WORK PLAN FOR PILOT TEST TO ADD NITRATE TO THE HYPOLIMNION OF ONONDAGA LAKE

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GPS	global positioning system
ISUS	*in situ* ultraviolet spectrophotometry
JSA	job safety analyses
Metro	Metropolitan Wastewater Treatment Plant (discharge of treated municipal and other pre-treated wastewater into the south (upstream) end of Onondaga Lake)
NYSDEC	New York State Department of Environmental Conservation
OCDWEP	Onondaga County Department of Water Environment Protection
PFD	personal flotation devices
RAO	remedial action objective
ROD	Record of Decision
SMU	sediment management unit
SOP	standard operating procedure
SU	Syracuse University
UFI	Upstate Freshwater Institute (based in Syracuse, NY)
USEPA	United States Environmental Protection Agency
YSI	Yellow Springs Instruments

GLOSSARY OF TERMS

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. The epilimnion is warm and 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.). The hypolimnion is not well-mixed by winds or inflows to the lake.

Methylmercury - An organic form of mercury, which can be created from metallic or elemental mercury by bacteria in sediments and water.

Nanogram per liter – The same as 1 part per trillion and 0.000001 milligram per liter or 0.000001 part per million. Water quality standards for mercury are often expressed in nannograms per liter.

Profundal Zone – The portion of a water body, in this case Onondaga Lake, where water depths are greater than the depth to which sunlight penetration can support aquatic plants, in contrast with the littoral zone closer to shore. The profundal zone stratifies each year from May to October based on water temperature (lighter weight – warmer – water over heavier, colder water).

Thermocline - During summer stratification, a layer of water at approximately mid-depth that shows temperature changes with depth from the epilimnion temperature at the top to the hypolimnion temperature at the bottom. This mid-depth layer where water temperatures change significantly with depth is referred to as the thermocline.

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EXECUTIVE SUMMARY

As agreed upon with the New York State Department of Environmental Conservation (NYSDEC), liquid calcium nitrate will be added to the hypolimnion (i.e., water greater than 9 meter water depth) of Onondaga Lake during 2011, 2012, and 2013 as a three-year Honeywell pilot test. The objective is to demonstrate the ability to maintain nitrate concentrations in the hypolimnion at levels sufficient to further inhibit release of methylmercury from lake sediment to the overlying waters. Releases of methylmercury from bottom sediment to the hypolimnion have historically taken place, although such releases have been significantly lower since 2006 due to upgrades by Onondaga County to the Metropolitan Wastewater Treatment Plant (Metro). Methylmercury bioaccumulates in fish and potentially poses a risk to wildlife and humans who consume fish.

The design of the pilot test is based on four years of extensive water column monitoring to date for Honeywell documenting the positive impacts of the nitrate added by Metro, an extensive bench test program, dye tracer tests conducted during 2008, and a nitrate application field trial conducted during 2009. Applying a calcium nitrate solution will not result in any potentially significant effects on biota in the lake or human health. Although nitrogen is a common nutrient needed by aquatic life forms such as algae, it is not a limiting nutrient in Onondaga Lake and its addition will not stimulate algae growth. Furthermore, the calcium nitrate solution will be added to the hypolimnion and not to shallower waters where algae reside. The nitrate solution to be used is an agricultural fertilizer which has been in use for many years with no known human health or biota toxicity effects when used in this manner.

NYSDEC, United States Environmental Protection Agency (USEPA), and Onondaga County will be notified prior to initiating nitrate addition each year consistent with the notification protocol successfully implemented prior to the 2008 dye tracer tests and 2009 field trial. Application of nitrate will be scheduled to avoid impacts to public events scheduled on the lake.

Nitrate will be added as full-scale barge-based applications to the hypolimnion. Nitrate will be added in liquid form during the summer through early fall of 2011, 2012, and 2013, typically starting in late June before nitrate concentrations drop below 1.0 milligram per liter at the 18-meter water depth and continuing until the lake turns over, which is typically in early-to-mid-October. The addition of nitrate has been designed as presented in this work plan based on three separate stationary applications per week of a diluted calcium nitrate solution to the hypolimnion. Each application of nitrate will be conducted continuously for up to eight hours during a single day at a predetermined location. The location for each application may be adjusted during the pilot test as new monitoring results are assessed. Monitoring of the applied nitrate and related parameters will be conducted approximately two times during the week prior

to the first application (as a baseline), three days per week during the application period and two times during the week following the last application. Results will be reported to the agencies for each year that nitrate is applied. During the spring of 2014, a summary report of the three-year pilot test will be submitted.

1.0 BACKGROUND

1.1 Basis for Pilot Test

This work plan provides the basis and design for completing the pilot test for adding liquid calcium nitrate to the hypolimnion of Onondaga Lake. This pilot test work is based on requirements included in the Statement of Work attached to the Consent Decree between Honeywell and the NYSDEC (United States District Court, Northern District of New York. 2007). The Consent Decree (United States District Court, Northern District of New York, 2007) implements the remedy for the Onondaga Lake bottom outlined in the Record of Decision (ROD) issued by NYSDEC and the USEPA in July 2005 (New York State Department of Environmental Conservation and United States Environmental Protection Agency, 2005). The objective of this pilot test is to demonstrate the ability to maintain nitrate concentrations in the hypolimnion of Onondaga Lake at levels sufficient to further inhibit release of methylmercury from lake sediment to the overlying waters.

The ROD references pilot testing of oxygen addition rather than nitrate addition. However following completion of the ROD, the Upstate Freshwater Institute (UFI) and Syracuse University (SU) proposed that adding nitrate could provide the same benefits as adding oxygen without the uncertainties associated with oxygen addition, such as potential implications to biota within the lake. Nitrate, like oxygen, is consumed by microorganisms as part of the sequence of biochemical reactions that must be exhausted before methylmercury can be released from sediment. As a result, the Statement of Work attached to the Consent Decree between Honeywell and NYSDEC specified that a nitrate addition pilot study could be performed.

Honeywell began baseline monitoring of lake water in 2006 before the Consent Decree was finalized, and that baseline monitoring is continuing to the present (at least through 2010). During 2008, five dye tracer tests were conducted to measure dispersion in the hypolimnion (UFI, 2009). During 2009, a field trial was conducted to demonstrate that nitrate could be added and monitored effectively in the lower hypolimnion waters of the lake (Parsons and UFI, 2010). During 2008 and 2009, laboratory incubation tests were conducted (Exponent, Michigan Tech University, and Syracuse University, 2009) which showed methylmercury flux from sediment to the overlying water is the key mercury transport mechanism and that this flux is inhibited by the presence of nitrate in the water. Adding oxygen in the future instead of nitrate remains a possibility until it is formally determined based on this pilot test that nitrate addition effectively and appropriately meets the objective of controlling methylmercury releases from sediment to the water.

1.2 Lake Conditions

Onondaga Lake is located in Central New York State immediately northwest of the City of Syracuse. The lake is approximately 4.5 miles long and 1 mile wide, with an average water depth of 36 ft. The profundal zone of Onondaga Lake is the zone where water depths exceed 30 ft.

Profundal zone waters stratify vertically during summer months based on water temperature into an upper warmer layer (called the epilimnion) and a lower cooler layer (the hypolimnion). The profundal zone of the lake covers approximately 1,900 acres (Figure 1). The profundal zone of Onondaga Lake has two deep basins, a northern and southern, which have maximum water depths of approximately 61 and 65 ft., respectively. These basins are separated by a saddle region which has a maximum water depth of approximately 56 ft. The hypolimnion of Onondaga Lake has a relatively constant temperature during summer months and is not significantly mixed due to wind or storm events.

Waters within Onondaga Lake are more saline than in most inland lakes. Naturally occurring salt springs also discharge to Onondaga Creek, contributing to the salinity of the lake. Natural salt springs present near the lake result in saline wetlands. In addition, Solvay wastebeds are known to contribute calcium, sodium, and chloride to Ninemile Creek and to the lake.

Onondaga Lake is part of a state system of canals maintained by the NYS Canal Corporation, which is part of the New York State Thruway Authority. A dam located approximately 15 miles downstream along the Oswego River in Phoenix, New York, maintains the water level in the lake at a relatively constant average water surface elevation of Onondaga Lake of 362.8 ft. above mean sea level (based on the 1988 North American Vertical Datum). The lake water level changes due to spring runoff and dry summers as well as due to significant weather events. The lake is generally at its highest elevation in the early spring due to increased tributary flows and at its lowest elevation during the summer months.

1.3 Methylmercury Formation

Decomposition of organic matter in the lake involves a variety of bacteria that have different means of generating energy from the decomposition process. The activity of these bacteria follows a well-known sequence of reactions, and is also connected to the formation of methylmercury in the lake. During the early spring of each year, when the lake water is well-mixed, dissolved oxygen is present throughout the water column and bacteria that use oxygen to generate energy are primarily responsible for bacterial decomposition of organic matter in the water column and in near-surface sediments. As oxygen is used up, decomposition switches to bacteria that use nitrate to generate energy. When nitrate is depleted, bacteria use sulfate to generate energy. Bacteria that use sulfate to generate energy are also the organisms responsible for methylmercury production (Benoit et al., 2003). Carbon dioxide is the final compound used by bacteria to generate energy. Manganese and iron are electron acceptors intermediate to nitrate and sulfate; however, they are much less important than oxygen, nitrate, sulfate, and carbon dioxide in Onondaga Lake, because oxidized forms exist as insoluble solids (Matthews et al., 2008).

This sequence of biochemical reactions takes place gradually over time (oxygen used first, then nitrate, sulfate, and carbon dioxide) and space (e.g., oxygen is used in water overlaying sediment followed in deeper sediment by zones of nitrate reduction, sulfate reduction, and methane formation as depth into the sediment increases). The sequence is based on the energy yield (i.e., oxygen yields the most energy followed by nitrate, sulfate, and carbon dioxide). For example, sulfate-reduction will not occur to any great extent until both oxygen and nitrate availability is exhausted. This sequence of reactions also provides insight into interpreting measurements of oxygen, nitrate, and sulfide concentrations. For example, if sulfide is detected, then one can assume that sulfate-reduction (and by association methylmercury production) is occurring (Figure 5).

Frequent water quality monitoring in the profundal zone of Onondaga Lake on behalf of Honeywell since 2006 has demonstrated that methylmercury is not detected as long as nitrate-nitrogen concentrations (as nitrogen) remain above 1.0 milligram per liter (mg/L). Monitoring in the lake since 2006 has included collecting and analyzing over 300 profundal zone water samples to date for nitrate and methylmercury. Profundal zone monitoring results from recent years have also shown that water quality in the North Basin as measured at North Deep closely resembles water quality in the southern portion of the lake as measured at South Deep (see for example Appendix C in UFI and SU, 2008). The similarity of water quality at North Deep and South Deep is expected based on horizontal dispersion observed during the 2008 dye tracer tests and during the 2009 nitrate application field trial. Information available on spatial variability of water quality in the hypolimnion of Onondaga Lake indicates that concentrations will be uniform rather than heterogeneous. In addition, surface water sampling for mercury in littoral areas and at South Deep during August and November 2008 demonstrated no consistent difference in mercury/methylmercury concentration between locations (Parsons, Exponent and Anchor QEA, 2009). On this basis, the pilot test objective and the primary focus of lake monitoring during the pilot test are on nitrate. However, mercury will be monitored in the lower hypolimnion as specified in Section 4.1 and Table 4 of this work plan.

During 2007, 2008, and 2009, releases of methylmercury to the hypolimnion in the late summer to early fall were found to be substantially lower than in previous years due primarily to upgrades at Metro that have positively affected water quality in the lake (Figures 2 through 5). In 2004, Onondaga County brought on-line a biologically active filter system at Metro that converts ammonia to nitrate, roughly doubling the available nitrate pool in the hypolimnion at the start of summer stratification in the lake. In 2005, Onondaga County activated a phosphorus-removal system resulting in decreased algal growth in the upper waters and reduced demand for oxygen and nitrate in the hypolimnion. As a consequence of these wastewater treatment upgrades, nitrate levels persisted in the hypolimnion for a significantly longer period during the summers of 2007, 2008, and 2009 and reduced the release of methylmercury from lake sediment to lake waters.

Nonetheless, future addition of nitrate to the hypolimnion through the use of an engineered system may be warranted to maintain a sufficient quantity of nitrate to further reduce methylmercury release from sediment and meet remedial action objectives (RAO) and remedial goals established in the ROD.

2.0 DESIGN

2.1 Design Criteria

The ROD for the lake bottom established five RAOs for the lake bottom:

- RAO 1: To eliminate or reduce, to the extent practicable, methylation of mercury in the hypolimnion
- RAO 2: To eliminate or reduce, to the extent practicable, releases of contaminants from the in-lake waste deposit and other littoral areas around the lake

- RAO 3: To eliminate or reduce, to the extent practicable, releases of mercury from profundal (sediment management unit (SMU) 8) sediments
- RAO 4: To be protective of fish and wildlife by eliminating or reducing, to the extent practicable, existing and potential future adverse ecological effects on fish and wildlife resources, and to be protective of human health by eliminating or reducing, to the extent practicable, potential risks to humans
- RAO 5: To achieve surface water quality standards, to the extent practicable, associated with chemical parameters of interest

All of these RAOs except Objective 2 are at least partially addressed by adding nitrate to reduce formation of methylmercury. The primary objective of the pilot test is to deliver nitrate to the hypolimnion to minimize the release of methylmercury from underlying lake sediments to the hypolimnion. Based on detailed data collection and evaluation for the years 2007 through 2009, a minimum nitrate concentration of 1.0 milligram per liter as nitrogen throughout the lower hypolimnion during summer stratification has been established as a guide for determining when to add nitrate as discussed in Section 2.2. Nevertheless, methylmercury concentrations will be measured in the lower hypolimnion waters during 2011 in addition to nitrate.

New York State water quality standards that are potentially applicable for nitrate addition in Onondaga Lake are as follows:

- The lowest applicable state water quality standard for mercury is 0.7 nanograms per liter (or 0.0000007 milligrams per liter) in soluble form. This standard is based on bioaccumulation of mercury in fish followed by human consumption of impacted fish. The objective of nitrate addition is to maintain nitrate levels in the lower hypolimnion to further inhibit release of mercury from sediment to waters of Onondaga Lake.
- The narrative state water quality standard for nitrogen is none in amounts that will result in growths of algae that will impair the waters for their best usage. Because algae growth in Onondaga Lake is not nitrogen limited, nitrate addition is not a concern with respect to promoting primary production. Furthermore, nitrate is to be added to the lower waters and would not be available to algae until after the lake waters turn over in early-to-mid October when algae blooms are not a concern.

The state water quality standard of 100 micrograms per liter for nitrite-nitrogen (based on propagation of warm-water fish) should not be exceeded due to nitrate addition. None of the state water quality standards are anticipated to be violated as a result of adding nitrate during the pilot test period.

Another key objective of remedial activities such as nitrate addition is to ensure protection of on-site workers, the surrounding community, and the environment from potential risks associated with the completion of the remedy.

2.2 Testing and Design Evaluations

The target area for nitrate addition has been identified as the lake area with water depths greater than 14 meters (46 ft.) (highlighted on Figure 1). Since 2006 it has been shown that nitrate does not become completely depleted in the hypolimnion from the thermocline to a water depth of 14 meters. This is due to the fact that nitrate consumption occurs at the sediment-water interface and that the rate of consumption at that interface, and the rate of transport from the upper to the lower portion of the hypolimnion is such that the end of the stratification period is reached before significant mass of nitrate from the upper hypolimnion can be utilized. During the pilot test, sufficient nitrate will be added near the bottom to meet the sediment demand directly; therefore, no significant demand on nitrate from the upper hypolimnion should be exerted.

The 2009 nitrate application field trial demonstrated that it is possible to target a specific water depth interval of Onondaga Lake for adding nitrate, by matching the density of the diluted calcium nitrate solution with the density of the lake water at the target depth. Density of Onondaga Lake hypolimnion water as a function of temperature and salinity, or its surrogate parameter specific conductance, has been established (UFI and SU, 2007a).

The target concentration for nitrate-nitrogen within the nitrate application area is 1.0 milligram per liter based on data available from Honeywell's ongoing baseline monitoring program. Figures 2, 3, and 4 show that during 2007, 2008, and 2009, respectively, methylmercury started to appear in the hypolimnion (at the 18-meter water depth) as nitrate-nitrogen concentrations fell below 1 milligram per liter. Figures 2 and 3 show methylmercury concentrations started to appear above 0.2 nanograms per liter after nitrate-nitrogen concentrations leveled off at approximately 0.9 to 1 milligram per liter and later fell below 0.5 milligram per liter.

In order to maintain the target minimum nitrate concentration of 1 milligram per liter, the maximum nitrate application rate that the pilot test equipment has been designed to achieve was conservatively determined based on peak four-week rolling average nitrate uptake rates in the hypolimnion water as measured at the South Deep station by UFI during the summers of 2007, 2008, and 2009 (Figure 6). The maximum nitrate uptake rate over any four-week period from 2007 through 2009 was 0.8 metric tons of nitrate-nitrogen per day or 5.6 tons per week. To add 5.6 tons of nitrate per week over three six-hour applications is equivalent to an application rate of 0.31 tons per hour of application. Similarly, to add 5.6 tons of nitrate per week over three eight-hour applications is equivalent to an application rate of 0.23 tons per hour of application. To achieve an application rate of 5.6 tons per week over three 6-hour application periods and incorporate a 20 percent safety factor, the maximum design flow for nitrate for the pilot test equipment is 0.373 tons per hour or 2.24 tons for a six-hour application. The 20 percent safety factor is included to account for adding more nitrate during a particular week or at a particular location if needed to account for factors such as dispersion variations over time and nitrate demand induced by higher nitrate concentrations at the sediment/water interface. Monitoring results from the pilot test will be assessed to determine the appropriateness of this estimated safety factor.

Nitrate will be added once per week at three locations within the hypolimnion for a minimum of six hours per day of continuous application. Adding nitrate once per week at three locations will allow implementation with a single barge system. One day is needed between each addition of nitrate to reload materials, check equipment and move the barge to the next location. The three locations for applying nitrate will be in the vicinity of North Deep, the Saddle, and

South Deep (Figure 1). These locations may be adjusted during implementation based on observations and monitoring results, as discussed in Section 2.3. If applying nitrate for six to eight hours a day at each of three locations on a weekly basis is not sufficient to maintain needed nitrate levels throughout the lower hypolimnion, then discussions between NYSDEC and Honeywell will be initiated to determine the most suitable course of action.

The determination to add nitrate once per week at three locations is supported by results obtained from five dye tracer tests conducted in 2008, two six-hour applications of nitrate conducted in 2009 as a nitrate application field trial, and quantitative analysis of nitrate spread based on a mass transport equation.

The 2008 dye tracer tests and the 2009 nitrate application field trial were conducted on behalf of Honeywell based on work plans approved in advance by NYSDEC (UFI, 2008 and Parsons, 2009b). The dye tracer tests consisted of five separate tests conducted by UFI between July 22, 2008 and October 7, 2008 (UFI, 2008 and UFI, 2009). The purpose of these tests was to inject a known quantity of dye (Rhodamine-WT) at a single point within the hypolimnion to track the plume of dye over a known period of time. Results from the dye tracer tests have been used to estimate dispersion coefficients for water within the Onondaga Lake hypolimnion.

The nitrate application field trial was conducted as two continuous, six-hour applications of nitrate on July 22, 2009 and July 29, 2009 (Parsons and UFI, 2010). The purpose of the nitrate application field trial was to demonstrate that a widely-available calcium nitrate solution could be effectively added and mixed with lake-bottom waters in a manner that retains the nitrate at the target depth to counteract nitrate depletion below critical levels that result in release of methylmercury. The nitrate application field trial was also designed to provide additional information about horizontal dispersion of nitrate as a follow-up to the 2008 dye tracer tests. Monitoring results confirmed that nitrate was successfully delivered to the target depth and that the nitrate remained within the target depth zone. Results from the nitrate application field trial also significantly increased understanding of the range of dispersion that is encountered in the hypolimnion of Onondaga Lake.

Dispersion coefficients observed during the 2008 dye tracer tests and during the 2009 nitrate application filed trial, are shown in Table 1 and are within the ranges of dispersion observed in hypolimnions from other lakes (Parsons and UFI, 2010).

Table 1. Dispersion Coefficients Determined from 2008 Dye Tracer Tests and the 2009 Nitrate Application Field Trial in Onondaga Lake (reported in Parsons and UFI, 2010)

Dye Test (2008) or Application (2009)	Location	Dates	Dispersion coefficient (E), square meters per second			Ratio
			E_L	E_V	E_R	E_L / E_V
1 (2008)	North Basin	22-25 July	0.037	0.016	0.035	2.3
2 (2008)	South Basin	12-14 Aug	0.030	0.0055	0.030	5.4
3 (2008)	North Basin	10-11 Sept	0.021	0.096	0.088	0.2
4 (2008)	South Basin	23-26 Sept	0.018	0.034	0.057	0.5
5 (2008)	North Basin	7-9 Oct	0.14	0.050	0.15	2.9
1 (2009)	North Basin	22-24 July	0.440	0.094	0.419	4.7
	North Basin	22-23 July	0.138	0.046	0.175	3.0
2 (2009)	South Basin	29-31 July	0.033	0.023	0.037	1.4

E_L – dispersion coefficient in the longitudinal direction

E_V – dispersion coefficient in the transverse direction, 90 degrees from the longitudinal direction in the horizontal plane

E_R – dispersion coefficient in the radial direction, as an average of the longitudinal and transverse directions also in the horizontal plane

Adding nitrate once per week at three locations was evaluated by applying results from the dye tracer tests and the field trial using an analytical equation for mass transport from a volume source set within a semi-infinite domain (a fixed vertical dimension and an infinite horizontal extent, Park and Zahn, 2001, equation 22):

$$C(x,y,z,t) = \frac{1}{4d}\int_0^t q_v(t-\tau')\exp(-\lambda\tau')\left[\operatorname{erfc}\frac{x-v\tau'-x_0}{2\sqrt{D_x\tau'}} - \operatorname{erfc}\frac{x-v\tau'}{2\sqrt{D_x\tau'}}\right]$$
$$\times\left[\operatorname{erfc}\frac{y-y_0}{2\sqrt{D_y\tau'}} - \operatorname{erfc}\frac{y+y_0}{2\sqrt{D_y\tau'}}\right]$$
$$\times\left[z_1 - z_0 + 2\sum_{n=1}^{\infty}\frac{d}{n\pi}\left(\sin\frac{n\pi z_1}{d} - \sin\frac{n\pi z_0}{d}\right)\cos\frac{n\pi z}{d}\right.$$
$$\left.\times\exp\left[-\left(\frac{D_z n^2\pi^2}{d^2}\right)\tau'\right]\right]d\tau' \qquad (22)$$

Where:

C	concentration of nitrate (and C_0 is the initial concentration where added
d	thickness (m) of modeled hypolimnion (i.e., thickness below 14m depth)
q_V	volumetric source strength function (grams per liter per second)
t	time after simulation begins (seconds)
τ'	time (after simulation begins) when source function starts (sec) – not used
λ	first order decay rate (per second)
x,y,z	coordinates (m) of observation point as per Figure 1 in Park and Zahn, 2001
i,j,k	coordinates (m) of observation point using volume source center as origin
v	velocity of water flow in the x-direction (meters per second) – set to zero
x_0, y_0, z_0, z_1	source dimensions (see Figure 1)
Dx	longitudinal dispersion coefficient (square meters per second)
Dy	transverse horizontal dispersion coefficient (square meters per second)
Dz	transverse vertical dispersion coefficient (square meters per second)

Input to the equation includes radial dispersion coefficients from the 2008 dye tracer tests and the 2009 field trial along with a first-order decay rate for biological uptake of nitrate based on observations in the hypolimnion of Onondaga Lake each summer as nitrate levels decline (Figures 2 through 5).

The Park and Zhan equation simulates effects of dispersion on the spread of nitrate from the location where nitrate is added. Concentrations of nitrate can be calculated for any location at any time, based on dispersion measured during the dye tracer tests and field trial and biodegradation measured as part of the annual baseline monitoring work. The equation was applied to evaluate the time needed for dispersion of nitrate to the perimeter of the 14-meter water depth.

Based on anticipated inputs of nitrate and epilimnion mix water, and dimensions of the lake hypolimnion, results from applying this analytical equation indicate weekly applications at three different locations within the hypolimnion are expected to provide sufficient nitrate spread to meet the objectives of the pilot test. Nonetheless, it is anticipated that the application strategy will be revised and optimized based on results from the monitoring program described in Section 4. This nitrate monitoring will guide the assessment of application locations and rates on a regular basis.

Results from applying the mass transport equation discussed above also indicate a lead time of two to four weeks should be sufficient to maintain sufficient concentrations of nitrate in the hypolimnion below the 14-meter water depth. During 2007, nitrate concentrations in the lower hypolimnion fell below 1 milligram per liter in mid-July (Figure 2). During 2008, nitrate concentrations in the lower hypolimnion fell below 1 milligram per liter in late June but subsequently leveled off until early August (Figure 3). During 2009, nitrate concentrations in the lower hypolimnion fell below 1 milligram per liter in early August (Figure 4). Therefore, mid-June has been conservatively selected as the timeframe for starting the pilot test in 2011.

2.3 Materials, Methods and Protocols

Calcium nitrate ($Ca(NO_3)_2$), a common agricultural fertilizer, is the source of nitrate that will be applied to the lower waters of the Onondaga Lake hypolimnion. The basis for selecting calcium nitrate is its liquid form, availability, common use as an agricultural fertilizer, chemical content, and successful application of liquid calcium nitrate during the 2009 nitrate application field trial. The solution of calcium nitrate identified to be applied is called CN-8 from Yara North America (www.yara.us) or equivalent. Product information for CN-8 is provided in Appendix A of the *Nitrate Application Field Trial Work Plan* (Parsons, 2009b) and is summarized in Table 2.

Table 2. Properties of the Calcium Nitrate Solution (from www.yara.us)

Property	Description
Preferred available form	CN-8 a 49.8 percent calcium nitrate ($Ca(NO_3)_2$) solution by weight including 8.55% nitrate-nitrogen
Other constituents	Common fertilizer ingredients: 0.02% ammonia nitrogen by weight
Specific gravity	1.48 (based on 1.00 for water)
Weight per gallon, pounds	12.3
Salt out temperature, degrees Fahrenheit	35
pH	5.0 to 7.0
Description	Clear, odorless liquid
Storage and handling	Plastic, fiberglass, or stainless steel
Instructions (for avoiding formation of insoluble precipitates)	Do not mix with phosphate or sulfate-containing materials
Trace contaminant concentrations(1)	Arsenic: less than 0.25 mg/L Cadmium: less than 2.0 mg/L Cobalt: less than 5.0 mg/L Lead: less than 1.5 mg/L Mercury: less than 0.02 mg/L Molybdenum: less than 2.5 mg/L Nickel: less than 5.0 mg/L Selenium: less than 0.5 mg/L Zinc: less than 3.0 mg/L

(1) Concentrations are in milligrams per liter (mg/L) as obtained from Yara North America, Inc. and (for lead) from a Honeywell contracted laboratory.

Applying the calcium nitrate solution will not result in any potentially significant effects on water quality, biota in the lake or human health (UFI and SU 2007a). Although nitrogen is a common nutrient needed by aquatic life forms such as algae, it is not a growth-limiting nutrient in Onondaga Lake. Furthermore, this calcium nitrate solution will be added to the hypolimnion and not to shallower waters where algae reside. It will be almost entirely consumed before lake turnover results in mixing of the hypolymnion with the overlying water. The CN-8 solution is most often used as an agricultural fertilizer and has been used as such for many years with no known human health or biota toxicity effects.

There is no statewide water quality standard applicable to Onondaga Lake for either calcium or nitrate (NO_3^-), however there is a statewide water quality standard of 100 micrograms per liter (μgN/L) for nitrite (NO_2^-) based on fish propagation in warm-water fishery waters. In June 2009, the UFI analyzed a sample of CN-8 solution for nitrite, nitrate, ammonia and phosphorus prior to adding the solution to the lake hypolimnion as part of the 2009 nitrate application field trial. Analytical results from UFI indicated the solution contained 0.11 milligrams of nitrite-nitrogen per liter. A nitrite concentration of 0.11 milligrams per liter applied as part of the calcium nitrate solution at the application rate specified in this work plan over a four-week time period throughout the hypolimnion below the 14-meter water depth would only amount to a nitrite-nitrogen concentration of 0.00126 micrograms per liter in the lower hypolimnion, which is five orders of magnitude below the statewide water quality standard of 100 micrograms per liter.

Concentrations of nitrite in the hypolimnion exceeded New York State water quality standard before, during, and after the 2009 nitrate application field trial. Elevated nitrite concentrations can occur in waters as a result of incomplete nitrification (conversion of ammonia to nitrate) or denitrification (conversion of nitrate to nitrogen gas). Nitrite concentrations in the oxygenated epilimnion before and after the 2009 field trial were below the water quality standard (Parsons and UFI, 2010). There is no evidence that the CN-8 application during the 2009 nitrate application field trial adversely affected Onondaga Lake. See UFI and SU (2007a) and references therein for a more complete discussion of nitrite toxicity and its history in Onondaga Lake. Furthermore, anoxic conditions in the hypolimnion preclude fish propagation, which is the basis for the statewide nitrite water quality standard.

In order for the CN-8 solution to remain in the lower hypolimnion following release to the lake, the CN-8 solution needs to be added at the density of the hypolimnion water. The specific gravity of the CN-8 solution is 1.48, which is almost 50 percent higher than the density of water. Therefore, a water less dense than hypolimnion water needs to be mixed with the CN-8 before being pumped to the lower hypolimnion. Water from shallower depths above the thermocline (i.e., the epilimnion) are warmer and less dense than hypolimnion waters. Table 3 shows an example determination of the rates of addition for both CN-8 and epilimnion water based on the maximum design flow rate. The actual flow rate will be determined prior to injection based on preceeding water quality monitoring results. The pilot test field crew will adjust the flow rates of CN-8 and epilimnion water to maintain the required dilution ratio based on field determinations of water temperature and specific conductance with specific conductance being a surrogate measurement for salinity. The example rates presented in Table 3 are representative of applying 40 percent of the weekly nitrate application over a single day of application.

Table 3. Determination of Rates for Adding CN-8 and Epilimnion Water Based on Maximum Flow.

Items	Value	Units	Note
Fraction of CN-8 that is Ca(NO3)2:	0.486		Constant based on information from chemical supplier
Density of CN-8	1.48	Gram per cubic centimeter	Constant based on information from chemical supplier
Molecular weight ratios:			
Nitrogen	1.0	Ratio of molecular weight of nitrogen to itself	Constant
Nitrate	4.43	Ratio of molecular weight of nitrate to molecular weight of nitrogen	Constant
Calcium nitrate	5.85	Ratio of molecular weight of calcium nitrate to molecular weight of nitrogen within calcium nitrate	Constant
Target average daily flow of nitrate as nitrogen based on a seven day per week application	0.80	Metric tons per day	Based on Figure 6
Target converted to weekly flow	5.600	Metric tons per week	Conversion from daily
Hour per day for nitrate addition	6 to 8	Hours	Practical limit.
Dilution ratio	250	Dimensionless	See Note below
Target nitrate for an application based on three six-hour applications weekly with a 20 percent safety factor added	2.24	Metric tons expressed as nitrogen	
Target nitrate for an application	2,240	Kilograms	Same mass in different units.
Target calcium nitrate for an application	13,120	Kilograms	Based on manufacturer's information about mass of CN-8 per mass of nitrate
Target CN-8 for an application	26,996	Kilograms	
Volume of CN-8 for an application	18	Cubic meters	Same volume in different units
Volume of CN-8 for an application	18,000	Liters	Same volume in different units
Volume of CN-8 for an application	4,755	Gallons	Same volume in different units
Flow rate of CN-8	9.91	Gallons per minute	
Flow rate of epilimnion water to be mixed with calcium nitrate solution based on a 250 to 1 dilution	2,476	Gallons per minute	
Flow rate of epilimnion water and CN-8 to enter the hypolimnion based on a 250 to 1 dilution	2,486	Gallons per minute	

Note: Dilution ratio may vary during the pilot test based on salinity and temperature measurements.

Figures 7 and 8 show the anticipated barge layout and schematic cross section, respectively. Piping on the barge will be used to withdraw epilimnion lake water to mix with the CN-8 and to deliver the solution to the hypolimnion. As was the case for the 2009 field trial, the CN-8 liquid will be diluted with epilimnion lake water at an approximate dilution ratio of 1:250. This ratio results in the density of the solution being approximately the same as that of the water in the hypolimnion where the solution is injected through an end-of-pipe diffuser. By matching densities in this manner, the CN-8 solution will remain near the lake bottom and spread horizontally following application. The anticipated diffuser depth for releasing the mixture is approximately 4 to 6 ft. (1.5 meters) above the lake bottom, which is the same depth where dye was released as part of the 2008 dye tracer tests and where nitrate and dye were released during the 2009 nitrate application field trial.

The two sets of diffusers will resemble the diffusers used during the 2009 field trail which consisted of the 4-nozzle, cross type, with the nozzles positioned on a 90 degree interval, pointing upward 10 degrees above horizontal. The design velocity for the CN-8 water mixture exiting each nozzle will range from 3 to 4 ft. per second. The flexible hosing transmitting the calcium nitrate mixed with epilimnion water from the barge to the deep hypolimnion will be 6 and 10 in. in diameter (Figure 7).

3.0 MOBILIZATION

Mobilization is anticipated to take approximately three weeks prior to mid-June and following procurement of materials and equipment. The first two weeks of mobilization will involve mobilization of the barge and installation of pumps, pipes, controls, and the on-board storage tanks with portable containment devices called spill guards that will be placed around the storage tanks and around the tanker truck and hosing when liquid calcium nitrate is delivered to the onshore support area to be constructed. A third week will be allotted to fill the barge tanks, move out into the lake and test the pumps, controls, and diffuser, if warranted. The third week of mobilization will also be the first week of monitoring.

The weeks beginning in mid-June following mobilization will be allotted for the nitrate applications and for monitoring until the lake waters turn over (typically in early-to-mid October). A final week is needed following lake turnover for demobilization and final monitoring.

To prepare for nitrate addition, the following mobilization activities will take place:

- One or two temporary on-shore support areas approximately 5,000 square feet in size will be established exclusively for the nitrate pilot test at secure locations accessible to Honeywell. A figure showing the location and footprint of the onshore support area(s) will be provided when available. This area(s) will be used for equipment and material transfer from land to the barge. If needed to hold the calcium nitrate solution onshore, the onshore support areas will also include temporary storage tanks with secondary containment. When use of the support area is completed, the area will be restored as warranted depending on plans for long-term land use at that location.
- It is anticipated that small barge sections (approx 8 ft. x 16 ft.) capable of being trucked will be transported to the site and craned from the truck to the water where

they will be 'pinned' together to create a larger barge. The barge is anticipated to be self propelled with outboard motors comparable to motors used on other barges of similar size. A tug boat will not be needed. The barge will hold a small crane capable of deploying and removing the necessary anchors to hold the barge on location during the application. The barge will be fitted with temporary storage tanks provided with secondary containment along with mixing equipment, temporary piping, and other equipment and supplies needed to conduct the pilot test. The barge will have ample usable deck space in addition to the working space of the crane. During mobilization and for nights and standby time between pilot test applications when the barge is not in use, the barge and support boat will be secured in the lake away from shore and most likely near the lake shoreline adjacent to the temporary on-shore support area offshore from the barrier wall. Multiple spuds or anchors will be used to hold the barge in place when moored. It is also likely that the barge will be stored nearshore in the North Basin the night before the next day's application to reduce travel time during the morning of North Basin applications.

- Equipment needed to add calcium nitrate will be mobilized including pumps, storage tanks, meters, suction piping, and distribution piping to transmit the nitrate-water mixture to predetermined depths in the hypolimnion.
- Monitoring equipment will be tested including a GPS sensor; the *in situ* ultraviolet spectrophotometry (ISUS) equipment, hand-held real-time monitoring equipment, and a laptop computer containing needed software.
- Software will be checked and modified as needed to allow reliable recording and display of field measurements on the on-board computer.

3.1 Site Security

The lakeshore support areas for nitrate application operations will most likely be located on or near Wastebed B south of Wastebeds 1 through 8. Wastebed B is being used on behalf of Honeywell as the support area for various construction projects, and has also been used as the support area for pre-design investigation work. Security procedures maintained on behalf of Honeywell during previous and ongoing remedial activities have been successful in controlling equipment, materials, and building security. These measures, including controlled access points, secondary locking fencing around key equipment/storage areas, and nighttime illumination, will be implemented during nitrate addition activities as needed.

3.2 Spill Prevention and Contingency

Spill contingency for nitrate addition operations will fall into one of three tiers of spill prevention and containment measures. The first tier is design control, which identifies the various liquids that will be used onsite, describes the locations where these liquids will be stored and/or used (see Figure 7), and identifies requirements for spill containment measures (such as secondary containment of chemical storage tanks included on land as needed and on the barge) that will ensure if a liquid was to spill from its primary containment vessel it would not be allowed to escape into the environment. Secondary containment equivalent to tank volumes will be provided for the storage tanks on the barge that will store calcium nitrate solution. The second tier of control is a list of preventive management practices during activities such as refueling of vehicles or transfer of chemicals; this second tier of control will be included in standard operating procedures (SOP)/activity hazard assessments that are part of the health and safety plan prepared and implemented previously for other lake efforts. If pilot test activities are identified that are not included in the Onondaga Lake project safety plan (O'Brien & Gere, 2008), new operating procedures/activity hazard assessments will be prepared prior to starting that task. In addition, regular monitoring of tanks, hoses, and connection will be conducted as a spill prevention measure. The third tier of control is spill response, for which procedures are or will be outlined in the project safety plan.

4.0 MONITORING

An in-lake monitoring program will be conducted before, during, and after each of the three years of nitrate addition. Data collected as part of the nitrate addition monitoring program will be used to guide rates and locations for application of the calcium nitrate solution, to track the fate of the chemical addition and verify that there are no negative impacts to water quality, and to assess nitrate addition as a means of abating methylmercury accumulation in the hypolimnion. There are three components to the overall monitoring program to support the nitrate pilot test: (1) fixed frequency monitoring to assess electron acceptors, redox constituents, mercury species and related conditions; (2) three-dimensional specification of nitrate and bi-sulfide levels during periods of nitrate addition; and (3) on-board measurements conducted during nitrate addition. Each of these is described below. Certain features of this monitoring program are currently included in Honeywell's ongoing Baseline Monitoring (Book 1) Program within the lake. The new features are use of in-lake monitors and collection of samples for laboratory analyses at many more profundal zone locations. UFI will conduct this monitoring work with the exception of measurements to be made on the application barge. If results from the pilot test monitoring indicate that there are any unexpected violations of water quality standards, NYSDEC will be notified within two business days of such results becoming available.

4.1 Fixed Frequency Monitoring

This component of the monitoring program allows for assessment of (1) in-lake conditions to establish the need for initiating and continuing nitrate addition; (2) the effectiveness of nitrate addition; and (3) important fluctuations and systematic changes that may influence the nitrate addition effort. Water column monitoring will be conducted weekly at South Deep and North Deep during the nitrate addition time period (approximately July-October), and also bi-weekly during June and November and monthly during April and May at South Deep and North Deep as part of the Onondaga Lake Baseline Monitoring Program that UFI has been implementing on behalf of Honeywell since 2007 (Parsons and Exponent, 2010). In addition, total mercury and methylmercury will be monitored monthly during the application period in lake water at one water depth in the lower hypolimnion near the underlying sediment at the ISUS locations monitored by UFI on behalf of Honeywell as part of the lake baseline monitoring effort (10 ISUS locations in addition to the South Deep and North Deep locations). Parameter listings, sampling depths, analytical methods for laboratory analyses and parameter justifications are summarized in Table 4. With the exception of calcium, all of the parameters in Table 4 are currently measured at South Deep as part of the Baseline Monitoring Program. Provisional laboratory data for key parameters (e.g., nitrate) will be made available within one week of sample collection. Formal data packages will be submitted within one month of sample collection. Robotic monitoring over the April to November time interval at South Deep will allow for assessment of the dynamics of density stratification, dissolved oxygen resources, and an array of auxiliary limnological conditions, with high time (daily) and depth (1 meter) resolution. Specifications of probe measurements for robotic monitoring are presented in Table 5. Robotic monitoring at South Deep is part of Honeywell's Baseline Monitoring Program.

A thermistor chain will be deployed near the South Basin application location during the 2011 portion of the pilot test. The thermistor chain will consist of an array of sensors measuring water temperature along a vertical chain to be suspended from a surface buoy. Water temperature will be recorded at regular intervals. These instruments will be deployed to observe water temperature fluctuations associated with internal wave (seiche) activity in the lake. Water motion in the portion of the hypolimnion where the nitrate will be applied is expected to occur largely as a result of this process. The thermistor observations will be processed and evaluated in order to determine the "thermocline range", defined as the range of vertical movement of the thermocline from a position above its mean (rest) position to a point below that position.

Table 4: Specifications for Water Column Monitoring Associated With the Pilot Test

Parameter	Method	Locations	Frequency	Depths (m)	Justification
Nitrate	EPA 353.2	North & South Deep	weekly during applications	2,10,12,14,16,18	injected chemical, electron acceptor, N cycle
Nitrite	EPA 353.2	North & South Deep	weekly during applications	2,10,12,14,16,18	N cycle, toxicity issue
Ammonia	EPA 350.1	North & South Deep	weekly during applications	2,10,12,14,16,18	N cycle, toxicity issue
Sulfide	SM 18-20 4500 S^{2-} G	North & South Deep	weekly during applications	14,16,18	redox constituent, Hg cycle
Ferrous iron (Fe^{2+})	Heaney and Davison, 1977	North & South Deep	Weekly during applications	14, 16, 18	redox constituent, Hg cycle
Total dissolved gases (TDG)	TDG sensor	North & South Deep	weekly during applications	full water column, 1 m intervals	N cycle, toxicity issue
Calcium	SM 18-20 3111B	North & South Deep	weekly during applications	2,10,12,14,16,18	injected chemical
Total Mercury	EPA 1631E	North & South Deep	weekly during applications	2,10,12,14,16,18	contaminant
Total Mercury	EPA 1631E	10 ISUS locations	Monthly during applications	Near sediment	contaminant
Methylmercury	EPA 1630	North & South Deep	weekly during applications	2,10,12,14,16,18	More toxic form of contaminant
Methylmercury	EPA 1630	10 ISUS locations	Monthly during applications	Near sediment	More toxic form of contaminant

Table 5: Specifications of Probes for Robotic Monitoring at South Deep

Parameter	Probe (YSI*)	Performance Accuracy/Resolution	Attribute/Value
dissolved oxygen (DO)	6562	± 2% reading/0.1% saturation	electron acceptor
temperature (T)	6560	± 0.15 °C/0.01 °C	thermal stratification, mixing
specific conductance (SC)	6560	± 0.5% reading/1 µS	tracer, signature of injected chemical
pH	6565	± 0.2 units/0.01 units	chemical equilibria, sulfide species
fluorometric chl (Chl_f)	6025	± NA/0.1 µg/L Chl	metric of phytoplankton biomass
redox potential	6565	± 20 mV/ 0.1 mV	indicator of redox status
turbidity (Tn)	6136	± 2 NTU/0.1 NTU	vertical pattern of particles

* Model number of Yellow Springs Instruments (YSI) instrumentation

A total of two Acoustic Doppler Velocimeter instruments (hereafter called velocity meters) will be deployed near the South Basin and near the North Basin application locations during the 2011 portion of the pilot test. These velocity meters measures water velocity based on the Doppler Effect by transmitting a short pulse of sound, listening to its echo, and measuring the change in pitch or frequency of the echo. The two velocity meters will each be housed in stationary steel-framed cage to ensure the vector's sensors remain in a fixed position approximately one meter above the lake bottom.

Following the 2011 portion of the nitrate pilot test, use of a thermistor chain and velocity meters during the subsequent year of the pilot test will be assessed.

4.2 Three-Dimensional Specification of Nitrate and Sulfide Levels

An important component of the nitrate addition program is near-real-time feedback on the detailed spatial resolution of the nitrate pool in the hypolimnion to assess the transport and fate of the added nitrate and guide subsequent additions. A three-dimensional representation of the distribution of nitrate will need to be obtained over a short time interval during nitrate addition. Further, occurrences of sulfide within the hypolimnion over three dimensions will help to identify the potential for occurrences and sources of methylmercury. These monitoring efforts will be conducted with modern rapid profiling instrumentation, which includes ISUS for measurements of nitrate and sulfide (Prestigiacomo et al., 2009).

Chemical manipulations are not needed with this technology. Instead, ISUS utilizes the characteristic absorption spectra of selected inorganic constituents within UV wave lengths and spectral deconvolution techniques to separate and quantify the concentrations of these constituents (Johnson and Coletti 2002). Validation of ISUS measurements has been completed (Prestigiacomo et al. 2009). Weekly ISUS gridding at 10 locations is conducted as part of the Baseline Monitoring Program. The number of locations and the frequency of gridding may be expanded as warranted to support nitrate addition requirements.

The ISUS will provide well-resolved patterns of both nitrate and sulfide within a single day. Specifically, the individual profiles (together a "gridding") necessary to support this resolution (approximately 30 profiles) can be collected in four hours, a shorter interval than the period for internal waves in this lake (Effler et al., 2004). Other sensors in the rapid profiling "package" (Table 6) provide an invaluable limnological context of stratification, tracer(s) patterns, and turbidity (e.g., bacterial and other microbial constituents, resuspended sediments). The goal is to provide viewer-friendly spatial patterns (e.g., contours) of the nitrate, sulfide, and other related characteristics within the same day of field measurements. This information will then be used to guide decisions on appropriate rates of application and locations for adding nitrate. ISUS gridding will be conducted three times per week within the hypolimnion during the nitrate addition time period. Turnaround time for ISUS monitoring results is anticipated to be less than 24 hours with the goal of providing results on the same day profiles are conducted. Backup ISUS instrumentation will be sufficiently available to minimize the potential for down time if ISUS equipment unexpectedly becomes inoperable.

If ISUS results indicate nitrate levels are not able to be maintained at or above approximately 1 mg/L as nitrogen, then NYSDEC will be notified and a path forward will be determined that would likely include additional monitoring of lower hypolimnion waters for methylmercury.

Table 6: Specifications for rapid profiling instrumentation

Parameter	Sensor	Performance Accuracy/Resolution	Attribute/Value
Nitrate	Satlantic ISUS V2	0.007 mg per liter as nitrogen	calcium nitrate being added to the hypolimnion
Bi-sulfide	Satlantic ISUS V2		redox constituent, sulfate reduction
Temperature	SBE 3F	± 0.002 °C/0.0003 °C	stratification
Specific conductance	SBE4	± 3 μS/cm/0.1 μS/cm	tracer/stratification
Beam attenuation coefficient	Wetlabs C-Star	± 0.1% transmission	particle indicator
Optical backscattering	D&A OBS-3	± 0.25 NTU/0.1 NTU	particle indicator
Chlorophyll	Wetlabs WETstar	± NA/0.1 μg/L Chl	indicator of phytoplankton biomass
Photosynthetically active irradiance	Li-Cor LI-193	± 5% reading	light penetration

4.3 On-Barge Measurements

Three types of monitoring are planned to be conducted on-board the vessel during nitrate addition: (1) measurements to assess the density of the calcium nitrate and discharge solution; (2) measurements of volumetric flow rates for calcium nitrate and the discharge solution; and (3) measurements of the nitrate addition positions within the lake. Density is a function of temperature and salinity. Salinity will be assessed by measuring specific conductance. Densities of the chemical solution and the diluted form to be added to the lake will be calculated in near-real-time by an on-board computer to guide the details of nitrate addition, including the extent of on-board dilution and depth(s) of discharge.

Measurements of flow rates of calcium nitrate, dilution water, and discharge solution will be measured with appropriately precise instrumentation. Calculations will be conducted to demonstrate closure of a total flow budget (chemical solution volume plus dilution volume equals discharge volume) and use of calcium nitrate.

A real-time global positioning system (GPS) unit will be used on the barge to monitor barge location during each application. It is intended the barge will stay stationary for the duration of each application.

4.4 Biota Monitoring

The objective of biota monitoring associated with this pilot test is to assess impacts of nitrate addition on methylmercury bioaccumulation in the lake food chain. Most of the biota monitoring work relevant to the nitrate pilot test is already being conducted; however some expansion of baseline biota monitoring will be conducted during 2011 as outlined in this section and summarized in Table 7.

Table 7: Biota Monitoring for Year 1 of the Nitrate Addition Pilot Test (2011)

Biota Type	Analytical Parameter	Number of Samples and Location(s)	Frequency
Additional zooplankton	Low-level total mercury and methylmercury	One sample at North Deep at 13-meter water depth(1)	Monthly April-June, Biweekly July-August, Weekly September until lake turnover, and Biweekly following lake turnover through November (approximately 19 sampling events)
Additional prey fish: smaller alewife and gizzard shad captured with gill nets(2)	Total mercury	One to two samples targeted at each of the eight locations in the littoral zone sampled during 2008-2011 as part of lake baseline monitoring (Book 2)	One time beginning in mid-May for alewife and prey fish based on likely presence in shallower waters

(1) Zooplankton will also be captured at the same water depth and frequency at South Deep using the same sampling equipment. These zooplankton samples collected at South Deep will also be analyzed for total mercury and methylmercury as part of the lake baseline monitoring (Book 1) work also being conducted on behalf of Honeywell.

(2) Five prey fish samples will also be collected at each of the same eight locations during August 2011 as part of the lake baseline monitoring (Book 2) work also being conducted on behalf of Honeywell.

Monitoring results are available lake-wide from work conducted annually on behalf of Honeywell beginning in 2008 and from work ongoing annually by Onondaga County and UFI.

Objectives for baseline monitoring in Onondaga Lake being conducted on behalf of Honeywell include the following (Parsons. Exponent and Anchor QEA, 2010b):

- Establish a comprehensive description of baseline chemical conditions prior to remediation to assess remedy effectiveness and to facilitate remedy design.
- Provide additional data for future understanding of remedy effectiveness in achieving remediation goals for Onondaga Lake.

Baseline biota monitoring conducted in the profundal zone on behalf of Honeywell during 2008, 2009, and 2010 included sampling and analysis of zooplankton at the South Deep location. Zooplankton samples were collected at South Deep monthly during April, May, and June; biweekly during July and August and following lake turnover; and weekly during September and October until the lake turned over. The collected zooplankton samples were analyzed for total mercury and methylmercury.

Baseline monitoring of lake fish conducted on behalf of Honeywell during 2008, 2009, and 2010 included collection and analysis of adult sport fish and prey fish from locations around the lake. Fish sampling was conducted at locations around the lake for tissue chemical analyses, population and community assessments, and gut content analysis. A maximum of 50 fillet samples each of adult smallmouth bass, walleye, brown bullhead, and pumpkinseed were targeted annually during June and analyzed for chemical content. A total of 40 prey fish composites were collected annually in August and analyzed for chemical content. Prey fish sampling included attempts to collect alewife.

Widespread lateral distribution of dissolved constituents such as nitrate is apparent within the hypolimnion of Onondaga Lake based on many rounds of water quality results conducted on behalf of Honeywell and by Onondaga County. Horizontal differences in either water column or zooplankton mercury concentrations as a result of nitrate addition are not anticipated. On this basis, monitoring in the profundal zone during 2011 will be expanded to include zooplankton sampling at North Deep at the same frequency as conducted during 2010 at South Deep as part of the lake baseline monitoring work. If noteworthy spatial differences in concentrations are observed during 2011, sampling at additional locations will be considered for 2012 and 2013.

Representative prey fish species (e.g., alewives for pelagic planktivores) are being targeted in the lake baseline monitoring program. To date, most of the prey fish collected for chemical analysis have been two to five years of age. Beginning in 2011, a more concerted effort using gillnets will be made to capture alewives one time beginning in mid-May when they are most likely available in shallow waters. In addition to alewife, gizzard shad less than 180 mm (i.e., prey fish) will also be targeted with gillnets one time beginning in mid-May. Gizzard shad of this size are likely to be planktivores while larger gizzard shad become omnivores. Based on gut content analysis and observations during processing for tissue samples, alewife apparently are the preferred pelagic prey in the stomachs of piscivorous fish such as smallmouth bass and walleye. In addition, piscivorous fish generally prey on soft-rayed fishes (e.g., alewife and gizzard shad) over spiny-rayed fishes (e.g., white perch); therefore, white perch will not be targeted for capture.

5.0 HEALTH AND SAFETY

The safety of all members of the project team and the general public is the highest priority for Honeywell and for Parsons. Written safety procedures for the nitrate pilot test will be prepared as needed to supplement the Project Safety Plan for Parsons' field efforts (Parsons, 2008) and the UFI Safety Plan (Appendix C of UFI and SU, 2007b) prepared for previous Onondaga Lake field activities. This safety documentation will be used during the pilot test and will be strictly followed by all personnel. Any task outside of the current scope defined in the relevant safety plans will have new job safety analyses (JSA) completed as warranted before the task begins. Copies of these Parsons and UFI safety plans will be maintained at the support zone and on the boat.

Various project-specific safety elements will be emphasized. For example, personal flotation devices (PFD) will be worn at all times by anyone on the team that is on a boat or barge and anyone involved in loading or unloading the barge from shore or docks must wear a PFD. Slip-resistant surfaces and electrical protection around water will be emphasized. Suitable hand and eye protection will be instituted as appropriate when working with the nitrate solution. Working conditions at this time of the year could include very warm weather; therefore, shade and plenty of water will be provided for the field crew. Hot work (e.g., welding) procedures will be approved by the project safety officer prior to implementation. Appropriate safeguards will be employed at the calcium nitrate storage units.

It is anticipated that during the application period, days will exist that it will not be safe to be on the barge due to weather. Some conditions that will preclude water work will include, but are not limited to, thunder and lightning storms and strong winds (winds that create waves that make working on and navigating barges/support boats unsafe). Anyone on the field application team will have the ability to terminate work if unsafe conditions occur.

Safe operation of water craft is important during field nitrate applications. The barge or boat will be tethered to the lake bottom to limit movement. While working on a barge or boat, the field team will be instructed to be aware of other boaters and weather conditions which may influence pilot test operations. All personnel will be required at a minimum to wear Level D personal protective equipment, approved coast guard life vests at all times by anyone on the team that is on a boat or barge and anyone involved in loading or unloading the barge from shore or docks must wear a PFD. Employees must follow the SOP for Marine Safety Operation found in the Onondaga Lake Pre-Design Investigation: Project Safety Plan, Attachment E (Parsons, 2010).

6.0 SCHEDULE CONSIDERATIONS

Nitrate will be added to the lake's lower hypolimnion starting in mid-June 2011 and ending when the lake turns over which is usually in early-to-mid October. As discussed in Section 2.2, nitrate will begin to be added during each of the three years prior to the nitrate-nitrogen levels measured in the lower hypolimnion declining below 1.0 milligrams per liter. Nitrate addition will be terminated each year when the lake turns over. “Blackout” dates, when nitrate will not be added, will be established to the extent practicable based on scheduled dates for public events on the lake between mid-June and late October.

7.0 NOTIFICATIONS AND COMMUNICATIONS WITH OUTSIDE PARTIES

The following protocol has been established by Honeywell for notifying NYSDEC, USEPA, and Onondaga County consistent with the notification protocol successfully implemented during the 2008 dye tracer tests and 2009 field trial.

- Items to be included in notifications:
  - Scope and purpose of work – Apply the calcium nitrate solution to bottom waters to measure the effectiveness of adding nitrate to reduce release of methylmercury from lake sediment.
  - Lake activity – A barge, support boat, and one or two boats will be moving slowly in a portion of the lake for a few days each week.
  - Schedule – Specific timeframes for the nitrate applications during the pilot test have not yet been determined but are anticipated to be from mid-June to October of 2011, 2012, and 2013. Follow up notifications will be provided once more detailed pilot test time frames are established.
  - Effects of the calcium nitrate solution – The calcium nitrate solution will not be visible because it is being applied into deep, stratified lake waters. Calcium nitrate is commonly used as an agricultural fertilizer. Use of calcium nitrate solution is acceptable to NYSDEC who has reviewed the work scope.
- Contacts to be notified by Parsons/Honeywell:
  - Onondaga County Department of Water Environment Protection (OCDWEP) and Onondaga County Parks
  - Tim Larson (NYSDEC Project Manager) and Tara Blum (NYSDEC Region 7 representative) who in turn can notify others at NYSDEC and at other state agencies as warranted
  - Bob Nunes (USEPA Region 2 Project Manager) who can notify other federal contacts as warranted

Every reasonable effort will be made to give agencies at least one week of notice prior to commencing the pilot test. Every reasonable effort will also be made to notify NYSDEC in a timely manner of any changes to the schedule and to confirm pilot test start dates once they are identified. In order to mobilize equipment and supplies and to provide reasonable notification, the decision about a date during which to conduct the pilot test will be made by Honeywell in conjunction with NYSDEC at least a few days in advance. This decision will be based primarily on lake conditions and the weather forecast.

8.0 QUALITY ASSURANCE

Work efforts not specifically described in this work plan, such as decontamination, spill contingency, and waste management, will be conducted in accordance with procedures documented in the Phase I Pre-Design Investigation Work Plan, such as for sample handling and waste management (Parsons, 2005), and specifications in the Onondaga Lake Pre-Design Investigation Project Safety Plan (O'Brien & Gere and Parsons, 2008). Laboratory procedures will be conducted in accordance with the SOP included in Book 1 Work Plan for Baseline Monitoring (UFI and SU, 2008).

Confirmation of ISUS nitrate concentrations with laboratory measurements will be completed on a regular basis.

9.0 DATA MANAGEMENT AND REPORTING

Because this work is required under a Consent Order through NYSDEC, approval of this work plan will provide basis for notice to proceed; therefore, a permit from NYSDEC will not be required to conduct this work.

Honeywell will present to the agencies results and an analysis of the data from 2011, the first year of the three-year pilot test, by the first quarter of 2012. By the spring of 2014, Honeywell will submit a report that summarizes results from the three-year nitrate addition pilot test so Honeywell and the agencies can together formulate a path forward. Several years of baseline monitoring data (i.e., hypolimnion surface water, zooplankton, adult sport fish, and prey fish data) will be available and assessed for the 2014 report to specify the benefits of nitrate addition. An assessment of the stability of the lake's stratification regime will also be included in the 2014 report.

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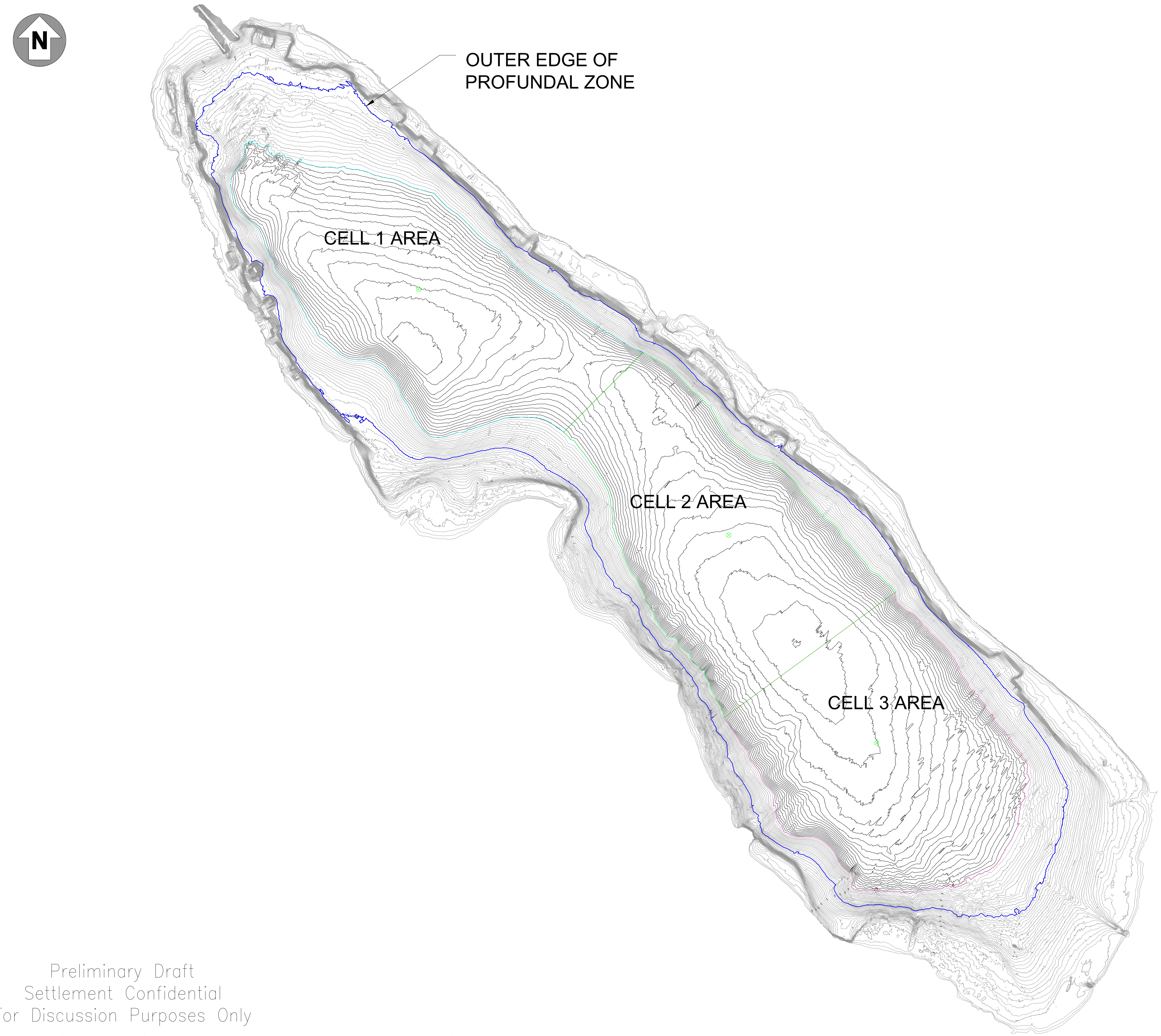
FIGURES



TOTAL PARCEL AREA (WITHIN 46 FT CONTOUR):
61,497,886 SQ FT
PERIMETER: 60,481.782'
VOLUME: 19,098,804 CU METERS

CELL 1 TOTAL AREA
TOTAL AREA: 21,496,825 SQ FT
PERIMETER: 21,999'
VOLUME: 5,117,948 CU METERS

CELL 2 AREA
TOTAL AREA: 20,007,859 SQ FT
PERIMETER: 19,670'
VOLUME: 6,996,359 CU METERS

CELL 3 AREA
TOTAL AREA: 19,995,103 SQ FT
PERIMETER: 18,888'
VOLUME: 6,984,497 CU METERS

⊗ CENTROID OF PARCEL

2000 1000 0 2000 4000

SCALE: 1"=2000'

FIGURE 1

Honeywell

ONONDAGA LAKE
SYRACUSE, NEW YORK

ONONDAGA LAKE
NITRATE APPLICATION PILOT TEST

SMU 8 VOLUMES

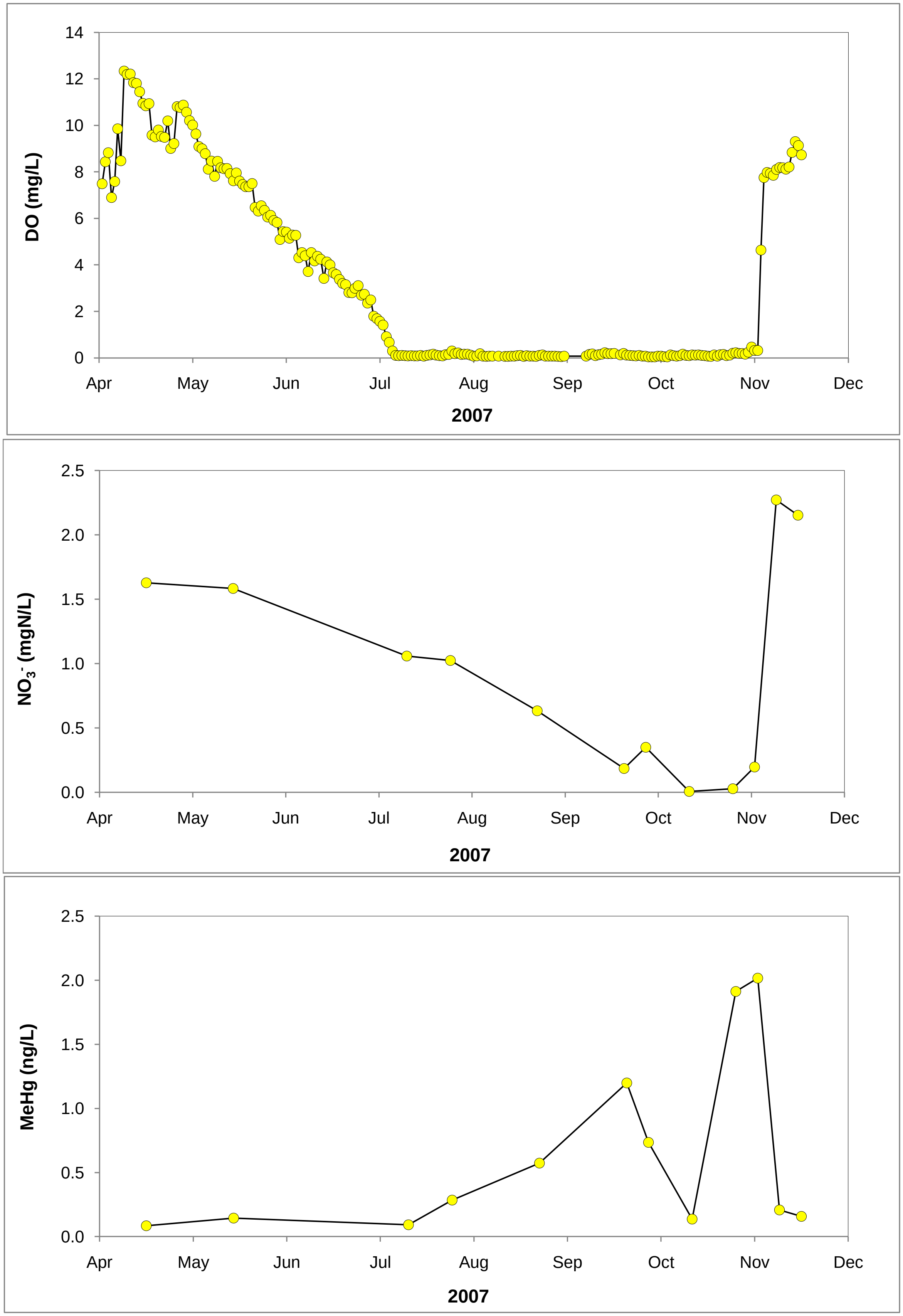
PARSONS

301 PLAINFIELD ROAD, SUITE 350, SYRACUSE, N.Y. 13212, PHONE: 315-451-9560

Preliminary Draft
Settlement Confidential
For Discussion Purposes Only

FILE NAME: P:\HONEYWELL -SYR\445093 SMU 8 NITRATE APPLICATION\10.0 TECHNICAL CATEGORIES\10.9 CAD\FIGURES\445093-SK005.DWG
PLOT DATE: 12/16/2010 11:42 AM PLOTTED BY: RUSSO, JILL

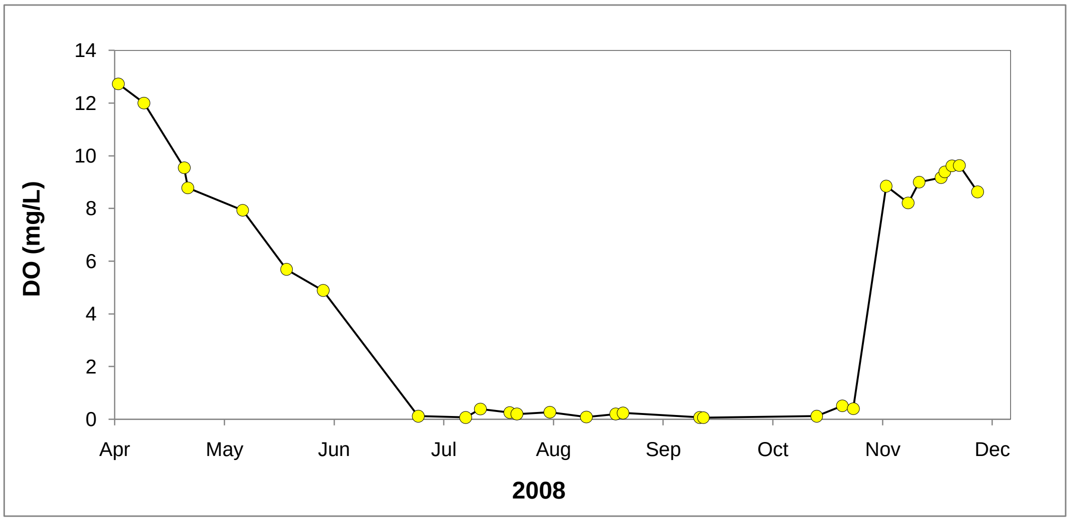
Figure 2 - Dissolved Oxygen, Nitrate, and Methylmercury Concentrations at South Deep at the 18-meter (59-foot) water Depth During 2007

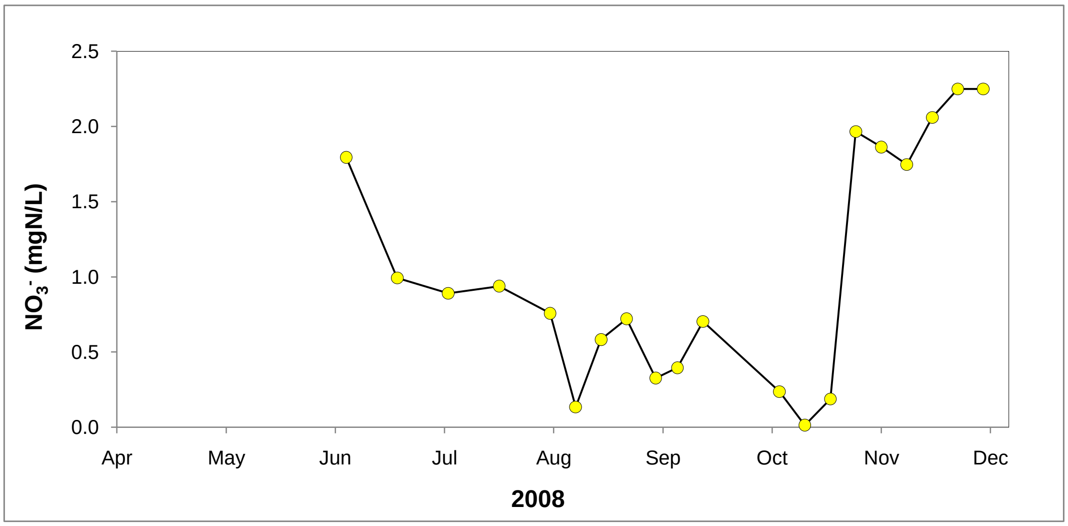


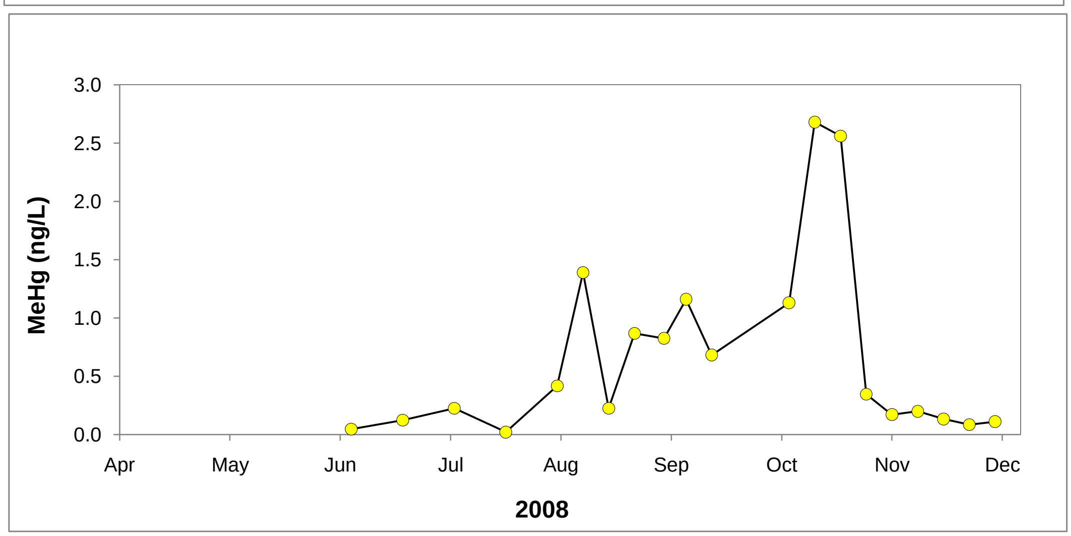
Notes:

1. Non-detects are shown at their detection limit.
2. The tick marks for each month shown on the x-axes correspond to the beginning of that month.

Figure 3 - Dissolved Oxygen, Nitrate, and Methylmercury Concentrations at South Deep at the 18-meter (59-foot) water Depth During 2008



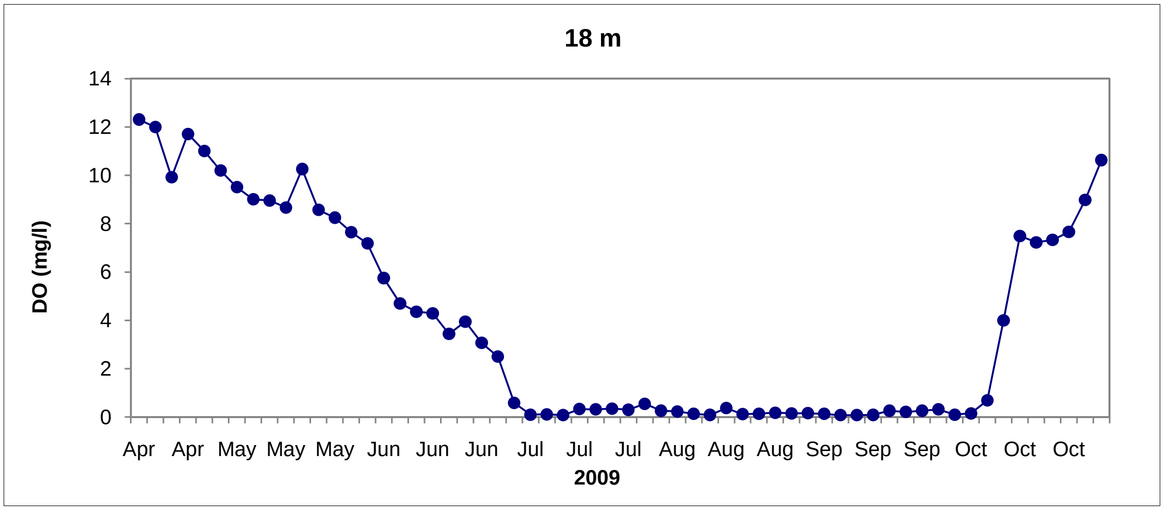


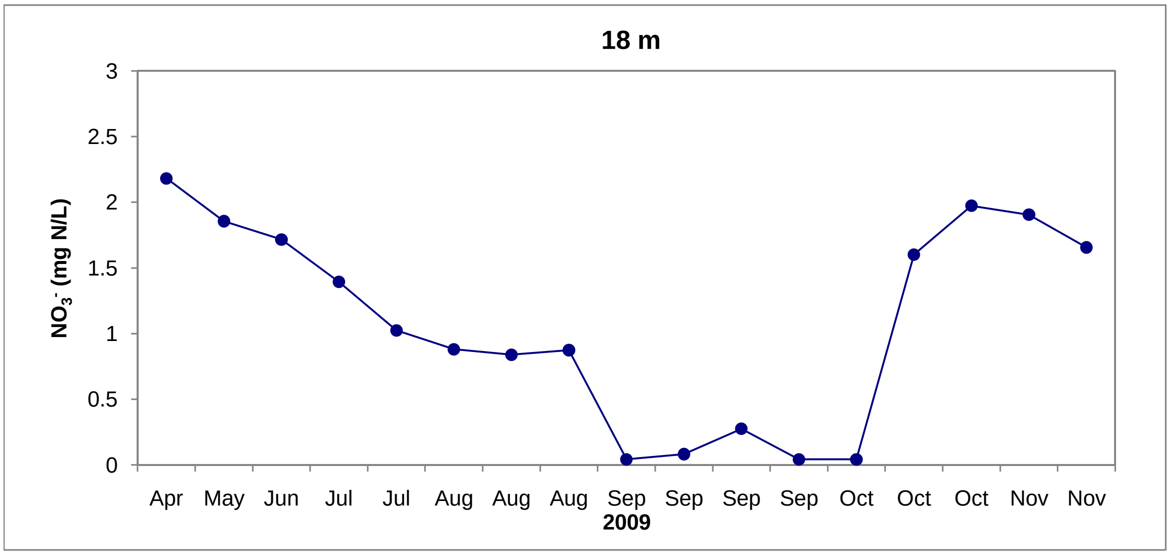


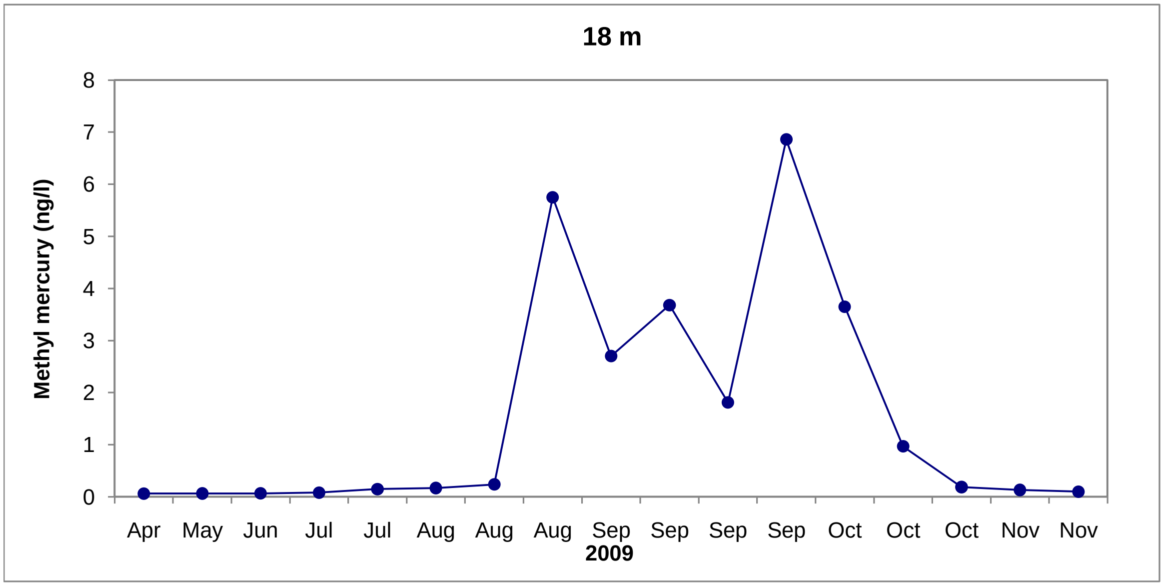
Notes:

1. Non-detects are shown at their detection limit.
2. The tick marks for each month shown on the x-axes correspond to the beginning of that month.
3. Note: On April 28, May 12 and May 27, 2008, nitrate-nitrogen and methylmercury were measured at the 19-meter (63-foot) water depth instead of at the 18-meter (59-foot) water depth. Results from the 19-meter water depth are not included in the figure above. Results for nitrate from the 19-meter water depth for April 28, May 12 and May 27 were 1.94 (J), 1.76 and 1.80 mgN/L, respectively. Results from the same three dates for methylmercury were 0.073, 0.08 and 0.047 (J) ng/L, respectively.

Figure 4 - Dissolved Oxygen, Nitrate, and Methylmercury Concentrations at South Deep at the 18-meter (59-foot) water Depth During 2009



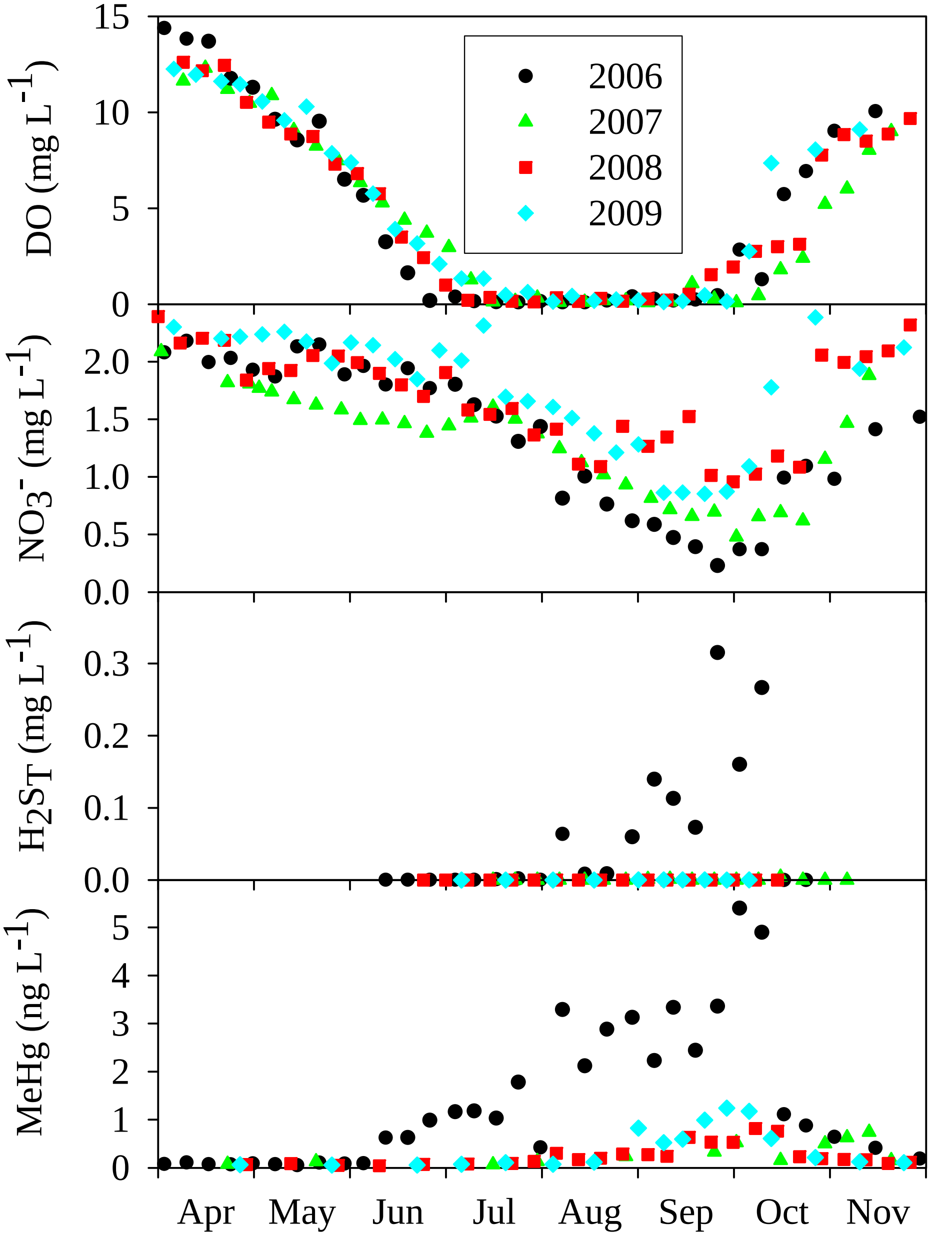




Notes:

1. Non-detects are shown at their detection limit.
2. The tick marks for each month shown on the x-axes correspond to the beginning of that month.

FIGURE 5 Relationship Between Dissolved Oxygen (DO), Nitrate (NO_3-), Sulfide (H_2S_T), and Methylmercury (MeHg) During the Summer Months of 2006 - 2009 Throughout the Hypolimnion of Onondaga Lake on a Volume-Weighted Average Basis



Note: The hypolimnion corresponds to the 10-meter to 19-meter water depth in the profundal zone.

FIGURE 6a Nitrate Availability and Depletion in Onondaga Lake Hypolimnion Waters During the Summers of 2007.

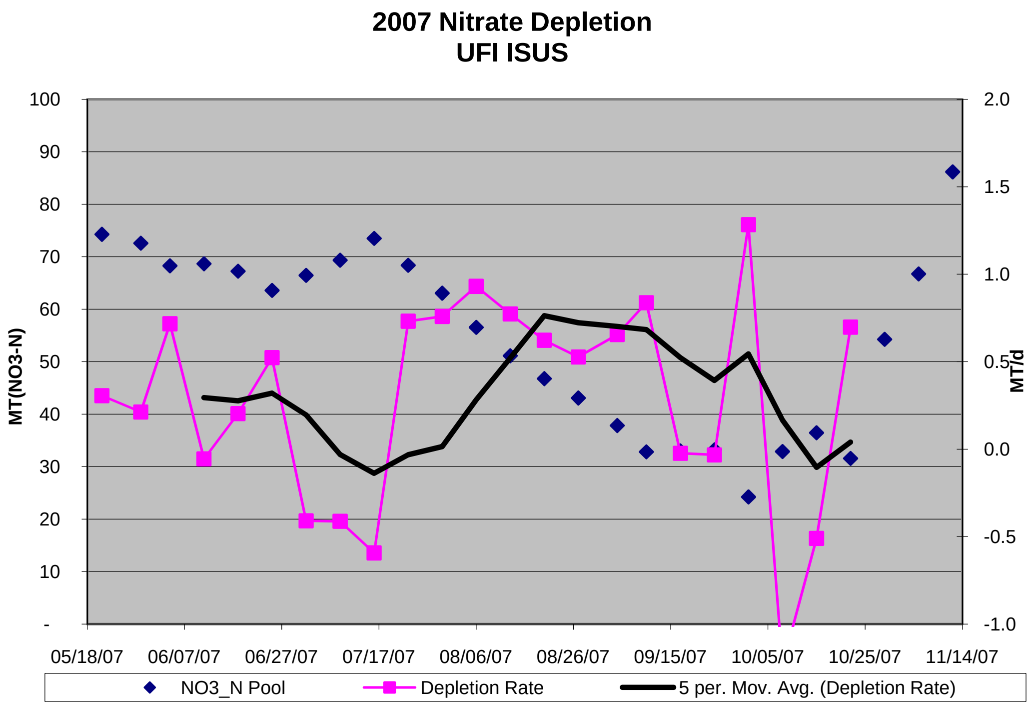


FIGURE 6b Nitrate Availability and Depletion in Onondaga Lake Hypolimnion Waters During the Summers of 2008.

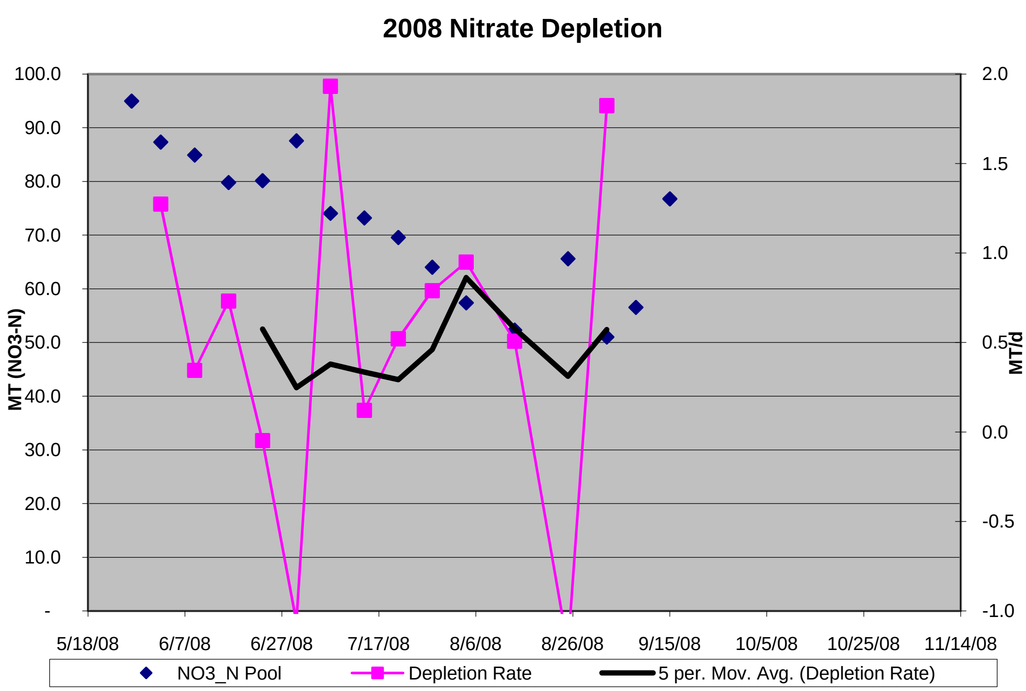
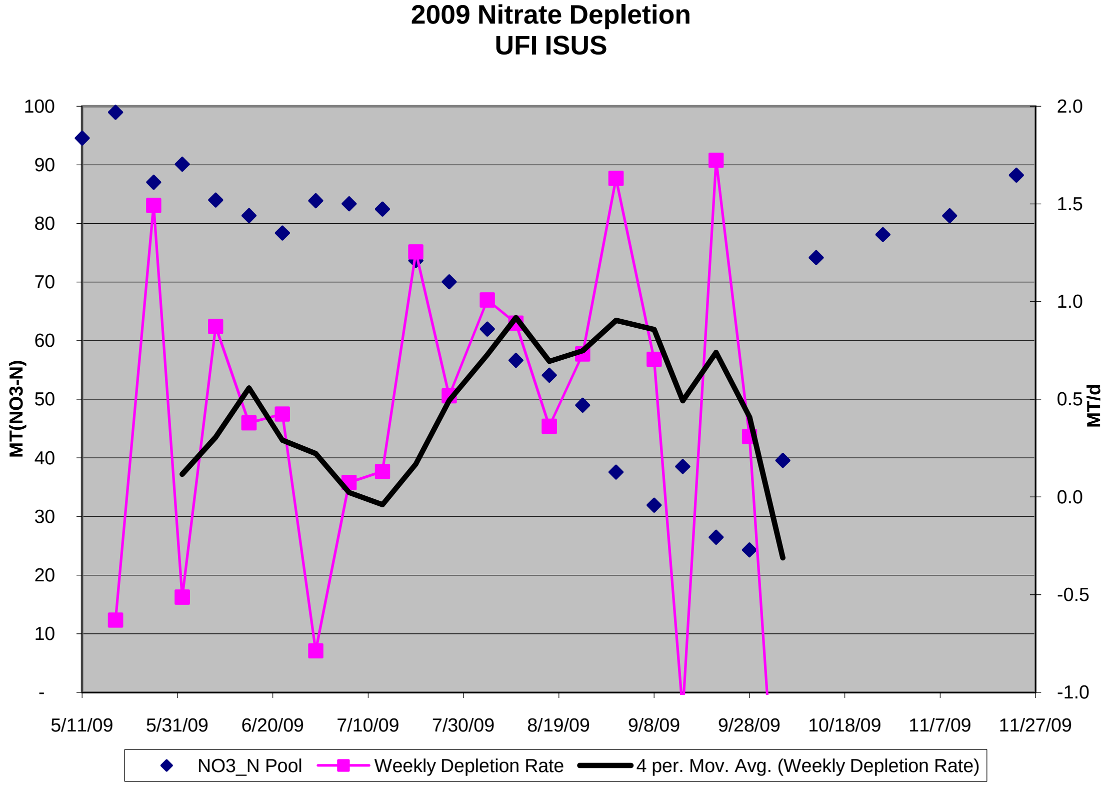
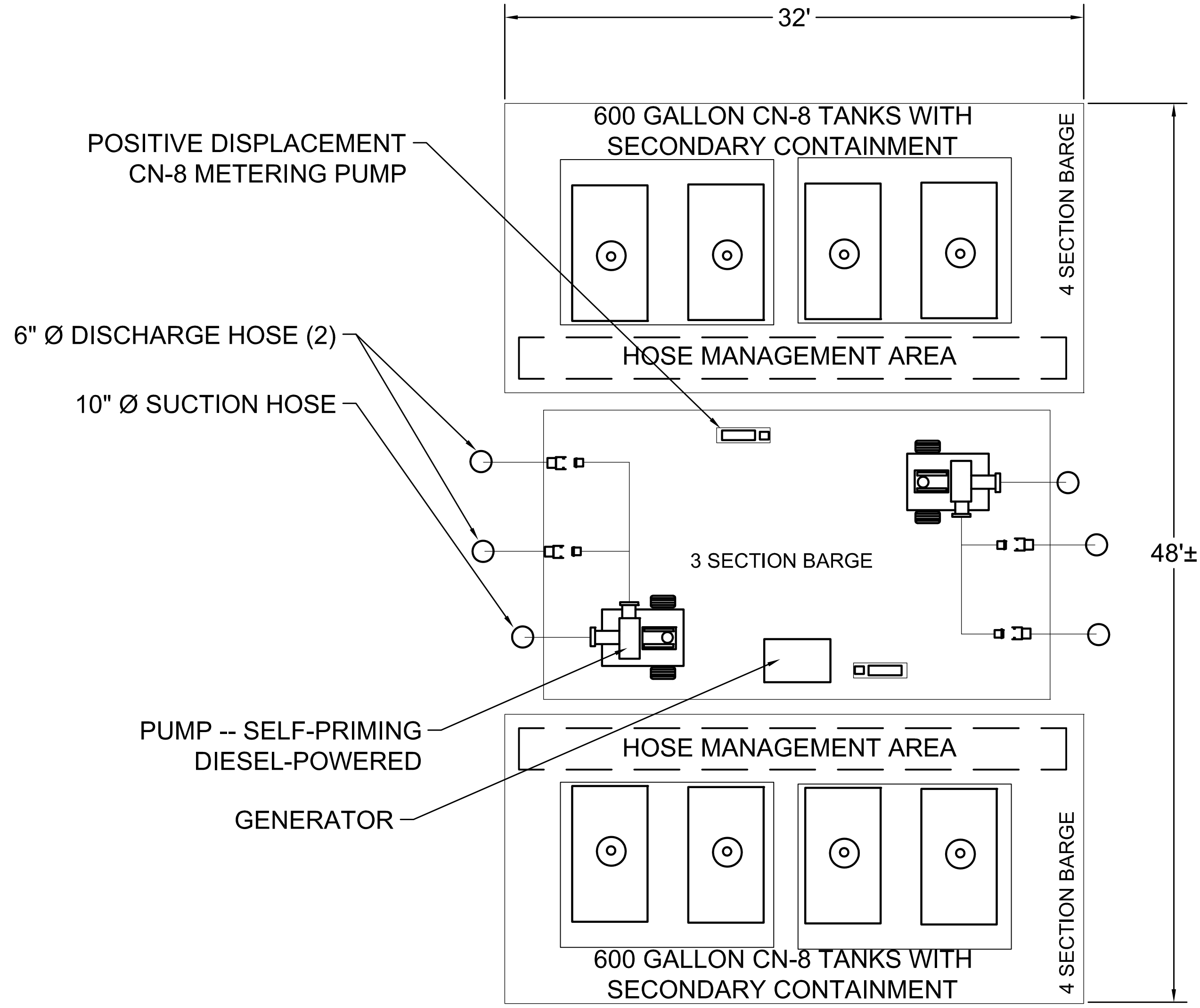


FIGURE 6c Nitrate Availability and Depletion in Onondaga Lake Hypolimnion Waters During the Summers of 2009.





NOTES:

1. SYSTEM SHOWN IS DESIGNED TO INJECT 2.24 METRIC TONS OF NO3-N OVER AN 8 HOUR PERIOD, AT 250:1: DILUTION RATIO.
2. BARGE DIMENSIONS AND WEIGHT CAPACITIES ARE BASED ON EQUIPMENT LOCALLY AVAILABLE.
   A. 4 SECTION BARGE WEIGHT LIMIT: 32,000 LBS NET
   B. 3-SECTION BARGE WEIGHT LIMIT: 24,000 LBS NET

NOT TO SCALE

PRELIMINARY DRAFT

SETTLEMENT CONFIDENTIAL.
NOT INTENDED FOR PUBLIC REVIEW.

FIGURE 7

Honeywell

ONONDAGA LAKE
SYRACUSE, NEW YORK

ONONDAGA LAKE
NITRATE APPLICATION PILOT TEST

PRELIMINARY LAYOUT
BARGE APPLICATION 2011

PARSONS

301 PLAINFIELD ROAD, SUITE 350, SYRACUSE, N.Y. 13212, PHONE: 315-451-9560

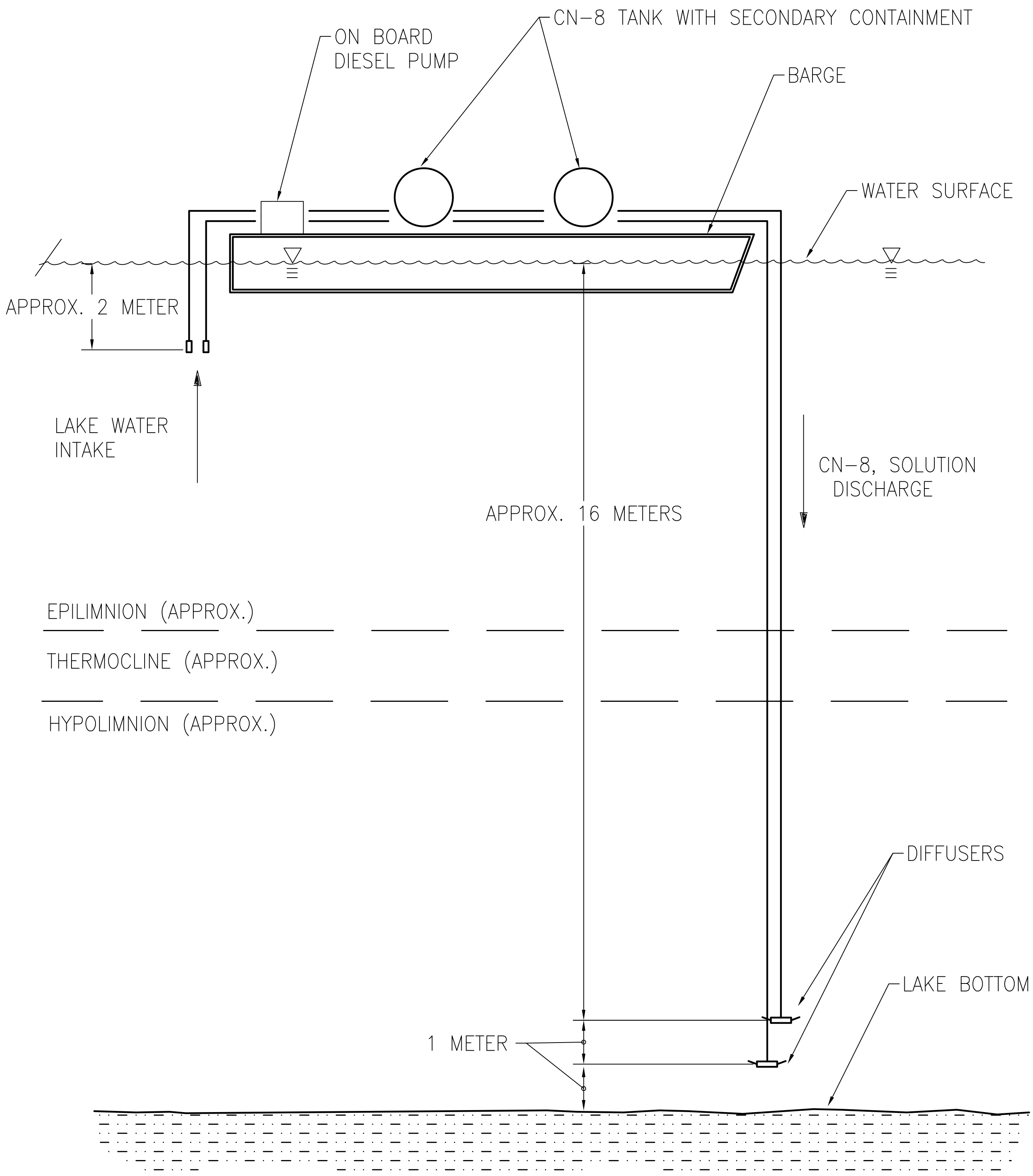


FIGURE 8

Honeywell

ONONDAGA LAKE
SYRACUSE, NEW YORK

ONONDAGA LAKE
NITRATE APPLICATION PILOT TEST

ANTICIPATED CROSS SECTION VIEW
OF APPLICATION

NOT TO SCALE

PRELIMINARY
DRAFT

SETTLEMENT CONFIDENTIAL.
NOT INTENDED FOR PUBLIC REVIEW.

PARSONS

301 PLAINFIELD ROAD, SUITE 350, SYRACUSE, N.Y. 13212, PHONE: 315−451−9560

FILE NAME: P:\HONEYWELL −SYR\445093 SMU 8 NITRATE APPLICATION\10.0 TECHNICAL CATEGORIES\10.9 CAD\FIGURES\445093−SK001.DWG
PLOT DATE: 6/24/2010 2:11 PM PLOTTED BY: RUSSO, JILL

APPENDIX A

MODELED DISPERSION OF DILUTED CALCIUM NITRATE IN THE HYPOLIMNION OF ONONDAGA LAKE

APPENDIX A

MODELED DISPERSION OF DILUTED CALCIUM NITRATE IN THE HYPOLIMNION OF ONONDAGA LAKE

This appendix provides basis for determining the extent of nitrate application needed to cover the entire lower hypolimnion of Onondaga Lake during the nitrate pilot test scheduled to start in June 2011. Results from this determination are being used as a tool for designing the pilot test. An analytical model of dispersion in a finite-thickness layer is presented herein and applied to the lower waters of Onondaga Lake to assess spreading of nitrate throughout the entire lower hypolimnion of the lake. The spreadsheet has been checked to confirm it accurately represents the analytical solution that is the source of the model. The spreadsheet has also been reviewed by NYSDEC.

DESCRIPTION

The overall objective of the nitrate pilot test is to maintain sufficient nitrate-nitrogen concentrations in the bottom waters of the hypolimnion so sulfate reduction does not commence in the surficial sediments. The focus is on the deepest portions of the lake because that is where nitrate depletion first occurs during summertime stratification. Previous work on behalf of Honeywell has demonstrated that methylmercury is released from profundal zone sediment to the overlying surface water once nitrate is depleted and sulfate reduction (and thus mercury methylation) occurs in surficial sediments of SMU 8.

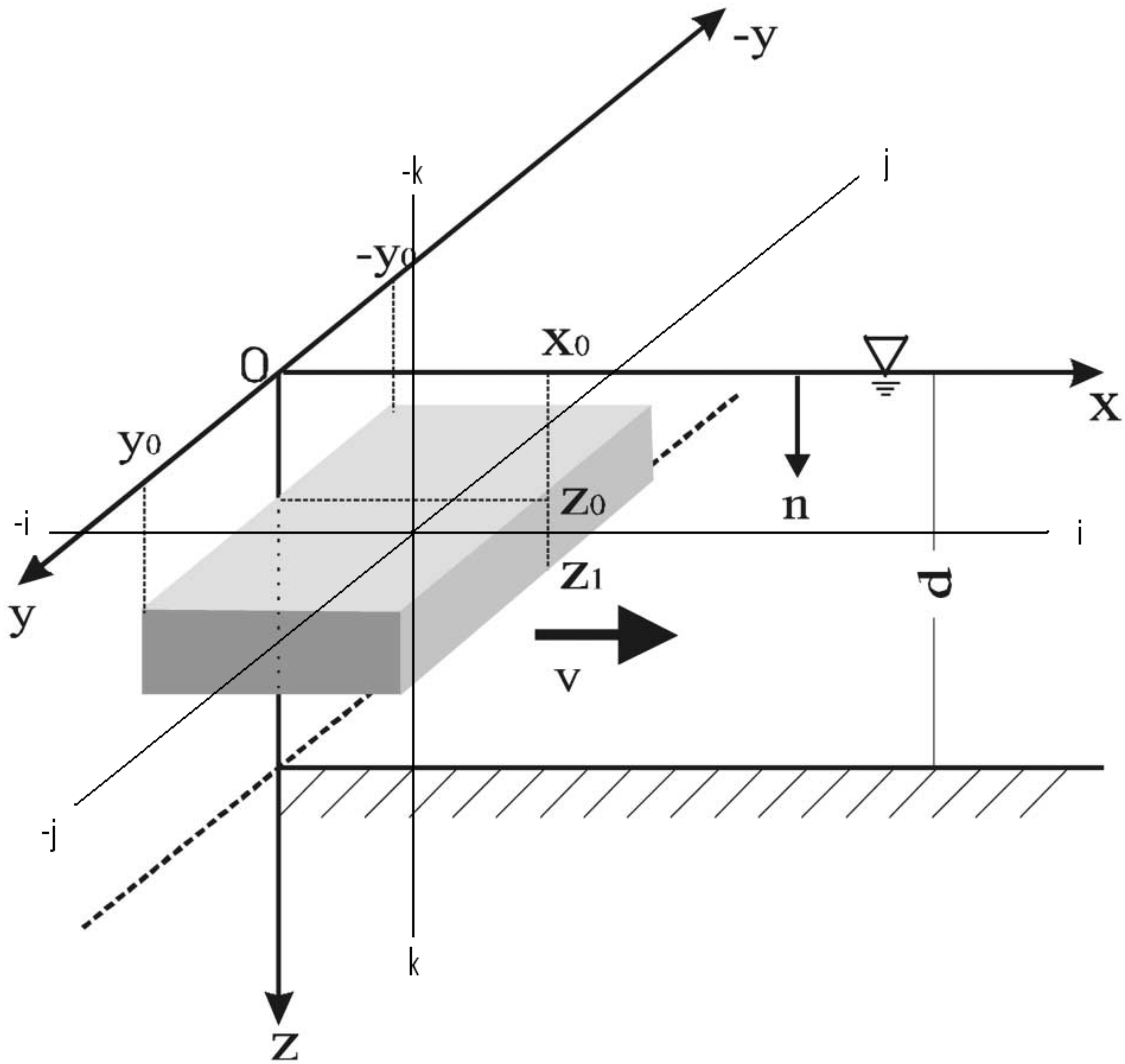
For any type of application, the primary mechanism by which a solution (in this case nitrate) will be distributed throughout the lower hypolimnion is the natural hydrodynamic force generated by wind. Wind moving along the lake water surface generates internal waves within the hypolimnion which cause variable currents and associated dispersion effects. Currents can move soluble compounds such as nitrate a considerable distance, but the currents continue in one direction for only a finite amount of time before turning 180-degrees and inducing transport in the opposite direction. Therefore, the analysis described in this memo focuses on the effects of dispersion only, based on field data generated over the last two years during the 2008 dye tracer study (UFI, 2009) and the 2009 nitrate application field trial (Parsons and UFI, 2010). The 2009 nitrate application field trial demonstrated that it is possible to target a specific water depth in Onondaga Lake for adding liquid calcium nitrate by matching the density of the diluted calcium nitrate solution with the density of the lake water at the depth where nitrate is to be applied.

This work plan for the nitrate pilot test indicates that nitrate addition would start approximately one month before supplementary nitrate mass is needed at the target depths in order to ensure there is adequate time for mixing across the target volume of lake water. Based on a minimum nitrate-nitrogen trigger concentration of 1 mg-N/l at the 59-foot (ft.) (18-meter) water depth (as described in the main text of the work plan), the first application should start by approximately June 21st.

The target lake volume for nitrate addition is the lower hypolimnion or waters below the 46-ft. (14-meter) depth, because waters above this depth have not run out of nitrate since 2006 due primarily to recent Metro wastewater treatment plant upgrades completed by Onondaga County. The average nitrate-nitrogen concentration at the 46-ft. (14-meter) water depth since 2007 has been at or above 1.6 mg-N/l on both June 21st and July 21st one month following the anticipated start of nitrate addition.

This analysis of lateral dispersion of nitrate is based on an analytical model of mass transport from a volume source set within a semi-infinite model domain (i.e., a fixed vertical dimension and an infinite horizontal extent [Park and Zahn, 2001, equation 22]). The model was developed to address groundwater and contaminant transport, but as long as the effective dispersion coefficients are properly scaled for a lake scenario (dispersion coefficients used here were, in fact, derived from lake testing), then the model is applicable to a lake.

The coordinate system employed in the Park and Zahn, 2001 paper (see Figure 1 of same) sets the origin of the coordinate system at the water layer surface and at the back face (in the y-direction) of the volumetric source. In order to facilitate a symmetrical representation of model results in a chart, the spreadsheet allows the user to enter the coordinates of the desired observation point based on its relation to the center of mass of the volume source. These coordinates are identified on the next page as i,j,k as rather than the x,y,z coordinates of the paper. Calculations are based on the x,y,z values of the Park and Zahn coordinate system, and that the transformation option is purely for the convenience of the user and to facilitate illustration of results.



The finite-thickness layer, with infinite extent horizontally, is a reasonable approximation of the situation being addressed which is a specified vertical interval within the lower hypolimnion of Onondaga Lake with the potential for very extensive horizontal transport. Of course, the boundary conditions of the model differ in several aspects from the actual boundary conditions in the lake. Mathematically, the model treats the upper and lower boundaries of the model domain as no-flow, no transport boundaries, using the method of images. This is appropriate for the lower boundary, the sediment-water interface, as long as some accommodation is made for nitrate uptake (which is handled in the model as a first-order decay process).

The upper boundary, the 14-meter water depth contour, in actuality presents no barrier to water or contaminant transport. However, as will be shown below, as long as the model results do not indicate significant vertical transport upward through the lower hypolimnion, there will be no violation of this boundary condition. In fact, since the nitrate concentrations at the 14-meter water depth have historically remained high during early summer, the model results would be valid as long as the predicted concentrations of nitrate at that depth did not exceed historical concentrations. This is because any mixing that would occur at that plane would force more nitrate mass from above than would have been transported there by the modeled vertical dispersion. As for the horizontal boundaries, a conservative assumption is incorporated into the model that nitrate can disperse laterally beyond the physical limits of the 14-meter water depth, or longitudinally beyond the limits of the cell being modeled.

For this application, the model simulates effects of dispersion on the spread of nitrate-nitrogen away from the source of calcium nitrate. Concentrations of nitrate can be quantified for any point in the model domain at any time, based on dispersion and biodegradation. Therefore, the model can be used to evaluate the time needed for dispersion of the injected material to the perimeter of the lake, and provide a perspective on the proposed field plan for application.

MODEL INPUTS

The inputs to the model are model domain dimensions, dispersion coefficients and biodecay rate.

Dimensions of Model Domain. The analytical model requires a simplification of the morphometry of Onondaga Lake. Dimensions of the model domain have been quantified in two ways: first, based on an average depth along a transect intersecting the South Deep station (which represents a deeper part of the Lake); and, second, based on the average depth in the North Basin (representing a shallower portion of the Lake). Therefore, two model runs are presented, and results are assessed to understand implications of the methodology for setting domain dimensions.

As stated above, the objective is to target the hypolimnetic volume below the 14-meter water depth which totals 5,000 million gallons (19 million cubic meters, based on the 2007 bathymetry completed by CR Environmental, 2007. The average lake water depth below the 14-meter contour in the South Basin is approximately 62 ft. (18.9 meters) yielding a vertical dimension of the model of 18.9 minus 14 or 4.9 meters. Given that the width of the lake at the 14-meter water depth is roughly one-fifth that of the length (at the 14-meter water depth contour), the width is calculated to be 2,900 ft. (880 meters) and the total length 4,400 meters. Breaking the lower hypolimnion of Onondaga Lake into three cells in plan view, the length of the model domain within each cell is 4,810 ft. (1,466 meters). Therefore, setting the modeled source in the middle of this volume, the distance to the side shores is 1440 ft. (440 meters), and the distance to the northern and southern extent is 2,400 ft. (730 meters). The model can be adapted to different geometries, such as the North Basin or Saddle Area or descending thermocline, but this analysis is based on a single homogenized, idealization of Onondaga Lake as a basis for determining the extent of nitrate to add for the upcoming pilot test.

The second model run is based on the average depth (below 14 meters) in the North Basin. According to the bathymetry, the volume of water in the North basin (setting the southern boundary near to the saddle) is 5.12 million cubic meters, and the surface area 2.00 million square meters. The average depth therefore is 2.56 meters. The North Basin is not only shallower than the southern portion of the Lake, it is a bit narrower and longer, with a length to width ratio of about 3:1. Given the overall surface area and this ratio, the model domain length is 2,448 meters and the model domain width is 816 meters. A volumetric source placed in the center of this domain is located 408m from the lateral or side shore, and 1,224 meters from the longitudinal shore.

As explained in the work plan, the nitrate pilot test has been designed based on adding 5.6 metric tons of nitrate-nitrogen per week to Onondaga Lake. Based on nitrate being applied as a total of three application events per week, then 1.87 metric tons of nitrate would be applied per event. Assuming the duration of each application event is six hours and a 250:1 dilution rate of epilimnion water with liquid calcium nitrate for density control, the volume of diluted liquid calcium nitrate would occupy 0.96 million gallons (3,620 cubic meters) of lower hypolimnion water and exhibit a nitrate concentration of 516 mg-N/l; this volume represents about 0.06 percent of the water volume in the cell, for a total of about 1 percent over the course of an application season (19 weeks). In the case of the transect model, assuming the vertical dimension of the diluted calcium nitrate is 6.6 ft. (2 meters), and a square footprint, the X and Y plan view dimensions are each 139 ft. (42.5 meters). The nitrate release depth is set at 3.0 ft. (0.91 meter) above the lake bottom between the 2-meter and 4-meter depths of the model domain. For the North Basin, where the hypolimnion is thinner, the assumed vertical dimension of the volumetric source is 4.9 ft. (1.5 meters), and the source is 161 ft. (49.1 meters) on a side. The nitrate release depth is set at 4.1 ft. (1.25 meters) above the lake bottom between the 0.5-meter and 2-meter depths of the model domain.

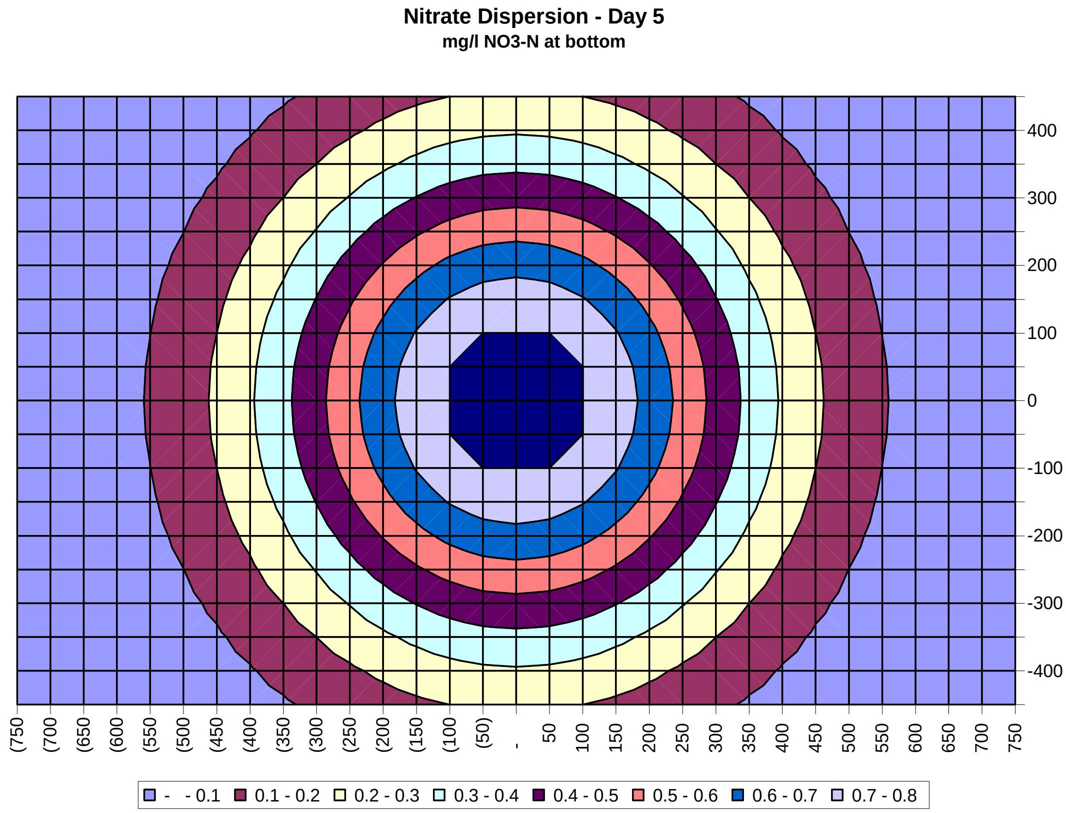
Dispersion Coefficients. Values for dispersion coefficients are based on the data set of radial dispersion coefficients developed from the five 2008 dye tracer tests and the 2009 nitrate application field trial (see attached spreadsheet cell O20). As indicated in the field trial report (Parsons and UFI, 2010), the radial dispersion coefficient may be a more reasonable basis for quantifying horizontal dispersion when the ratio of longitudinal to transverse dispersion coefficients is variable. While the dye tracer tests and field trial provided estimates of horizontal dispersion specifically for Onondaga Lake, vertical dispersion could not be quantified. However, very little vertical spreading was observed during the tests. As noted in the report for the 2009 field trial, the vertical dispersion coefficient is orders of magnitude less than the horizontal dispersion coefficient primarily as a result of the differences in water density with depth that inhibit vertical movement. Therefore, vertical dispersion was estimated by calculating a coefficient which yielded approximately 16 ft. (5 meters) of vertical spreading (as quantified by two standard deviations encompassing 95.4 percent of nitrate mass) over about five days. This is certainly much more vertical spreading than was observed, and yet does not result in a concentration at the top of the model domain which exceeds the 1.6 mg-N/l observed in Onondaga Lake during the early summer of prior years at the 14-meter water depth (a necessary condition if we are to abide by the model's boundary condition at the top of the model domain). The calculated vertical dispersion is one-ten thousandth that of the radial dispersion coefficient.

Biodecay Rate. The model allows incorporation of biological uptake of nitrate in the form of a decay rate. The assumed decay rate was based on Onondaga Lake nitrate depletion data from 2007 through 2009. As an example, for 2009 the total nitrate-nitrogen mass in the hypolimnion decreased from 82 metric tons on July 13, 2009 to 24 metric tons on September 28, 2009 approximately 10 days prior to fall turnover that year (see Figure 6c in Parsons and Upstate Freshwater Institute, 2010b). The half-life for nitrate calculated from the 2009 data is 38.5 days.

RESULTS

South Basin Transect Model

If the entire 1.87 metric tons of nitrate-nitrogen to be added during each of the nitrate pilot test applications were instantly and evenly distributed into the cell water volume below the 14-meter water depth, the concentration at all points would be 0.30mg-N/l. The distance between the center of Onondaga Lake and both the east and west edges of the lower hypolimnion is 440 meters. Using the more conservative geometric mean of the full data set of radial dispersion coefficients measured during 2008 and 2009 in the Onondaga Lake hypolimnion (0.0825 square meters per second), the concentration of nitrate added to the lake water after five days at the outer edges of the lower hypolimnion is calculated using the attached spreadsheet to be 0.23 mg-N/l. Therefore, after five days the concentration at the outer edge of the lower hypolimnion of Onondaga Lake is estimated to be 77 percent of the concentration that would have been reached if distribution of the injected material was instantaneous throughout the lower hypolimnion. The relatively high percentage of 77 percent suggests lateral spreading of the nitrate with a lead time of two weeks should be sufficient to maintain the 1.0 mg-N/L target level of nitrate throughout the lower hypolimnion. The following chart illustrates the concentration contours at the bottom of the cell on day five:



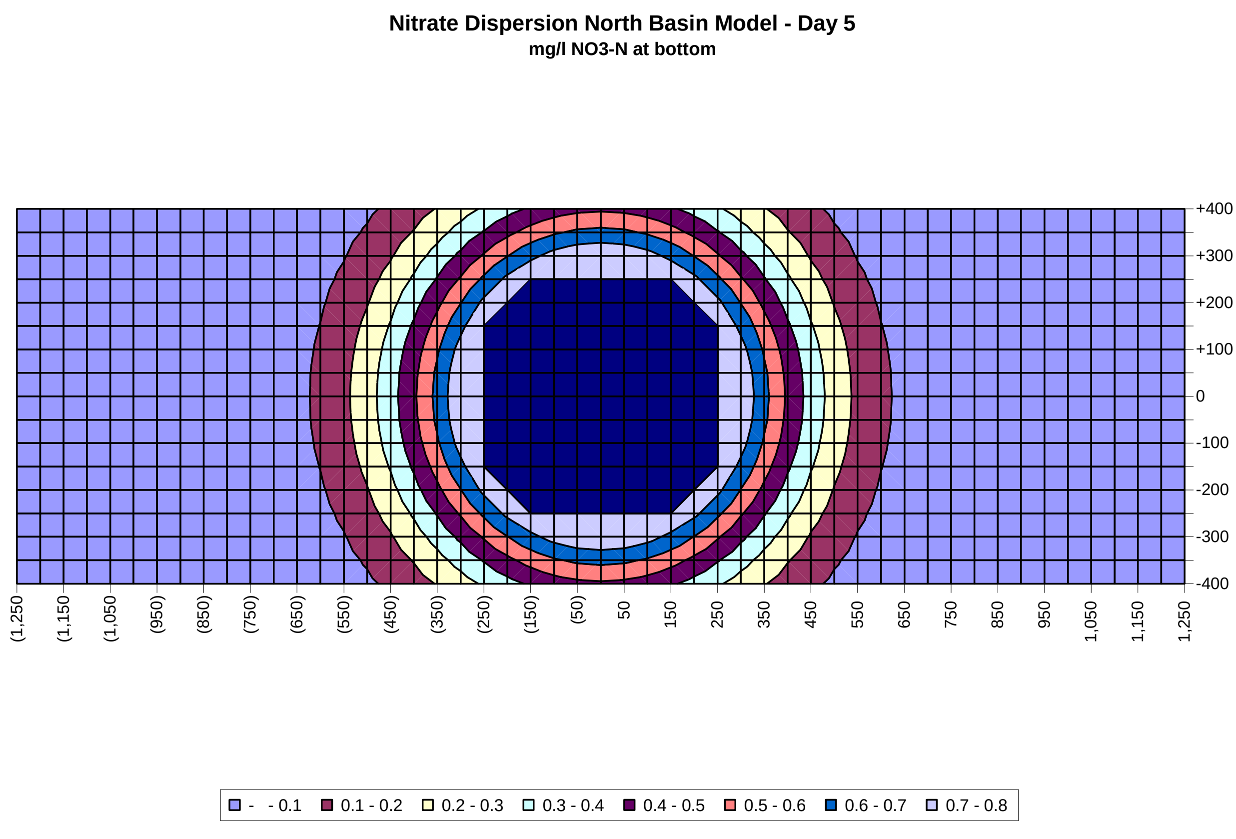
The chart indicates that more spreading is needed in the longitudinal direction. Additional spreading will be accomplished naturally by the currents set up in the hypolimnion (which are substantially along the long axis of the lake due to wind-induced seiches), or can be aided by alternating the application locations from week to week within a particular portion of the lower hypolimnion. Applying nitrate at two different locations within a particular portion of the lake by alternating the location weekly, as warranted, would help to ensure adequate spreading of the added nitrate. During each week of the pilot test, an in-lake survey of nitrate conditions will be conducted which will guide the selection of application locations for the following week.

The sensitivity of the model to the radial dispersion coefficient can be assessed by using the geometric mean of the full dataset minus the data from July 22-24, 2008 which are at the high end of the range reported for the lake and may therefore be outliers. Excluding dispersion results from July 22-24, 2008, the radial dispersion coefficient is reduced to 0.0555 square meters per second. At the end of day five, the model predicts a concentration at the east or west shore (440 meters directly to the side of the source) of 0.187 mg-N/l (64 percent of the equilibrium concentration), compared to 0.229 mg-N/l using the full dispersion data set. By day eight however, the concentration at this location reached 0.219 mg-N/l, or 74 percent of equilibrium.

Given that applications of nitrate will be started approximately one month before the nitrate is expected to be needed, the results indicate adequate time should be available for dispersion to distribute the nitrate appropriately. Adjustments can be made during the upcoming pilot test if the nitrate dispersion anticipated based on results presented here is not observed.

North Basin Model

The chart on the next page illustrates the distribution of nitrate-nitrogen at the bottom of the North Basin on day five, using the full dispersion coefficient dataset. Note that the North Basin model domain is slightly less wide than that of the transect model, significantly longer, and about one-half the thickness.



As a consequence of these changes in the geometry of the modeled hypolimnion, primarily the lower thickness, nitrate is seen to spread farther than was the case with the transect model. The outer reach of the 0.1 mg/l contour reaches approximately 620 meters from the source in the North Basin model, but only 560 meters in the transect model. The inner core, with concentrations above 0.8 mg/l, is also much larger. This intuitively makes sense, in that the thinner North Basin model domain contains less water per square meter, resulting in less dilution and stronger concentration gradients outward towards the boundaries. The concentration at the lateral boundary on day 5 is 0.46 mg/l, which is 127 percent of the concentration that would have been reached if distribution of the injected material was instantaneous throughout the lower hypolimnion of the North Basin (1.87 MT NO3-N into 5.118 cubic meters of water).

The chart also indicates that there is a significant portion of the North Basin domain which is not yet impacted by day five, due to the increased length relative to the transect model. It is true that significant transport longitudinally along the lake has been observed and is expected because of seiches and other internal waves. However, it seems appropriate to plan two distinct injection locations in the North Basin to be used on alternate weeks, as opposed to using the same location week after week. These two locations should be centered around the deepest portion of the North Basin, as it is the deepest sediments which are the first to run out of nitrate and thereby set the stage for sulfate reduction and mercury methylation.

Given the long lead time between the initiation of nitrate addition and the time when nitrate-nitrogen at the 18 meter depth goes below 1 mg/l, this additional modeling suggests that the proposed injection plan is appropriate (three events per week, one for each cell, with the possibility of alternating between two locations for each cell as opposed to using the same location each and every week).