SAVERY POND
2016 CUMULATIVE DATA REPORT

Monitoring Locations on Savery Pond

MAY 2017

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1.0 INTRODUCTION

Savery Pond is a 29.4-acre pond in Plymouth, Massachusetts that has experienced increasing occurrences of cyanobacteria blooms in recent time. Public health advisories associated with blooms were issued by Massachusetts Department of Public Health (MDPH) in 2011, 2014, 2015 and 2016; and high levels of algae have been observed by local residents in other years. The Plymouth Department of Marine & Environmental Affairs (DMEA), in cooperation with Friends of Ellisville Marsh (FoEM) and others, have worked diligently to collect data to better understand pond conditions, nutrient concentrations, algal blooms, and related factors. Ultimately, these cooperators hope to work with specialists in the field[1] to develop a pond assessment and a pond management plan. A critical element of the pond assessment will be a nutrient budget, which estimates nutrient sources and sinks for the pond.

The pond is spring fed and discharges to the Ellisville Marsh estuary via its outlet stream "Herring Brook". Nutrient inputs to the pond are both natural (from wildlife, shoreline plants and groundwater inflow) and anthropogenic (septic system discharge via groundwater, residential stormwater runoff, fertilizer applications to cranberry bogs and to residential landscaping, and historic accumulation of nutrients in pond sediments). It is worth noting that two cranberry bogs adjoin the pond: a 4-acre "West Bog" and a 6.5-acre "East Bog". The West Bog is comprised of three adjoining small bogs, is no longer irrigated, fertilized or commercially harvested, but is flooded seasonally during winter/spring months. The East Bog has been commercially managed through fall of 2016, but was recently acquired by the Town of Plymouth and will be restored to grassland habitat. Assuming commercial operation of the East Bog included significant fertilizer applications, fallowing the bog may lead to reduced nutrient inputs to the pond (potentially reflected in upcoming data collection during the summer of 2017).

This report compiles available water-quality and hydrologic data for Savery Pond. Review of these data will be used to characterize nutrient and hydrologic processes in the pond, identify data gaps, identify next steps towards data collection and interpretation, and provide a solid basis for seeking the funding towards developing the pond assessment and management plan. Compiled data were catalogued to provide a thorough overview of available information, graphs were generated where sufficient data are available, and preliminary data interpretations are provided. Prior to finalization of this report, FoEM reviewed a late-2016 report by TMDL Solutions summarizing and interpreting recent water-quality data, and some of the TMDL Solutions findings are referenced below.

2.0 SUMMARY OF FINDINGS & CONCLUSIONS

The following bullets summarize the key findings and conclusions of this report:

1. After an isolated baseline study back in 1970, recent intensification of algal blooms caused resumed data collection on Savery Pond in 2010, with emphasis on water-quality sampling for nutrients (phosphorus and nitrogen) and chlorophyll-a (phytoplankton indicator); as well as depth-profiling of physical parameters (temperature, dissolved oxygen, clarity). FoEM commissioned a general water-quality study soon thereafter (ACT, 2012), and in 2014 sampling by DMEA showed that Savery Pond was the most impaired pond (with respect to nutrient concentrations) among 39 local water bodies evaluated (SMAST, 2015). The most intensive data collection effort occurred over the 2016 summer/fall season, with a multi-parameter data-logging probe ("sonde") installed near the bottom of the deepest

[1] e.g. Ed Eichner and Brian Howes of the Coastal Systems Program, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth

point on the pond, datalogging temperature probes at various depths, and laboratory analysis of 8 water samples. Samples from the outfall channel of the "East" cranberry bog have also been analyzed for nutrients.

2. Other related data collection include: pond and groundwater levels, visual observations of Herring Brook outflow, and cyanobacteria sampling during algal blooms. While ACT (2012) analyzed nutrient storage in sediments, more rigorous methods are likely warranted. Other key data gaps include quantitative monitoring of Herring Brook outflow and estimates of current and historic nutrient inputs (e.g. from fertilizers, septic discharge to groundwater, stormwater runoff, etc.).

3. Algal blooms in Savery Pond have been more common since the beginning of the new millennium, with MDPH issuing public health advisories in 2011, 2014, 2015 and 2016. The blooms can be correlated to increased concentrations of chlorophyll-a and reductions in water transparency. Most summer measurements of transparency on Savery Pond are below the U.S. Environmental Protection Agency (EPA) reference threshold.

4. Savery Pond is considered to be a "warm water fishery", and measured temperatures do not exceed associated Massachusetts water-quality criteria. "Snapshot" temperature profiling has shown the occurrence of both "stratified" and "well-mixed" conditions, and lower temperatures near the pond bottom may be influenced by groundwater discharge. Continuous temperature profiling in 2016 showed extended periods of apparent stratification interrupted by brief periods of mixing during summer months, followed by loss of stratification in mid-August. Stratified conditions can promote accumulation of anoxic (low dissolved oxygen) conditions at the pond bottom and associated desorption of sediment-bound phosphorus; whereas mixing can transport deeper nutrient concentrations up into the shallower water.

5. Snapshot profiles of dissolved oxygen (DO) showed occurrences of depleted DO at the pond bottom (where concentrations fell below the Massachusetts water-quality standard of 5 mg/l – and sometimes approached anoxic conditions) along with other periods where DO exceeded the standard throughout the profile. Most profiles with depleted DO near the pond bottom corresponded to algal blooms. 2016 continuous monitoring near the pond bottom showed two anoxic periods, a short period beginning soon after the beginning of the algae bloom and a longer period spanning the middle and latter portions of the bloom. Anoxic conditions tend to support an increased rate of nutrient regeneration from lake-bottom sediments, and phytoplankton would be expected to respond to increased nutrient availability. Periods of warmer temperature also appear to reduce DO near the pond bottom, possibly due to increased algae production and subsequent algal decomposition on the pond bottom.

6. Eleven samples were taken near both the top and bottom of the water column in the summers of 2014, 2015 and 2016. All nutrient concentrations exceed the impaired reference thresholds for total phosphorus (TP) and total nitrogen (TN). The highest measured TP concentration was 20x the TP reference threshold, and the highest measured TN concentration was over 5x the TN reference threshold. Measured 2014 TP and TN concentrations were the highest out of 39 surveyed for the Plymouth Pond and Lake Atlas (SMAST, 2015), and that several of the 2015 and 2016 measurements exceeded the 2014 values. Several sampling events occurred where TP near the pond bottom exceeded 2x TP near the pond top, suggesting sediment regeneration of TP into the overlying water column.

7. Measurement of nutrients in pond sediments by ACT (2012) showed moderately high phosphorus contents that are expected to support recycling of phosphorus, although the employed laboratory method suggested that the majority of phosphorus was either tied up in organic forms or inert inorganic forms. Additional sampling and laboratory analysis using incubation techniques at various levels of oxidation is recommended.

8. The limited data record for pond and groundwater levels revealed a slow recovery in groundwater levels from the summer drought starting in late January 2017. Herring Brook showed negligible flow

from summer to early-winter 2016 (likely considerably lower than the only historic measurement of 0.77 cfs in 1970), with some recovery after the February 2017 thaw. It should be noted that any long-term declines in groundwater level (due to climatic or pumping causes) would reduce groundwater inflow to the pond, associated freshwater flushing, and pond outflow to Herring Brook. Reduced flushing would support increased pond temperature and accumulation of pond nutrients.

9. A September 2016 water sample from the East Bog outfall channel during discharge from harvest flooding showed TP concentrations 17x higher than pond background. Mass loading calculations suggest that this single event could have doubled TP concentration in pond water. Long-term nutrient loading from the bogs has not been quantified.

10. Climate change has already increased Massachusetts temperatures by about 1.7 ^{o}F since 1975, and predictions suggest that average annual temperatures along the northeast seaboard will increase by 3 to 9 ^{o}F during the 21st century. Such atmospheric temperature increases are expected to increase pond-water temperatures, thus increasing phytoplankton activity. Increased temperature will also reduce groundwater recharge (due to increased evapotranspiration), thus resulting in less freshwater flushing for the pond.

11. FoEM recommends the following next steps for upcoming monitoring towards developing a nutrient management plan:

    - Continue summer/fall nutrient sampling and profile "snapshots" of physical parameters.
    - Begin monitoring pond discharge to Herring Brook.
    - Collect sediment cores and incubate to measure stored nutrients.
    - Perform a plant and mussel survey for the Pond;

    DMEA, SMAST and FoEM should jointly pursuing grant funding to cover some of the monitoring activities listed above, for development of the nutrient budget, and for development of the Pond Assessment

12. In order to minimize nutrient inputs from the West and East bog parcels, it may be worthwhile to:

    - Work with the owner of the West Bog to optimize practices to minimize nutrient runoff to the lake resulting from bog-flooded conditions.
    - During restoration of the East Bog, consider isolating the former outfall channel from Savery Pond or performing a localized alum treatment to stabilize phosphorus adsorbed onto channel bottom sediments.

3.0 AVAILABLE DATA & KNOWN GAPS

Data collected on Savery Pond include:

1. Water-quality data collected from a 1970 baseline study performed by Lyons-Skwarto Associates for the Town of Plymouth. Though useful, these data have poorly documented in a variety of ways (e.g. sample date, sample depth, laboratory, analytical methods). Several elements of the 1970 study have not been reproduced elsewhere, including a bathymetric survey, immersed and submersed plant surveys, and a one-time measurement of stream outflow (0.77 cfs). The recorded pond temperature (65 ^{o}F) suggests that the pond visit may have occurred in late spring or early autumn.

2. Water-quality data collected in the summer of 2012 by Aquatic Control Technology (ACT). The ACT study was commissioned by FoEM, but limited funding dictated that most water samples were blended between multiple locations (i.e. the focus was on *general* water quality). However, the ACT study includes discrete temperature (T) and dissolved oxygen (DO) profiles, site-specific secchi disk measurements (indicating water clarity), and a discrete water-quality sample from the east bog outfall.

It also includes laboratory analysis of nutrient concentrations in pond sediments. FoEM assisted with the 2012 data collection.

3. FoEM has worked independently and with DMEA's Plymouth Pond and Lakes Stewardship (PPALS) Program to collect samples and profile water-quality conditions at fixed locations during the summers of 2010, 2011, 2014, 2015 and 2016. FoEM's independent sampling was performed several established near-shore locations around the pond, whereas cooperative sampling was performed at a fixed "profile location" (deepest spot on the pond).
   - In 2010 and 2011, FoEM took several water samples at established near-shore locations and from the East Bog outfall. Samples were analyzed for nutrients, temperature, pH, total dissolved solids (TDS).
   - FoEM and DMEA worked cooperatively in 2014 (single visit) and 2015 (six visits) to measure physical parameters (depth profiles of T and DO, secchi depth, pH) and take samples near the top and bottom of the profile. The samples were analyzed by SMAST for total phosphorus (TP), total nitrogen (TN), chlorophyll-a, pheophytin-a and alkalinity.
   - In 2016, DMEA installed and maintained a continuous datalogger ("sonde") to measure multiple parameters (T, DO, depth, specific conductance, chlorophyll) just above pond bottom (~3 meters depth). Temperature probes were also installed at multiple depths to facilitate continuous temperature profiling. DMEA performed 8 visits for profiling and sample collection. FoEM assisted with DMEA's efforts.
   - In September 2016, FoEM collected a sample from the East Bog outfall during discharging conditions from the 2016 cranberry harvest.
4. Both FoEM and DMEA have made visual observations of stream outflow over recent years. FoEM began measuring depth to groundwater in a local well starting in August 2016 and weekly pond stage starting in September of 2016.
5. MDPH has sampled the pond during algal blooms, and maintains records of cyanobacteria indicator levels and seasonal bloom durations. Typical analyses include: Anabaena, Aphanizomenon, Coelospaerium, and Microcystins. Sampling for coliform bacteria and/or E. Coli is performed at the Indianhead Resort beach by the resort owner.
6. Cape Cod Cranberry Growers Association (CCCGA) has reportedly collected some miscellaneous water-quality data from the pond, although the data have not been provided to DMEA or FoEM.
7. A plant identification survey was performed by Irina Kadis (Botanist from Arnold Arboretum) in June 2012. They survey did not include estimated areas of coverage.
8. The National Weather Service (NWS) maintains an Automated Surface Observation System (ASOS) climate monitoring station at the Plymouth Airport (PYM). FoEM downloaded daily statistics for temperature, precipitation and wind conditions.

Known data gaps include the following:

1. Long-term records of pond stage and groundwater elevations in the pond vicinity. It should be noted that pond stage is not expected to show significant variation because the weir controlling discharge to the outlet stream ("Herring Brook") likely maintains the pond at a near-fixed elevation. Records of local municipal groundwater pumping may be available from the Town of Plymouth.
2. Long-term or recent short-term pond discharge data to Herring Brook. Only one miscellaneous measurement is available (0.77 cfs, recorded by Lyons-Skwarto Associates in 1970).

3. Long-term pond temperature data for comparison to long-term atmospheric temperature. Pond temperature is influenced by both atmospheric conditions and groundwater inflow. Warming of the pond is expected due atmospheric trends (global warming) which affects both surface temperature and groundwater temperature. In addition, any changes in the rate groundwater inflow will produce temperature changes superimposed on climate-driven trends. For instance, less groundwater inflow will increase summer pond temperatures due to reduced flushing of (cool) groundwater entering the pond as discharge from springs.
4. Various historic data regarding the two adjacent cranberry bogs. Such data might include: pumping volumes from pond and subsequent return flows, estimates of percolation of bog water to shallow groundwater, rates of fertilizer application, and the quality of discharge water.
5. Estimates of potentially mobilized nutrients stored in the bog sediments. Note that it may be possible to hydrologically isolate the East Bog from the pond, and the owner of the west bog is sensitive to how harvest practices can potentially mobilize adsorbed nutrients from bog sediments into harvest discharge water.
6. Estimates of potentially mobilized nutrients stored in the pond sediments. ACT (2012) analyzed pond sediments for loosely-sorbed and iron-bound phosphorus; however, SMAST has found that controlled incubation studies are more useful for assessing potential phosphorus release under varying aerobic, chemical and anaerobic conditions.
7. Local climatic data. The nearest known climate gage is at the Plymouth Airport, approximately 9 miles to the west of Savery Pond. These regional data are probably sufficient for general trends, but may not accurately indicate local conditions. Pond temperature data suggest that temperatures at the Plymouth Airport are lower than Savery Pond (Section 3.3).
8. Estimated septic discharge from the large onsite septic system (LOSS) at Indianhead Resort. Septic discharge from individual residences can be estimated using published literature values; although information may be lacking as to the age, design and function of individual domestic septic systems.
9. Recent plant surveys with measured areas, and survey of freshwater mussels.
10. Concentrations of potential organic chemicals such as pesticides applied to adjacent cranberry bogs.

As noted above, the following review of existing data and the above identification of data gaps is intended to guide future data collection activities ultimately leading to preparation of a pond assessment and a pond management plan.

4.0 DATA REVIEW & INTERPRETATION

4.1 ALGAL BLOOMS

Savery Pond was characterized as eutrophic almost 50 years ago, during a reconnaissance survey in 1970 (Lyons-Skwarto Associates, 1970). However, long-term residents note that the pond had relatively clear water (ability to see bottom) and relatively low algal counts (ability to swim with eyes open, rare notable “blooms”) until the past ten to fifteen years. The pond has most recently begun to experience regular and severe algal blooms with high levels of cyanobacteria, which are known to generate toxins that are dangerous to humans and animals. In response to communications from pond residents, Massachusetts Department of Public Health (MDPH) has sampled pond conditions and issued the following cyanobacteria advisories:

Advisory recommended	Advisory rescinded
7/7/2011	7/29/2011
7/16/2014	9/12/2014
7/24/2015	8/7/2015
7/8/2016	8/4/2016

Advisory recommendation dates supersede initiation of the blooms, as time is required for communications, sampling and laboratory analysis. For instance, photos of the 2016 bloom were sent to DPH nine days before the advisory was recommended. In some cases, blooms have occurred without DPH sampling or below the guidelines for cyanobacteria cell counts (e.g. high algae occurrence was noted in the spring and July of 2012). MDPH guidelines for acceptable cyanobacteria cell counts and water consumption include the recommendation of avoiding contact with waters having cyanobacteria cell counts greater than 70,000 cells/mL or 14 µg/L microcystin (a cyanobacteria toxin).

Phytoplankton concentrations in pond water can be indirectly related to concentrations of chlorophyll-a and pheophytin-a (a breakdown product of chlorophyll-a). **Figure 1** shows laboratory analysis of chlorophyll-a and pheophytin-a in pond samples taken between 2014-2016, and **Figure 2** shows continuous chlorophyll concentrations measured with the YSI sonde positioned just 0.5 meters above the pond bottom during the summer of 2016. The following text, summarized from the Plymouth Pond and Lake Atlas (SMAST, 2015), provides perspective on these chlorophyll measurements:

> The average concentration of chlorophyll-a in surface samples from 191 ponds sampled during 2001 Cape Cod PALS Snapshot was 8.44 µg/L with a range from 0.01 to 102.9 µg/L. Data from this snapshot was used to develop a Ecoregion Limit and Unimpaired Reference concentrations of 1.7 µg/L and 1.0 µg/L, respectively. The Ecoregion Limit is roughly the same as the USEPA ecoregion chlorophyll-a concentration of 2.1 µg/L. Most ponds in the Plymouth ecoregion are expected to exhibit strong relationship between chlorophyll-a and total phosphorus concentrations. Unimpaired ponds in the ecoregion tend to have low chlorophyll-a concentrations *and* low nutrient concentrations.

Figure 1 shows that almost all summer pond samples have significantly exceeded the ecoregion limit of 1.7 ug/L. The summer 2016 continuous data shown on **Figure 2** reflect conditions near the pond bottom rather than the pond surface; however, the data exhibit both discrete periods of high phytoplankton concentrations (e.g. settling and concentration of chlorophyll-a near the pond bottom in late July and mid-August) as well as other periods where of chlorophyll-a near the pond bottom exhibits scattered variation.

4.2 WATER TRANPARENCY

Transparency (clarity) of pond water is typically measured as Secchi depth or as turbidity. The Secchi disk is an 8 inch disk with alternating black and white quadrants that is lowered to the depth at which visibility is lost. Based on 79 readings, USEPA currently has a reference threshold of 2 meters for ponds within Subecoregion 84, which includes Plymouth (USEPA, 2001). Among the 39 ponds sampled during the 2014 PPALS Snapshot, the median Secchi reading was 3.0 meters (SMAST, 2015). Turbidity is a relative measurement of the amount of suspended material in the water and can range from less than one to thousands of units. Turbidity in most ponds and lakes rarely rises above 5 NTU (ACT, 2012).

Figure 3 is a graph of summer Secchi measurements taken in Savery Pond from 2011 through 2016. DPH Cyanobacteria advisory periods are shown near the bottom of the chart along with 2012 months where high algal occurrence was observed by residents. All measurements were taken at the "profile location" (deepest pond depth of 3.5 m), with the exception of the 2011 measurement (average of multiple shallower locations). During the warm summer months (June through August), *most* Secchi depths range from 1 to 1.5 meters and therefore indicate less water transparency than the EPA reference threshold. Several summer measurements show acceptable transparency (2m-2.5m range), and fall measurements (September and October) range from 2 to 3.5 meters. Secchi depth measured during the 1970 pond study (date unknown) was 1.2m.

Turbidity measurements are far less common. Measurements from 3 open-water locations in 2010 ranged from 1.3 to 1.8 NTU; however, one location near the mouth of the East Bog outfall showed a turbidity of 40 NTU. Multi-location "composite" (blended) samples from the 2012 ACT study ranged from 2.6 NTU (July) through 1.5 and 1.0 NTU (September and October).

4.3 WATER TEMPERATURE

Pond water temperature plays an important role in how lake ecosystems function, which species are favored, and the solubility of dissolved oxygen. Massachusetts water quality regulations include numeric standards for temperature and distinguish between warm and cold water systems. SMAST (2015) notes that lakes less than 7-9 meters deep tend to have waters columns that are well-mixed by available winds, tend to have similar temperatures throughout the water column, would be considered warm-water fisheries, and that 7-day mean temperatures in warm-water fisheries should not exceed 28.3°C (83°F).

Temperature profiles, measured at the "profile location" (deepest location in pond) in 2012, 2015 and 2016, are plotted on **Figure 4**. Some profiles include measurements down to just above the pond bottom (3.4 or 3.5 meters), whereas others only go as deep as 3 meters. Summer profiles are plotted with a solid line whereas spring/fall profiles are plotted with a dashed line, and years are segregated by color. None of the measured temperatures exceed the warm-fisheries limit of 28.3°C. The spring/fall profiles generally show little temperature variation with depth; however, this is less true for the warmer summer profiles. Most notably, profiles taken 7/12/12, 7/24/15, 7/31/15 and 7/26/16 all show cooler temperatures near the pond bottom, sometimes by as much as 7°C (profiles only measured to a depth of 3m likely have cooler values on the pond bottom). Cooler temperatures on pond bottom likely occur due to a combination of spring (groundwater) inflow through the lakebed and lack of mixing activity from wind/waves. Such thermal stratification is commonly associated with resistance to mixing. All four dates above correspond to dates of DPH cyanobacteria advisories or noted algal blooms, though no causative mechanism is proposed herein.

In 2016, DMEA installed and maintained a YSI sonde to continuously measure multiple parameters (T, DO, depth, specific conductance, chlorophyll) just above pond bottom (~2.4 meters depth). Probes on the YSI sonde were calibrated on a monthly basis. DMEA also installed Hobo temperature probes along the profile cable at approximately 2m, 1.5m, and 0.5m depth[2]. The probes were checked for calibration at the end of the monitoring season and showed good agreement. FoEM installed "button probes" at the same 3 depths; however, these probes were not as accurate as the YSI (temperature measured in discrete 0.5°C steps).

Figure 5 shows the continuous data measured with the YSI and Hobo probes between 5/31/16 and 10/4/16 (data from the 2.5m button probe were used to fill a data gap in early June)[3]. The figure also shows daily average temperatures at the Plymouth Airport, which seem to be consistently several °C less than the pond surface temperatures and are therefore plotted on a separate Y axis (offset 2°C). The pond-

[2] These numbers are approximate because the guide line was not likely vertical in the water column.
[3] Several short-term departures from ambient trends can be noted when the probes were pulled out of the water for data downloads.

water data show decreasing temperature with depth, and measurements between mid-June and mid-August show notably cooler temperatures at the 2.4m YSI probe than at the overlying Hobo probes. All four probes track closer together after 8/16/16, which may be due to collapse of thermal stratification associated with surface-temperature cooling. Plymouth Airport temperatures, while assumed to differ from Ellisville temperatures due to microclimatic variations, exhibit general trends which appear to lead the pond temperatures, thus demonstrating the pond's response to atmospheric temperature.

Figure 5 also shows average daily precipitation and wind speed at the Plymouth Airport. In contrast to average daily temperature, neither of these two other climatic factors seem to significantly affect the Savery Pond temperature profile. Particularly windy days at the Plymouth Airport do not appear to cause significant mixing of pond water (temperature blending). As expected, temperature trends near the pond surface (~0.5m) exhibit significant diurnal variation. Near-surface water temperatures are likely affected by precipitation events; however the data were not evaluated to discern such effects.

4.4 DISSOLVED OXYGEN (DO)

Dissolved oxygen (DO) concentrations can play a critical role in both the biological and chemical elements of lake ecosystems. The following bulleted information about DO is excerpted from the Plymouth Pond and Lake Atlas (SMAST, 2015):

- State surface water regulations state that warm-water fisheries should have dissolved oxygen concentrations greater than 5 mg/L.
- Oxygen availability is impacted by temperature: higher temperature waters hold less dissolved oxygen.
- Oxygen concentrations determine the chemical solubility of many inorganic elements; for example, low oxygen in pond sediments can create chemical conditions that release phosphorus from solids where it is bound with iron and make it available to prompt growth of phytoplankton.
- DO concentrations typically fall below state limits when excessive plant growth causes sediment bacterial oxygen uptake greater than rates of oxygen replenishment.
- Biological interactions can also impact DO concentrations. Since one of the main by-products of photosynthesis is oxygen; a vigorous algal population can produce DO concentrations that are greater than the concentrations that would be expected based simply on temperature interactions with the atmosphere. These instances of "supersaturation" usually occur in ponds with high nutrient concentrations, since the algal population would need readily available nutrients in order to thrive. In some lakes, algal populations can cause oxygen maxima deeper in the pond, at or near the metalimnion, where the algae can utilize higher phosphorus concentrations leaking through from the hypolimnion, while still having adequate, albeit low, light for photosynthesis. Impaired water quality conditions can also be indicated by excessive DO concentrations.

DO profiles (measured at the "profile location" in 2012, 2014, 2015 and 2016) are plotted on **Figure 6**. Similar to temperature, the DO profiles vary from total depth from 3m to 3.5m. Among the 17 recorded DO profiles, at least six appear to trend towards depleted DO near the bottom of the pond (7/12/12, 7/24/15, 7/31/15, 8/6/15, 7/26/16, 9/20/16). Five of the six noted profiles occur either during a DPH cyanobacteria advisory or during locally noted conditions of high algae occurrence. Four of the six profiles only go down to a 3m depth, and further depletion between 3m and 3.5m is unknown. Of the remaining two profiles that extend from 3m to 3.5m, the 7/12/12 profile shows a significant DO reduction of 1.8

mg/l trending to anoxic conditions, whereas the 7/26/16 profile shows just a small DO reduction between 3m and 3.5m. Eight of the 17 recorded profiles show DO concentrations in deeper portions of the pond below the Massachusetts standard of 5 mg/l.

Miscellaneous profiles do not indicate the duration of depleted or anoxic DO concentrations near the pond bottom. Continuous DO concentrations were recorded by the YSI continuous datalogger installed in 2016 at 2.4m depth by DMEA. The DO probe was calibrated on a monthly basis[4]. **Figure 2** shows the 2016 continuous DO data measured with the YSI probe along with specific conductance (SC) and chlorophyll. The DPH cyanobacteria advisory occurred between 7/8/16 and 8/4/16 but was reported to DPH 9 days earlier (on 6/31/16). The following observations are noted:

1. Because the DO probe was situated as much as 0.8m above the pond bottom, it may not be representative of actual conditions in the bottom sediment. During DO depletion events, it may be reasonable to assume lower DO concentrations at the pond bottom.
2. The first recorded summer-2016 DO depletion event near the pond bottom begins around 6/20 but recovers on 6/27 before reaching anoxic conditions.
3. A second DO depletion event occurs between 6/28 and 7/8, and does reach anoxic conditions at the pond bottom before starting a recovery on 7/8.
4. A third major DO depletion event begins on 7/13 and reaches anoxic conditions at the pond bottom on 7/18. Anoxic conditions persist through 8/2 (16 days), and a peak in chlorophyll is noted during this 7/18-8/2 anoxic period.
5. Between early August and late September, DO at the pond bottom exhibits repeated oscillations. Four such oscillations in August bring DO at the pond bottom down to relatively low concentrations (<20%). One such oscillation, where DO dips and recovers between 8/11 and 8/17, corresponds to another chlorophyll peak.
6. DO oscillations in August are superimposed on a rising trend, which flattens out in September. Oscillations and variations in September exhibit lesser magnitude than August variations.

As stated above (and also noted by TMDL Solutions, 2016), anoxic conditions tend to support an increased rate of nutrient regeneration from lake-bottom sediments. Phytoplankton would be expected to respond to increased nutrient availability, and it therefore makes sense that a peak in chlorophyll is observed during the sustained anoxic period in late July. The chlorophyll peak occurs towards the end of the MDPH cyanobacteria advisory. TMDL Solutions interprets the timing of this chlorophyll peak as due to phytoplankton previously concentrated in the upper water column settling toward the pond bottom.

Comparison of pond-bottom DO to climatic data from the Plymouth Airport appear to exhibit no significant correlation to average daily precipitation or wind speed, but a potential relationship to average daily temperature. **Figure 7** compares temperature to DO (reverse-graphed on the Y-axis), and suggests several short-term warm-temperature events that precede reductions in pond-bottom DO by several days[5]. Warmer temperatures tend increase rates of biological production, which could result in rain-out (settling) and decay of algae on the pond bottom and subsequent depletion of DO. Warmer temperatures do not cause reductions in DO saturation because temperature reduces the solubility of oxygen and would therefore *increase* percent saturation.

[4] TMDL Solutions (2016) suggests that DO measurement accuracy may have been compromised after 8/23/16; however, our review suggest that this may be limited to mg/l (and not as percent saturation).
[5] Note that higher temperature events are circled in blue, and DO is plotted in reverse so a reduction follows the same visual trend as an increase in temperature.

4.5 NUTRIENTS IN POND WATER

Pond water samples taken at the "Profile Location", near the top and bottom of the water column, were analyzed for total nitrogen (TN) and total phosphorus (TP). The following bulleted information about nutrients in pond water is excerpted from the Plymouth Pond and Lake Atlas (SMAST, 2015):

- Phosphorus and nitrogen are essential macro-nutrients for plant growth. When nutrients are added to ponds or lakes, the phytoplankton are usually the first to respond, doubling or tripling in density and, if nutrients are sufficient, producing a noticeable bloom floating on the surface of the pond.
- Phosphorus is usually the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen. If the ratio between nitrogen and phosphorus is greater than 16 (also known as the Redfield Ratio[6]), phosphorus is generally the limiting nutrient, so adding phosphorus causes blooms. Blue-green algae (or cyanobacteria) have the ability to take (or fix) nitrogen from the atmosphere, which allows their rapid growth when phosphorus is relatively accessible.
- Nitrogen is added to the aquifer system from land use sources, such as septic system discharge, fertilizers, and stormwater runoff and generally flows with groundwater. These same sources add phosphorus to the groundwater, but phosphorus is significantly slowed mostly due to its binding to the iron minerals naturally contained in the aquifer sands.
- Most of the phosphorus in Plymouth ponds is generally due to additions from land uses directly adjacent to the pond and regeneration of past watershed additions from the pond sediments. Shoreline properties generally have impacts on the pond within land use and wastewater planning horizons.
- USEPA water-quality reference criteria (developed for Ecoregion 14, the near-coast regions of the eastern seaboard from New Hampshire to Georgia) include 0.32 mg/L for TN and 8 ug/L for TP. The Cape Cod PALS Program (coordinated by SMAST) used a similar approach for developing subregional impaired threshold criteria that are more directly applicable to the Plymouth ecoregion. Based on sampling over 175 Cape Cod ponds (most of which were considered impaired by nutrients) and identifying the lower 25th percentile concentrations, impaired ecoregion thresholds of 0.31 mg/L (TN) and 10 ug/L (TP) were developed.
- Ratios of shallow to deep TP concentrations greater than two (bottom/surface) strongly indicate sediment regeneration of TP into the overlying water column. Similar review of TN concentrations shows that, on average, TN regeneration is not a major driver of bottom water concentration.

Figure 8 shows the results of 11 sampling events during the summers of 2014 through 2016, where water samples were taken at the "Profile Location" at both shallow (0.5m) and deep (~2.5-3m) depths. ***All*** nutrient concentrations exceed the impaired reference thresholds for TP and TN. The highest measured TP concentration (199 ug/L) was 20x the TP reference threshold, and the highest measured TN concentration (1.6 mg/L) was over 5x the TN reference threshold. It's worth noting that the 2014 TP and TN concentrations were the highest out of 39 surveyed for the Plymouth Pond and Lake Atlas, *and* that several of the 2015 and 2016 measurements exceeded the 2014 values. It's also worth noting that each summer exhibits a sampling event where TP near the pond bottom exceeded 2x TP near the pond top (strongly indicating sediment regeneration of TP into the overlying water column). During each of these events (circled on

[6] The Redfield Ratio is the molar ration of TN to TP (TN/TP).

the graph), one of the shallow/deep exhibited a N:P ratio near-to or less-than 16[7]. While TP appears to be the limiting factor most of the time, the data suggest that TN can sometimes be the limiting factor for algal growth.

In addition to the 2014-2016 samples analyzed from the "Profile Location", several previous samples have been analyzed for nutrient concentrations. In the summer of 2012, ACT analyzed shallow-water, composite samples (combined from several locations) for TP and TN[8]. TP values ranged from 37 ug/L (July) to <10 ug/L (September) to 26 ug/L (October) ug/L; and TN values ranged from 1.6 mg/L (July) to 0.5 mg/L (September) to non-detect (October). FoEM sampled several locations for nutrients on 7/21/2010 and 7/5/2011. Analysis for orthophosphate found no detects in 2010 and values ranging from 50 to 70 ug/L in 2011. Samples from two pond locations in 1970 (date unknown) both showed TP values of 20 ug/L and nitrate values of 0.02 mg/L. Additional water-quality data from isolated sampling events are summarized in Appendix A.

4.6 NUTRIENTS IN POND SEDIMENTS

Sediment regeneration of nutrients can play a significant role in determining the overall water quality conditions in a pond including measured nutrient concentrations, the growth of algae, and water clarity. Lakebed sediments can adsorb phosphorus, particularly in lakes with abundant nutrient inputs. While nutrient inputs to Savery Pond have not yet been estimated, it is worth noting that this small pond has hosted: two adjacent, active cranberry bogs for over 60-100 years of operation[9]; a recreational vehicle campground/resort with a large onsite septic system (LOSS) for *almost* a half-century of operation, and rural residences with various vintages/types of underground wastewater disposal systems[10]. Given typical past fertilization practices and sandy local soils, such facilities have likely discharged nutrients into Savery Pond through both surface and sub-surface pathways, thus loading up the pond sediments. As noted by SMAST (2015): "When low oxygen conditions occur in sediments, the chemical characteristics of many of the compounds found in the sediments, including nutrients, can also be altered. Nutrients, like phosphorus are released from the sediments due to microbial processes of decay, but release can be accelerated under anoxic conditions, If these nutrients are made available to algae in well lit, upper waters, they support algal growth and even extensive blooms".

In the Plymouth Pond and Lake Atlas, SMAST (ibid.) recommended the following method of evaluating nutrient accumulation in pond/lake sediments: *"Collecting and incubating sediment cores would allow direct measurement of nutrient regeneration across the spectrum between aerobic and anaerobic dissolved oxygen conditions, help define management strategies that reliably account for sediment inputs, and distinguish which strategies can be used to reduce them."* SMAST's recommended method has not been applied in Savery Pond. However, ACT (2012) collected sediment samples at the geographic center of the pond and at each of the two cranberry bog outfalls and analyzed for TP, "iron-bound P" and "loosely-sorbed P" (below):

[7] N:P ratios: 8/18/14 shallow sample = 19, 8/6/15 deep sample = 13, 6/22/16 deep sample = 7.
[8] ACT analyzed nitrate as TLN, ammonia and nitrate (summed in the discussion above).
[9] Deed records suggest that the West Bog dates back to at least 1913, aerial photographs confirm both bots in the 1950's, and a USGS topographic map shows both bogs in 1951,
[10] Ten houses were estimated as "affecting the pond" in 1970 (Lyons-Skwarto Associates). Currently, GIS analysis indicates that 23 parcels are developed within 300 feet of the pond.

Location	Phosphorus as P (mg/kg dry)	% solids (%)	Moisture (%)	Iron Bound P (mg/kg dry)	Loosely-sorbed P (mg/kg dry)	Total Volatile Solids (%)
SED2 -West Bog	1,170	12.8	90.6	<19.5*	<3.9*	43
SED1 - East Bog (SP03)	700	23.2	84.6	12.0	14.0	22.0
SED3 - Center (SP05)	502	28.6	81.8	<8.74*	<1.75*	17.5

* results below detection limit

ACT interpreted the results as follows: *"All samples showed above average total phosphorus results, and the two bog outfall samples were significantly higher than the sample collected at the pond's center. Loosely sorbed and iron bound portions were relatively low however in all samples, indicating that a majority of the phosphorus is either still tied up in organic forms or other inert inorganic forms. This explanation is also supported by the relatively high percentage of volatile solids in the two bog outfall samples. The methods used to determine the fractionation of phosphorus in pond sediments are still relatively new and under development and some of the processes that occur are not yet well understood. Additionally, numerous non-conformances in the procedure were reported by the lab, which unfortunately is commonly scene in this type of testing and may skew the results. In any case, the results for Savery Pond do show moderately high phosphorus content and recycling of phosphorus, whether from iron-bound forms or decaying organic matter is likely to occur at some level during summer months*."

The 1970 sampling event collected a benthos sample (date, location, laboratory and analytical method not reported) with the following analytical results:

Total P	Total N	% Solids	Total Volatile Solids
546 mg/L	3.7 mg/L	6.5	.38

4.7 POND LEVEL, GROUNDWATER LEVEL, STREAM OUTFLOW

FoEM began monitoring groundwater level in a domestic well about 400 feet north of the northern tip of Savery Pond in the summer of 2015. Monitoring was initially conducted with an automatic datalogger; however, the well plumbing did not support retrieval of the probe (discovered in August 2016). Starting in November 2016, manual depth-to-water (DTW) measurements were taken from the well, and will continue on a monthly basis. FoEM began measuring pond stage on a near-weekly basis in late September 2016. With no device to measure discharge at the pond outflow (Herring Brook), monitoring is currently limited to occasional qualitative observations of flow.

Figure 9 presents the manual pond stage and DTW measurements from the nearby well. Starting at the first well measurement in mid-August 2016, DTW exhibited a falling trend through mid-January and showed a rising trend from late-January through early March. Total groundwater variation was on the order of about one foot. Pond stage, after a 0.34-foot decline associated with harvest at the, showed a gradual (0.5-foot) rise between early-October and late-January.

Visual observations of Herring Brook in mid/late 2016 indicate negligible flow through years end (including a dry channel all the way down to State Road on 9/12/16), with some recovery in flow observed during the February 2017 thaw. Some of this low flow may be related to 2016 drought conditions. The only recorded measurement of Herring Brook discharge is 0.77 cfs sometime back in 1970 (Lyons-Skwarto Associates, 1970). Discharge to Herring Brook is expected to respond directly to pond stage and to spring inflow into the pond (largely controlled by groundwater levels). Quantitative monitoring of Herring

Brook discharge is recommended, and continued monitoring of all three parameters should help to better understand their associated hydrologic function.

It should be noted that any long-term declines in groundwater levels will reduce groundwater inflow into the pond and associated groundwater flushing, along with pond discharge to Herring Brook. Reduced freshwater flushing will increase nutrient accumulation in the pond. Relatively large-scale, consumptive groundwater withdrawals have the potential to cause this effect, as demonstrated by a U.S. Geological Survey model of the Plymouth-Carver-Kingston-Duxbury Aquifer System (Masterson et al, 2009). In addition, warmer surface temperatures will increase evapotranspiration and reduce groundwater recharge, thus causing groundwater level decline. Both warmer surface temperatures and reduced groundwater flushing will increase pond water temperatures.

4.8 BOG OUTFALL

FoEM sampled water in the East Bog outfall twice for turbidity and nutrient concentrations:

- Turbidity measurements ranged from 0.2 NTU (9/27/12) to 14 NTU (9/28/16). In addition, sampling from a pond location near the bog outfall showed a turbidity of 40 NTU (7/21/10).
- TP measurements ranged from 260 ug/L (9/27/12) to 600 ug/L (9/28/16).
- TN measurements ranged from 0.8 mg/l (9/27/12) to 1.5 mg/L (9/28/16).

The September 2016 sample occurred immediately after the harvest as the flooded bog was draining back into the pond[11]. TP in the harvest effluent had a measured concentration about 17x higher than the pond "background" concentration of 35 ug/L (as shown on **Figure 8**). The following calculations combine observed TP concentrations with the volume of pond water pumped into the bog for harvest (based on pond level monitoring discussed in Section 3.7), and suggest that adding the harvest effluent back into the pond nearly doubled the aqueous concentration of TP relative to background. The contribution of TP in pond effluent during growing-season irrigation and fertilization events is unknown, but will be estimated as part of a nutrient budget during future phases of study. The nutrient budget will also address how recent fallowing of the East Bog is likely to effect the nutrient budget.

29.4	acre pond (PPALS)
7	foot average pond depth (1970's bathymetry)
205.8	acre-feet pond volume
0.34	feet reduction in pond stage during fall harvest (FoEM gage)
10.0	acre-feet pumped for bog harvest
0.035	mg/L total phosphorus "background" concentration
1233000	liters per acre-foot
8.9	kg total P in pond
0.60	mg/L total phosphorus in bog effluent after harvest
7.4	kg total P in harvest water return
83%	increase in total P in pond after harvest

[11] The sample was immediately frozen after collection and delivered to Envirotech Laboratories 2.5 months later. Although the sample was delivered outside of its holding period for referenced analytes, the measured values are not expected to be significantly lower than concentrations at the time of sampling.

4.9 CLIMATE

Changes in annual and seasonal precipitation can affect conditions in the pond. For instance, 2016 was a drought year and reduced precipitation caused the Town of Plymouth to issue conservation requests. Droughts can persist for several years. Longer-term climatic cycles are known to exist (e.g. Atlantic multidecadal oscillation) and global climate change can affect precipitation patterns. Reduced precipitation is expected to cause reduced direct recharge to the pond and reduced groundwater levels. Reduced groundwater levels will cause reduced groundwater inflow to the pond (reduced flushing), and therefore reduced pond outflow in Herring Brook. Thus, the recent low outflow in Herring Brook (Section XX) may be partly related to the 2016 drought.

Climate change has affected atmospheric temperatures and is expected to affect the temperature of the groundwater which discharges into the pond. **Figure 10** shows long-term temperature trends for the state of Massachusetts published online by the NOAA National Climatic Data Center[12]. Maximum annual temperature, representative of summer conditions, has risen about 1.7 ^{o}F since 1975, and the National Climate Assessment suggests that average annual temperatures along the northeast seaboard will increase by 3-9 ^{o}F during the 21st century (2000-2100)[13]. A warming of groundwater and atmospheric temperature will cause a warming of pond temperature, which directly affects the potential for algal blooms in three ways: 1) biological activity (algal growth) increases with warmer temperatures, 2) chemical activity (nutrient reactions) increase with warmer temperatures, and 3) warmer water temperatures reduce aqueous dissolved oxygen, thus increasing the likelihood of anoxic conditions and associated phosphorus desorption from lakebed sediments. In addition, warmer atmospheric temperatures will cause more evapotranspiration by plants, thus reducing groundwater recharge and causing groundwater level declines. This mechanism has not been quantitatively estimated, but could be explored with the U.S. Geological Survey groundwater flow model (Masterson et al, 2009).

4.10 PLANTS AND MUSSELS

The Plymouth Pond and Lake Atlas (SMAST, 2015) recommends that plant and mussel surveys be conducted for completing individual pond assessments:

> Rooted plants and phytoplankton/algae compete for the same nutrients so the extent of one is influenced by the extent of the other. Reliable management should account for the density and areal coverage of rooted plants. Determining plant species, both rooted plants and phytoplankton, will also help to refine possible management strategies. In addition, a number of freshwater mussels are classified as endangered species by Massachusetts Natural Heritage Program and management of pond sediments, especially in ponds with significant nutrient regeneration, will have to address these species if they are present. Ponds in the Plymouth ecoregion have characteristics that favor these species, but surveys completed on Cape Cod have shown that mussels may not be present in all ponds.

A recent review of the Massachusetts Natural Heritage Program indicates that the species of freshwater mussels observed to date in Savery Pond are listed as "species of concern". Savery Pond has habitat optimal for some species of freshwater mussel (e.g. coastal plain, stream connecting pond to sea).

A 1970 plant survey performed by Lyons-Skwarto Associates (1970) provides a list of emersed and submersed aquatic plants, along with the following summary:

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[12] https://www.ncdc.noaa.gov/temp-and-precip/state-temps/
[13] https://svs.gsfc.nasa.gov//cgi-bin/details.cgi?aid=4029

> Savery Pond is a natural, warm water, spring fed, non-stratified pond with a maximum depth of 12 feet. Macrophyte population is classified as medium. Floating and emersed populations are sparse. Submersed populations are medium through 35% of the total area, the dominant species are potamogetons. Blue-green filamentous algae covered about 5 acres on plants. On the plant trophic level list it ranked 15th. Unicellular algae is present.

A 2012 plant survey (Kadis, 2012) performed by a Botanist from Arnold Arboretum lists: 6 species of floating plants; 34 species of waterfront/shore herbaceous plants; 24 species of waterfront/shore shrubs, woody vines and trees, in June 2012; and 75 species of plants "away from the pond". The survey did not include estimated areas of coverage.

5.0 RECOMMENDED NEXT STEPS

Since the Town of Plymouth's recent purchase of the East Bog, summer 2017 will be the first growing season with neither of the two bogs under commercial operation. It is therefore valuable to collect more data under this new regime. Additional data are also needed to support the Pond Assessment which will form a basis for a nutrient management plan. Recommendations for near-future monitoring activities include the following:

1. Continued profile "snapshots" of physical parameters (T, DO, Secchi) and top/bottom water-column nutrient sampling.
2. Setting up a monitoring protocol to measure pond discharge to Herring Brook. Although visual observations are helpful (e.g. at lake headwaters, or at culvert immediately downstream, or State Road crossing), quantitative flow measurements are preferred.
3. Collecting and incubating sediment cores to allow direct measurement of nutrient regeneration across the spectrum between aerobic and anaerobic dissolved oxygen conditions.
4. Evaluate potential for nutrient export from the East Bog as a result of extended seasonal flooding and possible formation of anoxic conditions in accumulated water. This could be done by measuring DO and nutrients in bog water several times over the flooded period and/or collecting a sediment core at the bog.
5. Formalize the pond-level monitoring by surveying the elevation of the staff gauge and ensuring that gauge elevation is maintained between summer seasons (i.e. compensate for drift due to pond ice).
6. Continue manual groundwater level monitoring in the existing neighboring well, identify second well for continuous (electronic) water-level monitoring, and survey wellhead elevations.
7. Perform a plant and mussel survey for the Pond.
8. Although the East Bog will be restored to wetland habitat, the West Bog will continue to be flooded for non-commercial harvest (without fertilizer applications). Begin to work with the owners of the West Bog to consider dissolved oxygen levels during harvest so that anoxic conditions (which could mobilize sediment-adsorbed nutrients) can be avoided.
9. Restoration of the East Bog to grassland habitat should consider isolating the former outfall channel from Savery Pond or performing a localized alum treatment to stabilize phosphorus adsorbed onto bottom sediments. Data suggest that the outfall has historically conveyed relatively high concentrations of nutrients to the pond; therefore, nutrient adsorption to outfall sediments may also be high. Hydrologic isolation of the outfall from the pond or stabilization of nutrient adsorp-

tion could significantly benefit the pond by limiting potential contribution of adsorbed nutrients if subjected to anoxic conditions.

DMEA, SMAST and FoEM are jointly pursuing grant funding to cover some of the monitoring activities listed above, for development of the nutrient budget, and for development of the Pond Assessment. Fund-raising remains a top priority for moving the process forward and developing mitigative solutions to address the common occurrence of algal blooms in Savery Pond.

6.0 REFERENCES

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Lyons-Skwarto Associates. 1970. *A Base Line Survey and Modified Eutrophication Index for Forty-One Ponds in Plymouth, Massachusetts*. Volumes I-V. Westwood, MA.

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SMAST, 2015. *Town of Plymouth Pond and Lake Atlas, Final Report*. Prepared by Coastal Systems Program School for Marine Science and Technology (SMAST) University of Massachusetts Dartmouth, Dated June 2015.

TMDL Solutions, 2016. *Technical Memorandum Re: Savery Pond 2016 Water Quality Monitoring.* Prepared by Ed Eichner for Town of Plymouth, Dated December 9, 2016.

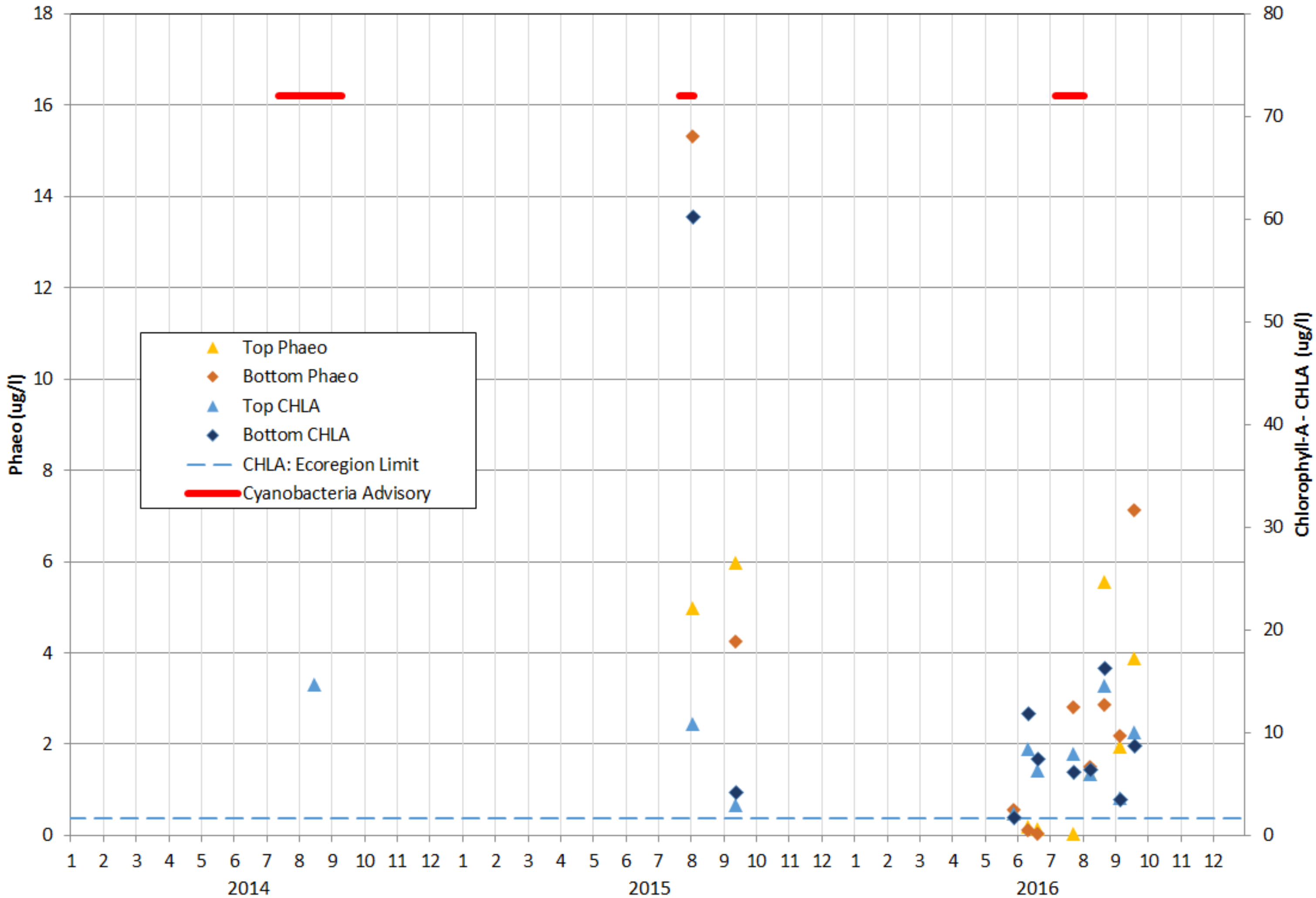


Figure 1
Chlorophyll-A and Phaeo Concentrations in Savery Pond

Savery Pond
2016 Data Summary

Friends of Ellisville Marsh, Inc.

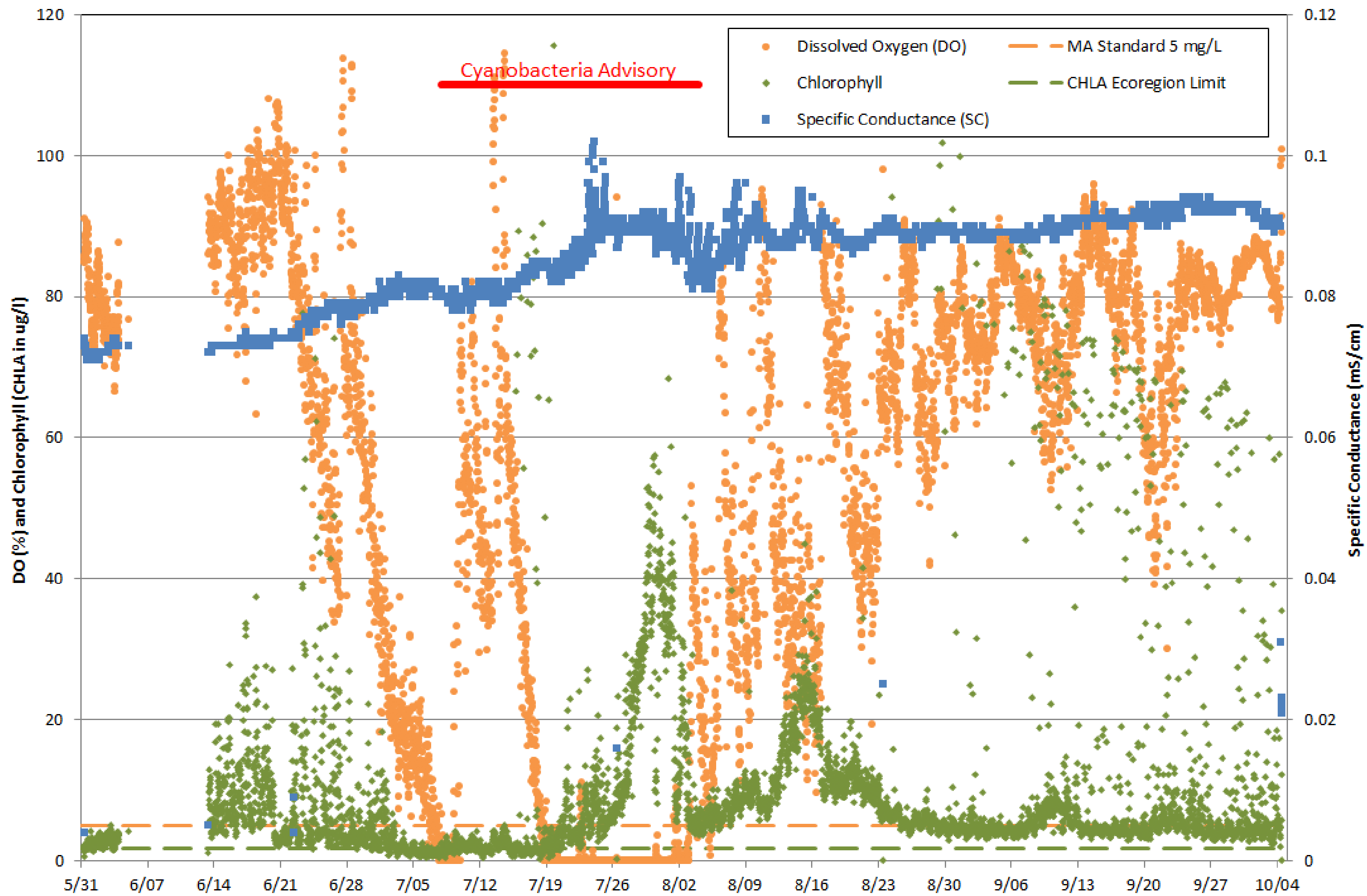


Figure 2
Summer 2016 DO, SC and Chlorophyll at Bottom of Savery Pond

Savery Pond
2016 Data Summary

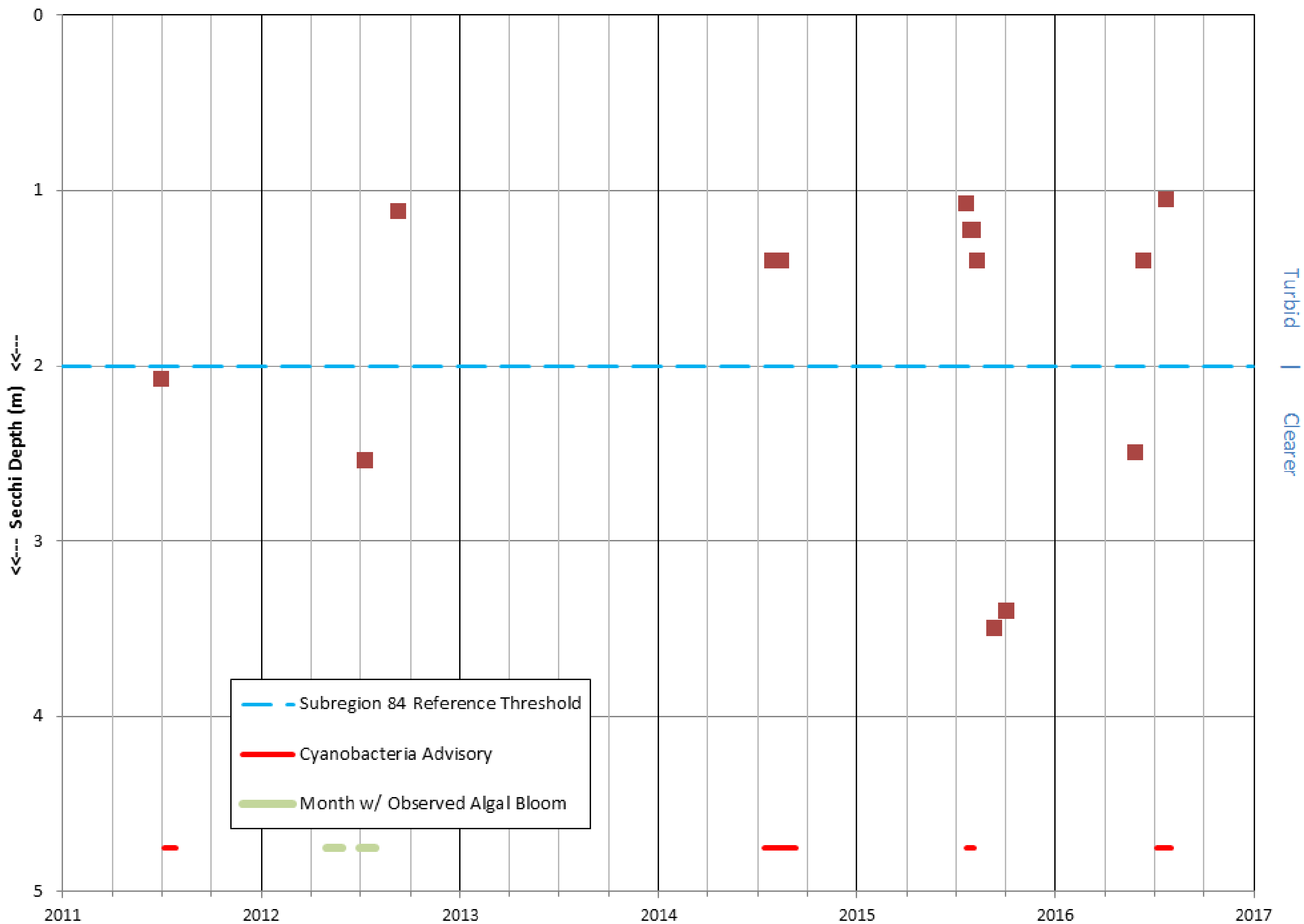


Figure 3
Secchi Disk Measurements

Savery Pond
2016 Data Summary

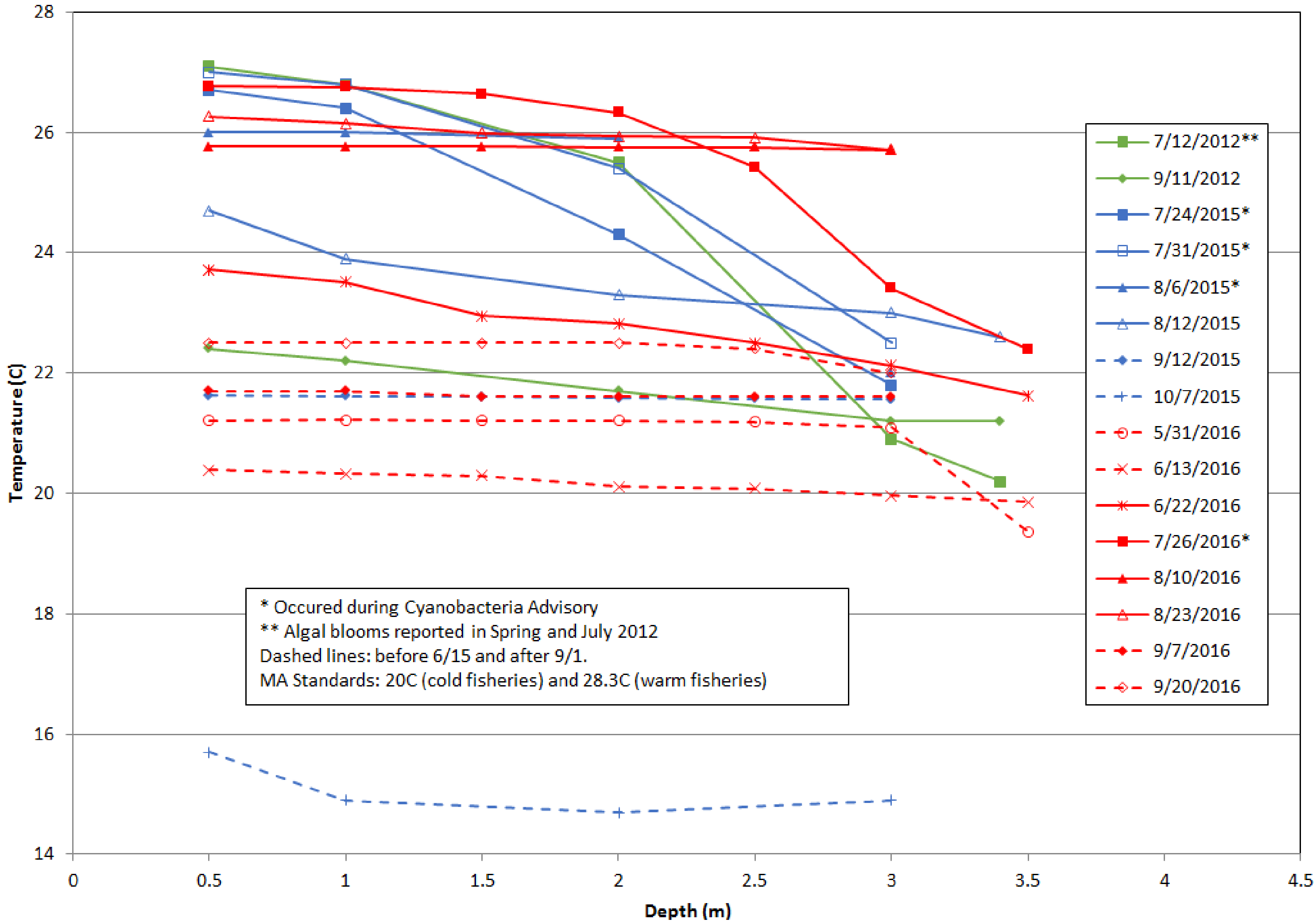


Figure 4
Temperature Profiles in Savery Pond

Savery Pond
2016 Data Summary

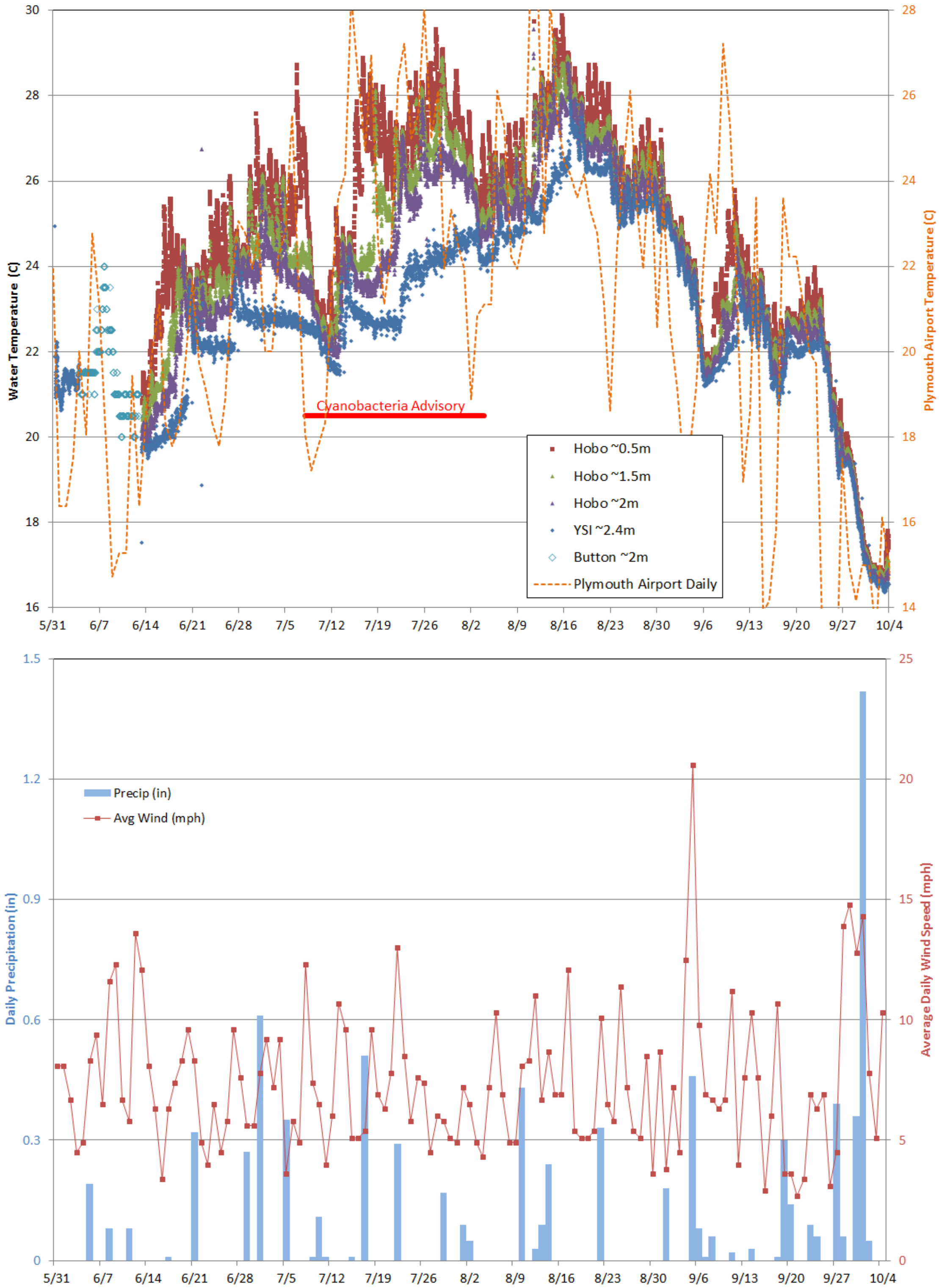


Figure 5
Summer 2016 Pond Temperature & Plymouth Airport Climate Trends

Savery Pond
2016 Data Summary

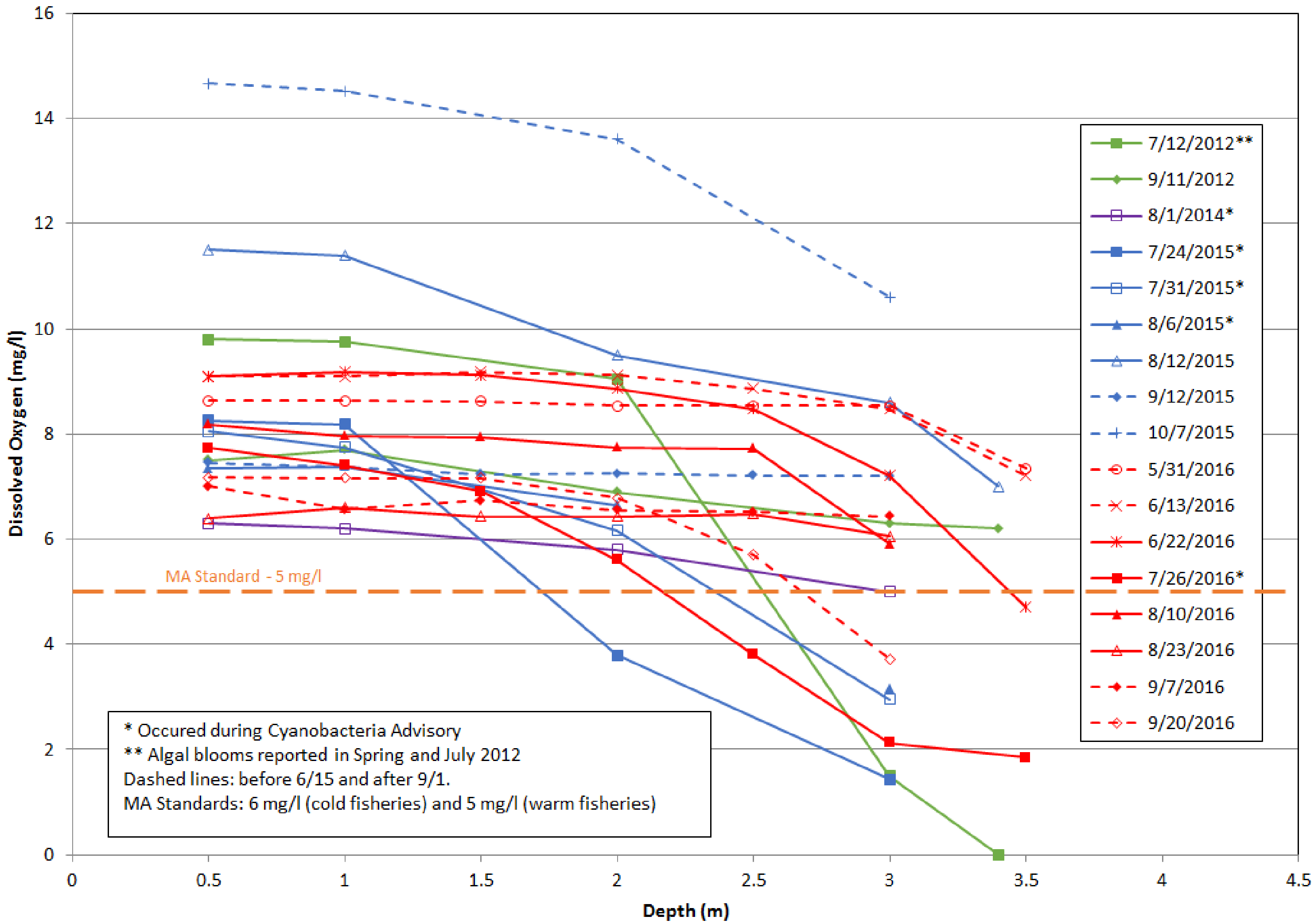


Figure 6
Dissolved Oxygen Profiles in Savery Pond

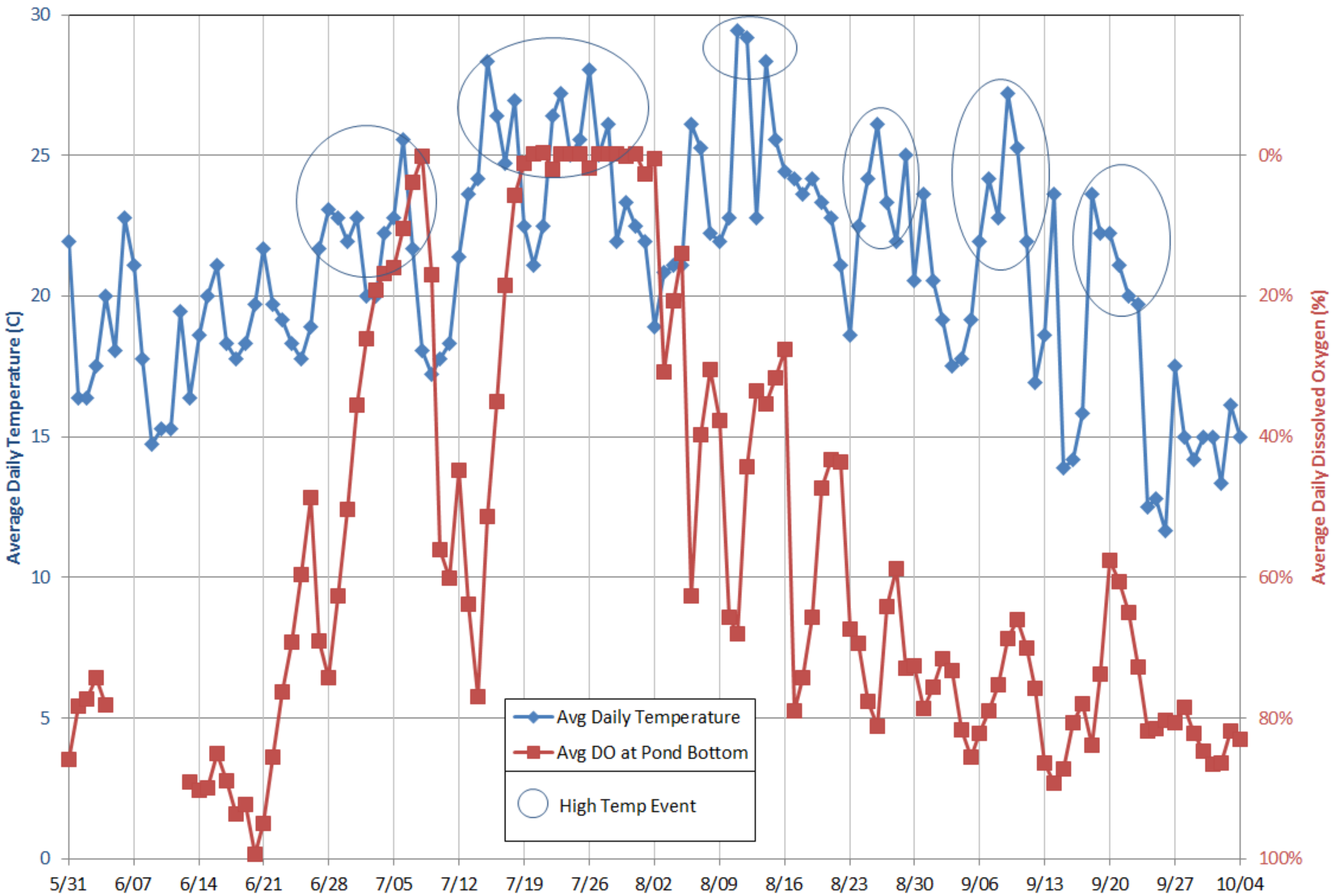


Figure 7
Summer 2016 Average Daily Plymouth Air Temperature and Pond-Bottom Dissolved Oxygen

Savery Pond
2016 Data Summary

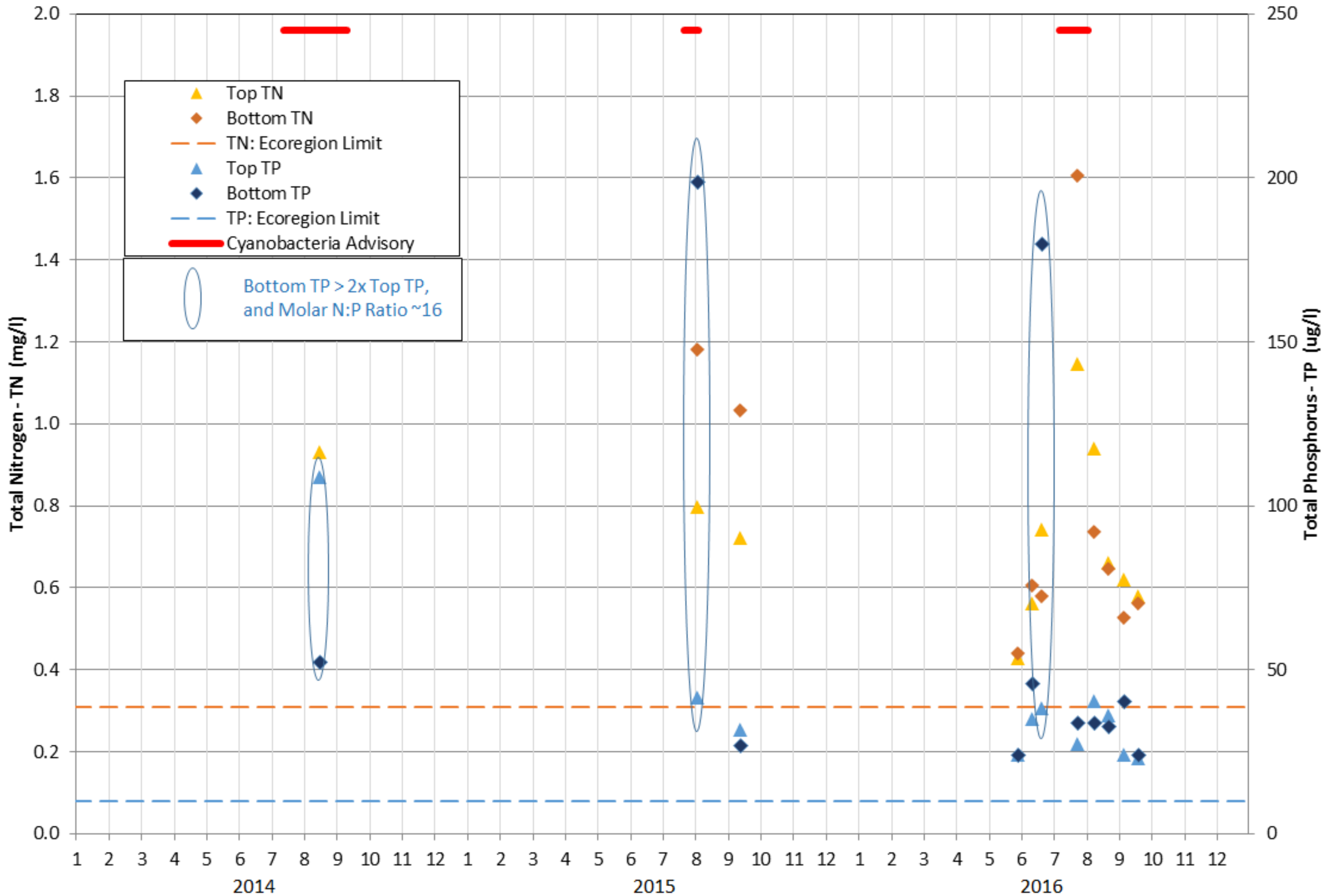


Figure 8
Nutrient Concentrations in Savery Pond (at Profile Location)

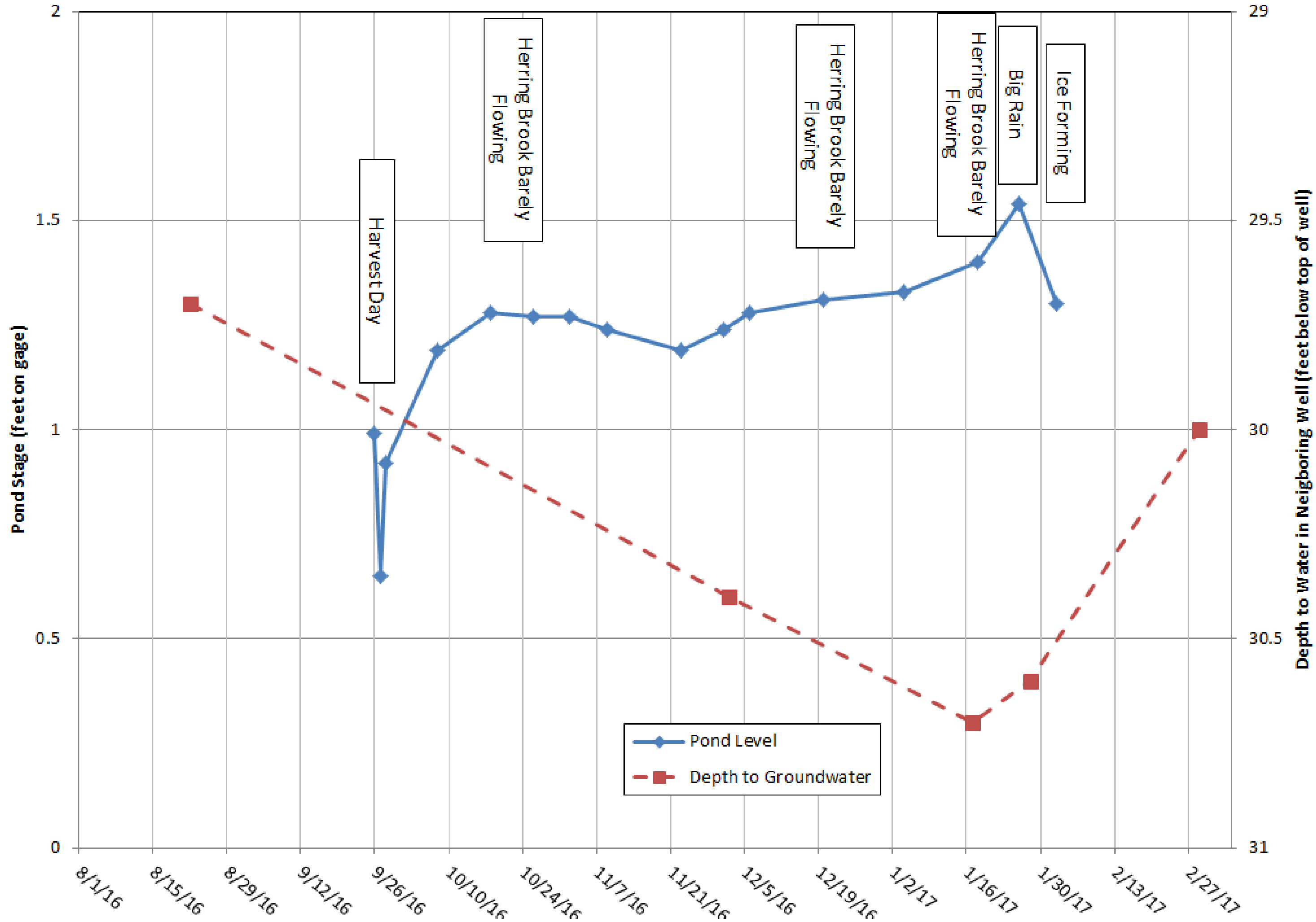
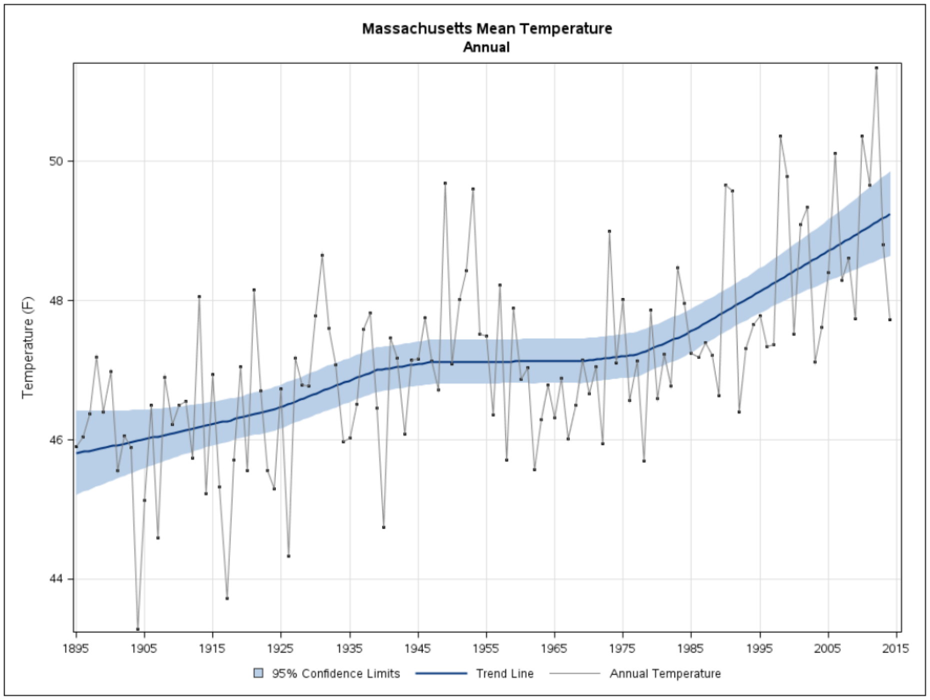
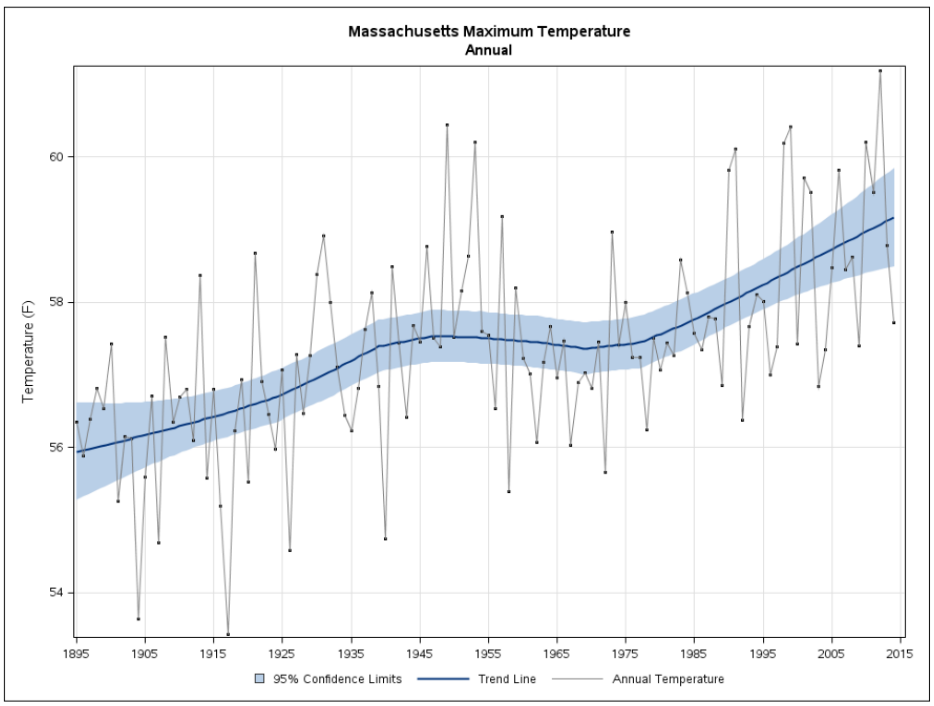


Figure 9
Water-Level Trends in Savery Pond & Neighboring Well

Savery Pond
2016 Data Summary





Reproduced from: https://www.ncdc.noaa.gov/temp-and-precip/state-temps/

Figure 10
Long Term Temperature Trends for Massachusetts

Savery Pond
2016 Data Summary

Appendix A

Miscellaneous Water-Quality Data

HISTORIC DATA - APPENDIX A IN 2012 ACT REPORT
(No data from deepest pond location (SP05)

Parameter	Date	Location	PPM
Orthophosphate	7/21/2010	SP01	0
Orthophosphate	7/21/2010	SP02 (42 Lake Rd.)	0
Orthophosphate	7/21/2010	SP03(nr. Bog outfall)	0
Orthophosphate	7/21/2010	SP04(nr. Campgrnd. B	NA
Orthophosphate	7/5/2011	SP01	0.1
Orthophosphate	7/5/2011	SP02 (42 Lake Rd.)	0.05
Orthophosphate	7/5/2011	SP03(nr. Bog outfall)	0.07
Orthophosphate	7/5/2011	SP04(nr. Campgrnd. B	0.05
Ammonia (NH3-N)	7/21/2010	SP01	0
Ammonia (NH3-N)	7/21/2010	SP02 (42 Lake Rd.)	0.01
Ammonia (NH3-N)	7/21/2010	SP03(nr. Bog outfall)	0
Ammonia (NH3-N)	7/21/2010	SP04(nr. Campgrnd. B	NA
Ammonia (NH3-N)	7/5/2011	SP01	0.3
Ammonia (NH3-N)	7/5/2011	SP01	0.8
Ammonia (NH3-N)	7/5/2011	SP02 (42 Lake Rd.)	0
Ammonia (NH3-N)	7/5/2011	SP03(nr. Bog outfall)	0.2
Total Nitrogen	5/23/1905	SP04(nr. Campgrnd. B	3.7
Temperature (C)	7/21/2010	SP01	26
Temperature (C)	7/21/2010	SP02 (42 Lake Rd.)	26.5
Temperature (C)	7/21/2010	SP03(nr. Bog outfall)	25
Temperature (C)	7/21/2010	SP04(nr. Campgrnd. B	26.5
pH	7/21/2010	SP01	8.59
pH	7/21/2010	SP02 (42 Lake Rd.)	8.21
pH	7/21/2010	SP03(nr. Bog outfall)	7.23
pH	7/21/2010	SP04(nr. Campgrnd. B	7.56
pH	7/5/2011	SP01	7.56
pH	7/5/2011	SP02 (42 Lake Rd.)	7.53
pH	7/5/2011	SP03(nr. Bog outfall)	9.21
pH	7/5/2011	SP04(nr. Campgrnd. B	9.39
TDS	7/21/2010	SP01	54
TDS	7/21/2010	SP02 (42 Lake Rd.)	53
TDS	7/21/2010	SP03(nr. Bog outfall)	53
TDS	7/21/2010	SP04(nr. Campgrnd. B	52
TDS	7/5/2011	SP01	65
TDS	7/5/2011	SP02 (42 Lake Rd.)	59
TDS	7/5/2011	SP03(nr. Bog outfall)	49
TDS	7/5/2011	SP04(nr. Campgrnd. B	49
Turbidity	7/21/2010	SP01	1.4
Turbidity	7/21/2010	SP02 (42 Lake Rd.)	1.3
Turbidity	7/21/2010	SP03(nr. Bog outfall)	39.7
Turbidity	7/21/2010	SP04(nr. Campgrnd. B	1.8
Conductivity	7/21/2010	SP01	83
Conductivity	7/21/2010	SP02 (42 Lake Rd.)	81

HISTORIC DATA - APPENDIX A IN 2012 ACT REPORT

(No data from deepest pond location (SP05)

Conductivity	7/21/2010	SP03(nr. Bog outfall)	82
Conductivity	7/21/2010	SP04(nr. Campgrnd. B	79
Conductivity	7/5/2011	SP01	98.6
Conductivity	7/5/2011	SP02 (42 Lake Rd.)	85.3
Conductivity	7/5/2011	SP03(nr. Bog outfall)	69.7
Conductivity	7/5/2011	SP04(nr. Campgrnd. B	68.9
Dissolved Oxygen	7/21/2010	SP01	7.74
Dissolved Oxygen	7/21/2010	SP02 (42 Lake Rd.)	8.13
Dissolved Oxygen	7/21/2010	SP03(nr. Bog outfall)	3.3
Dissolved Oxygen	7/21/2010	SP04(nr. Campgrnd. B	8.01
Dissolved Oxygen	7/5/2011	SP01	10
Dissolved Oxygen	7/5/2011	SP02 (42 Lake Rd.)	9
Dissolved Oxygen	7/5/2011	SP03(nr. Bog outfall)	9
Dissolved Oxygen	7/5/2011	SP04(nr. Campgrnd. B	10
Secchi	7/5/2011	SP01	DND
Secchi	7/5/2011	SP02 (42 Lake Rd.)	2.52
Secchi	7/5/2011	SP03(nr. Bog outfall)	0.0328
Secchi	7/5/2011	SP04(nr. Campgrnd. B	1.64

NOTES: NA = not analyzed, ND = not detected, NR = not reported, DND = did not disappear

DATA TABLES REPRODUCED FROM ACT STUDY (2012)

Table 5 – Composite Sampling Results (2012)

Parameter	Units	July 12th	September 11th	October 7th
pH	S.U	6.42	6.05	5.70
Alkalinity	mg CaCO3/l	5.00	6.00	3.00
Turbidity	NTU	2.60	1.50	1.00
True Color	Pt-Co	10	10	15
Apparent Color	Pt-Co	20.0	15.0	20.0
Total Phosphorus	mg/l	0.0370	<0.0100	0.0260
Dissolved Phosphorus	mg/l	<0.0100	<0.0100	<0.0100
Nitrate	mg/l	<0.100	<0.100	<0.100
Ammonia	mg/l	<0.100	<0.100	<0.100
Total Kjeldahl Nitrogen	mg/l	1.60	0.500	<0.100
Fecal Coliform	CFU/100 ml	<10	<10	NT

Table 6 – Grab Sample Results from Bog Outfall on 9/27/12

Parameter	Unit	Results
pH	S.U.	5.44
Alkalinity	mg CaCO3/l	2.50
Turbidity	NTU	0.210
True Color	Pt-Co	80
Apparent Color	Pt-Co	90.0
Total Phosphorus	mg/l	0.260
Dissolved Phosphorus	mg/l	0.260
Nitrate	mg/l	<0.100
Total Kjeldahl Nitrogen	mg/l	0.800
Ammonia	mg/l	<0.100

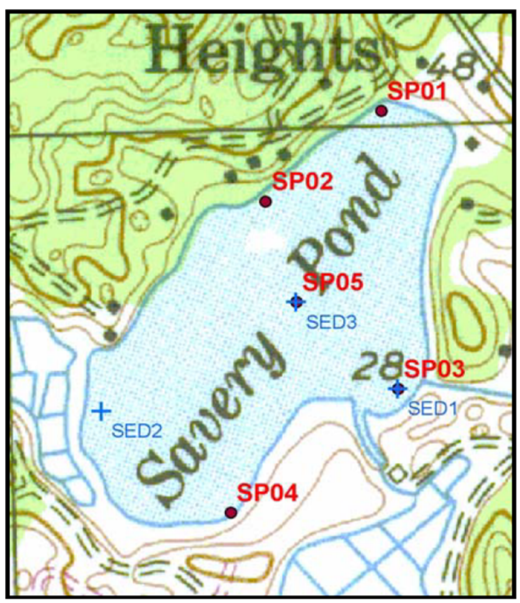


Figure 1 – Savery Pond Sampling Locations

DATA TABLES REPRODUCED FROM ACT STUDY (2012)

T able 7 – Temp/DO/pH Results

SP01

Depth (m)	July 12th		September 11th	
	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)
Surface	27.9	8.86	22.2	7.02
1	26.8	9.47	22.1	7.25
~1.5	-	-	22.0	6.30
pH (S.U.)	7.75		6.75	
Secchi	To Bottom (>2' 6")		To Bottom (>4' 8")	

SP02

Depth (m)	July 12th		September 11th	
	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)
Surface	27.3	9.42	22.1	7.08
1	26.4	9.7	21.7	7.20
2	26.1	9.23	21.6	7.30
~2.25	-	-	21.8	6.80
pH (S.U.)	7.75		6.5	
Secchi	3' 7"		To Bottom (>6' 0")	

SP03

Depth (m)	July 12th		September 11th	
	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)
Surface	27.4	9.14	22.5	7.47
1	26.0	9.42	22.3	7.50
~1.5	25.6	6.0	21.8	7.15
pH (S.U.)	7.75		6.75	
Secchi	To Bottom (>3' 0")		To Bottom (>3' 0")	

SP04

Depth (m)	July 12th		September 11th	
	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)
Surface	27.7	9.1	22.1	7.60
1	26.7	9.32	22.1	7.75
2	25.6	7.89	21.9	7.35
~2.5	25.5	6.25	21.1	6.60
pH (S.U.)	7.75		6.75	
Secchi	3' 2"		7' 6"	

SP05

Depth (m)	July 12th		September 11th	
	Temp (°C)	DO (mg/l)	Temp (°C)	DO (mg/l)
Surface	27.1	9.8	22.4	7.5
1	26.8	9.75	22.2	7.7
2	25.5	9.05	21.7	6.9
3	20.9	1.5	21.2	6.3
3.5	20.2	<1	21.2	6.15
pH (S.U.)	7.75		6.75	
Secchi	3' 8"		8' 4"	

DATA TABLES REPRODUCED FROM ACT STUDY (2012)

T able 8 – Sediment Quality Results

Location	Phosphorus as P (mg/kg dry)	% solids (%)	Moisture (%)	Iron Bound P (mg/kg dry)	Loosely-sorbed P (mg/kg dry)	Total Volatile Solids (%)
SED2 -West Bog	1,170	12.8	90.6	<19.5*	<3.9*	43
SED1 - East Bog (SP03)	700	23.2	84.6	12.0	14.0	22.0
SED3 - Center (SP05)	502	28.6	81.8	<8.74*	<1.75*	17.5

* results below detection limit

DATA FROM LYONS-SKWARTO ASSOCIATES (1970)

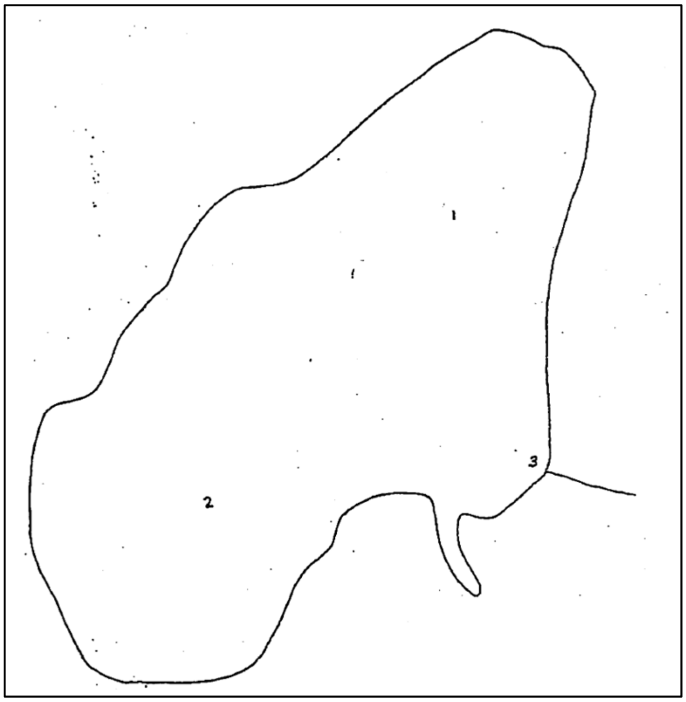
WATER ANALYSIS (mg/l)

	Pond Station			Outfall
	1	2	3	
Total P	0.02		0.02	0.02
Nitrate (N)	0.1		0.1	0.05
Free Acit	0			
Total Acidity	0			
Alkalinity	0			
DO	11			
Total Harness	16			
CO2	15			
Pn	7			
Temp (1' Levels), C	18			
Secchi (ft)	4			
Zn	0.005			
Cd	0.001			
Sn	0.01			
Au	0.001			
Fe	0.253			
PD	0.01			
Al	0.053			
Cu	0.008			
Ni	0.017			
Ag	0.008			

BENTHOS ANALYSIS (mg/l)

Total P	546
Total N	3.7
Percent Solids	6.5%
Total Volatile Solids	0.38

DATA FROM LYONS-SKWARTO ASSOCIATES (1970)



Using a modified trophic level index Savery ranks 32nd.

Savery Pond is a natural, warm water, spring fed, non-stratified pond with maximum depth of 12 feet. Macrophyte population is classified as medium. Floating and emersed populations are sparse. Submersed populations are medium throughout 35% of the total area, the dominant species are potamogetons. Blue-green filamentous algae covered about 5 acres on plants. On the plant trophic level list it ranked 15th. Unicellular algae is present. Secchi disc reading was 4 feet placing it 38th on the list in this parameter. Phosphate readings were permissable and nitrate readings were marginal.

Number of houses affecting pond: approximately 10

Cranberry bogs affecting pond: approximately 15 acres

Problem: Nitrate readings indicate large agricultural influence. This pond is rated eutrophic.