Lovers Lake and Stillwater Pond Nutrient Inactivation Treatment - Final Report

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EXECUTIVE SUMMARY

A nutrient inactivation treatment was conducted on Lovers Lake and Stillwater Pond in Chatham, MA over six field days during October 2010. Based on the information and data collected before, during and after the treatment, the following conclusions can be drawn:

- All pre-mobilization tasks, approvals, and activities were completed in accordance with the approved NOI Conditions.
- The mobilization/demobilization of equipment at the access points were conducted to the satisfaction of the Town and local property owner.
- The alum treatments were successfully and safely implemented in the two ponds without adverse impacts to aquatic biota and ensuring protection of shoreline endangered species.
- The ranges of the field monitored parameters (pH, alkalinity) were maintained within acceptable values during the treatments.
- Visual inspection of bottom sediments in treatment areas indicated good compliance with the proscribed limits of work and consistent application of alum floc in the treatment areas.
- Thermal structure indicated normal overturn occurring in Lovers Lake with full water column mixing in Stillwater Pond expected in early winter.
- Immediate post-implementation water quality results (i.e., within 2 weeks of treatment) indicated reduction in phosphorus fractions.

Overall, the alum treatments went very smoothly and were completed in a highly professional manner by Aquatic Control Technologies with little or no delays caused by access difficulties, equipment malfunctions, tanker truck deliveries or other causes. The initial post-implementation monitoring (November 2010) indicated substantial nutrient reductions and some residual traces of the alum treatment.

Water quality was measured and field observation made at regular seasonal intervals (April, June, August, October) in 2011 to provide for a full year of monitoring after the nutrient inactivation treatment. These samples provided a good measure of pond conditions following the nutrient inactivation and allowed for comparison to pre-implementation water quality data.

Strong evidence that the nutrient inactivation was successful and effective in restoring Lovers Lake and Stillwater Pond comes from several findings, including:

- Reduction in orthophosphorus and total phosphorus concentrations in both ponds when compared to pre-implementation conditions, particularly in the hypolimnion during the critical late summer period (Section 4.2.4).

- SDT values in August which were 2-3 times the clarity found in pre-implementation studies (Section 4.2.5).
- Return of dissolved aluminum concentrations to pre-treatment levels and no indications of any adverse effects to biota either during the alum application or during post-implementation monitoring (Section 4.2.3).
- Improvement in the ponds' trophic status as indicated by the shift from eutrophic to mesotrophic using the TSI assessment and/or approaching attainment of the CCC "healthy" pond total phosphorus criterion value (Section 4.3.2).
- Estimates of pre- and post-implementation "standing stock" of total phosphorus which suggest that most of the phosphorus supplied to the ponds by internal recycling has been eliminated (Section 4.4).
- Casual observations of excellent water clarity and pond conditions from informed viewers (Section 4.4).

Additional water quality monitoring and field observations were conducted in May and August 2012 (see Letter Report from Loon to Dr. Duncanson, dated Dec. 17, 2012 in Appendix G). Trends in water chemistry and physical data were both consistent with monitoring in 2011 and show significantly reduced nutrient availability and increased clarity in both ponds.

The Chatham Conservation Commission issued the final Certificate of Compliance for the project Notice of Intent (DEP #SE-10-2488) on December 13, 2012 (Appendix A).

Based on these findings, it appears that ecological restoration of Lovers Lake and Stillwater Pond has been successfully initiated. Given the chemical and essentially irreversible nature of nutrient inactivation, and the successful and predictable track record of alum treatment in Cape Cod ponds, it is highly likely that these favorable pond conditions will continue to prevail in the coming years.

1.0 Introduction

The Lovers Lake and Stillwater Pond Nutrient Inactivation Treatment Final Report ("Final Report") documents the alum treatment of Lovers Lake and Stillwater Pond conducted in fall 2010. This Final Report includes a summary of physical and water quality monitoring data obtained prior, during and after treatment. Alum treatment was determined to provide the most rapid and effective method to reduce internal phosphorus recycling in both ponds as determined by the year-long diagnostic/feasibility study summarized in the *Lovers Lake and Stillwater Pond Eutrophication Mitigation Plan Report - Final Report* (ENSR, 2008).

Loon Environmental LLC ("Loon Environmental") of Riverside, RI was selected as the Town of Chatham's (the "Town") technical consultant for this project in September 2009. The technical consultant's three principal tasks included (1) preparation of a Lovers Lake-Stillwater Pond Watershed Management Plan (LL-SP WMP), (2) assistance in preparation of the Town's request for proposal for nutrient inactivation, and (3) technical oversight and monitoring of the nutrient inactivation. Loon Environmental staff included a Lake Professional (Dr. David Mitchell) who acted as the Town's agent. The Town issued a Request for Proposal for the nutrient inactivation in April 2010. Aquatic Control Technologies (ACT) of Sutton, MA was the selected contractor responsible for the chemical application.

Application of the alum treatment was conducted by ACT during a two week period in October 2010. Monitoring prior to, during and post treatment was completed by Loon Environmental in accordance with the project work plan and the approved Notice of Intent (NOI) Orders of Conditions. Monitoring results during and post treatment indicated no adverse biological nor chemical effects to the Ponds.

In accordance with the monitoring reporting schedule, Loon Environmental has prepared this Final Report to provide details and documentation of the nutrient inactivation treatment and the post-implementation water quality results.

1.1 Description of ponds

Lovers Lake (15.3 hectares) and Stillwater Pond (7.6 hectares) are two natural and hydrologically connected kettlehole ponds located in Chatham, Massachusetts. The ponds are located in the north central part of Chatham. Flow is generally from Lovers Lake to Stillwater Pond then through a stream which discharges into Ryder's Cove, a marine system (Figure 1).

Figure 1. Lovers Lake and Stillwater Pond Locus Map.

0 250 500 1,000 Feet

January 2010; NAD83 MA State Plane, feet; 1:5,000 Orthophotography from MASSGIS, data collected in April 2005

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Figure 1 - Lovers Lake and Stillwater Pond Locus Map

These state-designated "Great Ponds[1]" are recreational and ecological resources for the Town of Chatham, featuring one of the two remaining alewife runs in the Pleasant Bay watershed (MADEP, 2007). [Note for convenience, both waterbodies will be collectively referred to as the ponds]. In addition, these ponds are located within the limits of the Pleasant Bay Area of Critical Environmental Concern (ACEC) and have species of special concern identified along shoreline areas and within the watersheds (H&W, 2003 and NHESP, 2008). Lovers Lake and Stillwater Pond are classified as Class B waters under the Massachusetts surface water quality standards (314 CMR 4.00). Both ponds are classified as warm water fisheries. Public use of both ponds includes boating with gasoline motors prohibited, swimming and fishing.

Lovers Lake (maximum depth = 11 m (36 ft); average depth = 4.6 m (15 ft)) is generally shaped like an "L" with two deep basins, one located at each end of the "L". Stillwater Pond (maximum depth = 15.5 m (51 ft); average depth = 7.4 m (22 ft)) has a simple central deep basin. Water volume for Lovers Lake is approximately 695,000 m^3 and that for Stillwater pond is just slightly below 500,000 m^3 (ENSR, 2008). Precipitation and groundwater in-seepage are the dominant sources of water for both ponds, with a negligible amount of runoff from the very sandy watershed. Most water leaves Lovers Lake as surface outflow into Stillwater Pond. Water exits Stillwater Pond by a combination of outflow and groundwater out-seepage. Total hydrologic through-flow was estimated, with an average annual detention time of 1.4 to 1.6 years for Lovers Lake and 1.3 years for Stillwater Pond (ENSR, 2008).

Prior to alum treatment the ponds suffered from poor water quality due to eutrophication (i.e., overabundant nutrient levels) and did not fully support the desired water uses including contact recreation and aquatic life support. These ponds have been historically characterized as "highly impacted" and "eutrophic" (CCC, 2003; EcoLogic and H&W, 2003). Residents surrounding the ponds have been concerned with the negative impacts to their visual character and direct and indirect contact recreational use. Symptoms have included low water transparency, frequent and dense algal blooms, loss of oxygen in bottom waters and degraded ecological habitat.

ENSR Corporation conducted a detailed diagnostic/feasibility study of the ponds between 2006 and 2008 which identified internal recycling of sediment phosphorus as the primary source of phosphorus loading to the ponds and the driving force of the observed undesirable conditions (ENSR, 2008). The diagnostic/feasibility reviewed the available pond management options and recommended nutrient inactivation by alum treatment as the most rapid and effective option to reduce internal phosphorus recycling in the ponds (ENSR, 2008).

[1] A "Great Pond" is defined as any pond or lake that contained more than 10 acres in its natural state.

Following review of the diagnostic/feasibility study, nutrient inactivation of bottom sediments by alum treatment was selected by the Town as the recommended management option for the ponds. Project funding for the pond treatment was secured at the May 2009 Annual Town Meeting.

1.2 Determination of target application dosage and bioassay tests

The selected pond treatment was nutrient inactivation achieved through application of an alum sulfate ("alum") and sodium aluminate ("aluminate") mixture to sediments in deeper portions of the ponds. Aluminum is widely used for phosphorus inactivation as it binds phosphorus well under a wide range of conditions, including anoxia. In practice, the alum/aluminate mixture is added to the water and colloidal aggregates of aluminum hydroxide ($Al(OH)_3$) are formed. These aggregates rapidly grow into a visible, brownish white floc, a precipitate that settles to the sediments in a few hours to a few days, carrying sorbed phosphorus and bits of organic and inorganic particulate. As the floc settles through the water column it typically has a very immediate clearing effect on water transparency. After the floc settles to the sediment surface it is incorporated into the sediment matrix where it continues to bind with phosphorus. If enough alum is added, a layer of aluminum hydroxide (1-2 inches) will cover the sediments and significantly retard the release of phosphorus into the water column.

1.2.1 Determination of sediment phosphorus

The amount of alum needed to treat sediment internal load is primarily based on the quantity and nature of phosphorus within the sediments in deeper areas of the ponds. Sediments were collected as part of the Eutrophication Mitigation Study and sediment phosphorus measured at Spectrum Analytical of Agawam, MA using a method which identified the phosphorus fraction most likely to be released or "available phosphorus" (ENSR, 2008). The analytical data clearly indicated that most sediments were highly enriched with phosphorus in a form which would be readily released under anoxic conditions. Available phosphorus fractions for sediments in the Lovers Lake basins ranged from 116 – 1,811 mg/kg dry weight and averaged 1,311 mg/kg dry weight (ENSR 2008). For the Stillwater Pond central basin, the available phosphorus ranged from 1,071 – 1,494 mg/kg dry weight and averaged 1,282 mg/kg dry weight (ENSR, 2008).

Due to the importance of sediment phosphorus measurements for calculation of volumes of alum needed (which is a principal cost factor in such treatments), sediment was again collected from both ponds (four sites in Lovers Lake and two in Stillwater Pond) in September 2009. Samples were sent to Spectrum Analytical for analysis of phosphorus concentrations. The 2009 available phosphorus values for Lovers Lake ranged from 1,104 to 2,543 mg/kg dry weight; while those for Stillwater pond were 1,379 and 1,485 mg/kg dry weight (Appendix E).

The 2009 results were in good agreement with the 2007 sampling results and the pond-specific results were pooled for the final estimates of sediment available phosphorus. The pooled Lovers Lake sediment samples (n=9) averaged 1,521 mg/kg dry weight available phosphorus while Stillwater Pond sediment samples (n=4) averaged 1,357 mg/kg dry weight.

The amount of aluminum necessary to inactivate these elevated levels of phosphorus in the top layers of the sediments was calculated in the diagnostic/feasibility (see Section 7.6.2; ENSR 2008) and more recently for the Town of Chatham Request for Proposal for Lovers Lake/Stillwater Pond Nutrient Inactivation (Alum) Application Treatment in spring 2010. These calculations indicated that the amount of aluminum necessary for inactivation was approximately 100 g Al^{+}/m^{2}, for each pond. As noted in the diagnostic/feasibility further sediment testing was recommended to determine if that dose level was necessary or whether a lesser amount would be sufficient to bind the sediment phosphorus (ENSR, 2008).

This additional testing was conducted in fall 2009 on a representative sediment sample taken from the deep hole of Lovers Lake (LL-02) (available phosphorus = 1,843 mg/kg dry weight). This sediment was used to test the chemical-binding effectiveness of the alum treatment at several alum concentrations to evaluate if a lesser alum dose would be effective. Using an alum:aluminate solution at a 2:1 ratio, the same ratio to be applied in the nutrient inactivation, Spectrum Analytical laboratory conducted a test applying the equivalent to doses of 0 (control), 5, 10, 20, 50 and 100 g Al^{+}/m^{2} to the Lovers Lake sediment and checked for levels of free soluble (i.e., unbound) phosphorus.

Based on the results, significant reduction of available phosphorus was only seen at the highest dose concentration (i.e., 100 g Al^{+}/m^{2}). This suggested that if the total application were confined to a single dose of 50 g Al^{+}/m^{2}, as described in the Order of Conditions (Appendix A), that appreciable sediment phosphorus could still be released under anaerobic conditions. Therefore, two doses of 50 g Al^{+}/m^{2} were proposed to meet a cumulative total dosage of 100 g Al^{+}/m^{2}. The scientific basis and rationale behind this cumulative treatment amount and why it could be safely applied was described fully in a letter to the Chatham Conservation Commission dated May 24, 2010 (Appendix A).

1.2.2 Calculation of aluminum dosage

The amount of alum/aluminate mixture needed to treat the extremely phosphorus-rich sediments of Lovers Lake and Stillwater Pond was estimated by consideration of the total mass of phosphorus in the top 2 – 4 cm of the sediments and application of stoichiometric ratios consistent with desired levels of aluminum binding with phosphorus (ENSR, 2008). Calculations indicated that 15,676 gallons of alum and 7,495 gallons of aluminate stock mixture were required for effective nutrient inactivation in Lovers Lake and 7,838 gallons of alum and 3,748 gallons of aluminate for Stillwater Pond. The ratio of alum to aluminate was approximately 2:1. This ratio was selected since it has been shown to be safe and effective for alum treatments in low alkalinity ponds, based on recent experiences in other Cape Cod ponds (e.g., Ashumet Pond, Mashpee/Falmouth; Long Pond, Brewster/Harwich).

The areas of application were dictated by the typical water depth at which anoxic conditions are routinely observed during seasonal thermal stratification. Based on these considerations, the nutrient inactivation application required treatment of 7.7 hectares of Lovers Lake overlying waters greater than 3.7 m (12 ft) in depth and treatment of 3.8 hectares of Stillwater Pond overlying water greater than 6.1 m (20 ft) in depth. Converting this nutrient inactivation into areal application rates resulted in a dosage of approximately 100 g Al/m^2 for the areas of application. This dose was administered in two separate treatments of approximately 50 g Al/m^2 for each pond.

1.2.3 Bioassay Testing

The addition of aluminum salts to lakes has the potential for serious negative environmental impacts, and care must therefore be exercised with regard to the dosage and buffering capacity. The potential for aluminum toxicity problems is directly related to the alkalinity and pH of the lake water. A major change in pH of lake water may cause dissolved aluminum to be made available during treatment and subsequently cause aluminum toxicity to the biota. The 2:1 ratio of alum:aluminate is generally considered sufficient to prevent any major shifts in pH from occurring. However, as an extra precaution, an aluminum bioassay was conducted to see if the suggested application dosage was of potential concern.

The bioassays were conducted by New England Bioassay, Inc. ("NEB") of Manchester, CT using Lovers Lake water collected on July 19, 2010. Following receipt of the pond water, NEB conducted a set of 48-hour, static tests with juvenile fathead minnows (*Pimephales promelas*) using three target aluminum (Al) concentrations and a control: 5 mg/L, 10 mg/L, 20 mg/L, and 0 mg/L (control). This dosage range allowed assessment of the average mixed volumetric dosage expected in the water columns of Lovers Lake (12.6 mg/L Al) and Stillwater Pond (6.4 mg/L Al) below 3 meters at half the total aluminum dose (50 g Al^+/m^2). Treatment application was set to occur at approximately 3 meters in water depth, therefore the volume of the upper 3 meters of the ponds was discounted when calculating the average mixed volumetric dosage. The alum:aluminate ratio was set at 2:1, mimicking the field application. The alum doses were prepared from stock solutions provided to the laboratory and the fish exposed immediately after mixing. Water quality parameters monitored over the test included: pH, specific conductivity, temperature and dissolved oxygen.

For each dose level, five replicates containers containing 5 fish (25 fish total) were tested. Bioassay endpoints included fish mortality and observations of fish stress (i.e., behavioral cues). Observations were taken at initiation of test and periodically during the testing period.

The bioassay results indicated that survival was 100% in all test levels at 24 hours. The only mortality occurred between the 24 and 48 hour checks. Mortality rates were one fish out of 25 (i.e., 4% mortality) in the 5 mg/L Al replicates, one fish out of 25 (4%) at 10 mg/L Al, and four fish out of 25 (16%) at 20 mg/L Al. It should be noted that the standard measure of toxicity in these tests is when >20% of test organisms die at a particular concentration.

Test observations noted a yellowish floc material in all test concentrations; the amount of floc increased with increasing alum/aluminate doses. The test fish appeared to avoid the floc. In the 20 mg/L concentration, fish were swimming near the water surface, but their swimming behavior appeared normal (i.e., not erratic nor twitching).

These results confirmed that the planned nutrient inactivation did not pose a toxic risk to aquatic organisms in the ponds since there was non-significant toxicity at all levels, particularly those closest to the expected field doses. In should also be noted that this test would be considered highly conservative since the fish were constantly exposed to the floc over the test period. During actual field application, the alum was to be applied sub-surface (approximately 3 meters below surface) and was expected to rapidly settle to the bottom waters reducing the actual exposure of fish in the ponds.

1.3 Coordination with NOI Permit Conditions and NHESP Requirements

As part of the environmental permitting for the selected nutrient inactivation option, an application for a Massachusetts Wetland Protection Act (WPA) Notice of Intent (NOI) was made by the Chatham Department of Health & Environment (CDH&E) to the Chatham Conservation Commission (the "Commission") in late 2008. The Notice of Intent (CWP-08-293; DEP file no. SE 10-2488) was approved in February 2009 along with a detailed Order of Conditions ("Conditions"), listing required activities before, during and after nutrient inactivation applications. The general provisions of the Conditions, included but were not limited to:

- Completing all pre-application consultation and approvals (e.g., acquiring MA license to apply chemicals, harbormaster permit for temporary dock).
- Development of a nutrient inactivation treatment work plan.
- Attendance at a kick-off meeting with the Conservation Agent and Lake Professional.
- Installation of erosion barriers, placement of spill control barriers and clean-up material, and posting all necessary signage at access points.
- Documentation of demobilization procedures and how any clean-up or repairs to access point(s) are to be handled.
- Documentation of Contractor's health and safety procedure for the nutrient inactivation application process.
- Placement of guide buoys and establishing limits of work for in-pond application treatment locations.
- Verification of alum:aluminate dosage calculations and associated documentation of treatment paths (e.g., maintenance of records showing the GIS-based locations of the areas treated, the amount of chemicals applied, etc.).

- Compliance with all field monitoring thresholds (e.g., alkalinity and pH monitoring records, site and weather conditions), subject to review and approval by the Lake Professional.

As part of the pond treatment, the Massachusetts Natural Heritage and Endangered Species Program (NHESP) was contacted with regard to the application of the target dose and approval was acknowledged via email (Regosin, 2010). In addition, information on an endangered species found along the shoreline of the ponds (i.e., strygose knotweed) was provided to ACT to help avoidance and protection of this species if encountered at the access points.

2.0 Pre-Implementation Activities

A number of pre-implementation tasks and activities were identified under the NOI Conditions. These included pre-treatment water quality monitoring, acquisition of necessary permits and approvals, preparation of the access points by ACT, and coordination with the Commission and town agencies. These activities are described below.

2.1 Pre-treatment water column monitoring methods and results

Pre-treatment water column monitoring occurred on September 22nd, 2010, approximately 2 weeks prior to the beginning of alum treatment. Monitoring included the collection of depth profiles taken at one meter intervals for temperature, pH, specific conductivity and dissolved oxygen at both deep basins in Lovers Lake and the one deep basin in Stillwater Pond (Figures 2 and 3). Depth profiles were collected using a Yellow Springs Instruments (YSI) 600 XL multi-parametric probe. Water samples were collected 1 m from the surface and 1 m from the bottom at each deep basin using an Aquatic Research Instrument Horizontal Point Water Sampler. Water samples were placed on ice and transported to Groundwater Analytical in Buzzards Bay, MA for analysis of alkalinity, dissolved aluminum, total phosphorus and orthophosphorus. Secchi disk transparency (SDT) depth was also determined at each site.

Temperature profiles indicated that the thermocline began at approximately 5-6 meters in depth for both ponds (Figure 4). The southern deep basin in Lovers Lake is only 6 meters deep, therefore, this area of the pond appeared to be close to a thermal mixed state (i.e., fall overturn) during the pre-treatment survey. Review of the depth profiles for dissolved oxygen concentrations also indicated that the thermocline began at 5 meters in depth, with oxygen values between 8.5 and 9.1 mg/L at the surface of each monitoring location and dropping rapidly to less than 0.5 mg/L after 4.5 to 5 meters in depth. The pH values for Lovers Lake did not vary greatly with depth; with pH values ranging between 6.6 and 7.1 standard units (S.U.). Stillwater Pond pH values did decline slightly from 7.4 to 6.5 at depth. Specific conductance values for both ponds were between 0.2 and 0.5 mS/cm, showing little variation with depth. The SDT depth was 1.7 meters at the northern deep basin and 2.4 at the southern deep basin in Lovers Lake. The SDT depth was 2.3 meters in Stillwater Pond.

Dissolved aluminum was measured in the ponds to provide background values for comparison with the alum treated water. Analytical results indicated that during the pre-treatment monitoring dissolved aluminum values were low, values ranged from less than the reporting limit to 0.017 mg/L (Table 1, Appendix E).

Orthophosphorus (a form of dissolved phosphorus) values were less than the reporting limit (0.005 mg/L) for all sites except the anoxic bottom of Stillwater Pond where values were reported as 0.27 mg/L orthophosphate (Table 1). Low values of orthophosphorus are not unusual since it is often the most available nutrient for algal uptake. Total phosphorus values ranged from less than the reporting limit to 0.019 mg/L in the surface waters. Total phosphorus values for the deep samples were consistently higher than the surface samples with the highest value reported as 0.39 mg/L in the bottom waters of Stillwater Pond. It would be expected that total phosphorus values would be higher below the thermocline as phosphorus is released from the bottom sediments under low oxygen conditions and becomes trapped below the thermocline. In addition, there is a seasonal input of phosphorus containing particulate matter associated with photosynthetic activity in the surface waters which eventually sinks into the deeper waters below.

Similarly, alkalinity values are also consistently higher in the bottom waters of all monitoring stations, potentially due to decay and breakdown of organic matter as well as potential input of salts from groundwater.

2.2 Pre-mobilization activities

In accordance with the NOI Conditions, ACT completed a number of pre-mobilization activities. These included completing all pre-application consultation and approvals (e.g., acquiring MA license to apply chemicals and harbormaster permit for temporary dock) and developing a nutrient inactivation treatment work plan which included a project work schedule showing the sequence in which the ponds would be treated. The work plan also described demobilization procedures and how any clean-up or repairs to access points would be handled. The work plan was reviewed and approved by the Lake Professional, who also confirmed that necessary approvals and licenses had been obtained.

Prior to initial access point preparation, ACT met with the Conservation Agent to review the location of requested vegetation cutting, limits of work, and placement of spill control barriers and clean-up materials. ACT then prepared the two access points by trimming and cutting vegetation and temporarily removing several obstructions (i.e., a bollard at Lovers Lake and some mailboxes at Stillwater Pond) to allow safe access for the treatment vessel and the alum chemical tanker truck needed for refilling the treatment vessel (Appendix D, photos 1, 3, 4, 15). Finally, ACT posted all necessary signage at the access points (Appendix D, photo 2).

2.3 Kick-off meeting

The kick-off meeting was held at the Town offices on October 7, 2010. The participants were the Conservation Agent, the CDH&E Director, ACT, and the Loon Environmental Lake Professional. The purpose of the meeting was to review the Orders of Condition, review and finalize comments on the draft work plan, discuss the project schedule, visit the access points and otherwise finalize work plans. As part of the meeting, contact information (cell phones, e-mail addresses) were shared and lines of communication discussed in the event of project schedule changes (e.g., need to delay due to weather conditions).

2.4 Confirmation of ACT plan and buoy locations

As part of the procedure for confining the treatments to the designated areas, ACT anchored a series of guide buoys to provide a visual reference of the end of the treatment area. Confirmation of ACT plan and buoy locations was completed daily by comparing the actual depth at buoy locations with the expected bathymetric information using a hand held depth meter. In addition, ACT utilized a Global Positioning System (GPS) system for real-time tracking of applicator vessel location in relation to location on the ponds. This track-line data was recorded and used to demonstrate compliance with the limits of work (Appendix B).

Table 1 - Summary of Pre-Treatment Monitoring

Pre-Treatment Monitoring 9/22/10

Lovers Lake Northern Deep Basin

Parameter	Unit	Surface	Deep
Dissolved Al	mg/L	<0.005*	<0.005*
PO_4-P	mg/L	<0.005*	<0.005*
TP	mg/L	<0.005*	0.057
$CaCO_3$ Alkalinity	mg/L	21	82

Lovers Lake Southern Deep Basin

Parameter	Unit	Surface	Deep
Dissolved Al	mg/L	0.008	0.012
PO_4-P	mg/L	<0.005*	<0.005*
TP	mg/L	0.013	0.059
$CaCO_3$ Alkalinity	mg/L	22	28

Stillwater Pond Deep Basin

Parameter	Unit	Surface	Deep
Dissolved Al	mg/L	0.017	<0.005*
PO_4-P	mg/L	<0.005*	0.27
TP	mg/L	0.019	0.39
$CaCO_3$ Alkalinity	mg/L	17	55

*Reporting limit
TP – Total phosphorus
PO_4-P - Orthophosphorus

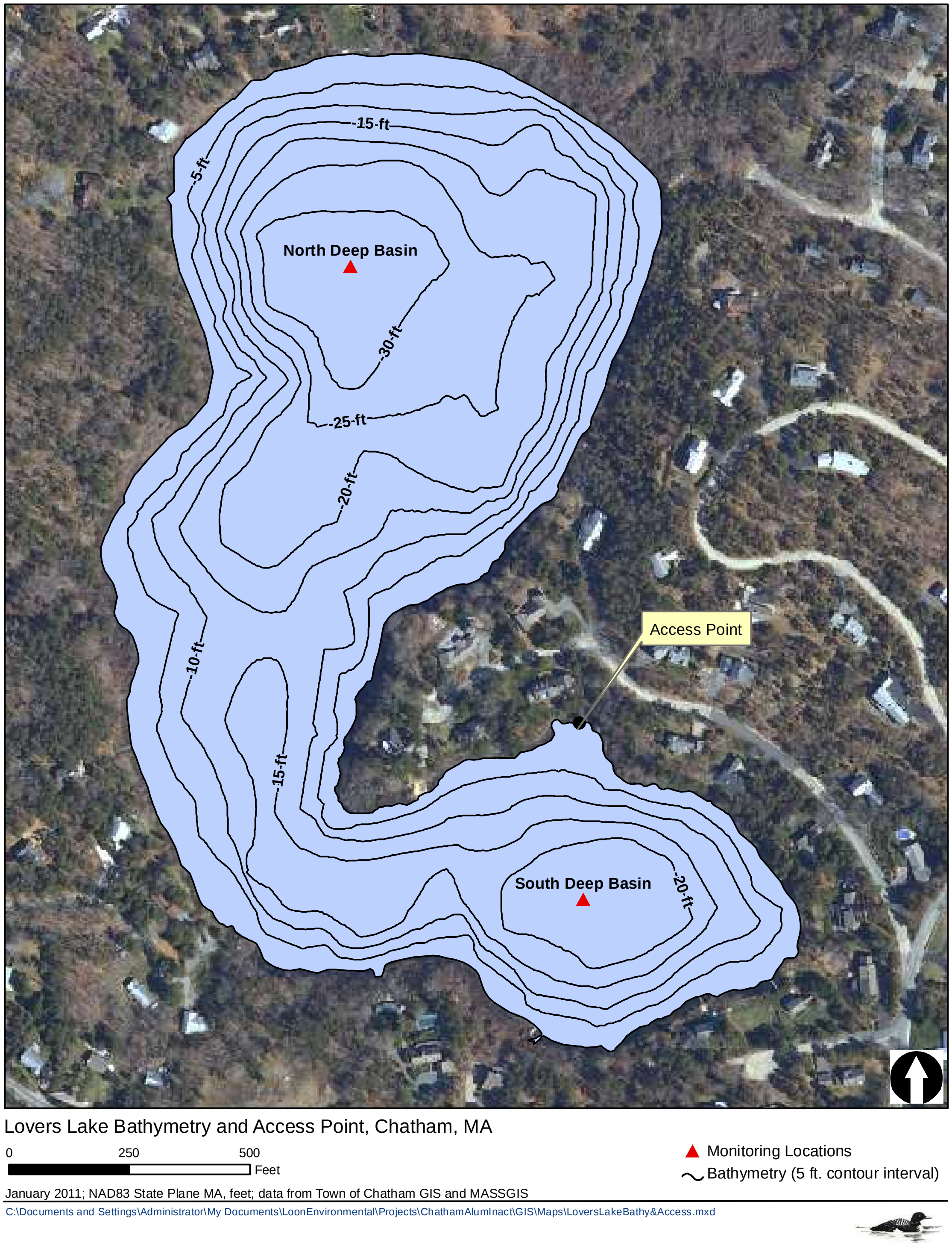

Figure 2 - Lovers Lake Monitoring Locations

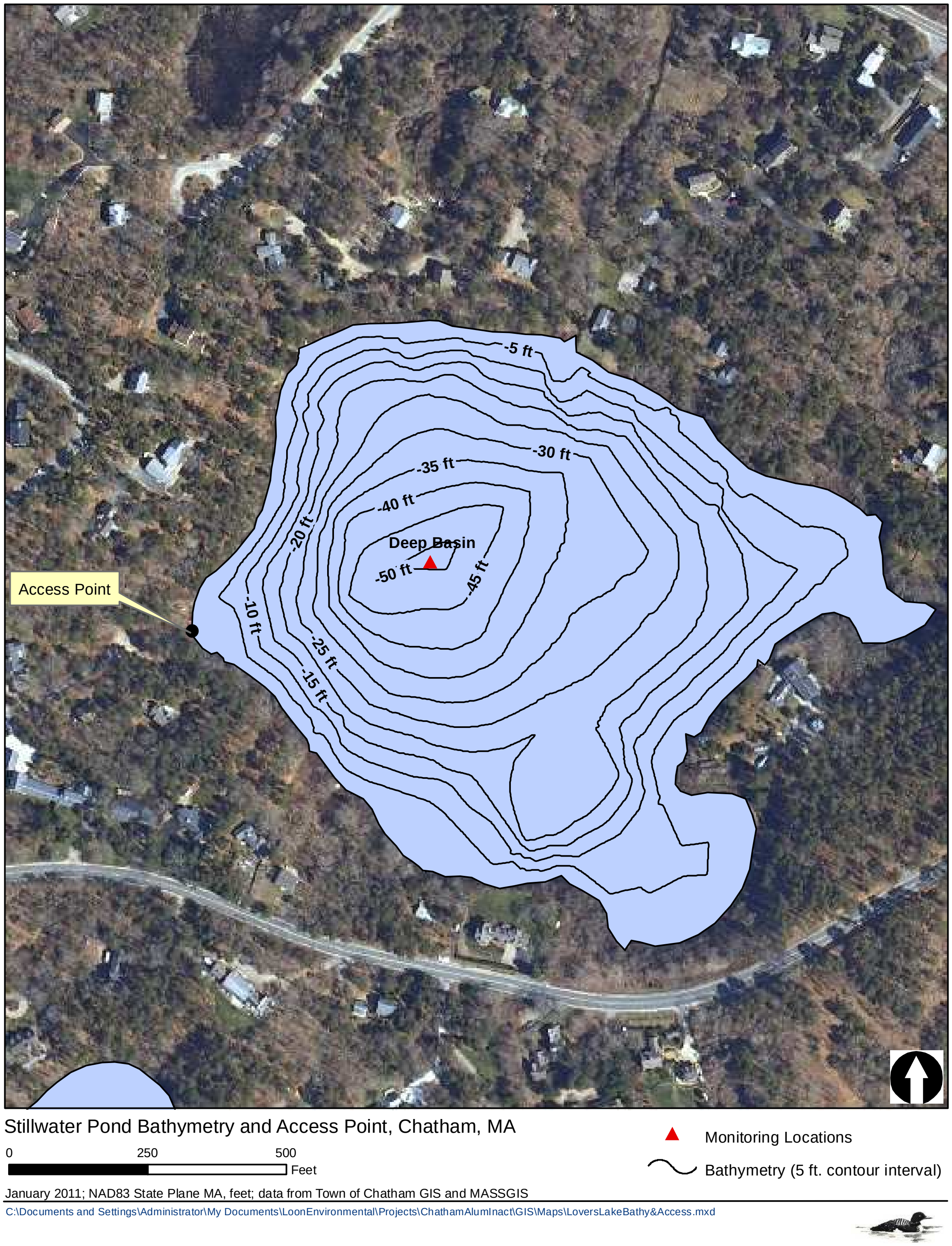

Figure 3 - Stillwater Pond Monitoring Locations

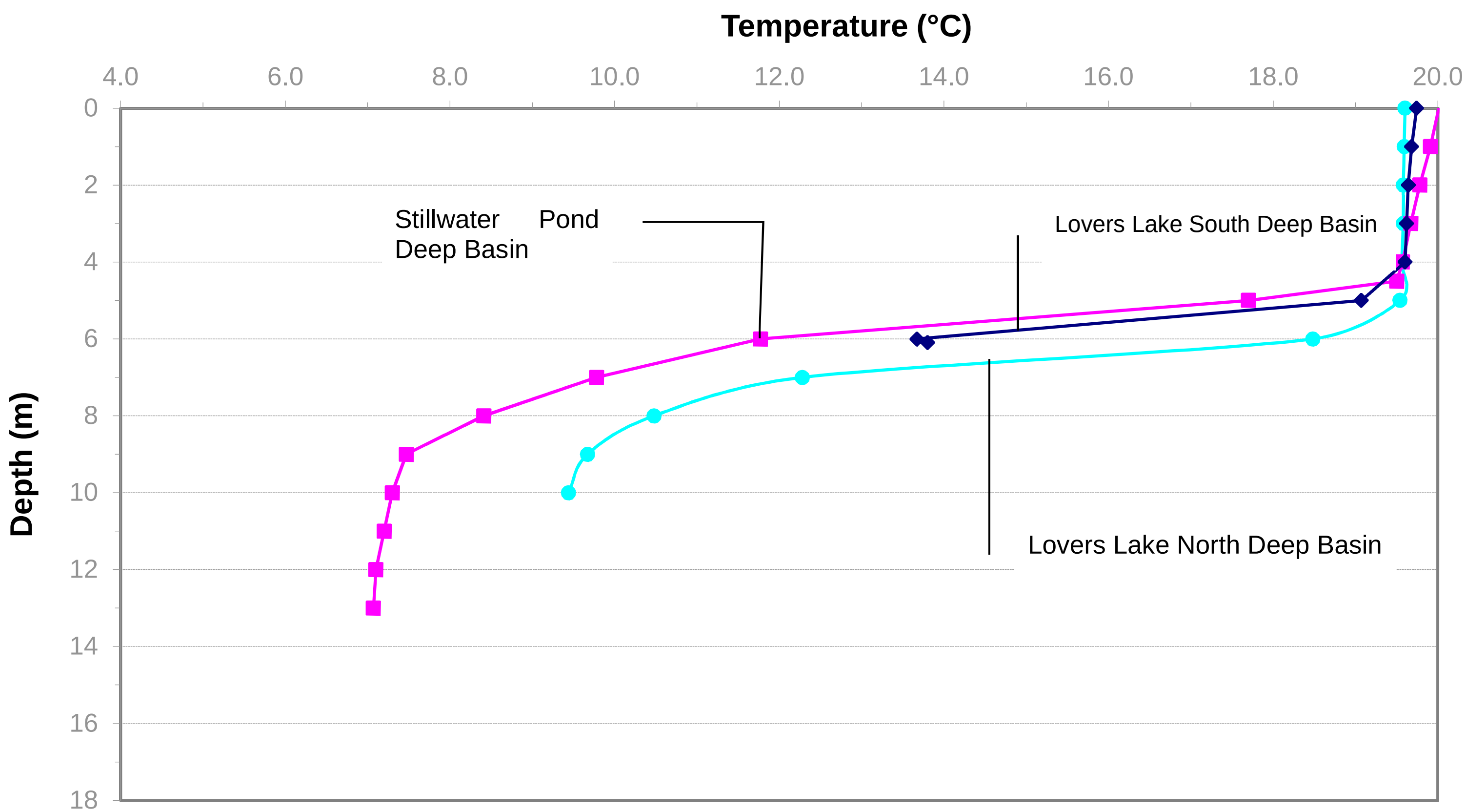

Figure 4 - Pre-treatment Temperature Profile: Lovers Lake and Stillwater Pond

3.0 Implementation Activities

3.1 Overview of pond implementation and treatment chronology

The treatment of Lovers Lake and Stillwater Pond began with the pilot test treatment of 6 acres of Lovers Lake on October 8th, 2010 (Table 2; Appendix D, photos 5-9). After the pilot test treatment a three-day waiting period was imposed, which included the Columbus Day holiday. The pilot test and subsequent observation period both yielded no indicators of adverse effects (e.g., water chemistry shifts, dead fish) confirming that the treatment was being safely applied.

Accordingly, full scale treatment of Lovers Lake then began on October 12th, 2010 (Appendix D, photos 10-12). After treatment of Lovers Lake at half the total dose, a one day waiting period was imposed as an added precaution associated with the large dose of alum/sodium aluminate to be applied. [Note: a two day waiting period was waived by the Lake Professional based on favorable field results and location of application]. The final dose to Lovers Lake began on October 14th, but since an unsatisfactory weather day (i.e., high winds) was expected for October 15th the application of the final dose was delayed until October 18th. ACT then demobilized its operation from Lovers Lake and moved equipment to the access point on Stillwater Pond.

The first application on Stillwater Pond was conducted on October 20th (Appendix D, photos 13-14). After the one day waiting period (a two day waiting period was waived by the Lake Professional based on favorable field results), the final dose for Stillwater Pond was applied on October 22nd (Appendix D, photo 16), with ACT demobilizing shortly thereafter.

Table 2 - Treatment Chronology Summary

Date		**Activity**
October 7, 2010	Thursday	Kickoff meeting with Chatham Cons. Com
October 8, 2010	Friday	Lovers Lake Pilot Test
October 9, 2010	Saturday	Waiting period
October 10, 2010	Sunday	Waiting period
October 11, 2010	Monday	Waiting period (Columbus Day holiday)
October 12, 2010	Tuesday	Lovers Lake Treatment
October 13, 2010	Wednesday	Waiting period
October 14, 2010	Thursday	Lovers Lake Treatment
October 15, 2010	Friday	Weather day
October 16, 2010	Saturday	No work
October 17, 2010	Sunday	No Work
October 18, 2010	Monday	Lovers Lake Treatment completed
October 18, 2010	Tuesday	Mobilize to Stillwater Pond
October 20, 2010	Wednesday	Stillwater Pond Treatment
October 21, 2010	Thursday	Waiting period
October 22, 2010	Friday	Stillwater Pond Treatment

3.2 Monitoring Methods

Monitoring of basic pond chemistry occurred both during the pilot test and full scale treatment of both ponds, consisting of activities occurring prior to, during and after treatment activities each day (Appendix D, photos 17-20). Monitoring thresholds were set and, if triggered, required mandatory review of application activities with applicator. Wind increasing to greater than 20 knots, a sharp drop in alkalinity or pH outside the range of 6 and 8 S.U. were set as monitoring thresholds.

Prior to treatment each day, samples were collected to assess pond chemistry at the same monitoring sites used for pre-treatment and post-treatment monitoring (Figures 2 and 3). In Lovers Lake these initial samples were collected at the northern and southern deep basins and consisted of a temperature profile of the water column (1 meter interval), Secchi depth, and discrete surface and bottom pH and alkalinity samples. During the Lovers Lake treatment it was difficult to designate a reference area as on some monitoring days almost the entire pond surface was treated. On those days when a specific basin (North or South) was not treated, this non-treated area was designated as the reference. Otherwise, monitoring values were generally compared to values collected prior to treatment on the given day or a prior day. In Stillwater Pond, samples were collected in the deep basin as well as a reference station outside the treatment area. The data collected in the deep basin of Stillwater Pond was the same as the deep basins in Lovers Lake. Samples collected in a non-treated (reference) area of Stillwater Pond consisted only of surface and bottom pH and alkalinity samples.

Temperature data were collected every 1 meter to provide temperature profiles using a YSI 95 Probe. Bottom pH and alkalinity samples were collected approximately 1 m off the pond bottom using an Aquatic Research Instrument Horizontal Point Water Sampler. Alkalinity was determined to the nearest tenth of a unit using a HACH Model AL-DT digital titrator kit and pH was determined to the nearest quarter of a unit using a HACH Model 17-N Wide Range Indicator pH kit. Secchi depth was determined using a standard Secchi disk.

During active treatment samples were collected several times a day in both the reference and treatment areas, often directly within an area of settling floc, subsequently floc particulates were observed in some samples (Appendix D, photos 21-22, 24). Surface and bottom samples were collected and analyzed for pH and alkalinity. An underwater camera was used to assess floc drift, and coverage levels. Visual inspections of the pond perimeter were completed regularly to look for distressed or dead organisms and wind speed was measured using a pocket anemometer.

After treatment was completed for the day, samples were collected from the surface and bottom of the reference area and the deep basin(s) in the areas treated. Samples were analyzed for pH and alkalinity. Additionally, a final visual inspection of the pond perimeter was completed.

3.3 Monitoring Results

3.3.1 Lovers Lake

Daily temperature profiles reveal that during the treatment period the water temperature decreased from 17 to 15 °C at the surface of the northern deep basin and 17 to 14 °C at the surface of southern deep basin. The southern basin temperature profiles revealed that by the end of the treatment the basin was completely unstratified, while the northern deep basin thermocline had eroded to approximately 8 meters, from 5 meters as observed during the pre-treatment monitoring.

SDT depth ranged from 0.95 to 2.15 meters in the southern deep basin and 0.95 to 2.05 meters in the northern deep basin during the monitoring period. SDT depth was affected by a major algae bloom which occurred during the treatment as well as wind driven surface wave action present on several monitoring days (Appendix D, photo 23). During the pre-treatment monitoring SDT was 1.70 and 2.35 meters in the northern and southern deep basins, respectively.

Alkalinity in Lovers Lake ranged from 17.0 to 20.0 mg/L (as $CaCO_3$) at the surface and 16.9 to 82.6 mg/L (as $CaCO_3$) for deep or non-surface samples during treatment. Deep or non-surface samples were collected at various depths, ranging from mid-water column to 1 m above the bottom. Pre-treatment alkalinity values were reported as 21 and 22 mg/L (as $CaCO_3$) at the surface and 28 and 82 mg/L (as CaCO3) for the deep stations. During treatment, the range of pH was 6.50 to 7.25 S.U. for all samples; pre-treatment values ranged from 6.6 to 7.1 S.U. The deepest samples taken from the northern deep basin had the highest alkalinity.

Floc inspections via underwater camera were completed each monitoring day to assess potential floc drift and bottom coverage. Floc coverage was generally described as heavy throughout the treatment area. Coverage extended out to the shallower areas of the pond due to drift during treatment as well as the small size of the ponds and proximity of the treatment areas to the shoreline in some points.

Visual inspections for distressed organisms along the shoreline were generally competed in the morning and afternoons during the treatment period. Only one dead fish was observed in Lovers Lake during the field monitoring and based on its decayed condition it was believed to be dead prior to treatment.

3.3.2 Stillwater Pond

Daily temperature profiles reveal that during the three day treatment period the water temperature profiles did not noticeably change. The thermocline remained at approximately 7 meters during the treatment (an increase in approximately 2 meters deeper than the pre-treatment monitoring). SDT depth ranged from 1.95 to 3.35 meters during the monitoring period, as compared to 2.30 meters during the pre-treatment monitoring.

Alkalinity in Stillwater pond ranged from 16.2 to 18.1 mg/L (as $CaCO_3$) for surface samples and 48.0 to 60.0 mg/L (as $CaCO_3$) for non-surface and deep samples. As with Lovers Lake, non-surface samples were taken at various depths, with the highest alkalinities associated with the deepest waters. pH ranged from 6.75 to 7.00 S.U. at the surface and 6.25 to 6.50 S.U. in the non-surface samples. Often floc was visible in samples collected. Pre-treatment monitoring revealed a pH of 7.4 S.U. at the surface and 6.5 S.U. at the bottom of the deep basin. Alkalinity was 17 mg/L (as $CaCO_3$) at the surface and 55 mg/L (as $CaCO_3$) at the deep basin during the pre-treatment monitoring.

Floc inspections via underwater camera were completed each monitoring day to assess potential floc drift and bottom coverage. As with Lovers Lake, floc coverage in Stillwater Pond was generally described as heavy throughout the treatment area with coverage extended in some areas out to the shallower areas of the pond.

Visual inspections for distressed organisms along the shoreline were generally competed in the morning and afternoons during the treatment period. No dead or distressed organisms were observed in Stillwater Pond. During the treatment, a chance discussion with the Chatham Herring Warden (Mr. Donald St. Pierre) indicated that he had observed herring passing downstream at the Stillwater Pond fish weir during the treatment.

3.4 Demobilization activities and CCC Certificate of Compliance

All demobilization activities were successfully completed by ACT following pond treatment to the satisfaction of the Conservation Agent and the property owners of the access point at Lovers Lake. The Chatham Conservation Commission issued the final Certificate of Compliance for the project Notice of Intent (DEP #SE-10-2488) on December 13, 2012 (Appendix A).

4.0 Post-Implementation Activities

Water quality was tested after the completion of the nutrient inactivation treatment in fall 2010 and monitored at regular seasonal intervals for a full year after treatment, the final samples were collected in October of 2011. Water quality sampling of surface and bottom waters was conducted at the northern and southern deep basins of Lovers Lake and the one deep basin of Stillwater Pond. All field measurements and water sample collection was completed using the same methods and procedures as the pre-treatment water column monitoring survey described in Section 2.1. Water samples for the April, June and August 2011 samples were placed on ice and transported to Groundwater Analytical laboratory in Buzzards Bay, MA for analysis of alkalinity, dissolved aluminum, total phosphorus and orthophosphorus. The October 2011 samples were placed on ice and transported by laboratory courier to Alpha Analytical of Westborough, Massachusetts due to the closure Groundwater Analytical.

4.1 Initial post-implementation water quality results

The initial water quality monitoring after the treatment of the ponds (i.e., post-implementation) was completed on November 2, 2010. Temperature profiles indicated that both the northern and southern basins in Lovers Lake were completely mixed, with the water column isothermal (i.e., of equal temperatures throughout) at approximately 12 °C (Figures 5 and 6). Specific conductivity was also very uniform at 0.2 mS/cm throughout the water column. Dissolved oxygen concentrations ranged from 9.7 to 10.1 mg/L throughout the entire water column and pH ranged from 7.1 to 7.2 S.U. in the northern deep basin and 6.7 to 7.0 S.U. in the southern deep basin. Pre-treatment pH values in Lovers Lake ranged from 6.6 to 7.1 S.U., approximately the same range observed in the November post-implementation data.

Stillwater Pond temperature profiles indicated that the pond had not "turned over" at the time of the post-implementation November sampling. The summer thermocline had eroded to approximately 9 m (Figure 7), an increase in depth from the 5-6 m thermocline observed during the pre-treatment monitoring. Stillwater Pond pH values ranged from 7.2 S.U. at the surface to 6.4 S.U. at depth, very comparable to the pre-treatment range of 7.4 to 6.4 S.U. Specific conductance was observed at 0.2 mS/cm throughout the water column. Dissolved oxygen concentrations decreased from 9.1 mg/L at the surface to less than 1 mg/L at depth, similar to the trend observed during pre-treatment monitoring and further indicating that Stillwater Pond had not yet destratified.

Review of the orthophosphorus data for the post-treatment monitoring indicates that values were uniformly below detection at 0.010 mg/L, except for the deep sample in Stillwater pond (Table 3, Appendix E). The residual influence of the alum treatment is indicated by the decrease in total phosphorus levels in both ponds. Some of the observed decrease in total phosphorus levels in Lovers Lake may be related to the diluting effect of the mixing of surface and bottom waters as the pond destratified and the binding of phosphorus with iron and subsequent precipitation out of the water column which may occur under oxygenated conditions. Total phosphorus in Stillwater Pond exhibited a decline in total phosphorus values in the surface and deep water samples, as well as a decrease in the orthophosphorus values in the deep basin. This would primarily be due to the alum treatment, rather than dilution/oxygenation, as the pond was still stratified.

Post-implementation dissolved aluminum samples exhibited concentrations higher than pre-treatment samples, but were well below the USEPA freshwater acute water quality criterion of 0.75 mg/L. The slightly elevated values in the upper waters of Stillwater Pond suggest that some of the floc was temporarily retained above the thermocline of the pond, the suspended floc would be expected to rapidly settle to the bottom sediments and not impact pond biota. Alkalinities declined noticeably in the bottom waters of Lovers Lake, likely due to the mixing of the water column and redistribution of materials upon destratification.

Table 3 - Pre-Treatment Monitoring and Initial Post-Implementation Water Quality Monitoring

		9/22/2010 Pre-Treatment		11/2/2010 Initial post-implementation monitoring	
Lovers Lake Northern deep basin					
Parameter	Unit	Surface	Deep	Surface	Deep
Dissolved Al	mg/L	<0.005*	<0.005*	0.087	0.096
PO_4-P	mg/L	<0.005*	<0.005*	<0.005*	<0.005*
TP	mg/L	<0.005*	0.057	0.009	0.012
$CaCO_3$ Alkalinity	mg/L	21	82	17	17
Lovers Lake Southern Deep Basin					
Parameter	Unit	Surface	Deep	Surface	Deep
Dissolved Al	mg/L	0.008	0.012	0.056	0.053
PO_4-P	mg/L	<0.005*	<0.005*	<0.005*	<0.005*
TP	mg/L	0.013	0.059	0.014	0.009
$CaCO_3$ Alkalinity	mg/L	22	28	20	20
Stillwater Pond Deep Basin					
Parameter	Unit	Surface	Deep	Surface	Deep
Dissolved Al	mg/L	0.017	<0.005*	0.071	0.059
PO_4-P	mg/L	<0.005*	0.27	<0.005*	0.12
TP	mg/L	0.019	0.39	0.009	0.25
$CaCO_3$ Alkalinity	mg/L	17	55	15	45

*Reporting limit
TP – Total phosphorus
PO_4-P - Orthophosphorus

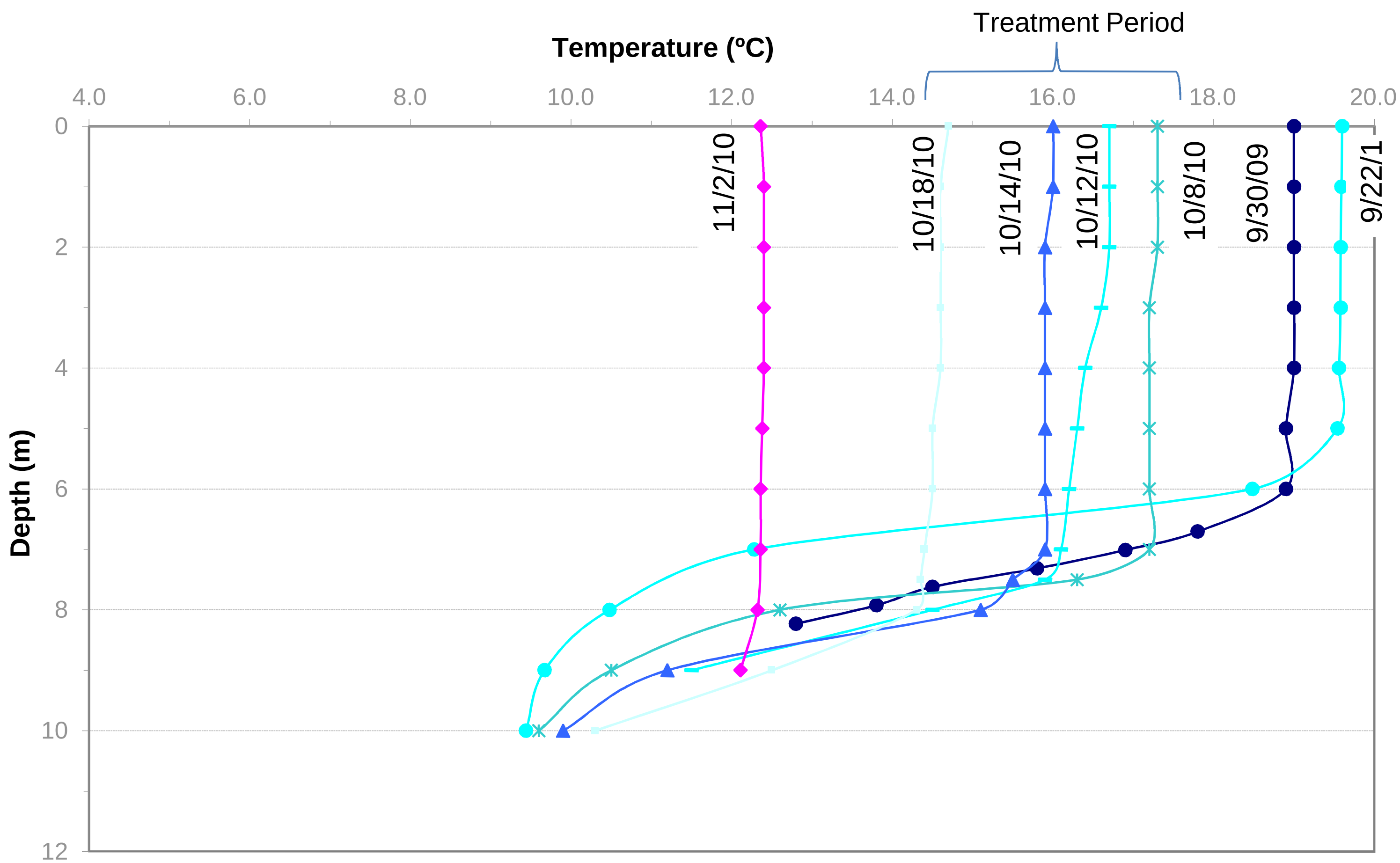

Figure 5 - Temperature Profile: Initial Post-Implementation Monitoring (2010), Lovers Lake Northern Deep Basin

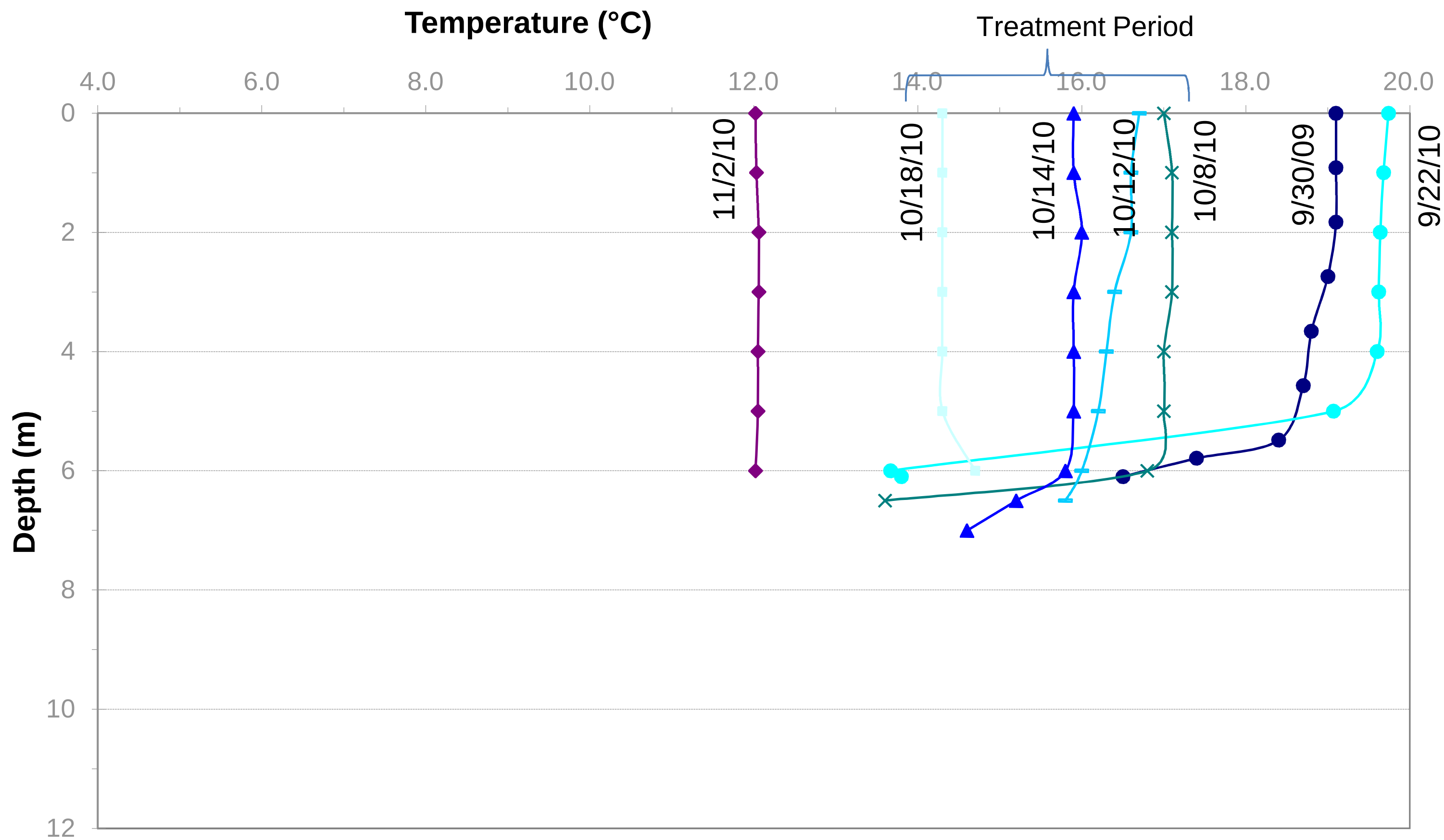

Figure 6 - Temperature Profile: Initial Post-Implementation Monitoring (2010), Lovers Lake Southern Deep Basin

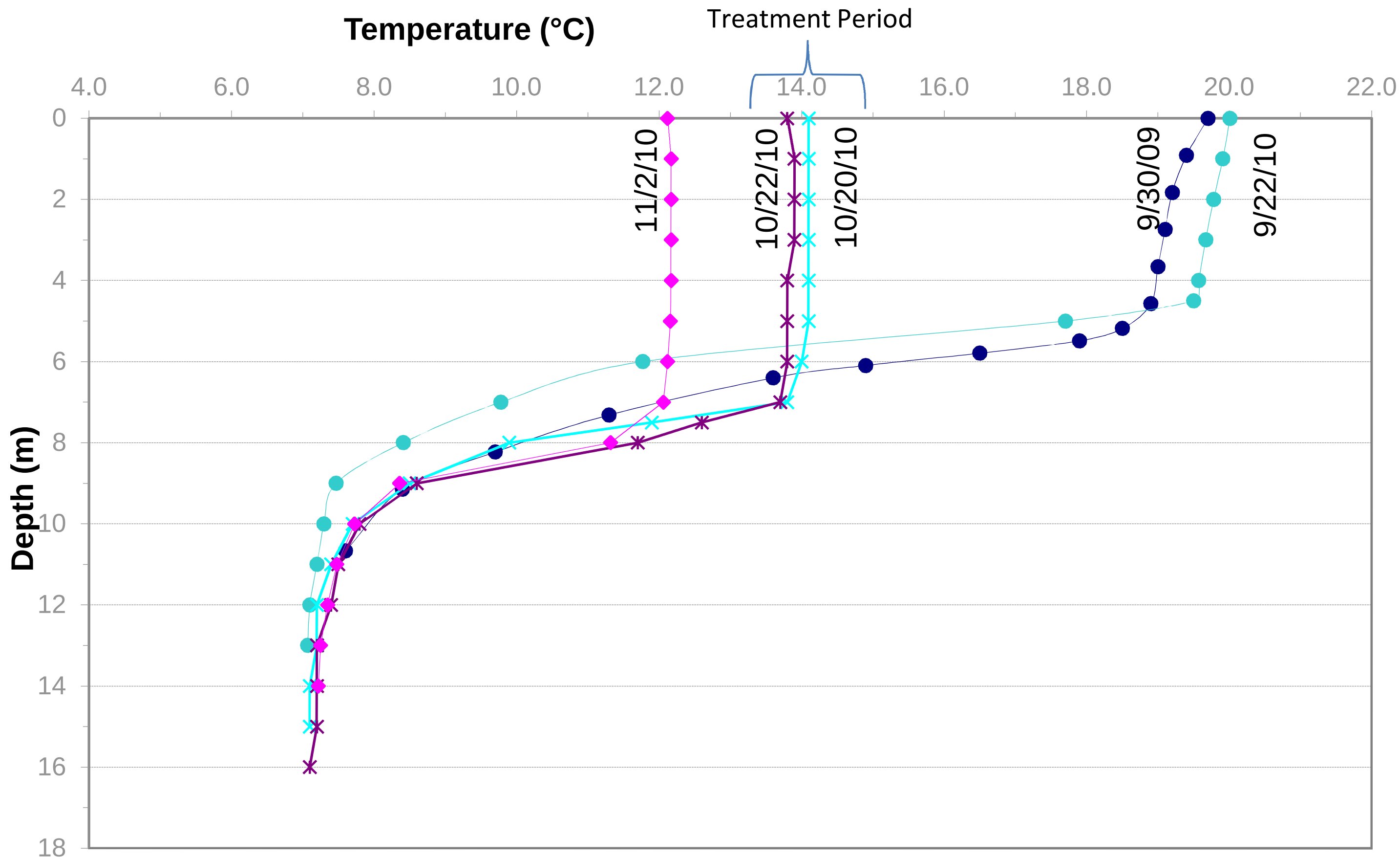

Figure 7 - Temperature Profile: Initial Post-Implementation Monitoring (2010), Stillwater Pond

4.2 Post-implementation monitoring: 2011 results

Post-implementation monitoring was conducted four times during 2011 on April 19, June 20, August 22 and October 25. The first water quality sampling was conducted approximately six months after the nutrient inactivation treatment. During the intervening winter months, both ponds underwent complete mixing from top to bottom, allowing homogenization of the chemical levels and aeration of the water column. During the spring months, increasing light levels started to warm the upper layers of the ponds, beginning the process of seasonal thermal stratification.

The April sample represents a period when Lovers Lake was still undergoing vernal (springtime) mixing and Stillwater Pond appeared to have just started the initial stages of stratification. Due to spring runoff and high groundwater tables, nutrient influxes into kettlehole ponds such as Lovers Lake and Stillwater Pond from the watershed are usually at a seasonal high during this period. This is also before the start of spring phytoplankton blooms (which usually begin with the onset of permanent stratification). Accordingly, pond waters typically are at their highest nutrient concentrations for the year during this time.

The following two monitoring samples (June, August) represent early and late summer periods and span the period of greatest biological activity in the ponds. The mid-summer June sample was collected during a period when seasonal thermal stratification was well developed and when biological activity in the ponds, in the form of phytoplankton growth and zooplankton grazing, is generally high. The August sample is highly important for diagnostic purposes since it provides evidence of the maximum expression of nutrient-based growth in the form of phytoplankton and often represents the most stressful conditions for aquatic life. During late summer, lake surface water temperatures are high, clarity is often at seasonal lows, dissolved oxygen may be absent in most deeper zones of the lake, and nuisance blue-green algal blooms are often observed.

Water chemistry from this period is particularly useful, since the historic Pond and Lake Stewardship (PALS) monitoring of Lovers Lake and Stillwater Pond (2001-2006), was typically conducted during late summer as well. Those water quality data, coupled with that from two August samples obtained during the more intensive summer sampling in 2007 (ENSR, 2008), allow comparisons of pre- and post-implementation pond conditions during this critical seasonal period.

The last sampling was conducted in late October during a period when the autumnal overturn was occurring in Lovers Lake while the seasonal thermal stratification in Stillwater Pond was still present, but clearly moving towards complete mixing. This period is one in which the mixing of the bottom waters into the upper ones may bring some reduction in water quality as the dissolved oxygen may be lowered by the infusion of organic material and associated biochemical oxygen demand. Further mixing and aeration bring the ponds back into atmospheric equilibrium as they head back into winter.

The series of four 2011 samples provides a good measure of the pond conditions following the nutrient inactivation. Rather than discuss each sampling individually, the following sections provide an overview of the seasonal trends; including that for temperature (Section 4.2.1), dissolved oxygen (Section 4.2.2), general water chemistry (pH, alkalinity, specific conductivity, dissolved aluminum) (Section 4.2.3), nutrients (Section 4.2.4), and Secchi disk transparency (section 4.2.5). Water quality data for each individual sampling are provided in Appendix E.

4.2.1 Pond temperature patterns

Temperature depth profiles are provided for the two basins in Lovers Lake (Figures 8 and 9) and Stillwater Pond (Figure 10). The general seasonal patterns are described below.

Lovers Lake

The April temperature profiles indicated that both the northern and southern deep basins in Lovers Lake were approximately isothermal at 10-11°C (Figures 8 and 9) indicating that stratification had not occurred yet. By June, the temperature profiles reveal that a thermocline has been established at about 5 m in both deep basins. Temperature of the upper layer (epilimnion) is fairly uniform at 19.4-21.7 °C. Below the thermocline, temperature in the bottom waters (hypolimnion) decreases with depth to 12 °C. The warmer hypolimnetic temperatures found in Lovers Lake as compared to Stillwater Pond indicate that thermal stratification occurred at a later date in Lovers Lake than in Stillwater Pond; thus allowing greater thermal energy intake in Lovers Lake before density-related resistance to mixing inhibited water exchange between upper and lower waters. In August, the temperature profiles indicate that both deep basins in Lovers Lake were strongly stratified with the top layers at 25.5 °C decreasing to about 15 °C at depths greater than 6 m. The pattern is somewhat truncated in the southern basin due to the shallower depth. The epilimnetic water temperatures are likely at a seasonal high during this period. By October, Lovers Lake had indications of being nearly fully mixed. Temperature profiles indicated that the water column in both deep basins in Lovers Lake were isothermal at approximately 16 °C.

Stillwater Pond

The April Stillwater Pond temperature profile indicated that the pond has already started to transition to a stratified condition (Figure 10). There is a 4 °C difference between top and bottom, and an observable thermocline at 7 m. The quicker shift to a stratified state exhibited by this pond, relative to Lovers Lake, is most likely a function of its greater depth and more sheltering shoreline. These factors contribute to a reduced effectiveness of wind and wave action to provide internal mixing. As evidenced by prior studies, thermal stratification occurs sooner and persists longer in this pond than Lovers

Lake (ENSR Corporation, 2008). In June, the temperature profiles indicated that the thermocline observed in April persisted with bottom waters at 7 °C, although there is evidence of a secondary stratification within the epilimnion at about 4 m. By August, Stillwater Pond exhibited a similar pattern of intense stratification with surface temperatures of 25.5 °C decreasing to below 10 °C at depths greater than 8 m. The October temperature depth profile indicated that the pond was still stratified with a thermocline at 8-9 m. This long persistence of stratification is characteristic of Stillwater Pond which did not mix until December in the 2007 season (ENSR, 2008).

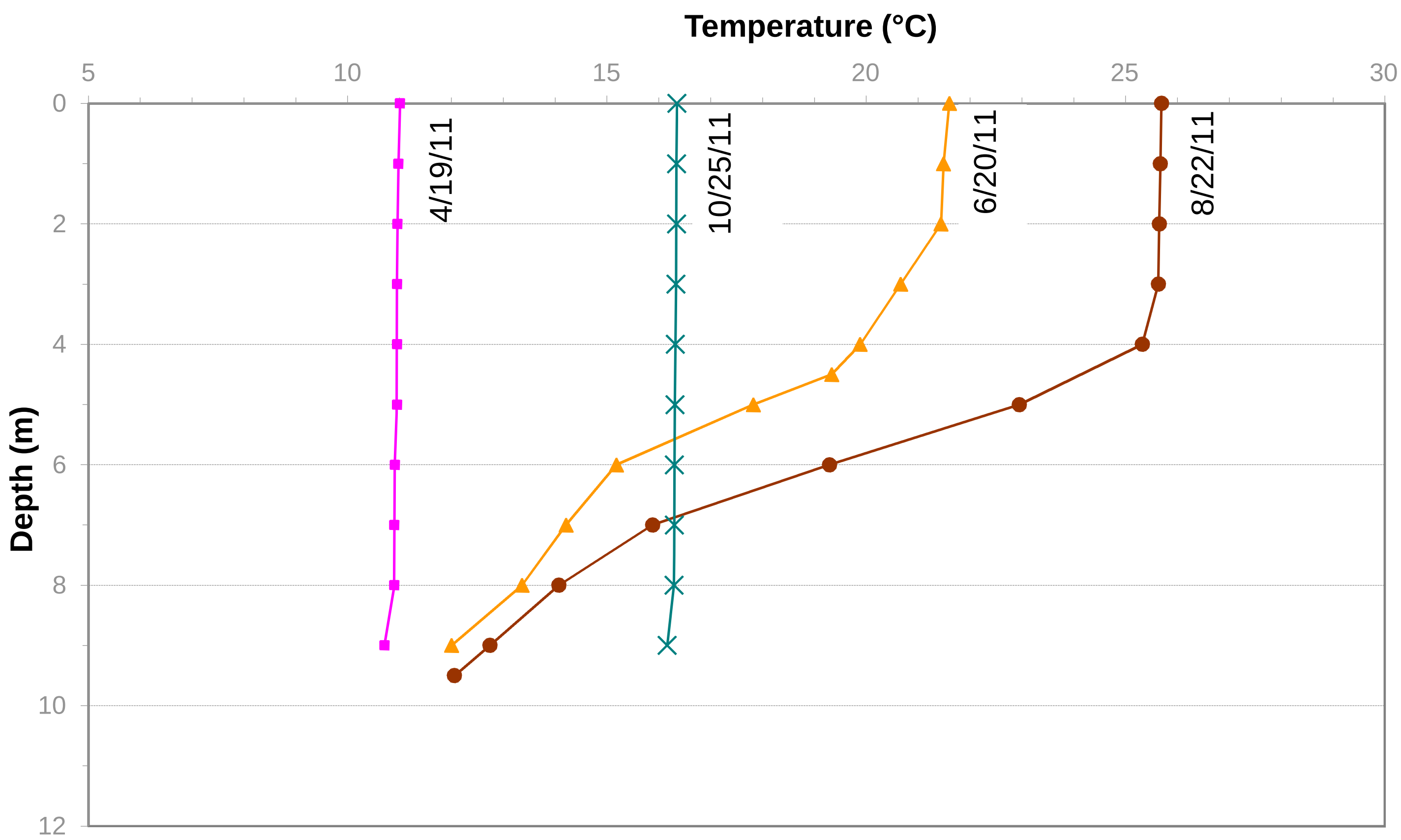

Figure 8 - Temperature Profile: Post-Implementation Monitoring (2011), Lovers Lake Northern Deep Basin

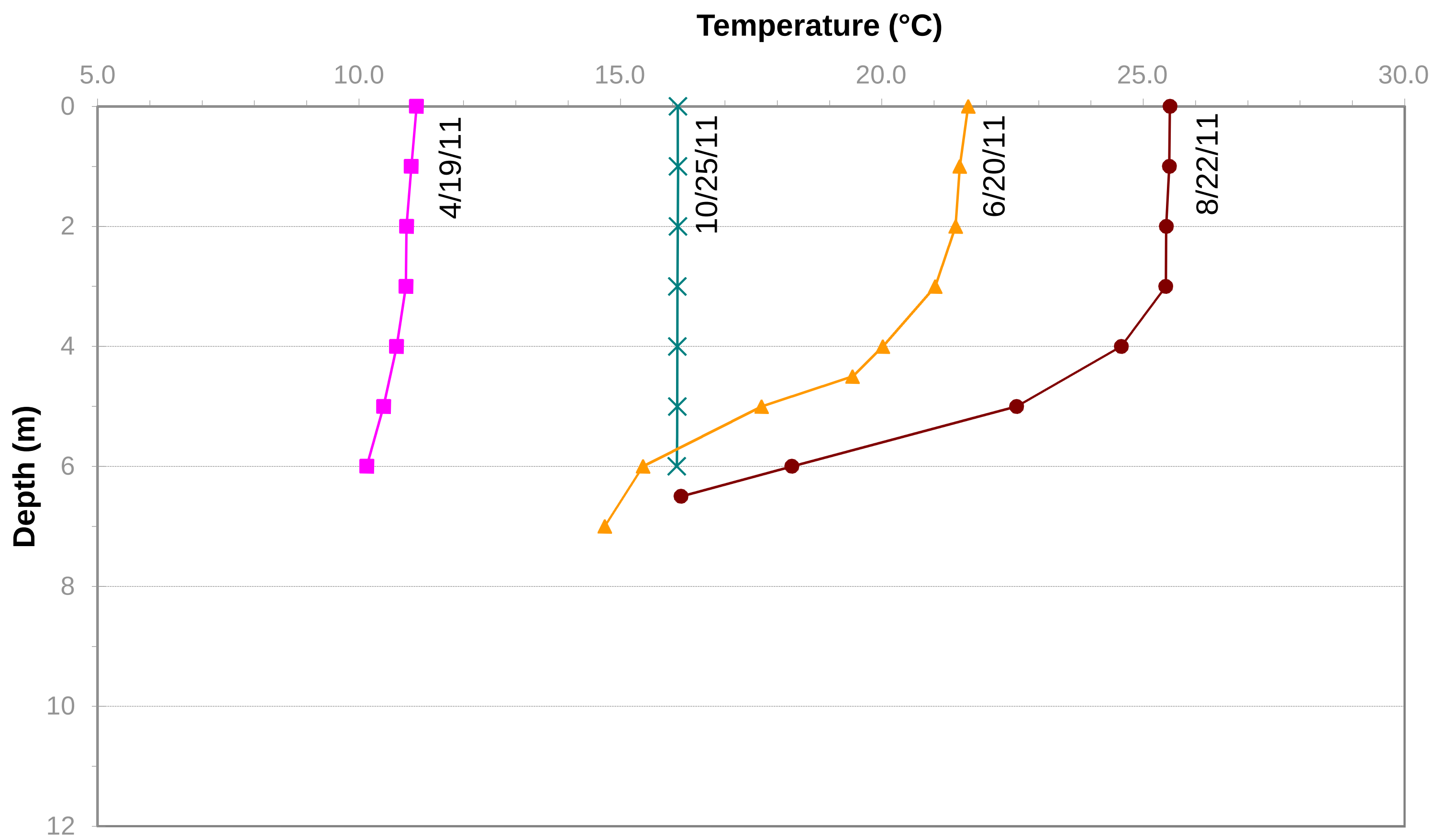

Figure 9 - Temperature Profile: Post-Implementation Monitoring (2011), Lovers Lake Southern Deep Basin

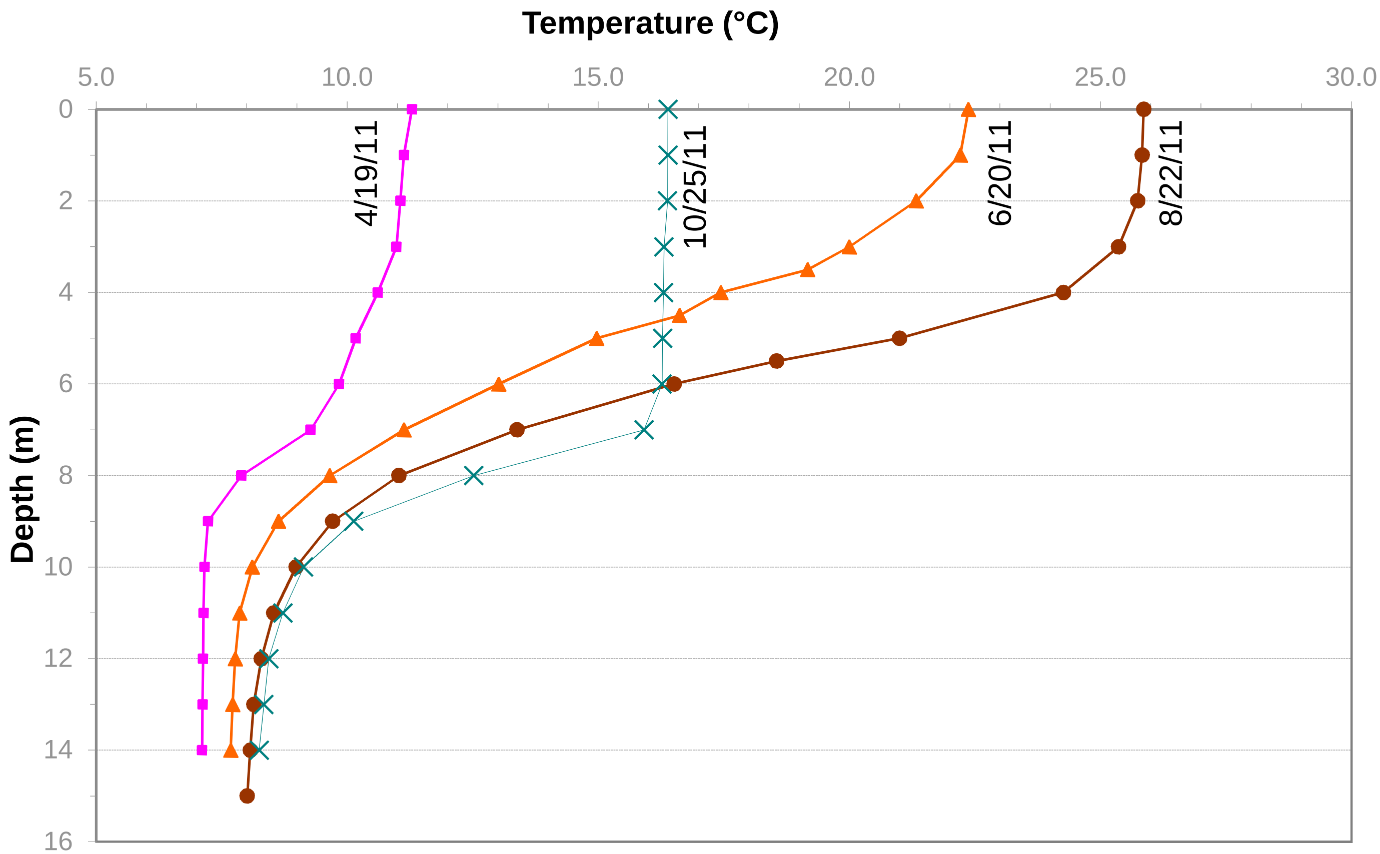

Figure 10 - Temperature Profile: Post-Implementation Monitoring (2011), Stillwater Pond Deep Basin

4.2.2 Dissolved Oxygen Patterns

Seasonal dissolved oxygen depth profiles are provided for the two deep basins in Lovers Lake (Figures 11 and 12) and Stillwater Pond (Figure 13). The figures exhibit the depth profiles of temperature-corrected relative percent saturation of dissolved oxygen, which provides a convenient indicator of the availability of dissolved oxygen relative to its equilibrium with atmospheric oxygen. The absolute dissolved oxygen measurements are provided in Appendix E. The general seasonal patterns are described below.

Lovers Lake

In the April profile dissolved oxygen ranged from 11.5 to 12.0 mg/L throughout, corresponding to levels above 100% saturation, which indicate a very well aerated water column (Figures 11 and 12). In June, stratification was established and while the epilimnion stayed at approximately 100% saturation, the dissolved oxygen in the bottom waters was sharply reduced by benthic oxygen demand, with near anoxic conditions (< 1.0 mg/L) found everywhere below 7 m. This disparity intensifies in August when dissolved oxygen concentrations remain at approximately 8.0 mg/L in the upper layer and decrease rapidly at 5 m to below 2.5-3.1 mg/L. At depths greater than 6.5 m, dissolved oxygen in both deep basins is below 1.0 mg/L. As thermal stratification breaks down in October and mixing occurs, the dissolved oxygen concentrations throughout the water column increase to approximately 8.0 mg/L in both basins. The percent saturation is reported as below 100% for the October data, but field notes indicted that the dissolved oxygen meter calibration was slightly out of expected parameters, most likely due to the cold air temperatures encountered in the field. However, it was noted that the 2007 data also indicated a percent dissolved oxygen saturation level of around 80% during autumnal mixing (ENSR, 2008). If true, this may be a function of the introduction of biodegradable material from the bottom into the water column leading to greater oxygen demand than expected, but this is uncertain.

Stillwater Pond

One consequence of the early thermal stratification in Stillwater Pond in April is a reduction of dissolved oxygen below 7 m (Figure 13). This very early decrease in dissolved oxygen appears to be due to a very strong oxygen demand in bottom waters which has been observed in other years (ENSR, 2008). The dissolved oxygen pattern in June and August is consistent with a very high oxygen demand in bottom waters and anoxic conditions existing below about 8 m. Additionally, there is a sizeable spike in the concentration of dissolved oxygen just above the thermocline (metalimnetic oxygen maxima) where a combination of light, nutrient availability and a density gradient that reduces the sinking of phytoplankton lead to a localized area exhibiting high levels of photosynthesis and therefore higher dissolved oxygen levels. This metalimnetic maxima is present, but not prominent in the August profile. The same general pattern is also present in the October profile (Figure 13).

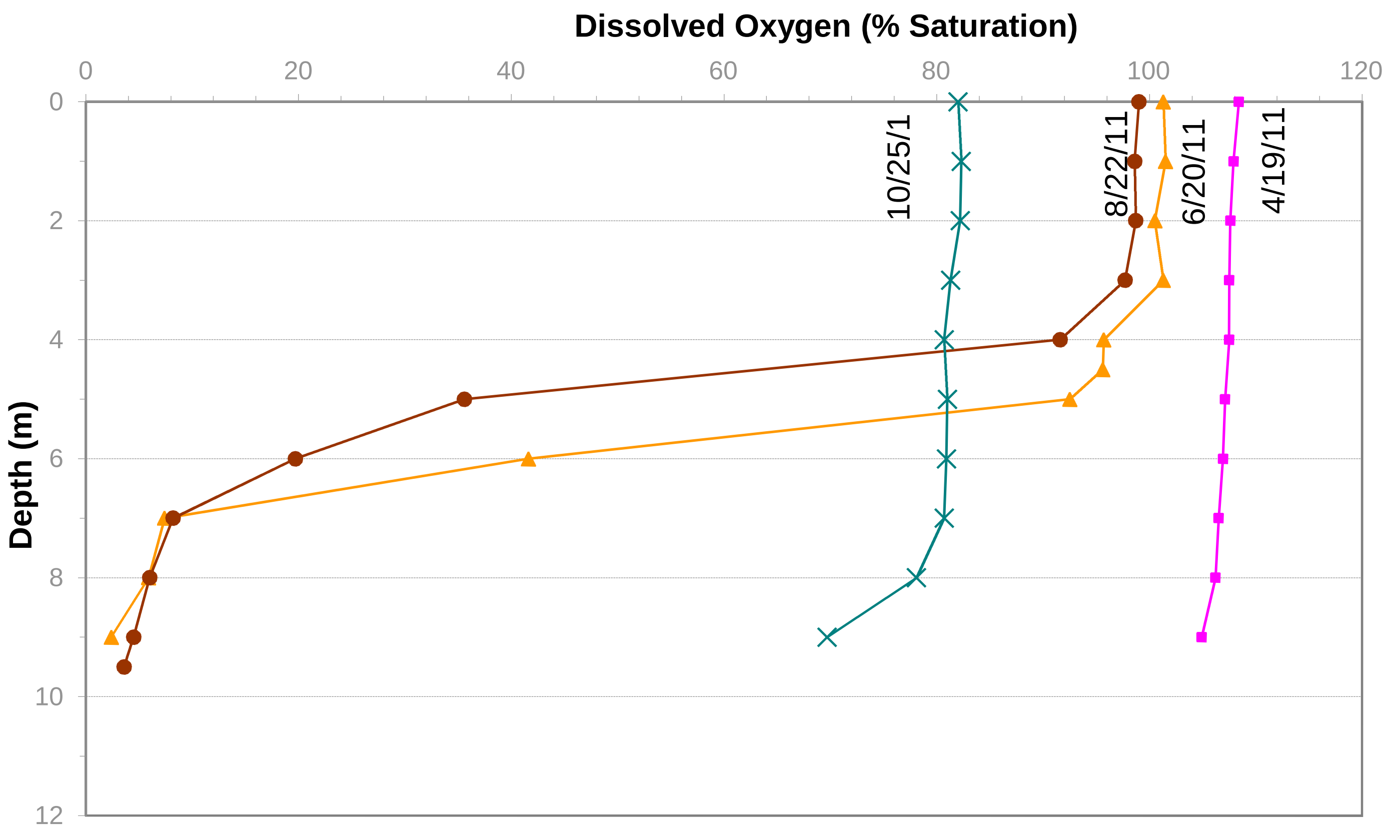

Figure 11 - Dissolved Oxygen Profile: Post-Implementation Monitoring (2011), Lovers Lake Northern Deep Basin

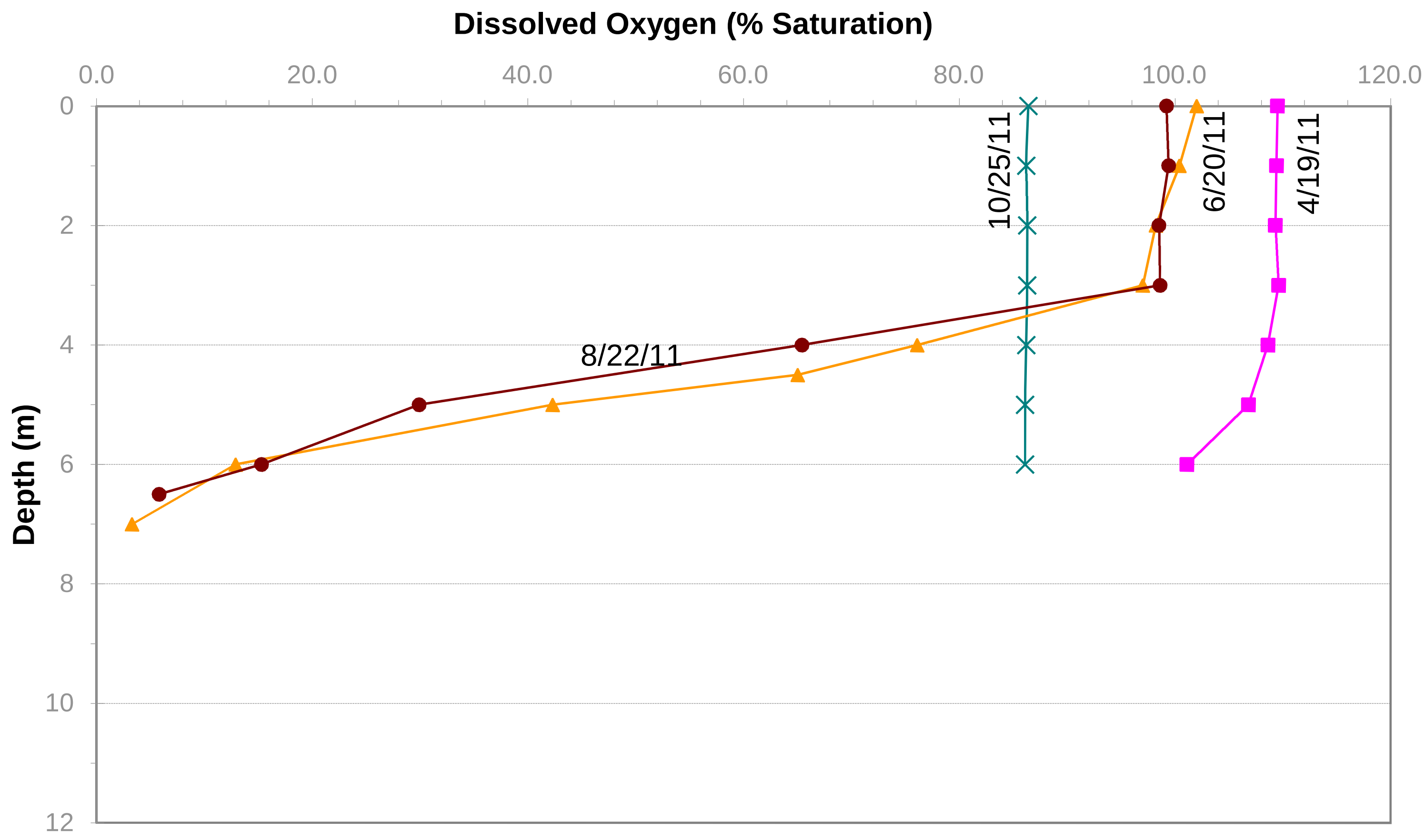

Figure 12 - Dissolved Oxygen Profile: Post-Implementation Monitoring (2011), Lovers Lake Southern Deep Basin

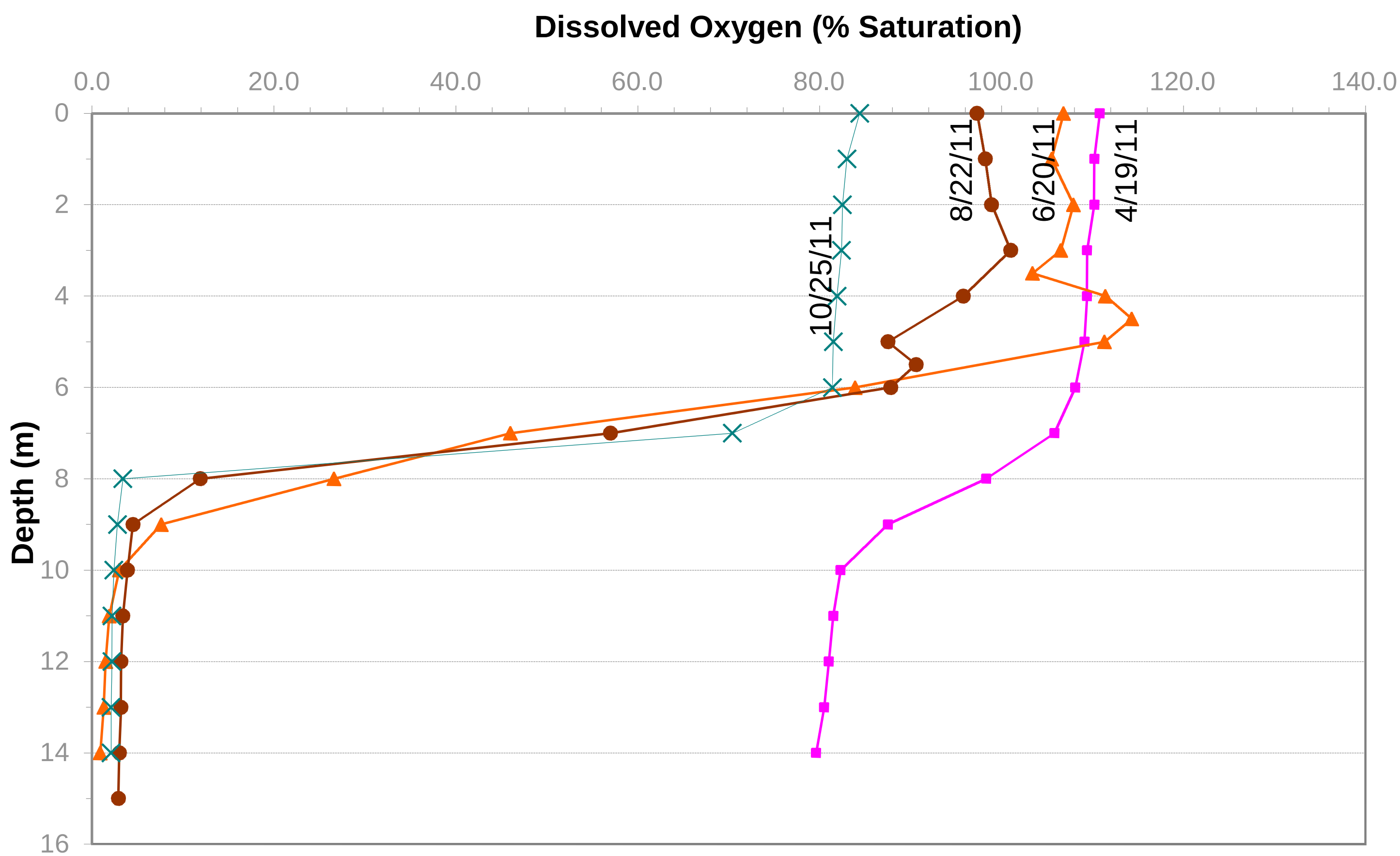

Figure 13 - Dissolved Oxygen Profile: Post-Implementation Monitoring (2011), Stillwater Pond Deep Basin

4.2.3 General Water Quality Characteristics

General water quality parameters monitored included specific conductivity, pH, alkalinity and dissolved aluminum. Water quality data for the samples are provided in Appendix E. The general trends are described below.

Lovers Lake

Specific conductivity is a non-specific water quality parameter related to the total amount of dissolved ions in a water sample. It provides a general indicator of the potential anthropogenic influence in a freshwater system. Due to the proximity of the ponds to the marine environment, it is likely that the ponds have a higher specific concentration due to introduction of salts from marine aerosols and storm events. In Lovers Lake, the specific conductivity generally ranged from 0.20 to 0.22 mS/cm with a few very high values in the measurements taken nearest the bottom (Appendix E). These elevated values are due to the decay and mobilization of materials from the bottom sediments.

The pH in Lovers Lake was highest (most basic) during the April monitoring, with the pH reported at levels from 8.9 to 8.2. However, calibration issues noted in the field notes with the probe suggest these values may be suspect since previous measurements of pH over the years have generally ranged from 6.0-7.9 S.U. (ENSR, 2008). For most of the year, pH ranged between 6.3 to 7.8 S.U. with some tendency toward higher values in the epilimnion.

Alkalinity (measured as mg/L as $CaCO_3$) is a measure of the relative buffering capacity of the water. In Lovers Lake, alkalinity generally ranged from 16-24 mg/L in 2011 (with one unexplained low value of 2 mg/L in August) (Table 4).

Dissolved aluminum in 2011 decreased from a range of 0.053 to 0.096 mg/L seen immediately after the alum treatment in November 2010 to levels generally below 0.020 mg/L for the remainder of 2011 (Table 4). The USEPA freshwater acute criterion for dissolved aluminum is 0.75 mg/L. Due to the necessary change in the laboratory contracted for the final round of sample analysis, the reporting limit for dissolved aluminum is higher for the October 2011 samples than previous sampling rounds. The detection limit of 0.10 mg/L is still substantially lower than the USEPA acute criteria for dissolved aluminum, although it artificially skews the data toward larger numbers. The reporting limit is the value above which the laboratory determines it can effectively define accuracy and precision of a sample; samples with concentrations lower than the reporting limit are reported as below this limit, with the actual value undefined.

Stillwater Pond

In Stillwater Pond, the specific conductivity in the surface water was relatively uniform fluctuating between 0.19-0.21 mS/cm (Appendix E). Values increased with depth in the hypolimnion during the monitoring. The pH values were slightly acidic to neutral, ranging from 6.3 to 7.9 S.U. with no extreme values observed. Surface alkalinities ranged from 12-23 mg/L as $CaCO_3$, in surface water, with slightly higher values at depth (14-44 mg/L). Dissolved aluminum concentrations were uniformly low (0.005-0.010 mg/L) in Stillwater Pond over the season (Table 4).

4.2.4 Orthophosphorus and Total Phosphorus

As discussed earlier, phosphorus concentrations are the key to pond productivity and the focus of the nutrient inactivation. Orthophosphorus and total phosphorus data are provided in Table 4 and discussed below.

Lovers Lake

The orthophosphorus concentrations in Lovers Lake were uniformly below detection (<0.005 mg/L) in all samples including the deep stations except for the October samples when very low concentrations were detected (0.004-0.009 mg/L). The absence of appreciable orthophosphorus, even in the deeper samples, suggests that availability may be limited, but due to the rapid cycling of this nutrient fraction, low concentrations may be found even in highly productive lakes, so this finding in itself is not significant.

The total phosphorus concentrations in 2011 in Lovers Lake were highest in the April samples. As noted above, this is expected since the annual spring runoff is typically the primary seasonal event which brings new nutrients into the ponds. In Lovers Lake, the northern deep basin stations (surface and deep) and surface southern deep basin station ranged between 0.035-0.042 mg/L, while there was a large concentration (0.077 mg/L) in the southern deep basin sample. While this may be simply due to analytical variability, it is also possible that the higher concentration is associated with the influence of the storm drain off Lake Shore Lane which could provide denser, more enriched inputs from street and salt runoff.

As the season progressed, the surface total phosphorus concentration declined to 0.009 to 0.014 mg/L, although bottom waters were generally higher ranging from 0.006 to 0.030 mg/L. As discussed later, these concentrations are significantly reduced from those seen in pre-treatment data.

Stillwater Pond

Like Lovers Lake, orthophosphorus concentrations in Stillwater Pond were below or just above detection for the entire year, at both surface and deep stations (Table 4.) In April, the total phosphorus concentrations in Stillwater Pond were uniform with depth at 0.041 mg/L. Total phosphorus values were much lower over the growing season with surface levels at 0.006 - 0.010 mg/L with deeper values somewhat higher at 0.013-0.022 mg/L. It should be noted that the orthophosphorus value for the surface sample in October exceeded the total phosphorus concentration - indicating some degree of analytical error. However, all of these total phosphorus concentrations measured in 2011 would be considered moderate to low. Overall, the availability of both of phosphorus fractions were significantly reduced from historic levels, particularly in deeper waters (see discussion below).

4.2.5 Secchi Disk Transparency Depths

Secchi disk transparency (SDT) depth measures the relative penetration of light into pond waters. The greater the SDT depth the further into the pond light can penetrate and provide energy for photosynthesis, particularly for rooted aquatic plants (macrophytes) on the bottom. SDT data is provided in Appendix E and the seasonal trends described below.

Lovers Lake

Following the vernal turnover, SDT values ranged between 4.3 - 4.6 m indicating good clarity of water. These values are consistent with spring readings in 2007 which saw SDT depths exceeding 4 m during May to mid-June (ENSR, 2008). As noted above, this is a period of the year where there is very little biological activity and heavy hydrologic input, so water is generally very clear. As the season progresses, biological activity (phytoplankton) begin to increase, so SDT values start to decrease. In Lovers Lake, the values decreased to 3.5-3.9 m, still in line with observations in 2007 (ENSR, 2008). In August 2011, the SDT ranged from 3.3 to 3.6 m, and the SDT was well above the 1.4 m (i.e., 4 ft) clarity benchmark which Massachusetts advises for recreational safety at bathing beaches. The October 2011 SDT values were a bit lower, at 2.0-2.3 m during a period of decreasing biological activity, but were consistent with the 2007 observations. While the exact reason is not certain, these lower values may be due to the presence of increased particulate matter in the water column due to watershed runoff during a storm event that occurred about a week prior to the sampling as well as mixing of materials from the bottom waters during fall overturn.

Stillwater Pond

Stillwater Pond also displayed good clarity in 2011 starting with a value of 3.3 m in April, 2.6 m in June, 3.5 m in August and 2.7 m in October. These SDT readings all met and exceeded the observations made during similar periods during 2007 (ENSR, 2008). Very similar results were seen as in Lovers Lake with regard to improved clarity during late summer. The October value (2.7 m) is above that for Lovers Lake, however. Recalling that Stillwater Pond was still stratified at this time and has a smaller, less developed watershed and a more sheltered fetch, it is likely that this pond was less affected by the storm during the week prior to sampling.

4.3 Comparison of 2011 Water Quality with Historic Data

As a measure of the effectiveness of the nutrient inactivation, the SDT and total phosphorus concentrations from August 2011 from the two ponds were compared to data from the historic PALS monitoring (2001-2006) and two August samples taken in 2007 (ENSR, 2008). As indicated earlier, this allows comparisons of pre- and post-implementation pond conditions under "worst-case" conditions.

4.3.1 Comparison of SDT and Total Phosphorus Values

Mean values and ranges for samples taken during the 2001-2006 PALS program (sampling dates were in August and September), those from two August days in 2007, and the sample taken in August 22, 2011 are presented in Table 5. Data are presented for the surface and deep samples from the deepest portion of the two ponds. Note that SDT is a physical observation of the light-transmitting characteristics of the entire water column thus only one reading is taken at each location.

Historic SDT values from 2001-2007 are all indicative of generally low pond clarity. There is a notable difference between the August 2011 SDT value and the historic data. In 2011, the SDT depth was 3.3 m in Lovers Lake and 3.5 m in Stillwater Pond. Thus, late summer clarity was from two to three times improved from what was observed in the pre-treatment period.

The second major comparison is the total phosphorus concentrations measured in late summer. For Lovers Lake, the surface values from the historic August data were between 0.030-0.040 mg/L and the deeper samples were higher, with averages ranging between 0.067-0.117 mg/L. In 2011, the surface water total phosphorus in Lovers Lake was 0.013 mg/L, while the deep sample was 0.030 mg/L, showing significant reduction from previous years. Similarly, Stillwater Pond exhibited low total phosphorus in August 2011, with a surface concentration of 0.009 mg/L as compared with 0.028-0.36 mg/L during 2001-2007. Of particularly note is the significant reduction of total phosphorus in the hypolimnion of Stillwater Pond. The 2001-2006 PALS measurements averaged 0.290 mg/L, with 0.469 mg/L measured in August, 2007. In August 2011, the total phosphorus concentration was 0.022 mg/L or a ten to twenty-fold decrease from pre-implementation levels.

There is little doubt that this reduction is attributable to the nutrient inactivation. The release of phosphorus from the bottom sediments under anoxic conditions typically results in high levels of dissolved phosphorus found near the sediments. In August 2007, the dissolved phosphorus values approximated 0.232 mg/L in Stillwater Pond, whereas orthophosphorus was not detected (<0.005 mg/L) in the bottom waters in 2011. While not as dramatic, there are similar reductions in Lovers Lake where dissolved phosphorus concentrations in the deep samples were at 0.018-0.039 mg/L in northern and southern basins, but were not detected in 2011. This is strong evidence that bottom release of phosphorus from the sediment has been greatly reduced by the nutrient inactivation.

Table 4 - 2011 Post-Implementation Water Quality Monitoring

Lovers Lake northern deep basin

		4/19/2011		6/20/2011		8/22/2011		10/25/2011	
Parameter	**Unit**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**
Dissolved Al	mg/L	0.024	0.018	0.005	<0.005*	0.011	0.006	<0.10*	<0.10*
PO_4-P	mg/L	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	0.009	0.004
TP	mg/L	0.035	0.039	0.008	0.026	0.013	0.030	0.009	0.006
$CaCO_3$ Alkalinity	mg/L	22	16	16	16	2	28	24	24

Lovers Lake southern deep basin

Parameter	**Unit**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**
Dissolved Al	mg/L	0.02	0.018	<0.005*	<0.005*	0.056	0.014	<0.10*	<0.10*
PO_4-P	mg/L	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	0.004	0.006
TP	mg/L	0.042	0.077	0.009	0.015	0.014	0.025	0.012	0.010
$CaCO_3$ Alkalinity	mg/L	24	21	16	14	16	18	23	24

Stillwater Pond deep basin

Parameter	**Unit**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**	**Surface**	**Deep**
Dissolved Al	mg/L	0.010	0.005	<0.005*	<0.005*	0.009	<0.005*	<0.10*	<0.10*
PO_4-P	mg/L	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	<0.005*	0.010	0.005
TP	mg/L	0.041	0.041	0.006	0.019	0.009	0.022	<0.010*	0.013
$CaCO_3$ Alkalinity	mg/L	23	22	12	14	12	34	21	44

*Reporting limit
TP – Total phosphorus
PO_4-P - Orthophosphorus

Table 5 - Pre- and Post-Implementation Secchi Disk Transparency and Total Phosphorus

PALS 2001-2006 Values

	SDT (m)			Total Phosphorus (mg/L)		
	mean	**minimum**	**maximum**	**mean**	**minimum**	**maximum**
Lovers Lake northern basin - surface	1.1	0.4	1.7	0.032	0.024	0.047
Lovers Lake northern basin - deep	-	-	-	0.116	0.051	0.174
Stillwater Pond - surface	1.6	0.6	3.0	0.028	0.014	0.045
Stillwater Pond - deep	-	-	-	0.290	0.177	0.427

August 2007 Values

	SDT (m)			Total Phosphorus (mg/L)		
	mean	**minimum**	**maximum**	**mean**	**minimum**	**maximum**
Lovers Lake northern basin - surface	0.9	0.7	1.1	0.043	0.026	0.059
Lovers Lake northern basin - deep	-	-	-	0.067	0.054	0.079
Stillwater Pond - surface	1.0	0.7	1.2	0.036	0.034	0.037
Stillwater Pond - deep	-	-	-	0.469	0.371	0.567

August 2011 Values

	SDT (m)			Total Phosphorus (mg/L)		
	Value			**Value**		
Lovers Lake northern basin - surface	3.3	-	-	0.013	-	-
Lovers Lake northern basin - deep	-	-	-	0.030	-	-
Stillwater Pond - surface	3.5	-	-	0.009	-	-
Stillwater Pond - deep	-	-	-	0.022	-	-

4.3.2 Trophic comparisons

The August data can be also used to estimate whether the ponds are currently supporting their designated water uses, as estimated by their overall trophic status. The concept of trophic status is based on the fact that changes in nutrient levels (measured by total phosphorus and total nitrogen) causes changes in algal biomass (measured by chlorophyll *a*) which in turn causes changes in lake clarity (measured by SDT). A trophic state index (TSI) is a convenient way to quantify this relationship. This consists of comparison of ambient values of key indicators (i.e., phosphorus and nitrogen fractions, chlorophyll a, and SDT) to previously established criteria or thresholds.

For this comparison, we used the Trophic State Index (TSI) developed by Carlson (1977). This method uses a log transformation of SDT values as a measure of algal biomass on a scale from 0 - 110. Each increase of ten units on the scale represents a doubling of algal biomass. Because chlorophyll a and total phosphorus are usually closely correlated to SDT, these parameters can also be assigned trophic state index values (EPA, 2011). Thus, the available trophic state indicators are input into a set of empirical equations:

$$TSI_{sdt} = 60 - 14.41 \, ln \text{ SDT (m)}$$

$$TSI_{chla} = 9.81 \, ln \text{ chlorophyll a } (\mu g/L) + 30.6$$

$$TSI_{tp} = 14.42 \, ln \text{ TP } (\mu g/L) + 4.15$$

where: TSI is Carlson trophic state index and *ln* is the natural logarithm. Interpretation of the output of the TSI model is by comparison of the resulting TSI scores and their relation to the overall trophic status of the pond. The general relationships are shown pictorially in Figure 14.

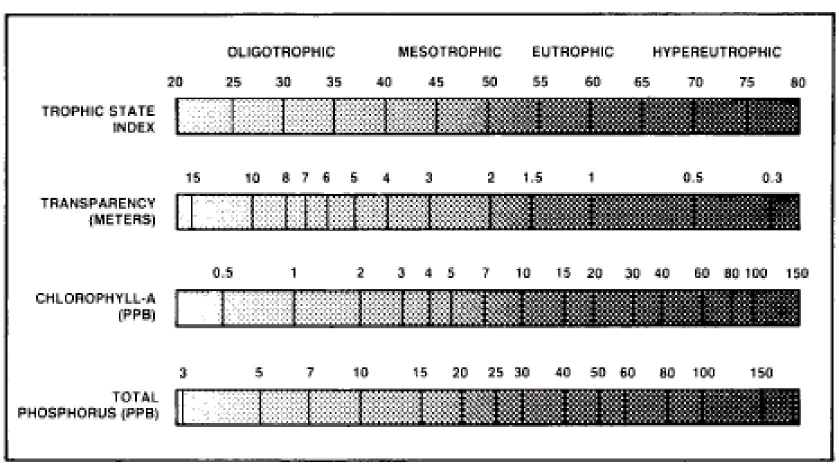

Figure 14 - Carlson's Trophic State Index Related to Perceived Nuisance Conditions (Heiskary and Walker, 1987)

Table 6 provides a summary of the values and TSI scores based on August surface values during the pre- and post-implementation periods. Values from both the northern and southern basins were used, where data were available for this analysis, although the two basins tracked very closely. Based on levels for the SDT, total phosphorus and chlorophyll a in 2001-2006, and SDT and total phosphorus in 2007, both Lovers Lake and Stillwater Pond would be judged eutrophic (over-fertilized). This also was the conclusion of a town-wide pond survey conducted in 2003 (EcoLogic, 2003). Using the data from 2011 leads to a finding of mesotrophic conditions throughout both ponds. The available TSI indicators also suggest that the conditions of the ponds are approaching the oligo-mesotrophic boundary. Thus, the TSI supports the conclusion that the nutrient inactivation has had its desired effect of improving the ponds' trophic status, one of the major objectives of this ecological restoration (ENSR, 2008).

However, while the Carlson TSI is useful for comparing lakes within a region and for assessing changes in trophic status over time, it should be acknowledged that its empirical equations were primarily based on data from mid-Western lakes, and thus its conclusions may not be directly applicable to kettlehole ponds on Cape Cod. The special sensitivity of Cape Cod lakes to nutrients has been described elsewhere (CCC, 2003; see also Section 2.5.1 in ENSR, 2008).

Based on analysis of 185 Cape Cod ponds, the Cape Cod Commission identified both reference (i.e., "*unimpacted*") and target ("*healthy*") values for nutrient and trophic indicators (CCC, 2003). For Cape Cod ponds the CCC established "*healthy*" levels as the upper 25% of total phosphorus values from all ponds in the database or at 0.010 mg/L. It can be seen from Table 6 that the present surface total phosphorus values in both ponds 0.009-0.014 mg/L are very close to achieving this standard for healthy lakes.

Table 6 – Trophic State Index (TSI) Summary

PALS 2001-2006 TSI Values

	SDT (m)	TP (mg/L)	Chl a (µg/L)	TSI-SDT	TSI-TP	TSI-Chl a	Mean TSI Value	Trophic State
Lovers Lake	1.1	0.0322	25.34	58	54	62	58	**Eutrophic**
Stillwater Pond	1.6	0.0275	22.96	53	52	61	56	**Eutrophic**

August 2007 TSI Values

	SDT (m)	TP (mg/L)	Chl a (µg/L)	TSI-SDT	TSI-TP	TSI-Chl a	Mean TSI Value	Trophic State
Lovers Lake North Basin	0.9	0.0425	NM	61	58	NA	60	**Eutrophic**
Lovers Lake South Basin	1.0	0.0365	NM	60	56	NA	58	**Eutrophic**
Stillwater Pond	1.0	0.0355	NM	61	56	NA	58	**Eutrophic**

August 20011 TSI Values

	SDT (m)	TP (mg/L)	Chl a (µg/L)	TSI-SDT	TSI-TP	TSI-Chl a	Mean TSI Value	Trophic State
Lovers Lake North Basin	3.3	0.013	NM	43	41	NA	42	**Mesotrophic**
Lovers Lake South Basin	3.6	0.014	NM	42	42	NA	42	**Mesotrophic**
Stillwater Pond	3.5	0.009	NM	42	36	NA	39	**Mesotrophic**

TSI Score & Trophic Classifications (Carlson, 1977)
Oligotrophic= < 38 (poorly fertilized)
Mesotrophic = 38-47 (moderately fertilized)
Eutrophic = 48-66 (well fertilized)
Hypereutrophic = > 66 (extremely fertilized)
August surface values were utilized for this table.

NM = not measured
NA = not applicable
SDT = Secchi Disk Transparency
TP = Total Phosphorus
Chl a = Chlorophyll a

4.4 Evaluation of Effectiveness of Nutrient Inactivation

The data presented in Section 4.3 indicates that concentrations of total phosphorus have uniformly gone down in all locations in both ponds when compared to historic, pre-implementation levels. While these reduced concentrations constitute improvement in water quality, it is somewhat difficult to directly correlate these concentrations to overall reduction of mass of phosphorus released into the ponds by internal recycling.

One method of determining the overall reduction of phosphorus is estimating the "standing stock" of total phosphorus in the water column for pre- and post-implementation periods. This was accomplished by estimating the mass of total phosphorus in the epilimnion and hypolimnion for each pond both pre- and post-implementation. For this estimate the surface and bottom total phosphorus concentrations from August 2007 and August 2011 for Lovers Lake and Stillwater Pond were utilized (Table 5). The volume of water in the epilimnion was estimated based on previous bathymetric and volume calculations (ENSR, 2008) using a thermocline of 5 m for Lovers Lake and 6 m for Stillwater Pond. The total phosphorus concentration was multiplied by the volume of each layer (epilimnion and hypolimnion) and the sum determined for each pond. The resulting total phosphorus for each year and each pond was then compared (see Appendix F.1 and F.2 worksheets).

Comparison of the 2007 and 2011 data yielded a reduction in total phosphorus of 21.1 kg for Lovers Lake and 76.2 kg for Stillwater Pond. These calculations are recognized as overestimates of total phosphorus removal (particularly for Stillwater Pond) for the following reasons:

1. The distribution of total phosphorus in the well-mixed epilimnion is likely to be relatively uniform throughout this stratum so that a surface sample is a reasonable estimate. However, the bottom sample total phosphorus concentration represents a localized highly enriched layer that is not likely to be representative of total phosphorus throughout the hypolimnion. This is because sediment phosphorus release is distributed into the hypolimnion more through molecular diffusion rather than physical wind or wave mixing so that a steep gradient of total phosphorus concentration generally exists within the hypolimnion volume.

2. The data used to determine the total phosphorus reduction was a snapshot in time, although generally representative of conditions in the ponds during the summer, conditions change on a daily basis.

To provide a more representative hypolimnetic value, the PALS monitoring data were examined. These data included samples collected in Stillwater Pond both near the bottom (13-14 m) and at a midpoint in the hypolimnion (9 m) over six years (2001-

2006). [Note: we were not able to do a similar comparison with Lovers Lake data since the PALS sampling depths only included a single hypolimnetic sample]. The hypolimnion midpoint data provides a more representative estimate of the average total phosphorus concentration of the hypolimnion.

For this analysis, we assumed that the difference between total phosphorus concentrations in the epilimnion and hypolimnion is due principally to internal recycling in the latter. Accordingly, the epilimnion value is assumed to approximate the influence from all other phosphorus sources. Comparison of the total phosphorus concentrations (corrected by subtracting the epilimnion value) in the mid-hypolimnetic samples to that in bottom samples revealed that phosphorus increased from 51% to 96% over the depth gradient of 9 m to 13 m, with an average increase of 82% observed.

Accordingly, total phosphorus samples collected at the bottom of Stillwater in 2007 and 2011 were reduced by 82%, to take into account the total phosphorus gradient between the bottom of the hypolimnion and the bottom of the epilimnion. Using this adjusted value as a representative value for the hypolimnion layer, the total phosphorus reduction in both ponds was calculated. With the adjusted hypolimnetic value, the differences before and after the inactivation were 18.6 kg for Lovers Lake and 24.6 kg for Stillwater Pond (see Appendix F).

While these estimates are based on a small amount of data and some general assumptions, they provide a reasonable estimate of the amount of phosphorus which has been inactivated by the alum treatment. Based on previous alum treatments, it was predicted that reduction of phosphorus release following treatment would be on the order of 60-90% (ENSR, 2008). Comparison of these estimates of total phosphorus reduction verses the estimated contribution of internal recycling to the ponds' phosphorus budget (see Section 4.2.3 and Tables 5.8 and 5.9 in ENSR, 2008) suggest that the nutrient inactivation treatment was highly effective in inhibiting bottom release. For example, in Lovers Lake, internal recycling was estimated to contribute 18.3 kg/yr of the annual phosphorus budget of 42.5 kg, while in Stillwater Pond, internal recycling was estimated at 27 kg of the annual phosphorus budget of 48.5 kg. Thus, it appears that nutrient inactivation has largely removed the sediments as a significant source of phosphorus to the ponds. As noted above, these estimates are based on little data and some strong assumptions, but they are consistent with the general trends seen in the total phosphorus and SDT data.

One of the predicted changes for the ponds following nutrient inactivation was a potential increase in the depth of the oxic zone (ENSR, 2008). This phenomenon was observed in other ponds after completion of an alum treatment (e.g., Hamblin Pond). Comparison of the pattern of dissolved oxygen availability in 2011 (Figures 11-13) to trends seen in 2007 indicated that dissolved oxygen concentrations were slighter higher at depth in Stillwater Pond but slightly lower at the same depth in Lovers Lake (see ENSR, 2008; Figures 3-2 and 3-4). The overriding factor in dissolved oxygen distribution is generally the depth of the thermocline. Due to the high level of oxygen demand found in both ponds, dissolved oxygen is generally absent by mid-summer below the thermocline. At best, it may take many years of reduced productivity to decrease the oxygen demand such that an increase of dissolved oxygen at depth would be observable, given the year-to-year variability of the thermocline, which is usually a function of year-specific weather events.

Another, less quantitative, but effective means of evaluating pond condition, is through direct observation. Due to the reduced schedule of monitoring, our observations have been limited. Conversation with an informed pond observer, Chatham Herring Warden Don St. Pierre, has confirmed marked improvement in the appearance of the ponds with better water clarity than in recent memory (pers. comm. St. Pierre, 2011). Mr. St. Pierre particularly noted the clarity in Stillwater Pond since he regularly accesses the dock near the herring run. In addition, there have been no reports or evidence of a late summer blue-green algal bloom that was often a regular feature in Lovers Lake, as recently as 2010 just prior to the treatment.

4.5 Long Term Prospects for Lovers Lake and Stillwater Pond

Nutrient inactivation was conducted in fall 2010 to significantly reduce internal recycling as a source of phosphorus in the water column, lower the frequency and intensity of nuisance algal blooms, and provide increased water clarity in Lovers Lake and Stillwater Pond. Based on field observations, water quality data, and other available evidence gathered during the first post-implementation year, these expectations have been met.

However, aquatic ecology has many examples of lakes where restoration "mission accomplished" had been proclaimed at too early a stage, so several more years of regular monitoring by the Town would be required before it can be conclusively stated that the nutrient inactivation was totally successful. This professional caveat aside, it can be conclusively stated that the early indicators are very good.

Due to the reduction in nutrients, both Lovers Lake and Stillwater Pond have exhibited a rapid response in water chemistry. This will result in physical and biological changes over the next few years as well as changes in the potential value of the ponds to the Town. Some potential long-term expectations for the ponds include:

- **Increased density and depth expansion of rooted aquatic plant beds in both ponds** - due to increased water clarity there will be denser and more abundant macrophytes in the shallow depths (<5 m). These plants will provide ecosystem benefits as nursery and refuge areas for fish and benthic invertebrates and will help shift the ponds from phytoplankton-dominated systems to ponds with a greater balance of open water and littoral habitats. Due to the pronounced kettlehole bathymetry and rapid drop-off of both ponds, there is little concern that aquatic plants will "take over" the ponds, although some shallower areas (e.g., Lovers Lake south basin) may have dense accumulations.

- **Greater improvement from historical conditions will be observed in Stillwater Pond** - application of alum to both ponds have led to significant reductions in their nutrient budgets, but Stillwater Pond will likely realize the greatest level of improvement. This is due to several factors, including Stillwater Pond's smaller and less developed watershed, the reduction of incoming phosphorus from treatment of Lovers Lake (i.e., less phosphorus import from this upstream water source), and the greater importance of internal recycling for nutrient supply in Stillwater Pond. The sheltered shoreline and deep bathymetry of Stillwater Pond lead to a remarkably stable seasonal stratification that may depress exchange from below the thermocline during late summer. In contrast, Lovers Lake has a complex configuration, longer fetch, and a shallower sill between the main basins that may lead to more episodic inputs of bottom water and nutrients into the epilimnion due to late season storms. Lovers Lake also receives more nutrients in runoff from its watershed than Stillwater Pond (see below). All these factors suggest that the restoration will be more complete in Stillwater Pond.
- **Nutrient inactivation increases the importance of controlling non-point sources** - all evidence points to the nutrient inactivation significantly reducing internal recycling, the major source of phosphorus to both ponds. While this is an important first step for the restoration of the ponds, it does not decrease the importance of controlling non-point sources of nutrients in the future. This is a more critical factor for Lovers Lake due to the contributions of stormwater systems including those that drain Skyline Drive and Lake Shore Drive and which show visible signs of high flow and erosive scour. In addition, the applicable watershed stewardship measures discussed in the Lovers Lake and Stillwater Pond Watershed Management Plan (Loon Environmental, 2010) should be implemented.
- **Improved water quality could increase recreational interest in ponds -** the restoration of Lovers Lake and Stillwater Pond has immediate benefits for the shoreline owners and watershed residents. The restoration should also spark additional recreational interest in the ponds from Town residents and seasonal visitors as word spreads about their greater water quality and aesthetic appeal. The newly-developed trail system and launch area for Lovers Lake from Old Comers Road provides a convenient means of sharing the improved waters with the greater Chatham community and should see additional usage.

5.0 Summary and Conclusions

5.1 Assessment of Treatment and Initial Post-Implementation Pond Condition

A nutrient inactivation treatment was conducted on Lovers Lake and Stillwater Pond in Chatham, MA over six field days during October 2010. Technical oversight and monitoring was provided by Loon Environmental. Based on the information and data collected before, during and after the treatment, the following conclusions can be drawn:

- All pre-mobilization tasks, approvals, and activities were completed in accordance with the approved NOI Conditions.
- The mobilization/demobilization of equipment at the access points were conducted to the satisfaction of the Town and local property owner.
- The alum treatments were successfully and safely implemented in the two ponds without adverse impacts to aquatic biota and ensuring protection of shoreline endangered species.
- The ranges of the field monitored parameters (pH, alkalinity) were maintained within acceptable values during the treatments.
- Visual inspection of bottom sediments in treatment areas indicated good compliance with the proscribed limits of work and consistent application of alum floc in the treatment areas.
- Thermal structure indicated normal overturn occurring in Lovers Lake with full water column mixing in Stillwater Pond expected in early winter.
- Immediate post-implementation water quality results (i.e., within 2 weeks of treatment) indicated reduction in phosphorus fractions.

Overall, the alum treatments went very smoothly and were completed in a highly professional manner by ACT with little or no delays caused by access difficulties, equipment malfunctions, tanker truck deliveries or other causes. The initial post-implementation monitoring (November 2010) indicated substantial nutrient reductions and some residual traces of the alum treatment.

5.2 Post-Implementation Monitoring in 2011 and Major Findings

Water quality was measured and field observation made at regular seasonal intervals (April, June, August, October) in 2011 to provide for a full year of monitoring after the nutrient inactivation treatment. These samples provided a good measure of pond conditions following the nutrient inactivation and allowed for comparison to pre-implementation water quality data.

Strong evidence that the nutrient inactivation was successful and effective in restoring Lovers Lake and Stillwater Pond comes from several findings, including:

- Reduction in orthophosphorus and total phosphorus concentrations in both ponds when compared to pre-implementation conditions, particularly in the hypolimnion during the critical late summer period (Section 4.2.4).
- SDT values in August which were 2-3 times the clarity found in pre-implementation studies (Section 4.2.5).
- Return of dissolved aluminum concentrations to pre-treatment levels and no indications of any adverse effects to biota either during the alum application or during post-implementation monitoring (Section 4.2.3).
- Improvement in the ponds' trophic status as indicated by the shift from eutrophic to mesotrophic using the TSI assessment and/or approaching attainment of the CCC "healthy" pond total phosphorus criterion value (Section 4.3.2).
- Estimates of pre- and post-implementation "standing stock" of total phosphorus which suggest that most of the phosphorus supplied to the ponds by internal recycling has been eliminated (Section 4.4).
- Casual observations of excellent water clarity and pond conditions from informed viewers (Section 4.4).

Based on these findings, it appears that ecological restoration of Lovers Lake and Stillwater Pond has been successfully initiated. Given the chemical and essentially irreversible nature of nutrient inactivation, and the successful and predictable track record of alum treatment in Cape Cod ponds, it is highly likely that these favorable pond conditions will continue to prevail in the coming years.

6.0 References

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Appendices

A. Approved NOI Special Order of Conditions, NHESP letter & Certificate of Compliance

B. ACT pond maps and dose calculations

C. Field Logs

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E. Laboratory results
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   2. Toxicity testing (July 2010)
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F. Evaluation of nutrient inactivation worksheets

G. Letter Report from Loon to Dr. Duncanson, dated Dec. 17, 2012 summarizing the additional monitoring work completed in 2012

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Appendix B. ACT pond maps and dose calculations

Appendix C. Field logs

Appendix D. Photographs

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1. **Sediment chemistry (September 2009)**
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Appendix F. Evaluation of Nutrient Inactivation Worksheets

Appendix G. Letter Report from Loon to Dr. Duncanson, dated Dec. 17, 2012 summarizing the additional monitoring work completed in 2012