INVESTIGATION OF ALGAL BLOOMS AND POSSIBLE CONTROLS FOR LOVELL’S POND, BARNSTABLE, MASSACHUSETTS, 2013

DRAFT REPORT

BY WATER RESOURCE SERVICES, INC.

MARCH 2014

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Project Background and Need

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 has not been actively used in recent years. Swimming in the pond has been generally discouraged by 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.

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 water and whatever contaminants had been released from the sediment during the anoxic period with the upper waters of the pond. This may have even worsened conditions, and cyanobacteria blooms were severe.

Inputs to the pond from surrounding cranberry bogs and residential development have also raised concerns. 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, so direct impacts have ceased, but legacy impacts through internal loading appear substantial.

This project was undertaken to evaluate current sources of nutrients to Lovell's Pond, to assess the status and potential for the air-driven circulation system to enhance water quality, and to evaluate alternative means to reduce algal blooms and improve the condition of Lovell's Pond overall.

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 substantially as a function of limited surface outflow and continuous evaporation and groundwater movement; water levels were at least a foot higher than normal at the end of a wet June in 2013, and can decline by up to two feet at the end of a very dry summer. 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.

Figure 1. Lovell's Pond general area.

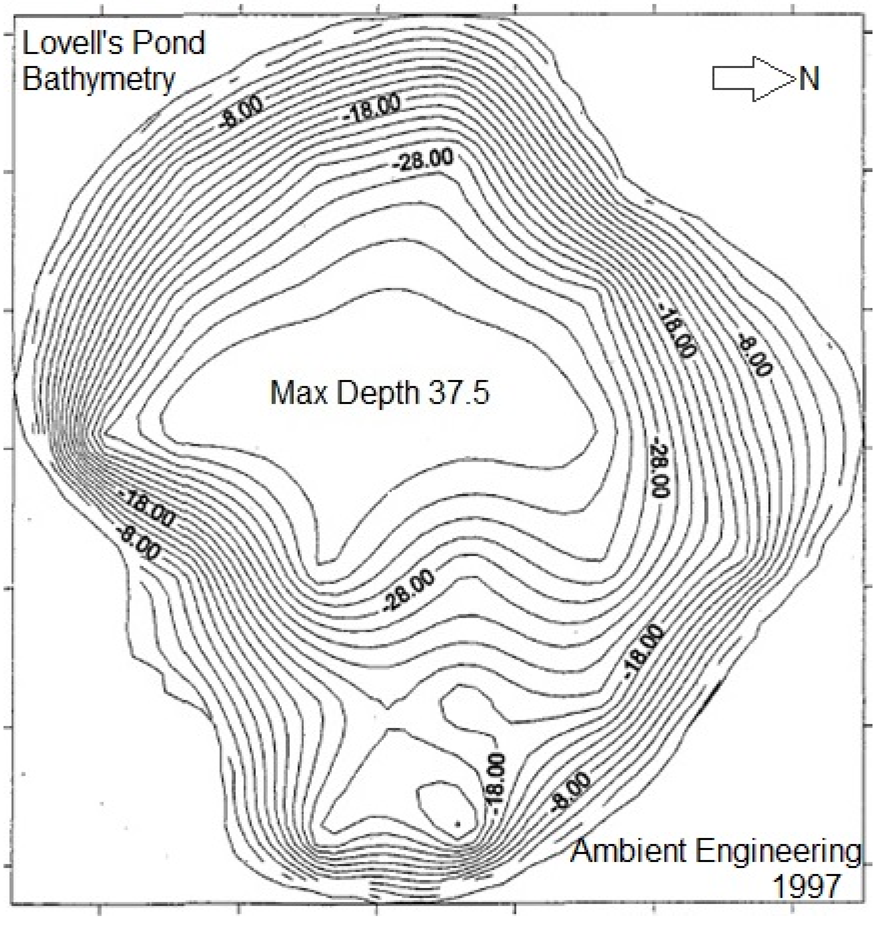


Figure 2. Bathymetric map of Lovell's Pond

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 late 1990s 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 (the town now owns the bogs), it is not clear that any flow is sent from Patty's Pond through the former bogs to Lovell's Pond. No flow was observed on any of 6 visits to the pond in 2013, and the structures that routed water to Lovell's Pond are all closed and not leaking appreciably. 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 (the Town now owns much of this area and has a conservation restriction on it) 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. Some water may still seep through, and vandalism has been recently reported, but the flow of water from Santuit Pond and other western drainage to Lovell's Pond is now small.

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.

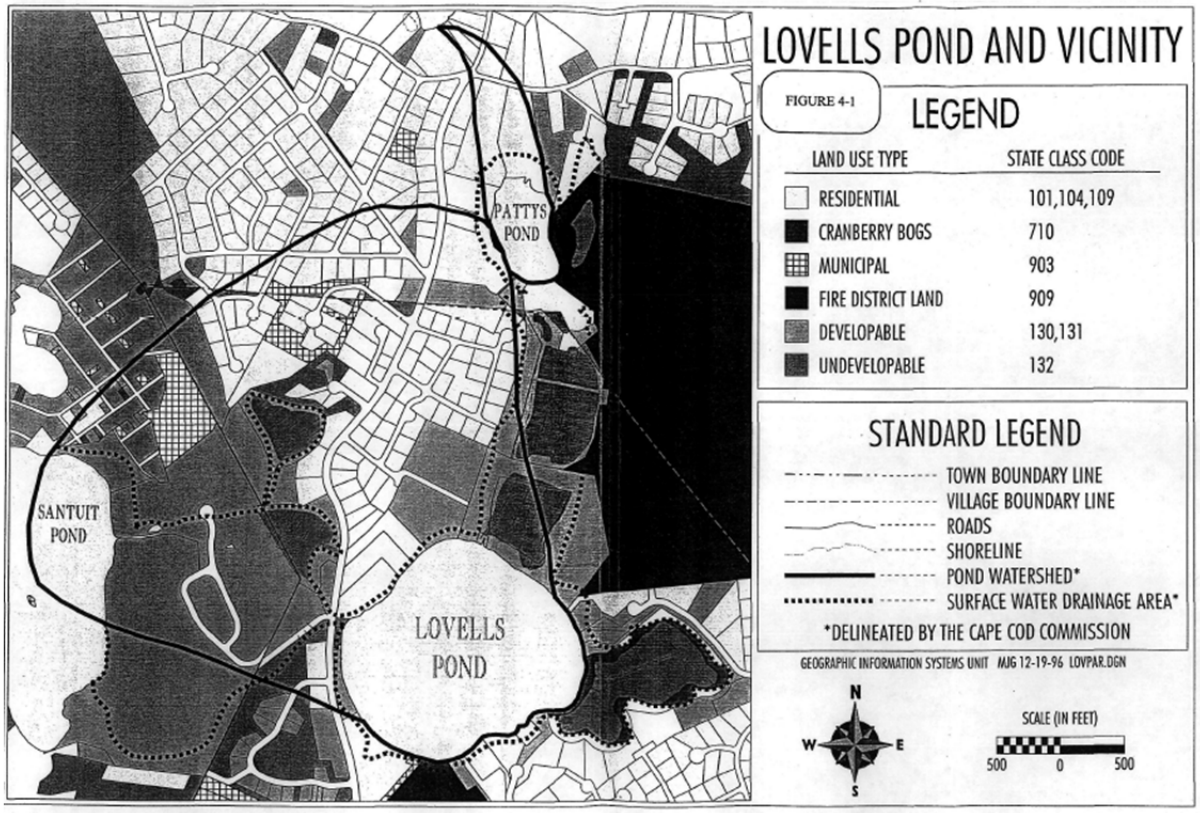


Figure 3. Ground and surface watersheds for Lovell's Pond.

Water can overflow from Lovell's Pond either into the cranberry bog to the east through a constructed, controlled overflow, or into a stream channel to the south through a pipe that has been blocked at various times in the pond's history and appears minimally functional now. There is no active management of the outflow at this time.

Designated Uses

Lovell's Pond is listed as Class B waters. Under the Massachusetts system, this means that the water is not intended for direct potable water supply, but is expected to meet water quality standards for recreational and habitat uses. The designated uses of Lovell's Pond include swimming, boating, fishing, and habitat for fish and wildlife. Those uses are impaired by low oxygen and algal blooms.

Rehabilitation Needs and Objectives

Improving water clarity and oxygen in deep water are the two primary needs, and these appear to be linked. Water clarity is largely reduced by algae blooms, and those blooms appear to be supported by internal recycling of phosphorus brought on by low oxygen in the deep waters of the pond. Therefore, the primary objective has been to improve oxygen throughout the pond and reduce the release of phosphorus from sediments, thus limiting algal blooms. This may not have been the only need when the cranberry bogs were operating and discharging to Lovell's Pond, but since the cessation of growing operations and limited further inputs from those sources, improving oxygen would indeed appear to be the main need.

Unfortunately, the circulation system that was installed did not operate as planned, and oxygen remained an intermittent problem. Release of phosphorus and other compounds is rapid upon depletion of oxygen, and restoration of the circulation system to operational condition appears to have aided the movement of phosphorus into the upper waters each time the circulation system was restarted after a period of operation. Additionally, the system was not always turned on before oxygen was depleted, effectively starting the summer by mixing extra phosphorus into the upper waters and promoting algal blooms.

Subsidiary objectives of this evaluation effort are therefore to determine under what conditions a circulation system might provide the desired conditions and to assess alternative means of preventing phosphorus from being moved into the upper waters of the pond during the growing season.

Additional Data Needs

The key data needs to reach management oriented conclusions for Lovell's Pond include:

1. Assessment of current conditions in the pond, especially with regard to oxygen status and nutrient levels.
2. Verification that external sources of phosphorus and other contaminants to the pond have indeed been curtailed.

3. Quantification of the amount of phosphorus in the surficial sediments that could be released into the water column, and assessment of the build-up over the course of the summer.
4. Assessment of the area of the pond subject to anoxia and potentially contributing to the internal phosphorus load.
5. Documentation of the algae in the pond that are impairing water clarity.
6. Inventory of biological components of the pond that may have bearing on which alternative actions can be implemented under current regulatory limits and that could affect the outcome of any action under consideration.
7. Assessment of water quality that might affect choice of management alternatives or constrain implementation.

The sampling and investigation program carried out in 2013 sought to provide the data necessary to address the above considerations within the time and financial constraints imposed.

Study Approach and Methods

Historic Data Review

The 1997 report by Ambient Engineering provided the starting point for data collection and evaluation. While this effort has shortcomings and a number of conditions have changed since this study was performed, it provided the best available summary of the situation into the late 1990s. Data from the Ponds And Lakes Stewards (PALS) program was obtained from the Town of Barnstable and the School of Marine Science and Technology at UMASS Dartmouth, which provides all analytical services. The value of the PALS program and the contribution made by SMAST cannot be overestimated and the involved staff and volunteers are to be commended for creating this important data base and making it available.

Watershed Assessment

The watershed was evaluated through field observation. We drove or walked nearly all of the potential contributory area to assess likelihood of any contribution and possible sources of contaminants, with a focus on phosphorus and nitrogen.

In-Lake Investigations

Lovell's Pond was visited and assessed to varying degrees on 11 dates in 2013. The first 5 dates in April and May involved temperature and dissolved oxygen profiles, plus Secchi transparency and surface pH readings, but a local volunteer, Mr. Robert Nichols, whose efforts on behalf of multiple ponds in Barnstable are acknowledged. Additional visits by WRS staff were conducted in June, July, August and the start of October. On one date (early July) only field water quality measures were conducted, as with the April and May visits, and plankton samples were collected. On the other four dates, in addition to field water quality assessment, samples were collected for nutrient analysis by a certified laboratory, Envirotech Labs of Sandwich, Massachusetts. Additional field and lab analyses were conducted through the PALS program on one additional date, in mid-September.

With the bowl-like shape of Lovell's Pond, a single sampling site in the center of the lake was deemed sufficient to characterize pond conditions on each date (Figure 4). In total, data relating to water quality were generated for temperature, dissolved oxygen, pH, alkalinity, conductivity, turbidity, total and dissolved phosphorus, nitrate + nitrite nitrogen, ammonium-nitrogen, total Kjeldahl nitrogen, Secchi transparency, phytoplankton and zooplankton.

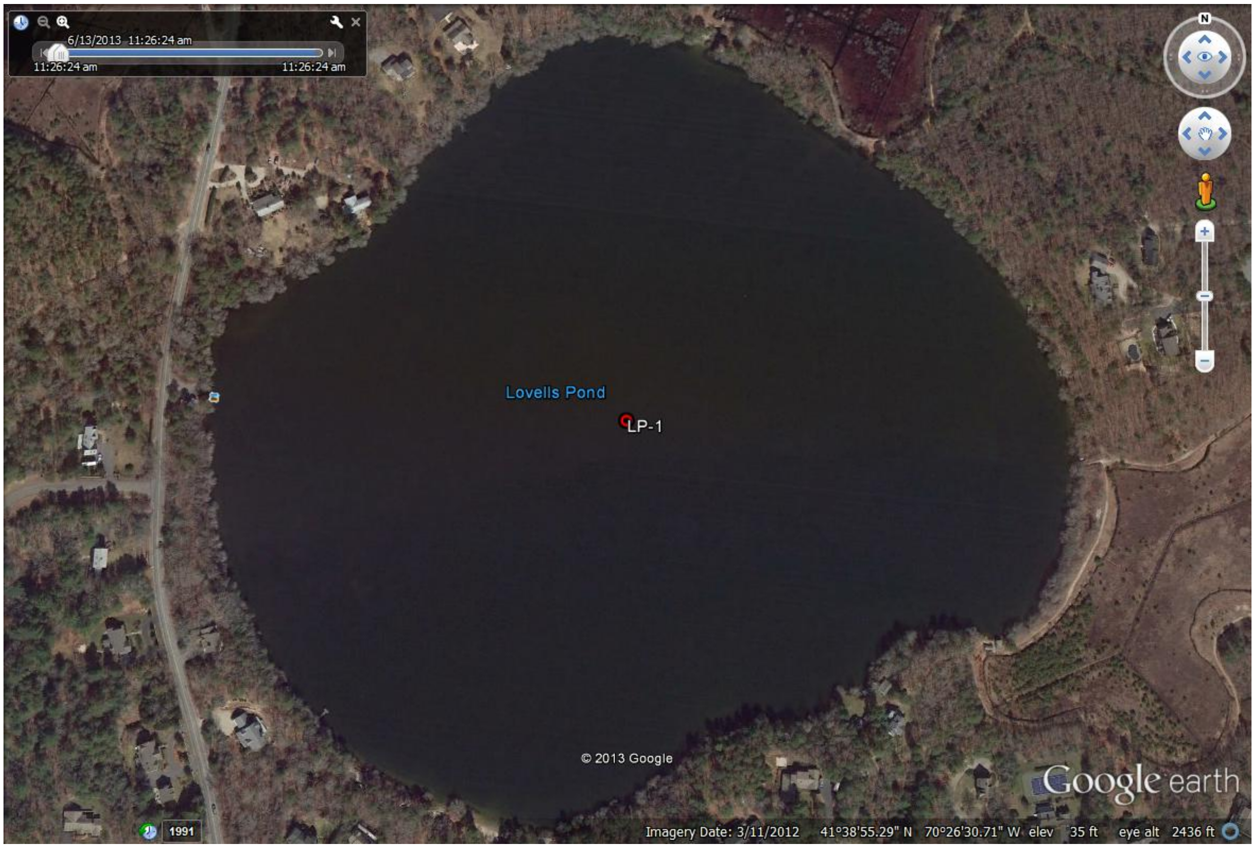


Figure 4. Map of water quality sampling station

Soft sediment distribution was assessed by underwater viewing system (a Marcum 820 series videocam on a cable, with a viewing screen in the boat). This allowed delineation of where muck sediment began to accumulate and where cover by muck was complete, but does not provide data on the depth of soft sediment. Surficial sediment quality was assessed by collecting samples with an Ekman dredge in three areas (Figure 5), with each area represented by a composite sample created from 5 individual samples (S2-S6, S7-S11, and S12-S16). Areas were selected on an east to west transect in locations where muck cover was complete and muck depth was at least 6 inches (15 cm). Each individual sample was obtained from the upper 2 inches (5 cm) of the retrieved muck.

Figure 5. Map of sediment sampling stations

Sediment testing included measurement of total phosphorus, iron-bound phosphorus, percent moisture, and percent organic matter. A critical calculation derived from these measures is the amount of available phosphorus in the surficial sediments. Phosphorus bound to iron can be released under anoxic conditions, and is a key component of internal load. Addition of aluminum transfers phosphorus from iron to aluminum, and resulting aluminum-phosphorus complexes are not subject to release under anoxia. Since aluminum treatment could be used to inactivate surficial sediment iron-bound phosphorus, aluminum dose testing was also conducted by Spectrum Analytical Laboratory. In this test, a known quantity of sediment is exposed to an aluminum solution representing one of several chosen doses in g/m^2. The treated sediment is settled and dried, then re-tested for iron-bound phosphorus. As the dose of aluminum rises, the fraction of phosphorus remaining in an iron-bound form declines, and the most effective and/or efficient aluminum dose can be determined for possible application.

Plankton samples were collected with temperature and dissolved oxygen profiles starting in June at the central station. Phytoplankton were collected as grab samples slightly under the water surface. Zooplankton were collected by vertical tows of an 80 μm mesh net until 380 liters of water were collected (30 m of tow with a 13 cm diameter net). Plankton samples were preserved with glutaraldehyde in the field (0.5% for phytoplankton, 2% for zooplankton) and concentrated in the lab prior to quantitative assessment under phase contrast microscopy.

Macrophytes were not a primary focus of this study, and are in fact not abundant in water more than about 3 feet (1 m) deep in Lovell's Pond. General assessment of types and abundance of aquatic vascular plants was made during a general survey of peripheral pond conditions and by viewing with the Marcum underwater video system while assessing soft sediment distribution in the pond.

Investigative Results

Historic Data Review

Water Quality Data

All data available to the WRS team has been placed in the Appendix, and includes data from the 1997 Ambient Engineering report and PALS reports from 2001-2012. The Ambient Engineering data exhibits some inappropriately high detection limits and some very high variability, so it is less reliable than later data, but elevated nutrient levels, algal blooms, and low water clarity are indicated. The PALS data covers more than a decade, and while there are a few gaps in the annual sampling, there are also a few years where more than one sample was collected, and these data tend to be very reliable.

Total nitrogen near the surface of Lovell's Pond (Figure 6) has varied from <0.3 mg/L, a desirable value, to slightly over 1.0 mg/L, a highly undesirable value, although the forms of nitrogen matter to its impact on the aquatic system, and we do not have a breakdown among nitrate, ammonium, and organic forms of nitrogen. Total nitrogen near the bottom of the pond (Figure 6) has been higher than the 0.5 mg/L level set as an approximate target for desirable pond water quality in most samples, and has been higher than the 1.0 mg/L threshold set for highly undesirable pond water quality in 4 of 10 years represented in the available data. It is likely that the high bottom values are dominated by ammonium nitrogen, which accumulates in anoxic bottom water as a function of anaerobic decay. Very high bottom values ceased once the circulation system was turned on in 2009, while surface values are higher after that time. Mixing was occurring, but apparently did not adequately suppress ammonium generation.

Total phosphorus near the surface of Lovell's Pond (Figure 7) is usually >0.01 mg/L, a desirable value, and has been >0.03 mg/L, an undesirable value, in 3 of the last 4 years. Total phosphorus near the bottom of the pond (Figure 7) has been higher than the 0.01 mg/L level set as an approximate target for desirable pond water quality in all samples, and has been higher than the 0.03 mg/L threshold set for undesirable pond water quality in all 10 years represented in the available data. Extremely high values (>0.10 mg/L) have been observed in half the years. It is likely

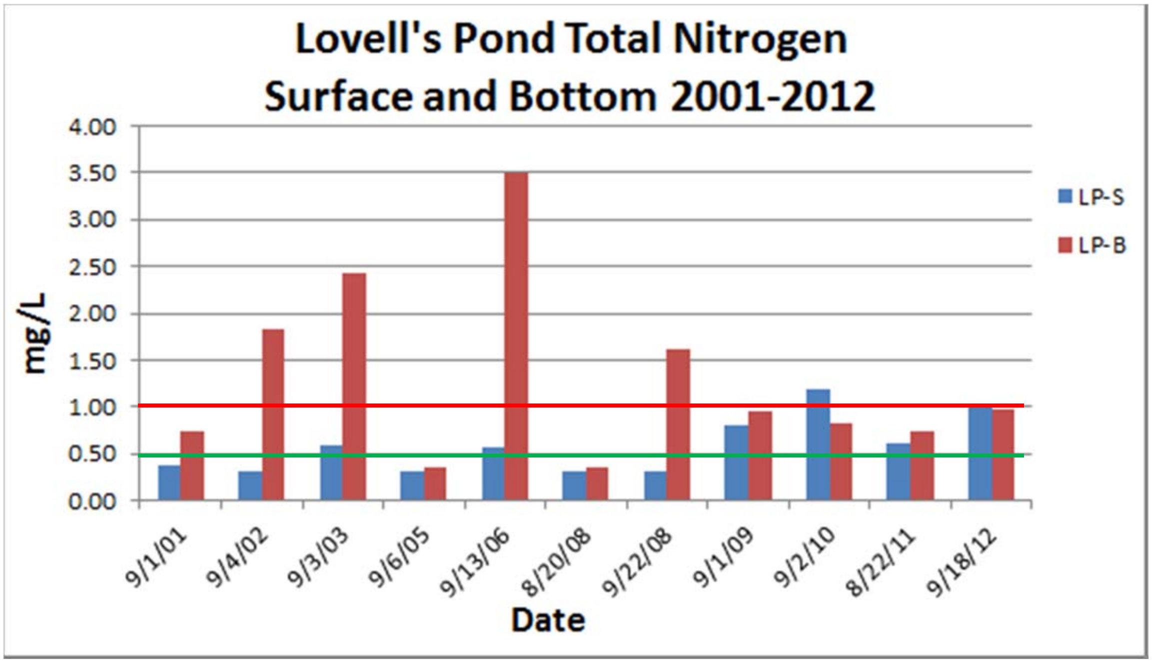


Figure 6. Total Nitrogen in surface and bottom samples in 2001-2012

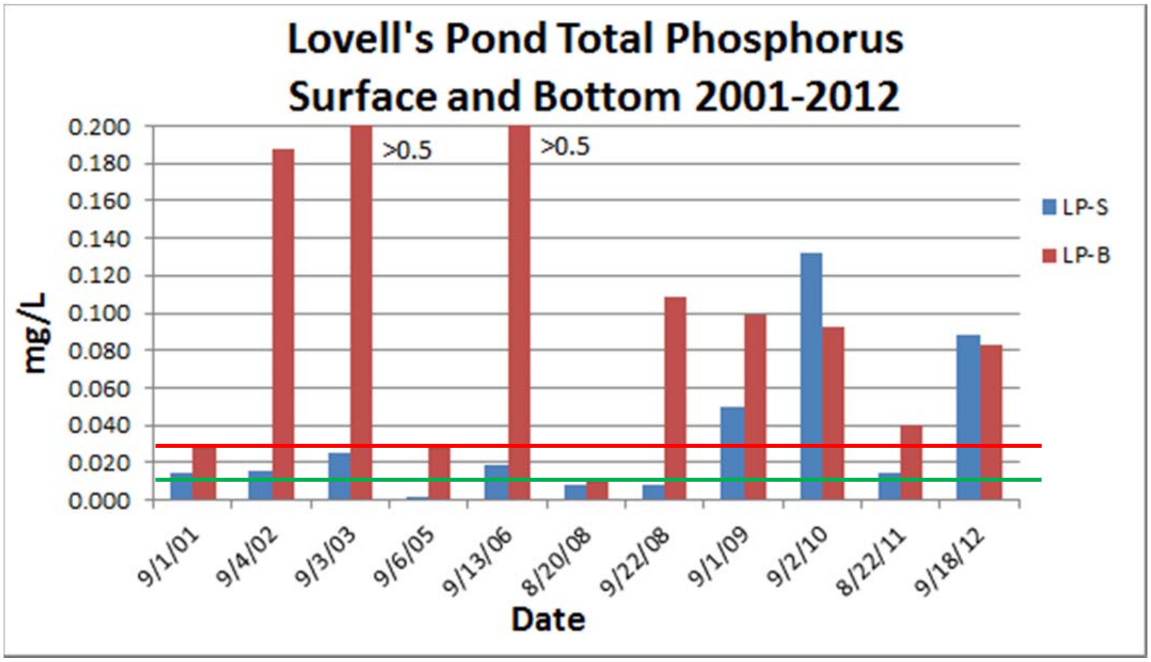
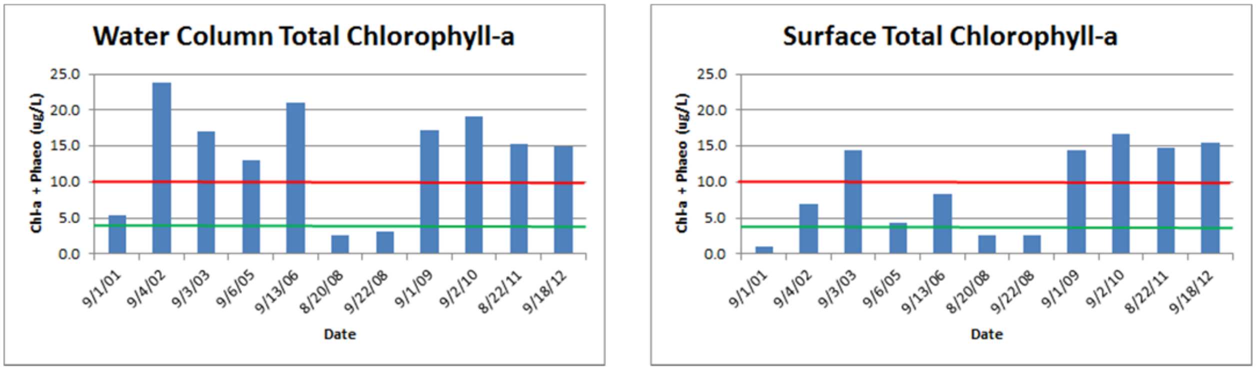


Figure 7. Total Phosphorus in surface and bottom samples in 2001-2012

that the high bottom values are dominated by dissolved phosphorus, which is released from iron compounds in the sediment under anoxic conditions. Very high bottom values continued after the circulation system was turned on in 2009, but surface values increased after that time. Mixing was occurring, but apparently did not adequately suppress phosphorus release from the sediment, and aided movement of that available phosphorus into the upper waters.

With frequently elevated nutrient levels, algae have been relatively abundant, as indicated by levels of chlorophyll-a, a primary algal pigment (Figure 8). There is substantial variation in values, undoubtedly related to other factors that affect algae, such as grazing by zooplankton, temperature, light, wind and the circulation system after 2009. Values have been below the desirable threshold (4 µg/L) on occasion, but are usually higher than the undesirable level (10 µg/L), and surface concentrations have been higher since the circulation system was installed.


Water Column Total Chlorophyll-a

Surface Total Chlorophyll-a

Figure 8. Total chlorophyll-a as a water column average and at surface 2001-2012

Water clarity is a function of multiple factors, but algae levels are certainly one of the more important influences. Water clarity, as assessed by Secchi disk transparency (Figure 9), has usually been between the former state swimming standard of 4 feet (1.22 m) and the desirable level of 13.2 feet (4 m). It was by far the highest in 2008, when nutrient levels were also the lowest observed in the last decade or more, and has been no better after the circulation system was installed.

Considering the main water quality variables monitored between 2001 and 2012 (Figure 10), there are significant but not overly strong correlations between total phosphorus, chlorophyll and Secchi transparency. The correlation between total nitrogen and chlorophyll is stronger, explaining much more of the variation in chlorophyll. However, the strongest correlation is between nitrogen and phosphorus, showing that they co-vary. These relationships would seem to suggest that phosphorus increases to the point where it is not a limiting factor for algal growth. That does not mean that nitrogen is the limiting factor; this is correlation, not necessarily cause and effect. However, it is most interesting to note that the highest chlorophyll levels correspond to the lowest N:P ratios, indicating that more nitrogen without more phosphorus will not necessarily yield more algae. Moreover, the low N:P ratios favor certain cyanobacteria, which can fix their own nitrogen from dissolved gas, and are the most prolific and undesirable bloom formers. Elevated nutrients are the problem for Lovell's Pond, and low N:P ratios at high levels for both nitrogen and phosphorus promote cyanobacteria blooms.

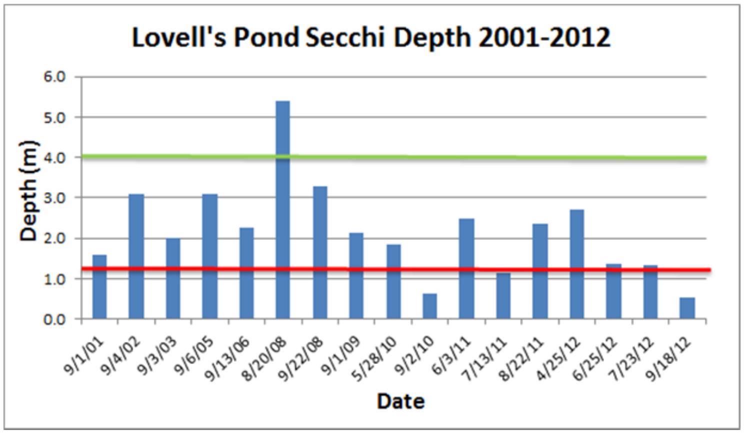


Figure 9. Secchi transparency in 2001-2012

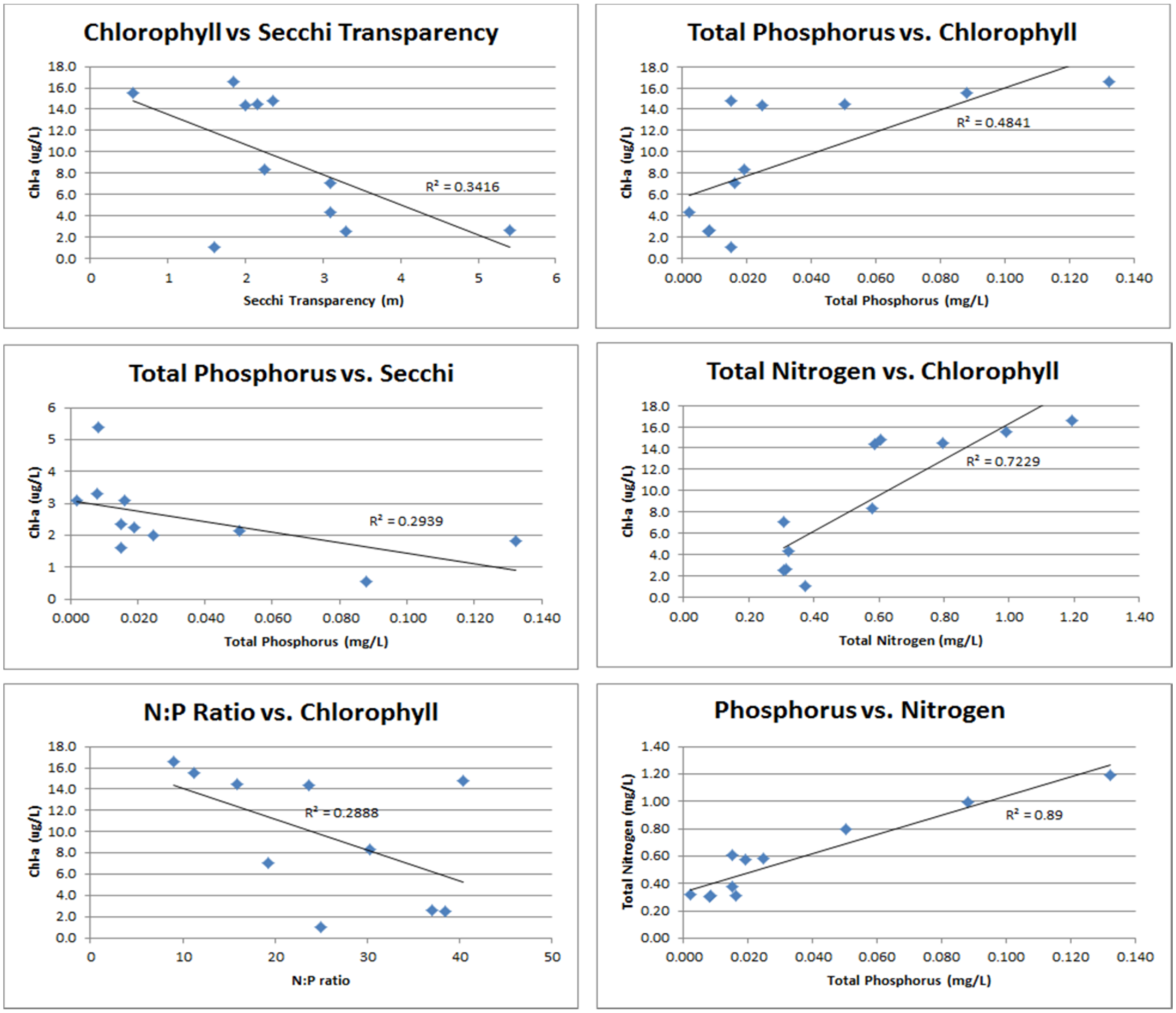


Figure 10. Relationships among key water quality variables for 2001-2012

Fishery data

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 sunfish, yellow perch, and bullheads. Various minnow species are also present, but there have been no recent surveys to itemize and quantify species of fish in this pond. 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. It is not known if any alewife remain in Lovell's Pond.

Circulation System

One option for enhancing water quality in lakes is to mix the water (Mattson et al. 2004, Cooke et al 2005). There are multiple possible approaches, but the most common has been to lay air lines in the bottom of the lake, mostly in deeper water that would be part of the bottom water layer when the pond is stratified, and to feed compressed air into those lines at a rate of about 1.3 standard cubic feet per minute (SCFM) for every acre of water body to be mixed. If the air is well distributed, this level of airflow has been documented to prevent stratification and to maintain fairly even conditions from top to bottom in the water body. The intended result is to homogenize water quality, maintain oxygen at the bottom, limit undesirable sediment-water interactions, and physically disrupt algae that prefer more stable conditions (which include most of the major bloom forming cyanobacteria).

The system designed and installed in Lovell's Pond met the basic premises upon which successful systems have been based. A 25 hp compressor delivers up to 112 scfm to a 56 acre pond through 6 air lines covering the target area, the longest line being 1700 feet (515 m). There are, however, several issues with the design and operation of mixing systems that can limit success. First and foremost, the compressor must operate nearly continuously during the period of potential stratification, which is May into October on Cape Cod. Thermal gradients can develop quickly, in under a week, and unless the system is oversized, may not be overcome for a month or more if allowed to develop. Release of undesirable substances from the sediment, most notably dissolved phosphorus but also ammonium nitrogen, occurs quickly when mixing ceases. Oxygen may be lost at the sediment-water interface in a day, and release of phosphorus will commence almost immediately. If the compressor is off for more than a week, even if it does have the capacity to overcome any thermal barrier that has formed, it will be mixing water with potentially elevated nutrient levels into the upper waters. Algal blooms are then likely.

A common problem with compressors is overheating. Adequate ventilation is critical, but the desire to reduce noise usually leads to housing the compressor in a building. Unless the building is air conditioned or has a ventilation system that would likely conflict with the noise reduction goal, heat build-up during summer in most climates creates unfavorable heat conditions and compressors shut down. In a review of circulation system applications, Wagner (2014) found no case where compressor shutdown was not a problem for air-driven systems. Rapid maintenance could overcome this limitation, but many systems performed sub-optimally as a result of periods of non-operation.

Another limitation of air-driven circulation systems is that the air input ports are normally set a foot or more off the bottom of the pond to minimize the potential to entrain loose bottom sediments and increase turbidity in the pond. The resuspended sediments may also transfer nutrients to the water, so a high premium is usually placed on avoiding movement of water right at the pond bottom. As a result, there may be a thin anoxic layer at the bottom in deep water even with mixing of most of the pond, and oxygen can become depleted and nutrients can be released from the sediment into that layer. Some transfer to the overlying water is likely, so circulation systems do not usually depress phosphorus and nitrogen to the maximum desired extent.

Finally, even with a properly designed air-driven circulation system, the heat input that creates thermal gradients comes from the top (from the sun), while the mixing force comes from the bottom (via air release), and the heat of the sun over a week of hot, sunny weather can put more heat energy into the pond than most circulation systems can mix in that same timeframe. Pockets of hot surface water develop, and mixing is incomplete. Variable conditions both horizontally and vertically can be almost unavoidable.

Solutions to these problems include greatly oversizing system capacity, laying extra lines for better distribution of air, and having a back-up compressor available for immediate operation if the primary compressor fails. A generator to run the compressor(s) is also needed in the event of a power failure. These add substantial expense to any circulation system cost and are rarely included.

The circulation system for Lovell's Pond experienced intermittent operation in every year as a consequence of compressor shutdown. Shutdowns lasted more than a few days in most cases. The system did appear to have the capacity to eventually mix the pond after a shutdown, but based on the available water quality data, nutrient levels in the upper water layer were increased over what would have been expected without operation of the circulation system and algal blooms were not reduced. Overall algal abundance may not have changed much, but surface blooms, especially of cyanobacteria, appear to have increased.

Watershed Assessment

This investigation focused on in-lake conditions, but a general survey of the watershed was performed, and indicated that surface water influence on Lovell's Pond is nominal at this time. There appears to be no flow from Patty's Pond through the northern cranberry bogs to Lovell's Pond. Those bogs are now inactive, so there is no active movement of water for agricultural purposes. Overland flow might occur in very large storms, but there was no indication of flow at any time during this survey. The western bogs are also inactive and the stream between them and Lovell's Pond has minimal flow most of the time and the connection with Lovell's Pond has been blocked. There has been some suggestion of vandalism and possible inputs from Santuit Pond via this channel, but it is minor if it happens at all. The eastern bogs are downgradient of Lovell's Pond and are also inactive; flow can leave the pond and enter those bogs, but no flow from the bogs enters Lovell's Pond. This leaves only a narrow strip of land around the pond to contribute runoff; this land is largely in low density residential development and second growth forest, with sandy soils and very little evidence of any runoff. The surface watershed of Lovell's Pond does not appear to represent much of a threat of contaminant input. Runoff from the road and boat launch area may be an exception, but this is a small area of limited consequence to the pond.

Ground water flow is generally from northwest to southeast, and an area of about 350 acres would be the strongest contributor of phosphorus. Nitrogen can move longer distances through the soil, but phosphorus is less mobile and requires anoxic groundwater to become significantly mobile. Contributions of nutrients via ground water may not be negligible, but are highly unlikely to be sufficient to support the observed algal blooms. The Ambient Engineering study concluded that watershed inputs were smaller than the internal load almost 20 years ago, and watershed influence has clearly been reduced since that time.

Direct precipitation is another minor source of nutrients, but also not one that typically supports algal blooms. This leaves internal loading of nutrients as the primary source for algae in Lovell's Pond. The nutrient budgets will be revisited later in this report.

In-Lake Water Quality Investigations

Complete data from the 2013 WRS investigative survey are contained in the Appendix. Data from the 2013 PALS survey of September 19, 2013 were combined with the WRS data and early T/DO profiles from Bob Nichols for a more complete picture of conditions in 2013. Water quality profiles were obtained for temperature and oxygen in April and May, then were expanded with different equipment from June into October to include pH, conductivity and turbidity (Figures 11-21). The circulation system was not operated in 2013, so a more natural pattern of thermal stratification and oxygen loss was observed. Relatively mixed conditions were observed in early to mid-April, but signs of a gradient were evident at the end of April, and the deepest part of the pond was anoxic throughout May, despite only a weak thermal gradient. Stronger stratification developed in June, but an odd pattern of low oxygen at the thermocline and no oxygen at the bottom with a bulge of slightly higher oxygen in between was observed. This could be caused by either strong decay of algae accumulating at the thermocline, depressing oxygen at that level more than it would be otherwise, or by oxygenated ground water inputs in deeper water. That oxygen bulge is gradually eliminated, with anoxic conditions prevailing at water depths >13.3 feet (4 m) by mid-July. Thermal stratification strengthened in late July and August, restricting anoxic waters to >20 feet (6 m) of depth. The pond was still stratified with no oxygen deeper than 20 feet (6 m) in early October, when monitoring was concluded.

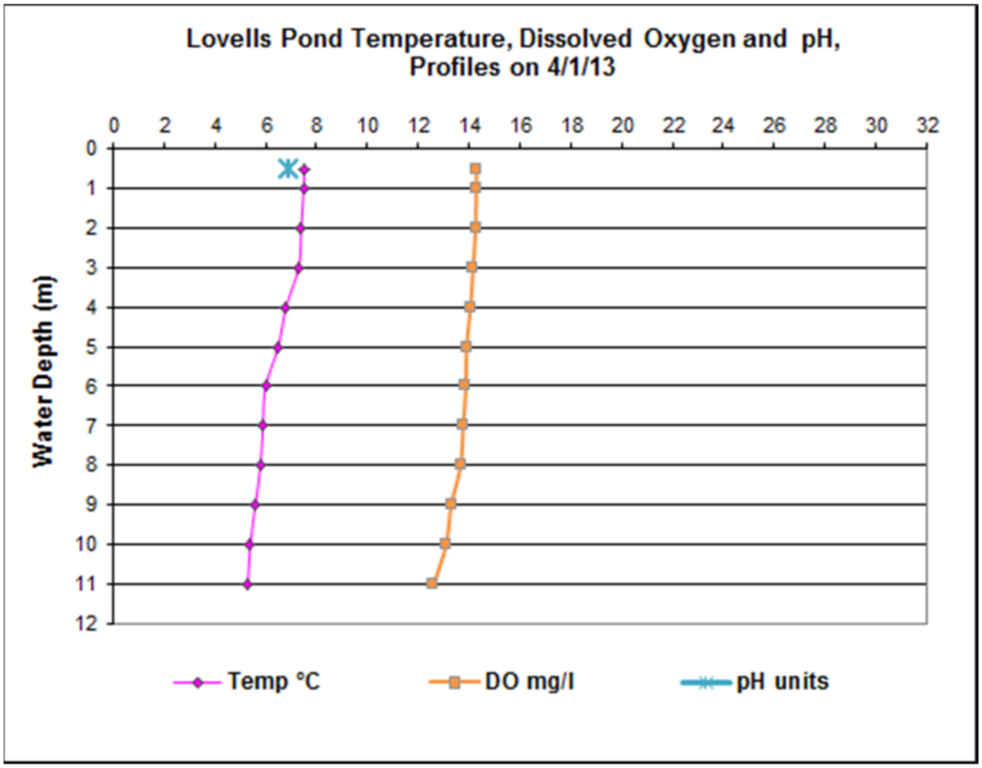


Figure 11. Temp, DO and pH profiles on 4/1/13

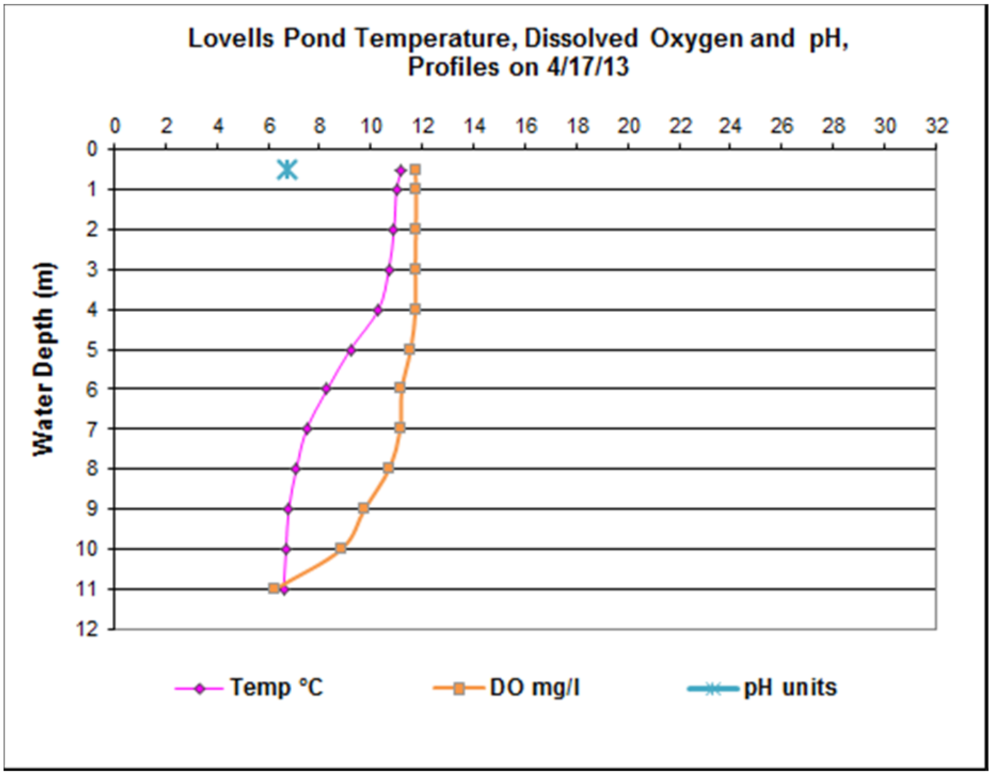


Figure 12. Temp, DO and pH profiles on 4/17/13

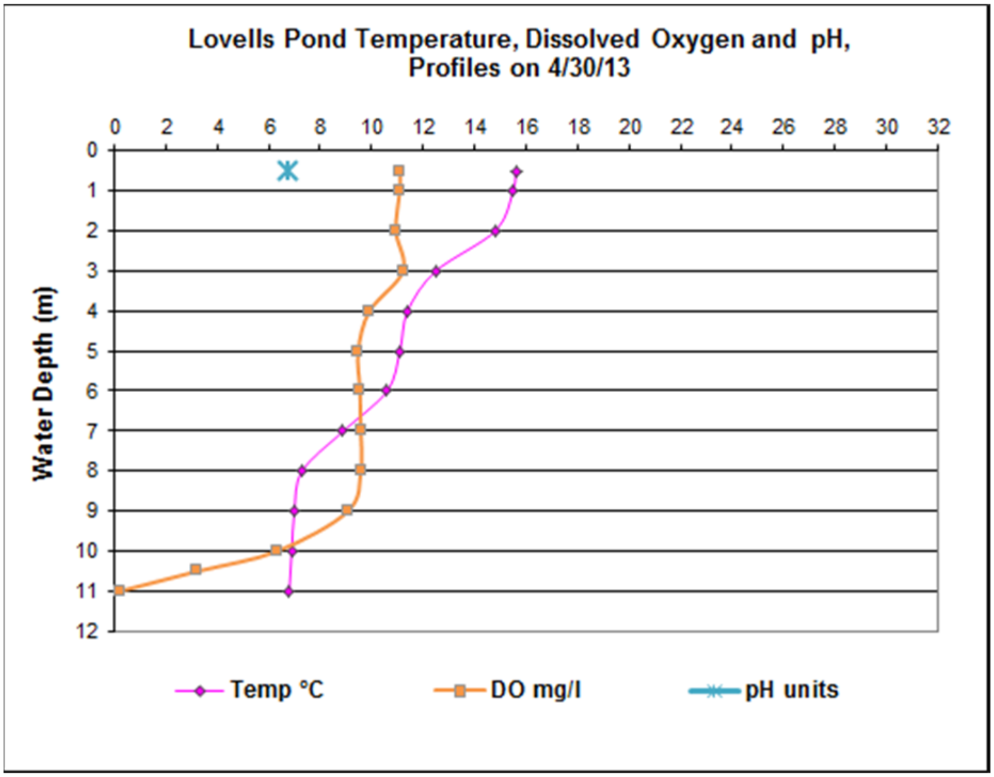


Figure 13. Temp, DO and pH profiles on 4/30/14

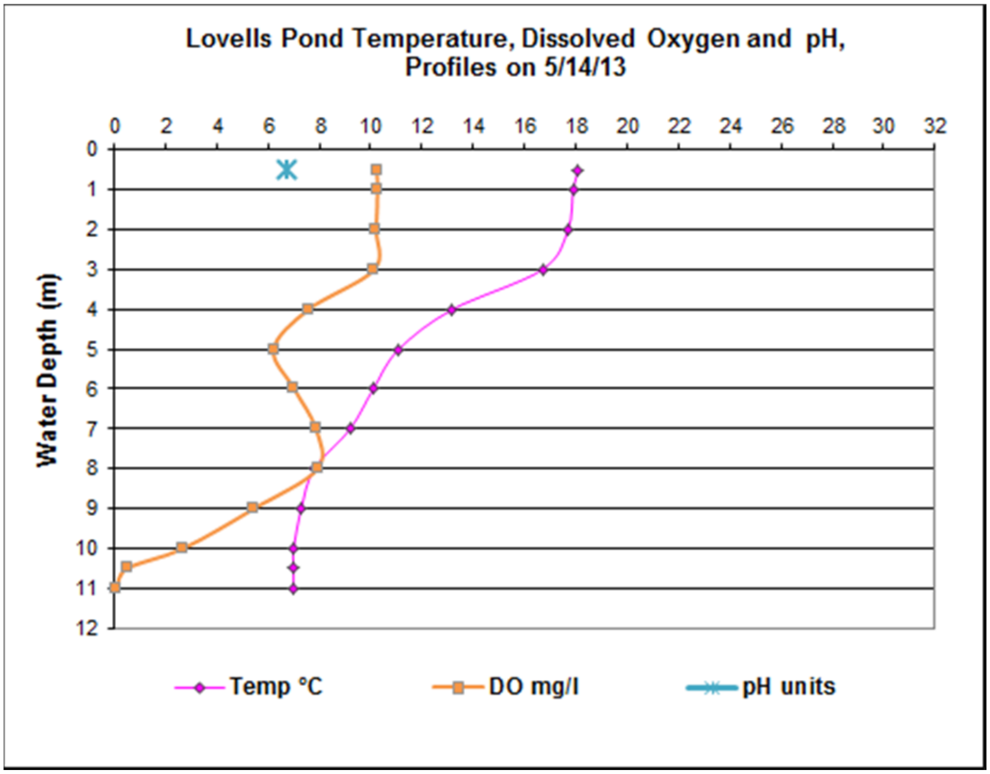


Figure 14. Temp, DO and pH profiles on 5/14/13

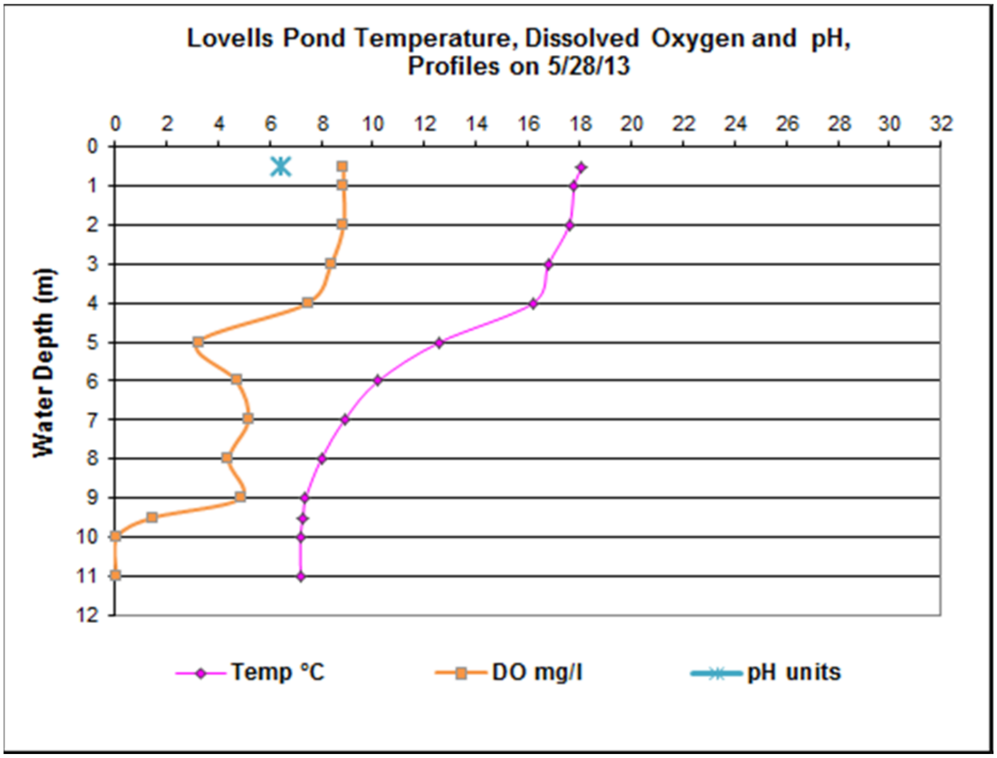


Figure 15. Temp, DO and pH profiles on 5/28/13

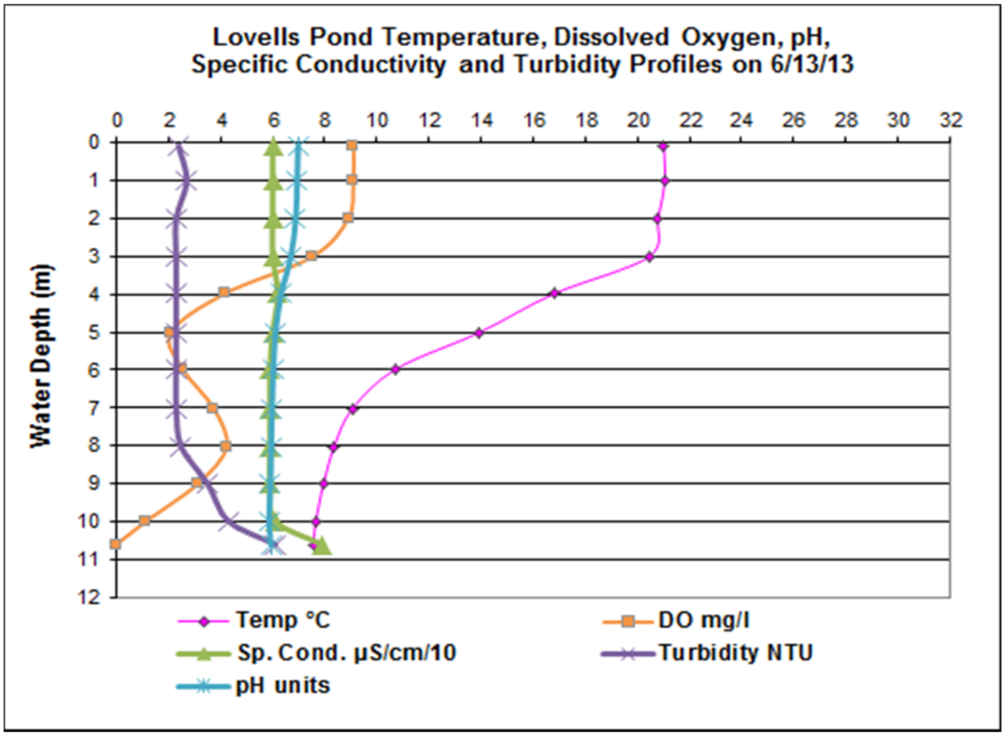


Figure 16. Temp, DO, pH, Specific Conductivity and Turbidity profiles on 6/13/13

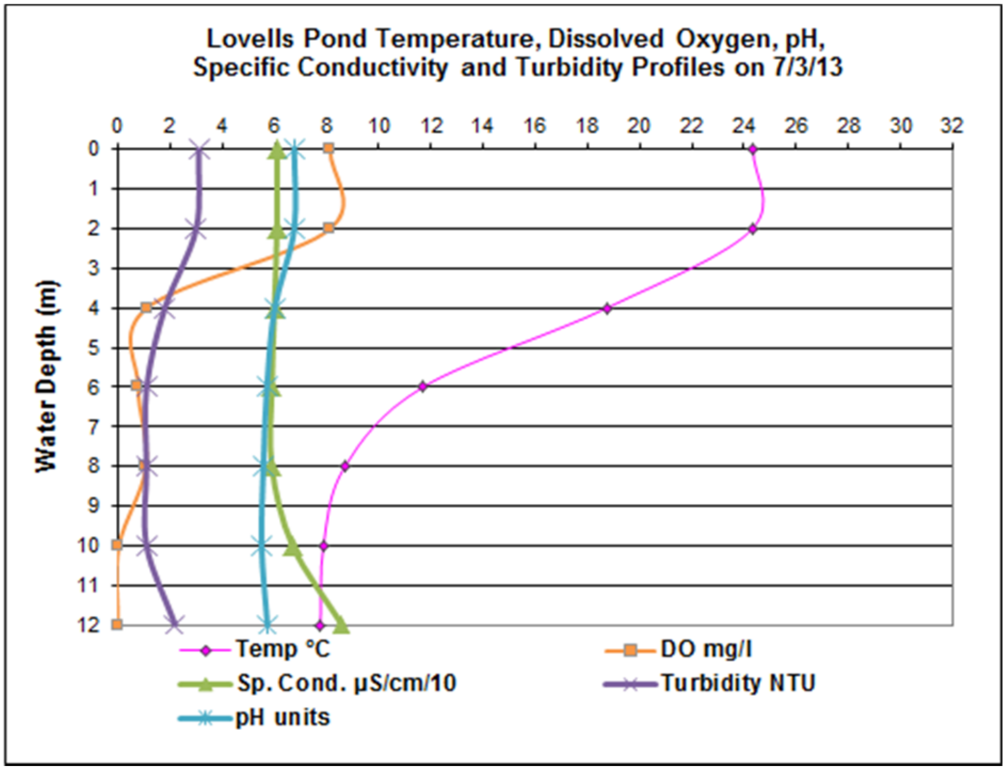


Figure 17. Temp, DO, pH, Specific Conductivity and Turbidity profiles on 7/3/13

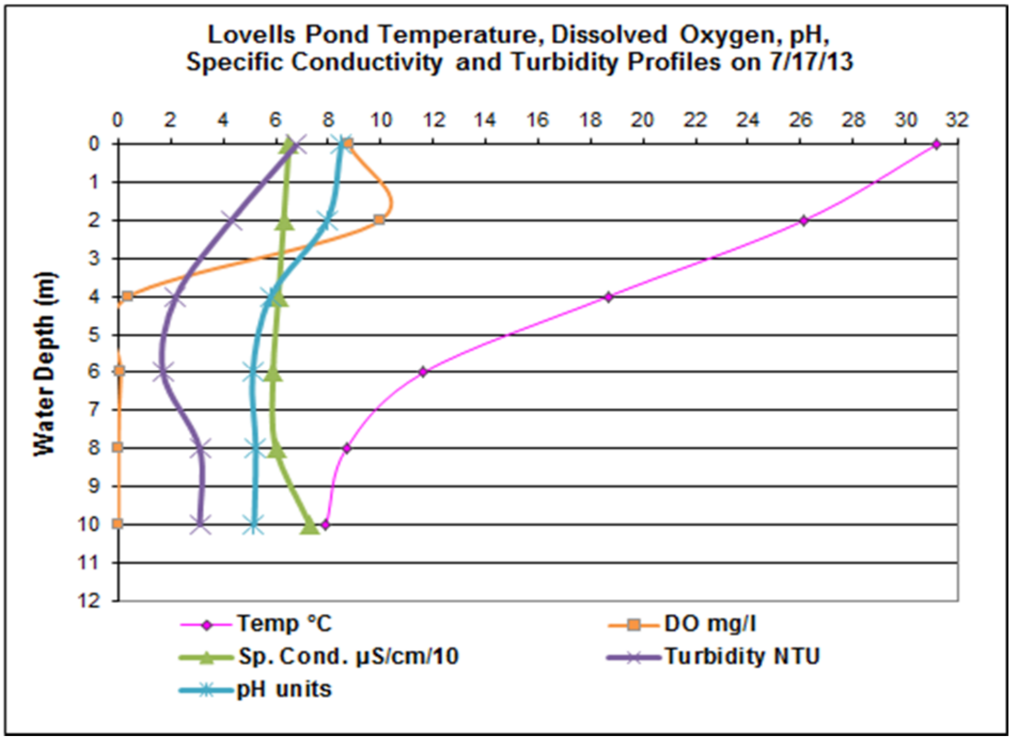


Figure 18. Temp, DO, pH, Specific Conductivity and Turbidity profiles on 7/17/13

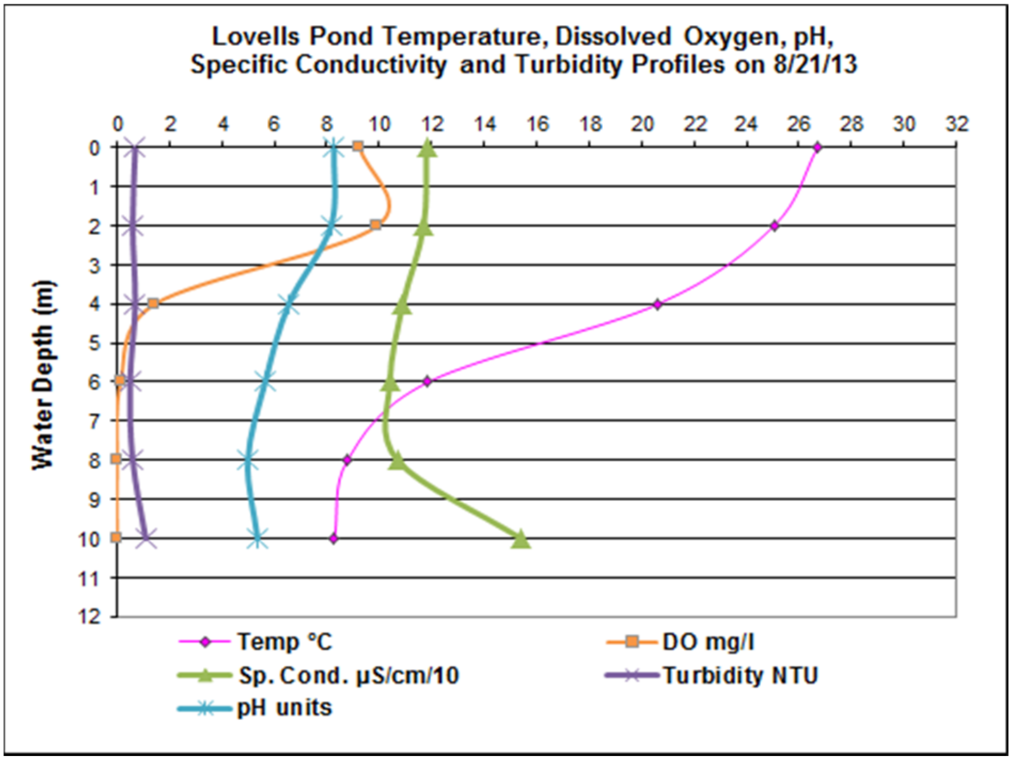


Figure 19. Temp, DO, pH, Specific Conductivity and Turbidity profiles on 8/21/13

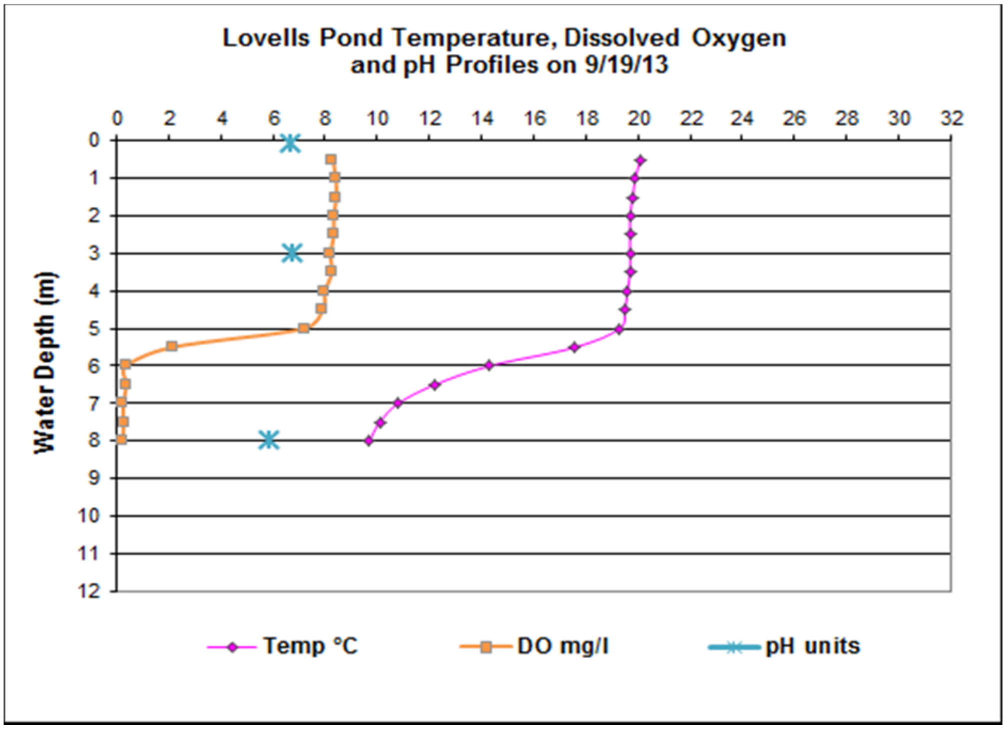


Figure 20. Temp, DO and pH profiles on 9/19/13

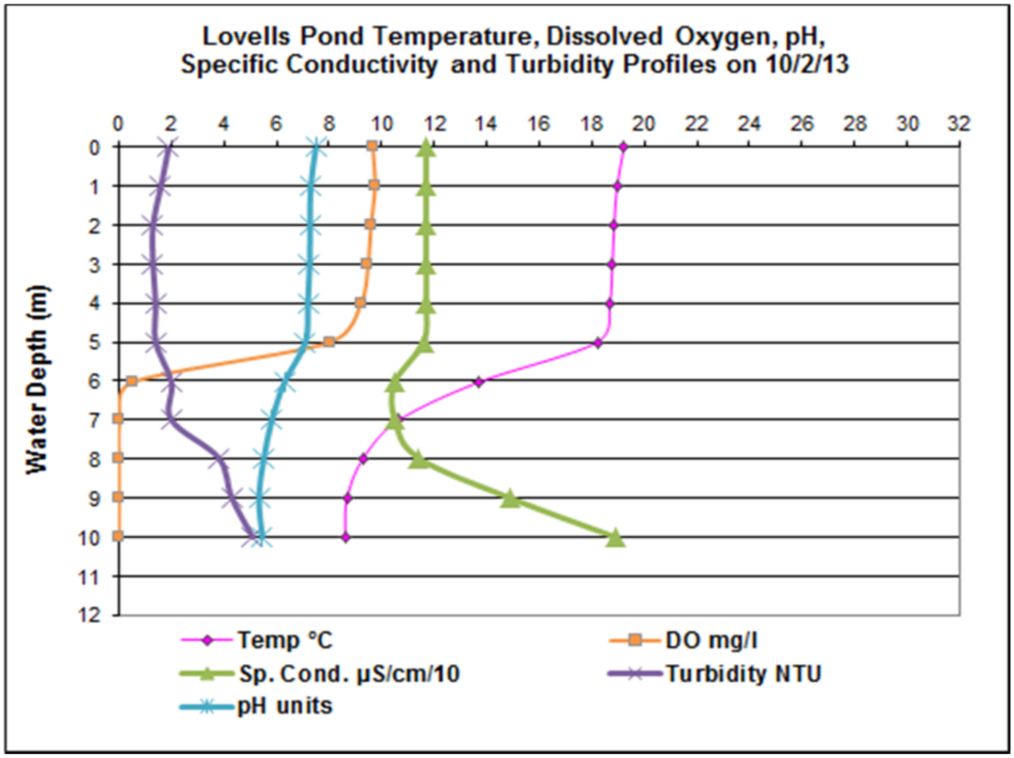


Figure 21. Temp, DO, pH, Specific Conductivity and Turbidity profiles on 10/2/13

The pH was relatively stable from top to bottom in the pond from the start of monitoring in early April through early July at a level near neutral (7.0 SU). As stratification strengthened and algae increased, the pH in the upper water layer increased to over 8.0 SU and the pH in the bottom layer declined to less than 6.0 SU. Algae removing carbon dioxide through photosynthesis raises the pH, while decomposition in the absence of oxygen allows accumulation of acids that lower the pH. Alkalinity is fairly low (Figure 22), providing little buffering capacity and allowing processes like photosynthesis and decomposition to alter the pH readily. This is a problem for most Cape Cod ponds, so minimizing algal production and maximizing deep water oxygen is important to limiting pH fluctuations that can be damaging to pond ecology.

Specific conductivity and turbidity are moderately stable in the upper waters over summer and increase in the bottom waters during this time period. There was one high set of turbidities in the upper water layer in response to an algal bloom in mid-July, but otherwise turbidity was not especially high. Conductivity increased markedly (from near 60 µS to near 120 µS) in late July for uncertain reasons, but probably also relates to the algae bloom.

Nutrient concentrations in Lovell's Pond were assessed on 5 dates in 2013, monthly from June into October (Figures 23-28), although forms of nitrogen were only assessed on the four dates when WRS performed the sampling (the PALS program assesses only total nitrogen). Ammonium nitrogen did not exceed the highly undesirable threshold of 0.6 mg/L in surface waters, but was higher on 3 of 4 dates in the bottom waters. The build-up of ammonium was apparent in the anoxic

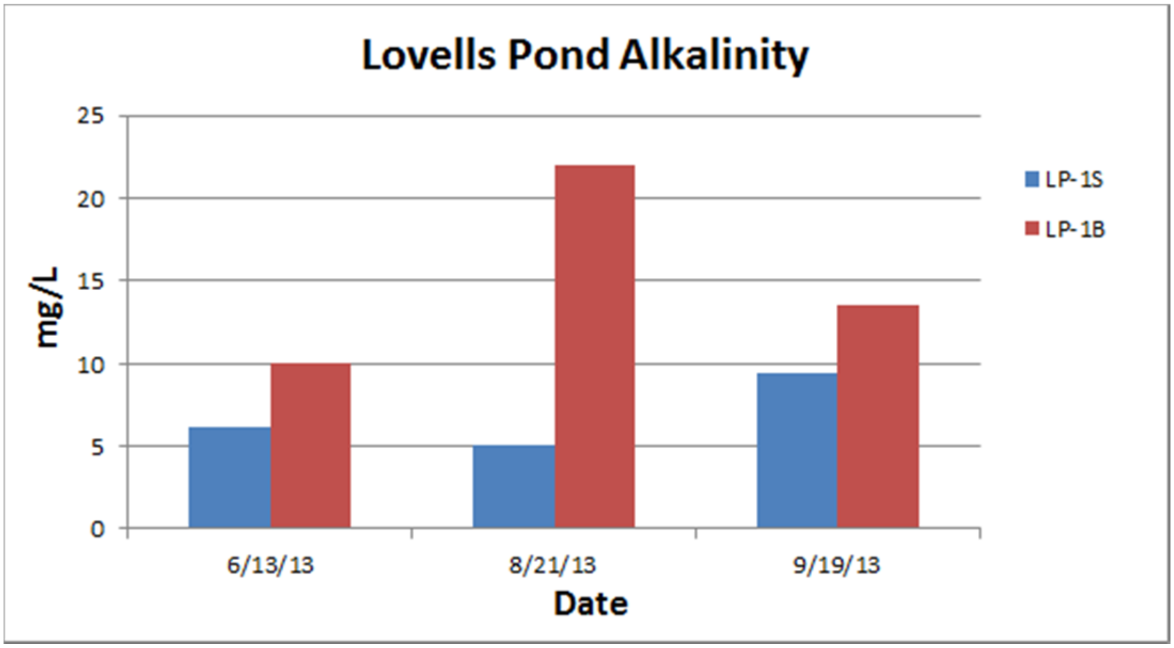


Figure 22. Alkalinity in 2013

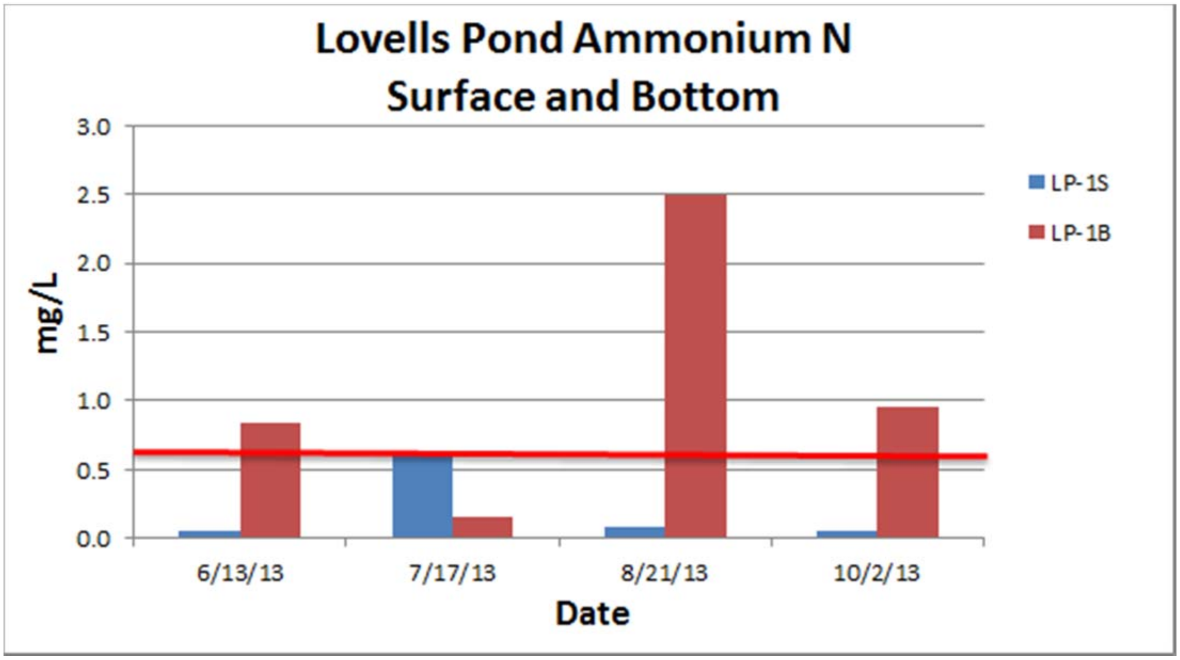


Figure 23. Ammonium N in surface and bottom water

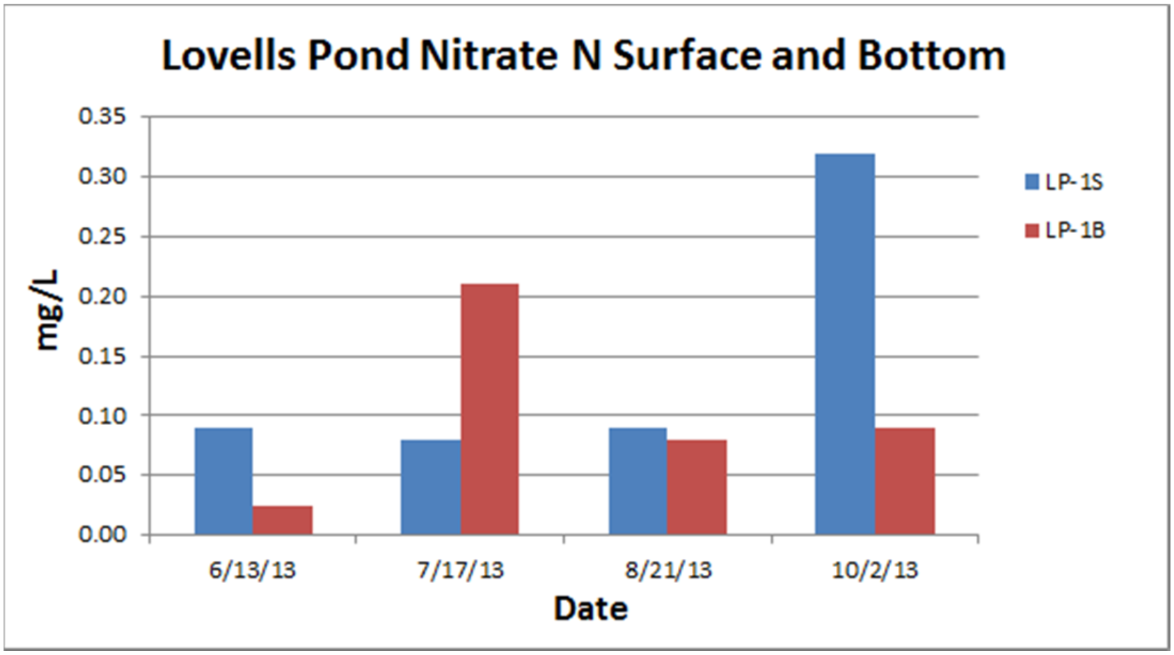


Figure 24. Nitrate N in surface and bottom water

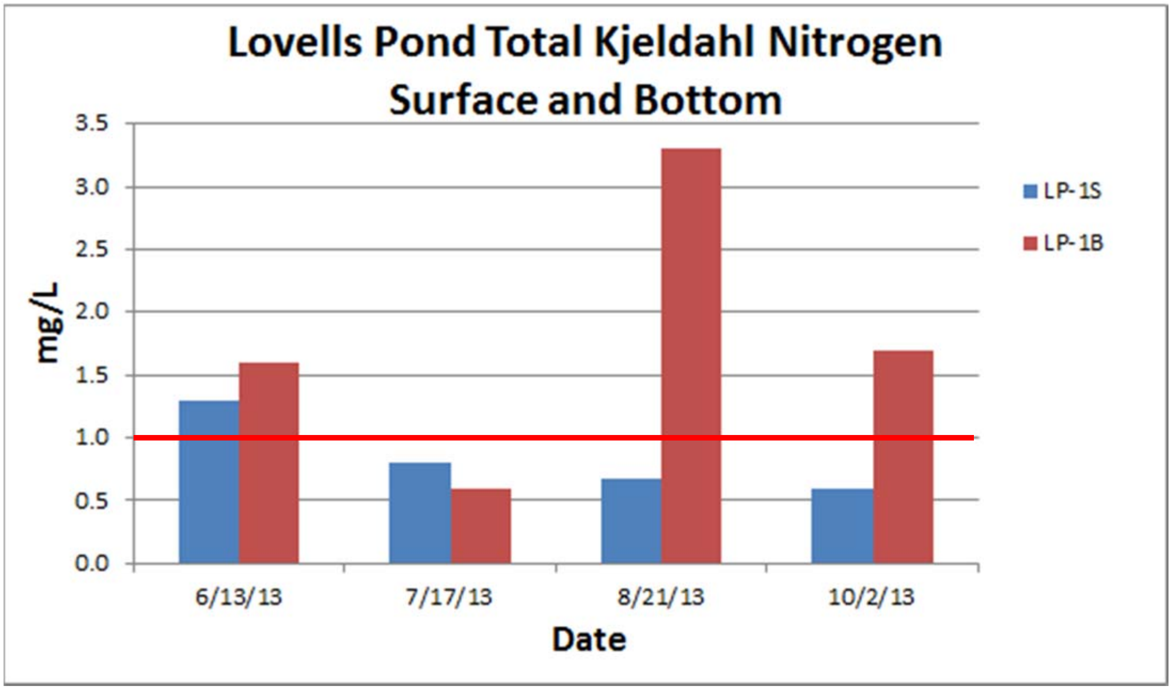


Figure 25. Total Kjeldahl Nitrogen in surface and bottom water

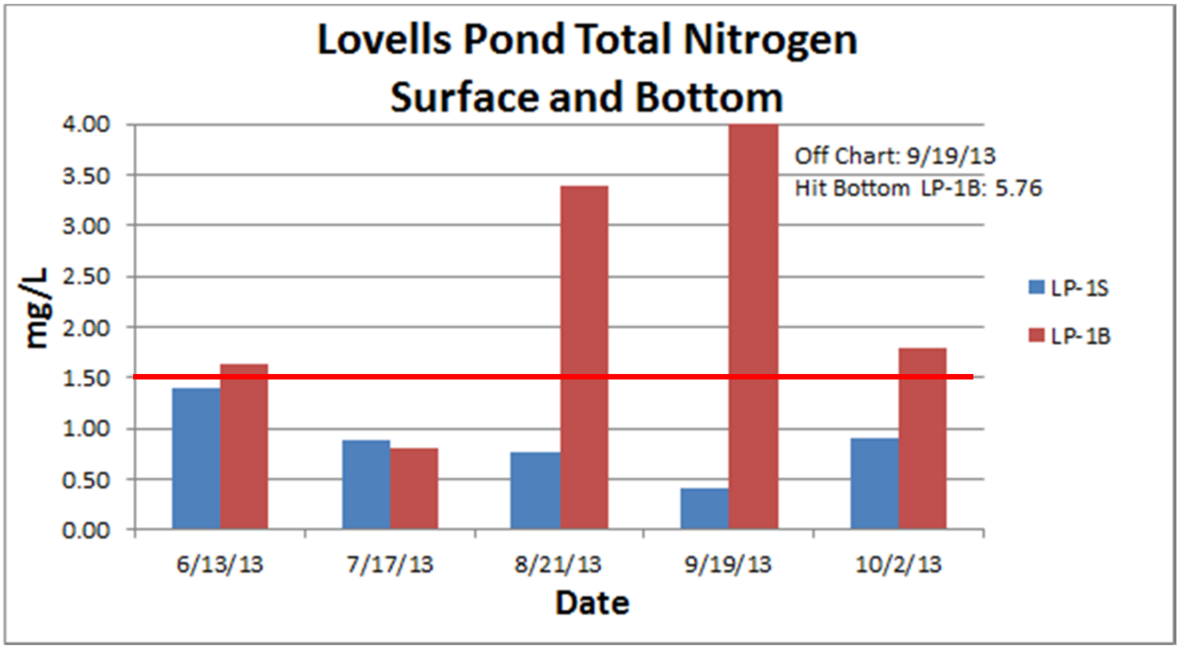


Figure 26. Total Nitrogen in surface and bottom water

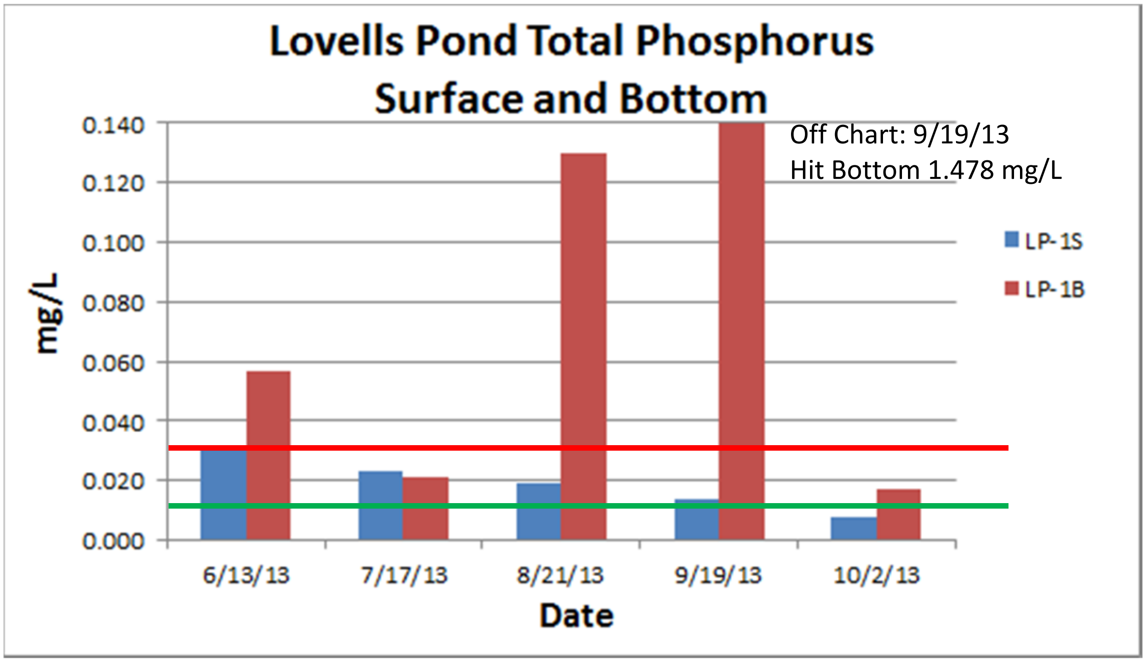


Figure 27. Total Phosphorus in surface and bottom water

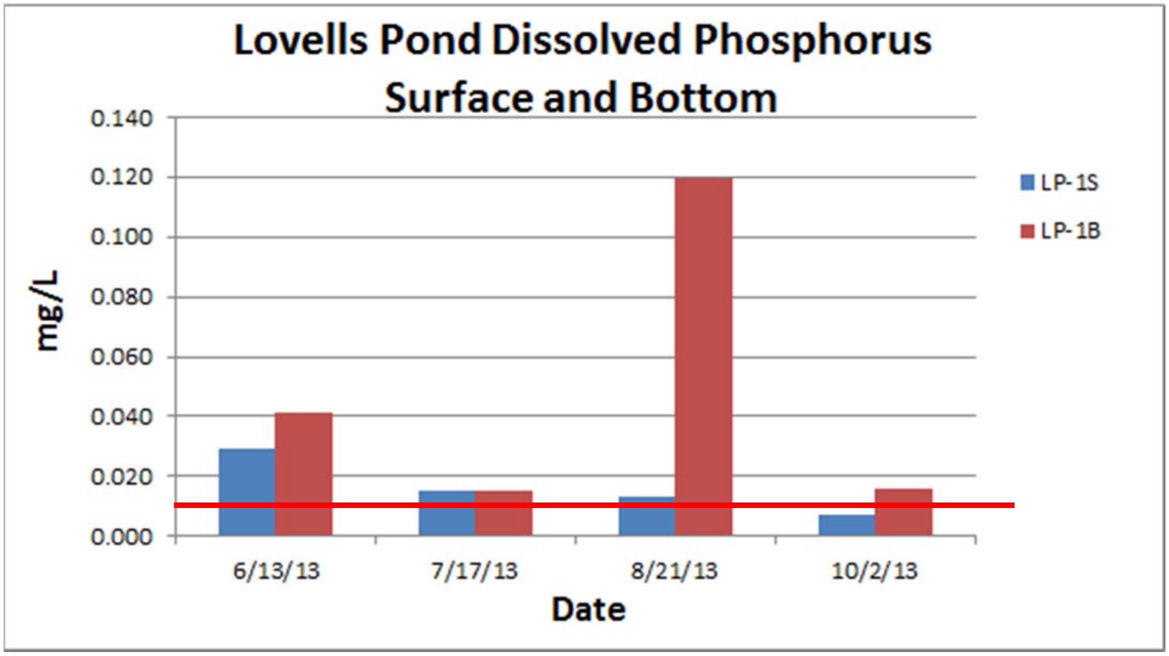


Figure 28. Dissolved Phosphorus in surface and bottom water

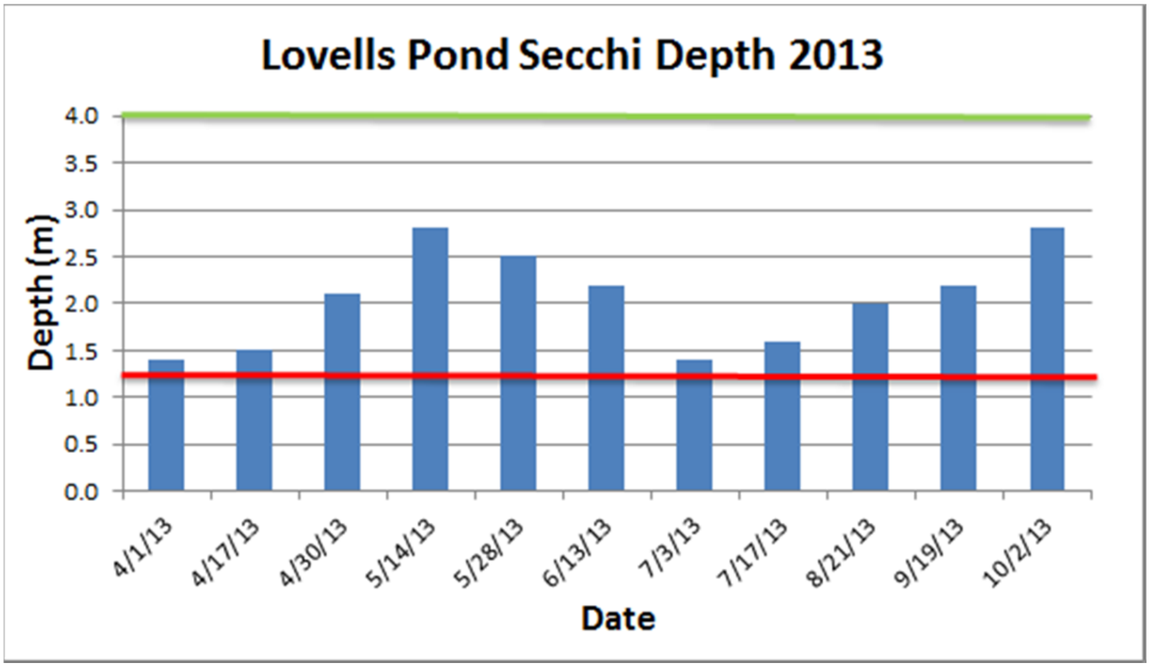


Figure 29. Secchi transparency in 2013.

lower water layer, but movement of that ammonium into the upper waters was minimal during this study in the absence of circulation system operation. Nitrate nitrogen was generally low, not approaching any water quality threshold. Nitrates are frequently low in productive ponds, being a preferred source of inorganic nitrogen for most algae. Total Kjeldahl nitrogen (TKN), the organic fraction plus ammonium nitrogen, generally mirrored ammonium nitrogen levels, suggesting that a substantial portion of TKN was ammonium nitrogen. TKN levels were elevated in the surface water in June and in the bottom water in all but the July sample. Total nitrogen also generally tracked ammonium and TKN values and was elevated in the same pattern as for TKN. Note that the deep PALS sample was noted as having hit bottom and included extra sediment that make those values non-representative of actual water column conditions.

Total phosphorus concentrations (Figure 27) did not exceed the highly undesirable level of about 0.03 mg/L, but were routinely above the desirable level of 0.01 mg/L in surface waters. There is a rather narrow range between acceptable and very unacceptable for phosphorus, making it one of the harder contaminants to regulate. Deep water exceeded the undesirable level in 3 of 5 deep water samples, but one of those was the PALS sample that apparently included bottom sediment. Deep phosphorus was only extreme in one sample for sure, that being the August sample after a period of strong stratification and severe anoxia; this is a typical response when there are substantial quantities of iron-bound phosphorus in surficial sediments exposed to anoxia. While surface phosphorus levels were not acceptable, they were much lower than the bottom concentrations in late summer, indicating a separation of water layers that trapped the phosphorus in the bottom at least until early October.

Dissolved phosphorus should be near or below the detection limit of 0.01 mg/L in clean lake samples; excess dissolved phosphorus indicates more available phosphorus than existing algae can use, which is never a good situation in a pond. Values (Figure 28) were near or below that threshold in Lovell's Pond surface waters in all but the June sample, but were well in excess of it in bottom waters in June and August, with the August value very large and indicative of sediment phosphorus release and accumulation in bottom waters. The value was relatively low in October, however, without a major increase in surface waters. It is not clear what happened, but any addition of oxygen would be expected to cause soluble iron and phosphorus to recombine and precipitate out.

Water clarity (Figure 29) peaked in May at 9.2 feet (2.8 m), a common phenomenon in Cape Cod and other New England ponds, as nutrient availability, warming temperature, and grazing by zooplankton all tend to be least favorable to algae between mid-May and mid-June, depending on weather pattern. Clarity was lower in April, increased in May, then declined in June and July before rising again in August, September and October, reaching a peak just above the May peak in early October. While the peaks were not especially high values, the low values were all above the unofficial threshold of 4 feet (1.2 m) that used to be the standard for having to close a swimming area in Massachusetts. Secchi transparency in 2013 was better than in any year the circulation system was operating.

Plankton Analysis

Chlorophyll measurements (Figure 30) yielded a pattern that was roughly the reverse of water clarity, with a peak in July during an algal bloom and lower values at other times. Only the September value was lower than the desirable threshold of 4 µg/L, and then not by much, but only the July value exceeded the undesirable level of 10 µg/L. While the chlorophyll level in the upper waters in September was the lowest value recorded in this study, the deeper sample accidentally included some bottom sediment which resulted in a very high value (Appendix). The PALS system noted this anomaly, but it points out an important factor in Lovell's Pond and many other Cape Cod water bodies; considerable live algae may be growing on the bottom, waiting for the right conditions to move upward into the water column. Light and temperature are usually limiting at greater depths, but with anoxia there are likely to be abundant nutrients that allow a layer of algae to develop on the sediment. Those sediment sources of nutrients must be addressed to control all algal blooms in such ponds.

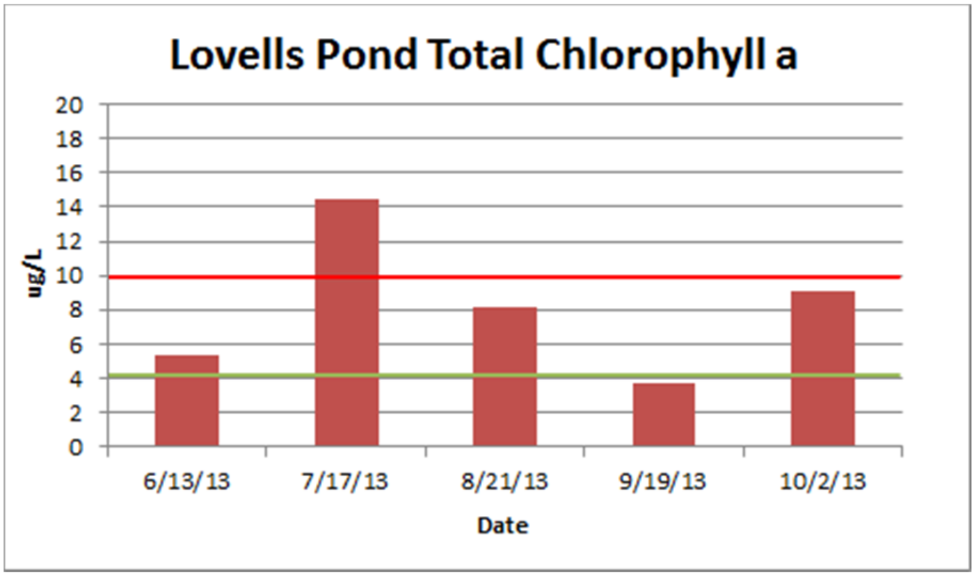


Figure 30. Total Chlorophyll-a

Algae counts (Figure 31) were low in June and early July, with a variety of algal divisions represented and no one group dominant. This matches well with water clarity and chlorophyll data, but stands in contrast to much of the older data. The 2013 data represent only one year, one with a wet June that raised the water level in the pond to a foot over normal, but also one in which the circulation system was not operating. As the influence of past inputs from cranberry bogs may also be waning, it is difficult to sort out the various influences, but the summer of 2013 started with more favorable conditions than in most recent years.

The algal bloom of mid-July was dominated by *Anabaena lemmermannii*, a species of cyanobacteria that tends to grow into a tangled mass of filaments as much as a millimeter in diameter (a fairly large algal particle) before developing gas vesicles and floating to the surface. In other words, the bloom really starts at the sediment-water interface and appears rapidly in the upper waters when the particles float upward, a somewhat synchronous event triggered by multiple factors including adequate nutrients and light that affect all the *A. lemmermannii* at the same time. The nutrient levels near the surface matter less than what is going on at the sediment-water interface, and the anoxia in June and early July would have made much phosphorus available. An interesting and more recent development in cyanobacteria ecology suggests that ferrous iron (the reduced iron released from the sediment with phosphorus) is also necessary to nitrogen fixing forms like *A. lemmermannii* (Molot et al. 2014). Further, light is a trigger, so the algae that are in the deepest water may not be the main source of the bloom, although with anoxia extending over area as shallow as 13.2 feet (4 m) in early July, much of the pond bottom could contribute.

Algae were still abundant in August, but not as abundant as in July, and the species composition had shifted. *Planktolyngbya limnetica*, another cyanobacterium, was dominant. *P. limnetica* does not fix nitrogen and tends to follow blooms of nitrogen fixers, which raise the available nitrogen level. The amount of ammonium nitrogen in surface waters had increased in mid-July with the *A. lemmermanii* bloom, but the accumulation of ammonium nitrogen in the bottom waters was also very high by August, and the *P. limnetica*, which often grows to bloom proportions near the thermocline, may have taken advantage of that nitrogen source before being mixed upward. Algal succession tends to be more explainable than predictable, but is governed by the forms and amounts of key nutrients, light and temperature above most other influences.

Small amounts of *Microcystis* and *Aphanizomenon*, two other bloom forming cyanobacteria with taste, odor and possible toxin production capability, were also observed over the summer, but neither formed a bloom in 2013. Very small amounts of *Aphanocapsa* and *Pseudanabaena*, two more cyanobacteria, were also detected; *Aphanocapsa* rarely causes problems, but *Pseudanabaena* can bloom and has been reported to produce toxins.

Algae were moderately abundant in early October, but with a major shift in compostion. The cyanobacteria were largely gone, and the golden alga *Dinobryon* was dominant. *Dinobryon* can discolor the water with a brownish hue, and does produce some taste and odor, but is not a major ecological or human health threat.

The summer of 2013 experienced lower algae levels than recent years, notably those years in which the circulation system was operating. In particular, there were no intense surface blooms and little accumulation of cyanobacteria around the edge of the pond.

Zooplankton were assessed along with phytoplankton, an important biological component of standing water bodies that is often understudied. Analysis of the types, sizes and abundance of zooplankters present (Figures 32 and 33) revealed a fairly robust zooplankton community in June that crashed in July and was nearly non-existent through early October. The June assemblage was dominated by large bodied *Daphnia* that filter algae from the water and make excellent food for

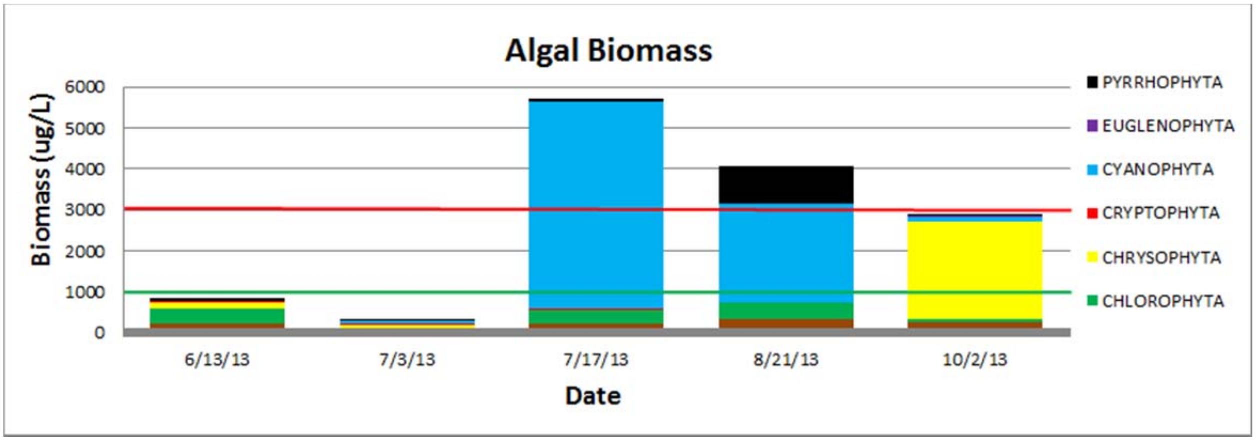


Figure 31. Phytoplankton biomass

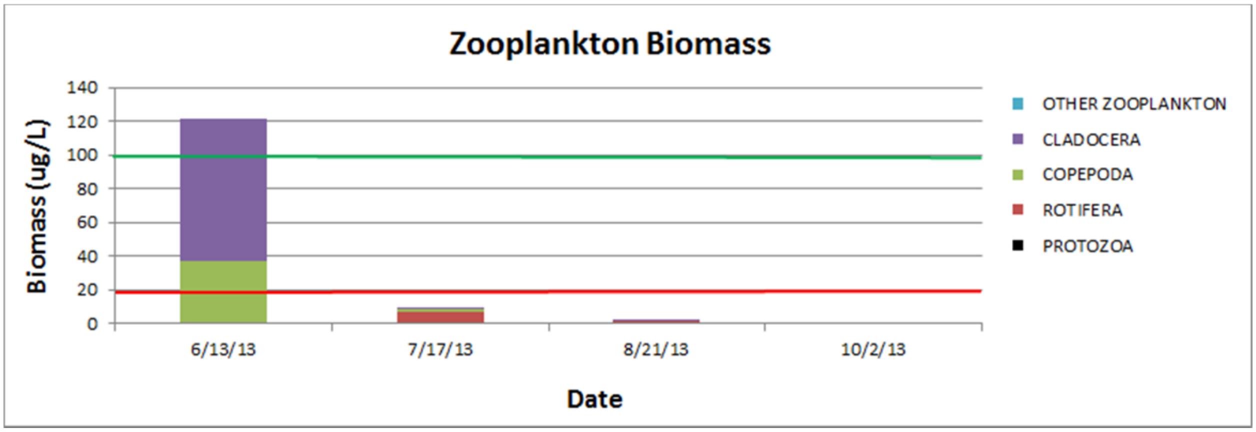


Figure 32. Zooplankton biomass

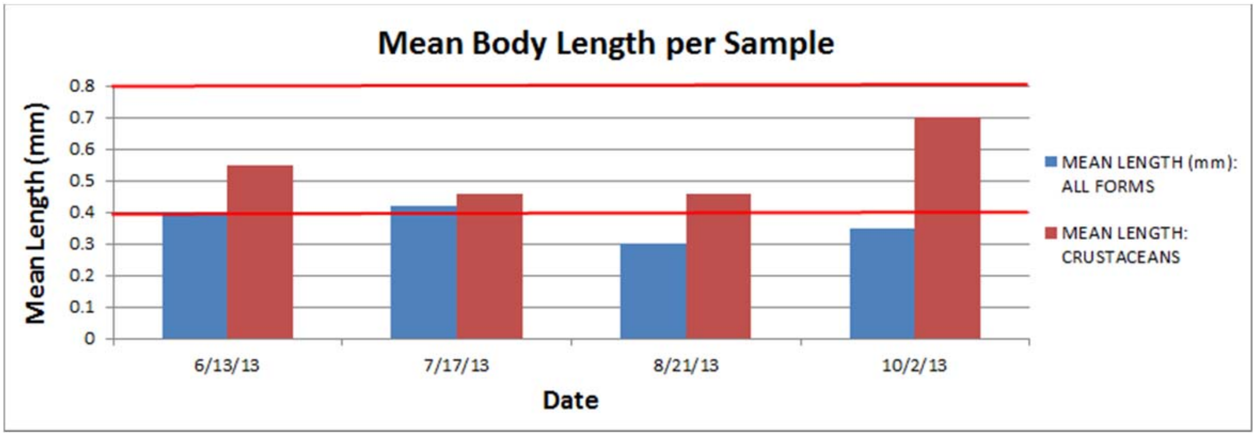


Figure 33. Zooplankton mean body length per sample

small fish. Small copepods that most prey on other zooplankton were moderately abundant, and a few rotifers (the smallest of the three main zooplankton groups and least useful for controlling algae) were observed in June. By mid-July there were not many zooplankton, and the assemblage was dominated by rotifers. In August and October there were very few zooplankton of any kind. The pattern of abundance is indicative of intense predation by young of the year fish. Most likely the 2013 late spring hatch of sunfish, perch and other species that eat zooplankton was large, leading to decimation of the zooplankton early in the summer.

The abundance of *Daphnia* in June undoubtedly helped keep phytoplankton abundance low, but that grazing pressure was eliminated when most *Daphnia* were consumed by sometime in July. The size distribution of zooplankton, exemplified by mean length (Figure 33) was still favorable through the summer, but the numbers and biomass of zooplankton were just too low to exert any grazing pressure on algae. This is largely a natural effect of a large planktivorous fish population, and is best managed by keeping the large, predatory gamefish population as large as possible, thereby consuming most of the small fish over the summer and maintaining more balance among the various levels of the food web. It should be noted, however, that the large cyanobacteria particles like those of *Anabaena, Microcystis* and *Aphanizomenon* are not grazed well by even the largest zooplankton, so complete control of algae blooms with a favorable zooplankton community is still not likely.

Macrophyte Analysis

As macrophytes are not a dominant component of the Lovell's Pond system and were not the focus of field investigations, we did not conduct detailed mapping of the plant community. A general assessment revealed only a few plant species, mostly peripheral forms and mostly emergent or floating leaved species (Table 1). 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. The only other plant found in water more than about 3 feet (1 m) was yellow water lily, with a substantial patch to the north of the boat ramp that normally harbors some large bass. Peripheral growths are substantial and help stabilize the nearshore zone and create habitat for fish and wildlife. Note that *Persicaria puritanorum*, a species of special concern, is listed for this pond but was not found. However, as it was formerly in the genus *Polygonum*, which was found, there could have been some confusion on identification.

Table 1. Macrophyte species in Lovell's Pond

Scientific Name	Common Name	Notes
Schoenoplectus validus	Bullrush	Patches in water <1 ft deep
Pontederia cordata	Pickerelweed	Extensive patches in water <1 ft deep
Polygonum amphibium	Water smartweed	Persicaria puritanorum listed for pond, but not noted here
Nuphar variegata	Yellow water lily	Main patch to north of boat ramp, lesser patches elsewhere
Sagittaria gramineus	Submerged arrowhead	Scattered growths in sandy areas <3 ft deep
Hydrocotyle umbellata	Water penny	Scatter growths in water <1 ft deep
Nitella flexilis	Nitella, stonewort	Scattered growths in water up to about 8 ft deep

Sediment Distribution 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.

The start of muck deposits in Lovell's Pond and the depth at which surficial sediment was all muck were determined and mapped (Figure 34). Although there was variability linked to slope, the sediment was largely sandy in water less than 12 feet 3.6 m) deep; a few muck deposits were found in shallow areas with minimal slope, like the lily patch to the north of the boat launch, but the pond periphery is very sandy overall. Thin and sometimes patchy muck deposits were noted to a depth of about 18 feet (5.5 m), beyond which all or nearly all area is covered completely by muck deposits. 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. The depth of deposits was not determined in areas of complete muck coverage, but use of an Ekman dredge to collect surficial sediments did not yield any sand in water >25 feet (7.6 m) deep, but did get some sand in a sample from about 25 feet (7.6 m) of water depth. The dredge collects sediment to a depth of about 6 inches (0.15 m).

Sediment Quality Assessment

There are many features of sediment worth examining in detail, but the focus here was on the available phosphorus contained in muck sediments that appears to be the primary source to Lovell's Pond at this time. Three composite samples were tested for total phosphorus, iron-bound phosphorus, percent moisture and organic content (Table 2). The iron-bound phosphorus is of primary interest, as this is the phosphorus that can be released under anoxia. However, if this is a tiny fraction of total phosphorus, some concern about other forms may be justified. The percent moisture and organic content aid calculation of the actual mass of phosphorus in the surficial sediment.

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.

For Lovell's Pond muck sediment, 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. Each of the three iron-bound phosphorus tests was repeated, and the variation among samples was 6 to 30%, typical of this method. This does, however, signal that one cannot depend on any one number to be extremely accurate, and we look at ranges and trends when evaluating the potential for an inactivation treatment.

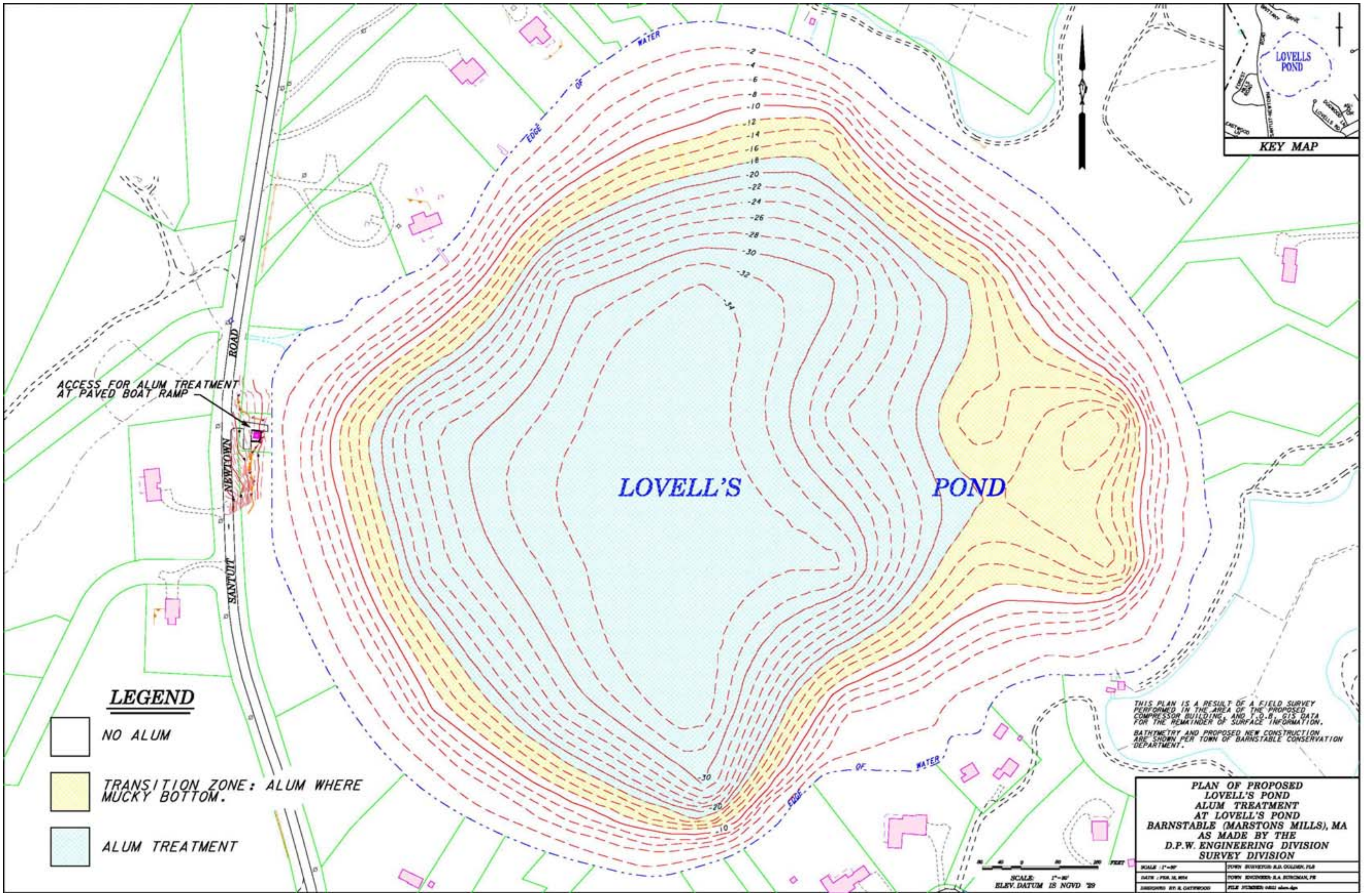


Figure 34. Start of muck deposits (yellow) and area completely overlain by muck (blue) in Lovell's Pond

Table 2. Sediment quality results

Location	Total Phosphorus	Iron bound Phosphorus	Moisture	Organic Content
	mg/kg/dry wt	mg/kg/dry wt	%	%
LP-S1	653	140	92.3	31.9
LP-S2	1,640	219	90.5	26.7
LP-S3	1,480	252	88.3	24.9

Aluminum Dose Testing

Dosing with aluminum (Figure 35) at three levels equating to doses of 10, 25 and 50 g/m^2 provides an indication of the level of reduction in iron-bound phosphorus availability that could be gained by an inactivation project. This is a lab assay, not a field pilot project, and one cannot simply assume that treatment in the field will provide identical results. However, based on past experience, these results can be translated into an inactivation dose with a high potential for improving the pond.

The target for tests like these 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, some interaction with other forms of phosphorus may compromise the results, and it may require much more aluminum to inactivate as much phosphorus as desired; there are diminishing returns to additional aluminum input. This is observable in the data; reductions through 10 and 25 g/m^2 doses are about as expected, but much less reduction is achieved for a doubling of the dose to 50 g/m^2.

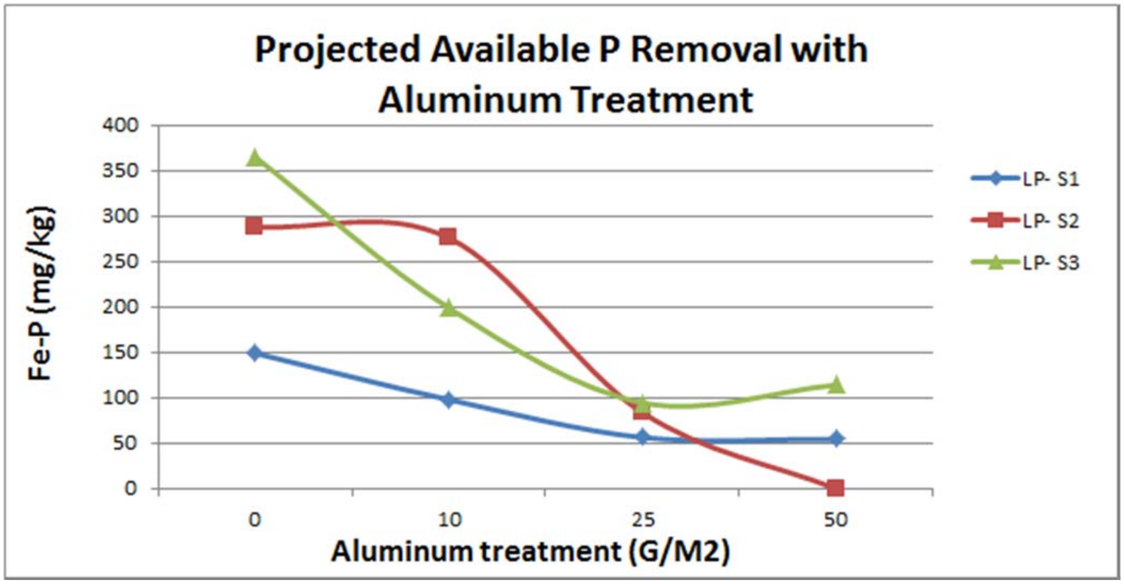


Figure 35. Graph of Decline in Fe-P with Increasing Al Dose

As the resulting iron-bound phosphorus level at a dose of 25 g/m^2 is between 50 and 100 mg/kg, that would be the minimum dose that would be applied. The 50 g/m^2 dose, or something in between, is worthwhile as a margin of safety, but will increase cost with no guaranteed improvement in results. Underdosing should be avoided; a dose >25 g/m^2 but not higher than 50 g/m^2 would be recommended.

Data Analysis and Interpretation

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 1.64 g/m^2/day. However, as the temperature of at least the upper waters is rising during that period and less oxygen can be dissolved in warmer water, a correction for temperature change is appropriate and suggests an oxygen demand of 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 the Lovell's Pond value is not unusual, but does explain the observed anoxia.

Countering that anoxia by adding oxygen will require more oxygen that the demand would indicate. Adding oxygen as pure oxygen or air causes water movement across the sediment, increasing the oxygen demand by a factor between 1.25 and about 5.0. This rather wide range must be addressed in any design effort. While pure oxygen causes less induced oxygen demand than air, the bubble size, release rate, and other factors also influence the induced demand. The cost of countering induced oxygen demand must therefore be carefully considered.

Hydrologic Loading

The Ambient Engineering report addressed the hydrologic load to some extent, but so much has changed since the 1990s that it may not be relevant. In the simplest terms, water inputs include direct precipitation, runoff, ground water flow, and any natural or directed stream flow. For Lovell's Pond in its current situation, there appear to be no direct overland flows other than a very small amount of runoff from a very small land area. Direct precipitation is easily calculated as annual precipitation falling on 56 acres of pond. Ground water flow is more difficult to estimate, but past work on Cape Cod has suggested directional flow of around 1 foot (0.3 m) per day and the contact zone for Lovell's Pond for the prevailing direction of ground water flow can be multiplied by that rate to estimate inflow (Guswa and LeBlanc 1985).

The resulting hydrologic load (Table 3) suggests a total inflow of about 21.5 million cubic feet (600,000 cubic meters) of water each year, although variability will be substantial as a function of precipitation differences among years. Slightly more ground water enters the pond than precipitation, but those two sources represent >97% of the water load. This may be a slight overestimate, as some overland flow may reach Lovell's Pond from Santuit Pond or Patty's Pond and the land in between, but we observed no evidence of such flows in 2013. The water in the pond is replaced about once every two years. This is a very rudimentary hydrologic load analysis, but the key point is that there is no major surface watershed load to the pond, limiting associated nutrient inputs.

Table 3. Hydrologic load to Lovell's Pond

Source	Assumptions	Ft3/yr	m3/yr	%
Precipitation	46 inches on 55 acres	9,200,000	260,000	42.8%
Ground water	1 foot per day 1600 horizontal feet to depth of 20 ft	11,700,000	331,000	54.5%
Direct runoff	16 inches per year from 10 acres	581,000	16,500	2.7%
Tributaries	No true tributaries	0	0	0.0%
Diversions	No longer any active diversions	0	0	0.0%
Total		21,481,000	607,500	100.0%
Pond Volume		45,000,000	1,300,000	
Flushing rate	Number of times water is completely exchanged/yr	0.48		
Detention time	Average residence time for water in the pond in yr	2.09		

Nutrient Loading

The Ambient Engineering report from 1997 provided a fairly detailed phosphorus loading estimate, which totaled to 208.5 kg/yr (Appendix). The basis for some components of this estimate are questionable, but none are impossible, and the load may have been that high at one time. Even then, the internal load was estimated at 100 kg/yr, almost half of the total and the largest single source. Tributaries and ground water made up most of the rest of the load, in roughly equal proportions (about 23% each). Tributaries included loading from the cranberry bogs, a likely large source at that time that is no longer a contributor. Reworking the phosphorus budget and adding a nitrogen component is necessary to update loading estimates.

The loading sources (Table 4) are the same as for the hydrologic load, except that there is also an internal load (release from sediment) and a wildlife load (mostly from water-dependent birds). As with the hydrologic load, a number of assumptions are made, each outlined in the table. The lack of true tributaries or diversions eliminates those sources, although it is possible that some small amount of nitrogen and phosphorus reaches the lake from outflows from Santuit and/or Patty's Ponds. Those loads would not begin to approach those from the days of active cranberry farming, however, and can generally be discounted for this analysis.

Precipitation, ground water and direct runoff inputs are straight calculations of estimated flow times, an assumed concentration for each of nitrogen and phosphorus that are reasonable for this area but not based on any data specifically for Lovell's Pond. Even if off by 100%, these are not large loads of phosphorus, and the precipitation and direct runoff nitrogen loads are also small, but the nitrogen load from ground water is substantial. Given typical nitrogen concentrations in this area

Table 4. 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%

and its mobility in the soil, this elevated ground water load seems justified, but is not a strongly reliable estimate. As nitrogen is hard to control, and cyanobacteria can utilize dissolved gaseous nitrogen (which is 78% of our atmosphere), there is little impetus to fine tune this estimate as long as it is within reasonable bounds.

Wildlife loads are usually estimated based on the typical input from an animal pro-rated for the amount of time spent at the pond. So a group of 100 birds that spends only the months of May through October on the lake would equate to 50 bird-years (100 birds present for one half a year). We did not do detailed wildlife counts, but a small population of birds (gulls, ducks, and herons) was noted on most visits. As a rough estimate, 20 bird-years were multiplied by literature values for inputs from larger birds, and the results are relatively small. As with all but the ground water nitrogen load, being off by even 100% would not result in a major shift in loading.

This leaves the internal load, which is mainly a function of releases of dissolved phosphorus and usually ammonium nitrogen from anoxic sediments. Oxic release is possible, but tends to be so much smaller as to be inconsequential in a lake where more than half the bottom is exposed to anoxic conditions each summer. With periodic mixing and flux of nutrients in and out of the sediments, there is no easy way to calculate the internal loading in this case, but average literature values for release are fairly reliable and have proven trustworthy for other Cape Cod ponds where direct estimates were more easily obtained. Multiplying typical release rates times the affected area times the number of days that anoxia is present yields a large number, which is generally correct for nitrogen but must be tempered with precipitation by phosphorus after it reaches the oxygenated portion of the water column and encounters iron that was also released from the sediment. Typically the portion of the internal load that becomes an effective load to the upper waters is between 10 and 40% from experience, and 20% is a reasonable value for this system.

The results of these calculations indicate a total phosphorus load of 42.6 kg/yr and a total nitrogen load of 815.5 kg/yr to Lovell's Pond. Since the water stays in the pond for about two years, that means that twice this load is mixed into the water over its average residence time. On a mass balance basis, this equates to a phosphorus concentration of 0.064 mg/L and a nitrogen concentration of 1.25 mg/L, but processes remove both phosphorus and nitrogen over time, most notably settling as organic matter that decays slowly if at all, so a lower concentration of each nutrient is expected. One way to estimate the concentrations of phosphorus and nitrogen from loading estimates, and vice versa, is to apply empirical models based on many other lakes that incorporate a settling term and use site specific data to provide modelled values.

Application of a series of five empirical models (Appendix) often used for New England lakes suggests that a phosphorus load of 42.6 kg/yr should result in an in-lake concentration of 0.024 mg/L when the actual concentration over the last decade has been between 0.019 and 0.030 mg/L. A set of three models for nitrogen suggest that a load of 815.5 kg/yr should result in a concentration of 0.68 mg/L when the average over the last decade has been 0.67 mg/L. The models certainly suggest that the estimated load is close to the total necessary to produce the observed in-lake concentration. Extensions of the models predict average chlorophyll-a in surface waters of 9.5 µg/L, while the average for the last decade has been 9.8 µg/L. Predicted Secchi transparency is 2.0 m, while the average for the last decade is 2.1 m. The models would appear to properly represent the situation in Lovell's Pond.

Working from concentration to load with the empirical models, achieving a desirable total phosphorus level of 0.01 mg/L would require a load of about 18 kg/yr, a 58% reduction from the currently estimated load. Reduction of nitrogen would be desirable as well, as long as a low N:P ratio is not fostered (which would continue to favor cyanobacteria); reduction of concentration to 0.5 mg/L would require a load of 599 kg/yr, a reduction of 27%.

In terms of phosphorus and nitrogen loading, Lovell's Pond appears to be in better condition than it was in the 1990s. The cessation of cranberry farming and diversion of flow from Santuit Pond away from Lovell's Pond may be important factors in any change. Title V wastewater management regulations may also have helped. We do not have the data to a more detailed analysis, but loading from external sources to Lovell's Pond does not currently appear to be excessive. At the same time, the internal load appears to be dominant and is the easiest target of management among the contributing sources of nutrients.

Biological Status

Lovell's Pond has been plagued by algal blooms for many years, particularly cyanobacteria, and the relation to elevated loads of nitrogen and phosphorus is evident. Changes in land use, especially related to town acquisition of land used for cranberry farming and other land that could have been developed, and reduction of overland inflows, has reduced nutrient loading to Lovell's Pond over the last decade. However, conditions did not improve substantially, and an artificial circulation system was installed to aid recovery by mixing the pond during the period of summer stratification. Algal blooms continued and may actually have worsened.

The low light created by blooms has minimized submergent vascular plant biomass. The continued low summer oxygen in deep water has minimized habitat for stocked trout during summer, and restricts habitat for warm water species to more peripheral areas. The zooplankton assemblage was highly desirable in terms of types, size and biomass in June of 2013, but virtually disappeared in July and for the rest of the summer. This indicates intense predation on zooplankton by small fish, most likely young-of-the-year sunfish and perch. Little recent data about the fish community is available, but bass fishing is popular and trout are still stocked on a put-and-take basis. A reduction in small fish would allow longer summer survival of larger zooplankton, particularly *Daphnia*, which consume algae and can both improve water clarity and reduce the oxygen demand of settling algae particles.

While greater biological balance is needed to optimize conditions in Lovell's Pond, all the desirable components are present. Reduced phosphorus loading that leads to reduced cyanobacteria would be expected to increase water clarity and could improve energy flow in the food web.

Whatever management actions are taken, proponents should be advised that the entire area around Lovell's Pond is listed as Priority Habitat 1375 by the Massachusetts Natural Heritage and Endangered Species Program, based on available online mapping. Further interaction with NHESP will be necessary to ascertain what species is/are present and how any management action may affect any protected species. It is likely that a terrestrial plant or animal is listed for most of PH1375, but some of the pond fringe is mapped and *Persicaria puritanorum*, a peripheral amphibious species close related to the genus *Polygonum*, may be present in Lovell's Pond.

Circulation System Evaluation

The installation of the circulation system was a logical measure based on a rational analysis. Based on system design, it should have improved the condition of Lovell's Pond. The layout, with six lines covering all areas that could stratify, is appropriate. The maximum air output is just over 2.0 SCFM/acre of pond, more than enough to maintain mixed conditions if the system operates from May through September, and enough to break stratification if it forms. The depth of the pond is great enough that complete mixing should result in enough dark exposure to reduce algae, but at the very least there should be a shift away from cyanobacteria to green algae and diatoms. The features of the pond and the design of the system are properly matched and improvement should have been realized, but was not.

The problems encountered have been discussed in the historical review section of this report, but the issue with the circulation system is centrally focused on failure of the compressor to operate as planned. Late starting in the spring and shutdowns over the summer allowed anoxia to develop at the bottom and for considerable phosphorus and ammonium nitrogen to accumulate before the compressor was operated. Operation after a period of inactivity results in mixing of poor quality (low oxygen, high nutrient) bottom water into the upper waters of Lovell's Pond.

In the three years of circulation system full operation (2010-2012) there is only one water quality assessment in each year, but the results are indicative of the problem (Table 5). In 2011 conditions were not ideal, but bottom levels of nitrogen and phosphorus were lowered over pre-circulation system conditions without a major increase in surface water levels. In other words, mixing appears to have prevented substantial release of phosphorus and nitrogen from the sediment, although what was released was mixed into the overlying water and may have raised surface levels slightly over the pre-circulation values. With natural variability and limited data, we can't be sure how well the circulation system functioned in 2011; 2005 and 2008 appear to have been much better years for the pond in the pre-circulation period, while 2002, 2003 and 2006 were much worse years and 2001 was similar to 2011. In comparison, 2010 and 2012 represent the highest surface water levels of nitrogen and phosphorus in the data base, while the bottom levels are among the lowest. It appears that poor quality bottom water was allowed to build up, then was mixed with the rest of the pond. The installation and testing year, 2009, was slightly better than 2010 and 2012, but worse than 2011. Compared to 2001-2008, some mixing of poor quality bottom water into upper waters is apparent, but 2009 was not a full operation year.

Table 5. Comparison of nutrient levels with (2009-2012) and without circulation system operation

WQ Variable	Units	Station	2001-2008	9/1/09	9/2/10	8/22/11	9/18/12	2013 Avg
Total Phosphorus	mg/L	LP-S (surface)	0.013	0.050	0.132	0.015	0.088	0.019
Total Phosphorus	mg/L	LP-B (bottom)	0.212	0.099	0.093	0.040	0.082	0.069
Total Nitrogen	mg/L	LP-S (surface)	0.40	0.80	1.19	0.60	0.99	0.87
Total Nitrogen	mg/L	LP-B (bottom)	1.55	0.96	0.82	0.75	0.97	1.94

The circulation system was not operated in 2013 by intent, and nutrients were assessed monthly from June into October (although the bottom values for September from PALS are unreliable). The results for 2013 are within the range of annual variation in the pre-circulation years, but on average are better than the pre-circulation period; it is possible that reduced loading has improved conditions somewhat, but the difference is not statistically different and the 2013 conditions would not be considered satisfactory to support the designated uses of Lovell's Pond. It is apparent that nitrogen and phosphorus accumulated in the bottom water layer of Lovell's Pond (the pond was stratified in summer 2013), while transfer to the upper layer was limited. Conditions were better than in 2010 and 2012, but not 2011, based on limited data.

It can be concluded that the circulation system did not improve the condition of Lovell's Pond, and actually appears to have made them worse as a function of intermittent operation. There is nothing conceptually wrong with the design of the circulation system, but the intermittent operation is directly contrary to the way circulation systems are supposed to be used. Late starting of the system in the spring is an operational error that must be avoided to achieve success. Inadequate ventilation of the building that houses the compressor may be a major factor in shutdowns that create serious water quality problems during summer. There has also been discussion that suggests that the compressor was simply not of the quality necessary to guarantee uninterrupted operation.

Diagnostic Conclusions

Returning to the list of goals from the project background and needs section, a response to the data needs can now be provided.

1. Assessment of current conditions in the pond, especially with regard to oxygen status and nutrient levels.

   The results of this task indicate that Lovell's Pond experiences anoxia in water as shallow as 13.2 feet (4 m) and has high concentrations of available phosphorus and ammonium nitrogen in bottom waters at times. Nutrient levels in surface waters were moderate in 2013. Conditions are not satisfactory for all uses of the pond, but are better than in recent years when a circulation system operated intermittently.

2. Verification that external sources of phosphorus and other contaminants to the pond have indeed been curtailed.

   The results of this task suggest that external loading is not excessive. All previously contributing cranberry bogs are now out of service and two are owned by the town as conservation land. Inflow from Santuit Pond has been greatly reduced. No flow from Santuit or Patty's Pond was observed in 2013. Calculation of atmospheric and direct runoff loads suggests very low loads from these sources. Ground water is likely to be a substantial source of nitrogen, but phosphorus loading appears low from this source. External loads are estimated to represent less than half of the total nitrogen load and less than a third of the total phosphorus load.

3. Quantification of the amount of phosphorus in the surficial sediments that could be released into the water column, and assessment of the build-up over the course of the summer.

   The results of this task demonstrate that there is a large but not extreme reserve of available phosphorus in the organic muck sediments of Lovell's Pond. Release occurs in response to anoxia, and is significant in nearly all years in which measurements have been made, but the build-up of phosphorus in deep water was not extremely high in 2013.

4. Assessment of the area of the pond subject to anoxia and potentially contributing to the internal phosphorus load.

   The muck sediments that harbor substantial available phosphorus reserves are found mostly under water greater than 18 feet (5.5 m) deep, but there are significant deposits in water as shallow 12 feet (3.6 m). Low oxygen extends to the 13.2 foot (4 m) depth contour, so most of this sediment can contribute to internal loading.

5. Documentation of the algae in the pond that are impairing water clarity.

   Phytoplankton in 2013 included a wide mix of types of algae and concentrations were not high until mid-July, when a bloom of the cyanobacterium *Anabaena* was observed. Concentrations declined in August and September, but were still near the unacceptable threshold at the start of October. There was a transition from Anabaena to another cyanobacterium, *Planktolyngbya*, in August, and by early October the algal assemblage was dominated by the golden alga *Dinobryon*. Other potential problem cyanobacteria were present but not abundant. Overall algal abundance was lower in 2013 than in most recent years when the circulation system was operating intermittently. It should be noted that considerable growth of algae can occur at the sediment-water interface using available nutrients at that location; levels of nutrients in surface waters may not closely correlate with observed levels of algae.

6. Inventory of biological components of the pond that may have bearing on which alternative actions can be implemented under current regulatory limits and that could affect the outcome of any action under consideration.

   There are few submergent plants, probably due to light limitation. However, at least one peripheral species, possibly *Persicaria puritanorum*, is listed under the Massachusetts Endangered Species Act for Lovell's Pond. The Natural Heritage and Endangered Species Program will have to be involved in permitting of any management activity. The fish community includes stocked trout, but conditions are very poor for cold water fish during summer (warm upper waters, anoxic lower waters). Largemouth bass are present and provide angling enjoyment, but the zooplankton assemblage indicates intense predation by abundant small fish. This suggests that the fishery is out of balance and that large, predatory fish are not abundant enough to control planktivorous fish abundance. A few large mussels (eastern floaters) were observed in shallower water, but no detailed invertebrate inventory was undertaken. Conditions at depths greater than about 13 feet (4 m) will be inhospitable to most aquatic organisms in most summers as a consequence of low oxygen.

7. Assessment of water quality that might affect choice of management alternatives or constrain implementation.

   The background pH in Lovell's Pond appears to be about 6.5 to 6.8 standard units and alkalinity is low, normally less than 10 mg/L. If a phosphorus inactivation treatment is desired, the choice of compounds will need to take the pH and alkalinity into consideration. The low oxygen in deeper water is a concern, one that led to the installation of the circulation system, but low oxygen remains a concern. Operation of any circulation or oxygenation system must be continuous enough to prevent anoxia. Phosphorus is not extremely high in surface waters, but must be reduced to limit algal growth in surface waters. However, growth of algae near the sediment-water interface, with potential movement of large amounts of algae into upper waters, represents a threat independent of surface nutrient levels.

Overall, Lovell's Pond was in better condition in 2013 than in two of three years when the circulation system was operating, and was similar to four of six years for which data were available prior to installation of the circulation system. The other two pre-circulation years had better conditions than in 2013. Circulation is a viable management strategy for Lovell's Pond, but only if circulation can be maintained from May into October with only a few days of shutdown. For the current system, this would likely involve a change in the compressor, building ventilation, and management responsiveness to necessary start dates and maintenance needs. Alternative management options exist that can be considered.

Control of phosphorus remains a valid approach to minimizing algae blooms, and would have to focus on the internal load, as it represents about 62% of the current annual load and a 58% reduction in loading is needed to reach the very desirable phosphorus level of 0.01 mg/L.

Management Options

Overview

Low oxygen and blooms of algae are the identified problems facing Lovell's Pond. These problems are linked, and other problems are largely a function of low oxygen and algae. There are many potential options for preventing and managing algal blooms. There are fewer options for enhancing oxygen at the bottom of a pond, but these overlap with algal control options. A tabular review of all options for the control of algae (Table 6) allows dismissal of inapplicable options, and narrows the field to the following applicable approaches:

- Watershed management
- Dredging
- Algaecides
- Sonication
- Circulation
- Oxygenation
- Phosphorus Inactivation
- Biomanipulation

Watershed management is nearly always applicable, and should be part of almost all lake management plans, but in this case the Town of Barnstable has been participating in active watershed management for over a decade, including the purchase of land that both reduced nutrient loading and prevented increases in nutrient loading. Water from Santuit Pond has largely been diverted away from Lovell's Pond. Enforcement of Title V, the Wetlands Protection Act, and other relevant state and local regulations has limited inputs to Lovell's Pond. There is little more to ask for in terms of practical watershed management.

Dredging is an ideal way to set a pond back in time; it is true lake restoration. Removal of accumulated soft sediment eliminates nutrient sources, oxygen demand and algae resting stages. Where external loads are nominal, the results should be spectacular. However, the cost and environmental constraints placed on dredging limits application of this technique. A substantial study would be needed to assess the feasibility of dredging Lovell's Pond, emphasizing quantification of sediment quantity and quality. Much more data would be needed than generated in this investigation to support a dredging project. If we assumed that only 1 foot (0.3 m) of sediment would have to be removed from only 27 acres of the pond (the minimum conceivable),

Table 6. Algae management options review

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
WATERSHED CONTROLS				
1) Management for nutrient input reduction	♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal nutrition ♦ Creates sustainable limitation on algal growth ♦ May control delivery of other unwanted pollutants to lake ♦ Facilitates ecosystem management approach which considers more than just algal control	♦ May involve considerable lag time before improvement observed ♦ May not be sufficient to achieve goals without some form of in-lake management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable algae	♦ Actions over the last decade by the Town of Barnstable have greatly reduced nutrient loading ♦ While always applicable at some level, the watershed of Lovell's Pond does not appear to be a major source of nutrients now
1a) Point source controls	♦ More stringent discharge requirements ♦ May involve diversion ♦ May involve technological or operational adjustments ♦ May involve pollution prevention plans	♦ Often provides major input reduction ♦ Highly efficient approach in most cases ♦ Success easily monitored	♦ May be very expensive in terms of capital and operational costs ♦ May transfer problems to another watershed ♦ Variability in results may be high in some cases	♦ Inapplicable; no current point source inputs

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
1b) Non-point source controls	♦ Reduction of sources of nutrients ♦ May involve elimination of land uses or activities that release nutrients ♦ May involve alternative product use, as with no phosphate fertilizer	♦ Removes source ♦ Limited ongoing costs	♦ May require purchase of land or activity ♦ May be viewed as limitation of "quality of life" ♦ Usually requires education and gradual implementation	♦ Minimally applicable; very few options. ♦ Need to watch possible development east of pond adjacent to former cranberry bog ♦ Could improve diversion of channel from Santuit Pond
1c) Non-point source pollutant trapping	♦ Capture of pollutants between source and lake ♦ May involve drainage system alteration ♦ Often involves wetland treatments (det./infiltration) ♦ May involve storm water collection and treatment as with point sources	♦ Minimizes interference with land uses and activities ♦ Allows diffuse and phased implementation throughout watershed ♦ Highly flexible approach ♦ Tends to address wide range of pollutant loads	♦ Does not address actual sources ♦ May be expensive on necessary scale ♦ May require substantial maintenance	♦ Minimally applicable; encourage shoreline property owners to further reduce runoff

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
IN-LAKE PHYSICAL CONTROLS				
2) Circulation and destratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ May disrupt growth of blue-green algae ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Can eliminate localized problems without obvious impact on whole lake	♦ May spread localized impacts ♦ May lower oxygen levels in shallow water ♦ May promote downstream impacts	♦ Applicable, but already attempted with poor results ♦ Would need change in some equipment and operation
3) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts	♦ Inapplicable; no source of water

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
4) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well	♦ Possible impacts on non-target resources ♦ Possible impairment of water supply ♦ Alteration of downstream flows and winter water level ♦ May result in greater nutrient availability if flushing inadequate	♦ Inapplicable; not outlet control
5) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with uses during dredging	♦ Applicable but very expensive ♦ Would need major study of sediment quality and quantity to move forward

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
5a) "Dry" excavation	♦ Lake drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left undrained ♦ Eliminates lake use during dredging	♦ Inapplicable; no way to drain pond
5b) "Wet" excavation	♦ Lake level may be lowered, but sediments not substantially exposed ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Requires least preparation time or effort, tends to be least cost dredging approach ♦ May allow use of easily acquired equipment ♦ May preserve aquatic biota	♦ Usually creates extreme turbidity ♦ Normally requires intermediate containment area to dry sediments prior to hauling ♦ May disrupt ecological function ♦ Use disruption	♦ Inapplicable; cannot reach shore with available equipment and shoreline impacts would be major ♦ Pond too small for any rational use of a barge
5c) Hydraulic removal	♦ Lake level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and impact on biota ♦ Can allow some lake uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle coarse or debris-laden materials ♦ Requires sophisticated and more expensive containment area	♦ Applicable but expensive ♦ Could potentially pump to nearby areas

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
6) Light-limiting dyes and surface covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water	♦ Inapplicable; would interfere with uses and ecology of the pond
6.a) Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Produces appealing color ♦ Creates illusion of greater depth	♦ May not control surface bloom-forming species ♦ May not control growth of shallow water algal mats ♦ Altered thermal regime	♦ Inapplicable
6.b) Surface covers	♦ Opaque sheet material applied to water surface	♦ Minimizes atmospheric and wildlife pollutant inputs	♦ Minimizes atmospheric gas exchange ♦ Limits recreation	♦ Inapplicable
7) Mechanical removal	♦ Filtering of pumped water for water supply purposes ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target aquatic life	♦ Inapplicable; microalgae not amenable to practical physical removal

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
8) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal	♦ Inapplicable; no structure available and gradient is too slight to create substantial flow ♦ Could discharge poor quality water downstream with some impact
9) Sonication	♦ Sound waves disrupt algal cells	♦ Supposedly affects only algae (new technique) ♦ Applicable in localized areas	♦ Unknown effects on non-target organisms ♦ May release cellular toxins or other undesirable contents into water column	♦ Applicable but not completely consistent with uses of pond ♦ Not certain that all problem species would be affected
IN-LAKE CHEMICAL CONTROLS				
10) Hypolimnetic aeration or oxygenation	♦ Addition of air or oxygen provides oxic conditions ♦ Maintains stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions reduce P availability ♦ Oxygen improves habitat ♦ Oxygen reduces build-up of reduced cpds	♦ May disrupt thermal layers important to fish community ♦ Theoretically promotes supersaturation with gases harmful to fish	♦ Applicable ♦ Would greatly enhance habitat, but would carry ongoing costs

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
11) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column , normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target species ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity ♦ Possible recycling of nutrients	♦ Applicable, but treats the symptoms when problem resolution appears available
11a) Forms of copper	♦ Cellular toxicant, disruption of membrane transport ♦ Applied as wide variety of liquid or granular formulations	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Possible toxicity to aquatic fauna ♦ Accumulation of copper in system ♦ Resistence by certain green and blue-green nuisance species ♦ Lysing of cells releases nutrients and toxins	♦ Applicable, but should limit repetitive treatment in any year
11b) Peroxides	♦ Disrupts most cellular functions, tends to attack membranes ♦ Applied as a liquid or solid. ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid action ♦ Oxidizes cell contents, may limit oxygen demand and toxicity	♦ Much more expensive than copper ♦ Limited track record ♦ Possible recycling of nutrients	♦ Applicable and more appropriate for cyanobacteria problems

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
11c) Synthetic organic algaecides	♦ Absorbed or membrane-active chemicals which disrupt metabolism ♦ Causes structural deterioration	♦ Used where copper is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on water use	♦ Inapplicable; used more for mat forming algae
12) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the lake ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment ♦ Permanence of binding varies by binder in relation to redox potential and pH	♦ Can provide rapid, major decrease in phosphorus concentration in water column ♦ Can minimize release of phosphorus from sediment ♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH ♦ Possible release of phosphorus under anoxia or extreme pH ♦ May cause fluctuations in water chemistry, especially pH, during treatment ♦ Possible resuspension of floc in shallow areas ♦ Adds to bottom sediment, but typically an insignificant amount	♦ Applicable; would attack internal load, the primary source of phosphorus at this time

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
13) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors to oxidize sediment ♦ Binding of phosphorus is enhanced ♦ Denitrification is stimulated	♦ Can reduce phosphorus supply to algae ♦ Can alter N:P ratios in water column ♦ May decrease sediment oxygen demand	♦ Possible impacts on benthic biota ♦ Longevity of effects not well known ♦ Possible source of nitrogen for blue-green algae	♦ Applicable; could reduce oxygen demand ♦ Not extensive practiced in USA
14) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation	♦ Inapplicable; would add to oxygen demand and not reduce internal recycling

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
15) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients ♦ Addition of non-limiting nutrients can change composition of algal community ♦ Processes such as settling and grazing can then reduce algal biomass	♦ Can reduce algal levels where control of limiting nutrient not feasible ♦ Can promote non-nuisance forms of algae ♦ Can improve productivity of system without increased standing crop of algae	♦ May result in greater algal abundance through uncertain biological response ♦ May require frequent application to maintain desired ratios ♦ Possible downstream effects	♦ Inapplicable; may get shift away from cyanobacteria, but will still have algae blooms
IN-LAKE BIOLOGICAL CONTROLS				
16) Enhanced grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of grazing zooplankton	♦ May increase water clarity by changes in algal biomass or cell size without reduction of nutrient levels ♦ Can convert algae into fish ♦ Harnesses natural processes	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms	♦ Applicable, but unlikely to maintain consistent control
16.a) Herbivorous fish	♦ Stocking of fish that eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefited	♦ Inapplicable; types of algae causing problems not consumable by fish

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
16.b) Herbivorous zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be high ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ Larger or toxic algal forms may be benefitted and bloom	♦ Applicable; need to adjust fish community to foster survival of *Daphnia*
17) Bottom-feeding fish removal	♦ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	♦ Reduces turbidity and nutrient additions from this source ♦ May restructure fish community in more desirable manner	♦ Targeted fish species are difficult to control ♦ Reduction in fish populations valued by some lake users (human/non-human)	♦ Inapplicable; bottom feeding fish not the source of current problems
18) Microbial competition	♦ Addition of microbes, often with oxygenation, can tie up nutrients and limit algal growth ♦ Tends to control N more than P	♦ Shifts nutrient use to organisms that do not form scums or impair uses to same extent as algae ♦ Harnesses natural processes ♦ May decrease sediment	♦ Minimal scientific evaluation ♦ N control may still favor cyanobacteria ♦ May need aeration system to get acceptable results	♦ Potentially applicable; may be able to reduce muck sediment, but need oxygenation system, and no peer reviewed literature supports this approach

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
19) Pathogens	♦ Addition of inoculum to initiate attack on algal cells ♦ May involve fungi, bacteria or viruses	♦ May create lakewide "epidemic" and reduction of algal biomass ♦ May provide sustained control through cycles ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ May promote resistant nuisance forms ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain	♦ Inapplicable; no commercially available products
20) Competition and allelopathy by plants	♦ Plants may tie up sufficient nutrients to limit algal growth ♦ Plants may create a light limitation on algal growth ♦ Chemical inhibition of algae may occur through substances released by other organisms	♦ Harnesses power of natural biological interactions ♦ May provide responsive and prolonged control	♦ Some algal forms appear resistant ♦ Use of plants may lead to problems with vascular plants ♦ Use of plant material may cause depression of oxygen levels	♦ Inapplicable; few submergent plants present and unlikely to cover enough of the pond to make a difference without compromising uses

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICABILITY TO LOVELL'S POND
20a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients ♦ Plants can exude allelopathic substances which inhibit algal growth ♦ Portable plant "pods" , floating islands, or other structures can be installed	♦ Productivity and associated habitat value can remain high without algal blooms ♦ Can be managed to limit interference with recreation and provide habitat ♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs	♦ Vascular plants may achieve nuisance densities ♦ Vascular plant senescence may release nutrients and cause algal blooms ♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes	♦ Inapplicable
20b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities	♦ Vascular plants can be more easily harvested than most algae ♦ Many floating species provide waterfowl food	♦ Floating plants can be a recreational nuisance ♦ Low surface mixing and atmospheric contact promote anoxia	♦ Inapplicable
20c) Addition of barley straw	♦ Input of barley straw can set off a series of chemical reactions which limit algal growth ♦ Release of allelopathic chemicals can kill algae ♦ Release of humic substances can bind phosphorus	♦ Materials and application are relatively inexpensive ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors ♦ Depression of oxygen levels may result ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms	♦ Marginally applicable, as it tends to impact cyanobacteria, but this is basically an unregistered herbicide and cannot be officially permitted or performed by a licensed applicator in Massachusetts

that would equate to over 43,000 cubic yards of material. At a low end cost of $30 per cubic yard, the cost would approach $1.3 million. Finding more sediment or any quality issues with that sediment that affected disposal options would increase the cost, possibly by a factor of four. As attractive as dredging is as a restoration approach, it is not feasible in many cases.

Algaecides represent a maintenance approach to reducing algal blooms. While not philosophically very satisfying (they do not address the source of the problem), algaecides can be practical and do not have to cause major environmental damage as is commonly assumed or claimed. Copper and peroxide based algaecides are by far the most common, and would both be applicable to Lovell's Pond. Peroxides present less risk of impact to non-target organisms, but are more expensive. Proper use of algaecides involves close tracking of the algae community and reaction before a bloom is formed. The cost of the monitoring program is likely to be more than the cost of the actual treatment.

Repetitive treatments tend to signify that the problem is more severe and that consideration should be given to nutrient controls. We believe this to be the case for Lovell's Pond even without having conducted any algaecide treatments; the potential for nutrient levels to support algae blooms is just too high in this pond. Use of algaecides may be appropriate on a very intermittent basis in the future, but does not appear to represent a solution to the current problem. Additionally, killing algae adds to oxygen demand and the nutrient reserves in the bottom of the pond, neither of which is desirable. We will therefore not further consider algaecides for Lovell's Pond.

Sonication can prevent algae blooms if continually applied at complete coverage, if the algae are susceptible. It is not clear that all problem algae in Lovell's Pond are susceptible, but most are, and a reduction in blooms would be expected. However, getting continual and complete coverage would require many units as substantial cost, and killing algae as they develop would add oxygen demand and increase nutrient reserves at the pond bottom. Units may interfere with fishing and would require power lines in the pond. As with algaecides, this technique may be useful as a supplement to other approaches, but is not well suited to be the mainstay of algae control in Lovell's Pond.

Biomanipulation in this case would involve altering the fish community to maximize large herbivorous zooplankton (mainly *Daphnia*), which would convert algae into a resource useable by fish. *Daphnia* are present in the pond already, and were abundant enough to depress algae in late spring 2013, but disappeared under what appears to be intense predation by early July. Biomanipulation would best be accomplished by stocking more gamefish that could reduce the panfish population, but lack of detailed data on the current fish community limits further evaluation or recommendation. Additionally, biomanipulation tends not to be very effective if phosphorus levels remain high, and levels in Lovell's Pond are marginal at best. Management of the fish community would help and is recommended, but requires more data than currently available to make valid recommendations on specific actions.

Reduction of the internal load is necessary to achieve the desired conditions. It is often difficult for people focused on source control and watershed management to grasp the significance of the internal load, but this has been documented as a major force in many lakes, one that cannot be reversed quickly by watershed management. Yet internal load, when dominant, can be controlled with extended benefits (Mattson et al. 2004, Cooke et al. 2005, NYSFOLA 2009).

There are three well documented ways to reduce internal loading of phosphorus: remove the sediment which harbors the available phosphorus, inactivate the phosphorus in place, or provide enough oxygen to prevent phosphorus from being released to surface waters. Removing the phosphorus involves dredging, which is a truly restorative technique, but extremely expensive and difficult to permit in Massachusetts. It has already been discussed and considered infeasible for Lovell's Pond without extensive additional study. Adding the technical difficulty of dredging in water more than 25 ft deep, this is not an option that is normally even considered for deeper lakes with any history of anthropogenic inputs and possible sediment contamination.

Inactivation could be accomplished with addition of oxygen if natural phosphorus binders are present in adequate supply. The most common phosphorus binder by far for Cape Cod ponds is iron. Phosphorus not bound to iron is largely in organic forms, some of which may decay and release that phosphorus, but very slowly. However, under anoxic conditions iron and phosphorus tend to resolubilize and increase in the overlying water column. By keeping oxygen levels high, the phosphorus stays bound to iron in insoluble compounds. Phosphorus released from organic compounds is likely to be bound by iron fairly quickly where oxygen is adequate. Even if oxygenation is not extended to the sediment-water interface, presence of enough oxygen below the boundary between lower and upper water layers during stratification can cause the iron and phosphorus to recombine and settle downward again. Creation of an oxygenated boundary layer can be achieved anywhere between the sediment-water interface and the bottom of the upper water layer, based on controlling water temperature to create a stable density gradient. The entire pond can also be kept in a mixed condition, circulating oxygen rich water from top to bottom.

Oxygenating all or part of the deeper water layer requires adequate input of oxygen from at least May through September every year, and success is often variable over space and time. The additional benefits of more oxygen in deeper water include better habitat for fish and invertebrates and reduced concentrations of ammonium, sulfides, iron and manganese, with those reduced concentrations highly desired in water supply situations. For most recreational lakes, however, the ongoing expense and load control uncertainty associated with deep water oxygenation are cause for hesitation, and this approach is less often used for internal load control.

Inactivation by a binder other than iron has been practiced in water and waste water treatment for many decades, with calcium and aluminum most often applied. Calcium only precipitates at higher pH than experienced in a healthy Cape Cod pond, so aluminum would be the binder of choice. Aluminum combines with phosphorus to form an insoluble floc between pH 6.0 and 8.0, settles to the bottom, and interacts with the sediment phosphorus in the upper few inches of sediment, preventing later release. Aluminum comes in several reactive forms, some causing the pH to decline and others causing it to rise, and a balanced addition of two aluminum compounds with opposite pH tendencies can maintain the pH at a desired level. Keeping the pH between 6.0 and 8.0, and preferably between 6.5 and 7.5, maximizes reaction efficiency and minimizes possible toxicity impacts of reactive aluminum (Mattson et al. 2004, Cooke et al. 2005).

Once reacted, there is no significant threat of aluminum toxicity, but during the reaction process there is a risk to aquatic organisms. The treatment of Hamblin Pond in 1995 did not have a balanced mix of aluminum compounds, and while available sediment phosphorus was greatly reduced, there was substantial fish mortality during the treatment. A similar situation occurred in a Connecticut lake in 2000, prompting research into causative agents, and avoiding mortality is now easily achieved. No deaths of fish or mussels have been documented in 7 aluminum treatments in Cape Cod ponds over the last decade.

By inactivating the phosphorus in surficial sediment, internal loading is lowered and algal growth can be limited. This approach has worked well in multiple Cape Cod lakes since 1995, despite early non-target impacts. Hamblin Pond in Marstons Mills experienced its first algae bloom in 19 years in September 2013, a brief *Anabaena* bloom that may be a fluke or may signal the need for another treatment. Nearby Mystic Lake was treated in 2010 and has been improving ever since. Long Pond in Brewster and Harwich was treated in 2007; cyanobacteria blooms have been eliminated and water clarity doubled after treatment through 2013. Oxygen levels in deeper water may or may not be improved, depending on the importance of ongoing inputs. Hamblin Pond experienced improved oxygen below the thermocline, to the extent that trout can now be supported year round, but there is still anoxia in the deepest waters. The oxygen status of Long Pond has not changed appreciably, but measured oxygen demand has decreased in the deepest basin of that pond.

More recently inactivation has been performed using lanthanum, an element that binds with phosphorus in the water column better than does aluminum and binds with phosphorus in the sediment to an acceptable degree based on limited data to date. The lanthanum is delivered in association with a bentonite clay slurry that also forms a sealing layer on the sediment and may further serve to limit release of phosphorus to the overlying water. This technique is too new to be able to cite longer term results, but it is a promising competitor for aluminum treatments.

While there are multiple techniques that may bear further consideration at a future time (e.g., algaecides, sonication, biomanipulation, or even dredging), currently applicable and feasible options for Lovell’s Pond include only circulation, oxygenation and phosphorus inactivation.

Circulation

Air-driven circulation has already been tried in Lovell’s Pond with unacceptable results. Conditions were not markedly improved over pre-circulation years and were worse in at least two years. This situation has been discussed previously in this report, and relates to failure to have the system operational throughout the late spring and summer. Problems relate to management of the system, inadequate ventilation of the compressor building, and the compressor itself. Whether or not those problems can be overcome is a matter for consideration by the Town of Barnstable; a commitment must be made to operate and maintain the system, the compressor building will need to be modified and will not likely be soundproof, and a new compressor will most likely be needed. The in-lake portion of the system appears adequate as is. The cost of rehabilitation is likely to be no more than $30,000.

Even if a commitment is made to the proper operation of the circulation system, there are a few drawbacks that disfavor use of this approach for Lovell's Pond. The bottom muck under >20 feet (6 m) of water is very loose and flocculant; this tends to increase expression of oxygen demand and makes resuspension of this sediment a potential threat. Air release points need to be far enough above the sediment to avoid entrainment of that sediment, and this will likely allow continued formation of a thin anoxic zone with poor quality water. This thin layer may not interact with the rest of the pond during the summer, but will eventually be mixed and add nutrients. Internal load would be much reduced, but probably not to the targeted level. Additionally, review of many other circulation systems (Wagner 2014) has revealed that most systems are able to shift the types of algae blooming, but not prevent blooms from occurring. Enough algae are tolerant of mixing, or even favored by it. Reducing actual algae quantity is more a matter of reducing available nutrients, which the circulation system should do, but not as effectively as might be desired. Finally, that same review has revealed that nearly all air driven circulation (and oxygenation) systems experience compressor problems; ongoing and rapid maintenance is essential to maximizing system performance, and is often not high on the priority of town governments.

It should also be noted that circulation can be accomplished by updraft or downdraft pumping instead of compressed air. Downdraft pumping would involve one floating unit in the middle of the pond, but a deflector plant would be needed to minimize resupension of sediment. Such a system could work to effectively mix Lovell's Pond, should increase deep water oxygen and minimize cyanobacteria, but may not eliminate algal blooms. The cost would be substantially more than rehabilitating the existing circulation system, on the order of $150,000 capital cost and $4000 annual operating cost.

Updraft pumping is the final mixing option, and involves smaller, often solar powered units that pull water up from a selected depth. Many cases have involved just circulating surface water, and this has sometimes reduced cyanobacteria blooms, but will not improve deep water oxygen or depress internal loading of phosphorus. Use of updraft pumps to completely mix the pond is possible, but studies (reviewed by Wagner 2014) have revealed that commercially available units have been unable to overcome the heat input during hot, sunny summer periods, reducing the effective mixing zone to as little as an acre and rarely more than 5 acres. At least a dozen units would be needed at a current cost of $50,000 each, a $600,000 expense. No power is required for solar-powered units, but maintenance contracts would carry an annual operational cost of at least $5000.

If the town was interested in continuing a circulation system, renovation and proper operation of the existing system would be much less expensive than updraft or downdraft alternatives. Given the shortcomings of the system to date, however, an alternative approach may be desirable.

Oxygenation

Circulation is a form of oxygenation, but it is also possible aerate water in a chamber and distribute that water to areas of low oxygen, or to put pure oxygen into those low oxygen waters. These oxygenation strategies include three air-based approaches and three oxygen-base methods:

1. Full lift aeration – Air is input at the bottom of a chamber that extends from the target zone to the surface of the water body. Oxygen exchange is fostered both from bubbles and at the surface. Water is returned to the target zone with much more oxygen than it had originally and is distributed laterally to improve oxygen levels in deeper waters without disrupting stratification.
2. Partial lift aeration – Much like full lift aeration, but the chamber does not extend to the surface of the water body and all oxygen transfer is from air bubbles. Efficiency is low, usually <3% transfer per vertical movement, with most systems transferring no more than 30% of the oxygen in the input air.
3. Layer aeration – Air input move water and transfers oxygen, but water from a warmer zone is mixed with water from a colder zone to make a stable, mid-temperature layer that is well oxygenated and minimizes transport of undesirable materials from deep water to shallow water.
4. Diffused oxygenation – Pure oxygen is released as tiny bubbles and absorbed in the target zone without disrupting stratification. These systems can have minimal moving parts and require no power, with liquid oxygen being turned into gas and moving through diffusion hoses under its own pressure. The cost of oxygen can offset the cost of power to run pumps or compressors, making this an attractive option in many cases.
5. Speece cone oxygenation – Water is pumped into a sealed cone from the top while pure oxygen is released from the bottom, and with proper balancing of the two flows, all oxygen is dissolved in the pumped water, which is then distributed within the target zone.
6. Sidestream supersaturation oxygenation – Water is pumped to a pressurized container where pure oxygen is added to achieve supersaturation of oxygen. The water is then pumped to the target zone to supply oxygen to that volume by lateral mixing and diffusion.

Each of these options is to some degree applicable to Lovell's Pond, and each carries considerable capital cost. Based on recent review (Wagner 2014), the least expensive option is diffused oxygen at an average cost of $2000/acre, or about $110,000 for Lovell's Pond. The operational cost of all the systems is relatively similar ($350 to $400 per acre per year), suggesting that a diffused oxygen system would cost around $20,000 per year to operate, mostly in oxygen cost. Results with diffused pure oxygen have also been very favorable, so if the town wishes to pursue an oxygenation system, a diffused pure oxygen system would be recommended.

Phosphorus Inactivation

The inactivation of phosphorus in Cape Cod ponds has been accomplished with aluminum in all cases to date. Lanthanum in bentonite clay (tradename PhosLock) may represent a viable alternative, but other than the problem at Hamblin Pond in 1995 due to unbalanced application of two aluminum chemicals that raised the pH, there has been no documented mortality of any aquatic animal of concern. Aluminum treatments, while not commonplace, have become relatively routine and have produced success in every case on Cape Cod. The results are not irreversible, with Hamblin Pond finally showing signs of a return to undesirable conditions after 19 years, but the return on the investment is quite high. If Lovell's Pond can follow the path of Hamblin Pond, the stocked trout might have a chance to survive the summer and biological balance might be restored to Lovell's Pond with limited additional effort.

The data collected as part of this investigation indicates moderate accumulation of iron-bound phosphorus in Lovell's Pond, less than found in Mystic Lake in Marston's Mills but slightly more than found in Long Pond in Brewster and Harwich. Aluminum doses can be estimated by calculation, but are best determined by lab assay. Even then, the lab is not the field, and some interpretation and professional judgment is needed. It is important not to underdose the pond sediment, while with proper precautions for pH control and the amount of aluminum put into an area at once, there is no downside other than increased cost to overdosing. The data for Lovell's Pond suggest that the minimum dose would be 25 g/m^2, while there is limited benefit expected beyond 50 g/m^2. Given the variability in just 3 sediment samples, either more testing should be done or the dose should be 50 g/m^2 to maximize success.

Review of aluminum treatments over the last decade suggests an average cost of $150 per gram of aluminum placed on each square meter of a hectare (2.5 acres) of pond sediment. At the recommended dose of 50 g/m^2 and a maximum treatment area of 15 hectares (37 acres), the anticipated cost would be $112,500. Monitoring during the treatment to guide the process and after the treatment for at least a year to document the results would cost about $25,000. Rounding up, the cost of an appropriate phosphorus inactivation project for Lovell's Pond would be estimated at about $140,000.

Additional pre-treatment testing might refine this estimate, but would cost on the order of another $10,000. Permitting would be expected to cost on the order of $10,000 as well.

If conducted in the spring, results from the treatment should be apparent in the following summer. If conducted in the fall, results should also be apparent in the following summer, but may not reach a peak for several years. While this phenomenon is not well understood, it appears to relate to limited ability of aluminum to strip phosphorus from the water column at low to moderate concentrations. With most phosphorus still in the sediment in spring, the treatment maximizes phosphorus binding. With considerable phosphorus in the water column in fall, but with those concentrations still low relative to sediment levels, the aluminum prevents most further release from the sediment but the existing water column phosphorus has to work its way through the system by uptake, settling, flushing with some recycling, and this may take several times the detention time of the pond (which is years in many cases).

It is difficult to predict how much oxygen benefit will be achieved by a phosphorus inactivation treatment, as the results have been inconsistent among treated lakes and ponds. Some benefit is expected, but continued anoxia near the sediment-water interface is likely during stratification, based on current oxygen demand. It may lessen over a period of years, but is not likely to be eliminated.

The duration of benefits from a one-time phosphorus inactivation are also not easy to predict, but the same variables as at Hamblin Pond are at work, and the recommended dose is almost the same. With continued limited watershed inputs, something close to 20 years of much improved conditions could be expected, after which a gradual decline may occur as more recent deposition of phosphorus allows increased internal recycling.

Conclusions and Recommendations

Given the expense associated with any viable option for improving conditions with regard to oxygen and algae in Lovell's Pond, rehabilitation and better operation of the existing circulation system would be preferred among circulation and oxygenation approaches. With the right compressor in a well-ventilated building operated by a committed staff, low oxygen can be prevented and cyanobacteria blooms can be greatly reduced. Algal blooms may still occur, but should be reduced in severity and frequency. There is both a capital and ongoing operational cost for this approach, and a high priority must be given to system operation in spring and summer.

If the circulation system is to be renovated, everything is in place, so the logistics are fairly straightforward. The existing building would need to be altered to provide cooling or better ventilation, and there should be two compressors to guarantee that downtime would be very limited. The two compressors would not each have to deliver as much air as the current one does, but together they should meet that total (about 112 scfm). One compressor can be operated in spring, both in summer, and if one shuts down, the other can maintain conditions long enough for prompt repairs to avoid anoxia. The expected capital cost for these improvements is no more than $30,000.

A more robust monitoring program should also be initiated in support of a circulation system, and would be best conducted with a monitoring buoy with temperature and oxygen sensors and online access to data. This would add about $25,000 to the cost, but would allow assessment of thermal and oxygen profiles about four times per day, facilitating prompt action if the compressor shuts down. It would also create a clear record of conditions for evaluation. If fluorescence could be added to the system, algal abundance could be tracked as well, as chlorophyll fluoresces in a quantitatively interpretable manner. This would add about $5000 to the capital cost for monitoring equipment.

Considering all needs, the actual capital cost of rehabilitating the circulation system and properly operating it could be as high as $60,000. Power costs and manpower for supervision and maintenance would be annual expenses. The operational expense of the circulation system is not precisely known, but based on other systems for which detailed costs are available, the annual cost is expected to be on the order of $15,000 to $20,000.

Phosphorus inactivation with aluminum represents an attractive alternative, requiring a single application and very likely to make rapid and favorable changes in algae abundance and water clarity. The level of improvement in dissolved oxygen is not likely to be as great as for an improved circulation system, but the reduction in algae should be more substantial than for circulation. Given the failure of the existing circulation system to accomplish the desired results (for whatever combination of reasons) and the success rate for aluminum treatments of Cape Cod ponds to reduce internal loading of phosphorus, the aluminum treatment would be recommended on the basis of probability of achieving the desired conditions. The capital cost differential is not small, with aluminum treatment expected to cost up to $140,000. There is no ongoing operating cost for the aluminum treatment, however, so even including some ongoing monitoring costs for documentation, the total cost of phosphorus inactivation would become less than that of circulation in only 6 years. With a projected benefit period of 20 years, the phosphorus inactivation treatment appears to have a favorable economic profile.

The phosphorus inactivation would be carried out as a contract operation, with the contractor handling all aspects of the project after any pre-treatment follow up testing and permitting. The key needs are a location from which to launch the treatment vessel and a place to park tanker trucks with the necessary aluminum chemicals. The current boat launch is sufficient for a launching site, and if closed to the public for the duration of treatment, may be sufficient for chemical delivery as well. If the launch area is deemed too small to serve as the chemical delivery site, the parking area for the community beach could be used, but the distance from the paved area to the edge of the pond is about 250 feet (76 m), which would have to be traversed by the chemical hose to facilitate filling the tanks on the treatment barge. A third option also exists, as a tanker truck could back up to within 50 feet (15 m) of the pond off Brittany Drive (itself off Santuit-Newtown Road) on town-owned land that was formerly a cranberry bog north of Lovell's Pond.

The proposed dose of aluminum over the estimated target area of 37 acres (15 ha) is just under 7400 kg. At the typical ratio of two parts aluminum sulfate to one part sodium aluminate by volume, this would require about 14,600 gallons of aluminum sulfate and 7300 gallons of sodium aluminate. Usually the delivery trucks carry about 4000 gallons each, so there would be six truck trips involved, with no more than two trucks present at one time (one with aluminum sulfate and one with sodium aluminate). At a typical rate of aluminum chemical placement over the target area, the actual treatment would be completed in four days. Assuming a week of good weather, set up, treatment and removal of all equipment could be accomplished in a week. Considering a two day waiting period to check for any non-target impacts and a day or two of bad weather, a two week treatment period should be assumed.

Monitoring just before treatment would include measurement of nutrient levels and alkalinity at the top and bottom of the pond, plus assessment of pH, temperature, oxygen, conductivity, turbidity and Secchi transparency as a profile over the complete water depth at 3.3 foot (1 m) intervals. Phytoplankton and zooplankton should also be sampled and assessed. Monitoring during treatment would include surveys of alkalinity and pH several times per day, near and away from the treatment barge, and assessment of any signs of stress for pond biota, based on visual assessment of the pond periphery and underwater viewing with a video system. Monitoring after the treatment would include monthly surveys of nutrients, alkalinity, pH, temperature, oxygen, conductivity, turbidity, Secchi transparency, phytoplankton and zooplankton through September following treatment and again in June through September the following year.

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Appendix A. Assembled Data for Lovell's Pond

Temperature °C																																
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	6/11/09	9/1/09	5/28/10	6/28/10	7/23/10	9/2/10	10/8/10	6/3/11	7/13/11	8/22/11	4/25/12	6/25/12	7/23/12	9/18/12	4/1/13	4/17/13	4/30/13	5/14/13	5/28/13	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters																																
0.5		20.48	22.08	24.6	19.5	24.7	20.8	19.00	23.6	19.90	25.00	27.30	24.8	18.80	21.10	26.50	26	14.90	26.60	26.30	22.6	7.50	11.20	15.60	18.10	18.10	21.02	24.35	31.19	26.71	20.10	19.23
1.0	24.77	20.45	22.03	24.5	19.4	24.7	20.9	18.75	23.6	19.90	24.90	27.30	24.7	18.80	21.10	26.30	26	14.80	25.70	26.30	22.7	7.50	11.00	15.50	17.90	17.80	21.05				19.90	18.96
1.5										19.90	24.90	27.30		18.80	21.10			14.80	25.70	26.30	22.7										19.80	
2.0	24.66	20.43	21.93	24.4	19.3	24.7	20.9	18.75	23.6	19.80	24.80	27.30	24.6	18.80	21.00	26.20	26	14.70	25.60	26.30	22.7	7.40	10.90	14.80	17.70	17.60	20.80	24.32	26.12	25.05	19.70	18.85
2.5										19.70	24.80	27.30		18.70	21.00			14.70	22.60	26.30	22.7										19.70	
3.0	24.5	20.42	21.88	24.2	19.2	24.6	20.8	18.75	23.6	19.70	24.80	27.30	24.5	18.70	18.50	26.10	25.8	14.70	21.70	26.20	22.7	7.30	10.70	12.50	16.70	16.80	20.46				19.70	18.78
3.5										19.70	24.80	27.30		18.70	16.30			14.70	21.70	26.20	22.8										19.70	
4.0	23.52	20.34	19.5	23.9	19.2	24.6	20.8	18.00	23.5	19.70	24.80	27.30	24.5	18.70	15.30	26.00	24.5	14.60	20.80	26.20	22.8	6.80	10.30	11.40	13.20	16.20	16.81	18.74	18.66	20.65	19.60	18.68
4.5										19.70	24.80	27.30		18.70	14.20			14.20	20.60	26.20	22.8										19.50	
5.0	19.98	20.13	14.56	17.7	19.1	23.5	20.6	17.50	23.5	19.70	24.80	27.30	24.5	18.70	13.60	25.90	24.4	11.80	20.60	26.20	22.7	6.50	9.20	11.10	11.10	12.60	13.92				19.30	18.21
5.5								17.25		19.60	24.80	27.30		18.70	13.30			10.70	20.50	26.20	22.7										17.60	
6.0	14.1	18.08	12.2	13.2	19.1	21.5	20.4	17.00	23.4	19.60	24.80	27.30	24.5	18.60	13.00	25.90	24.3	10.40	20.50	26.20	22.7	6.00	8.30	10.60	10.10	10.20	10.74	11.68	11.63	11.87	14.30	13.68
6.5								16.75		19.60	24.80	27.30		18.60	12.90			10.20	20.40	26.20	22.7										12.20	
7.0	10.84	12.44	11.04	11.8	15.2	21.5	19.4	16.50	23.4	19.60	24.70	27.30	24.5	18.60	12.70	25.90	24.3	9.70	20.40	26.20	22.7	5.90	7.50	8.90	9.20	8.90	9.06				10.80	10.66
7.5								16.75			24.70	27.30		18.60	12.40			9.00	20.30	26.20	22.7										10.10	
8.0	9	10.17	9.79	11.4			14.5	16.25	23.4		24.70	27.30	24.4	18.60	12.30	25.80	24.3	8.50	20.20	26.20		5.80	7.10	7.30	7.80	8.00	8.36	8.70	8.68	8.79	9.70	9.31
8.5								16.00			24.70	27.30		18.60	11.54			8.7.7	20.20	26.20												
9.0	8.18	8.68	9.07				10.6	16.00	23.4		24.70	27.30	24.4	18.50	10.80	25.80	24.1	7.30	20.00	26.20	22.4	5.60	6.80	7.00	7.30	7.40	7.96					8.68
9.5								15.75	23.2		24.70	27.20		18.50	10.60			7.30	19.80	26.10						7.30						
10.0	7.63	7.83	8.53		12.7			15.00			24.70	27.20	24.1		10.00	25.80	24	7.20	19.70	26.10		5.40	6.70	6.90	7.00	7.20	7.66	7.88		8.30		8.61
10.5			8.45					15.00				27.20						7.00						6.80	7.00		7.57		7.92			
11.0								14.75														5.30	6.60	6.80	7.00	7.20		7.77				
DO mg/L																																
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	6/11/09	9/1/09	5/28/10	6/28/10	7/23/10	9/2/10	10/8/10	6/3/11	7/13/11	8/22/11	4/25/12	6/25/12	7/23/12	9/18/12	4/1/13	4/17/13	4/30/13	5/14/13	5/28/13	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters																																
0.5		7.78	7.74	6.84	8.76	7.53	8.63	10.7	4.6	8.2	6.7	8.2	9.12	9.1	9.0	8.2	8.52	9.9	10.5	8.8	7.26	14.3	11.7	11.1	10.2	8.9	9.1	8.1	8.8	9.3	8.30	9.7
1.0	8.02	7.81	7.72	6.79	8.77	7.90	8.62	10.5	4.6	8.1	6.7	8.2	9.10	9.0	9.0	8.3	8.75	9.9	10.3	8.8	7.59	14.3	11.8	11.1	10.3	8.9	9.1				8.41	9.8
1.5										8.1	6.7	8.2		9.0	9.0			9.9	10.2	8.8	7.59										8.44	
2.0	7.72	7.76	7.68	6.81	8.66	7.45	8.60	10.4	4.6	8.1	6.7	8.2	8.89	9.1	9.0	8.3	8.75	10.0	11.5	8.9	7.58	14.3	11.8	10.9	10.2	8.9	8.9	8.1	10.0	9.9	8.33	9.6
2.5										8.1	6.7	8.2		9.0	9.0			10.0	12.3	8.8	7.45										8.34	
3.0	7.6	7.67	7.63	6.73	8.68	7.80	8.59	10.2	4.6	8.1	6.7	8.2	8.90	9.0	10.2	8.4	8.53	9.9	11.7	8.8	7.52	14.2	11.7	11.2	10.1	8.4	7.5				8.21	9.5
3.5										8.1	6.6	8.2		9.0	9.3			9.9	9.3	8.8	7.52										8.26	
4.0	6.05	7.23	7.31	6.55	8.64	7.96	8.58	9.9	4.7	8.1	6.7	8.2	8.80	9.0	6.4	8.3	6.14	10.0	7.7	8.8	7.45	14.1	11.7	9.9	7.6	7.5	4.2	1.1	0.4	1.5	8.00	9.2
4.5										8.1	6.7	8.2		9.0	4.1			9.4	7.1	8.7	7.48										7.92	
5.0	3.37	6.98	0.45	0.96	8.64	8.13	8.40	8.9	4.3	8.1	6.7	8.2	8.74	8.9	3.3	8.1	5.46	7.8	6.8	8.7	7.52	13.9	11.6	9.5	6.2	3.2	2.1				7.21	8.0
5.5								8.3		8.1	6.7	8.2		8.9	3.5			7.5	6.6	8.8	7.44										2.13	
6.0	0.91	0.53	0.17	0.97	8.45	8.06	8.02	7.9	4.4	8.1	6.7	8.2	8.60	8.9	3.8	8.0	5.42	7.4	6.5	8.7	7.28	13.9	11.2	9.6	7.0	4.7	2.6	0.8	0.1	0.1	0.38	0.5
6.5								7.2		8.0	6.7	8.2		8.9	4.4			7.3	6.2	8.6	7.38										0.39	
7.0	0.37	0.23	0.17	0.96	3.00	8.06	6.59	7.1	4.4	8.0	6.7	8.1	8.65	8.9	4.3	7.9	5.17	7.2	5.6	8.6	7.45	13.8	11.1	9.6	7.9	5.2	3.8				0.26	0.0
7.5								6.4			6.6	8.1		8.9	4.2			6.7	5.3	8.5	7.44										0.27	
8.0	0.26	0.26	0.16	0.17			2.11	5.0	4.2		6.7	8.2	8.61	8.9	4.2	7.9	4.87	6.1	4.2	8.5		13.7	10.7	9.6	7.9	4.4	4.2	1.1	0.0	0.0	0.26	0.0
8.5								5.1			6.6	8.2		8.9	2.3			5.1	3.5	8.6												
9.0	0.24	0.3	0.16				0.43	3.6	3.1		6.6	8.1	8.56	8.8	0.4	7.8	2.38	4.0	2.6	8.6	7.05	13.3	9.8	9.1	5.5	4.9	3.1					0.0
9.5								1.9	3.9		6.5	8.1		8.8	0.3			3.0	0.7	8.3	ND					1.5						
10.0	0.23	0.3	0.15		0.60			1.2			6.5	8.1	8.19		0.3	7.1	0.68	2.5	0.4	8.1		13.1	8.9	6.3	2.7	0.1	1.2	0.0		0.0		0.0
10.5			0.14					1.4				8.0						0.7						3.2	0.5		0.0		0.0			
11.0								1.1														12.6	6.3	0.2	0.1	0.1		0.0				

DO % Sat					
Depth	6/13/13	7/3/13	7/17/13	8/21/13	10/2/13
meters					
0.5	103.7	98.5	120.4	117.3	106.1
1.0	103.6				106.5
2.0	100.9	98.5	124.9	122.0	104.5
3.0	84.8				103.3
4.0	43.4	12.1	4.3	16.3	99.9
5.0	20.5				86.5
6.0	23.3	7.3	0.9	1.4	4.9
7.0	32.9				0.4
8.0	36.5	9.4	0.0	0.0	0.0
9.0	26.9				0.0
10.0	9.9	0.4		0.0	0.0
10.5	0.0		0.0		
11.0		0.0			

Specific Conductivity µS/cm					
Depth	6/13/13	7/3/13	7/17/13	8/21/13	10/2/13
meters					
0.5	60	61	65	118	117
1.0	60				117
2.0	60	61	63	117	117
3.0	60				117
4.0	62	60	61	109	117
5.0	60				116
6.0	59	59	59	104	105
7.0	59				105
8.0	59	59	60	107	114
9.0	59				149
10.0	61	67		154	189
10.5	79		73		
11.0		86			

Turbidity NTU					
Depth	6/13/13	7/3/13	7/17/13	8/21/13	10/2/13
meters					
0.5	2.4	3.1	6.8	0.7	1.9
1.0	2.7				1.6
2.0	2.3	3.0	4.3	0.6	1.3
3.0	2.3				1.3
4.0	2.3	1.8	2.2	0.7	1.4
5.0	2.3				1.4
6.0	2.3	1.1	1.7	0.5	2.0
7.0	2.3				2.0
8.0	2.5	1.1	3.1	0.6	3.8
9.0	3.5				4.3
10.0	4.3	1.1		1.1	5.1
10.5	6.1		3.1		
11.0		2.2			

Secchi (m)	
9/1/01	1.6
9/4/02	3.1
9/3/03	2
9/6/05	3.1
9/13/06	2.25
8/20/08	5.4
9/22/08	3.3
9/1/09	2.15
5/28/10	1.84
9/2/10	0.62
6/3/11	2.50
7/13/11	1.13
8/22/11	2.35
4/25/12	2.72
6/25/12	1.36
7/23/12	1.34
9/18/12	0.55
4/1/13	1.40
4/17/13	1.50
4/30/13	2.10
5/14/13	2.80
5/28/13	2.50
6/13/13	2.20
7/3/13	1.40
7/17/13	1.60
8/21/13	2.00
9/19/13	2.20
10/2/13	2.80

ORP mV		
Depth	8/21/13	10/2/13
meters		
0.5	141	110
1.0		104
2.0	146	103
3.0		104
4.0	175	107
5.0		109
6.0	186	124
7.0		108
8.0	179	46
9.0		26
10.0	105	20

Ammonium N mg/L						
Depth	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters						
0.5	0.06		0.60	0.08		0.06
10.0				2.50		0.96
10.5	0.84		0.16			

Nitrate N mg/L						
Depth	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters						
0.5	0.09		0.08	0.09		0.32
10.0				0.08		0.09
10.5	< .05		0.21			

TKN mg/L						
Depth	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters						
0.5	1.30		0.80	0.68		0.59
10.0				3.30		1.70
10.5	1.60		0.60			

Total Nitrogen mg/L																
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	9/1/09	9/2/10	8/22/11	9/18/12	6/13/13	7/17/13	8/21/13	9/19/13	10/2/13
meters																
0.5	0.37	0.31	0.59	0.33	0.58	0.31	0.31	0.80	1.19	0.60	0.99	1.39	0.88	0.77	0.40	0.91
3.0	0.49	0.35	0.35	0.34	0.58	0.33	0.32	0.86	0.89	0.63	0.96				0.48	
8.0															0.80	
9.0	0.74	1.83	2.44	0.38	3.50	0.36	1.62	0.96	0.82	0.60	0.97					
9.5									0.87		0.99					
10.0		2.89	2.61	0.32	4.37			0.98				1.63	0.81	3.38	5.76	1.79
10.5																
11.0										0.75						

Dissolved P mg/L				
Depth	6/13/13	7/17/13	8/21/13	10/2/13
meters				
0.5	0.029	0.015	0.013	0.007
10.0			0.120	0.016
10.5	0.041	0.015		

Total P mg/L																
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	9/1/09	9/2/10	8/22/11	9/18/12	6/13/13	7/17/13	8/21/13	9/19/13	10/2/13
meters																
0.5	0.015	0.016	0.025	0.002	0.019	0.008	0.008	0.050	0.132	0.015	0.088	0.031	0.023	0.019	0.014	0.008
3.0	0.021	0.008	0.012	0.031	0.022	0.011	0.008	0.051	0.053		0.098					
3.5															0.017	
8.0															1.478	
9.0	0.028	0.105	0.449	0.033	0.471	0.010	0.108	0.097	0.110	0.041	0.090					
9.5									0.076		0.075					
10.0		0.271	0.703	0.025	0.623			0.099						0.130		0.017
10.5												0.057	0.021			
11.0										0.040						

Alkalinity mg/L														
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	9/1/09	9/2/10	8/22/11	9/18/12	6/13/13	8/21/13	9/19/13
meters														
0.5	1.8	8.2	0.8	14.5	11.9	4.8	5.2	6.2	4.9	4.8	5.4	6.1	5.0	9.4
3.0	1.9	8.0	0.9	15.1	11.7	4.9	5.0	5.6	0.5	4.8	5.8			
3.5														10.0
8.0														13.5
9.0	2.6	19.6	2.5		70.4	4.7	15.8	6.6	0.5	4.6	5.8			
9.5									4.5		5.4			
10.0		33.3	2.6	16.1	76.7			6.3					22.0	
10.5												10.0		
11.0										4.7				

pH Units																					
Depth	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/1/09	9/2/10	8/22/11	9/18/12	4/1/13	4/17/13	4/30/13	5/14/13	5/28/13	6/13/13	7/3/13	7/17/13	8/21/13	9/19/13	10/2/13
meters																					
0.5	6.9	6.7	6.6	6.8	6.4	6.3	7.0	7.2	8.6	6.4	6.9	6.8	6.8	6.8	6.5	7.0	6.8	8.5	8.3	6.7	7.5
1.0																6.9					7.3
2.0																6.9	6.8	8.0	8.2		7.3
2.5																					
3.0	7.0	6.6	6.1	6.7	6.4	6.3	5.9	7.4	6.9	6.4						6.7					7.3
3.5																				6.8	
4.0																6.3	6.0	5.8	6.6		7.2
4.5																					
5.0																6.1					7.1
6.0																6.0	5.7	5.1	5.7		6.3
7.0																6.0					5.8
8.0																6.0	5.6	5.2	5.0	5.9	5.5
9.0	6.7	6.3	6.5		6.4	6.2	5.7	7.1	6.3	6.4						5.9					5.3
9.5								6.7		6.4											
10.0			6.4	6.2	6.5		5.9									5.9	5.5		5.4		5.5
10.5																5.9		5.2			
11.0									6.3								5.7				

Chlorophyll-a and Phaeophytin Data

(ug/L)	Depth (m)	9/1/01	9/4/02	9/3/03	9/6/05	9/13/06	8/20/08	9/22/08	9/1/09	9/2/10	8/22/11	9/18/12	6/13/13	7/17/13	8/21/13	9/19/13	10/2/13	Notes
Chl a																		
	0.5		6.4	14.3	3.4	4.8	1.7	2.1	8.3	16.6	13.9	10.2	1.1	5.0	2.1	2.8	5.6	
	3		5.4	7.8	3.7	7.3	1.5	2.7	0.4	20.8	14.7	11.0				3.8		
	8		0.1	2.9	15.7	<0.05										46.5		
	9		0.1				1.6	3.6	4.8	20.0	10.1	7.5						
	10			34.3	15.2	0.1			6.2	19.2	11.7	10.7						
Phaeo a																		
	0.5	1.1	0.6	0.1	0.9	3.6	0.9	0.5	6.1	<0.05	0.8	5.3	4.3	9.5	6.0	0.9	3.5	
	3	1.3	0.7	3.1	1.5	4.6	1.1	0.5	22.8	<0.05	1.3	5.9				0.9		
	8															201.8		Sample hit bottom
	9	13.7	26.8	5.3	5.7	32.5	0.9	0.1	8.0	<0.05	2.3	4.1						
	10		54.8	0.1	6.0	27.1			11.8	<0.05	6.5	5.0						
Total Chl a+Phaeo a																		
													5.4	14.5	8.1		9.1	

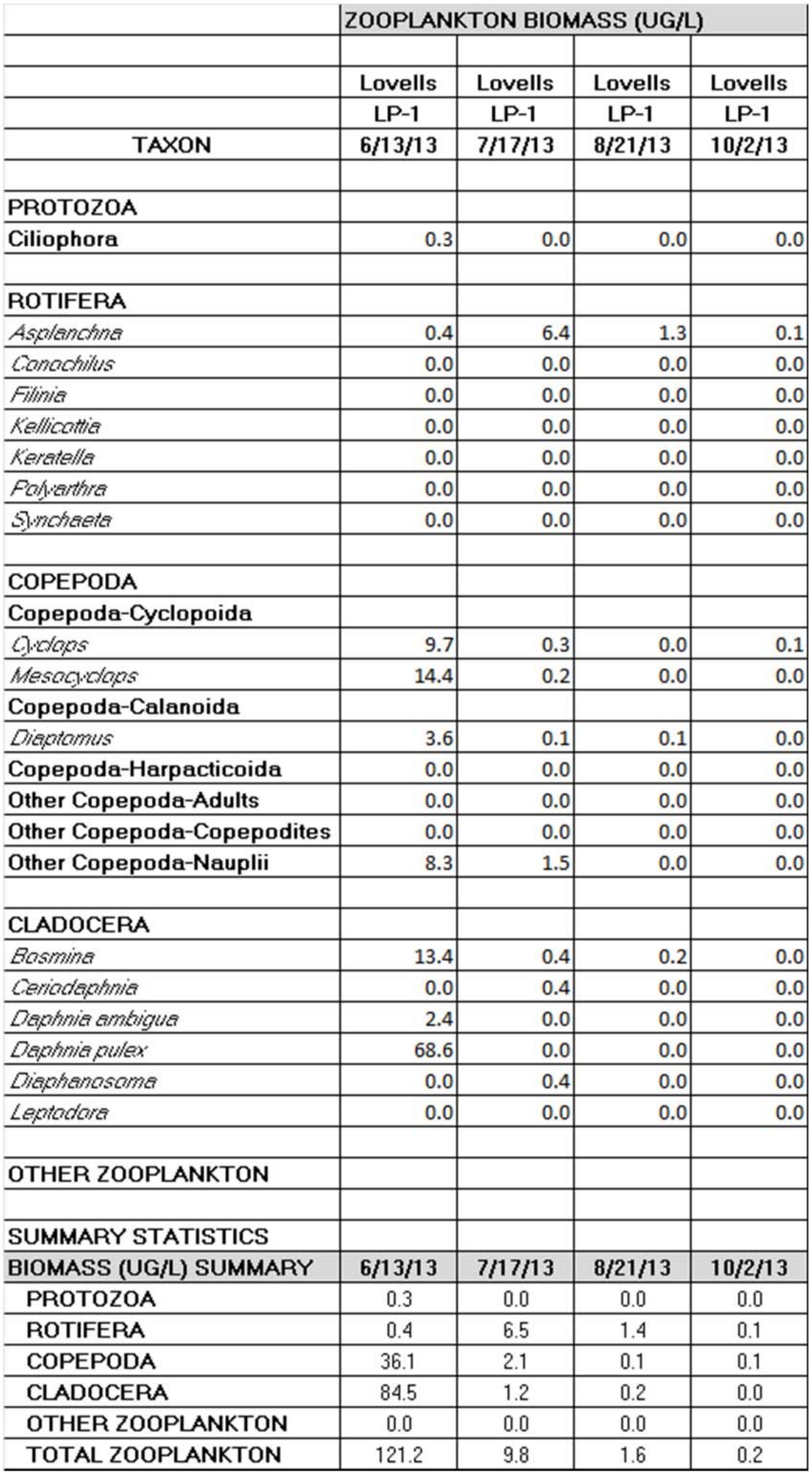
Phytoplankton Data

	PHYTOPLANKTON BIOMASS (UG/L)				
	Lovells	Lovells	Lovells	Lovells	Lovells
	LP-1	LP-1	LP-1	LP-1	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

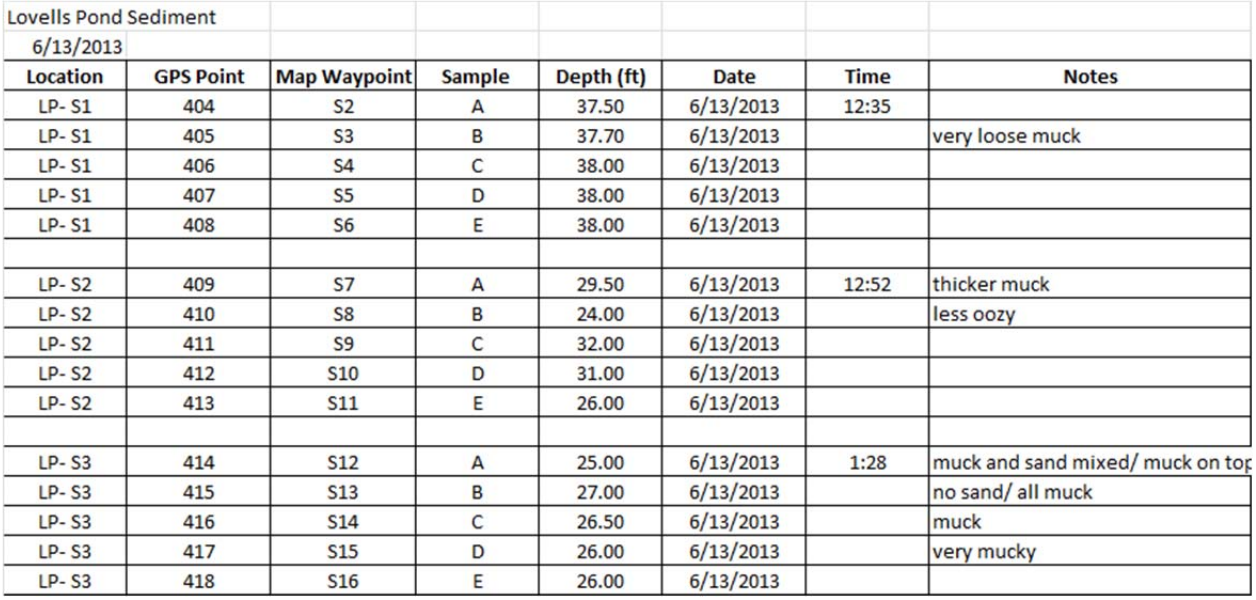
BIOMASS (UG/L) SUMMARY					
BACILLARIOPHYTA	**218.4**	**60.0**	**230.4**	**317.5**	**245.0**
Centric Diatoms	12.4	2.4	0.0	0.0	9.8
Araphid Pennate Diatoms	206.0	57.6	230.4	317.5	224.0
Monoraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0
Biraphid Pennate Diatoms	0.0	0.0	0.0	0.0	11.2
CHLOROPHYTA	**352.3**	**0.0**	**333.6**	**425.3**	**86.8**
Flagellated Chlorophytes	45.3	0.0	0.0	0.0	0.0
Coccoid/Colonial Chlorophytes	278.1	0.0	50.4	243.8	67.2
Filamentous Chlorophytes	0.0	0.0	0.0	0.0	0.0
Desmids	28.8	0.0	283.2	181.4	19.6
CHRYSOPHYTA	**168.9**	**124.8**	**0.0**	**0.0**	**2360.4**
Flagellated Classic Chrysophytes	168.9	72.0	0.0	0.0	2360.4
Non-Motile Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0
Haptophytes	0.0	0.0	0.0	0.0	0.0
Tribophytes/Eustigmatophytes	0.0	0.0	0.0	0.0	0.0
Raphidophytes	0.0	52.8	0.0	0.0	0.0
CRYPTOPHYTA	**12.4**	**52.8**	**19.2**	**7.6**	**5.6**
CYANOPHYTA	**0.0**	**60.0**	**5040.0**	**2394.6**	**131.6**
Unicellular and Colonial Forms	0.0	60.0	48.0	28.4	0.0
Filamentous Nitrogen Fixers	0.0	0.0	4992.0	551.9	128.8
Filamentous Non-Nitrogen Fixers	0.0	0.0	0.0	1814.4	2.8
EUGLENOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**14.0**
PYRRHOPHYTA	**86.5**	**50.4**	**100.8**	**929.9**	**29.4**
TOTAL	**838.4**	**348.0**	**5724.0**	**4074.8**	**2872.8**
BIOMASS DIVERSITY	**1.07**	**0.88**	**0.27**	**0.75**	**0.52**
BIOMASS EVENNESS	**0.85**	**0.93**	**0.27**	**0.59**	**0.40**
BIOMASS (UG/L) SUMMARY	**6/13/13**	**7/3/13**	**7/17/13**	**8/21/13**	**10/2/13**
BACILLARIOPHYTA	218	60	230	318	245
CHLOROPHYTA	352	0	334	425	87
CHRYSOPHYTA	169	125	0	0	2360
CRYPTOPHYTA	12	53	19	8	6
CYANOPHYTA	0	60	5040	2395	132
EUGLENOPHYTA	0	0	0	0	14
PYRRHOPHYTA	87	50	101	930	29

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
OTHER ZOOPLANKTON				
SUMMARY STATISTICS				
BIOMASS (UG/L) SUMMARY	6/13/13	7/17/13	8/21/13	10/2/13
PROTOZOA	0.3	0.0	0.0	0.0
ROTIFERA	0.4	6.5	1.4	0.1
COPEPODA	36.1	2.1	0.1	0.1
CLADOCERA	84.5	1.2	0.2	0.0
OTHER ZOOPLANKTON	0.0	0.0	0.0	0.0
TOTAL ZOOPLANKTON	121.2	9.8	1.6	0.2

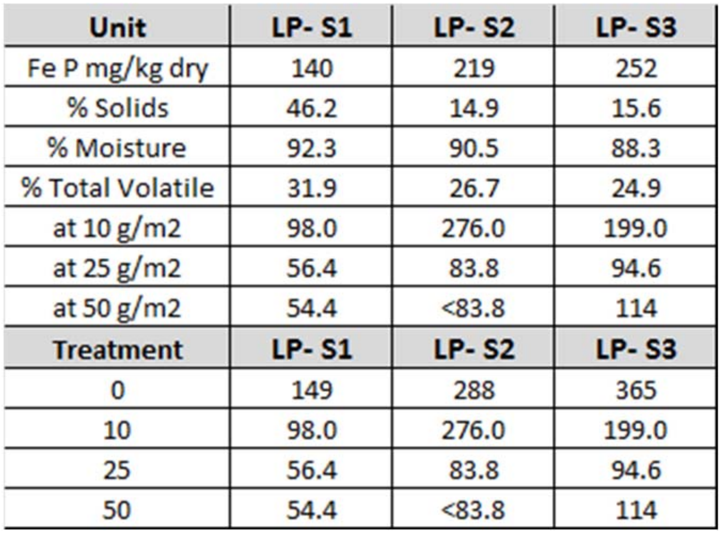
Sediment Metadata



Lovells Pond Sediment
6/13/2013

Location	GPS Point	Map Waypoint	Sample	Depth (ft)	Date	Time	Notes
LP- S1	404	S2	A	37.50	6/13/2013	12:35	
LP- S1	405	S3	B	37.70	6/13/2013		very loose muck
LP- S1	406	S4	C	38.00	6/13/2013		
LP- S1	407	S5	D	38.00	6/13/2013		
LP- S1	408	S6	E	38.00	6/13/2013		
LP- S2	409	S7	A	29.50	6/13/2013	12:52	thicker muck
LP- S2	410	S8	B	24.00	6/13/2013		less oozy
LP- S2	411	S9	C	32.00	6/13/2013		
LP- S2	412	S10	D	31.00	6/13/2013		
LP- S2	413	S11	E	26.00	6/13/2013		
LP- S3	414	S12	A	25.00	6/13/2013	1:28	muck and sand mixed/ muck on top
LP- S3	415	S13	B	27.00	6/13/2013		no sand/ all muck
LP- S3	416	S14	C	26.50	6/13/2013		muck
LP- S3	417	S15	D	26.00	6/13/2013		very mucky
LP- S3	418	S16	E	26.00	6/13/2013		

AL Dosing Data



Unit	LP- S1	LP- S2	LP- S3
Fe P mg/kg dry	140	219	252
% Solids	46.2	14.9	15.6
% Moisture	92.3	90.5	88.3
% Total Volatile	31.9	26.7	24.9
at 10 g/m2	98.0	276.0	199.0
at 25 g/m2	56.4	83.8	94.6
at 50 g/m2	54.4	<83.8	114
Treatment	**LP- S1**	**LP- S2**	**LP- S3**
0	149	288	365
10	98.0	276.0	199.0
25	56.4	83.8	94.6
50	54.4	<83.8	114

Data from Ambient Engineering 1997

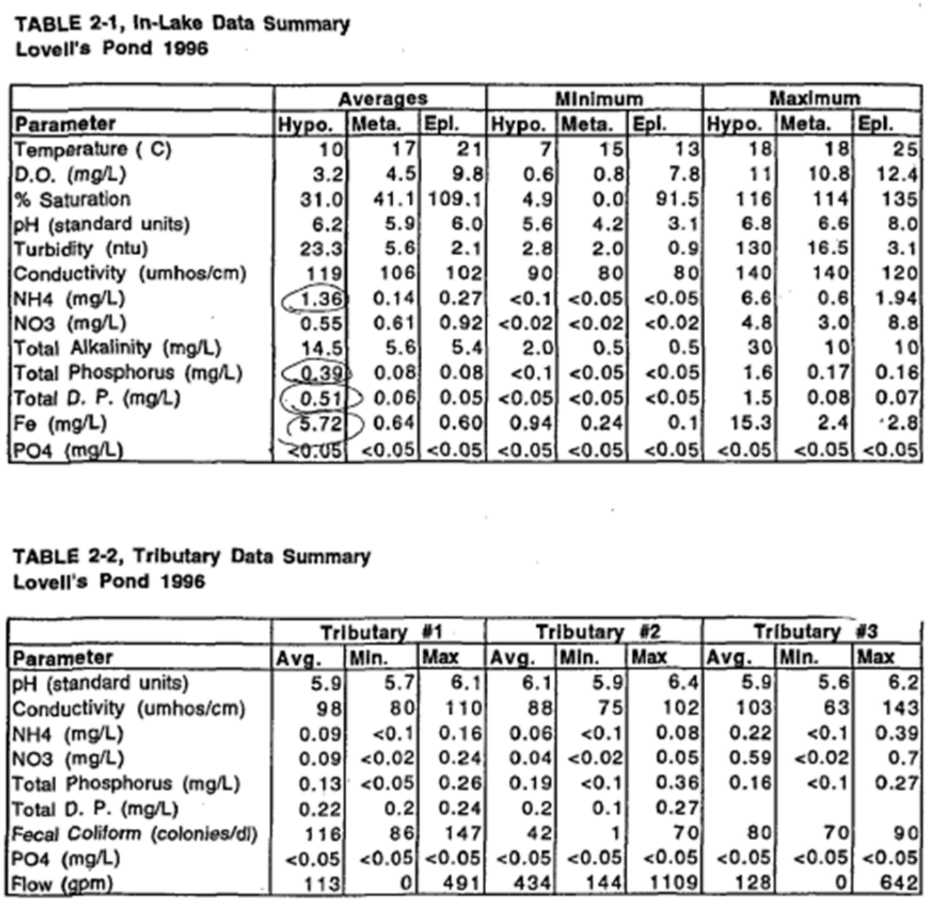
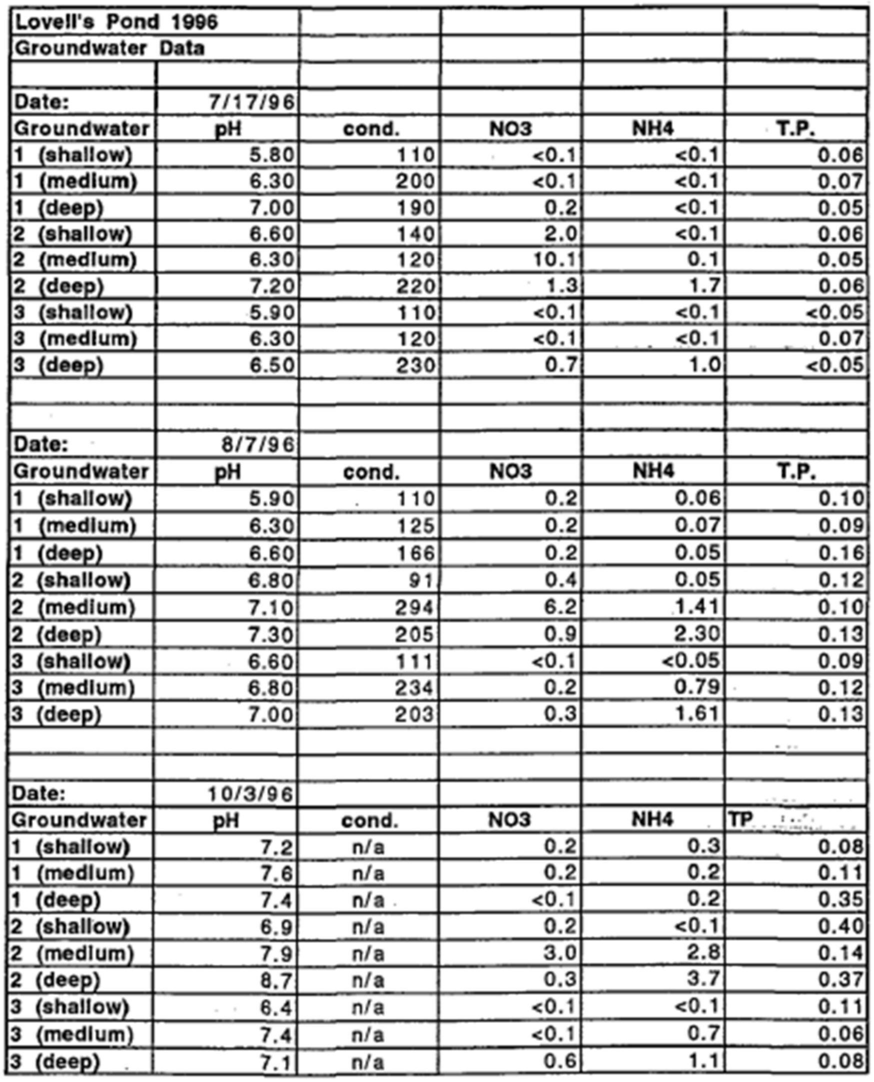


TABLE 2-1, In-Lake Data Summary
Lovell's Pond 1996

	Averages			Minimum			Maximum		
Parameter	**Hypo.**	**Meta.**	**Epi.**	**Hypo.**	**Meta.**	**Epi.**	**Hypo.**	**Meta.**	**Epi.**
Temperature (C)	10	17	21	7	15	13	18	18	25
D.O. (mg/L)	3.2	4.5	9.8	0.6	0.8	7.8	11	10.8	12.4
% Saturation	31.0	41.1	109.1	4.9	0.0	91.5	116	114	135
pH (standard units)	6.2	5.9	6.0	5.6	4.2	3.1	6.8	6.6	8.0
Turbidity (ntu)	23.3	5.6	2.1	2.8	2.0	0.9	130	16.5	3.1
Conductivity (umhos/cm)	119	106	102	90	80	80	140	140	120
NH4 (mg/L)	1.36	0.14	0.27	<0.1	<0.05	<0.05	6.6	0.6	1.94
NO3 (mg/L)	0.55	0.61	0.92	<0.02	<0.02	<0.02	4.8	3.0	8.8
Total Alkalinity (mg/L)	14.5	5.6	5.4	2.0	0.5	0.5	30	10	10
Total Phosphorus (mg/L)	0.39	0.08	0.08	<0.1	<0.05	<0.05	1.6	0.17	0.16
Total *D. P.* (mg/L)	0.51	0.06	0.05	<0.05	<0.05	<0.05	1.5	0.08	0.07
Fe (mg/L)	5.72	0.64	0.60	0.94	0.24	0.1	15.3	2.4	2.8
PO4 (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

TABLE 2-2, Tributary Data Summary
Lovell's Pond 1996

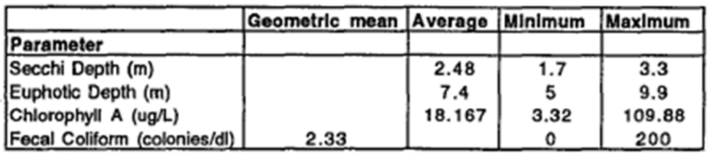
	Tributary #1			Tributary #2			Tributary #3		
Parameter	**Avg.**	**Min.**	**Max**	**Avg.**	**Min.**	**Max**	**Avg.**	**Min.**	**Max**
pH (standard units)	5.9	5.7	6.1	6.1	5.9	6.4	5.9	5.6	6.2
Conductivity (umhos/cm)	98	80	110	88	75	102	103	63	143
NH4 (mg/L)	0.09	<0.1	0.16	0.06	<0.1	0.08	0.22	<0.1	0.39
NO3 (mg/L)	0.09	<0.02	0.24	0.04	<0.02	0.05	0.59	<0.02	0.7
Total Phosphorus (mg/L)	0.13	<0.05	0.26	0.19	<0.1	0.36	0.16	<0.1	0.27
Total D. P. (mg/L)	0.22	0.2	0.24	0.2	0.1	0.27			
Fecal Coliform (colonies/dl)	116	86	147	42	1	70	80	70	90
PO4 (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Flow (gpm)	113	0	491	434	144	1109	128	0	642



Lovell's Pond 1996					
Groundwater Data					
Date:	7/17/96				
Groundwater	pH	cond.	NO3	NH4	T.P.
1 (shallow)	5.80	110	<0.1	<0.1	0.06
1 (medium)	6.30	200	<0.1	<0.1	0.07
1 (deep)	7.00	190	0.2	<0.1	0.05
2 (shallow)	6.60	140	2.0	<0.1	0.06
2 (medium)	6.30	120	10.1	0.1	0.05
2 (deep)	7.20	220	1.3	1.7	0.06
3 (shallow)	5.90	110	<0.1	<0.1	<0.05
3 (medium)	6.30	120	<0.1	<0.1	0.07
3 (deep)	6.50	230	0.7	1.0	<0.05
Date:	8/7/96				
Groundwater	pH	cond.	NO3	NH4	T.P.
1 (shallow)	5.90	110	0.2	0.06	0.10
1 (medium)	6.30	125	0.2	0.07	0.09
1 (deep)	6.60	166	0.2	0.05	0.16
2 (shallow)	6.80	91	0.4	0.05	0.12
2 (medium)	7.10	294	6.2	1.41	0.10
2 (deep)	7.30	205	0.9	2.30	0.13
3 (shallow)	6.60	111	<0.1	<0.05	0.09
3 (medium)	6.80	234	0.2	0.79	0.12
3 (deep)	7.00	203	0.3	1.61	0.13
Date:	10/3/96				
Groundwater	pH	cond.	NO3	NH4	TP
1 (shallow)	7.2	n/a	0.2	0.3	0.08
1 (medium)	7.6	n/a	0.2	0.2	0.11
1 (deep)	7.4	n/a	<0.1	0.2	0.35
2 (shallow)	6.9	n/a	0.2	<0.1	0.40
2 (medium)	7.9	n/a	3.0	2.8	0.14
2 (deep)	8.7	n/a	0.3	3.7	0.37
3 (shallow)	6.4	n/a	<0.1	<0.1	0.11
3 (medium)	7.4	n/a	<0.1	0.7	0.06
3 (deep)	7.1	n/a	0.6	1.1	0.08

Table 2-3a. Groundwater Quality

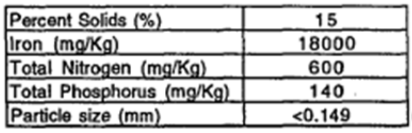
TABLE 2-4, In-lake Data Summary - Biological Parameters
Lovells Pond 1996



	Geometric mean	Average	Minimum	Maximum
Parameter				
Secchi Depth (m)		2.48	1.7	3.3
Euphotic Depth (m)		7.4	5	9.9
Chlorophyll A (ug/L)		18.167	3.32	109.88
Fecal Coliform (colonies/dl)	2.33		0	200

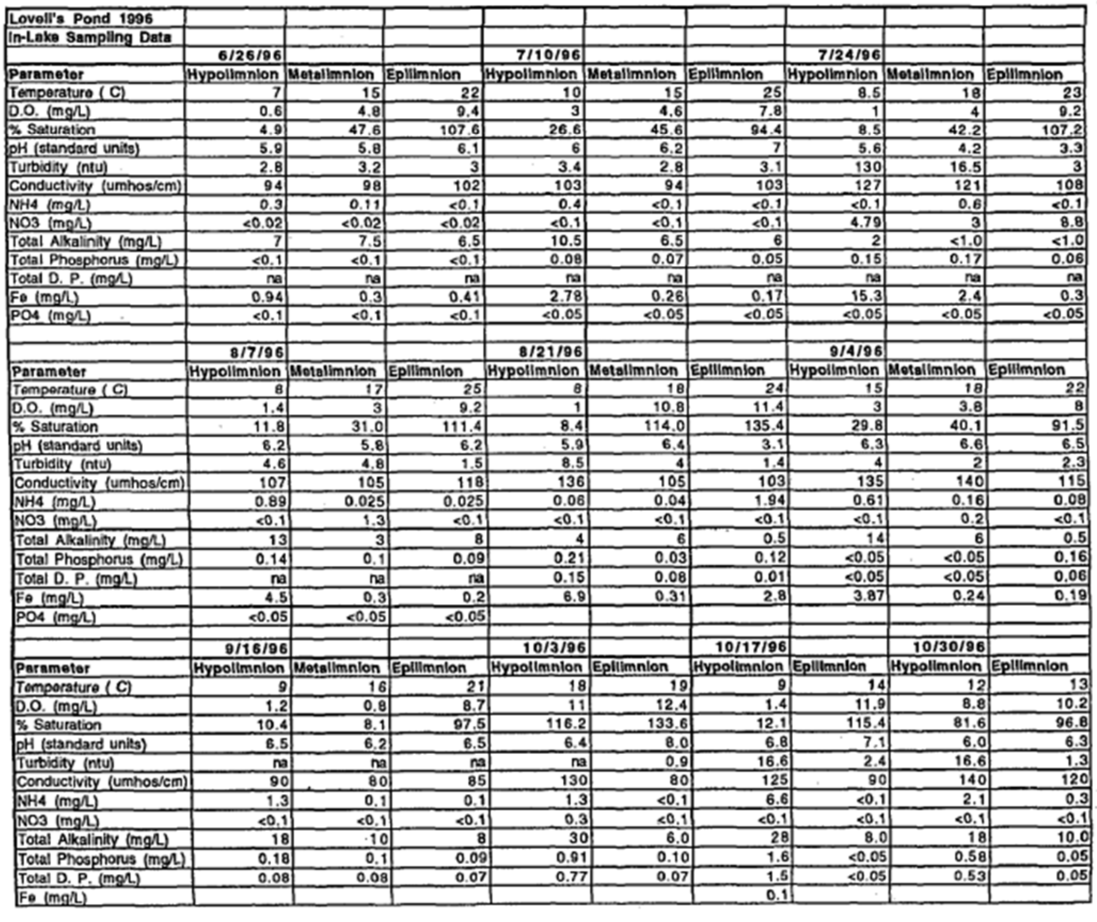
Note: Zero fecal coliform values considered 0.5 for geometric mean calculations.

TABLE 2-5, Sediment Analysis
Lovells Pond 1996



Percent Solids (%)	15
Iron (mg/Kg)	18000
Total Nitrogen (mg/Kg)	600
Total Phosphorus (mg/Kg)	140
Particle size (mm)	<0.149

(80% of the material has a particle size between 0.149 mm and 0.062 mm.)



Lovell's Pond 1996									
In-Lake Sampling Data									
	6/26/96			**7/10/96**			**7/24/96**		
Parameter	**Hypolimnion**	**Metalimnion**	**Epilimnion**	**Hypolimnion**	**Metalimnion**	**Epilimnion**	**Hypolimnion**	**Metalimnion**	**Epilimnion**
Temperature (C)	7	15	22	10	15	25	8.5	18	23
D.O. (mg/L)	0.6	4.8	9.4	3	4.6	7.8	1	4	9.2
% Saturation	4.9	47.6	107.6	26.6	45.6	94.4	8.5	42.2	107.2
pH (standard units)	5.9	5.8	6.1	6	6.2	7	5.6	4.2	3.3
Turbidity (ntu)	2.8	3.2	3	3.4	2.8	3.1	130	16.5	3
Conductivity (umhos/cm)	94	98	102	103	94	103	127	121	108
NH4 (mg/L)	0.3	0.11	<0.1	0.4	<0.1	<0.1	<0.1	0.6	<0.1
NO3 (mg/L)	<0.02	<0.02	<0.02	<0.1	<0.1	<0.1	4.79	3	8.8
Total Alkalinity (mg/L)	7	7.5	6.5	10.5	6.5	6	2	<1.0	<1.0
Total Phosphorus (mg/L)	<0.1	<0.1	<0.1	0.08	0.07	0.05	0.15	0.17	0.06
Total D. P. (mg/L)	na	na	na	na	na	na	na	na	na
Fe (mg/L)	0.94	0.3	0.41	2.78	0.26	0.17	15.3	2.4	0.3
PO4 (mg/L)	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	8/7/96			**8/21/96**			**9/4/96**		
Parameter	**Hypolimnion**	**Metalimnion**	**Epilimnion**	**Hypolimnion**	**Metalimnion**	**Epilimnion**	**Hypolimnion**	**Metalimnion**	**Epilimnion**
Temperature (C)	8	17	25	8	18	24	15	18	22
D.O. (mg/L)	1.4	3	9.2	1	10.8	11.4	3	3.8	8
% Saturation	11.8	31.0	111.4	8.4	114.0	135.4	29.8	40.1	91.5
pH (standard units)	6.2	5.8	6.2	5.9	6.4	3.1	6.3	6.6	6.5
Turbidity (ntu)	4.6	4.8	1.5	8.5	4	1.4	4	2	2.3
Conductivity (umhos/cm)	107	105	118	136	105	103	135	140	115
NH4 (mg/L)	0.89	0.025	0.025	0.06	0.04	1.94	0.61	0.16	0.08
NO3 (mg/L)	<0.1	1.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Total Alkalinity (mg/L)	13	3	8	4	6	0.5	14	6	0.5
Total Phosphorus (mg/L)	0.14	0.1	0.09	0.21	0.03	0.12	<0.05	<0.05	0.16
Total D. P. (mg/L)	na	na	na	0.15	0.08	0.01	<0.05	<0.05	0.06
Fe (mg/L)	4.5	0.3	0.2	6.9	0.31	2.8	3.87	0.24	0.19
PO4 (mg/L)	<0.05	<0.05	<0.05						
	9/16/96			**10/3/96**		**10/17/96**		**10/30/96**	
Parameter	**Hypolimnion**	**Metalimnion**	**Epilimnion**	**Hypolimnion**	**Epilimnion**	**Hypolimnion**	**Epilimnion**	**Hypolimnion**	**Epilimnion**
Temperature (C)	9	16	21	18	19	9	14	12	13
D.O. (mg/L)	1.2	0.8	8.7	11	12.4	1.4	11.9	8.8	10.2
% Saturation	10.4	8.1	97.5	116.2	133.6	12.1	115.4	81.6	96.8
pH (standard units)	6.5	6.2	6.5	6.4	8.0	6.8	7.1	6.0	6.3
Turbidity (ntu)	na	na	na	na	0.9	16.6	2.4	16.6	1.3
Conductivity (umhos/cm)	90	80	85	130	80	125	90	140	120
NH4 (mg/L)	1.3	0.1	0.1	1.3	<0.1	6.6	<0.1	2.1	0.3
NO3 (mg/L)	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	<0.1	<0.1	<0.1
Total Alkalinity (mg/L)	18	·10	8	30	6.0	28	8.0	18	10.0
Total Phosphorus (mg/L)	0.18	0.1	0.09	0.91	0.10	1.6	<0.05	0.58	0.05
Total D. P. (mg/L)	0.08	0.08	0.07	0.77	0.07	1.5	<0.05	0.53	0.05
Fe (mg/L)						0.1			

TABLE 2-7. Summary of In-Lake Water Quality

TABLE 2-6, Lovell's Pond Phytoplankton Analyses
(Sedgewick-Rafter Cell counts; reported as natural units per ml)

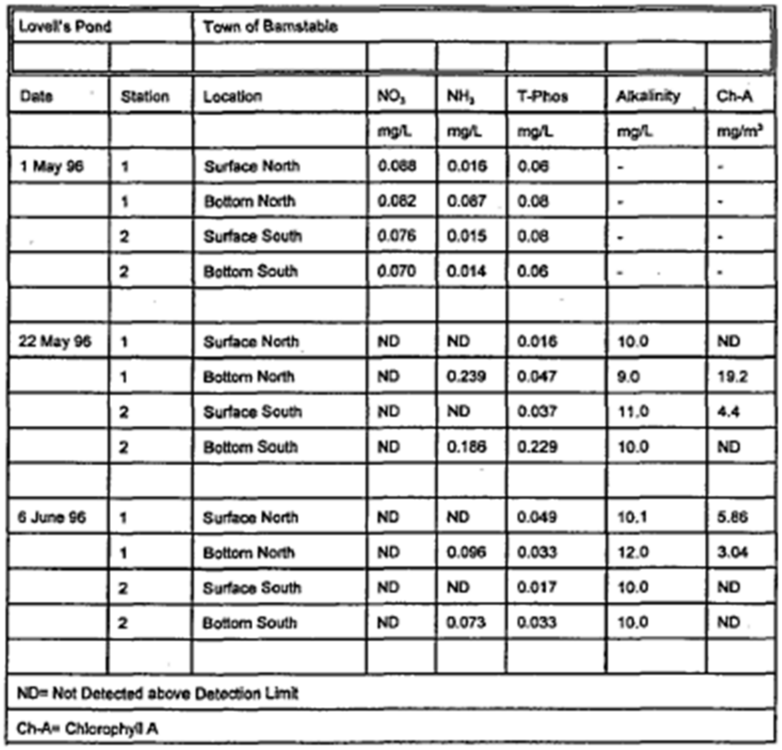
Phytoplankton Taxa	1996 Sampling Dates 26-Jun	 24-Jul	 21-Aug
Bacillariophyceae (diatoms)			
Asterionella	71	143	
Synedra	71	428	71
Chlorophyta (green algae)			
Ankistrodesmus		214	214
Chlamydomonas			143
Pediastrum	71	71	
Scenedesmus		71	71
Cyanophyta (blue-green algae)			
Anabaena	174	143	3,142
Chroococcus		500	
Coelosphaerium	71		
Microcystis	174	857	214
Lyngbya	25,116		3,142
Spirulina			286
Pyrrhophyta (dinoflagellates)			
Ceratium		71	71
Peridinium			71
Unidentified			
flagellates		643	286
testate rhizopods	71	143	143
other		214	
TOTAL (natural units/ml)	**25,821**	**3,570**	**7,925**

Secchi Transparency	5 feet	8 feet	8 feet

Table 2-8, Tributary Data
Lovell's Pond 1996

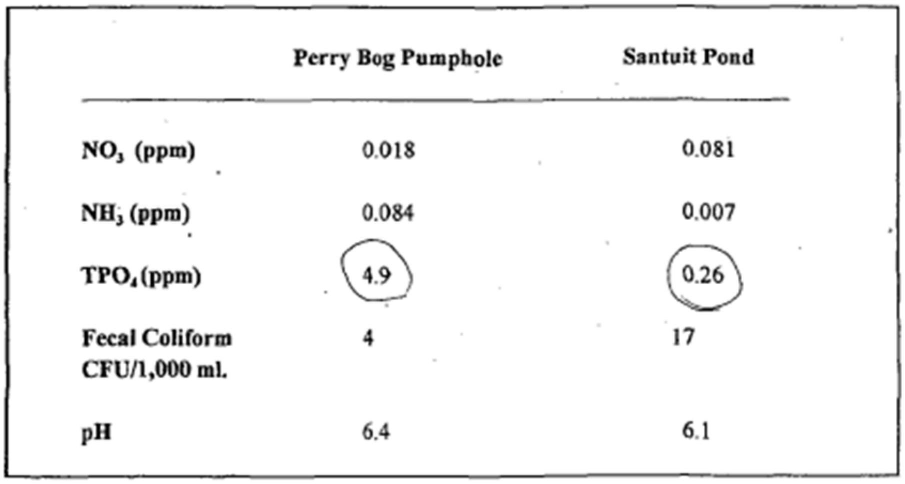
	26 Jun 96			24 Jul 96			21 Aug 96			16 Sep 96			17 Oct 96		
Tributary #	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
pH (Standard Units)	5.8	6.23	6.22	5.7	6.0	5.6	6.0	6.4			5.9		6.1	5.9	
Conductivity (umohs/cm)	105	93	63	110	102	143	95	92			75		80	80	
NH_4 (mg/L)	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.16	0.08			<0.1		<0.1	<0.1	
NO_3 (mg/L)	<0.02	>0.02	<0.02	0.24	<0.1	0.48	<0.1	<0.1			<0.1		<0.1	<0.1	
T-P (mg/L)	<0.1	<0.1	<0.1	<0.05	0.18	0.27	0.26	0.26			0.36		0.2	0.1	
T- DP (mg/L)	NA	NA	NA	NA	NA	NA	0.24	0.24			0.27		0.2	0.1	
Fecal Coliform (CFU/dl)	100	20	90	130	1	70	86	60			60		147	070	
PO_4 (mg/L)	<0.1	<0.1	<0.1	<0.05	<0.05	<0.05									
Flow (gpm)	0	346	642	0	245	0	74	144	0	0	327	0	491	1109	0

Table 2-9
Summary of In-Lake Nutrient Data Collected by Town of Barnstable



Lovell's Pond		Town of Barnstable					
Date	Station	Location	NO_3	NH_3	T-Phos	Alkalinity	Ch-A
			mg/L	mg/L	mg/L	mg/L	mg/m^3
1 May 96	1	Surface North	0.068	0.016	0.06	-	-
	1	Bottom North	0.062	0.067	0.08	-	-
	2	Surface South	0.076	0.015	0.08	-	-
	2	Bottom South	0.070	0.014	0.06	-	-
22 May 96	1	Surface North	ND	ND	0.016	10.0	ND
	1	Bottom North	ND	0.239	0.047	9.0	19.2
	2	Surface South	ND	ND	0.037	11.0	4.4
	2	Bottom South	ND	0.186	0.229	10.0	ND
6 June 96	1	Surface North	ND	ND	0.049	10.1	5.86
	1	Bottom North	ND	0.096	0.033	12.0	3.04
	2	Surface South	ND	ND	0.017	10.0	ND
	2	Bottom South	ND	0.073	0.033	10.0	ND
ND= Not Detected above Detection Limit							
Ch-A= Chlorophyll A							

Table 2-10
Upstream Sampling by the Town of Barnstable, August 1996



	Perry Bog Pumphole	Santuit Pond
NO_3 (ppm)	0.018	0.081
NH_3 (ppm)	0.084	0.007
TPO_4 (ppm)	4.9	0.26
Fecal Coliform CFU/1,000 ml.	4	17
pH	6.4	6.1

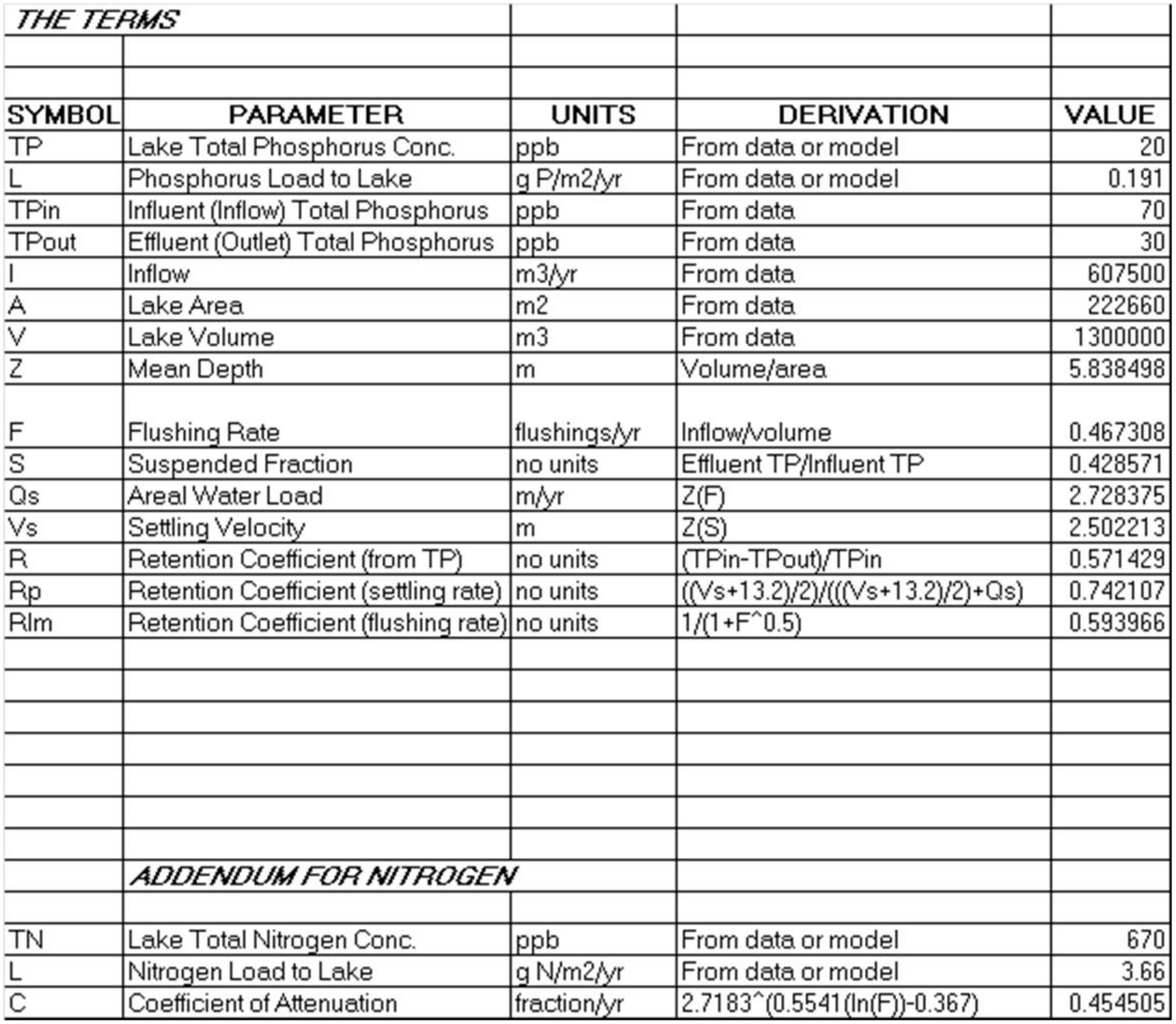
Total Land Area	13,790,289
Roads	1,158,681
Paved	62,000
Roof	248,000
Total Impervious Surfaces	1,468,681
Lawn	1,680,946
Natural Area	10,640,662

Table 4-1. Estimated Areas in the Lovell's Pond Watershed. Areas are given in ft^2

Source	Estimated Annual Loading (Kg)	
Groundwater	49.2	
Regeneration	100.2	
Tributaries	47.0	→ 22.5%
Atmospheric Deposition	4.4	
Lawns	1.8	
Septic Systems	5.9	
	208.5	

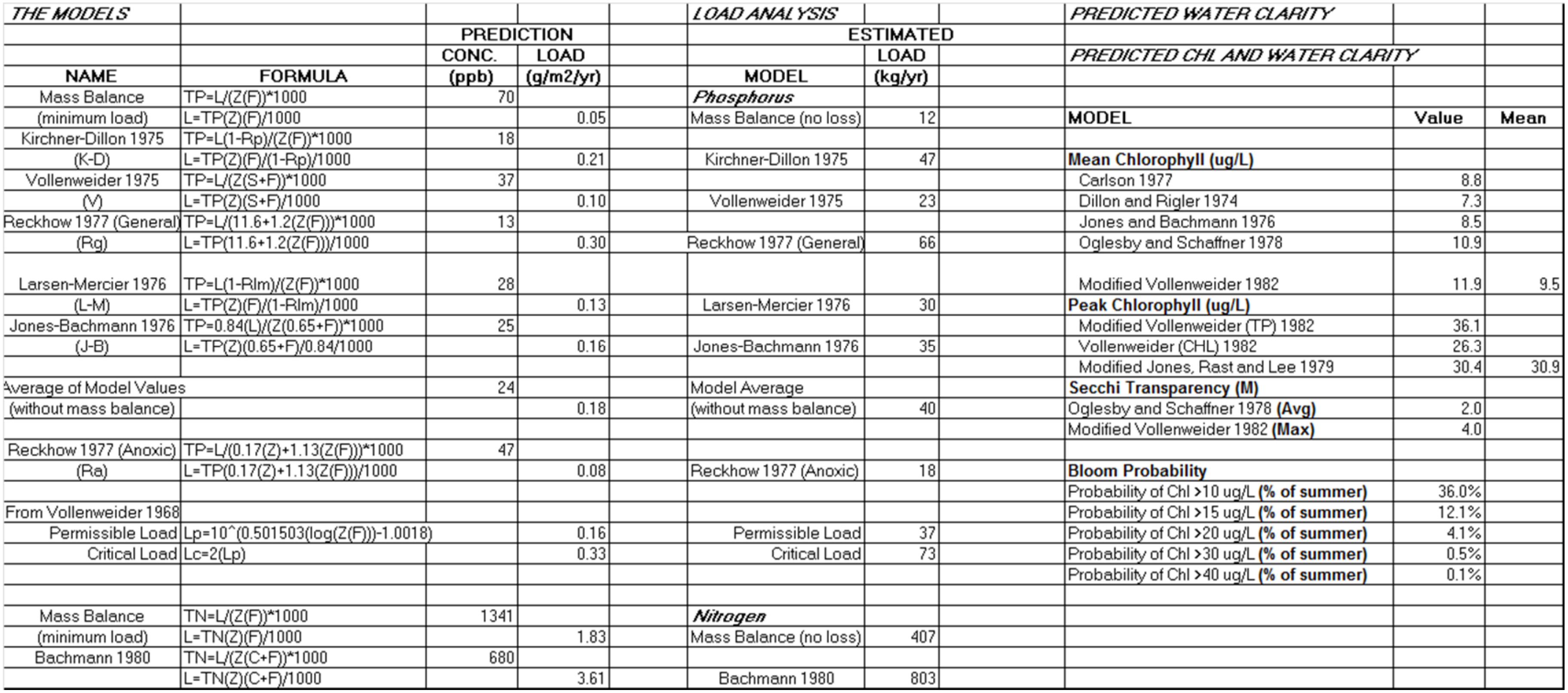
Table 4-2. Summary of Phosphorus Loading to Lovell's Pond.

Application of empirical models



THE TERMS

SYMBOL	PARAMETER	UNITS	DERIVATION	VALUE
TP	Lake Total Phosphorus Conc.	ppb	From data or model	20
L	Phosphorus Load to Lake	g P/m2/yr	From data or model	0.191
TPin	Influent (Inflow) Total Phosphorus	ppb	From data	70
TPout	Effluent (Outlet) Total Phosphorus	ppb	From data	30
I	Inflow	m3/yr	From data	607500
A	Lake Area	m2	From data	222660
V	Lake Volume	m3	From data	1300000
Z	Mean Depth	m	Volume/area	5.838498
F	Flushing Rate	flushings/yr	Inflow/volume	0.467308
S	Suspended Fraction	no units	Effluent TP/Influent TP	0.428571
Qs	Areal Water Load	m/yr	Z(F)	2.728375
Vs	Settling Velocity	m	Z(S)	2.502213
R	Retention Coefficient (from TP)	no units	(TPin-TPout)/TPin	0.571429
Rp	Retention Coefficient (settling rate)	no units	((Vs+13.2)/2)/(((Vs+13.2)/2)+Qs)	0.742107
Rlm	Retention Coefficient (flushing rate)	no units	1/(1+F^0.5)	0.593966
	ADDENDUM FOR NITROGEN			
TN	Lake Total Nitrogen Conc.	ppb	From data or model	670
L	Nitrogen Load to Lake	g N/m2/yr	From data or model	3.66
C	Coefficient of Attenuation	fraction/yr	2.7183^(0.5541(ln(F))-0.367)	0.454505



THE MODELS					*LOAD ANALYSIS*			*PREDICTED WATER CLARITY*		
		PREDICTION				ESTIMATED				
		CONC.	LOAD			LOAD		*PREDICTED CHL AND WATER CLARITY*		
NAME	**FORMULA**	**(ppb)**	**(g/m2/yr)**		**MODEL**	**(kg/yr)**				
Mass Balance	TP=L/(Z(F))*1000	70			***Phosphorus***					
(minimum load)	L=TP(Z)(F)/1000		0.05		Mass Balance (no loss)	12		**MODEL**	**Value**	**Mean**
Kirchner-Dillon 1975	TP=L(1-Rp)/(Z(F))*1000	18								
(K-D)	L=TP(Z)(F)/(1-Rp)/1000		0.21		Kirchner-Dillon 1975	47		**Mean Chlorophyll (ug/L)**		
Vollenweider 1975	TP=L/(Z(S+F))*1000	37						Carlson 1977	8.8	
(V)	L=TP(Z)(S+F)/1000		0.10		Vollenweider 1975	23		Dillon and Rigler 1974	7.3	
Reckhow 1977 (General)	TP=L/(11.6+1.2(Z(F)))*1000	13						Jones and Bachmann 1976	8.5	
(Rg)	L=TP(11.6+1.2(Z(F)))/1000		0.30		Reckhow 1977 (General)	66		Oglesby and Schaffner 1978	10.9	
Larsen-Mercier 1976	TP=L(1-Rlm)/(Z(F))*1000	28						Modified Vollenweider 1982	11.9	9.5
(L-M)	L=TP(Z)(F)/(1-Rlm)/1000		0.13		Larsen-Mercier 1976	30		**Peak Chlorophyll (ug/L)**		
Jones-Bachmann 1976	TP=0.84(L)/(Z(0.65+F))*1000	25						Modified Vollenweider (TP) 1982	36.1	
(J-B)	L=TP(Z)(0.65+F)/0.84/1000		0.16		Jones-Bachmann 1976	35		Vollenweider (CHL) 1982	26.3	
								Modified Jones, Rast and Lee 1979	30.4	30.9
Average of Model Values		24			Model Average			**Secchi Transparency (M)**		
(without mass balance)			0.18		(without mass balance)	40		Oglesby and Schaffner 1978 **(Avg)**	2.0	
								Modified Vollenweider 1982 **(Max)**	4.0	
Reckhow 1977 (Anoxic)	TP=L/(0.17(Z)+1.13(Z(F)))*1000	47								
(Ra)	L=TP(0.17(Z)+1.13(Z(F)))/1000		0.08		Reckhow 1977 (Anoxic)	18		**Bloom Probability**		
								Probability of Chl >10 ug/L **(% of summer)**	36.0%	
From Vollenweider 1968								Probability of Chl >15 ug/L **(% of summer)**	12.1%	
Permissible Load	Lp=10^(0.501503(log(Z(F)))-1.0018)		0.16		Permissible Load	37		Probability of Chl >20 ug/L **(% of summer)**	4.1%	
Critical Load	Lc=2(Lp)		0.33		Critical Load	73		Probability of Chl >30 ug/L **(% of summer)**	0.5%	
								Probability of Chl >40 ug/L **(% of summer)**	0.1%	
Mass Balance	TN=L/(Z(F))*1000	1341			***Nitrogen***					
(minimum load)	L=TN(Z)(F)/1000		1.83		Mass Balance (no loss)	407				
Bachmann 1980	TN=L/(Z(C+F))*1000	680								
	L=TN(Z)(C+F)/1000		3.61		Bachmann 1980	803				