WORKPLAN Lake Source Cooling Outfall Redesign

SPDES Number NY0244741

Cornell University
Dept. of Energy & Sustainability

Table of Contents

List of Figures

Cornell University
LSC Outfall Dedesign Workplan, Rev. 1.0
January 27, 2014

1. Introduction

1.1 Cornell Lake Source Cooling facility

Since the 1960s, Cornell University has used a central chilled water cooling system to air condition and dehumidify buildings on the university's Ithaca campus, and cool research equipment and spaces. Until the Lake Source Cooling (LSC) facility came on line in 2000, the university relied primarily on electrically-driven chillers to remove heat from the circulating chilled water. In the early 1990s, Cornell utilities engineers began planning to replace these chillers, which were reaching the end of their 35-year service life. At the time, several factors encouraged the university to examine alternative cooling technologies. The 1990 Clean Air Act Amendments legislated the phase-out of refrigerants (CFCs and HCFCs) known to deplete atmospheric ozone; these refrigerants were used in the university's chillers. Cornell was also committed to reducing overall campus energy consumption and its associated carbon footprint; this commitment was challenged by the projected growth in demand for campus cooling. The use of Cayuga Lake's deep, cold water as a renewable resource was considered; and the university decided to take on the detailed assessment and permitting required to make this innovative approach a reality.

The LSC process uses the naturally cold water deep in Cayuga Lake in a non-polluting heat exchange process. This process draws up to 46 million gallons per day (mgd) of water from a depth of 76 m (250 ft.) in Cayuga Lake, where water temperature remains cold year-round, and circulates lake water through a heat exchange facility, located on East Shore Drive in Ithaca. The lake water transfers its chill to a second closed loop of water that is connected to the campus cooling system. Slightly warmed lake water is returned to southern Cayuga Lake through an underwater diffuser at a depth of 4.3 m (14 ft.). The lake water and campus chilled waters never mix.

By investing in the LSC facility, Cornell was able to decommission six electrically-driven chillers, and reduce the energy used to cool central campus by 86%, saving over 25 million kilowatt-hours per year, about 10% of the entire campus electrical consumption. The LSC facility also helped Cornell accelerate the phase out of ozone-depleting CFC chemicals used as refrigerants.

1.2 Regulatory Requirement for the Outfall Redesign Study

A State Pollutant Discharge Elimination System (SPDES) permit has been in place for the LSC facility since March 1998. The facility came on line in July 2000. The existing permit has been renewed and modified, effective May 1, 2013, with several modifications and new conditions. This workplan addresses one of the permit requirements, which is to complete a preliminary redesign study for a modified outfall of the LSC facility. These modifications would be implemented in the event that Cornell determines that they would represent the most practical and cost-effective approach to prevent against a potential water quality impairment or to comply with a future phosphorus limit.

The permit language requiring the outfall redesign study is cited below.

In compliance with Title 8 of Article 17 of the Environmental Conservation Law of New York State and in compliance with the Clean Water Act, as amended, (33 U.S.C. 1251 et. Seq.), per SPDES Permit Number NY 0244741 (http://www.dec.ny.gov/docs/water_pdf/cornelllscprmt.pdf), effective May 1, 2013, Cornell (permittee) shall comply with the following schedule for permit compliance:

> "The permittee shall develop and submit an approvable plan for an Outfall Redesign Study to evaluate potential alternative sites for relocating the discharge from Outfall 001 to a location within the Class AA segment of Cayuga Lake (as depicted by transect A-A' on the Monitoring Locations map and defined in 6 NYCRR Part 898.4, Table I, Item 227).
>
> "The requirement of this Study shall be to evaluate the current mixing zone of the discharge, identify one or more discharge locations in waters of sufficient depth to ensure that the discharge plume remains below the photic zone and to determine that the discharge will not contribute to an impairment of the designated uses of the Lake.

1.3 Project Success Factors

Cornell University considers the following as indicators of the successful completion of the outfall redesign study in accordance with the SPDES permit requirements.

- Development, calibration and validation of a three-dimensional model of water movement that evaluates the impact of significant inflows to the southern basin of Cayuga Lake.
- Identification of a feasible outfall design and/or location that would not cause or contribute to impairment of a designated use.
- Identification of a feasible outfall design and/or location that minimizes project cost to Cornell and would not require a phosphorus limit for the LSC facility.
- Completion of the outfall redesign study on time and within budget.

2. Objectives and Tasks

Objective	Task	Responsible Party
Evaluate current mixing zone of the LSC return flow	Complete a three-dimensional (3D) model of the LSC return flow under current conditions: flow rate and temperature of LSC return flow; meteorological forcing (including stream flows); diffuser configuration; flow rates from IAWWTP and VCHWWTP.	Dr. Edwin A. (Todd) Cowen and colleagues at Cornell DeFrees Hydraulic Laboratory, Cornell University College of Engineering
	Validate the 3D model using data from the RUSS, thermistor at the pile cluster, LSC intake temperature records, and other existing data and information.	
	Use the validated model to simulate the 3D velocity and temperature fields under current conditions, from which estimates of the spatio-temporal evolution of the LSC outfall plume will be determined.	
	Quantify the effects of the LSC return flow on residence time of Cayuga Lake water on the shelf.	
Identify an alternative discharge location that meets criteria	Define the depth of photic zone in Cayuga Lake, based on statistical analysis of light profile data in Class AA segment collected 1999-2006, 2013.	Cornell Energy & Sustainability and consultants
	Apply the validated 3D model to a new outfall located within the Class AA segment of Cayuga Lake in order to project the size and configuration of the discharge plume of LSC return flow (defined as 3°F warmer than ambient conditions) during the critical period for phytoplankton growth (June 1-Sept 30).	Dr. Cowen and colleagues at Cornell DeFrees Hydraulic Laboratory, Cornell University College of Engineering
	Investigate potential effects of a range of realistic meteorological conditions on projected plume from relocated outfall.	

Objective	Task	Responsible Party
Compare environmental impacts of existing and alternative outfall	Use the Cayuga Lake Water Quality Model under development by UFI to project summer phosphorus and chlorophyll concentrations in 303(d) listed (Class A, southern shelf) segment with and without LSC return flow to this segment.	Project team and consultants
Develop alternative outfall	Complete conceptual design of outfall extension/relocation	Cornell Energy & Sustainability and consultants
	Develop (engineers opinion of) costs for permitting, design, survey, bidding, construction	
Prepare detailed implementation schedule	Identify potential suppliers and contractors; develop critical path timeline for acquisition of pipe and other materials.	Cornell Energy & Sustainability and consultants
	Identify required regulatory permits and approvals from NYSDEC, ACOE, and any local municipalities; including SEQRA compliance	
	Identify required easements from Office of General Services (OGS)	
Submit outfall redesign study to NYSDEC	Prepare report to comply with SPDES special condition	Cornell Energy & Sustainability and consultants

3. Definitions and Assumptions

3.1 Critical Period

Cayuga Lake is a monomictic lake, with thermal stratification developing late in the spring and breaking down in the fall. Plume behavior from a relocated LSC facility outfall will be modeled and evaluated for the four month period from June 1 through September 30, when the lake exhibits stable thermal stratification. During this period, circulation of deep water (at the depth of the LSC facility intake) to shallower regions of Cayuga Lake does not occur under most natural conditions. Outside of the June 1 – September 30 period, wind-induced circulation mixes Cayuga Lake water; thus water from the depth and location of the LSC intake can mix with water in the region of the existing (and relocated) LSC outfall.

- Cayuga Lake's thermal regime is well-documented. The Environmental Impact Statement prepared for the Lake Source Cooling facility (Stearns & Wheler 1997) included a hydrothermal model of the lake, which was verified based on measured temperature profiles. In addition, biweekly temperature profiles of the lake have been collected over the April-October interval over the period of 1998 to 2013. The model and monitoring data support the finding that wind-driven currents prevent development of persistent thermal stratification prior to early June of most years, and that thermal stratification begins to break down in October.

- The annual pattern of phytoplankton abundance in Cayuga Lake is also well-characterized; most of the data are reported as chlorophyll-a. These data confirm that phytoplankton abundance is highest in Cayuga Lake during the summer months.

Regulatory consistency:
Using June 1 – September 30 as the critical period is consistent with the averaging period used to develop the current NYS guidance value for phosphorus in lakes {NYS Fact Sheet Ambient Water Quality Value for Phosphorus (NYSDEC 1993)}, as well as the implementation strategy set forth in TOGS 1.3.6 for the removal of phosphorus from wastewater facilities. The final phosphorus TMDLs for Onondaga Lake, Chautauqua Lake, Silver Lake, etc. incorporate this four-month averaging period to define trophic state.

3.2 Mixing Zone

The mixing zone is defined as the region of Cayuga Lake where the LSC return flow causes a change in ambient lake water temperature greater than 3°F (1.6°C). The 3D hydrodynamic model will track the configuration of the plume from the LSC facility until water temperature returns to within 1.6°C of ambient.

Regulatory consistency:
§ 704.2 (b) (3) (ii) "The water temperature at the surface of a lake shall not be raised more than three Fahrenheit degrees over the temperature that existed before the addition of heat of artificial origin."

3.3 Photic Zone

The photic zone is defined as the depth in Cayuga Lake where 1% of the photosynthetically active radiation (PAR) striking the lake surface remains detectable. Photic zone depth is affected by materials dissolved and suspended in the water column that affect light penetration. In Cayuga Lake, light penetration (and thus, photic zone) is affected by algal cells and sediment particles. Both of these classes of particulate material are quite variable; the composition and abundance of the algal community varies seasonally, and sediment particles vary in response to storms and watershed runoff.

To capture this variability, we will define photic zone as the depth to which 1% of PAR is detectable, using light profile measurements collected in Cayuga Lake. These data have been collected by UFI over a total of ten years (1998-2006 and 2013) at various locations in Cayuga Lake (refer to Figure 1 at the end of this document for a map of monitoring locations during the LSC program and the CLMP program). For most years, biweekly profile data are available over the four month summer period.

Light profile data collected at the monitoring site LSC 6, which is north of the 303(d) line, will be used in the calculations of the depth of the photic zone during the June 1-Sept. 30 period. We will pool all the available light profile data collected at this location between June 1 and Sept 30, to capture the year-to-year variability in turbidity resulting from variations in meteorological conditions and variations in the phytoplankton community. The critical photic zone depth will be defined as the upper 75% of the 1% PAR depth measured at LSC site 6 (June 1-Sept. 30, all years).

Regulatory consistency:
We have selected the upper 75% of photic zone data as a conservative metric; and one that is consistent with existing NYSDEC practice. The overall objective of the outfall redesign exercise is to estimate the lake depth at which the LSC return flow remains below the photic zone, for the purpose of ensuring that any phosphorus will not be available for uptake by actively photosynthetic algal cells. NYSDEC policy (reference TOGS 1.3.1.E "**TOTAL MAXIMUM DAILY LOADS AND WATER QUALITY-BASED EFFLUENT LIMITS AMENDMENT - PERMIT LIMIT DEVELOPMENT FOR CERTAIN PARAMETERS"**) allows permit writers to utilize their professional judgment in selecting the upper 75% or upper 80% distribution of pH, for example, when defining critical conditions for ammonia toxicity. Unlike ammonia, phosphorus poses no risk of a toxic impact on the lake ecosystem. We conclude that using the upper 75% is therefore adequately protective and within regulatory precedence.

3.4 Designated Use

The language of the SPDES permit requires a demonstration that alternative outfall sites would not impair southern Cayuga Lake for its designated use as described in §701.5 for Class AA fresh surface waters:

> (a) The best usages of Class AA waters are: a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish, and wildlife propagation and survival.
>
> (b) This classification may be given to those waters that, if subjected to approved disinfection treatment, with additional treatment if necessary to remove naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

The comparable language for Class A fresh surface waters is set forth in §701.6:

> (a) The best usages of Class A waters are: a source of water supply for drinking, culinary or food processing purposes; primary and secondary contact recreation; and fishing. The waters shall be suitable for fish, shellfish, and wildlife propagation and survival.

> (b) This classification may be given to those waters that, if subjected to approved treatment equal to coagulation, sedimentation, filtration and disinfection, with additional treatment if necessary to reduce naturally present impurities, meet or will meet New York State Department of Health drinking water standards and are or will be considered safe and satisfactory for drinking water purposes.

The hydrodynamic model under development for the outfall redesign effort will be used to demonstrate that a relocated return flow from the LSC facility remains below the photic zone of the lake's Class AA segment during the critical period of June 1 – September 30th. This demonstration will be considered evidence that the return flow has no adverse impact on Cayuga Lake's designated best use.

4. Modeling Methodology

4.1 General Approach

Numerical simulations of the hydrodynamics of Cayuga Lake will be carried out with the goal of capturing and quantifying the spatio-temporal evolution of the LSC outfall plume in response to the various forcing functions. Simulations will be forced by available observational data (*e.g.*, Cornell University 2012), including the detailed bathymetric surveys commissioned by Cornell University for the construction of the Lake Source Cooling intake and outfall pipes. The model will be validated by comparing simulated time series of water temperature against observations collected at or near the RUSS station, the long-term record collected at the piling cluster (between LSC sampling sites 2 and 3[1]), the long-term temperature monitoring record at the LSC intake, as well as additional field observations collected during the performance period specifically for the purposes of model validation. The validated model will be used to simulate the three-dimensional (3-D) velocity and temperature fields, from which estimates of the spatio-temporal evolution of the LSC outfall plume will be determined.

4.2 Computational Model

The numerical simulations will be conducted with a 3-D free surface hydrodynamic model, Si3D (see Smith 2006, Rueda and Cowen, 2005). Si3D is based on the continuity equation for incompressible fluids, the Reynolds-averaged form of the Navier-Stokes equations for momentum, the transport equation for temperature, and an equation of state relating temperature to fluid density. The governing hydrodynamic equations are solved in layer-averaged form using a semi-implicit, three-level, leapfrog-trapezoidal finite difference scheme on a staggered Cartesian grid; only the vertical diffusive components of transport are treated implicitly. The scalar transport equation is solved using a two-level semi-implicit scheme; the advective scalar fluxes are estimated using flux-limiter methods. Vertical turbulent mixing is represented in the 3-D model following the level 2.5 Mellor-Yamada hierarchy of

[1] References to the LSC sampling sites refer to the locations monitored in southern Cayuga Lake from 1998-2012 (see Figure 1 at the end of this document).

turbulence closure models (Kantha and Clayson 1994) or using the open source GOTM (General Ocean Turbulence Model) suite of similar models. Horizontal mixing of momentum is parameterized using a Laplacian operator with constant mixing coefficients.

4.3 Model Forcing

In the simulations, the model will be forced with atmospheric records collected (at time intervals varying between 10 min-1 hour) by Cornell University either at the RUSS station over the lake (wind speed and direction, air temperature and relative humidity), a pile cluster-mounted meteorological station, or at the Game Farm Road meteorological station (which complies with USEPA protocols for Quality Assurance/Quality Control). Inflows into the lake model will occur at five locations: (1) Fall Creek, (2) Cayuga Inlet, (3) outfall of the Lake Source Cooling facility; (4) outfall of the Village of Cayuga Heights Wastewater Treatment Plant; and (5) outfall of the Ithaca Area Wastewater Treatment Plant. The model will include the specific diffuser design for the point sources to accurately capture the momentum flux from these sources. The model will seek to capture the dilution and spreading of the existing LSC diffuser plume either by direct simulation (that is, sufficient resolution to capture the relevant processes driving the entrainment and mixing of the outfall plume) or by incorporating specific relevant flow scenarios based on the CORMIX II framework. Inflow rates for the five sources will be taken from USGS gaging station data (Fall Creek and possibly others), estimates based on the ratios of watershed areas, and reported discharges from the three permitted point sources (IAWWTP, VCHWWTP, and LSC). River inflows will be accurately modeled as occurring through one or more cells with momentum flux onto the shelf accurately simulated. The USGS Cayuga Inlet lake level gage will be used to simulate lake level.

4.4 Model Results

Two conditions will be modeled: the existing conditions with the current outfall location and design, and a new location, with the outlet as a 63" (outer diameter), 57" (inner diameter) single port pipe discharging to the north and located 200 meters north of the 303(d) line and 1 to 5 m above the lake bottom. If this new location appears satisfactory, we may explore moving the outfall back as far as the model indicates is sufficient to keep the mixing zone below the statistically-defined critical depth (i.e., 75% upper limit of summer photic zone depth). If this location does not appear satisfactory, we will explore locations further north, or consider a diffuser, to meet the objective. We will track the elevation of the contour of water temperature varying +/-3°F from ambient, which we define as the LSC plume. We will investigate a broad range of ambient lake conditions that will span the following:

- Summer stratification regime, high tributary flows (for summer), high summer point source flows, strong winds
- Summer stratification regime, low tributary flows (for summer), high summer point source flows, low winds

- Summer stratification regime, low tributary flows (for summer), high summer point source flows, strong winds

4.5 Averaging Period

The hydrodynamic model calculates lake temperatures and velocities at very short intervals (order 30 seconds) to maintain numerical stability, but model calculations are not stored to disk every time step. The dominant process causing short-term variation in temperature in the vicinity of the proposed outfall location is the baroclinic seiche, which has a period of approximately 2.5 days, although the observed seiche period varies somewhat over time. To evaluate a meaningful temperature profile in the vicinity of the proposed outfall location we must both adequately resolve the baroclinic seiche and average over the temperature fluctuations it causes. We propose a 12 day rolling average based on model calculations stored to disk at 12 hour intervals. 12 days is equal to five seiche periods, so it should be long enough to adequately reduce bias due to averaging over partial seiche periods. Using a 12 day rolling-average temperature is consistent with the water quality issue driving an alternative outfall location, as eutrophication is not a toxicity issue.

4.6 Discussion

We will present plots under various forcing conditions that demonstrate the location of the LSC plume under existing conditions as well as a new location north of the 303(d) line. We will present the results of a study of the residence time of waters at specific locations around the shelf under each condition to demonstrate how the LSC outfall location affects the residence time of water on the shelf. These sites will, at a minimum, encompass areas of southern Cayuga Lake in the vicinity of LSC monitoring program sites 1, 3, 4, 5, and 7 (refer to Figure 1 at the end of this document).

5. Outfall Redesign Study: Report Content

The Outfall Redesign Study will include narrative, figures, drawings, tables, and timelines (schedules). At a minimum, the following items are anticipated to be included in the final report to be submitted to NYSDEC for review and approval.

- Summary of 3D modeling approach, assumptions, input files
- Documentation of model validation
- Model projections of LSC return flow plume (+/- 3°F) at current location – drawings
- Discussion of the impact of LSC return flow on water residence time on the shelf
- Model projections of LSC return flow plume (+/- 3°F) at potential location in the AA segment of Cayuga Lake – drawings

- Documentation of definition of photic zone (statistical summary and analysis of light profiles collected in Cayuga Lake in Class AA segment, north of 303(d) line)
- Discussion of compliance with permit requirements
- Table comparing projected conditions in two segments of Cayuga Lake (Class A-shelf; Class AA-main lake) with current outfall and redesigned outfall
- Bathymetric map of proposed route of extended outfall
- Cost analyses
- Conceptual design drawings and construction schedule
    - Site plan of the Heat Exchange Facility
    - Outfall profile
    - Materials list
- Summary of permitting requirements and compliance with SEQR
- Technical scope and associated schedule for preliminary and final design reports and construction, if relocation is determined to be a cost-effective means of compliance with future limits on the discharge from the LSC facility.

6. Schedule

- Submit an approvable plan for the Outfall Redesign Study - on or before Feb. 1, 2014
- Effective Date of NYSDEC approval (EDA), anticipated within 90 days
- Submit periodic Status Reports to NYSDEC
    - EDA plus 8 months
    - EDA plus 16 months
    - EDA plus 24 months
- Submit Final Outfall Redesign Study Report to NYSDEC: EDA plus 30 months

7. References

Cornell University (2012). Annual Monitoring Report, Cornell Lake Source Cooling Facility.

Kantha, L. H., and C. A. Clayson (1994). "An improved mixed layer model for geophysical applications." Journal of Geophysical Research, 99(C12), 25235-25266.

Rueda, F. J. and Cowen, E. A. (2005a). Exchange between a freshwater embayment and a large lake through a long, shallow channel. Limnol. Oceanogr., 50:169–183.

Rueda, F. J. and Cowen, E. A. (2005b). Residence time of a freshwater embayment connected to a large lake. Limnol. Oceanogr., 50:1638–1653.

Smith, P. E. (2006). A semi-implicit, three-dimensional model of estuarine circulation. Technical Report Open file report 2006-1004, USGS, Sacramento, CA.

Stearns & Wheler. 1997. Draft Environmental Impact Statement, Cornell Lake Source Cooling Facility. http://energyandsustainability.fs.cornell.edu/util/cooling/production/lsc/eis/default.cfm

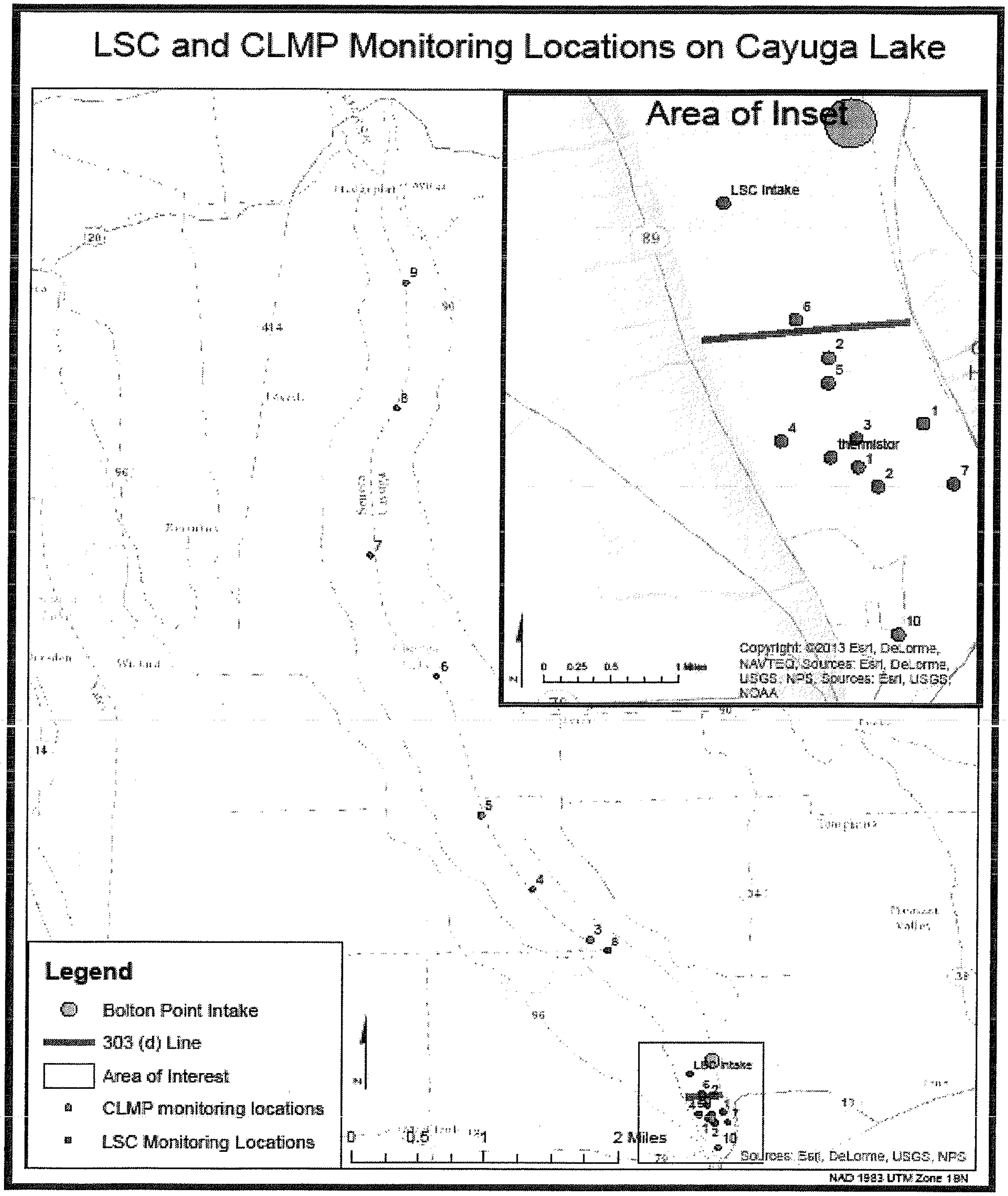

Figure 1. Map of monitoring locations used in the previous permit-required (LSC monitoring locations) and the monitoring locations used in 2013 for the Cayuga Lake Modeling Project (CLMP).