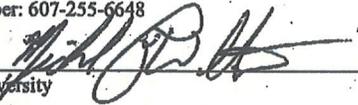
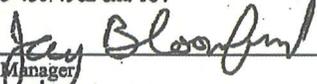


Upstate Freshwater Institute, Inc.

QUALITY ASSURANCE PROJECT PLAN for Phase 1: Monitoring and Modeling Support for a Phosphorus/Eutrophication Model for Cayuga Lake

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Effective: March 15, 2013

Approvals:

Approved:  Cornell University Project Director Phone number: 607-255-6648	Jim Adams Name	3/13/13 Date
Approved:  Cornell University Project Director Phone number: 607-255-2488	Todd Walter Name	3/14/2013 Date
Approved:  UFI Project Manager Phone number: 315-431-4962 ext. 102	Steven Effler Name	March 8 2013 Date
Approved:  UFI Quality Assurance Officer Phone number: 315-431-4962 ext. 104	MaryGail Perkins Name	March 8, 2013 Date
Approved:  NYSDEC Project Manager Phone number: 518-402-8107	Jay Bloomfield Name	March 12, 2013 Date
Approved:  DOW QA officer NYSDEC Division of Water Phone number: (518) 402-8156	Jason Fagel Name	March 12, 2013 Date

Prepared by
Susan O'Donnell, Senior Research Engineer
Upstate Freshwater Inst. Inc., 224 Midler Park Drive
Syracuse, NY 13206
www.upstatefreshwater.org
PH: 315-431-4962 x121 FAX: 315 431-4969

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DISTRIBUTION LIST

An electronic (pdf) copy of this document has been distributed to the following people and locations.

Name	Title	Organization	Address	Phone	email	Electronic/ Hard copy
Steve Beyers	Facilities Engineering	Cornell University	201 Humphreys Service Building, Ithaca, NY 14853	(607) 255-5491	smb75@cornell.edu	electronic
Jim Adams	Director of Utilities	Cornell University	135 Humphreys Service Building, Ithaca, NY 14853	(607) 255-6648	jra4@cornell.edu	electronic
Todd Walter	Cornell Principal Investigator	Cornell University	Cornell University Department of Biological and Environmental Engineering Riley-Robb Hall Ithaca, NY 14853	(607) 255-2488	mtw5@cornell.edu	electronic
Nelson Hairston, Jr.	Senior Associate Dean Frank H.T. Rhodes Professor of Environmental Science	College of Arts and Sciences Cornell University Department of Ecology and Evolutionary Biology	147 Goldwin Smith Hall, Ithaca, NY 14853 Department of Ecology and Evolutionary Biology Cornell University, Ithaca, NY 14853	(607) 255-1097 (607) 254-4231	ngh1@cornell.edu	electronic
Lars Rudstam	Director and Professor	Cornell Biological Field Station Cornell University	900 Shackelton Point Road, Bridgeport NY 13030 205 Bruckner Hall, Ithaca NY 14850	(315) 633- 9243 Ext. 25 (607) 255-1555	rudstam@cornell.edu	electronic
James Watkins	Postdoctoral Associate	Cornell Biological Field Station Cornell University	900 Shackelton Point Road, Bridgeport NY 13030 205 Bruckner Hall, Ithaca NY 14850	(315) 633- 9243	jmw237@cornell.edu	electronic

Name	Title	Organization	Address	Phone	email	Electronic/ Hard copy
Jeff Myers	Project Contact NYSDEC DOW	New York State Department of Environmental Conservation	625 Broadway Albany, NY 12233-3502	(518) 408-8179	jamyers@gw.dec.state.ny.us	electronic
Jay Bloomfield	Project Manager NYSDEC DOW	New York State Department of Environmental Conservation	625 Broadway Albany, NY 12233-3502	(518) 402-8107	jabloomf@gw.dec.state.ny.us	electronic
Jason Fagel	NYSDEC DOW QA Officer	New York State Department of Environmental Conservation	625 Broadway Albany, NY 12233-3502	(518) 402-8156	jrfagel@gw.dec.state.ny.us	electronic
Steven Effler	UFI Primary Project Manager	Upstate Freshwater Institute	224 Midler Park Dr., Syracuse, NY 13206	(315) 431-4962 Ext. 102	sweffler@upstatefreshwater.org	electronic
David Matthews	UFI Primary Assistant Project Manager	Upstate Freshwater Institute	224 Midler Park Dr., Syracuse, NY 13206	(315) 431-4962 Ext. 107	damatthews@upstatefreshwater.org	electronic
MaryGail Perkins	UFI Quality Assurance Officer/ Laboratory Director	Upstate Freshwater Institute	224 Midler Park Dr., Syracuse, NY 13206	(315) 431-4962 Ext. 104	mgperkins@upstatefreshwater.org	electronic, original hard copy
Anthony Prestigacomu	UFI Field Manager and Field QA Officer	Upstate Freshwater Institute	224 Midler Park Dr., Syracuse, NY 13206	(315) 431-4962 Ext. 118	tonyp@upstatefreshwater.org	electronic

Name	Title	Organization	Address	Phone	email	Electronic/ Hard copy
Susan O'Donnell	UFI Senior Research Engineer, modeler	Upstate Freshwater Institute	224 Midler Park Dr., Syracuse, NY 13206	(315) 431-4962 Ext.121	susanod@upstatefreshwater.org	electronic
Martin Auer	Professor Department of Civil and Environmental Engineering	Michigan Technological University	870 Dow Environmental Sciences 1400 Townsend Dr. Houghton, MI 49931	(906) 487-2799	mtauer@mtu.edu	electronic

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Acronyms and Abbreviations

2-D - two dimensional
 c_{660} - beam attenuation coefficient (BAC), surrogate of T_n , light scattering coefficient and TSS
 c_{660-f} - beam attenuation coefficient measured *in situ*
CBFS - Cornell Biological Field Station at Shackelton Point
CCB - continuing calibration blank
CCV - continuing calibration verification
Chl - fluorometric chlorophyll *a*, a trophic metric, proxy for phytoplankton biomass
Chl_f - field fluorometric chlorophyll *a* measured *in situ*
Chl_sp - spectrophotometric chlorophyll *a*
CHWWPT - Cayuga Heights Wastewater Treatment Plant
CLMP - Cayuga Lake Modeling Project
CMP - Cayuga Lake Monitoring Partnership
CoC - chain-of-custody
CSI - Community Science Institute
CU - Cornell University
CUBEE - Cornell University Department of Biology and Environmental Engineering
CUEEB - Cornell University Department of Ecology and Evolutionary Biology
CUGIR - Cornell University Geospatial Information Repository
CWA - Clean Water Act
DEM - digital elevation models
DOC - dissolved organic carbon
DOP - dissolved organic phosphorus
DOW - division of water
DQOs - data quality objectives
DRSi - dissolved reactive silica, a nutrient for diatoms
DUP - duplicate
EL - EcoLogic
ES - event sampling
FF -fixed frequency
FSS - fixed suspended solids
GWLF - General Watershed Loading Function, watershed model
HEC-RAS - Hydraulic Engineering Centers River Analysis System
IAWWTP - Ithaca Area Wastewater Treatment Plant
ICB - initial calibration blank
ICV - initial calibration verification
IPA - individual particle analysis
LCS - laboratory control sample
LOD - level of detection
LOQ - level of quantitation
LSC - lake source cooling
MB - method blank
MTUCEE - Michigan Technological University Department of Civil and Environmental Engineering

MS - matrix spike
MSD - matrix spike duplicate
NCDC - National Climatic Data Center
NOAA - National Oceanic & Atmospheric Administration
NO_x - the sum of nitrate and nitrite, used as a phytoplankton nutrient
NYC - New York City
NYCDEP - New York City Department of Environmental Protection
NYSDEC - New York State Department of Environmental Conservation
NYSDOH - New York State Department of Health
P - phosphorus
PAR - photosynthetically active radiation scalar irradiance
PAVm - projected area per unit volume, minerogenic particles
pH - negative log of the hydrogen ion concentration
PI - principal investigator
PP - particulate phosphorus
PP_o - organic particulate phosphorus, primarily associated with phytoplankton
PP_i - inorganic particulate phosphorus, primarily associated with minerogenic material
POC - particulate organic carbon associated with phytoplankton biomass
QAPP - Quality Assurance Project Plan
QA - quality assurance
QC - quality control
REF - reference sample
RMSE - root mean square error
RPD - relative percent difference
SAX - scanning electron microscopy interfaced with automated image and X-ray analyses
SC - specific conductance
SCM - software configuration management
SD - Secchi disc
SE - synoptic upstream event sampling
SEM - scanning electron microscope
SM - standard methods
SOP - standard operating procedures
SRP - soluble reactive phosphorus
SSURGO - Soil Survey Geographic Database
SWAT - Soil Water Assessment Tool
SWAT-VSA - Soil Water Assessment Tool - Variable Source Area
T - temperature
TOP - total organic phosphorus
Tn - turbidity
Tn_f - field measured turbidity; measured *in situ*
TN - total nitrogen is the sum of the organic and inorganic forms of nitrogen
t-NH₃ - total ammonia, a phytoplankton nutrient
TDN - total dissolved nitrogen
TDP - total dissolved phosphorus
TIP - total inorganic phosphorus

TMDL - total maximum daily load, a limit for material loading set for a constituent by a regulatory agency
TP - total phosphorus
TSS - total suspended solids, a gravimetric measurement of sediments
UFI - Upstate Freshwater Institute
USACE - United States Army Corps of Engineers
USDA - United States Department of Agriculture
USEPA - United States Environmental Protection Agency
USGS - United States Geological Survey
UV₂₅₄ - light attenuation at a wavelength of 254 nm, surrogate of precursors of disinfection by-products
VSLF - variable source loading function
YSI - Yellow Springs Instrumentation
W2 - hydrothermal/transport model CE-QUAL-W2
WWTP - waste water treatment plant

Introduction

The U.S. Environmental Protection Agency (USEPA) has developed the Quality Assurance Project Plan (QAPP) as a tool for project managers to document the type and quantity of data needed to make an environmental decision (USEPA, 2001; USEPA, 2002a; USEPA, 2002b). The QAPP documents the methods for data collection and assessment. USEPA's mandatory Quality System requires development, review, approval, and implementation of a QAPP. The QAPP is a blueprint for how the project will be carried out and integrates all the technical and quality aspects of the project. The USEPA provides guidelines for development of a QAPP, however, due to the large diversity in environmental projects they allow for considerable flexibility in adapting the QAPP requirements to a specific project. The USEPA defined a graded approach to QAPPs and modeling QAPPs in which the level of effort applied in designing a modeling QAPP is a function of the model(s) intended use and the project scope and magnitude (USEPA, 2002a). For example, projects that involve Congressional testimony, or development of new laws and regulations, or support of litigation would require a higher level of quality assurance and planning than a model with non-regulatory priorities (USEPA, 2002a). The USEPA states "Still lower levels of defensibility apply to basic exploratory research requiring extremely fast turn-around, or high flexibility and adaptability" (USEPA, 2002a). The USEPA has defined categories 1- 4 (1 requiring the highest level of effort and 4 the least) to aide those involved in designing a QAPP to determine the level of effort necessary (USEPA, 2006a). The USEPA also acknowledges that projects don't always fit nicely into one of these four categories and further supplied a list of requirements that may apply to specific situations (USEPA, 2006a).

This QAPP has been prepared under the guidance provided in "*EPA Requirements for Quality Assurance Project Plans* (USEPA, 2001), "*Guidance for Quality Assurance Project Plans*" (USEPA, 2002b), and "*Guidance for Quality Assurance Project Plans for Modeling*" (USEPA, 2002a). Further guidance on delineating the QAPP specifications was provided in two supplemental documents obtained from the USEPA web site (USEPA, 2006a). The first document lists the requirements when the project uses secondary data (USEPA, 2002c). The second document lists the requirements when the project involves development and/or application of a research model (USEPA, 2003). The project described in this QAPP is a 2.5 year effort involving data collection, laboratory analysis, data analysis and modeling, that corresponds to the first phase of an overall two-phase program. Review of the guidance documents for developing QAPPs (USEPA, 2001; USEPA, 2002b) and modeling QAPPs (USEPA, 2002a) showed that both types of QAPPs follow the same general outline. For this project, one QAPP has been written to cover the field program, laboratory analyses, data analysis and in-lake modeling. This document was prepared by the Upstate Freshwater Institute (UFI).

Phosphorus (P) plays a critical role in supporting plant growth in aquatic ecosystems. Phosphorus has long been recognized as the most critical nutrient controlling phytoplankton growth in most lakes in the north temperature zone. Degradation in water quality has been widely documented for lakes that have received excessively high inputs of P from man's activities. The southern end of Cayuga Lake has been designated as impaired by the New York State Department of Environmental Conservation (NYSDEC). One feature of the impairment is concentrations of total P (TP) that are deemed high; e.g., summer average TP concentrations that in some years exceed the State guidance value of 20 µg/L. The overall Cayuga Lake study that is specified here will support the development and testing of a water quality modeling system, which will link a

watershed/land use model to a lake phosphorus/eutrophication model. This initiative recognizes the bioavailability issue for external phosphorus inputs; e.g., that only a portion of the total loading is in a form that can support algal growth, and will effectively represent it in the overall program. It is intended that this integrated model will be capable of supporting a phosphorus TMDL analysis, for the targeted area, to be conducted subsequently by the NYSDEC.

The overall Cayuga Lake study initiative has five technical elements:

1. tributary monitoring to support specification of dynamic loading conditions, the bioavailability of the external phosphorus inputs and testing and application of the watershed/land use model.
2. lake monitoring for water quality variables and related biological communities.
3. a two-dimensional hydrothermal/transport model for the lake.
4. watershed/land use modeling that will quantify the dependence of tributary loading on land use and meteorological drivers, and
5. a phosphorus/eutrophication model for the lake.

This work is being conducted in a phased manner, as agreed to by Cornell University (CU) and NYSDEC. Technical elements 1-4 are all part of Phase 1 of this overall two-phased project. Technical element 5 corresponds to Phase 2. Data and limnological analyses from Phase 1 will be reviewed by UFI, Cornell scientists, and NYSDEC technical staff to contribute to the early design(s) of the phosphorus/eutrophication modeling in Phase 2 (Figure 1). Two QAPPs will be developed (Figure 1) over the course of this project, one under Phase 1 to be submitted in early 2013, and one in Phase 2 to be submitted following the completion of Phase 1 (~2015). This portion of the overall Cayuga Lake project is called "*Phase 1: Monitoring and Modeling Support for a Phosphorus/Eutrophication Model for Cayuga Lake*". For convenience throughout the remainder of the QAPP will be simple referred to as the Phase 1 project. This phased Cayuga Lake project will be an integrated and balanced program of monitoring and hydrothermal/transport and watershed/land use modeling that will ultimately produce a robust phosphorus/eutrophication model that will be capable of supporting related management applications, specifically a TMDL analysis.

A. Project Management

A.1. Project Task/Organization

The purpose of this section is to present the organization and lines of communication for the technical aspects of this project. This project includes the following organizations:

- Cornell University (CU)
- New York State Department of Environmental Conservation (NYSDEC)
- Cornell University Department of Biology and Environmental Engineering (CUBEE)
- Cornell University Department of Ecology and Evolutionary Biology (CUEEB)
- Cornell Biological Field Station (CBFS)
- EcoLogic (EL)

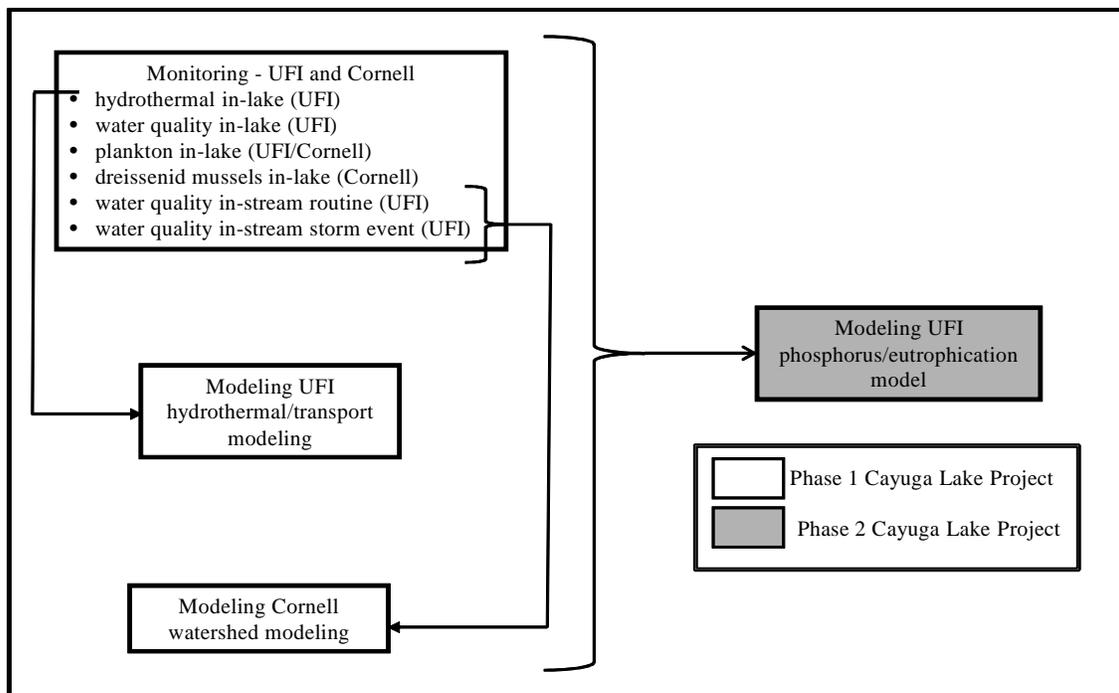


Figure 1 . Overall Project chart showing the division of the Project into Phase 1 and Phase 2.

- Cayuga Lake Monitoring Partnership (CMP)
- Upstate Freshwater Institute (UFI)
- Michigan Technological University Department of Civil and Environmental Engineering (MTUCEE)

The Phase 1 project, is a collaboration between CU and NYSDEC, as illustrated in the organization chart (Figure 2). The Project Managers for CU and NYDEC are Steve Beyers and Jay Bloomfield, respectively. Liz Moran (EL) will support project management for CU. The scientist and engineers responsible for the conduct of the project are from the Upstate Freshwater Institute (UFI) and selected departments of CU (Figure 2). Principal investigator (PI) and overall manager for UFI is Steven Effler; David Matthews will serve as a Co-PI and assistant manager. UFI's QC officer is MaryGail Perkins. She is responsible for overseeing all of UFI's quality control (QC). UFI will be responsible for water quality monitoring of both the tributaries and the lake, hydrothermal/transport modeling (Phase 1), and analyses of collected data as well as data obtained (and accepted) from other sources. UFI will be responsible for co-ordination and oversight and related sampling for phosphorus bioavailability assays to be conducted by Michigan Technological University Department of Civil and Environmental Engineering (MTUCEE; Martin Auer, PI), under a subcontract with UFI. UFI will also be responsible for coordination of the various groups involved in Phase 1 (Figure 2) to generate the single comprehensive Phase 1 final report. Technical stakeholder input, including appropriate supporting data sets, will enter the project primarily from CMP, through NYSDEC.

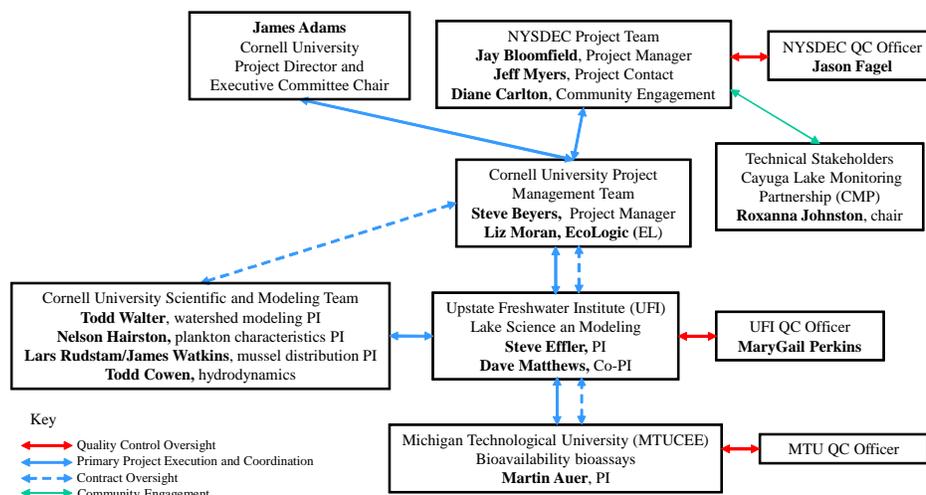


Figure 2 . Organizational chart for the overall Phase 1 project “Phase 1: Monitoring and Modeling Support for a Phosphorus/Eutrophication Model for Cayuga Lake”.

Cornell University scientists will be responsible for watershed/land use modeling (Phase 1; Figure 1 and Figure 2) and lake biology (Figure 2). Todd Walter is the PI for watershed/land use modeling. Nelson Hairston is the PI for phytoplankton and zooplankton monitoring, and Lars Rudstam and James Watkins are the PIs for monitoring of dreissenid mussels. Information, insights and technical opinions will flow freely between UFI and CU staff through the life of the project to enhance resolution of key phenomena and processes and thereby understanding of the ecosystem. Key information and findings will flow between CU and NYSDEC through the respective project managers. Moreover four technical meetings are planned over Phase 1 to promote effective briefing of NYSDEC on findings and to receive technical input from the agency. Project key personnel, their affiliations and their project title/responsibilities are summarized in Table 1. The project organization (Figure 2) features multiple forms of “checks and balances” to assure project quality. Technical oversight and assurances include: (1) the functioning and active communication among the project PIs, (2) inputs from the respective QA officers, and (3) inputs from NYSDEC technical staff.

A.2. Project Definition/Background

The Finger Lakes of central New York (Figure 3 a and b) consist of 11, elongated, north-south oriented lakes. These lakes originated as pre-glacial stream valleys, which were subsequently enlarged and deepened by a combination of ice and sub-glacial meltwater erosion during the Pleistocene (Mullins and Hinchey, 1989; Mullins et al., 1996). The modern Finger Lakes were last structured during the late Wisconsinan by a surge of the Laurentide ice sheet (Lajewski et al., 2003). Calcareous soil occurs widely, particularly in the watersheds of the eastern Finger Lakes (Bloomfield, 1978). European settlement of these watersheds occurred in the late 1700s and early 1800s. The Finger Lakes were the focus of some of the earliest limnological investigations (Birge and Juday, 1914; Birge and Juday, 1921) in the United States. Most of the Finger Lakes are multi-

Table 1: Project Key personnel, affiliations and title/responsibility.

No.	Project Personnel	Affiliation	Title/Responsibility
1	Jay Bloomfield	NYSDEC	Project Manager
2	Jeff Myers	NYSDEC	Project Contact
3	Diane Carlton	NYSDEC	Community Outreach
4	Jason Fagel	NYSDEC	QC Officer
5	Jim Adams	Cornell University	Project Director and Executive Committee Chair
6	Steve Beyers	Cornell University	Project Manager
7	Todd Walter	Cornell University	Watershed Modeling PI
8	Nelson Hairston	Cornell University	Plankton Characterization PI
9	Lars Rudstam	Cornell University	Mussel Distribution PI
10	Jim Watkins	Cornell University	Mussel Distribution Co-PI
11	Todd Cowens	Cornell University	Hydrodynamics PI
12	Steve Effler	UFI	Lake Science and Modeling PI
13	David Mathews	UFI	Lake Science and Modeling Co-PI
14	MaryGail Perkins	UFI	QC Officer
15	Martin Auer	MTUCEE	bioavailability bioassay PI
16	Liz Moran	EcoLogic (EL)	project management support
17	Roxanna Johnston	Cayuga Lake Monitoring Partnership (CMP)	chairman

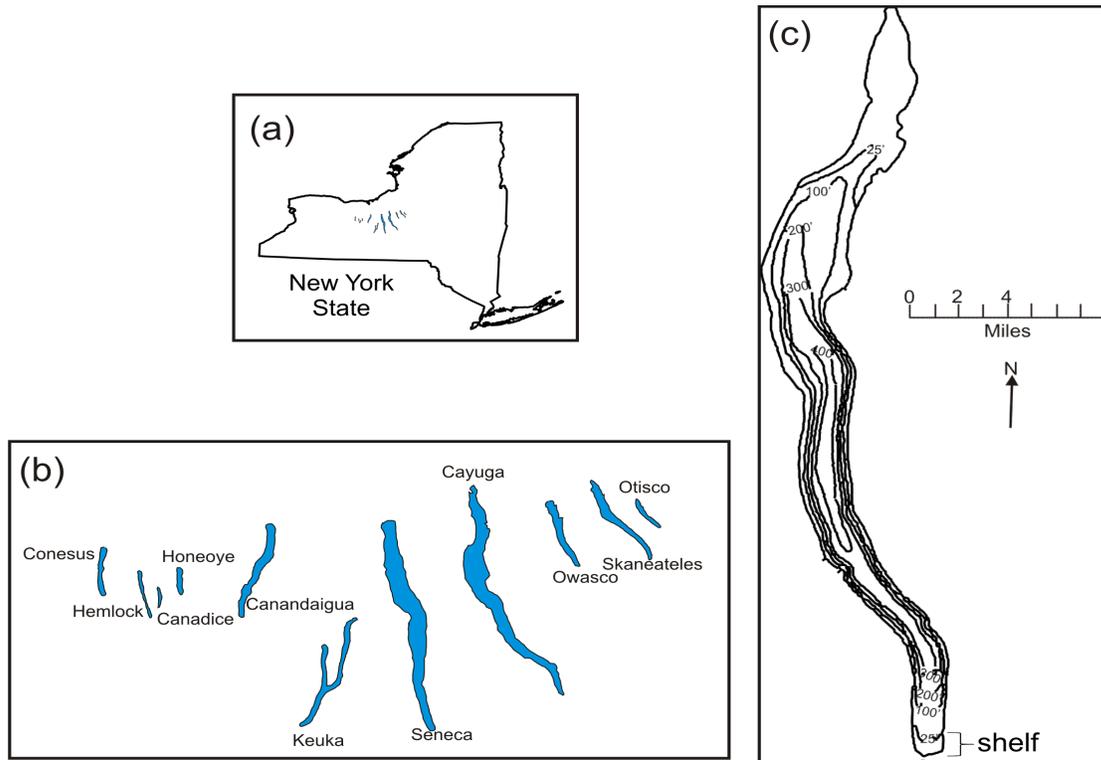


Figure 3 . Map of (a) Finger Lakes location in New York State, (b) Cayuga Lake’s position within the Fingers Lakes System, and (c) a bathymetric map of Cayuga Lake.

use systems. This system of lakes presently supports a substantial tourism industry. The esthetics of these lakes is an important feature of their resource value.

Cayuga Lake (42.69 °N; 76.69 °W) is the fourth easternmost of the New York Finger Lakes (Figure 3b). It has the second largest volume ($9.38 \times 10^9 \cdot \text{m}^3$) and the largest surface area of the Finger Lakes (Schaffner and Oglesby, 1978). The mean and maximum depths are 55 and 133 m, respectively. This alkaline hardwater lake has a warm monomictic stratification regime, stratifying strongly in summer, but only rarely developing complete ice cover (Oglesby, 1978). The hypolimnion remains well oxygenated (Oglesby, 1978). The lake is mesotrophic with an intermediate level of biological productivity (Callinan, 2001). The average retention time of the lake is about 10 years (Schaffner and Oglesby, 1978). Much of the tributary inflow received by the lake enters at the southern end of the lake; e.g., about 40% of the tributary inflow is contributed by Fall Creek and Cayuga Inlet. Parts of the shallow southern end of the lake were bordered by a marsh before it was filled in the early 1900s to support development. Phytoplankton growth in the lake is P limited (Oglesby, 1978). Zebra mussels invaded this lake and other waters of the region

in the early to mid-1990s (New York Sea Grant, 2000). The City of Ithaca (population ~30,000) borders the southern end of the lake and is the largest urban center in the watershed.

Cayuga Lake is an invaluable resource to the region that is used for contact recreation, fishing, navigation, as a water supply by several communities, a source of cooling water, and for disposal of treated municipal wastewater. The shallow southern end of the lake receives effluent from two domestic wastewater treatment facilities (Ithaca Area Waste Water Treatment Plant IAWWTP, Cayuga Heights Waste Water Treatment Plant (CHWWTP) with average discharge flows of 0.3 and 0.05 m³/s, and spent cooling water from a "lake source cooling" (LSC) facility (Cornell University). The limit for the concentration of total phosphorus (TP) of the WWTP effluents had been 0.4 mg/L for IAWWTP and 0.5 for the CHWWTP. Substantial reductions in effluent concentrations and loading of P from the CHWWTP and IAWWTP have been achieved recently from upgrades in treatment.

Since early July 2000, cold water has been withdrawn from a depth of 73 m by the LSC facility and returned to the shallow waters of the southern end of the lake. The discharge flow varies seasonally, from ~0.6 m³/s in the cold months to ~2 m³/s in summer. This represents an artificial form of internal cycling of P. Conditions in the shallow southern end of the lake have generally been considered degraded relative to the pelagic zone (Oglesby, 1978). This shallow southern zone, demarcated as the southernmost 2 km where depths are less than 6 m (Figure 3c), is designated here as the "shelf". There is great concern for water quality on the shelf because of the localized inputs, the proximity to the area's largest population center, and the associated demand for the lake's resources. Government regulators have identified phosphorus (P; cultural eutrophication), "silt/sediment" and bacteria (public health indicator) as water quality issues of concern for the shelf.

Phosphorus has long been recognized as the most critical nutrient controlling phytoplankton growth in most lakes in the north temperature zone. Degradation of water quality has been widely documented for lakes that have received excessively high inputs (loads) of P from man's activities (Wetzel, 2001). One feature of the designated impairment of the southern end of Cayuga Lake is high total P concentrations. In certain years the NYSDEC's guidance value of 20 µg/L (as a summer average in the upper waters) has been exceeded. Elevated concentrations of P may be accompanied by high concentrations of phytoplankton biomass, as measured by the concentration of chlorophyll a (Chl), and diminished water clarity, as measured with a Secchi disc. Contemporary water quality management is usually guided by mathematical models that quantitatively couple the effect of inputs, both external (point and non-point) and internal (within lake cycling), with in-lake concentrations and associated attributes of water quality (Chapra, 1997).

Thermal stratification is an ubiquitous phenomenon in deep lakes in temperate climates and is an important regulator of commonly monitored features of water quality (Wetzel, 2001). Features of stratification and its interplay with water motion mediate the cycling of key constituents, including phosphorus, and metabolic rates. These features are dependent on a number of factors (or drivers), including basin morphometry, setting, hydrology, and meteorological conditions. Substantial year-to-year variations in stratification/mixing occur as a result of natural variations in meteorological conditions. A mechanistic mathematical model is necessary to simulate the thermal stratification/mixing regime, as a function of the various drivers, as part of an overall

initiative to develop a mechanistic lake water quality model, where the water quality feature(s) of interest depends on this regime. Accordingly, a hydrothermal/transport model serves as the underpinning physical framework (a key sub-model) for the overall water quality model. To first set-up and test (separate from the overall water quality model) the hydrothermal/transport model, as adopted in this project's phased approach, is good modeling practice.

It is now well recognized that all forms of phosphorus are not immediately, nor ultimately, available to support algal growth. Dissolved forms of phosphorus are generally more available to support algal growth than particulate forms (Effler et al., 2012). The fraction of particulate phosphorus that is bioavailable can differ widely amongst tributaries and between effluents for different municipal wastewater treatment facilities (Young et al., 1982). Resolution of the bioavailability of the important inputs of phosphorus is important in driving phosphorus/eutrophication models, and in evaluating various sources to guide effective rehabilitation initiatives. Bioavailability bioassays were conducted for both key tributaries and the primary waste discharge to guide the development of loads for a phosphorus/eutrophication model for Onondaga Lake, that was implemented in a phosphorus TMDL analysis.

The bioavailability bioassays for this Cayuga Lake study will be conducted in the same manner as those performed for the Onondaga Lake study (Effler et al., 2012). The bioassays will be conducted using modifications of the Dual Culture Diffusions Apparatus (DCDA) developed by DePinto (1982), as applied to inputs of the Great Lakes (DePinto et al., 1981; Young et al., 1982), the New York City reservoir system (Auer et al., 1998), various receiving waters in Finland (Ekholm and Krogerus, 2003), and Onondaga Lake (Effler et al., 2002; Effler et al., 2012). In these bioassays, phosphorus mobilized from concentrated particulates diffuses across a semi-permeable membrane and is taken up by phosphorus-starved algae (*Selenastrum capricornutum*). The bioassays provide both the fraction of the particulate phosphorus that is bioavailable and a representation of the rate of conversion to a bioavailable form.

Cayuga Lake is the centerpiece of a 2070 km² (800 mi²) watershed, over 90% of which is land area that drains to the lake. The watershed includes 49 villages, towns and cities in seven counties. Nearly 60% of the watershed is in active agriculture, which is considered the primary source of phosphorus to the lake. Haith et al. (2009) estimated that nearly half of the total phosphorus loading to the lake is from agriculture within the watershed. Most of this was attributed to animal wastes applied to corn, hay, and small grain fields. The same study estimated that urban storm runoff and point sources, e.g., waste water treatment plants, combined to account for roughly 20% of the annual phosphorus load.

In this study CUBEE will use watershed modeling to identify major sources of phosphorus and sediments to Cayuga Lake and explore strategies for decreasing loads by modeling different scenarios. For example, some farms practice winter animal waste spreading, which likely contributes a substantial fraction of the agricultural phosphorus load. Using watershed models CUBEE can quantify the fraction of the load linked to this practice and how much of the total phosphorus load can be reduced by diminishing this practice.

A.3. Project/Task Description

A.3.1. Project Description

The Phase 1 project has eight main tasks, that are composed of twenty seven sub-tasks. The eight main tasks are made up of two support tasks, and the four technical tasks listed for Phase 1 in the *Introduction* of this QAPP.

- A. satisfy quality assurance (QA) requirements through the preparation of an approvable QAPP, and execution of the various QA elements stipulated therein.
- B. compile and critically review information specific to the system (Cayuga Lake and its watershed) and the phosphorus/eutrophication issue.
- C. conduct a tributary monitoring program (spring to fall 2013) to support testing of both the watershed/landuse model (Phase 1) and ultimately a lake phosphorus/eutrophication (Phase 2).
- D. conduct a lake monitoring program (spring to fall 2013) to support limnological analyses related to the phosphorus/eutrophication issue, and eventually (subsequent to this project; Phase 2) support testing of a phosphorus/eutrophication model.
- E. set-up and testing of a two-dimensional hydrothermal/transport model.
- F. develop a comprehensive database on the Cayuga Lake watershed relevant to watershed modeling (e.g., land use, soils).
- G. set-up and test a watershed hydrology and water quality modeling system.
- H. prepare Phase 1 final report

The overall Cayuga Lake project (see the *Introduction* of this QAPP for detailed description of both Phase 1 and 2 project phases) goal is to develop and test a phosphorus/eutrophication model (in Phase 2) for Cayuga Lake that addresses the water quality issue and is capable of supporting a phosphorus TMDL analysis for the southern portion of the lake. These tasks receive more treatment in the following *Section (A.3.2.)*.

A.3.2. Project Tasks

This section expands on the eight main tasks presented in *Section A.3.1* and lists the twenty seven sub-tasks under their respective tasks.

- A. satisfy quality assurance (QA) requirements through the preparation of an approvable QAPP, and execution of various QA elements stipulated therein.
- B. compile a critical review of related information.

This task is directed at establishing an existing data set that can directly support Phase 1 hydrothermal/transport model testing, Phase 1 watershed/land use model testing, and possible Phase 2 phosphorus/eutrophication model testing and provide related insights to inform the process. This task acknowledges that all model testing has two components, calibration and validation. The subsequently described field and laboratory programs focus on the collection of

data sets to support testing, an approach agreed upon with NYSDEC. Testing of the models will also rely on already existing data sets for the system. The long-term monitoring database for the southern portion of the lake collected by Cornell University related to the Lake Source Cooling (LSC) facility represents a particularly rich data set for these purposes. Other data sets may be available that can further enhance model testing or provide related insights. All data to be used in this project not collected under the auspice of this QAPP must pass the QA criteria set forth subsequently under *B.9. Non-Direct Measurements*.

C. conduct tributary monitoring

This task has five sub-tasks

1. conduct of fixed frequency monitoring near five (Cayuga Inlet, Six Mile Creek, Fall Creek, Salmon Creek and Taughannock Creek) selected tributary mouths, and maintenance at four sites (Cayuga Inlet, Six Mile Creek, Fall Creek, Salmon Creek) of automated sampling equipment; see Figure 4 for the location of sampling sites.
2. conduct of runoff event monitoring near the mouths of four (Cayuga Inlet, Six Mile Creek, Fall Creek, Salmon Creek) of the same selected tributary mouths, with the aid of automated sampling equipment; location of sampling sites shown in Figure 4.
3. conduct upstream synoptic surveys by monitoring at multiple sites along the length of two selected tributaries (Fall Creek and Salmon Creek; Figure 5 a and b respectively) during runoff events and one dry weather event to support watershed/land use modeling.
4. calculation of loads of selected constituents at the mouths of selected tributaries.
5. conduct assessment of bioavailability of particulate phosphorus in selected tributary mouths (Cayuga Inlet, Six Mile Creek, Fall Creek, Salmon Creek).

Specifics of this primary task (sites, parameters, frequency number of events) are described in *Section B.1.2*.

D. conduct lake monitoring.

This task has five sub-tasks

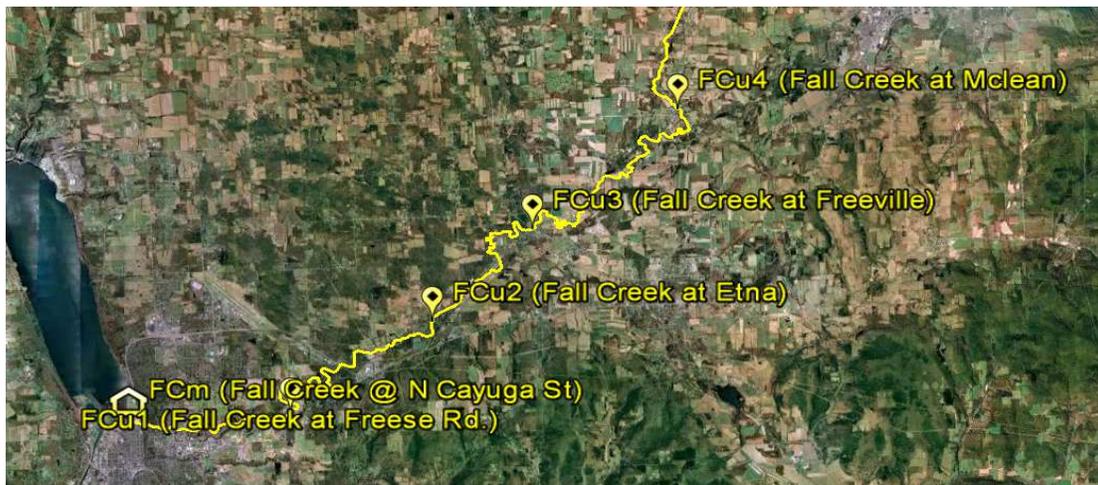
6. lake-wide field measurements of water quality; sampling site locations are presented in Figure 6. Lake sites 1-9 and Cayuga Inlet site (I_L), bounding the lake.
7. lake-wide collection of samples and laboratory water quality analyses at the same sampling sites (Figure 6).
8. lake-wide collection of biological communities; locations of phytoplankton and zooplankton sampling sites (1-9) are presented in Figure 6 and for dreissenids are presented in Figure 7.
9. spatially limited (sites 1, 2 and 3) more frequent sampling (referred to as frequent south sampling through the remainder of the report) for selected field and laboratory water quality parameters are presented in Figure 8. Lake sites 1-9 and I_L .
10. limnological analysis of collected data.

E. set-up and test a two dimensional (2-D; longitudinal segments, vertical layers) hydrothermal/transport model (e.g., Gelda et al., 2009; Gelda et al., 2012).



Figure 4 . Location of tributaries to Cayuga Lake to be monitored in this project. Four tributaries will be monitored by fixed frequency (routine) sampling (FF) and event sampling (ES) to be conducted with auto samplers. These include Cayuga Inlet, Six Mile Creek, Fall Creek and Salmon Creek (sampling locations marked on map with yellow huts). One tributary will be monitored with only FF sampling at the mouth of the creek (Taughannock Creek marked on map with yellow box).

(a)



(b)



Figure 5 . Locations of tributary sampling sites for runoff event synoptic surveys, for (a) Fall Creek, and (b) Salmon Creek.



Figure 6 . Lake-wide monitoring sites for water quality, phytoplankton and zooplankton on Cayuga Lake, 2013 (yellow push pins mark routine monitoring sites).

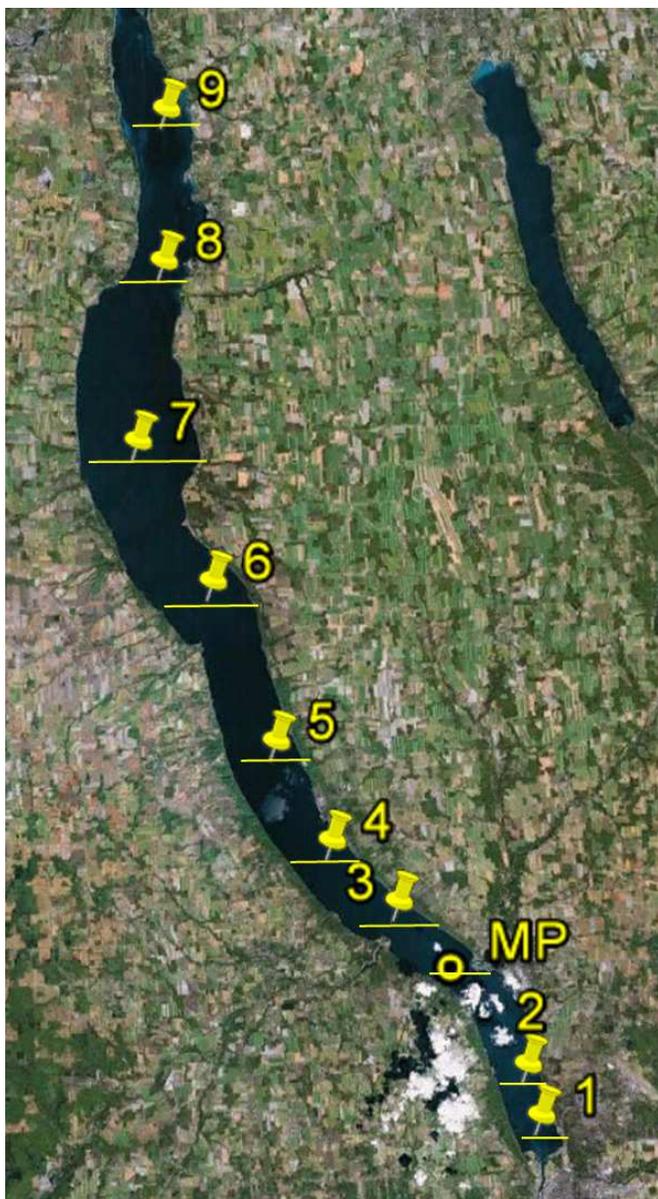


Figure 7 . Lake-wide sites for dreissenid mussel sampling (along lateral transects) on Cayuga Lake, 2013.



Figure 8 . Frequent south monitoring sites for selected parameters on Cayuga Lake, 2013.

The hydrothermal/transport model to be used is the hydrothermal/transport model CE-QUAL-W2 (W2 hereafter). This model was developed for the Army Corp of Engineers. It is a public domain model maintained by S.A. Wells at Portland State University. It is a two-dimensional laterally averaged model with longitudinal segments and vertical layers. Details on this model are discussed in *Section B.7*. Sub-tasks include

11. acquire bathymetric information and set-up segmentation (longitudinal segment bounds, and vertical layers) of the hydrothermal-transport model, according to guidelines of Cole and Wells (2002).
12. acquire hydrothermal/transport model input (driver) information for multiple years and establish appropriate data files.
13. establish inflows and outflows.
14. specify meteorological conditions - air temperature, wind speed and direction, dew point temperature and cloud cover.

15. specify light attenuation coefficient for downwelling irradiance.
16. set-up the hydrothermal/transport model for multiple years.
17. test hydrothermal/transport model performance for multiple years
18. performance will be evaluated graphically by degree of match to observations and statistically according to the root mean-square error (RMSE) statistic (adequate performance, $RMSE \leq 2^\circ C$ for spring to fall interval).
19. use hydrothermal/transport model to support limnological and preliminary mass balance analyses.

F. develop a comprehensive database on the Cayuga Lake watershed relevant to watershed modeling (e.g., land use, soils).

The purpose of this task is to compile a comprehensive database on the Cayuga Lake watershed that will be used as input to the watershed modeling. Data will include all available geospatial information (elevation, roads, land cover, etc.), stream discharge, water quality measurements, published research papers and agency reports, weather observations, land management information, and any other relevant data that comes to our attention. Stream water quality data collected will ultimately be included in this database. CUBEE anticipate using primarily historical data for calibrating the models and the collected data described herein for validation.

G. set-up and test a watershed hydrology and water quality modeling system

Because this project requires estimates of phosphorus and sediment loads to the entire lake but is primarily focused on the southern end of the lake, CUBEE will use a two-tier approach to modeling the Cayuga Lake watershed; each tier constitutes a sub-task.

20. The upper tier will use a model with a relatively coarse resolution to describe the watershed, e.g., the landscape will be segmented into sub-watersheds or units of homogenous land use (e.g., corn fields, residential areas, etc.). This will provide general pollutant loads from all tributaries feeding the lake.
21. The lower tier will use a finer resolution to represent the landscape in the southern end of the lake and any other tributary watersheds the project team decides warrant deeper investigation. The finer resolution modeling will sub-divide the sub-basins according to wetness-classes and any small-scale features that are likely important to pollutant transport (e.g., impoundments, storm water management structures, etc.). This small scale is necessary for targeting likely sources within sub-basins for which management options may be explored as part of Phase 2.

H. Phase 1 project report

22. summarize data patterns and limnological, mass balance and loading analyses
23. summarize the hydrothermal/transport model performance and results
24. summarize watershed model performance and results
25. make recommendations for structural design of TMDL phosphorus/eutrophication model (Phase 2) based on limnological analysis, hydrothermal/transport modeling and watershed modeling
26. propose land management model scenarios

27. make recommendations for additional validation detests)

A.3.3. Work Schedule

The project/work schedule for the overall Phase 1 project is described in the chart below (Table 2), according to the major tasks. This timeline is supported by Cornell University, NYSDEC, and UFI. The timeline is both aggressive and feasible. This timeline gives details for the six main tasks, certain sub-tasks for Phase 1, and the beginning of Phase 2 (phosphorus/eutrophication modeling; Table 2, marked in grey). There are critical features to the Phase 1 tasks in a timing context. There are four important drivers of the presented timing: (1) the monitoring/measurement program must contain the summer months of a single year (June-August), (2) the timing needs to extend from early spring (e.g., late March to early April) to fall (e.g., October to early November) to conform to good limnological (Wetzel, 2001) and modeling (Chapra, 1997) practice, (3) the collected data set will support calibration of the phosphorus/eutrophication model, to be developed and tested in Phase 2, and (4) adequate time is necessary (2014) to allow rigorous limnological analyses, and development of recommendations for a conceptual design for the phosphorus/eutrophication model (that would be implemented in Phase 2).

The development of the watershed models will begin as compilation of the underpinning database is finishing. Tier-two modeling will lag tier-one modeling in order to identify any tributary watersheds beyond the southern end of the lake that the project team may want to include in this effort.

The goal is to submit this QAPP for review in early 2013, and achieve approval by February, allowing for revision(s) following review(s). Certain activities are planned to commence during the QAPP review, that do not involve collection of new data, including (1) acquisition of previously collected related data sets, and (2) acquisition (from NYSDEC), testing and preliminary siting of automated tributary sampling equipment (see "trib program set-up" on chart). Allowance for start-up of the tributary monitoring component before (e.g., early March) the lake monitoring (late March to early April) component is included, as "lags" in lake response to external loading events are common (Chapra, 1997). Both the tributary and lake (water quality and selected biological communities) monitoring components would extend into late October (perhaps early November, depending on weather conditions).

The set-up and testing of the two-dimensional hydrothermal/transport model is planned for start-up in summer in 2013. However, this start date is not as critical as the monitoring components. Limnological and tributary loading analyses will commence near the end of the monitoring components, as these data sets become available. Mass balance analyses, to be conducted with the hydrothermal/transport model, will commence once this model is set-up and preliminarily tested. The report for the Phase 1 work will be prepared over the last three quarters of 2014, and will include (1) a summary of key related findings from previous studies, (2) recommendations for appropriate data sets from previous studies to support validation testing of the phosphorus/eutrophication model in Phase 2, (3) findings from limnological analyses, (4) findings from mass balance analyses, (5) description of the bioavailability of external phosphorus loads, (6) key findings from the watershed modeling and (7) recommendations for the structure (conceptual model) of the phosphorus/eutrophication model to be developed and tested in Phase 2. Four meetings are presently planned with technical staff of NYSDEC in 2013 and 2014 to

Table 2: Project work schedule* for the Phase 1 and limited tasks for the Phase 2 (phosphorus/eutrophication modeling; marked in grey). (● meeting with Cornell, UFI, and NYSDEC technical staff)

No.	Component Description	Phase 1												Phase 2
		2012				2013				2014				2015
		1	2	3	4	1	2	3 ●	4	1 ●	2	3 ●	4 ●	
1	develop QAPP Phase 1				→									
2	review available system information							→	→	→				
3	tributary monitoring program a). routine b). event c). tributary analysis d). loading calculations e). bioavailable particulate P estimates							→	→	→	→			
4	lake monitoring program a). lake monitoring b). limnological analysis c). mass balance analysis							→	→	→	→			
5	setup and testing of 2-D transport/ hydrothermal model								→	→	→			
6	setup and test a watershed model a) develop database b) tier-one model c) tier-two model							→	→	→	→			
7	Phase 1 report - summary of a). data analysis b). hydrothermal model c). watershed model d). recommended validation data set e). recommendations for Phase 2									→	→	→	→	
8	develop QAPP Phase 2													→
9	setup and test a phosphorus/eutrophication model													starts

* project work schedule is for project planning purposes only and is subject to reasonable modifications based on conditions encountered throughout the study. In addition, sampling in 2013 will require approval of the final permit conditions and the QAPP by the NYSDEC in early 2013 so as to allow for the planning and implementation of the sampling program. Delay in approvals will delay the entire sampling and modeling work approximately one year (i.e., until 2014) so that sampling can begin at the start of the spring period and capture the entire one-year continuous sampling period. As some elements of the model represent complexities that extend beyond standard modeling efforts used elsewhere, reasonable delays in completion of modeling steps may be necessary to improve the modeling. The modeling team will work with the NYSDEC to review and revise the modeling timetable as appropriate as modeling progresses

promote collaboration, insights, and agreed upon recommendations for a conceptual model for the phosphorus/eutrophication model for Phase 2.

A.3.4. Project Deliverables

The Phase 1 project deliverables include

1. a QAPP for the 2.5 year project, including monitoring of tributaries and the lake, data analyses, hydrothermal/transport modeling, and watershed/land use modeling.
2. four project meetings with NYSDEC technical staff, UFI, and Cornell University scientific staff to present, discuss and analyze data sets, document progress, discuss and analyze data sets, document processes and phenomena, and implications for recommended design of an appropriate structure for the phosphorus/eutrophication model to be developed and tested in Phase 2 of the overall Cayuga Lake project.
3. electronic versions of collected data sets for distribution to designated parties, identified by Cornell University and NYSDEC, and submitted to the Cornell library system where it will be publicly available and searchable.
4. electronic version of the calibrated hydrothermal/transport model for distribution to designated parties, identified by Cornell University and NYSDEC.
5. electronic versions of the calibrated watershed models for distribution to designated parties, identified by Cornell University and NYSDEC.
6. a final (Phase 1) report, due in the first quarter of 2015, that includes:
 - a. summary of key findings from the monitoring program of 2013.
 - b. summary of key findings from previous studies to support validation testing of the phosphorus/eutrophication model to be developed in (Phase 2).
 - c. recommendations for a conceptual phosphorus/eutrophication model in Phase 2.
 - d. findings from limnological analyses.
 - e. findings from mass balance analyses.
 - f. findings of bioavailability analyses
 - g. summary of key findings from the hydrothermal/transport modeling efforts
 - h. summary of key findings from the watershed modeling efforts
 - i. recommendations for Phase 2, including land management scenarios to model
 - j. recommendations for ways to improve the watershed modeling efforts.

A.4. Quality Objectives and Criteria

The overall quality assurance objective of the UFI field program is to collect samples in an accurate, and representative manner. It also includes tracking, handling and transporting samples to the laboratory, as well as documentation of all sampling and traceability of samples.

The overall quality assurance objective of the UFI laboratory is to develop and implement procedures for laboratory analysis, chain-of-custody (CoCs) and reporting that will provide results that are of known and documented quality. Data Quality Objectives (DQOs) are used as qualitative and quantitative descriptors in interpreting the degree of acceptability or utility of data. The principal DQOs are precision, accuracy, representativeness, comparability, completeness and detection limits. Table 3 summarizes principal DQOs. The same metrics of DQOs will be evaluated as part of the review of secondary data (see *Section B.9. Non-Direct Measurements*). Specific information on quality assurance is contained in all laboratory and field standard operating procedures (SOP)s for new data to be collected as part of this project. Detection and quantitation level limits for laboratory measurements (LOD and LOQs) are determined annually using the previous year's data for each analyte and using methods specified in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). Table 4 contains the LOD and LOQ limits for all water samples to be analyzed by UFI's laboratory in this project (UFI, 2013a). Precision and accuracy for these parameters is discussed in more detail in *Section B.5 Quality Control* and summarized on Tables 38-39. Specifications for the probes on field instrumentation being used by UFI field staff to monitor the lake and tributaries in the Phase 1 project are included in Tables 5 and 6, respectively. These specifications include operating range, accuracy and precision of probes. Field measurements are made as covered in their respective SOPs (*Appendix 1*).

The overall quality assurance objectives for UFI data analysis and modeling is to analyze, model and accurately report data collected and analyzed by the UFI field and laboratory staff. For data analysis and modeling the Data Quality Objectives (DQOs) are qualitative and quantitative statements that

- clarify the intended use of data,
- define the type of data needed to support a decision,
- identify the conditions of collecting the data

The DQOs for input data for the hydrothermal/transport model component are

- data quality for key model inputs (e.g., meteorological) will be representative to support specification of representative driving conditions within the hydrothermal/transport model.
- data quality for hydrothermal/transport model state variable(s) (temperature this case) will be representative to provide a robust test of model performance.
- data quality for both hydrothermal/transport model inputs and state variables will be representative seasonally and for multiple years.
- data collected under previous contracts/projects, to be used in this project, are consistent with and will be subject to those contract's QAPPs, or quality assurance protocols of this project (see protocols for non-direct measurement (*Section B.9*)).

The DQOs for model output (e.g., predictions, simulations) include both qualitative and quantitative perspectives.

- output will be consistent with well accepted limnological paradigms (e.g., Wetzel, 2001)

Table 3: UFI Metrics of Laboratory and Field Data Quality Objectives.

No.	Data Quality Objective (DOQs)	Description	Assessment (calculation)	Comments
1	precision	the degree in which two measurements are in agreement	relative percent difference (RPD)	--
2	accuracy	the degree of agreement between a sample and a true value or an accepted reference	reference samples (REF) matrix spikes (MS) laboratory control samples (LCS) blanks	improved by adherence to sample handling, preservation, and holding times
3	representativeness	degree to which samples accurately and precisely represent environmental conditions	collection of field replicates and calculation of relative percent difference or relative standard deviation	use of field clean sampling techniques; improved by using proper analytical technique and by adherence to sample handling, preservation, and holding times
4	completeness	the number of valid measurements taken from the number of total measurements taken in the entire project	acceptable level 95% or greater	--
5	comparability	confidence with which one set of data can be compared to another	comparison of two data sets	achieved by adherence to routine analytical methods, holding times, consistent detection limits, common units and consistent rule for reporting
6	correctness and reliability of test and calibrations	following contribute to this: human factors, environmental factors, laboratory methods, equipment sampling, traceability	--	achieved by training of qualified personnel, selection of equipment and development of well documented analytical and calibration methods
7	detection and quantitation	LOD - for a specific method and matrix; minimum concentration an analyte can be determined to be significantly different from a blank LOQ - concentration level above which values are associated with a high degree of confidence	Limit of Detection (LOD) Limit of Quantitation (LOQ)	--

Table 4: Summary of LODs and LOQs for UFI laboratory water quality parameters sampled in Phase 1 project, 2013 (UFI, 2013a).

No.	Parameter (unit)	LOD	LOQ	Method	Date Calculated
1	TP (µgP/L)	0.8	3.4	SM 18-21 4500-P E	1/4/2013
2	TDP (µgP/L)	0.8	3.4	SM 18-21 4500-P E	1/4/2013
3	SRP (µgP/L)	0.4	1.4	SM 18-21 4500-P E	1/4/2013
4	TIP (µgP/L)	0.5	1.9	SM 18-21 4500-P E	2/7/2013
5	NO _x (µgN/L)	12	48	USEPA 353.2 Rev. 2.0	1/4/2013
6	t-NH ₃ (µgN/L)	11	43	USEPA 350.1 Rev. 2.0	1/4/2013
7	TN (µgN/L)	85	343	SM 20-22 4500-N C	1/4/2013
8	TDN (µgN/L)	86	321	SM 20-22 4500-N C	1/4/2013
9	DOC (mgC/L)	0.3	1.0	SM 18-21 5310 C (00)	1/4/2013
10	POC (mgC/L) (low)	0.005	0.02	SM 18-22 5310 B	1/4/2013
	POC (mgC/L) (high)	0.019	0.074	SM 18-22 5310 B	1/4/2013
11	Chl (µgChl <i>a</i> /L)	0.1	0.3	USEPA 445.0 Rev. 1.2, 1997	1/4/2013
12	Chl _{sp} (µgChl <i>a</i> /L)	0.2	0.4	USEPA 446.0 Rev. 1.2, 1997	1/4/2013
13	DRSi (mgSiO ₂ /L) (low)	0.01	0.04	SM 18-19 4500-Si D	1/25/2012
	DRSi (mgSiO ₂ /L) (high)	0.09	0.31	SM 18-19 4500-Si D	1/4/2013
14	UV ₂₅₄ (1/m)	0.15	0.3	USEPA 415.3 Rev. 1.2	1/1/2006
15	c ₆₆₀ (1/m)	0.05	0.1	Wet Labs, 2011 Rev. V	1/4/2013
16	Tn (NTU)	0.3	1.0	SM 18-21 2130 B	1/4/2013
17	TSS (mg/L)	1	2.5	SM 18-21 2540 D	1/4/2013
18	FSS (mg/L)	1	2.5	SM 18-21 2540 E	1/4/2013

Table 5: Summary of the specifications of the sensors configured to the SeaBird profiler (SBE25 configured as below) to be used in the lake sampling portion of the project Phase 1 project.

No.	Parameter	Manufacturer	Range of Detection	Accuracy	Resolution	Reference
1	T (°C)	Sea-Bird Electronics Inc.	-5 - 35 °C	± 0.002 °C	*	SeaBird, 2012a
3	specific conductance (SC; $\mu\text{S}/\text{cm}$)	Sea-Bird Electronics Inc.	0-70,000 $\mu\text{S}/\text{cm}$	3 $\mu\text{S}/\text{cm}$	0.4 $\mu\text{S}/\text{cm}$	SeaBird, 2012b
4	beam attenuation coefficient, (c_{660_f} or BAC; 1/m)	WET Labs	~0.003 to 135 1/m	± 0.02% full scale	*	Wetlabs, 2011
5	turbidity (Tn_f , NTU)	D & A Instruments/Campbell Scientific	0-250 NTU	0.02% of the reading or 0.5 NTU	*	Campbell, 2012
6	chlorophyll <i>a</i> (Chl_f ; $\mu\text{g}/\text{L}$)	WET Labs	0.03 - 75 $\mu\text{g}/\text{L}$	0.03 $\mu\text{g}/\text{L}$	*	Wetlabs, 2012
7	scalar photosynthetic active radiation (PAR, $\mu\text{E}/\text{m}^2/\text{s}$)	LiCor	*	± 5%	*	LiCor, 2006
8	depth (m)	Sea-Bird Electronics Inc.	0 - 200m	0 - 1% full scale	*	SeaBird, 2012c

* manufacture does not specify.

Table 6: Summary of the specifications of the sensors configured to the YSI 660 sonde to be used in the tributary sampling portion of the Phase 1 project.

No.	Parameter	Manufacturer	Range of Detection	Accuracy	Resolution	Reference
	T (°C)	YSI	-5 - 50	± 0.15 °C	0.01°C	(YSI, 2011)
9	specific conductance (SC; µS/cm)	YSI	0 - 100 mS/cm	± 0.5 % reading + 1 µS/cm	1 µS/cm	(YSI, 2011)
10	Tn_f (NTU)	YSI	0.3-1000 NTU	± 2% reading or 0.3 NTU which ever is greater	0.1 NTU	(YSI, 2011)
11	depth (m)	YSI	61 m	0.12 m	0.001 m	(YSI, 2011)

- output will be consistent with mass balance constraints
- patterns of output in time and space will be consistent with the biogeochemical features of limnological paradigms
- responses of models to reasonable variations
- performance, according to metrics widely reported in similar modeling initiatives, is consistent with levels reported for other similar efforts

The overall quality assurance objective of the Cornell University Department of Ecology and Evolutionary Biology (CUEEB) is to provide an accurate assessment of the major zooplankton and phytoplankton populations of Cayuga Lake. This includes quality assurance objectives of the UFI field team to sample sites effectively in the lake following the sample design and accurately documenting site location and depth. All zooplankton and phytoplankton samples will be collected and preserved as documented in their respective SOP's. All deviations from protocol will be documented on the CoCs. The CUEEB laboratory team will identify the zooplankton and phytoplankton to the lowest taxonomic level practicable (species for the adults of the most abundant taxa, genus for rare groups), provide estimates of zooplankton and phytoplankton biomass, and aggregate them into functional groups. The data on zooplankton and phytoplankton, biomass, taxon and functional groups will be stored electronically in a database complete with sample location, depth, and dates.

The overall quality assurance objective of the Cornell Biological Field Station at Shackelton Point (CBFS) is to provide an accurate assessment of the dreissenid mussel population of Cayuga Lake. Quality assurance objectives for the field team are to effectively sample sites throughout the lake following the sample design and accurately documenting site location and depth. CBFS will follow protocols from their established sampling and analysis SOPs (*Appendix 2*). All live mussels will be separated from the substrate and sufficiently preserved for transport to the laboratory in clearly labeled containers. The laboratory team will identify the mussels by species and size of the shells for an estimate of mussel biomass. The data on mussel density, biomass, and size will be stored electronically in a database complete with sample location, depth, and substrate information.

The overall quality assurance objective of Michigan Technological University Department of Civil and Environmental Engineering (MTUCEE) is to provide an accurate assessment of the fraction of particulate phosphorus that is bioavailable in the four main tributaries to Cayuga Lake, and two main WWTP discharges. This sampling will be done under both dry and wet weather conditions. Preliminary flow rate specifications for wet weather are based on conditions at the Fall Creek gage, the longest record available for the system. The threshold is set at twice the median flows, seasonally, that correspond approximately to 410, 90 and 70 cfs, for spring, summer, and fall, respectively. Dry weather conditions are specified as those corresponding to less than twice the seasonal median for 7 days prior to sampling. The quality assurance objectives for the UFI field staff are to sample sites effectively following the sample design and SOP (*Appendix 1*) and accurately document site location, date, and time of sampling on CoCs. UFI staff will process, preserve and ship all samples along with CoCs as documented in their established UFI bioavailability bioassay filtering SOP (*Appendix 3*). All deviations from protocol will be documented on the CoCs. The MTUCEE laboratory staff will conduct all analyses related to bioavailability bioassays. The MTUCEE laboratory staff will follow the data quality objectives

listed in Table 3. This includes quality assurance objectives of the staff to conduct bioassays to accurately estimate the fraction of particulate phosphorus that is bioavailable, following SOP's and documenting any deviation from protocol. Table 7 contains the LOD and LOQ limits for all water samples to be analyzed by MTUCEE laboratory staff in this project. Precision and accuracy for these parameters is discussed in more detail in *Section B.5 Quality Control* and summarized on Table 41. The data on bioavailability, including sample location, dates and times, will be stored electronically in a database.

Table 7: Summary of LODs and LOQs for MTUCEE laboratory water quality parameters sampled in the bioavailability bioassay portion of the Phase 1 project, 2013 (UFI, 2013a).

No.	Parameter (unit)	LOQ	LOD	Method	Date Calculated
1	TP (µgP/L)	2.3	0.5	SM 18-21 4500-P E	3/1/2011
2	TDP (µgP/L)	2.3	0.5	SM 18-21 4500-P E	3/1/2011
3	SRP (µgP/L)	2.3	0.5	SM 18-21 4500-P E	3/1/2011
4	TSS (mg/L)	--	--	SM 18-21 2540 D	3/1/2011

The overall quality assurance objective of Cornell University Department of Biology and Environmental Engineering (CUBEE) is to accurately model the watershed of Cayuga Lake. DQOs for the CUBEE are

- data quality for key model inputs (e.g., meteorological) will be representative to support specification of representative driving conditions within the model.
- data quality for model state variables will be representative to provide a robust test of model performance.
- data quality for both model inputs and state variables will be representative seasonally and for multiple years.
- data collected under previous contracts/projects, to be used in this project, are consistent with and will be subject to those contract's QAPPs, or quality assurance protocols of this project (see protocols for non-direct measurement (*Section B.9*)).

While the watershed modeling group at Cornell strives to create and utilize models that require little direct calibration, the models proposed for use here must be calibrated so that the output for stream flow matches historical records. While these are among the more robust models available for this kind of analysis, there are limitations in representing the true physical and biological processes in a watershed. These limitations are well-understood in the modeling

community and will be summarized in the final report. There are also limitations in the precision of some input variables (e.g., soil properties) and these will also be explained in the final report. Uncertainties in measured stream flow, meteorological inputs, and assumptions made about land use, soil characteristics, and pollutant fate-and-transport in the modeled system, are all reflected by the error associated with analytical measurements when computer models are calibrated. Most analytical results will have confidence intervals that range between +/- 12 to 30% of the parameter measured. The primary success criterion for watershed modeling will be the acceptance of the "validation" results, i.e., how well the model reproduces independently measured fluxes in the tributaries.

A.5. Special Training/Certification

New training will be needed by the UFI field staff for phytoplankton and zooplankton sampling. This training is covered below in the paragraph on CUEEB. No new or additional special training is required for any UFI laboratory, data analysis or modeling staff for the Phase 1 project. UFI field and laboratory staff training is covered in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). UFI field staff are trained by experienced field staff and follow established SOPs for all measurements and tasks they perform in the field. The field staff must perform an initial demonstration of capability for each task. On-going annual training for all UFI field staff is conducted by the UFI Field Program Supervisor. This includes reading all UFI field SOP's and quality manuals for all field techniques, reviewing all paperwork documentation, and performing on-going demonstration of capability program as well as an annual ethics training. Field staff have received certification for first aid and boater safety as well as receiving on-going health and safety training from UFI's Safety Officer.

UFI laboratory staff are trained by an experienced laboratory technician and use established SOPs for the analyses they are performing. Staff must perform an initial demonstration of capability. They have on-going and annual training including reading and reviewing SOPs, quality manuals, completing an on-going demonstration of capability, and annual ethics training.

No further training is needed by UFI data analysis and modeling staff. They will perform the analysis and hydrothermal/transport modeling tasks in this project. The modeling staff are individuals with highly specialized expertise in their respective modeling and data analysis tasks. The staff has been involved in data analysis, model code development and model set up for the past 15 to 25 years.

Phytoplankton and zooplankton field sampling in this project is the responsibility of UFI field staff. UFI field staff will be trained by the UFI Field Program Supervisor to follow the field collection protocol outlined in the existing CUEEB phytoplankton and zooplankton field SOPs (*Appendix 2*). Training will involve the UFI field staff reading both SOPs and completing a demonstration of capabilities for these techniques prior to the field program beginning. No further new training is needed by laboratory staff of CUEEB that is conducting the laboratory phytoplankton and zooplankton analysis for this project. CUEEB staff has 40 years of experience in identifying and enumerating zooplankton and phytoplankton. The staff has followed the protocols outlined in the phytoplankton and zooplankton laboratory SOP's in similar studies on Oneida Lake, Onondaga Lake, Lake Constance (Europe), as well as in Cayuga Lake itself. New staff members will be trained by the lab project leader of CUEEB to follow the phytoplankton and

zooplankton laboratory SOPs. They must perform an initial and continued demonstration of capability.

No further new training is needed by field and laboratory staff of CBFS that are conducting the dreissenid mussel collection and analysis for this project. CBFS staff have followed the outlined protocols in similar benthic surveys of Oneida and Owasco Lakes and have training in safe boat use and laboratory safety. New staff will be trained by the project leader to follow the existing SOPs outlined for field collection and laboratory analysis. They must perform an initial and continued demonstration of capability.

UFI field staff is responsible for collecting water samples from four streams and two WWTP discharges for use in bioavailability bioassays. No new training is required. This water sampling is covered in the annual training of UFI field staff that is detailed in the first paragraph of this section. UFI staff responsible for processing, storage and shipping of these samples for bioavailability bioassays are already trained for tasks they are called upon to perform. They will follow the established UFI bioavailability bioassay SOPs developed for processing, storage and shipping of these samples and document any deviations from protocol on the CoCs. No new training will be required. Copies of CoCs for these samples will be transmitted along with the samples to MTUCEE. No special training or certification is required for the MTUCEE project team. They annually undergo General Safety Training and Chemical Hygiene Training. Forms demonstrating completion of that training are kept on file. The MTUCEE project leader will train laboratory staff in the conduct of the specific tests and equipment used in conducting the bioavailability bioassays. Considerable in-house experience is presently resident within the MTUCEE project team as it is actively involved in conducting assays for other projects.

No new or special training is needed for the CUBEE staff. Todd Walter and his lab leading the watershed modeling efforts have extensive experience. The personnel in the CUBEE lab are capable of training new students and staff. Historically they have experience in compiling several test data sets developed as part of our collaboration with the New York City (NYC) Department of Environmental Protection (DEP) and NYDEC in the NYC watershed project. All new modelers must demonstrate that they can setup the models using the test data sets and reproduce output at the same level of corroboration with measurements (flow, phosphorus concentrations, etc.) as published in our associated peer-reviewed papers.

UFI will provide training on the set-up and use of the hydrothermal/transport model. Todd Walter's modeling group will prepare a modeling workshop to train end-users on how to use the watershed models. This will be a hands-on workshop in which all the participants will run the models for Fall Creek using the input files developed as part of this project. Participants will also learn how to manipulate the input files to simulate different scenarios. Six-months prior to the workshop, The CUBEE group will request input from the workshop participants to assess their level of modeling experience and any specific objectives or outcomes they have for the workshop.

A.6. Documents and Records

Documentation and records for the water quality field and laboratory portion (UFI) and the biological portion (Cornell) of the Phase 1 project include, but are not limited to, those listed in Table 8. Record keeping, collection and maintenance of all UFI data are covered in the *Environmental Testing Laboratory and Field Quality Manual* (UFI, 2010). All records generated

Table 8: Examples of water quality field and laboratory documentation that will be generated for the Phase 1 project.

No.	Document Type	Document	Description
1	field	field packing sheets (Appendix 4 and 5)	ensure field staff have all equipment necessary for field tasks
2	field	field sampling sheets (Appendix 4)	document all field measurements made on the systems
3	field	float plan (Appendix 4)	document filled out prior to sampling trips that list all personnel on board, contains emergency contact numbers; check list of safety equipment being brought on the boat, and a safety inspection check list for all boats, trucks, trailers involved in the trip
4	field/laboratory	chain-of-custodies (CoCs; Appendix 6 and 7)	establish an intact continuous record of the physical possession of samples
5	laboratory	analyte data packets	contain all information on samples and analysis including raw data sheets and instrument printouts
6	laboratory	data reports	contain measured values for sample analytes
7	field and laboratory	corrective action reports (Appendix 8)	document problems that arise during sampling or analysis and fixes to these problems

in this project will be maintained for a minimum of five years beyond completion of the project to allow historical reconstruction of analysis. Details on handling and secure storage of these documents are covered in the *Environmental Testing Laboratory and Field Quality Manual* (UFI, 2010). All field and laboratory results will be reported to the Phase 1 assistant project manager, compiled and delivered as part of the final Phase 1 report.

The UFI data analysis and modeling teams will be responsible for documenting key data analyses, hydrothermal/transport model setup and findings, data files and software in the final Phase 1 report. Each modeling staff member will be responsible for documenting all assumptions and supporting analyses. They will maintain records of written correspondence, emails between the modeling team members and other project members. Progress will be documented as part of the technical meetings (n = 4) between UFI, Cornell University scientists and NYSDEC technical staff (project work schedule, *Section 3.3*). Record keeping for each step of the hydrothermal/transport modeling process will consist of various information, in the form of progress presentations, and multiple forms of graphics. Examples are given below:

- assumptions
- parameters and their source
- hydrothermal/transport model grid design
- input used, their sources, and any actions to compensate for missing data
- setup input and output files
- coefficient values

All files from the hydrothermal/transport modeling study will be maintained for auditing purposes and post-project reuse, including

- source code and executable code
- output from hydrothermal/transport model runs
- interpretation of output
- setup and testing procedures and results

No modifications of code are anticipated for this project. If modifications become necessary, all modification of the source code will be tested and documented in internal memos. Such modifications would be tested throughout the hydrothermal/transport model setup process by experienced modelers reviewing the hydrothermal/transport model output to determine that it demonstrates expected behavior and responds in the expected manner for each model run.

The phytoplankton and zooplankton field sampling will be documented by UFI field staff which is responsible for sampling phytoplankton and zooplankton in this project. Copies of CoCs for this sampling will be transmitted along with the samples to CUEEB. They will be responsible for documentation of laboratory phytoplankton and zooplankton analysis. Examples of such documents including field sheets, CoCs for samples, and data reports are outlined in Table 8. All records generated in this project will be maintained for a minimum of five years beyond completion of the project. Data reports including sampling information and laboratory analysis (taxon identification, enumeration, biomass estimates) will be reported to the UFI project manager.

CBFS is responsible for documenting sample collection and analysis of dreissenid mussels for this project. Examples of such documents including field sheets, CoCs for samples, and data reports are outlined in Table 8. All records generated in this project will be maintained for a minimum of five years beyond completion of the project. Data reports including sampling information and laboratory analysis (density and size distribution of dreissenid mussels) will be reported to the UFI project manager.

UFI field staff are responsible for collecting water samples from four tributary and two WWTP discharges to be used in conducting bioavailability bioassays in this project. UFI staff will be responsible for filling out CoCs for all water samples collected to be used in bioavailability bioassays. UFI field staff will relinquish the water samples and CoCs to UFI staff trained in the handling and processing of these water samples (*Appendix 3*). UFI will maintain hard copies of these CoCs. Copies of the CoCs for these samples will be transmitted along with the samples to MTUCEE. MTUCEE laboratory staff will be responsible for documentation of all laboratory analysis related to conducting bioavailability bioassays. The MTUCEE laboratory staff will maintain a file of raw data, instrument printouts, preparation and run logs, calibration information, analytical data, quality assurance data. MTUCEE laboratory staff will be responsible for maintaining CoCs throughout the life cycle of the samples. Data reports including sampling information and laboratory analysis will be reported to the UFI project manager.

The CUBEE team will be responsible for documenting key geospatial data and model setup and findings, data files and software in the final Phase 1 report. Each modeling staff member will be responsible for documenting all assumptions and supporting analyses. They will maintain records of written correspondence, emails between the modeling team members and other project members. Progress will be documented as part of the technical meetings ($n = 4$) between UFI, Cornell University scientists and NYSDEC technical staff. Record keeping for each step of the modeling process will consist of various information, in the form of progress presentations, and multiple forms of graphics. Examples are given below:

- assumptions and simplifications
- parameters and their sources
- model landscape discretization scheme
- input used, their sources, and any actions to compensate for missing data
- setup input and output files
- coefficient values

All files from the modeling study will be maintained for auditing purposes and post-project reuse, including

- source code and executable code
- output from model runs
- interpretation of output
- setup and testing procedures and results

No new code modifications to the watershed models are anticipated for this project. If modifications become necessary, all modification of the source code will be tested, documented, and shared with the project team. Such modifications would be tested throughout the model setup

process by experienced modelers reviewing the model output to determine that it demonstrates expected behavior and responds in the expected manner for each model run. The CUBEE watershed modeling team has experience modifying model code (e.g., Easton et al., 2009; Fuka et al., 2012). In addition to distributing these documents and records to the other Cornell participants, UFI, and NYSDEC, some information will also be submitted to the Cornell library system where it will be publicly available and searchable (*Section A.3.4*).

Any changes in this QAPP during the study period will be documented and noted in the revision table at the beginning of this document. After approval by the appropriate persons, the revised QAPP will be sent to each person listed on the distribution list. This QAPP is a UFI controlled document and will be managed by our quality assurance officer and is subject to rules set by UFI as part of our overall quality system (UFI, 2010). The QAPP will be reviewed annually.

The final report, and support documentation and data, will be submitted in electronic format. All electronic records discussed in this section will be stored on a secure server, write protected, and backed up for a period of five years beyond completion of the project. This server is part of a LAN network and is password protected and protected externally via a firewall (UFI, 2010).

Electronic records collected by CUEEB for phytoplankton and zooplankton data including field sheets, images, and data analysis, and data reports will be stored on a secure server on the Cornell University LAN network that is password protected and protected externally via a firewall. Data will be backed up to this server for a minimum of five years beyond completion of the project.

Electronic records collected by CBFS for dreissenid mussel including field sheets, images, and data analysis, and data reports will be stored on a secure server on the Cornell University LAN network that is password protected and protected externally via a firewall. Data will be backed up to this server for a minimum of five years beyond completion of the project.

Electronic records collected by MTUCEE for all laboratory analysis related to conducting bioavailability bioassay including raw data, instrument printouts, preparation and run logs, calibration information, analytical data, quality assurance data and data reports will be stored on a secure Michigan Technological University computer that is backed up routinely. Data will be stored for a minimum of five years beyond completion of the project.

Electronic records collected by CUBEE for watershed modeling including field sheets, images, and data analysis, and data, input and output files will be stored on a secure server on the Cornell University LAN network that is password protected and protected externally via a firewall. Data will be backed up to this server for a minimum of five years beyond completion of the project.

B. Measurement and Data Acquisition

B.1. Sampling Process Design

The sample design process for the Phase 1 project is described in this section. Professional judgment necessarily plays an important part in the design of a sampling (monitoring) program for a large ecosystem such as Cayuga Lake. Factors that influence such a design include:

- the issue of concern; here phosphorus/eutrophication.
- site specific background information; e.g., sources, existing spatial differences.
- is a in-lake hydrothermal/transport model involved?
- is a watershed/land use model involved?
- level of use of the product information; here, ultimately a TMDL analysis.
- availability of related monitoring information.
- experiences with similar issues and projects for other systems by UFI CUBEE and NYSDEC.
- watershed modeling strategies to be used, e.g., empirical vs. physically-based, lumped vs. spatially distributed

The features of the subsequently described monitoring program (sites, lake depths, parameters, frequency, tributaries included) have been developed based on 30 years of experience by UFI on such issues, with important input and approval by technical staff in NYSDEC.

B.1.1. Lake Sampling

Lake sampling task for the Phase 1 project has multiple features:

- multiple sites.
- multiple metrics.
- laboratory and field measurements.
- one lake-wide monitoring frequency.
- a second more frequent/less parameters monitoring frequency for sites 1-3.

These features were developed in collaboration with Cornell and NYSDEC technical staff.

B.1.1.1. sites

Two types of in-lake sampling will occur in the Phase 1 project, lake-wide sampling (Figure 6) and more frequent, less intensive, sampling (Figure 8). The lake-wide sampling sites (1-9) for field measurements and water quality sampling for laboratory analyses are presented in Figure 6. Sampling will be conducted from the north to south for those surveys. Justification for not changing the north to south sampling order include that the monitoring parameters are not sensitive to diel effects (such as DO and pH would be), and with the predominant wind from the north it is safer and easier to sample north to south. A more frequent sampling program, called the “frequent south sampling” throughout this document, will include field measurements and

water quality sampling conducted in the southern end of the lake (Figure 8). This more frequent south sampling program will focus on more limited water quality parameters (at sites 1, 2 and 3). Lake-wide and frequent south monitoring data will be collected in 2013, and be analyzed during Phase 1 to gain insights on the lake and its nutrient cycling. This data analysis will help guide the design of a conceptual framework for a phosphorus/eutrophication model to be developed in Phase 2. This model will be a lake-wide model, though the regulatory focus with the model will be on the southern end of the lake. This lake-wide sampling will support the lake-wide model framework chosen for this project.

Monitoring along the entire length of the lake has been rare. An exception was a survey conducted in August of 1996 by UFI with rapid profiling instrumentation (see Figure 12 in Effler et al., 2010) that informed the selected design. Nine monitoring sites are specified along the major axis of the lake for this study (Figure 6). Eight of these are approximately equally spaced along this axis of the lake. Two sites (No.'s 1 and 2) are positioned at the southern end, to support NYSDEC's focus on that portion of the lake. The site specifications are consistent with

- the results of the single previous entire lake survey (Effler et al., 2010)
- with sampling lay-outs adopted in similar previous studies (Effler et al. 2006; Gelda and Effler, 2007; Gelda et al., 2009; and Gelda et al. 2012)
- the goal of supporting preparation of summarizing length-depth contour plots for various parameters
- the goal of completing surveys of all sites within one day

Sites 1, 2, and 3 correspond to stations in the previous LSC monitoring program. The specified sites will support resolution of noteworthy spatial differences in water quality attributes of concern related to the phosphorus/eutrophication issue, as well as support regulatory focus on the southern end. Moreover, it is consistent with the structure of the hydrothermal/transport model (Phase 1) that will form the physical framework of the phosphorus/eutrophication model (Phase 2). It is also consistent with sampling site design of other long narrow basin studies in New York (Gelda and Effler, 2007a; Gelda and Effler, 2007b; Gelda et al., 2012; Effler et al., 2006). The location of sampling sites for the lake-wide sampling are specified as numbers 1-9 in Table 9 (Figure 6). The location of sampling sites for the frequent south monitoring are specified as numbers 1-3 in Table 9 (Figure 8). Parameters being tracked in lake-wide and frequent south sampling are discussed in more detail in *Section B.1.1.2*. Timing of lake-wide and frequent south sampling are discussed in more detail in *Section B.1.1.4*.

Biological sampling for phytoplankton and zooplankton will be conducted on a lake-wide basis at the same sites as lake-wide water quality is being assessed (Figure 6; Table 9). Biological monitoring data will be collected in 2013 and be analyzed during Phase 1 to gain perspective on the lake's a phytoplankton and zooplankton dynamics. Phase 1 analysis of phytoplankton and zooplankton data will aid in the conceptual model development for phosphorus/eutrophication modeling (Phase 2). More details of phytoplankton and zooplankton sampling are covered in *Section B.1.1.3*.

Biological sampling for dreissenid mussels will be conducted on a lake-wide basis (Figure 7). Sampling has been conducted previously (4-5 years earlier), but with more limited spatial coverage (Watkins et al., 2012). The purpose of this sampling is to acquire more updated

Table 9: Locations of sampling sites in Cayuga Lake for lake-wide and frequent south monitoring, (X indicates sampling at site, -- indicates no sampling).

No.	Site Name	Lake-Wide Monitoring (Figure 6)	Frequent South Monitoring (Figure 8)	Approximate	
				Latitude	Longitude
1	1	X	X	42.4680	76.5157
2	2	X	X	42.4885	76.5230
3	3	X	X	42.5543	76.5940
4	4	X	--	42.5787	76.6311
5	5	X	--	42.6189	76.6618
6	6	X	--	42.6836	76.6970
7	7	X	--	42.7402	76.7387
8	8	X	--	42.8130	76.7245
9	9	X	--	42.8745	76.7234
10	I _L	X	X	42.4542	76.5111

estimates of dreissenid mussel biomass and its distribution in the lake. Dreissenid mussel data will be collected in 2013 and be analyzed during Phase 1 to gain insights on the potential effects of their metabolism. Phase 1 data analysis of dreissenid mussel data will aid in the conceptual model development of a phosphorus/eutrophication modeling (Phase 2). Selection of sample site locations was based on the previous study (Watkins et al., 2012) as well as the long experience of the biological team conducting such studies. More details of dreissenid mussels sampling are covered in *Section B.1.1.3*.

B.1.1.2. lake water quality metrics

The metrics for lake monitoring can be partitioned according to field measurements and laboratory measurements. The field measurements, with the exception of Secchi disc depth (or transparency), will be made with rapid profiling instrumentation. This instrumentation has detailed depth resolution capabilities of ≤ 1 m, thereby providing detailed vertical profiles of various parameters over the instruments depth range. These measurements include: (1) temperature (T), (2) specific conductance (SC), (3) fluorometric chlorophyll, (4) scalar irradiance (PAR), (5) beam attenuation coefficient (c_{660} ; BAC), and (6) turbidity (Tn). The Secchi disc (SD) and instrumentation measurements will be made at all nine sites. The lake-wide field measurements of water quality will be made as full profiles from the surface to near bottom

(Table 9) at depth interval of $\leq 1\text{m}$ at all 9 sites (Figure 6; Table 9), contingent upon wave conditions; high waves will result in shallower profiles. The frequent south field measurements of water quality will be conducted in the same manner (number 1-3 Table 10) for sites 1-3 (Figure 8; number 1-3 Table 9). Field measurements for both sampling frequencies will be made with the SeaBird. Parameters measured by this instrument are listed in Table 5. A full list of field parameter measurements being collected, as well as their utility, is listed in Table 11.

Sampling depths, according to site for the various parameters, are presented for the lake-wide program in Tables 12-17, and for the frequent south program in Tables 18-19. Sampling for the complete lake surveys focuses on near surface waters for the complete suite of analytes, but also includes the 10m depth (metalimnion for P species, Chl and solids because of metalimnetic peaks observed for certain constituents earlier complete lake-length survey (Effler et al., 2010). Details of the site locations for lake-wide and frequent south sampling are presented in *Section B.1.1.1*. Details of timing of sample collection for lake-wide and frequent sampling are detailed in *Section B.1.1.4*. For frequent south monitoring the full suite of field measurements will be made (*Section B.1.1.2*). However, laboratory analyses will be limited to total phosphorus (TP), total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), total inorganic phosphorus (TIP) (*Appendix 9*), particulate organic carbon (POC), chlorophyll *a* (*Appendix 10*), total suspended solids (TSS), volatile suspended solids (VSS), beam attenuation coefficient measure at 660 nm (c_{660}), and PAV_m (by SAX) (*Appendix 11*). This lake-wide and frequent south data will be used in Phase 1 data analysis. This analysis will support the development of a conceptual framework for a phosphorus/eutrophication model in Phase 2.

Table 10: Lake-wide field water quality sampling stations and approximate depths, Cayuga Lake, 2013.

Station	Approximate maximum depth (m)
1	3
2	7
3	90
4	90
5	135
6	135
7	60
8	30
9	3
10	N/A surface sampling only

Table 11: Listing and utility of all field measurements collected for lake-wide and frequent south sampling for the Phase 1 project; (“_f” = field).

No.	Analyte	Abbreviation	utility
1	temperature	T	thermal stratification, important model input
2	specific conductance	SC	conservative tracer
3	field beam attenuation coefficient	C_{660_f}	surrogate of Tn, light scattering coefficient and TSS
4	field turbidity	Tn_f	surrogate of "sediment" [e.g., suspended particulate material (SPM)], and the light scattering coefficient
5	field fluorometric chlorophyll <i>a</i>	Chl_f	trophic metric, proxy for phytoplankton biomass
6	scalar photosynthetic solar radiation	PAR	light penetration
7	Secchi disk	SD	water clarity

Table 12: Proposed lake-wide sampling locations and depths for collection of phosphorus species; total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) samples (marked with X's) and total inorganic phosphorus (TIP) samples (marked with O's) in Cayuga Lake (FB = field blank, I_L = inlet lake sampling, see Figure 6; two sets of numbers under total number of samples per parameter are for X's and O's respectively).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X, O	X, O	X, O	X, O	X, O	X, O	XXX, OOO	X, O	X, O	X, O	X, O
5					X	X	X	X	X		
10					X, O	X, O	X, O	X, O	X, O	X, O	
20					X		X				
40					X		X				
60					X	X	X	X			
80					X		X				
100						X	X	X			
120							X				
bottom							X				
total # of samples per parameter	15, 15	15, 15	15, 15	15, 15	105, 30	75, 30	180, 60	75, 30	45, 30	30, 30	15, 15

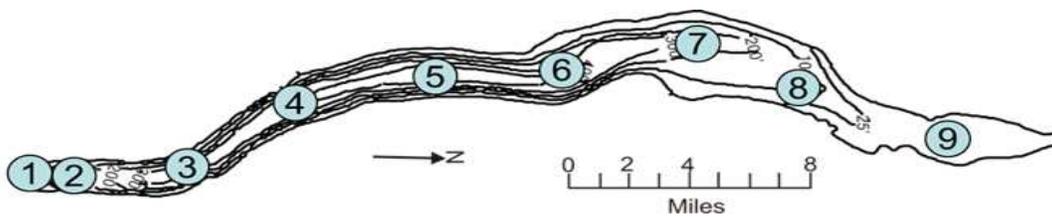


Table 13: Proposed lake-wide sampling locations and depths for collection of total ammonia (t-NH₃), and nitrate + nitrite (NO_x), samples in Cayuga Lake (FB = field blank, I_L = inlet lake sampling, see Figure 6).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X		X	X	X	X	XXX	X	X	X	X
5							X				
10							X				
20							X				
40							X				
60							X				
80							X				
100							X				
120							X				
bottom							X				
total # of samples per parameter	15	0	15	15	15	15	180	15	15	15	15

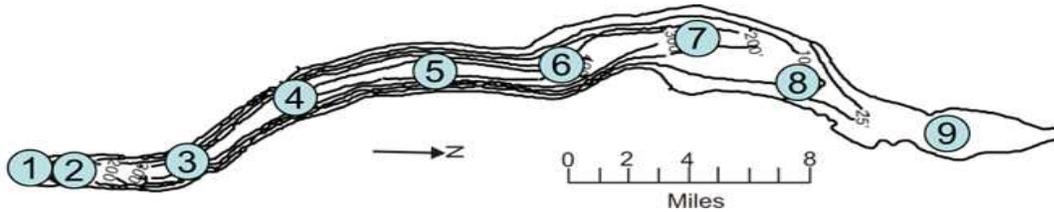


Table 14: Proposed lake-wide sampling locations and depths for collection of fluorometric chlorophyll *a* (chl), total suspended solids (TSS), and fixed suspended solids (FSS) samples in Cayuga Lake (FB = field blank, I_L = inlet lake sampling, see Figure 6).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X	X	X	X	X	X	XXX	X	X	X	X
5											
10					X	X	X	X	X	X	
total # of samples per parameter	15	15	15	15	30	30	60	30	30	30	15

Table 15: Proposed lake-wide sampling locations and depths for collection of dissolved organic carbon (DOC) and particulate organic carbon (POC) samples in Cayuga Lake(* no DOC for this sample, ** count for DOC; FB = field blank, I_L = inlet lake sampling, see Figure 6).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X	X*	X	X	X		XXX		X		X
5							X				
10							X				
20							X				
40							X				
60							X				
80							X				
100							X				
120							X				
bottom							X				
total # of samples per parameter	15		15, 0**	15	15	15	0	180	0	15	0

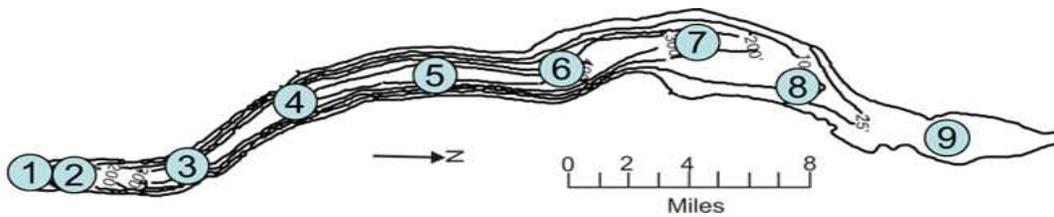


Table 16: Proposed lake-wide sampling locations and depths for collection of total nitrogen (TN), total dissolved nitrogen (TDN), turbidity (Tn), beam attenuation at 660 nm (c_{660}), and particle area concentration (PAV_m by SAX) samples in Cayuga Lake (*no TN, TDN for this sample, **count for TN, TDN; FB = field blank, I_L = inlet lake sampling, see Figure 6).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X	X*	X	X	X		XXX		X		X
total # of samples per parameter	15	15, 0**	15	15	15	0	45	0	15	0	15

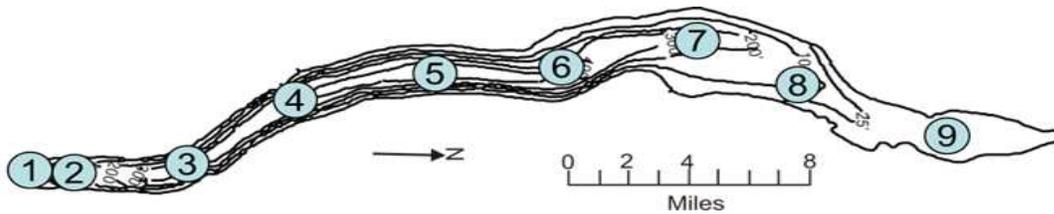


Table 17: Proposed lake-wide sampling locations and depths for collection of dissolved reactive silica (DRSi) and UV₂₅₄ samples in Cayuga Lake (FB = field blank, I_L = inlet lake sampling, see Figure 6).

Depth (m)	Sampling Sites										
	FB	I _L	1	2	3	4	5	6	7	8	9
0	X		X	X	X	X	XXX	X	X	X	X
5											
10							X				
20							X				
40											
60							X				
80											
100							X				
120											
bottom							X				
total # of samples per parameter	15	0	15	15	15	15	120	15	15	15	15

Table 18: Proposed frequent south sampling (reduced list of parameters with increased frequency sampling) locations and depths for collection of phosphorus parameters, total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP) samples (marked with X's) and total inorganic phosphorus (TIP) samples (marked with O's) in Cayuga Lake (FB = field blank, I_L = inlet lake sampling, see Figure 8).

Depth (m)	Sampling Sites				
	FB	I _L	1	2	3
0	X, O	X, O	X, O	X, O	X, O
5					X
10					X, O
20					X
40					X
60					X
80					X
total # of samples per parameter	15	15, 15	15, 15	15, 15	105, 30

Table 19: Proposed frequent south sampling (reduced list of parameters with increased frequency sampling) locations and depths for collection of X = fluorometric chlorophyll *a* (Chl), particulate organic carbon (POC), turbidity (Tn), and particle area concentration (PAV_m by SAX); O = beam attenuation coefficient (c₆₆₀), total suspended solids (TSS), fixed suspended solids (FSS) samples in Cayuga Lake (* not PAV_m or Tn collected at this depth, ** count for PAV_m and Tn; FB = field blank, I_L = inlet lake sampling, see Figure 8).

Depth (m)	Sampling Sites				
	FB	I _L	1	2	3
0	X	X	X	X	X
5					
10					X*
total # of samples per parameter	15	15	15	15	30, 15**

All laboratory parameters being collected for the lake-wide and the frequent south monitoring and the parameter utilities are identified (Table 20; laboratory SOPs are in *Appendices 9-11*), these include: (1) multiple fractions of P to describe pools and cycling, (2) other phytoplankton nutrients, (3) measures of phytoplankton biomass. Many of these parameters are widely included in studies to support development and testing of phosphorus/eutrophication models (Chapra, 1997). An exception is UV_{254} that is instead related to the disinfection by-product issue. It is included to provide data to potentially address that issue in other subsequent studies by other parties (i.e., not of interest for phosphorus/eutrophication model of Phase 2).

The parameters listed in Table 20 are directly measured parameters. Other parameters (particulate organic P (PP_o), and particulate inorganic P (PP_i)) are derived or calculated from the measured parameters, and will be used in analysis and to support phosphorus/eutrophication model development. Calculated parameters are covered in detail in *Section B.4*.

Parameters such as Tn, TSS, c_{660} and PAV_m (by SAX) impact the water clarity. Although not directly related to phytoplankton growth they are being measured because of their impact on water clarity, the light available to grow algae, and P cycling.

A number of important metrics for the study can only be measured in the laboratory, including the specified forms of phosphorus (P), other noteworthy nutrients (e.g., ammonia and silica), and organic carbon fractions (Table 20). Additionally, certain parameters will be measured in the lab as a check on field measurements of chlorophyll *a* (*Section B.4*), Tn, and c_{660} (Table 20).

The primary measure of chlorophyll *a* (Chl) will be laboratory measurements conducted using the fluorometric method (see SOP *Appendix 10*). Fluorometric methods are most widely used for this parameter due to great sensitivity at low chlorophyll concentrations (Arar and Collins, 1997; Welschmeyer, 1994). This will be measured at all sites in the epilimnion during both lake-wide (Table 14) and frequent south (Table 19) monitoring. *In situ* full profiles of fluorometric chlorophyll *a* (Chl_f) will be measured in the field with the rapid profiling instruments for both lake-wide and frequent south monitoring. This measurement will be used as a secondary measurement of chlorophyll that will give more detailed vertical resolution in the lake chlorophyll distribution. Another laboratory measurement of chlorophyll *a* will be made, on a sub-set (thirty to forty) of samples collected for primary measurements (at sites 1-3), according to a spectrophotometric method (see SOP, *Appendix 10*). The goal for these spectrophotometric measurements is to support development of a quantitative linkage to the fluorometric observations. This will support the potential use of the LSC monitoring program Chl data, obtained spectrophotometrically, as part of the phosphorus/eutrophication model analysis (Phase 2).

The specification of the depths of sampling of the various sites are based on several considerations: (1) the size and great depths of most of the lake, (2) focus on the upper (epilimnetic) layers for the phosphorus/eutrophication issue, because these are the depths where phytoplankton growth is localized and where related esthetic concerns (Secchi depth, turbidity) are manifested, (3) the need for robust vertical profiles for at least one site (No. 5) (good limnological practice), (4) the need for multiple profiles (i.e., more than one site) to assess the representativeness of recent increases in phosphorus concentrations in the LSC intake, (5) the

Table 20: Listing and utility of all directly measured laboratory measurements collected for lake-wide and frequent south sampling for the Phase 1 project.

No.	Analyte	pool	Abbreviation	Unit	utility
1	soluble reactive phosphorus	P	SRP	µgP/L	immediately available nutrient for phytoplankton
2	total phosphorus	P	TP	µgP/L	trophic state metric, limiting nutrient, quantifies the P pool
3	total dissolved phosphorus	P	TDP	µgP/L	available nutrient for phytoplankton
4	total inorganic phosphorus	P	TIP	µgP/L	inorganic phosphorus measured to calculate other pools of phosphorus see <i>Section B.4</i>
5	nitrate + nitrite	N	NO _x	µgN/L	phytoplankton nutrient
6	ammonia	N	t-NH ₃	µgN/L	phytoplankton nutrient
7	total nitrogen	N	TN	µgN/L	quantifies the N pool
8	total dissolved nitrogen	N	TDN	µgN/L	quantifies the overall dissolved N pool
9	dissolved organic carbon	C	DOC	mgC/L	quantifies the C pool
10	particulate organic carbon	C	POC	mgC/L	representation of phytoplankton biomass
11	chlorophyll <i>a</i>	algal	Chl	µg/L	trophic metric, proxy for phytoplankton biomass
12	dissolved reactive silica	algal	DRSi	mg SiO ₂ /L	phytoplankton nutrient (diatoms)
13	turbidity	clarity	Tn	NTU	surrogate of "sediment" [e.g., suspended particulate material (SPM)], and the light scattering coefficient
14	beam attenuation at 660 nm	clarity	<i>c</i> ₆₆₀	1/m	surrogate of Tn, light scattering coefficient and TSS

No.	Analyte	pool	Abbreviation	Unit	utility
15	total suspended solids	clarity	TSS	mg/L	gravimetric measure of total sediment
16	fixed suspended solids	clarity	FSS	mg/L	gravimetric measure of inorganic sediment
17	light attenuation at a wavelength of 254 nm		UV ₂₅₄	1/m	surrogate of precursors of disinfection by-products
18	projected area per unit volume, minerogenic particles (by SAX)	clarity	PAV _m	1/m	water clarity, inorganic particulate content

relative importance of the various parameters to support the phosphorus/eutrophication modeling initiative (including Phase 2), and (6) experiences in other similar modeling initiatives.

B.1.1.3. biological communities

Phytoplankton and zooplankton sampling will be conducted only as part of the lake-wide sampling. Some phosphorus/eutrophication models simulate the contributions of multiple groups of phytoplankton (e.g., diatoms, green-algae, cyanobacteria or blue-green algae) to the overall assemblage as they have different behavior and water quality attributes. Thus phytoplankton taxonomic composition will be monitored. Phytoplankton samples are subject to preservation (*Section B.4*). Samples will be collected in duplicate from the upper (0 to 10 m integrated sample) waters for 5 sites (No.'s 1, 3, 5, 7 and 9) bi-weekly, and preserved. Additionally deep water samples (60 m) will be collected at sites 3, 5 and 7. Approximately 100 of the samples will be analyzed (counts and identification; *Section B.4*). These data will be analyzed in Phase 1 to inform deliberations on the design of the Phase 2 phosphorus/eutrophication model, and may be directly incorporated in that model. Depending what the findings in Phase 1 show, the Phase 2 model may seek to resolve the timing of major phytoplankton groups in simulations of phytoplankton biomass. Selection of the samples to be analyzed will be made by the phytoplankton and zooplankton ecologist from Cornell University (Nelson Hairston), based on his review of other attendant limnological information and dialogue with the UFI project team. Salient features of the results will be presented in the final report of Phase 1 and at a project meeting(s).

Grazing zooplankton can play a critical role (1) in the regulation of phytoplankton biomass, (2) in the cycling of phosphorus, and (3) in regulating water clarity, when and where *Daphnia* are present in high concentrations. For these reasons, the effects of zooplankton may be represented in the subsequent phosphorus/eutrophication model. The details of sampling, sample handling/ and analyses for zooplankton are specified in separate SOPs (*Appendix 2*). The concentrations and composition of the zooplankton community will be monitored. Samples will be collected in duplicate at sites 1, 3, 5 and 7 bi-weekly. The 0 to 10 m depth interval will be sampled to

correspond to the depths of the phytoplankton samples. Additionally, deep water samples (from 40 to 60 m) will be collected from sites 3, 5 and 7. Unlike the phytoplankton samples, all zooplankton samples will be analyzed. Salient features of the results will be presented in the final report of Phase 1, and at project meetings.

Dreissenid mussels (both zebra and quagga) can have both direct effects (consumption through filter feeding) and indirect effects (nutrient excretion) on phytoplankton growth and biomass. Dreissenid mussels are well established in Cayuga Lake (Watkins et al., 2012). A survey (not repeated; i.e., one sampling of each site) will be conducted of these populations during the 2013 lake field program, to support potential representation of the effects of the metabolism of these bivalve mussels in the subsequent phosphorus/eutrophication model (Phase 2). The planned survey sites (Figure 7; Table 21) were selected to support lake-wide representation of these effects. *Section B.4* presents SOPs which specify the protocols for sampling and sample handling, and the identification and sizing of collected individuals. Salient features of the survey results will be presented in the final report of Phase 1 and at project meetings.

B.1.1.4. timing of lake monitoring

Timing features of the monitoring design are influenced by the project goals, precedents from similar initiatives elsewhere, and system-specific characteristics. The start time is critical, early spring of 2013. It is important to capture the period of early spring to quantify conditions prior to the onset of stratification and the spring algal bloom. The lake field program will extend, as a minimum, from April through October. These temporal bounds may be extended, contingent upon meteorological conditions. The lake-wide (i.e., 9 sites; Figure 6; Table 9) program will be conducted once every two weeks (bi-weekly). A certain day of the week will be targeted. However, some variation in the specific day will be unavoidable because of the effects of meteorological conditions, particularly given the size of the lake. Site locations for lake-wide sampling are discussed in more detail in *Section B.1.1.1*, and parameters being collected are discussed in more detail in *Section B.1.1.2*. Additionally, a reduced scope program, called the frequent south monitoring throughout this document (Figure 8; Table 9), will be conducted more frequently for the southern three sites (No.'s 1, 2 and 3) during the summer months (June-September), to provide more temporal resolution and support NYSDEC's focus on the southern end of the lake. The June-September interval corresponds to that used to assess status with respect to the state phosphorus guidance value. The frequency will be increased to twice per week for that interval, requiring three more days of sampling over a two week interval in an addition to the lake-wide bi-weekly surveys. Site locations for frequent south sampling are discussed in more detail in *Section B.1.1.1*, and parameters being collected are discussed in more detail in *Section B.1.1.2*. These design details are the outcome of related negotiations between Cornell University, UFI, and NYSDEC technical staff.

B.1.2. Tributary Program

B.1.2.1. tributary mouths

In Phase 1, tributary monitoring is being conducted to support material loading estimates. These material loading estimates will be used in Phase 1 to support testing of the watershed/land

Table 21: Location of proposed sampling sites in Cayuga Lake for dreissenid mussels in 2013. (ML = mid-lake; A represents the sample site closest to the west shore with increasing letters as you approach the east shore).

transect	No.	Site Name	goal Latitude	goal depth	comment
1	1	1ML	42.468	3	mid-lake
	2	1A	42.468	3	W-E
	3	1B	42.468	3	
	4	1C	42.468	3	
	5	1D	42.468	3	
2	6	2ML	42.4885	7	mid-lake
	7	2A	42.4885	3	W-E
	8	2B	42.4885	5	
	9	2C	42.4885	5	
	10	2D	42.4885	3	
Myers Point (MP)	11	MPML	42.5543	90	mid-lake
	12	MPA	42.5543	15	W-E
	13	MPB	42.5543	30	
	14	MPC	42.5543	45	
	15	MPD	42.5543	60	
	16	MPE	42.5543	75	
	17	MPF	42.5543	75	
	18	MPG	42.5543	60	
	19	MPH	42.5543	45	
	20	MPI	42.5543	30	
	21	MPJ	42.5543	15	
3	22	3ML	42.5543	90	mid-lake
	23	3A	42.5543	15	W-E
	24	3B	42.5543	30	
	25	3C	42.5543	45	
	26	3D	42.5543	60	
	27	3E	42.5543	75	
	28	3F	42.5543	75	
	29	3G	42.5543	60	
	30	3H	42.5543	45	
	31	3I	42.5543	30	
	32	3J	42.5543	15	
	33	3K	42.5543	3	

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transect	No.	Site Name	goal Latitude	goal depth	comment
4	34	4ML	42.579	90	mid -lake
	35	4A	42.579	15	W-E
	36	4B	42.579	30	
	37	4C	42.579	45	
	38	4D	42.579	60	
	39	4E	42.579	75	
	40	4F	42.579	75	
	41	4G	42.579	60	
	42	4H	42.579	45	
	43	4I	42.579	30	
	44	4J	42.579	15	
	45	4K	42.579	3	
5	46	5ML	42.6189	120	mid-lake
	47	5A	42.6189	15	
	48	5B	42.6189	30	
	49	5C	42.6189	45	
	50	5D	42.6189	60	
	51	5E	42.6189	75	
	52	5F	42.6189	90	
	53	5G	42.6189	105	
	54	5H	42.6189	105	
	55	5I	42.6189	90	
	56	5J	42.6189	75	
	57	5K	42.6189	60	
	58	5L	42.6189	45	
	59	5M	42.6189	30	
	60	5N	42.6189	15	
61	5O	42.6189	3		
6	62	6ML	42.684	120	mid-lake
	63	6A	42.684	15	
	64	6B	42.684	30	
	65	6C	42.684	45	
	66	6D	42.684	60	
	67	6E	42.684	75	
	68	6F	42.684	90	
	69	6G	42.684	105	

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transect	No.	Site Name	goal Latitude	goal depth	comment
6	70	6H	42.684	105	mid-lake
	71	6I	42.684	90	W-E
	72	6J	42.684	75	
	73	6K	42.684	60	
	74	6L	42.684	45	
	75	6M	42.684	30	
	76	6N	42.684	15	
	77	6O	42.684	3	
7	78	7ML	42.74	60	mid-lake
	79	7A	42.74	10	W-E
	80	7B	42.74	20	
	81	7C	42.74	30	
	82	7D	42.74	40	
	83	7E	42.74	50	
	84	7F	42.74	50	
	85	7G	42.74	40	
	86	7H	42.74	30	
	87	7I	42.74	20	
	88	7J	42.74	10	
	89	7K	42.74	3	
8	90	8ML	42.813	30	mid-lake
	91	8A	42.813	10	W-E
	92	8B	42.813	20	
	93	8C	42.813	20	
	94	8D	42.813	10	
	95	8D	42.813	3	
9	96	9ML	42.8745	3	mid-lake
	97	9A	42.8745	3	W-E
	98	9B	42.8745	3	
	99	9C	42.8745	3	
	100	9D	42.8745	3	

use model, and mass balance analyses for the lake. Ultimately the loads will be used in the phosphorus/eutrophication model developed and tested in Phase 2. Tributary monitoring will be relatively short intervals of high flow (runoff events). According to good monitoring and conducted over the April (perhaps mid-March) through October interval of 2013. Disproportionately large contributions to phosphorus and sediment loading commonly occur over watershed/land use modeling practice, increased sampling is often implemented during some events for important tributaries to improve the representativeness of loading estimates.

Specifications of the design of the tributary program (sites, parameters, frequency and number of events) evolved through technical dialogue between Cornell, NYSDEC and UFI. The five largest tributaries to the lake (Figure 4) were accepted as a reasonable and appropriate representation of inputs to support the subsequent watershed/land use modeling efforts. Other factors than size that supported selections included their position relative to the southern end and the availability of flow measurements for four of these tributaries.

Three types of tributary mouth sampling will be conducted as part of the Phase 1 project, routine sampling, event based sampling, and bioavailability bioassays. For the routine sampling, the selected tributaries were Salmon Creek, Fall Creek, Six Mile Creek, Cayuga Inlet and Taughannock Creek (the only ungauged one of these tributaries). Each of these tributaries will be monitored as close to the lake as conditions (e.g., accessibility, absence of backflow effects from the lake) allow (Figure 4), at a frequency of once every two weeks (bi-weekly). The routine sampling location on each tributary is listed on Table 22. This routine sampling is also referred to as fixed frequency (FF). A breakdown of the estimated samples to be collected according to various analytes for the FF component of the tributary monitoring is presented in Table 23. In addition to the water quality parameters being sampled, a YSI sonde will be used to measure temperature, specific conductance and turbidity at each of the five tributary sampling sites. Certain of these field data will be used in the Phase 1 hydrothermal/transport modeling.

Runoff event-based sampling (see *Section A.4* for definition of dry and wet weather stream sampling) will be conducted at the mouth for four of the tributaries; Salmon Creek, Fall Creek, Six Mile Creek, Cayuga Inlet (sites No. 1-4 on Table 22). Automated sampling equipment will be used to collect samples during runoff events (Figure 4). A break-down of parameters, and the estimated number of event (E) samples according to parameter and tributary, is presented in Table 23. The number of phosphorus samples to be collected during each event is expected to average ten. SRP will be collected during storm events by automatic samplers. Due to the nature of the collection technique, the samples will not be filtered within 15 minutes of collection as per the method requirements. All SRP samples collected via this technique will be appropriately flagged and qualified. Differences in the number of samples to be collected for the various parameters reflect the perceived differences in importance and behavior for the overall data analysis and watershed/land use modeling initiative. The goal is to monitor the effect of four runoff events. Such designs (Table 23), while necessary for planning purposes, generally can be expected to require modification during execution based on the reality of non-idealized conditions (e.g., meteorological, equipment performance, vandalism, health and safety issues) encountered during the execution of the program.

Samples for bioavailability (of particulate phosphorus) will be collected from four of the tributaries (Salmon Creek, Fall Creek, Six Mile Creek, and Cayuga Inlet, sites No. 1-4 Table 22) and two wastewater treatment plants (WWTP; Ithaca and Cayuga Heights; effluent point for

Table 22: Routine tributary sampling locations on Cayuga Lake, 2013.

No.	Tributary	Site	UFI Sampling Code	Approximate	
				Latitude (°N)	Longitude (°W)
1	Salmon Creek	Salmon Crk. near Ludlowville	SCm	42.5523	76.5342
2	Fall Creek	Fall Crk. North Cayuga St.	FCm	42.4548	76.5004
3	Six Mile Creek	Six Mile Crk. S. Titus	6MCm	42.4341	76.5040
4	Cayuga Inlet	Cayuga Inlet @ Inlet Rd.	CIm	42.4272	76.5218
5	Taughannock	Taughannock Crk. @ Taugh. Park	TCm	42.5460	76.6002

SPDES permit). Three samples will be collected from each of the four tributaries over the monitoring interval of 2013, one during dry weather conditions, the other two during runoff event (intervals of increased stream flow). Three collections will be made for both these WWTPs, spread out over the 2013 monitoring interval. Protocols for these collections are specified in the UFI bioavailability bioassay filtering SOP 405 (*Appendix 3*).

B.1.2.2. upstream event synoptic surveys

YSI hand held measurements of T, SC and Tn will be made for what is being called the upstream event synoptic surveys. Water quality samples will be also collected. These surveys will extend from the mouths upstream through much of the watersheds of Salmon Creek and Fall Creek, for two events, to support additional testing of the watershed/land use model (Phase 1). The parameters to be analyzed (total phosphorus, total dissolved phosphorus, soluble reactive phosphorus, total suspended solids, and turbidity; Table 22) are consistent with the state variables of the watershed/land use model(s) to be implemented (Phase 1). Five sites along the lengths of the two tributaries are being targeted for these surveys (Table 24; Figure 5). The timing of sampling during the events will target collections for both the rising and falling limbs of the hydrographs. A minimum of five samples per site per event is targeted. The design of this portion of the tributary program is an outcome of collaborative planning by UFI and NYSDEC technical staff. One dry weather run will be conducted for which each of the five sampling sites will be sampled one time. For watershed modeling CUBEE need measurements at both the mouths of several tributaries to assess how accurately CUBEE are simulating phosphorus loads to the lake. However, CUBEE also need measurements inside the tributary watersheds to ensure that CUBEE is correctly capturing the internal patterns of water and phosphorus. It is important to predict where the phosphorus is originating so that CUBEE can be sure that our model is correctly simulating the processes that contribute to the load at the outlet. For this project

Table 23: Tributary mouth sampling design for 2013 to support watershed/land use models; sample counts according to tributary for the Phase 1 project.

No.	Analyte	Tributary												Total
		Fall Creek			Cayuga Inlet		Salmon Creek			Six Mile Creek		Taughannock		
		FF ⁺	E [*]	SE ^{**}	FF	E	FF	E	SE ^{**}	FF	E	FF	E	
1	TP	15	40	55	15	40	15	40	55	15	40	15	--	345
2	TDP	15	40	55	15	40	15	40	55	15	40	15	--	345
3	SRP	15	--	55	15	--	15	--	55	15	--	15	--	185
4	TIP	7	20	--	7	20	7	20	--	7	20	7	--	115
5	NO _X	7	20	55	7	20	7	20	55	7	20	7	--	225
6	t-NH ₃	7	20	55	7	20	7	20	55	7	20	7	--	225
7	DOC	7	20	--	7	20	7	20	--	7	20	7	--	115
8	UV ₂₅₄	7	20	--	7	20	7	20	--	7	20	7	--	115
9	DRSi	7	20	--	7	20	7	20	--	7	20	7	--	115
10	Tn	15	40	55	15	40	15	40	55	15	40	15	--	345
11	TSS	7	20	55	7	20	7	20	55	7	20	7	--	225
12	⁺⁺ PAV _m	7	20	--	7	20	7	20	--	7	20	7	--	115
														345

⁺ FF - fixed frequency (mouth sampling) number of samples

^{*}E - event (auto samplers at the mouth) number of samples

^{**}SE - synoptic (upstream) event number of samples

⁺⁺ - samples will be archived; selected samples may be run

Table 24: Specification of sampling locations (5) for event based synoptic surveys of two tributaries to Cayuga Lake in 2013; Fall Creek and Salmon Creek.

Tributary	No.	Site	Description	Justification	UFI Sampling Code	Approximate	
						Latitude (°N)	Longitude (°W)
Fall Creek	1	Fall Creek N. Cayuga St.	near USGS gauge 04234000	upstream of Ithaca	FCm	42.4548	76.5004
	2	Fall Creek @ Freese Road	northeast of Cornell	upstream of Cornell and downstream of Etna, NY	FCu1	42.4569	76.4386
	3	Fall Creek @ Etna, NY	at Etna Lane bridge, Etna, NY	mid-point of stream locations and downstream of Dryden STP inputs	FCu2	42.4854	76.3849
	4	Fall Creek @ Freeville, NY	at Route 38 Bridge near intersection of Routs 366 and 38 in Freeville, NY	upstream of Freeville WWTP and Dryden STP	FCu3	42.5141	76.3470
	5	Fall Creek @ McLean, NY	bridge at School St. in McLean, NY	upstream location; upstream of several large farms; site of old USGS gage 04233633	FCu4	42.5115	76.2920

Tributary	No.	Site	Description	Justification	UFI Sampling Code	Approximate	
						Latitude (°N)	Longitude (°W)
Salmon Creek	6	Salmon Creek near Ludlowville	Salmon Creek near Ludlowville at USGS gauge No. 0423401815	at active gauge resolves potential backwater issue further downstream	SCm	42.5523	76.5342
	7	Salmon Creek @ Salmon Creek Road East Genoa, NY	Salmon Creek Road bridge near East Genoa, NY	downstream of large agricultural area	SCu1	42.6231	76.5382
	8	Salmon Creek @ Route 90, Genoa, NY	Route 90 Bridge, Genoa, NY	downstream of large agricultural area	SCu2	42.6677	76.5381
	9	Salmon Creek @ Tile Kiln Road, Venice, NY	Tile Kiln bridge 2.5 km south of Venice Corners, NY	mid-point of stream surrounded by large farms	SCu3	42.7140	76.5505
	10	Salmon Creek @ Scipio-Venice Townline Rd.	Salmon Creek at Scipio-Venice Townline Rd.	upstream location	SCu4	42.7548	76.5676

CUBEE will use synoptic surveys along the river systems in multiple tributary watersheds to evaluate the models' ability to capture the internal phosphorus fluxes.

B.2. Sampling Methods

Field sampling methods for the water quality collection portion of the Phase 1 projects are listed in Table 25. These SOP's include both lake and tributary sampling techniques. The field SOPs are included in the *Environmental Testing Field Methods Manual* (UFI, 2013b). Copies of these UFI field SOPs are provided here in *Appendix 1*. The exception to this is the field filtering SOP which can be found in the *Upstate Freshwater Institute Environmental Testing Laboratory Methods Manual* (UFI, 2013c). It is also provided in *Appendix 1*.

Table 25: UFI SOP's for the field water quality portion of the Phase 1 project; SOP found in *Appendix 1*.

No.	SOP No.	SOP Title
1	300	<i>Water Sample Collection of a Grab Sample</i>
2	301	<i>Water Sample Collection with a Bucket</i>
3	303	<i>Water Sample Collection with a Kemmerers/Van Dorns</i>
4	304	<i>Water Sample Collection with a Submersible Pump</i>
5	307	<i>Secchi Disk Measurements</i>
6	315	<i>YSI Sonde Calibration and Maintenance</i>
7	319	<i>YSI Profiling using the YSI 650</i>
8	320	<i>SeaBird</i>
9	323	<i>Transmissometry</i>
10	342	<i>Using the Churn Mixer</i>
11	343	<i>Sigma Auto Samplers</i>
12	114.1	<i>field filtering</i>

Several types of water collection techniques will be used in the water quality sampling of the lake and tributaries (Table 25, 1-4). In the lake at depths less than 20 m water quality samples will be collected with a submersible pump (Table 25, 4). If the depth of the sample is greater than 20 m the lake sample will be collected with a Van Dorn or Kemmerer sampler (Table 25, 4). For the tributary routine and upstream event synoptic surveys sample collection will be either a single grab sample directly or through the use of a bucket to collect a single sample from a bridge (Table

25 1 or 2). Choice of sampling technique will depend on the tributary conditions and accessibility to the tributary. Event sampling at the mouth will be conducted through the use of automatic samplers.

UFI's field staff are trained in sampling procedures. Prior to the start of the field season an annual review of this training, including field sampling, water collection and rapid profiling measurements is given to all field staff by the Field Program Supervisor. During these presentations sample collection and paper work documentation, including field sheets and CoCs, are reviewed. There are four types of water quality field sheets listed in Table 26 that will be used in all lake and tributary water quality monitoring in Phase 1 of this project. Examples of these water quality field sheets can be found in *Appendix 4*. There are six types of water quality CoCs listed in Table 27 that will be used in all lake and tributary water quality monitoring in Phase 1 of this project. Examples of these water quality CoCs can be found in *Appendix 6*.

Table 26: UFI list of field sheets to be used in the field water quality portion of the Phase 1 project; examples can be found in *Appendix 4*.

No.	Field Sheet Description
1	lake-wide routine bi-weekly monitoring
2	frequent south monitoring
3	routine mouth tributary monitoring

Table 27: UFI list of chain-of-custodies (CoCs) to be used in the water quality collection portion of the Phase 1 project; examples can be found in *Appendix 6*.

No.	Chain-of-Custody (CoCs) Description
1	lake-wide routine bi-weekly monitoring
2	frequent south monitoring
3	routine mouth tributary monitoring
4	bioavailability bioassays
5	event based tributary synoptic surveys
6	event based mouth monitoring with automatic samplers

Water quality field sheets will be filled out during every lake and tributary sampling event. These sheets document date, time of sampling, locations and sampling personnel. These contain an equipment checklist for field staff to ensure all equipment necessary for sampling is brought with them. These also contain information on the equipment used for profiling. The sheets also have a section for sampling staff to note any deviation from SOP's. The field sheet contains a

section for field signature and date for relinquishing of field sheet/samples and a section for signature and dating by the Field Program Supervisor who receives and reviews the field sheets (*Appendix 4*). Depending on the type of field sheet, the sampling staff will fill out different tables. For example, during routine lake-wide sampling the location, maximum depth, and time for each SeaBird profile is recorded as well as a Secchi disc measurement. All parameters in the profiles from the SeaBird will not be recorded on the field sheet since they are recorded to an electronic data file. For routine tributary monitoring the location, date, time and values of all parameters measured by the handheld YSI will be recorded on the field sheet for each site. All equipment used will be appropriately maintained and calibrated. Calibration and maintenance is covered for each piece of field equipment in its respective SOP (*Appendix 1*).

Water quality CoCs will be filled out during every lake and tributary sampling event. These sheets document date, time of sampling, locations and sampling personnel. They contain information on the sampling technique, the sample parameters to be collected at each depth and site, and what type of container the sample will be collected in. Field processing of samples such as field filtering or preservation are listed on the chain of custody. The sheets also have a section for sampling staff to note any deviation from SOP's. A list of CoCs used in this project for the UFI field water quality sampling (Table 27) can be found in *Appendix 6*.

Sample collection including sampling technique, and how to fill bottles correctly is covered in the field SOP (*Appendix 1*) for each type sampling technique, and for each individual parameter, in the lab SOP for each individual parameter (*Appendix 9-11*). Sample processing, handling and storage is covered in each individual water quality parameter SOP (*Appendix 9-11*). The CoCs also summarize sample collection, processing, handling and storage in the field (*Appendix 6*). The UFI CoCs also contain information on bottle codes and a space for the unique laboratory number to be assigned by the lab (*Appendix 6*). Container types are specified in UFI control document 12 (UFI, 2013a). The laboratory takes the sample temperature upon arrival and notes it on the CoCs when receiving the samples to ensure samples were handled properly prior to their receipt by the laboratory. Information for collecting and handling water samples is summarized in Table 28.

Biological field sampling methods for the Phase 1 project are listed in Table 29. UFI will be conducting the field sampling of phytoplankton and zooplankton following the first and second SOP listed in Table 29. The CBFS staff will be responsible for the field sampling of the dreissenid mussels following the third SOP listed in Table 29. All Biological SOP's can be found in *Appendix 2* and field sheets for biological sampling can be found in *Appendix 5*. Example biological CoCs are listed in Table 30 and examples can be found in *Appendix 7*. Biological sampling methods, handling, preservation, processing and storage is covered in the three individual SOP's (*Appendix 2*) as well as summarized on Table 31.

UFI field staff will collect water samples for bioavailability bioassays following the SOP (No. 2 in Table 25; see *Appendix 1*). UFI staff will be responsible for processing, handling and shipping particulate bioavailability bioassay samples to laboratory staff at MTUCEE. All SOPs used in sample handling through analysis are listed in Table 32 and can be found in *Appendix 3*. Bioavailability bioassay CoCs can be found in *Appendix 6*. Bioavailability sampling methods, handling, preservation, processing and storage is covered in the two individual SOP's (*Appendix 3*) as well as summarized on Table 33.

Table 28: Summary of sampling, preservation, storage, and holding times for water quality samples for lake and tributary sampling for the Phase 1 project. (X indicates sampling, -- no sampling; Lk. = lake, FF = fixed frequency (routine) tributary monitoring at the mouth, SE = synoptic event tributary monitoring upstream, E = event tributary monitoring at mouth with auto samplers)

No.	Parameter	Sampled		Sample Container	Field Handling/ Preservations Method	Laboratory Holding Times	Laboratory Handling/Storage, Preservation
		Lk.	Trib.				
1	TP	X	X	Lk., FF, SE - 500 ml glass bottle E - 1 L plastic bottle	Lk., FF, SE, E - stored in coolers on ice	28 days	preserved with 1ml 11N H ₂ SO ₄ so pH < 2; refrigerated at <6°C
2	TDP	X	X	Lk., FF, SE - 250 ml glass bottle E - 1 L plastic bottle	Lk., FF, SE - field filter 0.45 µm filter (SOP 114.1; <i>Appendix I</i>); stored in coolers on ice; E - stored in cooler on ice	28 days	preserved with 1ml 11N H ₂ SO ₄ so pH < 2; immediately upon receipt at laboratory refrigerated at <6°C
3	SRP	X	X	Lk., FF, SE - 250 ml glass bottle E - 1 L plastic bottle	Lk., FF, SE - field filter 0.45 µm filter (SOP 114.1; <i>Appendix I</i>); stored in coolers on ice; E stored in cooler on ice.	48 hours	immediately upon receipt at laboratory refrigerated <6°C
4	TIP	X	X	Lk., FF, SE - 500 ml glass bottle E - 1 L plastic bottle	Lk., FF, SE, E - stored in coolers on ice	28 days	refrigerated <6°C
5	NO _x	X	X	Lk., FF, SE - 125 ml plastic bottle E - 1 L plastic bottle	Lk., FF, SE, E - stored in coolers on	48 hours	refrigerated <6°C
6	t-NH ₃	X	X	Lk. FF, SE - 125 ml plastic bottle E - 1 L plastic bottle	Lk., FF, SE, E - stored in cooler on ice	7 days	refrigerated <6°C
7	TN	X	--	Lk. - 4 L plastic bulk chemistry bottle	Lk. - stored in coolers on ice	90 days	frozen 48 hours
8	TDN	X	--	Lk. - 125 ml plastic bottle	Lk.- stored in coolers on ice	90 days	frozen 48 hours
9	DOC	X	X	Lk., FF, SE - 40 ml glass vial E - 1L plastic bottle	Lk., FF, SE, E - stored in coolers on ice	28 days	preserve with H ₃ PO ₄ to pH < 2, refrigerate < 6 °C
10	POC	X	--	Lk. - 4 L plastic bulk chemistry bottle	Lk. - stored in coolers on ice	90 days	refrigerate < 6 °C
11	Chl	X	--	Lk. - 4 L opaque plastic bulk chemistry bottle	Lk. - stored in coolers on ice	21 days	filtered and frozen
12	Chl _{sp}	X	--	Lk. - 4 L opaque plastic bulk chemistry bottle	Lk. - stored in coolers on ice	21 days	filtered and frozen

No.	Parameter	Sampled		Sample Container	Field Handling/ Preservations Method	Laboratory Holding Times	Laboratory Handling/Storage, Preservation
		Lk.	Trib.				
13	DRSi	X	X	Lk., FF, SE - 125 ml plastic bottle E - 1L plastic bottle	Lk., FF, SE, E- stored in coolers on ice	28 days	refrigerate < 6 °C
14	UV ₂₅₄	X	X	Lk., FF, SE - 125 ml plastic bottle E - 1L plastic bottle	Lk., FF, SE, E - stored in coolers on ice	48 hours	refrigerate < 6 °C
15	c ₆₆₀	X	--	Lk. - 4 L plastic bulk chemistry bottle	Lk. - stored in coolers on ice	48 hours	refrigerate < 6 °C
16	Tn	X	X	Lk., FF, SE - 4 L plastic bulk chemistry bottle E - 1L plastic bottle	Lk., FF, SE, E stored in coolers on ice	48 hours	refrigerate < 6 °C
17	TSS	X	X	Lk., FF, SE - 4 L plastic bulk chemistry bottle; E - 1L plastic bottle	Lk., FF, SE, E stored in coolers on ice	7 days	refrigerate < 6 °C, filtered
18	FSS	X	X	Lk., FF, SE - 4 L plastic bulk chemistry bottle; E - 1L plastic bottle	Lk., FF, SE, E stored in coolers on ice	7 days	refrigerate < 6 °C, filtered
							refrigerate < 6 °C
19	PAV _m (by SAX)	X	X	Lk. - 4 L plastic bulk chemistry bottle	stored in coolers on ice	--	filter within 48 hours; filters sealed in clean plastic container

Table 29: List of SOP's used in the biological field sampling portion of the Phase 1 project; SOP can be found in *Appendix 2*.

No.	SOP Source	SOP Title
1	Cornell University	<i>Phytoplankton Sample Collection and Processing</i>
2	Cornell University	<i>Zooplankton Sample Collection and Processing</i>
3	Cornell University Biological Field Station	<i>Benthos Sample Collection (Dreissenid Mussel Density and Biomass)</i>

Table 30: List of chain-of-custodies to be used in the biological collection portion of the Phase 1 project; examples can be found in *Appendix 7*.

No.	Chain-of-Custody (CoCs) Description
1	phytoplankton and zooplankton
2	dreissenid mussels

Table 31: Summary of sample collection, preservation, storage, and holding times for biological samples for lake sampling for the Phase 1 project.

No.	Parameter	Collection Method	Sample Container	Field/Handling Preservations Method	Laboratory Handling/Storage, Preservation
1	phytoplankton	submersible pump	100 ml glass amber bottle	preserved 100 ml sample with 2 ml Lugol's solution, stored in coolers on ice	Uncounted portion of Lugol's preserved samples will be stored in glass screw-cap bottles in the dark at room temperature
2	zooplankton	metered Pudget Sound Closing Net of 50 cm diameter	250 ml plastic bottle	70% ethyl alcohol; stored in coolers on ice	Samples archived at room temperature in 70% ethyl alcohol in glass vials with expanded neoprene stoppers.
3	dreissenid mussels	benthic grab sample with Petite Ponar	100 ml - 1L wide mouth plastic bottles	3 samples pooled and diluted with lake water and passed through a 500 μ m screen sieve; placed in sample bottle and preserved with 95% alcohol	mussels manually picked from remaining benthos

Table 32: List of SOP's used in the bioavailability bioassay sample handling, processing and analysis portion of the Phase 1 project; SOP can be found in *Appendix 3*.

No.	SOP Source	SOP Title
1	Upstate Freshwater Institute	<i>405 bioavailabililty bioassay filtering</i>
2	Michigan Technological University (MTUCEE)	<i>bioavailability bioassay experiments</i>

B.3. Sample Handling and Custody

Sample handling and storage of water quality and biological samples in the field from the time of collection through relinquishing samples to the laboratory is covered in the individual field sampling SOP's (*Appendix 1* and *Appendix 2*) as well as in the individual laboratory parameter SOP's (*Appendix 9-11* and *Appendix 2*). The CoCs (*Appendix 6* and *Appendix 7*) also summarize this information. Laboratory handling, storage and holding times are covered in individual SOP's and summarized in Table 28. All information on water quality and biological field handling, storage, and laboratory sampling, handling, storage and holding times are summarized in Table 31. UFI's methods for water quality sample labeling, transport, tracking, receipt procedure, storage and acceptance by laboratory staff are all covered in detail in the Environmental Testing Laboratory and Field Quality Manual (UFI, 2010). UFI field staff are trained in field handling procedures and undergo an annual review of all of these procedures (Table 28) as discussed in *Section B.2*. UFI laboratory staff are trained in laboratory analytical procedures (Table 28) and undergo an annual review by the Laboratory Director.

CoCs will be completely filled out for all water quality and biological sampling events. These CoCs are used to establish an intact continuous record of the physical possession, storage and disposal of collected samples and aliquots. The CoC follows each sample that comes into the laboratory for analysis. This is necessary to preserve the traceability of samples and identify individuals who physically handled individual samples through the life cycle of the sample. CoCs document sampling date, time, location and sampling personnel.

UFI's CoCs contain the bottle ID, bottles being collected, including the type of bottle, and all analyses to be run on it. There is a comments section and a section for deviation from sampling protocol, a section for a signature and date for relinquishing of samples to the laboratory and a section for signature and dating by laboratory technicians that receive the samples and review the CoCs for completeness. All samples will be handled by the field staff as specified in Table 28.

UFI's field staff will transport the samples from the field to the UFI laboratory where they will relinquish the samples and chains of custody to UFI staff. UFI's laboratory technicians have been trained in procedures for sample receipt or rejection (UFI, 2010). Upon receipt of the samples at the laboratory, staff will assign unique sample IDs and note any lost or damaged samples. Any remaining problems encountered with equipment or samples will be recorded in the data

Table 33: Summary of sample collection, preservation, storage, and holding times for bioavailability bioassay samples for lake sampling for the Phase 1 project.

No.	Parameter	Collection Method	Sample Container	Field/Handling Preservations Method	Laboratory Holding Times	Laboratory Handling/Storage, Preservation
1	bioavailability bioassay collection at UFI	bucket	3-4 20L Jug	stored in coolers on ice	no set holding time filter within days of collection	fold filter paper and store in a petri dish in a freezer at <-10°C.
2	bioavailability bioassay at MTUCEE	--	filter paper stored in a petri dish	shipped on ice to MTUCEE	no set holding time	stored in petri dish in a freezer at <-10 °C.

packet for that analyte by the laboratory staff responsible for the analysis. Quality assurance samples such as field blanks will be assigned unique numbers and handled the same as other samples for any given analyte. Example copies of UFI CoCs for this project can be found in *Appendix 6*. Sample handling and storage for each analyte varies. Each UFI laboratory analyte SOP (*Appendix 9-11*) contains details of laboratory sample handling and holding times for the sample.

UFI field staff will be responsible for field sampling of phytoplankton and zooplankton using the Cornell SOPs (number 1 and 2 Table 25; *Appendix 2*). Training of UFI in these field sampling techniques is covered in *Section A.5* of this QAPP. UFI will be responsible for creating and filling out all water quality sampling CoCs, as well as phytoplankton and zooplankton CoCs (based on input from Cornell). The phytoplankton and zooplankton CoCs (*Appendix 7*) will be filled out by UFI staff and transported along with the samples to Cornell, where these will be relinquished to CUEEB lab staff responsible for analyzing these samples. These CoCs will be used to identify the samples, sample date, time and location of collection. They provide a traceability of samples and identify individuals who physically handled individual samples through the life cycle of the sample. CUEEB lab staff will be responsible for the laboratory portion of zooplankton and phytoplankton analysis. Training of Cornell staff for laboratory phytoplankton and zooplankton techniques is covered in *Section A.5* of this QAPP. The CUEEB methods for sampling and analyzing zooplankton and phytoplankton are discussed in *Section B.2*, Tables 29 - 31. These steps include zooplankton and phytoplankton identification and enumeration, and archival storage. CUEEB staff will maintain the CoCs for phytoplankton and zooplankton sampling throughout the life cycle of the samples in their laboratory.

The CBFS methods for sampling and analyzing dreissenid mussels are presented in *Section B.2*, Tables 29 - 31. CBFS staff will be responsible for creating and filling out all dreissenid mussels CoCs (*Appendix 7*). These CoCs will be used to identify the samples, sample date/time, location, and bottom depth where collected. They provide a traceability of samples and identify individuals who physically handled individual samples through the life cycle of the sample. These steps include sample collection, preservation, transport to CBFS, dreissenid species and size analysis, and archival storage.

UFI field staff will be responsible for water sample collection for bioavailability bioassays from the four tributaries and two WWTP discharges. They will follow steps laid out in the water collection SOP (*Appendix 1*). UFI will be responsible for creating and filling out CoCs for the water samples collected, to be used in conducting bioavailability bioassays. UFI field staff will transport these water samples to UFI where they will relinquish samples to a UFI staff member who is responsible for processing, storing and shipping samples along with their CoCs to MTUCEE. UFI staff will process the samples as indicated in the UFI SOP for filtering bioavailability bioassays (*Appendix 3*). Filtered samples will be stored in individual petri dishes that are labeled with the a sticker containing the volume filtered, the site name and date the sample is collected. These petri dishes are sealed with paraffin and stored in a cooler with freezer packs. These coolers will be shipped via an overnight courier to MTUCEE along with a chain of custody. These CoCs will be used to identify the samples, sample date, time and location where collected. They provide a traceability of samples and identify individuals who physically handled individual samples through the life cycle of the sample. MTUCEE laboratory staff will be responsible maintaining these CoCs and carrying them throughout the life cycle of the samples.

The MTUCEE methods for sample handling and storage throughout the life cycle of the bioavailability bioassays are covered in detail in the bioavailability bioassay SOP (*Appendix 3*).

B.4. Analytical Methods

Analytical methods for water quality used in the Phase 1 project are listed in Table 34. All water quality samples collected in this project will be analyzed by UFI. These laboratory SOPs are all part of the *Upstate Freshwater Institute Environmental Testing Laboratory Methods Manual* (UFI, 2013c). Other information on instrumentation, methods and reporting units is covered in *Upstate Freshwater Institute Control Document 12* (UFI, 2013a). Table 34 lists all UFI laboratory SOPs numbers and titles for laboratory methods to be used in this project. Copies of these laboratory SOPs are provided in *Appendix 9-11*. Other UFI staff handle the bioavailability bioassay samples (*Appendix 3*) and PAV_m (by SAX) samples (*Appendix 11*). These SOPs are listed on Table 35. These UFI staff are trained in the handling of the respective samples and follow the respective SOPs. Any deviations from this sample handling is noted on the CoCs for the samples. Laboratory staff from MTUCEE will be trained by knowledgeable staff to conduct all analysis that are a part of the MTUCEE SOP for bioavailability SOPs (Table 35). Copies of this bioavailability bioassay SOP can be found in *Appendix 3*. Measured sample constituents (Table 34) can be used to calculate derived constituents used in the final analysis in this project. All derived constituents are listed in Table 36, along with the equations used in their calculation from the measured constituents.

Analytical methods for the biological sampling used in the Phase 1 project are listed in Table 29. Phytoplankton and zooplankton samples will be analyzed by CUEEB staff. They will follow their respective SOP's which are provided in *Appendix 2*. Cornell Biological Field Station staff will be responsible for analyzing dreissenid mussels samples for this project. They will follow their respective SOP's which are provided in *Appendix 2*.

B.5. Quality Control

The water quality portion (UFI) of the project's quality control methodology is designed to establish and maintain standards that will ensure the validity of the data. UFI is responsible for maintaining internal quality control as part of their overall quality control system (UFI, 2010). The overall quality assurance is achieved by the UFI laboratory's implementation of the data quality objectives outlined previously in this QAPP (*Section A.4.*). This section describes how specific quality assurance objectives are achieved.

UFI field quality control includes use of field blanks and field triplicates (UFI, 2010). Field blanks test the sample handling process of UFI field staff. Field triplicates test the ability of the sampling procedure to be reproducible and therefore accurately reflect the variability of the system. Field quality controls also include calibration and maintenance of all rapid profiling instrumentation as well as pre-and post-calibration of the YSI sonde probes. Details on calibration and maintenance of rapid profiling instrumentation, as well as sonde calibration, are presented in *Section B.7* of this document. Their respective SOP's (Table 25) are provided in *Appendix 1*.

Table 34: UFI laboratory SOPs used in the Phase 1 project.

No.	SOP No.	SOP Title	Method No.	Appendix
1	114	Laboratory Filtering	N/A	11
2	107	Phosphorus, Orthophosphate (Soluble Reactive Phosphorus as P; SRP)	SM 18-21 4500-P E	9
3	108	Phosphorus, Total, Total Dissolved (as P; TP, TDP) low range	SM 18-21 4500-P E	9
	108.1	Phosphorus, Total, Total Dissolved (as P; TP, TDP) high range	SM 18-21 4500-P E	9
4	230	Phosphorus, Total Inorganic (as P; TIP) low range.	SM 18-21 4500-P E	9
	230.1	Phosphorus, Total Inorganic (as P; TIP) high range	SM 18-21 4500-P E	9
5	106.1	Nitrogen, Nitrate + Nitrite, Nitrite (as N; NO _x , NO ₂)	USEPA 353.2 Rev, 2.0	9
6	105.1	Nitrogen, Total Ammonia (as N; tNH ₃)	USEPA 350.1 Rev. 2.0	9
7	204	Nitrogen, Total, Total Dissolved (as N; TN, TDN)	SM 18-20 4500 N C	9
8	110	Carbon, Total Organic, Dissolved Organic (as C; TOC, DOC)	SM 18-21 5310 C (00)	10
9	214	Carbon, Total Particulate, Particulate Organic (as C; TPC,POC) low range	SM 18-22 5310 C	10
10	216	Chlorophyll <i>a</i> , fluorometric (Chla_fl)	USEPA 445.0 Rev. 1.2, 1997	10
11	216.1	Chlorophyll <i>a</i> , UV/VIS (Chla_sp)	USEPA 446.0 Rev. 1.2, 1997	10
12	111.1	Silica, Dissolved Reactive, (as SiO ₂ ; DRSi) low range	SM 18-19 4500-Si D.	10
	111	Silica, Dissolved Reactive, (as SiO ₂ ; DRSi) high range	SM 18-19 4500-Si D.	10

No.	SOP No.	SOP Title	Method No.	Appendix
13	222	<i>Turbidity (Tn)</i>	SM 18-21 2130 B	11
14	213	<i>Beam Attenuation Coefficient (BAC or c_{660})</i>	Wet Labs, 2011 Rev. V	11
15	101	<i>Solids, Total Suspended (AH filters; TSS_AH)</i>	SM 18-21 2540 D	11
16	202	<i>Solids, Fixed Suspended, Volatile Suspended (AH filters; FSS_AH, VSS_AH)</i>	SM 18-21 2540 E	11
17	223	<i>UV₂₅₄</i>	EPA/660/R-05/055	11

Table 35: Other SOPs used in the Phase 1 project

No.	SOP No.	SOP Title	Method No.	Appendix
1	405	<i>bioavailability bioassay filtering*</i>	DePinto, 1982	3
2	--	<i>bioavailablity bioassays including Orthophosphate (as P; SRP) Phosphorus, Total/ Total Dissolved, (as P; TP, TDP), and total suspended solids (TSS)</i>	DePinto, 1982; SM 18-21 4500-P E	3
3	404	<i>*PAV_m</i>	SAX/IPA; ASPEX, 2010	11

* part of *Upstate Freshwater Institute, Inc. Environmental Miscellaneous Methods Manual* (UFI, 2013).

Table 36: Derived constituents that will be determined from measured laboratory constituents (Table 20) for this project

No.	Parameter (units)	Abbreviation	utility	Calculation
1	particulate phosphorus (µgP/L)	PP	the sum of organic and inorganic particulate P; important P pool	$PP = TP - TDP$
2	dissolved organic phosphorus (µgP/L)	DOP	delayed, algal nutrient	$DOP = TDP - SRP$
3	total organic phosphorus (µgP/L)	TOP	important P sub-pool	$TOP = TP - TIP$
4	particulate organic phosphorus (µgP/L)	PP _O	the organic portion of particulate phosphorus associated phytoplankton	$PP_O = TOP - DOP$
5	particulate inorganic phosphorus (µgP/L)	PP _I	the inorganic portion of particulate phosphorus associated with minerogenic particles	$PP_I = PP - PP_O$

Most chemical analyses in this project will be performed by UFI's laboratory which is certified (NELAC ID 11462) by the New York State Department of Health (NYSDOH). A summary of the types of laboratory quality control (QC) samples used by UFI is presented in Table 37. The QC samples applied to each analysis are contained within the individual method laboratory SOP (*Appendix 9-11*). Tables 38 and 39 summarize QC conducted for each of the water quality parameters collected in this project. Table 40 summarizes the statistics tracked for each of the QC samples. The data obtained from these QC procedures are used to

- estimate quality of analytical data
- identify deficiencies
- determine need for corrective actions for deficiencies
- interpret results after corrective actions were taken

QC sample results that fall within UFI's acceptance criteria limits allow the data to be categorized as valid or acceptable.

UFI establishes control limits annually as specified in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). All QC data (Table 38-40) are assessed and evaluated on an ongoing basis. Individual QC is tracked and charted by each analyst. Control charts are designed to display the mean, the upper and lower warning limits and the upper and lower control limits. These charts become part of the data packet. The analytical process will be shut down and trouble shooting performed for any of the following reasons.

- a single measurement outside the control limits (run may continue but analyst must flag data appropriately)
- 2-3 measurements between the warning and control limits
- 7 consecutive measurements above or below the mean
- 6 consecutive measurements all steadily increasing or decreasing
- 14 consecutive measurements alternating up or down
- an obvious non-random pattern

All data outside the QC limits will be reported with the appropriate flag (UFI, 2010; UFI, 2013c). QC values outside the acceptable limits are considered outside of control and require a corrective action. The cause will be investigated and rectified. If a cause is found then a corrective action is indicated and documented. For example, a negative control such as a method blank (MB), evaluate possible contamination of a batch during the analysis. If the sample is contaminated (e.g. MB concentration > LOQ) the source of the contamination will be determined.

A second example is a positive control, such as a laboratory control sample (LCS), which evaluates the total analytical system. If LCS% recovery is outside established limits the run will be stopped until the system is brought back into control. In addition to these quality control samples UFI participates in the NYS Department of Health Proficiency Testing program every six months. Comparison between UFI laboratory and field measurements of c_{660} , Tn, and Chl will be made as described in detail in *Section B.10*.

Table 37: Summary of quality control samples used by UFI.

No.	Name	Abbreviation	Use	How often run
1	duplicate	DUP	replicate aliquot of the same sample taken through the entire analytical procedure	every 10 or one per sample batch if under 10.
2	reference	REF	a standard solution made from a different lot number from the calibration standard	every sample batch; follows the LCS
3	initial calibration verification	ICV	a mid-range calibration standard; analyzed after initial instrument calibration	first sample run
4	continuing calibration verification	CCV	a mid-range calibration standard analyzed periodically throughout the run; The CCV should be the same standard used for the ICV	every 10 samples after the ICV and the last sample of the run
5	laboratory control sample	LCS	a quality system matrix (typically type II DI water known to be free of the target analyte, spiked with a known verified concentration of analyte	one per batch follows initial calibration blank (ICB)
6	matrix spike	MS	a quality system matrix (typically type II DI water) containing a known volume and concentration of the target analyte, added to the sample matrix	every 20 samples or one per batch if less than 20
7	matrix spike duplicate	MSD	same as MS repeated on a replicate sample aliquot	minimum one per ~250 samples directly follows MS
8	initial calibration blank	ICB	a standard solution (matrix match; typically Type II DI water) that does not contain the target analyte and is used for initial calibration and zeroing the instruments responds	immediately follows ICV
9	continuing calibration blank	CCB	a standard solution (matrix match; typically Type II DI water) that does not contain the target analyte and is used to verify blank responses and freedom from carryover	every 10 or one per run follows CCV
10	method blank	MB	a type II DI water sample free of target analyte that contains all reagents and is subject to all laboratory preparation steps associated with the sample	one per batch where applicable

Table 38: Summary of phosphorus and nitrogen QC analyses and associated limits conducted by UFI.

No.	QC sample abbreviation	TP high	TP low	TDP	SRP	TIP high	TIP low	NO _x	t-NH ₃	TN	TDN
1	ICV	85.9 - 115.9 %	87.4 - 117.4%	87.4- 117.4 %	85.4- 115.4 %	85.0- 115.0%	92.7- 122.7%	86.4- 122.0%	74.2- 118.2%	86.8- 118.2%	86.2- 116.2%
2	ICB	<4.9 µgP/L	<3.4 µgP/L	<3.4 µgP/L	<1.4 µgP/L	<4.5 µgP/L	<1.9 µgP/L	<48µgN/L	<43 µgN/L	<343 µgN/L	<321 µgN/L
3	LCS	88.5 - 118.5%	88.1 - 118.1%	88.1- 118.1%	87.2- 117.2%	85.0- 115.0%	94.3- 124.3%	87.3- 125.3%	66.6- 118.8%	69.3- 136.5%	78.4- 128.8%
4	REF	87.4 - 117.4%	88.2 - 118.2%	8.2- 118.2%	87.1- 117.1%	85.0- 115.0%	93.0- 123%	87.5- 117.5%	90.5- 120.5%	80.4- 110.4%	80.9- 110.9%
5	MB	<4.9 µgP/L	<3.4 µgP/L	<3.4 µgP/L	<1.4 µgP/L	<4.5µgP /L	<1.9 µgP/L	<48µgN/L	<43 µgN/L	--	<321 µgN/L
6	DUP	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
7	CCV	85.9 - 115.9%	87.4 - 117.4%	87.4- 117.4%	85.4- 115.4%	85.0- 115.0%	92.7- 122.7%	86.4- 122.0%	74.2- 118.2%	86.8- 118.2%	86.2- 116.2%
8	CCB	<4.9 µgP/L	<3.4 µgP/L	<3.4 µgP/L	<1.4 µgP/L	<4.5 µgP/L	<1.9 µgP/L	<48µgN/L	<43 µgN/L	<343 µgN/L	<321 µgN/L
9	MS	91.3 - 121.3%	92.7 - 122.7%	92.7- 122.7%	85.4- 115.4%	85.0- 115.0%	89.6- 122.0%	69.9- 146.7%	69.9- 140.1%	79- 129.4%	85.2- 126.6%
10	MSD	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%

Table 39: Summary of carbon, chlorophyll, silica, and other parameter QC analyses conducted by UFI.

No.	QC sample abbreviation	DOC	POC low	Chl (µg/L)	Chl_sp (µg/L)	DRSi low	DRSi high	UV ₂₅₄	c ₆₆₀ (1/m)	Tn (NTU)	TSS (mg/L)	FSS (mg/L)
1	ICV	85.2-115.2%	83.1-128.7%	95-105%	--	85-115%	82.9-113.7%	85-115	--	82.3-127.5%	--	--
2	ICB	<1 mgC/L	<0.02 mgC/L	<0.3 µg/L	<0.4 µg/L	<0.09 mgSiO ₂ /L	<0.31 mgSiO ₂ /L	<0.3	<0.1 1/m	<1 NTU	--	--
3	LCS	83.5-113.5%	80.2-111.4%	--	--	85-115%	88.3-118.5%	--	--	82.1-122.3%	--	--
4	REF	84.5-114.5%	85.2-115.2%	--	--	85-115%	82.9-112.9%	85-115	--	86.5-118.9%	--	--
5	MB	<1 mgC/L	<0.02 mgC/L	<0.3 µg/L	<0.4 µg/L	<0.09 mgSiO ₂ /L	<0.31 mgSiO ₂ /L	--	--	--	<2.5 mg/L	<2.5 mg/L
6	DUP	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
7	CCV	85.2-115.2%	83.1-128.7%	95-105%	--	85-115%	82.9-113.7%	85-115	--	82.3-127.5%	--	--
8	CCB	<1 mgC/L	<0.02 mgC/L	<0.3 µg/L	<0.4 µg/L	<0.09 mgSiO ₂ /L	<0.31 mgSiO ₂ /L	<0.3	<0.1 1/m	<1 NTU	--	--
9	MS	80.4-117%	--	--	--	70-130%	67.8-132.8%	--	--	--	--	--
10	MSD	15%	--	--	--	15%	15%	--	--	--	--	--

Table 40: Summary of QC statistics tracked by UFI laboratory for various QC samples.

No.	QC sample abbreviation	Statistic Tracked in QC charts
1	ICV	percent recovery
2	ICB	value
3	LCS	percent recovery
4	REF	percent recovery
5	MB	value
6	DUP	relative percent difference (RPD) between 1st and 2nd samples
7	CCV	percent recovery on each; RPD between sample and ICV
8	CCB	value
9	MS	percent recovery
10	MSD	RPD sample and MS

Quality control methodology of the PAV_m samples run by UFI staff include three types; sampling, sample preparation and analytical. Field triplicates are collected to check the sampling technique (UFI, 2010). Sample preparation is tested by running filtering duplicates every 5 to 8 samples. The analytical method is tested with duplicate analysis being run on every 8 to 10 samples.

Quality control methodology of CUEEB is designed to ensure validity of the phytoplankton and zooplankton population assessments. Key aspects for the field collection include rejection of zooplankton hauls where the net was tangled, or not deployed and assurance that an accurate site location and depth are recorded for each sample. Key aspects for laboratory analyses include accurate sub-sampling and taxon identification. For all sample sites and dates duplicate samples will be collected and counted.

The identification and enumeration of phytoplankton taxa will be undertaken either by an established expert or by a technician carefully trained by the expert. In the latter case, either the expert or another independently trained expert in Hairston's laboratory will cross check identifications. When necessary identification of abundant taxa will be carried out in consultation with national experts for particular phytoplankton groups. Five percent of phytoplankton samples will be independently checked for taxonomic validity, as will any phytoplankton cells for which the technician is uncertain of taxonomic identification when they are present at greater than two cells in a standard count (i.e., all but very rare taxa). Counted cells will be identified at least to

genus whenever possible, though many small diatoms, flagellates and microflagellates cannot be identified to genus using standard counting methodologies, and identification to the genus level is not informative for establishing the abundance of major functional groups. Counting procedures will be cross-checked by duplicate counts, and by independent calculations of concentrations and biovolumes for 5% of samples. If enumeration or calculation errors are identified, mistakes will be traced back through all samples and corrected. Repeatability of counts on the same subsample will be within 5%, or the sample will be recounted.

Quality control methodology of CBFS is designed to ensure validity of the mussel population assessment. Key aspects for the field collection include rejection of benthic grab misfires (empty grabs or those where the jaws are open on return due to material blockage) and assurance that an accurate site location and depth are recorded for each grab. Key aspects for laboratory analysis include species identification, comparison of manual and automated shell counts, and length calibration checks. For 10% of the benthic samples, triplicate grabs will be analyzed separately rather than be pooled to provide a measure of site variability.

The identification of the two dreissenid species by the trained technician will be double-checked for 10% of the samples by dreissenid experts Jim Watkins and/or Kristen Holeck of CBFS through review of archived mussel samples and images. If more than 5% of mussels are misidentified the experts will meet with the technician to discuss and correct this discrepancy and all samples will be reanalyzed. Agreement of manual and automated shell counts and length measurements will be evaluated for 10% of the samples where both methods will be used. If shell counts or average length of primary histogram modes (populations often have age structure) differ by >10% images will be reanalyzed to evaluate the reason for this discrepancy. Potential image analysis errors include calibration errors, overlapping shells, low contrast with the background in the photo, and improperly set thresholds for minimum size. All samples analyzed solely by image analysis will be reviewed for clear outliers for shell counts and sizing. If discrepancies between the two methods cannot be explained all samples will be manually measured.

UFI field staff will be responsible for collecting water samples for bioavailability bioassays. UFI quality control methodology in sample collection is the accurate documentation of samples collection locations, dates, and times. UFI staff will be responsible for processing water samples to be used in running bioavailable bioassays. The water samples will be filtered to separate out the particulate form of phosphorus from the dissolved form. Bioavailability bioassays will be run on the particulate form. The sample processing, including filtering, is covered in detail in the established UFI bioavailability bioassay filtering SOP (*Appendix 3*). UFI quality control methodology in sample processing includes the inspection of the filter paper for tears upon completion of filtering. If there are tears in the filter paper the filtered samples are rejected and the filtering process is repeated if enough water sample is still available, as detailed in the UFI bioavailability bioassay filtering SOP (*Appendix 3*). The MTUCEE quality control methodology is designed to ensure validity of the particulate phosphorus bioavailability estimates. MTUCEE will follow all steps and quality control procedures summarized on Table 41 and detailed in the established MTUCEE bioavailability bioassay SOP (*Appendix 3*). Table 42 is a summary of statistics tracked for each of these QC samples. Corrective action is mandated when these objectives, as detailed in the SOPs, are not met.

Table 41: Summary of QC analysis conducted for the project by MTUCEE for analysis and acceptance criterion run on bioavailability bioassays for this project.

No.	QC sample abbreviation	SRP (µgP/L)	TDP (µgP/L)	TP (µgP/L)	TSS (mg/)
1	ICV	±10% @ 5 µgP/L	±10% @ 5 µgP/L	±5% @ 200µgP/L	--
2	ICB	<0.5 µgP/L	<0.5 µgP/L	<0.5 µgP/L	--
3	MB	<0.5 µgP/L	<0.5 µgP/L	<0.5 µgP/L	0.2 mg/L
4	DUP	±10%	±10%	±10%	--
5	CCV	±10% @ 5 µgP/L	±10% @ 5 µgP/L	±10% @ 5 µgP/L	--
6	CCB	<0.5 µgP/L	<0.5 µgP/L	<0.5 µgP/L	--

Table 42: Summary of QC statistics tracked by MTUCEE laboratory for analysis run on bioavailability samples.

No.	QC sample abbreviation	Statistic Tracked in QC charts
1	ICV	percent recovery
2	ICB	value
3	MB	value
4	DUP	relative percent difference (RPD) between 1st and 2nd samples
5	CCV	percent recovery on each; RPD between sample and ICV
6	CCB	value

B.6. Instrumentation/Equipment Testing/Inspection and Maintenance

For the water quality portion (UFI) of the Phase 1 project field instrumentation/equipment testing, inspection and maintenance is handled in individual field SOPs (UFI, 2013b), which are listed in Table 25. Copies of these field SOPs are provided in *Appendix 1*. Sondes undergo twelve maintenance steps as part of the maintenance program every time before calibration and use. These steps include cleaning and inspection of all parts by a UFI staff member trained in proper calibration technique as covered in *Section A.5* of this document. Spare parts and probes are maintained on-site to ensure the ability to properly maintain sondes and probes, and allow for as little downtime of equipment as possible. Maintenance of the supply of spare parts follow procedures described in *Section B.8* of this document and in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). The maintenance of the SeaBird profiling instrument is covered in the *UFI Field SOP No. 320: In situ SeaBird Profiling, Data Retrieval and Maintenance*, which is provided in *Appendix 1*. The maintenance of the YSI is covered in detail in the *UFI Field SOP No. 315: YSI Sonde Calibration and Maintenance*, which is provided in *Appendix 1*. Instrument maintenance log books are kept by field staff. These books contain a complete history of past maintenance both routine and non-routine. All trucks and boats are inspected and maintained on a regular basis as specified in the float plan (*Appendix 4*).

Laboratory technicians that operate the instruments conduct routine instrument preventative maintenance as specified in their SOPs (UFI, 2013c) which are listed in Table 34. Copies of these laboratory SOPs are provided in *Appendix 9-11*. The need for instrument repair is initially diagnosed by the technician who notifies the Laboratory Director. All instrument maintenance is performed in accordance with manufacturer guidelines. Preventative maintenance is scheduled according to manufacturers instructions. Maintenance is performed annually or when performance degrades (e.g. failure to meet quality control criteria). Instrument maintenance log books are maintained by laboratory staff. These books contain a complete history of past maintenance both routine and non-routine.

The UFI field staff will inspect the zooplankton net to ensure that it does not have holes or tears and that it deploys correctly. A back-up net will be available from the CUEEB in cases of equipment failure. In the laboratory, the automatic pipet will be inspected for accuracy and calibrated regularly.

The CBFS field crew will inspect the benthic grab to ensure that the screens have not been punctured and that the jaws are completely closing. A back-up grab sample will be available in cases of equipment failure. In the laboratory, weighing scales will be inspected for accuracy.

UFI field staff are responsible for inspecting and maintaining all field equipment used to collect water samples for bioavailability experiments as documented in the field sampling SOP (*Appendix 1*). UFI staff responsible for processing, handling and shipping bioavailability bioassay samples inspect and clean the filter units before each use. The MTUCEE laboratory staff uses an analytical balance and spectrophotometer in the bioavailability bioassay (see SOP *Appendix 3*). The analytical balances inspected and maintained on an annual basis by the manufacturer. MTUCEE laboratory staff inspect and clean this instrument before each use. If problems arise the analytical balance is sent to the manufacture for repair. The MTUCEE laboratory staff clean the optics on the spectrophotometer with a soft cloth and DI water before

each use. If problems arise the spectrophotometer is sent to the manufacture for repair. Maintenance logs for both instruments are maintained by the MTUCEE laboratory staff.

B.7. Instrument/Equipment and Model Calibration

B.7.1. Instruments and Equipment

Water column profiles of temperature, specific conductance, chlorophyll, and turbidity will be made with a Seabird calibrated according to the manufacturer's recommendations. For the SeaBird profiling instrument used for in-lake monitoring, the calibration of each component is done annually by each respective manufacture of the component. UFI performs an annual in-house calibration prior to the start of the field season to the beam attenuation coefficient sensor and the turbidity sensor. Procedures for this calibration can be found in *UFI Field SOP No.323 In situ Transmissometry Measurements with Wetlabs C-Star and UFI Field SOP No. 320 In Situ SeaBird Profiling, Data Retrieval, and Maintenance* respectively. Copies of both SOP's can be found in *Appendix 1*. For the YSI sondes used in tributary monitoring, the calibration procedure for each probe is described in *UFI Field SOP No. 315: YSI Sonde Calibration and Maintenance*, which is provided in *Appendix 1*. All calibration and maintenance activities performed on the sondes are documented in a log book.

Laboratory instruments/equipment that require calibration have the calibration procedures specified in their method laboratory SOPs listed in Table 34. Copies of these UFI laboratory SOPs (UFI, 2013c) are provided in *Appendix 9-11*. Records of calibration are maintained for each instrument. Typically analytes have between 5-7 calibration standards. The lowest standard in a calibration curve must be at or slightly below the LOQ (Table 4). The highest standard in the calibration curve must be in the linear response range. Any samples that fall outside the calibration range of the instrument have less certainty and need to be flagged (UFI, 2010). QC samples, LCS and REF (Table 37) are run after the calibration curve and before any samples to validate the calibration. If a LCS or REF fail the run should be stopped. Other QC samples are run at the start (ICV, ICB; Table 37), during, and at the end of the run (CCV and CCB; Table 37) to ensure calibration is maintained throughout the run of a batch of samples. Samples that fail these QC samples need to be appropriately flagged (UFI, 2013a; UFI, 2013c). All data results and copies of reports and certifications of calibrations, adjustments, acceptance criteria and due dates for next calibrations are maintained by the laboratory. Records are also kept by the laboratory for instrument damage, malfunction, repair and modification.

In the field, the UFI field staff will calibrate the plankton net flow meter by recording flow meter readings for vertical phytoplankton and zooplankton hauls from a series of depths during conditions of dead calm. Calculated volume sampled (cylinder of water traversed by the net from each depth) will then be used to establish the relationship between meter readings and sample volume. Automatic pipets are calibrated professionally at least every two years, and checked frequently using a graduated cylinder.

In the field, the CBFS field staff will compare the bottom sounder depth reading with the line out at the time the grab hits the lake bottom. In the laboratory, the primary equipment in need of calibration are weighing scales and the automated image analysis software. Scale readings will be

checked with standard weights. The image analysis is calibrated with a length scale with mm and cm markings. The size calibration will be included within each image taken of mussel shells.

Calibration is not required for any of the equipment used by UFI to sample, process and handle the bioavailability bioassay samples. MTUCEE laboratory staff calibrate their spectrophotometer prior to running each batch of phosphorus samples. This instrument calibration is covered in detail the bioavailability bioassay SOP. Records of calibration are maintained for each batch run. Quality control and quality assurance criteria for these standard curves and proper flagging of data that fail to meet these criteria are covered in detail in the MTUCEE bioavailability bioassay SOP (*Appendix 3*). All data results and copies of reports and certifications of calibrations, adjustments and acceptance criteria are maintained in the laboratory.

B.7.2. Analysis and Modeling

Calibration does not apply to the data compilation task B, data analysis (Task D, sub-task 10) or the loading analysis (Task C, sub-task 4) and mass balance analysis (Task E, sub-task 17). Loading rates of constituents of concern are calculated as products of concentrations and stream flow, in the case of tributaries, concentrations and discharge flow rates, in the case of discharge inputs. Stream flow will be measured continuously for Salmon Creek, Fall Creek, Six Mile Creek, and Cayuga Inlet, by the USGS. Discharges are also continuously monitored. Measurements of constituent concentrations, as is the norm, will be more limited, depending on the collection and laboratory analysis of water samples. Concentrations often systematically change during runoff events, a phenomenon that will be addressed through increased sampling during these intervals, as described in *Section B.1.2.1*. Multiple approaches have been developed to optimize estimates of concentrations during intervals without samples to improve loading rate estimates.

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). An "off-the-shelf" public domain two-dimensional hydrothermal/transport model (submodel of CE-QUAL-W2; W2 hereafter) has been chosen for this Cayuga Lake project. This model specification is supported by a number of factors: (1) structural features of the model are consistent with the Cayuga Lake basin (long/relatively narrow), (2) the success of an earlier version of this model (W2) in simulating key physical features of the lake (LSC EIS; Stearn and Wheler, 1997), (3) it is the most widely used hydrothermal/transport model in the US, (4) UFI has successfully set-up, tested, and applied W2 for a number of NYS lakes (several Finger Lakes) and New York City water supply reservoirs (Gelda et al., 1998; Gelda and Effler, 2007a; Gelda and Effler, 2007b; Gelda et al., 2009; Gelda et al., 2010), (5) NYSDEC and other regulators have approved related modeling programs that adopted W2, and (6) UFI has successfully linked phosphorus-eutrophication and turbidity (sediment) sub-models with W2 previously.

W2 is a dynamic, laterally averaged, two-dimensional (2-D) model. The model is based on the finite-difference solution of laterally averaged fluid motion and mass transport. The basic equations of the model that describe horizontal momentum, hydrostatic pressure, free water surface elevation, continuity, density dependencies, and constituent transport, have been presented in journal papers (Chung and Gu, 1998). The heat budget of the model represents the effects of evaporative heat loss, short- and long-wave radiation, convection, conduction, and back radiation (Cole and Wells, 2002). Model inputs include inflows and outflows, metrological

conditions (air temperature, wind speed and direction, dew point temperature and cloud cover or solar radiation), and the light attenuation coefficient for downwelling irradiance. UFI has been actively using W2 for multiple systems in New York since the mid-1990s. The model was developed and maintained by the Army Corp; maintenance and continuing upgrades have been turned over to Portland State University. UFI has implemented two upgrades of W2 for NYC reservoirs, without noteworthy changes in model performance. Version 3.7 of W2 will be implemented in this project.

W2 will represent the lake in the form of a grid of cells consisting of longitudinal segments and vertical layers. The geometry of the computational grid is determined by the boundaries of the longitudinal segments, the depth interval of vertical layers and average cross-sectional width. Segmentation will be implemented according to the guidelines of Cole and Wells (2002) and will be consistent with the water quality issues and the regulatory focus on the southern end of the lake. The hydrothermal/transport model has six coefficients that may be adjusted in the calibration process (Table 43); example values for a New York City reservoir are presented on the table for reference. The values of the coefficients for longitudinal eddy viscosity, eddy diffusivity and wind sheltering directly affect simulated hydrodynamics that in turn influence the distribution of heat. The other two coefficients, the fraction of incident solar radiation absorbed at the water surface and the coefficient for bottom heat exchange, directly influence the heat budget. Experience with application of W2 to multiple systems in this region (Gelda and Effler, 2007a; Gelda et al., 2009; Gelda et al., 2012) and elsewhere indicate these coefficients generally do not differ greatly, with the exception of the wind sheltering coefficient that reflects local topography.

Table 43: Two-dimensional hydrothermal/transport model (W2/T) coefficients for Schoharie Reservoir.

Coefficients	Values
Longitudinal eddy viscosity	1 m/s
Longitudinal eddy diffusivity	10 m/s
Chezy coefficient	70 m ^{0.5} /s
Wind sheltering coefficient	1.0
Fraction of incident solar radiation absorbed at the water surface	0.45
Coefficient of bottom exchange	7.0x10 ⁻⁸ W·m/m ² /s

Sources of data to specify the necessary inputs and state variables of W2 are listed in Table 44. Set-up and testing will initially focus on thermal stratification data collected at the southern stations (No.'s 1, 2 and 3) during the LSC monitoring program. Other data sets will be considered, as these emerge in review of available data from all sources. Temperature data collected in the intensive 2013 monitoring program will be a primary target for testing, starting in late fall of that year. Multiple years of thermal stratification will be addressed in testing this model. The hydrothermal/transport modeling process consists of five stages, model development, setup, testing, calibration and validation. The first stage of model development was completed previously in other projects (Gelda and Effler, 2007a; Gelda and Effler, 2007b, Gelda et al., 2009; Gelda et al., 2012). It will not be covered in this QAPP. The second stage, model setup, will utilize data from tasks 2 and 3. The third stage, model testing involves running the model and comparing the model predictions to system specific observations (from task 2 and 3).

Table 44: Listing of data type, description and source of data to be used in the set-up and testing of W2 for Cayuga Lake (Phase 1) .

Data Type	Data Description	Data Source
bathymetric data	volume and area of lake at 1m layers to designate 2-D segmentation	NYSDEC or Cornell GIS database
stream flows	daily average stream flows	U. S. Geological Survey
meteorological data	air temperature, dew point temperature, wind speed, and incident solar radiation; daily average	NOAA National Climatic Data Center (NCDC)
temperature profiles	in-lake temperature profiles for determining thermocline depth for volume weighting model results and observations and for a model testing data set from a station representative of the lakes lacustrine zone	LSC monitoring data, UFI
stream temperatures	observed stream temperatures	UFI
light extinction coefficient	light extinction coefficient at a site representative of the lakes lacustrine zone; this coefficient is calculated from measurements from the PAR sensor (SeaBird; Table 5)	UFI

The fourth stage of hydrothermal/transport modeling is model calibration. During the calibration stage, the hydrothermal/transport model is tested by adjusting or tuning model calibration parameters to achieve a model fit to a set of field data. The adjustment or tuning is based on a rational set of theoretically defensible parameters and is not merely a curve fitting exercise (Thomann and Mueller, 1987; and Chapra, 1997). Boundary conditions, initial conditions, forcing conditions and physical system parameters (e.g., bathymetry) were measured or determined before the calibration process began and are not varied during the calibration process. The calibration parameters or hydrothermal/transport model kinetics are varied within a reasonable range to obtain the best model fit (Chapra, 1997). The fifth stage of hydrothermal/transport modeling is validation. The hydrothermal/transport model is said to be validated once it is tested against an additional set of field data, preferably under different external conditions (Thomann and Mueller, 1987). During the validation process the hydrothermal/transport model calibration parameters or kinetics are not varied from the original calibration. If the hydrothermal/transport model fits, using the original calibration parameters, the model is said to be validated; otherwise the model may need modest recalibration (Chapra, 1997). The modeling process also typically involves sensitivity tests to determine the effect of various model inputs and coefficients. Sensitivity analyses typically give the modeler some qualitative insight into model performance.

Hydrothermal and water quality models are an approximation of natural systems. Since they are an approximation of reality they can not precisely represent a natural system. There is also no single accepted statistic or test that determines if a model is validated. Model performance will be evaluated both qualitatively and quantitatively.

Model applications from stages 2-4 include, data base development, system characterization, and setup and testing. QA issues are important throughout all of these phases but are especially important to the fourth and fifth phases (calibration and validation). The outcome of these phase establishes how well the model represents the study system. One goal of modeling is to accurately numerically represent the study system so the model can then be used to effectively make management decisions.

Performance of the hydrothermal/transport model will be evaluated both qualitatively and quantitatively. Salient features of the stratification regime on which model performance will be evaluated qualitatively will include (Gelda and Effler, 2007): (1) the timing of the onset of stratification in spring and turnover in fall, (2) the duration of stratification, (3) the dimensions of the stratified layers (e.g., epilimnion and hypolimnion), (4) the temperature of the stratified layers, and (5) overall temperature differences in the water column. These features of performance will be evaluated in various graphical formats. The primary quantitative basis of evaluating model performance adopted will be the root mean square error (RMSE) statistic (e.g., Thomann, 1982), calculated according to

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (T_{i,obs} - T_{i,prd})^2}{N}}$$

where N is the number of observations, $T_{i,obs}$ is the observed value of the i th observation of $T_{i,obs}$ and $T_{i,prd}$ is the predicted value of it observation of T . The RMSE is statistically well behaved and is an indicator of the average error between observations and predictions. A lower RMSE indicates a better model fit to observations. The target RMSE for adequate performance in simulating the spring to fall thermal stratification for the lake is 2 °C (includes all dates and depths; Gelda and Effler, 2007a).

For the watershed modeling CUBEE is adopting a two tier, ensemble approach. Tier one will allow for computationally efficient estimates of tributary loads to the entire lake. These loads are necessary inputs to the phosphorus/eutrophication lake model. CUBEE will use an ensemble of the General Watershed Loading Function (GWLf) and Soil Water Assessment Tool (SWAT) for this task. GWLF has previously been applied to Cayuga Lake and the watershed modeling team has also had experience using this model in the NYC watersheds as part of its collaboration with the New York City (NYC) Department of Environmental Protection (DEP) and NYSDEC. The model is relatively simple can be calibrated with a relatively low level of complexity. Unfortunately, GWLF lacks some potentially important processes, primarily in-stream erosion, which is a considerable source of sediment to the lake. SWAT has the capacity to simulate in-stream erosion. The primary short-coming of SWAT is that its increased complexity makes it somewhat more difficult to meaningfully calibrate. By using both models CUBEE will be able to obtain good estimates of phosphorus and sediment loads to the lake and meaningful insights to the sources of these materials. Unlike GWLF, SWAT also maintains a coarse nutrient budget to estimate pollutant loads for each land use/soil type combination, which will allow us to make long term simulations as well. Both models discretize watersheds into sub-basins and simulate storm runoff and pollutant transport as a function of land use, soil type, and soil moisture status. The output from these models is nutrient, sediment, and water fluxes or loads at the mouth of each tributary.

The tier-two modeling effort will primarily focus on the tributary watersheds feeding the southern end of Cayuga Lake, and other sub-watersheds that may constitute unusually large phosphorus and sediment contributions to the lake. Unlike the tier-one models, the models CUBEE will use in tier-two allow us to simulate hydrologic and pollutant transport processes at scales representative of those at which CUBEE make management decisions, e.g., riparian areas, fields and sub-fields. This level of precision is especially useful when developing model scenarios to investigate the impacts of different management strategies (which will be part of Phase 2). CUBEE will also use an ensemble approach to the tier-two modeling effort, employing the Variable Source Loading Function (VSLF) and SWAT-VSA. VSLF was derived by the CUBEE group from GWLF, and has been subsequently used by the NYC-DEP (Schneiderman et al., 2007; Easton et al., 2008a). SWAT-VSA was also developed by the CUBEE group to capture small scale hydrologic and management patterns while retaining the other functionalities of SWAT (e.g., Easton et al., 2008b). CUBEE has previously applied VSLF to Salmon Creek, so CUBEE has good confidence that it will work in the Cayuga Lake watershed. As with the use of SWAT in tier-one, SWAT-VSA can simulate in-stream erosion processes and maintain nutrient budgets in the landscape, which VSLF cannot.

In addition to the meteorological data (Table 44), the watershed models will require the following input data: digital elevation models (DEM) (available from the USGS), soil data (USDA SSURGO database), land use/land cover (several sources, e.g., Cornell University

Geospatial Information Repository, CUGIR), and stream channels (available from the USGS). Other data sets will be considered if/as they emerge.

As with W2, the watershed modeling process includes five stages, model development, setup, testing, calibration, and validation (sometimes called corroboration). Model development has been completed previously, SWAT (Arnold et al., 1998; several updates), GWLF (Haith and Shoemaker, 1987; several updates), VSLF (Schneiderman et al., 2007), and SWAT-VSA (Easton et al., 2008a). These will not be covered in this QAPP. The second stage, setup, will utilize some of the data from Task B (*Section A.3.4*); see preceding paragraph for data types. The models will be setup to run for each sub-basin independently.

The third stage, testing, involves running the watershed model for sub-basins with measurements of discharge, nutrient concentrations, and sediment concentrations and comparing model results to the measurements. The measured data will be compiled as part of Task B (*Section A.3.4*). The fourth stage, model calibration, follows essentially the same procedure as described for the hydrothermal/transport model, W2. Model parameters that CUBEE is not able to determine independently will be adjusted within an acceptable range to achieve the best model fit. Embedded in the calibration process will be sensitivity tests to determine how responsive model predictions are to small changes in model parameters. The last step, typically referred to as validation, tests the model predictions against independent measurements, i.e., measurements other than those used to calibrate the model. When very few data are available, the calibration/validation procedures are often coupled in a process called "bootstrapping". This involves splitting the data set into a random subset that is used to calibrate the model and the remainder, which are used to validate the model. This process is repeated many times with different random calibration/validation subsets to determine best-fit average parameters. CUBEE anticipate using the tributary data collected in this Phase 1 project for final validation of the watershed models and for assessing the confidence in our predictions. Data collected on the streams by UFI will be shared with CUBEE in a timely fashion in the form of XLS spreadsheet for use with watershed modeling.

The performance of watershed models is typically assessed using the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970):

$$E = \left(\sum_{i=0}^n (Y_i^o - Y_i^p) \right) / \left(\sum_{i=0}^n (Y_i^o - \bar{Y}_i) \right)$$

Where n is the number of measured values, Y^o is a measured or observed value, Y^p is a model predicted value and \bar{Y} is the average of all the measured values. For daily discharge, an $E > 0.65$ is considered very good and $0.65 > E > 0.50$ is considered satisfactory to very good (Moriassi et al., 2007). Because discharge is a large factor in determining sediment and phosphorus loads, similar but somewhat lower E values would likely apply to these predictions.

For sub-basins without measurements, CUBEE will apply the parameters from the calibrated basin(s) that is most similar in topography, land use, and soils. Then all sub-basins can be run to estimate daily fluxes of water, nutrients, and sediments to the lake from each tributary.

Once the watershed models are fully calibrated and tested, they will be used to both forecast and hind-cast changes in water quality relative to current conditions. Forecasting simulations will consider both large-scale and small-scale changes to the watershed. Large-scale changes include projected changes in precipitation, temperature, and major land uses. Small-scale changes include establishment of best management practices, both structural (e.g., riparian buffers) and behavioral (e.g., timing and location of animal waste disposal). GWLF and SWAT will be only be used to examine water quality responses to large-scale changes because they do not consider the landscape at small enough units to meaningfully represent small-scale changes. For these the CUBEE will use VSLF and SWAT-VSA. Structural BMPs are incorporated into these models by changing the physical base-maps and behavioral BMPs are represented by changes to the input files that describe day-to-day inputs to the watershed (see Easton et al. 2008a). Both VSLF and SWAT-VSA are flexible enough to represent most forecasted scenarios. Hind-casting will be done to estimate water quality under "pristine" or pre-development conditions. The CUBEE will use historical documents from the Cornell Library, the History Center in Tompkins County, and similar sources of archived historical material to approximate landscape conditions prior to European settlement of the watershed, e.g., fraction of forest vs. open-space, location of major wetlands. All changes to the landscape will be fully rationalized and the sources of information used to justify these changes will be documented. Documentation will be detailed enough for others to replicate our pre-settlement watershed. There will invariably be a high degree of uncertainty in re-establishing this pre-development landscape and precise locations of specific features is unlikely. Therefore CUBEE will use GWLF and SWAT to establish these hind-casted or baseline water quality conditions.

B.8. Inspection/Acceptance Requirements for Supplies and Consumables

UFI has a purchasing officer who maintains a log book of all laboratory equipment and supplies and a list of current vendors. Prior to the acceptance of any supplies and consumables for the laboratory or field, the items will be inspected for breakage or discrepancies with packaging lists. These are noted in the log and all packaging slips given to the purchasing officer. This process is outlined in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010).

CUEEB laboratory supplies are ordered and orders are checked by the same person - the Research Support Specialist in the CUEEB laboratory. Records of all supplies ordered are maintained by the Cornell University purchasing program through which they are ordered and verified by CUEEB accounting staff. Prior to the acceptance of any supplies and consumables for the laboratory or field, the items will be inspected for breakage or discrepancies with packaging lists.

CBFS staff will inspect delivered supplies and consumables for breakage or discrepancies with packaging lists prior to acceptance. All package slips are collected and archived by the laboratory manager of CBFS.

As stated above the UFI purchasing officer will be responsible for ordering any supplies and consumables needed for the field, processing and shipping of bioavailability bioassays samples. Prior to the acceptance of any supplies and consumables the items will be inspected for breakage

or discrepancies with packaging lists. These are noted in the log and all packaging slips given to the purchasing officer. This process is outlined in detail in the “*Environmental Testing Laboratory and Field Quality Assurance Manual*” (UFI, 2010). All supplies and consumables for conducting the bioavailability bioassay experiments will be ordered by the MTUCEE project team. MTUCEE laboratory staff will inspect delivered supplies and consumables for breakage or discrepancies with packaging lists prior to acceptance. All package slips are collected and archived by the project leader of MTUCEE.

B.9. Non-direct Measurements

The Phase 1 project will use compiled system-specific data sets related to this issue. The goals are to acquire valuable related insights from the earlier work and to develop data sets that can be used to support calibration and validation of the hydrothermal/transport model (W2) and the watershed model in this project (Phase 1), and validation testing of the future (Phase 2) phosphorus/eutrophication model. The monitoring program documented in this Phase 1 QAPP will support calibration of the phosphorus/eutrophication model. Validation of that model will rely on already existing data sets for the system. All appropriate data sets for the system will be pursued. Particular emphasis will be placed on the following types of information.

- USGS flows for tributaries,
- meteorological data,
- discharge information for point sources, including flow and constituent concentrations,
- lake intake information for related constituents,
- historical limnological information-particularly P, phytoplankton and clarity,
- historic tributary information-particularly for P and suspended solids,
- food web studies on the lake over the last 20 years that could influence the phosphorus/eutrophication issue,
- all related technical reports and papers.
- bathymetric data

This will involve a comprehensive search. The extent of potentially valuable data sources is not known at this time. Potential data sources include:

- earlier studies by UFI.
- NYSDEC monitoring data.
- Cornell University - LSC-based lake monitoring data.
- Cornell University-research studies on lake/tributaries.
- other local academic institutions - research studies.
- monitoring data by discharging facilities.
- intake monitoring by water supplies and other users.
- United States Geological Survey (USGS).
- National Oceanic & Atmosphere Administration (NOAA).

- National Climatic Data Center (NCDC).
- Community Science Institute (CSI)
- Ithaca Area Waste Water Treatment Plant (IAWWTP)

A table of compiled data sets and their potential utility will be maintained through the project. Data files will be transferred to all appropriate entities. In addition, Figure 9 is a conceptual diagram of how data will flow from data sources including community stakeholders to a publicly accessible web site maintained by Cornell. The Tompkins County Water Resources Council has convened a subcommittee, the “Cayuga Lake Monitoring Partnership” (CMP; Figure 9), that has been active for several years on water quality issues related to Cayuga Lake and the watershed. This partnership, chaired by Roxanna Johnston of the City of Ithaca, has offered to support the project by identifying and compiling existing data sets of potential utility. The website maintained by the Cornell project management team (Figure 2) possible at the Cayuga Lake Modeling Project (CLMP) website (<http://energyandsustainability.fs.cornell.edu/util/clmp/>). It will be well organized and contain meta data (see example *Appendix 8*) on all data sources as well to links to active data sets. This website will be accessed by scientists on the project when needed for appropriate modeling or data analysis efforts.

UFI's procedures/criteria for determining the usability of secondary (non-direct) data are described here. The intent is to utilize data collected as part of local research and monitoring efforts to the greatest extent possible. The USEPA has developed guidelines (USEPA, 2000; USEPA, 2002d; USEPA, 2006b) for screening data sets developed by others for use in modeling projects. UFI will use these guidelines as an important starting point for their review. All data that were collected under approved QAPPs have an important starting advantage. Data not collected under approved QAPPs will receive even greater scrutiny. All laboratory analyses from ELAP or NELAC certified laboratories will also have an advantage. However, the lack of such certification will not itself be a basis for rejection. UFI has extensive experience in review of secondary data for potential use in limnological analysis and modeling for Onondaga Lake and the New York City watershed. The data will be reviewed and analyzed by UFI professional staff experienced in both limnology and modeling. Consistency with limnological paradigms and other system-specific data sets that address the same topic is a critical feature of the UFI review. This will be evaluated for all data sets, including those for which QAPPs were prepared. Analyses typically include graphing to evaluate seasonal, historic and vertical consistencies. Methods/protocols for all collected data will be critically reviewed. Reviews will be conducted above and beyond the formal QA/QC procedures and protocols of the source agency. All data that passes the UFI review and is identified for further use (e.g., support for validation of phosphorus/eutrophication model of Phase 2), will be addressed by the combined "UFI-Cornell University scientific staff - NYSDEC technical staff" group for its general acceptability for future use. An associated agenda item will be included in the four planned technical meetings. As required by the USEPA (USEPA, 2002c), a related disclaimer will be added to the deliverables; "the quality of the secondary data has not been evaluated by USEPA for this specific application".

The CUBEE will use the same procedures and subset of data compiled as part of Task B (*Section A.3.2*), with emphasis on the tributaries and watershed characteristics relative to watershed modeling. As noted in *Section B.7.2.*, additional data will include: digital elevation models (DEM) (available from the USGS), soil data (USDA SSURGO database), land use/land

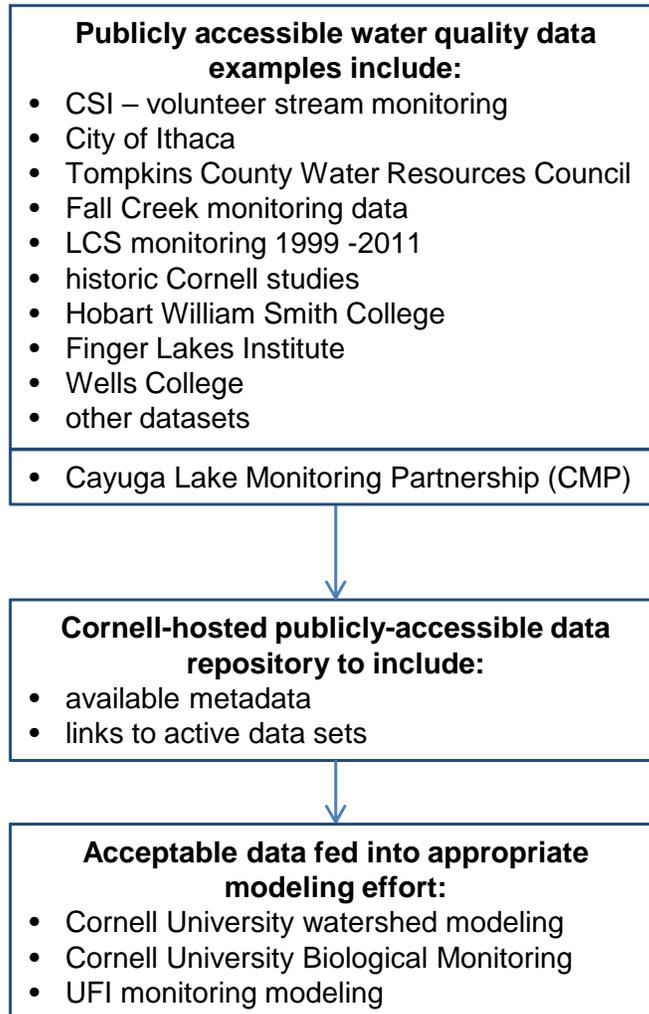


Figure 9 . Flow diagram to showing the potential pathways for compiling secondary data.

cover (several sources, e.g., Cornell University Geospatial Information Repository, CUGIR), and stream channels (available from the USGS). If new or previously unknown data are discovered during this project, metadata will be developed for each set fully describing the data. For geospatial data The CUBEE will adopt the standard ISO 19115-2 format for metadata. For water quality, weather, or discharge data, CUBEE will use the generic metadata form the CUBEE group has developed (see *Appendix 8*). A table of compiled data sets and their potential utility will be maintained through the project. Data files will be transferred to all appropriate entities.

B.10. Data Management

The procedures for managing UFI field and laboratory data are documented in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). All data generated by the laboratory and field program are stored in hard copy and electronically in secure locations. Electronic data are stored on a server with restricted access through a local area network (LAN). Access to the server is password protected. This server is backed up routinely. Backups can not be edited or deleted except by the IT/database manager. All data stored in the laboratory database are secured from unauthorized access. UFI accesses this data through use of a proprietary database interface (DataBoy).

All data collected by the UFI field staff are either hand written or electronic. UFI field staff upload all electronic data from field computers or data loggers to a designated location on a secure server. Handwritten UFI field data are entered using a predetermined format into a commercial spreadsheet. The format is in a “database style” that documents the system, station, sampling date and time. For this project the spreadsheets will contain T (°C), SC (µS/cm), Chl (µg/L), Tn (NTU) and SD (m). Entry of data into these sheets and uploaded electronic data are overseen by the UFI field program supervisor. All data are reviewed by the UFI field program supervisor or other qualified UFI staff.

UFI’s laboratory uses DataBoy for entering, tracking, storing, retrieving and reporting all data collected or analyzed by UFI’s laboratory (UFI, 2010) as well as laboratory quality control information for each analyte. Analytes being entered into the database are logged in from the CoC by trained laboratory technicians whose primary responsibility involves database activities. All data analyzed by the laboratory are entered into electronic data packets which are commercial spreadsheets. Each analyte has its own UFI template that is filled in by typing or cutting and pasting from an instruments electronic output. These data packets are committed to the database by the primary laboratory technician for any given analyte. These data are accessible by other trained UFI staff for use, but are write protected so users may not change numbers.

Task B of this project is to compile data sets that already exist for bathymetry and water quality on these systems. All data obtained that are electronic will be converted to a database style format in a commercial spreadsheet with system, station, date, time and any data that exist along with the source of the data. Hard copy data will be entered in this same format style in a commercial spreadsheet. Data for this project, for the most part, exist in electronic format as commercial spreadsheet files in space or tab-delimited ASCII file format. All profiling and hand held data collected in this project will be reported in the units specified on Tables 5-6. Measurements of SD will be reported in meters. All latitude and longitude measurements of sampling sites (Table 9, 21, 22, and 24) will be reported in decimal degrees. Laboratory water

quality parameters will be reported in the units specified in Tables 4, 20, and 34. All biological parameters will be reported in commonly used units. Any data obtained in hardcopy form will be entered into a spreadsheet and screened against the hard copy by reviewing the printouts and comparing them to the original paper documents. All data obtained for this project including all data used in the hydrothermal/transport modeling will be compiled and placed in a centralized location, organized by data source. Records of hard copy data will be maintained by UFI staff. Electronic data will be stored on a secured server accessible to UFI staff only. Electronic backups of the data will be maintained and will be write protected. The data will be formatted into the appropriate input files for analysis and modeling. The original data, as well as the input files and QA/QC graphs, will be maintained by UFI in hardcopy and electronic format to document the data management process. All data will be maintained for at least 5 years beyond completion of the project.

All handwritten field sheets from UFI field staff will be transferred to electronic spreadsheets and archived. In the CUEEB laboratory, species identifications, phytoplankton and zooplankton counts, and sizes will be handwritten and then transferred to an electronic spreadsheet. Quality checks will be done continually to ensure that data within handwritten field/lab sheets and electronic spreadsheets are consistent.

All handwritten field sheets from CBFS field staff will be transferred to electronic spreadsheets and archived. In the laboratory, species identifications, manual shell counts, and total wet weight will be handwritten and then transferred to an electronic spreadsheet. Images and automated shell counts and sizes will be stored electronically. Quality checks will be done continually to ensure that data within handwritten field/lab sheets and electronic spreadsheets are consistent.

Packaging slips and CoCs will be maintained by UFI staff responsible for processing and shipping samples to MTUCEE. MTUCEE laboratory staff will transfer all handwritten CoCs and handwritten laboratory data sheets, and instrument printouts to an electronic database. Quality checks will be done continually to ensure that data within handwritten field/lab sheets and electronic spreadsheets are consistent.

The CUBEE team will compile data from Tasks B and H and from measurements made by UFI. All data will be stored in a "database" using commercial software; a geo-database will be used to store all geospatial data and the locations of all point measurements. Electronic data will be copied and pasted into the database and hard copy data will be entered manually in this same format style as the electronic data. Once in the database, hardcopy data will be screened against the original hard copy. All data obtained for this project will be placed in a centralized location in the CUBEE lab on a dedicated hard disk. An associated metadata file will be developed as the database is populated. Electronic backups of the data will be maintained and will be write-protected. The data will be formatted into the appropriate input files for modeling. CUBEE anticipate maintaining the database with the expectation that it will eventually be publicly available pending approval from the project team.

C. Assessment and Oversight

C.1. Assessment and Response Actions

Assessment and oversight of UFI field and laboratory staff are covered in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). In addition to training of field and laboratory staff (*Section A.5* of this QAPP), both groups undergo annual internal reviews and third party external review by the NYSDOH. These reviews focus on the overall implementation of UFI's quality system to ensure proper sample collection, handling, tracking, analysis and reporting. Also as part of its overall quality system UFI tracks deviations from established protocols. In the field this is handled on field sheets and CoCs. In the laboratory this is handled within data packets and corrective action forms for the individual analytes. Errors that result in the field and laboratory typically occur because of analytical or equipment problems or problems resulting from deviation from procedures. Data that falls outside of control limits (see *Section B.5* of this QAPP) are flagged and documented through use of memos and corrective actions (UFI, 2010).

A field audit will be conducted by the UFI Field Program Supervisor once during the mid-summer of the field season. An example field audit form is presented in *Appendix 8*. The internal laboratory audit will be conducted in early November, 2013 with audit results available 10 days after the audit and audit responses due 30 days after that. The laboratory audit follows the NYS ELAP standards and uses a standardized check list. NYSDEC has the authority to audit any part of this project, at any time during the course of this project, for any reasons they deem necessary.

UFI's corrective action process has four steps: 1) a procedure for determining the root cause of the problem, 2) selection and implementation of the appropriate corrective action, 3) monitoring of the corrective action, and 4) additional follow-up actions or audits.

UFI field staff notify the UFI Field Program Supervisor of any problems encountered in the field. A field correction action form is filled out. An example is provided in *Appendix 8*. The UFI Field Program Supervisor follows the four steps listed above to complete the corrective action process for the field.

For UFI's laboratory either the analyst or laboratory director may be responsible for identifying a potential problem or issue. The laboratory director is responsible for determining the course of action to be taken and the time frame for the corrective action process based on the nature and severity of the problem. The laboratory director will work in conjunction with the analyst to ensure the corrective action plan is properly executed. The laboratory director will determine when the problem has been resolved and is authorized to close out the investigation.

Once a (potential) problem has been identified, the analyst and laboratory director meet and a corrective action (CA) process will be initiated. The CA process is based on a root cause analyses of the problem, including a review of all records and actions related to the problem, a review of the method with the technician, and a discussion outlining any areas of uncertainty or possible excursions. A remedial plan will then be laid out. This process typically takes anywhere from 1 to 5 days to accomplish depending on the nature of the problem. Follow-up should occur 30 - 45 days after the remedial plan has been implemented to see if the CA was successful. The CA will

be considered resolved if the process implemented was successful; otherwise, a new corrective action will be implemented.

Model performance assessments will be made frequently by the UFI modeling staff during the testing phase for the hydrothermal/transport model. Performance audits will consist of comparing the model output to observed data collected on the respective systems. The individual modeling team members will review model performance to ensure the model behavior of the state variable makes sense and is consistent with historic data and the modelers understanding of the system and experience with this particular model. This hydrothermal model will be linked to a water quality model in Phase 2 of the Cayuga Lake project. During the Phase 1 modeling process of comparing data to model outputs the modeling code will be examined to determine if discrepancies in parameter predictions and observations are a result of modeling errors. If any code errors are found, these errors will be fixed, documented and the overall effect of the errors on model calibration/validation will be documented.

Testing of the hydrothermal/transport models is covered in *Section B.7*. This section covers QA/QC of the testing process. One primary point of concern in modeling is QA/QC of model inputs. Data files for task 6 will be generated from the data source files into the proper file format required for the individual model's inputs. QA/QC of these data will take three main forms. The model input data will be graphed and inspected visually by the modeling staff. These graphs will be compared with input data from historic data from Task 3 to determine if they fall in expected ranges. Any anomalies will be checked against original source data. Data format will be QA/QC'ed by running it in the model. Typically format problems show up during the original model run because the model either will not run or the model runs and gives obviously erroneous results. The final QA/QC of input data are the model output results themselves. Errors in input results typically lead to model parameters behaving in a way not expected based on experience with the model. The hydrothermal/transport model input files, setup programs and code will be tracked with a software configuration management (SCM) tool. This software is discussed in more detail later in this section.

Sensitivity analyses are model runs conducted with coefficient ranges that differ from the calibration values, often with limits that are below and above the calibration values by a certain percentage. Such analyses are routinely included in an overall modeling analysis. Sensitivity analyses yield insights into model behavior and illustrate the reliability of model predictions relative to acknowledged or independently quantified uncertainty in model inputs and coefficients.

No code enhancements are anticipated for task E (7-19). The 2-D hydrothermal/transport model has already been calibrated and validated for other systems (Gelda et al., 1998; Gelda and Effler, 2007a; Gelda et al., 2009; Gelda et al., 2012). UFI developed software is logged and tracked with a software configuration management (SCM) tool, using the Subversion Version Control System. This tool tracks changes made to the hydrothermal/transport model over time. Additionally the SCM tool allows multiple developers to work together on common source code, tracking individual developer's changes and merging these changes into a single source. The SCM tool provides the modelers with a documented history of the hydrothermal/transport model changes. Any errors that may be found, and code development and enhancements made to the code, will be documented in the final report. All hydrothermal/transport model coding is done in Fortran.

Prior to release, the hydrothermal/transport model will be assigned a version number. At the time of submission all bug-fixes and model enhancements are documented in the final report. The submission letter will clearly state the version numbers for each piece of software. In the event that changes are required or bugs are found after this submission, UFI protocol is to make all fixes/changes and re-submit the software with the appropriate version number changes. Any changes between the original submission and this supplemental submission will be documented in a memo to the project managers.

The software and hardware requirements for the 2-D hydrothermal/transport model (task E; 9-17) are as follows:

Computer Hardware:

- > 1 GHz processor
- Minimum 32 MB of memory
- Minimum 124 MB hard drive space available

Software:

- Windows Version Windows 9x, 2000, XP, Vista, Windows 7 operating system
- Optional software - a word processor and spreadsheet software to prepare and process various input and output files

UFI and CUEEB record deviations from the outlined SOPs on field sheets, laboratory data sheets, and chain of custody forms. These sheets and forms will be checked continually by the project leader at CUEEB to identify potential issues. Errors can occur because of equipment failures or deviations from protocols. Once an error is identified these data will be flagged. Some laboratory errors (phytoplankton and zooplankton counts, size measurements, species identifications) can be corrected by returning to archived samples and repeating the analyses.

CBFS tracks deviations from the outlined SOPs within field sheets, laboratory data packets, and CoC forms. These forms will be checked continually by the project leader at CBFS to identify potential issues. Errors can occur because of equipment failures or deviations from protocols. Once an error is identified these data will be flagged. Some laboratory (shell count or size measurement) errors can be corrected by returning to archived samples and repeating the analyses.

UFI staff will track all deviations from protocols for sampling and handling of bioavailability samples outlined in the field sampling SOP (*Appendix 1*) and bioavailability bioassay SOP (*Appendix 3*). MTUCEE laboratory staff will track deviations from the protocol outlined in the bioavailability bioassay SOP. These forms will be checked continually by the project leader at MTUCEE to identify potential issues. Corrective actions will be identified and implemented as required. Errors can occur because of equipment failures or deviations from protocols. Once an error is identified these data will be flagged. Sample analysis will be repeated when archive samples exist.

Watershed model performance assessments will be made frequently by the watershed modeling staff during the testing, calibration, and validation phases for the watershed models. Performance audits will consist of comparing the model output to observed data collected on the

respective systems. The individual modeling team members will review model performance to ensure the model behavior of the state variables is consistent with our understanding of the physical system, with historic data and the modelers experience with the particular models. The watershed models will be linked to a water quality model in Phase 2 of the Cayuga Lake project. If any code errors are found during the watershed modeling in Phase 1 process of comparing measured data to model outputs, these errors will be fixed, documented, and the overall effect of the errors on model calibration/validation will be documented. Testing of the watershed models is covered in *Section B.7.2*. This section covers QA/QC of the testing process. One primary point of concern in modeling is QA/QC of model inputs. Data files for Phase 1 Task C will be generated from the data source files into the proper file format required for the individual model's inputs. QA/QC of these data will take three main forms: (1) the model input data will be inspected visually by the modeling staff and (2) compared with input data from historic data from Phase 1 task B to determine if they fall in expected ranges; (3) also the modeling staff will evaluate whether obvious model output errors are directly linked to problems with the input data. Format problems are of little concern because they typically result in either the models unable to run and/or the models generate obviously erroneous results. All errors will be documented electronically including, modeler(s) involved, relevant date(s), description of the problem, and description of the solution.

Sensitivity analyses are watershed model runs conducted with coefficient ranges that differ from the calibration values, often with limits that are below and above the calibration values by a certain percentage. Such analyses are routinely included in an overall modeling analysis. Sensitivity analyses yield insights into model behavior and are used to assess the reliability of model predictions relative to acknowledged or independently quantified uncertainty in model inputs and measured parameters. No code enhancements are anticipated for watershed modeling in Phase 1 Task I because the proposed models have been extensively used and modified previously by the watershed modeling team. Should any previously undetected errors need to be corrected or code-modifications deemed necessary, this information will be thoroughly documented and included in an appendix to the final report and documented in a memo to the project managers.

As with the hydrothermal/transport modeling, the CUBEE team will use a Subversion system to track and document changes made to the models over time and store this information in a single source for each model. Any errors that may be found, and code development and enhancements made to the code, will be documented in the final report. SWAT, SWAT-VSA, and GWLF are coded in Fortran and the original version of VSLF is coded in Vensim but is currently being recoded in R.

Prior to release, all models will be assigned a version number, which will be clearly noted where in the submission materials. All bug-fixes and model enhancements will be documented in the final report. In the event that changes are required or bugs are found after submission, CUBEE will make the necessary modifications and re-submit the software with the appropriate version number changes. Any changes between the original submission and this supplemental submission will be documented in a memo to the project managers.

Because the watershed modeling requires substantial geospatial data manipulation, the recommended software and hardware requirements for the watershed modeling (task I) are those consistent with ESRI ArcGIS Desktop 10, which are fully described at the product website: <http://>

/resources.arcgis.com/content/arcgisdesktop/10.0/arcgis-desktop-system-requirements#ArcGISDesktop-HardwareRequirements

C.2. Reports to Management

A data report will be generated for all field and laboratory data collected during this project. These data will be reported following the guidelines laid out in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). Data reports will contain a cover sheet, sample results and additional information related to the sample results such as QC flags, LOQs, and LODs.

There will be four progress meetings between Cornell, NYSDEC, and UFI. A single final technical report will be submitted at the end of the project. It will summarize data analyses, loading analysis, bioavailability study findings, mass balance findings, related biological community information, and hydrothermal/transport and watershed modeling performed during the entire Phase 1 project, identify major findings, and give recommendations on phosphorus/eutrophication model structure for Phase 2. The report will be maintained and stored on a secure server for at least five years beyond completion of the project in accordance with UFI's overall quality system (UFI, 2010). Any major deviation from this QAPP will be documented in the final report.

The CUEEB project leader will generate timely data reports of field and laboratory operations from this project that include sample site location and phytoplankton and zooplankton population data. This report includes a cover sheet, sample results, and additional information such as QA/QC results. Through coordination with the other groups this material will be incorporated in the final group project report. All reports generated by CUEEB will be archived for at least five years beyond completion of the project on a secure server at Cornell University.

The CBFS project leader will generate timely data reports of field and laboratory operations from this project that include sample site location and mussel population data. This report includes a cover sheet, sample results, and additional information such as QA/QC results. Through coordination with the other groups via the four progress meetings and other communication CBFS will provide this material to be incorporated within the final group project report. All reports generated by CBFS will be archived for at least five years beyond completion of the project on a secure server at Cornell University.

The MTUCEE project leader will generate a timely data report of laboratory operations from this project that include sample site location, date and times and the fraction of phosphorus that is bioavailable. This report includes a cover sheet, sample results, and additional information such as QA/QC results. Through coordination with the other groups via the four progress meetings and other communications MTUCEE will provide this material to be incorporated within the final group project report. All reports generated by MTUCEE will be archived for at least five years beyond completion of the project on a secure computer at Michigan Technological University.

D. Data Validation and Usability

D.1. Data Review, Verification and Validation

This section discusses the criteria for determining whether to accept, reject or qualify data collected for this project. Validation criteria are those that are used to determine whether the data satisfies the users requirements and verification criteria determine whether the data are sufficient for drawing conclusions related to the data quality objectives.

All new field data collected by UFI are entered by field staff and reviewed by the Field Program Supervisor as outlined in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). Secondary data will be entered by the UFI data analysis and modeling team and reviewed as outlined in *Section B.9* of this QAPP.

Laboratory data goes through a number of review, verification and validation steps as part of the overall laboratory quality system. All steps for review and validation of data are covered in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010), as well as individual analyte laboratory SOPs which are listed in Table 34. Copies of these UFI laboratory SOPs (UFI, 2013c) are provided in *Appendix 9-11*. Laboratory data are reviewed by the analyst during data entry. These are later reviewed by senior staff and the Laboratory Director during reporting. Data undergoes extensive QC (UFI, 2010) as summarized in *Section B.7* of this QAPP. Data that passes QC criteria are said to be validated (*Section B.5*; UFI, 2010).

Prior to data analysis or hydrothermal/transport modeling, all data and hydrothermal/transport modeling results will undergo extensive review. This is described in more detail in *Section B.9* of this QAPP. The review will be conducted by experienced professionals throughout the hydrothermal/transport modeling and data analysis process. Modeling staff will be responsible for reviewing input data for completeness and adherence to QA requirements. Data will be scanned to determine that all parameters fall within a typical range (e.g., similar patterns and ranges as measured historically in these systems). Data manipulations will be done using specialized programs or commercial spreadsheets programs. Values outside typical ranges will not be used to develop the model calibration data set or model kinetic parameters. Data quality will be assessed by comparing data to hard copy originals or by comparing to model results using criteria documented in *Section B.7* of this QAPP.

Field and laboratory data generated by UFI and CUEEB will undergo extensive review by the project leader. Site locations and depths recorded by the field teams will be checked during each sampling trip. Phytoplankton and zooplankton density calculations will be checked using raw phytoplankton and zooplankton count sheets. Length measurements will be checked for reasonable size ranges. Biomass calculations from phytoplankton and zooplankton size measurements will be checked for equation errors throughout spreadsheets.

Field and laboratory data generated by CBFS will undergo extensive review by the project leader. Site locations and depths recorded by the field teams will be checked using GIS based bathymetry maps to confirm consistency. Mussel density calculations will be checked using raw shell counts, shell images, and archived collections. Length measurements will be checked for reasonable size ranges. Biomass calculations from shell lengths will be checked for equation errors throughout spreadsheets.

Field and laboratory data generated by MTUCEE will undergo extensive review by the project leader. Estimates of the fraction of bioavailable particulate phosphorus calculations will be checked using raw data sheets, CoCs and instrument printouts; also the calculations will be checked for equation errors throughout spreadsheets.

CUBEE will extensively review all watershed data and watershed modeling results. This is described in more detail in *Section B* of this QAPP. The review will be conducted by experienced professionals throughout the watershed modeling and data compilation process. CUBEE modeling staff will be responsible for reviewing input data for completeness and adherence to QA requirements. CUBEE will review all data they use to ensure that all parameters fall within a typical range (e.g., similar patterns and ranges as measured historically in regional watersheds). Values outside typical ranges and for which rational explanations are not obvious will not be used. Data quality will be assessed by comparing data to hard copy originals or by comparing to model results using criteria documented in *Section B* of this QAPP.

D.2. Verification and Validation of Methods

Verification and validation of all data collected and analyzed by UFI is covered in detail in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). The data are said to be validated if these pass a general review of QC coupled with a limnological analysis and understanding of the system (*Section B.5* of this QAPP). During the hydrothermal/transport modeling process all newly collected data and secondary data will be reviewed as detailed in *Section A.3, B.1* and *B.9* of this QAPP. Hydrothermal/transport model input data will undergo extensive review as discussed in *Section B.7*. Data will be reviewed by the modeling team prior to its use to determine if data fall outside of typical ranges for the parameter in question. All data problems and gaps will be clearly documented in modeling memos and internal notes by the modeling team.

As in the case of the UFI component of the project, the data that is collected by CUEEB, CBFS, and MTUCEE are said to be validated if they pass QC criteria outlined in this QAPP. All data and calculations generated by these groups will undergo extensive review.

During the watershed modeling process all newly collected data and secondary data will be reviewed by CUBEE as detailed in *Sections A.3, B.1* and *B.9* of this QAPP. Watershed model input data will undergo extensive review by CUBEE as discussed in *Section B.7*. Data will be reviewed by the CUBEE modeling team prior to its use to determine if data fall outside of typical ranges for the parameter in question. All data problems and gaps will be clearly documented in memos and internal notes by the CUBEE team.

D.3. Reconciliation of User Requirements

This section of the QAPP addresses issues of whether data collected during field sampling meet data quality objectives. Each data type is reviewed for adequacy in terms of precision, accuracy, representativeness, completeness and comparability. QA of field data are covered in the *Environmental Testing Laboratory and Field Quality Assurance Manual* (UFI, 2010). The data analysis and hydrothermal/transport modeling task in this project (5-6) will address data as it relates to the hydrothermal/transport model testing and setup as documented in *Section B.7* and

B.9 of this QAPP. The UFI modeling team will document all analyses and assumptions in modeling memos and internal notes by the modeling team.

Data generated by the CUEEB component of this project regarding zooplankton and phytoplankton density and biomass will be reviewed for precision, accuracy, representativeness, completeness, and comparability. CUEEB will work with the all project scientists to ensure that the phytoplankton and zooplankton data are properly integrated into the overall project, including clearly stated units.

Data generated by the CBFS component of this project regarding dreissenid mussel density and biomass will be reviewed in terms of precision, accuracy, representativeness, completeness, and comparability. CBFS will work with the all project scientists to ensure that our data are properly integrated into the overall project including clearly stated units and realistic implications in filtering and excretion estimates.

Data generated by the MTUCEE component of this project regarding estimating the fraction of particulate phosphorus that is bioavailable will be reviewed in terms of precision, accuracy, representativeness, completeness, and comparability. MTUCEE will work with the all project scientists to ensure that our data are properly integrated into the overall project.

There are two forms of reporting for this project. The first is via the four technical meetings over the 2013-2014 interval, that will include UFI, Cornell University scientific staff, and NYSDEC technical staff. Progress on all components of the work will be addressed at these meetings. The second is a single final report that will be submitted at the end of this project (i.e., end of Phase 1). Scheduling of these reporting elements was described previously (Table 2).

The data compiled or generated by the CUBEE team (tasks H and I) regarding the watershed modeling will be reviewed for precision, accuracy, representativeness, completeness, and comparability. CUBEE will work with the all project scientists to ensure that the data and model results are properly integrated into the overall project. The CUBEE team will document all analyses and assumptions in modeling memos and internal notes by the modeling team.

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