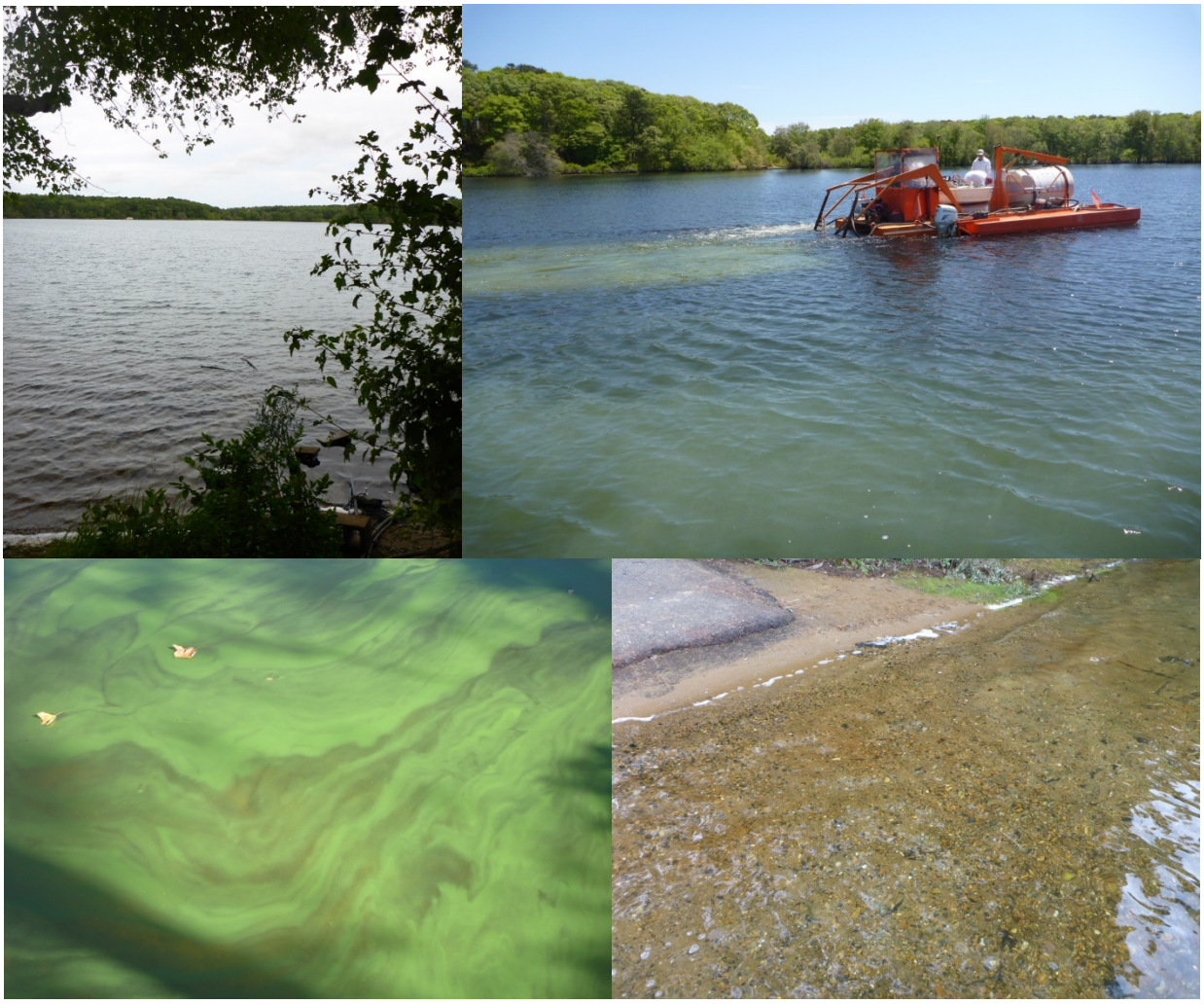
PHOSPHORUS INACTIVATION PROJECT FOR LOVELL'S POND, BARNSTABLE, MASSACHUSETTS



FINAL REPORT

BY WATER RESOURCE SERVICES, INC.

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Project Background and Need

Introduction

Lovell's Pond covers approximately 55 acres (22 ha) in the Town of Barnstable, near the boundary of the Town of Mashpee (Figure 1). It has public access directly off Santuit-Newtown Road, with a public boat launch, and has been stocked with trout for years. It has also been popular as a warmwater fishery. There is a community beach slightly off Santuit-Newtown Road, with a parking area and bathhouse, but it had not been actively used for some years, owing to serious blooms of cyanobacteria, also known as blue-green algae. Further, oxygen levels in the deeper waters of the pond are depleted in most summers, causing the release of a number of undesirable compounds from deep sediments, including phosphorus, iron, manganese, and hydrogen sulfide. The water is therefore murky much of the year and unattractive. The pond remains popular with waterbirds, such as herons, and hosts a productive fishery. There are few submergent plants, a consequence of low light.

In an effort to improve water quality in Lovell's Pond, a circulation system was installed in 2009 and operated fully in the summers of 2010 through 2012, but conditions did not improve. The system did not operate as planned, as the air compressor frequently shut down and oxygen depletion occurred in deep waters. Eventual repair of the compressor and restarting of the system mixed the low oxygen, deep water and whatever contaminants had been released from the sediment during the anoxic period with the upper waters of the pond. This may have worsened conditions, and cyanobacteria blooms were severe.

Water from at least two and probably three cranberry farming operations was discharged to Lovell's Pond for many years. Research on cranberry bog discharges has demonstrated high concentrations of phosphorus. Usually the volume of water discharged from the bogs is small relative to the volume of the receiving pond, and immediate impacts are not large, but the accumulation of phosphorus in pond sediments represents a major threat of internal recycling when low oxygen develops in deep water. All the contributing bogs went out of service over 5 years ago, and two have been purchased by towns (Barnstable and Mashpee) for open space. Direct impacts have therefore ceased, but legacy impacts through internal loading remained substantial.

Evaluation of current sources of nutrients to Lovell's Pond suggested that watershed inputs were minor and that internal loading was the dominant force in water quality. It was determined that there was potential for the air-driven circulation system to enhance water quality, but a new compressor and much more active management would be needed, at considerable cost. The cost of a phosphorus inactivation project using aluminum was favorable in comparison, and given success in other Cape Cod ponds, the town opted to pursue a phosphorus inactivation project.

Figure 1. Lovell's Pond general area.

Lovell's Pond Features

The pond is roughly circular in shape and bowl-like in three dimensions, with a maximum depth of 37.5 feet (11.4 m); physically it appears to be a classic kettlehole lake, formed by stranded ice at the end of the last glacial period over 10,000 years ago, based on bathymetry from the 1997 study by Ambient Engineering (Figure 2). The shoreline is about 5800 feet (1770 m) long, and the diameter of the pond is about 2000 feet (600 m). Pond volume is approximately 45 million cubic feet (1.3 million cubic meters), suggesting an average depth of just under 19 feet (5.7 m). However, the water level can fluctuate by about 3 feet as a function of limited surface outflow and continuous evaporation and groundwater movement. Volume therefore fluctuates between about 0.9 and 1.5 million cubic feet (25,500 and 42,500 m^3).

Kettlehole lakes tend not to have inlets or outlets, but Lovell's Pond has both. Human action may have been involved in the creation or at least alteration of those inlet and outlet points, and neither has a continuous direct connection to the pond at this point. Inflow from Santuit Pond is blocked off, as this is not the normal outlet for Santuit Pond, although vandalism and some leakage have allowed some water to enter through the former cranberry bogs to the northwest. The outlet pipe just east of the town beach is filled with sand; flow is evident several hundred meters downstream of the pond, but most water appears to leave as ground water seepage. There are no controls on inlet or outlet that allow finer flow control.

Watershed Features

The Lovell's Pond watershed is difficult to delineate, as it has separate ground water and surface water components that are not congruent. In the 1997 study from Ambient Engineering, contributory areas were delineated (Figure 3) and appear to be rational representations of the areas that provided water to Lovell's Pond at that time.

Water from Patty's Pond to the north flowed through a large cranberry bog and into Lovell's Pond; that flow path may have been created by human action to provide water to the bogs and discharge it downgradient. With the cessation of cranberry farming in that area, it is not clear that any flow is sent from Patty's Pond through the former bogs to Lovell's Pond. This entire northern drainage area may no longer contribute any surface water to Lovell's Pond.

Water from Santuit Pond, running in a channel sometimes referred to as the Santuit River but not the primary channel of that stream, used to enter Lovell's Pond from the west after passing through a cranberry bog; again, the flow route may have been created by human actions for irrigation purposes and was at least altered for those purposes. With the cessation of cranberry farming in that area and the blocking of the flow of water into Lovell's Pond from that route, surface flow from the area west of the pond has been minimized. The flow of water from Santuit Pond and other western surface drainage to Lovell's Pond is now small.

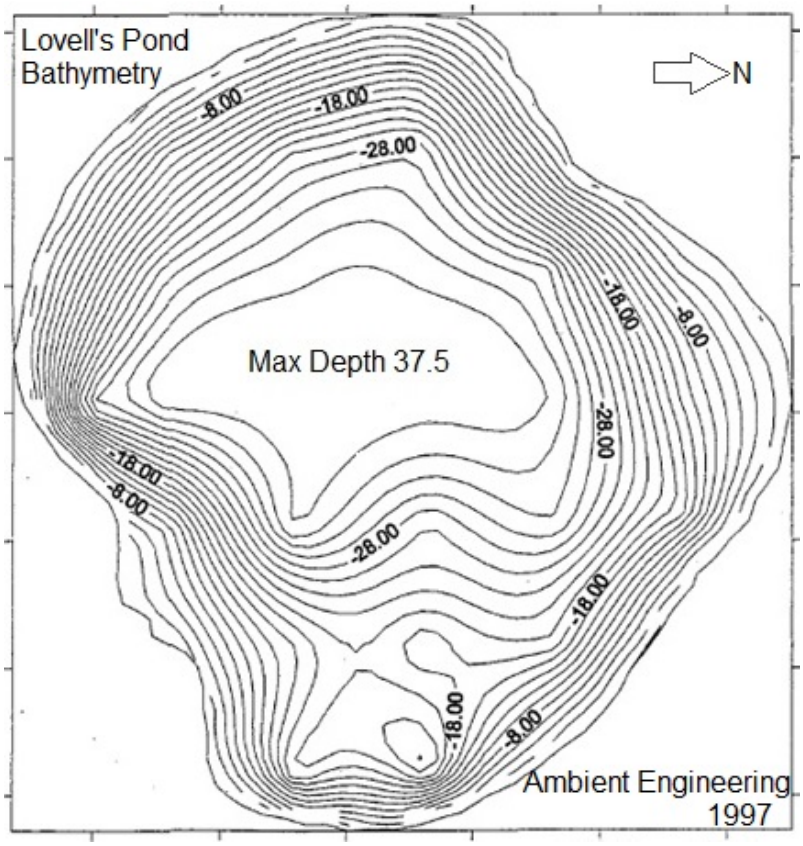


Figure 2. Bathymetric map of Lovell's Pond

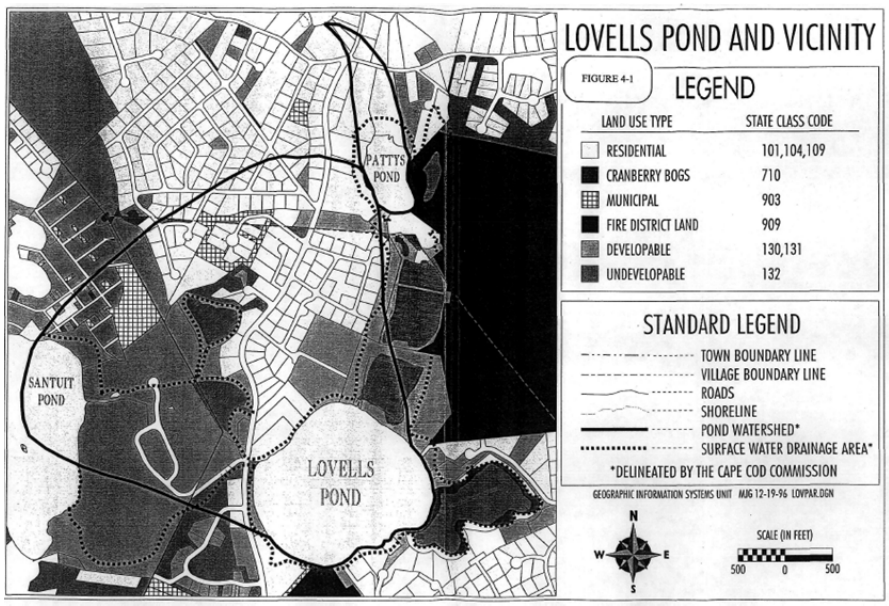


Figure 3. Ground and surface watersheds for Lovell's Pond.

The bog to the east of Lovell's Pond is downgradient of the pond. Water from Lovell's Pond was released into that bog for irrigation and harvest, but it is unclear whether withdrawn water was pumped back into the pond or released into some downstream channel. However, this bog is also no longer active, and is functionally no longer an influence on Lovell's Pond.

Contributory area for surface flow is therefore now largely restricted to land very close to Lovell's Pond, an area of only about 10 acres, most of it in low density residential development with sandy soils, so runoff potential is low. The ground water contributory area is probably much as suggested by the 1997 Ambient Engineering report, and covers an area of about 350 acres. This area is a mix of moderate density residential development, former cranberry bog, and land in second growth forest. With current land ownership, the pattern of land use is likely to remain as is indefinitely, and external loading to Lovell's Pond is considered low.

Lovell's Pond Fishery

Lovell's Pond does thermally stratify, although the portion of the pond that remains cold water through the summer is small, and throughout the period of record it has been mostly anoxic during summer. Consequently, there is very little suitable habitat for cold water fish such as trout. The pond is stocked annually in the spring with trout, however, providing a put-and-take fishery. Some trout might survive the summer, but not many and not in good condition, given the stress of warm water in the upper layer and low oxygen in the lower layer.

Lovell's Pond does host a substantial warm water fishery, with largemouth bass as the primary gamefish. Lack of extensive macrophyte beds limits habitat for chain pickerel. Smallmouth bass may be present but are not regularly reported by anglers. Other fish include pumpkinseed sunfish, yellow perch, and bullheads. Various minnow species are also present, Alewife used to enter the pond from Santuit Pond through the western cranberry bog during water transfers, but this practice was halted when the bog was purchased by the town. There do not appear to be any alewife in Lovell's Pond, based on a 2013 survey by DFW.

There is a substantial population of eastern elliptio mussels, but no other major invertebrate resources have been noted.

Plankton

Summer algae have been dominated by *Dolichospermum* (formerly *Anabaena*), *Microcystis*, *Aphanizomenon, Planktolyngbya* and *Pseudanabaena,* all cyanobacteria. Surface scums form when wind speeds are minimal, but windblown accumulations have been common along shore, particularly near the boat ramp on the west side of the pond. A variety of green algae are present, dinoflagellates are sometimes abundant, and golden algae are more abundant over the winter.

Zooplankton have been abundant in the spring but scarce in the summer, probably a function of intense predation by small fish, but also possibly related to poor food resources. Larger bodied

Daphnia have been observed in spring, but do not survive the summer. This is consistent with intense predation pressure (many small yellow perch were observed in a 2014 fishery survey) and the shift to dominance by cyanobacteria during summer.

Macrophytes

Macrophytes have not been a dominant component of the Lovell's Pond system. Peripheral forms, mostly emergent or floating leaved species (Table 1) are observed but are not abundant beyond the very edge of the pond. The only submergent form in water more than about 3 feet (1 m) deep was the macroalga *Nitella*, which grows reasonably well under low light conditions. The bottom is sandy to a depth of at least 12 feet (3.6 m) in most places, limiting many forms of submergent growths, but the lack of plants is still striking and suggests that shading from algal blooms has been a persistent problem in Lovell's Pond. Note that *Persicaria puritanorum*, a species of special concern related to smartweed (*Polygonum*), is listed for this pond. It is a peripheral species found in small patches along the northern shore of the pond.

Sediment Assessment

The substrate, or pond bottom material, matters greatly to habitat and water quality. Rocky to sandy substrates have limited impact on overlying water quality, while organic sediments, also called muck sediments, tend to have more interaction with water and can substantially alter water quality. Where there is concern over possible release of phosphorus from sediment exposed to anoxia, both the distribution of anoxia and the types of sediment are of interest.

Muck deposits in Lovell's Pond (Figure 4) were noted at depths beyond about 18 feet (5.5 m). In total, there are just under 27 acres completely covered by muck and almost 10 more acres partially covered by muck, all of which could be subjected to anoxia at times. Muck deposits exceed 0.5 feet (0.15 m) in water >25 feet (7.6 m) deep.

Lovell's Pond soft sediment is fairly typical pond muck, low in solids (high in moisture) content with moderate organic content (25 to 32%). It could be easily resuspended and would be expected to exert a high oxygen demand. Iron-bound phosphorus ranged from 140 to 365 mg/kg, all in what would be considered the moderate range. Values in excess of 1000 mg/kg are sometimes recorded for Cape Cod ponds, and other Barnstable ponds treated with aluminum have had values similar to or higher than the ones recorded for Lovell's Pond.

Oxygen Demand

Oxygen profile data can be used to assess oxygen demand from data where oxygen levels have not dropped to levels too low (<2 mg/L) to allow linear interpretation of loss over depth or time. Applying data from April and May of 2013, the loss rate for oxygen is estimated at 1.31 g/m^2/day. Ponds with oxygen demand levels in excess of about 0.55 g/m_2/day will often experience some anoxia (Hutchinson 1957), and those with oxygen demand >1.0 g/m^2/day are likely to experience substantial anoxia, and values as high as 4.0 g/m^2/day have been recorded for Cape Cod ponds. So

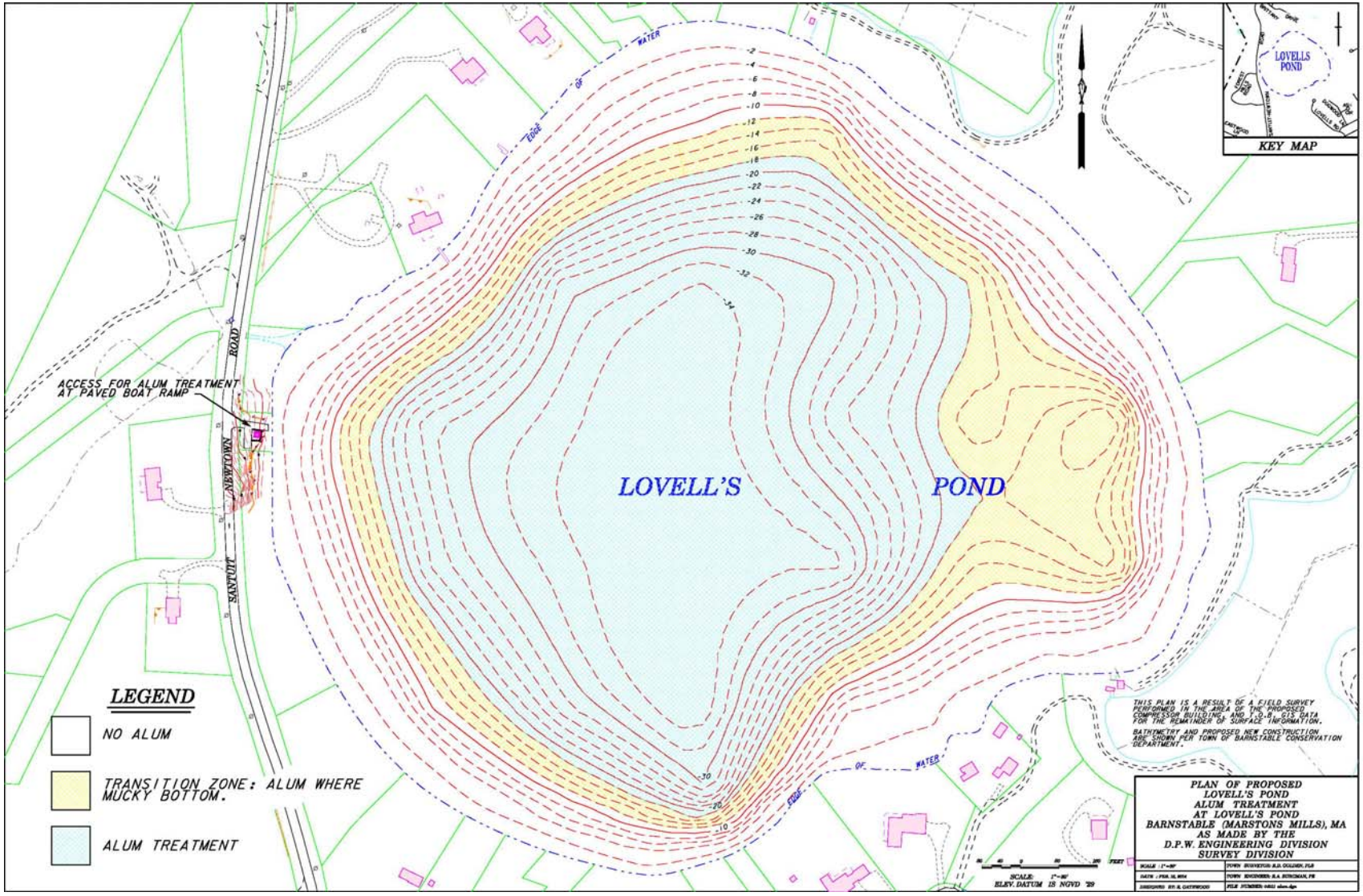


Figure 4. Start of muck deposits (yellow) and area completely overlain by muck (blue) in Lovell's Pond

the Lovell's Pond value is not unusual and is consistent with the observed anoxia. Countering that anoxia by adding oxygen will require more oxygen than the demand would indicate, by a factor between 1.25 and about 5.0 based on other studies (Wagner 2015).

Water and Nutrient Loading

Based on detailed data from 2013 and consideration of PALS data from single samplings each year since 2001, water, nitrogen and phosphorus loads were summarized (Table 1). The water load of a little over 600,000 m^3/yr suggests a detention time for this 1.3 million m^3 pond of just over 2 years. About 62% of the phosphorus load of 42.6 kg/yr is contributed by internal loading from sediments, while just under half of the total nitrogen load of 815.5 kg/yr is from internal sources. To reach a desirable phosphorus concentration of 0.01 mg/L, which would minimize algae blooms, a 58% reduction in phosphorus loading is needed. This can only be obtained by addressing the internal load.

Table 1. Nutrient loads to Lovell's Pond

Source	Assumptions	Water Flow (m3/yr)	P (kg/yr)	%	N (kg/yr)	%
Precipitation	P @ 0.015 mg/L; N @ 0.2 mg/L	260,000	3.9	9.2%	52.0	6.4%
Ground water	P @ 0.02 mg/L; N @ 1.0 mg/L	331,000	6.6	15.6%	331.0	40.6%
Direct runoff	P @ 0.10 mg/L; N @ 1.0 mg/L	16,500	1.7	3.9%	16.5	2.0%
Tributaries	None	0	0.0	0.0%	0.0	0.0%
Diversions	None	0	0.0	0.0%	0.0	0.0%
Internal load	12 mg P/m2/d for 100 d over 27 ac (110,000 m2), 20% reaching upper waters; same approach for N, but with 36 mg N/m2/d and 100% reaching upper waters.	0	26.4	62.0%	396.0	48.6%
Wildlife	20 bird-years with P @ 0.2 kg/bird-yr, N @ 1.0 kg/bird-yr	0	4.0	9.4%	20.0	2.5%
Total		607,500	42.6	100%	815.5	100%

Project Need

With the reduction in watershed loading represented by cessation of cranberry bog operation and the failure of the circulation system to reduce algae blooms and improve clarity, the Town of Barnstable sought an alternative means to reduce internal loading of phosphorus. The circulation system was not run in 2013, and conditions in the absence of any further management did improve somewhat, but clarity was still lower than desired, oxygen remained low in deep water, and cyanobacteria were still abundant by late summer. Given the success of aluminum applications in other ponds in town, an aluminum treatment was planned and implemented.

Phosphorus Inactivation Project

Dosing suspensions of sediment with aluminum in lab assays provides an indication of the level of reduction in iron-bound phosphorus availability that could be gained by an inactivation project. Based on past experience, these results can be translated into an inactivation dose with a high potential for improving the pond, although lab assays may not translate perfectly into field results. The target for lab tests is to reduce iron-bound phosphorus to levels below detection, which is usually somewhere between 15 and 50 mg/kg. However, with the iron-bound phosphorus fraction representing only 13 to 21% of the total phosphorus content of the muck sediment in Lovell's Pond, some interaction with other forms of phosphorus may compromise the results, and there are diminishing returns to additional aluminum input. More phosphorus is inactivated per unit of aluminum added at lower doses than higher doses, but enough must be added to attain the level of reduction in iron-bound phosphorus necessary to limit internal loading to the desired degree. For Lovell's Pond, the target dose was set at 50 g/m^2, based on the lab assays.

A stoichiometric approach in which the aluminum dose is set based on the amount of iron-bound phosphorus in surficial sediment times a factor to sway equilibrium chemistry in favor of moving phosphorus from iron to aluminum compounds (anywhere from 10 to 100) suggests a target dose between 24 and 65 g/m^2 using a factor of 20, generally supporting the 50 g/m^2 dose estimated from lab assays.

The proposed dose of aluminum over the estimated maximum target area of 35 acres (15 ha) was just under 7400 kg, planned to be delivered at a 2:1 ratio of aluminum sulfate to sodium aluminate by liquid volume. Aquatic Control Technology of Sutton, Massachusetts conducted the treatment, as it has nearly all other treatments of Cape Cod lakes. The skill and professionalism of ACT in the conduct of aluminum treatments is acknowledged and appreciated. Actual application involved 13,901 gallons of aluminum sulfate and 6998 gallons of sodium aluminate, a ratio of 1.99:1, applied to 35 acres over 4 days between May 30 and June 4, 2014. This equates to 7046 kg of aluminum applied to an area just slightly smaller than the blue and yellow shaded areas in Figure 4. An initial 10 acre pilot area was treated on Friday, May 30th and monitored for water quality and biological impacts through the weekend. With no significant adverse impacts detected, treatment was performed Monday through Wednesday, June 2-4. The total aluminum dose of 50 g/m^2 was applied in two separate applications, limiting the dose at any one time to 25 g/m^2 and keeping the initial aluminum concentration in the water column between 2.5 and 6.0 mg/L, and acceptable range to minimize the risk of toxicity.

The pH was in the highly desirable target range of 6.5-7.2 more than 95% of the time during treatment and never got outside 6-8 except for the pre-existing bottom pH in the deepest part (>10 m) of about 5.8. The highest pH was 7.6, recorded just prior to treatment at the surface under very calm conditions. As soon as the wind picked up, surface pH dropped to near 7.0. The most common pH during treatment was 6.9, a very desirable value for effective, nontoxic treatment. Alkalinity never changed more than 1 mg/L in treatment areas and ranged from 3-7 mg/L at the top and 8-14 mg/L at the bottom. Oxygen was low in water >8 m from the start, and water >10 m deep was anoxic, resulting in a fairly large area with a very thin anoxic layer; this layer corresponded to the

higher alkalinity and lower pH values obtained, but was only about 5-6 feet thick. Temperature was <20 C everywhere, warmest at the top, and was <10 C at the bottom.

No widespread mortality was observed in daily surveys that included visual observation along the shoreline and inspection with underwater video equipment in deeper areas. A total of 9 dead fish were detected from surveys during and after treatment, no more than 3 per day, and included white suckers, yellow perch, one pumpkinseed sunfish and one pickerel. These fish may have been casualties of aluminum exposure, but mortality of fish is common at that time of year from natural causes. No damage indicative of fishing mortality was observed, but at least one fish had cuts that suggested boat motor impact. All dead fish were noticeably thin, and may not have been very healthy to start with. Large and healthy bass were observed swimming around the edge on several survey laps. A few old carcasses were observed on the bottom, possibly stocked trout, but these were in advanced stages of decay and not related to treatment. No confirmed trout were observed during the treatment, alive or dead, but 760 trout of 12+ inches in length had been stocked by DFW over a month prior to treatment.

Water clarity at the start was relatively high, just over 4 m, the highest recorded for Lovell's Pond in recent years, but with low oxygen at the bottom and the start of a cyanobacteria bloom (mainly *Microcystis*) at the surface on the first day of treatment. Water clarity was 4.6 to 4.7 m everywhere in the pond at the end of treatment. Zooplankton were very abundant just prior to treatment, and were still moderately abundant after treatment. Some capture and flocculation of zooplankton is expected during treatment, but recovery is usually rapid, and abundance did not seem severely depressed by treatment. Water quality samples for nutrients and dissolved aluminum were collected prior to treatment and several hours after the end of treatment, then monthly through September 2014 and again between June and September 2015.

Monitoring Results

Late summer data for temperature and oxygen prior to initiation of circulation in 2009 (Figure 5 and Appendix A) suggests thermal stratification with a boundary between 3 and 5 m and anoxia below 5 to 6 m. When the circulation system was running properly, temperature and oxygen were fairly constant from top to bottom, but a thermal gradient and oxygen depression or depletion were observed when the system was offline. Example profiles from early summer during the years in which circulation was applied (Figure 6) indicate that 3 out of 4 times the pond was not isothermal and oxygen at the bottom was low. Example profiles from late in summer during the circulation years (Figure 7) suggest better success at preventing stratification, but oxygen was sometimes well below saturation, suggesting that the oxygen demand had not been adequately countered. Compressor failure, lack of monitoring and rapid response to shutdowns, and often late initiation of circulation in the spring prevented better results. Circulation is a technique that must prevent poor conditions from developing to deliver full benefits. There was nothing wrong with the theory behind the stratification system; it was a failure of operation that yielded poor results.

Oxygen levels in 2013, without the circulation system running but before any aluminum application, were similar to the period before circulation (Appendix A), with thermal stratification, loss of oxygen in deep water, and elevated phosphorus from internal recycling during summer. Very slight improvement may have reflected some decrease in oxygen demand from 4 years of circulation, or may just have been a function of weather-induced variation; 2013 was not an especially hot, sunny summer.

Aluminum was applied in late May and early June of 2014. Thermal stratification was setting in on May 30th, the start of treatment, with no oxygen below a depth of 9 m (Appendix A). Profiles from June 4 through September 9 or 2014 indicated less strong thermal stratification, with no sharp thermocline forming and the mixed depth increasing from 3 m on June 4 to 6 m on September 9 (Figure 8). Oxygen was not depleted above a depth of 10 m, and improved in deep water over the summer, contrary to the previously observed pattern of increasing oxygen deficit. While oxygen was still too low for most fish and other desirable forms of aquatic life below a depth of 8 m, this represented substantial improvement over previous years, when inadequate oxygen to support desirable aquatic life was observed below depths of 5 to 6 m through most of summer.

The thermal and oxygen profiles for 2015 (Figure 9) indicate stratification at between 5 and 6 m, similar to the post-treatment period in 2014, and oxygen was depleted only below depths of about 10 m. Oxygen was adequate for most fish at depths up to 8 m until the very end of summer. While there is still a substantial oxygen demand exerted in deep water, conditions are much improved over pre-treatment years (Figure 5). Calculated oxygen demand from spring profiles in 2015 was 0.61 g/m^2/day, slightly less than half the pre-treatment value.

Phosphorus levels in Lovell's Pond (Figure 10) were not extremely high in surface water prior to circulation, averaging about 20 µg/L. This is enough to support algae blooms, but is not really excessive. However, deep water phosphorus levels were often >100 µg/L, and algae growing near

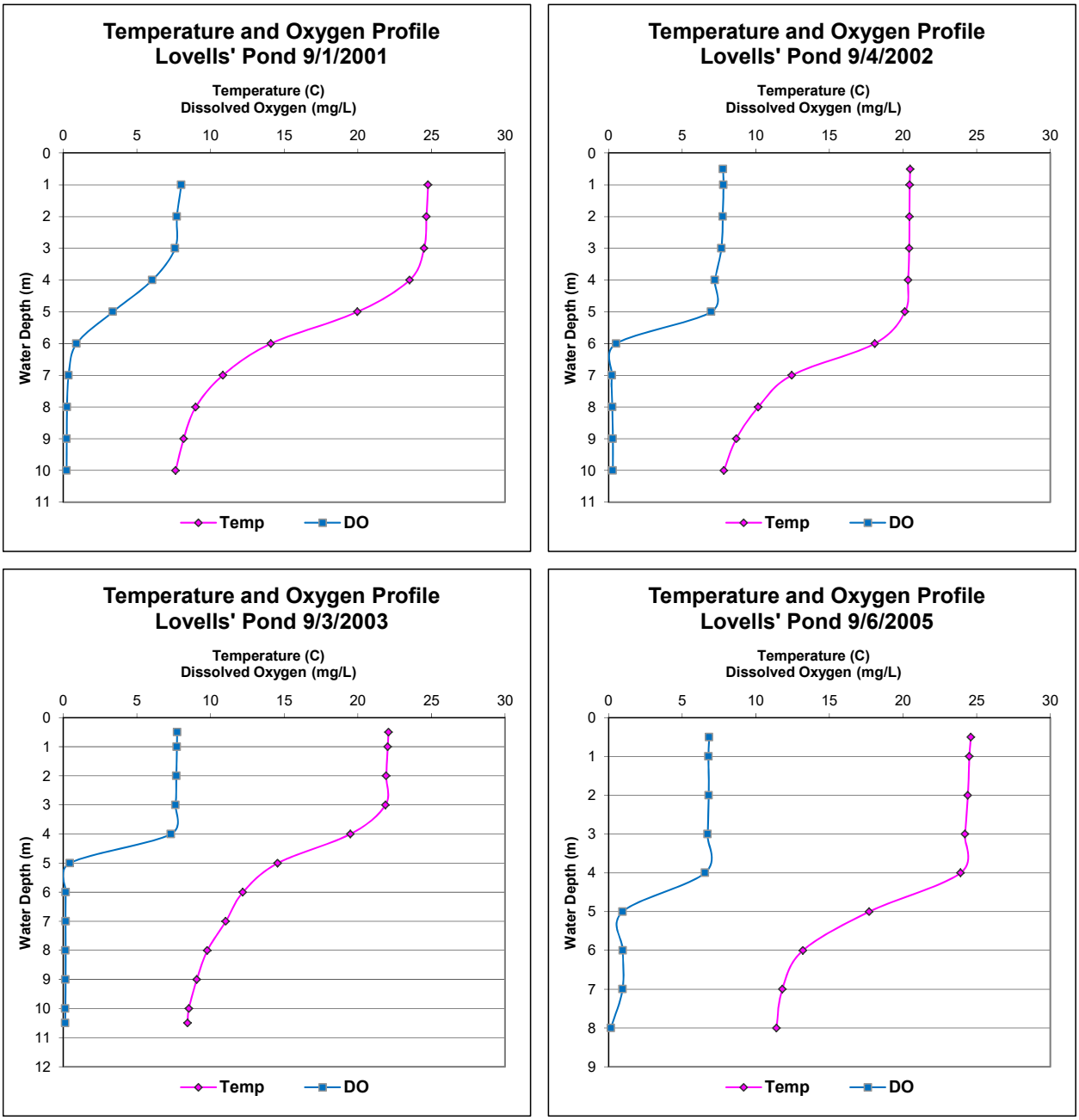


Figure 5. Late summer T/DO profiles prior to circulation or aluminum treatment in Lovell's Pond

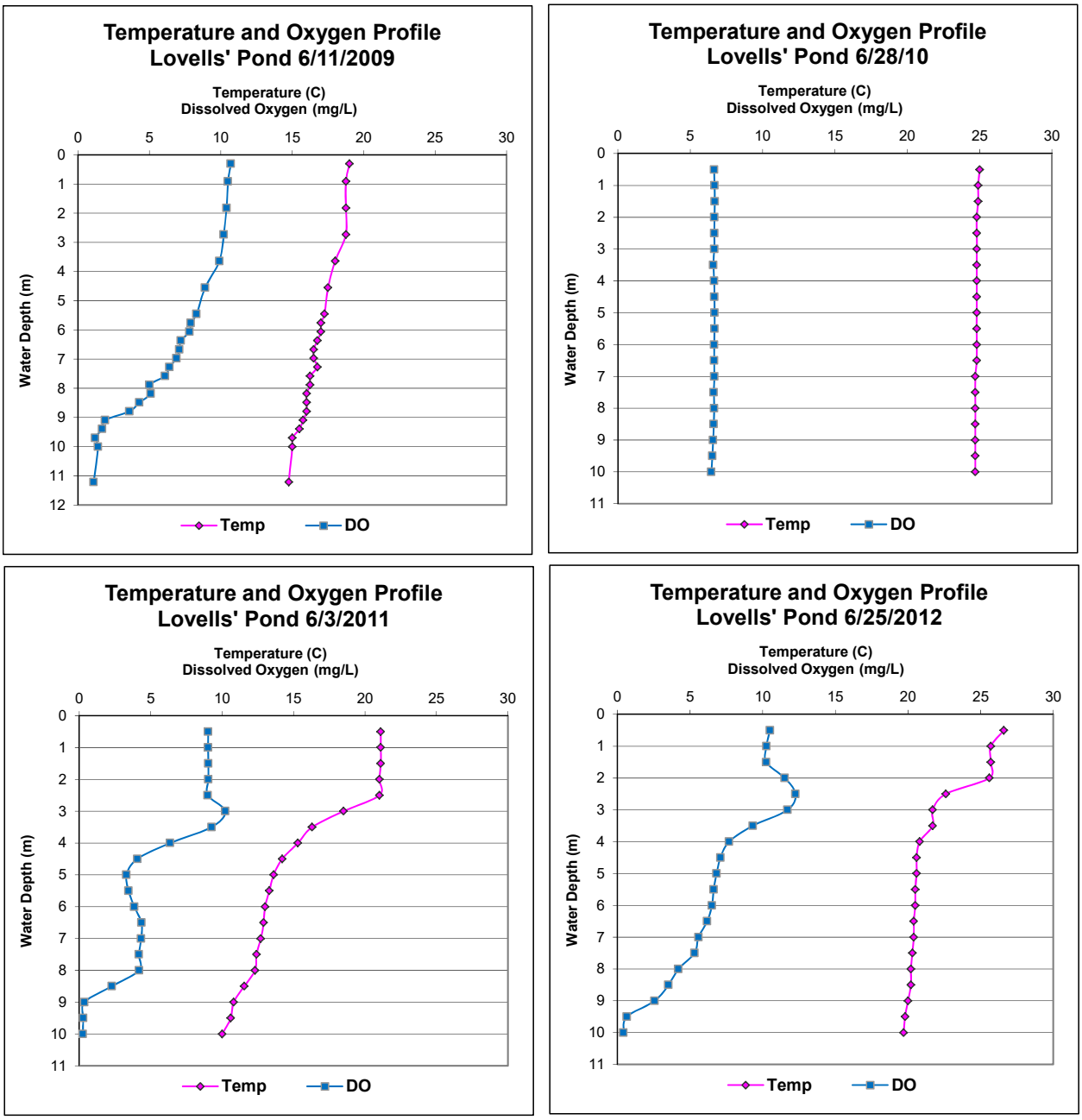


Figure 6. Early summer T/DO profiles in circulation years in Lovell's Pond

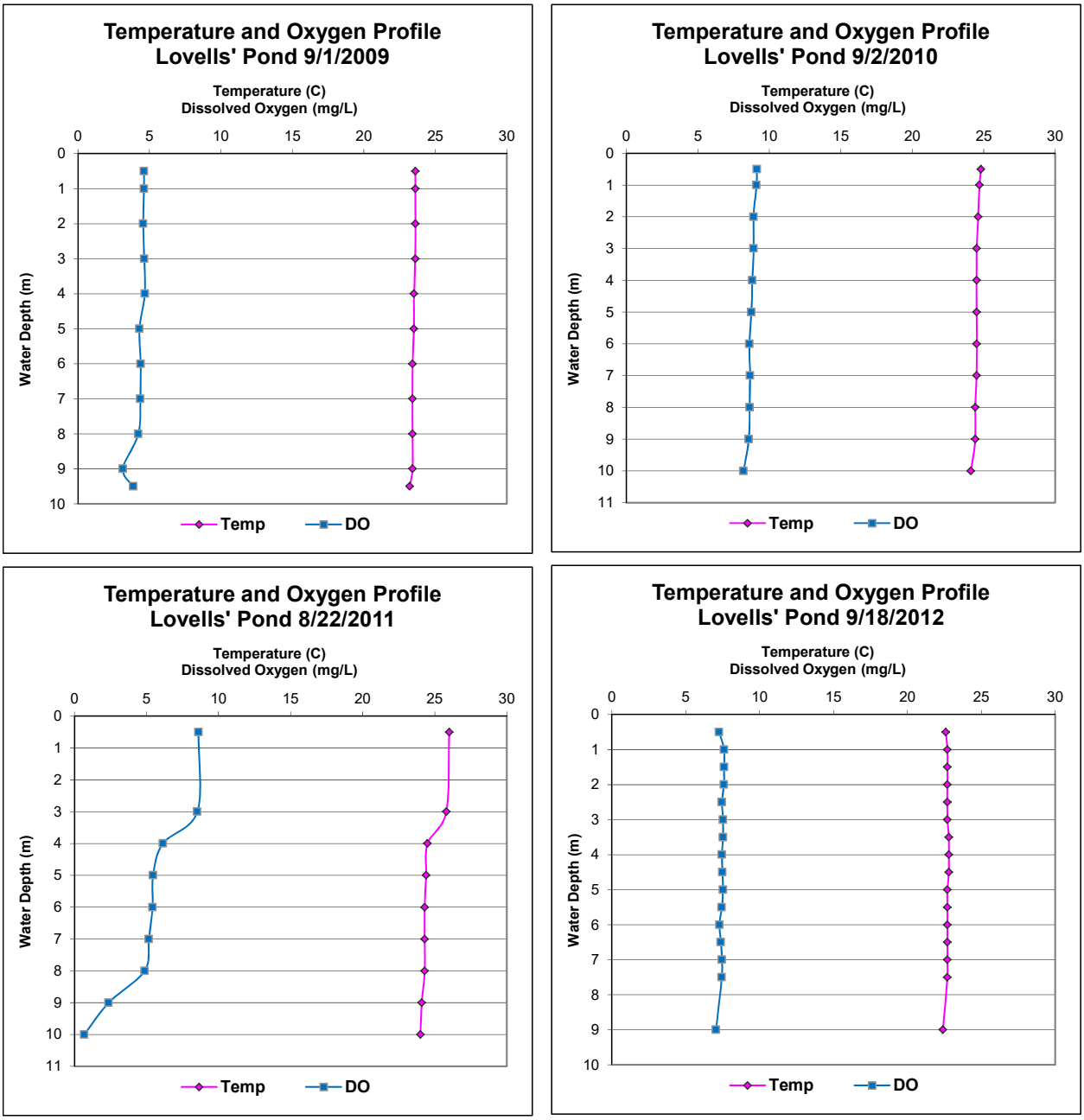


Figure 7. Late summer T/DO profiles in circulation years in Lovell's Pond

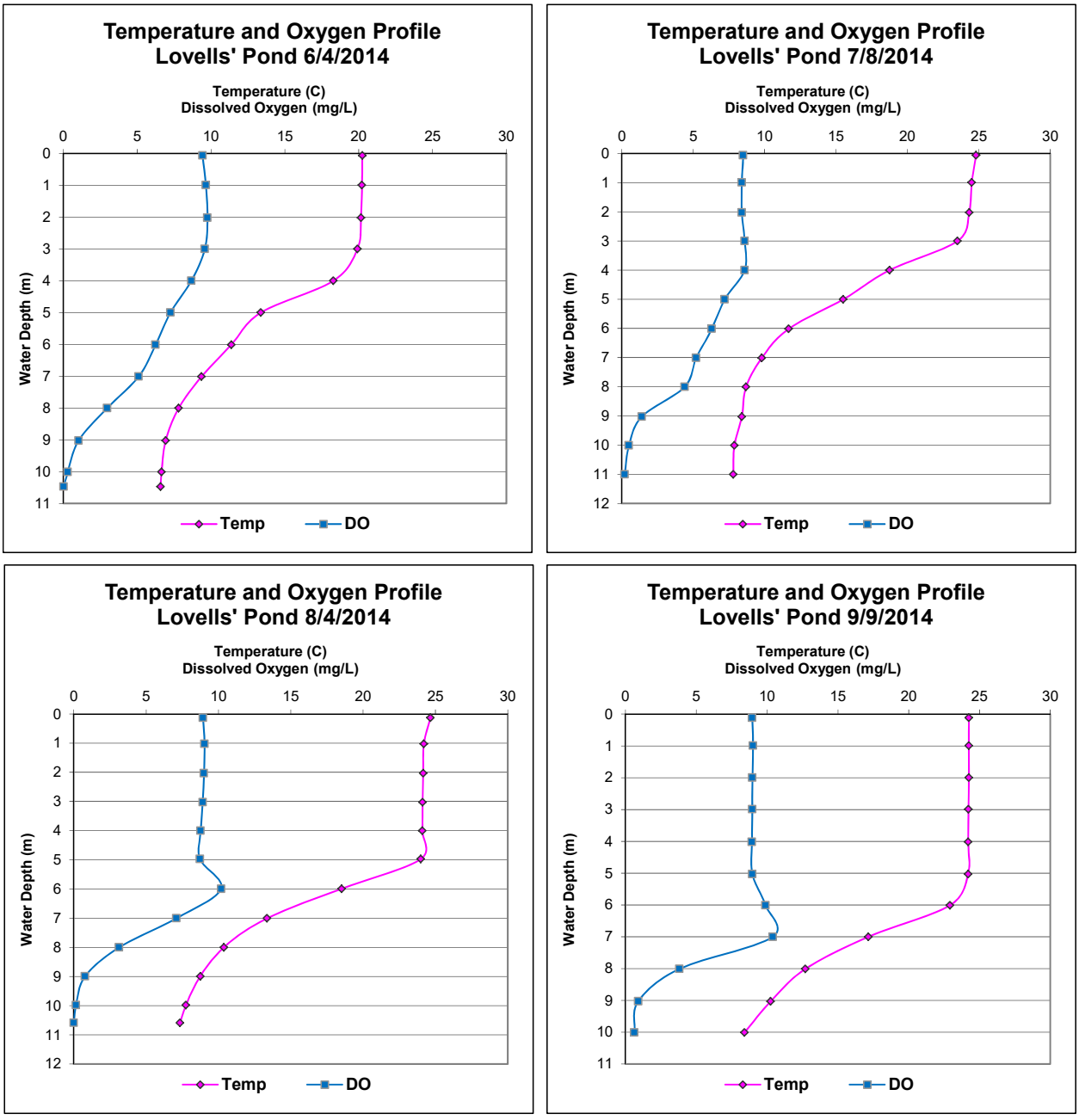


Figure 8. T/DO profiles after aluminum treatment in Lovell's Pond, 2014

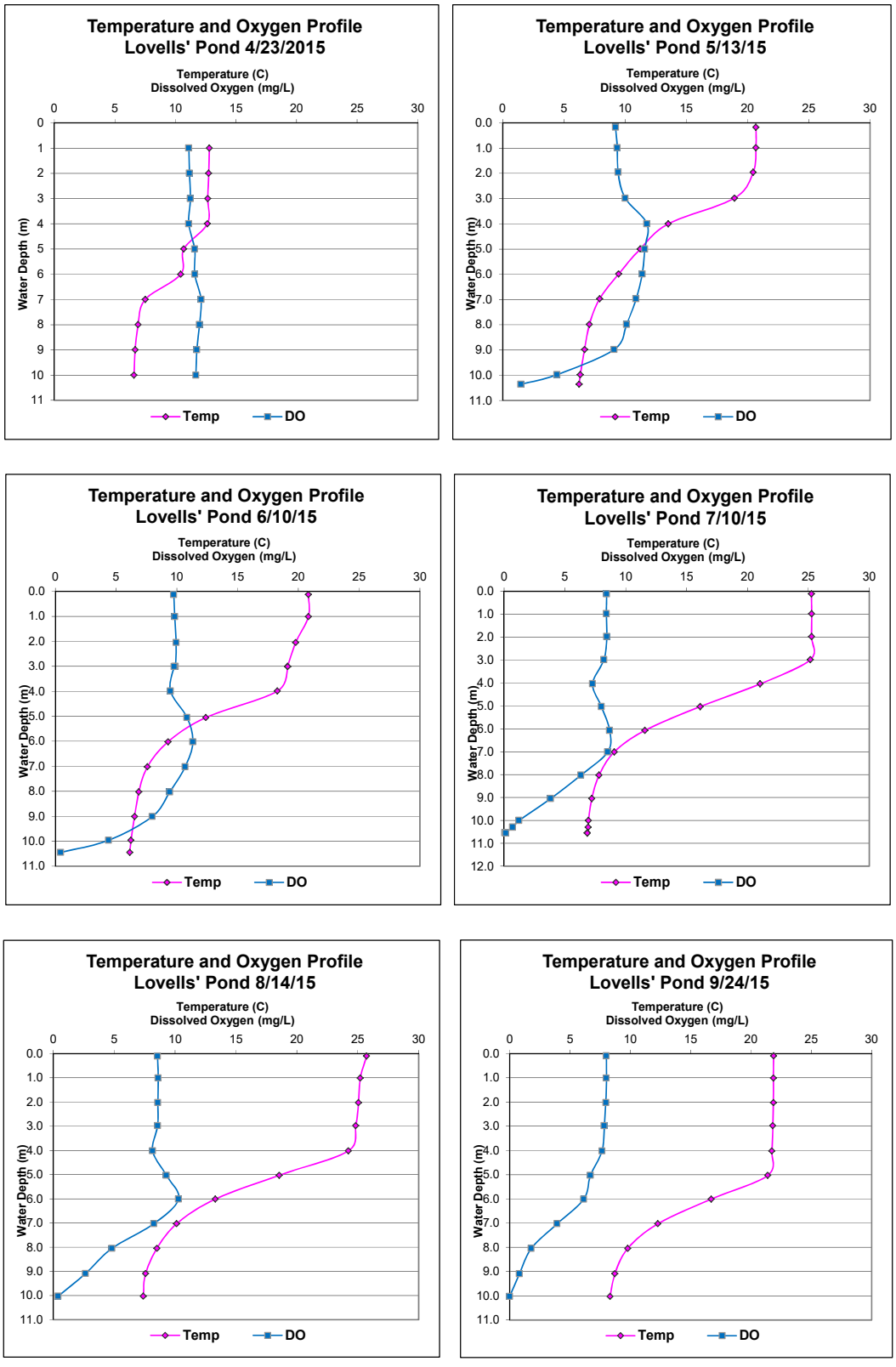


Figure 9. T/DO profiles after aluminum treatment in Lovell's Pond, 2015

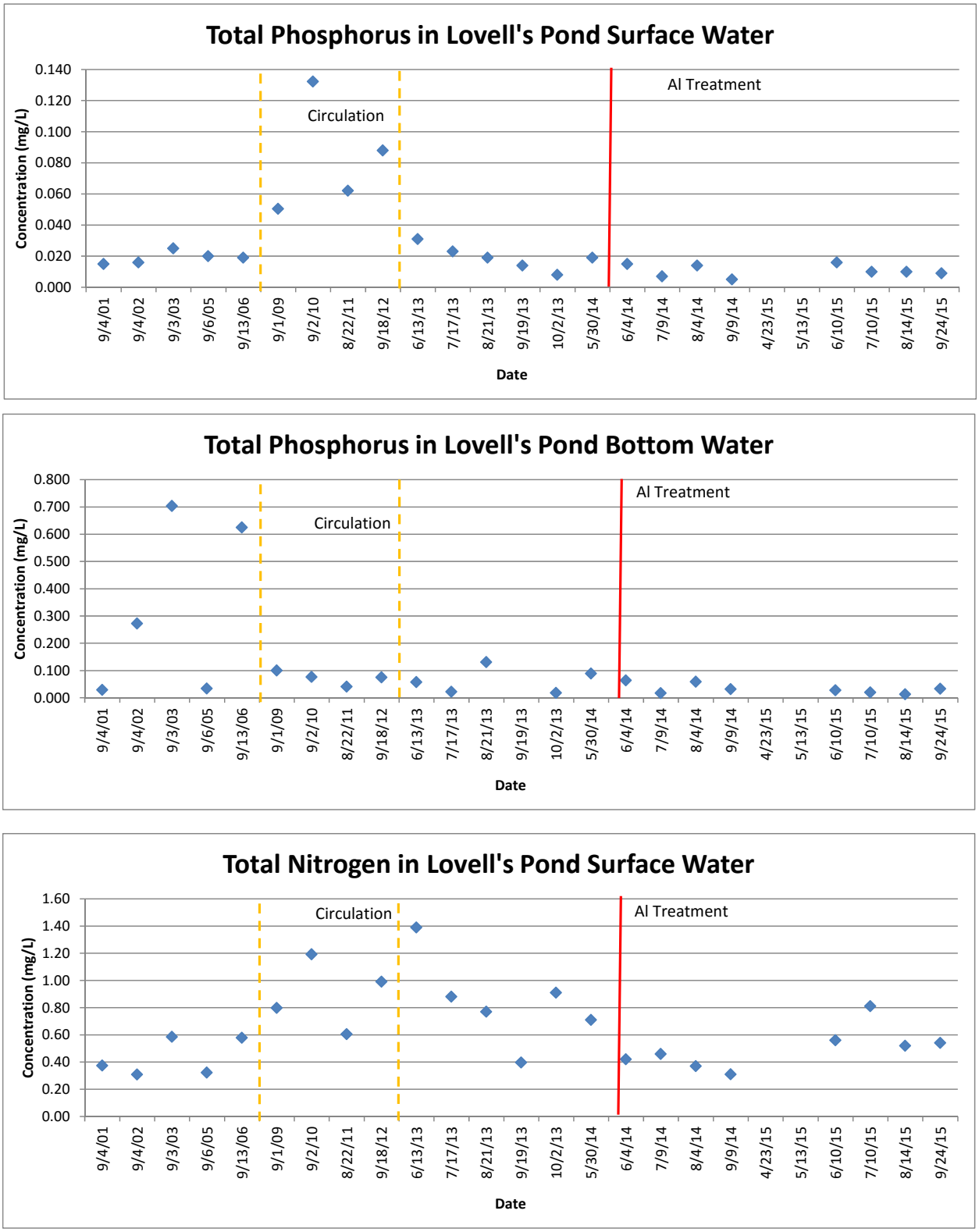
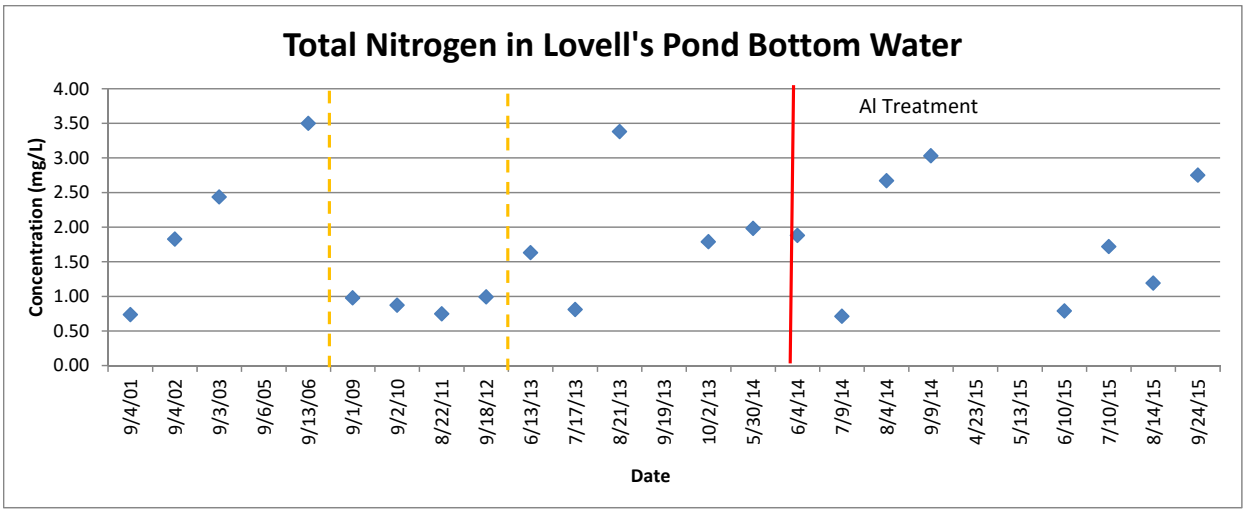
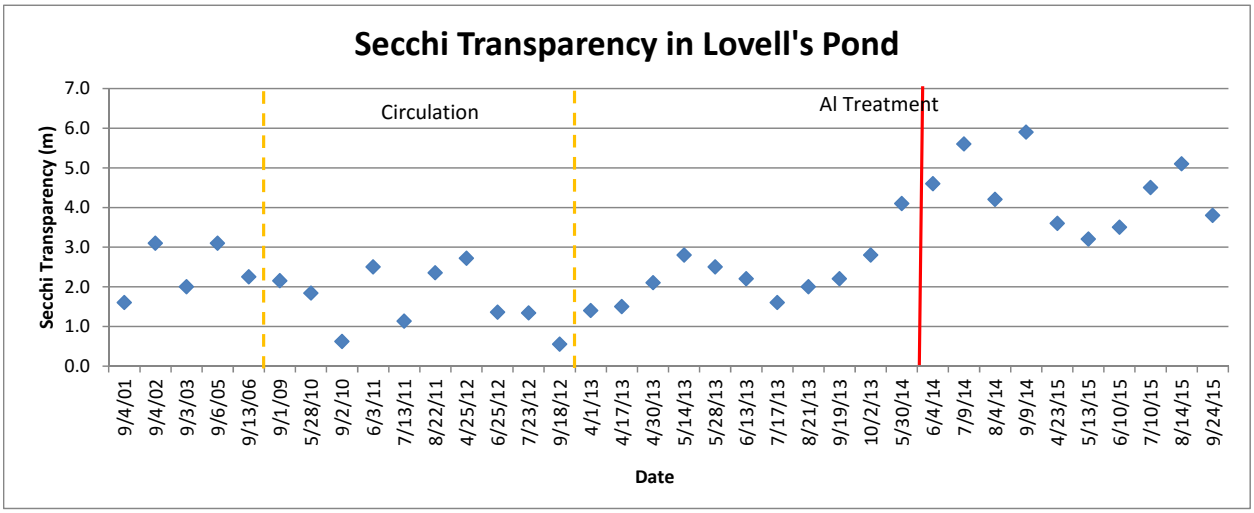


Figure 10. Water quality in Lovell's Pond – Part 1.





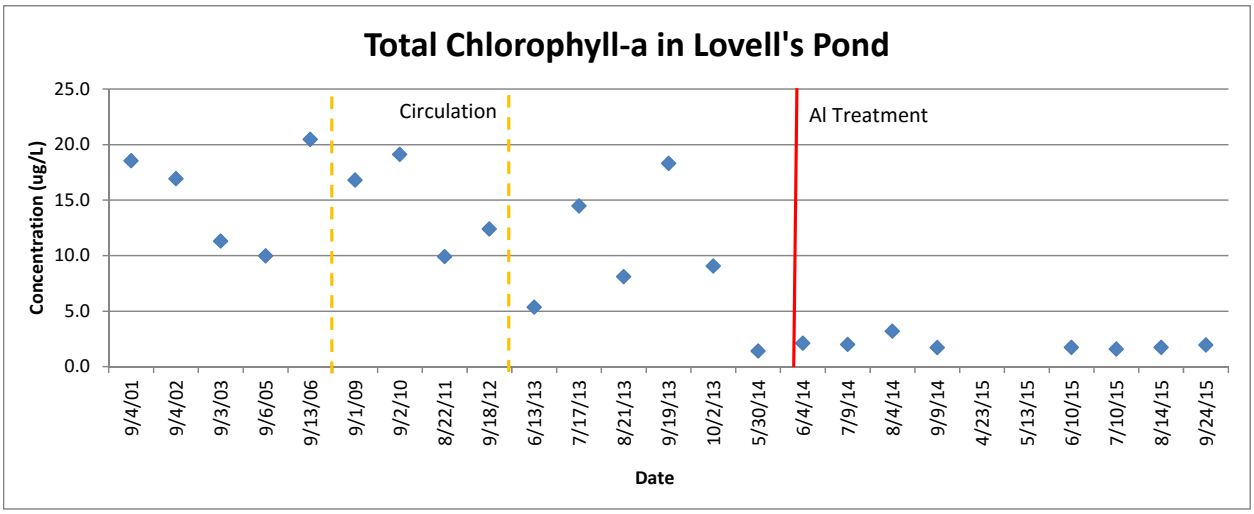


Figure 11. Water quality in Lovell's Pond – Part 2.

the thermocline or at the sediment-water interface could become very dense. Many cyanobacteria utilize this method to accumulate substantial nutrients prior to developing gas pockets in cells and rising to the surface, where resulting blooms can be severe; this appears to have been an important mechanism of bloom formation in Lovell's Pond prior to treatment with aluminum.

Circulation reduced the phosphorus concentration in deep water, but increased it in the upper water layer (Figure 10). Successful circulation should have minimized phosphorus release from the sediment, but the intermittent operation experienced in Lovell's Pond resulted in pulsed release with mixing into the upper layer, to a point where the vertical distribution of phosphorus was roughly reversed from the pre-circulation period. Algae blooms were readily supported. Conditions were variable but more like pre-circulation times in 2013. After aluminum treatment, phosphorus was lower on average in the top and bottom layers of Lovell's Pond than in previous periods of record and considerably less variable (Figure 10).

The pattern for nitrogen was very similar to that for phosphorus up to the point of aluminum treatment, with moderate values near the surface and higher values in deep water prior to circulation, followed by a reversal during circulation, then a return to pre-circulation conditions in 2013 (Figures 10 and 11). However, aluminum treatment has limited impact on nitrogen, possibly affecting the forms of nitrogen, but not greatly reducing the total. However, as phosphorus is greatly reduced by aluminum treatment, the nitrogen:phosphorus ratio is raised. Average N:P ratios increased by almost threefold in surface water and almost fivefold in deep water after aluminum application.

The combination of lowered phosphorus and increased N:P ratio both reduced algae abundance and changed the composition of the phytoplankton, shifting it away from cyanobacteria. Chlorophyll-a was greatly reduced from values observed over the past 13 years and water clarity, measured as Secchi transparency, increased greatly (Figure 11). Cyanobacteria abundance in 2013 was not as high as visually observed in other past years, but was still considerably greater than in 2014 after aluminum treatment (Figure 12). Phytoplankton composition in 2014 was more varied and included none of the bloom forming cyanobacteria observed in past years.

Phytoplankton in April and May of 2015 exhibited moderate biomass (Figure 12) and no problem species, typical of spring assemblages that support a desirable food web. Biomass declined in June, a common occurrence in lakes called a clear water phase, then increased gradually to moderate levels in September with several blue-greens at higher abundance than expected two growing seasons after treatment (Mattson et al. 2004). Conditions were still far better than before treatment, but the bloom-forming *Microcystis* and *Anabaena* (now called *Dolichospermum* for future reference) were abundant enough in the phytoplankton to represent a slight concern. Golden algae were still most abundant, and clarity was still quite acceptable, but the pond did not have the strikingly clear appearance of mid-summer that we have come to expect following aluminum treatments. This bears monitoring in 2016.

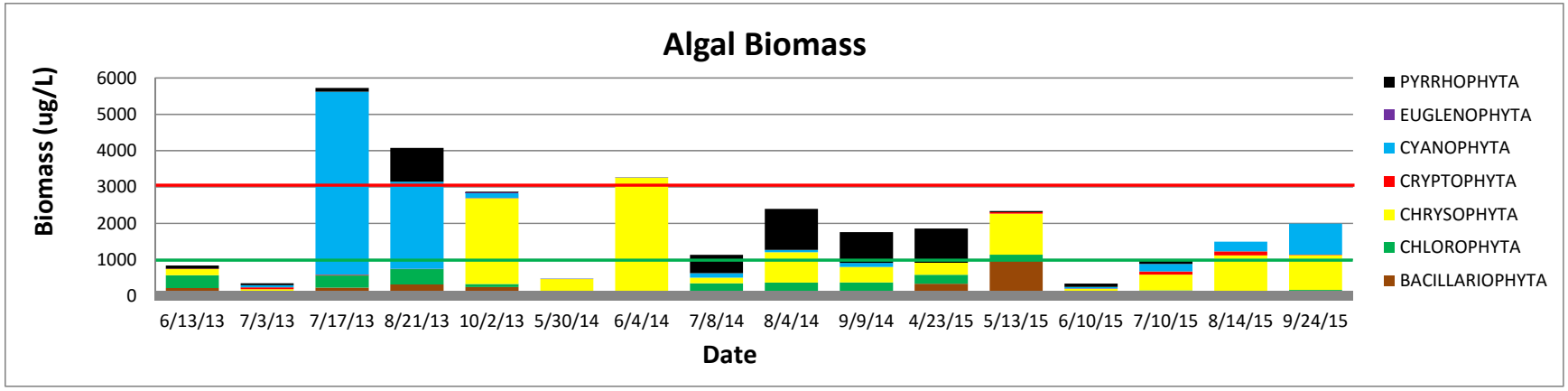


Figure 12. Phytoplankton biomass in Lovell's Pond

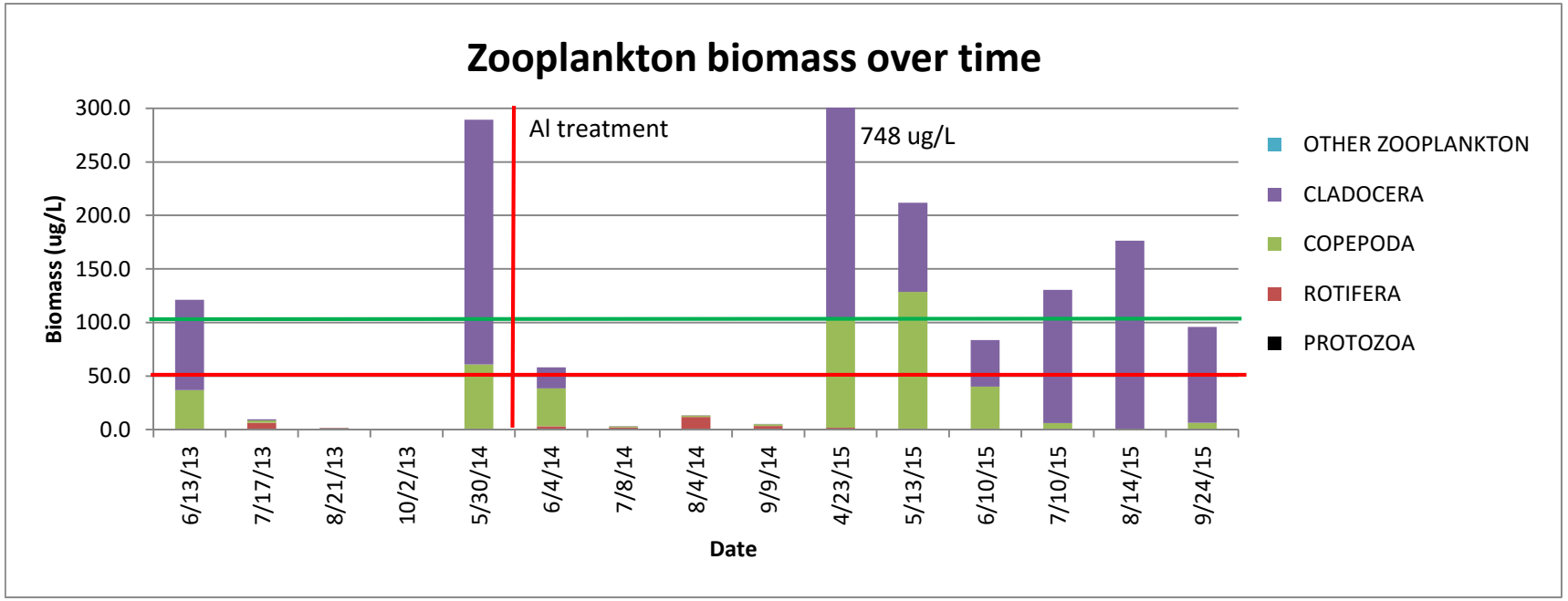


Figure 13. Zooplankton biomass in Lovell's Pond

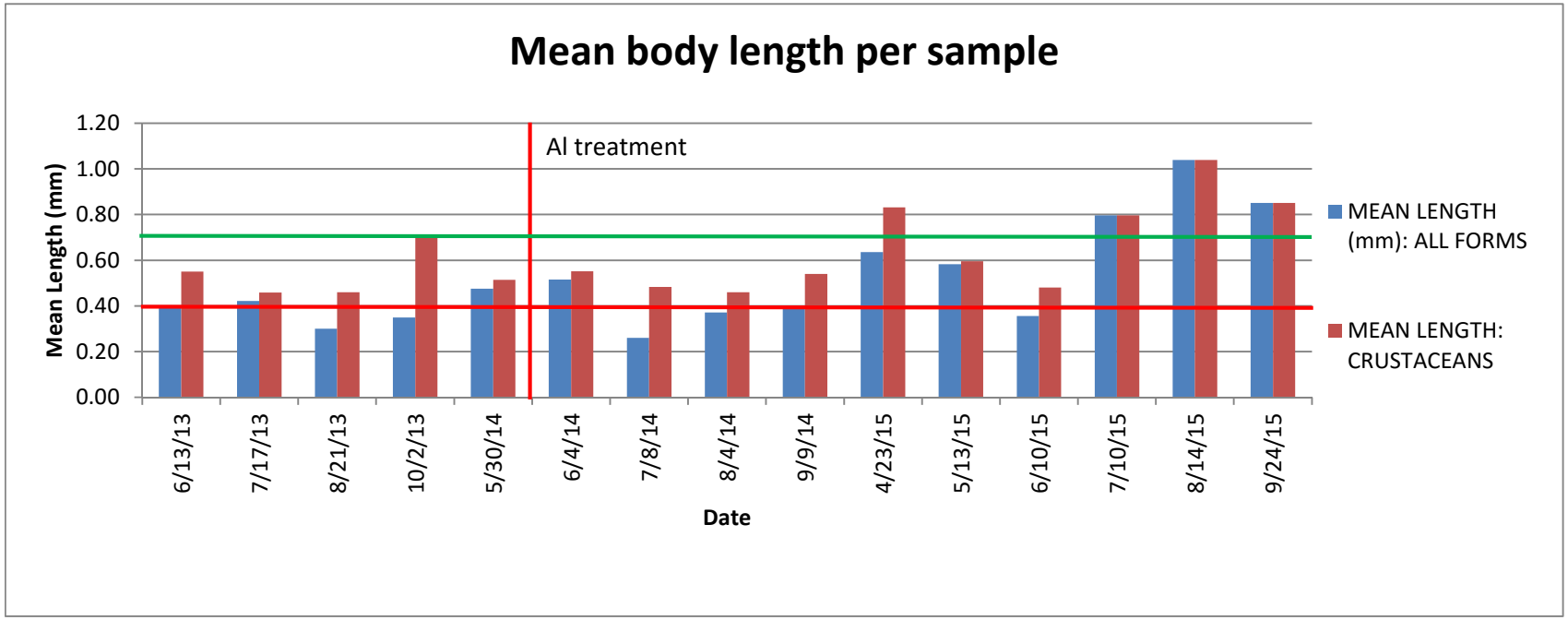


Figure 14. Zooplankton mean length in Lovell's Pond

Zooplankton (Figures 13 and 14) reveal encouraging results. Prior to treatment, summer zooplankton biomass in Lovell's Pond was very low and included only very small-bodied forms. Spring zooplankton were not typically measured, but many Cape Cod lakes exhibit winter peaks in zooplankton biomass and a decline through spring and summer, an evolutionary response to anadromous alewife populations often supplemented by intense predation by young of the year sunfish and perch. Lovell's Pond was subjected to alewife runs for many years and had a large population of small perch prior to treatment, so such a pattern would not be surprising. Low water clarity would limit predation by larger fish on smaller fish, maximizing predation on zooplankton. A moderate biomass peak was observed in May just before treatment, with a strong decline in June immediately after treatment. While predation would be expected to reduce biomass during this period, it is more likely that the aluminum treatment cleared the water of zooplankton as well as algae; this phenomenon has been observed in other lakes and usually represents no more than a one-year depression of zooplankton. No recovery was observed in 2014, consistent with expected summer predation pressure.

In April of 2015, zooplankton biomass achieved a very high level. No other samples are available from this time of year, so this not necessarily unusual or a result of treatment, but is encouraging, especially since most biomass was large-bodied cladocerans like *Daphnia*. Biomass decreased in May, but was not far below the pre-treatment value observed in 2014. Biomass continued to decrease over the summer, but not to the previously observed low levels, and larger cladocerans remained an important component of the zooplankton community. This provides more algae grazing capacity and better food for small fish. In other cases, the clear water created by the aluminum treatment allows larger fish to find and consume smaller fish, reducing grazing pressure on zooplankton and allowing a more substantial population to survive the summer. One year of data is not sufficient to draw this conclusion for Lovell's Pond, but the data are consistent with a greatly improved fish community structure.

Lovell's Pond appears to have only one species of mussel, the eastern elliptio (*Elliptio complanata*), which was abundant in peripheral sandy areas prior to treatment. That mussel remained very abundant after treatment, with no signs of mortality as a direct or indirect result of treatment.

Submergent rooted plants were rare in Lovell's Pond prior to treatment, and have not increased dramatically after treatment, although gradual colonization of areas with sufficient organic sediment and light is expected. However, much of the well-lighted portion of the pond is very sandy and unlikely to support dense submergent growths. Peripheral emergent growths are limited by substrate. No negative impacts of the aluminum treatment were evident.

Aluminum was assessed before and after application of the aluminum compounds (Figure 15). Aluminum is one of the most common metals in the crust of the earth, but is usually relatively insoluble as a function of one-way hydrolysis reactions and not found in substantial quantities in lakes without severe acid rain impacts. When present in a reactive form at levels in excess of about 1000 ug/L, aluminum can be toxic to many forms of aquatic life, so there is concern about potential toxicity during treatment and afterward until such time as all added aluminum has become inert Mattson et al. 2004). With pH between 6 and 8 SU, reactive aluminum is usually minimal and post-

treatment levels are usually well below any threshold for impact, but monitoring is conducted to document conditions.

Other than one elevated aluminum concentration near the surface immediately after treatment was completed, all values were fairly low, although the lowest value was the pre-treatment concentration. No obvious toxic effects were observed during treatment, and patterns of phytoplankton and zooplankton after treatment do not suggest any lasting aluminum toxicity. Certainly there were no significant fish kills associated with this treatment, and post-treatment aluminum levels do not suggest any appreciable risk of impact.

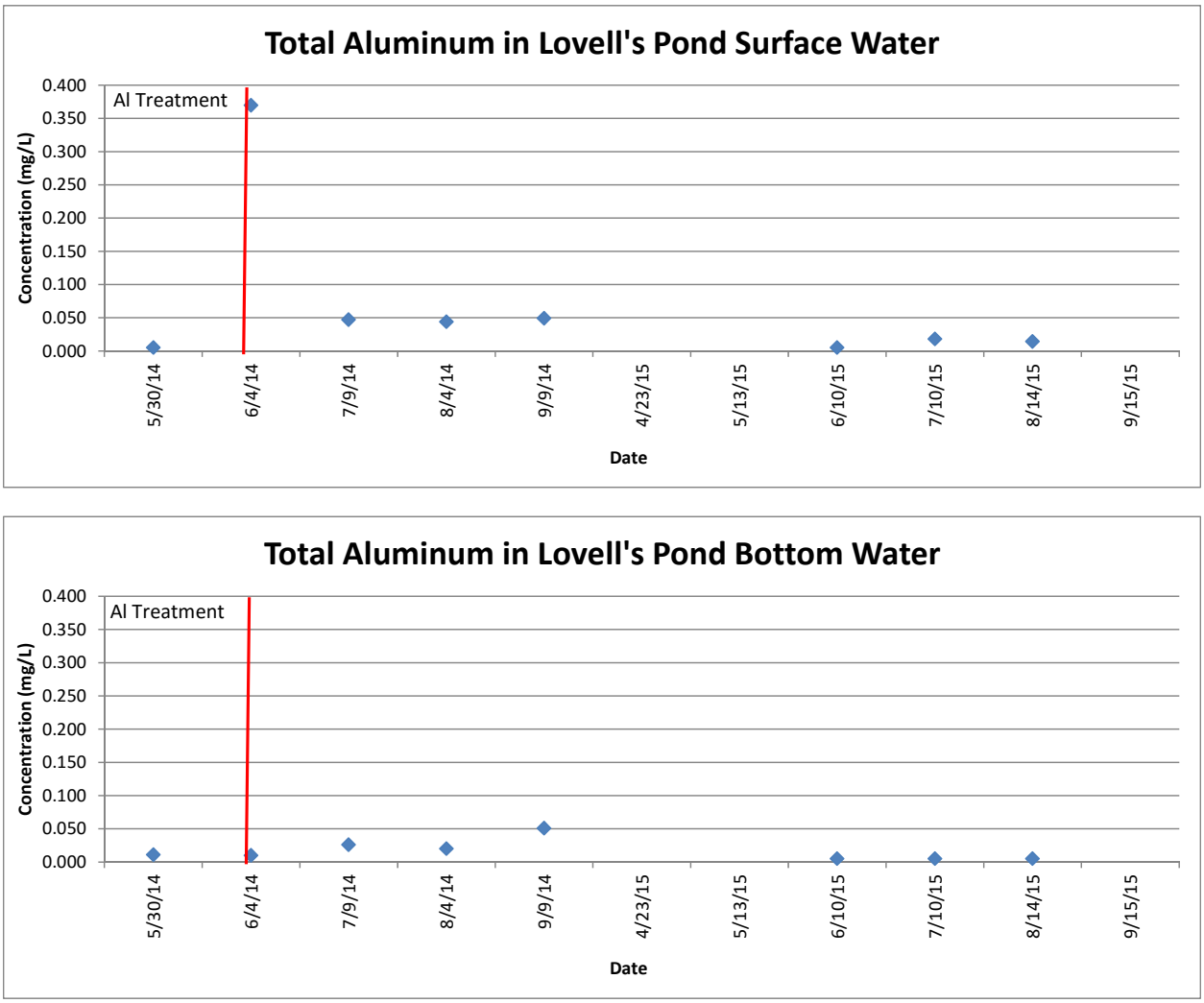


Figure 15. Aluminum concentrations in Lovell's Pond

Conclusions and Recommendations

Lovell's Pond appears to have been subjected to elevated nutrient loading from its watershed, primarily from cranberry bog operations, that facilitated development of a large internal phosphorus load from anoxic sediments over an extended period of time. With the cessation of cranberry bog operations in the watershed, conditions may have gradually improved, but the presence of the substantial internal load and associated cyanobacteria blooms prompted deployment of an air-driven circulation system to maintain oxygenated conditions near the bottom and limit release of phosphorus. Unfortunately, operational problems resulted in inadequate oxygenation on a regular basis, and periodic mixing of poor quality bottom water with the upper water column appears to have made conditions worse than before circulation was implemented.

Consideration of alternative management options led to an aluminum treatment in early June of 2014. Use of the circulation system was discontinued and 13,901 gallons of aluminum sulfate and 6998 gallons of sodium aluminate were applied over 35 acres at a ratio of 2:1, equivalent to a dose of 50 g/m^2. With the internal load largely inactivated, water clarity increased dramatically over the two summers following treatment, relative to pre-treatment conditions, reflecting a documented major decrease in available phosphorus throughout the water column. Nitrogen levels were minimally changed, elevating the N:P ratio in a way that also disfavors cyanobacteria. So there were less algae present and algae that were present were mainly forms of greater utility in the food web. However, there was a slight upsurge of problem cyanobacteria in late summer of the second year after treatment, something we usually do not see and warranting continued monitoring.

The thermal structure of Lovell's Pond does not appear to have been altered by treatment, but oxygen status was more desirable deeper into the water column. Measures from the spring following treatment (2015) indicate that oxygen demand has been cut by slightly more than half. Continued demand by organic sediments is to be expected and is sufficient to cause anoxia in the deepest water by late summer, but the reduction in phytoplankton biomass settling to the bottom for decay has appreciably reduced the oxygen demand. This equates to more of the pond being suitable for fish and other forms of desirable life for more of the year.

Zooplankton community features improved with increased water clarity and shifts in the phytoplankton assemblage. Zooplankton biomass did decrease to low levels following treatment, but rebounded a year later and both summer biomass and average zooplankter size was increased into a highly desirable range the second summer after treatment. No aluminum toxicity was observed and none was indicated by aluminum levels for two summers after treatment. The fish community has not been surveyed since a year before treatment, but it appears that larger fish have been benefitted and the abundance of small fish has been reduced in a desirable manner through predation under clearer water conditions.

Populations of mussels and rooted plants do not appear to have been appreciably altered by aluminum treatment and are largely controlled by sediment features that were unaffected by the treatment.

The duration of aluminum treatment benefits is not precisely predictable, but is undertood to depend on continued loading from the watershed, decomposition of organic matter in the lake with release of associated phosphorus, and migration of uninactivated phosphorus upward from below the treated zone. For lakes that stratify, the upward migration of uninactivated phosphorus appears to be a key process, and up to 20 years of benefit appear possible. The 1995 treatment of nearby Hamblin Pond resulted in 18 years of benefit, with cessation of benefit highly indicative of upward migration of sediment phosphorus as the controlling factor. However, Lovell's Pond is not so deep as to support very strong stratification, and the other processes may have enough influence to be of concern. Certainly the less than optimal clarity at the end of the second summer after treatment and the presence of two bloom-forming cyanobacteria warrants further monitoring of this system.

With the above results and processes in mind, it is recommended that the levels of phosphorus, nitrogen, phytoplankton and zooplankton be monitored for at least another two years on a monthly basis between June and September. Profiles of temperature and oxygen should also be assessed with the water quality sampling. Assessment at a single central site in Lovell's Pond is sufficient, so the recommended program is essentially a continuation of what has been done since the treatment was conducted. If conditions remain favorable for the next two years, monitoring could be reduced to a single late summer check-up involving the above elements.

A request should be made to the Massachusetts Division of Fisheries and Wildlife to conduct a follow-up survey of the fish community in Lovell's Pond. Positive changes are expected as a result of treatment, including improved gamefish growth rates and more desirable size distribution of sunfish and perch, and it would be nice to confirm those expected changes.

The circulation air lines remain in place in Lovell's Pond, but could be removed at any time if so desired. As the lines are weighted, this requires use of a functioning compressor to fill the associated auxiliary lines with air, which should float the lines and allow detachment of the weights and removal of the lines.

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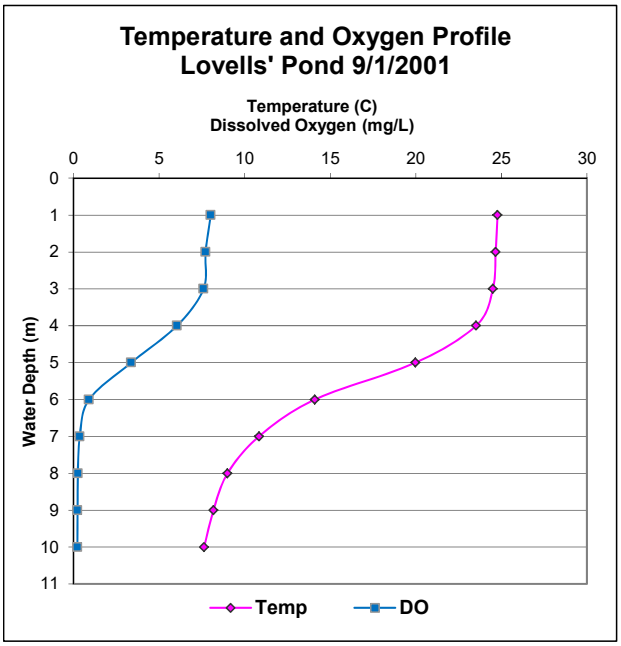
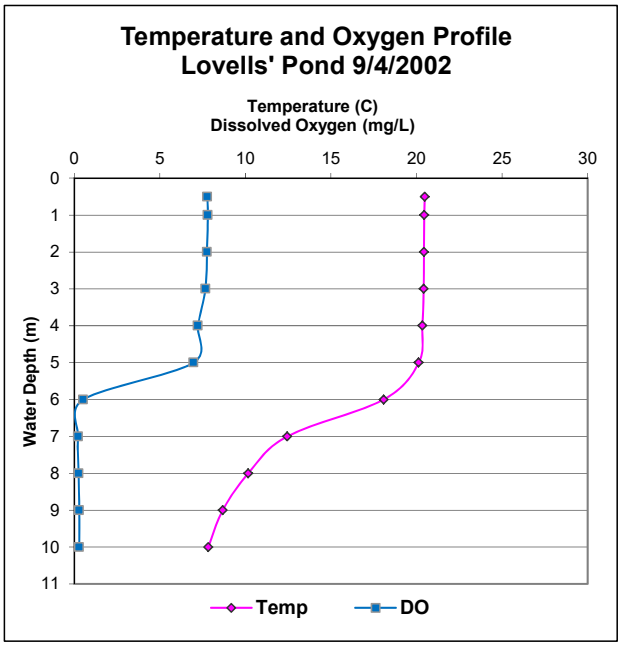
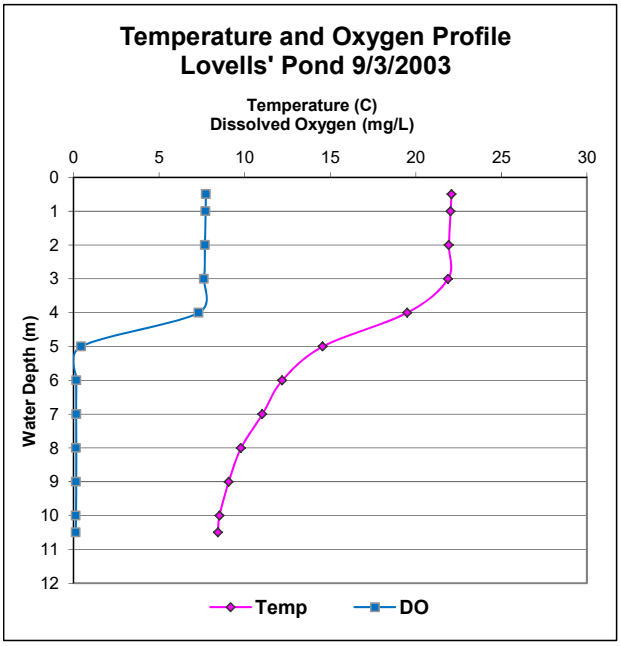
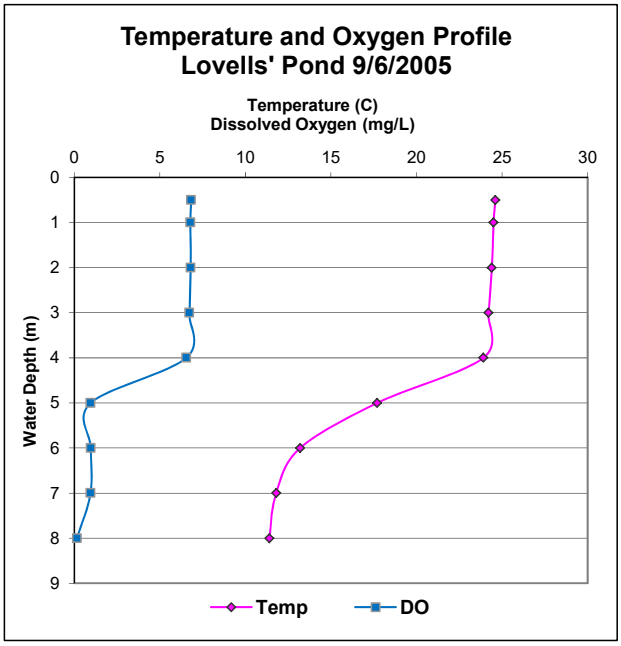
APPENDIX: Water Quality and Biological Data

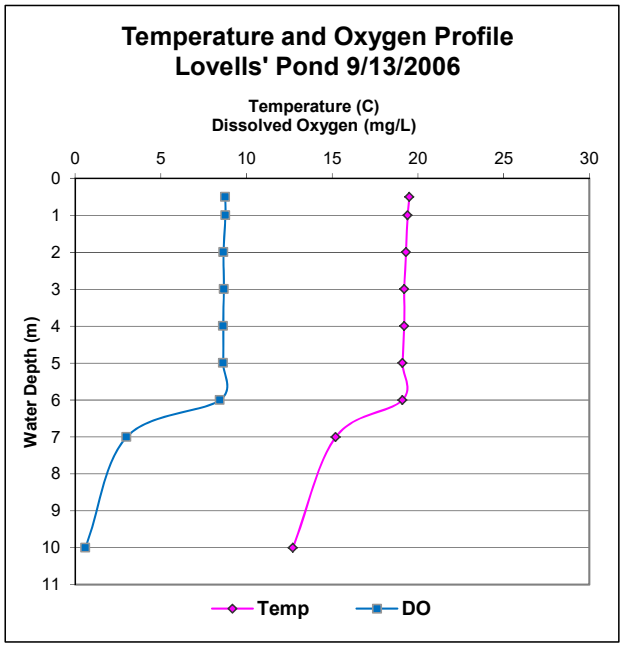
Temperature/Dissolved Oxygen Profiles







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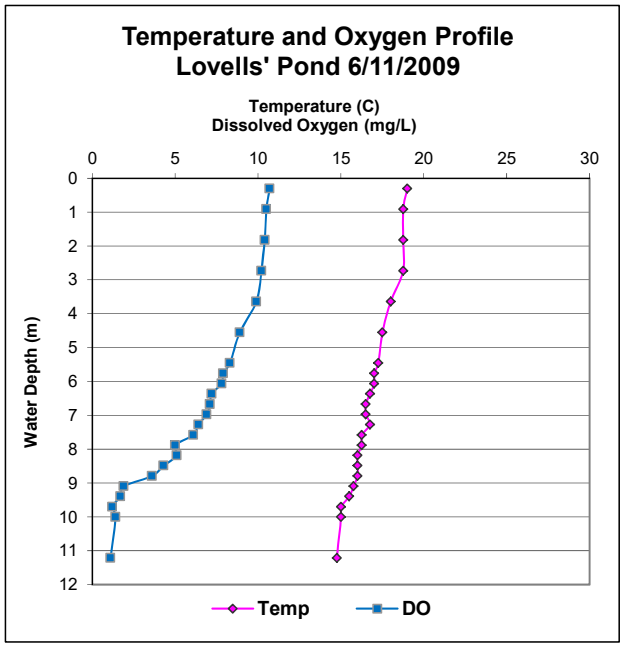
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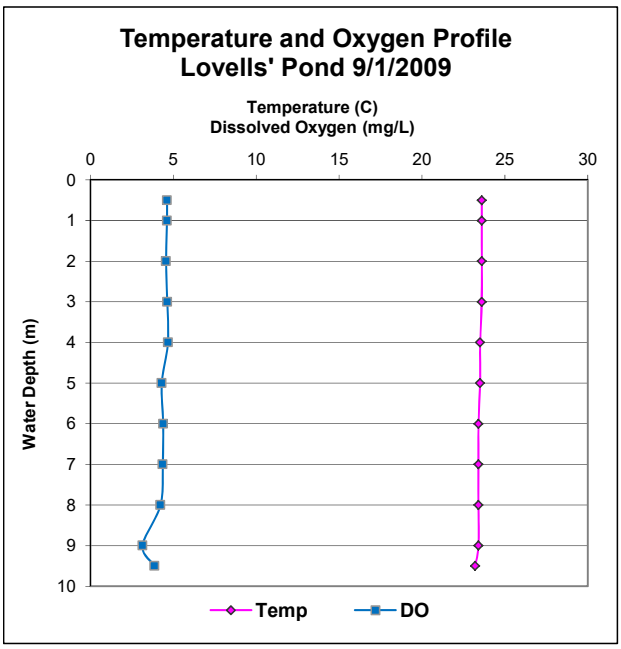
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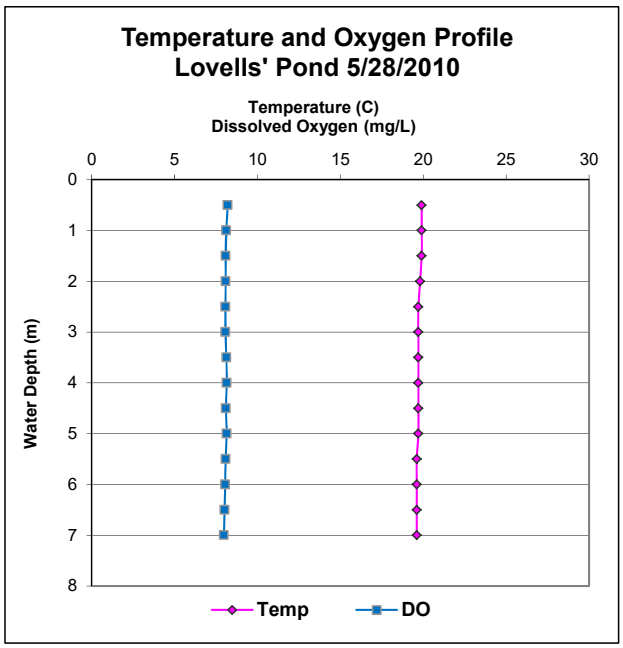
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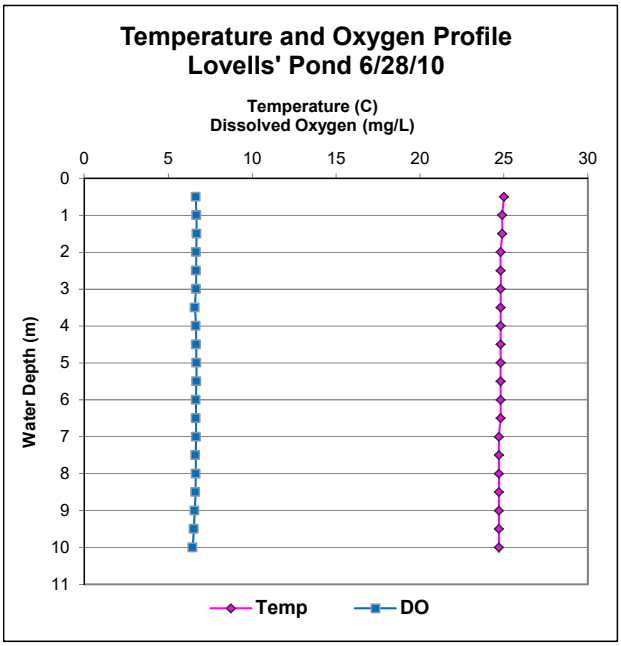
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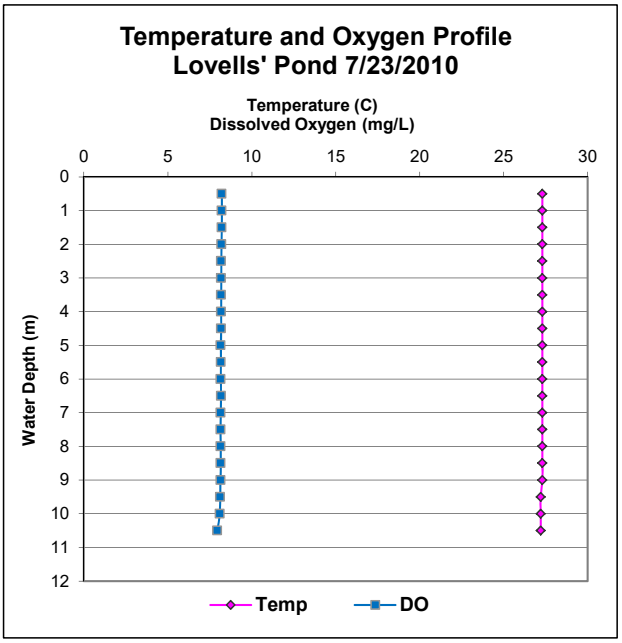
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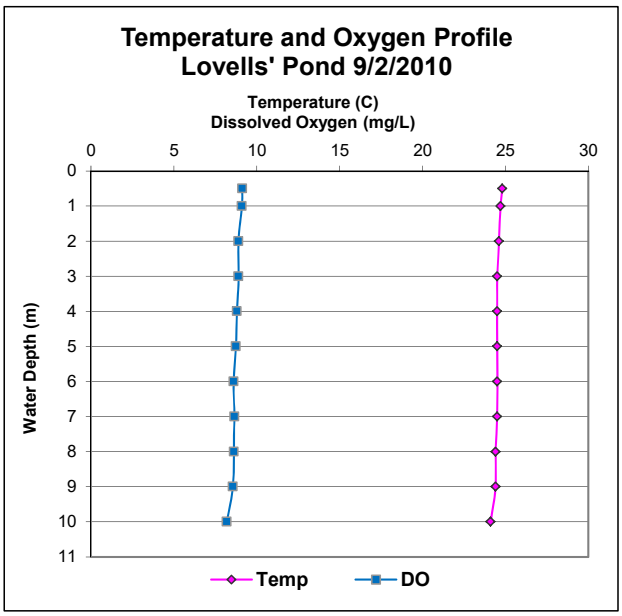
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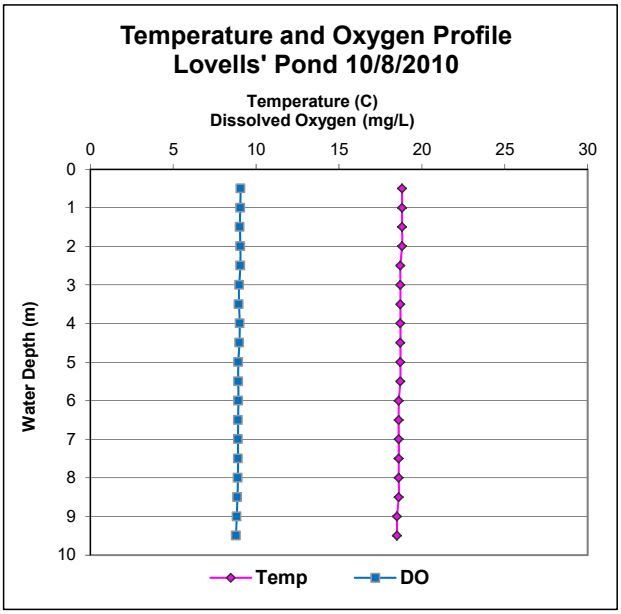
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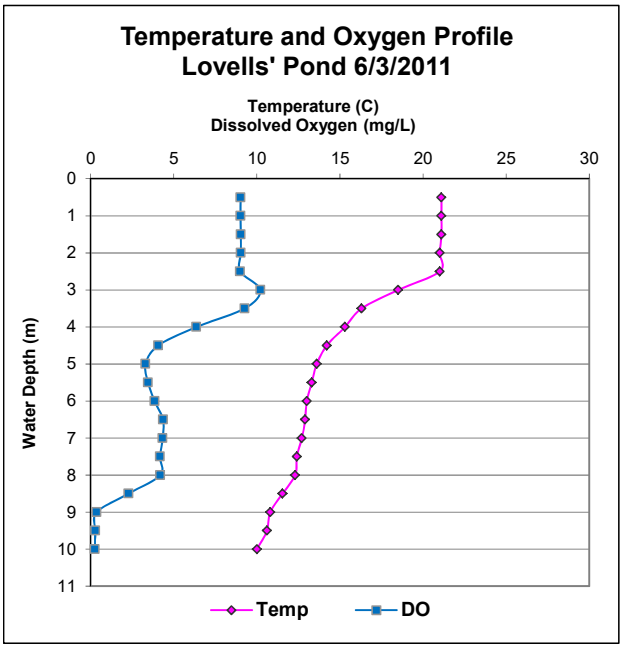
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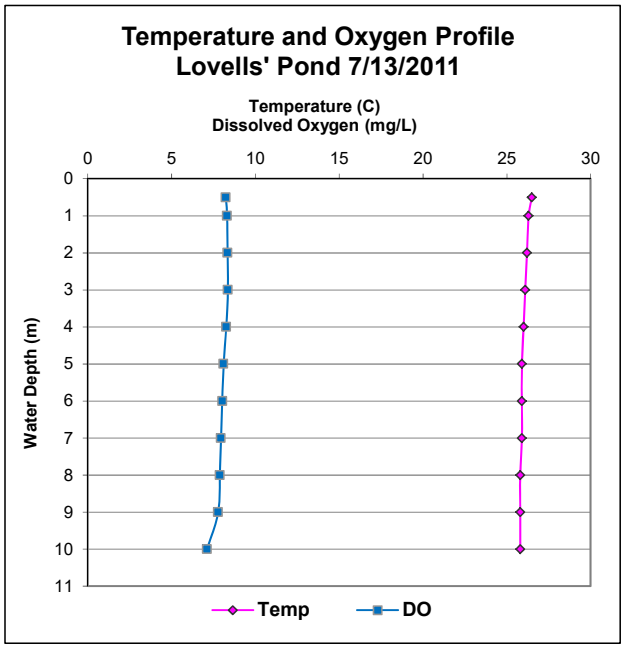
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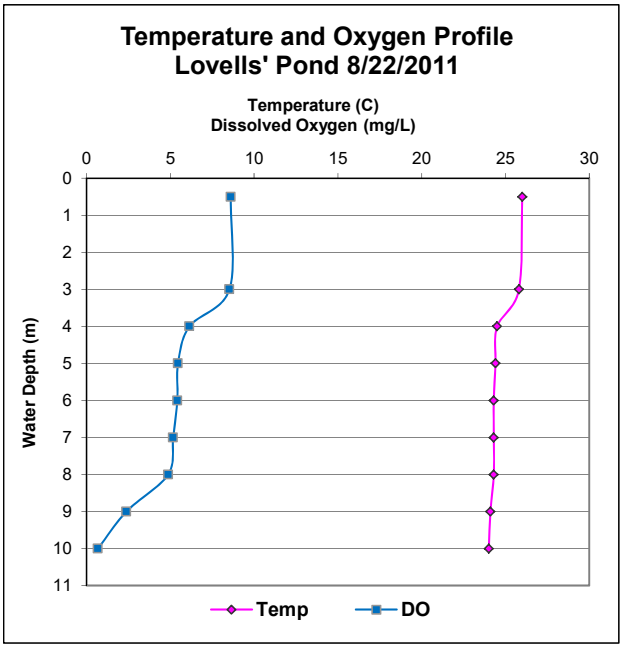
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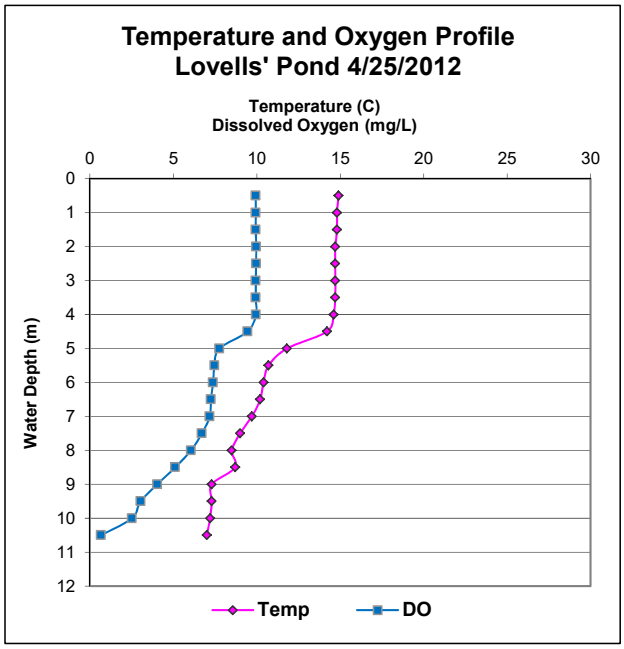
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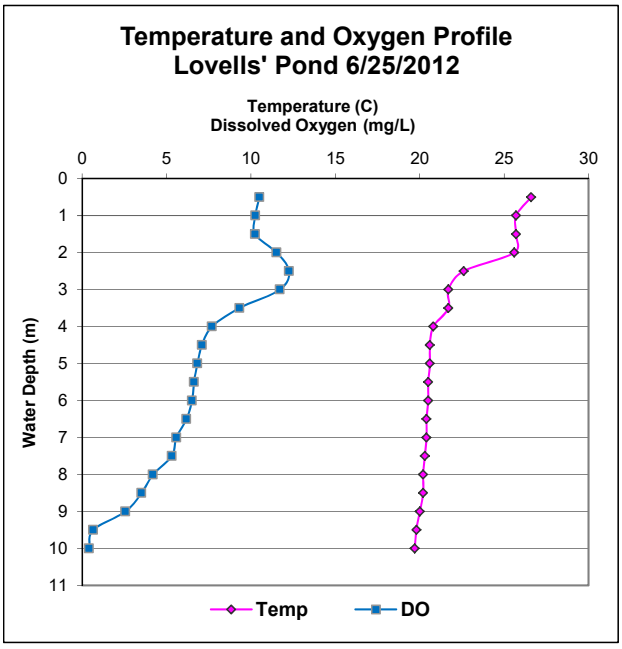
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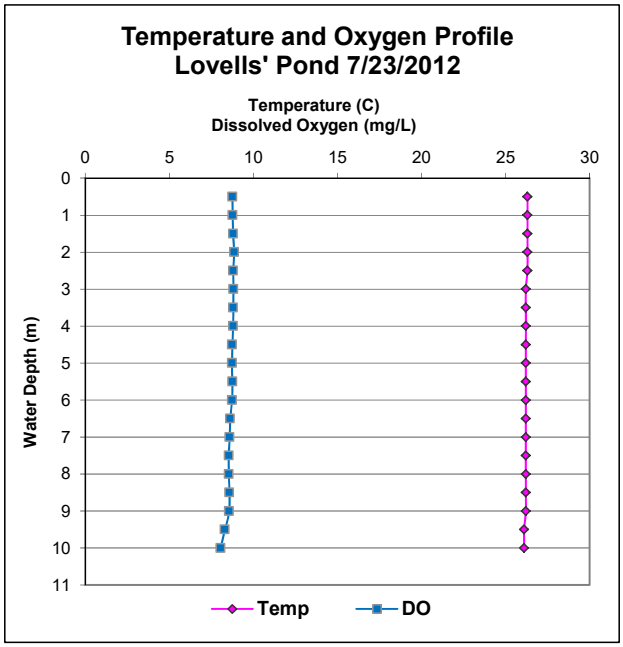
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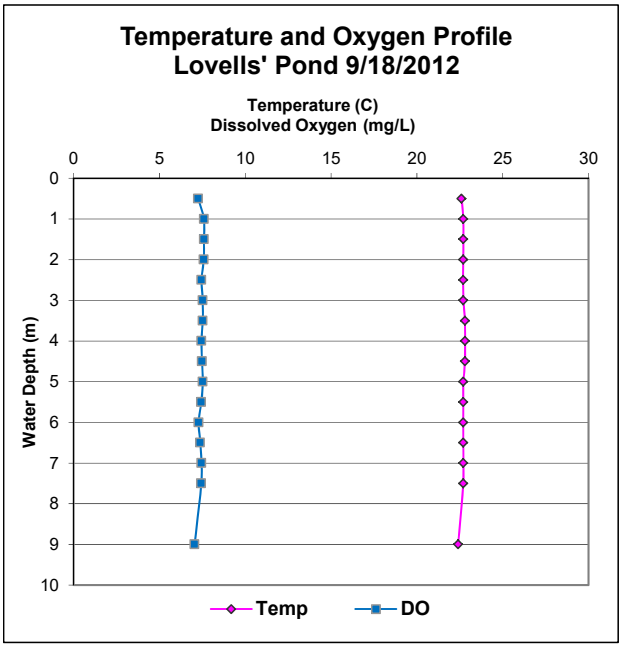
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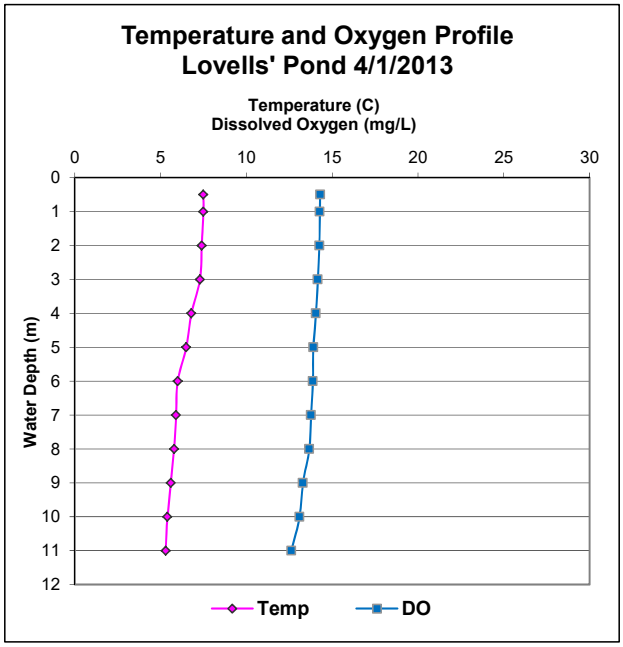
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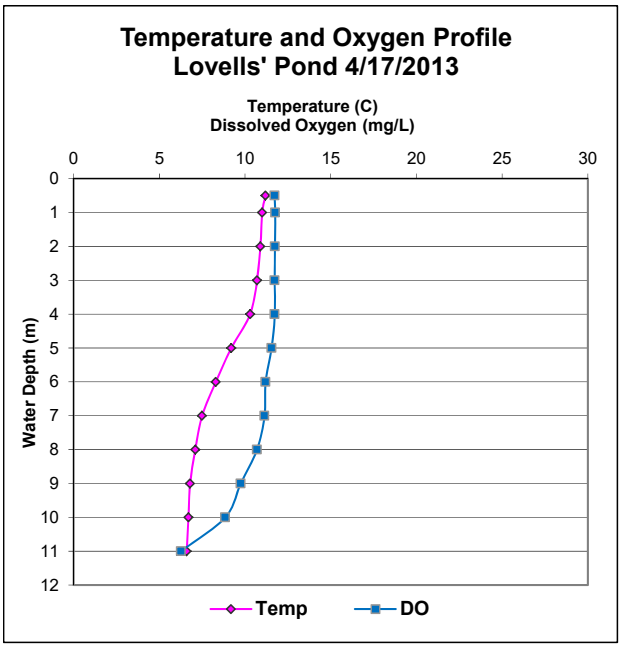
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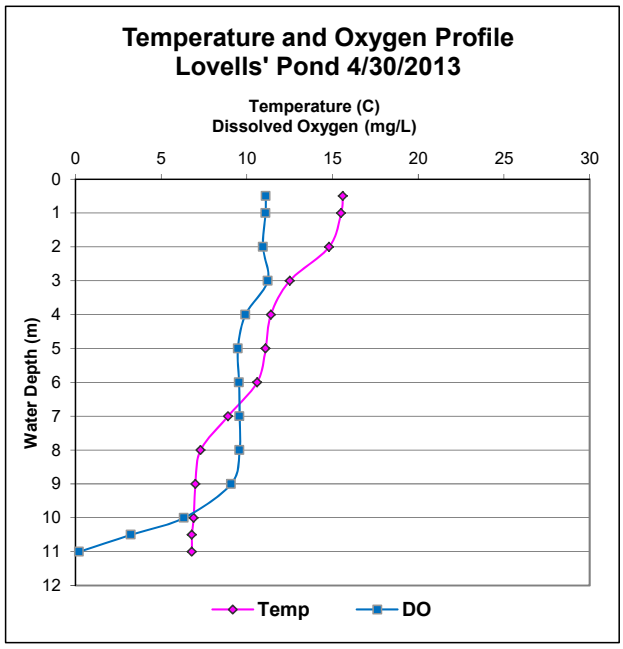
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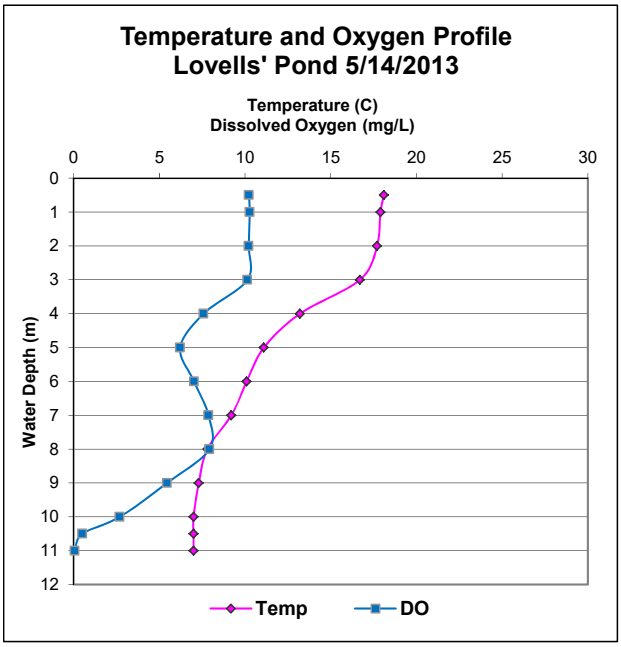
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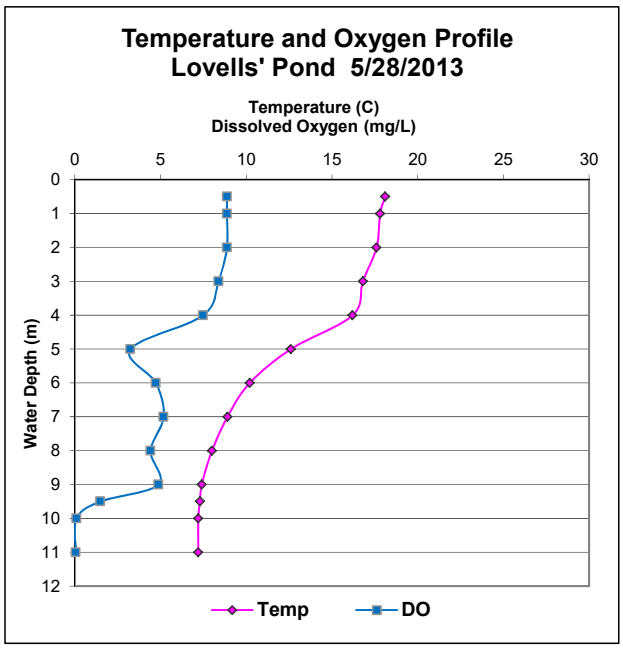
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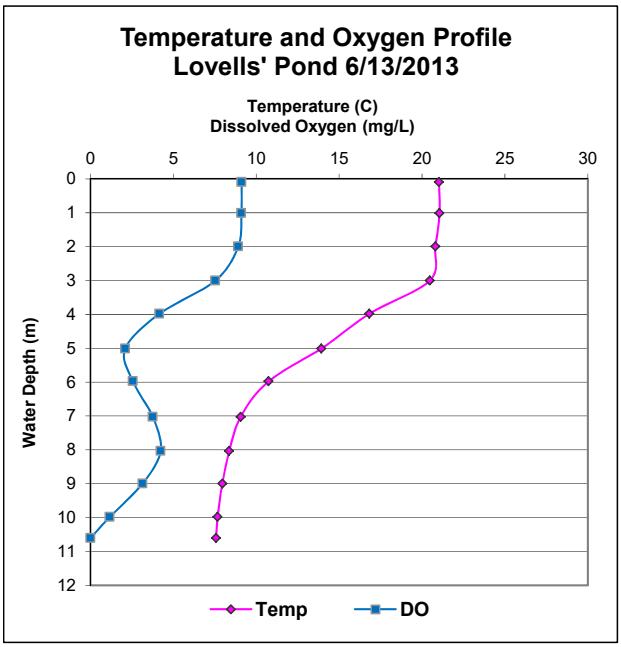
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Temp
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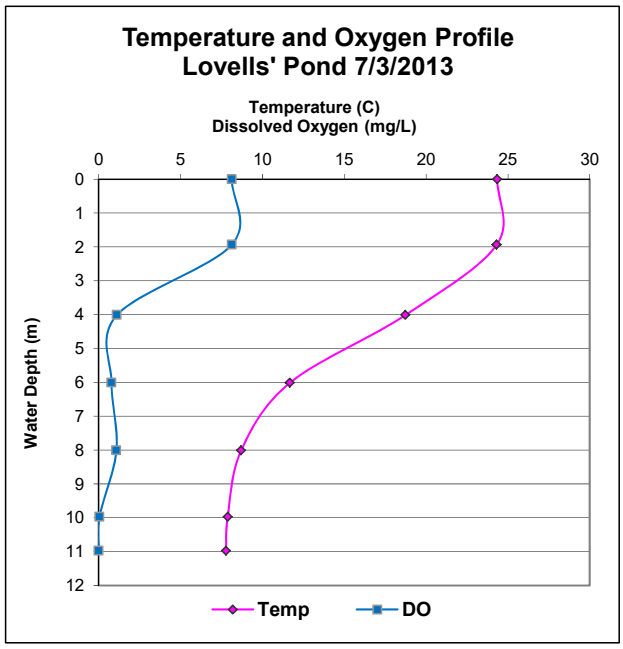
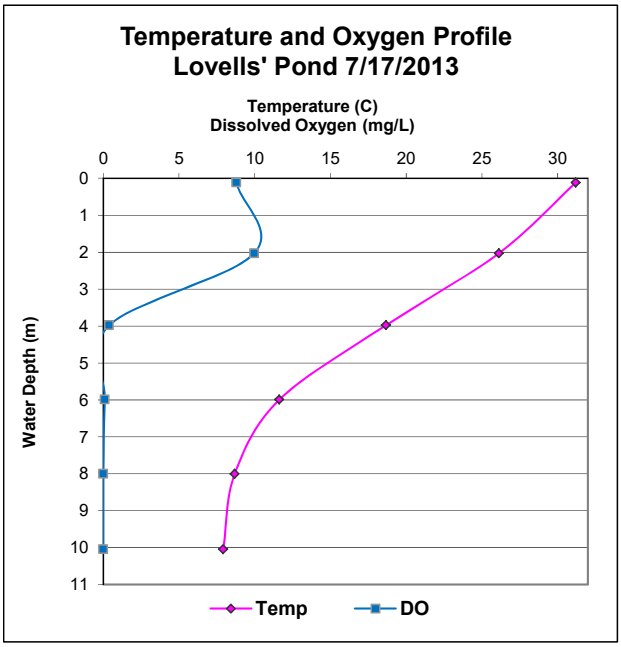
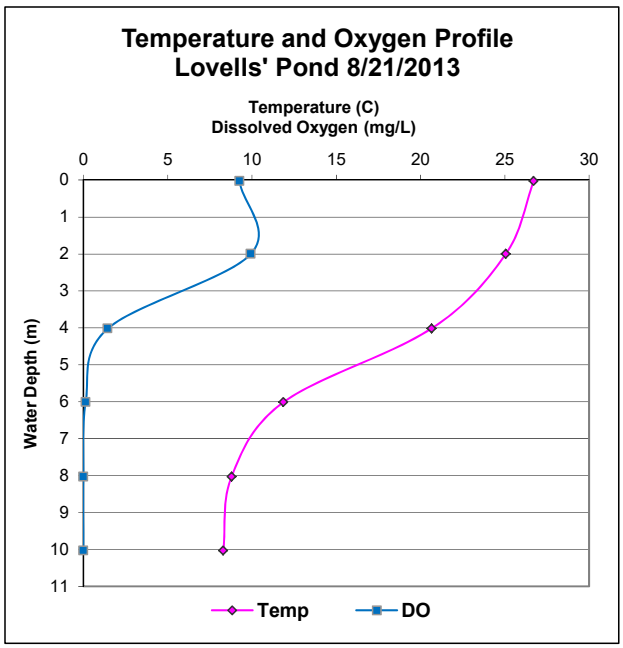
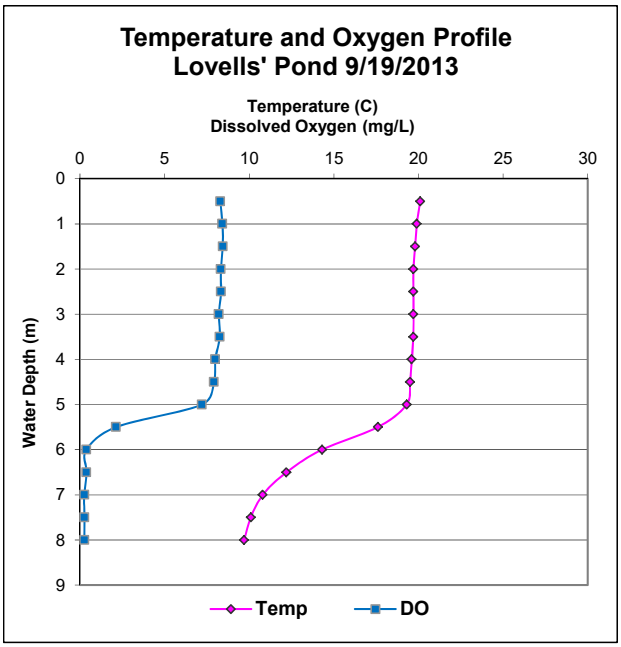
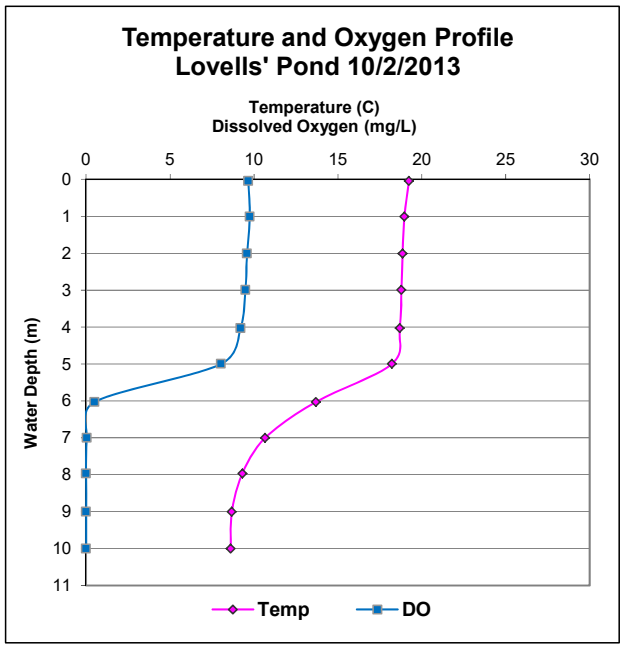
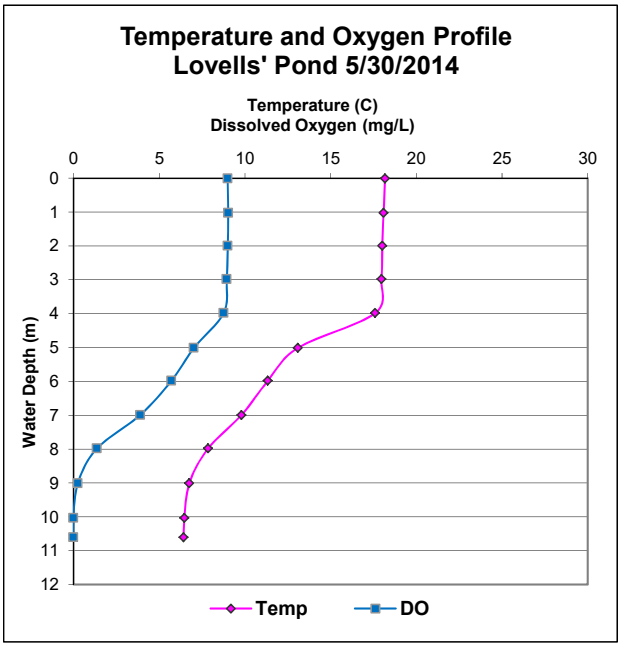

Temperature and Oxygen Profile
Lovells' Pond 7/3/2013
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

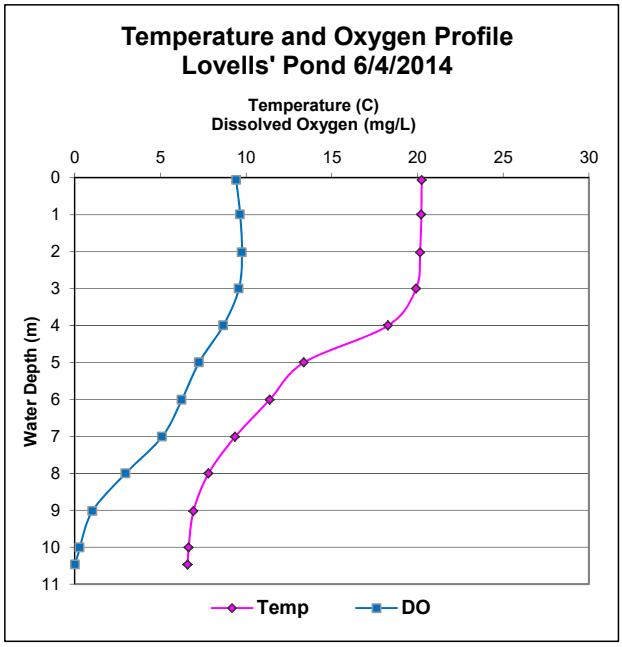

Temperature and Oxygen Profile
Lovells' Pond 7/17/2013
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

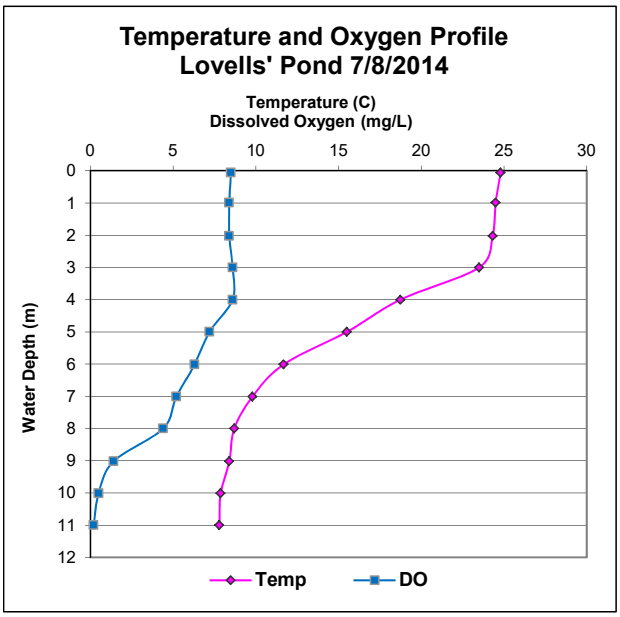

Temperature and Oxygen Profile
Lovells' Pond 8/21/2013
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

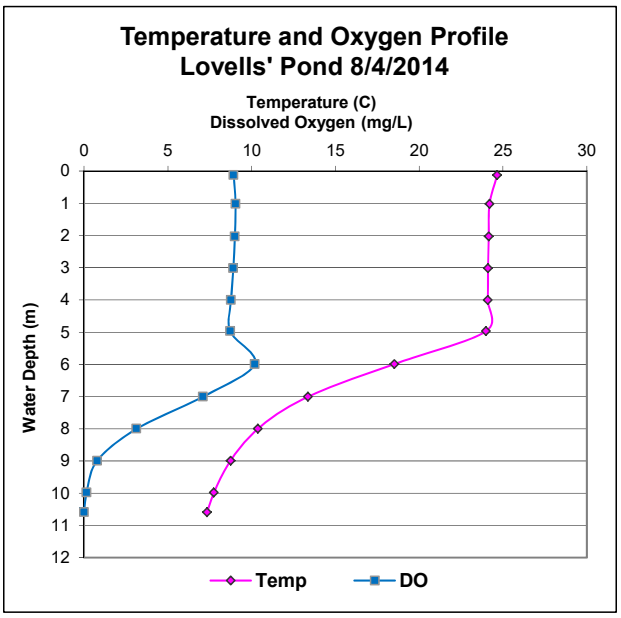

Temperature and Oxygen Profile
Lovells' Pond 9/19/2013
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

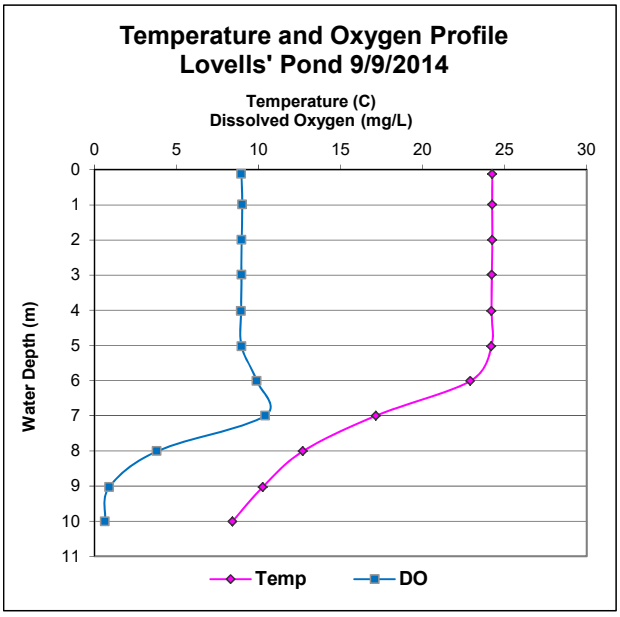

Temperature and Oxygen Profile
Lovells' Pond 10/2/2013
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

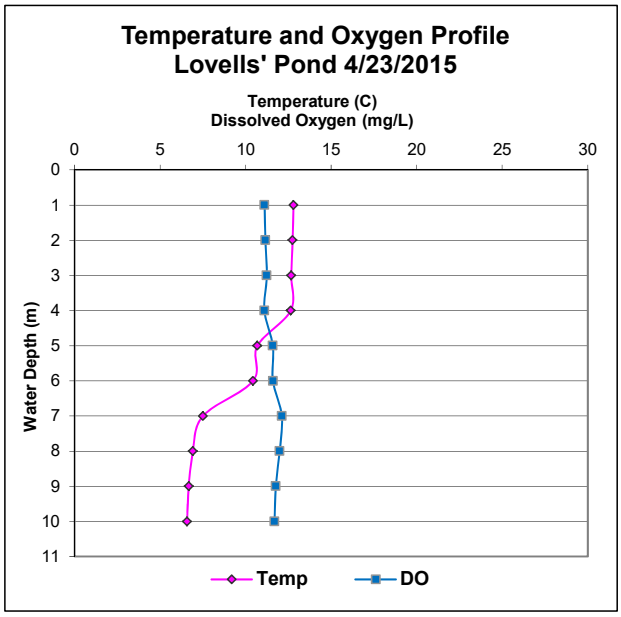

Temperature and Oxygen Profile
Lovells' Pond 5/30/2014
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

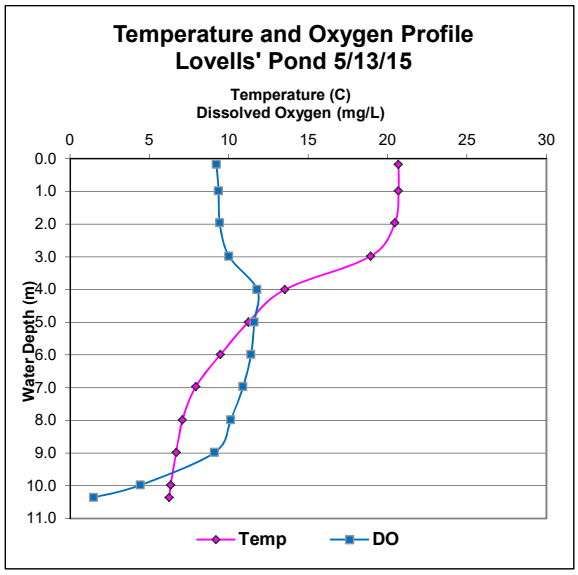

Temperature and Oxygen Profile
Lovells' Pond 6/4/2014
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

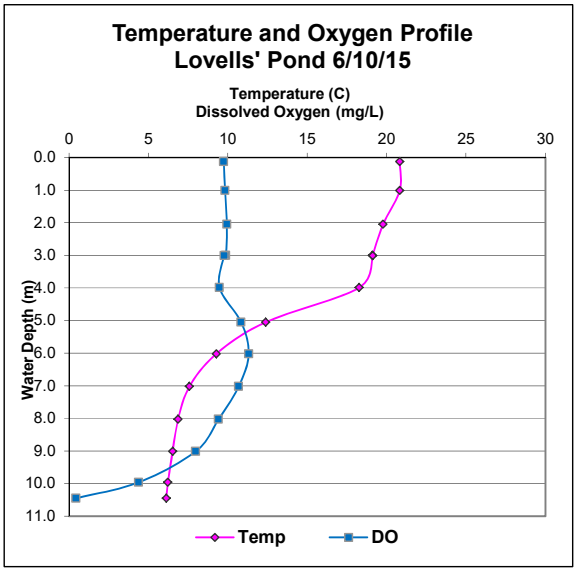

Temperature and Oxygen Profile
Lovells' Pond 7/8/2014
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

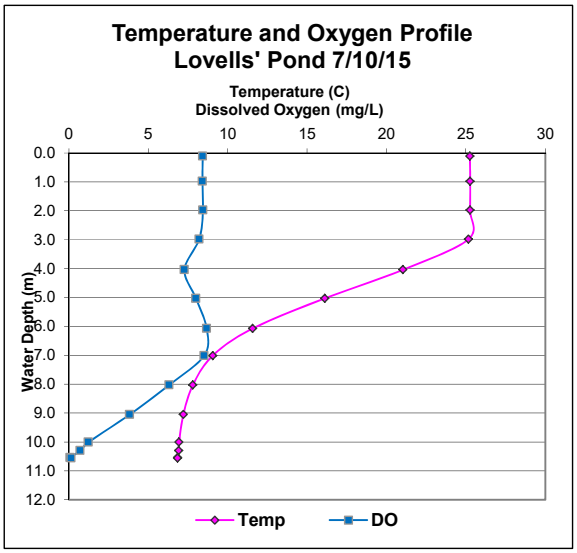

Temperature and Oxygen Profile
Lovells' Pond 8/4/2014
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

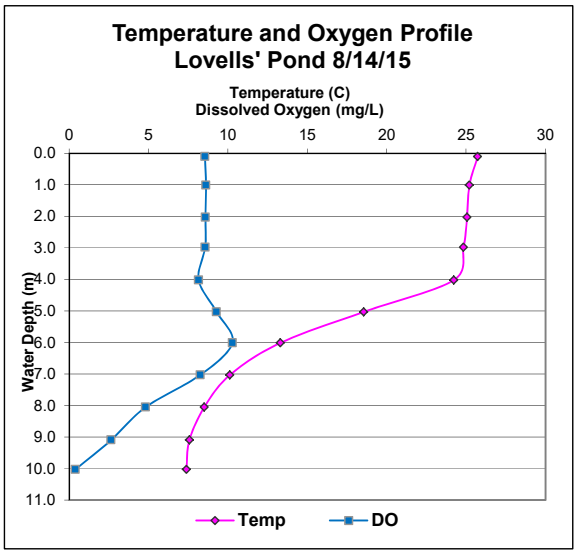

Temperature and Oxygen Profile
Lovells' Pond 9/9/2014
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

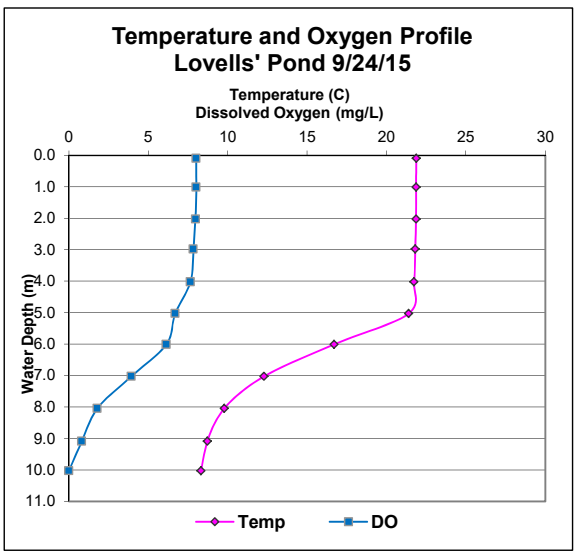

Temperature and Oxygen Profile
Lovells' Pond 4/23/2015
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO


Temperature and Oxygen Profile
Lovells' Pond 5/13/15
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO


Temperature and Oxygen Profile
Lovells' Pond 6/10/15
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO


Temperature and Oxygen Profile
Lovells' Pond 7/10/15
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO


Temperature and Oxygen Profile
Lovells' Pond 8/14/15
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO


Temperature and Oxygen Profile
Lovells' Pond 9/24/15
Temperature (C)
Dissolved Oxygen (mg/L)
Water Depth (m)
Temp
DO

Water Chemistry – Near Surface (1S) and Near Bottom (1B)

Station	Date	Depth	pH	Alkalinity	NH4-N	NOx-N	TKN	Total N	Diss. P	Total P	TN:TP
	MM.DD.YY	meters	Std Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
LP-1S	9/4/01	0.5	6.9	1.8				0.37		0.015	24.9
LP-1S	9/4/02	0.5	6.7	8.2				0.31		0.016	19.3
LP-1S	9/3/03	0.5	6.6	0.8				0.59		0.025	23.4
LP-1S	9/6/05	0.5	6.8	14.5				0.32		0.020	16.1
LP-1S	9/13/06	0.5	6.4	11.9				0.58		0.019	30.4
LP-1S	9/1/09	0.5	7.0	6.2				0.80		0.050	15.8
LP-1S	9/2/10	0.5	7.2	4.9				1.19		0.132	9.0
LP-1S	8/22/11	0.5	6.8	13.9				0.60		0.062	9.8
LP-1S	9/18/12	0.5	6.4	5.4				0.99		0.088	11.3
LP-1S	6/13/13	0.1	7.0	6.1	0.06	0.09	1.30	1.39	0.029	0.031	44.8
LP-1S	7/17/13	0.1	8.5		0.60	0.08	0.80	0.88	0.015	0.023	38.3
LP-1S	8/21/13	0.1	8.3	5.0	0.08	0.09	0.68	0.77	0.013	0.019	40.5
LP-1S	9/19/13	0.1	6.7	9.4				0.40		0.014	28.3
LP-1S	10/2/13	0.1	7.5		0.06	0.32	0.59	0.91	0.007	0.008	113.8
LP-1S	5/30/14	0.1	7.5	4.3	0.08	0.11	0.60	0.71	0.012	0.019	37.4
LP-1S	6/4/14	0.1	7.0	4.7	0.33	0.10	0.32	0.42	0.013	0.015	28.0
LP-1S	7/9/14	0.1	6.8	9.0	0.08	0.09	0.37	0.46	0.005	0.007	65.7
LP-1S	8/4/14	0.1	7.3	7.5	0.04	0.025	0.34	0.37	0.013	0.014	26.4
LP-1S	9/9/14	0.1	7.0	8.2	0.04	0.025	0.28	0.31	0.005	0.005	62.0
LP-1S	4/23/15	0.1	7.0								
LP-1S	5/13/15	0.2	7.6								
LP-1S	6/10/15	0.1	6.5	10.8	0.07	0.26	0.30	0.56	0.012	0.016	
LP-1S	7/10/15	0.1	8.5	4.9	0.17	0.22	0.42	0.81	0.006	0.010	81.0
LP-1S	8/14/15	0.1	1.7	6.0	0.06	0.16	0.36	0.52	0.010	0.010	52.0
LP-1S	9/24/15	0.2	6.6	8.0	0.09	0.10	0.44	0.54	0.008	0.009	60.0
LP-1B	9/4/01	10.0	6.7	2.6				0.74		0.028	26.3
LP-1B	9/4/02	10.0	6.3	19.6				1.83		0.272	6.7
LP-1B	9/3/03	10.0	6.5	2.5				2.44		0.703	3.5
LP-1B	9/6/05	10.0	6.2	16.1						0.033	
LP-1B	9/13/06	10.0	6.4	70.4				3.50		0.624	5.6
LP-1B	9/1/09	9.6	5.9	6.3				0.98		0.099	9.9
LP-1B	9/2/10	9.8	6.7	4.5				0.87		0.076	11.5
LP-1B	8/22/11	10.6	6.3	4.7				0.75		0.040	18.5
LP-1B	9/18/12	9.5	7.1	5.4				0.99		0.075	13.3
LP-1B	6/13/13	10.6	5.9	10.0	0.84	0.03	1.60	1.63	0.041	0.057	28.6
LP-1B	7/17/13	10.0	5.2		0.16	0.21	0.60	0.81	0.015	0.021	38.6
LP-1B	8/21/13	10.0	5.4	22.0	2.50	0.08	3.30	3.38	0.120	0.130	26.0
LP-1B	9/19/13	8.0	5.9	13.5							
LP-1B	10/2/13	10.0	5.5		0.96	0.09	1.70	1.79	0.016	0.017	105.3
LP-1B	5/30/14	10.6	5.9	11.8	1.00	0.08	1.90	1.98	0.059	0.088	22.5
LP-1B	6/4/14	10.5	6.1	12.0	1.00	0.08	1.80	1.88	0.011	0.063	29.8
LP-1B	7/9/14	11.0	6.1	10.0	0.27	0.09	0.62	0.71	0.006	0.016	44.4
LP-1B	8/4/14	10.6	6.0	19.4	1.7	0.07	2.6	2.67	0.024	0.058	46.0
LP-1B	9/9/14	10.0	6.3	34.2	2.8	<0.05	3.0	3.03	0.024	0.031	97.7
LP-1B	4/23/15	10.0	6.7								
LP-1B	5/13/15	10.4	6.7								
LP-1B	6/10/15	10.5	5.7	10.9	0.57	0.19	0.60	0.79	0.015	0.027	29.3
LP-1B	7/10/15	10.6	7.5	8.1	0.59	0.20	0.93	1.72	0.007	0.019	90.5
LP-1B	8/14/15	10.0	6.1	10.3	0.75	0.09	1.10	1.19	0.008	0.012	99.2
LP-1B	9/24/15	9.7	6.0	38.0	1.7	0.05	2.7	2.75	0.008	0.032	85.9

Date	Secchi
MM.DD.YY	m
9/4/01	1.6
9/4/02	3.1
9/3/03	2.0
9/6/05	3.1
9/13/06	2.3
9/1/09	**2.2**
5/28/10	1.8
9/2/10	0.6
6/3/11	2.5
7/13/11	1.1
8/22/11	2.4
4/25/12	2.7
6/25/12	1.4
7/23/12	1.3
9/18/12	0.6
4/1/13	1.4
4/17/13	1.5
4/30/13	2.1
5/14/13	2.8
5/28/13	2.5
6/13/13	2.2
7/17/13	1.6
8/21/13	2.0
9/19/13	2.2
10/2/13	2.8
5/30/14	4.1
6/4/14	4.6
7/9/14	5.6
8/4/14	4.2
9/9/14	5.9
4/23/15	3.6
5/13/15	3.2
6/10/15	3.5
7/10/15	4.5
8/14/15	5.1
9/24/15	3.8

Station	Date	Aluminum
	MM.DD.YY	mg/L
LP-1S	5/30/14	0.005
LP-1S	6/4/14	0.370
LP-1S	7/9/14	0.047
LP-1S	8/4/14	0.044
LP-1S	9/9/14	0.049
LP-1S	4/23/15	
LP-1S	5/13/15	
LP-1S	6/10/15	0.005
LP-1S	7/10/15	0.018
LP-1S	8/14/15	0.014
LP-1S	9/15/15	
LP-1b	5/30/14	0.011
LP-1b	6/4/14	0.010
LP-1b	7/9/14	0.026
LP-1b	8/4/14	0.020
LP-1b	9/9/14	0.051
LP-1b	4/23/15	
LP-1b	5/13/15	
LP-1b	6/10/15	0.005
LP-1b	7/10/15	0.005
LP-1b	8/14/15	0.005
LP-1b	9/24/15	

Date	Tot Chl-a
MM.DD.YY	µg/L
9/4/01	18.5
9/4/02	16.9
9/3/03	11.3
9/6/05	10.0
9/13/06	20.5
9/1/09	16.8
9/2/10	19.1
8/22/11	9.9
9/18/12	12.4
6/13/13	5.4
7/17/13	14.5
8/21/13	8.1
9/19/13	18.3
10/2/13	9.1
5/30/14	1.4
6/4/14	2.1
7/9/14	2
8/4/14	3.2
9/9/14	1.7
4/23/15	
5/13/15	
6/10/15	1.7
7/10/15	1.6
8/14/15	1.7
9/24/15	1.9

Phytoplankton Data

	PHYTOPLANKTON BIOMASS (UG/L)				
	Lovells LP-1	Lovells LP-1	Lovells LP-1	Lovells LP-1	Lovells LP-1
TAXON	**06/13/13**	**07/03/13**	**07/17/13**	**08/21/13**	**10/02/13**
BACILLARIOPHYTA					
Centric Diatoms					
Aulacoseira	12.4	0.0	0.0	0.0	8.4
Cyclotella	0.0	2.4	0.0	0.0	1.4
Araphid Pennate Diatoms					
Asterionella	8.2	0.0	0.0	0.0	0.0
Synedra	16.5	19.2	0.0	60.5	156.8
Tabellaria	181.3	38.4	230.4	257.0	67.2
Monoraphid Pennate Diatoms					
Biraphid Pennate Diatoms					
Nitzschia	0.0	0.0	0.0	0.0	11.2
CHLOROPHYTA					
Flagellated Chlorophytes					
Chlamydomonas	45.3	0.0	0.0	0.0	0.0
Coccoid/Colonial Chlorophytes					
Actinastrum	0.0	0.0	0.0	0.0	0.0
Ankistrodesmus	2.1	0.0	0.0	11.3	7.0
Closteriopsis	0.0	0.0	12.0	9.5	21.0
Coelastrum	0.0	0.0	0.0	158.8	22.4
Golenkinia	0.0	0.0	0.0	3.8	0.0
Kirchneriella	0.0	0.0	0.0	15.1	0.0
Oocystis	33.0	0.0	0.0	0.0	0.0
Paulschulzia	33.0	0.0	0.0	0.0	0.0
Pediastrum	0.0	0.0	38.4	30.2	0.0
Scenedesmus	8.2	0.0	0.0	15.1	5.6
Schroederia	103.0	0.0	0.0	0.0	0.0
Sphaerocystis	98.9	0.0	0.0	0.0	0.0
Tetrastrum	0.0	0.0	0.0	0.0	11.2
Filamentous Chlorophytes					
Desmids					
Closterium	0.0	0.0	192.0	151.2	0.0
Cosmarium	16.5	0.0	0.0	15.1	0.0
Staurastrum	0.0	0.0	19.2	15.1	11.2
Staurodesmus	12.4	0.0	72.0	0.0	8.4
CHRYSOPHYTA					
Flagellated Classic Chrysophytes					
Chrysococcus	24.7	0.0	0.0	0.0	302.4
Dinobryon	61.8	72.0	0.0	0.0	2058.0
Mallomonas	82.4	0.0	0.0	0.0	0.0
Non-Motile Classic Chrysophytes					
Haptophytes					
Tribophytes/Eustigmatophytes					
Raphidophytes					
Gonyostomum and related taxa	0.0	52.8	0.0	0.0	0.0
CRYPTOPHYTA					
Cryptomonas	12.4	52.8	19.2	7.6	5.6
CYANOPHYTA					
Unicellular and Colonial Forms					
Aphanocapsa	0.0	24.0	48.0	0.0	0.0
Microcystis	0.0	36.0	0.0	28.4	0.0
Filamentous Nitrogen Fixers					
Anabaena	0.0	0.0	4992.0	453.6	56.0
Aphanizomenon	0.0	0.0	0.0	98.3	72.8
Filamentous Non-Nitrogen Fixers					
Planktolyngbya	0.0	0.0	0.0	1814.4	0.0
Pseudanabaena	0.0	0.0	0.0	0.0	2.8
EUGLENOPHYTA					
Trachelomonas	0.0	0.0	0.0	0.0	14.0
PYRRHOPHYTA					
Peridinium	86.5	50.4	100.8	929.9	29.4

	PHYTOPLANKTON BIOMASS (UG/L)				
	Lovells	Lovells	Lovells	Lovells	Lovells
TAXON	**05/30/14**	**06/04/14**	**07/08/14**	**08/04/14**	**09/09/14**
BACILLARIOPHYTA					
Centric Diatoms					
Aulacoseira	0.0	0.0	9.0	5.8	6.8
Urosolenia	0.0	0.0	0.0	34.6	18.2
Araphid Pennate Diatoms					
Asterionella	0.0	0.0	0.0	7.7	1.5
Tabellaria	0.0	7.4	12.0	7.7	0.0
Monoraphid Pennate Diatoms					
Biraphid Pennate Diatoms					
Nitzschia	0.0	0.0	0.0	7.7	12.2
CHLOROPHYTA					
Flagellated Chlorophytes					
Coccoid/Colonial Chlorophytes					
Ankistrodesmus	0.0	0.0	0.0	9.6	6.1
Coelastrum	0.0	0.0	0.0	23.0	0.0
Crucigenia	0.0	0.0	0.0	7.7	0.0
Dictyosphaerium	6.3	0.0	0.0	0.0	12.2
Golenkinia	0.0	0.0	3.0	1.9	1.5
Micractinium	0.0	0.0	180.0	28.8	0.0
Oocystis	0.0	14.7	12.0	7.7	0.0
Pediastrum	0.0	0.0	0.0	0.0	12.2
Scenedesmus	0.0	3.7	42.0	65.3	21.3
Selenastrum	0.0	0.0	22.5	0.0	0.0
Sphaerocystis	16.8	0.0	0.0	0.0	0.0
Filamentous Chlorophytes					
Desmids					
Closterium	0.0	0.0	60.0	153.6	182.4
Staurodesmus	0.0	0.0	9.0	5.8	9.1
Teilingia/related taxa	0.0	0.0	0.0	0.0	91.2
CHRYSOPHYTA					
Flagellated Classic Chrysophytes					
Chromulina	2.6	1.4	0.0	0.0	12.2
Dinobryon	441.0	3229.2	135.0	835.2	410.4
Mallomonas	0.0	0.0	22.5	0.0	0.0
Non-Motile Classic Chrysophytes					
Haptophytes					
Tribophytes/Eustigmatophytes					
Raphidophytes					
CRYPTOPHYTA					
Cryptomonas	4.2	1.8	0.0	0.0	0.0
CYANOPHYTA					
Unicellular and Colonial Forms					
Microcystis	3.2	1.8	1.5	1.0	0.0
Filamentous Nitrogen Fixers					
Anabaena	0.0	0.0	120.0	38.4	30.4
Filamentous Non-Nitrogen Fixers					
Planktolyngbya	0.0	0.0	0.0	28.8	83.6
EUGLENOPHYTA					
PYRRHOPHYTA					
Peridinium	0.0	0.0	504.0	1126.1	843.6

	PHYTOPLANKTON BIOMASS (UG/L)					
	Lovells	Lovells	Lovells	Lovells	Lovells	Lovells
TAXON	**04/23/15**	**05/13/15**	**06/10/15**	**07/10/15**	**08/14/15**	**09/24/15**
BACILLARIOPHYTA						
Centric Diatoms						
Araphid Pennate Diatoms						
Asterionella	324.0	998.4	0.0	0.0	0.0	0.0
Synedra	16.0	0.0	0.0	0.0	0.0	0.0
Monoraphid Pennate Diatoms						
Biraphid Pennate Diatoms						
CHLOROPHYTA						
Flagellated Chlorophytes						
Coccoid/Colonial Chlorophytes						
Crucigenia	0.0	25.6	0.0	0.0	44.6	96.0
Dictyosphaerium	0.0	0.0	17.5	0.0	0.0	0.0
Elakatothrix	36.0	0.0	0.0	0.0	0.0	24.0
Oocystis	0.0	25.6	0.0	76.8	0.0	48.0
Pediastrum	0.0	12.8	0.0	0.0	0.0	0.0
Scenedesmus	16.0	64.0	17.5	0.0	0.0	0.0
Schroederia	150.0	0.0	0.0	0.0	0.0	0.0
Sphaerocystis	0.0	0.0	0.0	76.8	0.0	0.0
Filamentous Chlorophytes						
Desmids						
Staurastrum	0.0	12.8	0.0	0.0	0.0	0.0
Teilingia/related taxa	40.0	0.0	0.0	0.0	0.0	0.0
CHRYSOPHYTA						
Flagellated Classic Chrysophytes						
Chromulina	26.0	14.4	17.5	43.2	0.0	0.0
Dinobryon	300.0	1104.0	131.4	288.0	0.0	0.0
Mallomonas	0.0	8.0	0.0	96.0	0.0	0.0
Uroglena	0.0	0.0	0.0	0.0	1071.4	960.0
Non-Motile Classic Chrysophytes						
Haptophytes						
Tribophytes/Eustigmatophytes						
Centritractus	6.0	2.4	6.6	7.2	0.0	0.0
Raphidophytes						
CRYPTOPHYTA						
Cryptomonas	0.0	35.2	17.5	86.4	111.6	12.0
CYANOPHYTA						
Unicellular and Colonial Forms						
Aphanocapsa	0.0	0.0	0.0	0.0	33.5	72.0
Chroococcus	0.0	0.0	0.0	115.2	9.5	0.0
Microcystis	0.0	0.0	8.8	19.2	22.3	180.0
Snowella	0.0	0.0	0.0	0.0	0.0	120.0
Filamentous Nitrogen Fixers						
Anabaena	0.0	0.0	35.0	76.8	200.9	480.0
Filamentous Non-Nitrogen Fixers						
EUGLENOPHYTA						
PYRRHOPHYTA						
Peridinium	942.0	33.6	92.0	100.8	0.0	0.0

Zooplankton Data

	ZOOPLANKTON BIOMASS (UG/L)			
	Lovells	Lovells	Lovells	Lovells
	LP-1	LP-1	LP-1	LP-1
TAXON	6/13/13	7/17/13	8/21/13	10/2/13
PROTOZOA				
Ciliophora	0.3	0.0	0.0	0.0
ROTIFERA				
Asplanchna	0.4	6.4	1.3	0.1
Conochilus	0.0	0.0	0.0	0.0
Filinia	0.0	0.0	0.0	0.0
Kellicottia	0.0	0.0	0.0	0.0
Keratella	0.0	0.0	0.0	0.0
Polyarthra	0.0	0.0	0.0	0.0
Synchaeta	0.0	0.0	0.0	0.0
COPEPODA				
Copepoda-Cyclopoida				
Cyclops	9.7	0.3	0.0	0.1
Mesocyclops	14.4	0.2	0.0	0.0
Copepoda-Calanoida				
Diaptomus	3.6	0.1	0.1	0.0
Copepoda-Harpacticoida	0.0	0.0	0.0	0.0
Other Copepoda-Adults	0.0	0.0	0.0	0.0
Other Copepoda-Copepodites	0.0	0.0	0.0	0.0
Other Copepoda-Nauplii	8.3	1.5	0.0	0.0
CLADOCERA				
Bosmina	13.4	0.4	0.2	0.0
Ceriodaphnia	0.0	0.4	0.0	0.0
Daphnia ambigua	2.4	0.0	0.0	0.0
Daphnia pulex	68.6	0.0	0.0	0.0
Diaphanosoma	0.0	0.4	0.0	0.0
Leptodora	0.0	0.0	0.0	0.0
MEAN LENGTH (mm): ALL FORMS	0.40	0.42	0.30	0.35
MEAN LENGTH: CRUSTACEANS	0.55	0.46	0.46	0.70

	ZOOPLANKTON BIOMASS (UG/L)				
	Lovells	Lovells	Lovells	Lovells	Lovells
TAXON	5/30/14	6/4/14	7/8/14	8/4/14	9/9/14
PROTOZOA					
Ciliophora	0.0	0.0	0.0	0.0	0.0
ROTIFERA					
Asplanchna	0.0	3.1	2.0	11.7	3.2
Filinia	0.0	0.0	0.0	0.0	0.0
Kellicottia	0.5	0.0	0.0	0.0	0.0
Keratella	0.0	0.0	0.0	0.0	0.0
Polyarthra	0.0	0.0	0.0	0.0	0.0
Trichocerca	0.0	0.0	0.0	0.0	0.0
COPEPODA					
Copepoda-Cyclopoida					
Cyclops	48.7	12.4	0.3	0.4	1.3
Mesocyclops	3.9	2.4	0.0	0.0	0.0
Copepoda-Calanoida					
Diaptomus	2.0	3.9	0.1	0.1	0.0
Other Copepoda-Nauplii	5.6	16.5	0.7	1.0	0.5
CLADOCERA					
Bosmina	96.6	6.2	0.1	0.2	0.2
Chydorus	24.9	0.8	0.0	0.0	0.0
Daphnia ambigua	45.9	9.5	0.2	0.0	0.0
Holopedium	61.3	3.3	0.0	0.0	0.0
MEAN LENGTH (mm): ALL FORMS	0.48	0.52	0.26	0.37	0.39
MEAN LENGTH: CRUSTACEANS	0.51	0.55	0.48	0.46	0.54

	ZOOPLANKTON BIOMASS (UG/L)					
	Lovells #1	Lovells #1	Lovells #1	Lovells #1	Lovells #1	Lovells #1
TAXON	**4/23/2015**	**5/13/2015**	**6/10/2015**	**7/10/2015**	**8/14/2015**	**9/24/2015**
PROTOZOA						
Ciliophora	0.0	0.0	0.3	0.0	0.0	0.0
Mastigophora	0.0	0.0	0.0	0.0	0.0	0.0
Sarcodina	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA						
Conochilus	1.5	0.0	0.0	0.0	0.0	0.0
Keratella	0.2	0.2	0.0	0.0	0.0	0.0
Polyarthra	0.1	0.0	0.0	0.0	0.0	0.0
COPEPODA						
Copepoda-Cyclopoida						
Cyclops	92.2	99.9	16.1	0.0	0.0	3.8
Copepoda-Calanoida						
Diaptomus	0.0	0.5	3.2	1.0	1.0	1.9
Copepoda-Harpacticoida	0.0	0.0	0.0	0.0	0.0	0.0
Other Copepoda-Adults	0.0	0.0	0.0	0.0	0.0	0.0
Other Copepoda-Copepodites	0.0	0.0	0.0	0.0	0.0	0.0
Other Copepoda-Nauplii	8.3	27.8	20.4	5.2	0.0	0.7
CLADOCERA						
Bosmina	17.5	12.3	16.2	1.9	2.1	1.5
Ceriodaphnia	0.0	2.7	0.0	0.0	0.0	0.0
Chydorus	2.1	0.0	0.0	0.0	0.0	0.0
Daphnia ambigua	91.7	59.6	6.4	3.8	3.4	0.0
Daphnia pulex	534.1	0.0	11.9	14.3	157.3	35.8
Diaphanosoma	0.0	0.0	0.0	4.6	2.1	0.3
Holopedium	0.0	8.8	9.2	99.7	10.7	51.9
MEAN LENGTH (mm): ALL FORMS	0.64	0.58	0.36	0.80	1.04	0.85
MEAN LENGTH: CRUSTACEANS	0.83	0.60	0.48	0.80	1.04	0.85