REPORT FOR THE FIRST YEAR OF THE NITRATE ADDITION PILOT TEST IN THE HYPOLIMNION OF ONONDAGA LAKE (2011)

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LIST OF ACRONYMS

ADV	Acoustic Doppler Velocimeter
CN-8	Calcium nitrate solution applied during the field trial (supplied by Yara Chemical)
ISUS	*In Situ* Ultraviolet Spectrophotometer
Metro	Metropolitan Wastewater Treatment Plant (located at the southern end of Onondaga Creek adjacent to the mouth of Onondaga Creek)
MT	Metric ton
NYSDEC	New York State Department of Environmental Conservation
SMU	Sediment Management Unit
SU	Syracuse University
UFI	Upstate Freshwater Institute (based in Syracuse, NY)
USEPA	United States Environmental Protection Agency

GLOSSARY OF TERMS

Deep Water (Profundal) – Offshore zone within a water body where water depths are greater than the depth to which sunlight can penetrate to support aquatic plants, in contrast with the littoral zone closer to shore. In Onondaga Lake, the profundal zone typically stratifies each year from May to October based on water temperature. The profundal zone of Onondaga Lake occupies 64 percent of the lake surface area based on a minimum water depth of 30 ft. (9 meters).

Epilimnion –During summer stratification, the upper portion of the thermally-stratified water column located between the 0- and 30-ft. (0- and 9-meter) water depth in Onondaga Lake. Epilimnion waters are warmer than the underlying stratified layers and relatively well-mixed by wind and waves.

Hypolimnion - The lower portion of the water column during summer stratification where water temperatures are cooler than upper waters (typically in the portion of Onondaga Lake where water depths exceed 30 ft. [9 meters]). Mixing levels are diminished in the hypolimnion relative to the epilimnion.

Methylmercury - An organic form of mercury, which can be created from inorganic mercury by bacteria in sediments and water. Methylmercury is a neurotoxin, and the form of mercury most easily able to bioaccumulate in organisms.

Thermocline - Located within the interval of water between the epilimnion and hypolimnion corresponding to the water depth of the maximum rate of decrease in temperature with respect to depth.

EXECUTIVE SUMMARY

The first year of a three-year nitrate addition pilot test in Onondaga Lake has been completed successfully and has met its objective: to demonstrate the ability to maintain nitrate concentrations in the hypolimnion (i.e., water deeper than 30 ft.) at levels sufficient to inhibit release of methylmercury from lake sediment to the overlying waters during stratification. Methylmercury concentrations measured in deep waters during 2011 were lower than during any recent prior year as a result of adding nitrate.

Methylmercury release from Onondaga Lake bottom sediment occurs when oxygen and nitrate are depleted from overlying water during summer stratification. Stratification is a natural process in Onondaga Lake and other temperate lakes whereby upper waters are warm and well-mixed during the summer while lower waters remain cool and isolated. Dissolved oxygen and nitrate concentrations in the lower waters naturally decline in a gradual manner as stratification continues through the summer. Depletion of oxygen and nitrate eventually results in the release of methylmercury from bottom sediments to the overlying deep waters in the middle of the lake. At fall turnover, when the upper waters cool and mix completely with the lower waters, fish are potentially exposed to methylmercury that has accumulated in the lower waters. The presence of oxygen and/or nitrate in the lower waters limits methylmercury release, and therefore reduces the exposure of fish to methylmercury.

The first year of nitrate addition consisted of continuous applications of a diluted calcium nitrate solution (calcium nitrate) to bottom waters of the lake during 40 non-consecutive days between June 30 and October 10, 2011. The liquid calcium nitrate was a commercially-available and commonly-used product that was mixed with lake water to an appropriate density for placing the nitrate near the lake bottom. A self-propelled barge approximately 40 ft. long and 24 ft. wide was used to conduct each of the nitrate applications. The target dose for each daily application was 4,800 gallons of calcium nitrate (2.3 metric tons of nitrate-nitrogen) at water depths of 42 to 62 ft. (13 to 19 meters), or 7 to 17 ft. (2 to 5 meters) above the lake bottom. The dose could be easily controlled and modified to meet target nitrate levels in the lake water. The added nitrate was able to spread laterally throughout the entire deep water area of the lake, as determined by extensive monitoring.

A potential water quality impact from adding nitrate is increased nitrite-nitrogen levels in the hypolimnion to concentrations above the applicable New York State water quality standard. Therefore, nitrite-nitrogen concentrations were also measured in lake water. Results indicate that adding nitrate did not significantly affect nitrite levels.

1.0 INTRODUCTION

This report describes the first year of a three-year pilot test to measure the effect of nitrate addition in the hypolimnion waters of Onondaga Lake on the release and/or production of methylmercury, a substance that bioaccumulates in fish and may prove harmful to humans through fish ingestion. On behalf of Honeywell International, nitrate was added to the lower, stratified waters of Onondaga Lake as 40 single-day applications between June 30 and October 10, 2011. During that timeframe, a target dose of 4,800 gallons of liquid calcium nitrate solution (labeled CN-8 by the supplier Yara Chemical, of Tampa, Florida) was applied over a four- to seven-hour period during each of the 40 applications. The liquid nitrate solution was added directly to the lower waters at three locations. Each single-day application was conducted at a single location. Typically, nitrate was applied at each location one day a week. One application location was in the northern half of Onondaga Lake, and the other two application locations were in the southern half of the lake (Figure 1). Each of the three application locations was at or near the center of one third of the Onondaga Lake hypolimnion water volume.

The remedy for the Onondaga Lake bottom is described in a 2005 Record of Decision prepared by the New York Department of Environmental Conservation (NYSDEC) and the United States Environmental Protection Agency (USEPA). The Statement of Work appended to the Consent Decree for the Onondaga Lake remedy (United States District Court, Northern District of New York, 2007) specifies that Honeywell conduct a study to determine if nitrate addition would effectively reduce formation of methylmercury in the water column while preserving the normal lake stratification cycle.

As Onondaga Lake becomes thermally stratified each year (typically from late May through mid-to-late October), oxygen and nitrate concentrations decline gradually over time in the hypolimnion. When concentrations of oxygen and nitrate are low enough, sediments can release methylmercury to the water column, and inorganic mercury in the water column can become methylated.

As described in the related work plan approved by NYSDEC (Parsons and Upstate Freshwater Institute [UFI] 2011), the purpose of the nitrate addition pilot test is to demonstrate that a widely-available nitrate solution can be effectively added and mixed with lake bottom waters to reduce accumulations of methylmercury in hypolimnion waters by effectively limiting the release of methylmercury from sediment when the middle of the lake is stratified in late summer. Results from this pilot test also provide additional information about horizontal distribution of nitrate as a follow-up to the 2008 dye tracer tests (UFI 2009) and the 2009 nitrate application field trial (Parsons and UFI 2010).

During 2007 and 2008, releases of methylmercury to the hypolimnion were found to be substantially lower than in previous years due primarily to elevated nitrate concentrations in the Lake. The increase in nitrate was a consequence of wastewater treatment upgrades implemented at the Onondaga County Metropolitan Wastewater Treatment Plant (Metro) located along the southern (upstream) shore of Onondaga Lake. Wastewater treated at Metro is discharged into the nearshore waters of the lake between the south shore and Sediment Management Unit (SMU) 8. In 2004, Onondaga County began operating a biologically-active filter system at Metro that converts ammonia to nitrate. As a result, the available pool of nitrate in the hypolimnion at the start of summer stratification roughly doubled. In 2005, Onondaga County activated a phosphorous-removal system resulting in decreased algal growth in the upper waters and reduced demand for electron acceptors in the hypolimnion. As a consequence of these wastewater treatment processes added at Metro, in 2007 and 2008, nitrate levels persisted in the Onondaga Lake hypolimnion for a significantly greater duration during summer months compared to previous years, which inhibited the release of methylmercury from SMU 8 sediments (UFI and Syracuse University (SU) 2007, Todorova et al. 2009). The nitrate addition pilot test is being conducted in the hypolimnion of Onondaga Lake as a follow up to the Metro upgrades.

In 2011, stratification of waters in Onondaga Lake ended during the week of October 31st, when the lake waters became completely mixed (called turnover). Turnover of the lake was complete on or about November 4, 2011.

In addition to the executive summary and this introduction, this report presents barge design and as-built information in Section 2, pilot test procedures and observations in Section 3, and a discussion and summary of results in Sections 4 and 5 respectively. Appendix A is a photo log. Appendix B is an example of daily monitoring information generated and provided by UFI the day the data were collected. Appendix C is a summary of nitrate concentrations observed one meter above the lake bottom from late June through early November of 2011.

2.0 PILOT TEST DESIGN AND 2011 AS-BUILT SUMMARY

2.1 Design Basis and Summary

Nitrate addition has been designed to commence just prior to hypolimnetic nitrate-nitrogen concentrations falling below 1 milligram per liter (mg/L) at the 18 meter depth and continue through the fall turnover each year. The basis for commencing nitrate addition based on 1 mg/L of nitrate-nitrogen at the 18-meter water depth is the nitrate and methylmercury concentration plots from 2008 through 2010 presented as Figures 3 and 4 in the approved work plan for this effort (Parsons and UFI, 2011) and in the 2010 baseline monitoring report for Onondaga Lake (Parsons, Exponent and Anchor QEA, 2011). Results from nitrate addition during 2011 reported herein further show the suitability of a target nitrate-nitrogen threshold of 1 mg/L

The additions of nitrate were designed to be conducted three times weekly in one of three predetermined locations in the lake (based on continuous monitoring results) called North (N), South Location #1 (S1), and South Location #2 (S2). In order to maintain the desired minimum concentration of nitrate (1 mg/L), the maximum nitrate application rate was determined based on peak four-week rolling average nitrate uptake rates in the hypolimnion as measured by UFI during the summers of 2007, 2008, and 2009. Based on these data and an assessment of the potential for induced demand, the design demand was set at 1.0 metric ton (MT) of nitrate-nitrogen per day or about 7.0 MT per week. In order to meet the nitrate demand, an average of

4,800 gallons of liquid calcium nitrate needed to be added to the lower waters of the lake during each of three applications per week.

2.2 Application Barge As Built

The design objectives and basis for the barge used to deliver the nitrate are presented in the approved work plan (Parsons and UFI 2011). Figure 2 shows the barge layout. The application system consisted of a modular barge made up of three joined 8.5-ft. by 40-ft. sections that housed the storage and delivery equipment. Three barge sections provided adequate space for all necessary equipment while allowing passage of the barge through Onondaga Creek to the onshore nitrate staging area at the Syracuse Inner Harbor. The barge storage equipment consisted of two polyethylene nitrate holding tanks housed inside basins that provided secondary containment. Each of the two tanks had an 8-ft.-diameter footprint based on height limitations imposed by the need to pass beneath the railroad bridge at the outlet of Onondaga Creek between the Syracuse Inner Harbor and Onondaga Lake. Other equipment aboard the barge consisted of two dilution water pumps, two chemical pumps, a propulsion-driven power unit, a generator, a manifold for delivering dilution water and calcium nitrate, a shed for storage and protection, a portion, and a deck crane. Each of the two dilution water pumps were equipped with a 10-inch-diameter suction line and discharge line connected to a chemical pump and associated piping (Figure 4). The barge was specifically designed and constructed to contain needed equipment while minimizing potential hazards and obstacles affecting system operations and optimizing operating work space and efficiency.

The preliminary layout of the barge was modified following approval of the work plan to reduce the number of nitrate holding tanks to two 2,500-gallon tanks and decrease the size and number of sections making up the barge (Figure 3). Positioning of the two nitrate holding tanks and the two dilution water pumps was based on distributing the total weight evenly throughout the surface area of the barge.

3.0 2011 PILOT TEST PROCEDURES AND OBSERVATIONS

3.1 Nitrate Application Sequence

Monitoring of lake conditions during 2011 began in late May as part of baseline monitoring also conducted on behalf of Honeywell International (Parsons and Exponent 2011) and continued through late November. Measurements of dissolved oxygen, nitrate and other water quality concentrations in the deep portion of Onondaga Lake prior to the first application provided information needed to determine when to start adding nitrate to the lake.

Agencies were notified at least one week prior to the start of nitrate additions during Year 1. The event schedules for Onondaga Lake Park and Syracuse Inner Harbor were checked in advance weekly to be sure nitrate additions would not affect scheduled public activities.

An onshore support zone for storing and refilling the nitrate holding tanks on the barge was located at the Onondaga Lake Willis Wall Shoreline until August 2011 when this onshore support was moved to the Syracuse Inner Harbor, which adjoins Onondaga Creek about 0.6 mile upstream of the southern end of Onondaga Lake. Onshore support included a l6,000-gallon portable nitrate holding tank fitted with secondary containment and associated pumps and hosing.

Each application of nitrate was conducted by applying CN-8 continuously for approximately four to seven hours a day at one of three pre-determined locations. The daily duration for nitrate addition was determined based on how much nitrate was to be added that day and based on the water density differences between the lower hypolimnion where the nitrate was added and the upper epilimnion dilution water. A total of 40 nitrate applications were completed during 2011, including 14 applications at South Location #1, 12 applications at the South Location #2, and 14 applications at the North Location.

Each application involved three basic steps. First, the barge was moved and anchored at one of the three application locations. The barge was held stationary at a location for the duration of the application by a concrete block anchoring system. Second, inflow and outflow piping with an end-of-pipe diffuser were positioned deep within the lake water column. Third, the pumps were started and CN-8 was mixed with epilimnetic lake water on the barge and applied to the lower waters in the hypolimnion of the lake via diffusers as a neutrally buoyant nitrate-water mixture. Photographs of the barge, equipment, pumps, and diffusers are presented in Appendix A.

Table 1 summarizes the application reports prepared for each application of nitrate. The initial application was conducted on June 30, 2011, and involved the injection of 2,200 gallons of CN-8 (1.06 MT of nitrate-nitrogen) at South Location #1. In general, injection events were conducted on Mondays, Wednesdays and Thursdays, moving from location to location so that all three locations received at least one application each week. Table 2 provides operational information, including application location, target dilution factor, lake water temperature and specific conductivity data, nitrate and dilution water flow rates, durations, and the total amount of calcium nitrate applied during each application.

3.2 In-Lake Monitoring

In-lake monitoring completed in association with the 40 applications of nitrate completed during 2011 is summarized in Table 3. In-lake monitoring was conducted by UFI from a single boat deploying an *in situ* ultraviolet spectrophotometer (ISUS). UFI provided near real-time feedback on the vertical position of added nitrate several times a day during which an application occurred. Figure 6 illustrates the 2011 lake monitoring locations. Monitoring elements included in the work plan for nitrate addition that are not reported herein are reported in the draft Onondaga Lake Baseline Monitoring Report for 2011 in preparation by Parsons, Exponent and Anchor QEA.

Monitoring was conducted to observe and characterize the distribution of nitrate in the vertical dimension and to monitor spreading of the nitrate horizontally across the lake. The monitoring boat used a global positioning system to locate a particular station, deploy the ISUS monitor to within 3 ft. (one meter) of the bottom, and then retrieve the ISUS monitor over the course of two to three minutes. Measurements were collected every 0.25 meter vertically throughout the water column recording water depth, nitrate-nitrogen, sulfide, temperature, specific conductivity, turbidity and parameters associated with light penetration and primary productivity. These data were downloaded and processed, and a summary of the day's results was provided the same day nitrate was applied. Each data summary included nitrate-nitrogen profiles at each monitoring location (Figure 6), as well as bubble plots illustrating nitrate-nitrogen concentrations at particular depths within the hypolimnion, including one plot of all measurements taken one meter above the lake bottom across the footprint of the hypolimnion.

In addition, the monitoring boat approached the barge about an hour or two after the start of a nitrate application to collect profiles to identify the effective water depth where the calcium nitrate solution was applied (see comments row in Table 2).

The performance of the ISUS optical nitrate probe in Onondaga Lake has been compared with laboratory measurements of nitrate in Onondaga Lake water since 2006. The ISUS and laboratory results have compared closely for recent years demonstrating that ISUS measurements are reliable (Figure 7).

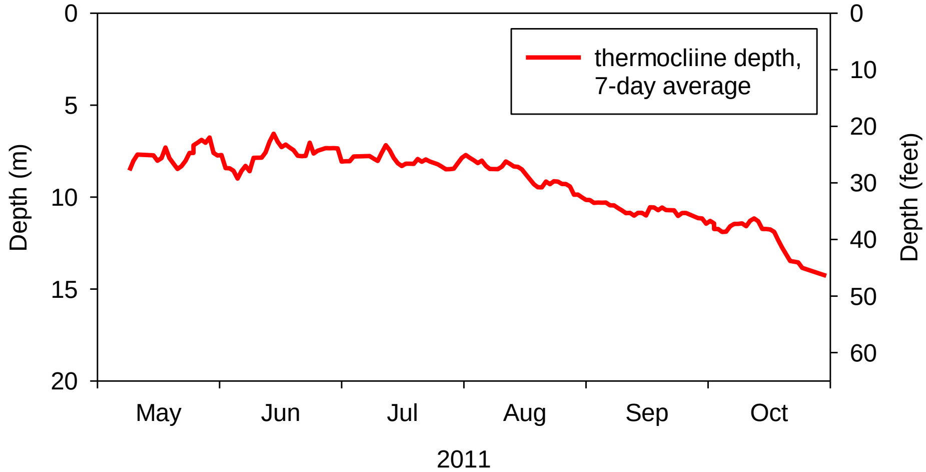
4.0 DISCUSSION OF 2011 PILOT TEST RESULTS

The Year 1 (2011) objective for the nitrate addition pilot test was to maintain summertime nitrate-nitrogen levels in the lower hypolimnion at or above 1 mg/L below the 14-meter water depth thereby limiting accumulations of methylmercury in hypolimnion waters. This section describes:

- The natural development of thermal stratification over time
- The oxygen and nitrate resources of the hypolimnion
- The effect of nitrate applications on nitrate levels
- Effects of a temporary shutdown from late July to mid-August, spatial distribution of nitrate, the method with which dilution of the nitrate solution with lake water was implemented
- Nitrite concentrations in lake water
- Other related monitoring from June through October 2011 when nitrate was being applied

4.1 Thermal Stratification Observed Over Time

The thermocline of a lake is located at the position of maximum temperature change with water depth and is the boundary between the epilimnion and the hypolimnion. Changes in average thermocline depth at the South Deep UFI robotic monitoring location (ISUS-11 on Figure 6) over the course of the 2011 season are as follows (data from the ourlake.org website):



Stratification became established in early to mid-May 2011, shutting off further significant inputs of nitrate from the epilimnion downward to the hypolimnion. Stratification initiates a period of oxygen depletion and locks in place the "ambient" nitrate pool or supply that is available to support nitrate reduction in the sediments. The depth of the thermocline between the epilimnion and hypolimnion was stable through June and then slowly descended through mid-October, after which the rate of descent accelerated until the water column was effectively mixed by early November.

4.2 Dissolved Oxygen and Nitrate Observations

The average dissolved oxygen concentration at the time of stratification setup in mid-May 2011 was approximately 10 mg/L, yielding an oxygen pool of 450 MT in the hypolimnion (typically below the 30-ft. water depth in Onondaga Lake). Figure 8 illustrates the depletion of the oxygen pool after the start of stratification, based on readings from the UFI robotic buoy located at South Deep. Most of the oxygen in the hypolimnion was consumed by early July.

Figure 9 illustrates the average nitrate-nitrogen concentrations in the hypolimnion over time, along with a record of the cumulative mass of nitrate-nitrogen applied to the lower hypolimnion over time. While the average nitrate-nitrogen concentration in the lake after ice-out (in March) was nearly 2 mg/L, corresponding to a pool of about 90 MT of nitrate-nitrogen, this average concentration declined prior to the start of stratification in mid May. The reason for the decline was dilution due to a very wet spring in 2011. As a result, the average nitrate-nitrogen concentration in lake waters at the start of stratification (about 1.7 mg/L) was lower than the typical concentration of 2 mg/L based on 34 years of recent records (UFI and SU 2007). Higher-than-average spring runoff flows during early 2011 is believed to be the reason for the lower-than-normal nitrate concentrations at the onset of stratification. This smaller initial nitrate pool in the lake presented a more difficult condition for the nitrate application effort than should exist in most years. The decline in nitrate concentrations continued until the time of the first application of nitrate on June 30, 2011.

The red line in Figure 9 tracks cumulative additions of nitrate to the lower hypolimnion of Onondaga Lake during 2011. In general, for the first month of applications, the averaged rate of addition was 1.0 MT of nitrate-nitrogen per day, which was the design basis for nitrate demand included in the Work Plan. Figure 9 also illustrates the response of the Lake system to these applications, with average nitrate concentrations leveling off and then starting to increase. A drop-off in nitrate concentrations was observed over the period July 30 through August 16, 2011 as a consequence of a system shutdown (see section 4.3). From August 16 forward, nitrate concentrations increased until October 10, when the last application was conducted.

Figure 10 illustrates the nitrate depletion rates in the hypolimnion of Onondaga Lake for 2011 represented by measurements at South Deep and at North Deep (see Figure 6 for locations). Volume-weighted nitrate concentrations were calculated with respect to lake surface area and specific water volume and shown as a function of time. During the July 28 to August 16 period when nitrate was not being added to the lake (see Section 4.3 below), nitrate depletion in the northern half of the lake was 14.6 micrograms of nitrate-nitrogen per liter per day, which was 24 percent higher than the rate of 11.8 micrograms of nitrate-nitrogen per liter per day in the southern half. This higher nitrate depletion rate in the northern half of the lake during 2011 may be due to the higher ratio of nitrate-consuming sediments to overlying water volume in the northern half of the lake. However, a review of nitrate depletion rates in Onondaga Lake from previous years indicates that higher nitrate depletion rates in the northern half of the lake compared to the southern half is not a recurring phenomenon based on data available since 2007.

4.3 Effects of Temporary Shutdown

On July 28, 2011, a delivery of calcium nitrate was made to the site, and field personnel detected and identified a volatile organic odor inside one of the nitrate storage tanks on the barge. The material analysis confirmed toluene was present in a small quantity. Applications of nitrate were temporarily suspended until the toluene could be removed and the tanks cleaned. Applications were re-started on August 16, 2011.

The response of the Lake system to this temporary shutdown was instructive (Figure 9). The rate of nitrate uptake during the shutdown period was approximately 1.0 MT per day, which matched well with the design demand.

Following the temporary shutdown, nitrate was added at an average rate of 1.3 MT per day for the following three weeks (four events per week), to accelerate replenishment of the nitrate pool, followed by applications at a rate of 1.0 MT per day (three events per week) until the end of nitrate applications for 2011 on October 10. The lower hypolimnion responded to the additional applications of nitrate with increased average nitrate concentrations. After October 10, the thermocline descended rapidly and the size of the hypolimnion decreased. However average nitrate-nitrogen concentrations after October 10 were monitored and remained above 1 mg/L.

Figure 11 is a vertical profile showing average nitrate concentrations at various depths in the hypolimnion from June through October 2011. For most of the time when nitrate was being applied, water depths below 17.5 meters (57 ft.) were exposed to nitrate-nitrogen concentrations greater than 2 mg/L. Sediments below the 16-meter (52-ft.) water depth were exposed to concentrations greater than 1.5 mg/L, except during a portion of the temporary shutdown period. There was a period between mid-August and mid-September when average nitrate-nitrogen concentrations in the 10 to 13-meter (33- to 43-ft.) water depth interval declined below 1 mg/L, though only marginally; the average nitrate-nitrogen concentration in this depth interval over this period was 0.91 mg/l.

Figure 12 illustrates the spatial and temporal extent of the measured nitrate-nitrogen concentrations, at a water depth of 1 meter (3 ft.) above the sediments, before and after the temporary system shutdown. At restart of nitrate applications on August 16, the lowest nitrate-nitrogen concentrations ranged from 0.5 to 1.0 mg/L. However, by October 3, 2011, measured concentrations ranged from 1.0 to 4.0 mg/L. During this time interval, the maximum concentration of methylmercury observed in the lower waters of the lake was 0.44 nanograms per liter (ng/L, where 1 ng/L is 0.000001 mg/L) observed on August 22, 2011, at South Deep (see Figure 13).

Volume-weighted average hypolimnion water concentrations for dissolved oxygen, nitrate-nitrogen, and methylmercury for the summer-fall time period from 2006 through 2011 demonstrate how low methylmercury concentrations were in the hypolimnion of Onondaga Lake in 2011 compared to recent prior years (Figure 14). Very low methylmercury concentrations during 2011 are consistent with the higher nitrate concentrations compared to recent prior years resulting from the additions of nitrate. Detailed 2011 methylmercury monitoring results from the middle of Onondaga Lake are presented in the Baseline Monitoring Report for 2011 (Parsons, Exponent and Anchor QEA 2012).

4.4 Dilution and Dispersion of Applied Nitrate

Given that the specific gravity of the CN-8 material provided by Yara Chemical is 1.5, significant dilution was required to produce near neutrally buoyant nitrate, an essential characteristic in order to take advantage of natural hydrodynamic forces that spread the nitrate around the lower depths of the Lake. The model selected to calculate densities of lake water and density of the solution to be added was developed by Chen and Millero (1978) and had been applied to the study of Onondaga Lake (Effler et al. 1996) as stated in the 2010 Report for the Nitrate Application Field Trial (Parsons and UFI 2010). Solution density is a function of water temperature and salinity. Salinity values were quantified based on measured specific conductance values.

Figure 15 provides a timeline of water temperatures at relevant depths within the epilimnion and the hypolimnion, as well as the calculated/predicted dilution factors for those dates, and the actual dilution factor that was needed to produce a near neutrally-buoyant nitrate-water mixture on those dates. For the initial additions of nitrate, the Chen and Millero equation underestimated the needed dilution (see Parsons and UFI 2010), while for additions of nitrate later in 2011 the equation overestimated the needed dilution.

Dispersion by natural hydrodynamic forces was adequate to distribute nitrate horizontally across the hypolimnion from the three application locations. Appendix B provides an example of the Daily ISUS Data Reports produced and issued by UFI to verify the application and distribution of the applied nitrate. Appendix C presents all of the bubble plots prepared by UFI illustrating conditions across the hypolimnion at a distance of 1 meter (3 ft.) above the lake bottom. Given the success in meeting the target nitrate-nitrogen concentration of 1 mg/L in lower hypolimnion waters over the course of the season and the minimal concentrations of methylmercury observed in the lower waters, three fixed locations successfully accomplished project objectives during 2011 as predicted in the work plan for this pilot test based on applying the analytical solution developed by Park and Zhan (2001). The assessment of lateral distribution of diluted liquid calcium nitrate as presented in the work plan for this effort provided a suitable basis for determining the number of locations in the lake at which to add nitrate in 2011.

By mid-August, the dilution water pumps were operating at a maximum capacity of 3,000 gallons per minute. For applications from mid-August through the last application on October 10, 2011, the calcium nitrate flow rate had to be adjusted throughout an application to achieve neutral buoyancy. This did require an increase to the duration (hours) of pumping each day in order to apply the daily target volume of CN-8 while producing near-neutrally buoyant, diluted nitrate.

4.5 Significance of Nitrite Concentrations

Nitrite-nitrogen (NO_2^--N) concentrations measured in Onondaga Lake during 2011 and in recent prior years (2006-2010) were compared to the New York State surface water quality standard established to protect warm water fish from effects of nitrite (Figure 16). Although the standard for nitrite was exceeded in deeper waters during each year, there was no evidence for higher concentrations associated with nitrate addition in 2011. In addition, none of the concentrations above the New York State surface water quality standard for nitrite were recorded in the upper waters where fish move and feed during the summertime period.

4.6 Other Related Monitoring During the 2011 Nitrate Application Period

4.6.1 Thermistor Chain Measurements

UFI deployed a single 12.5-meter thermistor chain at South Deep from June through November of 2011. The thermistor chain consisted of an array of 11 water temperature sensors each separated by 1.25 meters (4 ft.) of water depth. The array was suspended vertically from a surface buoy, with the uppermost sensor at a water depth of 5.4 meters (18 ft.) and the lower-most sensor at a water depth of 17.9 meters (59 ft.). Water temperature was recorded every five minutes. These instruments were deployed to observe the water temperature fluctuations associated with internal wave (seiche) activity in the lake. Water motion in the portion of the hypolimnion where the nitrate releases occurred is expected to occur largely as a result of this process. The thermistor data were used to identify conspicuous seiche events. The amplitude of internal waves was found to be greatest near the thermocline at a water depth of 10.4 meters (34 ft.). Significant seiche events occurred during five time periods: May 23 through 25, June 1 through 4, June 7 through 10, July 26 through 28, and October 4 through 7 (Figure 17). The average seiche period during 2011 was 12.5 hours and ranged from 8.5 to 14.5 hours, as compared to a theoretical period of 13 hours quantified for Onondaga Lake (Effler et al. 2004). The amplitude of seiche events at a water depth of 10.4 meters at South Deep ranged from minus

3 to plus 5 meters. Calculated amplitudes were based on a two-day moving average. The component of wind speed along the main axis of the Lake was also measured by UFI and ranged from approximately 10 to 25 miles per hour.

4.6.2 In-Lake Water Velocity Measurements

Two Acoustic Doppler Velocimeters (ADVs) were deployed in the vicinity of the nitrate application locations. These ADVs transmit a short pulse of sound, and listening to its' echo and measure the change in pitch or frequency of the echo. To deploy the ADVs, a stationary frame made of steel was utilized to ensure that the vector's sensors remained in a fixed location throughout from June through October 2011.

Prior to the initial nitrate applications, two ADVs were deployed approximately 100 ft. from N and approximately 100 ft. from S2. The ADV at N was positioned 1 meter above the sediment-water interface, or mudline, and the ADV at S2 was positioned 2 meters above the mudline. Both ADVs were programmed to record data once every 15 minutes. Peak velocities of 0.8 meters per second in the North and 0.095 meters per second in the South were recorded in late September and early October respectively.

5.0 SUMMARY OF 2011 PILOT TEST RESULTS

The first year of this three-year pilot test successfully demonstrated the ability to deliver sufficient quantities of liquid calcium nitrate to the lower hypolimnion of Onondaga Lake during summer stratification to minimize the release of methylmercury concentrations in deep waters of the lake. The minimum required nitrate-nitrogen concentration of 1 mg/L was maintained, on average, both vertically near the lake bottom and laterally throughout the lake, thus inhibiting the release of methylmercury from the sediments. Methylmercury release into the water column was controlled even when nitrate-nitrogen concentrations were less than 1.0 mg/L one meter above the lake bottom between mid-August and mid-to-late September at some of the outer (most shallow) profundal zone locations.

By the completion of the 2011 portion of the nitrate addition pilot test on October 10, a total of 88.4 metric tons of nitrate-nitrogen had been added to the hypolimnion of Onondaga Lake. In 2011, applications of nitrate were made at rates of 1.0 and 1.3 metric tons per day. These were higher rates than the average of 0.8 metric ton per day calculated from 83 metric tons over the 102 days between June 30 and October 10 because of the temporary shutdown from July 29 until August 16.

Figures 18 and 19 present the methylmercury and unfiltered total mercury results measured at South Deep and at North Deep over time at water depths of 2 meters (epilimnion), 12 meters (near the top of the hypolimnion), and 16 meters (mid-to-lower hypolimnion). The same parameters were also measured at a water depth of 18 meters (bottom of the hypolimnion) at South Deep where total water depths are greater than at North Deep. In addition, total mercury and methylmercury concentrations in water near the lake bottom at 12 profundal zone locations are summarized in Table 4. Methylmercury was not significantly released from underlying sediment to lower hypolimnion waters during stratification. The peak methylmercury concentration (0.44 nanograms per liter or ng/L) in the hypolimnion was observed in late August following a 17-day period when nitrate could not be applied due to short-term contamination concerns on the application barge.

Figures 20A and 21A present total mercury and methylmercury concentrations measured in zooplankton collected at North Deep and South Deep respectively during 2011. Figures 20B and 21B present methylmercury as a percentage of total mercury for these samples. Total mercury concentrations in zooplankton were less than 0.4 milligrams per kilogram (or parts per million) (mg/kg) on a wet-weight basis, and the highest concentrations were observed in mid-October prior to fall turnover. Methylmercury concentrations in zooplankton were less than 0.015 mg/kg throughout the May through November sampling period. Methylmercury as a percentage of total mercury was 10 percent or less until fall turnover the week of October 31 when the percentage of methylmercury increased to 13 to 19 percent. Figures 22 and 23 present total mercury and methylmercury concentrations measured in deep lake water (at the 18-meter water depth) and in zooplankton at South Deep from 2007 or 2008 through 2011. Results presented in Figures 22 and 23 show methylmercury concentrations were substantially lower during 2011 than during recent prior years. Results from the North Deep location were consistent with results from the South Deep location.

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TABLES

TABLE 1

2011 NITRATE ADDITION SUMMARY

Date/Location[1]	Metric Tons (as N) of CN-8 Applied[2]	Application Water Depth[3] (feet)	Dilution Water to CN-8 Solution Volume Ratio	Date/Location	Metric Tons (as N) of CN-8 Applied	Application Water Depth (feet)	Dilution Water to CN-8 Solution Volume Ratio
June 30 / S1	1.06	60	214.29	August 29 / S1	2.3	47	468.75
July 5 / S2	2.3	55	191.75	August 30 / N	2.3	42	340.91
July 7 / N	2.3	55	206.39	August 31 / S2	2.3	47	340.91
July 8 / S2	2.3	61.5	185.57	Sept 1 / S1	2.3	47	375.00
July 11 / S1	2.3	55	185.57	Sept 6 / S2	2.3	47	375.00
July 13 / N	2.1	42	183.67	Sept 7 / N	2.0	47	340.91
July 14 / S1	2.3	51	184.43	Sept 9 / S1	2.3	47	340.91
July 19 / N	2.3	48	181.71	Sept 12 / S2	2.3	47	340.91
July 20 / S2	2.3	53	178.47	Sept 14 / N	2.3	47	340.91
July 21 / S2	2.3	45	156.97	Sept 15 / S1	2.3	47	363.64
July 25 / S1	2.3	45	154.49	Sept 19 / N	2.3	42	416.67
July 27 / N	2.3	47	255.79	Sept 21 / S1	2.3	42	535.71
July 28 / S2	2.3	49	321.05	Sept 22 / S2	2.3	42	357.14
August 16 / S1	2.3	46	449.78	Sept 26 / N	2.3	46	258.62
August 17 / N	2.3	42	449.78	Sept 28 / N	2.3	47	267.86
August 18 / S2	1.7	42	375.00	Sept 29 / S1	2.3	47	288.46
August 19 / S1	1.9	42	441.18	Oct 1 / S2	2.3	52	267.86
August 22 / S2	2.3	42	375.00	Oct 7 / N	2.3	52	267.86
August 23/ N	1.4	42	625.00	Oct 10 / S1	2.3	52	258.62
August 24 / S1	2.3	47	375.00				
August 25 / N	2.3	47	375.00				

Total nitrate applied = 88.43 Metric Tons

NOTES:

[1] S1 is the South Location 1, S2 is the South Location 2, and N is the North Location (see Figure 1).

[2] 2.3 metric tons = 4,800 gallons for CN-8.

[3] Water depth at the bottom of the 4-foot long diffuser at the lower end of each application pipe.

[4]Ratio utilizes the following values:

$$\frac{\text{H20 Pump A (gpm) + H20 Pump B (gpm)}}{\text{Chemical System A (gpm) + Chemical System B (gpm)}}$$

TABLE 2
Summary of 2011 Nitrate Application Data Collection and Calculations

Date		6/30/2011	7/5/2011	7/7/2011	7/8/2011	7/11/2011	7/13/2011	7/14/2011	7/19/2011	7/20/2011	7/21/2011	7/25/2011	7/27/2011	7/28/2011	8/16/2011
Location		S1	S2	N	S2	S1	N	S1	N	S2	S2	S1	N	S2	S1
DF		N/A	192	206	152	185	185	151	180	163	147	142	214	205	280
Q_CN8_gauge	gpm	12.25	12.13	12.13	12.13	12.13	12.2	12.2	12.52	13.7	15.34	15.88	10.8	10.51	8.34
Q_CN8_Correction Factor	gpm	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Q_CN8_actual	gpm	9.8	9.7	9.7	9.7	9.7	9.8	9.76	10.016	10.96	12.27	12.7	8.89	8.41	6.67
Q_epi_Pump A	gpm	2100	1860	2002	1800	1800	1800	1800	1820	1956	1926	1962	2200 --> 2513	1726 --> 2667	2801 --> 2992
Q_epi_Pump B	gpm	2100	1860	2002	1800	1800	1800	1800	1820	1956	1926	1962	2210	1726	N/A
T_epi	degreeC	22.9	24.3	23.9	24.9	25.4	24.6	24.78	25.4	26.3	27.5	28	25.7	25.9	23.58
SC_epi	uS/cm	1583	1630	1673.83	1549	1627	1624	1722.68	1638	1661	1658	1686	1737	1727	1806.03
Water depth	ft (m)	63 (19)	62 (19)	59 (18)	63 (19)	62 (19)	57 (17)	63 (19)	NR	63 (19)	63 (19)	62 (19)	58 (19)	63 (19)	64 (19)
Target depth[8]	ft (m)	60 (18)	55 (17)	55 (17)	62 (19)	55 (17)	42 (13)	51 (16)	48 (13)	53 (16)	45 (14)	45 (14)	47 (14)	49 (15)	46 (14)
T_target depth	degreeC	9.6	9.6	10.5	10.3	10.9	11.1	10.51	10.06	10.1	10.2	10.9	10.4	10.5	10.7
SC_target depth	uS/cm[6]	1484	1490	1,484	1430	1450	1469	1581.14	1541	1464	1490	1456	1470	1473	1612
Start time_dosing		4:00 PM	10:30 AM	10:00 AM	9:38 AM	12:00 PM	9:43 AM	10:00 AM	9:34 AM	10:28 AM	7:48 AM	10:54 AM	9:58 AM	8:55 AM	9:53 AM
Start Volume_Tank A[7]	gallons	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Start Volume_Tank B[7]	gallons	2400	2400	2400	2400	2400	1900	2400	2400	2400	2400	2400	2400	2400	2400
End Volume_Tank A[7]	gallons	200	0	0	0	0	0	0	0	0	0	0	0	0	0
End Volume_Tank B[7]	gallons	2400	0	0	0	0	0	0	0	0	0	0	0	0	0
Total CN8 Applied	gallons	2200	4800	4800	4800	4800	4300	4800	4800	4800	4800	4800	4800	4800	4800
Total Applied	MT NO3-N[9]	1.06	2.31	2.31	2.31	2.31	2.06	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31
Comments		N/A	N/A	N/A	N/A	N/A	N/A	N/A	First detection at 17.3m, made adjustment to water_Q.	Nitrate detected at 18.2m.	Initial detection at 18m, adjusted chemical_Q to 14 gpm on meter and nitrate lifted off the bottom slightly.	Winds and weather was too severe for UFI boats, we had to shutdown early due to severe T-storms.	Nitrate was detected at 16m, and then dropped to 17.5m.	Nitrate detected 17-18m, water_Q increased to 2500 gpm. Nitrate was then detected at 16m, so water_Q raised to 2700 gpm.	Nitrate was falling to bottom, after Q_water was turned up to 3000, nitrate hovered at 15.5m.
End Time_dosing		7:00 PM	2:30 PM	2:00PM	1:10 PM	3:30 PM	12:00 PM	2:00 PM	1:34 PM	2:05 PM	11:13 AM	11:56 AM	2:30 PM	1:35 PM	4:55 PM

Note: Yellow-highlighted comments indicate that nitrate was near-neutrally buoyant detected off the bottom.

Definitions:

1 CN8: Liquid calcium nitrate as specified by Yara Chemical.

2 DF: Dilution factor, or the ratio of epilimnetic water flow to CN8 flow. The DF was quantified by utilizing the Chen and Millero (1978) model to calculate the densities of the lake water and of the CN8. Solution density is a function of temperature and salinity; the salinity input values were based on measured specific conductance values.

3 Q: Flow as measured in gallons per minute (gpm).

4 T: Temperature of lake water.

5 SC: Specific Conductance of lake water.

6 uS/cm: Microsiemens per centimeter, or the unit of measure of specific conductance.

7 Start Volume and End Volume: Applies to CN8.

8 Target Depth: The specific depth of release of the CN8 as controlled by the length of individual hoses which were manually connected to the manifold prior to each application. Early on in the season the target depth identified by a height of 2-3m off of the bottom depending on what the specific water depth was at N, S1 or S2 on a given day. Where the target depths are not consistent with being 2-3m off the botttom, the depths are based on insight from monitoring regarding specific depths at N, S1 or S2 within the hypolimnion that exhibited a higher nitrate demand between applications.

9 MT NO3-N: Metric tons of nitrate-nitrogen.

TABLE 2
Summary of 2011 Nitrate Application Data Collection and Calculations

Date		8/17/2011	8/18/2011	8/19/2011	8/22/2011	8/23/2011	8/24/2011	8/25/2011	8/29/2011	8/30/2011	8/31/2011	9/1/2011	9/6/2011	9/7/2011
Location		N	S2	S1	S2	N	S1	N	S1	N	S2	S1	S2	N
DF		278	251	246	253	321	277	291	344	362	329	330	309	360
Q_CN8_gauge	gpm	8.34	10	8.5	10	6	10	10	8	11	11	10	10	11
Q_CN8_Correction Factor	gpm	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Q_CN8_actual	gpm	6.67	8	6.8	8	4.8	8	8	6.4	8.8	8.8	8	8	8.8
Q_epi_Pump A	gpm	3000	3000	3000	3000	2850	2800, 3000	3000	3000	3000	3000	3000	3000	3000
Q_epi_Pump B	gpm	3000	3200	3000	3000	2850	2800, 3000	3000	3000	3000	3000	3000	3000	3000
T_epi	degreeC	23.5	24.36	24.66	23.9	24.42	23.2	22.87	22	22.115	22.39	22.3	22.5	21.4
SC_epi	uS/cm	1786	1814.38	1859	1787	1814	1845	1852.28	1894	1880.97	1870.13	1866	1814	1872
Water depth	ft (m)	58 (18)	63 (19)	64 (20)	62 (19)	63 (19)	64 (20)	64 (20)	64 (20)	58 (18)	63 (19)	64 (20)	63 (19)	64 (20)
Target depth[8]	ft (m)	42 (13)	42 (13)	42 (13)	42 (13)	42 (13)	47 (14)	47 (14)	47 (14)	42 (13)	47 (14)	47 (14)	47 (14)	47 (14)
T_target depth	degreeC	11.8	10.56	10.78	11.5	10.56	12	10.55	11.9	10.79	10.2	11.7	11.3	11.2
SC_target depth	uS/cm[6]	1611	1613.56	1633.43	1743	1614	1598	1595.37	1655	1642.01	1641.01	1577	1592	1602
Start time_dosing		10:10 AM	10:49 AM	10:23 AM	1:22 PM	11:00 AM	8:56 AM	9:50 AM	11:05 AM	9:00 AM	9:15 AM	9:45 AM	10:20 AM	8:47 AM
Start Volume_Tank A[7]	gallons	2400	1754.7	1973.9	2400	1159.3	2400	2400	2400	2400	2400	2400	2400	2125
Start Volume_Tank B[7]	gallons	2400	1754.7	1879.9	2400	1660.6	2400	2400	2400	2400	2400	2400	2400	2125
End Volume_Tank A[7]	gallons	0	0	0	0	0	0	0	0	0	0	0	0	0
End Volume_Tank B[7]	gallons	0	0	0	0	0	0	0	0	0	0	0	0	0
Total CN8 Applied	gallons	4800	3509.4	3853.85454	4800	2819.9	4800	4800	4800	4800	4800	4800	4800	4250
Total Applied	MT NO3-N[9]	2.31	1.69	1.85	2.31	1.35	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.04
Comments		Nitrate hovered at 15.5m.	Nitratedetected and hovering at 15-16m.	Nitrate detected and hovering at 15-16m.	Too rough for UFI boats.	Turned up chemical to 8 gpm_actual as nitrate was originally detected between 11.5-13m.	Nitrate was detected on and near the bottom, after turning up water Q, nitrate was detected between 15-17m.	Nitrate detected and hovering 15m-bottom.	Nitrate detected @14-15m so turned up CN8 to 10 gpm_meter and plume dropped to 15m.	Nitrate detected @ 15.5-16m.	Nitrate detected @ 15m then dropped to 17.5m.	Nitrate detected @ 17m so raised manifold up 3' moving nitrate to 16.5m, decreased CN8 to 8 gpm_meter which caused 3 peaks at 14.5, 16.5m and to	Nitrate detected @ 14.5-15m so turned CN8 up to 11 gpm_meter and nitrate dropped to 16-16.5m.	Nitrate detected @ 16-16.5m.
End Time_dosing		6:00 PM	3:00 PM	3:00 PM	6:07 PM	2:30 PM	1:57 PM	2:35 PM	4:00 PM	1:39 PM	2:15 PM	3:35 PM	2:50 PM	12:30 PM

Note: Yellow-highlighted comments indic

Definitions:

1 CN8: Liquid calcium nitrate as specified by Yara Chemical.

2 DF: Dilution factor, or the ratio of epilimnetic water flow to CN8 flow. The DF was quantified by utilizing the Chen and Millero (1978) model to calculate the densities of the lake water and of the CN8. Solution density is a function of temperature and salinity; the salinity input values were based on measured specific conductance values.

3 Q: Flow as measured in gallons per minute (gpm).

4 T: Temperature of lake water.

5 SC: Specific Conductance of lake water.

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7 Start Volume and End Volume: Applies to CN8.

8 Target Depth: The specific depth of release of the CN8 as controlled by the length of individual hoses which were manually connected to the manifold prior to each application. Early on in the season the target depth identified by a height of 2-3m off of the bottom depending on what the specific water depth was at N, S1 or S2 on a given day. Where the target depths are not consistent with being 2-3m off the botttom, the depths are based on insight from monitoring regarding specific depths at N, S1 or S2 within the hypolimnion that exhibited a higher nitrate demand between applications.

9 MT NO3-N: Metric tons of nitrate-nitrogen.

TABLE 2
Summary of 2011 Nitrate Application Data Collection and Calculations

Date		9/9/2011	9/12/2011	9/14/2011	9/15/2011	9/19/2011	9/21/2011	9/22/2011	9/26/2011	9/28/2011	9/29/2011	10/3/2011	10/7/2011	10/10/2011
Location		S1	S2	N	S1	N	S1	S2	N	N	S1	S2	N	S1
DF		347	341	337	376	498	552	502	423	384	465	643	933	673
Q_CN8_gauge	gpm	11	11	11	11	9	9 --> 7	7 --> 10.5	11 --> 14.5	12 --> 14	13	14	14	14.5
Q_CN8_Correction Factor	gpm	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Q_CN8_actual	gpm	8.8	8.8	8.8	8.8	7.2	7.2 --> 5.6	5.6 --> 8.4	8.8 --> 11.6	9.6 --> 11.2	10.4	11.2	11.2	11.6
Q_epi_Pump A	gpm	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Q_epi_Pump B	gpm	3000	3000	3000	3200	3000	3000	3000	3000	3000	3000	3000	3000	3000
T_epi	degreeC	21.5	21.8	21.7	20.9	19.2	18.7	19.2	20.1	20.8	19.6	17.8	16.3	17.6
SC_epi	uS/cm	1836	1795	1741	1729	1765	1797	1789	1727	1754	1768	1739	1767	1744
Water depth	ft (m)	64 (20)	64 (20)	63 (19)	64 (20)	61 (19)	64 (20)	63 (19)	58 (18)	58 (18)	64 (20)	64 (20)	62.25	64 (20)
Target depth[8]	ft (m)	47 (14)	47 (14)	47 (14)	47 (14)	42 (13)	42 (13)	42 (13)	46 (14)	47 (14)	47 (14)	52 (16)		52 (16)
T_target depth	degreeC	11.1	11.5	11.6	11.8	12.7	11.8	12.8	13.4	12.4	13	11.2	14	12
SC_target depth	uS/cm[6]	1629	1598	1630	1623	1654	1654	1660	1667	1680	1714	1678	1749	1695
Start time_dosing		9:27 AM	11:17 AM	9:22 AM	8:55 AM	10:38 AM	8:52 AM	9:00 AM	10:53 AM	9:12 AM	8:48 AM	11:02 AM	9:03 AM	1:19 PM
Start Volume_Tank A[7]	gallons	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
Start Volume_Tank B[7]	gallons	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400
End Volume_Tank A[7]	gallons	0	0	0	0	0	0	0	0	0	0	0	0	0
End Volume_Tank B[7]	gallons	0	0	0	0	0	0	0	0	0	0	0	0	0
Total CN8 Applied	gallons	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800
Total Applied	MT NO3-N[9]	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31	2.31
Comments		UFI wasn't avail. due to our scheduling change.	Nitrate detected 18.5m to bottom. Reduced CN8 to 9 gpm_meter, nitrate rose to 17.2m and hovered 15.8-16.2m and then 16.2m - bottom.	Nitrate detected 16.3m to the bottom.	Nitrate detected at 15.8m to the bottom.	Nitrate detected at 14.6m for duration of application.	Nitrate first detected 18.9m to bottom; after adjusting CN8, at 13.5 to 16m; adjusted CN8 to 7 gpm and nitrate at 14.5m for duration.	Nitrate first detected at 14.5m; adjusted to 8 gpm, nitrate at 17m; adjusted to 9 gpm, nitrate at 16 - 17.5m; last detected 18.8m to bottom.	Nitrate detected from 15.8m initially, then between 15.6 and 15.7m after CN8 was turned up to 14.5 gpm.	Nitrate detected 16.7-17.2m, increased CN8 flow to target bottom; nitrate detected 16.6-17.3m, adjusted to 14 gpm for duration.	Pump B wasn't running until last hour of application after Godwin rep. came out and fixed it (water got into the diesel); nitrate detected 17.5-18m duration of	Nitrate detected at 18m to bottom, no adjustments needed since 18m was indeed our target today.	Nitrate detected 17.2m to the bottom, no adjustments needed.	Nitrate detected 18.5m to the bottom, no adjustments made; last day of operation for 2011 Field Season.
End Time_dosing		1:58 PM	4:51 PM	2:00 PM	1:30 PM	4:22 PM	3:55 PM	2:37 PM	2:39 PM	1:07 PM	3:40 PM	2:40 PM	12:50 PM	5:30 PM

Note: Yellow-highlighted comments indic

Definitions:

1 CN8: Liquid calcium nitrate as specified by Yara Chemical.

2 DF: Dilution factor, or the ratio of epilimnetic water flow to CN8 flow. The DF was quantified by utilizing the Chen and Millero (1978) model to calculate the densities of the lake water and of the CN8. Solution density is a function of temperature and salinity; the salinity input values were based on measured specific conductance values.

3 Q: Flow as measured in gallons per minute (gpm).

4 T: Temperature of lake water.

5 SC: Specific Conductance of lake water.

6 uS/cm: Microsiemens per centimeter, or the unit of measure of specific conductance.

7 Start Volume and End Volume: Applies to CN8.

8 Target Depth: The specific depth of release of the CN8 as controlled by the length of individual hoses which were manually connected to the manifold prior to each application. Early on in the season the target depth identified by a height of 2-3m off of the bottom depending on what the specific water depth was at N, S1 or S2 on a given day. Where the target depths are not consistent with being 2-3m off the botttom, the depths are based on insight from monitoring regarding specific depths at N, S1 or S2 within the hypolimnion that exhibited a higher nitrate demand between applications.

9 MT NO3-N: Metric tons of nitrate-nitrogen.

TABLE 3

Summary of 2011 ISUS[1] Measurements

Measurement period	June 20 to October 31
Frequency of measurements	Typically three days of profiling each week (61 days total)
Vertical resolution	Measurements every 0.25 meters of water depth from lake surface to bottom
Locations	34 each day on average
Number of vertical profiles	2,238
Number of nitrate measurements	117,000
Parameters[2] and accuracy	Nitrate to plus or minus 0.028 mg/L as nitrogen (N)
	Sulfide to plus or minus 0.064 mg/L as sulfur (S)
	Water Temperature to plus or minus 0.1 degree Celsius
	Specific conductivity to plus or minus 3 microsiemens per centimeter

Notes:

1 ISUS – in situ ultraviolet spectroradiometer
2 Other parameters measured using the ISUS were turbidity, beam alteration coefficient, backscattering, chlorophyll fluorescence, and photosynthetically-active irradiance.

Table 4
Mercury Concentrations in Surface Water Near the Lake Bottom at 12 Locations
(Concentration (ng/l) One Meter Above Lake Bottom)

2011 Date	North Deep ISUS-27	South Deep ISUS-11	ISUS-5	ISUS-9	ISUS-14	ISUS-18	ISUS-21	ISUS-22	ISUS-23	ISUS-26	ISUS-29	ISUS-32	Average Concentrations at 10 Locations[1]	Range at 10 Locations[1] Min	Max
Total Mercury															
6/22/11	1.1	1.4	1.8	1.3	1.8	1.6	2	1.2	1.8	1.6	1.4	1.2	1.57	1.2	2
7/20/11	0.43	0.87	2.2	1.5	0.61	0.48	0.38	0.49	0.33	0.32	0.52	0.68	0.75	0.32	2.2
8/17/11	1	1.3	2.8	1.4	4.4	0.87	0.91	1.2	1.1	0.87	0.78	1.4	1.57	0.78	4.4
9/21/11	1	1.2	4.8	5.3	1.7	1.3	2	1.2	1.2	0.89	1.3	0.68	2.04	0.68	5.3
10/13/11	0.59	0.95	1.4	0.71	0.5	0.85	0.66	0.54	0.66	0.51	0.6	0.51	0.69	0.5	1.4
Methyl Mercury															
6/22/11	0.063	0.067	0.064	0.061	0.067	0.12	0.086	0.063	0.05	0.058	0.045	0.046	0.07	0.045	0.12
7/20/11	0.13	0.14	0.06	0.071	0.08	0.11	0.068	0.1	0.082	0.09	0.078	0.074	0.08	0.06	0.11
8/17/11	0.23	0.16	0.086	0.079	0.14	0.14	0.084	0.22	0.13	0.26	0.12	0.11	0.14	0.079	0.26
9/21/11	0.1	0.12	0.11	0.044	0.09	0.17	0.12	0.14	0.11	0.088	0.074	0.064	0.10	0.044	0.17
10/13/11	0.085	0.063	0.027	0.042	0.034	0.091	0.085	0.078	0.07	0.087	0.076	0.063	0.07	0.027	0.091

[1] These 10 locations are all of the locations listed above except South Deep and North Deep.

FIGURES

Date Revised: 2/1/2012 9:41:37 AM

Path: Q:\GIS\GIS_Lake\Baseline_Monitor\MXDs\2011_NitrateInjectLocs.mxd

2011 Nitrate Application Locations

Bathymetry Contours For Water Depth

10 Foot Intervals

30 Foot Water Depth Contour

0 1,200 2,400 4,800 7,200

Feet

Figure 1

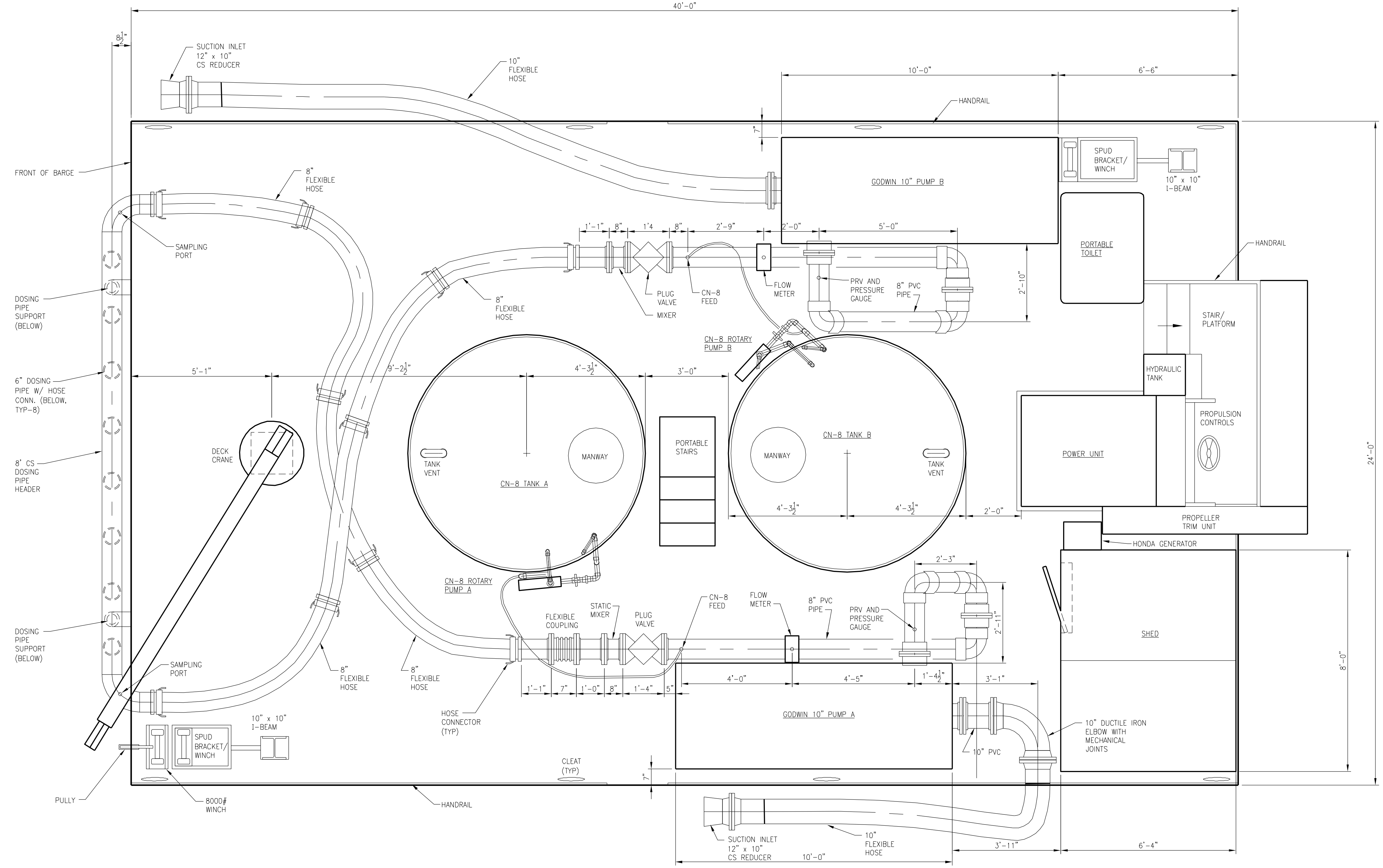
Honeywell

Onondaga Lake
Syracuse, New York

2011 Nitrate Application Locations

PARSONS

301 Plainfield Road, Suite 350; Syracuse NY 13212 Phone:(315)451-9560



NO	DESCRIPTION	DATE	DRAWN	CHK'D	APPV'D
A	FOR INFORMATION ONLY	10/26/11	JTS		

DRAWN BY / DATE
CHECKED BY / DATE
APPROVED BY / DATE
PROJECT MGR. / DATE
SEAL

PARSONS
COMMERCIAL TECHNOLOGY GROUP

OFFICE
301 PLAINFIELD ROAD
SYRACUSE, NY 13212
(315) 451-9560

JOB 446625
WBS 10001

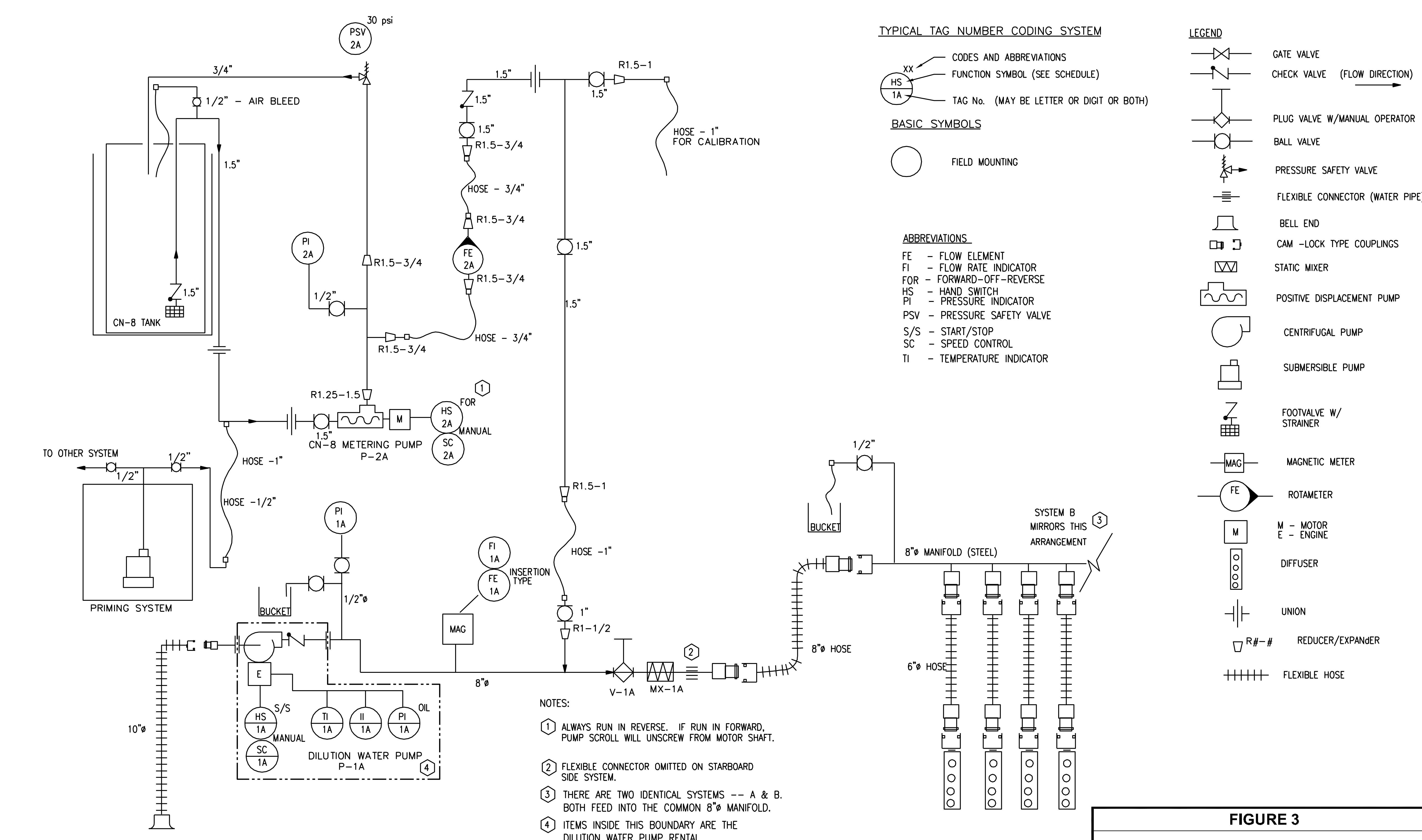
PROJECT TITLE
Honeywell
ONONDAGA LAKE
NITRATE ADDITION PILOT TEST
SYRACUSE, NEW YORK

DRAWING TITLE
FIGURE 2
BARGE AS-BUILT 2011

SCALE 1"=50'
(IF PRINTED ON 22x34 SHEET)

DRAWING NO. 446625-M-001
REV. A

FILE NAME: P:\HONEYWELL -SYR\446625 - NITRATE ADDITION PILOT TEST 2011\10.0 TECHNICAL CATEGORIES\10.16 CAD\BARGE AS-BUILT\BARGE 2011.DWG
PLOT DATE: 1/18/2012 1:14 PM PLOTTED BY: SIVALIA, JACK



09-12-11

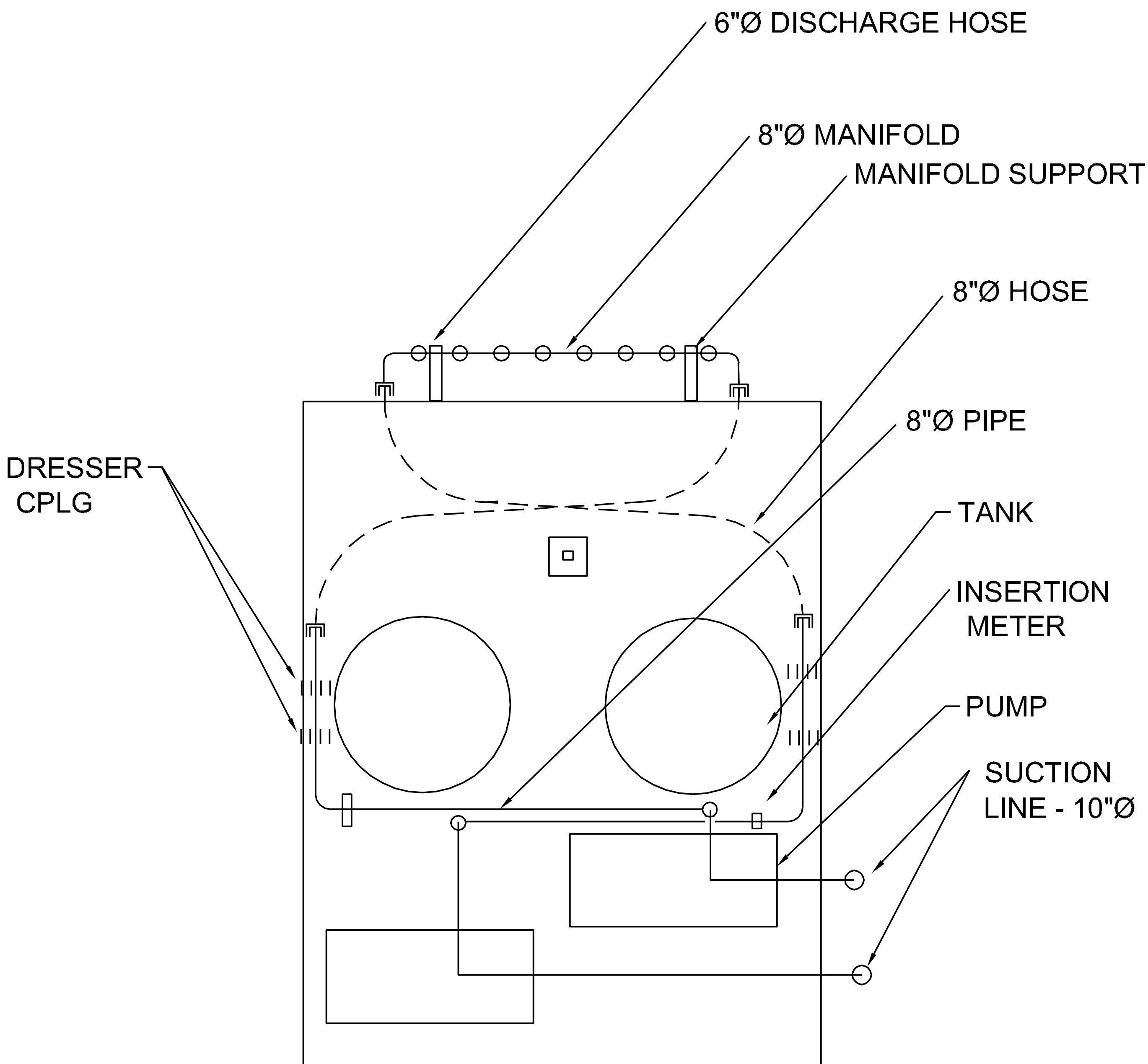
FIGURE 3

Barge Piping & Instrumentation Diagram

Syracuse, NY

PARSONS

446625 Onondaga Lake P&ID-09-12-11.dwg



EQUIPMENT POSITIONING PLAN -- OPTION C

NOTE: MINIMUM BEND RADIUS OF HOSE IS 5 FEET.

Figure 4

On-deck Arrangement Plan-Option C
Onondaga Lake Nitrate Application Pilot Test Year 1
Syracuse, NY

PARSONS

LAYOUT2.DWG

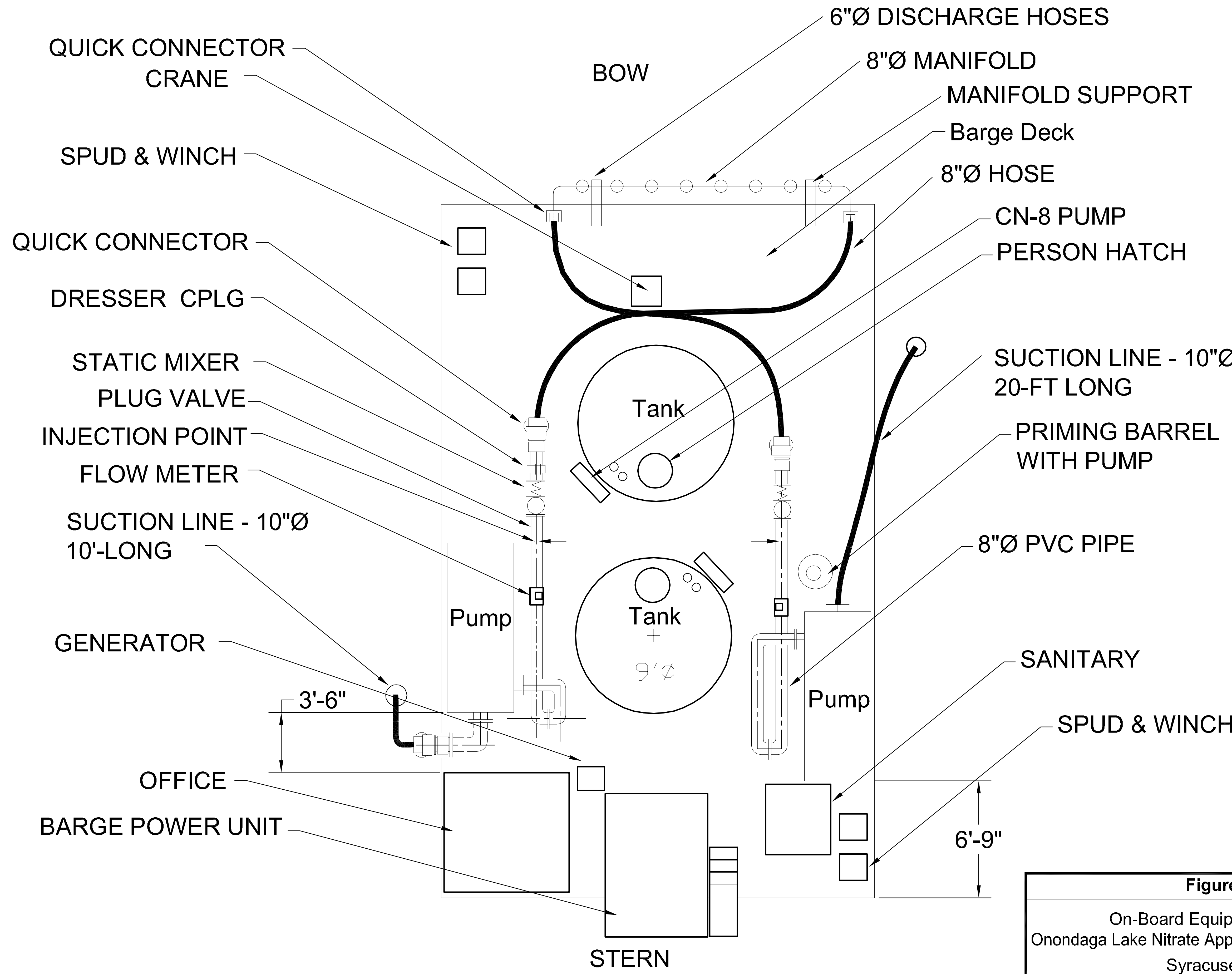


Figure 5

On-Board Equipment Layout

Onondaga Lake Nitrate Application Pilot Test Year 1

Syracuse, NY

PARSONS

ON-BOARD LAYOUT-09-14-11.DWG

Date Revised: 1/31/2012 2:58:13 PM

Path: Q:\GIS\GIS Lake\Baseline Monitor\MXDs\2011 WaterSampleLocs.mxd

North and South Deeps

ISUS Sample Location

Bathymetry Contours For Water Depth

10 Foot Intervals

30 Foot Water Depth Contour

0 1,200 2,400 4,800 7,200

Feet

Figure 6

Honeywell

Onondaga Lake
Syracuse, New York

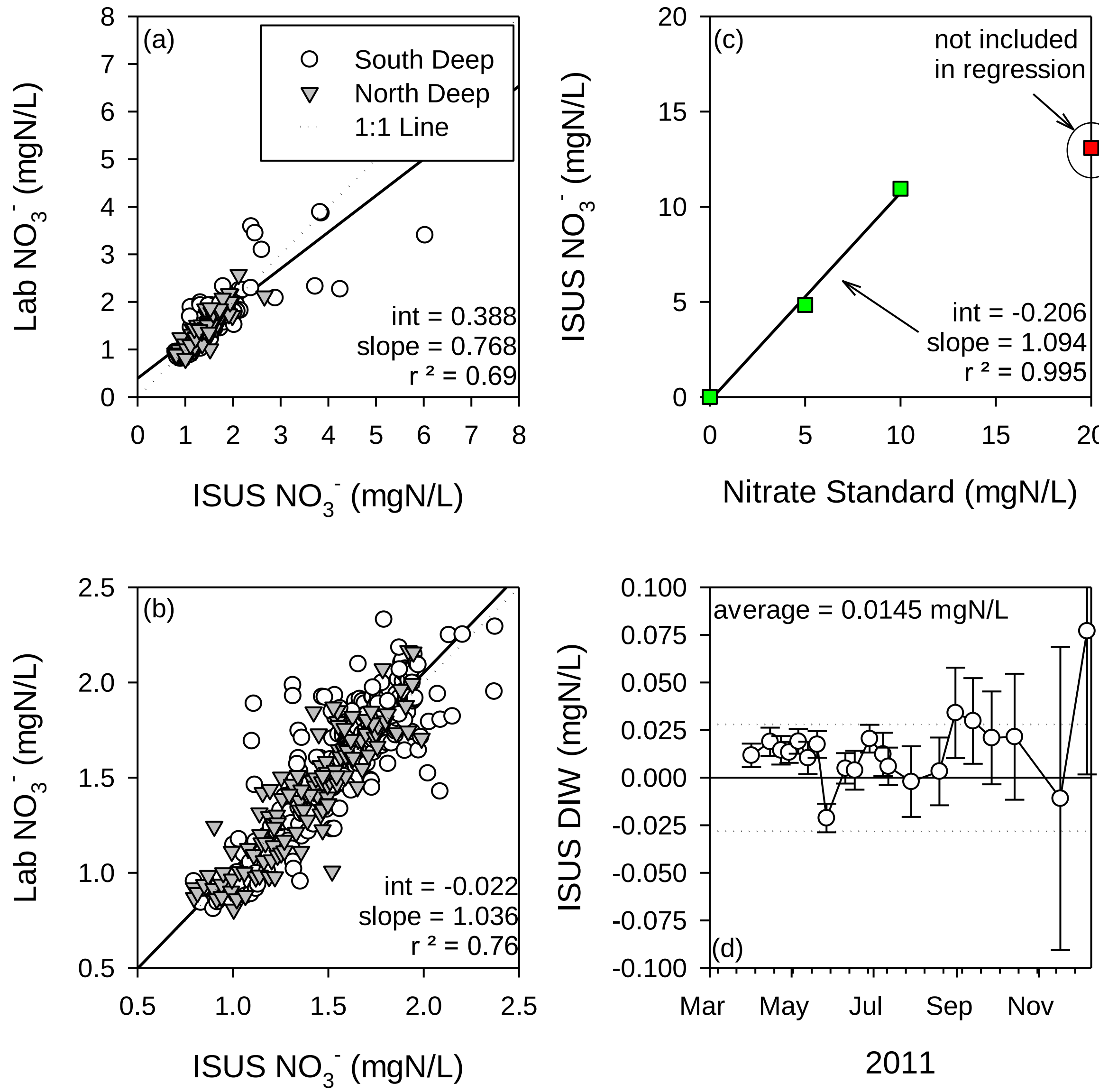
2011 ISUS Monitoring Locations

PARSONS

301 Plainfield Road, Suite 350; Syracuse NY 13212 Phone:(315)451-9560

Figure 7

Comparison of 2011 Nitrate Water Concentrations Determined using ISUS and in the Laboratory

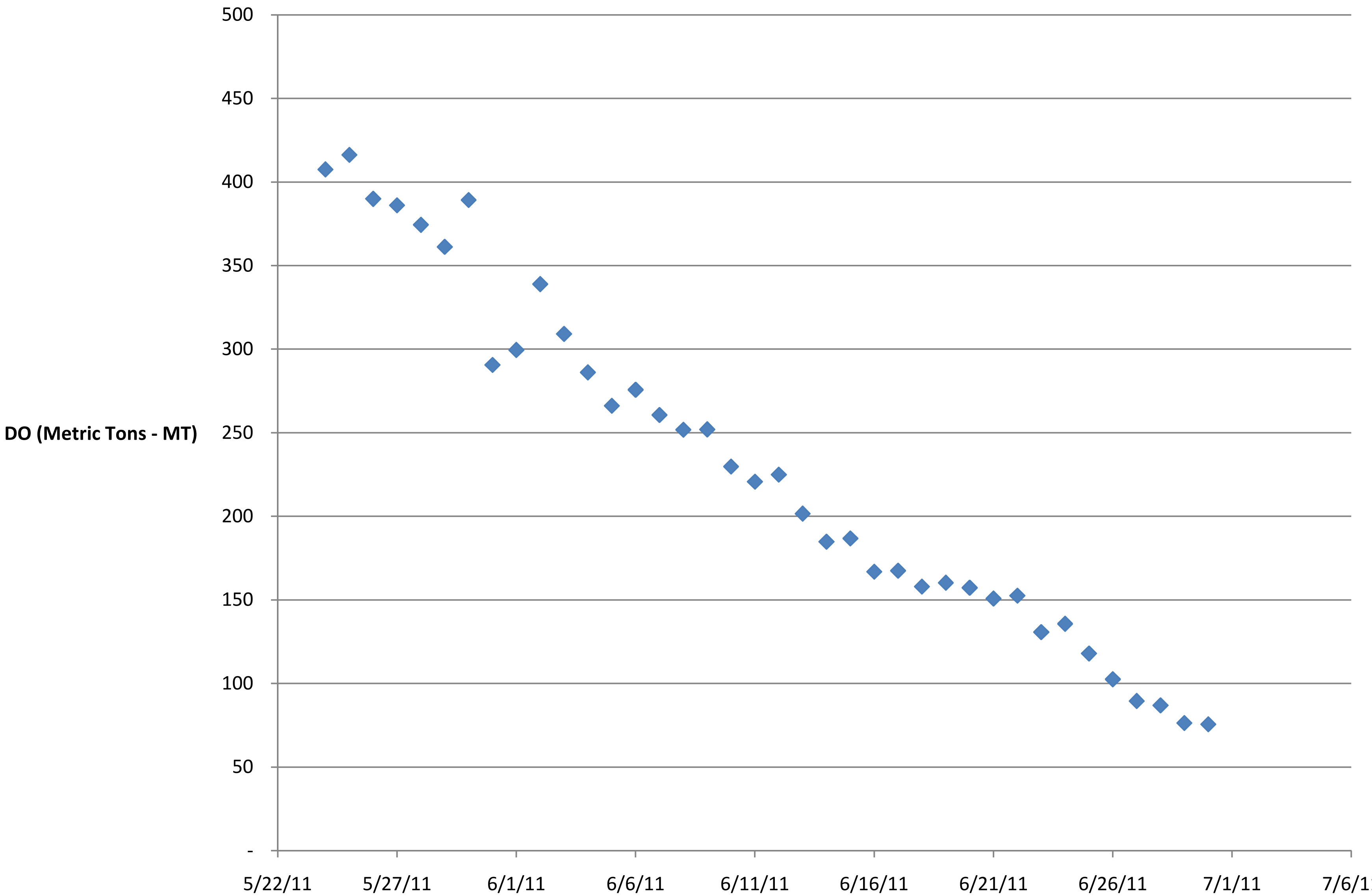


The four plots are: (a) nitrate results from South Deep and North Deep, (b) nitrate results from South Deep and North Deep in the 0 to 2.5mg/L range, (c) ISUS verification with laboratory nitrate standards, and (d) time series of ISUS DIW[1] laboratory checks with the zero line and upper and lower bounds of ISUS accuracy (±0.028 mgN/L).

Notes:

1. DIW = DeIonized Water (pure water)

Figure 8
Dissolved Oxygen Mass (MT) in Hypolimnion after Stratification



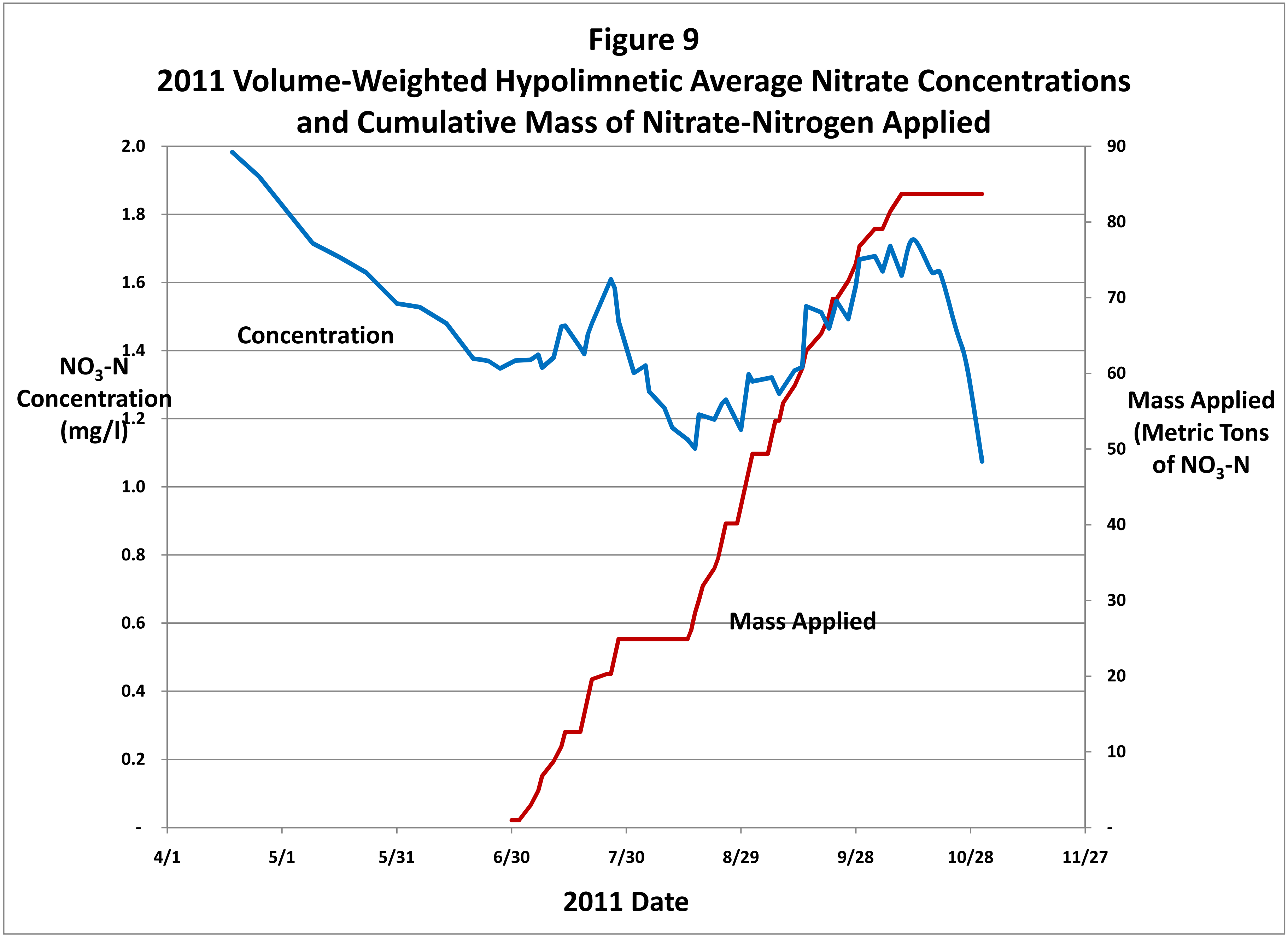


Figure 9
2011 Volume-Weighted Hypolimnetic Average Nitrate Concentrations
and Cumulative Mass of Nitrate-Nitrogen Applied
NO3-N Concentration (mg/l)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
-
Concentration
Mass Applied
Mass Applied (Metric Tons of NO3-N
90
80
70
60
50
40
30
20
10
-
4/1
5/1
5/31
6/30
7/30
8/29
9/28
10/28
11/27
2011 Date

Figure 10

2011 Nitrate Depletion rates in the Hypolimnion Measured at South Deep and at North Deep

- volume weighted (10 to 19 meters) concentrations calculated with respect to unique basin area and volume
- Nitrate depletion rate measured at North Deep was 24% higher than at South Deep
- two potential causes for a higher rate of nitrate depletion in the north basin
  - greater sediment nitrate demand
  - differences in morphometry

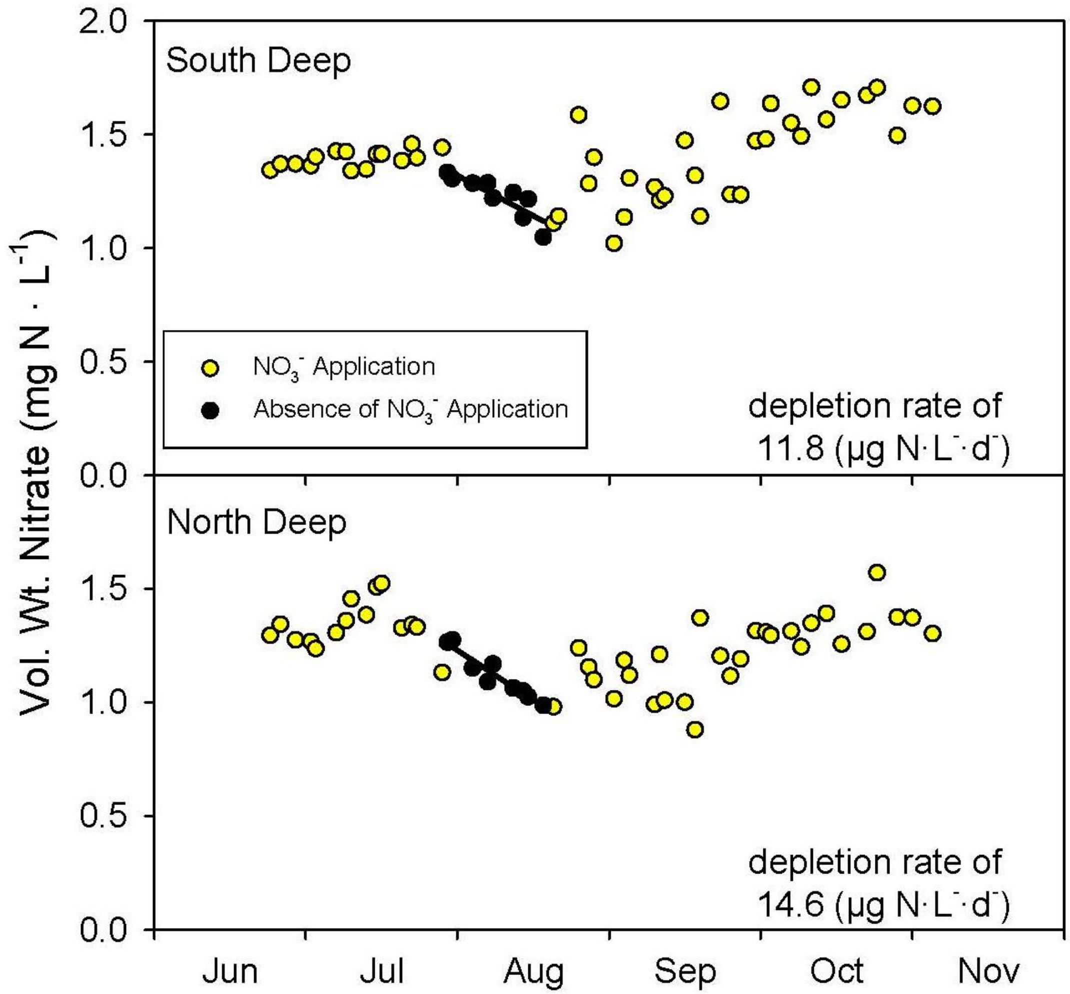


Figure 11
Hypolimnetic NO3-N profile (mg/l) through 2011 Season

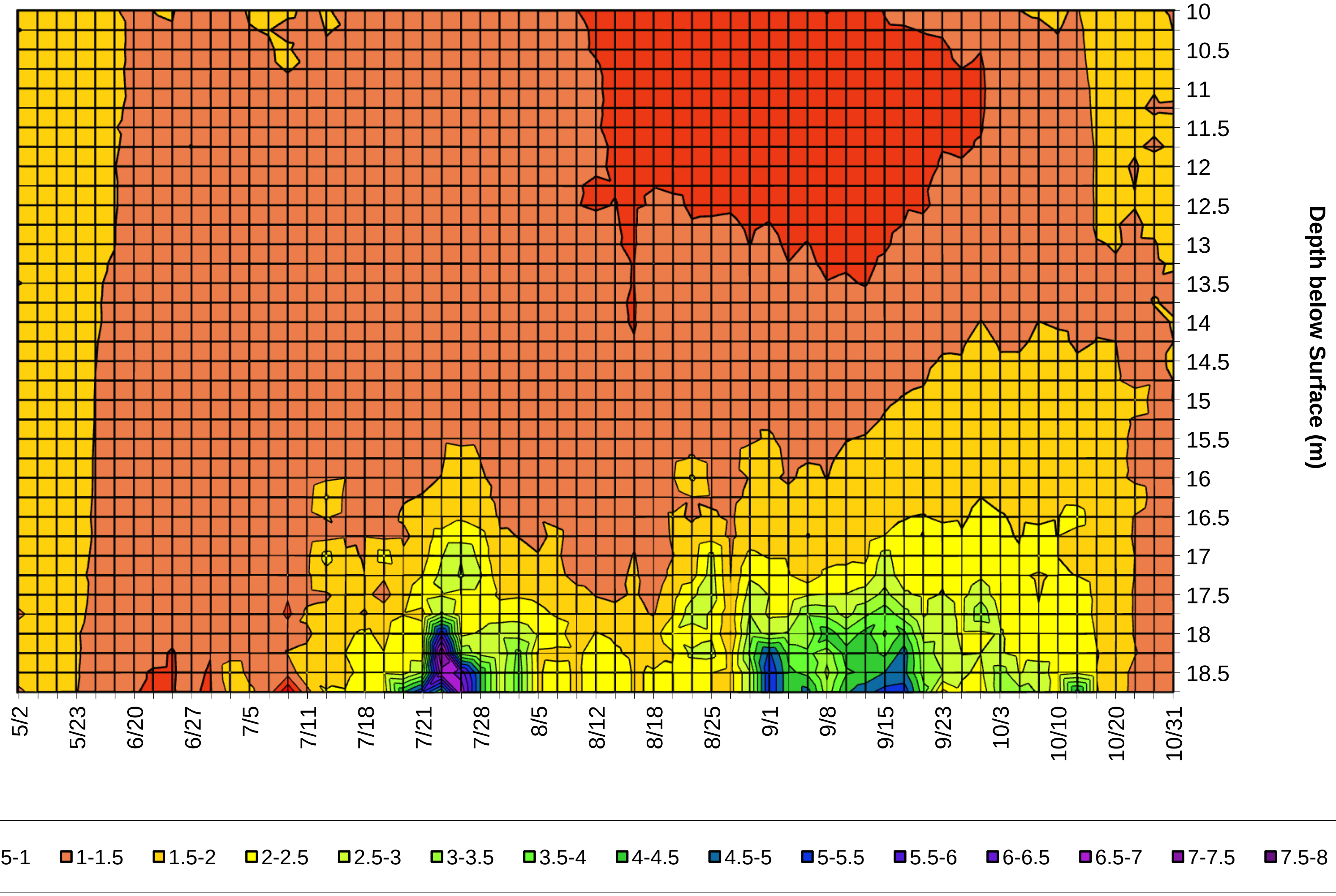
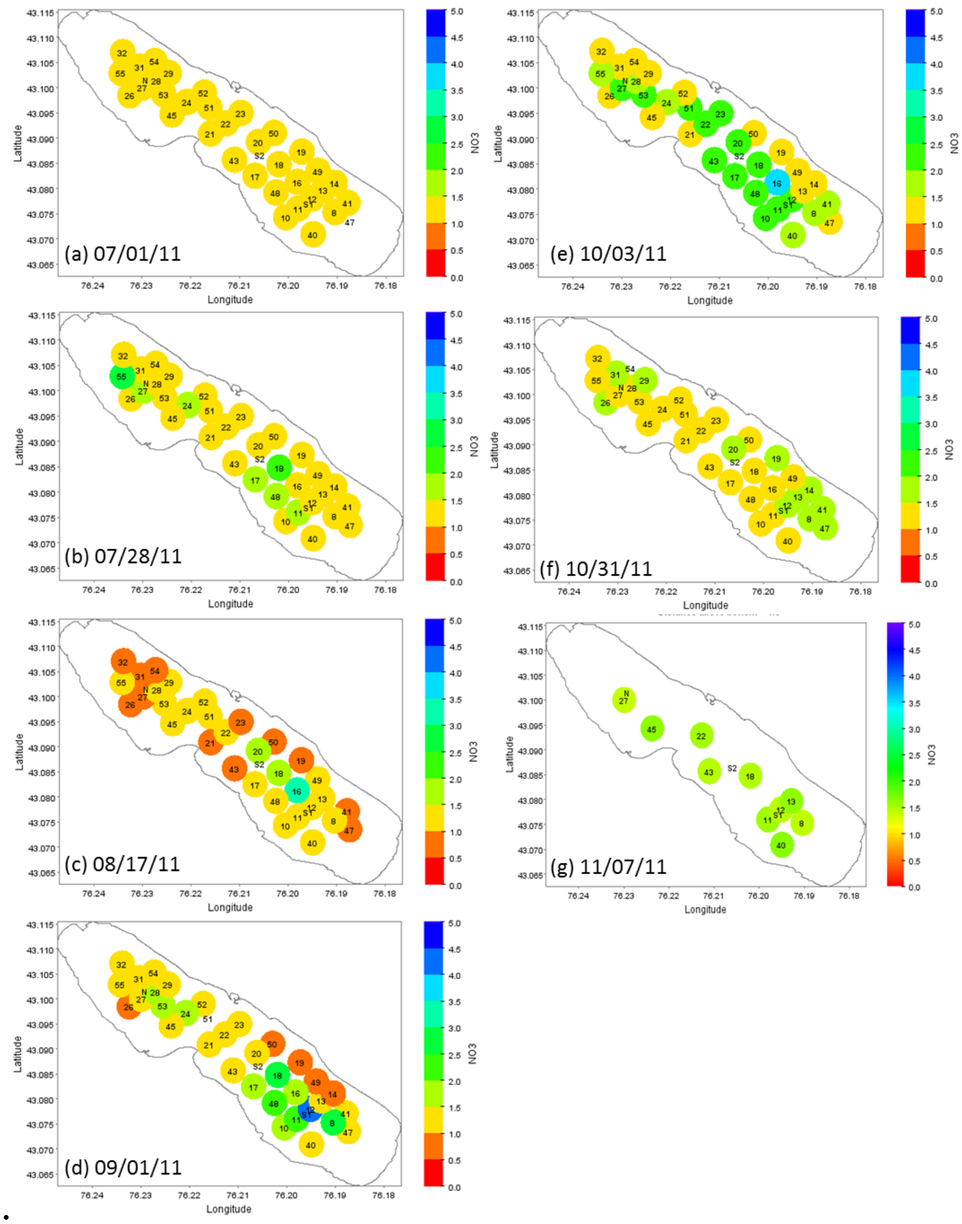


Figure 12

Plan View Plots of Nitrate[1] Water Concentrations One Meter Above the Lake Bottom for Seven Different Dates: July 1 at the Start of Nitrate Addition through November 7 Following Turnover



•

Note

1 Concentrations provided as nitrate (NO_x)-nitrogen in mg/l

Figure 13

Vertical Profiles of 2011 Methylmercury (MeHg) Water Concentrations at South Deep and at North Deep From July 5 Through October 31.

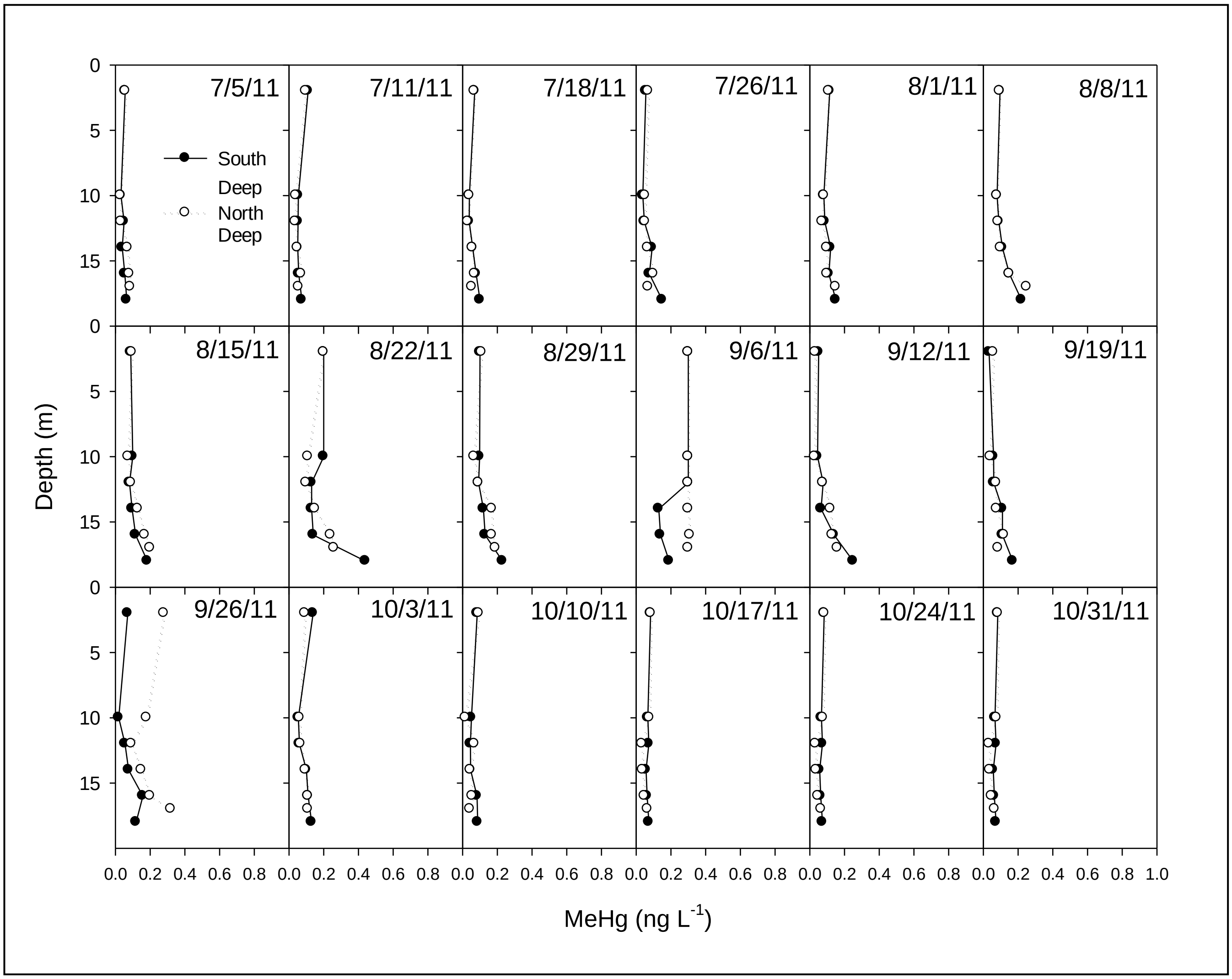
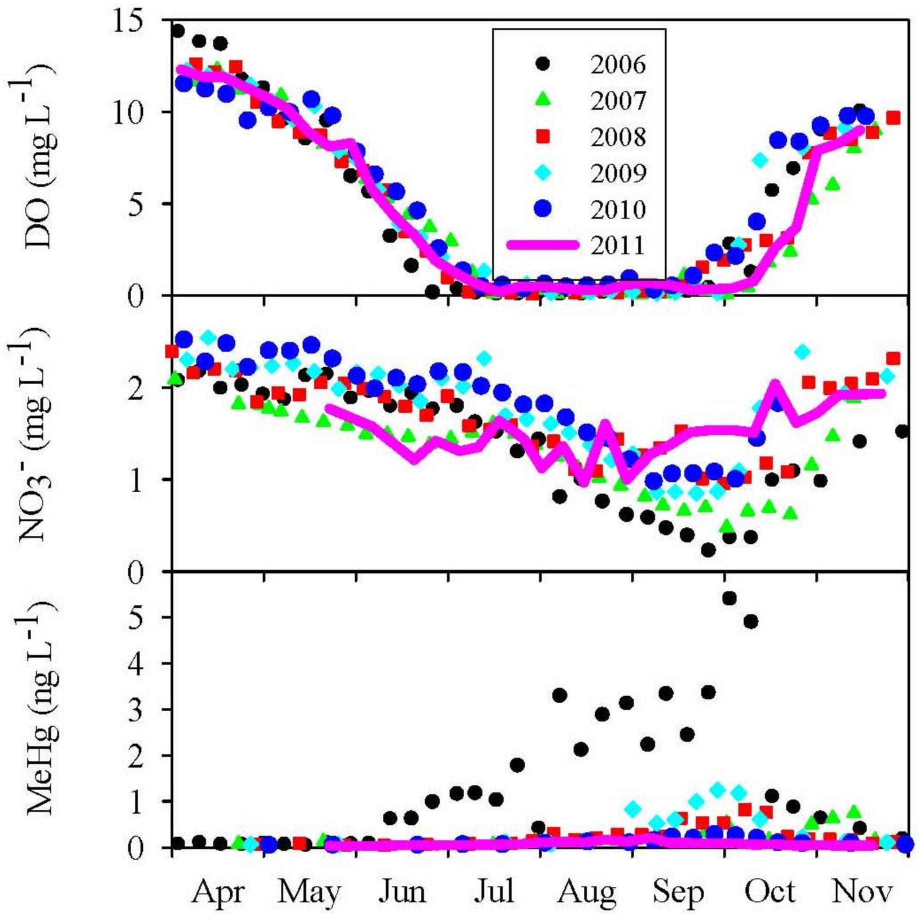


Figure 14

Hypolimnion Average Dissolved Oxygen, Nitrate and Methylmercury Water Concentrations from 2006 Through 2011

- Recurring seasonal depletion of nitrate and increases in methylmercury prevented by 2011 Nitrate Addition Pilot Test operations
- 2011 methylmercury levels were the lowest on record

Values plotted are volume-weighted average concentrations from the 10 to 19-meter water depths



DO - dissolved oxygen
NO_3^- - nitrate as nitrogen
MeHg - methylmercury

mg L^{-1} - mg/L
ng L^{-1} - ng/L or 0.000001 mg/L

Figure 15
2011 Epilimnion and Hypolimnion (Upper and Lower Water) Temperatures (T) and Dilution Factors (DF)

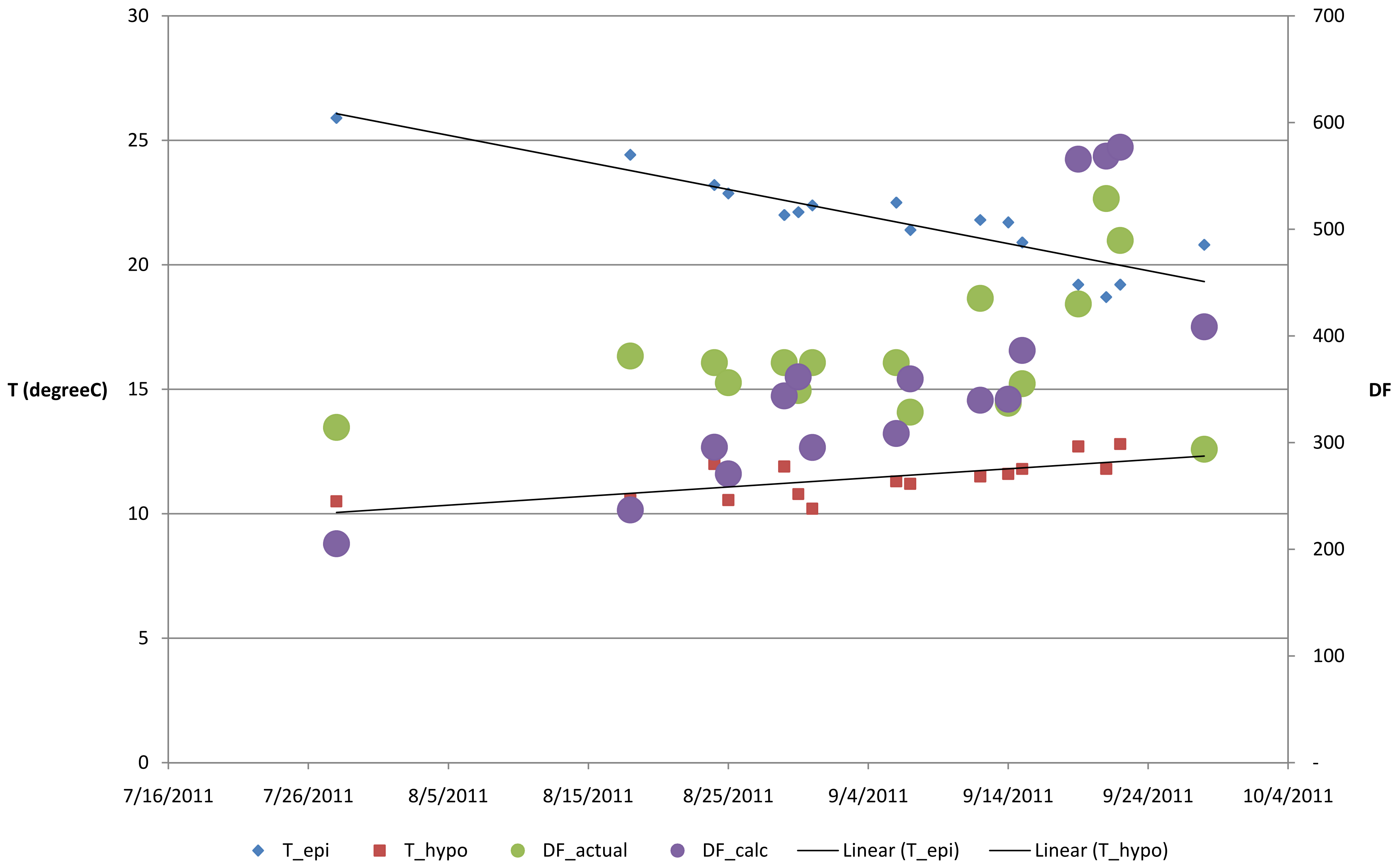
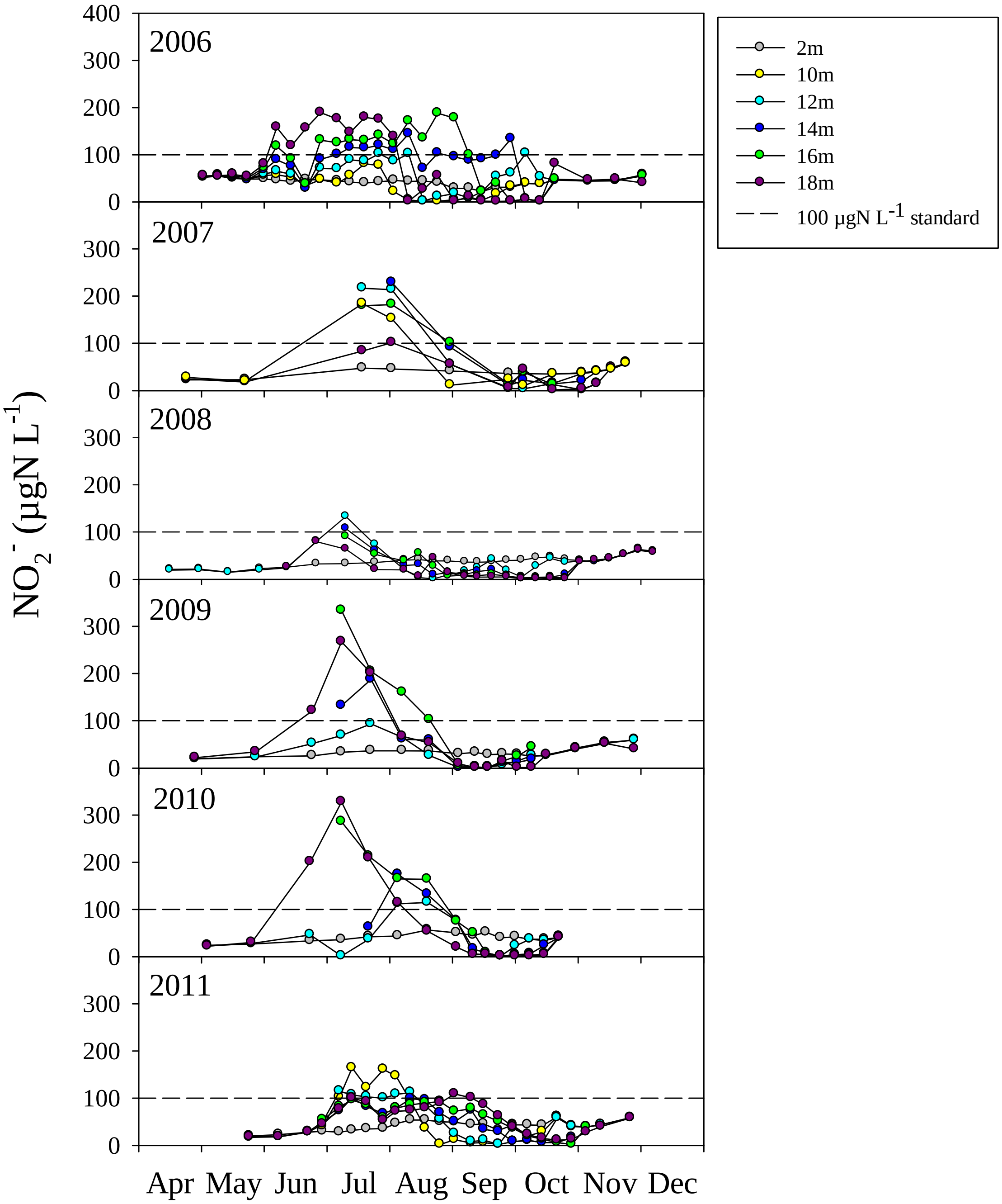


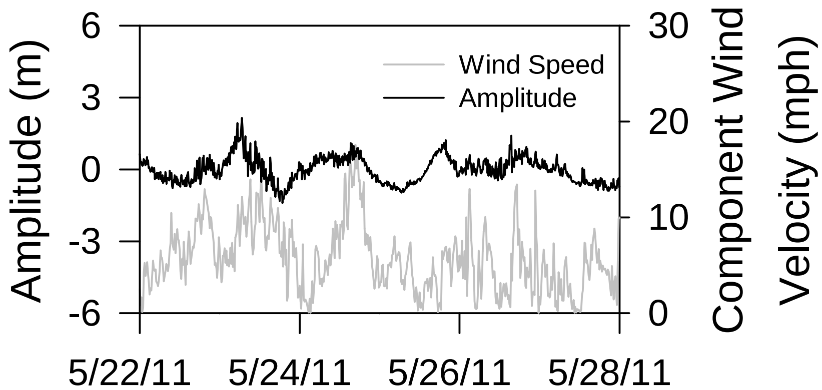
Figure 16

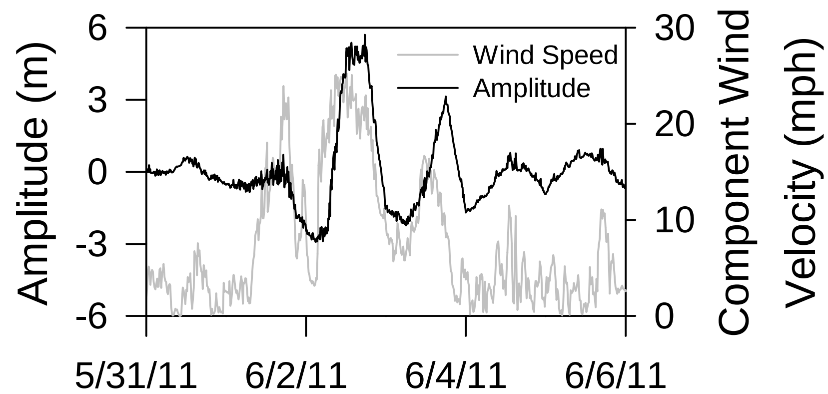
2006 Through 2011 Time Series of Nitrite-Nitrogen (NO_2^-) At South Deep For Six Different Water Depths From 2 to 18 Meters

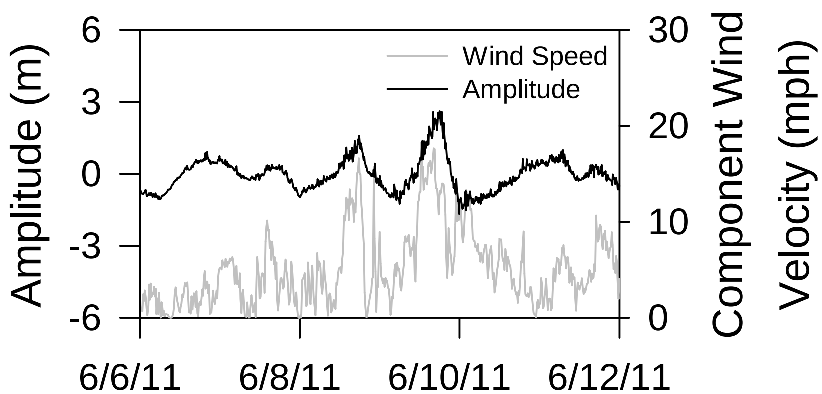


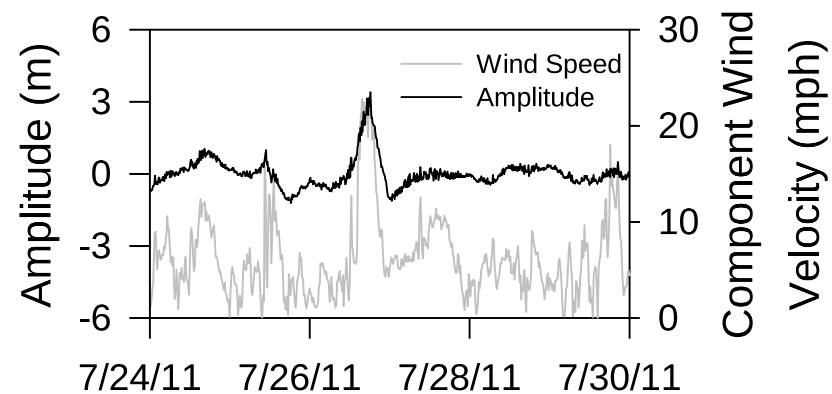
Note: 100 micrograms per liter (ug L^{-1}) as nitrogen (N) is the NYSDEC surface water quality standard for nitrite applicable to a warm-water fishery.

Figure 17
2011 Wave Amplitudes and Wind Speed for Seiche Events



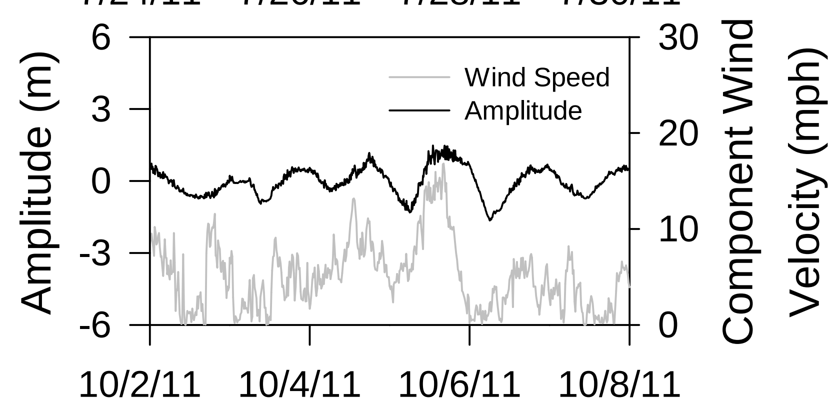






- average seiche period was 12.5 h and ranged from 8.5 h to 14.5 h
- theoretical period for Onondaga Lake is 13 h (Effler et al. 2004)

Seiche Events
5/23 – 5/25
6/1 – 6/4
6/7 – 6/10
7/26 – 7/28
10/4 – 10/7



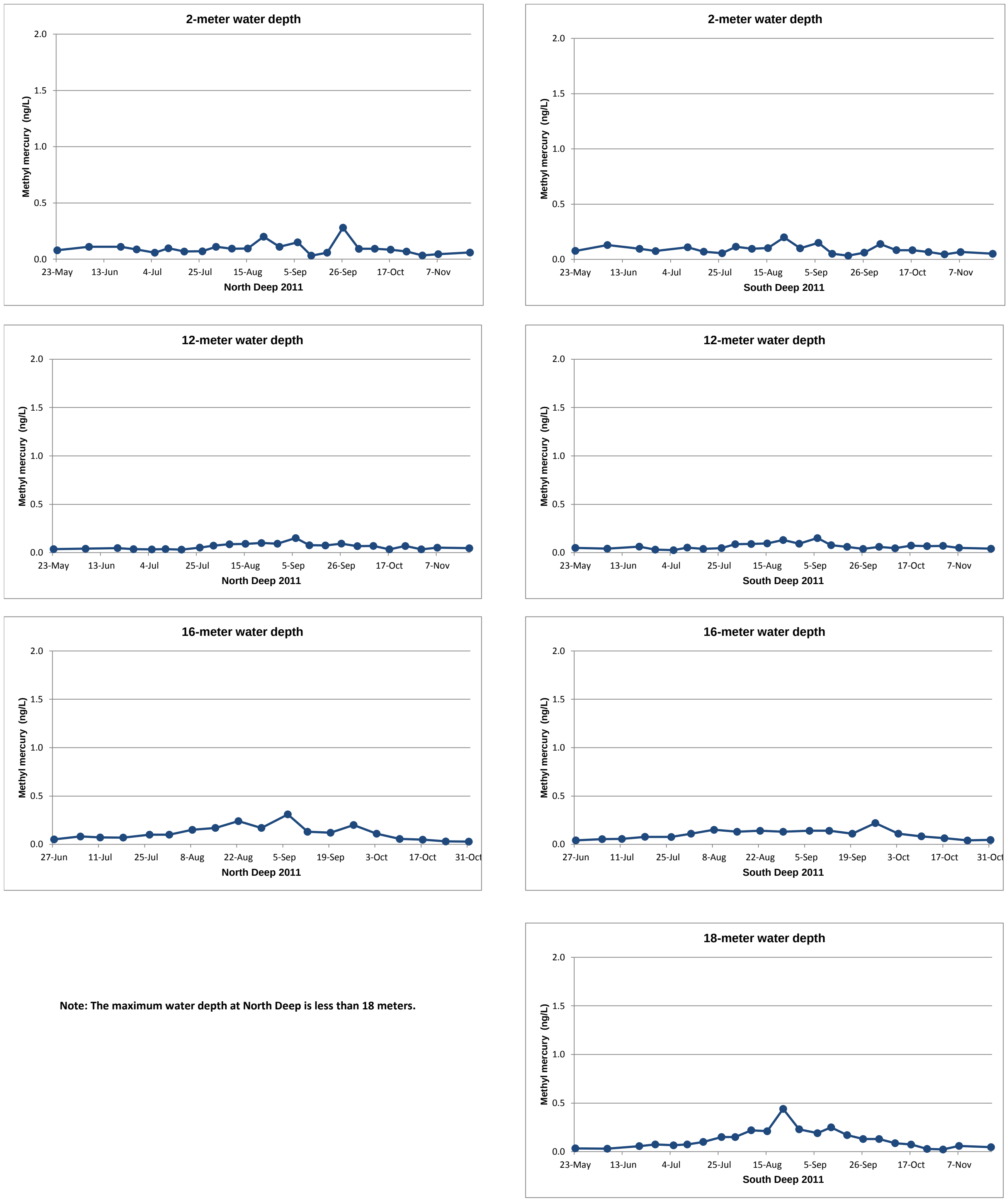


Figure 18 Methylmercury Concentrations at 2, 12, 16, and 18-meter Water Depths at North Deep and South Deep in 2011

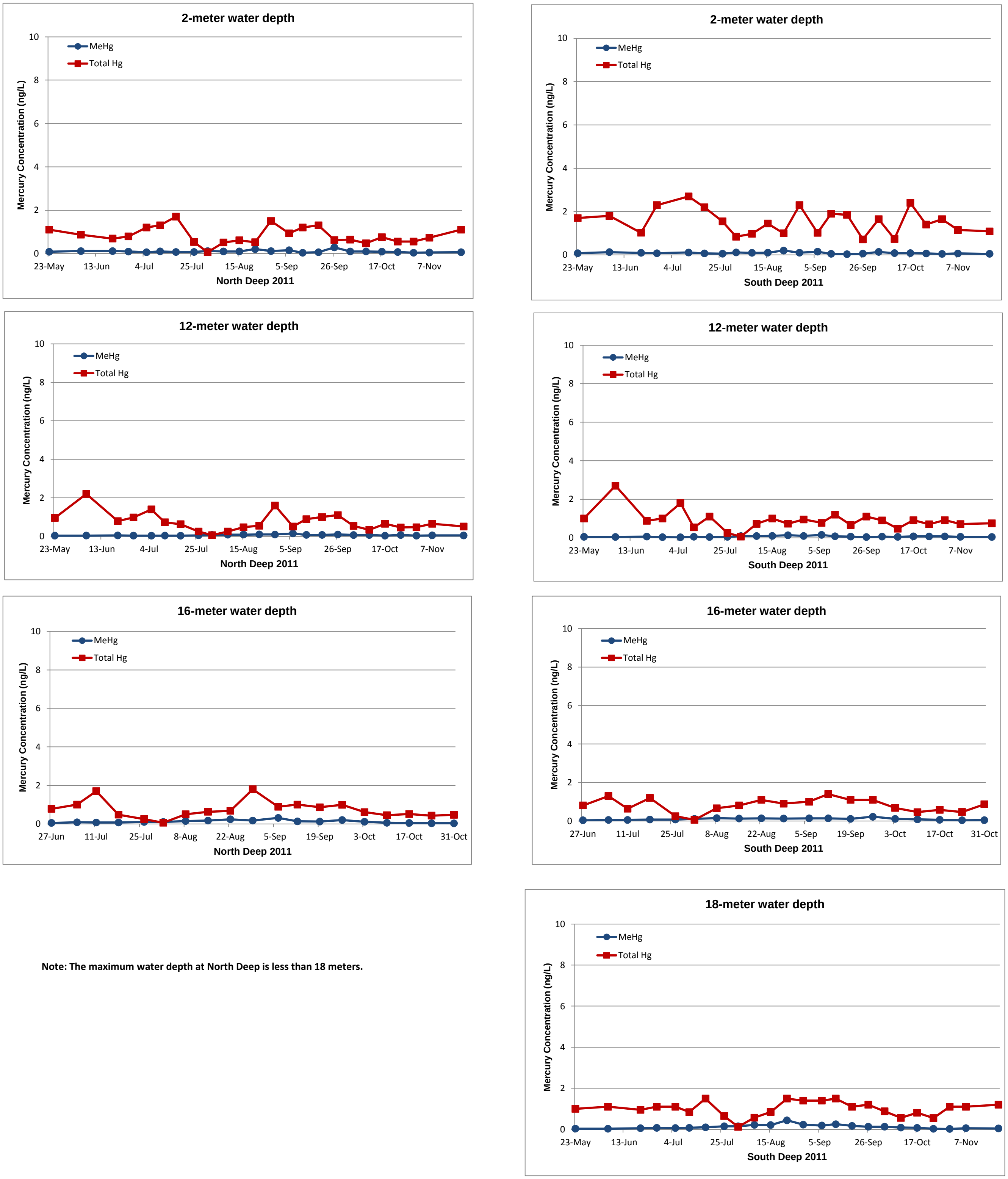


Figure 19 Total and Methylmercury Water Concentrations at 2, 12, 16, and 18-meter Water Depths at North Deep and South Deep in 2011

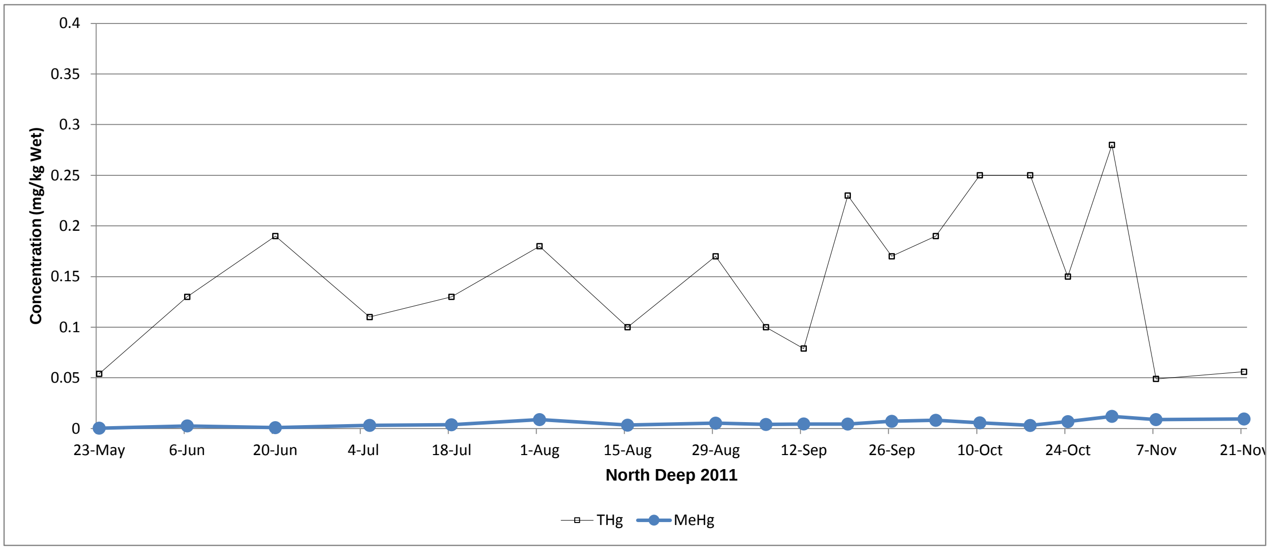


Figure 20A Total Mercury and Methylmercury in Zooplankton at North Deep During 2011

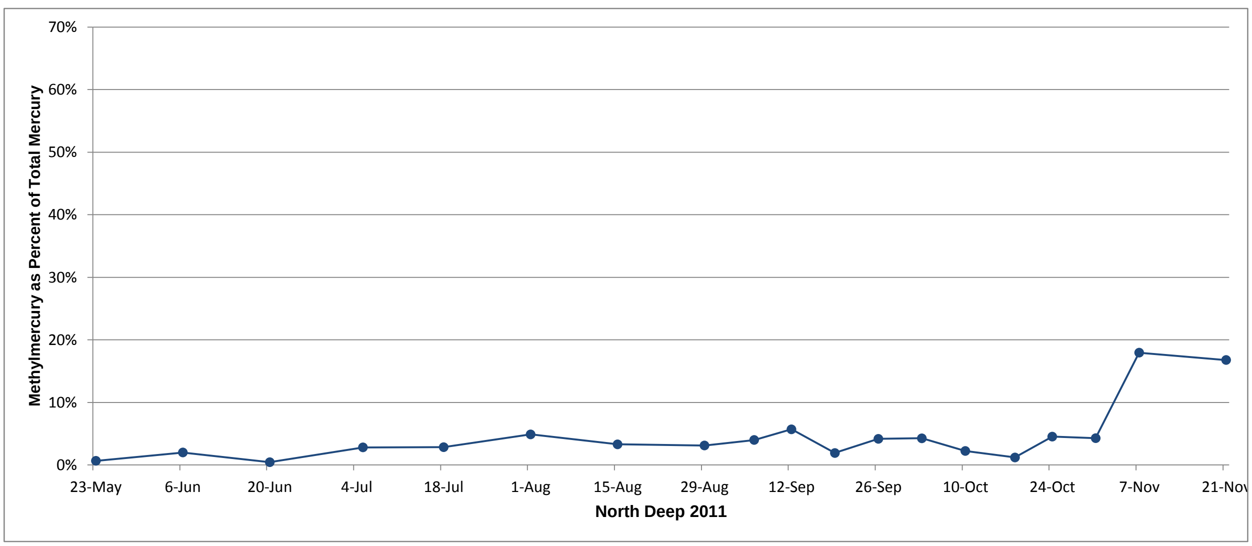


Figure 20B Methylmercury as a Percent of Total Mercury in Zooplankton at North Deep During 2011

Notes:

1. These results are for zooplankton assemblages.
2. These results are based on validated mercury data from laboratory analyses conducted by Test America (North Canton,OH).

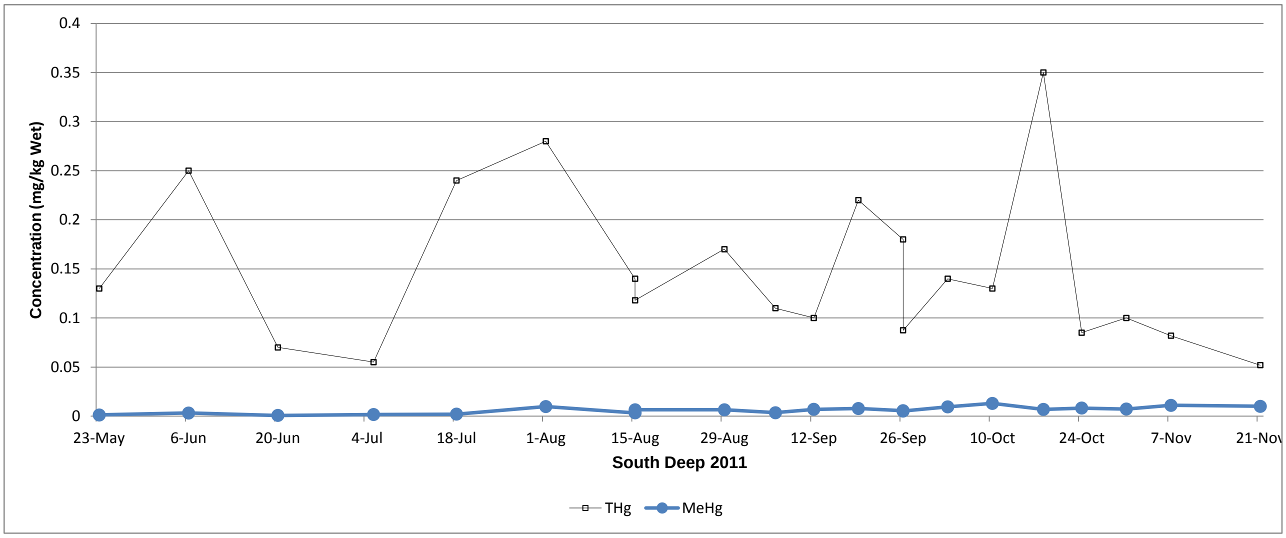


Figure 21A Total Mercury and Methylmercury in Zooplankton at South Deep During 2011

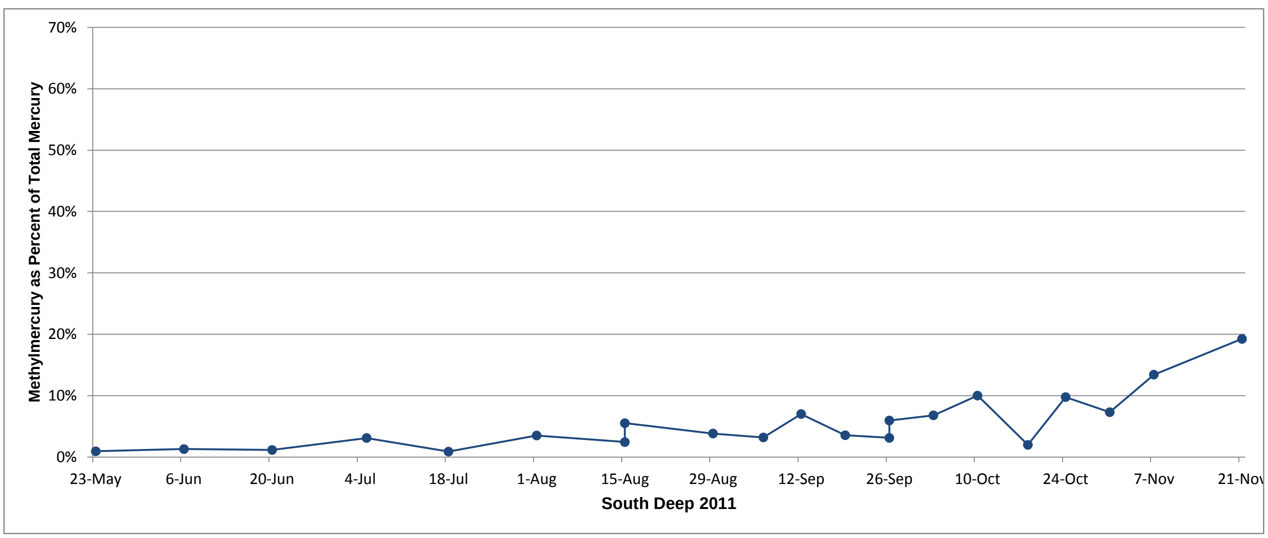


Figure 21B Methylmercury as a Percent of Total Mercury in Zooplankton at South Deep During 2011

Notes:

1. These results are for zooplankton assemblages.
2. These results are based on validated mercury data from laboratory analyses conducted by Test America (North Canton,OH).

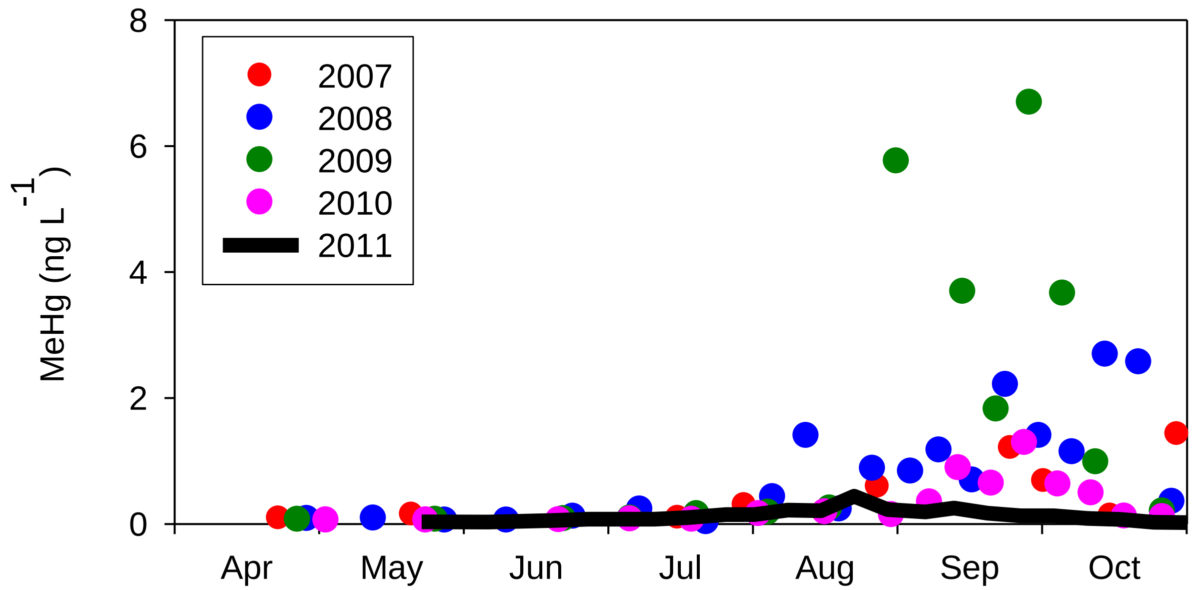
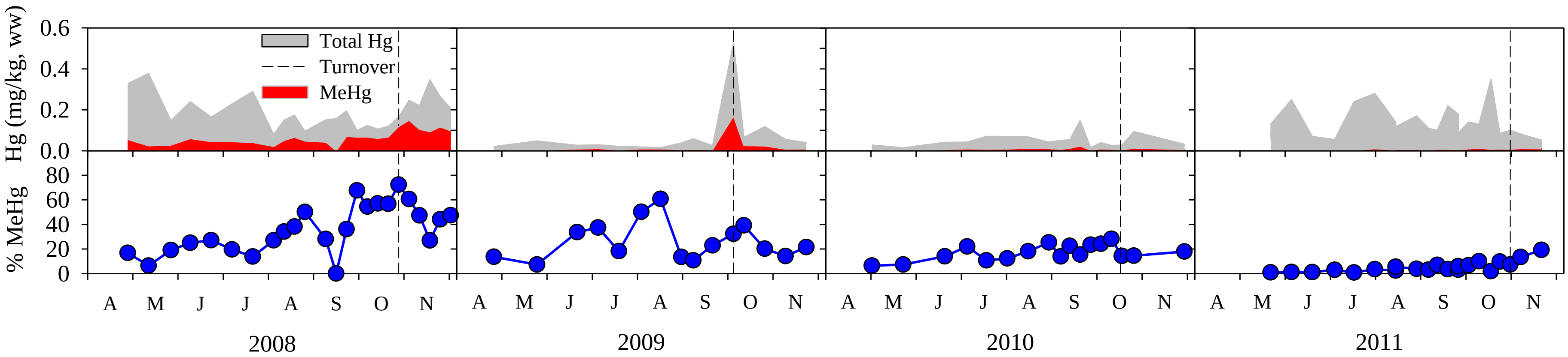


Figure 22 Methylmercury Concentrations in Surface Water at the 18-meter water depth measured at South Deep from 2008 through 2011



ww – wet weight

Figure 23 Mercury Concentrations in Zooplankton at South Deep From 2008 Through 2011

APPENDIX A

PHOTO LOG OF NITRATE APPLICATION PROCEDURES

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

LOCATION: Syracuse, New York
CLIENT: Honeywell

Status as of: 6/28/11

Description: Side view of the barge showing: (a) portions of both 2,500 gallon (white) tanks carrying calcium nitrate (CN-8), (b) both 2,500 gallon per minute dilution water pumps (orange), (c) the crane used to maneuver the 8-inch flexible discharge lines (left side), (d) the discharge manifold (left end) with the option to have up to eight discharge lines operating at one time, (e) the shed used for inside work space (right end), and (f) two spuds in the “up” position used to hold the barge in place when stored each evening.

Photo by: KMM

Status as of: 6/28/11

Description: Front view of the barge showing (a) one of the two CN-8 tanks (white), (b) both dilution water pumps (orange), (c) one of the two flexible 10-inch suction lines (orange at left), and (d) the discharge manifold (front)

Photo by: ATL

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

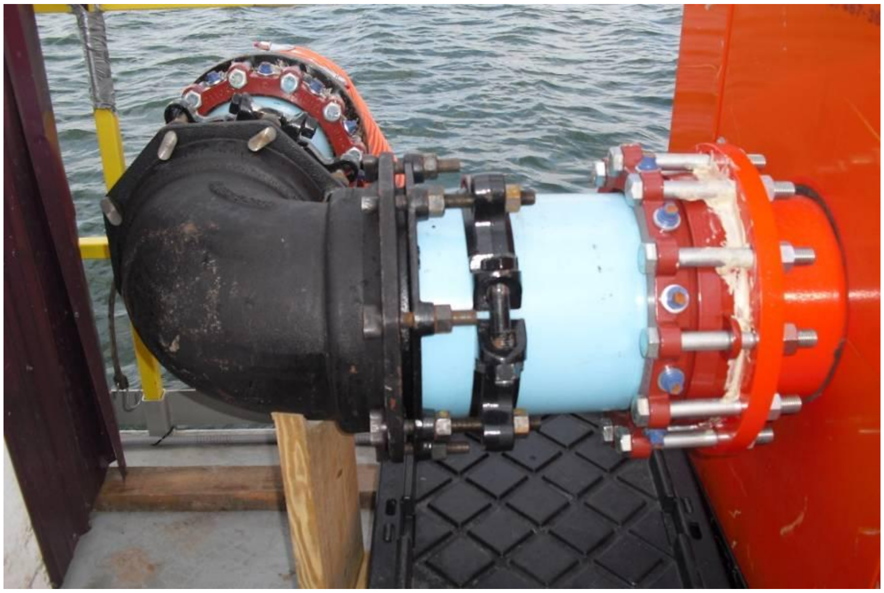
LOCATION: Syracuse, New York
CLIENT: Honeywell

Status as of: 6/28/11
Description: Side view of the barge that includes the propulsion unit (right side)
Photo by: ATL

Status as of: 7/13/11
Description: Dilution water pump with rigid blue and white pipes carrying epilimnion water into and out of the pump, respectively.
Photo by: KMM

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

LOCATION: Syracuse, New York
CLIENT: Honeywell



Status as of: 8/10/11
Description: 10" Ductile Iron Elbow with Mechanical Joints for the suction inlet.
Photo by: KMM

Status as of: 7/13/11
Description: 10-inch flexible orange pipe and 8-inch flexible green pipe upstream and downstream, respectively, of the one of the two dilution water pumps.
Photo by: KMM

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

LOCATION: Syracuse, New York
CLIENT: Honeywell

Status as of: 8/16/11
Description: Manifold with 6-inch diameter dosing pipe with hose connection from the front of the barge and two 8-inch flexible pipe extending downward into the water. The rest of the hose connectors are capped.
Photo by KMM

Status as of: 8/16/11
Description: White discharge line downstream of one of the dilution water pumps. The purpose of the three 90-degree bends is to provide sufficient straight pipe lengths so the flow meter can provide useable flow measurements.
Photo by: KMM

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

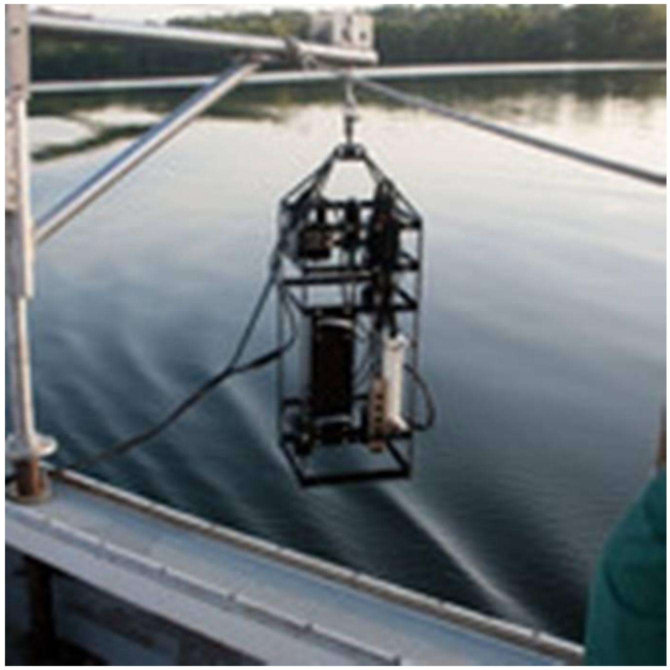
LOCATION: Syracuse, New York
CLIENT: Honeywell

Status as of: 10/07/11
Description: Pressure and flow controls from the dilution water pump to the CN8 poly tank.
Photo by: KMM

Status as of: 8/08/11
Description: Pontoon (support) boat secured to the left of the barge.
Photo by: UFI

PROJECT: Honeywell Nitrate Pilot Test
PROJECT #: 446625

LOCATION: Syracuse, New York
CLIENT: Honeywell



Status as of: 9/06/11
Description: UFI in-situ ultraviolet spectroradiometer (ISUS) unit used to measure nitrate, sulfide and other parameters in water.
Photo by: UFI

APPENDIX B

EXAMPLE DAILY ISUS DATA REPORT

Onondaga Lake Gridding Summary Using an In-Situ Ultraviolet Spectrophotometer (ISUS):

Nitrate Addition Pilot Monitoring

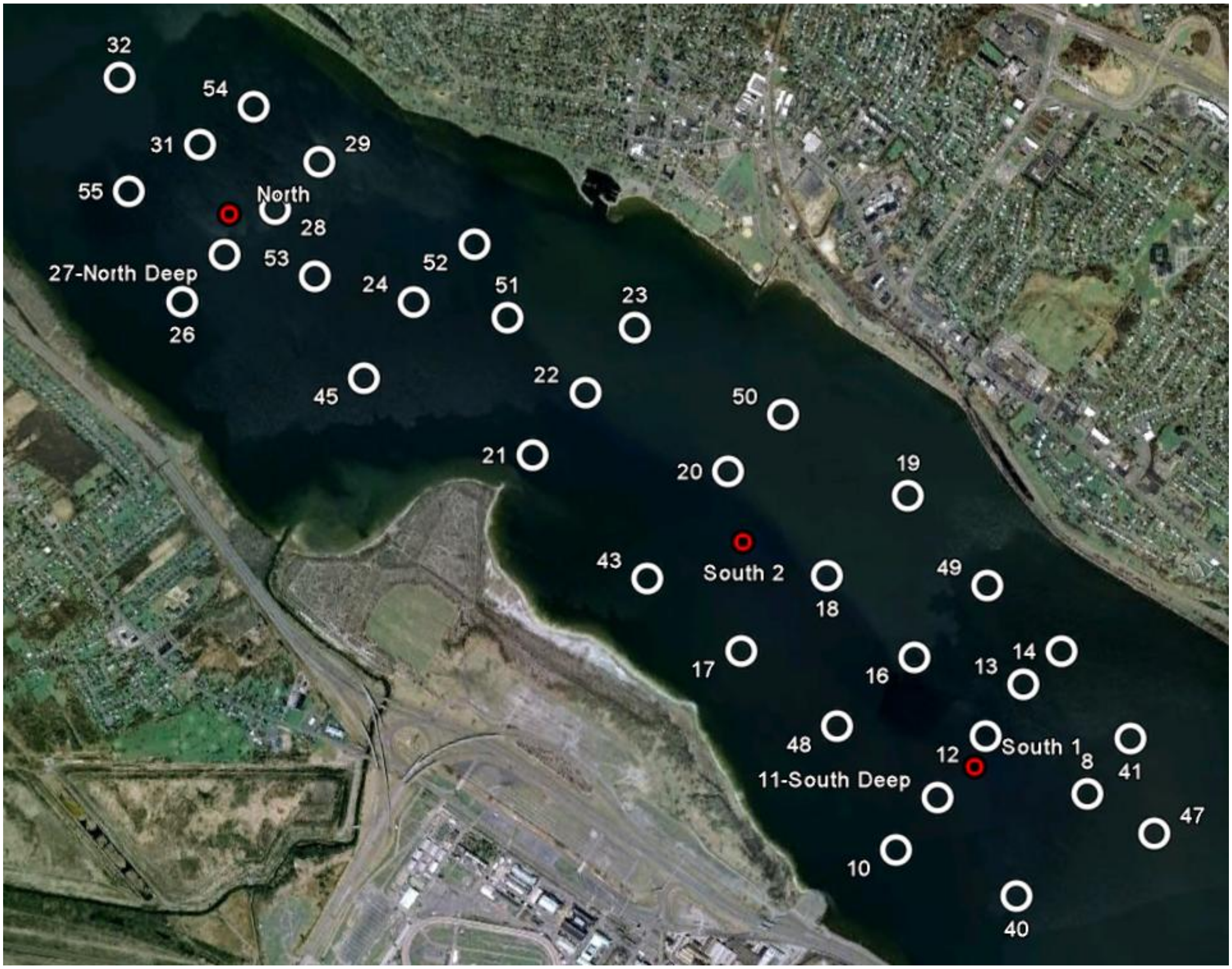
October 10, 2011

UPSTATE
FRESHWATER
INSTITUTE

Provisional Data Summary
for discussion purposes only

Submitted October10, 2011
Anthony R. Prestigiacomo
Research Scientist

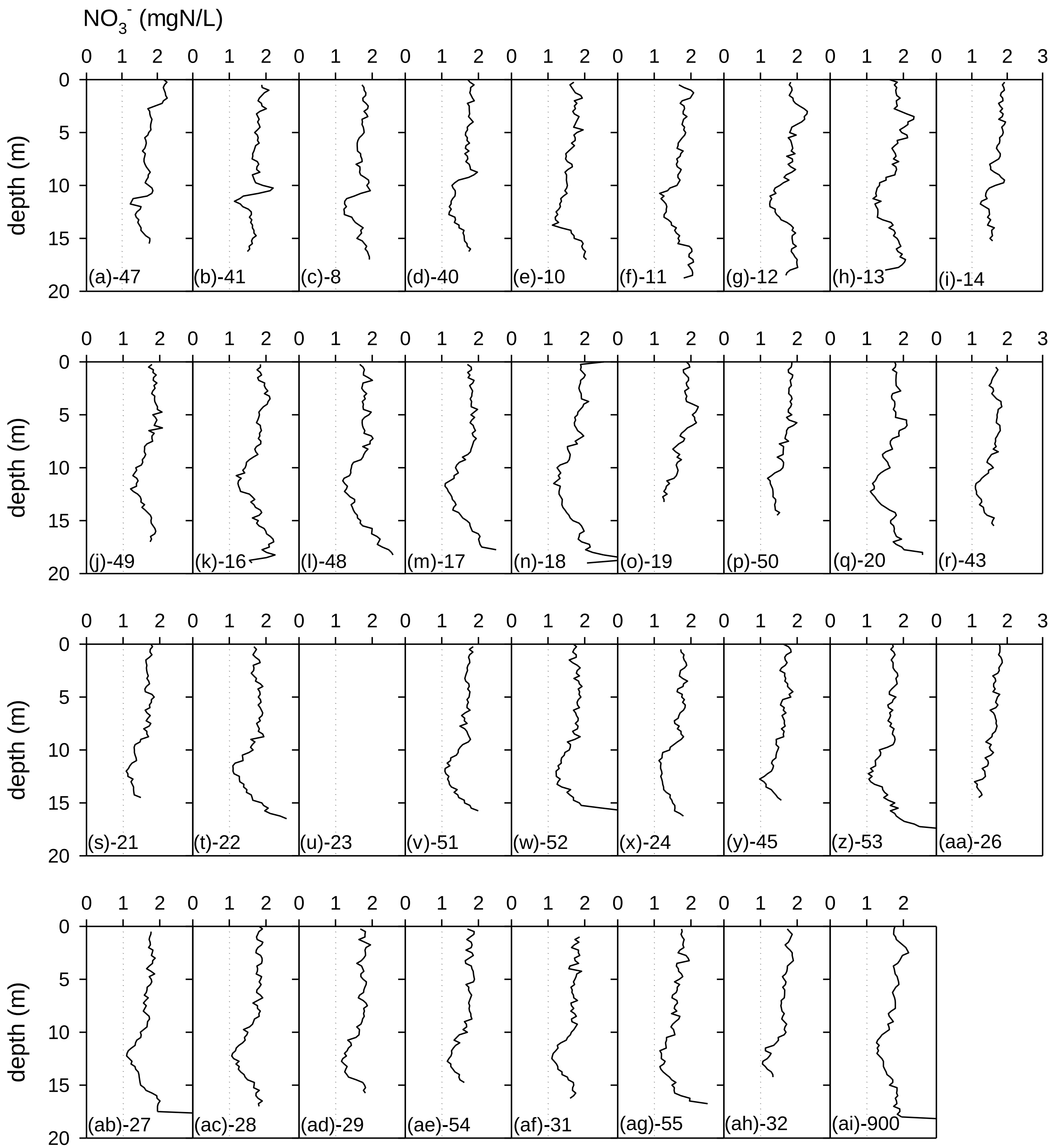
Gridding Locations



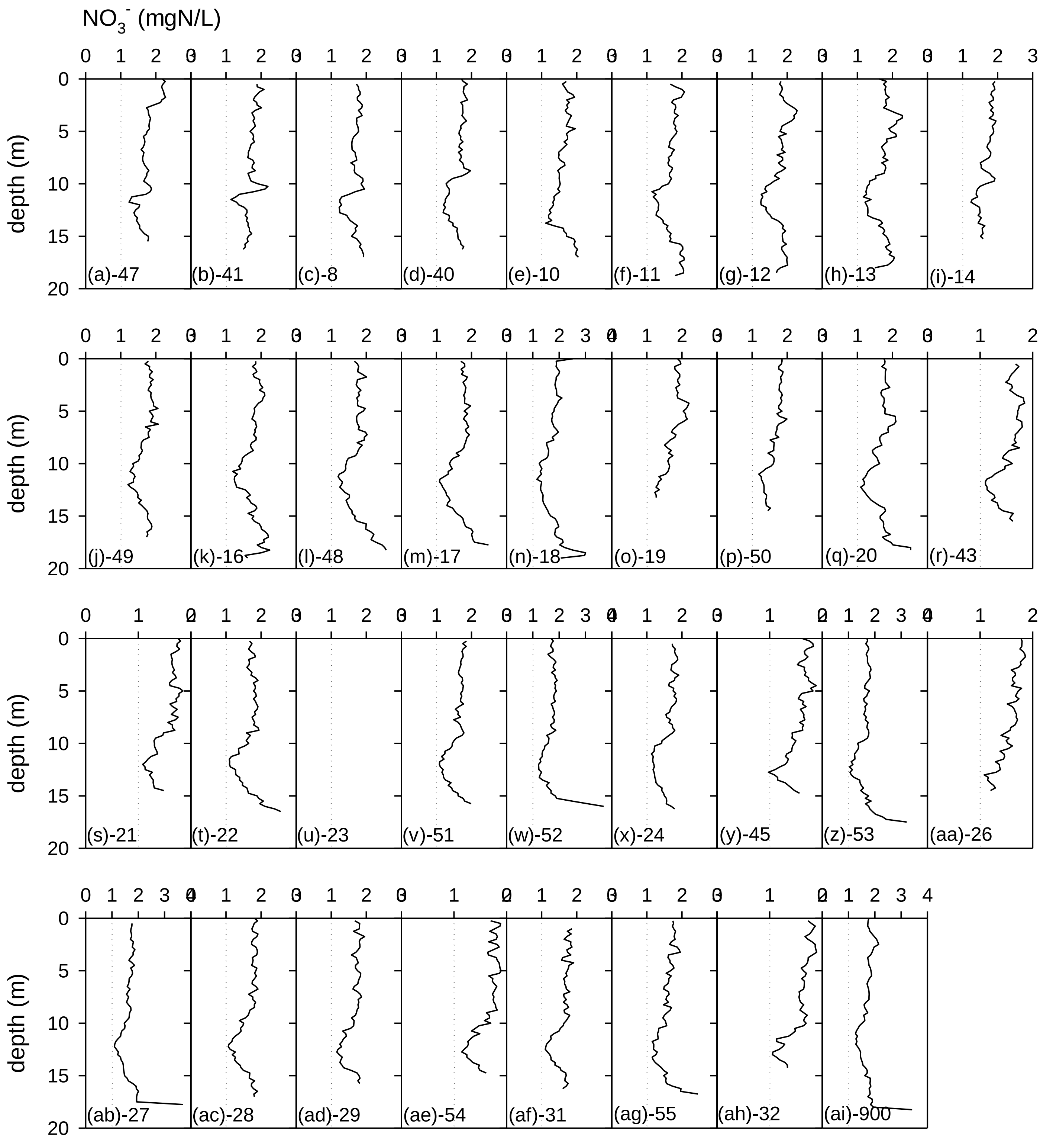
Today’s injection: NORTH

white circle: gridding location
red circle: injection site

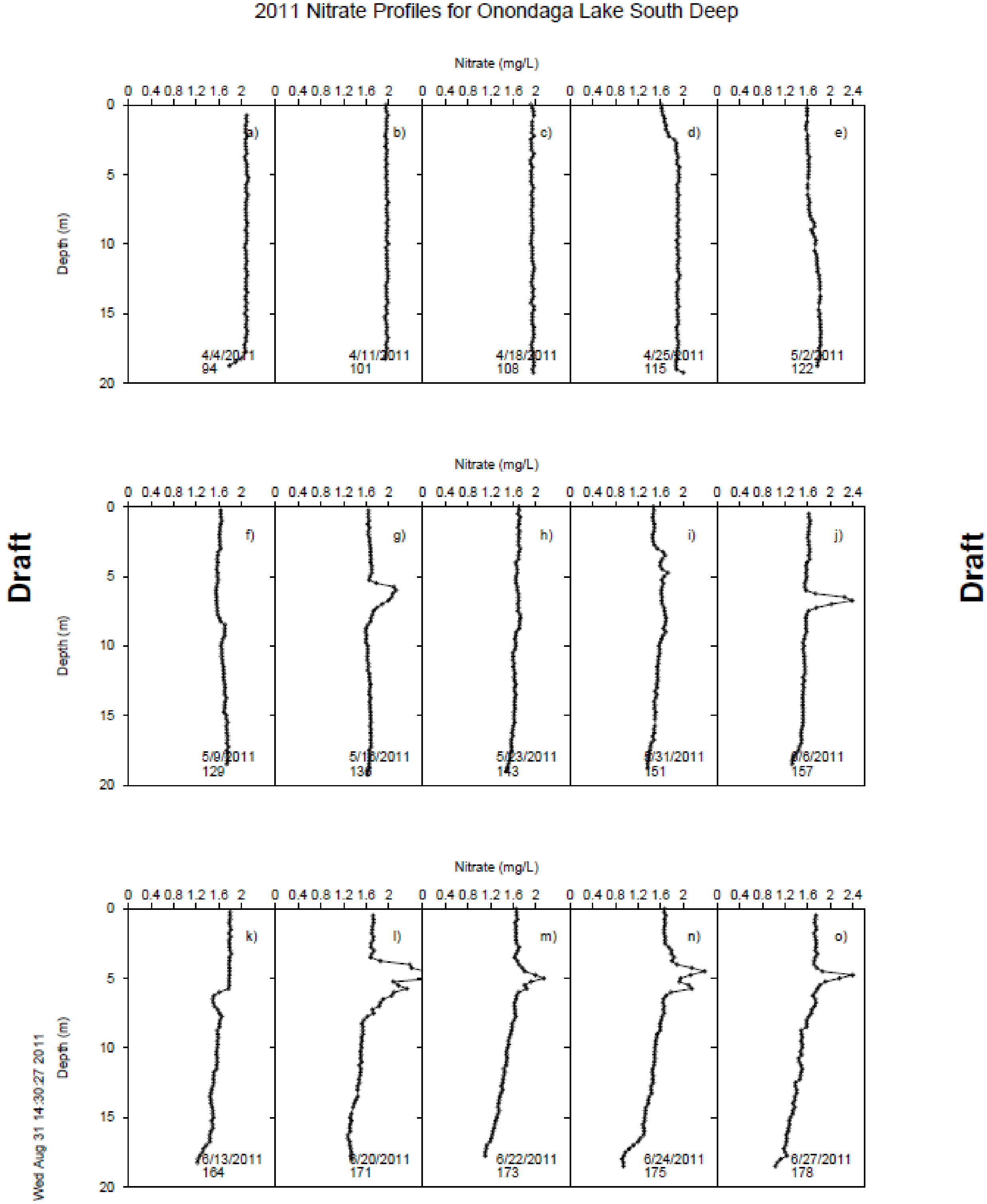
Nitrate Profiles at Each Gridding Location (0-3 mgN/L)



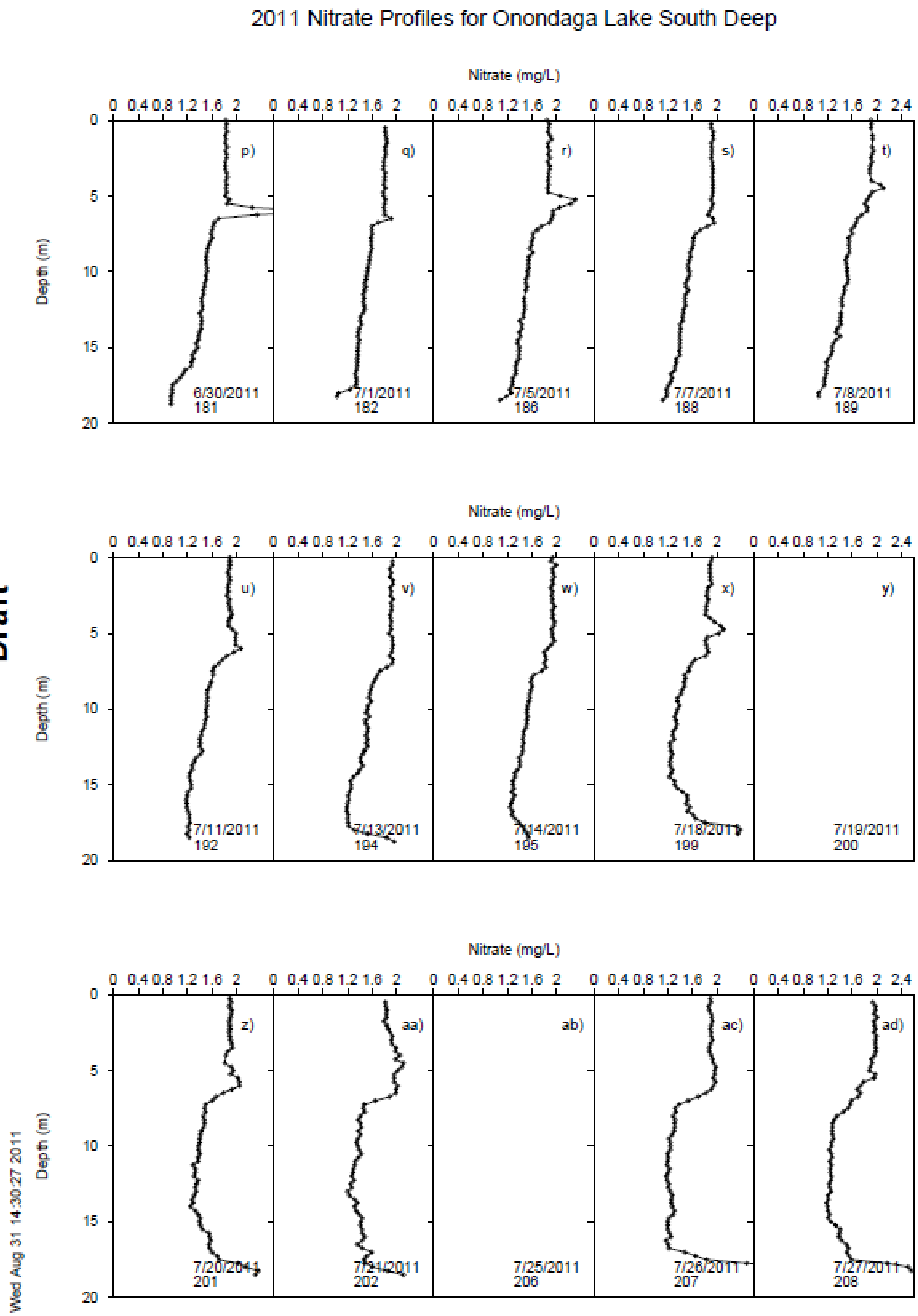
Nitrate Profiles at Each Gridding Location (Autoscale mgN/L)



Nitrate Profiles at South Deep, Time Series



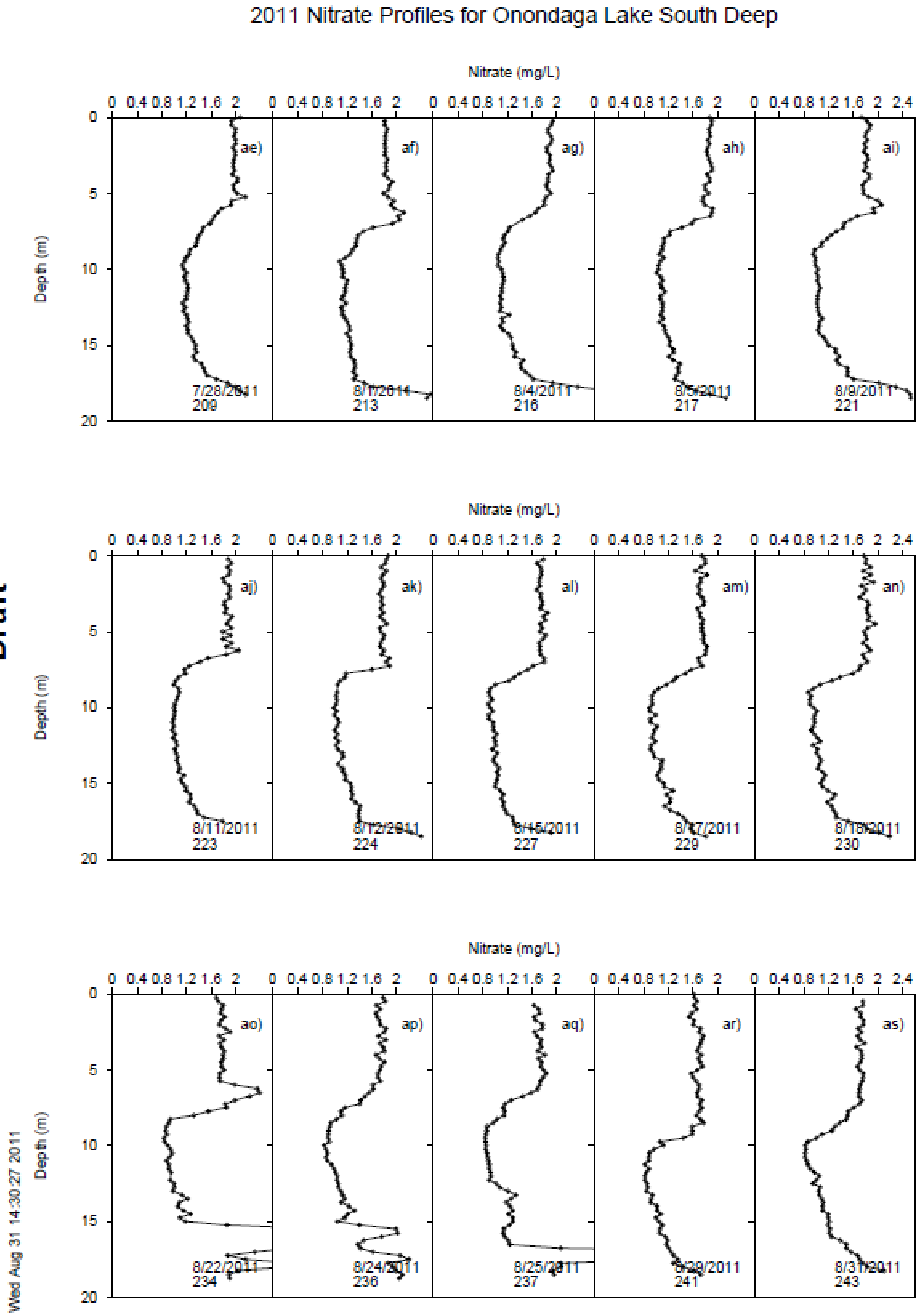
Nitrate Profiles at South Deep, Time Series continued



Draft

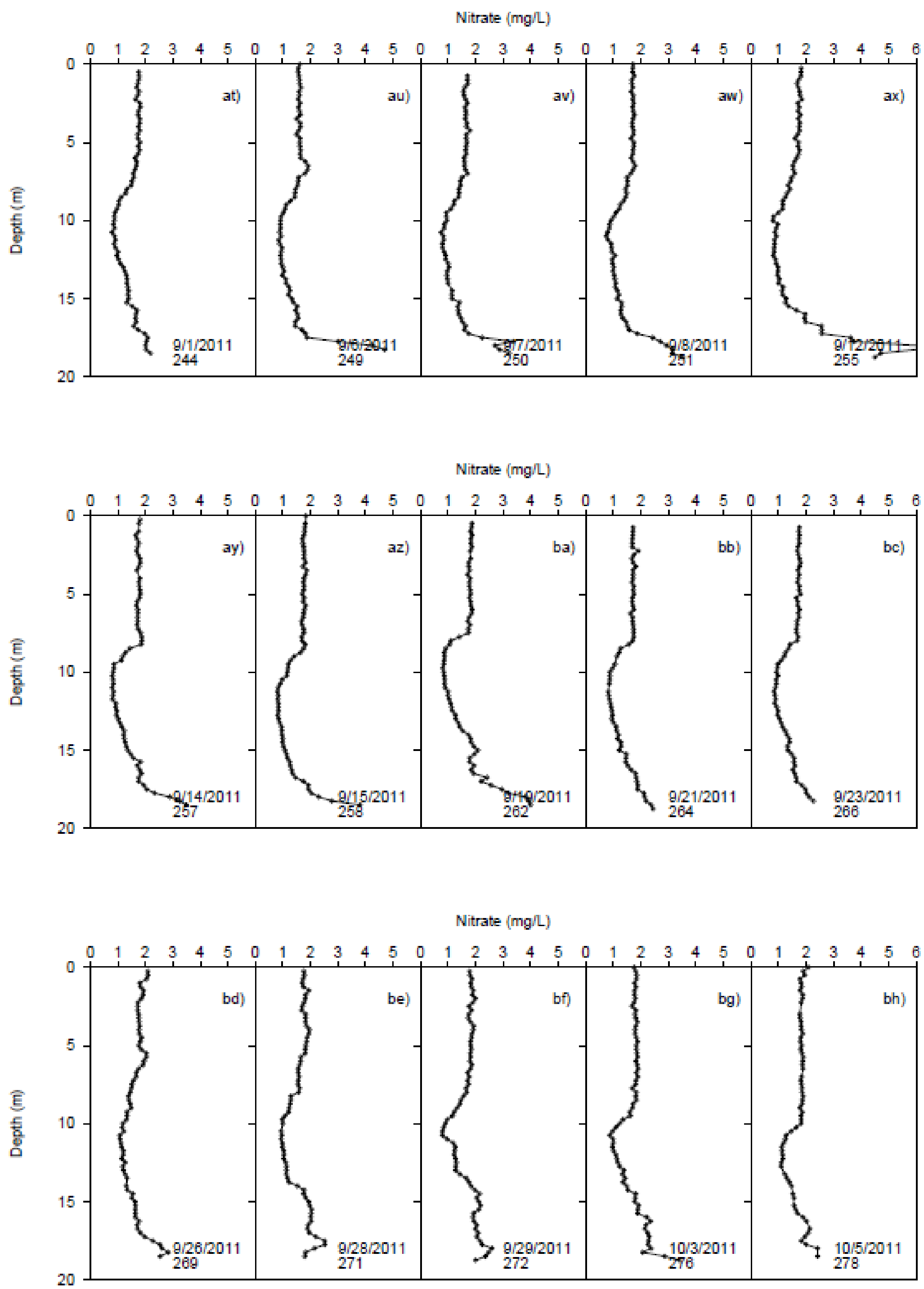
Draft

Nitrate Profiles at South Deep, Time Series continued



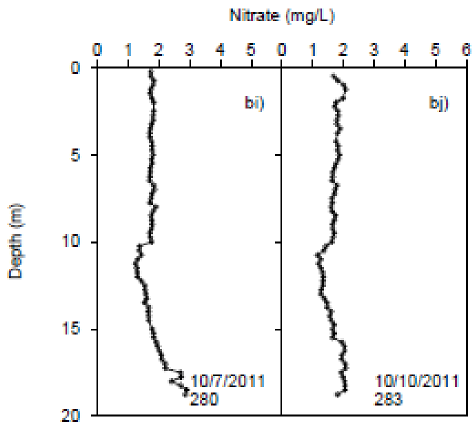
Nitrate Profiles at South Deep, Time Series continued

2011 Nitrate Profiles for Onondaga Lake South Deep



Nitrate Profiles at South Deep, Time Series continued

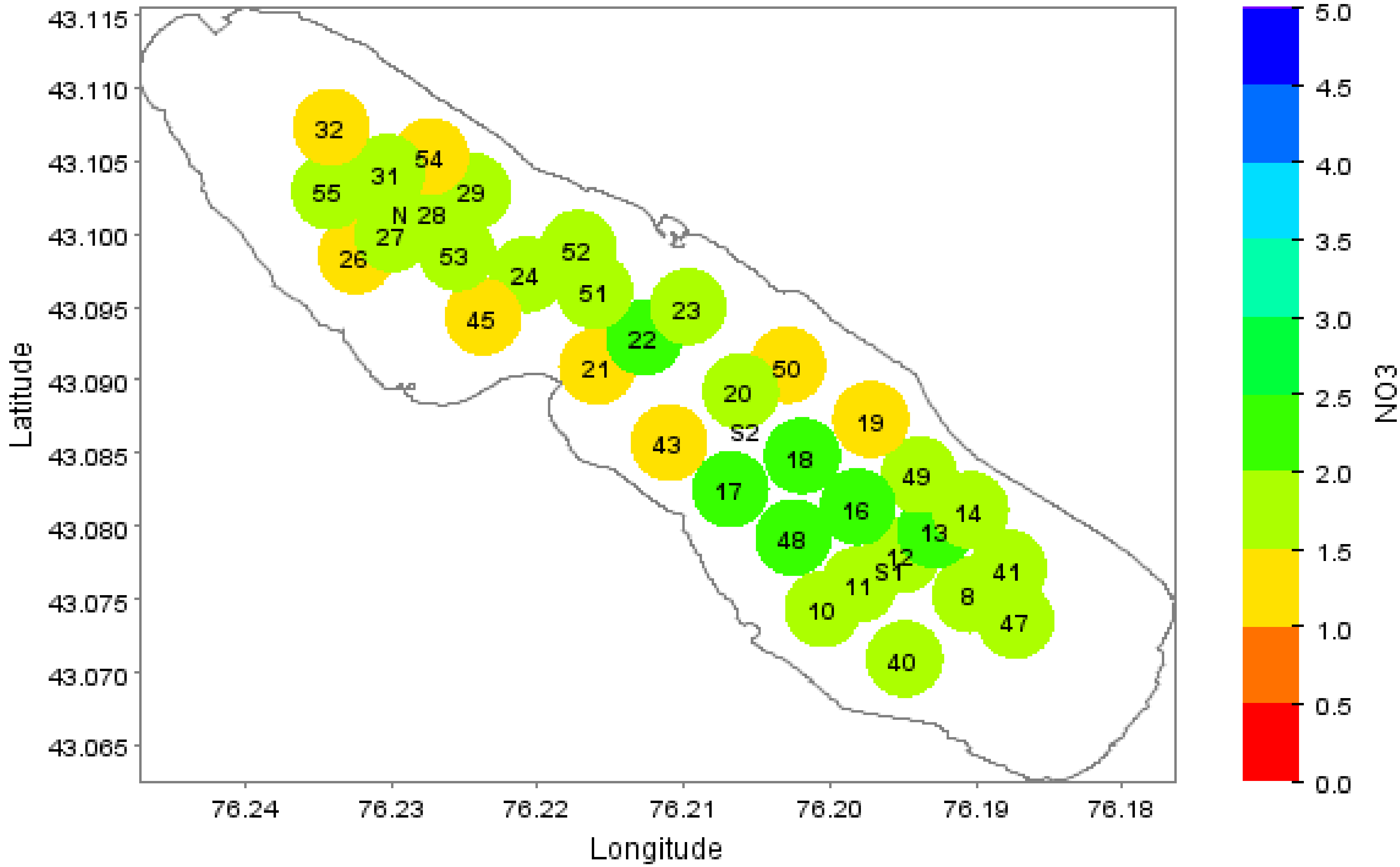
2011 Nitrate Profiles for Onondaga Lake South Deep



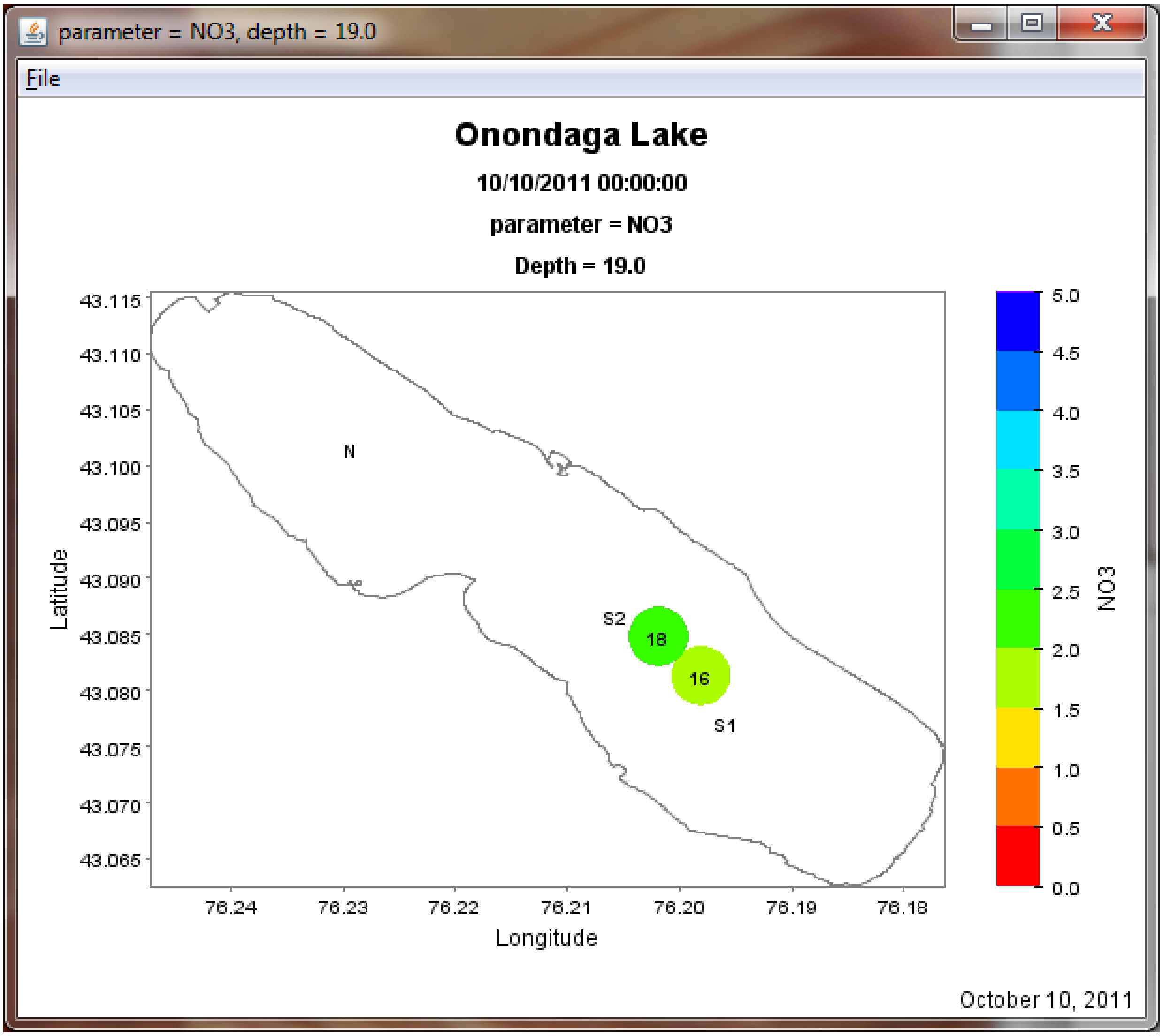
Draft

Mon Oct 10 14:45:10 2011

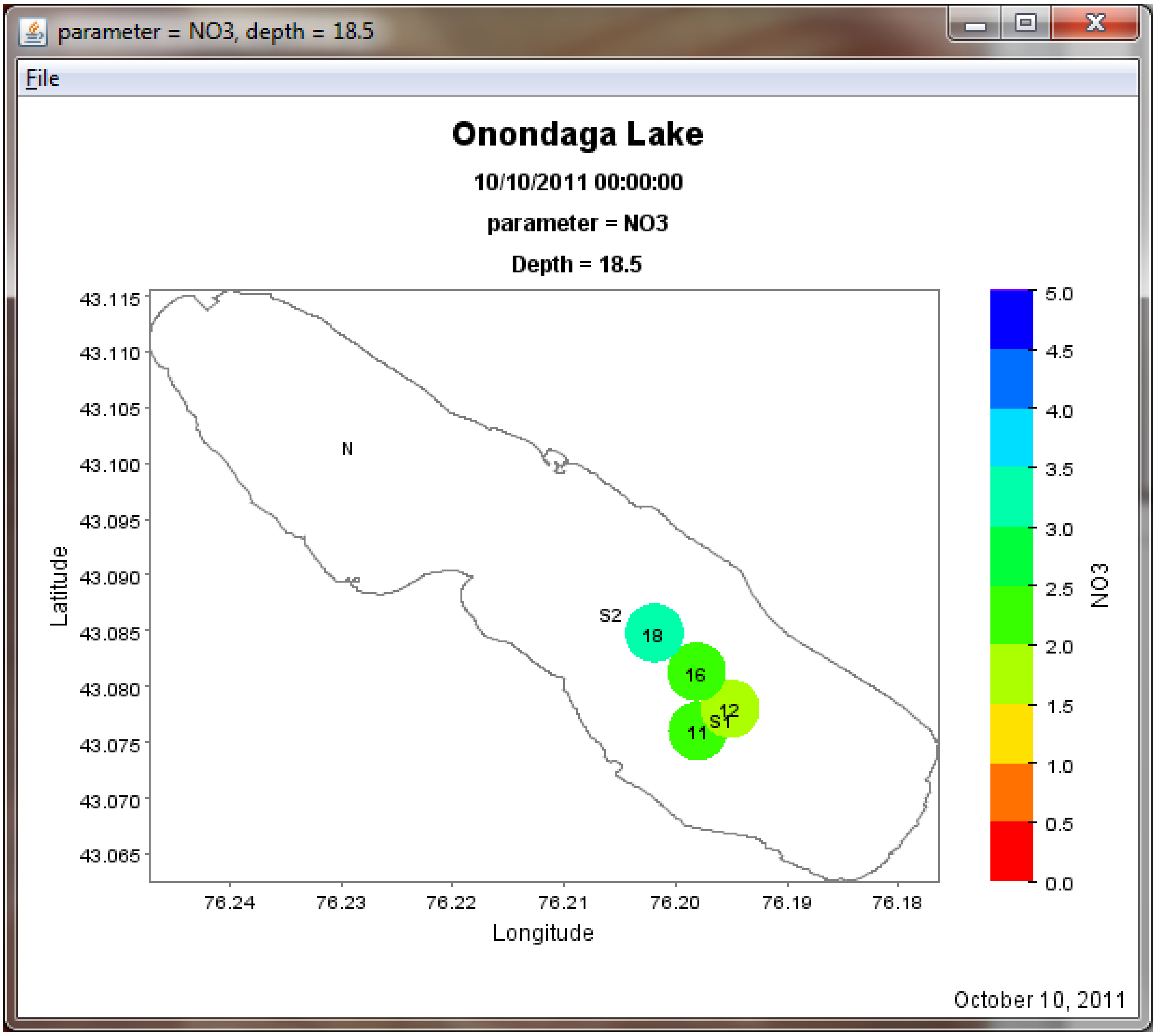
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)



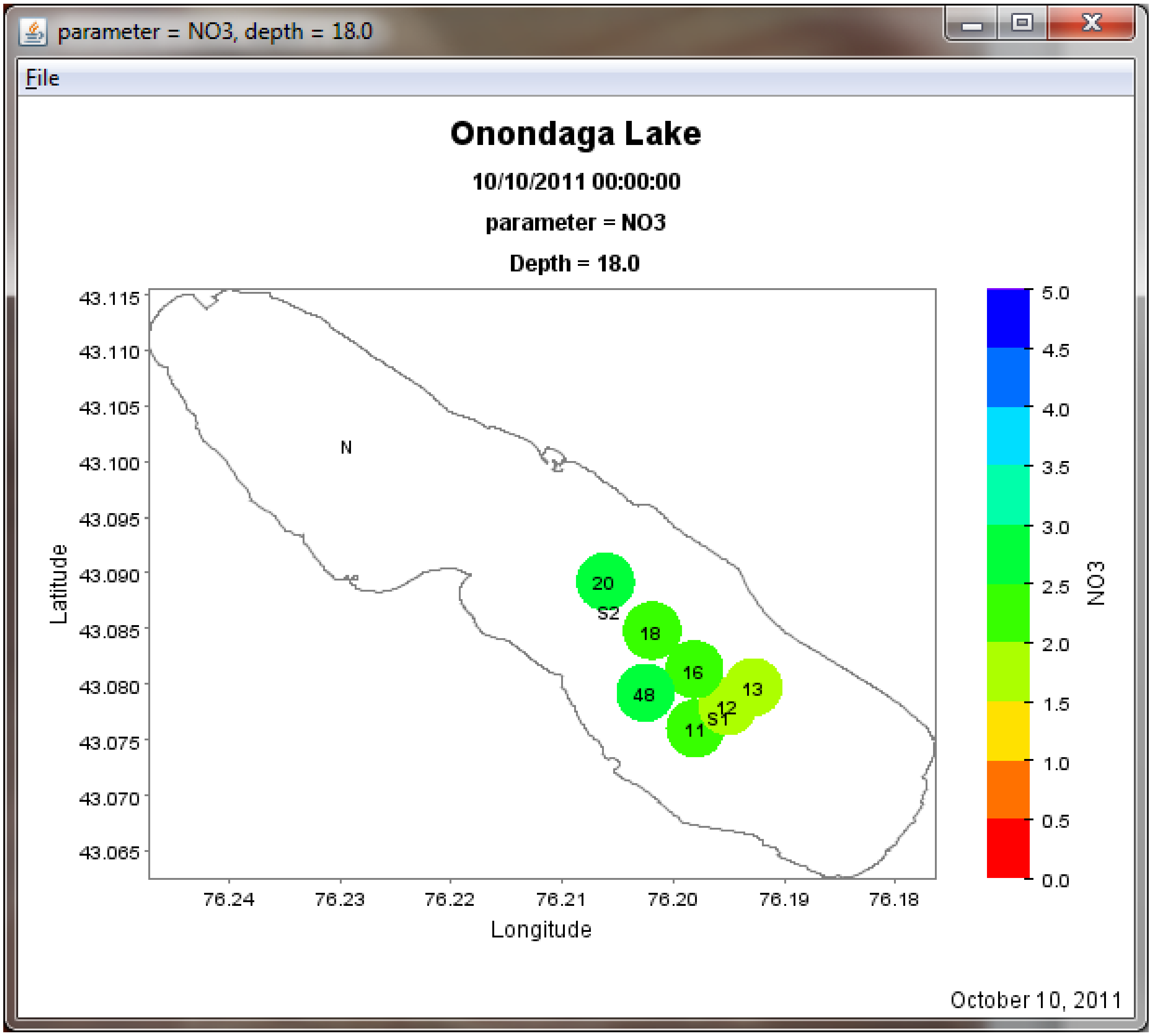
Color Bubble Plots at 19m, Nitrate (mgN/L)



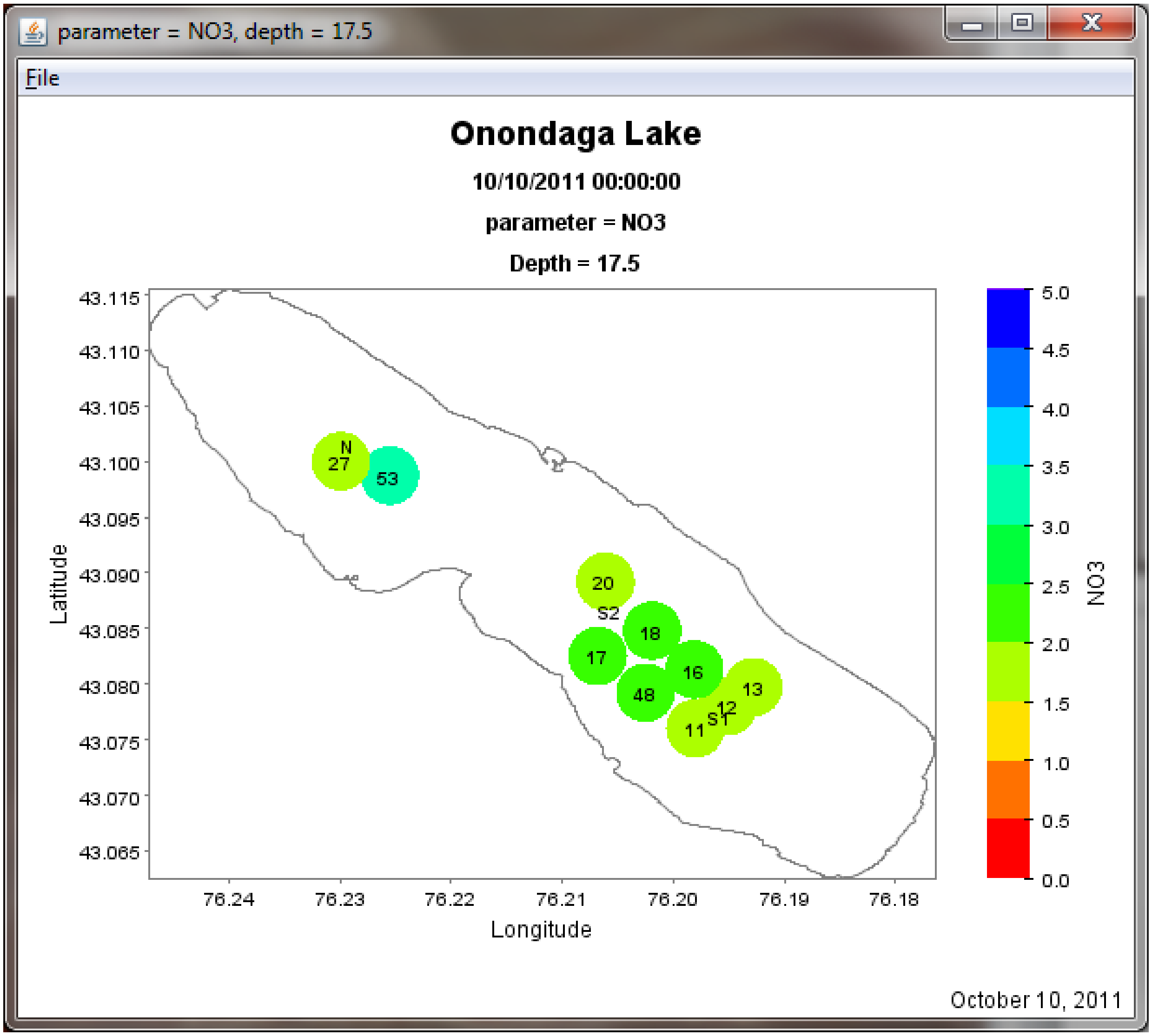
Color Bubble Plots at 18.5m, Nitrate (mgN/L)



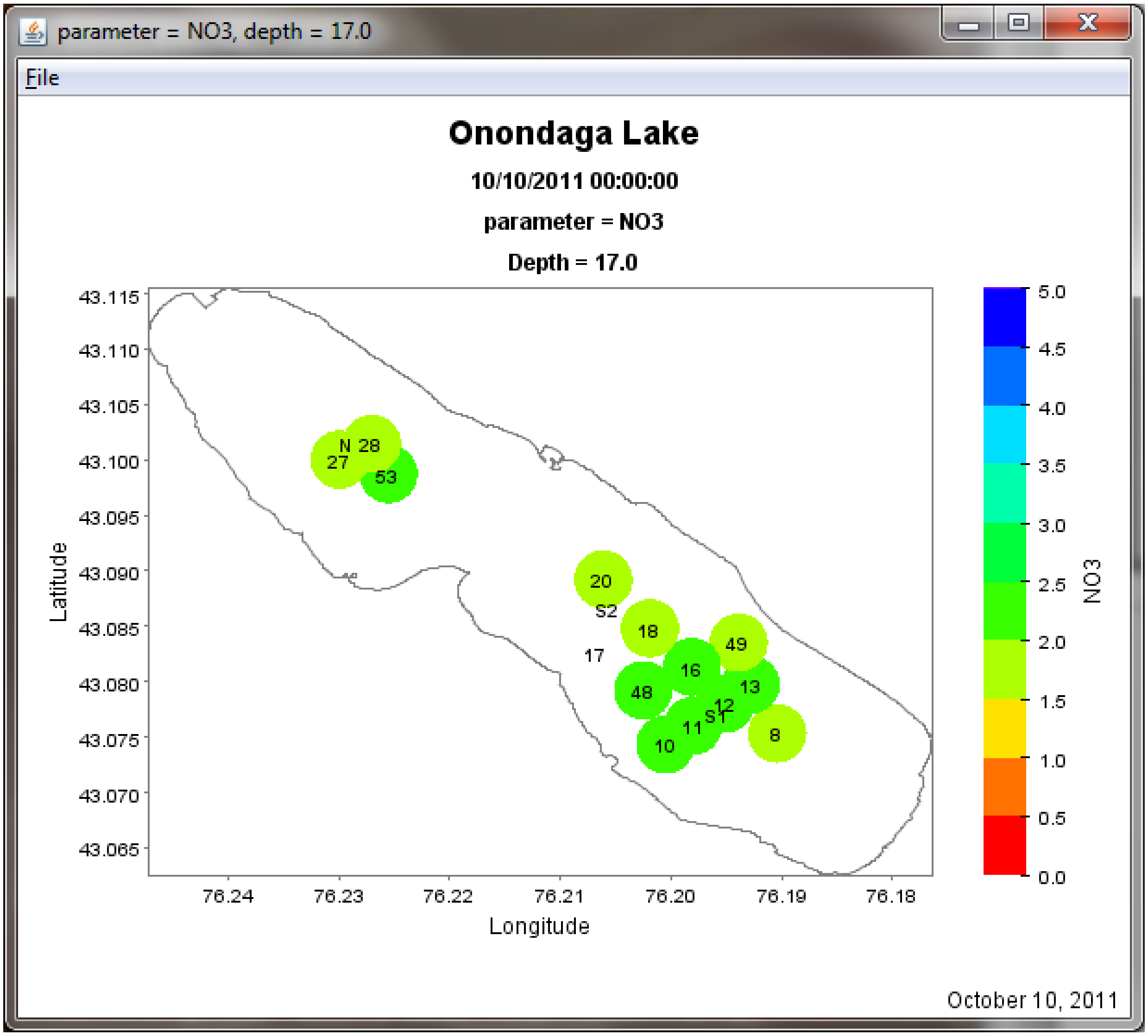
Color Bubble Plots at 18m, Nitrate (mgN/L)



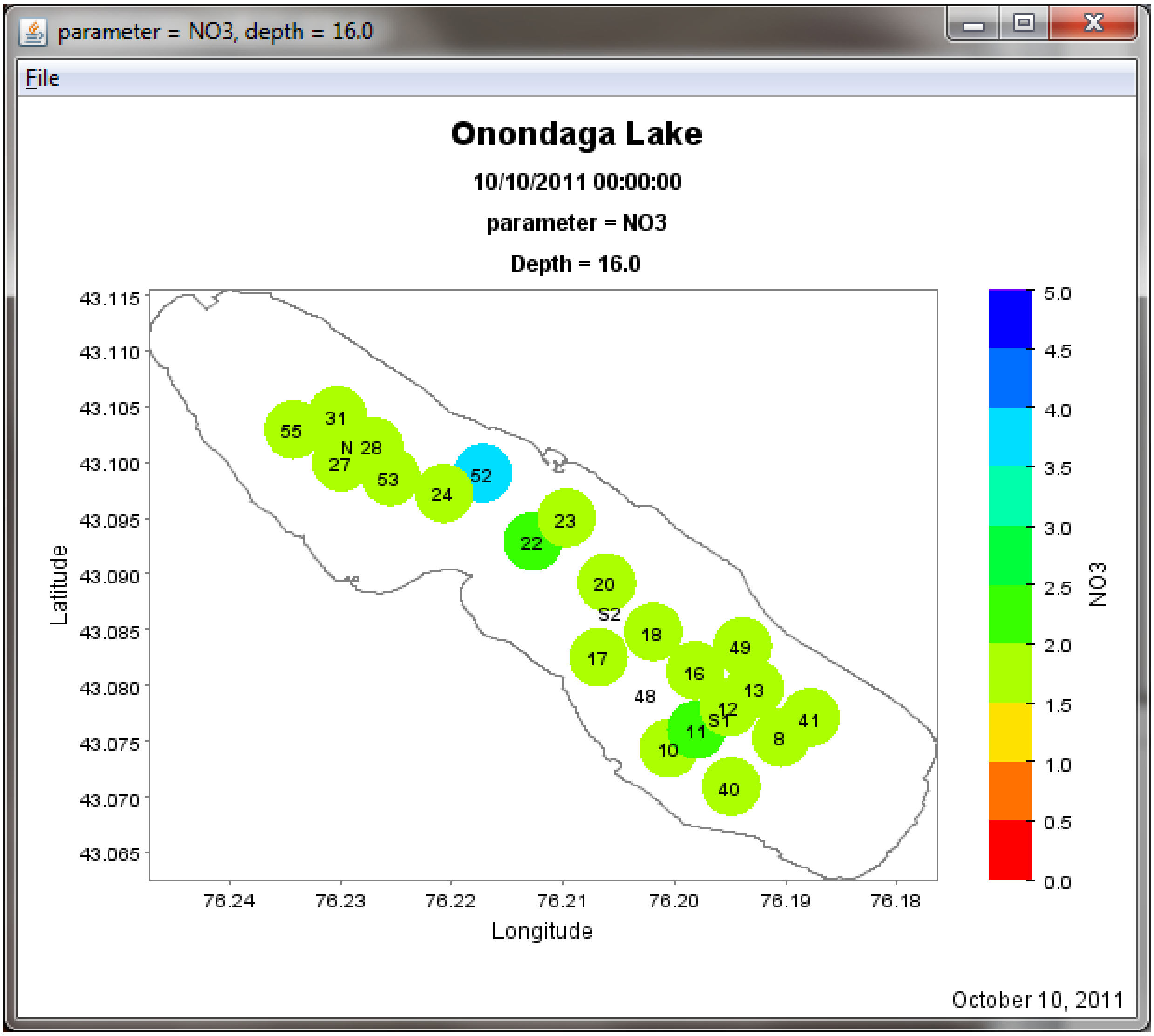
Color Bubble Plots at 17.5, Nitrate (mgN/L)



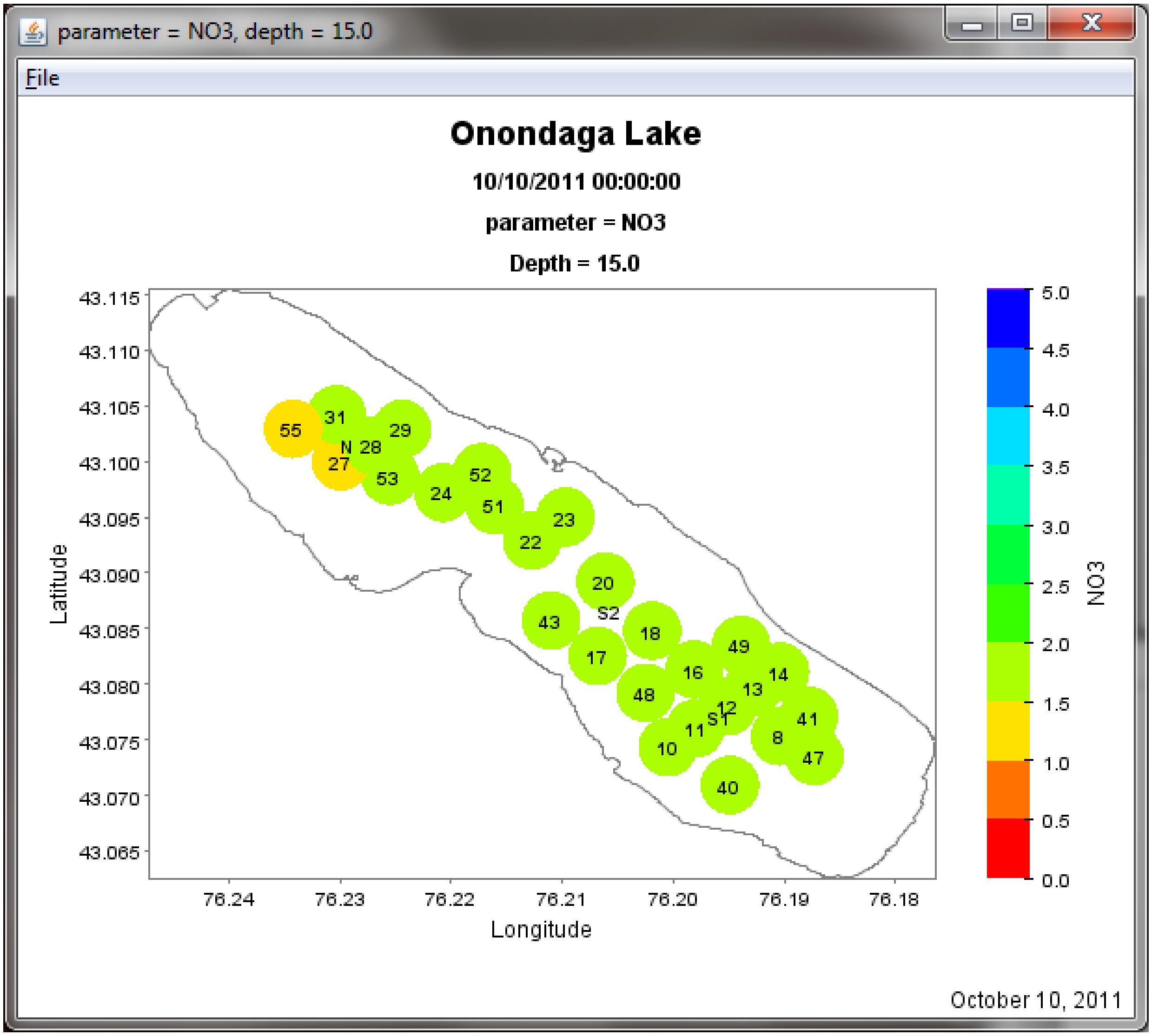
Color Bubble Plots at 17m, Nitrate (mgN/L)



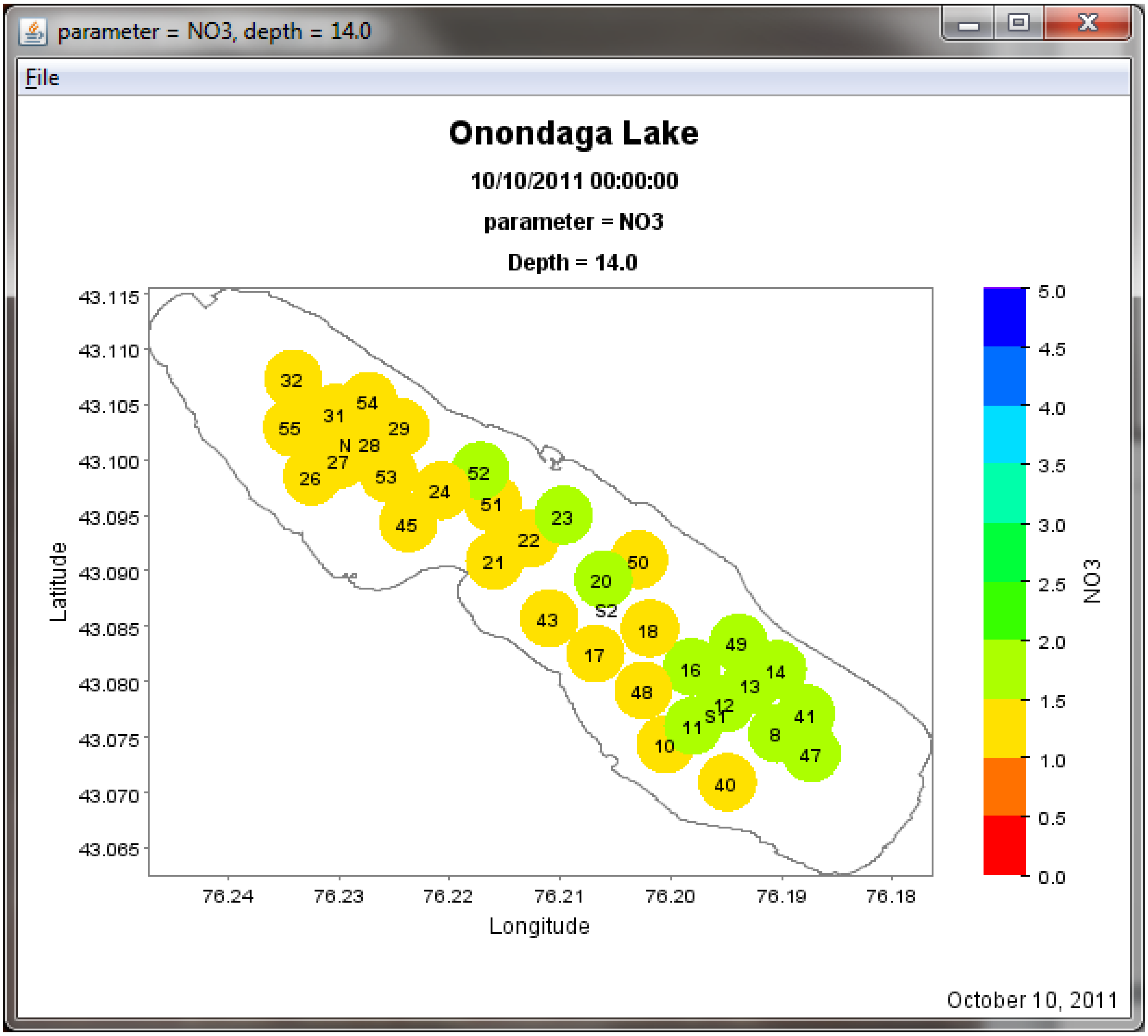
Color Bubble Plots at 16m, Nitrate (mgN/L)



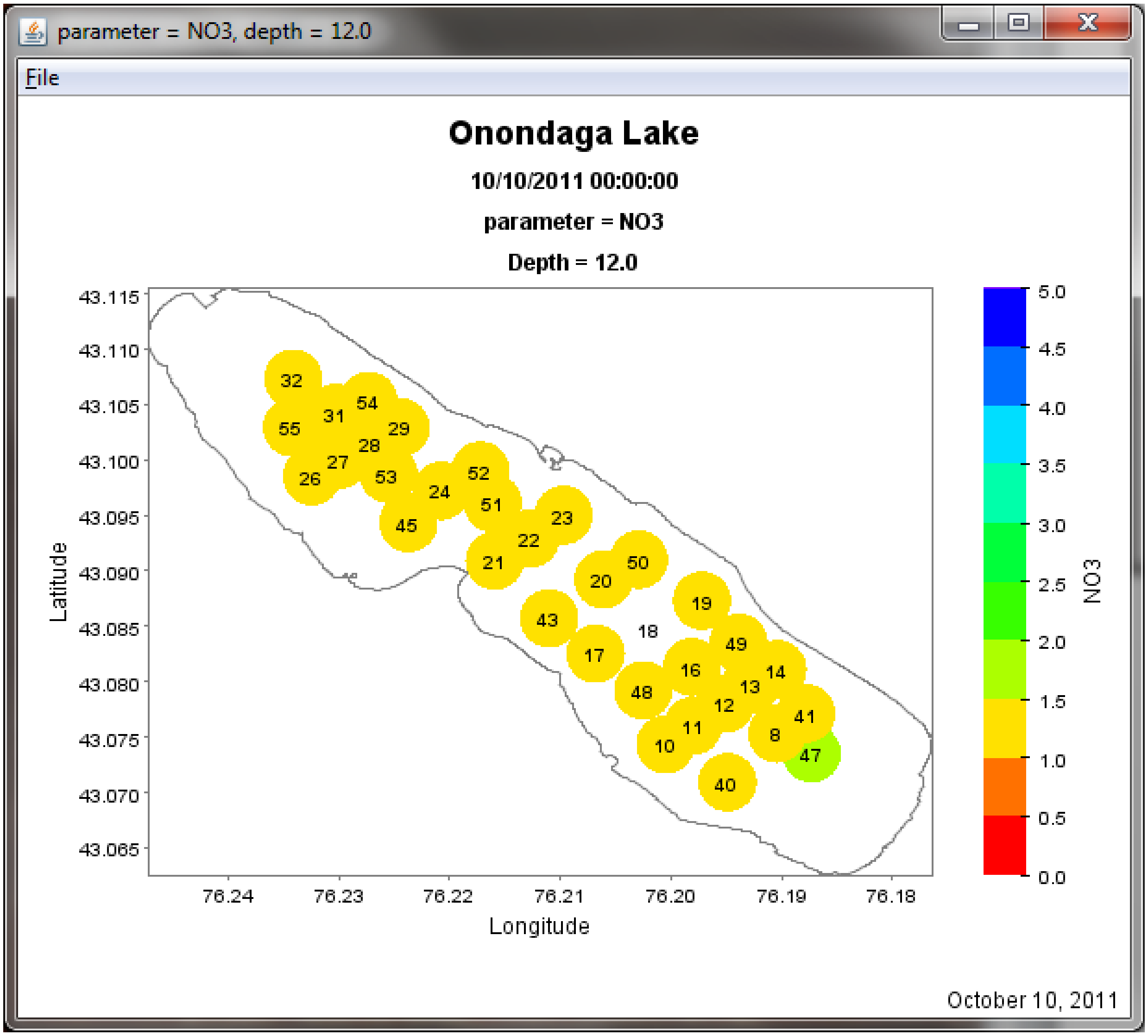
Color Bubble Plots at 15m, Nitrate (mgN/L)



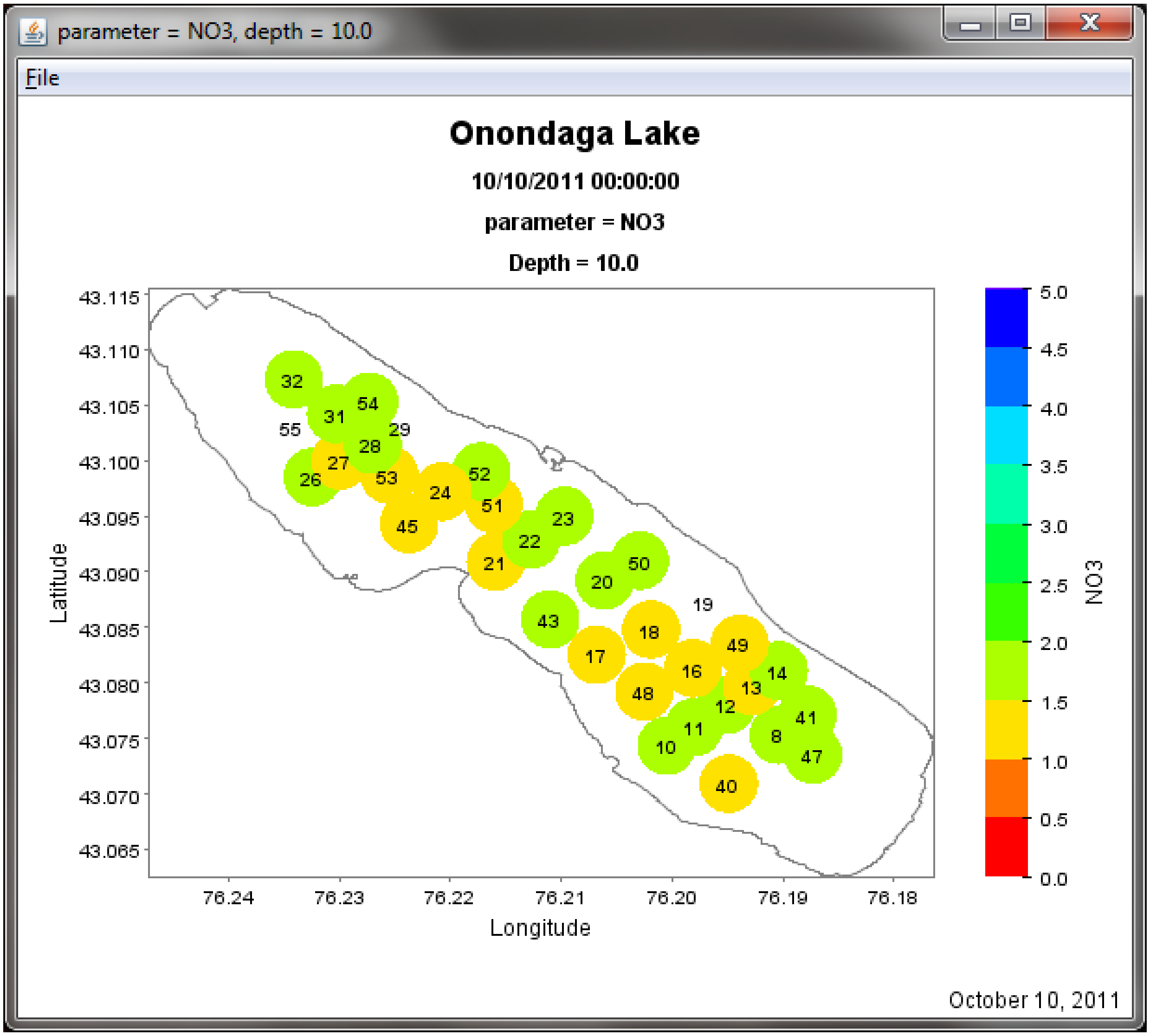
Color Bubble Plots at 14m, Nitrate (mgN/L)



Color Bubble Plots at 12m, Nitrate (mgN/L)



Color Bubble Plots at 10m, Nitrate (mgN/L)



APPENDIX C

NITRATE DATA SUMMARIES FOR ONE METER ABOVE THE LAKE BOTTOM

Onondaga Lake Gridding Summary Using an In-Situ Ultraviolet Spectrophotometer (ISUS):

Nitrate Addition Pilot Monitoring

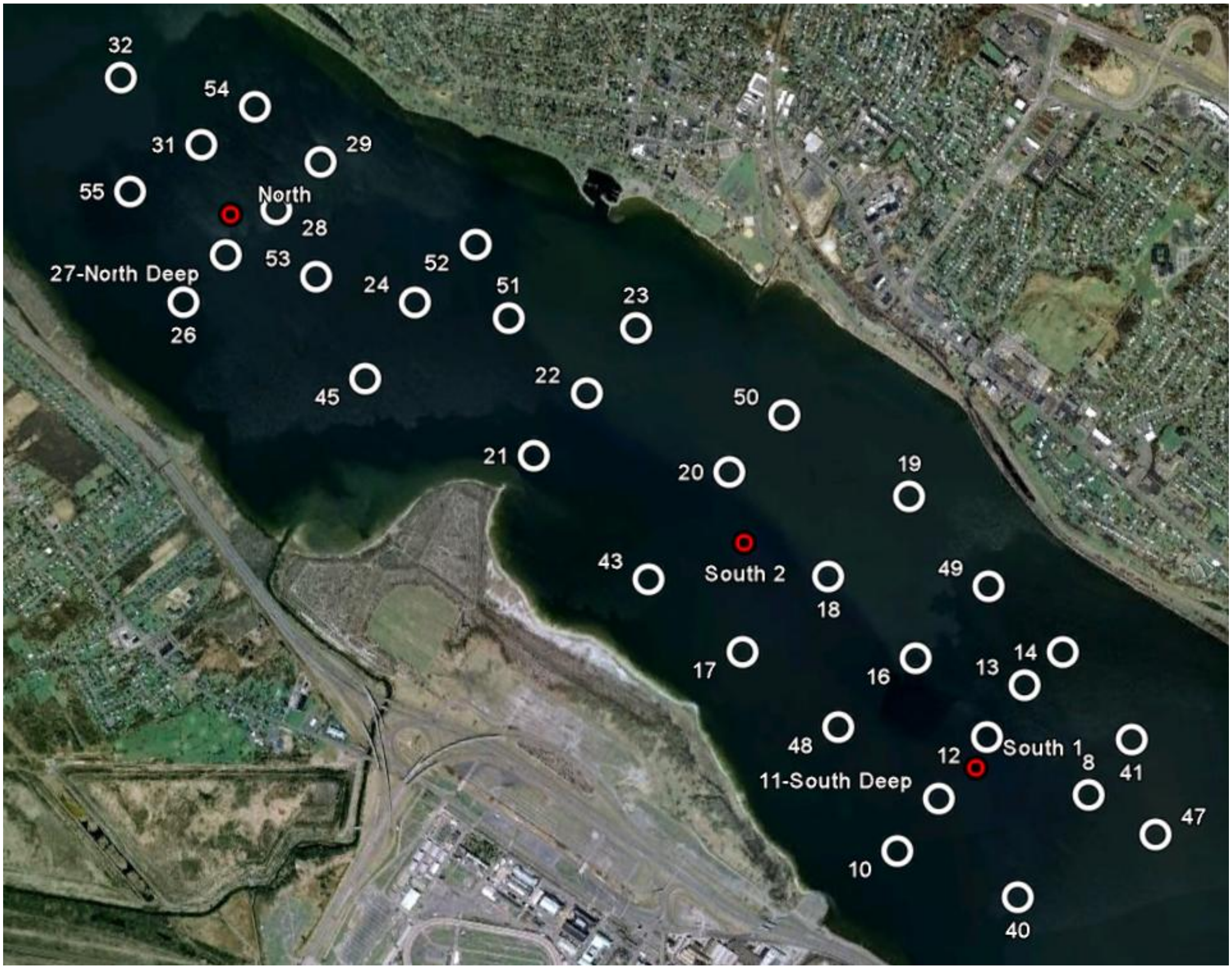
Weekly Summaries One Meter Above Lake Bottom

June 24 to November 7, 2011

Provisional Data Summary
for discussion purposes only

Submitted December 14, 2011
Anthony R. Prestigiacomo
Research Scientist

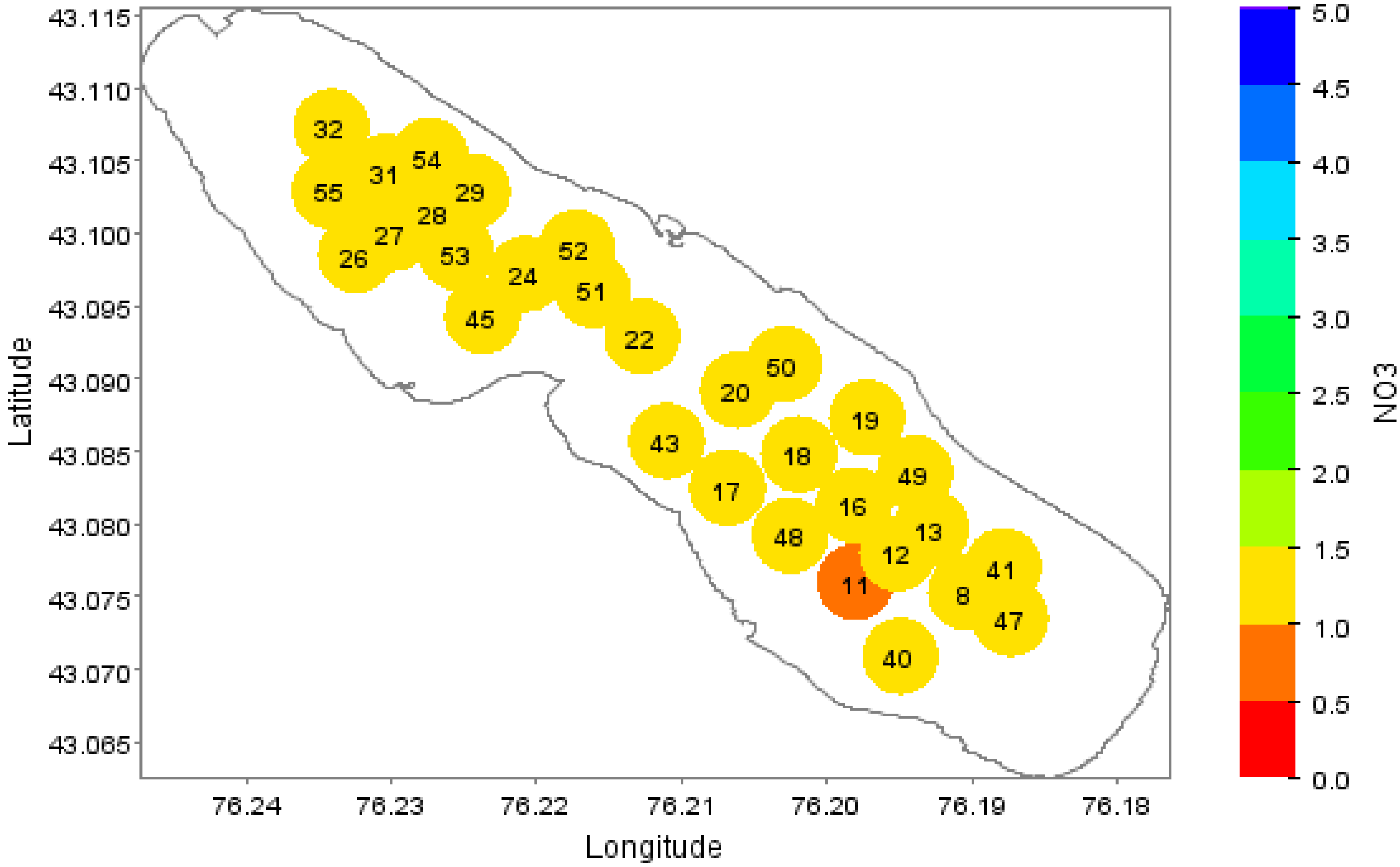
Gridding Locations



white circle: ISUS monitoring loocation
red circle: nitrate application location

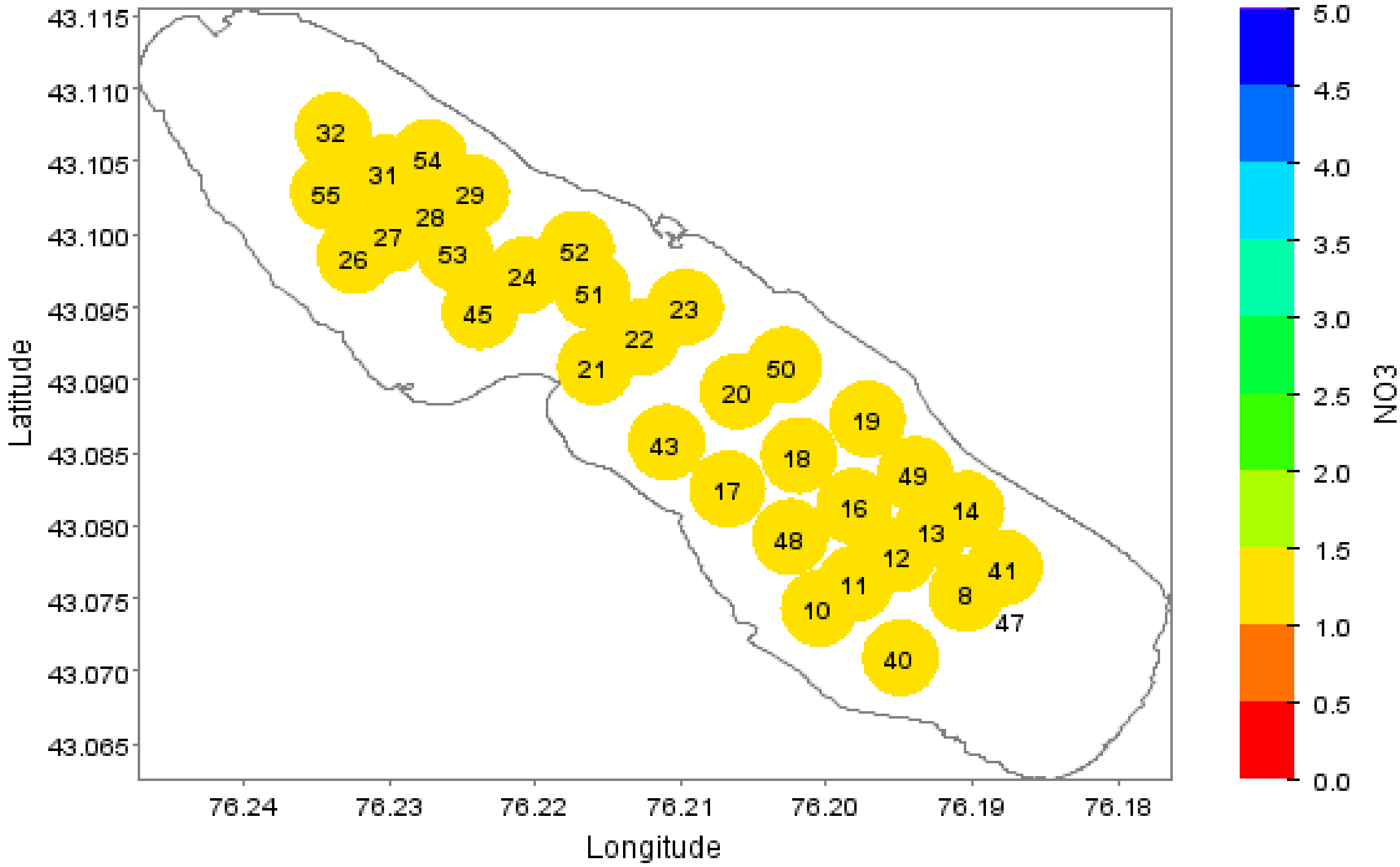
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

June 24, 2011



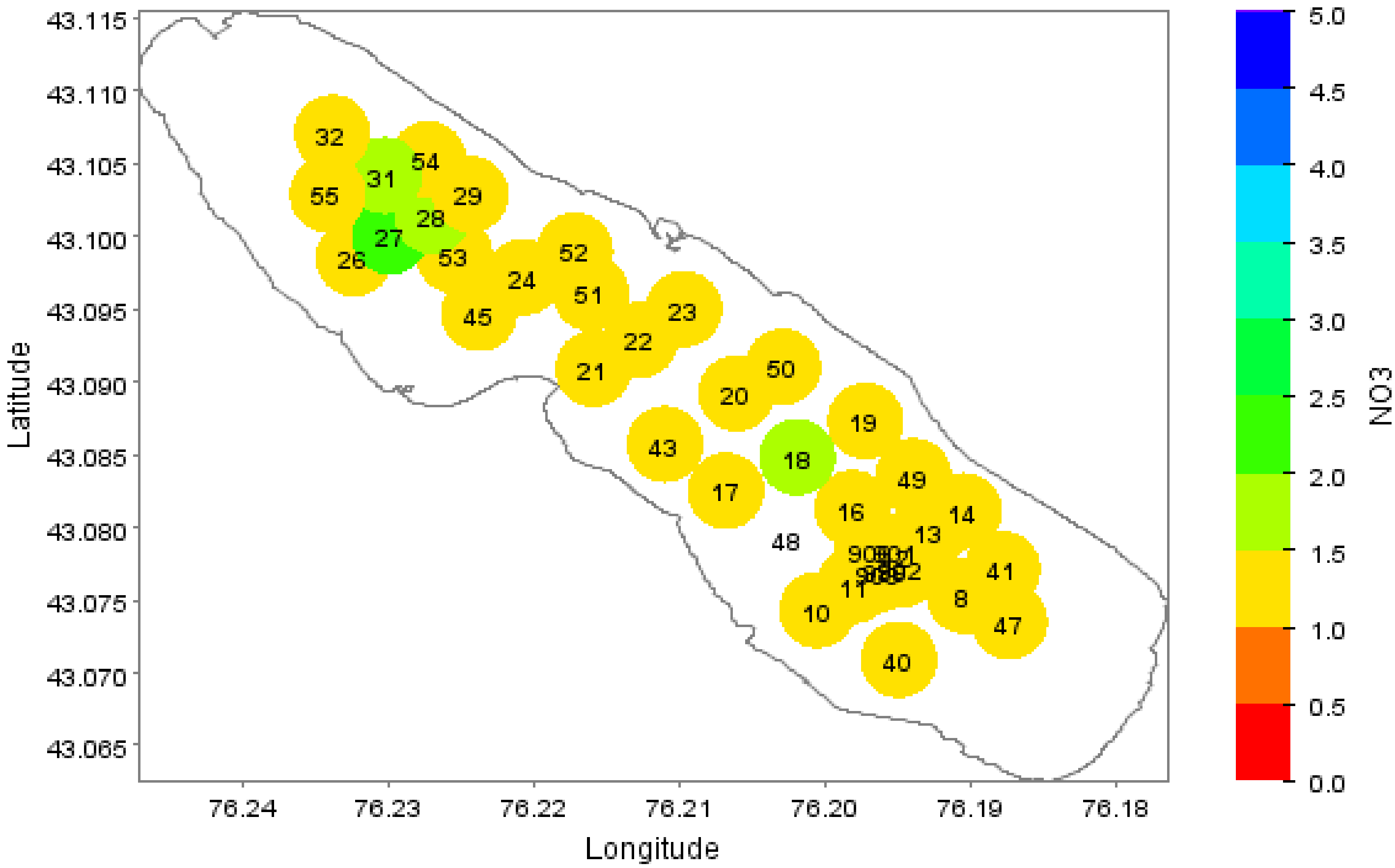
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

July 1, 2011



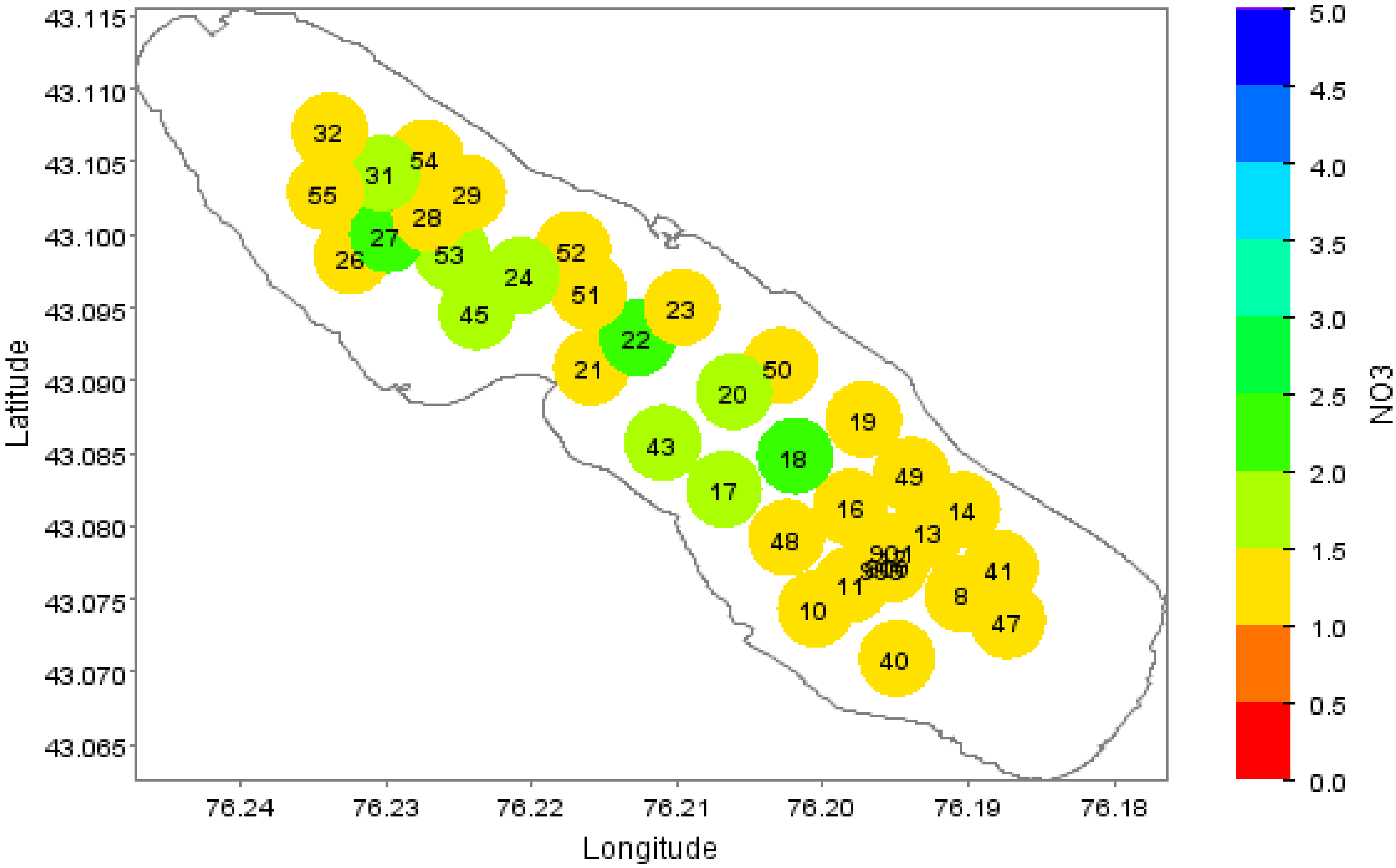
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

July 8, 2011



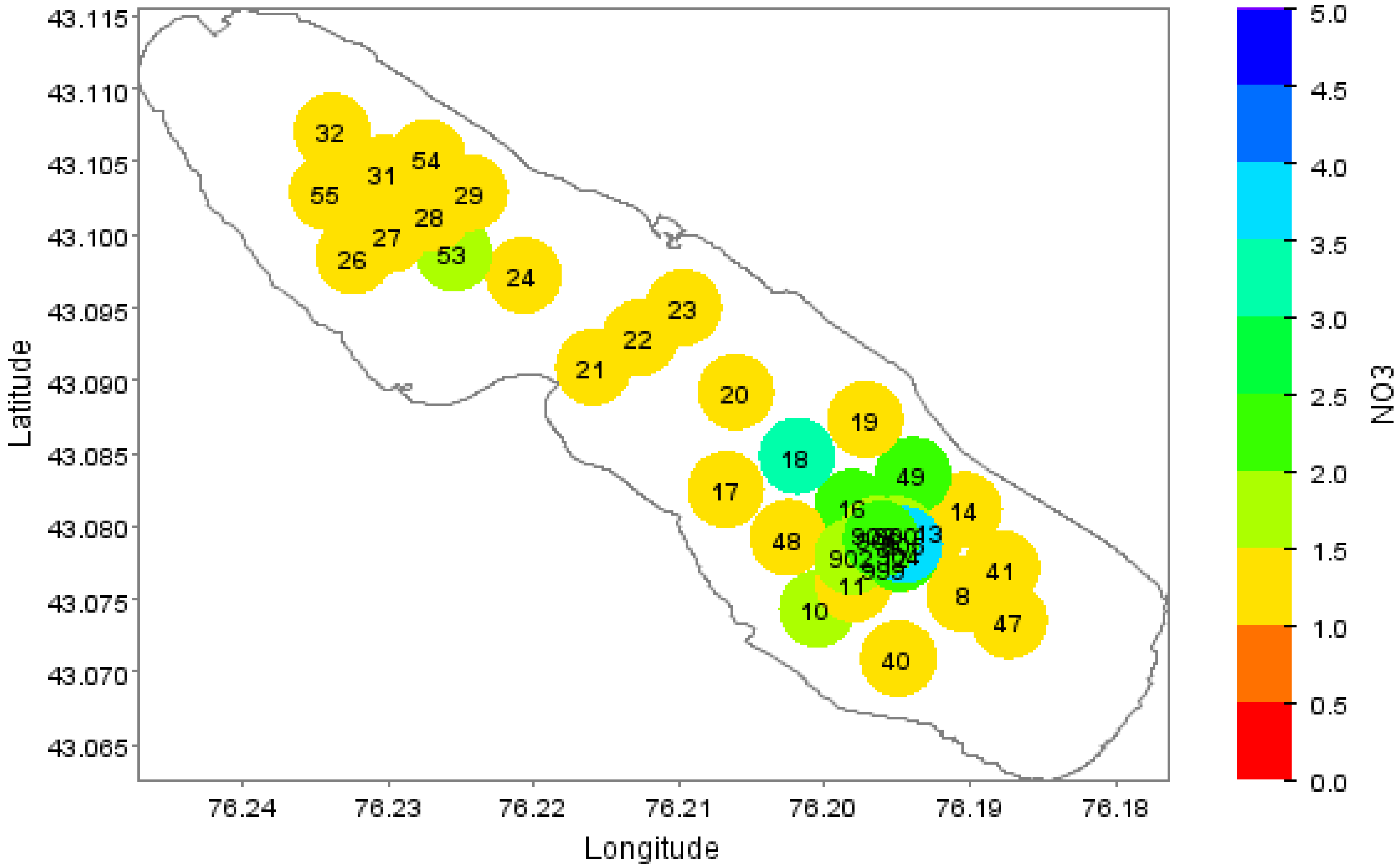
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

July 14, 2011



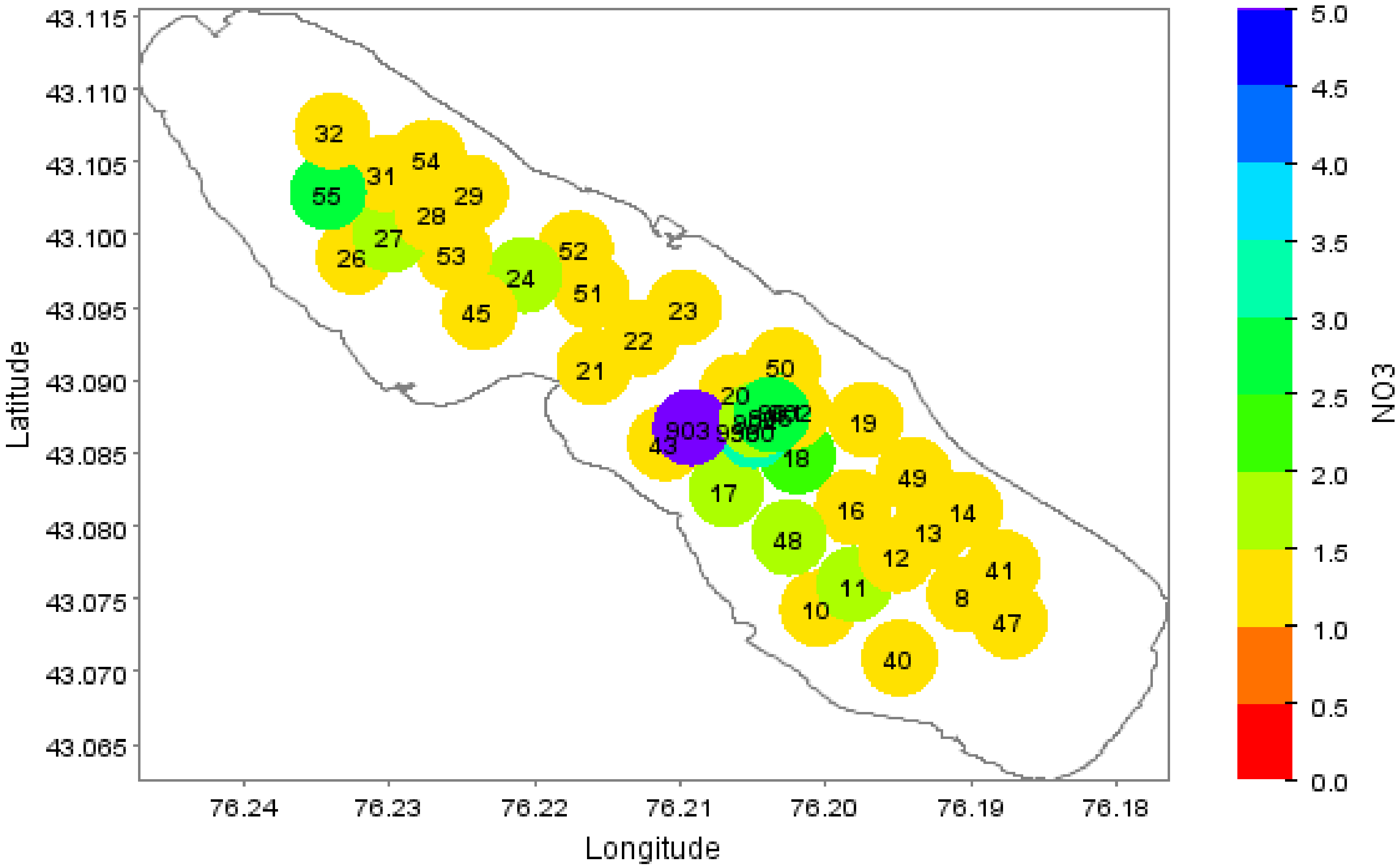
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

July 21, 2011



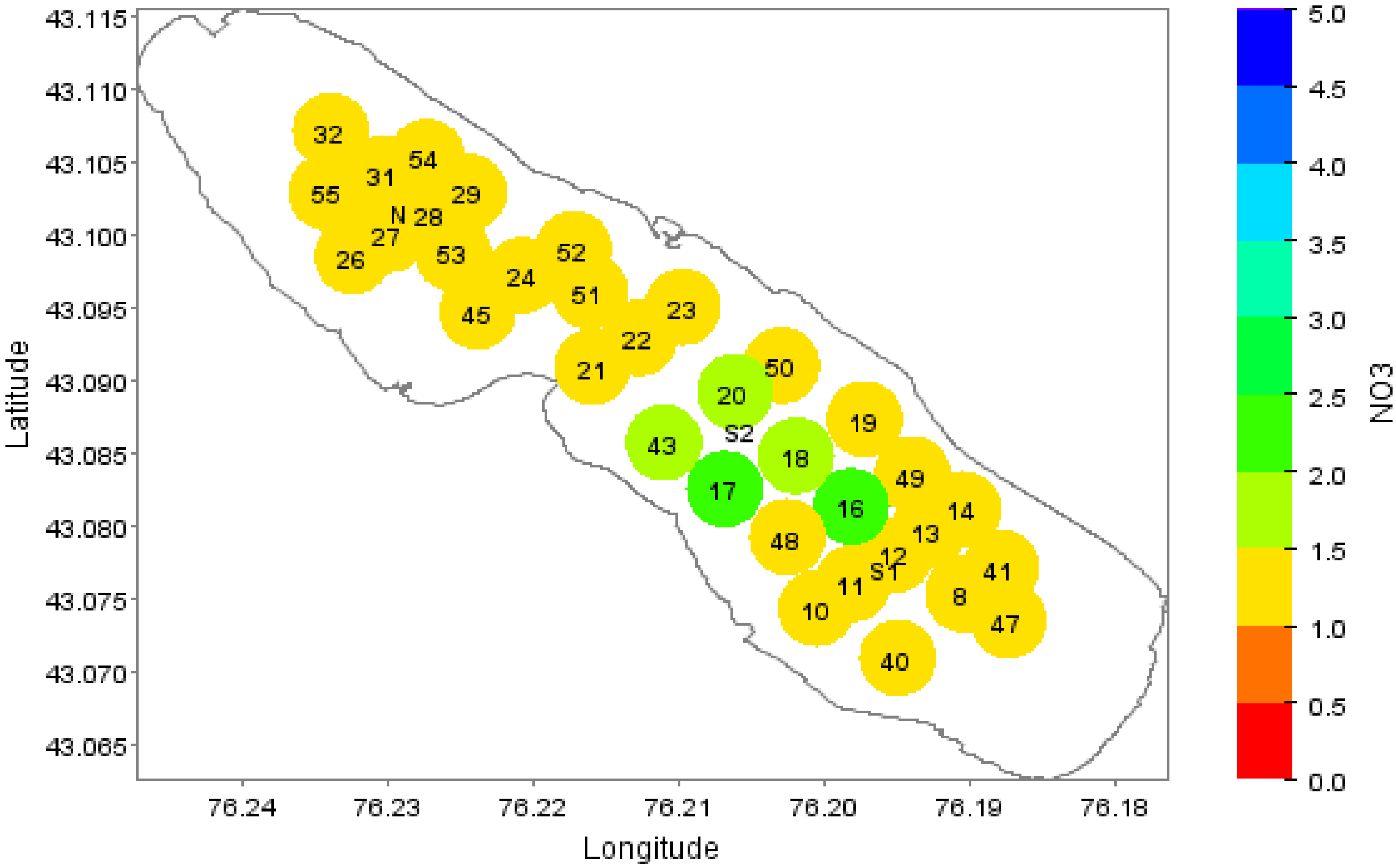
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

July 28, 2011



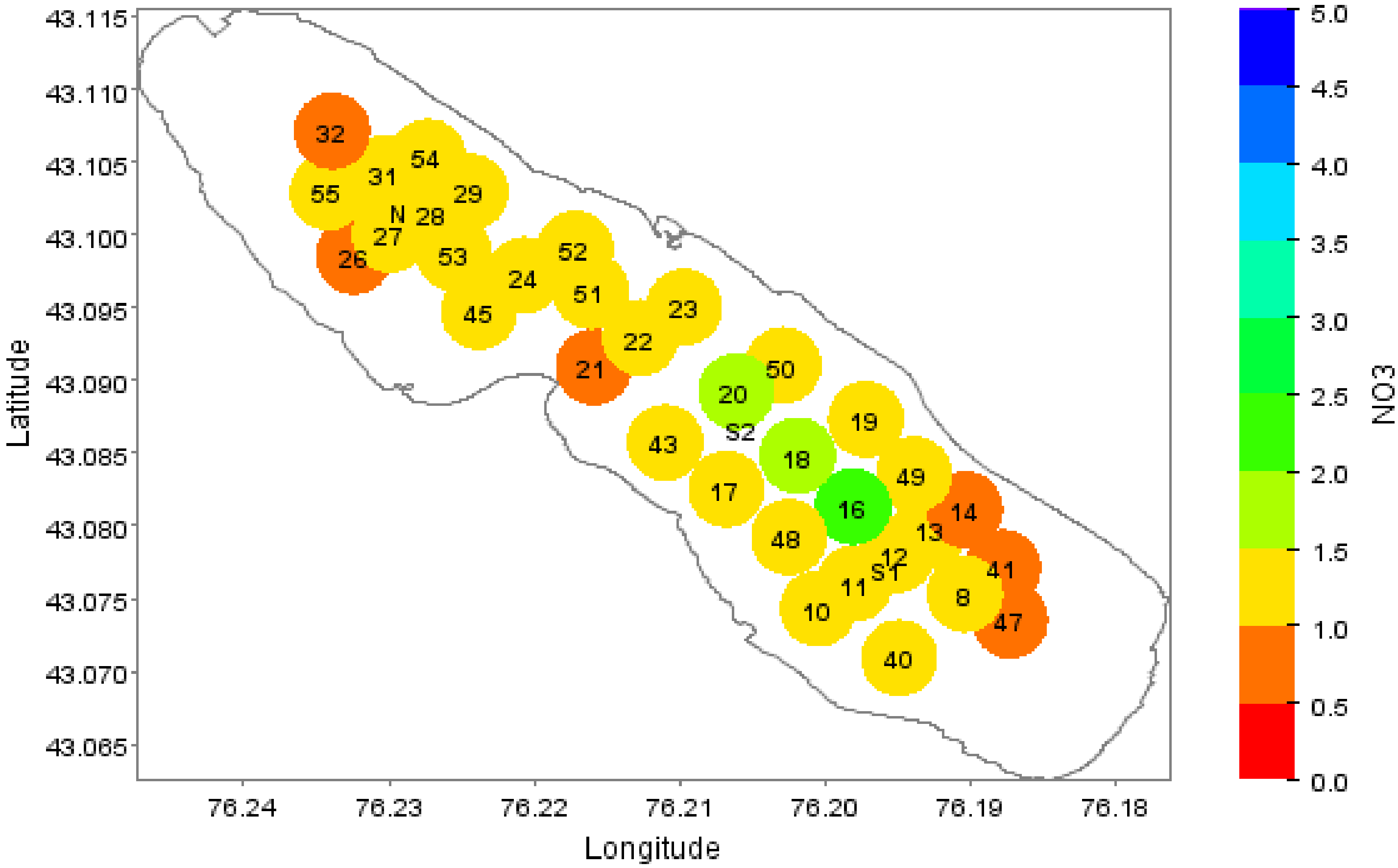
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

August 5, 2011



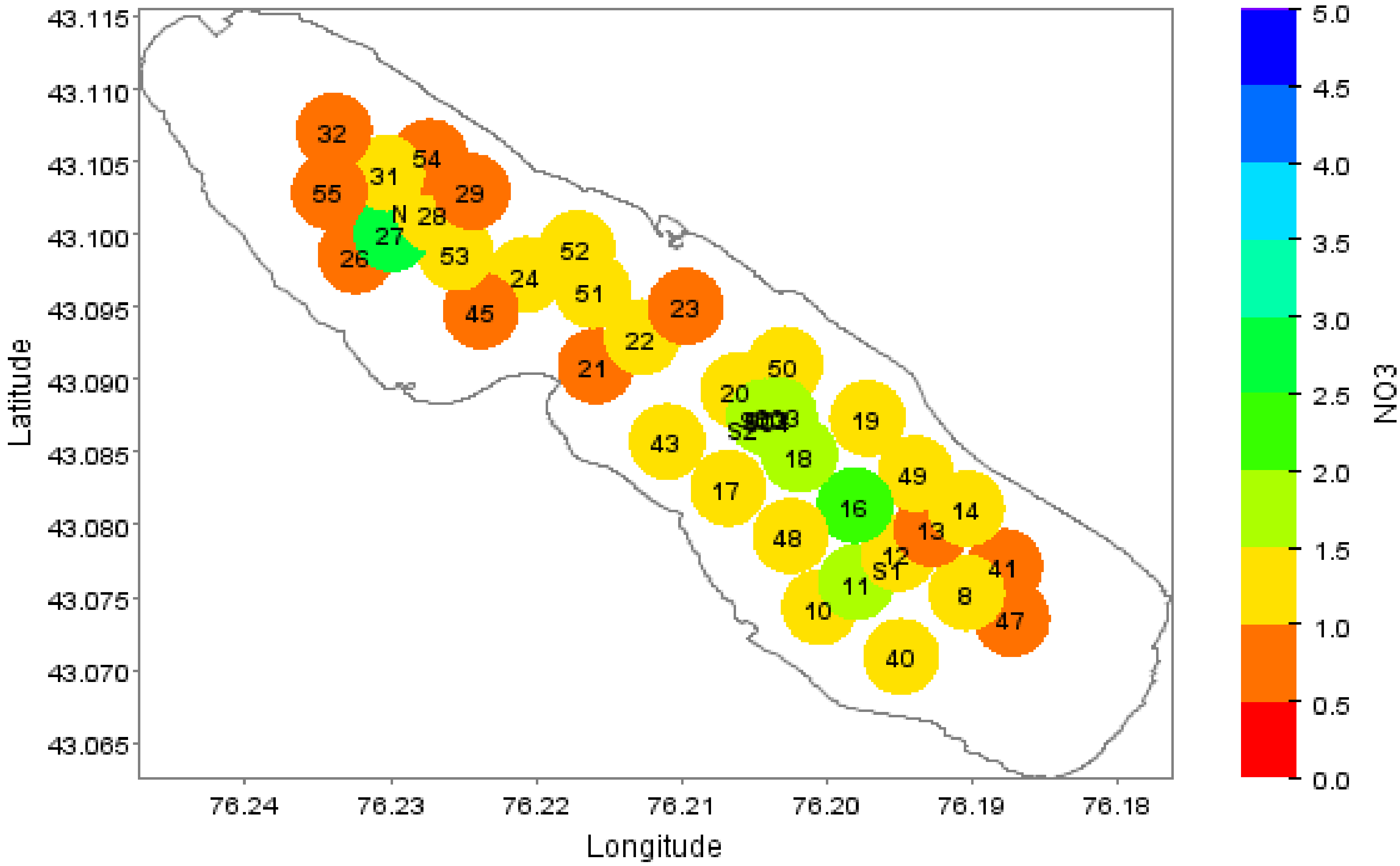
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

August 12, 2011



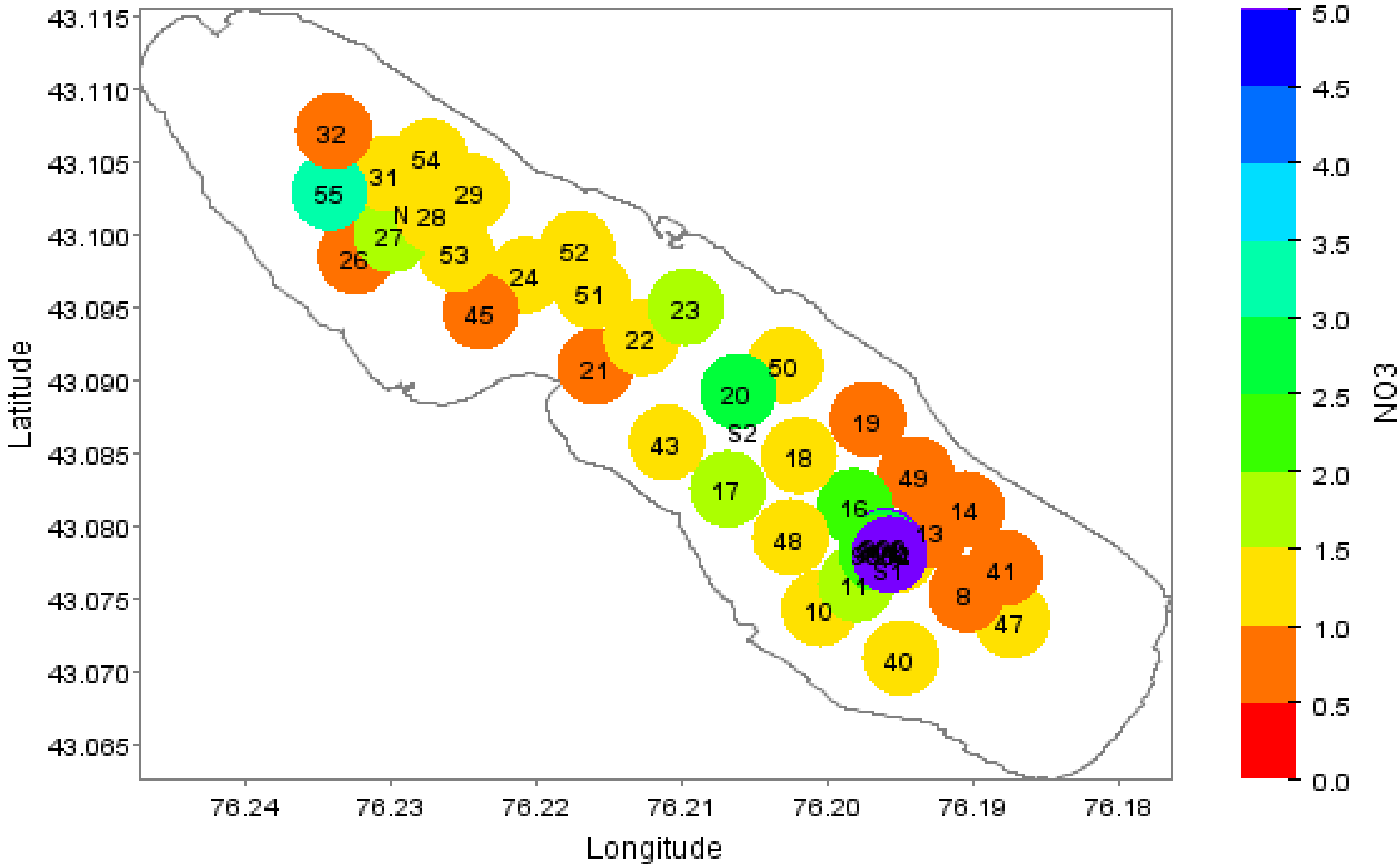
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

August 18, 2011



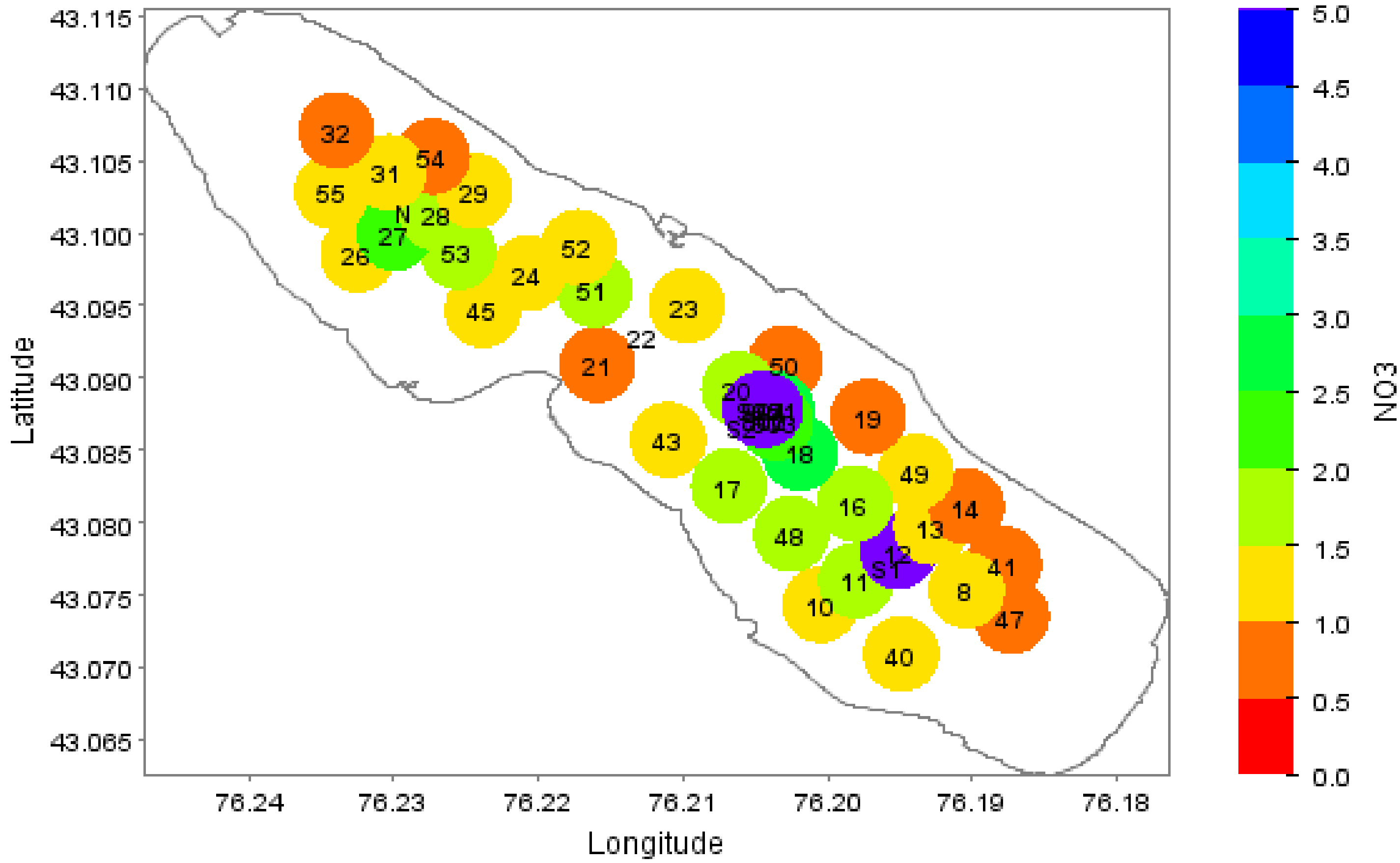
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

August 24, 2011



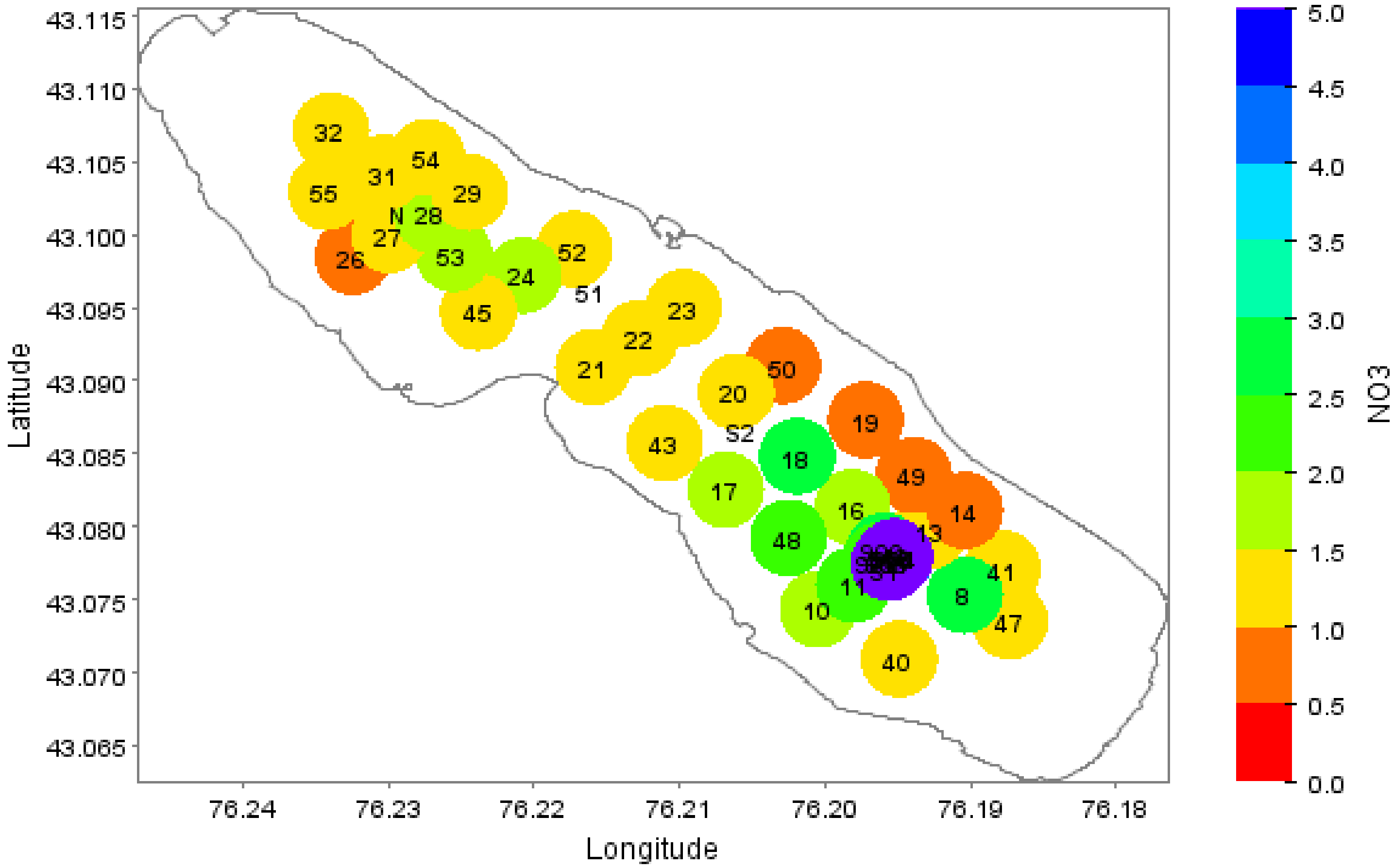
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

August 31, 2011



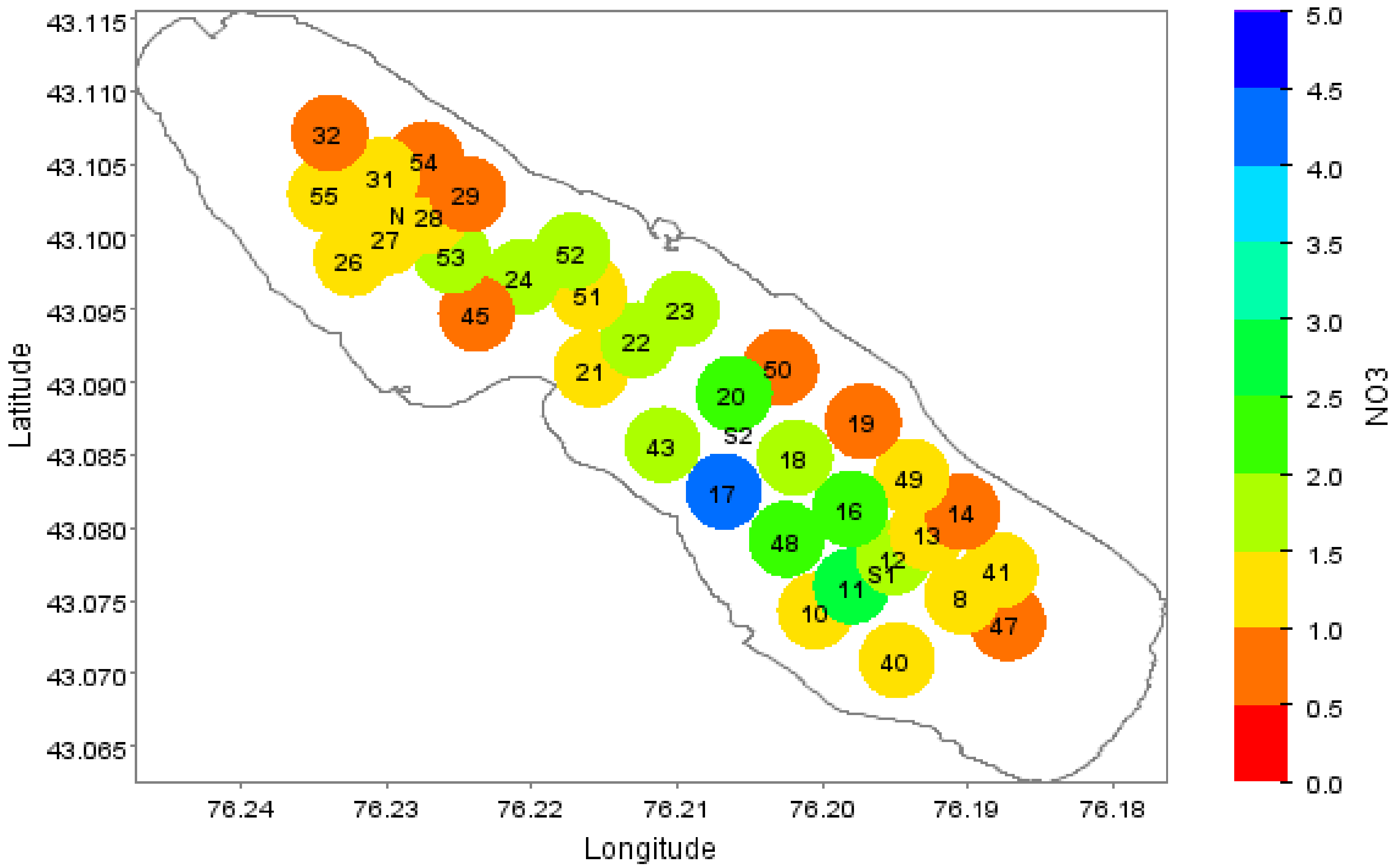
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

September 1, 2011



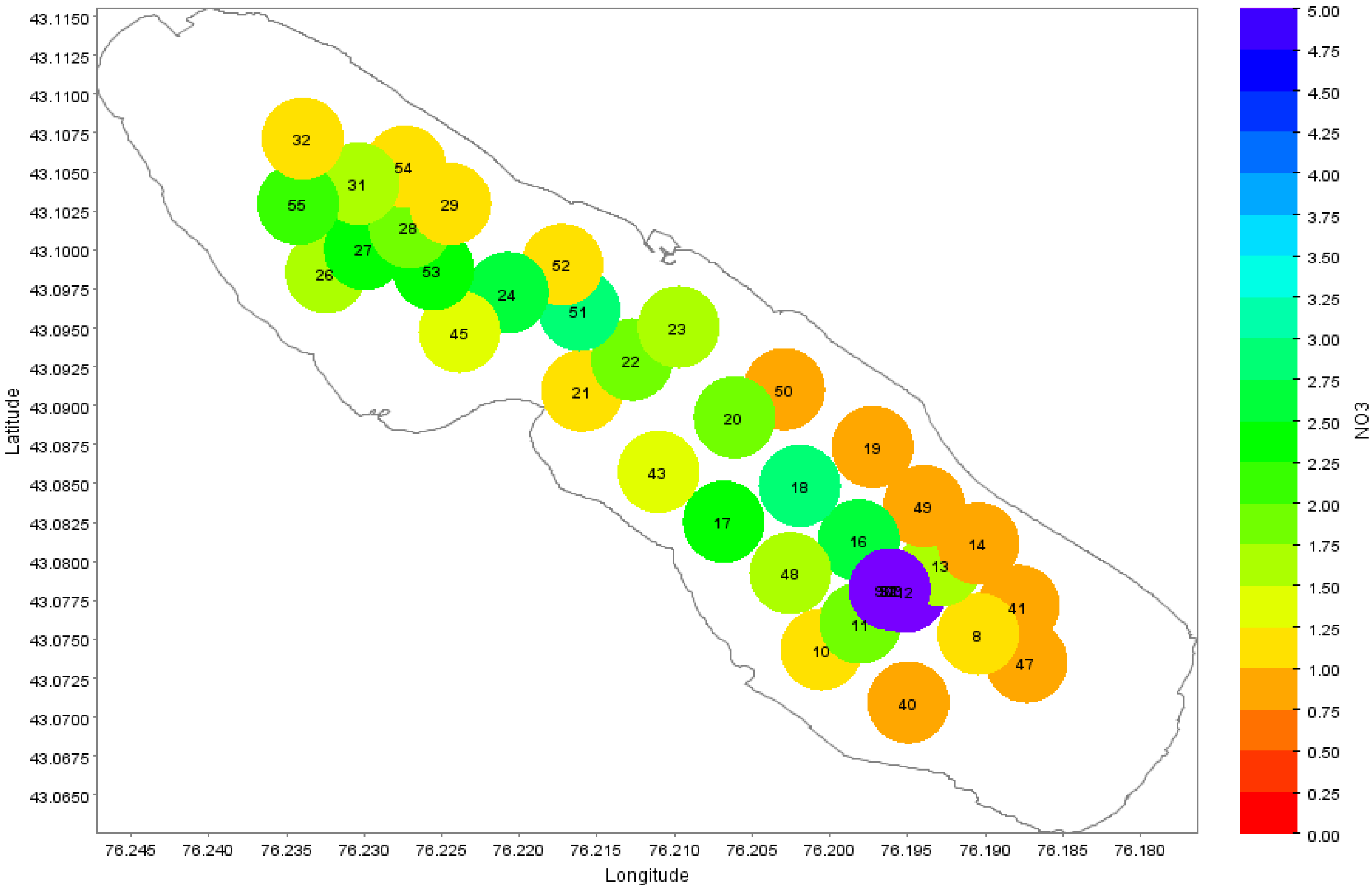
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

September 8, 2011



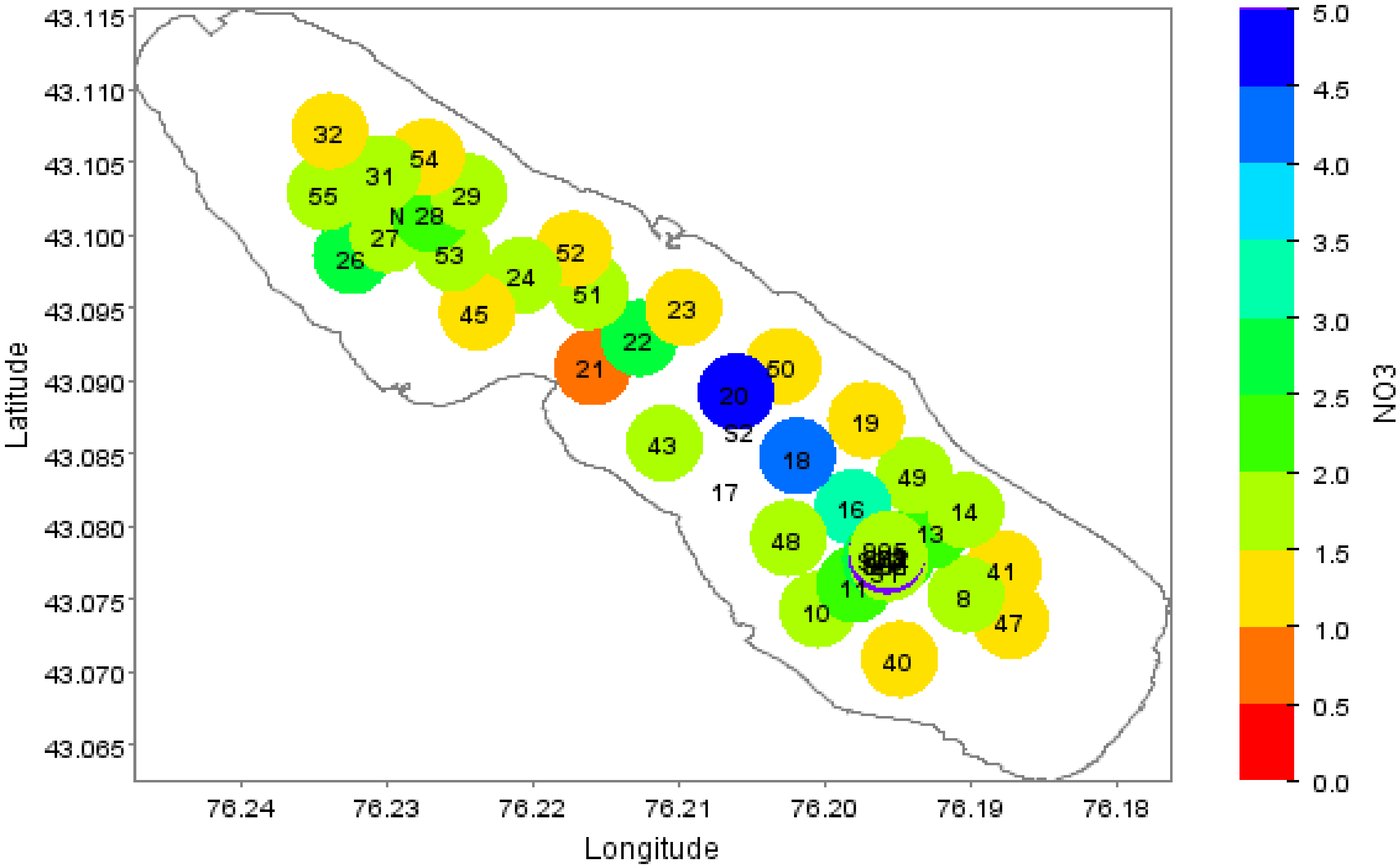
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

September 15, 2011



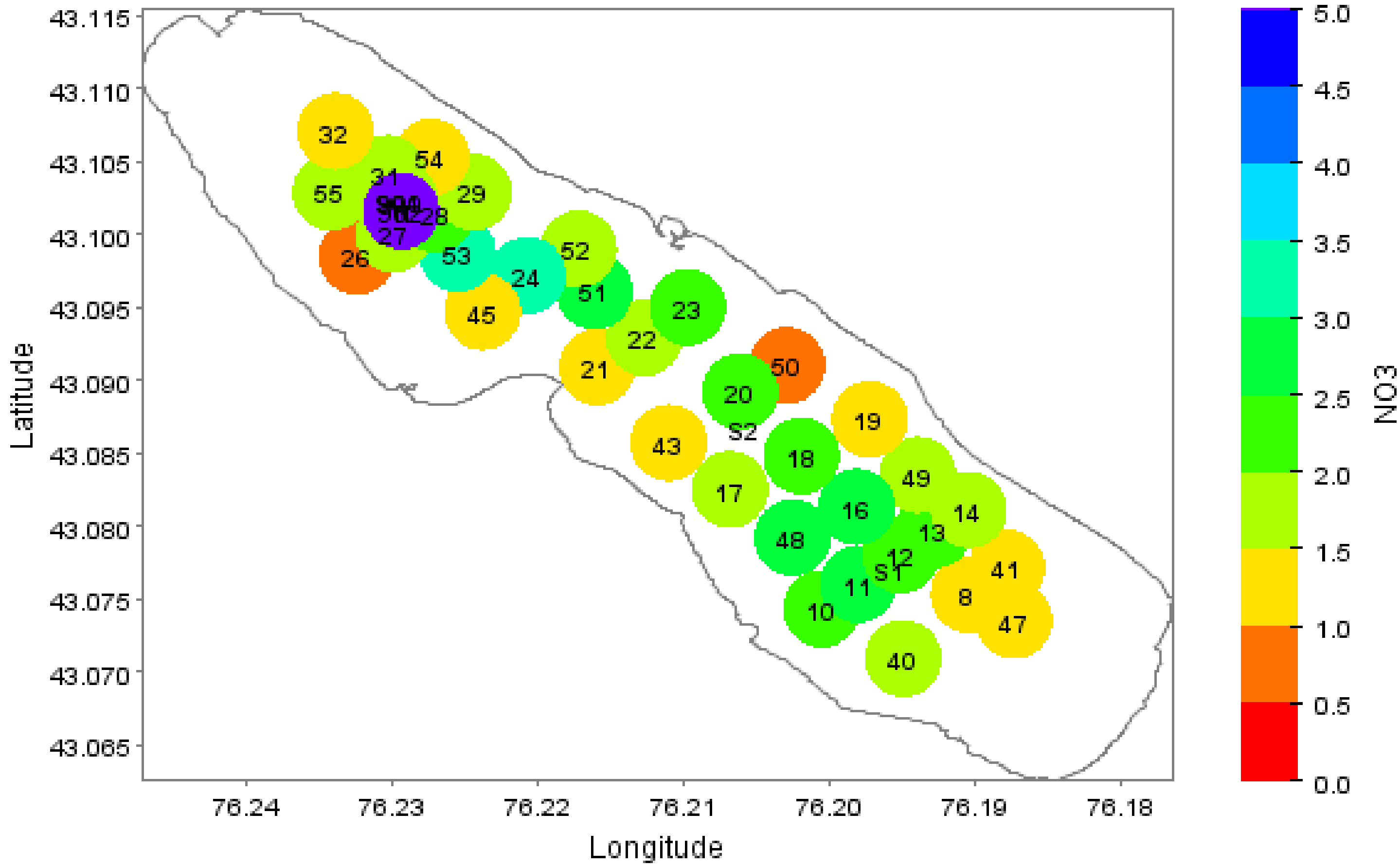
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

September 21, 2011



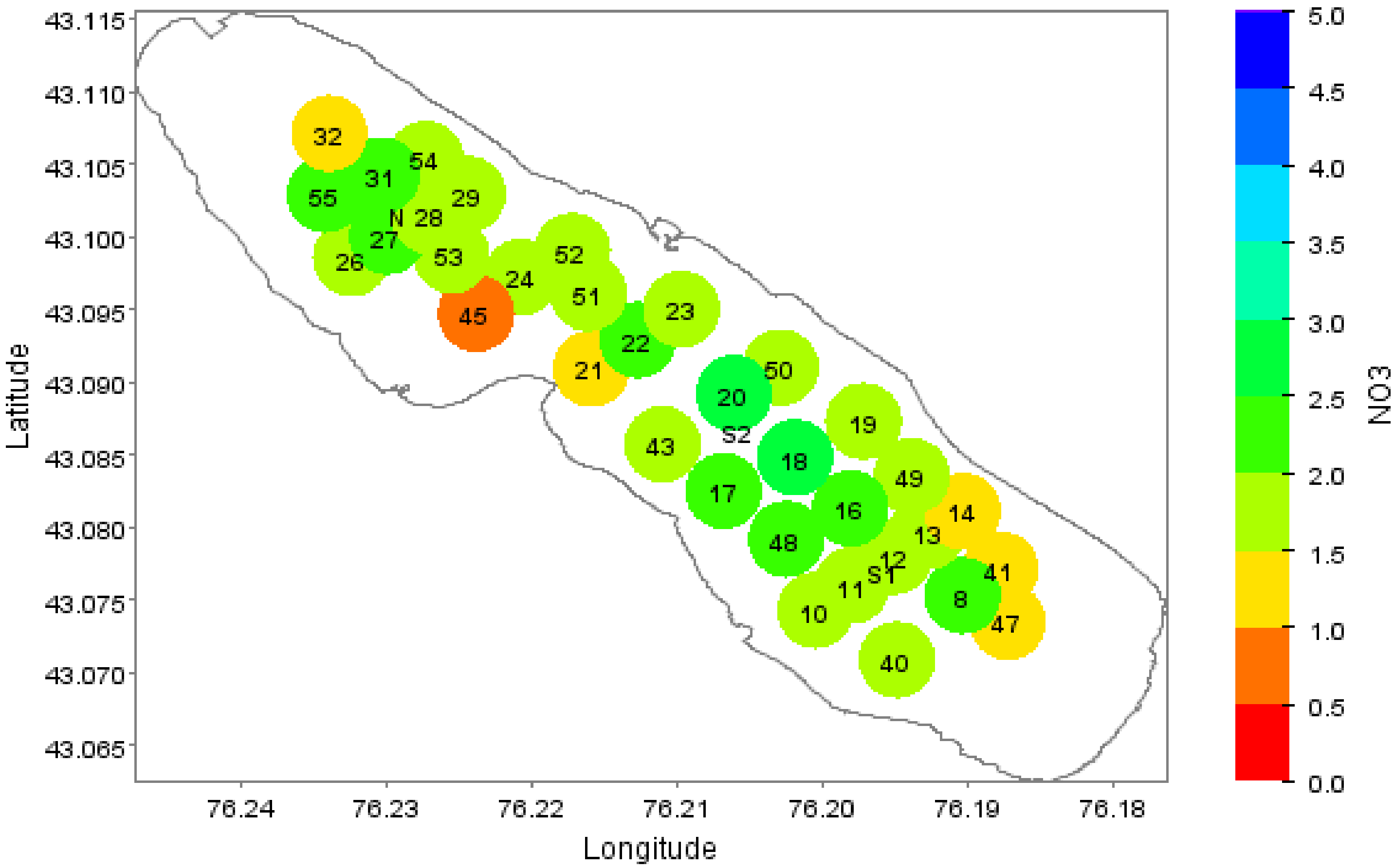
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

September 28, 2011



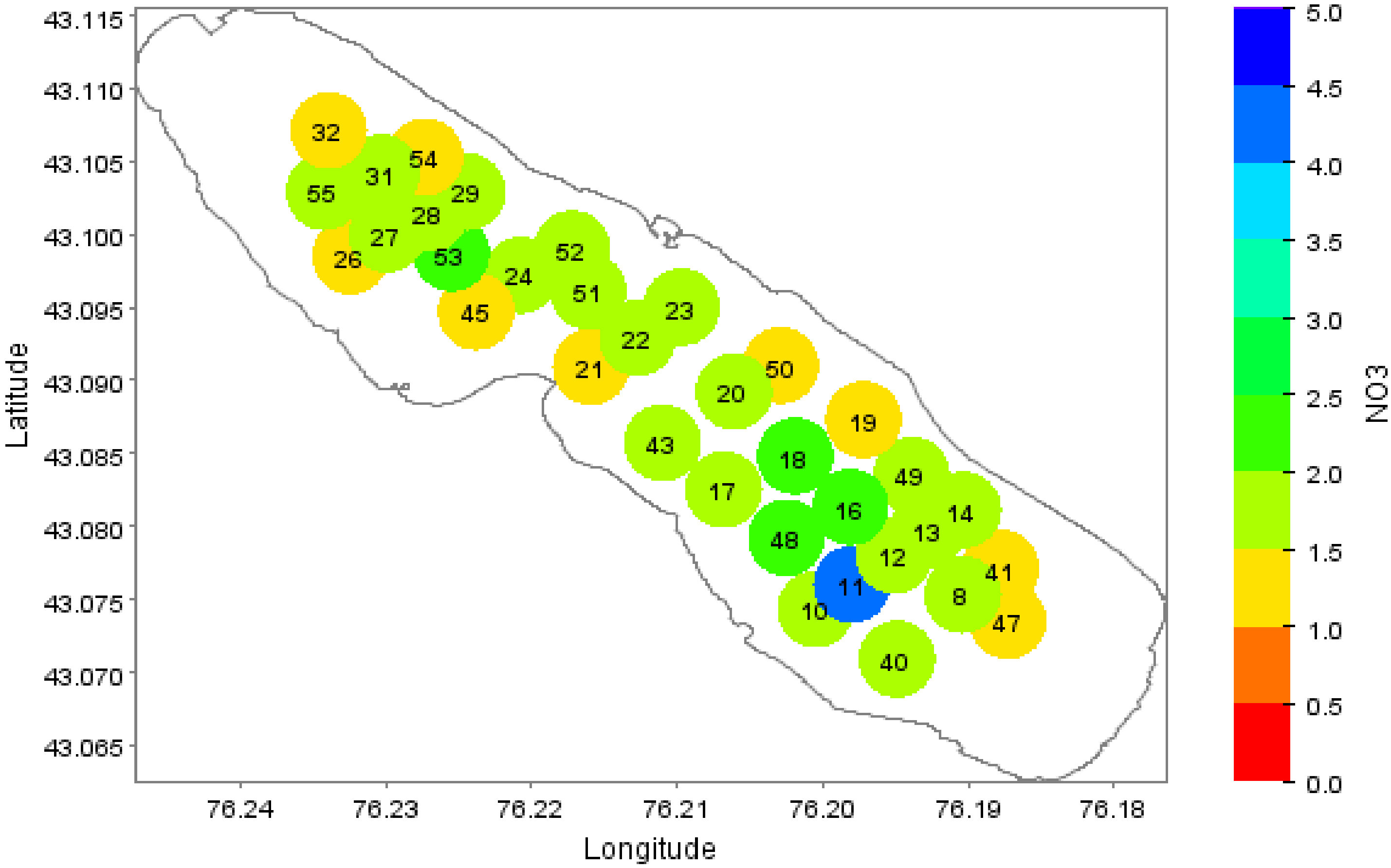
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

October 5, 2011



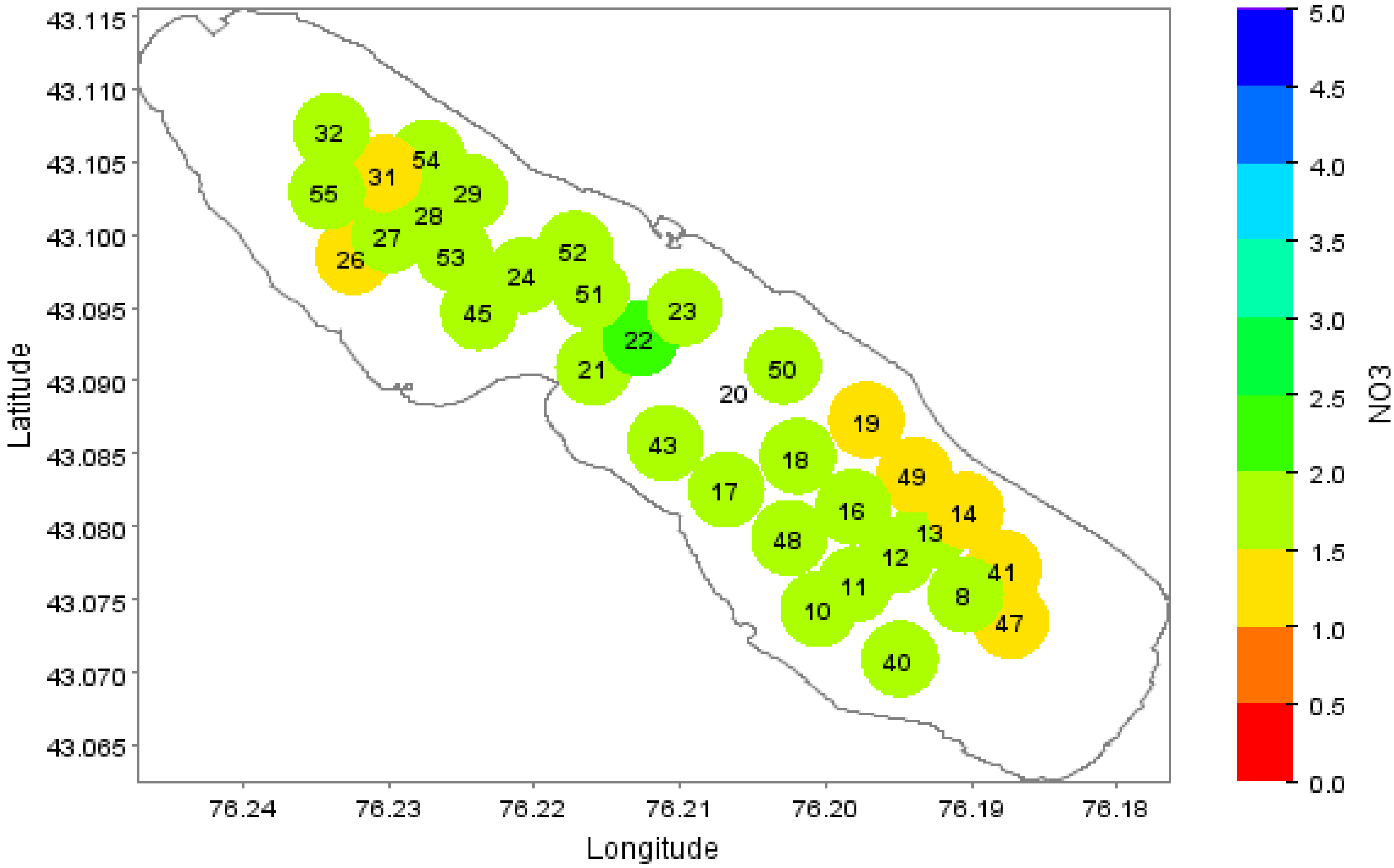
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

October 13, 2011



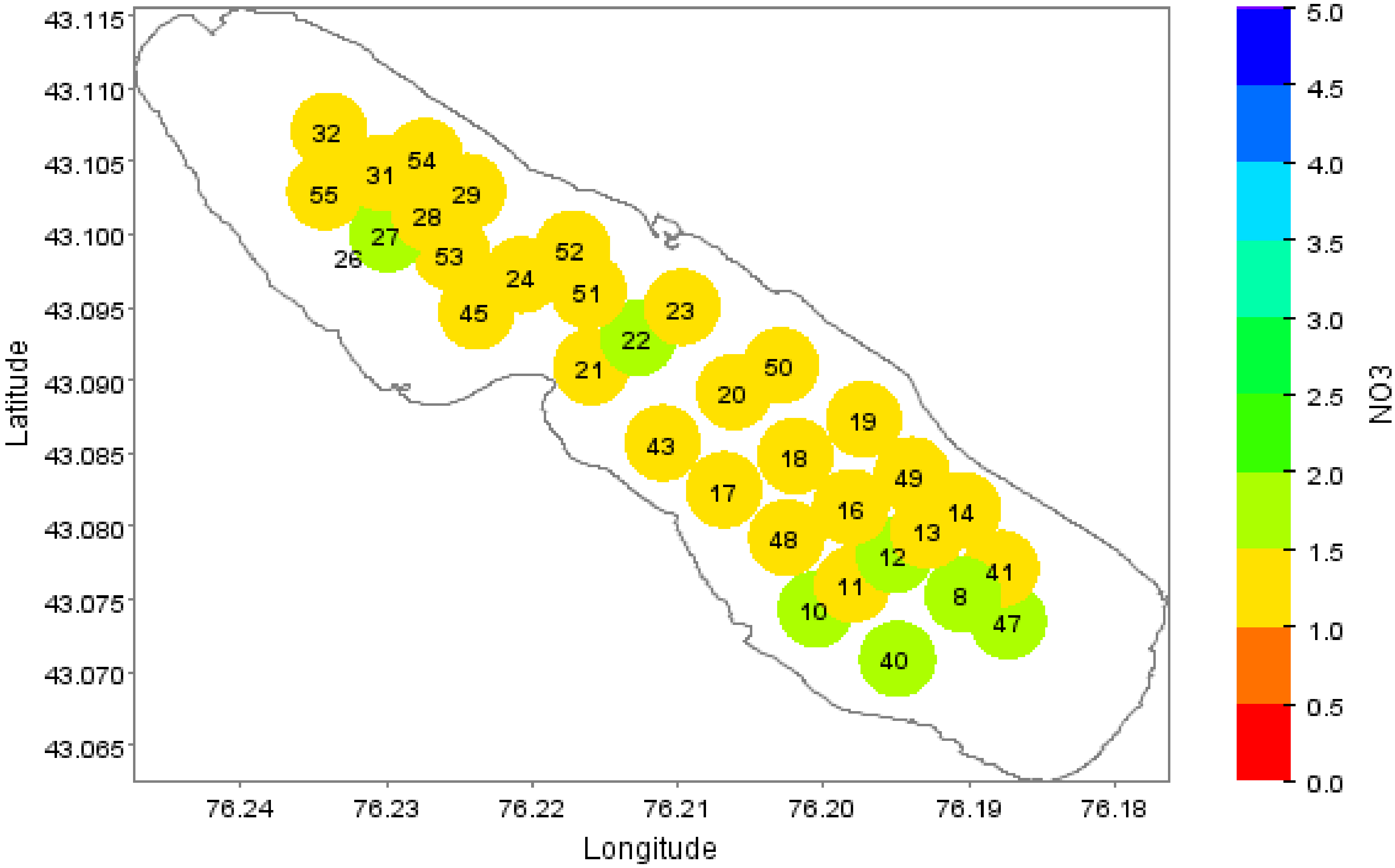
Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

October 20, 2011



Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

October 27, 2011



Color Bubble Plots at ~1.0 m off Bottom, Nitrate (mgN/L)

November 7, 2011