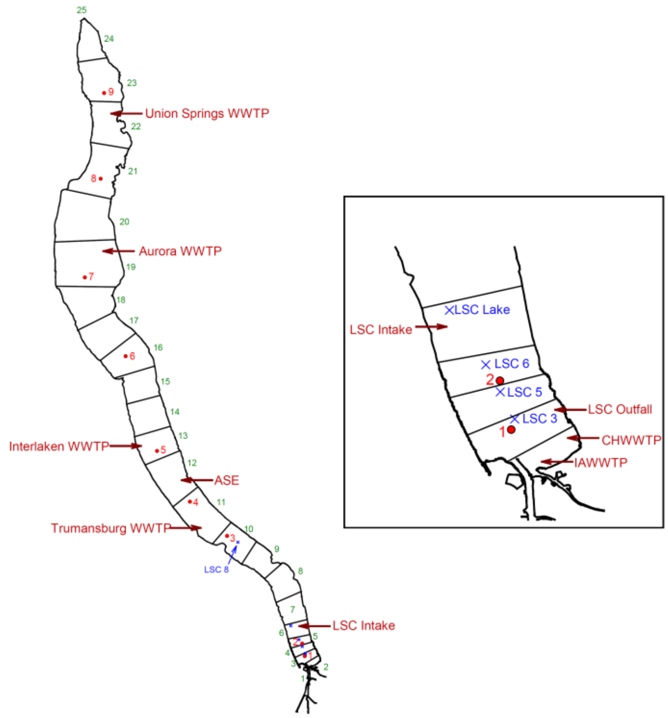
Data Requirement	Data Type	Purpose
1	Bathymetric map of lake – a three dimensional map of lake length, width, and depth	Define dimensions of model segments and layers
2	Hourly meteorological records (air temperature, dew point temperature, wind speed, wind direction, solar radiation, and cloud cover)	Define meteorological forcings
3	Time series of inflow flow rates, water temperatures, and concentrations of water quality constituents for all inflows (tributaries, direct drainage, point sources, etc.)	Define boundary conditions
	Time series of outflow flow rates and locations of all outflows (outlets, withdrawals, etc.)	Define downstream boundary conditions.
	Water surface elevation records	Model calibration
4	In-lake water temperature and water quality records	Model calibration
5	Measured kinetic or estimated model coefficients from field data (if available)	Defining initial parameter values

Geometric Data/Model Bathymetry

CLM-2D requires the same bathymetric data as CE-QUAL-W2 (Cole and Wells 2015). Bathymetric data define the physical size and shape of a lake and consists of a number of vertical layers and longitudinal segments. The grid formed by these layers and segments (cells) is called the computational grid. The geometry of the computational grid is determined by: (1) longitudinal spacing, (2) vertical spacing, and (3) average cross-sectional width. Segment boundaries were first established on contour maps for the lake. Dimensions for each of the computational cells were then obtained from analysis of the bathymetric data.

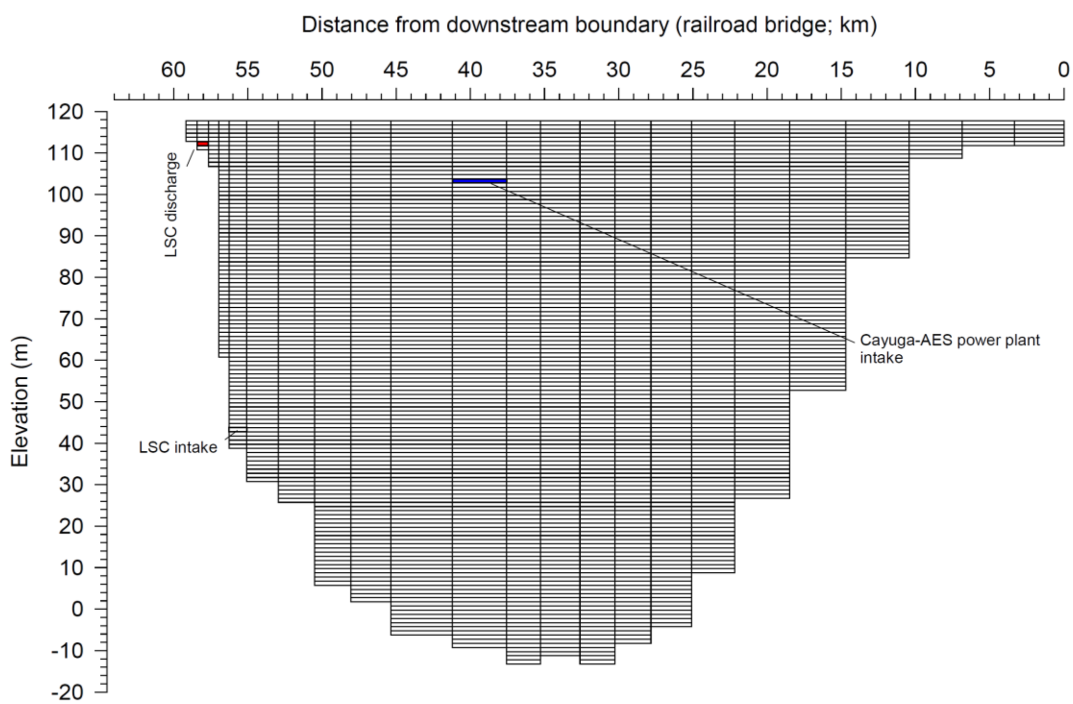
Meteorological Data

CLM-2D requires hourly average air temperature, dew point temperature, wind velocity and cloud cover (or solar radiation) data to calculate surface heat exchange and wind stress. Three meteorological stations are located near Cayuga Lake; two stations belong to Cornell University (the "pile cluster" meteorological station and the Game Farm Road meteorological station) and the third station is a NOAA station that collects data from the Ithaca Airport. These data are available for different periods (Table B2).



(a)

Figure B1a (from Figure 7-2, UFI 2017). Plan view of the CLM-2D model geometry with model segment number, calibration year monitoring site, and point sources. Inset is the southern shelf and LSC water intake. WWTP = wastewater treatment plant (or facility), IA – Ithaca Area, CH = Cayuga Heights, LSC = Lake Source Cooling



(b)

Figure B1b (from Figure 7-3, UFI 2017). Side view of the CLM-2D model geometry with the location of the LSC intake, LSC discharge, and Cayuga-AES power plant intake. Figure is orientated from south (left) to north (right).

Table B2. Meteorological station summary.

Station Name	Latitude	Longitude	Availability	Elevation (ft)	Notes
Piling cluster	42.46	-76.52	10/27/2011-12/31/2013	380	10 minute frequency; missing data (Tair and Tdew 1/3/2013 – 5/13/2013 filled in from Ithaca Airport
Game Farm Road	42.44	-76.45	1987-2013	950	Hourly frequency; missing data (0.8% days) were filled in from Ithaca Airport data
Ithaca Airport	42.49	-76.46		1080	

Flow Budget

CE-QUAL-W2 (Cole and Wells 2015) requires specification of daily average inflows from tributaries, outflows, withdrawals, and water surface elevation. A hydrologic flow budget was constructed for Cayuga Lake for the period 1987 – 2013 from the available inflow and lake volume data. Imbalances in the hydrologic budget were attributed to uncertainty in the estimation of ungauged inflows and outflows as well as potential inflow from the Seneca River to the north end of Cayuga Lake. A summary of the tributaries monitored in this study, ranked according to watershed area, is presented in Table B3. Detailed explanation of the flow budget, including procedures to estimate flow in ungagged watersheds can be found in UFI 2017.

Table B3. Tributary watershed areas and 2013 mean flow rate.

Tributary	USGS Gage No.	Watershed Area (acres)	Percent of Total Watershed (%)	2013 Mean Flow (m^3/s)
Fall Creek	04234000	81,792	17.7	5.95
Cayuga Inlet Creek	04233255	59,528	12.9	2.69
Salmon Creek	0423401815	57,773	12.5	3.75
Taughannock Creek	-a	42,749	9.3	3.11
Sixmile Creek	04233300	33,137	7.2	2.09
Ungaged tributaries	-a	187,355	40.5	11.98
Total	-	462,260	100	29.56

[an] estimated from product of Fall Creek flow and Taughannock Creek to Fall Creek watershed areas
[b] estimated from product of gaged flow and ratio of total watershed area to gaged watershed area

Briefly, the overall flow budget is shown in the equations below:

$$Qin - Qout, total = \Delta$$

$$(Qin, g + Qin, ung + Qin, pt) - (Qout, pt + Qout) = \Delta$$

where: Qin (total flow into the lake) is the sum of gaged stream flow (Qin, g), ungaged stream flow (Qin, ung), and the point source inflows (Qin, pt.). Total flow out of the lake is the sum of all point source withdrawals (Qout, pt) and outflow from the lake (Qout), Δ = the change in water volume in the lake which is estimated from water surface elevation and bathymetry data.

Fall Creek, the largest tributary to Cayuga Lake, has a watershed area of 330.9 km^2, which represents approximately 17.7 percent of the total Cayuga Lake watershed area (Figure B2; Haith et al. 2012). In addition to the four gaged tributaries (Table B3), Taughannock Creek was also monitored for constituents in Phase 1 (UFI 2014) but was ungaged for flow. Taughannock Creek flows were estimated using Fall Creek flows and the ratio between the Fall Creek and Taughannock Creek watershed areas. Point source inflows (Qin, pt) and outflows (Qout,pt) were measured or estimated. The change in water volume (Δ) was estimated from a seven-day average of the daily measured USGS water surface elevation and known bathymetry. The total ungaged inflow (Qin, ung) was estimated as the product of the gaged inflow times the ratio of the ungaged watershed area (from Haith et al., 2012) to the gaged watershed areas (Taughannock Creek estimates included as gauged).

A flow budget was used to solve for outflows from the lake Qout to the Seneca River. In 2013, the flow budget predicted negative outflows from the lake approximately 14% of the time.

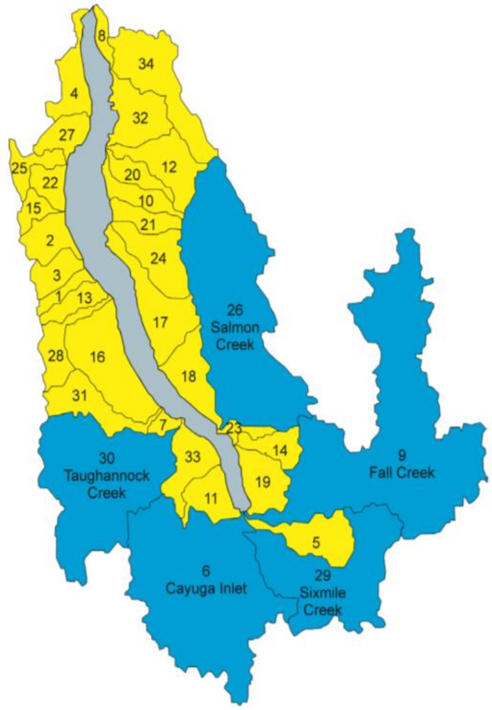


Figure B2. Revised map from Haith et al. (2012; Figure 2) with gaged watersheds colored blue, ungaged watersheds colored yellow. Watershed number and related model segments are shown in Table B4.

An assumption was made that allowed the negative outflows to be set to the value of the Seneca River inflow to the lake. The Seneca River can flow into the north end of Cayuga Lake and the USGS verified that does occur during certain times of the year, typically Fall and Spring when the elevation of the downstream lock (Mud Lock) is adjusted (W. Coon, personal communication). This assumption was verified by conducting a separate flow budget for 2015. In 2015, flows were measured both upstream of the Seneca River entering Cayuga Lake and downstream of Cayuga Lake's outlet. The difference between the two gages in 2015 was compared to the estimated Seneca River inflow in 2015 as calculated by the flow budget. For the April – October interval of 2015 the estimated outflows tracked the measured outflows well, corroborating the use of this flow budget technique. Observed and predicted water surface elevations matched well for the CLM (Figure B3).

Figure B2 is a modified figure from Haith et al. (2012) showing the five gaged tributaries colored in blue and the remaining 29 ungaged tributaries in yellow. For the CLM, these 29 areas were aggregated to 15 ungaged sub-basins (Table B4).

Table B4. The listing of the ungaged watersheds and the model segment that these tributaries enter the into the lake.

Ungaged Tributary Number	CLM-2D Segment No.	Watershed Name (from Haith et al. 2012)
ug1	2	Cascadilla C.
ug2	7	Glenwood C. area; Lansing area
ug3	8	Gulf C. area
ug4	9	Willow C.; Minnegar C.
ug5	11	Lake Ridge Point area; Trumansburg C.; Cayuga View area
ug6	14	King Ferry Sta. area
ug7	15	Sheldrake C.; Interlaken area
ug8	16	Grovers/Powel Creek area

Ungaged Tributary Number	CLM-2D Segment No.	Watershed Name (from Haith et al. 2012)
ug9	17	Barnum Creek area
ug10	18	Bloomer/Mack Ck. area
ug11	19	Little C. Area; Paines C.; Hicks Gully; Big Hollow area
ug12	20	Glen/Dean Ck. Area; Red C.; McDuffie Town area
ug13	21	Great Gully; Lavanna area; Schuyler C. area; Union Springs area
ug14	22	Canoga C. area
ug15	23	Cayuga Village area; Yawger C.

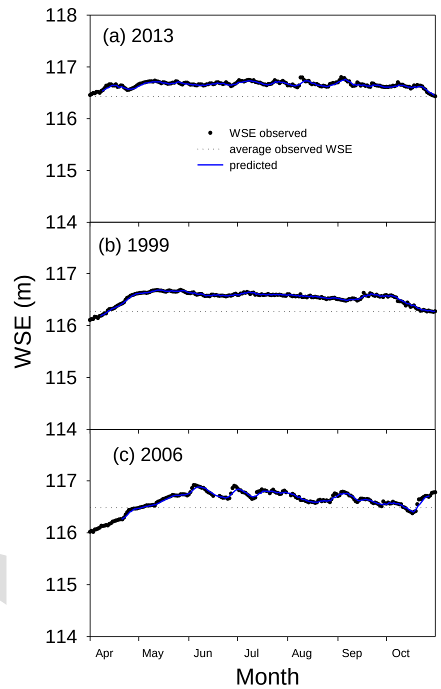


Figure B3. Time series of predicted (CLM -2D) and observed water surface elevations in Cayuga Lake in (a) 2013, (b) 1999, and (c) 2006.

Inflow Temperatures

CLM-2D requires daily inputs of stream temperature. During Phase 1 (UFI 2014), the daily stream temperatures used for the distributed inflows were assumed to be the same as those measured at a USGS site near Cayuga Lake. During Phase 2, the hydrothermal/transport model was updated to use estimates of daily temperatures based on in-stream measurements for 2013 and estimates for other years based on site-specific relationships. As part of the Phase 1 work, UFI routinely monitored stream temperatures on the five main tributaries during 2013. UFI had previously developed a method of estimating daily stream temperatures from daily air temperatures and a routine set of monitoring data (UFI 2001, UFI 2007). This method was used to estimate daily stream temperatures in 2013 for input to the hydrothermal/transport model. A final assumption that the ungaged tributaries had the same temperature as Salmon Creek was based on measurements at several of the ungaged streams made on a single day in June 2013.

Stream temperatures were not routinely measured for the validation years. UFI developed an air temperature - stream temperature regression for each of the streams monitored in 2013. These regressions and the measured air temperatures were used to develop stream temperatures for the other hydrothermal/transport model needs (UFI 2017)

Water Quality Loadings

Daily time series of water quality constituent (nutrients and sediment) concentrations are needed for tributary inflows in CLM-2D. Concentrations of were derived from tributary measurements or estimates (UFI 2014). Table B5 is a summary of required water quality inputs and methods applied to derive inflow concentrations for CLM-2D state variables.

Table B5. Inflow concentrations to CLM-2D with descriptions

Inflow Concentration	Description	Notes/Derivation
SRP	Soluble reactive phosphorus	from tributary measurements and calculations, see UFI 2014
NH4	Ammonium nitrogen	from tributary measurements and calculations, see UFI 2014
NO3	Nitrate nitrogen	from tributary measurements and calculations, see UFI 2014
DSi	Dissolved reactive silica	from tributary measurements and calculations, see UFI 2014
PSi	Particulate silica	estimated to be 0, see UFI 2014
LDOM	Labile Dissolved Organic Matter	Fraction of the from sum of Particulate and Dissolved Organic Carbon, from tributary measurements, see UFI 2014, 2017
RDOM	Refractory Dissolved Organic Matter	
LPOM	Labile Particulate Organic Matter	
RPOM	Refractory Particulate Organic Matter	
DO	Dissolved oxygen	see UFI 2014, 2017
LDOM_P	Labile Dissolved Organic Phosphorus	from tributary measurements and calculations, particle analysis, and bioavailability assays, see UFI 2014, 2017
RDOM_P	Refractory Dissolved Organic Phosphorus	
LPOM_P	Labile Particulate Organic Phosphorus	
RPOM_P	Refractory Particulate Organic Phosphorus	
LDOM_N	Labile Dissolved Organic Nitrogen	see UFI 2014, 2017
RDOM_N	Refractory Dissolved Organic Phosphorus	
LPOM_N	Labile Particulate Organic Phosphorus	
RPOM_N	Refractory Particulate Organic Nitrogen	
LPIP	Labile Particulate Inorganic Phosphorus	from tributary measurements and calculations, particle analysis, and bioavailability assays, see UFI 2014, 2017
RPIP	Refractory Particulate Inorganic Phosphorus	
PAVm1	Projected (Particle) Area per unit Volume – size class 1 ()	used to determine lake clarity and sediment transport, from individual particle analysis, tributary measurements and calculations, see UFI 2014, 2017
PAVm2	Projected (Particle) Area per unit Volume – size class 2 ()	
PAVm3	Projected (Particle) Area per unit Volume – size class 3 ()	
PAVm4	Projected (Particle) Area per unit Volume – size class 4 ()	

Atmospheric Loadings

Due to the size of the Cayuga Lake watershed and the importance of external nutrient loading and internal nutrient recycling, atmospheric inputs to Cayuga Lake were considered negligible and not modeled as part of the CLM-2D.

Water Quality Constituents

The in-lake water quality constituents modeled in the CLM-2D can be found in Section B5.

Bottom Sediments

Cayuga Lake's water column is fully oxygenated and does not experience anoxic conditions. Therefore, sediment nutrient release from these conditions was considered to be zero and not modeled in the CLM-2D.

Sediment Temperature

Sediment temperatures were set in the control file under variable TSED to be 10°C. This value was set as part of the hydrothermal model calibration (Gelda et al., 2015).

Initial Values

The model was initialized by the measurements made on the first day of sampling (April 8) in 2013. The setup and testing and data needs for this hydrothermal model CE-QUAL-W2 as well as final model coefficients are described in detail in the Phase 2 report (UFI, 2017). The water quality model for Cayuga Lake was CLM-2D and its parameterization is presented in Section 7.6 of the Phase 2 report (UFI, 2017). The state variables and units are listed in Table 7-6. Conceptual diagrams are presented in Figure 7-18 through 7-25. List of model drivers is presented in Table 7-12. All mass balance equations are listed in Appendix 2 of the Phase 2 Report. Table A2-1 is a full listing of all model coefficients used in the CLM-2D model calibration of Cayuga Lake including the coefficient symbol, description, value (where applicable) and unit (UFI, 2017).

Simulation Period

The simulation period for the CLM is January 1, 1998 through December 31, 2013.

B4. Calibration, Validation and Performance of the Hydrothermal Model

Section of Validation Years

In Phase 1 the hydrothermal/transport model was calibrated for 2013 and validated for 1998-2012. In Phase 2 the upgraded hydrothermal/transport model was validated for two years, 1999 and 2006. The two validation years represent a wide range of hydrologic conditions out of the 16-year study period, with 1999 ranking as the 12^{th} wettest summer (15^{th} on an annual basis) and 2006 ranking as the wettest summer (7^{th} on an annual basis). Values of these metrics for the calibration year of 2013 were generally between those measured in 1999 and 2006. The wide range of meteorological forcing conditions included in the calibration and validation data sets represents a robust test of the hydrothermal/transport model.

Hydrothermal/transport Model Calibration and Validation

Model testing was based on comparisons of model predictions with measured: (1) vertical temperature profiles at multiple locations in the lake (Figure B1a), (2) signatures of oscillations in stratified layers and intrusions of hypolimnetic waters into surface layers (upwelling events) from high frequency temperature measurements in the Southern End, and (3) signatures of tributary entry.

The coefficients used for calibration and validation of the hydrothermal/transport model are shown in Table B5. These are the recommended default values except for wind sheltering (set to 1.0) and the Chezy coefficient (set to 70). Applications for numerous lakes and reservoirs under a wide variety of conditions have shown the hydrothermal/transport model generates remarkably accurate temperature predictions using default values when provided with accurate geometry and boundary conditions. Another important parameter, the light extinction coefficient, was determined from site-specific measurements of the underwater light (UFI 2017).

Table B5. Hydrothermal/transport coefficients in CE-QUAL-W2.

Coefficient	**Symbol**	**Model Values**
horizontal eddy viscosity	Ax	1 m2/sec

horizontal eddy diffusivity	Dx	1 m2/sec
Chezy coefficient (all segments)	Ch	70 m0.5/sec
wind sheltering coefficient (all segments)	Wsc	1.0
fraction of incident solar radiation absorbed at the water surface	β	0.45
coefficient of bottom heat exchange	CBHE	0.3 W/m2/°C

Evaluation of Hydrothermal/transport Model Performance

Simulation of temperature by the hydrothermal model is a test that the model is simulating transport of heat (and therefore mass in the water quality model) in both the vertical and longitudinal directions in the lake. Temperature also regulates a number of biological processes in the lake.

The primary basis for evaluation of the hydrothermal/transport model comparisons of predictions with observations. Goodness of model fit was based on both visual inspection of model predictions to observed data and statistics, including Root Mean Square Error (RMSE). A RMSE of 1 degree C is considered sufficient model performance. Examples of the model fit are presented for site 5 (Figure B4), the primary water quality monitoring site (UFI 2014), and site 3 (Figure B5), a site with a long-term monitoring record (1998-2012). Similar plots for 2013 at the other monitoring sites are provided in UFI 2017 and in Appendices C of this TMDL. The hydrothermal model simulated observations well for the calibration year of 2013.

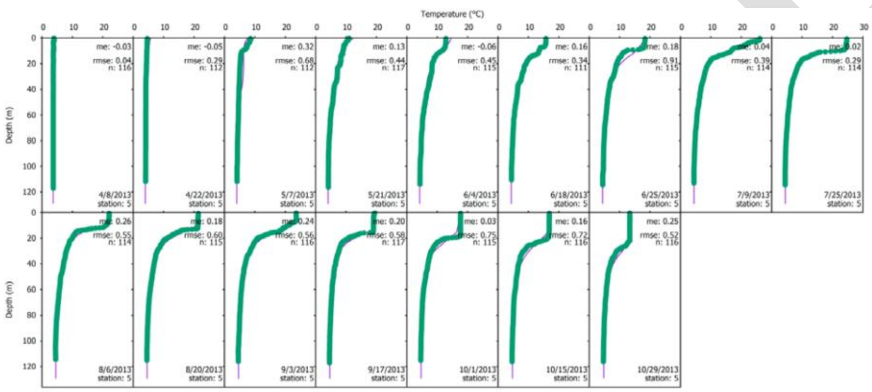


Figure B4 (from Figure 7-11, UFI 2017). Comparisons of predicted and observed 2013 temperature profiles for Cayuga Lake, site 5. Mean errors (me), root mean square errors (rmse), and number of observations (n) are included for reference. Line = model predictions, green circles = observed temperatures.

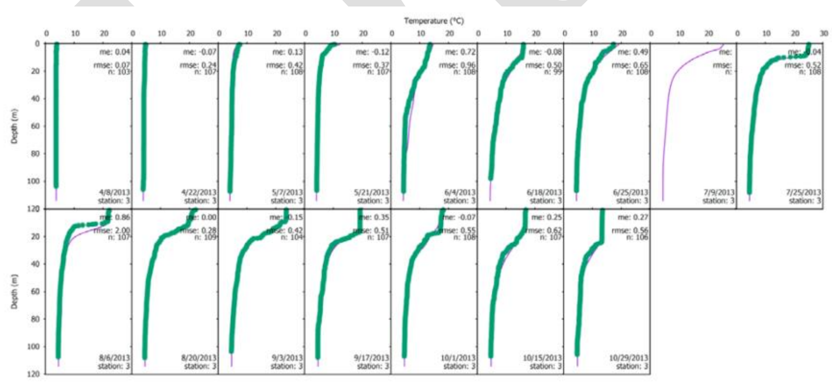


Figure B5 (from Figure 7-12, UFI 2017). Comparisons of predicted and observed 2013 temperature profiles for Cayuga Lake, site 3. Mean errors (me), root mean square errors (rmse), and number of observations (n) are included for reference

Model fits for 2013 are also presented as time series, with temperature observations and simulations shown for multiple depths at each of the nine monitoring sites (Figure B6). The model tracked the observed temperatures sufficiently at all sites and depths. The model also performed well in simulating temperatures for the two years of model validation, 1999 and 2006 (Appendix C).

B5. Nutrient-Phytoplankton water quality model

Conceptual framework: Background and approach

The overall model utilized for the Cayuga Lake TMDL is an integrated two dimensional hydrothermal/transport and water quality model utilizing the hydrothermal/transport portion of CE-QUAL-W2 (version 3.72; Cole and Wells 2015) and a separately developed water quality model described in UFI 2017. This integrated model is referred to as CLM-2D (Cayuga Lake Model - 2D). The inflow concentrations for the water quality model followed the same formatting and daily input frequency of CE-QUAL-W2.

The constituents and characteristics predicted by the water quality model are described as the state variables (Table B6). The model also includes several derived constituents, which are calculated from the state variables (Table B7). Multiple forms of P are predicted, including particulate and dissolved fractions of nutrients, which are partitioned according to labile (subject to reactions/transformations) and refractory (not subject to reactions/transformations), and organic versus inorganic, components. Phytoplankton biomass and organic carbon (C) are simulated, with multiple forms of C (dissolved versus particulate, labile versus refractory) predicted. Chlorophyll-a (Chl-a), a surrogate of phytoplankton biomass, is derived as the product of simulated phytoplankton biomass (ALG) and the Chl-a:ALG ratio. Two groups of phytoplankton are modeled, diatoms (ALG1) and other algal taxa (ALG2). Total phosphorus (TP) was derived by summing the simulated dissolved and particulate forms of phosphorus. Secchi disk depth (ZSD) was predicted by the optics sub-model (UFI 2017).

Multiple metrics of sediment were simulated, including PAV, turbidity, and suspended solids. Optical metrics were predicted by the optics sub-model. Nitrate+nitrite (NOx) and silica (Si) were added to the Phase 1 list of model state variables because both had distinctive depletion signatures in the pelagic waters of the lake (UFI 2014). Dissolved oxygen (DO) is included as a state variable because it is needed for certain reactions. However, no effort was made to calibrate this parameter because DO is not a water quality issue for Cayuga Lake as there is no evidence of oxygen depletion in the lake’s lower waters.

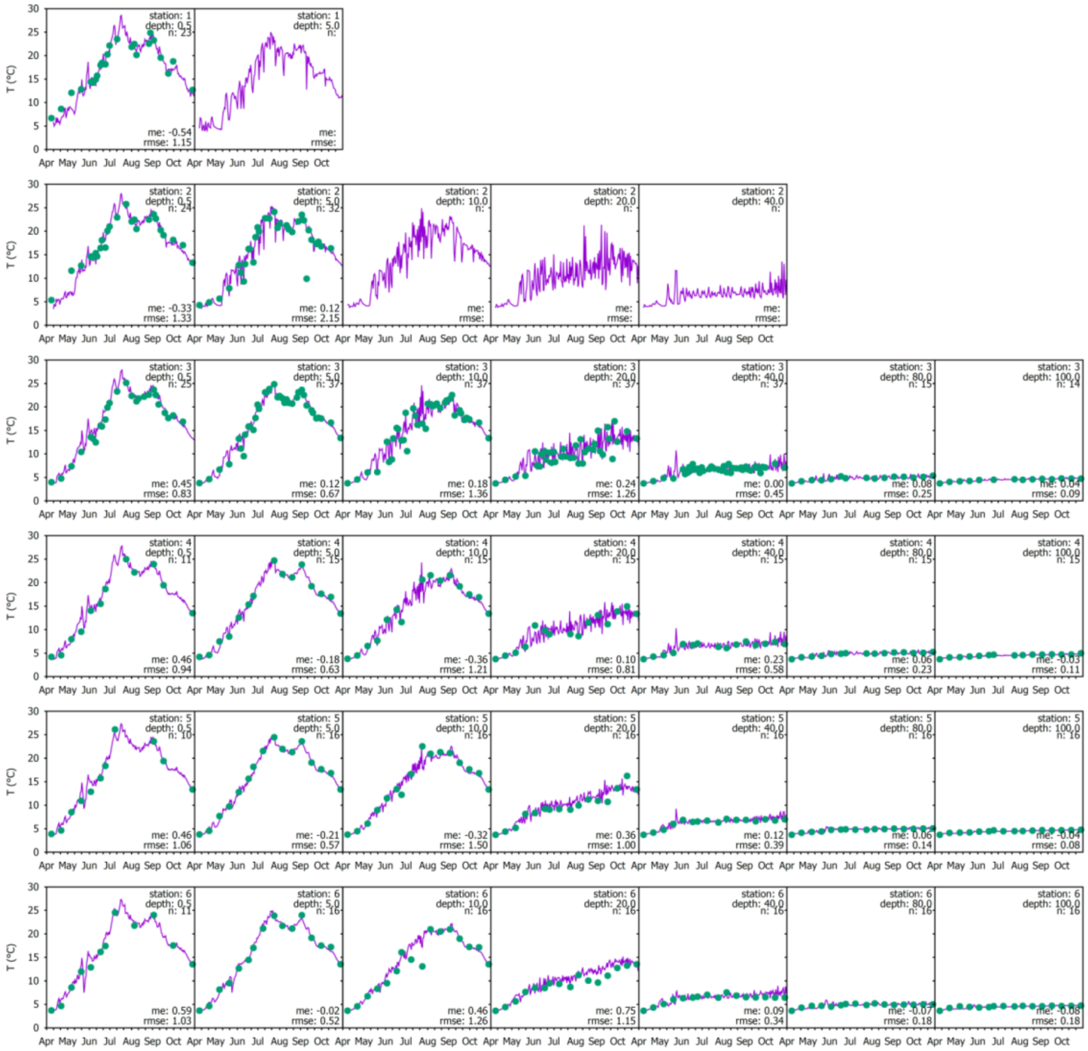


Figure B6 (from Figure 7-13, UFI 2017). Time series of predicted and observed temperatures for 2013 at nine monitoring sites and multiple depths (0.5, 5, 10, 20, 40, 80, and 100 meters – if applicable) in Cayuga Lake. Mean errors (me), root mean square errors (rmse), and number of observations (n) are included for reference. Sites 1-2 are from the Southern End segment, sites 3-6 are from the Main Lake, Mid-South segment.

Table B6. Listing of CLM-2D state variables.

Symbol	Description	Input/Output unit
T	temperature	°C
Alg1, Alg2	algae in terms of carbon	µg C/L
DO	dissolved oxygen	mg O2/L
Carbon		
LDOC	labile dissolved organic carbon	mg C/L
RDOC	refractory dissolved organic carbon	mg C/L
RPOC	labile particulate organic carbon	mg C/L
RPOC	refractory particulate organic carbon	mg C/L
CO2	carbon dioxide	mg C/L
Nitrogen		
NH3	total ammonia	µg N/L
NOX	sum of nitrate plus nitrate plus nitrite	µg N/L

Symbol	Description	Input/Output unit
LDON	labile dissolve organic nitrogen	µg N/L
RDON	refractory dissolve organic nitrogen	µg N/L
LPON	labile particulate organic nitrogen	µg N/L
Phosphorus		
SRP	soluble reactive phosphorus	µg P/L
LDOP	labile dissolve organic phosphorus	µg P/L
RDOP	refractory dissolve organic phosphorus	µg P/L
LPOP	labile particulate organic phosphorus	µg P/L
RPOP	refractory particulate organic phosphorus	µg P/L
LPIP	labile particulate inorganic phosphorus	µg P/L
RPIP	refractory particulate inorganic phosphorus	µg P/L
DSi	dissolved silica	mg Si/L
PSi	particulate silica	mg Si/L
Zooplankton		
Zoo1	zooplankton carbon, modeled or fixed	mg C/L
Mussels (fixed not modeled)		
MusDW	Mussel dry weight, fixed not modeled	g DW/m2

Table B7. Listing of CLM-2D derived variables (calculated from state variables).

Symbol	Description	Input/Output unit
Chl	chlorophyll a	µg /L
N:P	ratio of nitrogen to phosphorus	µg N/µgP
Carbon		
DOC	dissolved organic carbon	mg C/L
POC	particulate organic carbon	mg C/L
TOC	total organic carbon	mg C/L
Nitrogen		
DON	dissolved organic nitrogen	µg N/L
PN	particulate nitrogen	µg N/L
TDN	total dissolved nitrogen	µg N/L
TN	total nitrogen	µg N/L
Phosphorus		
TDP	total dissolved phosphorus	µg P/L
DOP	dissolved organic phosphorus	µg P/L
PP	particulate phosphorus	µg P/L
TP	total phosphorus	µg P/L

Carbon sub-model

Dissolved components of the carbon sub-model include carbon dioxide (CO_2), labile dissolved organic carbon (LDOC), and refractory dissolved organic carbon (RDOC). Particulate forms include zooplankton, algal carbon, labile particulate organic carbon (LPOC), and refractory particulate organic carbon (RPOC). Labile and refractory forms are differentiated by decay rates, which were determined in model calibration. Organic carbon is an important regulator of lake metabolism (Wetzel 2001, Hanson et al. 2003). CLM-2D uses POC as the primary metric of phytoplankton biomass. Sinks for algal carbon include grazing by zooplankton, mortality, settling, and ingestion by dreissenid mussels.

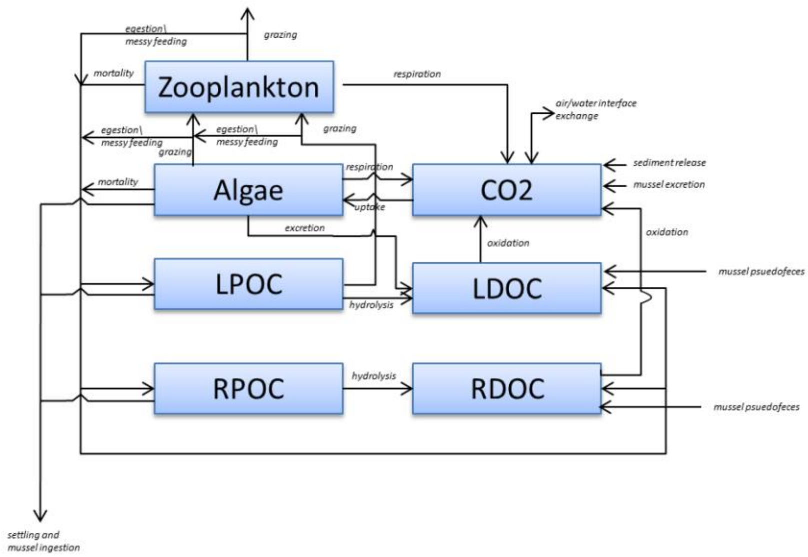


Illustration of the Carbon sub-model

Nitrogen sub-model

Dissolved forms included in the nitrogen (N) sub-model are ammonia (NH_3), nitrate+nitrite (NOx), labile dissolved organic nitrogen (LDON), and refractory dissolved organic nitrogen (RDON). The model also tracks four particulate forms of N: zooplankton, algae, labile particulate organic nitrogen (LPON), and refractory particulate organic nitrogen (RPON). Labile and refractory forms are differentiated by decay rates, which were determined in model calibration. Although both ammonia and nitrate can be used to support algal growth, ammonia is preferred for energetic reasons (Wetzel 2001). Ammonia concentrations are low in Cayuga Lake, and algal demand for N is met primarily by nitrate.

Algal N is lost through respiration (i.e., dark respiration) and excretion (i.e., photorespiration) processes to the NH_3 and LDON pools. Particulate forms of N that are lost to settling and ingestion by dreissenid mussels include algae, LPON, and RPON.

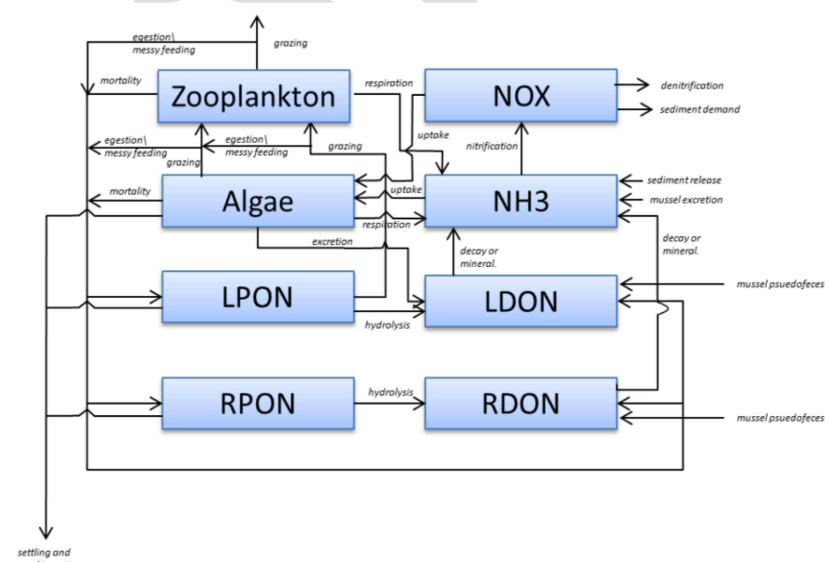


Illustration of the Nitrogen sub-model

Phosphorus sub-model

Dissolved components of the phosphorus (P) sub-model include soluble reactive P (SRP), labile dissolved organic P (LDOP), and refractory dissolved organic P (RDOP). Particulate forms include zooplankton, algal carbon, labile particulate organic carbon (LPOC), and refractory particulate organic carbon (RPOC). Labile and refractory forms were differentiated by decay rates, which were specified according to the results of P bioavailability assays. Soluble reactive P supports algal growth, which is largely limited to the epilimnion of the lake because of limited light penetration. Sources of SRP to the water column include microbial decay of LDOP and RDOP, respiration/decay of algal phosphorus, zooplankton respiration, and dreissenid mussel excretion.

Particulate P in the form of algae and non-algal particles is lost from the water column due to settling and ingestion by dreissenid mussels. Settling velocities were determined through calibration, with lower values for algal P and higher values for non-living particulate components. The external loading of PP and DOP was partitioned according to the outcome of system-specific bioavailability experiments described in the Phase 1 report (UFI 2014). The primary modeling performance target for P was the summer average TP concentration in the upper waters, consistent with the NYSDEC guidance value for TP.

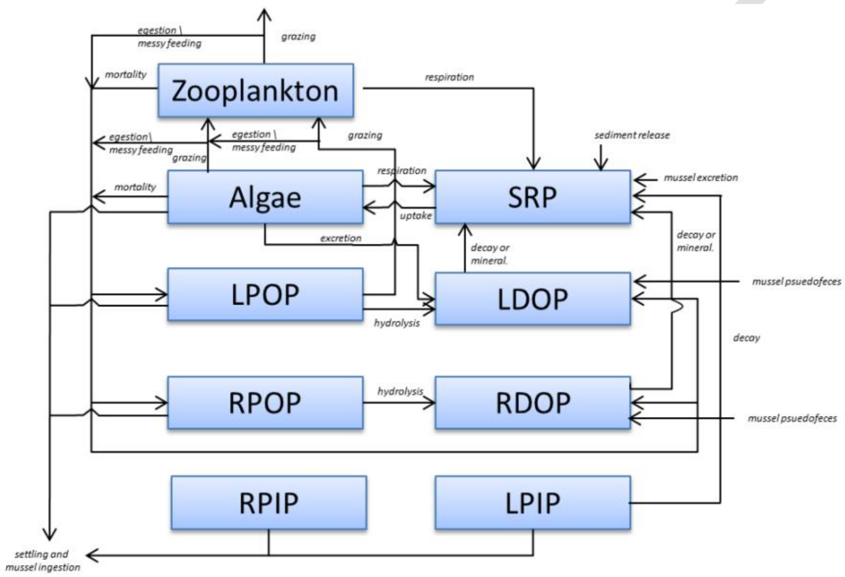


Illustration of the Phosphorus sub-model

Algae sub-model

Algal biomass in lakes in the North Temperate Zone is typically limited by a combination of phosphorus availability and seasonally intense zooplankton grazing (Wetzel 2001). However, diatoms, which use dissolved silica to form frustules, can also be limited by the availability of silica. For this reason two algal groups are modeled in CLM-2D, diatoms (ALG1) and other algae (ALG2). Algal growth is limited by temperature, light and nutrient availability.

Inorganic forms of carbon, nitrogen, and phosphorus are used to support algal growth. Although ammonia is the form of nitrogen preferred by algae, nitrate is used as an alternative when ammonia is unavailable. Sinks for algae include grazing by zooplankton, mortality, settling, and ingestion by dreissenid mussels. The processes of algal mortality and excretion transfer algal carbon to particulate and dissolved organic forms in the water column.

The primary metric of algal biomass in CLM-2D is particulate organic carbon (POC). The modeling goal for algal biomass was simulation of major seasonal dynamics and the summer average in the upper waters. The concentration of chlorophyll-a (Chl-a) is not simulated directly, but estimated as the product of the state variable POC and the Chl-a:POC ratio. Simulation of Chl-a was also a target of the initiative, at a time scale of summer average, consistent with the TMDL lake Chl-a targets. This is consistent with the known dependence of Chl-a on species composition, ambient light, and other environmental conditions (Reynolds 2006). Indeed, the Chl-a:POC ratio has been reported to be dependent on not only light availability but nutrient status (Chalup and Laws 1990, Laws and Chalup 1990, Hecky et al. 1993).

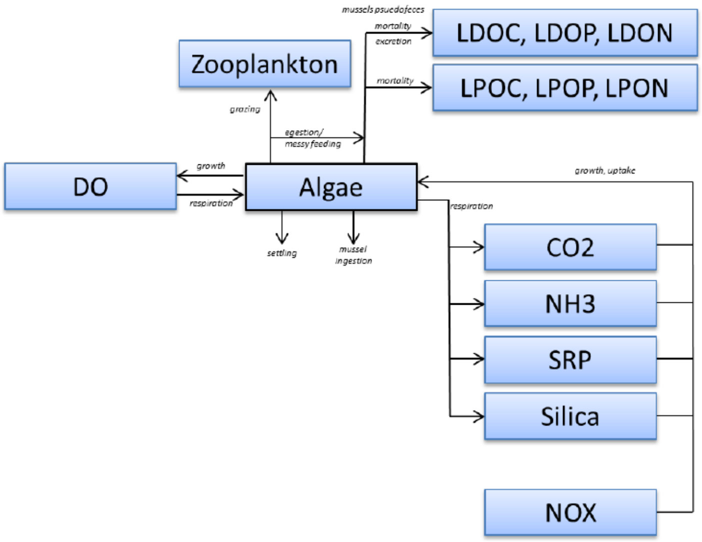


Illustration of the Algae (Chl-a) sub-model

Zooplankton sub-model

A zooplankton sub-model was included in CLM-2D to accommodate the effects of grazing on the algal community of Cayuga Lake. Zooplankton are modeled as a single group that consumes algae. Zooplankton respiration recycles algal nutrients (CO_2, NH_3, SRP) back to the water column. Labile forms of dissolved and particulate organic matter are produced as a result of zooplankton mortality.

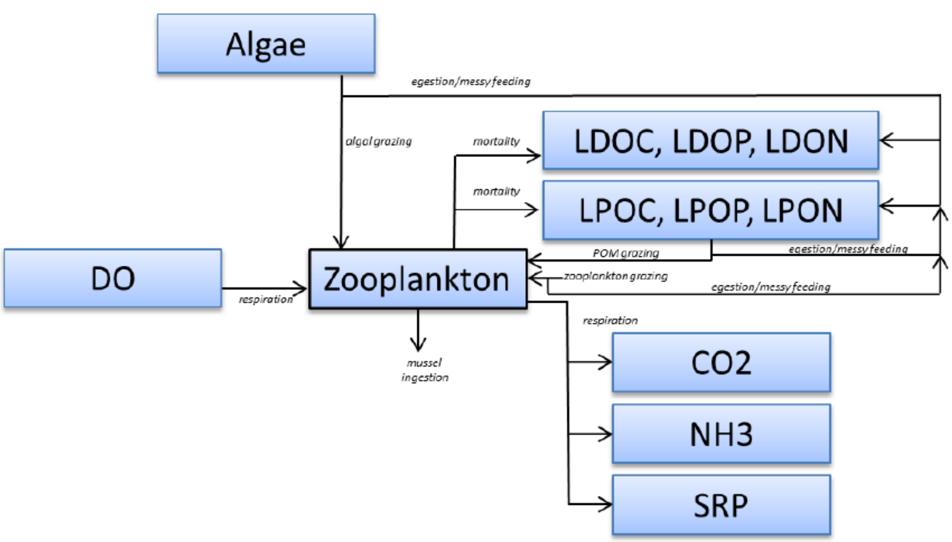


Illustration of the Zooplankton sub-model

Modeling the effects of dreissenid mussels

The water quality sub-model was updated to accommodate the water quality impacts of dreissenid mussels found on the floor of Cayuga Lake. The model simulates the impact of dreissenid mussels on the water column by removing particulate constituents and converting a fraction of the particulates to dissolved constituents (e.g., SRP). However, the growth and mortality of the mussels were not modeled. Instead, the mussel biomass measured in 2013 as part of Phase 1 (UFI 2014, https://www.dec.ny.gov/docs/water_pdf/cltacdrei.pdf) was used as a model driver. Vertical profiles of areal density (dry weight mass per unit area of lake bottom, gDW/m^2) were developed at each sampling location for both zebra and quagga mussels. A single dreissenid mussel group was formed by summing the measured biomass of the two species. These profiles were assumed to be representative of the biomass within the model segment that the sample site was located in. The data were then spatially interpolated, both vertically and horizontally, to obtain vertically detailed profiles of dreissenid mussel density for each of the 25 model segments. The filtering rate of dreissenid mussels was determined through calibration, guided by literature reviews, laboratory experiments performed during Phase 1 (UFI 2014).

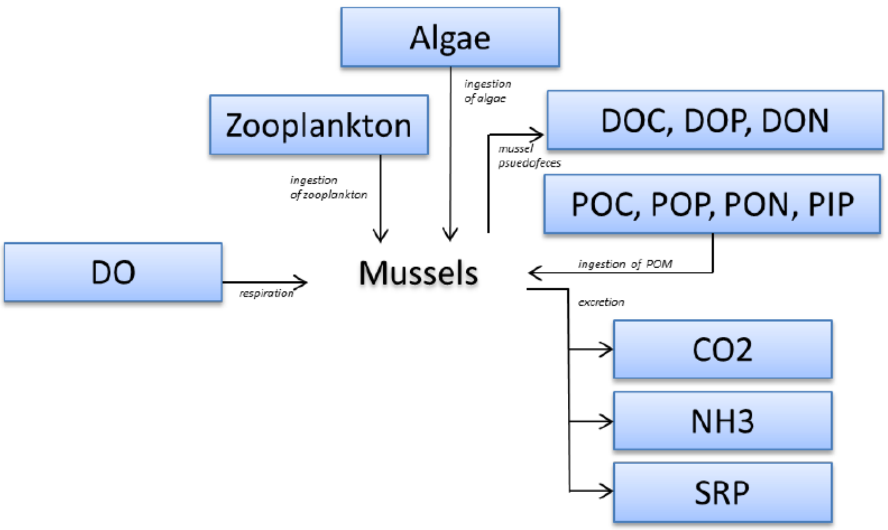


Illustration of the Dreissenid mussel sub-model

Silica sub-model (not shown)

The silica sub-model was included in CLM-2D to allow for simulation of diatoms as a separate algal group. Dissolved silica (DSi), which is used in the formation of diatom frustules, can limit diatom growth when depleted to low levels (Reynolds 2006). Sources of DSi to the water column include tributary loading and hydrolysis of particulate silica (PSi). Diatom mortality, zooplankton egestion, and messing feeding by zooplankton are the primary sources of Psi to the water column. PSi is lost to the water column through settling and ingestion by dreissenid mussels.

Dissolved oxygen sub-model (not shown)

As discussed previously, modeling of dissolved oxygen (DO) was not a priority for CLM-2D because DO is not a water quality issue for Cayuga Lake. However, the DO sub-model was operative in CLM-2D because a DO concentration is necessary for certain reaction in other sub-models. Sources of DO in the oxygen sub-model include photosynthesis (largely limited to the epilimnion) and reaeration (epilimnion, only). Oxygen sinks include algal respiration, zooplankton respiration, dreissenid mussel respiration, nitrification, and oxidation of DOC.

Minerogenic particle submodel (not shown)

As described in the Phase 1 report (UFI 2014, Section 5) and UFI publications (Gelda et al. 2016a and b, and Peng and Effler 2015), minerogenic particles delivered to Cayuga Lake from its watershed play an important role in metrics of water quality in the lake, including phosphorus, turbidity, clarity and light penetration. The key model state variable is the projected area of minerogenic particles per unit volume (PAVm).

Optics submodel (not shown)

The optics sub-model provides predictive capabilities for optical metrics of water clarity, as represented by Secchi depth (SD) and the attenuation coefficient for scalar irradiance (K0(PAR)). SD is a primary trophic state and water quality metric of concern for lacustrine systems, including Cayuga Lake. K0(PAR) is important as it specifies the light available at various depths to support photosynthesis and phytoplankton growth.

Water quality modeling protocols

The time step of hydrologic, material loading, and meteorological forcing function inputs to the water quality model is daily. The computational time step of the model calculations is one hour. The model was initialized by the measurements made at sites 1-9 on the first day of sampling (April 8) in 2013. Coefficient values were selected based on earlier work on Cayuga Lake, from the literature, or based on professional judgement and accepted limnological paradigms (UFI 2017).

Development and specification of water quality model drivers

Inflow concentrations

Constituent loads were estimated from a combination of observed concentrations (C), and those estimated from flow (Q) measurements, as described by C-Q relationships (UFI 2014). These estimates were developed using the FLUX32 software that provides flow and concentration estimates at a daily time step. Loading estimates for periods without regular tributary monitoring of concentrations were estimated from the C-Q relationship developed from the 2013 data set (UFI 2014).

Constituent concentrations for all tributary and point source inflows are a critical form of input for CLM-2D. Concentrations of various constituents were measured in 2013 at the mouths of five Cayuga Lake tributaries and in the Inlet channel, as described in the Phase 1 QAPP (UFI 2014). The methods used to calculate loads were documented in detail in the Phase 1 final report (UFI 2014, Prestigiacomo et al. 2016) and in Section 3 of UFI 2017. The resulting loads were divided by the flows to develop tributary-specific inflow concentrations.

In-lake calibration and validation data sets

The model calibration data set was collected in 2013 (UFI 2013). Data analyses and summary of findings from 2013 are documented in detail in the Phase 1 final report (UFI 2014). The validation data sets for CLM-2D rely heavily on data collected as part of Cornell University's long-term (1998-2012) monitoring program for the Lake Source Cooling facility (https://energyandsustainability.fs.cornell.edu/util/cooling/production/lsc/default.cfm). Data was collected at seven sites on the southern shelf and one deeper water site. Three of these monitoring sites corresponded to the locations of sites 1, 2, and 3 from the 2013 monitoring program. Measurements from these sites serve as the validation datasets for 1999 and 2006.

Summary of non-direct measurements

Table B8 summarizes these non-direct measurements utilized in the both phases of the modeling project.

Table B8. Non-direct measurements utilized in the Cayuga Lake Modeling Project.

No.	Data Type	Source of data	How used
1.	stream flows	United States Geological Survey (USGS)	used in flow budget and as input to the model
2.	watershed areas	Haith et al. 2012	used to adjust USGS flows and partition unmonitored flows that were utilized in a flow budget and as an input to the model
3.	meteorological data	Cornell University – pile cluster data	driver of the hydrothermal/transport model
		Cornell University – Game farm Road data	
		National Oceanic & Atmosphere Administration (NOAA)	

No.	Data Type	Source of data	How used
4.	point source flows and constituents	Cornell University – LSC based lake monitoring	flow and P data as model inputs, tNH3 as model input for WWTPs only
		IAWWTP, biweekly P data, 1995-2013, DMR data sets 2009-2013	
		CHWWTP, DMR data sets 2000-2013 for P, 2009-2013 others	
		ASE power plant	
		Minor WWTP, DMR data sets 2009-2013	
5.	stream temperatures	CSI ~2000-2013 (stream dependent)	validation of 2013 UFI air temperature vs. creek temperature regressions used to estimate creek temperatures between measurement days
6.	stream constituents	UFI 2003-2006 TP, TDP, SRP, Tn data	model inputs for years 2003-2006
		CSI ~2000-2013 (stream dependent) for TP, t-NH3, NOX, TSS, Tn	validation of 2013 concentration/flow regressions used to estimate constituents between measurement days
		DEC 2007 TP, DOC	validation of 2013 concentration/flow regressions used to estimate constituents between measurement days
		LSC based lake monitoring data	validation data sets
7.	historical limnological information – phosphorus, clarity and plankton	earlier studies by UFI and Cornell University	validation data sets utilized to develop model grid
8.	bathymetric data	Cornell University	Set-up of hydrothermal/transport model

Water Quality Model Calibration, 2013

Model performance is evaluated primarily through comparisons of model predictions with in-lake observations. Target performance thresholds for CLM-2D are provided in Table B9 for TP and Chl-a. These performance thresholds were applied on a summer average basis for lake upper waters, consistent with regulatory standards and TMDL goals.

Table B9. Targeted thresholds of model performance for multiple metrics of interest.

Predicted Metric	Targeted Thresholds of Performance[1] % Error[2]
TP	< 25%
Chl-a	< 50%

1 summer (June-September) average values for the upper waters
2 % Error = absolute value of (prediction – observation)/observation ×100

Observed and predicted summer average concentrations are presented in Table B10-B12 for modeled and observed TP and Chl-a concentrations for the Southern End, Main Lake, Mid-South, and Main Lake, Mid-North segments respectively.

Table B10. Comparisons of model results with performance criteria for the Southern End segment, 1998-2013.

Year	Observed TP (µg/L)	Modeled TP (µg/L)	Percent Error (%)	Observed Chl-a (µg/L)	Modeled Chl-a (µg/L)	Percent Error (%)
1998	24.2	19.5	19%	5	6	32%
1999	14.8	11.7	21%	5	4	7%
2000	19.6	19.5	1%	5	6	10%
2001	20	15.4	23%	5	5	2%
2002	20.7	20.2	2%	5	5	6%
2003	13.7	17.6	28%	7	6	15%
2004	21.8	24.2	11%	5	7	49%
2005	19	15.4	19%	5	6	16%
2006	24.9	28.9	16%	7	7	4%
2007	23.2	12.7	45%	5	5	6%
2008	17.2	13.8	20%	6	5	18%
2009	16.5	13.8	16%	5	5	4%
2010	15.7	11.5	27%	6	5	30%
2011	16.5	24	45%	5	6	19%
2012	15.3	11.4	25%	4	5	15%
2013	27	21.4	21%	4	6	32%
Average	**19.4**	**17.5**	**21%**	**5**	**6**	**16%**

Table B11. Comparisons of model results with performance criteria for the Main Lake, Mid-South segment, 1998-2013.

Year	Observed TP (µg/L)	Modeled TP (µg/L)	Percent Error (%)	Observed Chl-a (µg/L)	Modeled Chl-a (µg/L)	Percent Error (%)
1998	14.7	13.5	8%	5	5	0%
1999	9.8	8.3	15%	5	3	28%
2000	11.6	12.9	11%	5	4	8%
2001	14.1	9.5	33%	5	3	27%
2002	14.1	11.7	17%	5	4	25%
2003	10.6	10.9	3%	5	5	15%
2004	14.2	13.8	3%	5	5	2%
2005	12.6	11.7	7%	5	5	7%
2006	15.2	16.6	9%	8	6	22%
2007	13.4	10.8	19%	7	5	29%
2008	12.2	10.9	11%	7	5	33%
2009	11.6	10.7	8%	7	5	29%
2010	13	10	23%	6	4	24%
2011	14.5	15	3%	7	6	23%
2012	12.3	10.1	18%	6	5	18%
2013	15	12.1	19%	5	5	9%
Average	**13.1**	**11.8**	**13%**	**6**	**5**	**19%**

Table B12. Comparisons of model results with performance criteria for the Main Lake, Mid-North segment, 1998-2013.

Year	Observed* TP (µg/L)	Modeled TP (µg/L)	Percent Error (%)	Observed Chl-a (µg/L)	Modeled Chl-a (µg/L)	Percent Error (%)
1998	12	11	8%	6	4	34%
1999	11	6	44%	4	2	37%
2000	8	9	15%	3	3	12%
2001	10	7	24%	7	2	63%
2002	10	8	22%	5	3	45%
2003	10	9	9%	5	4	19%
2004	8	11	42%	not available	4	not available
2005	12	10	22%	3	4	23%
2006	11	12	17%	5	5	10%
2007	not available	9	not available	not available	4	not available
2008	not available	9	not available	not available	4	not available
2009	not available	9	not available	not available	4	not available
2010	not available	9	not available	not available	4	not available
2011	not available	13	not available	not available	5	not available
2012	not available	9	not available	not available	4	not available
2013	14	10	27%	3	4	47%
Average	**11**	**10**	**23%**	**4**	**4**	**32%**

*Observed Data from Makerawicz 2007.

B6. Conclusions

The Cayuga Lake Model (CLM) was used to support development of a phosphorus TMDL for Cayuga Lake. Model performance criteria were successfully met for TP and Chl-a, and other water quality parameters (UFI 2017).

Appendix C. Cayuga Lake CE-QUAL-W2/Cayuga Lake Model Performance Plots

Water Temperature Profile Plots

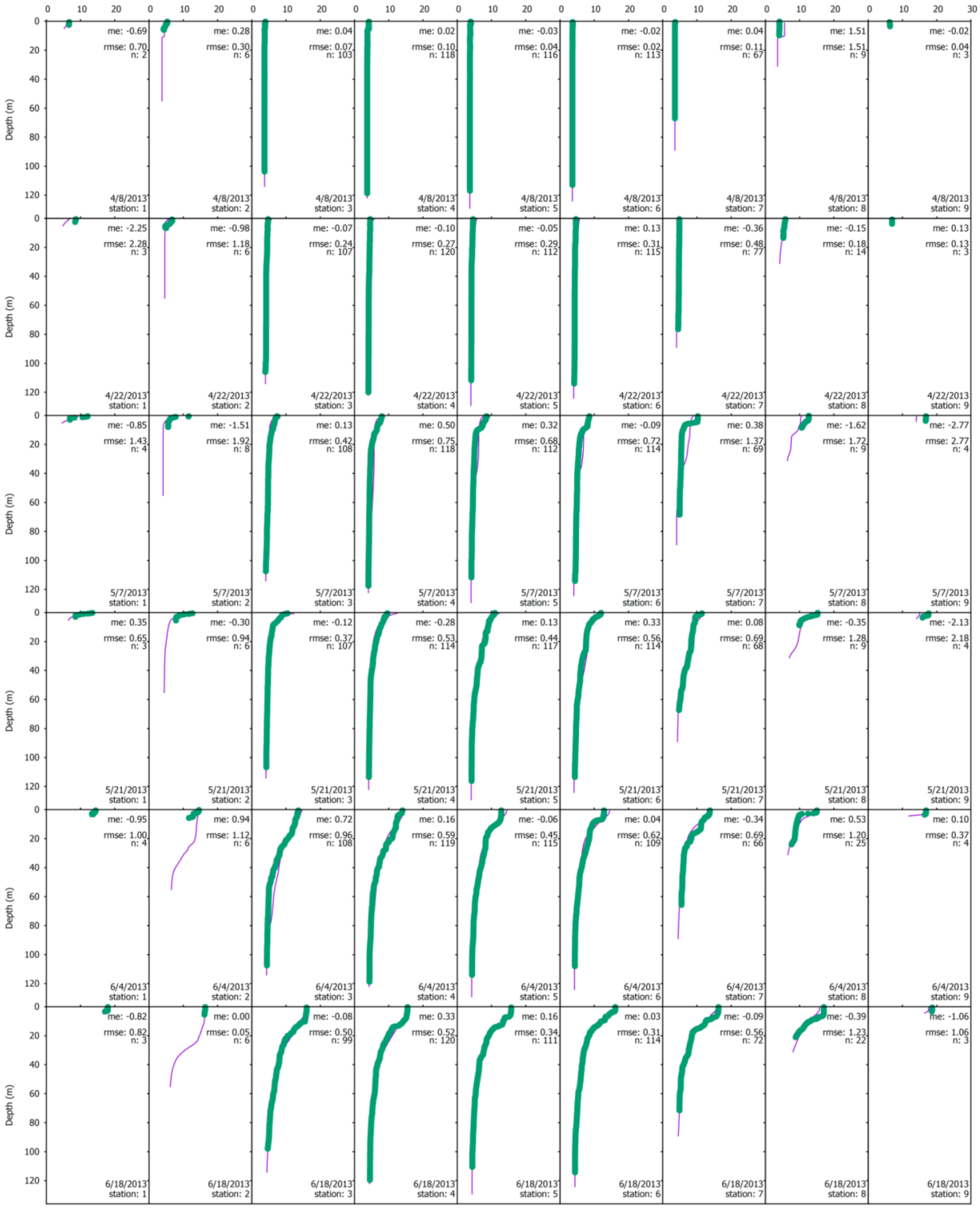


Figure C1. Comparison of predicted and observed temperature profiles for all sites from Cayuga Lake 2013, the model calibration year, for bi-weekly sampling dates.

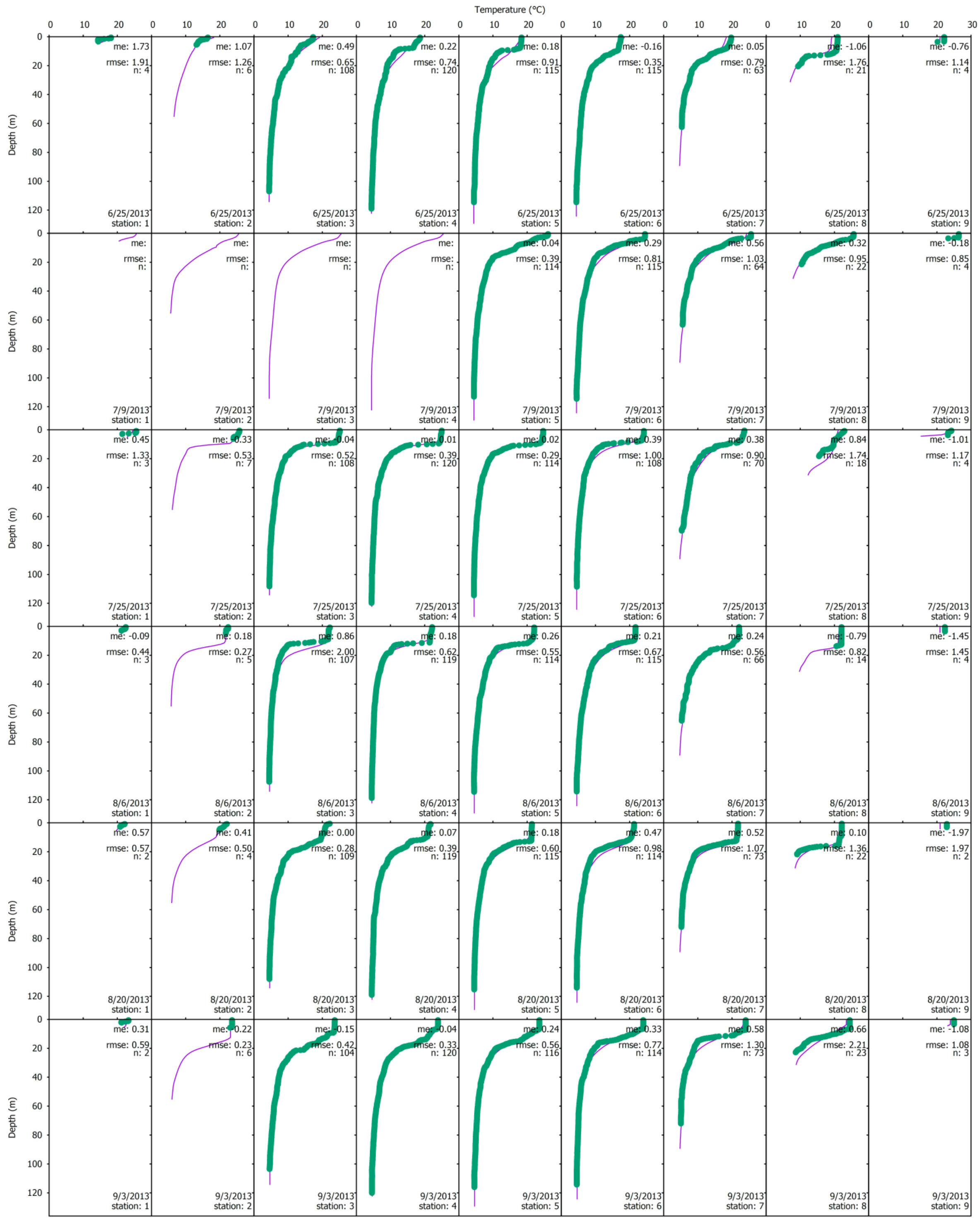


Figure C1-continued. Comparison of predicted and observed temperature profiles for all sites from Cayuga Lake 2013, the model calibration year, for bi-weekly sampling dates.

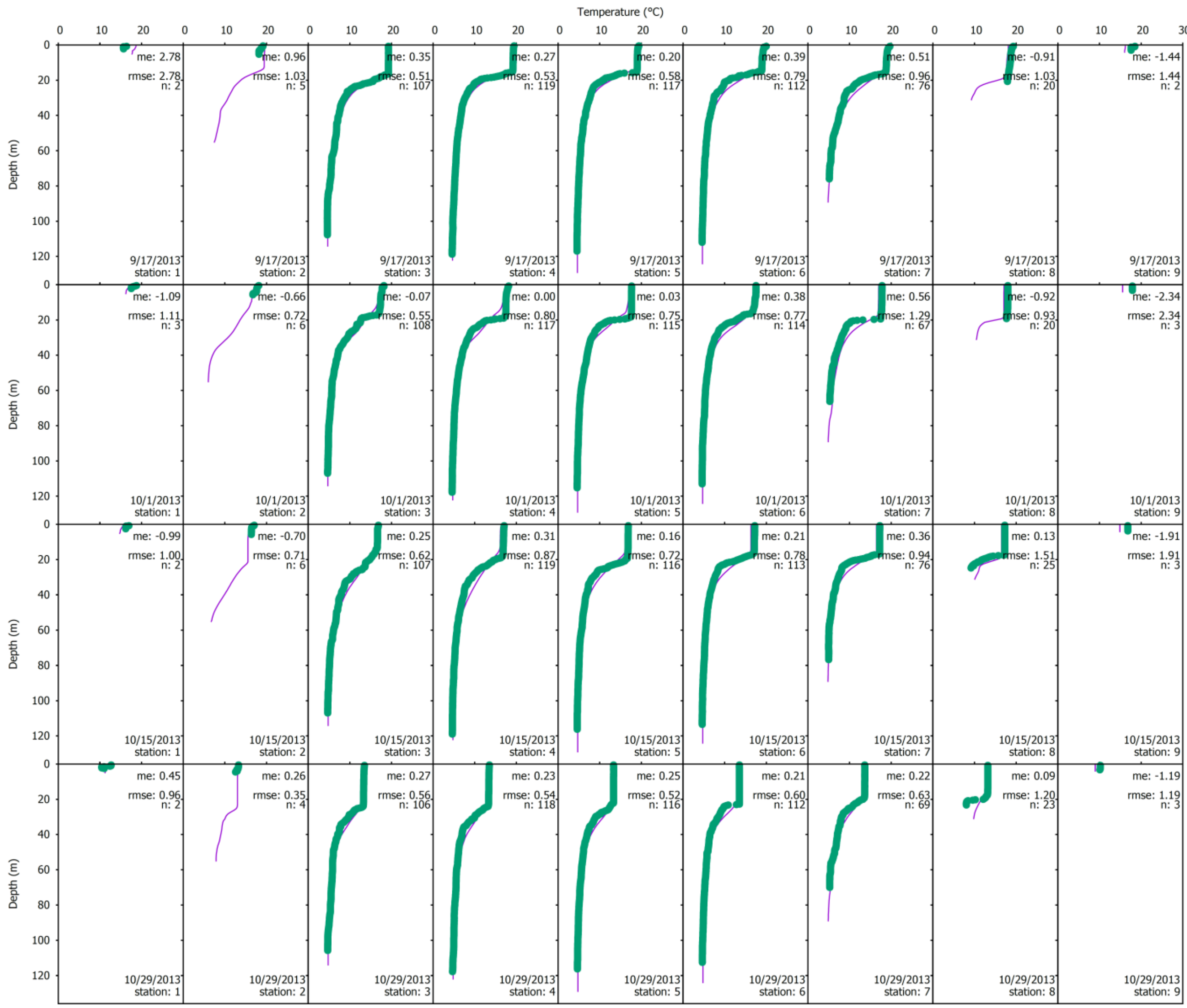


Figure C1-continued. Comparison of predicted and observed temperature profiles for all sites from Cayuga Lake 2013, the model calibration year, for bi-weekly sampling dates.

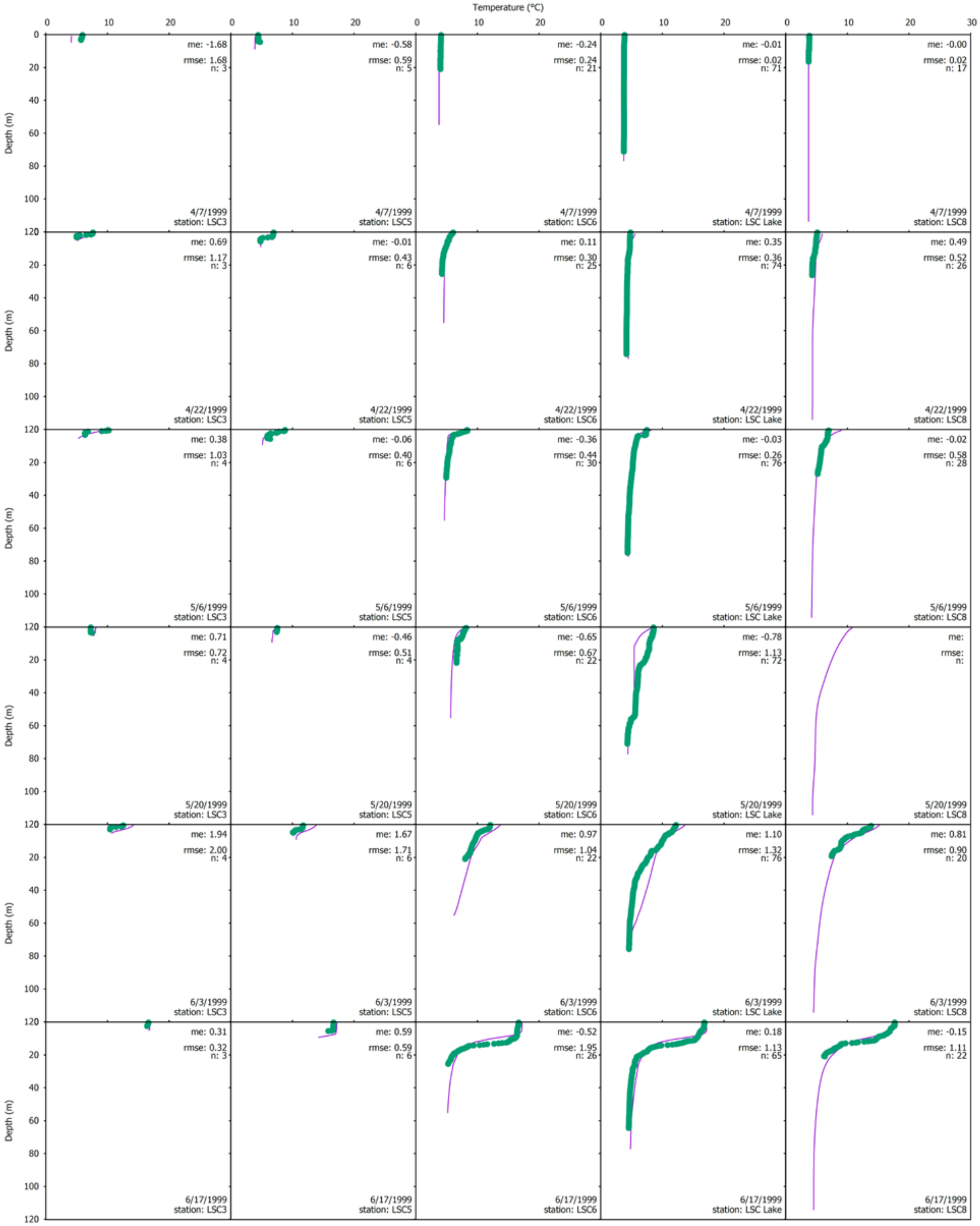


Figure C2. Comparison of predicted and observed temperature profiles from Cayuga Lake 1999, a model validation year.

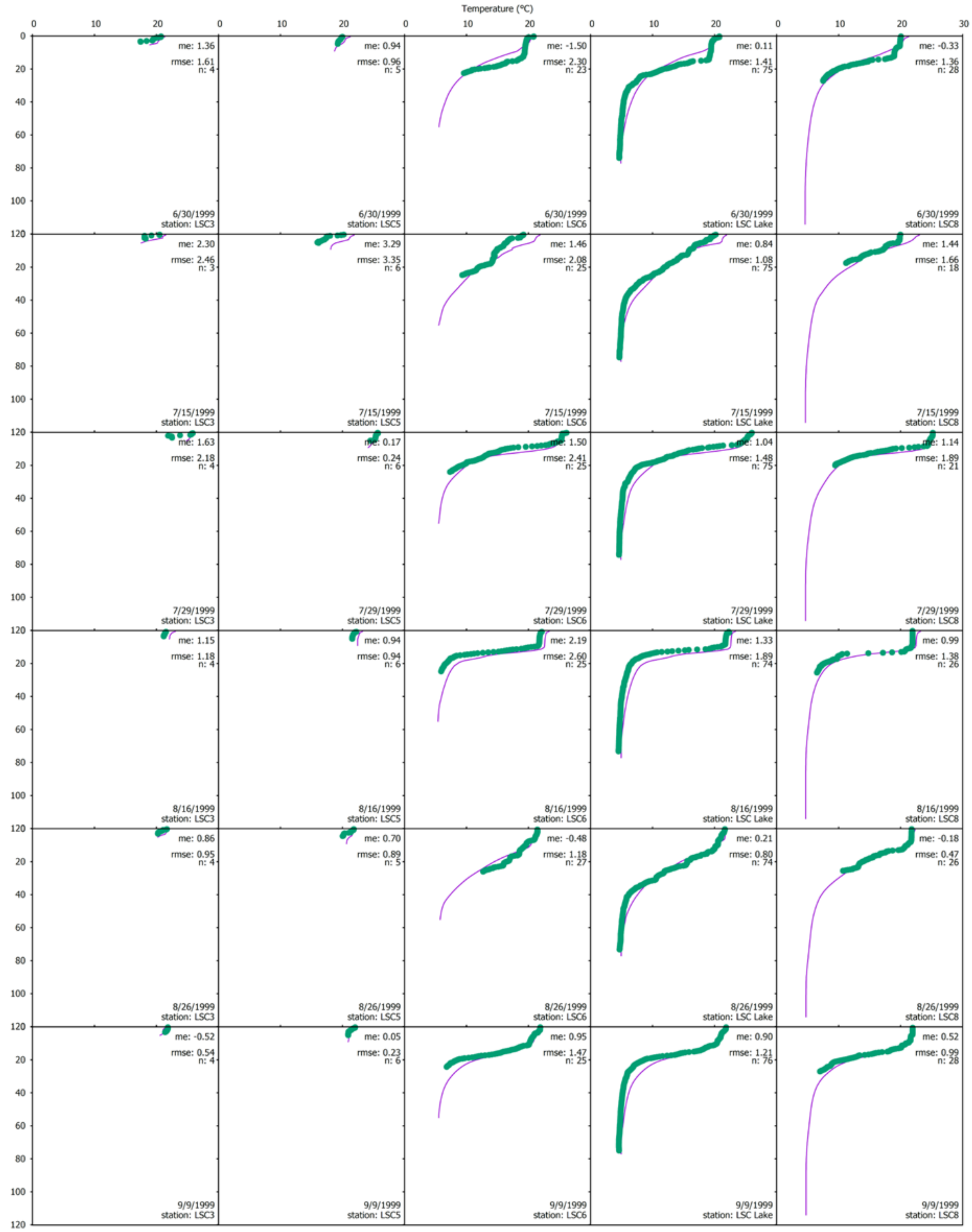


Figure C2-continued. Comparison of predicted and observed temperature profiles from Cayuga Lake 1999, a model validation year.

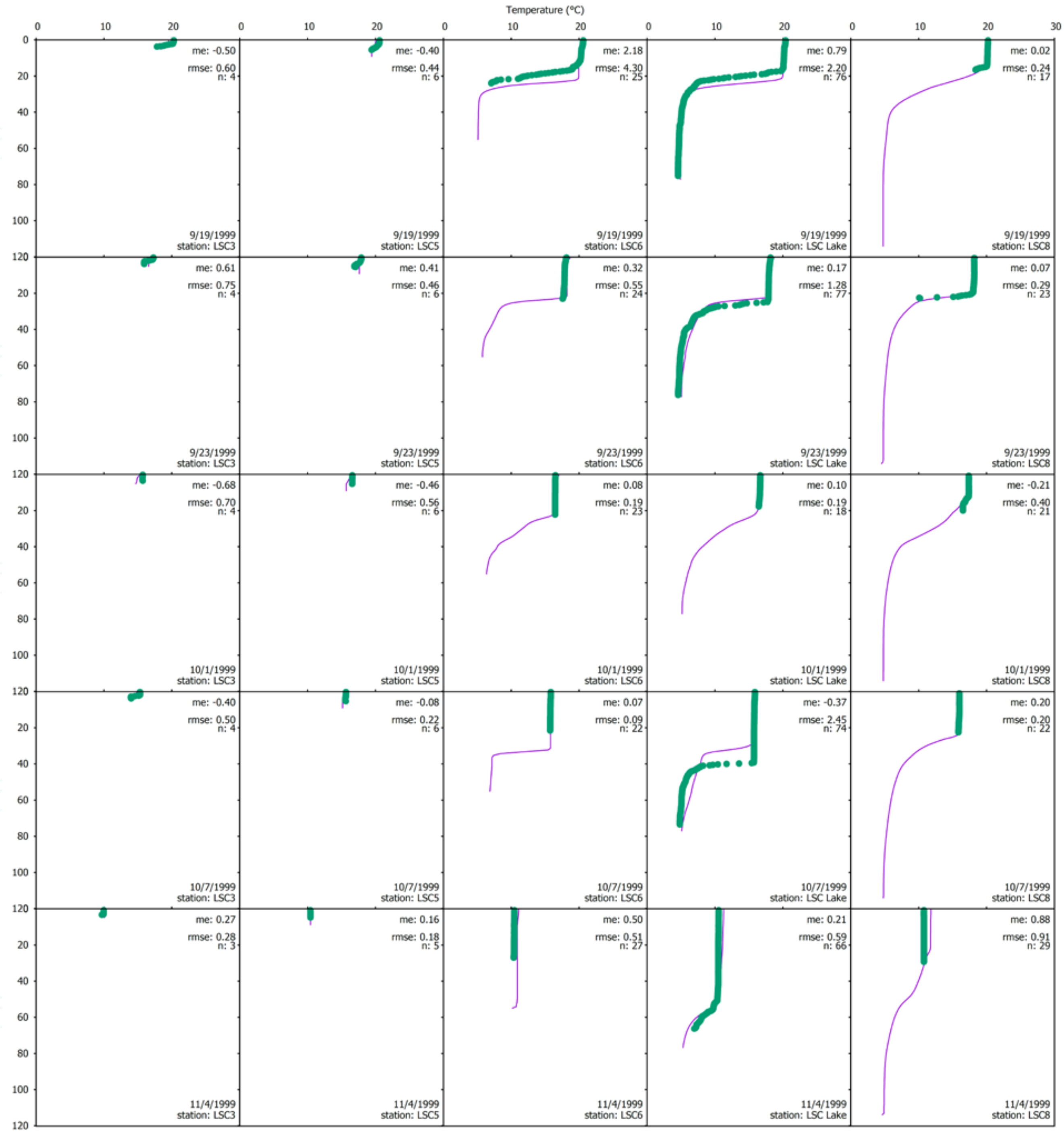


Figure C2-continued. Comparison of predicted and observed temperature profiles from Cayuga Lake 1999, a model validation year.

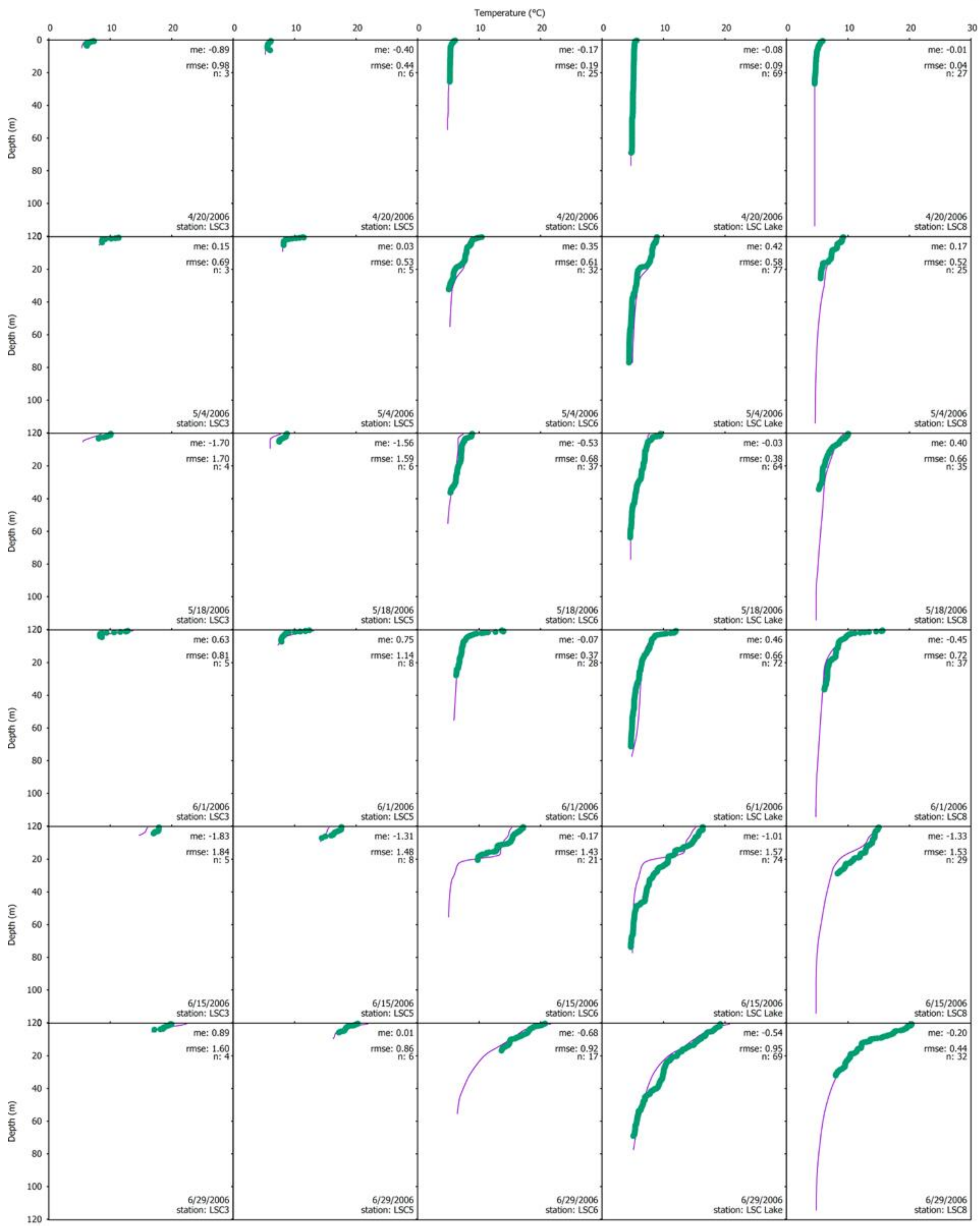


Figure C3. Comparison of predicted and observed temperature profiles from Cayuga Lake 2006, a model validation year.

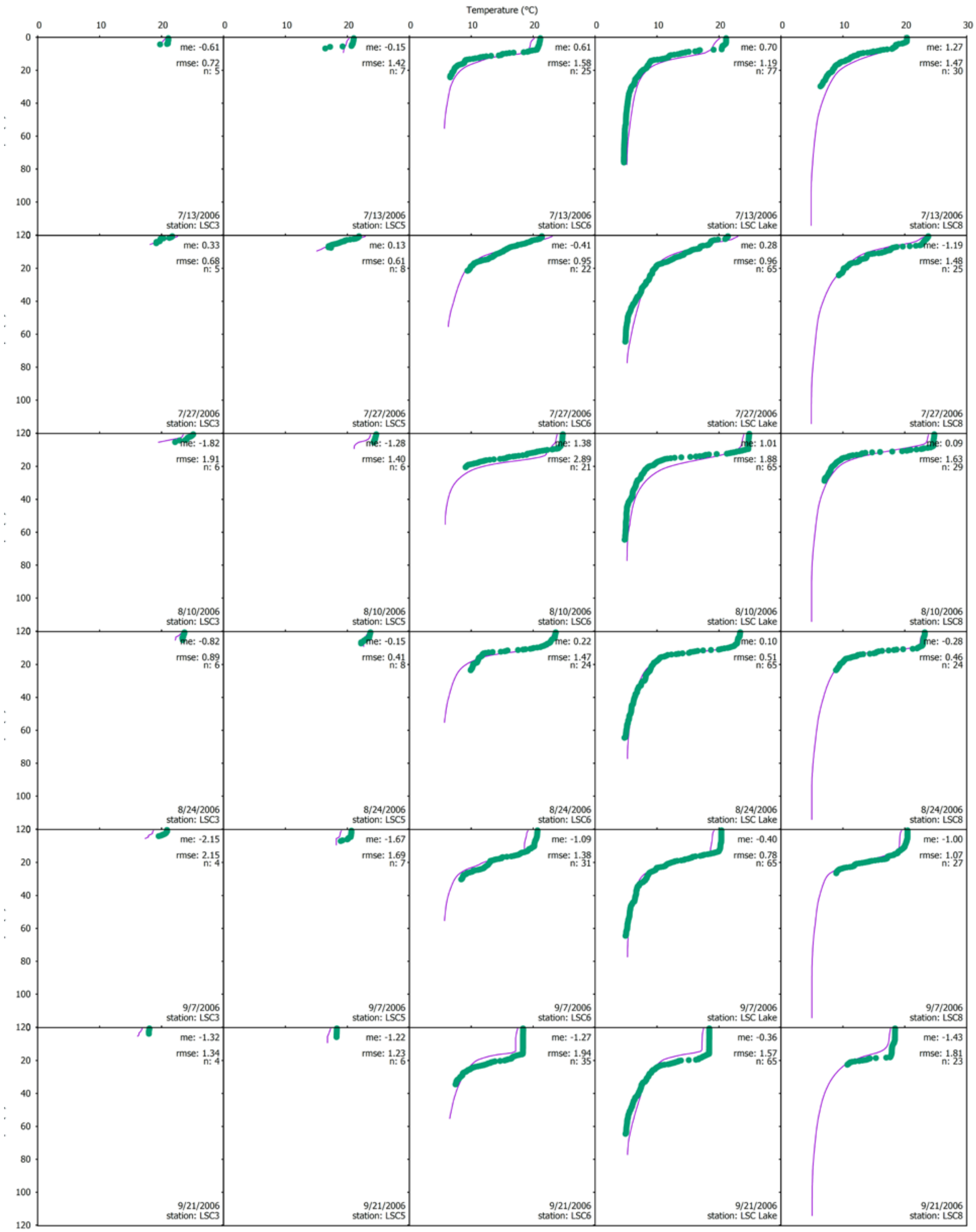


Figure C3-continued. Comparison of predicted and observed temperature profiles from Cayuga Lake 2006, a model validation year.

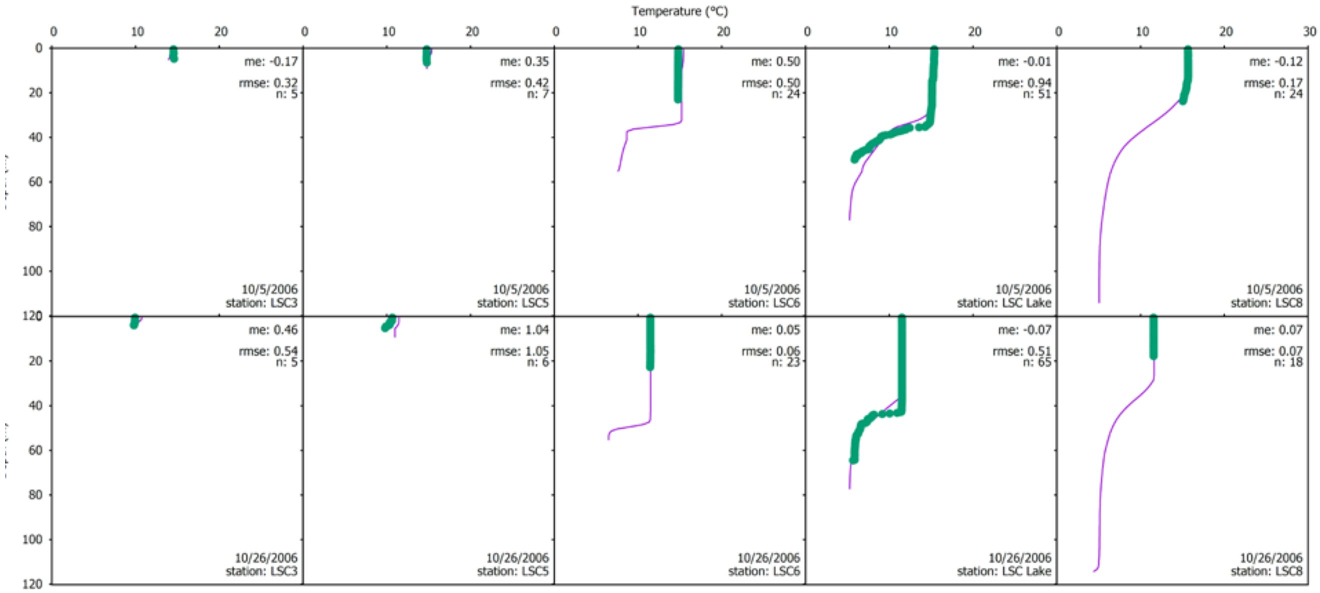


Figure C3-continued. Comparison of predicted and observed temperature profiles from Cayuga Lake 2006, a model validation year.

2013: Total P Time Series

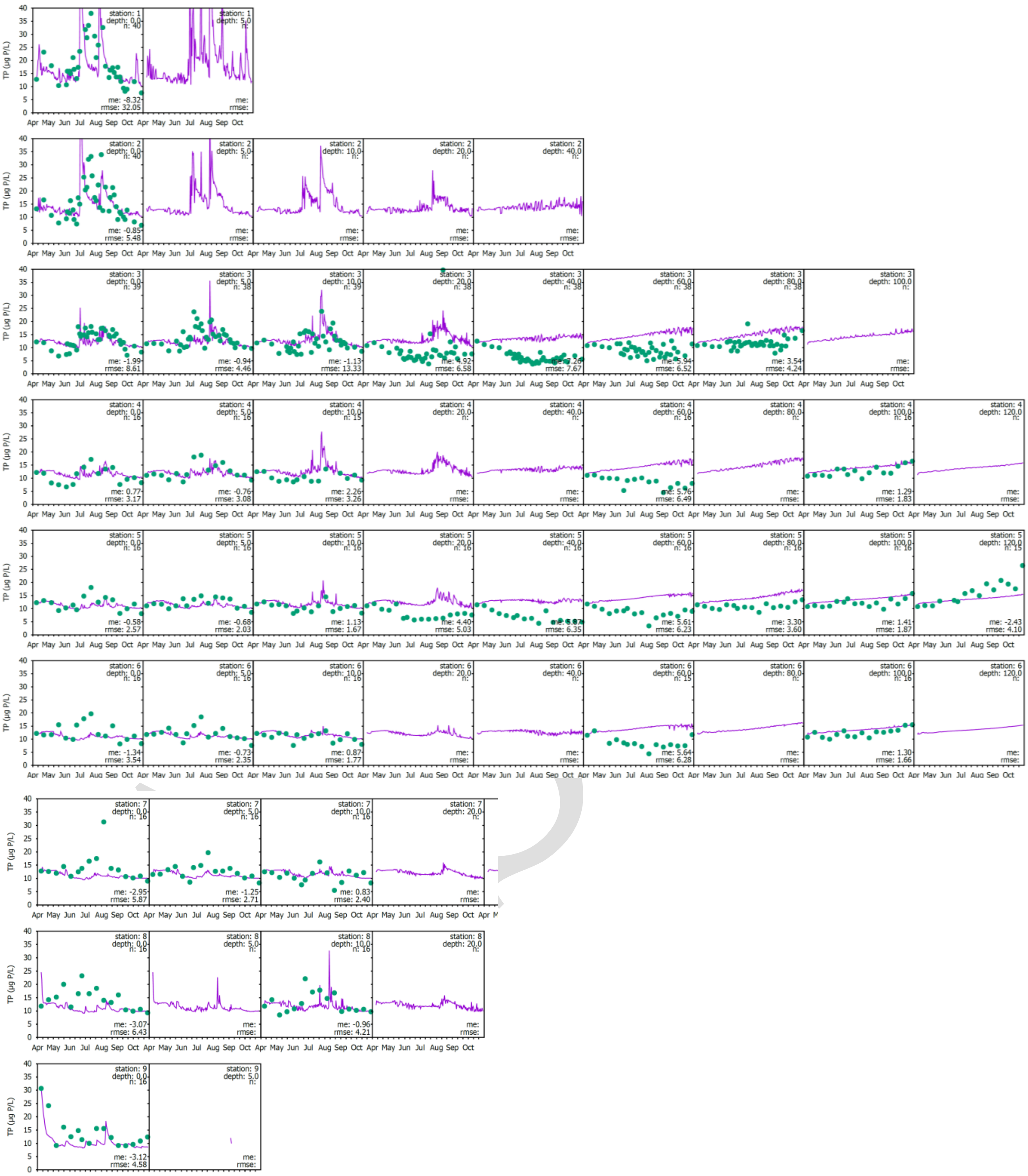


Figure C4. Comparison of predicted and observed total phosphorus time series for all sites from Cayuga Lake 2013, the model calibration year.

2013: Soluble Reactive P Time Series

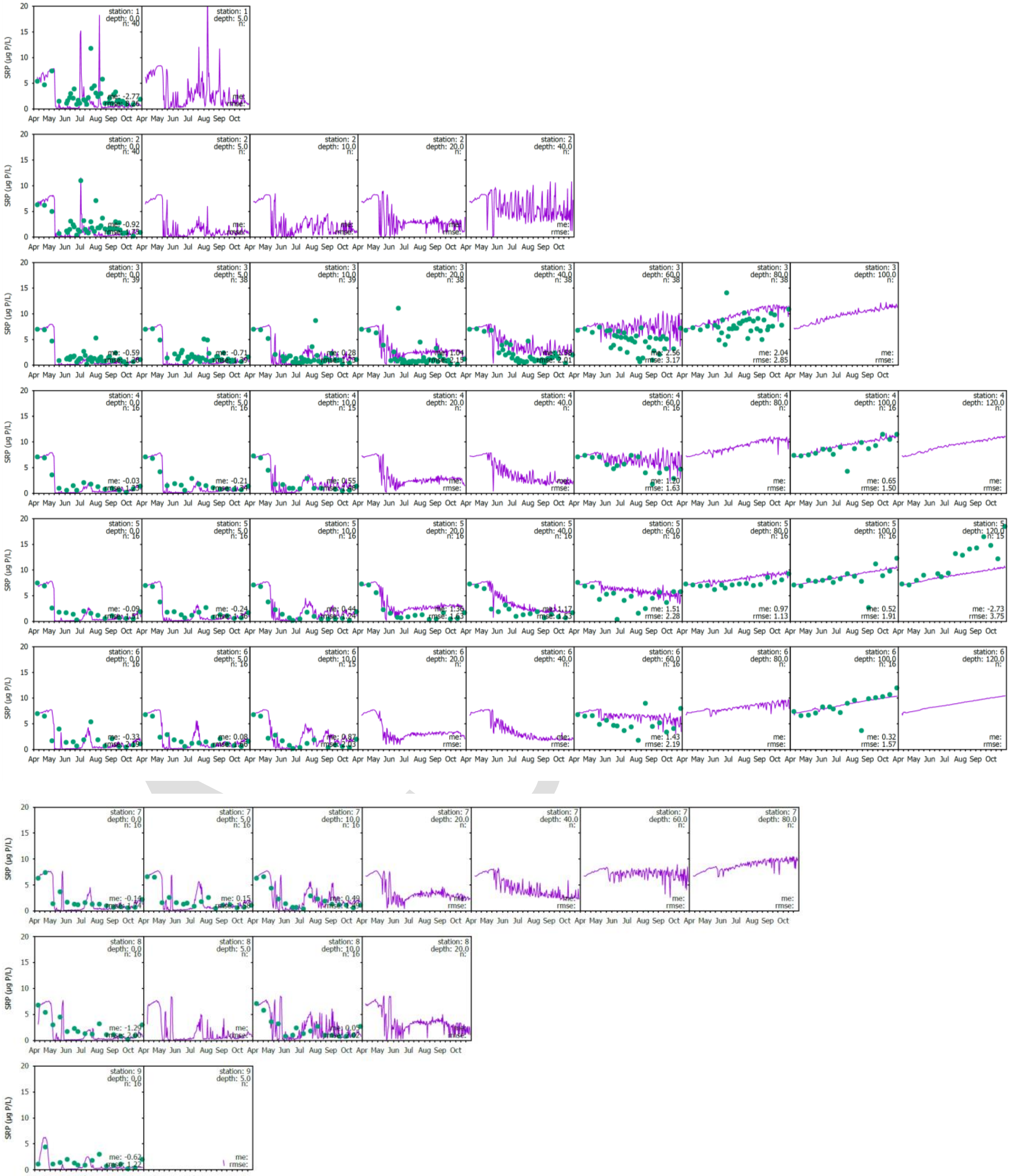


Figure C5. Comparison of predicted and observed soluble reactive phosphorus (SRP) time series for all sites from Cayuga Lake 2013, the model calibration year.

2013: Chlorophyll-a Time Series

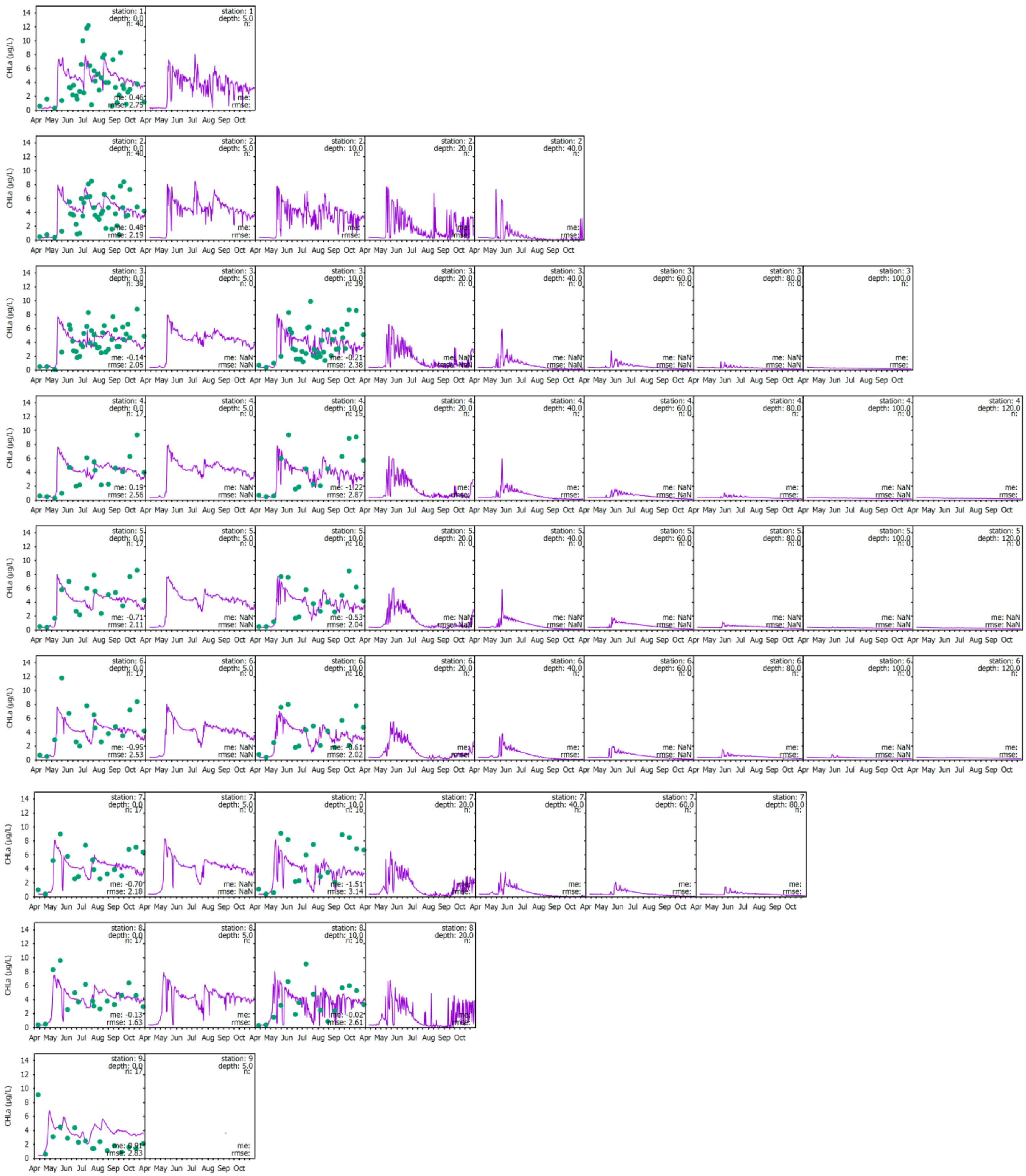


Figure C6. Comparison of predicted and observed chlorophyll-a (Chl-a) time series for all sites from Cayuga Lake 2013, the model calibration year.

2013: POC Time Series

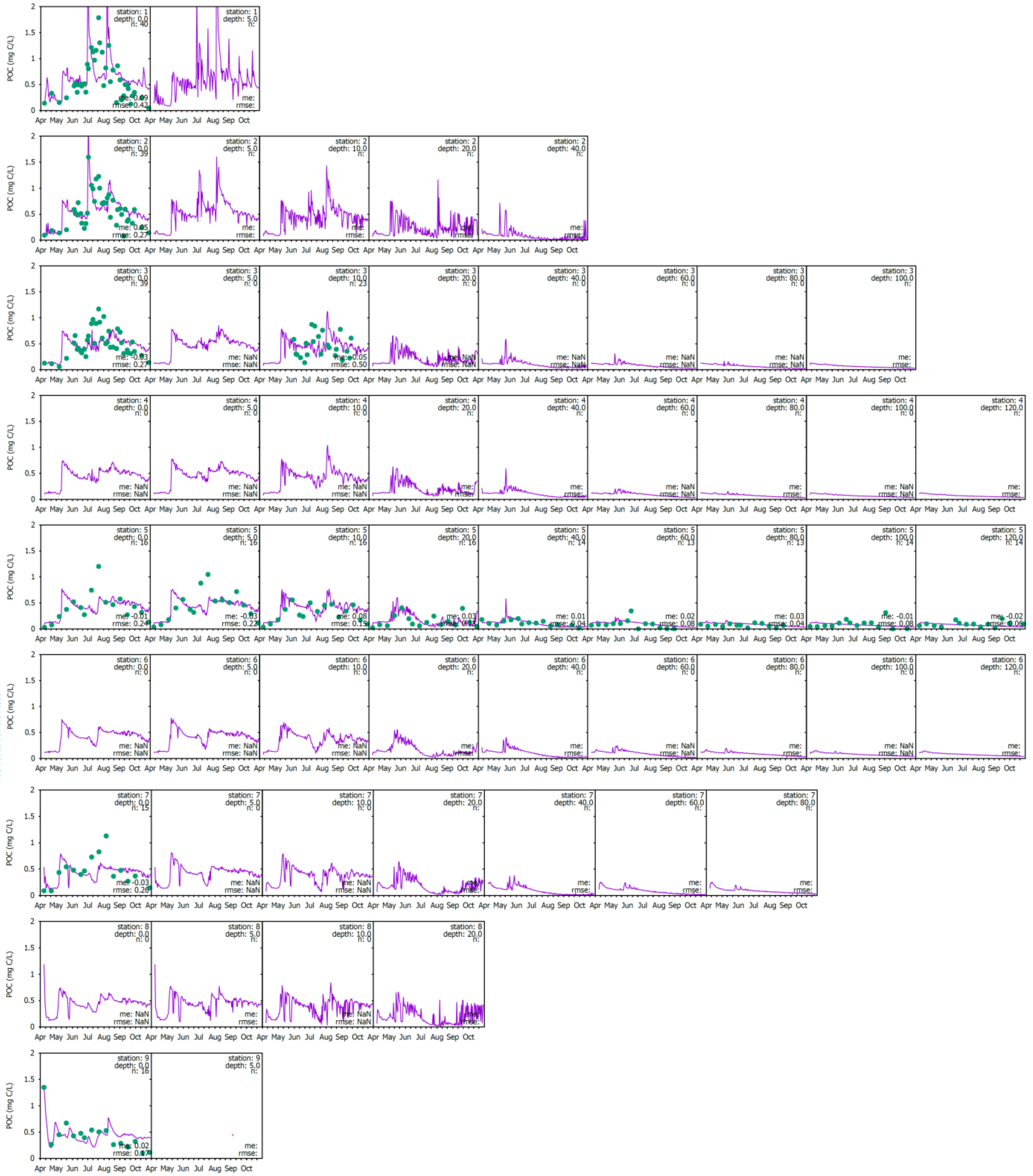


Figure C7. Comparison of predicted and observed particulate organic carbon (POC) time series for all sites from Cayuga Lake 2013, the model calibration year.

2013: NOx Time Series

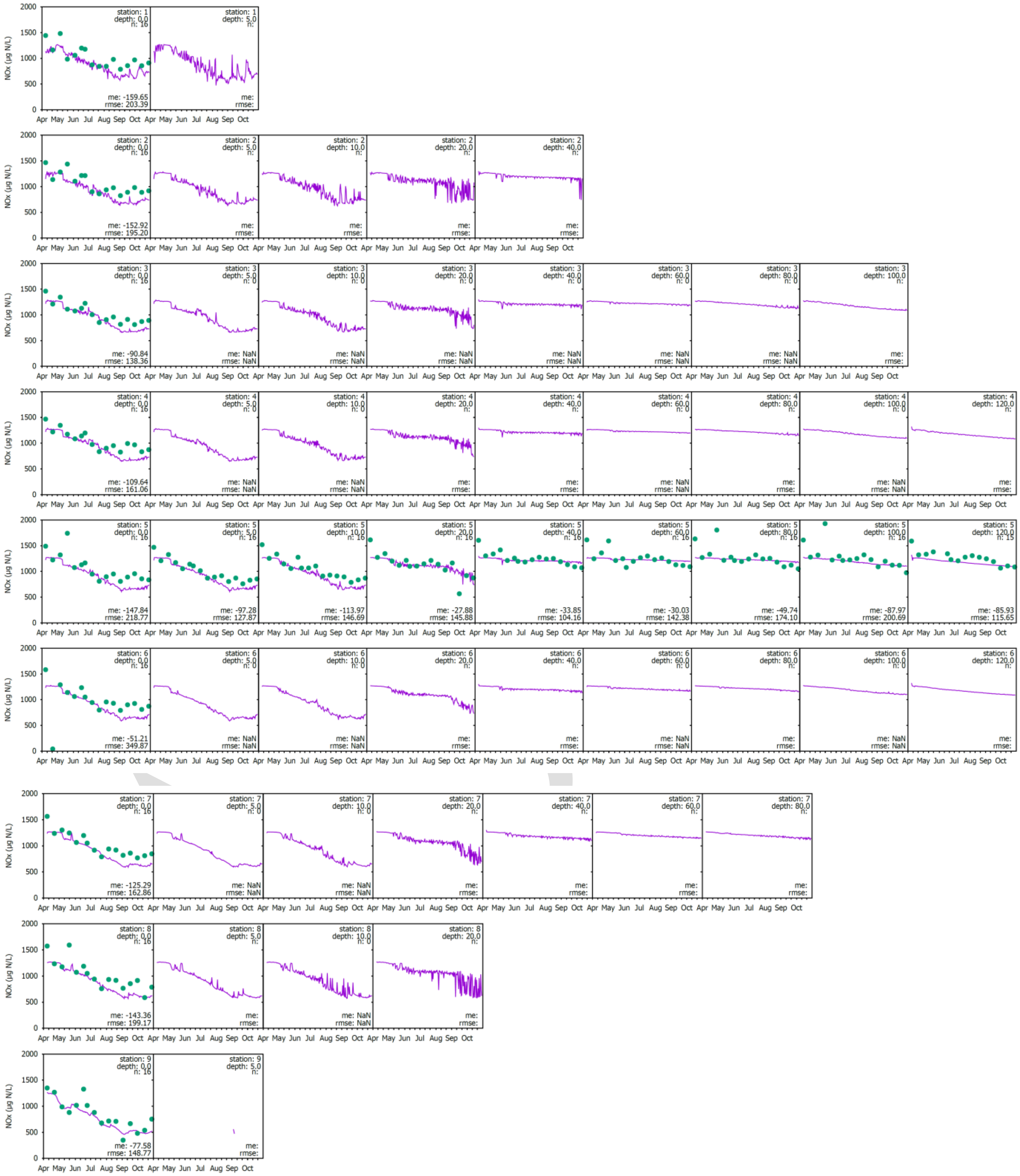


Figure C8. Comparison of predicted and observed NOx (nitrate+nitrite) time series for all sites from Cayuga Lake 2013, the model calibration year.

2013: Silica Time Series

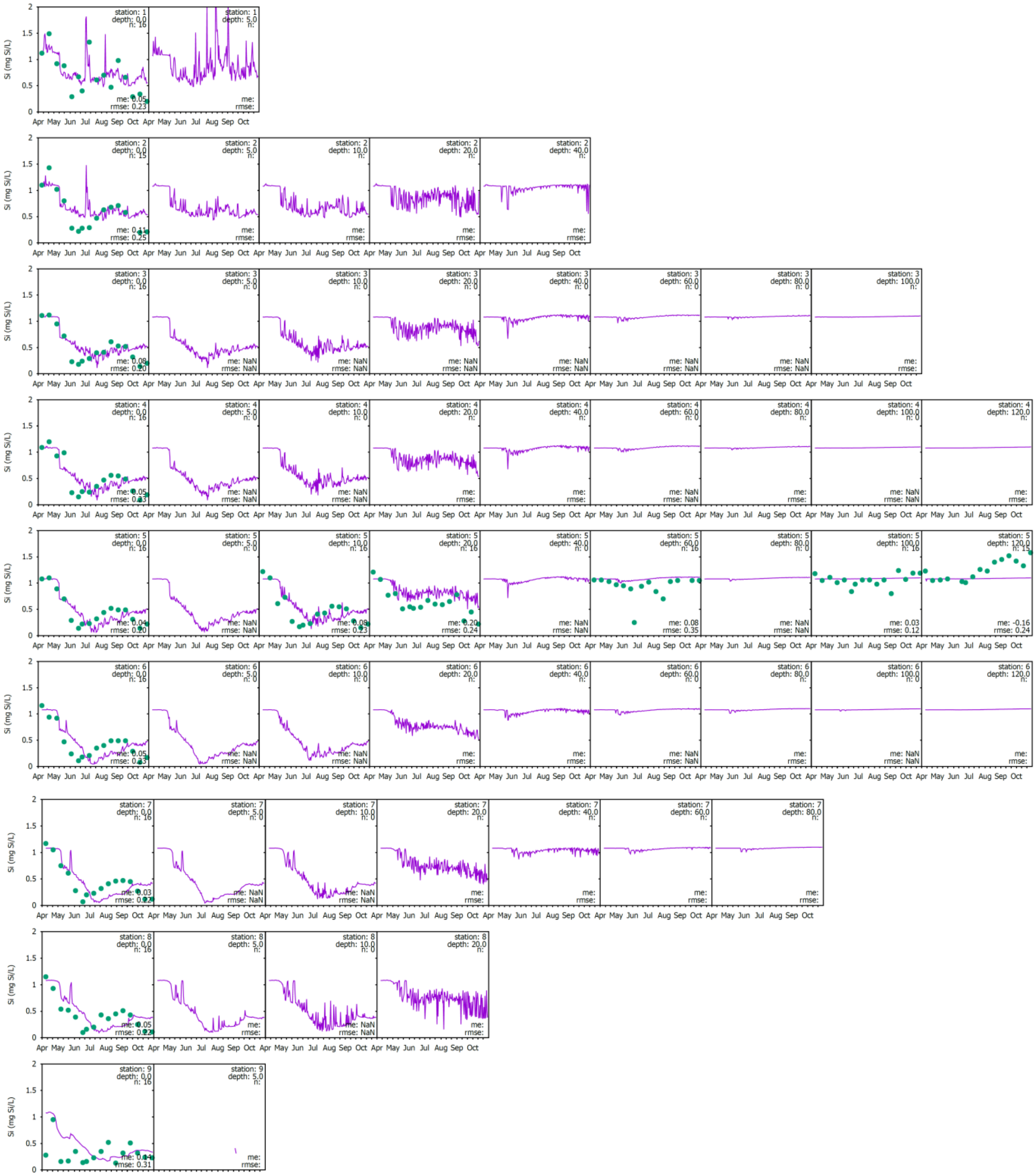


Figure C9. Comparison of predicted and observed silica (Si) time series for all sites from Cayuga Lake 2013, the model calibration year.

1999: Total P Time Series

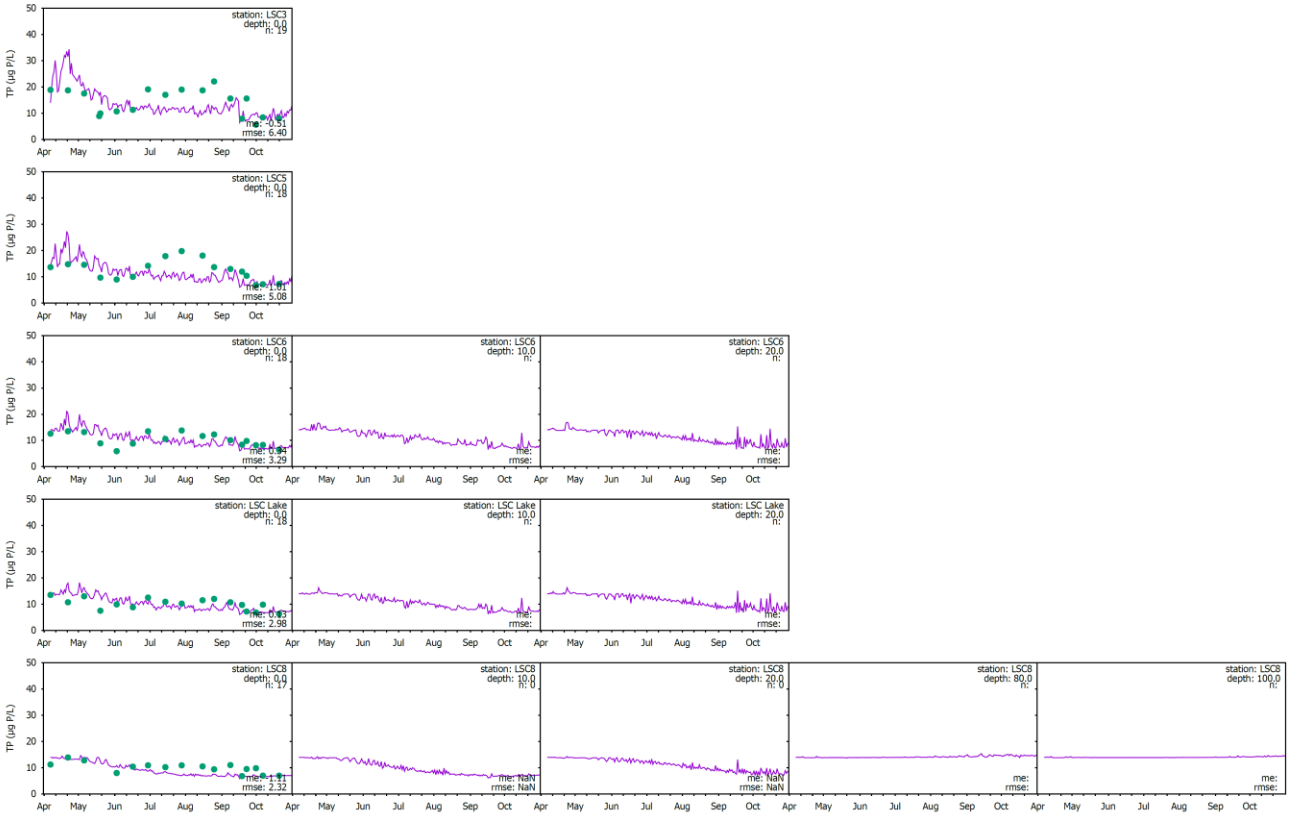


Figure C10. Comparison of predicted and observed total phosphorus time series for all sites from Cayuga Lake 1999, a model validation year.

1999: Soluble Reactive P Time Series

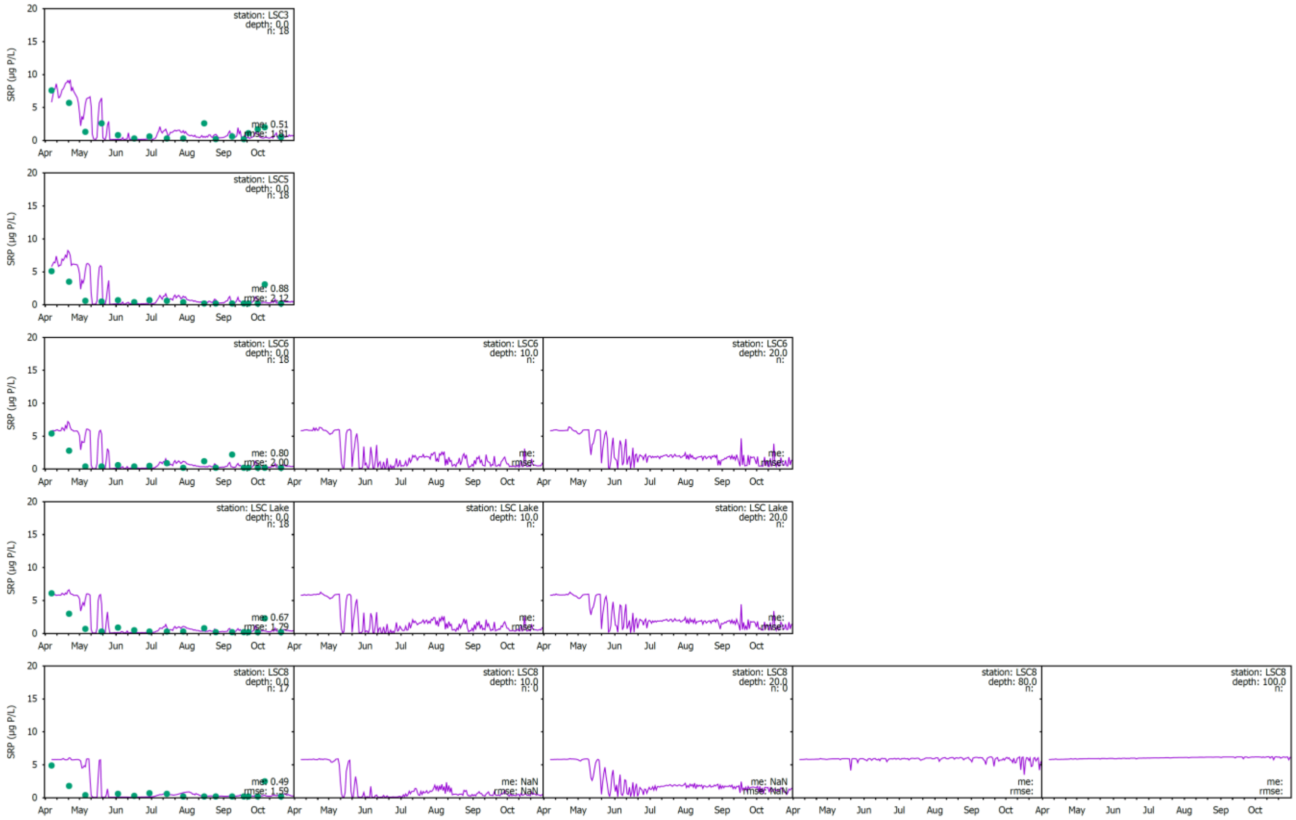


Figure C11. Comparison of predicted and observed soluble reactive phosphorus (SRP) time series for all sites from Cayuga Lake 1999, a model validation year.

1999: Chlorophyll-a Time Series

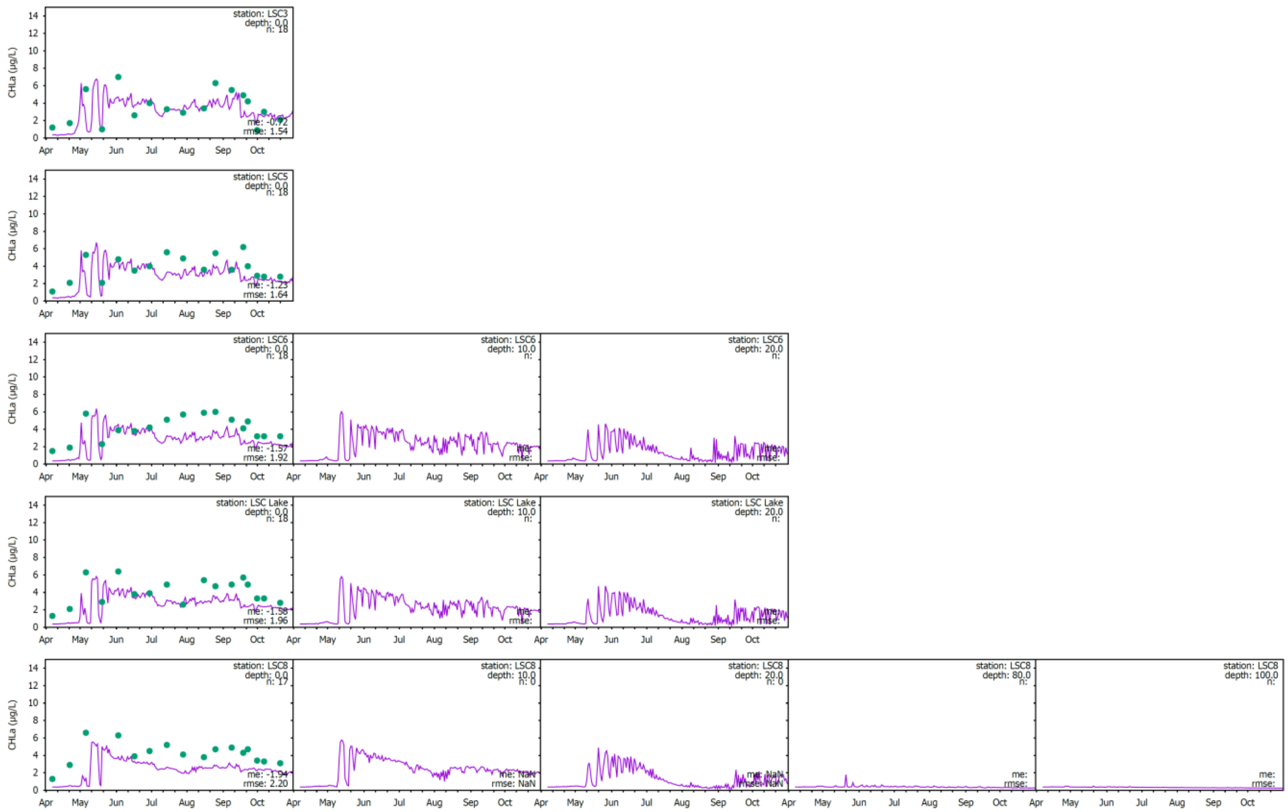


Figure C12. Comparison of predicted and observed chlorophyll-a (Chl-a) time series for all sites from Cayuga Lake 1999, a model validation year.

1999: POC Time Series

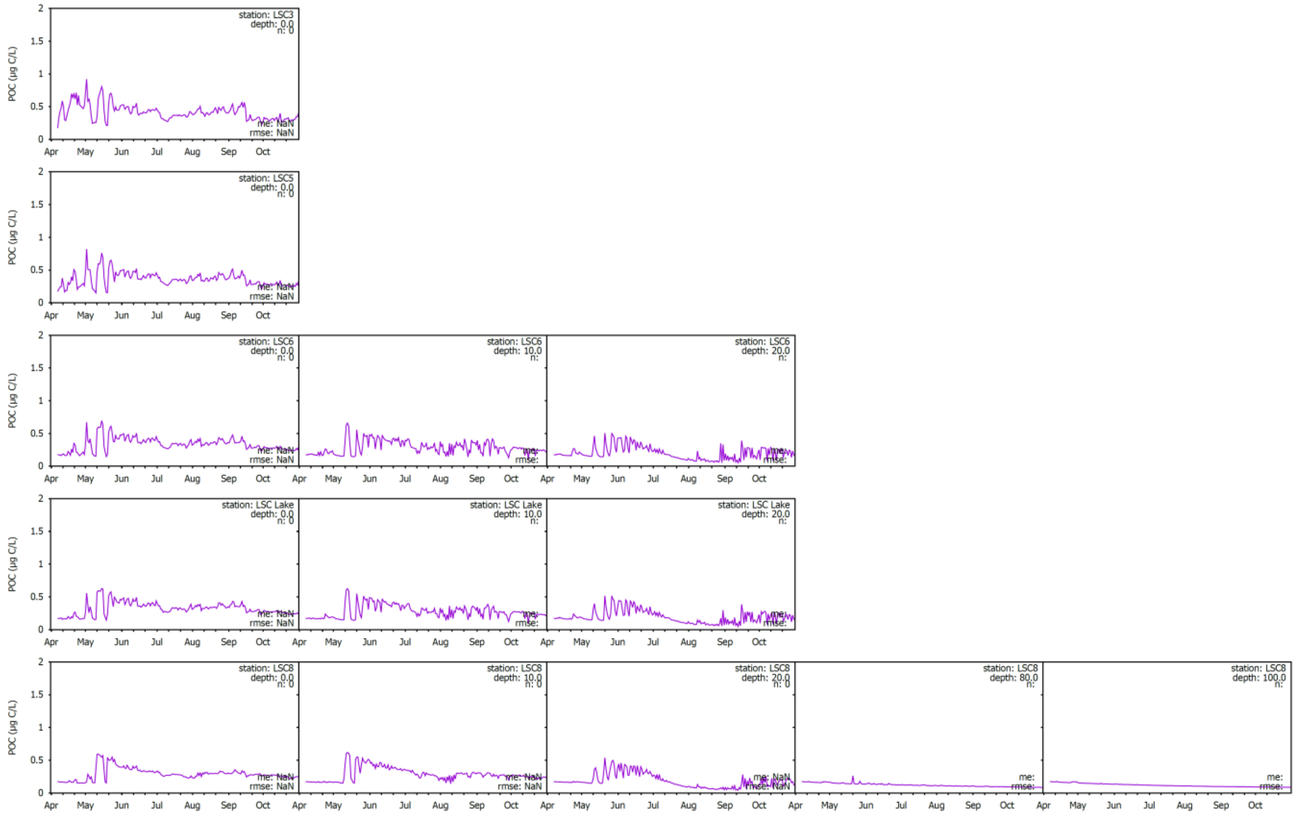


Figure C13. Predicted particulate organic carbon (POC) time series for all sites from Cayuga Lake 1999, a model validation year.

1999: NOx Time Series

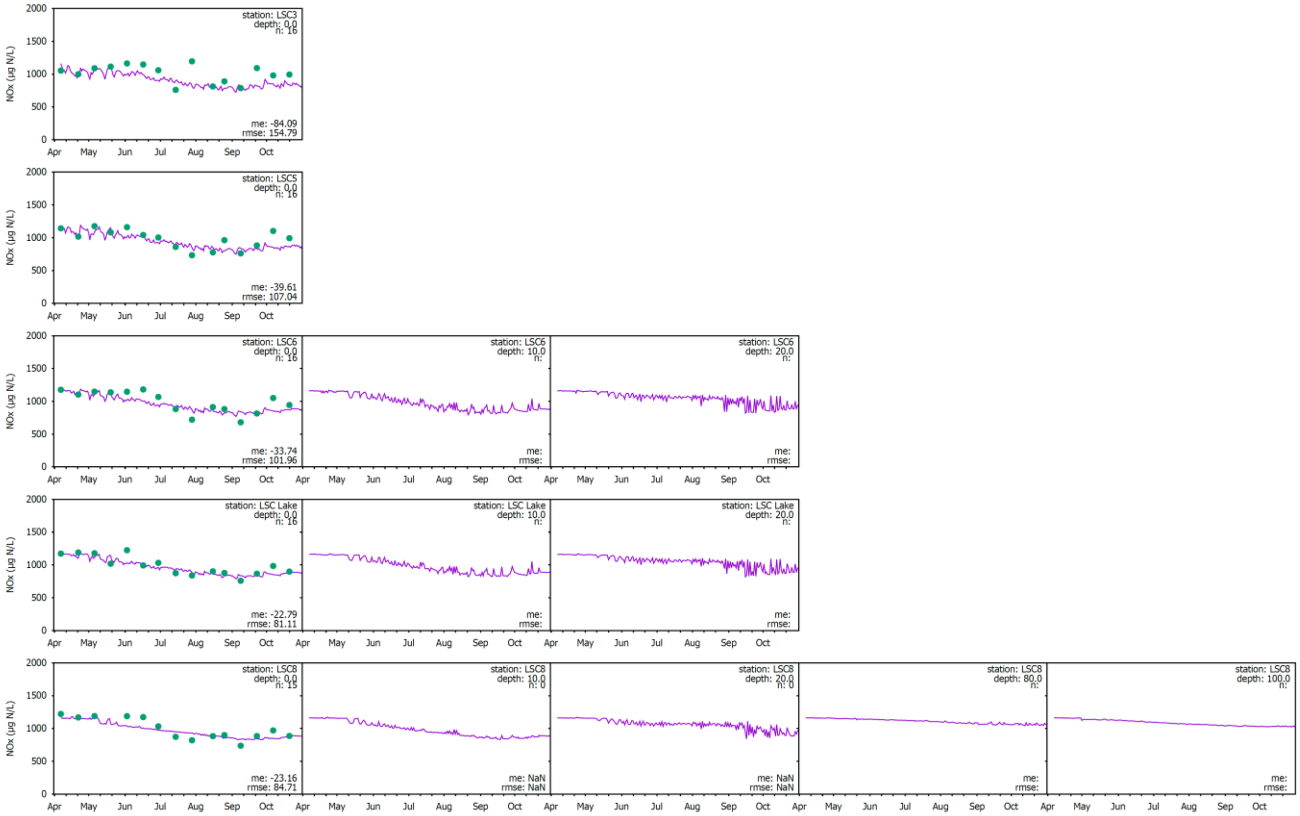


Figure C14. Comparison of predicted and observed NOx (nitrate+nitrite) time series for all sites from Cayuga Lake 1999, a model validation year.

1999: Silica Time Series

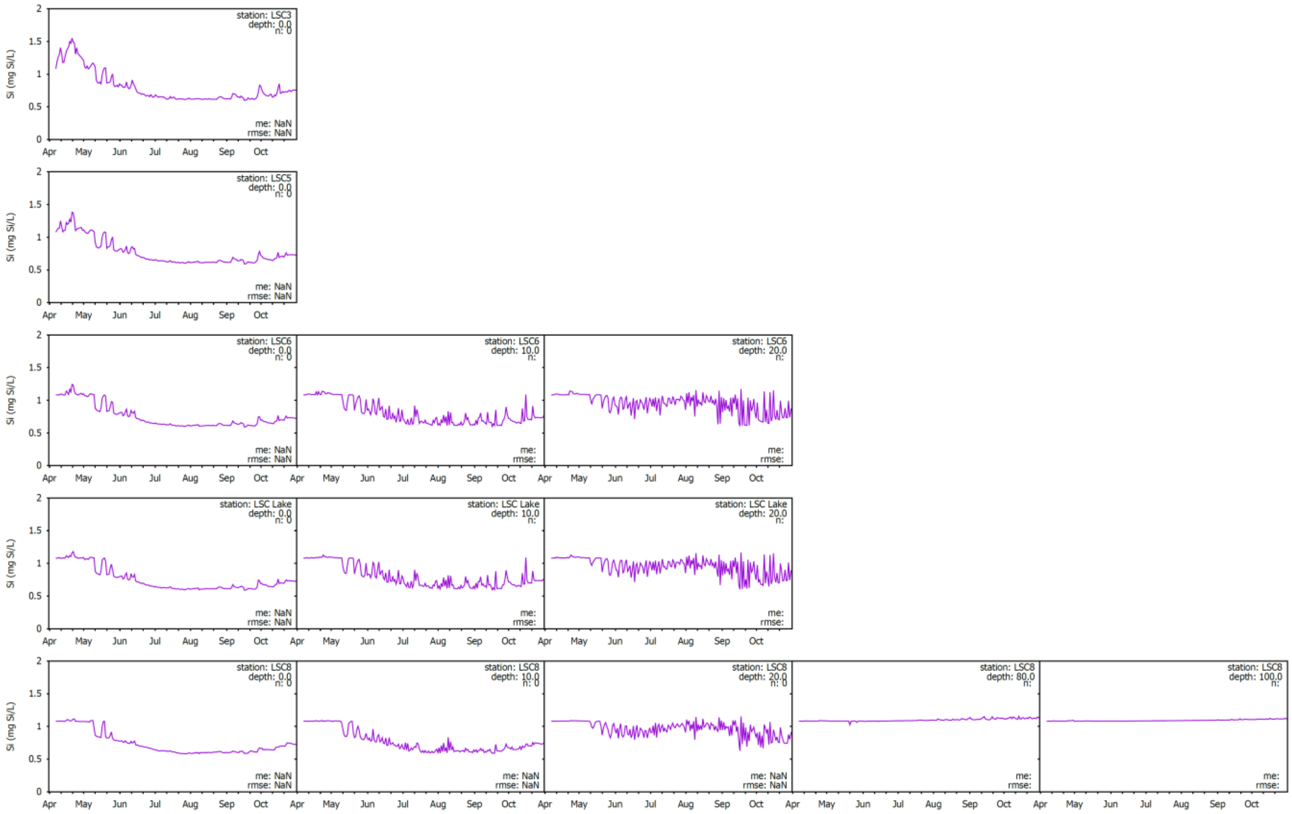


Figure C15. Predicted silica (Si) time series for all sites from Cayuga Lake 1999, a model validation year.

2006: Total P Time Series

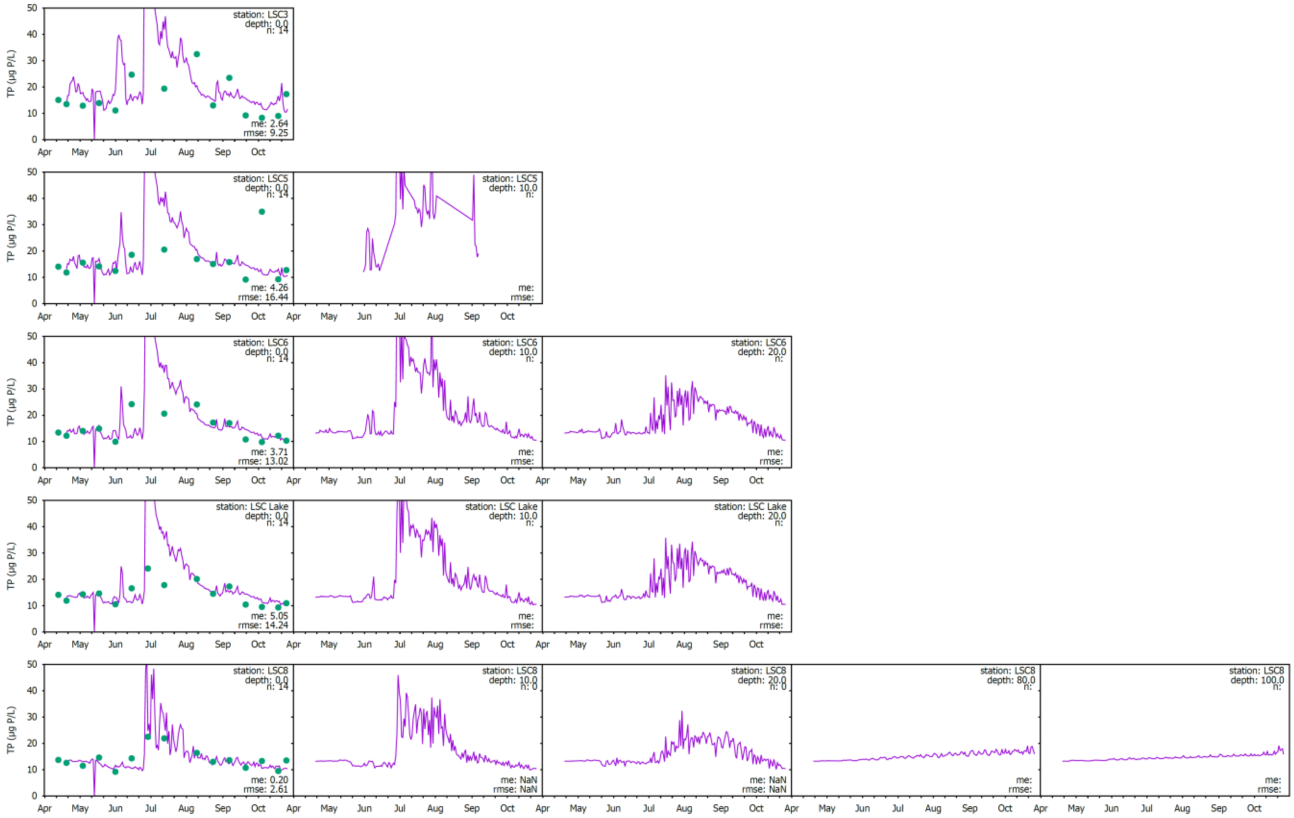


Figure C16. Comparison of predicted and observed total phosphorus time series for all sites from Cayuga Lake 2006, a model validation year.

2006: Soluble Reactive P Time Series

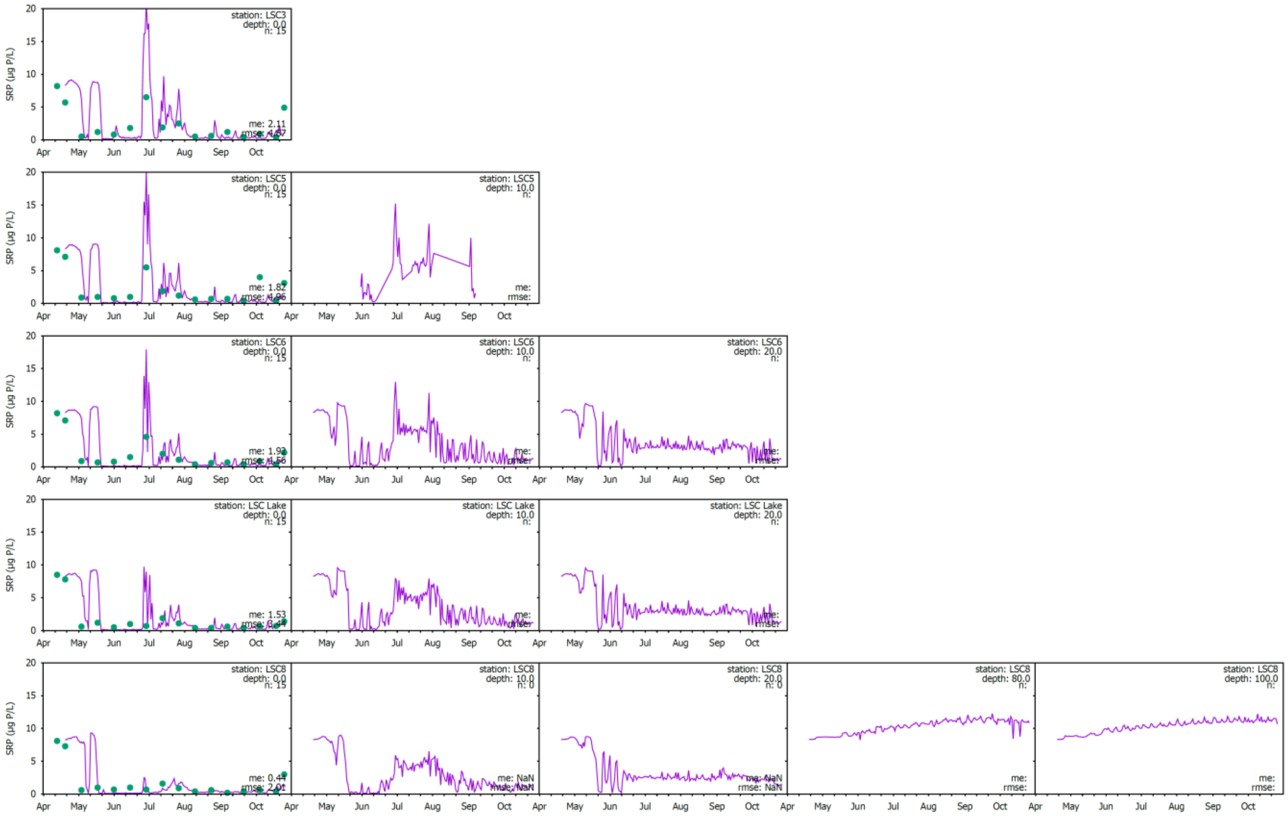


Figure C17. Comparison of predicted and observed soluble reactive phosphorus (SRP) time series for all sites from Cayuga Lake 2006, a model validation year.

2006: Chlorophyll-a Time Series

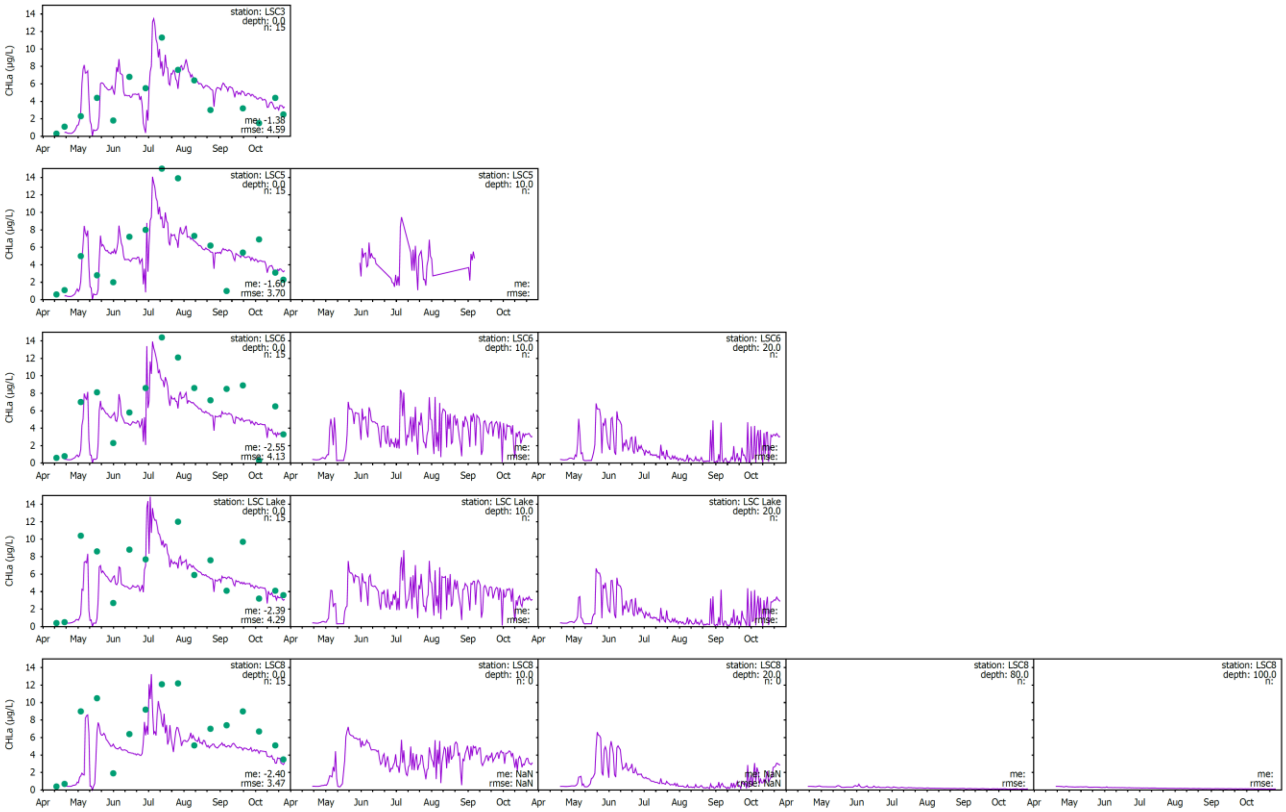


Figure C18. Comparison of predicted and observed chlorophyll-a (Chl-a) time series for all sites from Cayuga Lake 2006, a model validation year.

2006: POC Time Series

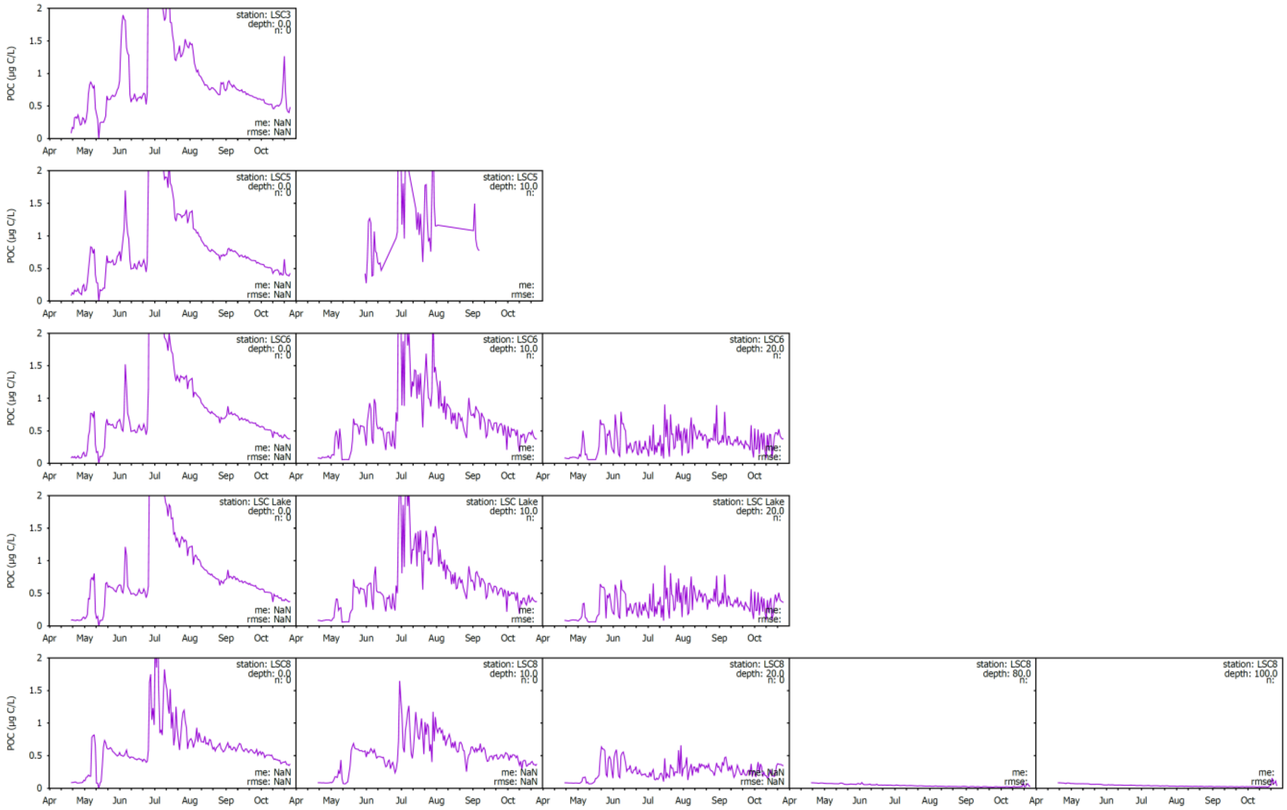


Figure C19. Predicted particulate organic carbon (POC) time series for all sites from Cayuga Lake 2006, a model validation year.

2006: NOx Time Series

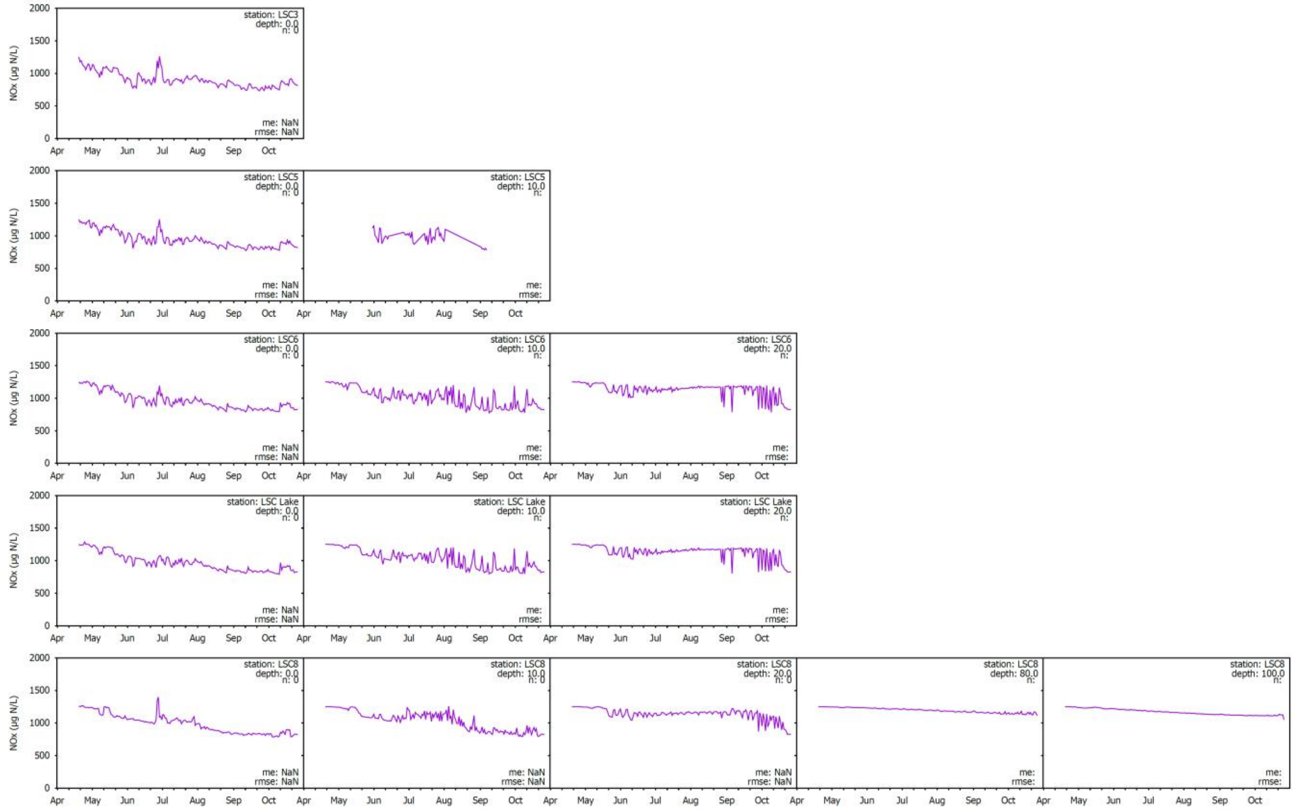


Figure C20. Predicted NOx (nitrate+nitrite) time series for all sites from Cayuga Lake 2006, a model validation year.

2006: Silica Time Series

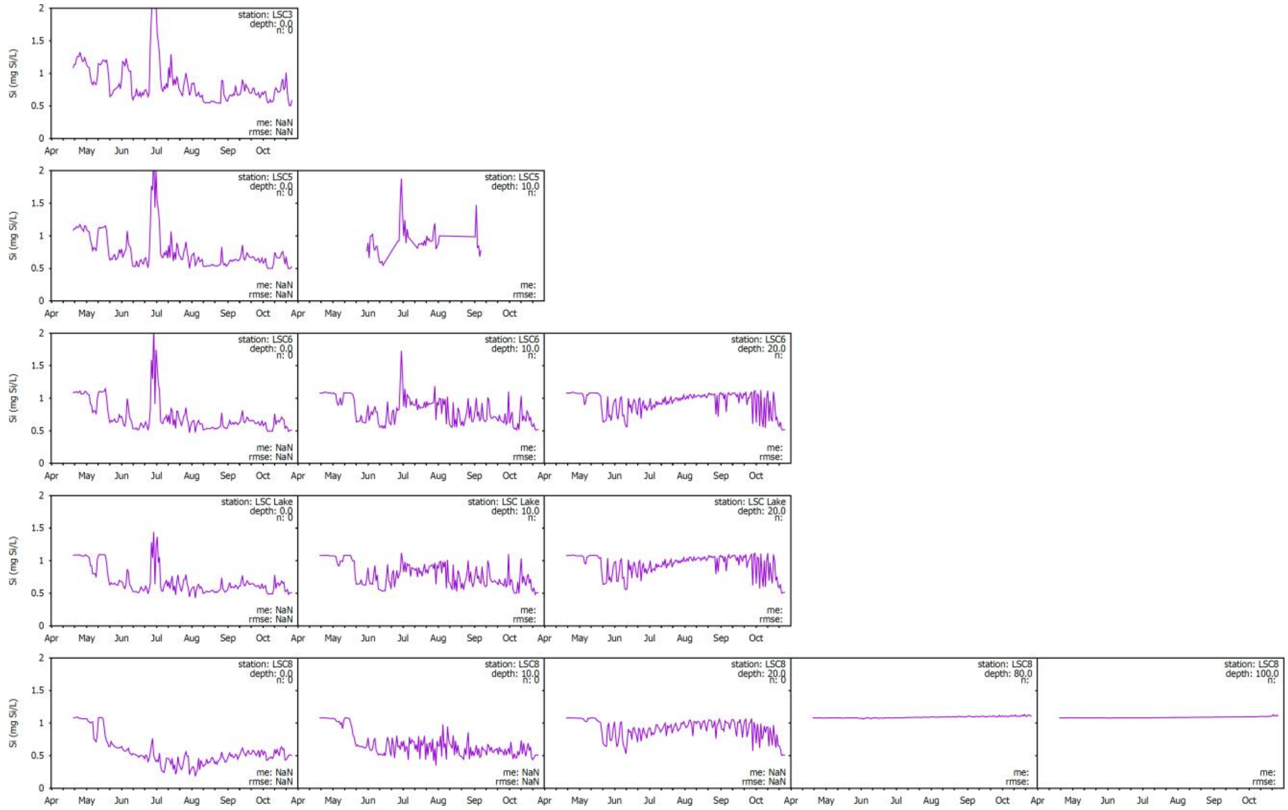


Figure C21. Predicted silica (Si) time series for all sites from Cayuga Lake 2006, a model validation year.

Appendix D. Review of Modeling Scenarios used to Develop the Cayuga Lake TMDL

To guide the development of loading (LA) and waste load allocations (WLA) for the Cayuga TMDL, approximately 30 management scenarios were investigated using the Cayuga Lake Model. All scenarios involved theoretical reductions in nutrient inputs from both point sources and nonpoint sources as a result of potential management actions. For each scenario, after nutrient loads were reduced, the model was rerun and the changes in water quality (i.e., summer average total phosphorus and chlorophyll-a) in each of the four lake segments for each of the sixteen modeled years (1998-2013) were recorded and assessed. Table D1, below contains descriptions of the management scenarios investigated for the TMDL.

Table D1. List of modeling scenarios evaluated as part of the Cayuga TMDL.

Run #	Dreissenid Mussels Module	Point Source Loads (PS)	Non-Point Source Loads (NPS)	Lake Source Cooling
28	on[1], no Quaggas	measured/estimated[3]	measured/estimated	measured/estimated
31	on	measured/estimated	measured/estimated	permit
33	on	permit[4]	measured/estimated	permit
34	on	permit	20% reduction	permit
35	on	permit	measured/estimated	permit with relocated outfall[5]
36	on	permit	30% reduction	permit
37	on	permit	50% reduction	permit
38	on	measured/estimated	20% reduction	permit
39	on	measured/estimated	30% reduction	permit
40	on	measured/estimated	50% reduction	permit
41	off[2]	measured/estimated	measured/estimated	permit
42	off	permit	measured/estimated	permit
43	on	measured/estimated	measured/estimated	120 % of permit
44	on	permit	measured/estimated	120 % of permit
45	off	measured/estimated	measured/estimated	measured/estimated
46	off	permit	20% reduction	permit
47	off	permit	measured/estimated	permit with relocated outfall
48	off	permit	30% reduction	permit
49	off	permit	50% reduction	permit
50	off	permit	measured/estimated	120 % of permit
51	on	permit except Interlaken reduced 1mg/L	measured/estimated	permit
52	on	permit except Interlaken reduced 1mg/L	20% reduction	permit
53	off	permit except Interlaken reduced 1mg/L	measured/estimated	permit
54	off	permit except Interlaken reduced 1mg/L	20% reduction	permit
55	on	permit	measured/estimated	reduction to 4.8 lb/d
56	off	permit	measured/estimated	reduction to 4.8 lb/d
57	on	measured/estimated w/o Milliken	measured/estimated	permit
58	on	permit	30% reduction	reduction to 4.8 lb/d

Run #	Dreissenid Mussels Module	Point Source Loads (PS)	Non-Point Source Loads (NPS)	Lake Source Cooling
59	on	permit	30% reduction	permit with relocated outfall
60	on	permit	30% reduction	120 % of permit

1 dreissenid module activated for scenario
2 dreissenid module inactivated for scenario
3 point source load inputs measured/estimated from 2013 conditions
4 point source load inputs assumed to be at design flow and permitted TP effluent limit
5 Lake Source Cooling outfall moved to Main Lake, Mid-South segment

Tables D2-D8 describe the projected changes in water quality in Cayuga Lake from the Base model for selected management scenarios.

Table D2. Changes in total phosphorus (TP) in-lake water quality from select model scenarios for the Southern End A (0705-0040).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	18	18	(5.1)	17	-(0.7)	17	-(0.6)	16	-(7.7)	15	-(11.9)	14	-(19.5)
1999	14	15	(6.8)	14	-(0.8)	14	-(0.8)	14	-(3.1)	13	-(4.7)	13	-(7.7)
2000	20	20	(1.0)	20	-(0.5)	20	-(0.7)	18	-(8.6)	17	-(12.9)	16	-(21.5)
2001	18	18	(1.1)	18	-(0.3)	18	-(0.8)	17	-(5.9)	16	-(8.9)	15	-(14.9)
2002	23	24	(1.8)	23	-(0.4)	23	-(0.6)	21	-(10.1)	20	-(15.2)	17	-(25.2)
2003	21	22	(2.3)	21	-(0.3)	21	-(0.6)	19	-(9.2)	18	-(13.8)	16	-(23.0)
2004	26	26	(1.9)	25	-(0.4)	25	-(0.4)	23	-(11.9)	21	-(17.9)	18	-(29.8)
2005	18	18	(2.3)	17	-(0.6)	17	-(0.9)	17	-(5.7)	16	-(8.5)	15	-(14.3)
2006	31	32	(2.1)	31	-(0.4)	31	-(0.4)	27	-(13.7)	25	-(20.5)	21	-(34.1)
2007	17	17	(1.7)	17	-(0.4)	17	-(0.9)	16	-(5.1)	16	-(7.6)	15	-(12.5)
2008	18	19	(4.0)	18	-(0.6)	18	-(0.9)	17	-(5.9)	16	-(9.0)	15	-(14.9)
2009	18	18	(2.1)	18	-(0.4)	18	-(0.8)	17	-(6.2)	16	-(9.3)	15	-(15.5)
2010	16	16	(3.0)	16	-(0.7)	16	-(0.9)	15	-(4.7)	15	-(7.0)	14	-(11.6)
2011	28	29	(3.9)	28	-(0.6)	28	-(0.5)	25	-(12.1)	23	-(18.1)	19	-(30.1)
2012	16	16	(2.2)	16	-(0.6)	16	-(1.0)	15	-(4.4)	15	-(6.6)	14	-(10.9)
2013	25	26	(3.1)	25	-(0.6)	25	-(0.5)	22	-(11.2)	21	-(16.8)	18	-(27.9)
Average	**20.4**	**20.9**	**(2.8)**	**20.3**	**-(0.5)**	**20.2**	**-(0.7)**	**18.6**	**-(7.8)**	**17.7**	**-(11.8)**	**16.0**	**-(19.6)**

[1] Percent change from Base Run (#33). No sign indicates an increase in TP, negative sign indicates a decrease in TP from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D2. Changes in chlorophyll-a (Chl-a) in-lake water quality from select model scenarios for the Southern End A (0705-0040).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	6	6	(3.3)	6	-(0.5)	6	-(0.5)	5	-(6.2)	5	-(9.4)	5	-(15.4)
1999	5	6	(4.4)	5	-(0.6)	5	-(0.9)	5	-(2.8)	5	-(4.1)	5	-(6.6)
2000	6	6	(0.5)	6	-(0.3)	6	-(0.8)	6	-(6.6)	6	-(9.8)	5	-(16.4)
2001	6	6	(0.7)	6	-(0.2)	6	-(0.8)	6	-(4.5)	6	-(6.8)	5	-(11.3)
2002	7	7	(1.4)	7	-(0.3)	7	-(0.7)	6	-(7.9)	6	-(12.0)	6	-(20.1)
2003	7	7	(1.6)	7	-(0.1)	7	-(0.7)	6	-(6.9)	6	-(10.4)	6	-(17.3)
2004	7	8	(1.1)	7	-(0.1)	7	-(0.5)	7	-(9.3)	6	-(13.8)	6	-(23.3)
2005	6	6	(1.9)	6	-(0.3)	6	-(0.8)	6	-(4.7)	6	-(7.1)	5	-(12.0)
2006	8	8	(1.6)	8	-(0.3)	8	-(0.5)	7	-(11.0)	6	-(16.6)	6	-(27.9)
2007	6	6	(1.1)	6	-(0.2)	6	-(1.1)	6	-(4.2)	6	-(6.2)	6	-(9.9)
2008	6	7	(2.7)	6	-(0.3)	6	-(1.4)	6	-(4.4)	6	-(6.7)	6	-(11.6)
2009	6	6	(1.3)	6	-(0.3)	6	-(1.0)	6	-(4.8)	6	-(7.1)	5	-(11.8)
2010	6	6	(2.1)	6	-(0.5)	6	-(1.0)	6	-(3.6)	6	-(5.5)	5	-(9.1)
2011	8	8	(3.0)	8	-(0.5)	8	-(0.8)	7	-(8.9)	7	-(13.3)	6	-(22.4)
2012	6	6	(2.2)	6	-(0.3)	6	-(0.9)	6	-(3.7)	6	-(5.6)	5	-(9.4)
2013	7	7	(2.2)	7	-(0.4)	7	-(0.7)	6	-(7.7)	6	-(11.8)	6	-(19.8)
Average	**6.5**	**6.6**	**(1.9)**	**6.4**	**-(0.3)**	**6.4**	**-(0.8)**	**6.1**	**-(6.1)**	**5.9**	**-(9.1)**	**5.4**	**-(15.3)**

[1] Percent change from Base Run (#33). No sign indicates an increase in Chl-a, negative sign indicates a decrease in Chl-a from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D3. Changes in total phosphorus (TP) in-lake water quality from select model scenarios for the Main Lake Mid-South AA (0705-0050).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	12	12	(0.2)	12	(0.1)	12	(0.0)	11	-(5.7)	11	-(9.1)	10	-(14.9)
1999	10	10	(0.1)	10	(0.0)	10	-(0.2)	10	-(2.6)	10	-(4.1)	10	-(6.8)
2000	13	13	(0.1)	13	(0.0)	13	-(0.2)	12	-(6.8)	12	-(10.2)	11	-(17.1)
2001	11	11	-(0.1)	11	(0.1)	11	-(0.2)	11	-(4.0)	11	-(6.1)	10	-(10.1)
2002	13	13	(0.0)	13	(0.0)	13	-(0.2)	12	-(7.2)	12	-(10.8)	11	-(17.9)
2003	13	13	(0.0)	13	(0.1)	13	-(0.2)	12	-(5.7)	11	-(8.5)	11	-(14.3)
2004	14	14	(0.1)	14	(0.0)	14	-(0.2)	13	-(8.0)	12	-(12.0)	11	-(20.0)
2005	12	12	-(0.1)	12	(0.1)	12	-(0.3)	11	-(5.2)	11	-(7.8)	10	-(13.1)
2006	17	17	(0.2)	17	-(0.1)	17	-(0.2)	15	-(9.9)	15	-(14.8)	13	-(24.7)
2007	11	11	-(0.2)	11	(0.0)	11	-(0.3)	11	-(4.5)	11	-(6.8)	10	-(11.3)
2008	12	12	-(0.1)	12	(0.0)	11	-(0.3)	11	-(4.7)	11	-(7.0)	10	-(11.7)
2009	11	11	(0.0)	11	(0.0)	11	-(0.3)	11	-(3.9)	11	-(5.9)	10	-(9.9)
2010	11	11	-(0.1)	11	(0.0)	11	-(0.3)	10	-(3.4)	10	-(5.1)	10	-(8.3)
2011	16	16	(0.2)	16	-(0.1)	16	-(0.2)	14	-(9.2)	13	-(13.8)	12	-(22.8)
2012	11	11	(0.0)	11	(0.0)	11	-(0.3)	10	-(3.9)	10	-(5.8)	10	-(9.6)
2013	13	13	(0.3)	13	(0.0)	13	-(0.2)	12	-(6.4)	11	-(9.6)	11	-(16.0)
Average	**12.5**	**12.5**	**(0.0)**	**12.5**	**(0.0)**	**12.4**	**-(0.2)**	**11.7**	**-(5.7)**	**11.3**	**-(8.6)**	**10.6**	**-(14.3)**

[1] Percent change from Base Run (#33). No sign indicates an increase in TP, negative sign indicates a decrease in TP from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D4. Changes in chlorophyll-a (Chl-a) in-lake water quality from select model scenarios for the Main Lake Mid-South AA (0705-0050).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	5	5	(0.0)	5	-(0.2)	5	-(0.2)	5	-(5.3)	5	-(7.7)	4	-(11.1)
1999	5	5	(0.0)	5	(0.0)	5	-(0.2)	4	-(2.2)	4	-(3.5)	4	-(5.9)
2000	5	5	(0.0)	5	(0.0)	5	-(0.2)	5	-(4.5)	5	-(6.7)	5	-(11.2)
2001	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(3.1)	5	-(4.6)	4	-(7.5)
2002	5	5	(0.0)	5	(0.0)	5	-(0.2)	5	-(4.6)	5	-(6.9)	5	-(11.8)
2003	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(4.0)	5	-(6.1)	5	-(10.1)
2004	6	6	-(0.2)	6	(0.0)	6	-(0.4)	5	-(5.7)	5	-(8.8)	5	-(14.5)
2005	5	5	(0.0)	5	(0.0)	5	-(0.2)	5	-(3.2)	5	-(5.2)	5	-(9.3)
2006	6	6	(0.0)	6	(0.0)	6	-(0.2)	6	-(7.4)	6	-(11.1)	5	-(18.5)
2007	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(3.5)	5	-(5.1)	5	-(8.2)
2008	5	5	-(0.2)	5	(0.0)	5	-(0.4)	5	-(3.5)	5	-(5.2)	4	-(8.5)
2009	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(3.3)	5	-(5.0)	4	-(8.5)
2010	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(2.6)	5	-(3.8)	4	-(6.6)
2011	6	6	(0.0)	6	(0.0)	6	-(0.2)	5	-(6.5)	5	-(9.4)	5	-(15.4)
2012	5	5	(0.0)	5	(0.0)	5	-(0.2)	5	-(3.0)	5	-(4.3)	4	-(7.0)
2013	5	5	(0.2)	5	(0.0)	5	-(0.2)	5	-(4.1)	5	-(6.3)	5	-(10.7)
Average	**5.1**	**5.1**	**-(0.1)**	**5.1**	**(0.0)**	**5.1**	**-(0.2)**	**4.9**	**-(4.2)**	**4.8**	**-(6.2)**	**4.5**	**-(10.3)**

[1] Percent change from Base Run (#33). No sign indicates an increase in Chl-a, negative sign indicates a decrease in Chl-a from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D5. Changes in total phosphorus (TP) in-lake water quality from select model scenarios for the Main Lake Mid-North A (0705-0025).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	10	10	-(0.1)	10	(0.2)	10	(0.1)	10	-(5.2)	9	-(8.3)	9	-(13.7)
1999	9	9	(0.1)	9	(0.1)	9	(0.0)	8	-(2.3)	8	-(3.8)	8	-(6.3)
2000	11	11	(0.0)	11	(0.0)	10	-(0.1)	10	-(5.7)	10	-(8.6)	9	-(14.4)
2001	10	10	(0.0)	10	(0.0)	10	-(0.1)	9	-(4.0)	9	-(6.1)	9	-(10.0)
2002	10	10	-(0.1)	10	(0.0)	10	-(0.1)	10	-(5.0)	10	-(7.5)	9	-(12.5)
2003	10	10	-(0.1)	10	(0.0)	10	-(0.1)	10	-(4.4)	9	-(6.6)	9	-(11.1)
2004	11	11	(0.0)	11	(0.1)	11	-(0.1)	11	-(6.4)	10	-(9.6)	10	-(15.9)
2005	10	10	(0.0)	10	(0.1)	10	-(0.1)	9	-(4.9)	9	-(7.5)	9	-(12.5)
2006	13	13	-(0.1)	13	(0.0)	13	-(0.1)	12	-(7.2)	11	-(10.7)	10	-(17.8)
2007	10	10	-(0.1)	10	(0.0)	10	-(0.1)	9	-(4.5)	9	-(6.6)	9	-(11.1)
2008	9	9	-(0.2)	9	(0.0)	9	-(0.1)	9	-(4.3)	9	-(6.4)	8	-(10.6)
2009	9	9	-(0.1)	9	(0.0)	9	-(0.1)	9	-(3.5)	9	-(5.2)	8	-(8.8)
2010	9	9	-(0.1)	9	(0.1)	9	-(0.1)	9	-(2.8)	9	-(4.3)	8	-(7.2)
2011	14	14	(0.0)	14	(0.1)	14	(0.0)	12	-(8.9)	12	-(13.3)	11	-(22.2)
2012	9	9	-(0.1)	9	(0.0)	9	-(0.1)	9	-(3.6)	9	-(5.5)	8	-(9.0)
2013	10	10	-(0.1)	10	(0.0)	10	-(0.1)	10	-(4.8)	10	-(7.2)	9	-(11.9)
Average	**10.2**	**10.2**	**-(0.1)**	**10.2**	**(0.0)**	**10.2**	**-(0.1)**	**9.7**	**-(4.8)**	**9.4**	**-(7.3)**	**8.9**	**-(12.2)**

[1] Percent change from Base Run (#33). No sign indicates an increase in TP, negative sign indicates a decrease in TP from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D6. Changes in chlorophyll-a (Chl-a) in-lake water quality from select model scenarios for the Main Lake Mid-North A (0705-0025).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	4	4	-(0.2)	4	(0.0)	4	(0.0)	4	-(4.6)	4	-(6.9)	4	-(10.3)
1999	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(1.8)	4	-(2.6)	4	-(4.6)
2000	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(4.1)	4	-(6.2)	4	-(10.0)
2001	4	4	(0.0)	4	(0.0)	4	-(0.2)	4	-(2.9)	4	-(4.3)	4	-(6.9)
2002	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(3.6)	4	-(5.2)	4	-(8.7)
2003	5	5	-(0.2)	5	(0.0)	5	(0.0)	4	-(3.3)	4	-(5.1)	4	-(8.6)
2004	5	5	(0.0)	5	(0.0)	5	(0.0)	5	-(4.3)	4	-(6.6)	4	-(11.1)
2005	4	4	-(0.2)	4	(0.0)	4	(0.0)	4	-(4.2)	4	-(6.3)	4	-(10.7)
2006	5	5	-(0.2)	5	(0.0)	5	-(0.2)	5	-(5.2)	5	-(7.8)	5	-(13.2)
2007	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(3.8)	4	-(5.4)	4	-(8.5)
2008	4	4	-(0.2)	4	(0.0)	4	(0.0)	4	-(3.6)	4	-(5.3)	4	-(9.0)
2009	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(2.7)	4	-(3.9)	4	-(6.9)
2010	4	4	-(0.2)	4	(0.0)	4	(0.0)	4	-(2.0)	4	-(3.2)	4	-(5.2)
2011	5	5	-(0.2)	5	(0.0)	5	(0.0)	5	-(5.7)	5	-(8.2)	4	-(13.3)
2012	4	4	-(0.2)	4	(0.0)	4	-(0.2)	4	-(2.7)	4	-(4.0)	4	-(6.4)
2013	4	4	(0.0)	4	(0.2)	4	(0.0)	4	-(3.1)	4	-(4.7)	4	-(7.8)
Average	**4.4**	**4.4**	**-(0.1)**	**4.4**	**(0.0)**	**4.4**	**(0.0)**	**4.2**	**-(3.6)**	**4.1**	**-(5.3)**	**4.0**	**-(8.8)**

[1] Percent change from Base Run (#33). No sign indicates an increase in Chl-a, negative sign indicates a decrease in Chl-a from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D7. Changes in total phosphorus (TP) in-lake water quality from select model scenarios for the Northern End B (0705-0030).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	8	8	-(0.2)	8	(0.2)	8	(0.1)	8	-(6.1)	8	-(9.7)	7	-(16.1)
1999	7	7	(0.1)	7	(0.1)	7	(0.1)	7	-(3.4)	6	-(5.3)	6	-(8.8)
2000	9	9	(0.1)	9	(0.1)	9	(0.0)	8	-(6.7)	8	-(10.3)	7	-(17.2)
2001	8	8	(0.0)	8	(0.0)	8	-(0.1)	8	-(6.1)	7	-(9.1)	7	-(15.0)
2002	9	9	-(0.1)	9	(0.0)	9	-(0.1)	8	-(5.8)	8	-(8.7)	7	-(14.5)
2003	9	9	-(0.1)	9	(0.0)	9	-(0.1)	8	-(5.8)	8	-(8.7)	7	-(14.5)
2004	11	11	-(0.1)	11	(0.0)	11	-(0.1)	10	-(8.9)	10	-(13.2)	9	-(22.0)
2005	8	8	-(0.1)	8	(0.0)	8	-(0.1)	7	-(6.3)	7	-(9.5)	7	-(16.0)
2006	12	12	-(0.2)	12	(0.0)	12	-(0.1)	11	-(8.9)	10	-(13.4)	9	-(22.3)
2007	8	8	(0.0)	8	(0.1)	8	(0.0)	7	-(5.8)	7	-(8.5)	7	-(14.4)
2008	7	7	-(0.3)	7	(0.0)	7	-(0.1)	7	-(5.0)	7	-(7.6)	6	-(13.0)
2009	7	7	(0.0)	7	(0.0)	7	-(0.1)	7	-(4.8)	7	-(7.3)	7	-(12.1)
2010	7	7	-(0.1)	7	(0.0)	7	-(0.1)	7	-(4.4)	7	-(6.7)	7	-(11.1)
2011	23	23	-(0.1)	23	(0.0)	23	(0.0)	19	-(14.7)	18	-(22.1)	14	-(36.8)
2012	7	7	(0.0)	7	(0.0)	7	(0.0)	7	-(4.7)	7	-(7.0)	6	-(11.7)
2013	10	10	(0.0)	10	(0.1)	10	(0.0)	9	-(7.1)	9	-(10.6)	8	-(17.8)
Average	**9.3**	**9.3**	**-(0.1)**	**9.3**	**(0.0)**	**9.3**	**-(0.1)**	**8.6**	**-(6.5)**	**8.3**	**-(9.9)**	**7.6**	**-(16.5)**

[1] Percent change from Base Run (#33). No sign indicates an increase in TP, negative sign indicates a decrease in TP from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Table D8. Changes in chlorophyll-a (Chl-a) in-lake water quality from select model scenarios for the Northern End B (0705-0030).

Run No.	33	35		44		55		34		36		37	
Year	Base	LSC Moved	%[1]	LSC 120%	%	LSC 4.8 lbs/d	%	NPS Red. 20%	%	NPS Red. 30%	%	NPS Red. 50%	%
1998	3	3	-(0.3)	3	(0.0)	3	(0.0)	3	-(6.5)	3	-(9.8)	3	-(13.6)
1999	3	3	(0.0)	3	(0.0)	3	(0.0)	3	-(2.1)	3	-(3.5)	3	-(5.7)
2000	3	3	(0.3)	3	(0.0)	3	(0.0)	3	-(4.9)	3	-(7.6)	3	-(13.1)
2001	3	3	(0.3)	3	(0.0)	3	(0.0)	3	-(4.2)	3	-(6.4)	3	-(10.6)
2002	4	4	(0.0)	4	(0.0)	4	(0.0)	3	-(5.0)	3	-(7.5)	3	-(12.5)
2003	4	4	-(0.3)	4	(0.0)	4	(0.0)	3	-(4.7)	3	-(7.0)	3	-(12.0)
2004	4	4	(0.0)	4	(0.0)	4	(0.0)	4	-(6.4)	4	-(9.8)	4	-(16.2)
2005	3	3	(0.0)	3	(0.0)	3	(0.0)	3	-(6.2)	3	-(9.6)	3	-(17.1)
2006	5	5	(0.0)	5	(0.0)	5	(0.0)	4	-(6.8)	4	-(10.4)	4	-(17.6)
2007	3	3	-(0.3)	3	(0.0)	3	(0.0)	3	-(6.0)	3	-(9.2)	3	-(14.9)
2008	3	3	-(0.3)	3	(0.0)	3	(0.0)	3	-(5.2)	3	-(8.8)	3	-(14.6)
2009	3	3	-(0.3)	3	(0.0)	3	-(0.3)	3	-(4.0)	3	-(5.6)	3	-(9.6)
2010	3	3	-(0.3)	3	(0.0)	3	-(0.3)	3	-(3.3)	3	-(4.7)	3	-(7.7)
2011	5	5	-(0.2)	5	(0.0)	5	(0.0)	5	-(10.1)	4	-(14.4)	4	-(22.9)
2012	3	3	(0.0)	3	(0.0)	3	(0.0)	3	-(3.6)	3	-(5.6)	3	-(9.3)
2013	4	4	-(0.3)	4	(0.0)	4	(0.0)	4	-(5.6)	3	-(8.2)	3	-(13.0)
Average	**3.5**	**3.5**	**-(0.1)**	**3.5**	**(0.0)**	**3.5**	**(0.0)**	**3.3**	**-(5.3)**	**3.2**	**-(8.0)**	**3.0**	**-(13.1)**

[1] Percent change from Base Run (#33). No sign indicates an increase in Chl-a, negative sign indicates a decrease in Chl-a from scenario implementation. Note: Run 36 was the scenario selected as the loading reduction required for the Cayuga Lake TMDL.

Appendix E. Lake Source Cooling (LSC) Facility

In 1994, Cornell University proposed the installation of a lake source cooling (LSC) facility as an alternative to significant replacement and expansion of the university's central campus cooling system. The central campus cooling system contained eight electric chillers, six of which contained ozone depleting chlorofluorocarbons (CFCs) that required replacement with non-ozone depleting alternatives (Cornell 2005). In addition, the system could not meet the increased demand to cool expanded building facilities on campus. The LSC was proposed as an alternative that would allow for decommissioning of the six existing chillers that contained ozone depleting CFCs and also significantly reduce reliance on electricity produced from burning of fossil fuels. It was estimated that electric energy usage for cooling would be reduced by 86% while meeting additional demand using the LSC facility (Cornell 2005).

NYSDEC was declared lead agency in the environmental review process for the LSC facility. Following a voluntary public hearing into the scope of the review, the university and its consultants prepared a draft Environmental Impact Statement (EIS) that was submitted to the NYSDEC and eleven other agencies in the spring of 1997. After the agencies approved the statement for its completeness, there was a sixty-day public review period, followed by a final environmental impact statement that confirmed LSC's status as the best available technology for cooling Cornell in the next century. Construction took place from the spring of 1999 until the summer of 2000 when the new LSC system was commissioned and put in service to cool the campus.

The LSC operates as a closed loop system, pumping cold water from Cayuga Lake to a heat exchanger, where it absorbs some of the heat in water used to cool facilities at Cornell University and Ithaca High School. Deep water of Cayuga Lake is naturally cold (on average around 39° F at the intake pipe located at 250 feet deep; Figure E1). The cold lake water flows through the system, the water absorbs heat from the building facilities and is discharged at a warmer temperature. The discharge point is located on the Southern End of Cayuga Lake, which is naturally more shallow and warmer than the cool water intake.

Although it is a closed loop system with no contaminants or nutrients added to the water withdrawn from the lake, the discharge from the cooling facility contains phosphorus that was in the water when withdrawn from the lake. NYSDEC issued a State Pollutant Discharge Elimination System (SPDES) permit in 2013 to regulate the levels of phosphorus and other substances in the facility's discharge. Specifically, the permit included interim limits for phosphorus. Under the terms of the permit, Cornell University funded a lake monitoring study and developed a water quality model (the Cayuga Lake Model) to characterize and quantify sources and impacts of the phosphorus, with the purpose informing the development of the Cayuga Lake TMDL.

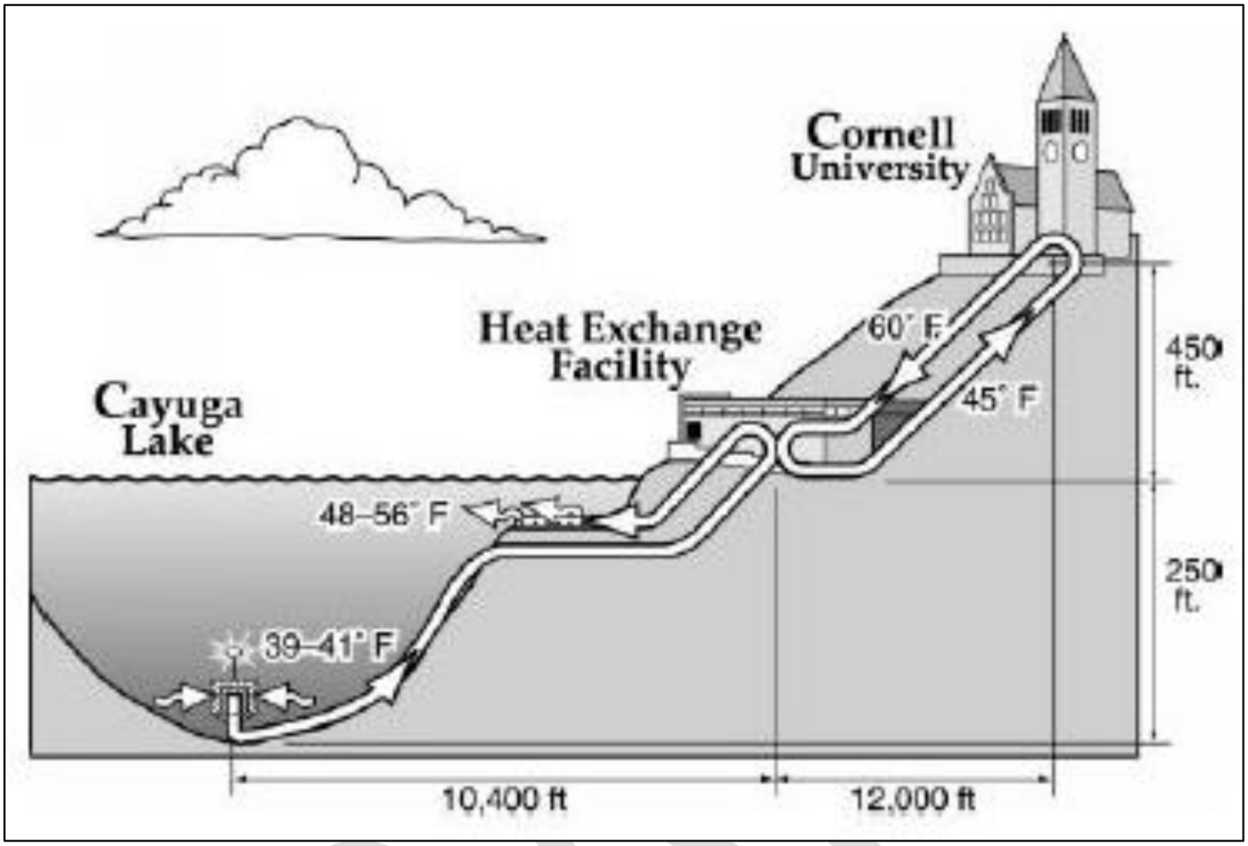


Figure E1. Cornell Lake Source Cooling Facility Diagram (Cornell 2015)

Lake Source Cooling Facility Alternative Outfall Redesign

As a condition of the SPDES permit issued by NYSDEC, Cornell University was required to develop and submit an approvable plan for an outfall redesign study. The objective of this permit condition was to evaluate potential alternative locations for the LSC outfall within the lake's Class AA segment (Main Lake, Mid-South). The final report can be found here: https://www.dec.ny.gov/docs/water_pdf/cornelllscoutfall4.pdf

2020 Cornell Lake Source Cooling Permit

In 2020, Cornell University received a permit modification for the Lake Source Cooling Facility for the existing outfall to the Southern End segment that established the TP effluent limitation of 6.4 lbs/day. For more information please see: https://www.dec.ny.gov/data/IF/SPDES/NY0244741/Permit.IndSPDES.NY0244741.2020-06-01.Modification_x.pdf.

Appendix F. SPDES Facilities in the Cayuga Watershed

Table F1. Concentrated Animal Feeding Operations (CAFO) Environmental Conservation Law (ECL) General Permits within the Cayuga Lake Watershed. There are not Clean Water Act CAFO permits within the Cayuga Lake watershed.

SPDES ID	CAFO Size	PWL ID
NYA00E263	LARGE	0705-0050
NYA00E417	LARGE	0705-0050
NYA00E124	LARGE	0705-0025
NYA00E449	MEDIUM	0705-0040
NYA00E420	LARGE	0705-0050
NYA00E422	LARGE	0705-0040
NYA00E042	LARGE	0705-0050
NYA00E272	MEDIUM	0705-0050
NYA00E273	MEDIUM	0705-0050
NYA00E038	LARGE	0705-0050
NYA00E009	LARGE	0705-0050
NYA00E008	LARGE	0705-0025
NYA00E031	LARGE	0705-0050
NYA00E071	MEDIUM	0705-0050
NYA00E012	MEDIUM	0705-0050
NYA00E007	LARGE	0705-0025
NYA00E123	LARGE	0705-0025
NYA00E411	MEDIUM	0705-0050
NYA00E457	MEDIUM	0705-0040
NYA00E412	MEDIUM	0705-0040
NYA00E416	LARGE	0705-0040
NYA00E269	MEDIUM	0705-0050
NYA00E055	LARGE	0705-0040
NYA00E121	LARGE	0705-0050
NYA00E255	MEDIUM	0705-0040
NYA00E311	LARGE	0705-0040
NYA00E312	MEDIUM	0705-0050
NYA00E440	LARGE	0705-0050
NYA00E323	MEDIUM	0705-0050
NYA00E056	MEDIUM	0705-0050
NYA00E325	MEDIUM	0705-0050
NYA00E484	MEDIUM	0705-0025
NYA00E469	MEDIUM	0705-0025

Table F2. Municipal Separate Stormwater Systems (MS4s) General Permits within the Cayuga Lake Watershed.

PWL ID	
0705-0040	0705-0050
SPDES ID	
NYR20A134	NYR20A134
NYR20A220	NYR20A214
NYR20A151	NYR20A222
NYR20A283	NYR20A283
NYR20A182	NYR20A182
NYR20A231	NYR20A231
NYR20A254	NYR20A254

Table F3. Individual, Municipal and Private/Commercial/Institution (PCI) Permits within the Cayuga Lake watershed. Permit class 01= , 02=

SPDES ID	Permit Class	PWL ID	Discharge Type
NY0023566	04	0705-0025	Surface
NY0025241	07	0705-0025	Surface
NY0024228	07	0705-0025	Surface
NY0002933	01	0705-0040	Surface
NY0244261	01	0705-0040	Surface
NY0231878	01	0705-0040	Surface
NY0157635	02	0705-0040	Surface
NY0156019	02	0705-0040	Ground
NY0232424	02	0705-0040	Surface
NY0151980	02	0705-0040	Ground
NY0156817	02	0705-0040	Ground
NY0233064	02	0705-0040	Ground
NY0156183	02	0705-0040	Ground
NY0262536	02	0705-0040	Surface
NY0155004	02	0705-0040	Ground
NY0155292	02	0705-0040	Surface
NY0284076	04	0705-0040	**
NY0034657	04	0705-0040	Surface
NY0077607	04	0705-0040	Surface
NY0107077	04	0705-0040	Surface
NY0262773	04	0705-0040	Ground
NY0026638	05	0705-0040	Surface
NY0110752	07	0705-0040	Ground
NY0029190	07	0705-0040	Surface
NY0110493	07	0705-0040	Surface
NY0155730	09	0705-0040	Surface
NY0104710	09	0705-0040	Surface
NY0213632	09	0705-0040	Surface

SPDES ID	Permit Class	PWL ID	Discharge Type
NY0284238		0705-0040	**
NY0213730	01	0705-0050	Surface
NY0244741	01	0705-0050	Surface
NY0101290	01	0705-0050	Surface
NY0244236	01	0705-0050	Surface
NY0261823	02	0705-0050	Ground
NY0102296	02	0705-0050	**
NY0098451	02	0705-0050	Ground
NY0155501	02	0705-0050	Surface
NY0213446	02	0705-0050	Surface
NY0232980	02	0705-0050	Surface
NY0213802	02	0705-0050	Ground
NY0153851	02	0705-0050	Surface
NY0213365	02	0705-0050	Surface
NY0001333	03	0705-0050	Surface
NY0231240	04	0705-0050	Ground
NY0020958	05	0705-0050	Surface
NY0024902	07	0705-0050	Surface
NY0029289	07	0705-0050	Surface
NY0023558	07	0705-0050	Surface
NY0098302	09	0705-0050	Surface
NY0262269	09	0705-0050	Surface
NY0284190	09	0705-0050	**
NY0231916	09	0705-0050	Surface
NY0284068		0705-0050	**

Appendix G.

Implementation Resources

Funding Programs

The New York State Environmental Protection Fund (EPF) was created by the state legislation in 1993 and is financed primarily through a dedicated portion of real estate transfer taxes. The EPF is a source of funding for capital projects that protect the environment and enhance communities. Several NYS agencies administer the funds and award grants, including NYSDAM, NYSDEC, and Department of State. The following two grant programs are supported by the EPF to award funding to implementation projects to address nonpoint source pollution:

The Agricultural Nonpoint Source Abatement and Control Program (ANSACP), administered by the NYSDAM and the Soil and Water Conservation Committee, is a competitive financial assistance program for projects led by the Soil and Water Conservation Districts that involves planning, designing, and implementing priority BMPs. It also provides cost-share funding to farmers to implement BMPs. For more information visit https://www.nys-soilandwater.org/aem/nonpoint.html.

The Water Quality Improvement Program (WQIP), administered by the NYSDEC Division of Water, is a competitive reimbursement program for projects that reduce impacted runoff, improve water quality, and restore habitat. Eligible applicants include municipalities, municipal corporations, and Soil and Water Conservation Districts.

The Environmental Facilities Corporation (EFC) is a public benefit corporation which provides financial and technical assistance, primarily to municipalities through low-cost financing for water quality infrastructure projects. EFC's core funding programs are the Clean Water State Revolving Fund and the Drinking Water State Revolving Fund. EFC administers both loan and grant programs, including the Green Innovation Grant Program (GIGP), Engineering Planning Grant Program (EPG), Water Infrastructure Improvement Act (WIIA), and the Septic System Replacement Program. For more information about the programs and application process visit https://www.efc.ny.gov/.

Wastewater Infrastructure Engineering Planning Grant is available to municipalities with median household income equal to or less than $65,000 according to the United States Census 2015 American Community Survey or equal to or less than $85,000 for Long Island, NYC and Mid-Hudson Regional Economic Development Council (REDC) regions. Priority is usually given to smaller grants to support initial engineering reports and plans for wastewater treatment repairs and upgrades that are necessary for municipalities to successfully submit a complete application for grants and low interest financing.

Clean Water Infrastructure Act (CWIA) Septic Program funds county-sponsored and administered household septic repair grants. This program entails repair and/or replacement of failing household septic systems in hot-spot areas of priority watersheds. Grants are channeled through participating counties.

CWIA Inter-Municipal Grant Program funds municipalities, municipal corporations, as well as soil and water conservation districts for wastewater treatment plant construction, retrofit of outdated stormwater management facilities, as well as installation of municipal sanitary sewer infrastructure.

CWIA Source Water Protection Land Acquisition Grant Program funds municipalities, municipal corporations, soil and water conservation districts, as well as not-for-profits (e.g., land trusts) for land acquisition projects providing source water protection. This program is administered as an important new part of the Water Quality Improvement Project program.

Consolidated Animal Feeding Operation Waste Storage and Transfer Program Grants fund soil and water conservation districts to implement comprehensive nutrient management plans through the completion of agricultural waste storage and transfer systems on larger livestock farms.

Water Infrastructure Improvement Act Grants funds municipalities to perform capital projects to upgrade or repair wastewater treatments plants and to abate combined sewer overflows, including projects to install heightened nutrient treatment systems.

Green Innovation Grant Program provides municipalities, state agencies, private entities, as well as soil and water conservation districts with funds to install transformative green stormwater infrastructure.

There may be other opportunities to implement management actions through watershed programs (https://www.dec.ny.gov/chemical/110140.html) or other funding mechanisms.

Agricultural Environmental Management (AEM) Program

The New York State AEM Program (www.nys-soilandwater.org) supports farmers in their efforts to protect water quality and conserve natural resources, while enhancing farm viability in a voluntary, incentive-based approach. Started as an initiative in 1996 and codified in New York State law in 2000, New York's AEM Program helps farmers protect water quality by providing a framework to assess environmental stewardship and coordinate technical and financial assistance from the Federal, State, and local levels to address priority water quality issues[1] on the farm. The driving principle of AEM's success is a farm specific focus, coordinated through locally developed watershed based strategic plans and an educational component to elicit landowner confidence.

Why AEM was Developed

AEM was created to provide a consistent format to address environmental challenges facing NY agriculture in a manner that enhances long-term economic viability. AEM is the "umbrella program" that efficiently identifies environmental concerns through a comprehensive environmental assessment and matches these identified needs with existing financial opportunities for farms. With over 30,000 farms making up New York State's diverse agricultural industry, the coordination and screening function of AEM is critical to targeting technical and financial assistance to the issues and farms that will yield the greatest environmental benefit. AEM also is the cornerstone of the agricultural component of New York's Nonpoint Source Water Quality Management Strategy[2] developed to meet requirements of the Clean Water Act, The Safe Drinking Water Act, and the Coastal Zone Management Act.

Who is Involved in the AEM Program?

AEM is administered by the NYS Soil & Water Conservation Committee (SWCC) housed at the NYS Department of Agriculture and Markets. Key partners advising the SWCC that helped develop and have endorsed AEM include the NYS Departments of Environmental Conservation, Health, and State; the US Department of Agriculture (USDA) – Natural Resources Conservation Service (NRCS); Cornell University, SUNY College of Environmental Science and Forestry; Cornell Cooperative Extension, and New York State's County Soil and Water Conservation Districts. AEM is administered and implemented at the local level through County Soil and Water Conservation Districts who engage local partners such as Cooperative Extension, NRCS, AEM Certified Planners, Certified Crop Advisors, USDA Technical Service Providers, and agri-businesses to work as a team to develop, implement, and evaluate conservation plans on farms. New York's Conservation Districts have also formed coalitions of Districts that include partner agencies, universities, and organizations working together on the needs of our major watersheds to promote cooperation, coordination, and the sharing/pooling of resources in advancing AEM.

[1] Priority water quality issues are based on available resource assessments, including the NYS Priority Waterbodies List, the federal 303(d) list, Total Maximum Daily Loads, Source Water Assessment, NRCS Rapid Watershed Assessment, AEM Watershed Site Evaluation, locally identified water quality priorities, county-level AEM Strategic Plan, and county-level Annual Action Plan.

[2] The NYS NPS Water Quality Management Strategy was last updated by DEC in 2000. It had four priority issues with agriculture as one of them and it was to be addressed through AEM.

Such coalitions include the Upper Susquehanna Coalition, the Finger Lakes-Lake Ontario Watershed Protection Alliance, Mohawk River Coalition, and others throughout the State.

How the AEM Program Works

The AEM process at the County level begins with the Conservation District forming an AEM Steering Committee made up of local resource professionals[3] and stakeholders. These committees often include local representatives of USDA NRCS and Farm Service Agency (FSA), Cornell Cooperative Extension, County Health and/or Planning Departments, Farm Bureau, environmental organizations, watershed associations, agri-business, farmers, and interested citizens. The committee is tasked with developing an AEM Strategic Plan meeting minimum criteria developed by the State Soil & Water Conservation Committee to guide the local AEM effort for the upcoming five years.

AEM's on-farm framework is designed to be highly interactive and utilizes resource professionals and peers working with the farmer throughout the process. This framework and associated process increases farmer awareness of the impact farm activities have on the environment and by design; it encourages farmer participation and seeks behavioral change, which are important overall goals. AEM utilizes the NRCS Planning Process that is enhanced through a five-tiered framework:

Tier 1 – A resource professional collects farm contact information; inventories farm infrastructure, land use, and livestock; determines the farm's future plans; informs the farmer of their watershed(s) and watershed concerns and identifies potential environmental concerns and opportunities (www.nys-soilandwater.org/aem/techtools.html).

Tier 2 – A resource professional utilizes pertinent worksheets to conduct an on farm environmental assessment based on watershed concerns and the potential concerns and opportunities identified in Tier 1. Tier 2 documents existing environmental stewardship, provides an educational opportunity with the farmer, and verifies environmental concerns or flags issues for further evaluation during the planning process (www.nys-soilandwater.org/aem/techtools.html).

Tier 3 – Priority farms develop a conservation plan with assistance from a team of resource professionals addressing priority resource concerns derived from the integration of the farm's business objectives, watershed concerns (as derived through the local AEM Strategic Plan), condition of the involved resources (water, soil, air, plants, and animals) and environmental risk. The level and extent of planning considers farm resources and is often progressive (on-going and seeking continual improvement through behavioral change). All BMPs must be planned according to NRCS Conservation Practice Standards and Cornell University Guidelines. Plan components addressing nutrient management must be completed by an AEM or NRCS Certified Planner. Conservation planning activities are supported through the AEM Base Program or competitive

[3] The term "resource professional" refers to a person who is qualified – based on the general expertise of their employer, or on their job description – to provide conservation assistance to farmers. In New York's public sector, resource professionals are typically employed by federal agencies (e.g. USDA), state agencies (e.g. NYSDEC or NYSDAM), local Soil and Water Conservation Districts, or Cornell Cooperative Extension. Private sector resource professionals in New York may include AEM Certified Planners and Professional Engineers.

State and Federal programs such as NYS Agricultural Nonpoint Source Abatement and Control Program (ANSACP) or USDA's Environmental Quality Incentives Program (EQIP).

Tier 4 – Implementation of priority BMPs in priority conservation plans. All BMPs must meet NRCS Conservation Practice Standards and Cornell University Guidelines. BMPs designated as engineering must be designed by Professional Engineers licensed in NYS. Technical assistance for BMP design and installation oversight is supported by the AEM Base Program, or by successful application to NYS ANSACP or USDA Farm Bill Programs.

Tier 5 – Conduct evaluations of conservation plans and implemented BMPs to ensure effectiveness in protecting the environment, proper operation and maintenance, and needed support to the farmer to safeguard public investment. Conservation plan updates according to current standards and guidelines assure continuous improvement and address concerns resulting from expanding operations and management changes. Tier 5 activities are supported through the AEM Base Program. Through various AEM tools, evaluation can take place at the BMP, farm, watershed and/or county levels.

Programs Associated with AEM

State and Federal programs are coordinated through AEM to work together to efficiently provide technical and financial assistance to priority farms and priority environmental issues.[4] Both the AEM and EQIP programs require adherence to the same technical standards as CAFOs under permit. NRCS requires producers to have a current CNMP to be eligible for EQIP funds to install livestock waste practices. Only practices required in the CNMP are eligible for EQIP funding. New York State and NRCS also provide funding for the development of CNMPs for producers who do not have them. These programs include:

- **AEM Base Program** – www.nys-soilandwater.org/aem/basefunding.html
- **Agricultural Nonpoint Source Abatement and Control Program (ANSACP)** – www.nys-soilandwater.org/aem/nonpoint.html
- **USDA Farm Bill Programs** –A description of Farm Bill programs available to support New York's farms is in *Section*
- *NYS and Federal Agriculture Program* **Implementation and Targeting**, under the header *USDA Farm Bill Programs*.

Incentives to Participate in the AEM Program

CAFOs (large and medium) are required to participate in AEM. Additionally, there are several incentives for small farm voluntary participation in AEM which include:

[4] Resource professionals work with farmers to prioritize projects that will improve soil and water quality, and have a strong likelihood of being successfully implemented and maintained. This process also results in prioritization of farms in the watershed.

- Free technical assistance to identify and address environmental risks, watershed needs, and farm goals through conservation plans

- Technical assistance to implement conservation plans and practices that can improve farm profitability including, but not limited to: nutrient management, prescribed grazing, cover crops, buffers
- To help maintain and improve farm natural resources for future generations
- Improved consideration when applying for competitive Farm Bill cost share programs
- Eligibility for the NYS ANSACP cost-share program
- Eligibility to participate in NYS Farmland Protection Program
- The desire to be viewed and recognized as an environmental steward. NYS has a program that provides an AEM sign to farms that demonstrate and maintain high levels of environmental stewardship, as well as a Statewide and several County AEM Farmer of the Year Awards
- Discounts for related SWCD services such as Soil Group Worksheets required for Agricultural Tax Assessments
- The desire to be a good neighbor
- Eligibility for the Agricultural Water Quality Revolving Loan Fund - provides low interest loans to farmers to implement BMPs

AEM Tools

To improve the effectiveness of the AEM framework and related conservation programs in addressing priority farms, environmental and pollutant concerns, several tools have been developed by the AEM Partnership. AEM tools include multiple worksheets:

- Manure Storage Screening Tool
- AEM Tool for the Evaluation of Manure Storage Structures
- AEM Tool for the Evaluation of Vegetated Treatment Areas
- AEM Report Card

NYS Concentrated Animal Feeding Operation Program

Following the first Concentrated Animal Feeding Operation (CAFO)[5] general permit issuance in New York in 1999, CAFO operators were required to obtain and comply with state wastewater discharge permits. Thirteen years later, New York has one of the most robust CAFO permitting programs in the nation, providing coverage for 230 large- and over 246 medium-sized CAFO farms (Table G1 below shows the cutoffs between medium and large CAFOs by the type of animal). New York's CAFO program is clear, actively implemented and enforced by DEC, of state-wide

[5] Concentrated Animal Feeding Operation (CAFO) means an Animal Feeding Operation (AFO) that is a point source as defined pursuant to New York Environmental Conservation Law Section 17-0105(16) and is a CAFO. Two or more AFOs under common ownership are considered to be a single AFO for the purposes of determining the number of animals of an operation.

applicability, practical and scientifically supported. New York recognizes the need for farm-specific, technical evaluations by qualified professionals, in the form of Certified Planners and Professional Engineers, to ensure that the farm understands and implements the latest developments in land grant university guidelines, United States Department of Agriculture Natural Resources Conservation Services (NRCS) technical standards and State regulatory requirements.

Since the start of the CAFO permitting program in 1999, New York has required New York Certified Planners to develop Comprehensive Nutrient Management Plans (CNMP) for CAFO farms and Professional Engineers to design and certify NRCS engineering practices on farms. This type of science-based, risk reduction approach to CAFO regulation should be considered the national standard; anything less is inconsistent with the Clean Water Act's "best technology" requirements. The New York CAFO program has persisted in its efforts to afford superior protection of the environment through continued education, enforcement and applied research efforts. These efforts are supported by New York's regulated farms as documented by a very high rate of compliance.

New York's CAFO farms must comply with stringent technical standards designed to afford superior protection of the environment. These technical standards take the form of NRCS conservation practice standards and state regulatory requirements, both of which exceed the minimum requirements set by EPA and NRCS and are tailored to be most effective for New York's conditions based on applied research from Cornell University – New York's land grant university. As such, CAFO farms must use professional engineers in the design and implementation of their waste management and storage structures, must adhere to stringent setbacks for nutrient applications in farmlands adjacent to New York's waters, must control erosion on crop fields and must make nutrient applications in accordance with science-based nutrient management plans. The CAFO program ensures that manure nutrients from medium and large livestock farms are recycled to grow crops rather than allowing those nutrients to reach the waters of New York State. It is these stringent technical standards and the CAFO program's proven rate of implementation and enforcement that protects water quality.

Table G1. New York Medium and Large CAFO Cutoffs by Number of Animals

Animal Type	**Number of Animals to be Considered a Medium CAFO**	**Number of Animals to be Considered a Large CAFO**
Mature Dairy Cows	200-699	700
Veal Calves	300-999	1,000
Cattle	300-999	1,000
Swine (55 lbs or more)	750-2,499	2,500
Swine (less than 55 lbs)	3,000-9,999	10,000
Horses	150-499	500
Sheep or Lambs	3,000-9,999	10,000

Turkeys	16,500-54,999	55,000
Laying Hens or Broilers (if using liquid manure handling system)	9,000-29,999	30,000
Chickens (if using other than a liquid manure handling system)	37,500-124,999	125,000
Laying Hens (if using other than a liquid manure handling system)	25,000-81,999	82,000
Ducks (if using other than a liquid manure handling system)	10,000-29,999	30,000
Ducks (if using a liquid manure handling system)	1,500-4,999	5,000
Note: Refer to New York's CAFO General Permits for more detailed definitions of medium and large CAFOs. Visit DEC's CAFO Program webpage (http://www.dec.ny.gov/permits/6285.html) to download copies of New York's permits.		

Comprehensive Nutrient Management Program

Key among the permit's requirements is the development, implementation and maintenance of a Comprehensive Nutrient Management Plan (CNMP), developed by an AEM Planner certified through New York's AEM Program and conforming to the technical standards established by the USDA Natural Resources Conservation Service (NRCS). Successfully becoming a Certified Crop Advisor (CCA) in the Northeast Region is the first step in obtaining certification to develop CNMPs for farm operations needing the CAFO permit in New York State.

The Certified Crop Advisor program is one of the certification programs of the American Society of Agronomy (ASA) and is also governed by ARCPACS, a federation of certifying boards in agriculture, biology, earth and environmental sciences. The CCA program in New York is administered by the Northeast Regional CCA Board, which covers New York and all of the New England states. Nationally, a Certified Crop Advisor is recognized by the Natural Resources Conservation Service as an individual who is qualified to service certain NRCS programs as a Technical Service Provider (TSP). In New York, a CCA is eligible to seek further certification, as an AEM Planner, to develop CNMPs required as a condition of the CAFO permit.

Technical Standards for CAFO Best Management Practices

All CNMPs developed in New York must be prepared in accordance with "NRCS Conservation Practice Standard No. 312" and all applicable technical standards where invoked by NY312 (NY590, NY748, etc.). All New York NRCS technical standards meet and/or exceed the minimum national requirements as they are tailored to the stringent regulatory requirements and environmental sensitivities found in New York. The New York technical standards are reviewed and revised by a Standards Committee consisting of technical staff from NRCS, DEC, the New York State Department of Agriculture and Markets, Cornell University and others. These revisions, under the oversight of the Standards Committee, ensure implementation of state-of-the-art best management practices on New York farms.

CAFO Program Highlights in the Cayuga Basin

Since 1999, New York State has exceeded the federal minimum CAFO requirements by permitting over 450 medium-sized CAFO farms. New York requires erosion control to "Tolerable Soil Loss" on all CAFO crop land, a technical requirement of NRCS NY590 for nutrient management.

No direct discharge of process water is permitted, except during extreme precipitation events.

In 2009, New York State once again exceeded the federal CAFO requirements through the issuance of the State Environmental Conservation Law (ECL) permit for CAFO-sized farms. The CAFO program provides permit coverage to CAFOs, whether or not there is a discharge to surface waters. There are 32 ECL CAFO permits in the Cayuga watershed (Table 1, Appendix F). The federal CAFO program would require permits for only a small number of the New York permitted CAFOs. There are no Clean Water Act CAFO permits in the Cayuga Lake watershed.

High level of regulatory oversight

CAFO permitted farms in NYS are required to utilize the AEM framework and tools when developing their Comprehensive Nutrient Management Plan with their AEM Certified Planner. The advantages of this requirement include:

- Prioritizing CAFOs for ANSACP and Farm Bill financial assistance programs
- Identifying resource needs and opportunities beyond CAFO Permit requirements leading to advanced environmental stewardship
- The educational component of AEM helps farmers better understand the impact their farm has on the environment
- Opening the door for improved teamwork between certified planners, agency resource professionals, and agri-business in developing, implementing, and evaluating conservation plans and BMPs leading to advanced environmental stewardship and continuous improvement

NYS and Federal Agriculture Program Implementation and Targeting

The proposed management practice implementation levels in this TMDL reflect practical implementation considering the type of agriculture conducted in New York, climate, social/economic and relevant site-specific details, and an estimate of state and federal funding realistically expected to be available through 2025. Funding comes from State sources, a large part of which is awarded in contracts[6] on a competitive basis and through various USDA – NRCS programs.

[6] State staff reviews projects before costs are fully reimbursed.

State and Federal programs are coordinated through the Agricultural Environmental Management Program to work together to efficiently provide technical and financial assistance to priority farms and priority environmental issues. These programs include:

New York State AEM Base Program

The AEM Base Program (www.nys-soilandwater.org/aem/basefunding.html) is noncompetitive technical assistance funding to New York's Soil and Water Conservation Districts to inventory and assess farms in priority watersheds then plan and design best management practices (BMP), and evaluate effectiveness of planning and BMPs on priority farms based on County AEM Strategic Plans and Annual Action Plans. This program provides the financial resources to prepare and prioritize farms for participation in various State and USDA Farm Bill programs that provide financial assistance to implement BMPs; then supports the farmer as they manage, operate and maintain their plan and the associated BMPs.

AEM Base also supports outreach, educational, and data management activities needed to assure successful planning, BMP implementation, maintenance, and continuous improvement.

NYS Soil and Water Conservation Committee (SWCC) staff members perform a quantitative review of AEM Base deliverables such as assessments, conservation plans, BMP designs, and evaluations. These reviews advance quality, adherence to policies and participation requirements on an annual basis.

AEM Base requires Conservation Districts to complete an AEM Self-Evaluation Report Card to assess impacts and progress toward watershed goals.

County AEM Strategic Plans and TMDL Alignment

The findings and recommendations in this TMDL align with the AEM Strategic Plan mission for Cayuga, Tompkins, and Seneca Counties (the three largest counties in the Cayuga Lake watershed).

Cayuga County's mission statement:

"*It is the mission of the Cayuga County AEM Program to assist the County's agricultural producers with improving environmental stewardship and the economic viability of their farm, through a voluntary method of assessment, planning, implementation, evaluation along with educational and outreach forums to address natural resource concerns involving the improvement of water quality, reduction of soil erosion, creation of wildlife habitat, and the long term sustainability of existing recreational activities while promoting a diverse economy of industry, commerce, tourism and agriculture***."**

AEM Strategic Plans identify local water resource concerns specific to sub-watersheds where agriculture is a primary cause and assess the likelihood of improvement. A general summary of environmental concerns for Cayuga Lake outlined in those plans are: (1) phosphorus loading into surface waters, (2) silt and sediment loading in surface water, (3) nutrient and pathogen loading in surface and ground water, and (4) streambank erosion.

The findings in this TMDL can be used by SWCDs to adjust future AEM plans and focus on different areas of the Cayuga Lake watershed identified as concerns here. For example, load allocations for multiple sub-watersheds (Section #) show that phosphorus and soluble P are concerns throughout the basin and not limited to those identified in Table # (from Cayuga County Soil and Water Conservation District's 2015-2020 AEM Strategic Plan). Expanding resources and outreach to newly identified areas provide opportunities for large gains in water quality improvement.

Example AEM Strategic Plan goals and objectives to improve environmental quality for the Cayuga watershed are: (1) update existing AEM plans and expand AEM participants, (2) secure funding to implement site specific BMPs to address priority natural resource concerns, (3) expand cover crop participation, (4) develop and/or update Tier 3A or Tier 3B plans to lay out implementation schedules to address concerns on individual farms, and (5) complete Tier V Worksheets on 5 farms annually to ensure the farms are maintaining their installed practices.

Again, these objectives are consistent with the approach taken improve water quality in this TMDL. As agricultural loading was found to be the dominant source of P and represents the largest controllable source, AEM expansion on non-permitted farms needs to be a priority of Cayuga Lake stakeholders to meet suggested load allocations.

Agricultural BMPs listed subsequently in this TMDL are example practices that in many cases are already being utilized by SWCDs through AEM and CAFO permit requirements. This TMDL has identified TP and SRP as priority pollutants to Cayuga Lake (on the sub watershed level) and provides example best management practices to reduce soluble P losses from the watershed (Section 7.2 and Table 31). These findings, with current and expanded AEM efforts will provide a roadmap to effectively, efficiently improve Cayuga Lake water quality.

Summary of Areas of Concern, Tributary Sub-Watersheds Where Agriculture is a Primary Cause				
Parameter	Location	Use Affected	Primary Cause	Potential for Improvement
Sediment	Fall Creek Cayuga Inlet Sixmile Creek Yawger Creek Cascadilla Creek	Fishing, fish propagation, water supply	Streambank erosion, Agriculture, Urban runoff	Moderate. Requires field investigations to identify causes and contributing factors. In some areas only viable solution may be riparian greenbelt to allow natural meanders. Requires watershed –wide commitment to land use and riparian zone management
Phosphorus	Salmon Creek	Water clarity, aesthetics	Agriculture	Moderate
Nitrate	Great Gully Paines Brook Salmon Creek Mack Br Williams Cr Indian Creek	Potential water supply	Agriculture	Unknown. Highly dependent on mix of agriculture and practices in watershed.
Pesticides	Salmon Creek, Paines Brook, Yawger Creek (other locations not surveyed)	Presently, none detected over limits of concern. Could affect drinking water use.	Agriculture	Highly dependent on mix of agriculture and practices in watershed.
Sediment	Mouths of tributaries, particularly in the southern portion of the lake	Aesthetics (water clarity and enhanced habitat for macrophytes) Drinking water	Streambank erosion, agriculture, urban erosion	Difficult. Requires watershed-wide commitment to land use and riparian zone management

AEM Base Program accomplishments in the Cayuga Lake Watershed over the 2011-2016 interval are summarized in Table G2.

TableG2. AEM Base Program Funded Deliverables for Farms in the Cayuga Lake Watershed from 2011 – 2019.

AEM Base Year	**AEM Tier 1**	**AEM Tier 2**	**AEM Tier 3A**	**AEM Tier 3B**	**AEM Tier 4**	**AEM Tier 5A**	**AEM Tier 5B**	**AEM Base Funds**
2011	20	19	12	13	0	0	$118,774.00	2011
2012	28	27	16	8	1	9	$128,180.00	2012
2013	17	13	13	3	8	20	$145,186.00	2013
2014	34	23	6	8	0	4	$169,532.50	2014
2015	23	17	5	6	6	0	$117,866.83	2015
2016	21	31	5	2	0	8	$137,037.48	2016
2017	31	22	4	4	0	4	$139,262.32	2017
2018	26	35	29	3	0	8	$206,563.72	2018
2019	38	25	7	13	0	2	$148,428.00	2019
Grand Total	238	212	97	60	15	55	$1,310,830.85	Grand Total

Note, these data only include funds reimbursed to Cayuga, Seneca, and Tompkins SWCDs for their technical assistance via the AEM Base Program. Additional projects for agricultural environmental management were completed via other local, State, and federal funds than those represented here. The farm and completed AEM Tier numbers are solely from within the Cayuga Lake Watershed, but the "AEM Base Funds" column of data represents work performed across the entire county.

Targeting within New York's AEM Program

AEM was created to provide a coordinating framework to target the limited technical and financial resources available from all levels of government toward the watersheds, issues, pollutants, farms, practices, and BMPs that are of the greatest concern and where the most significant water quality benefits will occur. To accomplish this task, County Soil and Water Conservation Districts are required to form a county level AEM Steering Committee to develop a Strategic Plan identifying priority water bodies/watersheds, associated water quality impairments, pollutants of concern from agricultural sources, BMPs to address the identified pollutants, and potential sources of technical and financial assistance. Coordination on the strategic plans between Counties is accomplished through the existing major watershed coalitions of Conservation Districts established throughout the State Resources utilized to create AEM Strategic Plans included the State's Priority Waterbodies List (PWL) and Source Water Assessment (SWA), Federal designations such as 303 d watersheds and TMDLs, and locally generated studies and information. Once completed the County AEM Strategic Plan prioritizes all waterbodies/watersheds within the County identifying the impairment associated with agriculture, the priority agriculturally generated pollutants, and the appropriate BMPs generally needed to address the priority pollutants. AEM Base funds are then used to systematically inventory and assess (AEM Tiers 1 & 2) willing farms in order of priority waterbodies/watersheds.

On the farm resource professionals working with farmers utilize the AEM *Tier 1 Questionnaire*, the *Watershed Site Evaluation Worksheet*, and appropriate *Tier 2 Assessment Worksheets* to gather information on the farm's position on the landscape (topography, proximity to waterbodies, soil types, etc.), potential pollution sources, and management practices to determine the lack or presence of an environmental concern, or the need to collect additional information to be analyzed. Armed with this information, decisions can be made by the Conservation District where to rank farms for further technical and financial assistance.

The Agricultural Nonpoint Source Abatement and Control Program (ANSACP) targets projects based on priority farms, pollutants and watersheds. ANSACP proposals must be cost effective with farm commitment to complete and maintain the project. ANSACP projects receive bonus points when in a Federal TMDL designated watershed and if the proposal includes conservation buffers as part of the proposed BMP system.

- **New York State Agricultural Nonpoint Source Abatement and Control Program** (www.nys-soilandwater.org/aem/nonpoint.html) is a competitive financial assistance program available to Conservation Districts that provides funding to plan, design, and implement priority BMPs, as well as cost-share funding to farmers to implement BMPs. Farmers are eligible to receive between 75 and 87.5% of BMP implementation costs depending on their contribution to the project.

- **USDA Farm Bill Programs**

- **Environmental Quality Incentives Program (EQIP)**

- **Conservation Reserve Program (CRP)**[7]

- **Farmable Wetlands Program (FWP)**[8]

- **Conservation Reserve Enhancement Program (CREP)**[9]

- **Conservation Stewardship Program (CSP)**[10]

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[7] Details about the Conservation Reserve Program can be found on the USDA FSA website at: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp.

[8] Details about the Farmable Wetlands Program are on the USDA-Farm Service Agency website at: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=fwp.

[9] Details about the Conservation Reserve Enhancement Program can be found on the USDA-Farm Service Agency website at: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=cep.

[10] Details about the Conservation Stewardship Program are on the USDA NRCS website at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp.

- **Agricultural Management Assistance Program (AMA)** [11]
- **Wetland Reserve Program (WRP)**[12]
- **Debt for Nature Program (DFN)**
- **Grassland Reserve Program (GRP)**[13]
- **Farm and Ranch Lands Protection Program (FRPP)**14

Other Agricultural Best Management Practices

A description of several major Agriculture BMPs, as useful examples understood and practiced in New York State from the Chesapeake Bay Watershed Implementation Plan are described below. Efficiency rates, when provided, are based on the Chesapeake Bay Program "Non-Point Source Best Management Practices and Efficiencies currently used in Scenario Builder" document dated October 27, 2011. The list below is intended for informational purposes only.

Landowners should work their County Soil and Water Conservation District (SWCD), Certified Nutrient Management Planners (CNMP), Watershed Coordinators, and county planning boards to help identify the BMPs best suited for the agricultural activities. The New York State AEM Program (www.nys-soilandwater.org) supports farmers in their efforts to protect water quality and conserve natural resources, while enhancing farm viability in a voluntary, incentive-based approach. Started as an initiative in 1996 and codified in New York State law in 2000, New York's AEM Program helps farmers protect water quality by providing a framework to assess environmental stewardship and coordinate technical and financial assistance from the Federal, State, and local levels to address priority water quality issues[15] on the farm. The driving principle of AEM's success is a farm specific focus, coordinated through locally developed watershed based strategic plans and an educational component to elicit landowner confidence.

BMP: Conservation Tillage

Conservation tillage involves planting and growing crops with minimal soil disturbance. Conservation tillage requires two components: (1) a minimum 30% residue coverage at the time

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[11] Details about the Agricultural Management Assistance program are on the USDA NRCS website at http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ama.

[12] Details about the Wetlands Reserve Program are on the USDA NRCS website at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/wetlands.

[13] Details about the Grassland Reserve Program are on the USDA NRCS website at: http://www.ny.nrcs.usda.gov/programs/grp/index.html.

[14] Details about the Farm and Ranch Lands Protection Program are on the USDA NRCS website at: http://www.ny.nrcs.usda.gov/programs/frpp/index.html.

of planting and (2) a non-inversion tillage method. No-till farming is a form of conservation tillage where the crop is seeded directly into vegetative cover or crop residue. Minimum tillage farming involves some disturbance of the soil but uses tillage equipment and leaves much of the vegetation cover or crop residue on the surface.

The opportunities for success on the proposed acreage for conservation tillage are based on several factors. Although not currently found in widespread use, this practice can be successful on some farms and on better-drained soils. This practice can be adopted on any farm but larger farms can more readily accommodate changes in management because they already have more versatile equipment, and because they are often better positioned financially to purchase specialized equipment. Larger farms also have a greater ability to adopt this practice because they tend to control larger acreages of the better drained valley soil, and in general they have larger acreages and field sizes which are more conducive to using custom operators.

BMP: Continuous No-Till

The same factors limiting conservation tillage (e.g., late spring warm up, wetter soils and capital expenditures for equipment) will limit continuous no-till. The adoption of continuous no-till may not be broadly feasible for New York agriculture, which is predominantly dairy farms with a cropping system and rotation of corn/soybean and alfalfa/grass that is used to supply forages for feed. Some tillage is necessary to return to hay from a row crop. Tillage is also needed to control weed population and pest build-up. It is, however, reasonable to expect that through education and outreach, and by expanding on current practices, some of our better drained soils that will warm and dry more quickly and are more suitable for harvest later in the season could be utilized for continuous no-till.

A system to support farmers who implement these practices is necessary to buffer the economic risks they take in the early years of implementation. Demonstration sites would augment outreach and education efforts to encourage implementation. Equipment cost-share or rental options, yield/performance insurance or guarantees, and incentive payments would stimulate long term use and adoption.

BMP: Cereal and Commodity Cover Crops

Cereal cover crops reduce erosion and nutrients leaching to groundwater or volatilizing by maintaining a vegetative cover on cropland and holding nutrients within the root zone. This practice involves planting and growing, but not harvesting, cereal crops with minimal soil disturbance. The crop is seeded directly into vegetative cover or crop residue and captures nitrogen in its tissue as it grows. When the cover crop is plowed down in spring, trapped nitrogen is released and used by the following crop. Two challenges associated with this practice include difficulty in establishing the crop because of early frost and difficulty in plowing under a heavy crop. Crops capable of nutrient removal include rye, wheat, barley, and to a much lesser extent, oats.

Commodity cover crops differ from cereal cover crops because they may be harvested for grain, hay or silage and they may receive nutrient applications, but only after March 1 of the spring following their establishment. The intent of this practice is to modify normal small grain production practices by eliminating fall and winter fertilization so that crops function similarly to cover crops by scavenging available soil nitrogen for part of their growing cycle. This practice can encourage planting of more acreage of cereal grains by providing farmers with the flexibility of planting an inexpensive crop in the fall and delaying the decision to either kill or harvest the crop based on crop prices, silage needs or weather conditions.

Because fertilizer may be applied in the spring, commody crop efficiencies may be reduced. The same planting date criteria apply as specified under cereal cover crops.

In 2018, NYSDEC and NYSDAM developed the Eastern Finger Lakes Cover Crop Implementation project to increase land area utilizing cover crops in the region. To further unify the efforts to reduce erosion and protect water quality in the Finger Lakes, NYSDEC has agreed to provide funding through the New York State EPF to support utilizing NYS Soil & Water Conservation Districts to implement cover crops focusing first on non-animal agricultural operations within the Eastern Finger Lakes watershed region. The Eastern Finger Lakes watershed region is defined as the watershed areas of Cayuga, Owasco, Skaneateles, and Otisco Lakes. The Soil & Water Conservation Districts are the best partner to implement cover crops at the local level. This project provided $300,000 to the above watersheds over the 2018-2020 period.

BMP: Conservation Plans – Field and Pasture Erosion Control Practices

Farm conservation plans are a combination of agronomic, management and engineered practices that protect and improve soil productivity and water quality and prevent natural resource deterioration on a farm. Soil conservation plans are comprehensive plans that meet USDA-NRCS criteria. Soil conservation plans help control erosion by modifying operational or structural practices. Operational practices include crop rotations, tillage practices, or cover crops and may change from year to year. Structural practices are longer-term and include, but are not limited to, grass waterways in areas with concentrated flow, terraces, diversions, sediment basins and drop structures. In New York, "Conservation Plans" are completed through NYSDAM's AEM program on all farms participating at the Tier 3 level and as part of CNMPs. Through AEM Base Program funding, county SWCDs will work with farms in the watershed to progressively plan their farms to achieve the Tier 3 level, and beyond to Tier 4 implementation and Tier 5 plan and BMP evaluation and updates. Given projected AEM base funding levels for planning, the many associated incentives and the requirement for Tier 3 planning in order for farms to be eligible for State grant funding for BMP implementation,

BMP: Comprehensive Nutrient Management Plans

Comprehensive Nutrient Management Plans (CNMPs) optimize nutrient use to minimize nutrient loss while maintaining yield. These plans attempt to maximize use of on-farm nutrients such as manure and cover crops and minimize nutrient imports such as purchased fertilizer. Comprehensive Nutrient Management BMPs are developed by certified planners in New York. Certified planners come from both the public and private sector. In order to sustain nutrient reductions, technical support for plan development, continued plan implementation and regular updates are necessary.

BMP: Buffers (Agriculture)

Besides nutrient reduction value, buffers contribute to habitat improvement. Buffer designs based upon “variable source area” hydrology, which incorporate an analysis of field slopes, drainage patterns and concentrated points of entry at the streambank, are priority projects because they maximize water quality benefits. NYSDAM’s Soil and Water Conservation Committee (SWCC) Agricultural Non-point Source Abatement and Control Grants Program scoring system gives added priority to buffers.

Agricultural Riparian Forest Buffers are linear wooded areas, usually accompanied by shrubs and other vegetation, that are adjacent to rivers, streams and shorelines. Forest buffers help filter nutrients, sediments and other pollutants from runoff as well as remove nutrients from groundwater. This practice meets some resistance by farmers because of the loss of cropland, added expense of tree planting, maintenance and potential to shade crops. A graded approach that transitions from trees at the water’s edge to shrubs near the crops provides maximum benefits while reducing farmer concerns of shading.

Agricultural Riparian Grass Buffers are linear strips of grass or other non-woody vegetation maintained between the edge of fields and streams or rivers that help filter nutrients and sediment and improve habitat. Credit is given for riparian grass buffers in the model when the recommended buffer width is the same as riparian forests buffers (35ft minimum). This practice is similar to stream protection in pastures (see below). This practice has tremendous potential and would be more widely used if it were eligible for CREP funding on more than just cropland and if the grass grown on the buffer could be cut and utilized. A “natural regeneration” buffer that could ultimately revert to forest also has tremendous potential to reduce nutrient and sediment loss.

BMP: Land Retirement

Agricultural land retirement takes marginal and highly erosive cropland out of production by establishing permanent vegetative cover such as shrubs, grasses and trees. Land retired and planted with trees is reported under the “Tree Planting” BMP. Wetland construction could also be considered a form of land retirement. USDA NRCS Programs such as CRP, CREP and Wildlife Habitat Incentives Program (WHIP) provide incentives for retirement. Some agricultural land is also going out of production as farms cease to operate.

BMP: Tree Planting

The Tree Planting BMP, or forestation (converting agricultural land to forest), includes tree planting on agricultural lands, except those used to establish riparian forest buffers, which is a separate practice. The tree planting practice targets highly erodible lands and critical resource areas.

Programs exist at the federal, state, and local levels to support tree planting and reforestation in the region. The NRCS provides cost share assistance though its CRP and WHIP programs. DEC encourages planting trees and shrubs by providing nursery service to supply low cost, quality stock that is readily available to the public. The nursery program has been an integral part of forest stewardship on public and private lands since its inception in 1902. Also, every Soil and Water

Conservation District has a seedling program for conservation cover and reforestation to private landowners.

BMP: Non-Urban Stream Restoration

A collection of site specific engineering techniques are used to stabilize an eroding streambank and channel. For more information see NYSDEC Non-Point Source Program BMP catalogue (https://www.dec.ny.gov/chemical/96777.html)

BMP: Best Management Practices that Specifically Treat Pasture

This BMP combines all buffer types, cow exclusion practices, and prescribed grazing to address both agricultural sustainability and community needs in relation to stream bank erosion, habitat improvement and flooding. It is anticipated that education and outreach through the AEM program combined with cost-share and incentive payment programs such as CRP, CREP, EQIP, Grazing Lands Conservation Initiative, and state funding, will result in a very high level of BMP implementation to treat pasture and degraded riparian pasture acres.

BMP: Stream Access Control with Fencing

Direct contact of pastured livestock with surface water results in manure deposition, streambank erosion, re-suspension of streambed sediments and nutrients, and aquatic habitat degradation. Stream access also affects herd health by exposure to water borne pathogens and risk of hoof problems. Stream access control with fencing involves excluding a strip of land with fencing along the stream corridor to provide protection from livestock. The fenced areas may be planted with trees or grass, or left to natural plant succession, and can be of various widths (recommended minimum of 35 feet from top-of-bank to fence line). However, the stream access control with fencing BMP is applied specifically to the degraded riparian pasture area when the buffer zone is between 10 and 35 feet between top of stream bank and fence line. The implementation of stream fencing provides stream access control for livestock but does not necessarily exclude animals from entering the stream if incorporating limited and stabilized in-stream crossing or watering facilities. By reducing constant stress on streambanks from hooves, cattle exclusion is also a very important practice for stabilizing stream banks.

Alternative Watering Facility – This practice requires the use of alternative drinking water troughs or tanks away from streams. The source of water supplied to the facilities can be from any source including pipelines, spring developments, water wells, and ponds. To be effective, this practice should also include shade away from streams for livestock. To be successful, the practice should show reduced livestock manure deposition in and near streams and move heavy traffic areas surrounding water sources to more upland locations.

BMP: Prescribed Grazing/Precision Intensive Rotational Grazing

The *Prescribed Grazing* system objective is to manage forage availability by reducing the time livestock spend grazing on a paddock. Reducing grazing time improves the uniformity of manure and urine deposition over the pasture. The cattle's urine can be taken up by grass, thus lowering ammonia emissions. Prescribed grazing also helps to prevent soil erosion, reduce surface runoff and improve forage cover, while utilizing animal manures. Livestock overgrazing and direct access to surface water are also reduced. Specific practices include exterior and interior fencing, laneway development or improvement, pasture seeding or improvement, watering systems (well, pond, spring development, pipelines, water troughs), and brush management. Prescribed grazing brings added benefits because some of the grazing practices are associated with other practices, such as livestock exclusion from streams and riparian buffers. A major barrier to overcome with this practice is that switching to grazing can be a major change in operational management.

Prescribed Grazing can be applied to pastures intersected by streams or upland pastures outside of the degraded stream corridor (10-35 feet width from top of bank). The modeled benefits of prescribed grazing practices can be applied to pasture acres in association with or without alternative watering facilities. They can also be applied in conjunction with or without stream access control.

Additional grazing initiatives in New York are currently being supported through the SWCC Agricultural Non-point Source Abatement and Control Grants Program, NYS Ecosystem Based Management, and the National Fish and Wildlife Foundation.

BMP: Animal Waste Management Systems

These important practices are designed for proper handling, storage, and utilization of wastes generated from confined animal operations. They include a means of collecting, scraping or washing wastes and contaminated runoff from confinement areas into appropriately designed waste storage structures. Waste storage structures are typically made of concrete and require continued operation and maintenance, making them a significant cost item. Controlling runoff from roofs, feedlots and "loafing" areas are an integral part of these systems (See, *BMP: Barnyard Runoff Control Practices and Loafing Lots*, below). Scraping or flushing manure more frequently can reduce ammonia emissions from barns and animal confinement areas, as would manure transfer systems that separate feces from urine. Covered manure storage also emits less ammonia. Failure to properly collect and store generated manure may result in losses of liquid manure to surface water and nutrient leachate to groundwater. For dry manure, contact with precipitation or wet soils under stockpiles can result in nutrient leaching.

BMP: Barnyard Runoff Control Practices and Loafing Lots

These practices may be installed as part of a total animal waste management system or as a stand-alone practice, particularly on smaller operations. Barnyard runoff control practices include diversions, rainwater gutters, and similar practices. The rotational loafing lot practice, by proximity, is grouped with barnyard control practices and are defined as the stabilization of areas frequently and intensively used by people, animals or vehicles by establishing vegetative cover, surfacing with suitable materials, and/or installing needed structures.

BMP: Wetland Restoration (Agriculture)

Agricultural wetland restoration activities re-establish natural hydrologic conditions that existed prior to installing subsurface or surface drainage. Projects may restore, create or enhance a wetland. Restored wetlands may be any wetland type including forested, scrub-shrub or emergent marsh.

BMP: Precision Feed Management on Dairy Farms

Nutrient management planning on dairy farms, with a focus on nutrient source reduction, is vital for farm economic sustainability and water quality improvement. Previous studies at Cornell University have reported that 60 to 80% of nitrogen and phosphorus imported onto dairy farms remains after accounting for all nutrients that leave. Long-term and sustainable nutrient reduction will only occur by reducing nutrient imbalances i.e., decreasing imports and/or increasing exports. As two-thirds or more of the imported nutrients to dairy farms come in purchased feed, significant reductions in nutrient imports can be accomplished with changes in ration and crop management. Several studies have demonstrated, and it is widely accepted that precision feed management can reduce manure nutrient excretions, including volatilized ammonia, an important atmospheric pollutant.

New York State has a track record of implementing Precision Feed Management (PFM)[16] [17] [18] on dairy farms in the Delaware River Basin since 2000 and the Susquehanna River Basin since 2005.

Cornell Cooperative Extension and Cornell University have developed software tool applications to aid in generating implementation of PFM on farms and to assist in the quantification of economic and environmental impact.

BMP: Mortality Composting

Composting provides an inexpensive alternative for disposal of all dead animals, butcher wastes and other biological residuals. Mortality composters involve composting routine mortality in a designed, on-farm facility, with subsequent land application of the compost. This prevents the necessity to bury dead animals that could result in nutrient leachate or rendering of dead animals for processing into animal feeds or incineration. Mortality composting can be, and is applied, to various species including poultry, swine and dairy cows.

In addition to water quality benefits, mortality composting benefits both human and animal health. The temperatures achieved during composting will kill or greatly reduce most pathogens, reduce the risk of disease transmission, prevent nuisances such as flies, vermin and scavenging animals, and combat odors resulting from the anaerobic breakdown of proteins. Properly composted material is environmentally safe and a valuable soil amendment for growing certain crops.

The pollution reductions associated with mortality composting is calculated using a set of equations incorporating the average mortality weight, nitrogen and phosphorus composition,

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[16] Cerosaletti, P.E., D.G. Fox, and L.E. Chase. 2004. Phosphorus reduction through precision feeding of dairy cattle. J. Dairy Sci. 87:2314-2323

[17] Ghebremichael, L.T., P.E. Cerosaletti, T.L. Veith, C.A. Rotz, J.M.Hamlett, W.J. Gburek. 2007. Economic and Phosphorus-Related Effects of Precision Feeding and Forage Management at a Farm Scale. J. Dairy Sci. 90:3700-3715.

[18] Cerosaletti, P.E., 2008. Phosphorus reduction through precision feeding implementation project phase I; Final technical report. Available at: http://cornellpfm.org/technicalReports.htm. Accessed November 9, 2010.

percent mortality, the number of animals each year and an effectiveness estimate. Mortality is not consistent; it increases with animal weight. To account for this, average mortality weight is within the 70th weight percentile. The average nutrient composition, percent mortality and number of animals each year is dependent on each animal type.

Resource Guide for NYS Farm Owners and Operators

The *2011-2012 Resource Guide for New York State Farm Owners and Operators* was created by the Environmental Finance Center at Syracuse University, with support from USDA Rural Development. The guide is intended to help NYS farmers and agricultural Technical Service Providers identify available funding programs and other resources available to them. The guide identifies federal, state, and local funding resources by the name of the funding program, the source agency or organization, and the source agency's contact information, as well as eligible applicants, funding cycles, program description, and other relevant information.

The full *Resource Guide* is available for download on the Environmental Finance Center website at http://efc.syracusecoe.org/efc/sub.html?skuvar=7.

Other Considerations for Agriculture Sector

CAFO farm expansion or farm expansion above CAFO requirements are required to be accompanied by the addition of appropriate land base prior to additional animals being brought on. New York has an abundant land base available to handle any potential additional expansions for CAFO size farms (https://www.dec.ny.gov/permits/6285.html).

Research

New York is actively engaged in new research to improve the best management practices and technical standards for the agriculture sector. New York is considering several practices that may be better at reducing nutrient or sediment loads to waters. These areas of current research include:

- Groundwater Guidance Revisions and Pilot Program
- Variable Source Area Hydrology - Enhanced P index standard using VSA hydrology[19]
- Mass Balance for Agriculture

Groundwater Guidance Revisions and Pilot Implementation Program

Drinking water well contamination issues related to manure management occur in certain areas of New York State. "Karst" is the term used for areas associated with carbonate bedrock (limestone or dolomite), where cracks, fractures and other channel irregularities are present. Karst conditions deteriorate over time due to flowing water which creates sinkholes, depressions in the land surface, disappearing streams, etc. These conditions provide a direct connection between surface and groundwater. This type of landscape and geology allows water to rapidly flow into (or out of) bedrock with little or no filtration. In such areas where groundwater is under the influence of

[19] Hydrologically Sensitive Areas: Variable Source Area Hydrology Implications for Water Quality Risk Assessment by M.Todd Walter, Michael F. Walter, Erin S. Brooks, Tammo S. Steenhuis, Jan Boll, Kirk Weiler

surface water, recharge waters influenced by residential, commercial, industrial, wildlife, or agricultural activities may also generate a contaminant risk to surface and groundwater supplies. Protection of groundwater resources requires additional measures in these areas. DEC is currently working with Cornell University, USDA-NRCS and NYSDAM to develop guidance and a pilot program for farmers and planners to evaluate land conditions in karst areas and implement appropriate best management practices.

Variable Source Area Hydrology

A cost effective and meaningful watershed approach also relies on a firm understanding of how each watershed functions in relation to its hydrological characteristics, drainage patterns, topography, land cover, land uses and misuses, precipitation events and other parameters. Targeting implementation sites using a "Variable Source Area" (VSA) hydrology concept may further increase success. Details of the VSA concept can be found at this Cornell University website: http://soilandwater.bee.cornell.edu/Research/VSA/extension.html.

This BMP focuses on the concept that a relatively small portion of the watershed influences a majority of runoff exiting in a watershed. By implementing practices in these areas, substantial water quality improvements can be accomplished in a more cost-effective manner.

Mass Balance for Agriculture

Source control relies on understanding a farm's nutrient budget. Mass balance analysis (difference between nutrients entering the farm through feed, fertilizer, fixation etc. and the amount leaving the farm through sales of milk, meat, animals, crops, manure etc.) can determine excess nutrients based on nutrient inputs and outputs. Mass balancing information is useful because it:

- Provides important baseline information for planning and implementation projects;
- Prioritizes practices where excess nutrients are documented;
- Has outreach potential by showing nutrient loading to farmers in a more understandable format;
- Demonstrates economic and yield benefits that should attract greater farmer participation;
- Can be used to develop a mass balance for a watershed; and
- Can be used as a tool for documentation if nutrient trading is initiated.

Climate Change

Climate change is an important consideration when selecting management actions for implementation. There is still uncertainty in the understanding of BMP responses to climate change conditions that may influence best management practice efficiencies and effectiveness. More research is needed to understand which BMPs will retain their effectiveness at removing nutrient and sediment pollution under changing climate conditions, as well as which BMPs will be able to physically withstand changing conditions expected to occur because of climate change.

Where possible, selection of BMPs should be aligned with existing climate resiliency plans and strategies (e.g., floodplain management programs, fisheries/habitat restoration programs, or hazard mitigation programs). When selecting BMPs, it is also important to consider seasonal, inter-annual climate or weather conditions and how they may affect the performance of the BMPs. For example, restoration of wetlands and riparian forest buffers not only filter nutrient and sediment from overland surface flows, but also slow runoff and absorb excessive water during flood events, which are expected to increase in frequency due to climate change. These practices not only reduce disturbance of the riverine environment but also protect valuable agricultural lands from erosion and increase resiliency to droughts.

In New York State, ditches parallel nearly every mile of our roadways and in some watersheds, the length of these conduits is greater than the natural watercourses themselves. Although roadside ditches have long been used to enhance road drainage and safety, traditional management practices have been a significant, but unrecognized contributor to flooding and water pollution, with ditch management practices that often enhance rather than mitigate these problems. The primary objective has been to move water away from local road surfaces as quickly as possible, without evaluating local and downstream impacts. As a result, elevated discharges increase peak stream flows and exacerbate downstream flooding. The rapid, high volumes of flow also carry nutrient-laden sediment, salt and other road contaminants, and even elevated bacteria counts, thus contributing significantly to regional water quantity and quality concerns that can impact biological communities. All of these impacts will be exacerbated by the increased frequency of high intensity storms associated with climate change.

For more information about climate change visit DEC's website:
https://www.dec.ny.gov/energy/44992.html