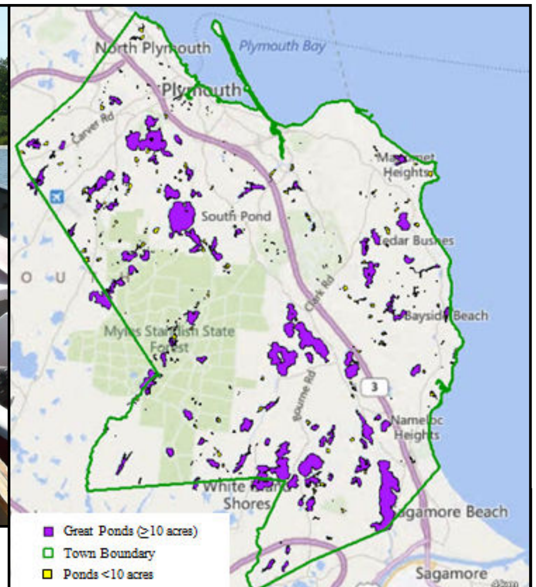
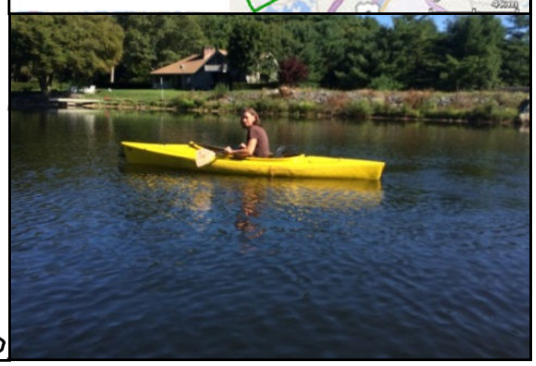
Town of Plymouth
Pond and Lake Atlas

FINAL REPORT
JUNE, 2015





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Prepared for:
Town of Plymouth
Department of Marine & Environmental Affairs

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EXECUTIVE SUMMARY

Plymouth is a town blessed with hundreds of ponds and lakes. Early histories of the town recount use of the ponds for fishing and establishment of herring runs.[1] Later developments show the use of the ponds as drinking water supplies, water sources for cranberry bogs and active management to encourage recreational fishing. In more recent times, Plymouth's ponds and lakes have become recreational centers and premium prices are paid to live near or along their shorelines. However, as populations around the ponds and lakes have increased, so have concerns about their water quality.

Plymouth has an active community of pond associations and the Town of Plymouth has made ponds and lakes a priority focus of the Department of Marine & Environmental Affairs (DMEA). In the late 1970's the Town conducted baseline water quality surveys for 41 ponds in Plymouth[2], but since then surveys have generally been limited to periodic snapshots of individual ponds. Pond and watershed associations have assisted by collecting limited data with their available resources, but inquiries and concerns from the residents of Plymouth regarding water quality of their ponds have continued to increase.

In order to begin to address resident concerns and lay the groundwork for more effective pond and lake management, the Town DMEA working in concert with the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) and the local pond associations has begun the Plymouth Pond and Lakes Stewardship (PPALS) program. The PPALS program has begun by organizing past pond water quality data, standardizing procedures for current and future sampling of all ponds, and assessing the current status of 38 selected ponds based on a unified PPALS water quality sampling effort during late summer 2014. These sampling results are included and discussed in this Atlas. This Atlas also includes a listing of all Plymouth ponds and lakes, synthesis of available past sampling data, comparison of current data to past data where possible, and assessment of the current water quality status of individual ponds. This Atlas documents the initial year of an on-going effort to engage and educate the community and provide reliable water quality data for effective management of the ponds and lakes of Plymouth.

The first step in the Plymouth PALS program was to identify all the ponds within the Town of Plymouth, gather past sampling results, and identify details to facilitate additional pond sampling. Town and CSP-SMAST staff worked together to develop a town-wide pond database, including numbering of individual ponds, review of potential sampling sites within the ponds, and confirmation of pond access. The resulting Plymouth Ponds database includes a unique number for each pond, its area, whether it has bathymetric (depth) information, the source and age of the bathymetric information, and whether it has a boat ramp.

The Plymouth Ponds database shows there are 450 ponds within the Town of Plymouth with a total combined area of 5,002 acres. Among this count, 83 ponds are greater than

[1] Thacher, J. 1835. History of the town of Plymouth, from its first settlement in 1620, to the present time. Marsh, Capen & Lyon, Boston, MA.

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

10 acres and are, therefore, Great Ponds under Massachusetts law and 130 of the ponds have assigned PALIS numbers under the MassDEP pond numbering system. Fifty-four (54) of the ponds have bathymetric/depth information, which is slightly more than the 41 bathymetric surveys completed for the initial 1970s baseline survey.[3] The largest portion of the ponds (46%) are less than 1 acre, but review of the aerial maps shows that all of these have standing water during even low groundwater conditions.[4] The pond list also includes 18 artifical ponds created after 1995; these are mostly golf course ponds although a few were created and/or expanded for use in cranberry bog operations. Review of this database indicates that basic physical information, such as bathymetry/depth data, is a significant data need for effective assessment and management of Plymouth ponds and lakes.

Working with the local pond associations, the town and CSP-SMAST worked to develop a pond sampling list for the inaugural 2014 Plymouth PALS Water Quality Snapshot. The pond sampling list was developed based on ease of access, community interest, and whether depth/bathymetric information was available. A sampling protocol was developed based on the Cape Cod PALS sampling protocol, which has been used for 13 years. The protocol and other associated sampling procedures (such as sample handling and transfers to a laboratory) were incorporated into a Plymouth PALS QAPP that was approved by MassDEP. As part of project quality assurance, the town and CSP-SMAST staff conducted a training session on the sampling protocol for the Plymouth pond volunteers.

For freshwater ponds in the Plymouth region and Cape Cod, the poorest water quality conditions generally occur in late summer, making this period the primary focus for management. Between August 15 and September 15, 2014, volunteers and town staff used the PPALS procedures to collect 104 water quality samples from 39 ponds. The collected samples were analyzed at the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth using standard procedures for the following constituents: 1) pH, 2) alkalinity, 3) chlorophyll *a*, 4) pheophytin *a*, 5) total phosphorus, and 6) total nitrogen. While samplers were at the pond, they also collected measurements of dissolved oxygen and temperature throughout the water column and water clarity.

Results from the 2014 Plymouth PALS sampling generally conform to other overviews of ponds and lakes in the ecoregion. Based on the water quality data, all of the ponds were phosphorus limited, which means that phosphorus levels are the key to water quality management. Three ponds had ratios close to nitrogen/phosphorus balance point which would suggest management control of both nutrients, but this would have to be explored in more refined, pond-specific assessments.

Total phosphorus (TP) concentrations showed that 15 of the PPALS ponds (39%) had surface levels that sufficient to cause impairment. Most of the ponds (26 of 36) have TP concentrations in their deep waters that are higher than in the surface layer and, of these, 13 have deep water concentrations that are more than twice as high as their surface concentrations. Ratios greater than two indicate significant sediment TP regeneration into the overlying water column from the sediments. Review of ponds either above or below the TP thresholds does not initially appear to be related to their location, surrounding level of development, or size. This

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

[4] Based on comparison of USGS groundwater water level monitoring in Plymouth and dates of Google Earth aerials.

finding combined with the sediment regeneration results suggests there are other factors, such as basin depth, stream inflows or historic uses, which would need to be evaluated in individual pond assessments to determine the causes of current water quality conditions.

Phytoplankton pigments were measured as an indicator of phytoplankton/algal biomass in the water column. Concentrations of phytoplankton/algae pigments generally match up with the phosphorus results, although slightly more ponds have excessive chlorophyll-*a* concentrations. Twenty (or 51%) of the PPALS ponds had phytoplankton biomass levels that are consistent with habitat impairment. The average chlorophyll-*a* concentration among all the ponds sampled in the 2014 Snapshot (3.6 µg/L) was more than twice the ecoregion threshold. If pheophytin-*a* and chlorophyll-a surface water concentrations were added, only one pond had a combined concentration less than the unimpaired reference concentration: Clam Pudding Pond. Clam Pudding Pond is surrounded by an undeveloped buffer with a width of 100 to 150 ft.

Alkalinity and pH readings generally match the slightly acidic readings expected in this ecoregion, although some pH readings are elevated due to high levels of photosynthesis or past buffering attempts. The median surface pH for the 39 Plymouth ponds measured during the 2014 Snapshot was 6.71. Collected readings also appear to be consistent with most data collected by pond associations. The median 2014 surface alkalinity was 5.9 mg/L as $CaCO_3$. Thirteen (or 32%) of the ponds had a surface pH less than the 6.5 pH, the minimum required in the state surface water regulations. This finding is expected natural condition given the geologic setting with the lack of buffering minerals in the sandy materials that form most of Plymouth.

Secchi readings generally showed reduced clarity, although there was a wide range of readings. Among the 39 ponds sampled during the 2014 Plymouth PALS Snapshot, the median Secchi reading (3.0 m) was more than half (60%) of the total depth. Five of the ponds had sufficient clarity that the Secchi disc could be seen on the pond bottom; the greatest total depth among these was 3 m. The lowest relative Secchi reading was 9% for Long Pond, which had a Secchi reading of 2.5 m over its 25.7 m deepest point. The shallowest Secchi reading among ponds where the disc was not resting on the bottom was 1.4 m, which was recorded in both Fresh Meadow Pond (total depth of 2.9 m) and Savery Pond (total depth of 3.5 m). Among the 10 ponds with the lowest relative Secchi readings (e.g., Secchi depth divided by total depth) were: Long, Great Herring, Russell Mills, Clear, Great South, and White Island West Basin.

Among the ponds with longer term Secchi readings collected by pond associations, the 2014 PPALS readings are generally a reasonable match of long-term average conditions. For example, Great Herring Pond has 16 Secchi and total depth readings collected between July 2010 and October 2013 with 10 readings collected during the greatest period of management interest (June to September). The June through September average clarity at the deepest location (GH10) was 2.31 m, which was only 22% of its total depth. The corresponding 2014 PPALS readings were 2.0 m and 16%, respectively. Both of 2014 readings were below the longer term summer averages, but were within one standard deviation, and would be considered reasonable matches with average summer conditions.

Dissolved oxygen (DO) concentrations generally showed the same number of ponds with impaired conditions as indicated in the TP concentrations. Out of the 39 ponds sampled, 14 have at least one DO concentration measurement below state regulatory limits. Six (6) of the ponds have anoxic concentrations near the sediments: Morey's Hole, Russell Mills, Round, Gunners

Exchange, Boot, and Long. Sustained anoxic conditions (DO <1 mg/L) typically cause the greatest phosphorus regeneration from pond sediments. Hypoxic conditions (less than the state DO limits) would also release phosphorus from the sediments, but the residual DO would help to suppress the amount released. Further measurements of water quality and characterization of sediments, typically through incubation of collected cores, would allow direct measurement of aerobic and anoxic phosphorus regeneration mass.

DO concentrations typically fall below state limits when excessive plant growth supplies substrate to sediment bacterial populations and their respiration increases sediment oxygen uptake. Excessive nutrients can also sustain phytoplankton populations that add DO to the water column in excess of what would otherwise exist if mixing of atmospheric oxygen was the only process occurring. These conditions result in DO concentrations more than 100% of atmospheric saturation and are also indicative of impaired water quality conditions. Six ponds had DO saturation readings >110% during the 2014 Plymouth PALS Snapshot: Billington Sea (both basins), Little Long, Forges, Gallows, Little, and Long. These ponds should be considered impaired and considered for management options.

Review of temperature data shows a wide range of different conditions. State regulations have upper limits for temperature and use a 20°C threshold as the criterion for labeling a cold water fishery. During the summer, waters of this temperature typically have to be sustained in the deeper portions of a pond. All of the surface temperatures during the 2014 Plymouth PALS Snapshot were above 20°C and eleven (11) ponds had deep temperatures below 20°C: Little Long, Forges, Russell Mills, Clear, Gunners Exchange, Fresh, Boot, Big Sandy, Little, Great South, and Long. Based on past ecoregion measurements, it would be expected that ponds greater than 9 m deep would have deep waters with temperatures less than 20°C, but some of these Plymouth ponds are very shallow and, obviously, have other factors that are influencing water column temperatures other than wind mixing and solar warming. Other factors that can cause these sorts of temperature signatures can include significant groundwater inflow, topographic protection from winds, and/or a small surface area relative to the pond depth. Further examination of each individual pond would help to clarify these results and refine the classification of these ponds as cold water or warm water fisheries for the purposes of the state surface water regulations.

Collectively, the 2014 Plymouth PALS results show a significant number of the 39 ponds surveyed have impaired conditions. Because the PPALS Snapshot data is only indicative of one year's water quality and the Snapshot is designed to assess these ponds during what is likely to be their worst water quality conditions, additional, longer term data is necessary to evaluate how representative the Snapshot data is of general ecological conditions in individual ponds. Available longer term monitoring by pond associations generally agree with the PPALS results.

Continuation of the PPALS Snapshots would allow tracking of long-term trends and eventually lead to better characterization of the water quality in these ponds, their year-to-year fluctuations, and identification of other factors necessary to develop water quality management strategies. It is clear from review of historic sampling that development of reliable management options for many of these ponds will also require targeted collection of accompanying data, such as evaluation of sediment nutrient contributions, watershed delineations, measurement of stream inflows and outflows, plant distributions, and summer-long water quality measurement. This Atlas includes brief reviews of historic monitoring for selected ponds, which generally reinforces the need to complete updated assessments in order to develop reasonable and reliable water quality management strategies.

In order to encourage and sustain the nascent Plymouth PALS program, the following are recommended as future steps:

1. Continue to support pond association and annual PPALS Snapshot monitoring, including adequate sampling equipment, regular volunteer training, and review and feedback on sampling results.
2. Review and adjust association monitoring strategies to more efficient and integrated with management strategy development
3. Begin to develop targeted data necessary for individual pond assessments, including bathymetry, stream flows, sediment characterization, and plant and mussel surveys. Data collection could be developed in the context of individual pond assessments or through collection of one characteristic for multiple ponds (*e.g.,* bathymetry for all Great Ponds).
4. Begin to prioritize the completion of pond assessments and water quality management planning.

ACKNOWLEGEMENTS

The authors acknowledge the contributions of the many individuals who have worked tirelessly for the restoration and protection of Plymouth Ponds. Without these stewards and their efforts, this project would not have been possible.

In particular, we would like to recognize and applaud the commitment shown by the Town of Plymouth in carrying forward with the Plymouth Pond and Lake Stewards program as part of their commitment to the restoration of all the ponds within the Town of Plymouth. Significant time and attention has been dedicated to this effort by Kim Tower and David Gould, whose support has been instrumental to completion of this Atlas and the 2014 PPALS Snapshot. Equally important has been the volunteer support provided by the town's many pond associations including Herring Ponds Watershed Association, Billington Sea Watershed Association, Six Ponds Improvement Association, White Island Ponds Conservation Alliance, Sands of White Horse Beach Association, Southeastern Massachusetts Pine Barren Alliance and Friends of Ellisville Marsh.

In addition to local contributions, we are also thankful the assistance and long hours in the field and laboratory spent by CSP-SMAST staff, including Jen Benson, Michael Bartlett, and Dahlia Medieros, and interns and students within the Coastal Systems Program at SMAST-UMD.

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I. Introduction

Plymouth is a town blessed with hundreds of ponds and lakes. Early histories of the town recount use of the ponds for fishing and establishment of herring runs.[5] Later developments show the use of the ponds as drinking water supplies, water sources for cranberry bogs and active management to encourage recreational fishing. In more recent times, Plymouth's ponds and lakes have become recreational centers and premium prices are paid to live near or along their shorelines. However, recently as populations around the ponds and lakes have increased, so have concerns about their water quality.

Generally, these lakes and ponds are depressions left in the land surface after the glaciers from the last Ice Age slowly moved north approximately 12,000 years ago. In addition, these glaciers occasionally left large chunks of ice as they retreated. These chunks were surrounded and covered by the sands carried by the glacial meltwater as it flowed from the edges of the glaciers. As these ice chunks melted, the landscape above them collapsed forming large depressions called "kettle holes". As water levels began to rise as the glaciers melted, the Plymouth/Carver aquifer system developed and these kettle hole depressions filled with groundwater and created the hundreds of ponds and lakes that Plymouth enjoys today.

Typical kettlehole ponds or lakes lack streams flowing into or out of them, but there are a wide variety of pond configurations in Plymouth. Kettlehole ponds are replenished by steady inflow and outflow of groundwater along their sandy shorelines. These pond surfaces generally fluctuate up and down in response to the seasonal rise and fall of the water table. In ponds with outflowing streams, large portions of watershed inflow can follow this path of least resistance with groundwater outflow becoming a more minor component. But even this can vary from season to season or year to year depending on the size of the outflow or if it is controlled by boards for herring fisheries, cranberry bogs, or desired pond levels.

Plymouth has an active community of pond associations and the Town has made ponds and lakes a priority focus of the Department of Marine & Environmental Affairs (DMEA). In the late 1970's the Town conducted baseline water quality surveys for 41 ponds in Plymouth[6], but have been limited to periodic snapshots of individual ponds since then. Pond and watershed associations have assisted by collecting limited data with their available resources, but inquiries and concerns from the residents of Plymouth regarding water quality of their ponds have continued to grow.

In order to begin to address resident concerns and lay the groundwork for more effective pond and lake management, the Town DMEA working in concert with the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) has begun the Plymouth Pond and Lakes Stewardship (PPALS) program. The PPALS program has begun by organizing past pond water quality data, formalizing procedures for current and future sampling of all ponds, and assessing the current status of 39 ponds based on a unified PPALS sampling during the late summer of 2014. Sampling was coordinated with a

[5] Thacher, J. 1835. History of the town of Plymouth, from its first settlement in 1620, to the present time. Marsh, Capen & Lyon, Boston, MA.

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

number of local pond associations, town staff and SMAST staff. These sampling results are included and discussed in this Atlas. This Atlas also includes a listing of all Plymouth ponds and lakes, synthesis of available past sampling data, comparison of current and past data, and a preliminary assessment of the current water quality status of individual ponds. This Atlas documents the initial year of an on-going effort to engage and educate the community and provide reliable water quality data for effective management of the ponds and lakes of Plymouth.

A. How ponds function

Lake and pond ecosystems are controlled by interactions among physical features and internal chemical interactions. Physical features include the surface area and shape of the lake, surrounding topography, bathymetry, and watershed size. Chemical interactions occur between and among the plants and animals in the lake and the sediments, water, and constituents in the water. Outside factors such as strength and direction of wind, air and water temperature, groundwater and surface water inflows and outflows, and extent of surrounding development also play important roles in how a given ecosystem functions.

The ecosystems of Plymouth ponds and lakes change throughout the seasons of the year and from year to year depending on all of the factors above, but temperature changes are a key factor for every pond and especially for deeper ponds. Beginning in early spring, air and water temperatures begin to rise as the days become longer. If the winds are strong enough to keep the lake well mixed, the warming of the water is consistent and the same temperature can be measured throughout the water column.

In deeper ponds, the process is more complex and leads to temperature layering or stratification. In these ponds, surface warming during the late spring or early summer becomes too rapid at some point for winds to maintain water column mixing and cooler bottom waters become separated from warmer upper waters. This upper layer of water is called the epilimnion and can usually reach between 24 and 27°C (75 to 80°F). The cooler, bottom waters generally maintain a temperature close to the overall temperature of the lake just prior to the onset of stratification (usually 10 to 15°C or 50 to 60°F). This lower layer is called the hypolimnion. The transition zone between these two layers, where temperature changes rapidly with changes in depth, is called the metalimnion (Figure 1). This process reverses itself in the fall. Monitoring throughout the region shows that this layering generally occurs in ponds that are 9 meters or deeper.

The features of a pond, including its stratification often play a large role in determining the variety of species within a pond or lake. Cooler waters can hold more dissolved oxygen, so fish such as trout, which require high oxygen and cooler temperatures, usually require a cool summer hypolimnion in order to have a sustainable year-round population. Warmer waters in both stratified and unstratified lakes generally support fish such as bass, perch, or bluegills. Pond bottom sediments are rich in nutrients and usually support catfish and other bottom feeding fish, as well as invertebrates living in the sediments. Since rooted aquatic plants and floating algae need light for photosynthesis, water clarity plays an important role in where these plants will be found.

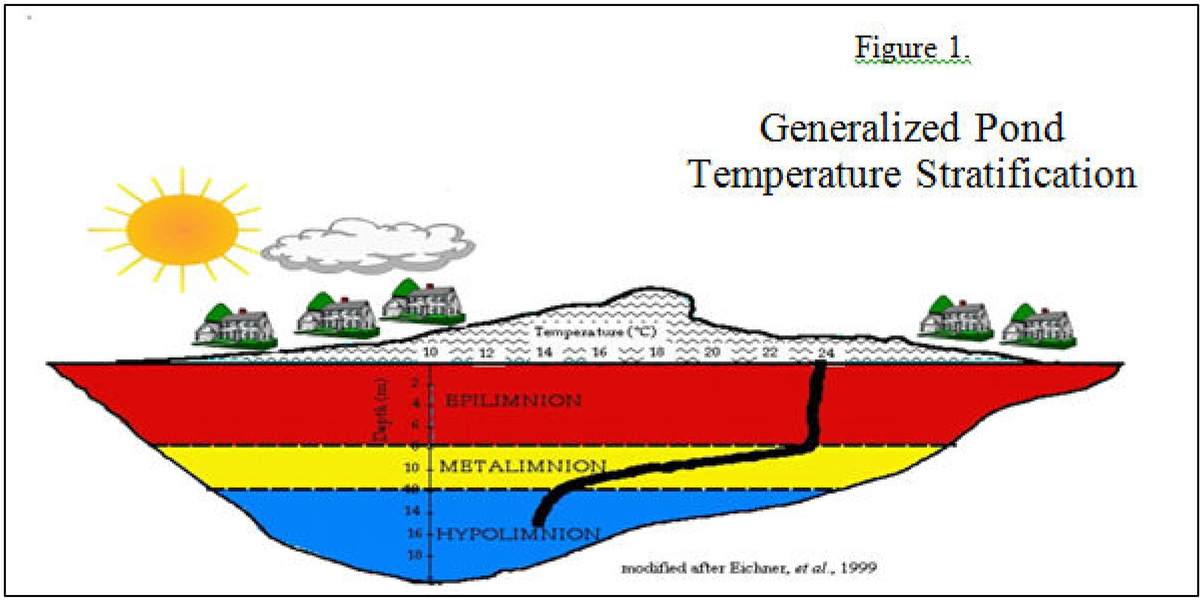


Figure 1.
Generalized Pond Temperature Stratification

Although temperature is a key determinant in the amount of oxygen dissolved in lake water, some lakes will have low oxygen conditions in their deeper, cooler waters. This condition occurs because there is so much organic material (*e.g.*, dead algae or other plant material) in the sediments of the lake, that the bacteria population decomposing or breaking down the material takes oxygen out of bottom waters faster than it can be resupplied from waters above. If there are sufficient organic materials in the pond, bacterial respiration in the sediments can remove virtually all of the dissolved oxygen and create anoxic conditions.

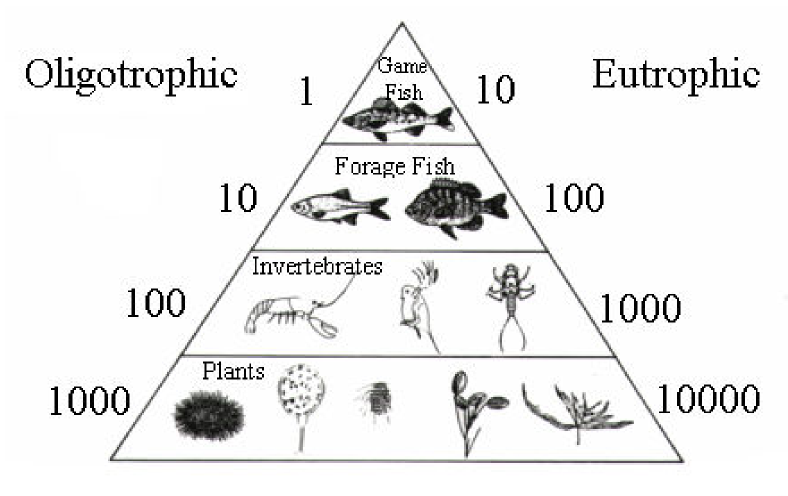
This loss of oxygen impacts the fisheries and can add sediment nutrients into the pond water to the pond. Since fish also need oxygen from the water, low oxygen or hypoxic conditions will cause them to swim to areas where oxygen is more plentiful. However, if they are a cool water fish, like trout, their habitat effectively disappears with the loss of oxygen from the colder bottom waters. If anoxic or very low oxygen conditions develop rapidly, all the fish in that portion of the lake can be killed (*i.e.*, a "fish kill"). Anoxic or hypoxic conditions can occur in any lake, regardless of depth. Shallow lakes can have well mixed conditions with regular replenishment of oxygen through mixing of surface waters with surrounding air, but even in these ponds, if the organic load in the sediments is sufficient, oxygen concentrations can be low. 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.

Plants in ponds are generally the predominant source of organic sediment materials, both as free-floating algae (or phytoplankton) and/or rooted aquatic plants (or macrophytes). As the population of plants grows and dies over a series of years, the leftover plant material or detritus falls to the bottom of ponds and is degraded by bacteria. This material usually gathers in the deepest portions of pond and continues to degrade. The accumulation of this material forms the sediments. In ponds with stream inputs, the streams can also be sources of sediment materials.

The plants in ponds grow based on the amount of nutrients available to them. Nutrients enter ponds from their watershed; mostly from the properties abutting the pond, but also from stream inflows. Watersheds can be expanded by stormwater structures on nearby roads or parking areas that pipe stormwater runoff and accompanying nutrients into the nearshore areas or directly to the pond. As discussed, nutrients can also be added from sediment regeneration.

Since available nutrients determine the amount of plant growth in a pond and plants form the base of ecosystems, the amount and types of plants generally determines the total amount of other organisms within a pond. The total weight or mass of all organisms in a lake is usually characterized as the lake's trophic status and is often related to the amount of a key nutrient, like phosphorus (Figure 2). Lakes are often grouped into categories based on how much plant growth is occurring. Oligotrophic lakes have low nutrient inputs and consequently have relatively little plant growth. Eutrophic lakes have higher nutrient inputs and significantly more plant growth. Scientists have used water quality monitoring information (*e.g.*, nutrient concentrations, clarity measurements, etc.) to establish ranges for various measurements that correspond to these trophic categories. Some of these classification schemes have included additional labels, such as mesotrophic (*i.e.*, middle trophic, between oligotrophic and eutrophic) or hypereutrophic (*i.e.*, more than eutrophic).

Figure 2. Relative Phosphorus Mass at Lake Trophic Levels



Modified after McComas (1993)

Ponds with more nutrients will generally support more diverse ecosystems up to a point, which generally mean more varieties of plants, fish, and other animals. However, if too many nutrients are added, the conditions can preclude certain species from growing in their preferred portion of a pond and cause diversity to decline. One example previously mentioned is that trout prefer colder waters found in the hypolimnion of stratified lakes, but too many nutrients can produce too much decaying plant matter in the sediments and lead to anoxic conditions in the trout's primary habitat. In this case, the nutrients levels have crossed a threshold and created conditions that have excluded trout from their usual habitat.

Phosphorus is the key nutrient in ponds and lakes because it is usually more limited in freshwater systems than nitrogen. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1 P:7 N:40 C per 500 wet weight[7]. Therefore, if the other constituents are present in excess, phosphorus, as the limiting nutrient can theoretically produce 500 times its weight in algae. Because it is more limited, 90% or more of the phosphorus is bound up in plant and animal tissue or their wastes and any available inorganic phosphorus (mostly orthophosphate (PO_4^{-3})) is quickly reused by the biota in the lake. Much research has been directed towards trying to determine the most important phosphorus pool for determining the overall productivity of lake ecosystems, but to date most of the work has found that a measure of total phosphorus is the best predictor of productivity of lake ecosystems.[8]

While Plymouth pond ecosystems are similar to pond ecosystems seen in other parts of the country, there are features of these systems that are somewhat unique. First, Plymouth ponds tend to be naturally acidic with low pH.[9] Because the Plymouth-Carver aquifer is largely composed of sand, there are no carbonate-based rocks (*e.g.*, limestone) available to provide carbonate to buffer the natural acidity of rainwater. Rain water in equilibrium with the carbon dioxide in the atmosphere has a naturally acidic pH of 5.65. This precipitation recharging the aquifer may pick up some buffering capacity as it moves through the root zone of plants; monitoring of background pH in groundwater on Cape Cod, which has a similar aquifer system, found a median pH of 6.1.[10] The plants and animals in and around Plymouth ponds have developed in this low pH, acidic environment.

Water level fluctuations are another feature of Plymouth ponds that is somewhat unique. Because water levels in kettlehole ponds tend to be reflective of the surrounding groundwater water table, the water level in the pond will fluctuate based on seasonal and annual precipitation trends. Review of water levels in Plymouth has shown fluctuations of up to 8 ft.[11] Reviews of water levels in the similar Cape Cod aquifer system have shown higher fluctuations toward the interior and a gradual decline in fluctuations as one moves closer toward the coast.[12] These water level fluctuations create a series of habitats and plant assemblages that are common for these types of lakes, but these types of lakes are only found in select areas along the near coastal areas of the eastern United States and Canada (collectively known as the Atlantic Coastal Plain). For example, the Plymouth gentian (*Sabatia kennedyana*) is relatively common among these ponds, mostly in New England, while the New England Boneset (*Eupatorium novae-angliae*) is only found in ponds in Plymouth, southern Rhode Island, and Cape Cod.[13]

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[7] Wetzel, R. G. 1983. *Limnology*. Second Edition. CBS College Publishing, New York, NY.

[8] Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Paris, Rep. OECD, DAS/CSI/68.27.

[9] pH is a measure of hydrogen ion concentration; measures above 7 are basic, measures below 7 are acidic

[10] Frimpter, M.H. and F.B. Gay. 1979. Chemical Quality of Ground Water on Cape Cod, Massachusetts. Water Resources Investigations 79-65. US Geological Survey. Boston, MA.

[11] Masterson, J.P., Carlson, C.S., and Walter, D.A., 2009, Hydrogeology and simulation of groundwater flow in the Plymouth-Carver-Kingston-Duxbury aquifer system, southeastern Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5063, 110 p.

[12] Frimpter, M.H. and G.C. Belfit. Estimation of High Ground-Water Levels for Construction and Land Use Planning, A Cape Cod, Massachusetts, Example – Updated 2006. Cape Cod Commission Technical Bulletin 92-001. Prepared in Cooperation with the U.S. Geological Survey, Water Resources Division. Barnstable, MA.

[13] US Department of Agriculture, Natural Resources Conservation Service, Plants Database. Plants.usda.gov.

B. How do we use and manage ponds

Over the years, the ecosystems of many of southeastern Massachusetts ponds have been altered in either planned or unplanned ways by human activities. These alterations have included the enhancement or creation of herring runs, construction of spillways, weirs, or dams to try to control water levels or power mills, removal of water for cranberry bog operations, addition of trout, bass or other fish by agencies and/or individuals to create a population for fishing, construction of public water supply wells near ponds that alter how water levels fluctuate, and the increased addition of nutrients from houses and roads built close to ponds. The ecosystems have adapted to these changes, but often pondshore residents and other users of the ponds have not been pleased with the adaptations.

Over the past few years, more attention has been focused on pond issues, largely one would assume because more people are choosing to live closer to ponds and have expectations about the conditions in their nearby pond. Local newspapers have described concerns over harmful algal blooms, rising and falling water levels, and fish kills. Public debates have also included discussions about permitting of public drinking water supply and golf course irrigation wells and their impact on nearby pond levels and conflicts between swimmers and watercraft users. These debates have in turn often led to the creation of watershed or pond associations by concerned citizens and subsequent management action by a town or state agency to resolve the issues of concern.

In order to understand what management options can be used on ponds, some understanding of the legal issues surrounding some of the options is necessary. Ponds greater than 10 acres are "waters of the Commonwealth of Massachusetts" and, therefore, are publicly owned under Massachusetts Law.[14] Because these ponds are public resources, substantial activities on, in, or near them, including adopting local bylaws, generally require some sort of public notice and discussion by or among government agencies, like a local conservation commission and/or state agency. For example, the building of a new permanent dock requires a Chapter 91 license from the local conservation commission, but depending on the impact, the proposed dock could also be reviewed by the MassDEP. This regulatory requirement for public participation in the review of proposed pond changes to characteristics (*e.g.*, pond levels) or use (*e.g.*, horsepower limitations on watercraft) generally ensures that current decisions regarding pond management are subject to public discussion.

Pond water quality is also a current management concern expressed through law and associated regulations. Massachusetts maintains regulatory standards for all of its surface waters.[15] These regulations include <u>numeric</u> standards for dissolved oxygen, pH, temperature, and bacteria, as well as <u>descriptive</u> standards for various classes of waters that largely depend on their use. For example, Class A waters are used for drinking water and "are designated as excellent habitat for fish, other aquatic life and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation,

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[14] Massachusetts General Law, Ch. 131, sec. 1 specifies all ponds greater than 10 acres are "Great Ponds" and all Great Ponds are "waters of the Commonwealth" and, as such, are publicly owned.

[15] 314 CMR 4.00 (CMR = Code of Massachusetts Regulations)

even if not allowed. These waters shall have excellent aesthetic value."[16] Further distinctions are made between warm and cold water fisheries.

Class B waters, which are generally freshwater ponds not used for drinking water supplies, must meet the following numeric standards:

a) dissolved oxygen shall not be less than 5.0 mg/L,
b) temperature shall not exceed 83°F (28.3°C),
c) pH shall be in the range of 6.5 to 8.3, and
d) bacteria shall not exceed 235 colonies per 100 ml at bathing beaches (with variations available for multiple samples).

The descriptive standards for Class B waters are "designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and for primary and secondary contact recreation. Where designated in 314 CMR 4.06, they shall be suitable as a source of public water supply with appropriate treatment ("Treated Water Supply"). Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value."[17]

Under the federal Clean Water Act, surface waters failing to attain state surface water standards are considered impaired. Impaired waters are required under the Clean Water Act to have a maximum concentration or load limit defined for the contaminant causing the impairment.[18] This limit is labeled as a Total Maximum Daily Load or TMDL. States are required to list all waters that are impaired as part of an Integrated List of Waters, which must be updated and approved by the Environmental Protection Agency (EPA) ever two years. This list includes a listing of all waters in the state and their status, including whether their water quality has been assessed and whether they have been judged impaired. The latest list from Massachusetts was the 2012 list and it included the listing of Plymouth ponds shown in Table 1.[19] This list reinforces the need for updated water quality data since 55% of the listed ponds have not been assessed and, therefore, do not have sufficient data to support assessment or management.

The current regulatory structure in many ways, however, is primarily addressing legacy management decisions, whether active or inadvertent, that occurred long before the current system was developed. For example, past road designs often directed stormwater runoff into ponds because they were at the lowest elevation point, septic systems were placed too close to ponds or homeowners destroyed all natural pondshore vegetation in order to expand lawns or improve access to the pond. Much of the current concerns raised about ponds in southeastern Massachusetts, especially in the area of water quality, are the result of impacts caused by decisions made during the past 50 years.

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[16] 314 CMR 4.05(3)(a)

[17] 314 CMR 4.05(3)(b)

[18] 40 CFR 130.7 (CFR = Code of Federal Regulations)

[19] Massachusetts Department of Environmental Protection. March, 2013. Massachusetts Year 2012 Integrated List of Waters, Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act. MassDEP, Division of Watershed Management, Watershed Planning Program. Worcester, MA.

As the study of lakes has advanced, science has provided details about the impacts of these decisions and, more importantly, translation of these understandings into activities to restore and prevent future impairments of lake ecosystems. Examples have included local bylaws requiring naturally vegetated buffers to decrease nutrient-laden stormwater or lawn runoff or the addition of alum or other sequestering agents to prevent internal regeneration of collected nutrients from pond sediments. Plant harvesters have been developed to remove excessive growth of aquatic vegetation and their associated nutrients which would be released as they decay within the pond. Chemists have developed herbicides that target specific invasive plant species. Massachusetts has recently signed a law to restrict the application of phosphorus in turf fertilizers and is in the midst of preparing draft regulations.[20] Targeted use of these lake management techniques has begun to reverse the impacts of past decisions.

Table 1. **Massachusetts Department of Environmental Protection water quality condition of Plymouth Ponds.** Based on approved 2012 Integrated List of Waters.

category	Integrated List category description	Number of Plymouth ponds	Selected Plymouth ponds in listed category
1	Waters attaining all designated uses	0	No waters in MA
2	Attaining some uses; other uses not assessed	12	Charge, College, Curlew
3	No uses assessed	31	Ezekiel, Kings, Little Long, Triangle
4a	TMDL is completed	3	White Island (East and West Basin) (nutrients), Great Herring (mercury in fish tissue), Great South (mercury in fish tissue)
4b	Impairment controlled by alternative pollution control requirements	0	No waters in MA
4c	Impairment not caused by a pollutant – TMDL not required	8	Long Island, Cooks, Federal (most "non-native aquatic plants")
5	Waters requiring a TMDL	2	Billington Sea, Russell Millpond
	TOTAL number listed	56	

Although certain management activities are consistent from one pond to the next, identification of the source of water quality problems and selection of the best/lowest cost management options begins with having an adequate understanding of the specific pond ecosystem. Characterizing a pond ecosystem typically includes completing a watershed delineation, sufficient measurement of surface water inputs or outputs, determining the pond volume/bathymetry, measuring water quality over the course of a year or several seasons, and measuring sediment nutrient content and nutrient release, if indicated by other measures. Many of these activities can benefit from trained volunteer help, but a clear overall strategy and goals need to be developed by professionals to ensure that available funding is used efficiently.

[20] 330 CMR 31.00.

Additional requirements may need to be addressed if data will be used in regulatory settings. Funding for these types of activities usually are provided from public sources, including towns and the state agencies such as MassDEP (*e.g.*, 604(b) Program, 319 Program, and 104(b)(3) Program). The listed MassDEP programs are all federal funds directed to DEP for administration of the Clean Water Act. Most the individual lake assessments completed in Plymouth were funded under Section 314 of the Clean Water Act, which was funded during the 1980's, but currently does not have a budget at the federal level.

Lake assessments may be completed to address any number of problems. Aside from water quality issues, there are a number of other management issues that are somewhat related, but often have their own special concerns. Three of these other issues are briefly discussed below.

1. Land Use

As the study of lakes and their water quality has advanced, the impact of nearby land uses on pond water quality has been clearly established. The results of these studies show that in settings like those in Plymouth benefit from the sand that surrounds most of the town ponds. Sand contains grains with iron coating that chemically binds phosphorus, so phosphorus loads coming from septic systems, lawns, and runoff are naturally filtered and move at a very slow rate (*e.g.*, 20-30 years to travel 300 feet[21]) toward pond shorelines. However, if the phosphorus flows directly into a lake, either overland or when collected and discharged from stormwater pipes, the natural filtering is avoided and the impact is more substantial. These findings mean that pond assessments of watershed phosphorus loads should generally focus on phosphorus additions from parcels directly abutting the pond, as well as any stormwater or wastewater pipes that might discharge loads directly into the pond.

In order to mitigate these issues, a number of standard recommendations have been made regarding nearshore phosphorus management activities, including a) setbacks for septic system leachfields, b) maintaining pondshore buffers with natural vegetation, c) limiting lawn fertilizer applications, and d) infiltrating stormwater runoff. For example, the federal Clean Lakes Program recommended a 100 meter setback for leachfields to minimize phosphorus transport to ponds within usual septic system design lifetimes. Some communities in southeastern Massachusetts (*e.g.*, Brewster) have adopted local Board of Health regulations to require maximum possible septic system leachfield setbacks for pondshore properties. Also, as previously mentioned, Massachusetts approved a law limiting phosphorus fertilizer applications. The Massachusetts Wetlands Protection Act, which is administered through town Conservation Commissions also provides towns with the authority to regulate activities within 100 feet of any pond. MassDEP has adopted a stormwater design policy, which includes best management practices for municipalities, and towns have been encouraging MassHighway to address runoff to surface waters on state roads. Figure 3 shows examples of good and poor shoreline landscaping practices that will minimize direct overland discharge directly into ponds.

Together, these land use management practices have led to greater protection of pond water quality, but one of the on-going challenges for many ponds is dealing with legacy nutrient

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[21] Robertson, W.D. 2008. Irreversible Phosphorus Sorption in Septic System Plumes? *Ground Water*. 46(1): 51-60.

loads. In many towns, regulations have been updated and motivated pondshore owners have adjusted their land uses, but water quality has not improved because of the combined impacts of past land uses, existing development, and the natural function of ponds to retain and recycle nutrients in their sediments. Assessment of current loads should include sediment testing to ensure that management strategies achieve the water quality goals that are desired.

In order to organize and facilitate discussion of management options and an evaluation of their costs and benefits, communities often develop pond management plans. These plans usually include an assessment of each pond that develops a reasonable understanding of the causes of its water quality problems. This assessment is then used to establish and review options that could be taken in or around the pond in order to meet community goals. Costs are developed for a set of the options and a preferred set of options is recommended that will attain the water quality goals for the pond. Development of these plans allows communities to make informed decisions about management of their pond resources.

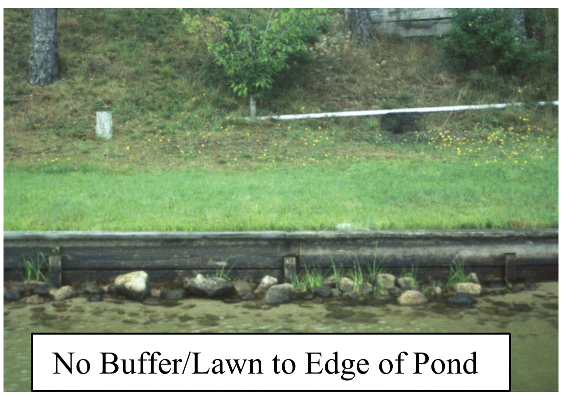

Figure 3. Examples of Nearshore Landscaping and Buffers. Natural buffers slow overland stormwater flow by encouraging infiltration of water and associated contaminants, especially on steeper slopes. Natural buffers also reduce areas of potential fertilizer applications. Buffers also encourage more diverse and, therefore, more resilient ecosystems. Photos courtesy of Ken Wagner, ENSR.

2. Fisheries

Fisheries management is a pond management activity that has been practiced for far longer than any other management technique. Given that many of the ponds in Plymouth have neither a stream inlet nor outlet, it is possible that many of these ponds had no fish in them during their early development and only developed fisheries as a result of people adding/stocking fish from other ponds. Common fish currently found in Plymouth ponds include perch (yellow and white), brown bullhead, pumpkinseed, bass (largemouth and smallmouth), various trout, American eel, and alewife. The Massachusetts Division of Fish and Wildlife (MassDFW) in the Department of Fish and Game is responsible fish management in freshwater ponds. MassDFW management activities include regular stocking and fishing licensing.[22] Current efforts in support of sport fishing in freshwater ponds have included stocking of trout and bass.

[22] http://www.mass.gov/eea/agencies/dfg/licensing/

Although current fish management activities are more holistic, past fisheries management decisions have included activities that did not support sustainable ecosystem function. In order to maintain active sport fisheries, past MassDFW activities have included applying poison (*e.g.*, rotenone and toxaphene) to ponds in concentrations designed kill the entire fish population in order to “reclaim” them for trout fisheries. Big Sandy Pond, for example, has been “reclaimed” twice (in 1967 and 1970); some ponds on Cape Cod have been reclaimed more than five times. Other fisheries activities in the region have included applying fertilizer and digging of herring runs. MassDFW staff provides summaries of past fisheries management activities on their pond maps website.[23]

3. Watersheet Management

Pond surfaces are used for many activities: fishing, swimming, and a variety of different types of boating. Some of these uses will occasionally conflict with others (*e.g.*, swimmers and personal water craft). Over a period of time, most lake communities and states have adopted “watersheet” regulations that strive to avoid these conflicts; for example, boaters needing to keep a specified distance from swimmers. Another example of these types of regulations is the horsepower restrictions for boat motors on selected ponds.[24] As populations grow near ponds, it is likely that additional conflicts will develop over the use of pond surfaces.

II. Plymouth Pond and Lake Stewards (PPALS)

The Plymouth Pond and Lake Stewards (PPALS) program is designed to establish the foundation for effective pond management. Initial PPALS activities are to organize past pond water quality data, formalize procedures for current and future sampling of all ponds, and assess the current status of the initial 39 selected ponds. The Town will work to use these activities to engage and communicate with the community for a larger discussion about town-wide pond management and stewardship. This Atlas summarizes the first year of these efforts. It is anticipated that these efforts will be the initial year of an on-going effort that will include regular public feedback and updates. Funding for these initial activities has been provided by the Massachusetts Environmental Trust, the Town of Plymouth, local pond associations, and the Coastal Systems Program, School of Marine Science and Technology at UMASS-Dartmouth.

A. Development of a Town-wide Ponds Database

Town and CSP-SMAST staff have worked together to develop a town-wide pond database, including numbering of individual ponds, review of potential sampling sites, and confirmation of pond access. The development of the Plymouth Ponds database began with two GIS coverages: a) a town-maintained, open water coverage and b) a MassGIS wetland coverage.[25] These coverages were reviewed and compared to historic aerial photographs available through Google Earth.[26] These photographs provided information on pond area fluctuations due to water level changes, as well as creation and expansion of ponds at golf courses and those associated with cranberry agriculture. Project staff reviewed the pond areas in

[23] MassDFG Southeast District pond maps: http://www.mass.gov/eea/agencies/dfg/dfw/maps-destinations/pond-maps-southeast-district.html

[24] *e.g.*, Long Pond has a 50 horsepower limit on outboard motors.

[25] MassDEP Wetlands (1:12,000) coverage, January 2009. Available at: http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/depwetlands112000.html

[26] Google Earth maintains multiple aerial photographs for many portions of Plymouth. Earliest photos are from 1995.

the two available databases and modified areas if indicated, but generally tried to utilize the areas available in one of the two coverages. The resulting Plymouth Ponds database includes a unique number for each pond, its area, whether it has bathymetric (depth) information, the source and age of the bathymetric information, and whether it has a boat ramp.

The Plymouth Ponds database shows there are 450 ponds within the Town of Plymouth with a total combined area of 5,002 acres (Figure 4). Among this count, 83 ponds are greater than 10 acres and are, therefore, Great Ponds under Massachusetts law and 130 of them have assigned PALIS numbers under the MassDEP pond numbering system. Fifty-four (54) of the ponds have bathymetric/depth information, which is slightly more than the 41 bathymetric surveys completed for the initial 1970s baseline survey.[27] The largest portion of the ponds (46%) are less than 1 acre, but review of the aerial maps shows that these small basins have standing water in them during even low groundwater conditions.[28] The pond list also includes 18 ponds created after 1995; these are mostly golf course ponds although a few were created and/or expanded to support cranberry bog operations. Most of the ponds and most of the Great Ponds are located west of Route 3 (Figure 5). Review of this database indicates that basic physical information, such as bathymetry/depth data, is a significant data need for effective management of Plymouth ponds and lakes.

B. Pond and Lake Water Quality

In the late 1970's the Town conducted baseline water quality surveys for 41 ponds within Plymouth,[29] but data collection since that initial survey has generally been limited to periodic snapshots of individual ponds. Selected ponds have had follow-up monitoring, but most of these have been limited in scope. Watershed association monitoring has also provided additional information, but these too have been necessarily limited by available resources. The Town DMEA has worked with associations to create a more consistent and comprehensive sampling network and this has been reinforced by the current PPALS program. Associations involved in sampling of Plymouth waters have included: Herring Ponds Association, Billington Sea Association, Six Ponds Improvement Association, White Island Ponds Conservation Alliance, Sands of White Horse Beach Association and Friends of Ellisville Marsh. The Plymouth PALS program is designed to unify and standardize the pond and lake sampling program, ensure that collected data is reviewed and interpreted, and to provide feedback to associations and the town so that reliable pond and lake management decisions can be evaluated and implemented. The following sections provide a brief overview of past pond and lake monitoring and a more in-depth discussion of the 2014 PPALS Snapshot results.

1. Past Water Quality Reviews and Data Collection

In the late 1970s, the town contracted with Lyons-Skwarto Associates to review the water quality in 41 selected ponds. These reviews generally included collecting water quality samples at a number of locations within the ponds and their inlet and outlet if present, location and identification of aquatic plants, collection of depth information, collection and analysis of sediment samples, measurement of flow at the inlet and outlet if present, and a one page

[27] Lyons-Skwarto Associates. 1970. A Base Line Survey and Modified Eutrophication Index for Forty-One Ponds in Plymouth, Massachusetts. Volumes I-V. Westwood, MA.
[28] Based on comparison of USGS groundwater water level monitoring in Plymouth and dates of Google Earth aerials.
[29] Lyons-Skwarto Associates. 1970.

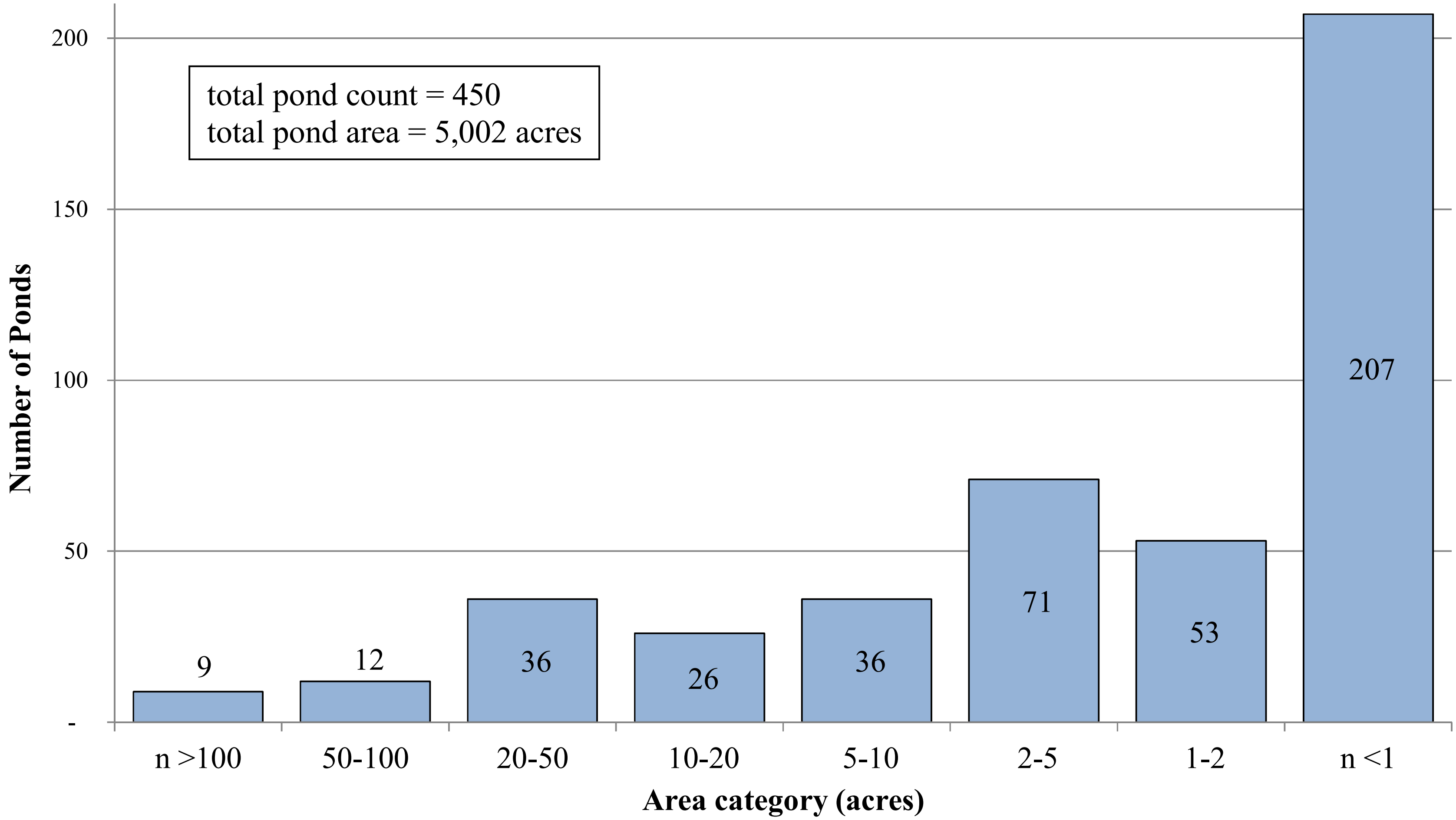

Figure 4. Areas of Town of Plymouth Ponds and Lakes. Ponds are assigned to area categories that are defined by adjacent categories. For example, the 71 ponds in the greater than 2 acres category are ponds with areas between 2 and 4.99 acres. There are 83 Great Ponds in the Town of Plymouth; Great Ponds are ≥10 acres under Massachusetts law. There are 367 additional ponds in the Town with 160 having areas between 1 acre and 9.99 acres. As indicated, the total area of all ponds within the town is 5,002 acres.

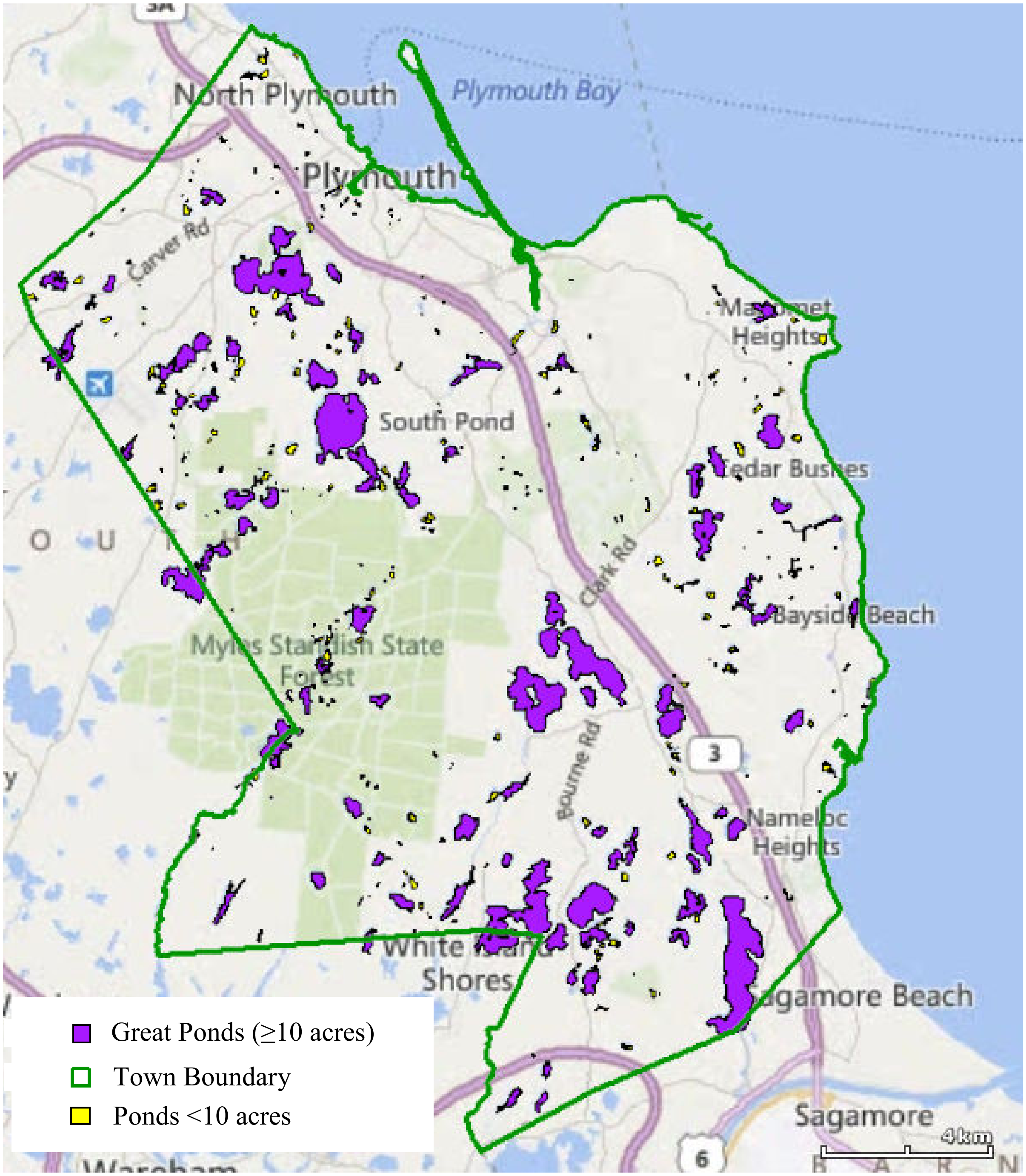

Figure 5. Map of Plymouth Ponds. Great Ponds are greater than 10 acres in area and are publicly owned resources under Massachusetts law. There are 83 Great Ponds and 367 smaller ponds within the Town of Plymouth.

summary review of collected information. Data collected during this project forms the baseline water quality data for the selected ponds and lakes.

Although good for its time, the Lyons-Skwarto Associates data collection has a number of issues that limit the usefulness for comparison to present conditions. All data collection save Secchi measurements and sediment samples were collected at the surface of the ponds, so little is known about temperature and dissolved oxygen throughout the water column which is information crucial for understanding compliance with Massachusetts surface water standards. Dates are not presented for most sampling runs and some of the recorded surface temperatures suggest that some samples were collected during winter conditions. Laboratory methods and sample handling techniques are not listed, so detection limits and holding times cannot be determined. Field data collection methods are not listed, so it is not clear how samples were collected or whether they were preserved. These types of information are generally provided in current pond reports based on guidance developed largely since the baseline studies were completed. It is noteworthy that a state water quality study of White Island Pond completed around the same time did include measurements throughout the water column.[30]

During the 1980's, Lyons-Skwarto Associates completed a few more extensive assessments for selected ponds. These assessments generally followed the same sampling strategies as the late 1970's snapshot, but included sampling throughout the year often with twice a month sampling during the summer. These assessments were completed for the following ponds: Russell Mill Pond, Great South Pond, Little Pond, Long Pond, Little Herring Pond, Big Sandy Pond, and Fresh Pond. There was another, more targeted, assessment of Billington Sea that was also completed.[31] All of these assessments appear to have been completed to obtain federal funding through the Clean Lakes Program.

As mentioned previously, the federal Clean Lakes Program (CLP) was funded the Environmental Protection Agency through section 314 of the Clean Water Act based on 1980 regulations. The CLP provided grant assistance of up to $70,000 to communities to complete diagnostic/feasibility studies that characterized the target pond or lake, developed a list of potential management strategies, and then recommended preferred management strategies and associated costs. Billington Sea was the only Plymouth pond funded for such a diagnostic/feasibility study.[32] The only other assessment of a Plymouth pond that approaches the level of data collection typically found in a diagnostic/feasibility study is the 2012 White Island Pond assessment.[33]

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[30] Massachusetts Department of Environmental Quality Engineering. 1980. White Island Pond Water Quality Study 1976-1978. Division of Water Pollution Control, Westborough, MA.

[31] New England Research, Inc. 1982. Water Quality Studies for Plymouth, Massachusetts: Part III: Final Report. Worcester, MA.

[32] Gale Associates, Inc. and K-V Associates, Inc. 1990. Billington Sea Diagnostic/Feasiblity Study. Prepared for Town of Plymouth and Massachusetts Division of Water Pollution Control, Clean Lakes Program. Weymouth, MA and Falmouth, MA.

[33] Eichner, E., B. Howes, and C. DeMoranville. 2012. White Island Pond Water Quality and Management Options Assessment. Completed for the Cape Cod Cranberry Growers Association. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 108 pp.

During the rest of the 1980's and the 1990's, project staff could only find two pond water quality assessments completed in Plymouth and both of these were narrowly targeted to assess the impact of trying to raise the pH of selected ponds by adding limestone. In 1987-88 and in 1991, Living Lakes, Inc. added a total of 9.5 tonnes[34] and 26 tonnes of limestone to Round Pond and Gallows Pond, respectively. After treatment, pH in both ponds rose above 7, but this goal was not sustained given the low pH of the surrounding groundwater feeding into the ponds and its gradual replacement of treated pond water.

During the late 2000's, the town and pond associations began to conduct regular monitoring. Town, pond association and grant funding was used to collect various levels of data. Between 2007 and 2010, the town completed a number of snapshots of selected ponds usually including dissolved oxygen and temperature profiles of the water column, clarity measurements, and qualitative phytoplankton sampling. Associations and DMEA have continued the field measurements since 2010. Ponds sampled included: Little, Great Herring, Great South, Billington Sea, Little Long, Long, Clear, Boot, Bartlett, Fresh, Big Sandy, Lout, and Little South. During this same time period, town pond associations also began collecting water quality samples for laboratory analysis. Billington Sea Association, Herring Ponds Watershed Association, and Six Ponds Improvement Association collected samples at numerous locations within and around the ponds. These samples were analyzed for 22 different factors during the initial years and this list was trimmed back to 8 factors in 2010. The 8 factors were: pH, specific conductance, nitrite-N, nitrate-N, total Kjeldahl N, total phosphorus, E. coli, and turbidity. The town completed a Quality Assurance Project Plan (QAPP) in 2011 that documented the monitoring procedures and included volunteer training.[35] A completed QAPP should ensure that collected data can be used in state, federal, and local regulatory decisions provided all QAPP provisions are met.

2. 2014 PPALS Water Quality Snapshot

Working with the pond associations and CSP-SMAST, the town worked to develop a pond sampling list for the inaugural 2014 Plymouth PALS (PPALS) Water Quality Snapshot. The pond sampling list was developed based on ease of access, community interest, and whether depth information was available. A sampling protocol was developed based on the Cape Cod PALS sampling protocol, which has been used for 13 years. The protocol and other associated sampling procedures (such as sample transfers to a laboratory) were incorporated into a PPALS QAPP that was submitted and approved by MassDEP. Prior to the PPALS sampling period, town and CSP-SMAST staff conducted a training session on the sampling protocol for the pond volunteers.

The field sampling protocol during the 2014 Snapshot targeted the deepest point in each pond or lake as the PPALS sampling point. This point generally has the best mix of pond water, so it best represents general pond water quality conditions. In order to identify the deepest point, CSP-SMAST staff reviewed available depth information for all ponds, including MassDFG maps, spot depths from the 1970s Lyons-Skwarto Associates baseline pond characterizations, and any subsequent reports. A sampling point map was prepared for each pond and this

[34] tonne = 1,000 kilogram or a metric ton; one tonne equals 2204.62 pounds

[35] Plymouth Pond and River Monitoring Program. Quality Assurance Project Plan 2011-2013. Prepared by Cindy Delpapa, MassDFG, Kim Michaelis, Town of Plymouth, and Eberhard von Goeler, Herring Ponds Watershed Association. Approved by MassDEP, May 2011.

information was conveyed to the town and volunteers. Once in the field, the location depth was confirmed to within one meter using a variety of methods including: a sonar depth finder, Secchi disks lowered to the bottom, and GPS for associations with regular sampling programs. GPS was used to establish coordinates for all sampling points during the 2014 PPALS Snapshot.

Once the sampling location was established, the PPALS protocol requires collection of a water clarity reading using a Secchi disk and a temperature/dissolved oxygen profiles collected at 1 meter increments. A Niskin or Van Dorn sampler was then used to collect a whole water sample at various depths depending on the total depth of the pond. In ponds of 1 m or less, two near surface (0.5 m) samples were collected. In ponds less than 9 meters deep, a sample was collect just below the surface (0.5 m) and one meter above the bottom. In ponds with a total depth of 10 meters and greater, a third sample at 3 m depth is added (samples at 0.5 m below the surface, 3 m down, and 1 m above the bottom). In ponds with a total depth of 11 meters and deeper, a fourth sample is added (samples at 0.5 m, 3 m, 9 m, and 1 m above the bottom). Duplicate samples were collected for 10% of the samples for quality assurance/quality control purposes. Samples were collected in 1 liter dark plastic bottles, which had been previously been acid washed. No preservatives were used. Samples were placed in a cooler with ice or ice packs following collection and were delivered to the laboratory either the same day or the following morning. A 2014 Plymouth PALS field sampling sheet is included in Appendix A.

Between August 15 and September 15, 2014, volunteers and town staff collected 104 water quality samples from 39 ponds. The collected samples were analyzed at the SMAST Coastal Systems Analytical Facility for: 1) pH, 2) alkalinity, 3) chlorophyll *a*, 4) pheophytin *a*, 5) total phosphorus, and 6) total nitrogen. Table 2 shows the parameters tested from the collected PPALS samples at the SMAST laboratory, along with the methods and their respective detection limits.

Table 2. – Plymouth PALS Samples: CSP-SMAST Laboratory Analytical Methods

Analyte	Method	Detection Limit	References
pH	Potentiometric	NA	Standard Methods, 1995
Alkalinity	Titrimetric	0.5 mg/L	Standard Methods, 1995
Chlorophyll a/ Pheophytin	Acetone Extraction/Fluorometry	0.1 µg/L	Standard Methods, 1995, Parsons *et al.* 1989
Total Nitrogen	Persulfate Digestion/ Cadmium Reduction/Colorimetry	0.1 µM	Standard Methods, 1995, D'Elia *et al*., 1977
Total Phosphorus	Boiling Acid Digestion/Colorimetry	0.1 µM	Standard Methods, 1995, Murphy and Riley, 1962

a. Physical Characteristics of 2014 Plymouth PALS Ponds

The 39 ponds sampled during the inaugural 2014 Plymouth PALS Snapshot ranged in depth between 1.2 m and 30.5 m (Little Herring Pond and Long Pond, respectively). In order to reach the bottom of Long Pond, a longer probe cord needed to be purchased by the town using MET grant funds. Sampled ponds had areas ranging between 5.3 acres and 427 acres (Jakes Pond and Great Herring Pond, respectively) with a median area of 36 acres. The combined area of the ponds was 2,850 acres or 57% of the total pond area in the town. Of the ten largest ponds in the town, eight were sampled during the 2014 Snapshot.

b. 2014 PPALS Snapshot Water Quality Results

People using or living next to a pond or lake often want to know the answer to a version of the following question: "Is my pond ok?" The state surface water regulations attempt to provide a comparison point to help answer that question by setting numeric and descriptive standards. The federal Clean Water Act includes a regulatory structure that relies on state water quality standards to define ponds and lakes that have impaired water quality and require a limit on the source of impairment.[36] The scientific community also has spent considerable time on this question and has created the field of limnology over the last 100 years that specifically includes lake science.

Defining what is "ok" for an individual pond usually requires some understanding of the characteristics of the pond, including its depth, area, watershed, and hydrology. A large part of limnology and regulatory standards is defining commonalities among similar ponds in order to establish standards that can be applied to groups of ponds. Plymouth shares a similar hydrogeology with select portions of the northeast, including Cape Cod, Martha's Vineyard, and Nantucket. USEPA has classified Plymouth as part of their Level IV Subecoregion 84 (Atlantic Coastal Pine Barrens), which also includes Nantucket, Martha's Vineyard, Cape Cod, Block Island in Rhode Island, eastern Long Island, and southern New Jersey (Figure 6). These regions are all characterized by sandy soils and ponds that are generally fed by groundwater.

USEPA reviewed available data in 2001 and released proposed reference values (or acceptable thresholds) for lakes and reservoirs in Subecoregion 84 and the overall Ecoregion 14, which includes the near-coast regions of the eastern coast of the United States from New Hampshire to Georgia.[37] This review found 92 lakes had been sampled in subecoregion 84 between 1990 and 1999 and this data was analyzed to develop reference values for Secchi depth, total phosphorus, total nitrogen, and chlorophyll *a* (Table 3). The available data included sampling during all four seasons and USEPA determined that the most frequently sampled season in Subecoregion 84 had less than 10 samples for three of the parameters and 33 samples for total phosphorus (see Table 3). These reference values were developed using the lower 25th percentile of all the available data.

During the course of developing the proposed Ecoregion thresholds, USEPA utilized a proposed a two-tiered method for determining reference criteria that depends on the amount and quality of the data that is available.[38] One approach is to determine the upper 25th percentile (or 75th percentile) of a water quality parameter (*e.g.*, total phosphorus) from measurements collected only from unimpacted or reference lakes (Figure 7). The reference lake method is preferred by USEPA because it is likely associated with minimally impacted water quality

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[36] Impaired water bodies are required to have a Total Maximum Daily Load (TMDL) prepared for the cause of impairment. If the TMDL is achieved, the water body will have acceptable water quality under state regulatory standards.

[37] U.S. Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations. Information Supporting the Development of State and Tribal Nutrient Criteria for Lakes and Reservoirs in Nutrient Ecoregion XIV. EPA 822-B-01-011. US Environmental Protection Agency, Office of Water, Office of Science and Technology, Health and Ecological Criteria Division. Washington, DC.

[38] U.S. Environmental Protection Agency. 2000. Nutrient Criteria Technical Guidance Manual: Lakes and Reservoirs. First Edition. EPA-822-B00-001. US Environmental Protection Agency, Office of Water, Office of Science and Technology. Washington, DC.

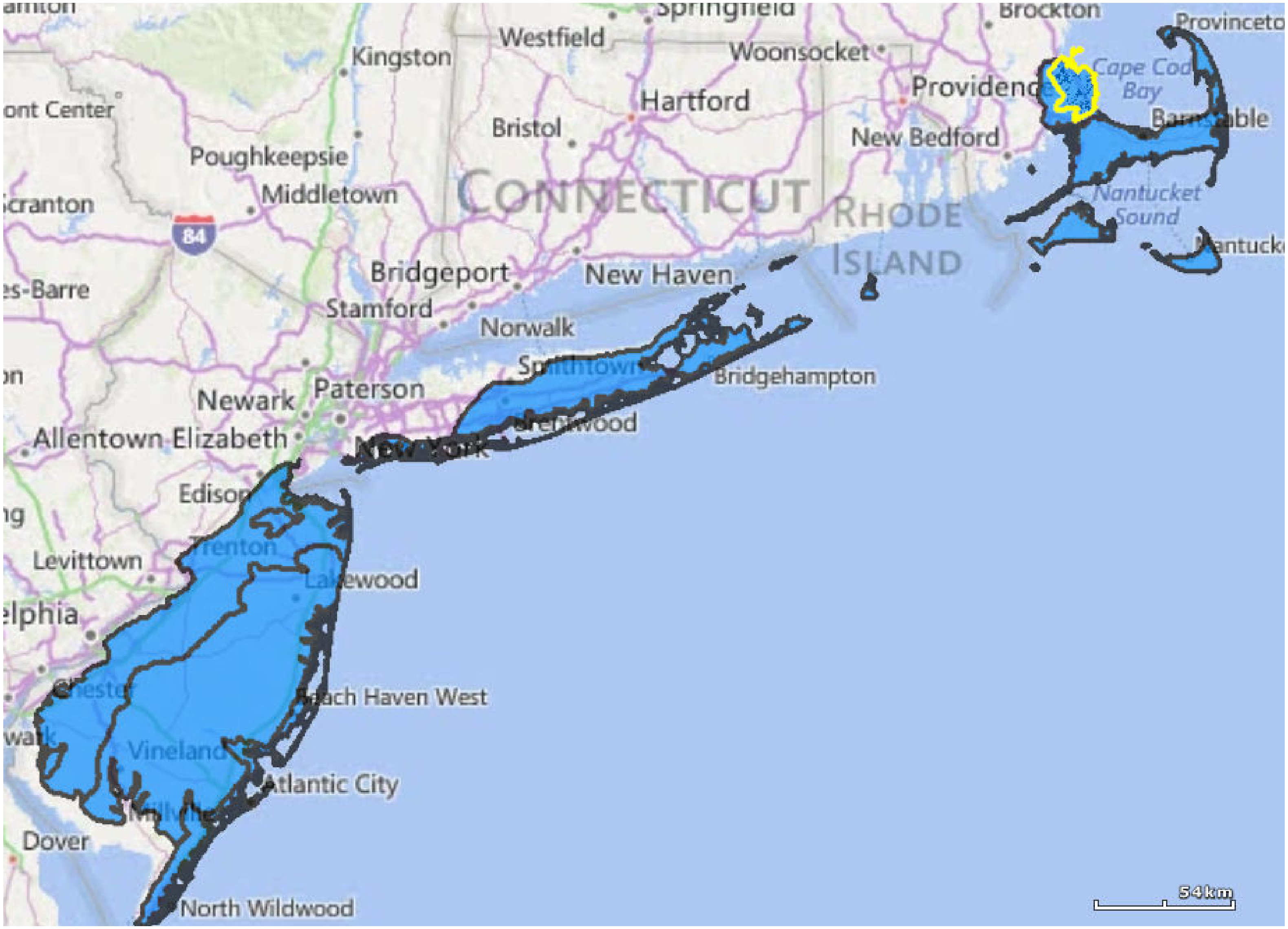
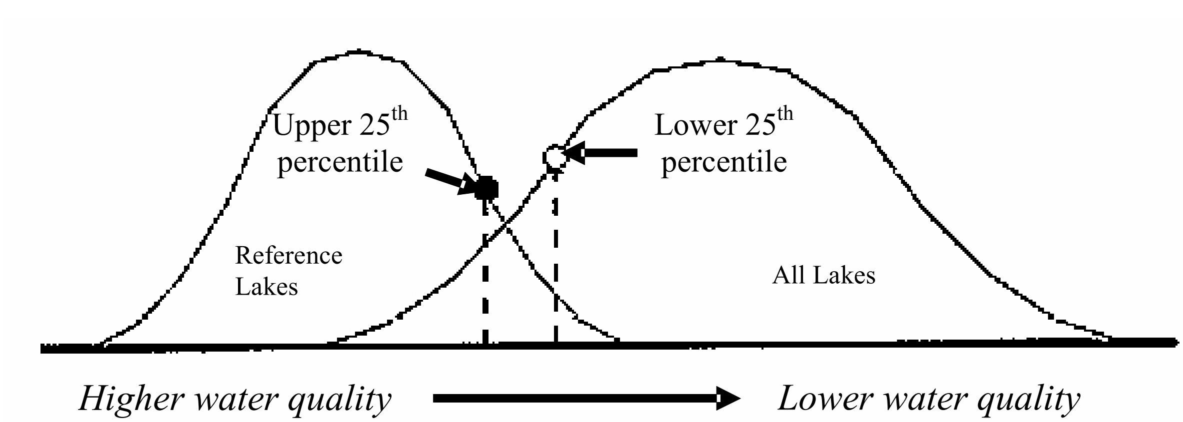


Figure 6. EPA Subecoregion 84 (Atlantic Coastal Pine Barrens). This region shares similar hydrogeologic characteristics and contains largely groundwater-fed kettle ponds. Most of Plymouth, which is outlined in yellow, is located within this ecoregion. Delineation from http://www.epa.gov/wed/pages/ecoregions/level_iii_iv.htm (downloaded 12/10/14).

Table 3. USEPA Ecoregion 14 and Subecoregion 84 Reference Information				
			Ecoregion 14	Subecoregion 84
		# of lakes	647	92
		# of lake stations	910	100
Nutrient Parameters Considered	# of records in		Reference Thresholds	
	Ecoregion 14	Subecoregion 84	Ecoregion 14	Subecoregion 84
Secchi depth	14,581	79	4.5 m	2 m
chlorophyll *a*	5,977	73	2.1 µg/L	6 µg/L*
total nitrogen (TN)	925	1	0.32 mg/L	0.41 mg/L*
total phosphorus (TP)	12,386	106	8 µg/L	9 µg/L

*fewer than 4 lakes used to develop threshold
Source: USEPA, 2001; table modified from Eichner, *et al*., 2003.

Figure 7. USEPA Methods for setting reference water quality thresholds. Reference thresholds are criteria that allow a surface water to have acceptable water quality conditions. USEPA's two-tiered method utilizes either the data from all lakes and uses the lower 25th percentile for the threshold or data from only unimpacted lakes and the upper 25th percentile from that data for the threshold. USEPA review tends to show that large enough datasets produce similar reference thresholds.



Source: USEPA, 2000; figure modified from Eichner, *et al*, 2003

conditions. The second approach uses all sampling data within a region and determines a parameter's lower 25th percentile as the reference concentration. This approach is used when unimpacted lakes have not been adequately identified. Limited analysis comparing the two methods seems to indicate that results from the two methods are similar when sufficient data is available.[39]

[39] *Ibid*.

CSP-SMAST has coordinated the Cape Cod PALS Program with the Cape Cod Commission (CCC) and the towns of Cape Cod for more than a decade. During the inaugural 2001 Cape Cod PALS Snapshot, 195 lakes were sampled across Cape Cod. This produced more samples and sampled lakes/ponds than USEPA used in the 2001 subecoregion reference criteria review.[40] CCC staff applied the USEPA reference criteria approaches to the 2001 Cape Cod PALS Snapshot results, including determining the least impacted ponds, and determined reference criteria for chlorophyll *a*, total phosphorus, total nitrogen, and pH (Table 4). Comparison of the Cape Cod reference criteria to the USEPA Ecoregion 14 criteria generally produced comparable concentrations when using all data (*e.g.*, the lower 25th percentile), but analysis of the least impacted ponds produced much lower concentrations.[41] This review tended to confirm the CCC results as being consistent with the USEPA Ecoregion results, but also suggested that "unimpacted" ponds are very rare in the region. Since the CCC results are in the same ecoregion as Plymouth, it is reasonable to use the reference criteria for comparison to the Plymouth PALS results.

Table 4. – Water Quality Reference Criteria for Cape Cod Ponds

Category	Measure	chl *a*	TN	TP	pH
		µg/L	mg/L	µg/L	
2001 Snapshot (All ponds)	# of ponds sampled	191	184	175	193
2001 Snapshot (All ponds)	Median	3.6	0.44	16	6.28
2001 Snapshot (All ponds)	Lower 25th percentile	1.7	0.31	10	5.62
USEPA Ecoregion 14	Lower 25th percentile	2.1	0.32	8	*
4 List Ponds (8 ponds)	upper 25th percentile	1.0	0.16	7.5	5.19
3 List Ponds (26 ponds)	upper 25th percentile	1.1	0.22	7.7	5.24

Notes:

a) * not used in USEPA nutrient criteria determination
b) USEPA (2001) is source of USEPA concentrations
c) "4 List Ponds" are the least impacted ponds, while "3 List Ponds" are slightly more impacted
d) Modified from Cape Cod Pond and Lake Atlas (2003)

Since scientific-based pond and lake assessments are often difficult to communicate to the general public, some scientists have attempted to develop single number indexes or classification strategies to simplify the public communication of water quality status. One of the better known classification strategies is the Carlson Index that was developed from data from Wisconsin and Minnesota lakes.[42] This strategy, called the trophic status index, uses total phosphorus, chlorophyll *a*, or Secchi disk depth to classify a pond or lake as to the amount of biomass expected in the lake (Table 5). Developing a trophic index usually incorporates an understanding of the regional geologic or climate setting, so the comparison of Wisconsin and Minnesota lakes to Plymouth lakes should be approached with caution. However, because the Carlson index has been used so extensively, it is often helpful to provide this information to reinforce the measured constituents.

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[40] U.S. Environmental Protection Agency. 2001. Ambient Water Quality Criteria Recommendations.

[41] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas. Cape Cod Commission. Barnstable, MA.

[42] Carlson, R.E. 1977. A trophic state index for lakes. *Limnology and Oceanography*. 22: 361-369.

Table 5. – Carlson Trophic State Index (TSI)					
TSI Calculations					
TSI(SD) = 60 - 14.41 ln(SD)				SD = Secchi disk depth (meters)	
TSI(CHL) = 9.81 ln(CHL) + 30.6				CHL = Chlorophyll a concentration (µg/L)	
TSI(TP) = 14.42 ln(TP) + 4.15				TP = Total phosphorus concentration (µg/L)	
TSI values and likely pond attributes					
TSI Values	Chl a (µg/L)	SD (m)	TP (µg/L)	Attributes	Fisheries & Recreation
<30	<0.95	>8	<6	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	Salmonid fisheries dominate
30-40	0.95-2.6	8-4	6-12	Hypolimnia of shallower lakes may become anoxic	Salmonid fisheries in deep lakes only
40-50	2.6-7.3	4-2	12-24	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia during summer	Hypolimnetic anoxia results in loss of salmonids.
50-60	7.3-20	2-1	24-48	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	Warm-water fisheries only. Bass may dominate.
60-70	20-56	0.5-1	48-96	Blue-green algae dominate, algal scums and macrophyte problems	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70-80	56-155	0.25-0.5	96-192	Hypereutrophy: (light limited productivity). Dense algae and macrophytes	
>80	>155	<0.25	192-384	Algal scums, few macrophytes	Rough fish dominate; summer fish kills possible
after Carlson and Simpson (1996); Carlson TSI developed in algal dominated, northern temperate lakes					

Aside from the concerns about using factors from another ecoregion, it should also be noted that the popularity of the Carlson Index has led to a number of other caveats and concerns about how it is used. Subsequent evaluations of Carlson's Index have found that one measure or another is better for use at various times of year (*e.g.*, total phosphorus may be better than chlorophyll at predicting summer trophic state), but these evaluations have found that the best overall predictor of algal biomass is chlorophyll-*a* concentrations.[43] This finding should not be surprising given that chlorophyll-*a* is a more direct measure of biomass than the other measurement factors. Subsequent uses of the Carlson Index by other investigators have included

[43] Carlson, R.E. 1983. Discussion on "Using differences among Carlson's trophic state index values in regional water quality assessment", by Richard A. Osgood. Water Resources Bulletin. 19: 307-309.

combining and averaging the various TSI values. Carlson (1983) regards this as a misuse of the indices and states "There is no logic in combining a good predictor with two that are not."

Trophic indices are appropriate for first order comparison among ponds, especially when data is limited, but in order to develop reasonable management strategies, more refined assessments and measures are needed. More in-depth pond by pond analysis of individualized measures (*e.g*., total phosphorus, dissolved oxygen, macrophyte cover, etc.) and their various interactions should be evaluated to assess the "health" of a particular lake. It should also be further noted that higher Carlson values do not necessarily mean that the water quality in a pond is "poor"; although water quality and biomass levels are linked, higher biomass levels are valuable for warm water fisheries (*e.g*., bass) and may be appropriate for shallow, more naturally productive pond ecosystems. That said, available pond monitoring data within the ecoregion suggests that Plymouth pond ecosystems are naturally low in biomass and that higher trophic levels/TSI values are generally associated with impacted or "unhealthy" pond ecosystems.

The following sections discuss each of the water quality parameters measured during the 2014 PPALS Snapshot and their importance in assessing whether a pond ecosystem is impacted or impaired. Included in this discussion are individual pond comparisons to ecoregion thresholds.

i. Nutrients: Phosphorus and Nitrogen

Phosphorus and nitrogen are essential macro-nutrients for plant growth, both for rooted plants and microscopic algae or phytoplankton. Addition of these nutrients to ecosystems causes plant growth. For example, when fertilizers are added to a lawn or a field of crops, the plants in the lawn or field grow by producing more roots, stems, or more plants. 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. Typical plant organic matter contains phosphorous, nitrogen, and carbon in a ratio of 1 P: 7 N: 40 C per 500 wet weight.[44] Therefore, if the other constituents are present in excess, phosphorus, as the limiting nutrient, can theoretically produce 500 times its weight in phytoplankton.

Comparison of phosphorus and nitrogen concentrations typically shows which nutrient is more limiting to plant growth. As a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16 (also known as the Redfield ratio), phosphorus is generally the limiting nutrient, so adding phosphorus causes blooms.[45] It should be noted that this approach to determining nutrient limitation also needs to take into account phototrophs that have the ability to utilize organic phosphorus, not just inorganic phosphorus. For this reason, phosphorus-limited systems generally have N to P ratios that are 2-5 times the Redfield ratio of 16. Plants, including phytoplankton, have different nutrient needs and, in some cases, have adapted to grow better when ratios of nutrients are closer or further away from the Redfield ratio. For example, blue-

[44] Wetzel, R. G. 1983.

[45] Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of sea-water, in *The Sea*, (M.N. Hill (ed.). New York, Wiley, pp. 26-77.

green algae (or cyanobacteria) have the ability to take (or fix) nitrogen from the atmosphere, which allows their rapid growth when phosphorus is relatively more accessible.

Most ponds and lakes in the Plymouth ecoregion have relatively high N to P ratios because of the binding properties of phosphorus in the surrounding glacially-derived sands and the abundant sources of nitrogen and its high mobility in the groundwater system. 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 (rate of ~1 ft/d). These same sources add phosphorus to the groundwater, but phosphorus is significantly slowed (rate of 0.01-0.02 ft/d),[46] mostly due to its binding to the iron minerals naturally contained in the aquifer sands. Once nitrogen is in the aquifer system, it is generally fully oxidized to nitrate-nitrogen and largely unattenuated unless it reaches a pond or stream along its flow path.[47] Most of the phosphorus in Plymouth ponds is generally due to a) additions from land uses directly adjacent to the pond and b) regeneration of past watershed additions from the pond sediments. Since phosphorus movement in the aquifer is so slow, management of P inputs to ponds generally focuses on properties within 250 to 300 ft of the pond[48] shoreline unless there are direct water inputs from streams or stormwater runoff. Shoreline properties generally have impacts on the pond within land use and wastewater planning horizons.

Results from the 2014 Plymouth PALS sampling generally conform to other overviews of ponds and lakes in the ecoregion. All of the ponds had N to P ratios above 16, suggesting that phosphorus was generally the key management nutrient; three ponds had ratios close to 16 which would have to be explored in more refined, pond-specific assessments (Figure 8). As would be expected in a nitrogen-rich environment, 27 of 38 (71%) surface water total nitrogen (TN) samples exceed the impaired ecoregion threshold (0.31 mg/L) and none of the TN concentrations were less than the unimpaired reference concentration (0.16 mg/L) (Figure 9). Among the surface total phosphorus (TP) concentrations, 15 (or 39%) exceeded the impaired ecoregion threshold (10 µg/l) (Figure 10). More ponds (17) had surface TP concentrations that were less than the unimpaired reference concentration (7.5 µg/l TP). Ratios of shallow to deep TP concentrations show that most of the ponds (26 of 36) have higher deep concentrations and 13 have deep water concentrations more than twice as high as surface water concentrations (Figure 11). Ratios 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. These observations are consistent with low level hypoxia since sediment release of nitrogen is less chemically favorable than release of phosphorus in hypoxic settings, especially in low pH waters.[49] The spatial distribution of the ponds either above or below the TP thresholds does not initially appear to be related to their location, surrounding level of development, or size, which suggests there are factors that would need to be evaluated in individual pond assessments to determine the causes of current water quality conditions.

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[46] Robertson, W.D. 2008.

[47] The impact of nitrogen additions to coastal harbors and bays is being addressed through the Massachusetts Estuaries Project (MEP).

[48] *e.g.*, Eichner and others, 2006; Eichner, 2007; Eichner, 2008

[49] Stumm, W. and J.J. Morgan. 1981. *Aquatic Chemistry*. John Wiley & Sons, Inc., New York, NY.

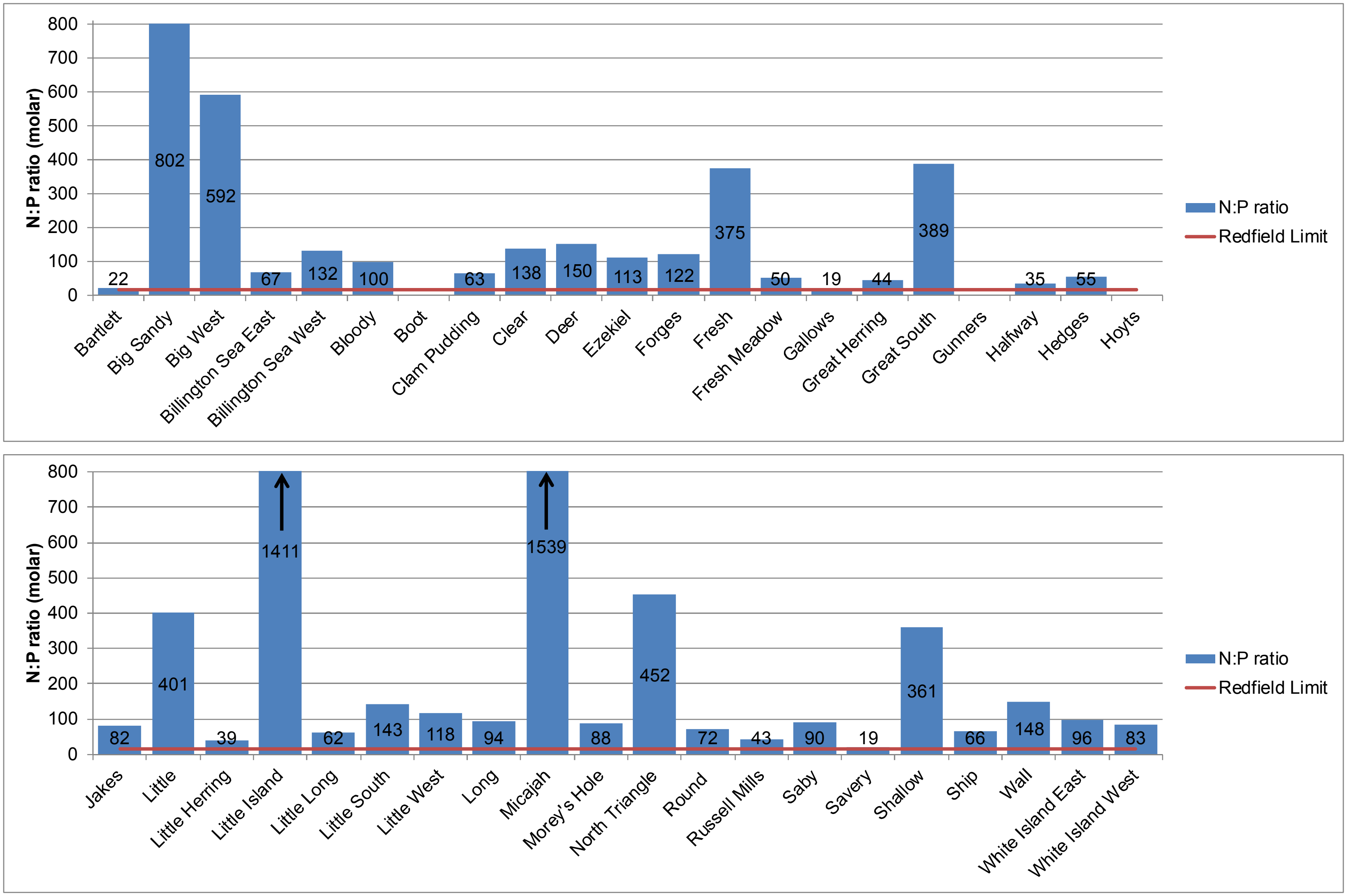


Figure 8. 2014 Plymouth PALS Snapshot: Nitrogen to Phosphorus Ratios for Surface Waters. All ponds have ratios greater than Redfield ratio, indicating phosphorus as the key nutrient for managing water quality. Three ponds have ratios close to the Redfield limit, which may indicate nitrogen and phosphorus need to be managed. Individual pond assessment would be required to refine these one time, snapshot measurements.

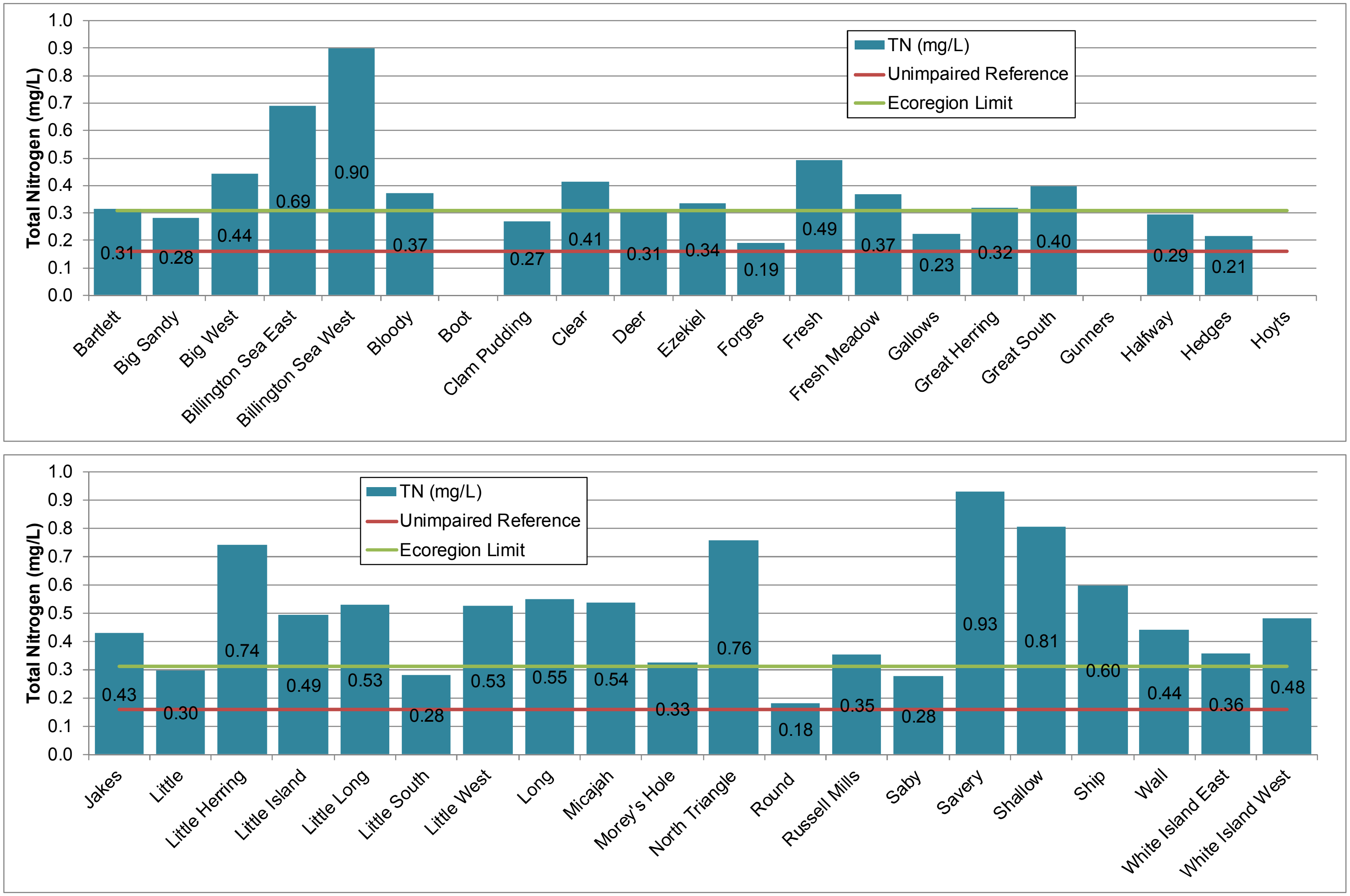


Figure 9. 2014 Plymouth PALS Snapshot: Total Nitrogen Concentrations. Snapshot surface water concentrations are compared to Ecoregion Limit (0.31 mg/L) and Unimpaired Reference (0.16 mg/L), both of which were developed from a snapshot of 195 ponds on Cape Cod. As would be expected in a nitrogen-rich environment, 27 of 38 (71%) TN concentrations in Plymouth ponds exceeded the impaired ecoregion threshold and none were less than the unimpaired reference concentration.

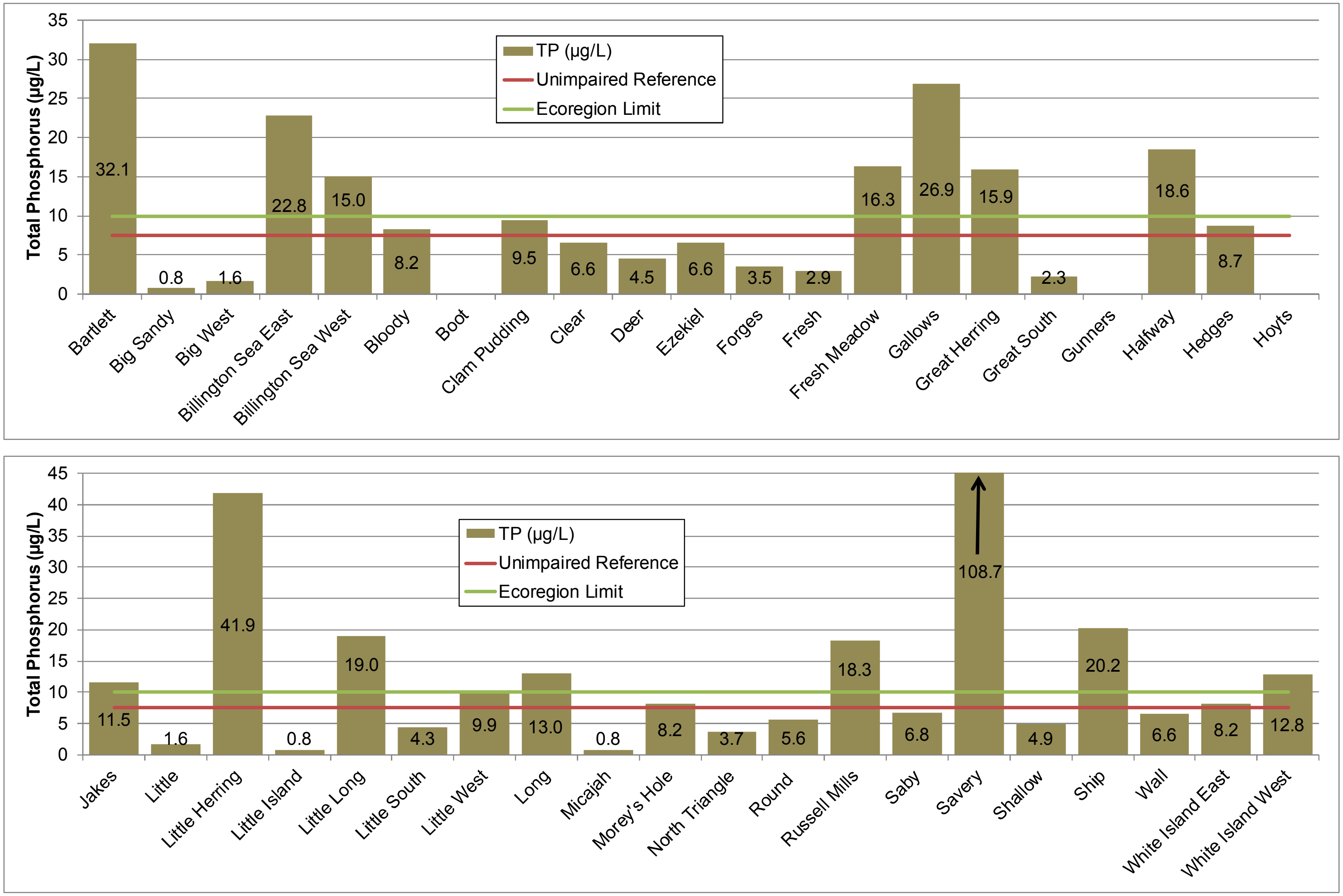


Figure 10. 2014 Plymouth PALS Snapshot: Total Phosphorus Concentrations. Snapshot surface water concentrations are compared to Ecoregion Limit (10 µg/L) and Unimpaired Reference (7.5 µg/L), both of which were developed from a snapshot of 195 ponds on Cape Cod. Concentrations from 15 ponds (or 39%) exceeded the impaired ecoregion threshold, while more ponds (17) were less than the unimpaired reference threshold concentration.

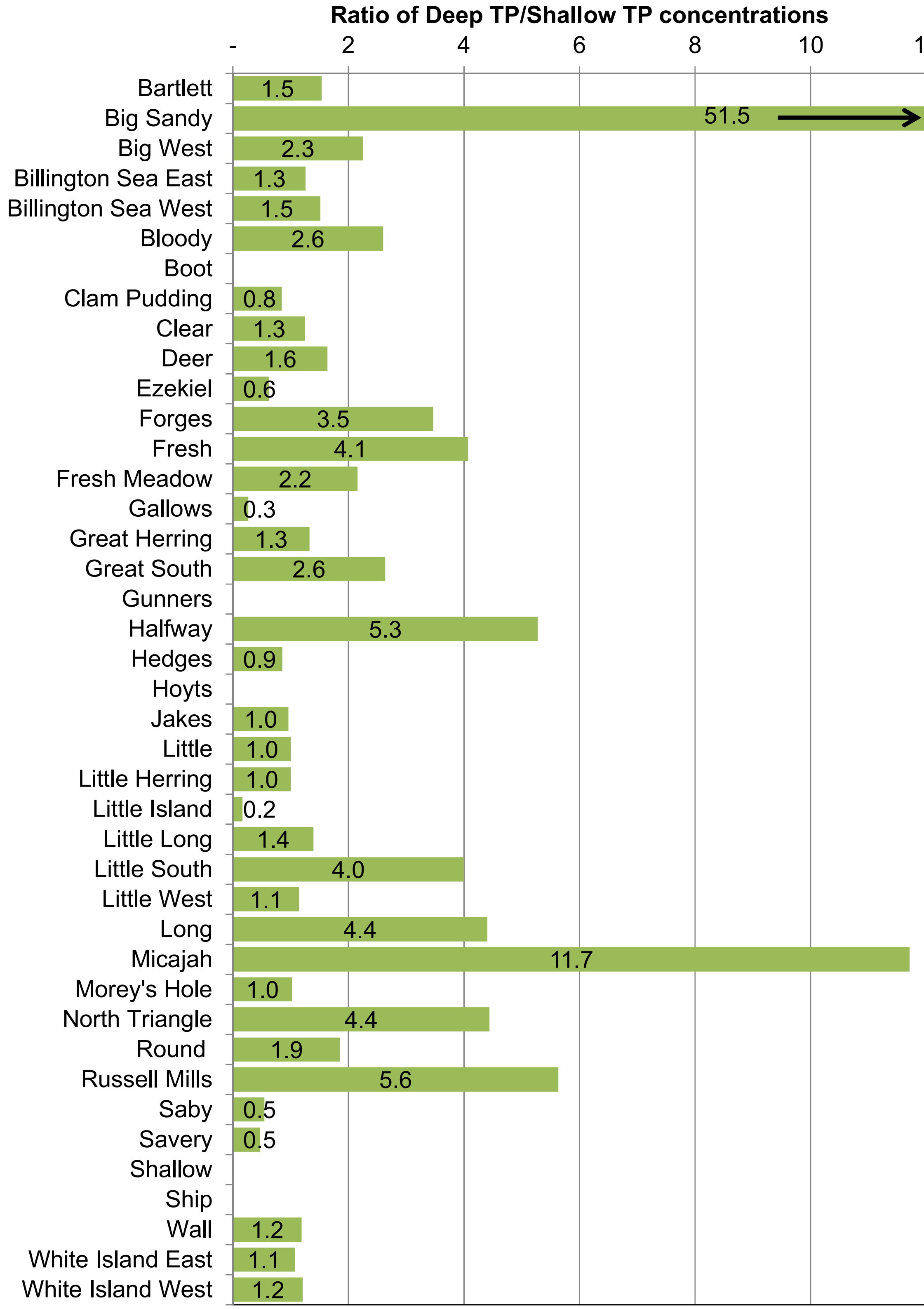


Figure 11. Comparison of Deep and Shallow Total Phosphorus Concentrations. Ratios of deep to shallow water TP concentrations show that 26 of 36 ponds had higher deep concentrations and 13 have deep concentrations >2X surface concentrations. Ratios greater than two strongly indicate sediment regeneration of TP into the overlying water column likely from periodic hypoxia.

ii. Plant Pigments: Chlorophyll-*a* and Pheophytin

Plants capture energy from the sun through the process of photosynthesis. Plants have specialized molecules called pigments that absorb energy from sunlight and the most common among these is chlorophyll-*a*. A water quality laboratory test of chlorophyll-*a* provides a direct measure of this pigment and an indirect measure of the amount of phytoplankton in the sample. Pheophytin-*a* is a modified form of chlorophyll that is the most immediate breakdown product of chlorophyll-*a*.

Chlorophyll is not directly mentioned in Massachusetts surface water regulations, so it is generally addressed in the descriptive standards (see Section I.B.). Anecdotal evidence from Cape Cod ponds with undeveloped land around them suggests that "natural" ponds in this ecoregion tend to be phytoplankton-dominated and, therefore, should have a strong relationship between chlorophyll-*a* and total phosphorus concentrations. However, this relationship can be skewed when rooted plants out-compete phytoplankton for phosphorus. For example, Long Pond in the Town of Barnstable has an extensive rooted macrophyte population[50] that has consumed most of the available phosphorus and kept chlorophyll concentrations relatively low.[51] These types of ponds are largely unrepresentative of the ecology in most ponds in the Plymouth ecoregion.

Because unimpaired ponds in this ecoregion tend to have low nutrient concentrations, they also tend to have low chlorophyll-*a* concentrations. The average concentration of 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.[52] 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.[53] The Ecoregion Limit is roughly the same as the USEPA ecoregion chlorophyll-*a* concentration of 2.1 µg/L.[54]

Results from the 2014 Plymouth PALS sampling generally match up with the phosphorus results, although slightly more ponds have excessive chlorophyll-a concentrations. Twenty (or 51%) of the ponds had surface chlorophyll-*a* concentrations greater than the ecoregion threshold (1.7 µg/L) and only six had concentrations below the unimpaired reference concentration (1.0 µg/l) (Figure 12). The average concentration among all the ponds sampled in the 2014 PPALS Snapshot (3.6 µg/L) was more than twice the impaired threshold. Review of pheophytin-*a* concentrations generally found that pheophytin-*a* concentrations were 10-20% of the total measured pigments. If pheophytin-*a* and chlorophyll-*a* surface water concentrations were added, only one pond had a combined concentration less than the unimpaired reference concentration: Clam Pudding Pond. Clam Pudding Pond is surrounded by an undeveloped buffer with a width of 100 to 150 ft.

[50] IEP, Inc. and K-V Associates. 1989. Diagnostic/Feasibility Study of Wequaquet Lake, Bearses, and Long Pond. Prepared for Town of Barnstable, Conservation Commission. Sandwich and Falmouth, MA.
[51] Eichner, E. 2008. Barnstable Ponds: Current Status, Available Data, and Recommendations for Future Activities. School of Marine Science and Technology, University of Massachusetts Dartmouth and Cape Cod Commission. New Bedford and Barnstable, MA.
[52] Eichner and others. 2003.
[53] *Ibid*.
[54] US Environmental Protection Agency. 2001.

Figure 12. 2014 Plymouth PALS Snapshot: Chlorophyll-*a* Concentrations. Snapshot surface water concentrations are compared to Ecoregion Limit (1.7 µg/L) and Unimpaired Reference (1.0 µg/L) levels, both of which were developed from a snapshot of 195 ponds on Cape Cod. 22 ponds had surface chlorophyll-*a* concentrations greater than 1.7 µg/L and only six had concentrations below 1.0 µg/l. The average surface water concentration among all the ponds sampled in the 2014 Snapshot (3.6 µg/L) was more than twice the impaired threshold.

Since CHL-a is the primary constituent for the application of the Carlson (1977) Trophic State Index (TSI), Atlas authors also used the Carlson Index (see Table 5) to evaluate the 2014 Plymouth PALS Snapshot data. This evaluation shows that 25 of the 41 sampled ponds had surface chlorophyll-*a* concentrations in the oligotrophic category (TSI range of <30 – 40), 9 were in the mesotrophic category (TSI range of 40-50), and 7 were in the eutrophic category (TSI range of 50-70) (Figure 13). The high percentage of ponds classified as oligotrophic should not be surprising given that the Ecoregion Limit for chlorophyll (1.7 µg/L) results in a TSI classification in the middle of the Carlson oligotrophic range (35.8). This finding illustrates the caution that should be used when assessing ponds in different ecoregions; ponds in the Plymouth ecoregion are more sensitive to nutrient inputs and may be classified as being nutrient poor under the Wisconsin-based Carlson index, while they actually have excessive nutrients and impaired conditions.

iii. pH and Alkalinity

pH is a measure of acidity, while alkalinity is a cumulative measure of compounds[55] that can buffer or reduce acidity. pH values less than 7 are considered acidic, while pH values greater than 7 are considered basic. Natural rainwater, in equilibrium with carbon dioxide in the atmosphere, has a pH of 5.65, which is acidic. Photosynthesis takes carbon dioxide and hydrogen ions out of the water causing pH to increase, so more productive lakes will tend to have higher pH measurements.

During the 1850's, English scientists[56] began to evaluate changes in chemical characteristics of rain near an industrial center burning coal for power including a lowering of pH that led the coining of the term "acid rain." During the 1970's this same phenomenon was measured in the Northeast United States due to coal-fired power and industrial plants in the Midwest and included ecosystem and watershed changes that altered water quality.[57] Technology requirements instituted through the federal Clean Air Act have largely ameliorated these impacts.

Given that the Plymouth Ecoregion is largely made up of sand deposited during the last continental glaciation, there are no carbonate minerals (such as, limestone) to provide alkalinity to buffer the acidity that is naturally present in precipitation. As such, ponds and lakes in this ecoregion naturally have low pH and alkalinity except in cases where there is a large amount of growth/photosynthesis or nutrients present. The plant and animal species that live in ponds and lakes in the ecoregion have evolved within these naturally low pH environments. The 2001 Cape Cod PALS Snapshot of 193 ponds within the same ecoregion had an average pH of 6.16 with a range of 4.38 to 8.92 and an average alkalinity is 7.21 mg/L as $CaCO_3$ with a range of 0 to 92.1.[58] Using this data, ecoregion reference thresholds of 5.62 for pH and 1.55 mg/L as $CaCO_3$ for alkalinity were calculated for the Plymouth Ecoregion.

55 *e.g.*, carbon dioxide, carbonate, and bicarbonate
56 *e.g.*, Robert Angus Smith
57 Probably most famously at Hubbard Brook in New Hampshire (http://www.hubbardbrook.org/)
58 Eichner and others. 2003.

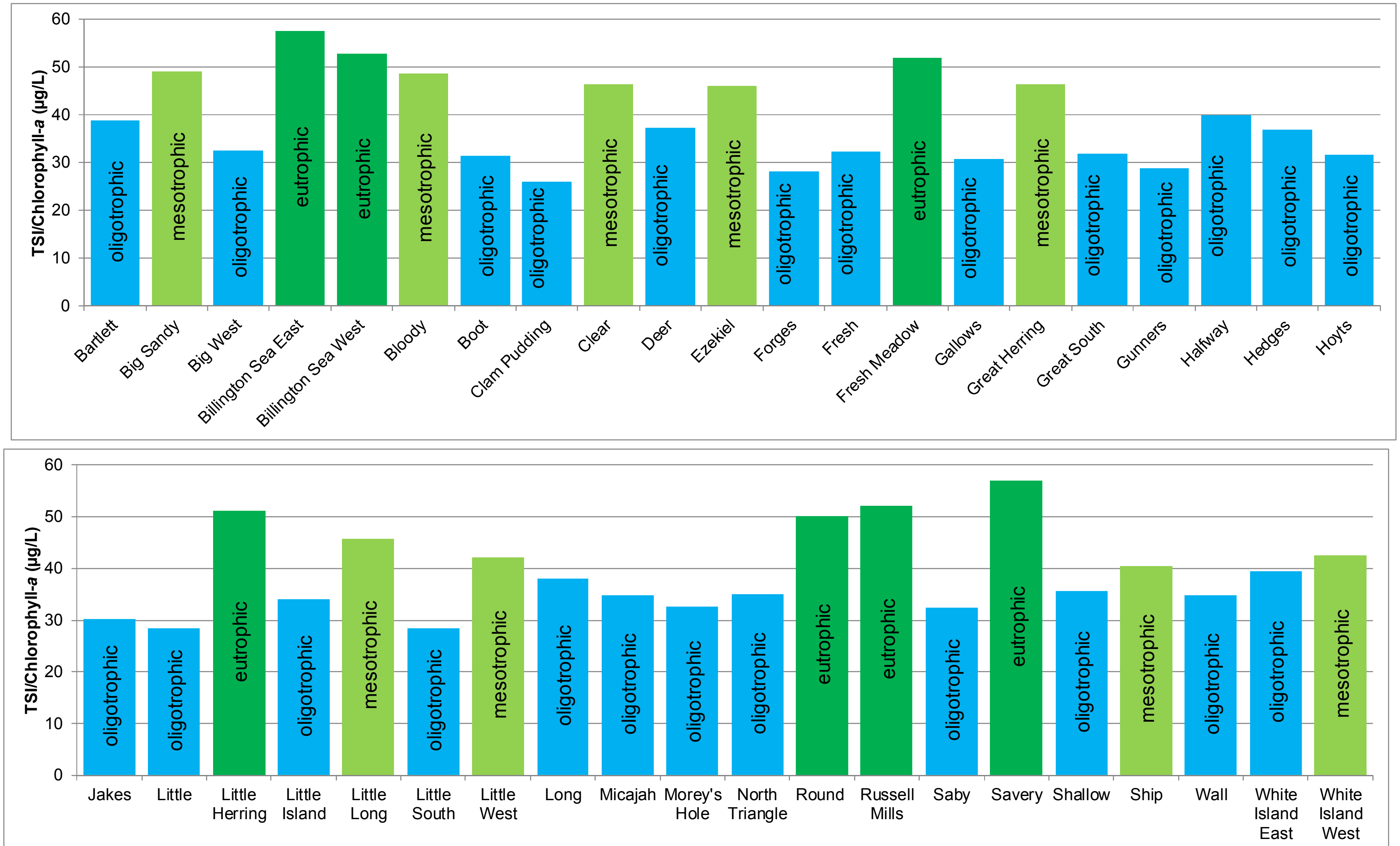


Figure 13. 2014 Plymouth PALS Snapshot: Carlson Trophic Status Index Classification. Classifications are based on chlorophyll-a concentrations using TSI = 9.81 ln(CHL) + 30.6 Carlson TSI calculation (see Table 5).

Massachusetts surface water regulations include numeric ranges for acceptable pH, although the specified ranges do not seem to account for the low pH's commonly measured in the ecoregion that includes Plymouth. Class A and B waters are required to have pH's between "6.5 through 8.3 standard units and not more than 0.5 units outside of the natural background range."[59] The upper limit of the range is increased to 9.0 for Class C waters. The "natural background range" would seem to allow better definition of an acceptable range for the Subecoregion 84 ponds, but that interpretation has not been addressed.

Results from the 2014 Plymouth PALS sampling generally fit within the ranges measured on Cape Cod. The median surface pH for the 41 Plymouth ponds measured during the 2014 Snapshot was 6.71 with a range of 4.21 to 9.22 (minimum = Forges Pond, maximum = Billington Sea East). The median 2014 surface alkalinity was 5.9 with a range of 1.3 to 22.6 mg/L as $CaCO_3$ (minimum = Clam Pudding Pond, maximum = Ship Pond). Thirteen (or 32%) of the ponds had surface pH reading less than the 6.5 pH minimum required in the state surface water regulations and three (7%) were greater than the 8.3 pH upper limit (Figure 14). The higher than expected median reading is consistent with the high chlorophyll concentrations since photosynthesis would tend to raise pH.

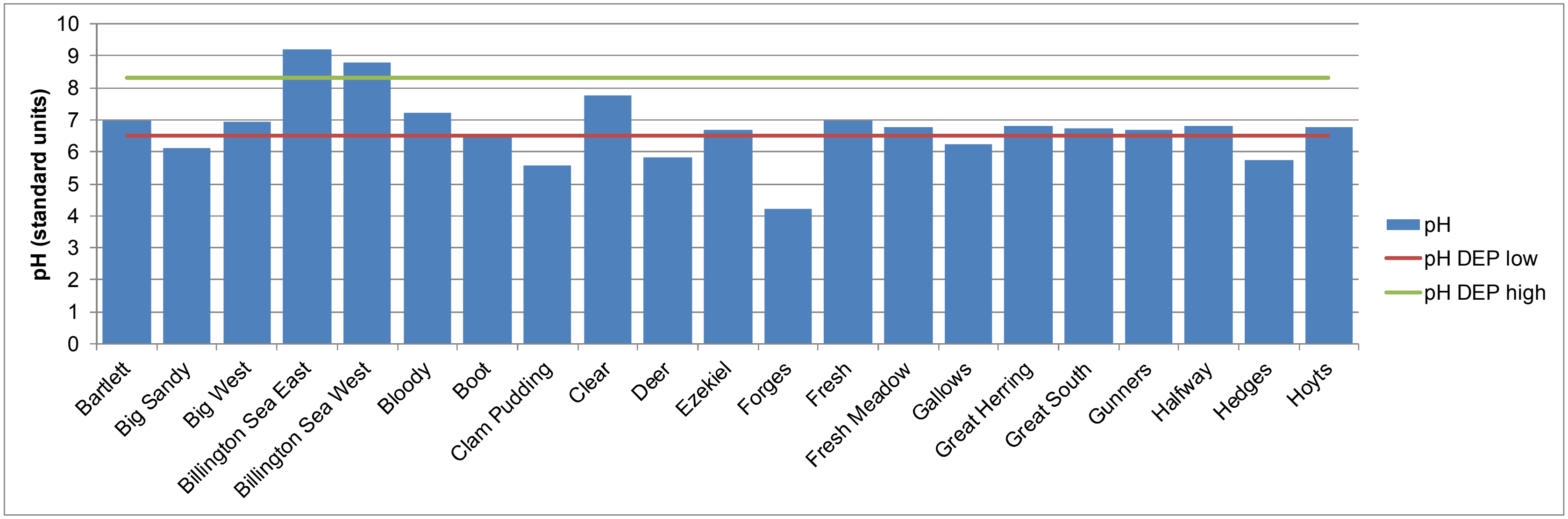
Collected readings also appear to be consistent with most data collected by pond associations. For example, Billington Sea East has been sampled 17 times between 2008 and 2014, while Great Herring Pond (GH10 site) has been sampled 19 times between 2010 and 2014. Billington Seas East had an average pH of 7.83 and a range of 7.04 to 9.37, while Great Herring Pond had an average pH of 7.04 and a range of 6.31 to 7.43. The surface pH reading in the 2014 PPALS Snapshot for the two ponds was 9.22 and 6.8, respectively. Both of these readings are with the range established by previous readings.

iv. Clarity/Transparency (Secchi Depth)

The clarity of water influences the availability of light for phytoplankton and rooted aquatic plants and, thus, how much plant growth can occur in a lake or pond. How well light is transmitted through water is influenced by particles of various sizes in the water and to a great extent by particles in the range of sizes associated with phytoplankton. Because of this, measurements of transparency are linked to concentrations of plankton or inorganic particles and have been linked through a variety of analyses to trophic status of lakes.[60] Transparency is usually measured using a Secchi disk (Figure 15), which is traditionally in freshwater studies an 8 inch disk with alternating black and white quadrants. It is notable that since phytoplankton populations change based on a large number of factors, Secchi measurements are best collected over a period of time to assess the likely fluctuations.

Measured Secchi disc transparencies range from a few centimeters in very turbid lakes to over 40 m in a few clear lakes.[61] Based on 79 readings, USEPA currently has a reference threshold of 2 meters for ponds within Subecoregion 84, which includes Plymouth.[62] Although it varies among individual ponds, kettlehole ponds in the Plymouth region would tend to have

[59] 314 CMR 4.05(3)
[60] *e.g.*, Carlson, 1977
[61] Wetzel, 1983
[62] USEPA, 2001



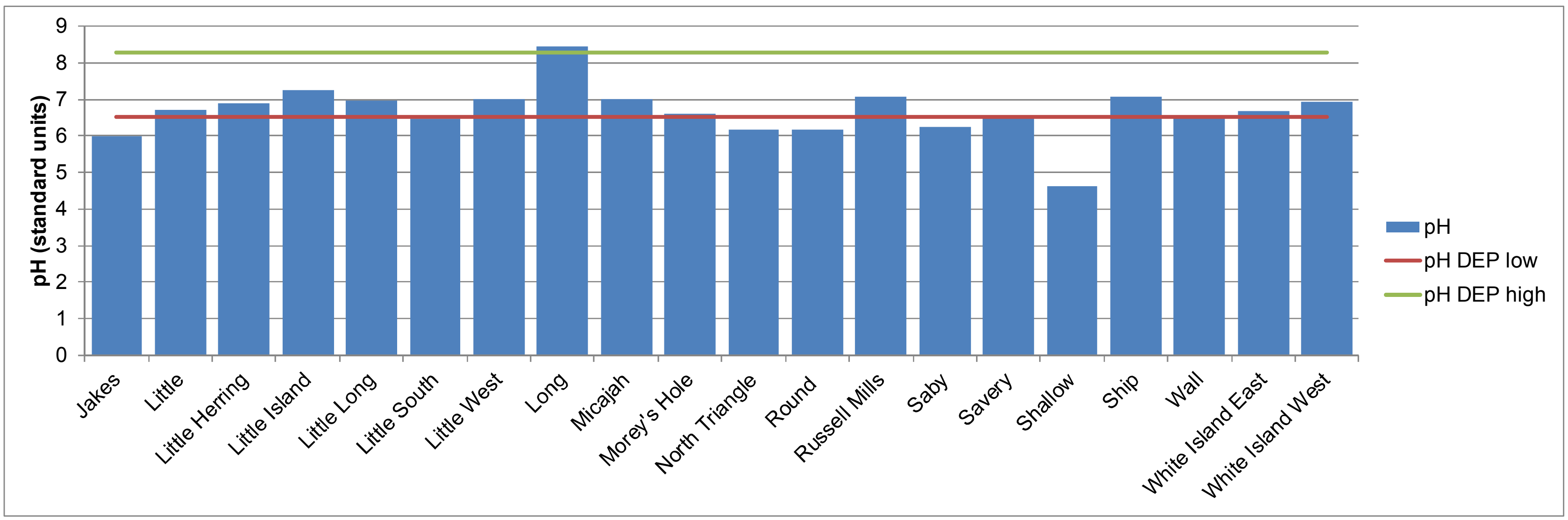
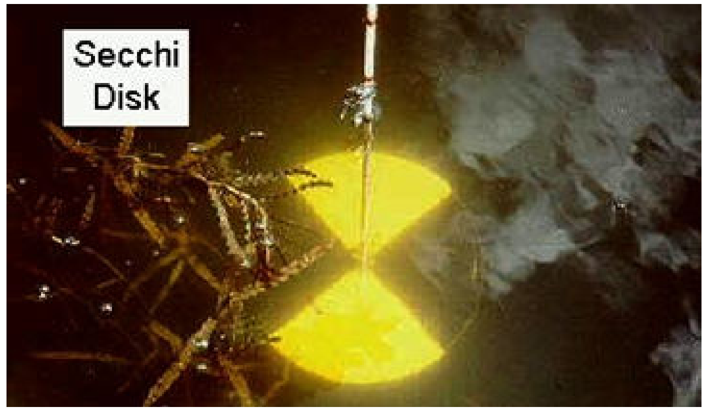


Figure 14. 2014 Plymouth PALS Snapshot: pH readings. Snapshot surface water readings are compared to state surface water range: 6.5 to 8.3 [314 CMR 4.05(3)]. 13 ponds had pH less than 6.5 and 3 ponds had pH greater than 8.3.

clarity determined almost exclusively by phytoplankton because of the lack of particle inputs from streams or rivers

Figure 15. – Secchi Disk



From: www.epa.state.il.us/water/conservation-2000/volunteer-lake-monitoring/secchi-disk.jpg

Secchi depth is also related to the overall depth of a pond; if the pond is relatively shallow, the disk may be visible on the bottom even with significant algal densities. In many shallow ponds, the Secchi disk can be seen on the bottom of the pond. In these ponds, the transparency is not limited by the clarity of the water, but by the depth of the pond. For this reason, comparison of Secchi readings between ponds should group ponds of similar depths.

Among the 39 ponds sampled during the 2014 Plymouth PALS Snapshot, the median Secchi reading (3.0 m) was more than half (60%) of the total depth. Five of the ponds had sufficient clarity that the Secchi disc could be seen on the pond bottom; the greatest total depth among these was 3 m (Figure 16). The lowest relative Secchi reading was 9% for Long Pond, which had a Secchi reading of 2.5 m over its 25.7 m deepest point. The smallest Secchi reading among ponds where the disc was not resting on the bottom was 1.4 m, which was recorded in both Fresh Meadow Pond (total depth of 2.9 m) and Savery Pond (total depth of 3.5 m). Among the 10 ponds with the lowest relative Secchi readings were: Long, Great Herring, Russell Mills, Clear, Great South, and White Island West Basin.

A select number of Plymouth ponds have had Secchi readings collected over a number of years by their pond associations. These longer term records provide some sense of whether the conditions measured during the 2014 Plymouth PALS Snapshot are representative of average conditions. For example, Great Herring Pond has 16 Secchi and total depth readings collected between July 2010 and October 2013 with 10 collected during the greatest period of interest (June to September). Among the whole dataset, the average Secchi depth reading at the deepest location (GH10) was 2.91 m, while the average was 2.31 m during June through September. The corresponding averages for relative Secchi readings were 27% and 22%. The Secchi reading and relative Secchi reading for Great Herring Pond during the 2014 Plymouth PALS Snapshot were 2.0 m and 16%, respectively. Both of these readings were below the longer term summer averages, but were within one standard deviation, and would be considered reasonable matches with average summer conditions.

v. Dissolved Oxygen and Temperature

Oxygen concentrations and temperature play an important role in how lake ecosystems function, including where species live and which species are favored. For example, the availability of oxygen plays an important role in the distribution of various fish species: trout require higher concentrations, while bullheads are more tolerant of occasional low oxygen

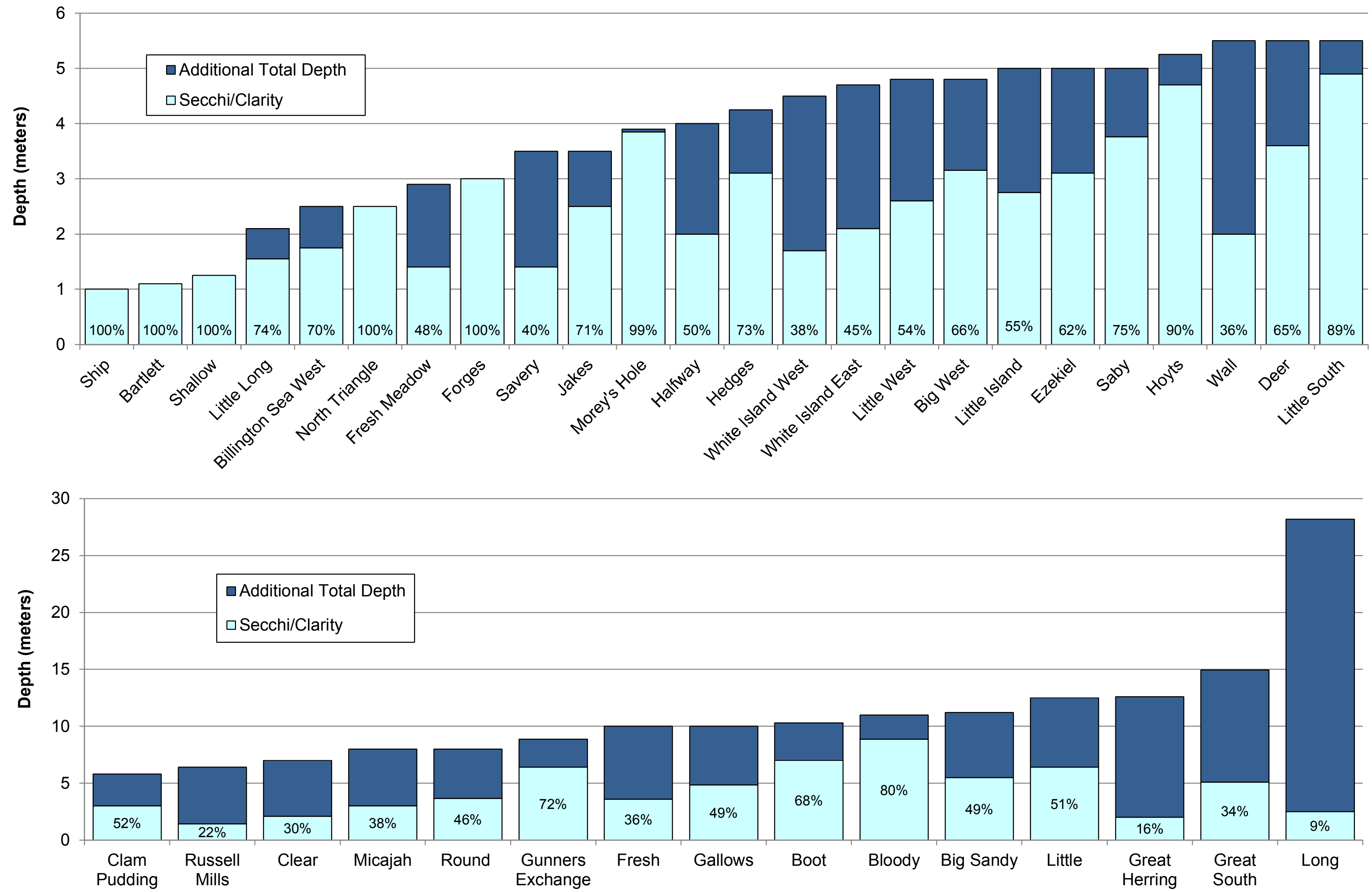


Figure 16. 2014 Plymouth PALS Snapshot: Secchi/Clarity and Total Depth Readings. Total bar lengths indicate total depth, while light blue bars indicate Secchi/clarity depths. Data labels within bars indicate Secchi depth as a percentage of total depth.

concentrations. Oxygen concentrations also 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. Oxygen availability is also impacted by temperature higher temperature waters can hold less dissolved oxygen. Temperature also plays a role in favoring species in different parts of a pond ecosystem: fish species, such as bass, prefer warmer shallow waters. Also, as mentioned above, layering or stratification of the water column is largely a temperature-driven phenomenon.

Biological interactions can also impact DO concentrations. Since one of the main byproducts 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.

The discussion of dissolved oxygen and temperature reinforces the need to consider depth in the characterization of pond ecosystems. Most water quality regulations and regulatory guidance try to get at this indirectly (*e.g.*, cold and warm water fisheries in Massachusetts surface water regulations). The USEPA reference methodology, for example, focusses on chlorophyll and nutrient concentrations which are likely to be influenced by conditions deeper in a pond, but usually assumes that a state already has dissolved oxygen minima.

As mentioned in the above discussion, Massachusetts water quality regulations include numeric standards for both temperature and dissolved oxygen and distinguish between warm and cold water systems. Experience during 13 years of Cape Cod PALS sampling has shown that ponds and lakes in this ecoregion tend to have cold water fisheries if they are greater than 7 to 9 m deep. Ponds shallower than this depth tend to have waters columns that are well-mixed by available winds, tend to have similar temperatures throughout the water column, and would be considered warm water fisheries. State surface water regulations state that Class A and B cold water fisheries should have dissolved oxygen concentrations greater than 6 mg/L, while warm water fisheries should have dissolved oxygen concentrations greater than 5 mg/L.[63] Class C waters have somewhat more relaxed standards, but shall be no lower than 3 mg/L. Temperatures in cold water fisheries should not exceed 68°F (20°C) based on a seven day mean and warm water fisheries should not exceed 83°F (28.3°C). The regulations allow some flexibility in these standards if "natural conditions" are above or below these limits. All ponds and lakes in Plymouth are classified as either Class A or Class B waters.

Figure 17 shows DO concentrations collected during the 2014 Plymouth PALS Snapshot. These readings are compared to the state surface water regulation limits of 5 and 6 mg/L. Out of the 39 ponds sampled, 14 have at least one DO concentration measurement below one of the

[63] 314 CMR 4.05

state limits. Six (6) of the ponds have concentrations less than 1 mg/L: Morey's Hole, Russell Mills, Round, Gunners Exchange, Boot, and Long. These ponds are likely to have the greatest impact from enhanced sediment regeneration of phosphorus, since sustained anoxic conditions (DO <1 mg/L) typically release the most weakly bound phosphorus. Further measurements of water quality and characterization of sediments, typically through incubation of collected cores, would allow direct measurement of the potential phosphorus regeneration mass. Hypoxic conditions (less than the state DO limits) would also release phosphorus from the sediments, but the residual DO would help to suppress the amount released.

DO concentrations typically fall below state limits when excessive plant growth causes sediment bacterial oxygen uptake greater than rates of oxygen replenishment, but impaired water quality conditions can also be indicated by excessive DO concentrations. Phytoplankton populations sustained by excessive nutrients can add DO to the water column in excess of what would otherwise exist if atmospheric mixing of DO was the only process occurring. These conditions result in DO concentrations more than 100% of atmospheric saturation. Since DO saturation just above 100% could be due to a variety of causes and therefore is not diagnostic, project staff identified ponds with DO saturation readings above 110%. Six (6) ponds had DO saturation readings >110% during the 2014 Plymouth PALS Snapshot: Billington Sea (both basins), Little Long, Forges, Gallows, Little, and Long. These ponds would be added to the list of ponds with DO concentrations <1 mg/L as ponds with water quality impairments that should be considered for management options.

As mentioned above, temperature plays a role in determining how much oxygen can be dissolved in water, but it also is a key measurement in determining whether a pond has a cold water fishery. State regulations use the 20°C threshold as the criterion for cold water fishery. During the summer, temperatures in the upper portion of a pond's water column will exceed 20°C; all of the surface temperatures during the 2014 Plymouth PALS Snapshot were above 20°C. Eleven (11) ponds had deep water temperatures below 20°C: Little Long, Forges, Russell Mills, Clear, Gunners Exchange, Fresh, Boot, Big Sandy, Little, Great South, and Long. It would be expected that ponds greater than 9 m deep would have deep waters with temperatures less than 20°C, but some of these ponds are very shallow and, obviously, have other factors that are influencing water column temperatures other than wind mixing and solar warming. Typical factors that can cause these sorts of temperature signatures can include significant groundwater discharge, topographic protection from winds, and/or a small surface area relative to the pond depth. Further examination of each individual pond would help to clarify these results and refine the classification of these ponds as cold water or warm water fisheries for the purposes of the state surface water regulations.

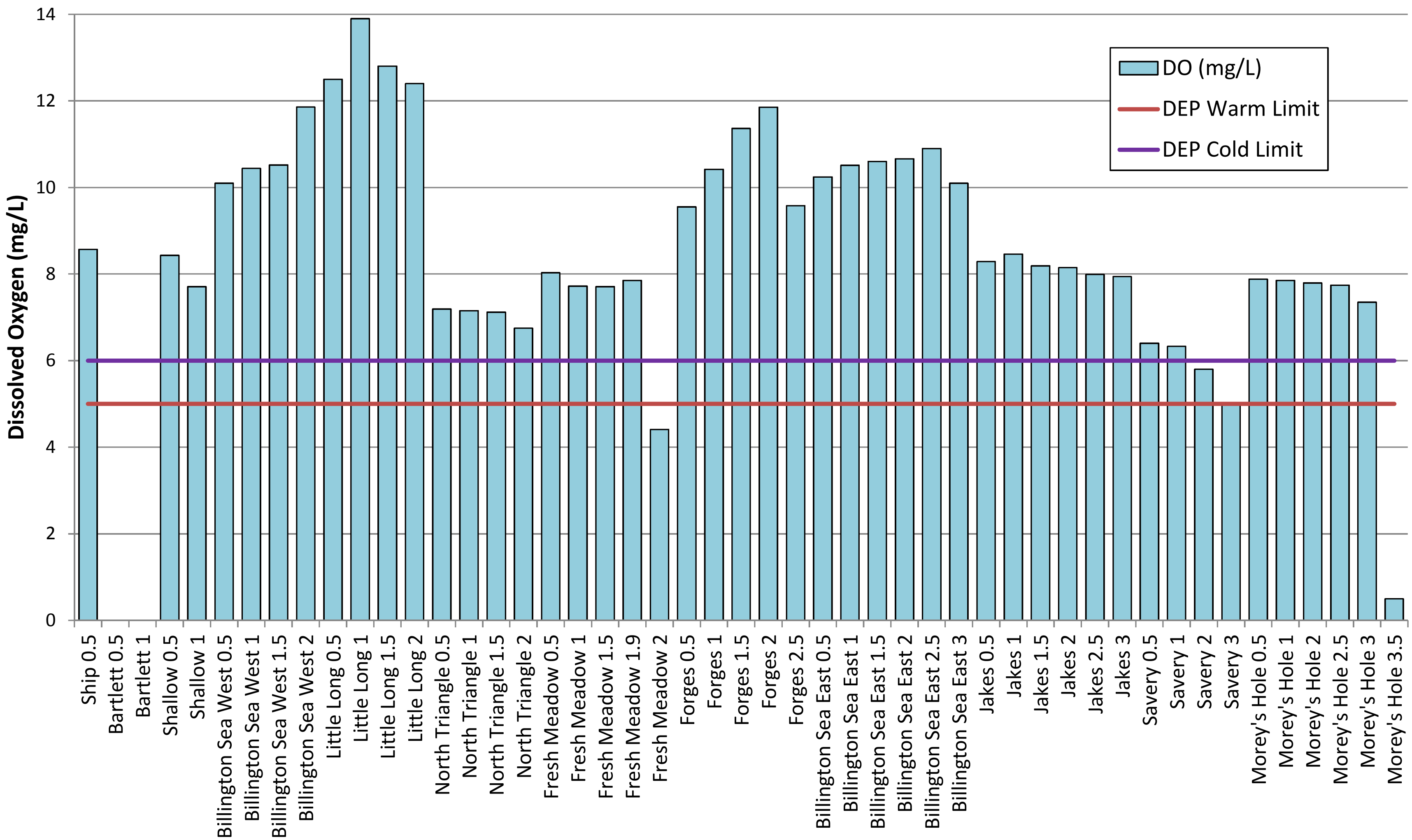


Figure 17a. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings (Ponds with total depth ≤ 3.9 m). Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

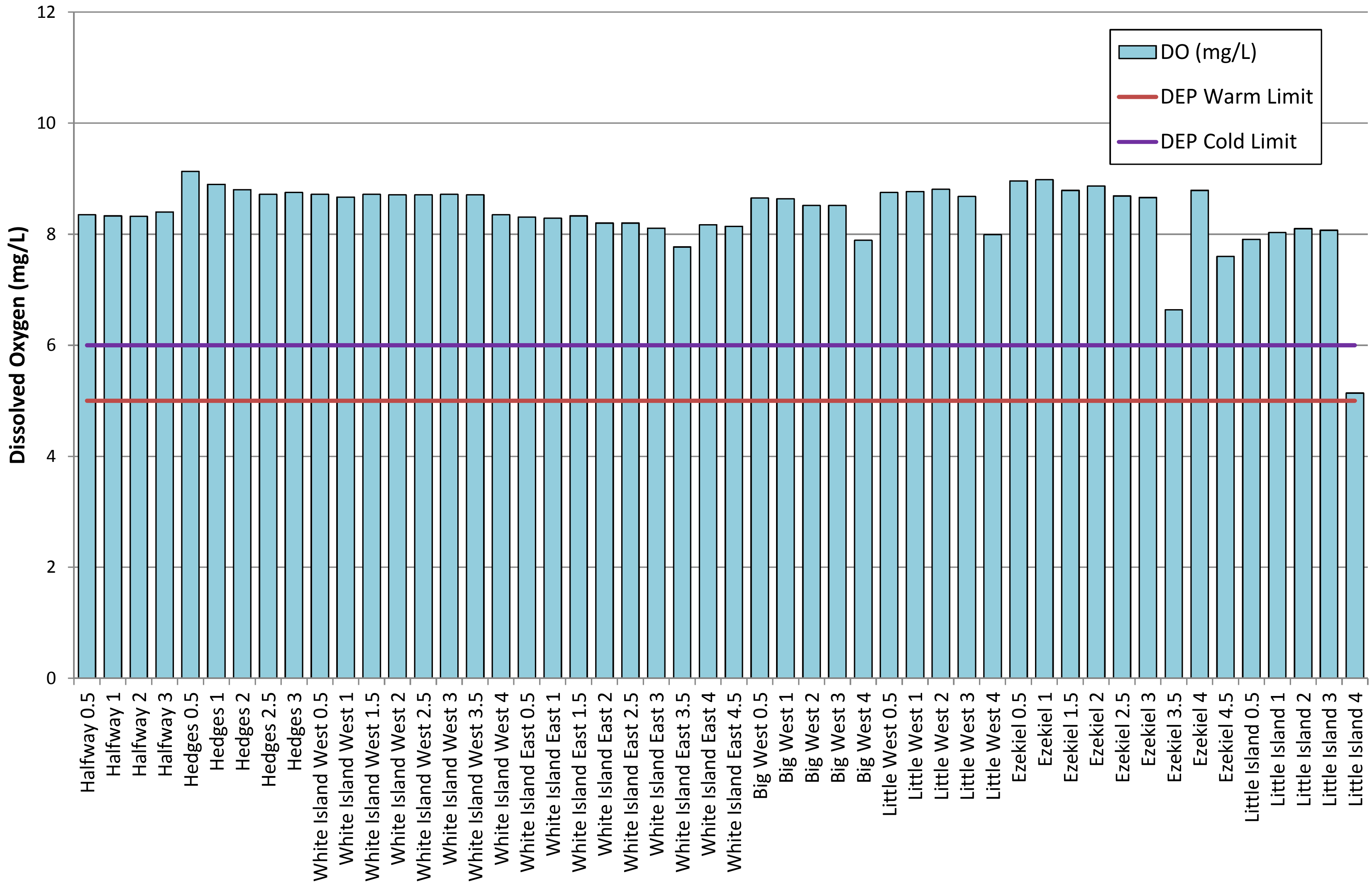


Figure 17b. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings [Ponds with total depth 4 m to 5 m (Little Island)]. Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

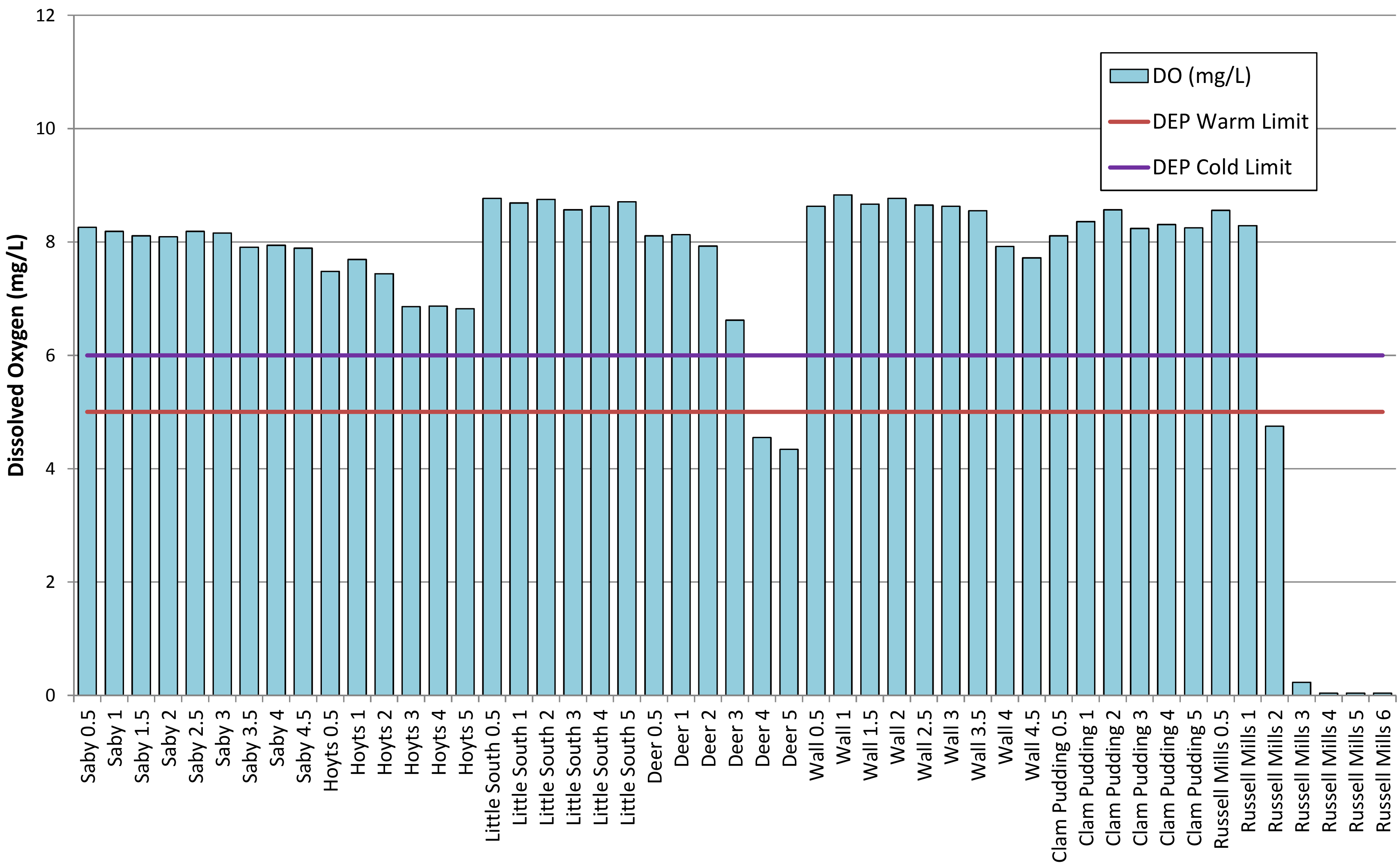


Figure 17c. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings [Ponds with total depth 5 m (Saby) to 6.4 m]. Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

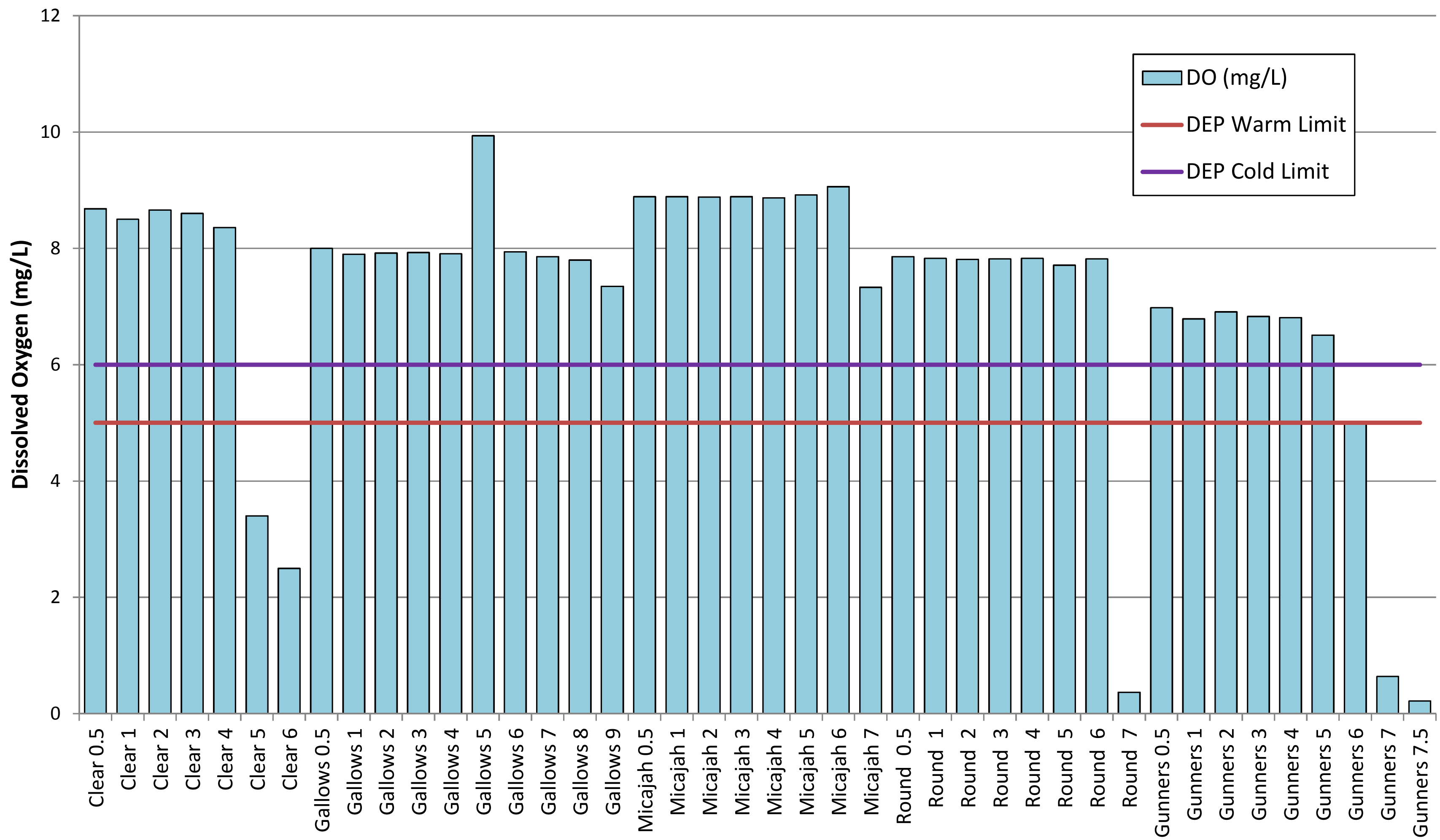


Figure 17d. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings (Ponds with total depth 7 m to 9 m). Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

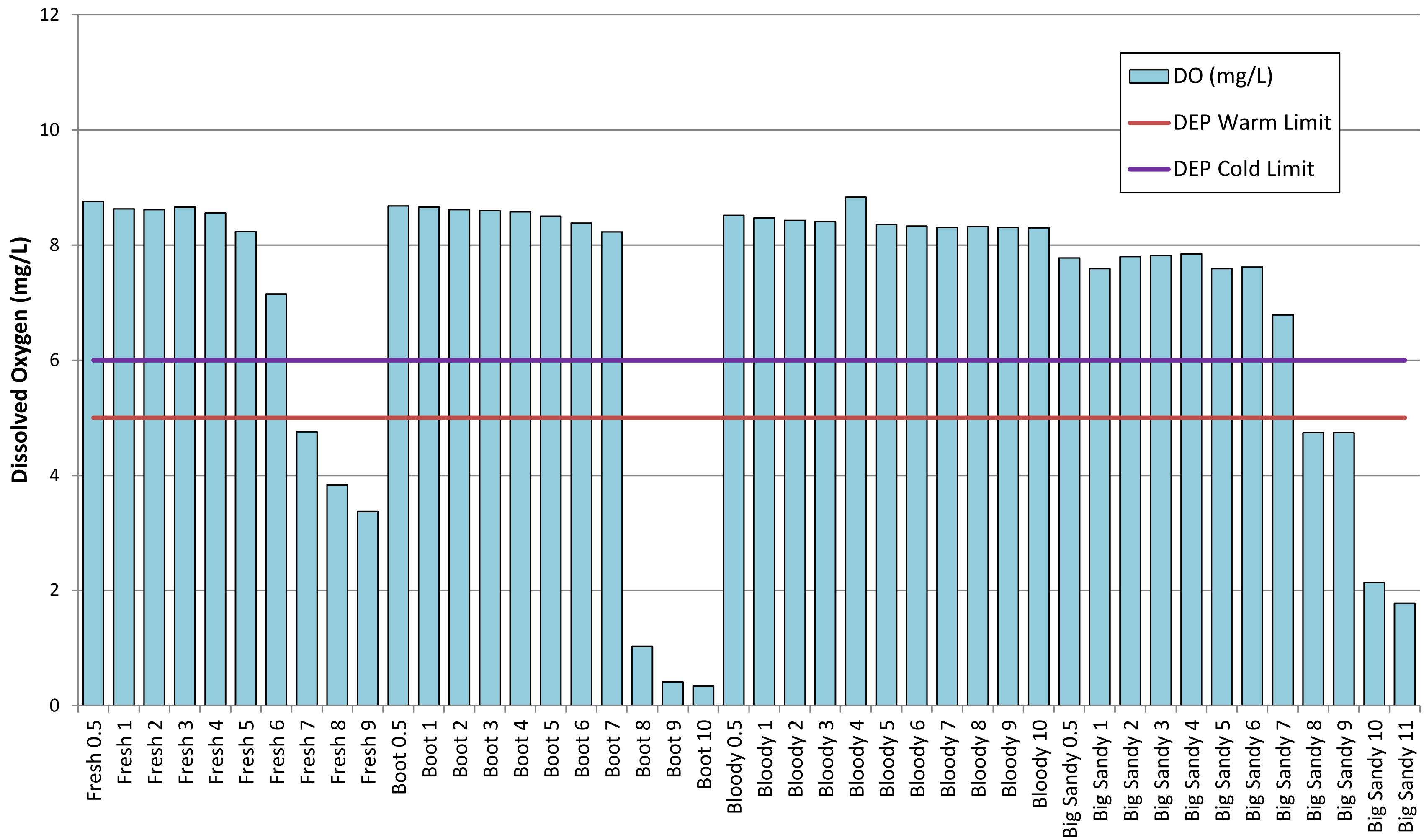


Figure 17e. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings (Ponds with total depth 10 m to 12 m). Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

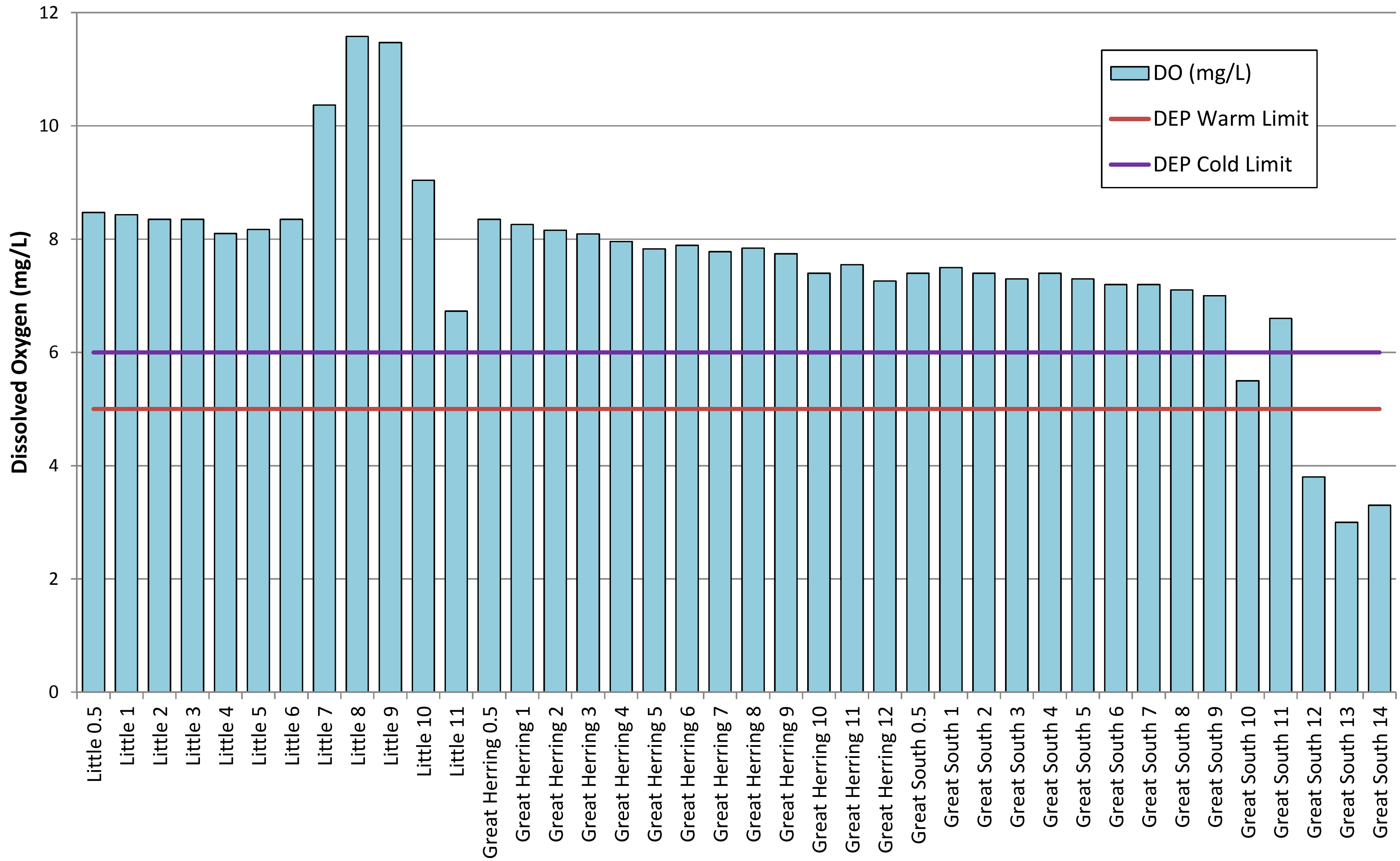


Figure 17f. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings (Ponds with total depth 12.5 m to 15 m). Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

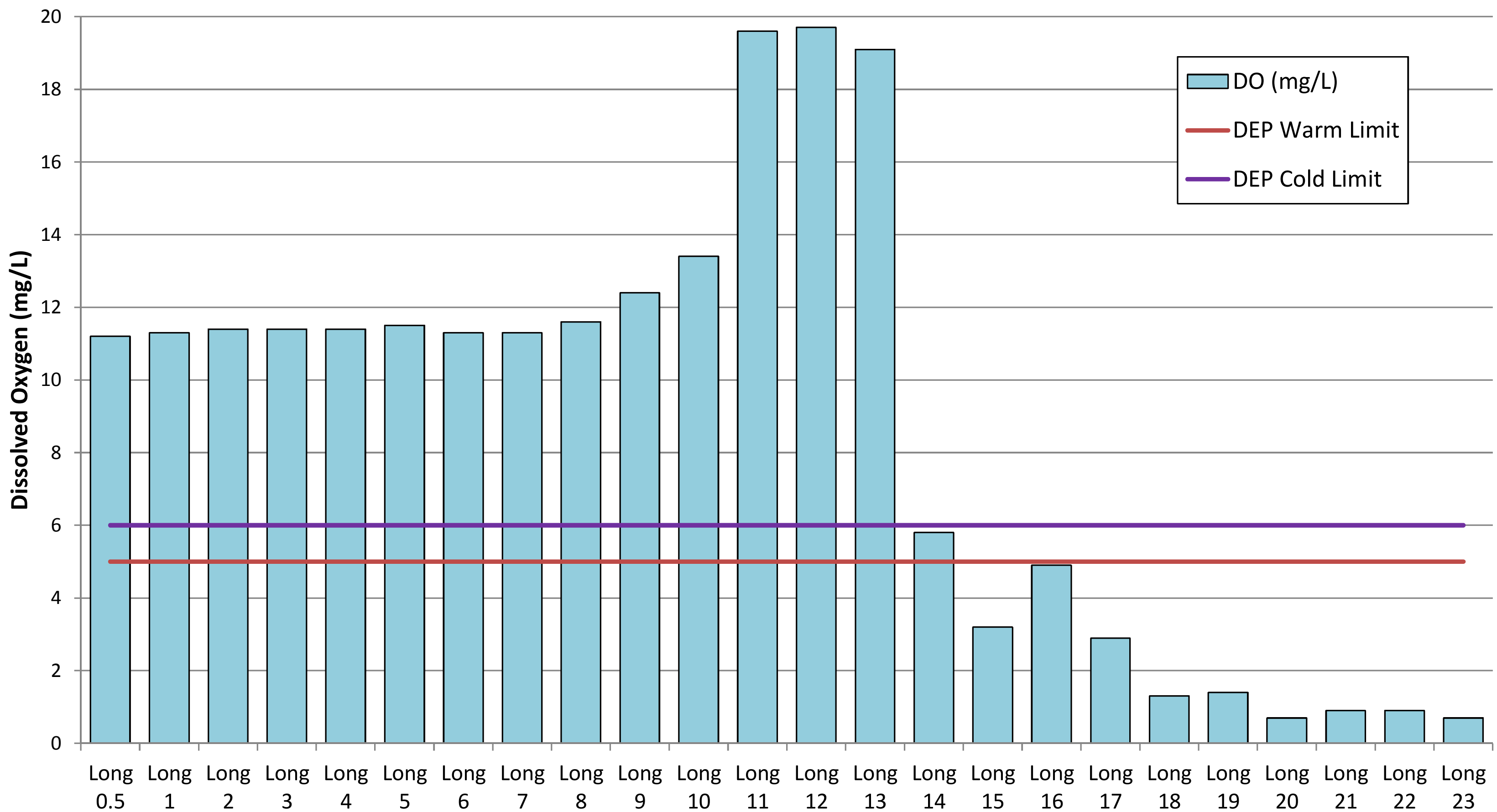


Figure 17g. 2014 Plymouth PALS Snapshot: Dissolved Oxygen Readings (ponds >15 m total depth: Long Pond). Snapshot DO readings are compared to state surface water regulatory limits: 5 mg/L for warm water fisheries and 6 mg/L for cold water fisheries [314 CMR 4.05(3)]. 14 of the 41 ponds sampled had at least one measured DO concentration below one of the state limits.

C. Other Plymouth Pond and Lake Water Quality Concerns

While the 2014 Plymouth PALS Snapshot provides the most extensive sampling of Plymouth ponds and lakes since the 1970s, there are a number of ponds and pond water quality issues that local pond associations, the town, the state, and other stakeholders have been concerned about. Aside from the water quality standards compliance issues discussed above (e.g., TMDLs), these other issues have included: 1) limits on fish consumption due to mercury contamination, 2) harmful algal blooms, 3) bacterial contamination, and 4) growth of invasive or exotic species. Each of these issues is briefly discussed below.

1. Mercury

Mercury is a naturally occurring element that is often released into the atmosphere by burning of fossil fuels. Mercury is also a neurotoxin that can bioconcentrate in fish tissue to levels that are a human health concern. Studies of lake pH levels and concentrations of mercury in fish have shown that low pH/acidic conditions generally favor high mercury concentrations.[64] Given the generally low pH of most ponds and lakes in southeastern Massachusetts (see above), this relationship has raised concerns about the safety of consuming fish caught in these ponds.

The most recent Massachusetts advisory list for freshwater fish consumption includes 154 ponds and lakes in the commonwealth with pond-specific mercury advisories.[65] Two of these ponds are in Plymouth: Great Herring Pond and Great South Pond. Great Herring Pond has advisories for small mouth bass, while Great South Pond has advisories for all fish species. These advisories include recommendations to avoid consumption for children under 12 years old and women who are pregnant, who may become pregnant, or are nursing, as well as consumption limits for the general public. Sampling of fish tissue for mercury contamination has been accomplished by both the Massachusetts Department of Public Health[66] and the Massachusetts Department of Environmental Protection (MassDEP).[67] It is unclear from a review of their respective websites how many ponds and lakes and fish species in each have been tested.

MassDEP was also a party to a 2007 regional TMDL for mercury that was developed by the New England states and New York and approved by EPA.[68] This TMDL provided a strategy for primarily reducing atmospheric mercury sources in the Northeast. MassDEP has classified ponds and lakes with documented mercury contamination of fish tissue as having a "TMDL completed" (Category 4a) in the most recent proposed Massachusetts Integrated List of Waters.[69] The same two Plymouth ponds with pond-specific consumption advisories are listed in this category in the 2014 proposed Integrated List: Great Herring Pond and Great South Pond.

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[64] *e.g.*, Greenfield, *et al*. (2001), MADEP (1997)

[65] Massachusetts Department of Public Health, Bureau of Environmental Health, Freshwater Fish Consumption Advisory List, August 2013.

[66] MassDPH: http://www.mass.gov/eohhs/gov/departments/dph/programs/environmental-health/exposure-topics/fish-wildlife/fish/, Fish Consumption Advisories list only Great Herring Pond and Great South Pond, does not list any other ponds where testing may have not resulted in advisories

[67] MassDEP: http://public.dep.state.ma.us/fish/, Fish Mercury Research Data Portal does not list any Plymouth ponds or lakes as having been tested.

[68] http://www.epa.gov/region1/eco/tmdl/pdfs/ne/Northeast-Regional-Mercury-TMDL.pdf. Northeast Regional Mercury Total Maximum Daily Load. October 24, 2007.

[69] Massachusetts Department of Environmental Protection. June, 2014. Massachusetts Year 2014 Integrated List of Waters, Proposed Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act. MassDEP, Division of Watershed Management, Watershed Planning Program. Worcester, MA.

2. Harmful Algal Blooms

As mentioned above, phytoplankton form the base of most pond and lake ecosystems in southeastern Massachusetts; they collect solar energy and that energy is passed up the food chain as they are consumed. Phytoplankton populations are a mix of a large number of different plant species with different survival and competition strategies. Within this mix is a class of species labeled blue-green algae or cyanobacteria. These algae are usually part of the phytoplankton population in a pond or lake, but some species have competition strategies that include the ability to take nitrogen directly from the air and these often produce toxins.

The ability to take nitrogen from the atmosphere is a competitive advantage in situations with excessive phosphorus. Green algae will have to search out dissolved nitrogen, while blue-green algae can grow and reproduce more rapidly. In these situations, the blue-green algae outcompete other phytoplankton, expand their population rapidly, and form a "bloom." Blue-green algal blooms often look like latex paint spilled on the surface of a pond.

The toxins some species of blue-green algae[70] can produce have been variously characterized as harmful to neurological, hepatic, and cellular systems. Extended contact with water in the midst of a bloom has resulted in skin rashes and eye and ear irritations. Consumption of blue-green algae by dogs along pond shorelines has resulted in over 400 documented cases of cyanotoxin poisoning in the United States since the late 1920's.[71]

In order to begin to address health concerns associated with blue-green algal blooms, MassDPH has released guidelines for acceptable cyanobacteria cell counts and water consumption.[72] These guidelines include the recommendation of avoiding contact with waters have cyanobacteria cell counts greater than 70,000 cells/mL or 14 µg microcystin (one of the toxins) per liter water. The guidelines also include sign posting recommendations for waters exceeding these limits, as well as retesting recommendations prior to allowing a return to normal water contact.

MassDPH, usually in coordination with MassDEP, responds to potential blue-green algal blooms as personnel and funding allow. MassDPH had a federal grant to conduct limited monitoring of five ponds for blue-green algae between 2009 and 2013, but this funding has ended. MassDPH maintains a Harmful Algal Bloom database that includes a history of the all the ponds MassDPH or MassDEP have tested or listed for advisories. As of the end of 2013, this database included 555 testings and/or advisory listings.[73] Among these, Plymouth has listings for testing of four ponds: Halfway, Little Long, Savery, and White Island Pond. Savery Pond was tested twice and the other three ponds were tested once each. Advisories were issued for each testing[74], plus two additional advisories for White Island Pond based on observations of "scum." Posted advisories for Plymouth ponds had durations of between 11 and 92 days.

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[70] e.g., *microcystis*, *anabaena*

[71] Backer, L. C., Landsberg, J. H., Miller, M., Keel, K., & Taylor, T. K. 2013. Canine Cyanotoxin Poisonings in the United States (1920s–2012): Review of Suspected and Confirmed Cases from Three Data Sources. *Toxins*, 5(9), 1597–1628. doi:10.3390/toxins5091597

[72] Available at: www.neiwpcc.org/neiwpcc_docs/protocol_MA_DPH.pdf

[73] Personal communication, Mike Celona, MassDPH, Chief, Water Toxics Unit, Environmental Toxicology Program

[74] All test results were greater than the 70,000 cells/ml guideline limit.

Blue-green algal blooms typically occur in ponds and lakes with excessive nutrients. Other conditions that seem to favor blooms include high temperatures and still waters. Management of water quality to reduce nutrient additions from watersheds or internally from sediments usually produces the added benefit of reducing or eliminating blue-green algal blooms in ponds and lakes.

3. Bacterial Contamination

Since Plymouth ponds and lakes are used extensively for swimming, ensuring that waters are safe for swimming is an important pond management consideration. In 2001, Massachusetts adopted the Beaches Bill, which required regular testing of all public and semi-public bathing beaches. State regulations to implement the law are contained 105 CMR 445 and require weekly bacterial testing. The Town of Plymouth Health Department tracks this testing and provided historic testing results for the preparation of this Atlas.[75]

Review of 2005 and 2014 testing shows that pond beaches in Plymouth are generally safe for swimming. Of the 2,638 samples collected from the pond beaches during those years, <1% of them exceeded the state regulatory limit of 235 *E. coli* colony forming units allowed per 100ml sample. In 2014, none of the samples in the Health Department database exceeded the limit. In all cases in the database, the subsequent week's sampling had results below the regulatory limit. Table 6 lists the 29 ponds with beaches sampled for bacteria between 2005 and 2014.

Table 6. Plymouth Ponds with beach bacterial testing between 2005 and 2014. Highlighted cells indicate ponds tested during 2014.

Barretts Pond	Curlew Pond	Fresh Meadow Pond	Long Pond
Big Sandy Pond	Darby Pond	Gallows Pond	Micajah Pond
Billington Sea	Elbow Pond	Great Herring Pond	Round Pond
Bloody Pond	Fawn Pond	Hedges Pond	Sandy Pond
Charge Pond	Fearings Pond	Hyles Pond	Savery Pond
Clear Pond	Five Mile Pond	Island Pond	Wall Pond
College Pond	Fresh Pond	Little West Pond	White Island Pond
			Whites Pond

4. Invasive/Exotic Species

Pond and lake ecosystems in Plymouth reflect their watersheds and all the factors that influence them. The species that make up the ecosystems have adapted to these factors and are in a dynamic balance with them and each other. Introduction of non-native and invasive species upset this balance and often cause instability in the ecosystem and how it responds to normal changes in influencing factors, especially if the non-native species have no natural predators or controlling species.

Massachusetts has a number of agencies tracking invasive species including the Department of Conservation and Recreation (DCR) and Coastal Zone Management (CZM). Invasive species listed for ponds and lakes include: Asian clam, Eurasian Milfoil, Fanwort,

[75] personal communication, Holly Ricardo, 2/15

Phragmites, and Zebra Mussel.[76] As part of the integrated listing of all Massachusetts waters required under the Clean Water Act, MassDEP also provides a list of ponds and lakes that are impaired by factors other than pollutants (*e.g.*, Category 4c waters). Most of the ponds and lakes in this category are impaired due to "non-native aquatic plants." It is unclear how comprehensive this list is.

Given the ecosystem disruption usually associated with the introduction of invasive species, most management efforts have focused on preventing the transfer of these species into ponds or lakes. During 2004 to 2008, DCR instituted a boat ramp monitor program to survey and prevent invasive aquatic plant transfers between ponds by inspecting boats and trailers.[77] During the five years of the program, monitors inspected 10,941 boats. Of these boats 2,132 were carrying plant fragments and 879 had fragments that were non-native.[78] Removal of these non-native plant fragments prevented 879 potential transfers of invasive species to other ponds.

Examples of invasive aquatic plant infestation show the potential costs and long-term challenges of control. In the Town of Barnstable, hydrilla (*Hydrilla verticillata*) was first detected in Long Pond in 2002. Hydrilla is a tropical Asian aquatic plant, but has shown a high level of adaptability. It was first discovered in the United States in 1960 at two Florida locations and it spread throughout the state very rapidly; covering 20,000 ha by 1988 with a jump to 40,000 ha in 43% of the public lakes by 1995.[79] Long Pond was the first identification of hydrilla in Massachusetts and DEM and the town responded rapidly to address the potential threat. By June 2002, the state and the town had appropriated approximately $50,000, selected a contractor, and completed an herbicide application. Since that initial application, the town has funded annual herbicide applications and follow-up plant surveys. In 2013, no hydrilla tubers were found during the annual plant survey.[80] Total estimated cost for removing the hydrilla infestation from this one pond was over $200,000.

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[76] http://www.mass.gov/eea/agencies/dcr/water-res-protection/lakes-and-ponds/aquatic-invasive-species.html (accessed Feb 2015).

[77] http://www.mass.gov/eea/agencies/dcr/water-res-protection/lakes-and-ponds/boat-ramp-monitor-program-generic.html (accessed Feb 2015).

[78] 8% of all boats inspected.

[79] Langeland, K.A. 1996. Hydrilla verticillata (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". *Castanea*. 61: 293-304. Available at: plants.ifas.ufl.edu/hydcirc.html

[80] Aquatic Control Technology. 2014. Town of Barnstable, Long Pond & Mystic Lake Non-Native Vegetation Management Program. Project Completion Report for 2013 Hydrilla Management.

III. Summary: Overall Condition of Plymouth Ponds

Plymouth has an active community of local pond associations and the Town has made ponds and lakes a priority focus of the Department of Marine & Environmental Affairs (DMEA). Plymouth has a total combined pond area of 5,002 acres divided among 450 ponds. Among this count are 83 ponds that are Great Ponds under Massachusetts law[81] and, therefore, public waters. The ponds are distributed throughout the town, but more of them are located west of Route 3. In the late 1970's the Town conducted baseline water quality surveys for 41 ponds within Plymouth[82], but since then only limited to periodic snapshots of individual ponds have been conducted. Pond and watershed associations have assisted by collecting limited data with their available resources, but inquiries and concerns from the residents of Plymouth regarding current water quality and management concerns continue to increase.

In order to begin to address resident concerns and lay the groundwork for more effective pond and lake management, the Town DMEA working in concert with the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) has begun the Plymouth Pond and Lakes Stewardship (PPALS) program. The PPALS program has begun by organizing past pond water quality data, formalizing procedures for current and future sampling of all ponds, and assessing the current status of 38 ponds based on a unified PPALS sampling during the late summer of 2014.

The ponds in the inaugural 2014 Plymouth PALS Snapshot have areas between 5.3 acres and 427 acres with a combined area of 2,850 acres or 57% of the total pond area in the town. Of the ten largest ponds in the town, eight were sampled during the 2014 Snapshot. The Snapshot was coordinated among the town DMEA, CSP/SMAST, pond associations, and volunteers. The Snapshot followed accepted sampling protocols with measurement of dissolved oxygen and temperature profiles and water clarity in the field and collection of water quality samples that were analyzed by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth. Water quality analysis included a number of parameters to assess key nutrient management targets, potential sediment regeneration of nutrients, and algal populations.

Massachusetts has water quality regulations that largely rely on descriptive standards, although there are four numeric water quality standards for dissolved oxygen, temperature, pH, and bacteria.[83] Potential regional standards for phosphorus, nitrogen, pH, and chlorophyll were developed for Cape Cod using sample results from 195 ponds.[84] Comparison of 2014 Plymouth PALS results to these standards show the following:

- 15 ponds (39%) had surface total phosphorus (TP) concentrations exceeding the impaired ecoregion threshold (10 µg/l).
- 27 ponds (71%) had surface water total nitrogen (TN) concentrations exceeding the impaired ecoregion threshold (0.31 mg/L). This finding is consistent with the extensive use of septic systems for wastewater treatment.

[81] MGL, Ch. 131, sec. 1 specifies all ponds greater than 10 acres are "Great Ponds" and all Great Ponds are "waters of the Commonwealth" and, as such, are publicly owned.
[82] Lyons-Skwarto Associates. 1970.
[83] 314 CMR 4.
[84] Eichner, E.M., T.C. Cambareri, G. Belfit, D. McCaffery, S. Michaud, and B. Smith. 2003. Cape Cod Pond and Lake Atlas.

- All of the ponds had nitrogen to phosphorus ratios above 16, suggesting that phosphorus was generally the key management nutrient; only three ponds had ratios close to 16 which needs to be explored in more refined, pond-specific assessments
- 26 ponds (72%) had shallow to deep water TP concentration ratios with higher concentrations in the deep waters and 13 ponds have deep water concentrations more than twice as high as surface water concentrations. Ratios greater than two strongly indicate sediment regeneration of TP into the bottom waters.
- 20 ponds (51%) had surface water chlorophyll-*a* concentrations exceeding the impaired ecoregion threshold (1.7 μg/L). The average concentration among all the ponds sampled in the 2014 Snapshot (3.6 μg/L) was more than twice the impaired threshold.
- 13 ponds (32%) had surface pH readings less than the Massachusetts surface water regulatory minimum (6.5) and three (7%) ponds had pH higher than the regulatory maximum (8.3). Low pH is a natural condition in the Plymouth ecoregion, while elevation pH is typically associated with high nutrient conditions.
- 14 ponds (37%) have at least one DO concentration that was less than one of the Massachusetts surface water regulatory minimums (5 or 6 mg/L depending on classification as a cold or warm water fishery).

Collectively, the 2014 Plymouth PALS results show a significant number of the surveyed 39 ponds currently have nutrient-related impairments. Because the PPALS Snapshot data is only indicative of one year's water quality and the Snapshot is designed to assess these ponds during what is likely to be their worst water quality conditions, additional, longer term data is necessary to evaluate how representative the Snapshot data is of general ecological conditions in individual ponds. Continuation of the PPALS Snapshots would allow tracking of long-term trends and eventually lead to better characterization of the water quality in these specific ponds, their year-to-year fluctuations, and identification of other factors necessary to develop water quality management strategies. It is clear from review of historic sampling that development of reliable management options for many of these ponds will also require targeted collection of process and source data, such as evaluation of sediment nutrient contributions, watershed delineations, measurement of stream inflows and outflows, plant distributions, and summer-long water quality measurement.

IV. Recommendations for Next Steps

The 2014 PPALS Snapshot and the review of the limited available historic pond monitoring information completed for preparation of this Atlas indicate that there are a number of ponds in Town of Plymouth with impaired conditions. The PPALS Snapshot indicated that 15 to 25 Great Ponds of the 39 sampled ponds had measured impaired conditions.[85] Considering that the PPALS Snapshot did not sample the remaining 47 Great Ponds located in Plymouth or the remaining 370 smaller ponds in Town, questions about overall pond management and monitoring strategies naturally arise.

Reliable pond management is based on sufficient understanding of pond ecosystems, generally how water and nutrients are added, removed and retained within a given pond. With this in mind, the extent of this characterization involves the availability of funding to collect the information, which in turn is generally related to community interest and support. The Plymouth PALS program, including both this Atlas and the water quality sampling during the 2014 Snapshot, is step toward addressing pond management town-wide.

In order to maintain the momentum toward addressing pond management in Plymouth and based on the review of historic reports and the 2014 PPALS Snapshot results, the following steps are recommended to continue and refine pond management in Plymouth:

1. Continue to support local pond association and PPALS Snapshot monitoring
   Rationale: these data collection and volunteer training steps are long-term maintenance steps that will eventually produce reliable data that can be incorporated into individual pond assessments and development of management strategies, as well as trend and variability analysis. These data will also allow identification of which ponds are in need of higher level assessments. Management of monitoring should include annual overview and a three to five year comprehensive review and Atlas update. Continued PPALS Snapshots can also provide the additional benefit of raising community awareness of issues and challenges in pond management, as well as a regular forum to discuss community concerns.

2. Review and adjust association monitoring strategies
   Rationale: Review of historic data from some of the pond associations shows that monitoring strategies could be adjusted to be more efficient and provide data that is needed or is more applicable for development of future management strategies

3. Begin to develop targeted data necessary for individual pond assessments, including bathymetry, stream flows, sediment characterization, and plant and mussel surveys. Data collection could be developed in the context of individual pond assessments or through collection of one characteristic for multiple ponds (*e.g.,* bathymetry for all Great Ponds).
   Rationale:
   a. Bathymetry: comparison of the refined bathymetry volume developed by CSP-SMAST for White Island Pond was 38% different than the volume developed from MassDFW contours using less precise techniques.[86] Other refined

[85] The count varies depending on the single parameter being reviewed.
[86] Eichner, E., B. Howes, and C. DeMoranville. 2012. White Island Pond Water Quality and Management Options Assessment.

bathymetric measurements have revealed differences of 3-41% from volumes based on MassDFW contour maps. These differences stem from the newer high resolution techniques used in the recent surveys. Differences influence determination of the balance of nutrient inputs and outputs, and thus management strategies.

b. Streamflow: review of historic information shows a number of ponds with inflow and/or outflow streams. Monitoring these flows over a hydrologic year would be necessary to determine the impact of these streams on phosphorus, nitrogen, and water balances within ponds,
c. Sediments: comparison of shallow and deep water monitoring results from the 2014 PPALS Snapshot show that 72% of the ponds had higher nutrient concentrations in the deep versus shallow waters. 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. 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.
d. Plant and mussel surveys: 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[87] 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.[88]

4. Begin to prioritize the completion of pond assessments and management planning. *Rationale:* Development of reliable management plans requires the integration of a number of datasets to provide an empirical-based model of how the pond system functions. Once this model is developed, communities can explore the details of options, including their costs, to restore pond water quality. Developing a prioritization strategy would assist the town in targeting funding including grant options and integration with community concerns.

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[87] Massachusetts List of Endangered, Threatened and Special Concern Species. http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/species-information-and-conservation/mesa-list/list-of-rare-species-in-massachusetts.html#MESAinvert (accessed Feb 2015).

[88] Eagle Pond and Cedar Pond Technical Support Project: Bathymetry, Submerged Aquatic Vegetation and Mussel Surveys, Water Bird Survey. December, 2012. CSP/SMAST Technical Memorandum. From: E. Eichner, B. Howes, and D. Schlezinger. To: Suzanne Brock, Chair, Water Quality Advisory Committee; Karen Johnson, Director of Natural Resources, Town of Dennis

5. Consider a Pondshore Landowner Education Program and a review of Town regulations for opportunities to enhance pond water quality protection.
   Rationale: Phosphorus in the ponds and their sediments was added by land uses within their watersheds. Opportunities to reduce watershed loads will help prolong and preserve the benefits of in-pond pond management strategies and enhance pond stewardship. Since sewer system are limited in much of the Town, septic systems will continue to be the predominant wastewater treatment technology and the primary source of watershed P loads to many ponds. The town may want to consider review of Board of Health regulations to maximize septic system leachfield setbacks and groundwater P travel times, as well as additional efforts to assist and educate pondshore homeowners with clear understanding of setbacks, buffer designs, alternative groundcover options, and other activities that will minimize stormwater and fertilizer phosphorus loading to the ponds.

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Appendix A

Town of Plymouth PALS Snapshot Field Sampling Sheet

POND AND LAKE SAMPLING DATA SHEET

Plymouth Pond and Lake Stewardship (PPALS) Monitoring Program

LAKE/POND NAME: ______________________________

Sample Collector(s): ______________________ Date:__________ Time: _______ (AM or PM)

Observations (write in or circle as appropriate):

Water Color: ____________________ (blue, brown, green, blue/green, red/orange, white, etc)

Weather (circle): 1. Cloudless, 2. Pt. Cloudy, 3 Overcast, 4. Rain, 5. Fog/Haze, 6. Drizzle, 7. Intermit. Rain

Wind (circle): 1. Calm, 2. Light Breeze, 3. Steady Wind, 4. Strong Wind

Plants on Pond (check conditions):	Over 50%	25% to 50%	10% to 25%	up to 10%	less than 1% or None
Waterlilies coverage of pond surface:					
Floating Algae on pond surface:					
Emergent Grasses/Sedges of surface:					
Other plant #1________________:					
Other plant #2________________:					
Other Notes:					

TOTAL DEPTH: ______________________________meter

SECCHI READING: Disappearing: _______ meter Reappearing: _______ meter

DISSOLVED OXYGEN/TEMPERATURE PROFILE

Meter Manufacturer: ______________________ Model# ______________________

Record DO/Temp profile in one-meter increments except for the first surface reading which is taken at 0.5 m (*for example:* 0.5 m, 1 m, 2 m, 3 m, etc). If the pond is very shallow (3 meters or less), record readings at 0.5 meter increments (*for example*: 0.5 m, 1 m, 1.5 m, 2 m, etc.).

Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)	Depth (m)	Temp (°C)	Dissolved Oxygen (mg/l)

LAKE/POND NAME: ____

GPS Coordinate: ____

Sample Collector: ________________________ Date:__________

LIST TOWN, POND NAME, SAMPLE DEPTH, AND DATE ON BOTTLE LABEL

⇒ ***POND GREATER THAN 9 METERS DEEP*** ⇐	
Sampling Depth	Bottle Label (Town, Pond Name, Sample Depth, Date & Time)
a. just below the surface	
b. 3 m down	
c. 9 m down	
d. 1 m above the bottom	

⇒ In ponds ~9 m deep, collect three samples (just below the surface, 3 m down, and 1 m above the bottom).

⇒ ***POND LESS THAN 9 METERS DEEP*** ⇐	
Sampling Depth	Bottle Label (Town, Pond Name, Sample Depth, Date & Time)
a. just below the surface	
b. 1 m above the bottom	

⇒ In ponds approximately 1 m deep, please collect two samples just below the surface.

TIME SAMPLING COMPLETED: ________ (AM or PM)

All water samples must be kept cold, in a cooler with ice packs. **Please call Kim Tower 774-244-0236** to either notify what time you will be delivering to town hall (before 2pm) or to have a pick-up samples/equipment. You will need to relinquish samples to the Town (signature below). Kim will deliver to the Coastal Systems Program/SMAST lab the same day (prior to 3:30 PM)!

Coastal Systems Program/SMAST lab is at 706 South Rodney French Blvd., New Bedford, Massachusetts 02744-1221, 508-910-6314.

SAMPLE SIGNOFFS

	Signature	*Recei*	*Deliver*
		Date/	*Date/Ti*
Pond Sampler			
Town - Deliverer			
Lab Analysis			

Appendix B

2014 Town of Plymouth Pond and Lake Stewardship (PPALS) Atlas

Individual Pond Briefs

The Plymouth Ponds water quality characterizations in this Appendix are based on available information including the 2014 PPALS Snapshot data. It is acknowledged that the PPALS Snapshot is designed to sample during the likely worst water quality period and that in many cases additional data is necessary to provide definitive context. Historic data in available references has been reviewed in these characterizations. Ponds characterized as impaired generally have dissolved oxygen concentrations below MassDEP regulatory minimums, chlorophyll-*a* and total phosphorus concentrations above ecoregion thresholds, and restricted clarity. The basis for these characterizations is detailed in each individual pond brief.

KEY:	Not Impaired	Borderline	Impaired

Ponds Included:

Bartlett	Hoyts
Big Sandy	Jakes
Big West	Little
Billington Sea	Little Herring
Bloody	Little Long
Boot	Little South
Clam Pudding	Little West
Clear	Long
Deer	Long Island
Ezekiel	Micajah
Forge	Moreys/Moreys Hole
Fresh	North Triangle
Fresh Meadow	Round
Gallows	Russell Mill
Great Herring	Saby
Great South	Savery
Gunners Exchange	Shallow
Halfway	Ship
Hedges	Wall
	White Island E / White Island W

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Bartlett

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Big Sandy

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Big West

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Billington Sea

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Bloody Pond

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Boot Pond

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Clam Pudding Pond

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Clear Pond

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Deer Pond

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Ezekiel Pond

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Forge Pond

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Fresh Meadow Pond

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Fresh Pond

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Gallows Pond

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Great Herring Pond

1. Lyons-Skwarto Associates. 1970. A Base Line Survey and Modified Eutrophication Index for Forty-One Ponds in Plymouth, Massachusetts. Volume II. Westwood, MA.
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5. Memo: Great Herring Pond and Little Herring Pond Monitoring Program. June 29, 2011. To: David Gould and Kim Michaelis, DPW Environmental Management, Town of Plymouth. From: David Worden, Limnologist/Biologist.
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Great South Pond

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Gunner Exchange Pond

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Halfway Pond

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2. Howes B.L., R.I. Samimy, E.M. Eichner, S.W. Kelley, J.S. Ramsey, D.R. Schlezinger (2013). Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Wareham River, Broad Marsh and Mark's Cove Embayment System, Wareham, Massachusetts, SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.
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Hedges Pond

No references

Hoyts Pond

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Little Pond

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Little Long Pond

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4. Memo: Pond Monitoring Program: Results for July 2008. July 24, 2008. To: David Gould and Kim Michaelis, DPW Environmental Management, Town of Plymouth. From: David Worden, Limnologist/Biologist.
5. Memo: Pond Monitoring Program: Results for October 2008. November 10, 2008. To: David Gould and Kim Michaelis, DPW Environmental Management, Town of Plymouth. From: David Worden, Limnologist/Biologist

Little South Pond

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Little West Pond

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Long Island Pond (aka Little Island Pond)

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Long Pond

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3. Massachusetts Division of Fisheries and Wildlife. Pond Maps-Southeast District: Long Pond; March 8, 2007 update. http://www.mass.gov/eea/docs/dfg/dfw/habitat/maps-ponds/dfwlongp.pdf (accessed 10/9/14).
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Micajah Pond

1. Eichner, E.M., B.L. Howes, and R. Samimy. July 2013. Final Report/Technical Memorandum for Task 1B (of 8): Cumulative Nitrogen Loading Determination. Massachusetts Estuaries Project Partnership for Nitrogen Management of the Plymouth Harbor - Duxbury Bay - Kingston Bay Estuarine System. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts – Dartmouth.
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North Triangle Pond

1. Lyons-Skwarto Associates. 1970. A Base Line Survey and Modified Eutrophication Index for Forty-One Ponds in Plymouth, Massachusetts. Volume IV. Westwood, MA.

Round Pond

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Russell Mill Pond

1. Inter-Fluve, Inc. 2007. Eel River, MA Restoration Project Concept Design Report. Prepared for David Gould, Town of Plymouth. Madison, WI.
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Sabys Pond

No references

Savery Pond

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

Shallow Pond

1. Lyons-Skwarto Associates. 1970. A Base Line Survey and Modified Eutrophication Index for 8 Ponds in Plymouth, Massachusetts. Westwood, MA.

Ship Pond

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

Wall Pond

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

White Island Pond

1. Eichner, E., B. Howes, and C. DeMoranville. 2012. White Island Pond Water Quality and Management Options Assessment. Completed for the Cape Cod Cranberry Growers Association. Coastal Systems Program, School of Marine Science and Technology, University of Massachusetts Dartmouth. 108 pp.
2. Massachusetts Department of Environmental Protection. 2013. Massachusetts Year 2012 Integrated List of Waters. Final Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act. CN: 400.1. Worcester, MA.
3. Massachusetts Department of Environmental Protection. April 13, 2010. Final Total Maximum Daily Load of Total Phosphorus for White Island Pond Plymouth/Wareham, MA. MassDEP, DWM TMDL Report MA95166-201009-1 CN 330.2.
4. Lyons-Skwarto Associates. 1970. A Base Line Survey and Modified Eutrophication Index for Forty-One Ponds in Plymouth, Massachusetts. Volume V. Westwood, MA.
5. Massachusetts Department of Environmental Quality Engineering. 1980. White Island Pond Water Quality Study, August 1976-May 1978. Water Quality and Research Section, Westborough, MA.

Bartlett Pond

PPALS Pond Number: 175
MassDEP PALIS Number: 94005

Area (acres): 31
Bathymetry: 1970s spot depths
Maximum Depth (m): 1.8
Lake Association: Sands of White Horse Beach

PPALS Sampling	9/4/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.1 m		
Total Depth	1.1 m		
Surface pH	6.97	6.5 – 8.3	MassDEP
Deepest DO	Not measured	5.0 mg/L	MassDEP
Shallow temperature	22.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.33 µg/L	1.7 µg/L	CCC
Surface TP	32.1 µg/L	10 µg/L	CCC
Surface TN	0.31 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.5		

OVERVIEW
Bartlett Pond is located just west of Taylor Avenue and approximately 750 ft from Cape Cod Bay. The pond receives upgradient groundwater discharge and receives surface water input from Beaver Dam Brook and discharges back to the Brook on the eastern shoreline. Shoreline is well developed, mostly with single family residences. There is limited public access through a town-owned property at the intersection of Brian's Way and Lopresti Road with parking available for 2-3 vehicles and car-top boats.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (1) and DO, pH, temperature, and specific conductivity profile readings were collected in April 2010 (2). Both sampling runs were accompanied by aquatic plant and phytoplankton surveys. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Bartlett Pond is shallow with clarity to the bottom at the time of the 2014 PPALS Snapshot. Temperatures show a well-mixed water column. Chlorophyll-*a* concentration was slightly higher than regional ecoregion standard, while total phosphorus was significantly higher (>3X higher). Clarity and lower than expected chlorophyll-*a* concentration likely due to extensive benthic algae community noted in 2010 (2). The extent of these algae appears to be a change from the 1970's era measurements, which noted extensive aquatic plants (1). April 2010 measurements (2) also noted anoxic dissolved oxygen conditions (<1 mg/L) near the sediments, which would also be consistent with the higher deep total phosphorus concentrations noted during the 2014 PPALS Snapshot.

Based on the available information, Bartlett Pond is impaired. This finding is generally based on the high total phosphorus concentrations, the extensive benthic algae community, and past DO concentrations below the MassDEP regulatory minimum. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Big Sandy Pond

PPALS Pond Number: 382
MassDEP PALIS Number: 95011

Area (acres): 148
Bathymetry: DFW map
Maximum Depth (m): >12 m
Lake Association:

PPALS Sampling	8/28/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	5.5 m		
Total Depth	11.2 m		
Surface pH	6.11	6.5 – 8.3	MassDEP
Deepest DO	1.78 mg/L	6.0 mg/L	MassDEP
Shallow temperature	24.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	6.59 µg/L	1.7 µg/L	CCC
Surface TP	<1.55 µg/L	10 µg/L	CCC
Surface TN	0.28 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	51.5		

OVERVIEW

Big Sandy Pond is located north of Gunning Point Road and south of Scarlet Drive and is near a number of ponds, including White Island Pond, Ezekiel Pond, and Whites Pond. The pond is a true kettlehole pond with no surface water inflows or outflows. Shoreline is well developed with mostly with single family residences except for an approximately 800 ft portion. There is a state boat ramp with a parking area for public access.

Fish population is actively managed by MassDFW, including two "reclamations" in 1967 and 1970 followed by stocking of trout and smallmouth bass (1). Pond is annually stocked in the spring and fall with brook, brown and rainbow trout. The pond was treated with limestone in 1974 and 1983 to try to raise its pH.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (2) and extensively in 1982 as part of a management plan (3). DO, pH, temperature, and specific conductivity profile readings were collected in May 2010 (4). The 1970s-era and 2010 sampling runs were accompanied by aquatic plant and phytoplankton surveys. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Big Sandy Pond is deep enough to support a cold water fishery; the temperature profile collected during the 2014 PPALS Snapshot shows a cold water layer beginning to develop around 8 m. The dissolved oxygen profile from the 2014 PPALS Snapshot show sediment oxygen demand in this cold water layer and concentrations below the MassDEP minimum regulatory limit. Elevated nutrient concentrations measured at depth also show regeneration of sediment nutrients. Elevated surface chlorophyll concentrations suggest potential surface nutrient inputs separate from the sediment nutrient regeneration.

Based on the available information, Big Sandy Pond is impaired. This finding is generally based on DO concentrations below the MassDEP regulatory minimum and high chlorophyll-*a* concentrations. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Big West Pond

PPALS Pond Number: 13
MassDEP PALIS Number: 95012

Area (acres): 43
Bathymetry: 1970s spot depths
Maximum Depth (m): 4.9
Lake Association:

PPALS Sampling	8/26/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.15 m		
Total Depth	4.8 m		
Surface pH	6.95	6.5 – 8.3	MassDEP
Deepest DO	7.89 mg/L	5.0 mg/L	MassDEP
Shallow temperature	25.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.21 µg/L	1.7 µg/L	CCC
Surface TP	1.65 µg/L	10 µg/L	CCC
Surface TN	0.44 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	2.25		

OVERVIEW
Big West Pond is located north and west of Federal Furnace Road and is hydrologically connected to Grassy Pond, Little West Pond, Spring Pond, and Great West Pond. Shoreline is well developed with mostly with single family residences except for an approximately 1000 ft portion of the southern shoreline that is owned by MassDEM. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Big West Pond is relatively shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings show a well-mixed water column with some slight loss of DO near the sediments. Chlorophyll-a and total phosphorus readings show elevated concentrations at depth indicating some sediment nutrient regeneration. 1970's-era readings showed extensive rooted aquatic plant populations, which would tend to keep water column TP concentrations low. High total nitrogen concentration would be consistent with septic system inputs and would appear to make this pond very sensitive to phosphorus inputs.

Based on the available information, Big West Pond is not impaired. This finding is generally based on acceptable DO concentrations near the sediments and chlorophyll-*a* and TP concentrations below ecoregion thresholds. Additional monitoring would be required to confirm this assessment. Some of the readings (high TN and TP ration >2) suggest areas for concern, but available monitoring is insufficient to resolve the need or extent of management options.

Billington Sea

PPALS Pond Number: 163
MassDEP PALIS Number: 94007

Area (acres): 278
Bathymetry: DFW map
Maximum Depth (m): 3.8
Lake Association: Billington Sea Watershed Association

PPALS Sampling	8/25/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi (East/West)	1.5/1.75 m		
Total Depth (E/W)	3.3/2.5 m		
Surface pH (E/W)	9.22/8.80	6.5 – 8.3	MassDEP
Deepest DO (E/W)	10.1/11.9 mg/L	5.0 mg/L	MassDEP
Shallow temperature (E/W)	24.2/24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a (E/W)	13.8/9.5 µg/L	1.7 µg/L	CCC
Surface TP (E/W)	20/15 µg/L	10 µg/L	CCC
Surface TN (E/W)	0.69/0.90 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow) (E/W)	1.3/1.5		

OVERVIEW

Billington Sea is located just west of Route 3 and south of Summer Street. The pond receives upgradient groundwater discharge from the west and is part of the Town Brook watershed (1). Shoreline is approximately 50% developed with single family residences, while remaining shoreline is owned by the town including Morton Park on the north side. Morton Park includes a public sand boat ramp for access.

According to MassDFW, Billington Sea has been extensively managed and has been stocked with a wide variety of fish species during its recorded history: largemouth bass, smallmouth bass, chain pickerel, bluegill, sunfish, crayfish, brook trout, black crappie and yellow perch (2). It has never been "reclaimed," but intensive netting was done in 1950-54 to remove suckers, shiners and small panfish ["some six tons of worthless fish were removed" (3)]. Periodic fish kills have been documented and the pond has been treated with herbicides.

Water quality samples were collected from the pond monthly at eight sampling locations as part of 1970s-era baseline pond survey (4), at 10 locations in an October 1982 snapshot (5), monthly at two in-lake locations 1987-88 (6), and DO, pH, temperature, and specific conductivity profile readings were collected in July 2008 (7). The 1970s-era, 1987-88, and July 2008 sampling events were accompanied by aquatic plant and phytoplankton surveys, while the 1982 snapshot and monthly 1987-88 readings included extensive bacteriological sampling. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Billington Sea is shallow with restricted clarity at both the East and West stations measured at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings showed a well-mixed water column at both station with dissolved oxygen concentrations well above saturation indicating excessive nutrients and an active phytoplankton community. Chlorophyll-a concentrations throughout the water column at both stations were 5-8X higher than regional ecoregion standard, while total phosphorus concentrations were also elevated with a slight gradient with depth indicating sediment regeneration.

Based on the available information, Billington Sea is impaired. This finding is consistent with the in-depth diagnostic/feasibility study completed in 1990 (6), which also noted a blue-green algal bloom and recommended reductions in watershed phosphorus inputs and steps to reduce sediment nutrient regeneration. Additional monitoring and synthesis of available information would be required to evaluate any changes in nutrient sources and water quality management strategies since the 1990 study.

Bloody Pond

PPALS Pond Number: 160
MassDEP PALIS Number: 94015

Area (acres): 97
Bathymetry: DFW map
Maximum Depth (m): 11.6
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	9/10/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	8.85 m		
Total Depth	11 m		
Surface pH	7.24	6.5 – 8.3	MassDEP
Deepest DO	8.30 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	6.30 µg/L	1.7 µg/L	CCC
Surface TP	8.25 µg/L	10 µg/L	CCC
Surface TN	0.37 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	2.60		

OVERVIEW
Bloody Pond is located just west of Route 3 and east of Long Pond Road. The pond has two basins. Western shoreline is generally developed with single family residences, while the eastern shoreline is largely undeveloped. Access is via a footpath across town land.

According to MassDFW, Bloody Pond has been stocked with a variety of fish species and has had surveys a number of times (1). Before 1946, it was stocked with rainbow trout, brown trout, salmon, bullheads, white perch, yellow perch and crappie and was stocked in 1985 with northern pike.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (2). The Six Ponds Improvement Association has sampled various locations in and around the pond 17 times between 2002 and 2013; only one of these sampling runs was within the PPALS sampling period (August 15 – September 30) and DO and temperature data was not available for these samplings. The 2014 PPALS sampling run appears to be one of three sampling runs conducted during the key management months of July through September.

WATER QUALITY
Bloody Pond is relatively deep with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings show a well-mixed water column with little loss of DO near the sediments; the 1970's era monitoring indicated that the pond was stratified, but no profile information is available to confirm this. Chlorophyll-a and total phosphorus readings show elevated concentrations at depth indicating some sediment nutrient regeneration. The elevated 2014 surface chlorophyll-a concentration raises some concern about nutrient inputs. 1970's-era readings showed very sparse rooted aquatic plant populations. The near-complete separation of the two basins may require separate management and monitoring strategies.

Based on the available information, Bloody Pond is not impaired. This finding is generally based on acceptable DO concentrations near the sediments and TP concentrations below ecoregion thresholds, but there are some concerns based on the high chlorophyll-*a* concentrations. Some of the Six Ponds monitoring suggests some sediment TP regeneration and higher TP concentrations, but definitive conclusions are constrained by the limited number of summer samplings. Additional monitoring would be required to confirm this assessment and address the readings that suggest areas for concern. Available monitoring is insufficient to resolve the need or extent of management options.

Boot Pond

PPALS Pond Number: 165
MassDEP PALIS Number: 94016

Area (acres): 71
Bathymetry: 2010 contour map
Maximum Depth (m): 11.0
2014 Secchi Depth (m):
Lake Association: Boot Pond Homeowners Association

PPALS Sampling	8/20/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	7 m		
Total Depth	10.3 m		
Surface pH	6.57	6.5 – 8.3	MassDEP
Deepest DO	0.34 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.1 µg/L	1.7 µg/L	CCC
Surface TP	-	10 µg/L	CCC
Surface TN	-	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW
Boot Pond is located just west of College Pond Road and near a number of other ponds, including: Great South Pond, Hoyt Pond, Orchard Pond, and Ingalls Pond. The pond has a small outlet flow to Great South Pond and a connection to a small (8 ac) historic cranberry bog. Eastern and northern shorelines are generally developed with single family residences, while the western and southern shorelines are sparsely developed or undeveloped. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (1) and DO, pH, temperature, and specific conductivity profile readings were collected in April 2010 (2). The 1970s-era sampling run was accompanied by aquatic plant and phytoplankton surveys and similar surveys were also completed in June 2010 (3). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot; another PPALS Snapshot is planned for 2015.

WATER QUALITY
Boot Pond is relatively deep with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures readings showed some stratification beginning between 7 and 8 m depth. Dissolved oxygen at 8 m and deeper was less than MassDEP minimum, which suggest significant sediment oxygen demand. Total phosphorus and total nitrogen analyses were not available, so confirmation of sediment nutrient regeneration is unavailable. Low surface chlorophyll-a concentration suggests that nutrient regeneration was not significantly impacting surface waters. The 1970's era plant survey indicated a significant Fanwort density in the "toe" of the boot (1), while the 2010 survey also indicated significant plant density in this area, but identified the primary plants as Water-starwort, Water-milfoil, and Bladderwort (3).

Based on the available information, Boot Pond is impaired. This impairment is generally based on dissolved oxygen concentrations below state regulatory minimum and the high plant densities. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies, including potential export of nutrients to Great South Pond.

Clam Pudding Pond

PPALS Pond Number: 134
MassDEP PALIS Number: 94025

Area (acres): 7.4
Bathymetry: 1970s spot depths
Maximum Depth (m): 6.1
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/15/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3 m		
Total Depth	5.8 m		
Surface pH	5.58	6.5 – 8.3	MassDEP
Deepest DO	8.25 mg/L	5.0 mg/L	MassDEP
Shallow temperature	22.9°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.62 µg/L	1.7 µg/L	CCC
Surface TP	9.48 µg/L	10 µg/L	CCC
Surface TN	0.27 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.85		

OVERVIEW
Clam Pudding Pond is located just east of Old Sandwich Road and south of Hidden Cove Road. The pond is a true kettlehole pond with no surface water inflows or outflows. Shoreline is generally developed with condominiums and single family residences, but natural buffers of 80 ft or more separate the land uses, including lawns from the pond shoreline. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Clam Pudding Pond is shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings showed a well-mixed water column with little loss of DO near the sediments. Chlorophyll-a, total phosphorus, total nitrogen, and alkalinity readings show little difference between shallow and deep concentrations indicating no significant sediment oxygen demand or sediment nutrient regeneration. All surface water concentrations were less than regional ecoregion limits. The 1970's era macrophyte survey indicated that the rooted aquatic plant community was generally sparse, but total phosphorus concentrations were high (80-90 µg/L); these TP concentrations seem to be error given 2014 sampling.

Based on the available information, Clam Pudding Pond is not impaired. This finding is generally based on acceptable DO concentrations near the sediments and TP, TN, and chlorophyll-*a* concentrations below ecoregion thresholds. Additional monitoring would be required to confirm this assessment. None of the 2014 Snapshot readings suggest areas for concern, but available monitoring is insufficient to resolve the need or extent of management options.

Clear Pond

PPALS Pond Number: 220
MassDEP PALIS Number: 95028

Area (acres): 13.6
Bathymetry: 1970s spot depths
Maximum Depth (m): 6.1
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/26/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.1 m		
Total Depth	7 m		
Surface pH	7.75	6.5 – 8.3	MassDEP
Deepest DO	2.5 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.4°C	28.3°C	MassDEP
Surface Chlorophyll-a	5.03 µg/L	1.7 µg/L	CCC
Surface TP	6.6 µg/L	10 µg/L	CCC
Surface TN	0.41 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.25		

OVERVIEW
Clear Pond is located just north of Carver Road and east of Esta Road. The pond has a small inlet flow from a small (6 ac) historic cranberry bog to the north and an outlet to the south. Shoreline is nearly all developed with residential development (single family residences and condominiums) except for a town-owned parcel along the western shoreline. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (1) and DO, pH, temperature, and specific conductivity profile readings were collected in April 2010 (2). The 1970s-era sampling run was accompanied by aquatic plant and phytoplankton surveys and similar surveys were also completed in June 2010 (3). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Clear Pond is shallow with a significant loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures readings showed stratification between 4 and 5 m with low dissolved oxygen concentrations below 5 m. April 2010 temperature readings showed a gradual loss with increasing depth and also showed decreased DO concentrations below 5 m (2). Chlorophyll-a and total phosphorus readings did not show elevated concentrations at depth indicating that sediment nutrient regeneration was still limited. 1970's-era readings showed extensive rooted aquatic plant populations in the south half of the pond, which would tend to keep water column TP concentrations low (1). The June 2010 plant survey confirmed the extent of the aquatic plant population (3).

Based on the available information, Clear Pond is impaired. This impairment is generally based on limited clarity, DO concentrations below MassDEP regulatory minimums, and chlorophyll-*a* concentrations greater than ecoregion thresholds. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Deer Pond

PPALS Pond Number: 431
MassDEP PALIS Number: 95036

Area (acres): 10.9
Bathymetry: 1970s spot depths
Maximum Depth (m): 4.6
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/26/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.6 m		
Total Depth	5.5 m		
Surface pH	5.81	6.5 – 8.3	MassDEP
Deepest DO	4.34 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.97 µg/L	1.7 µg/L	CCC
Surface TP	4.5 µg/L	10 µg/L	CCC
Surface TN	0.31 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.64		

OVERVIEW
Deer Pond is located just east of Wareham Road and west of White Island Pond. The pond is a true kettlehole pond with no surface water inflows or outflows and is located within the White Island Pond watershed (1). Shoreline is nearly undeveloped except for a cranberry bog pumphouse on the northeastern shore; aerial reviews seem to indicate a hydroconnection to the adjacent bog. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (2). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Deer Pond is shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures readings showed a well-mixed water column with some sediment oxygen demand reducing dissolved oxygen concentrations at 4 m and deeper. 1970's-era readings showed an "abundant" rooted aquatic plant populations (water milfoil) ringing the deeper portion of the pond (2). This type of plant community would reduce TP water concentrations, while creating enough organic material to prompt sediment oxygen demand.

Based on the available information, Deer Pond is slightly impaired, based largely on having DO concentration just below MassDEP regulatory limits. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Ezekiel Pond

PPALS Pond Number: 4
MassDEP PALIS Number: 95051

Area (acres): 41
Bathymetry: DFW map
Maximum Depth (m): 4.6
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/25/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.1 m		
Total Depth	5 m		
Surface pH	6.7	6.5 – 8.3	MassDEP
Deepest DO	7.6 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.5°C	28.3°C	MassDEP
Surface Chlorophyll-a	4.78 µg/L	1.7 µg/L	CCC
Surface TP	6.6 µg/L	10 µg/L	CCC
Surface TN	0.34 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.63		

OVERVIEW

Ezekiel Pond is located just west of Bourne Road and southeast of White Island Pond. The pond is a true kettlehole pond with no surface water inflows or outflows. Shoreline is intensely developed with small residential lots (~0.25 acres). MassDFW does not provide a stocking history, but the pond was "reclaimed" in 1952 and 1958 (1). There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (2). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Ezekiel Pond is relatively shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings showed a well-mixed water column with some slight loss of DO near the sediments and DO concentrations mostly above atmospheric saturation. Chlorophyll-*a* and total phosphorus readings showed similar concentrations at both the surface and near the sediments, which generally confirms mixing of the water column and lack of significant sediment nutrient regeneration. Elevated chlorophyll-*a* concentrations and lack of an indication of sediment regeneration tends to suggest watershed inputs of nutrients. 1970's-era readings showed pockets of extensive rooted aquatic plant populations (bladderwort), which may tend to keep water column TP concentrations low depending on density (2).

Based on the available information, Ezekiel Pond is not impaired. This finding is generally based on acceptable DO concentrations near the sediments and TP concentrations below ecoregion thresholds. Additional monitoring would be required to confirm this assessment. Some of the readings (*e.g.*, chlorophyll-*a*) suggest areas for concern, but available monitoring is insufficient to resolve the need or extent of management options.

Forge Pond

PPALS Pond Number: 182
MassDEP PALIS Number: 94036

Area (acres): 14.4
Bathymetry: 1970s spot depths
Maximum Depth (m): 3.4
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/4/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3 m		
Total Depth	3 m		
Surface pH	4.21	6.5 – 8.3	MassDEP
Deepest DO	9.58 mg/L	5.0 mg/L	MassDEP
Shallow temperature	25.7°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.79 µg/L	1.7 µg/L	CCC
Surface TP	3.5 µg/L	10 µg/L	CCC
Surface TN	0.19 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	3.47		

OVERVIEW
Forge Pond is located just west of Old Sandwich Road and south of Forge Drive. The pond is a part of the Eel River watershed (1) and receives groundwater and surface water inflow, while discharging surface water downstream along the river to Howland Pond (2). Shoreline is a mix of residential and agricultural landuses, mostly on large lots (3-4 acres). A cranberry bog (~11 acres) near its southern shoreline likely uses the pond for flood waters and manages the impounded water. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (2). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Forge Pond is shallow with clarity to the bottom at the time of the 2014 PPALS Snapshot. Temperatures readings showed very warm surface waters compared to the rest of the water column, while dissolved oxygen concentrations are all above MassDEP limits, but well above atmospheric saturations levels (117% to 134% of saturation). Chlorophyll-*a* and total phosphorus readings showed elevated concentrations at depth indicating that sediment nutrient regeneration was occurring. 1970's-era readings showed extensive rooted aquatic plant populations throughout the pond bottom with 65% of the pond area classified as having dense plant coverage (2). This survey also noted attached algae covering the bottom too.

Based on the available information, Forge Pond is impaired. This finding is generally based on excessive DO concentrations and extensive plant and algae coverage. Even though water quality parameters are generally below available threshold, these results would be consistent with extensive plant coverage. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, the current status of plant growth, and evaluate potential water quality management strategies.

Fresh Pond

PPALS Pond Number: 190
MassDEP PALIS Number: 94040

Area (acres): 66.7
Bathymetry: DFW map
Maximum Depth (m): 9.1
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/26/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.6 m		
Total Depth	10 m		
Surface pH	6.89	6.5 – 8.3	MassDEP
Deepest DO	3.37 mg/L	5.0 mg/L	MassDEP
Shallow temperature	25.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.09 µg/L	1.7 µg/L	CCC
Surface TP	2.5 µg/L	10 µg/L	CCC
Surface TN	0.43 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	4.07		

OVERVIEW

Fresh Pond is located just west of State Road and just east of Bartlett Road. It is also located close to a number of smaller ponds, including Warner Pond and Rabbit Pond. The pond is near the headwaters of a series of connected ponds and cranberry bogs that eventually flow into Beaver Dam Brook and Bartlett Pond. Fresh Pond has a number of surface water inputs and outputs, including inflow from Warner Pond and outflow to a large (~185 acre) cranberry bog that is currently inactive. Most of the shoreline is developed with residential development on small lots, but there are select portions with larger lots, including a municipal park with a town beach at the southern tip. The town maintains a unpaved boat ramp off Bartlett Road.

Fish population is actively managed by MassDFW, including annual spring stocking of rainbow, brook and/or brown trout since 1961(1). Older records indicate past stocking of white perch, crappie and bullheads. The pond was treated with limestone in 1983 to try to raise its pH.

Water quality samples were collected from the pond 14 times as part of 1970s-era baseline pond survey (2) and DO, pH, temperature, and specific conductivity profile readings were collected in April 2010 (3). The 1970s-era sampling run was accompanied by aquatic plant and phytoplankton surveys and similar surveys were also completed in June 2010 (4). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Fresh Pond is relatively deep with a significant loss of clarity at the time of the 2014 PPALS Snapshot. Comparison of 2014 and 1970's-era Secchi clarity readings showed a loss of ~1 m at the same time of year. 2014 temperatures readings showed stratification beginning between 6 and 7 m with low dissolved oxygen concentrations at 7 m and deeper. April 2010 temperature readings showed a gradual loss with increasing depth and showed decreased DO concentrations below 8 m (3). 2014 PPALS chlorophyll-a and total phosphorus readings showed elevated concentrations at depth indicating that sediment nutrient regeneration was significant. 1970's-era aquatic plant survey showed limited populations and this was generally confirmed in June 2010. June 2010 phytoplankton survey showed that blue-green algae (*Microcystis*) dominated the phytoplankton population, but green algae (*Spirogyra*) dominated in April 2010.

Based on the available information, Fresh Pond is impaired. This finding is generally based on DO concentrations below MassDEP regulatory minimums, the occasional dominance of blue-green phytoplankton, and high TP regeneration ratio. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Fresh Meadow Pond

PPALS Pond Number: 25
MassDEP PALIS Number: 95174

Area (acres): 58
Bathymetry: 1970s spot depths
Maximum Depth (m): 3.4
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/10/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.4 m		
Total Depth	2.9 m		
Surface pH	6.79	6.5 – 8.3	MassDEP
Deepest DO	4.41 mg/L	5.0 mg/L	MassDEP
Shallow temperature	22.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	8.72 µg/L	1.7 µg/L	CCC
Surface TP	16.3 µg/L	10 µg/L	CCC
Surface TN	0.37 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	2.16		

OVERVIEW
Fresh Meadow Pond is located just south of Peter Road and straddles the Plymouth/Carver town boundary. The pond is a part of a series of connected ponds and cranberry bogs with Clear Pond, Narragansett Pond, and a small (~4 acre) bog upstream and a large collection of bogs and wetlands downstream. Most of northern and southern shoreline is largely residentially developed with significant seasonal use, although there are some sparsely developed areas in between the residential areas. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Fresh Meadow Pond is shallow with significant loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures readings showed a well-mixed water column with slightly depressed dissolved oxygen concentrations (88% to 92% of saturation) that dropped below the MassDEP regulatory limit ~1 m above the bottom sediments. Chlorophyll-a and total phosphorus readings showed elevated concentrations at depth indicating that sediment nutrient regeneration was occurring; with the shallow depth and mixing of the water column, any nutrient regeneration would be available to prompt phytoplankton growth. 1970's-era plant survey showed dense rooted aquatic plant populations throughout the pond bottom and green and blue-green algae on the bottom (1).

Based on the available information, Fresh Meadow Pond is impaired. This finding is generally based on DO concentrations below the MassDEP regulatory minimums, extensive plant growth, and TP, TN, and chlorophyll-*a* concentrations above ecoregion thresholds. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Gallows Pond

PPALS Pond Number: 120
MassDEP PALIS Number: 95059

Area (acres): 50.8
Bathymetry: Living Lakes map
Maximum Depth (m): 10
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	9/10/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	4.85 m		
Total Depth	10 m		
Surface pH	6.25	6.5 – 8.3	MassDEP
Deepest DO	7.35 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.02 µg/L	1.7 µg/L	CCC
Surface TP	26.9 µg/L	10 µg/L	CCC
Surface TN	0.23 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.27		

OVERVIEW
Gallows Pond is located just west of W Long Pond Road and Long Pond. Aside from Long Pond, other ponds around Gallows Pond include: Little Long Pond, Halfway Pond, and Round Pond. The pond is a true kettlehole pond and has no direct surface water connections to any of the surrounding ponds (1). Most of the shoreline is undeveloped with some residential development along the eastern shore and a large Girl Scout Camp along the northern shore.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). Pond was also sampled 10 times between 1988 and 1991 as part of two limestone additions totaling 26 tonnes to try to raise its pH (2); these sampling runs included measurements of nitrogen, metals, and DO and temperature water column profiles, but no phosphorus measurements. The Six Ponds Improvement Association has sampled various locations in and around the pond 17 times between 2002 and 2013; only one of these sampling runs was within the PPALS sampling period (August 15 – September 30) and DO and temperature data was not available for these samplings. The 2014 PPALS sampling run appears to be one of three sampling runs conducted during the key management months of July through September.

WATER QUALITY
Gallows Pond is relatively deep with significant loss of clarity at the time of the 2014 PPALS Snapshot; Secchi readings between 1988 and 1991 (2) and the 1970's-era baseline (1) generally show greater clarity. Temperatures readings showed no stratification of the water column; the 1970's-era baseline characterizes the pond as "stratified", but temperature profile data is not presented. 2014 water column dissolved oxygen generally was generally above MassDEP minimum and similar throughout the water column except for an elevated reading at 5 m. One of the three August DO readings collected near the sediments between 1988 and 1991 was below the MassDEP minimum (2). 2014 total phosphorus concentrations have an extremely high surface concentration, but this does not match with the chlorophyll-a and TN concentrations; these results cannot be compared to the 1988 and 1991 results, since these water samples appear to have been analyzed with lab methods with detection limits too high for natural waters (2). The 1970's-era plant survey indicated only sparse rooted and emergent plants in the pond.

Based on the preponderance of available information, Gallows Pond does not appear to be impaired, but there are factors that suggest that it may be borderline impaired (*e.g.*, occasional low DO near the sediments and the 2014 DO "bulge" at 5 m). Some of the Six Ponds monitoring suggests some sediment

TP regeneration and higher TP concentrations, but definitive conclusions are constrained by the limited number of summer samplings. Additional monitoring would be required to confirm this assessment. Some of the readings suggest areas for concern, but available monitoring is insufficient to resolve the need or extent of management options.

Great Herring Pond

PPALS Pond Number: 162
MassDEP PALIS Number: 94050

Area (acres): 427
Bathymetry: DFW map
Maximum Depth (m): 14
2014 Secchi Depth (m):
Lake Association: Herrings Ponds Watershed Association

PPALS Sampling	8/19/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2 m		
Total Depth	12.6 m		
Surface pH	6.80	6.5 – 8.3	MassDEP
Deepest DO	7.26 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	5.03 µg/L	1.7 µg/L	CCC
Surface TP	15.87 µg/L	10 µg/L	CCC
Surface TN	0.32 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.32		

OVERVIEW
Great Herring Pond is located in southern Plymouth, just west of Route 3, and with a small portion extending into the Town of Bourne. It receives surface water inflow from a connection to Little Herring Pond at its northernmost extent and discharges flow to the Herring River along the southern shoreline (1). Herring River flows into the Cape Cod Canal. Residential development surrounds most of the shoreline with varying lot sizes, including areas of 0.2-0.25 acre lots. There is a state boat ramp with a parking area for public access at the southern end of the pond.

Aside from supporting an abundant herring run, Great Herring Pond has been stocked with a variety of fish species, including: brown trout, smallmouth bass, largemouth bass, bluegills, brown bullheads, white perch, yellow perch, chain pickerel, black crappie, and walleyes (2). Two artificial tire reefs were installed in 1975 to provide additional fish shelter. MassDPH has a current fish consumption advisory for smallmouth bass from Great Herring Pond (3).

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton and macrophyte measurements were collected in August 2008 (4) and June 2011 (5). Similar measurements without a macrophyte survey were collected in April 2009 (6). Town staff and Association members have sampled the pond at 13 stations between 2008 and 2014. Samples have been analyzed for a number of constituents, including total phosphorus, pH, and nitrogen. The range of samples at each station is between 1 and 27.

WATER QUALITY
Great Herring Pond is deep with consistently limited clarity. Temperature profiles generally show limited stratification with deep summer temperatures only occasionally just meeting the MassDEP cold water fishery criterion (≤20°C). Dissolved oxygen profiles generally have deep concentrations above the MassDEP minimum regulatory limit, although August 2008 concentrations in waters deeper than 8 m and June 2011 concentrations in waters deeper than 9 m were below the limit. Elevated TP and chlorophyll-a concentrations throughout the water column during the 2014 PPALS Snapshot are consistent with limited stratification. These concentrations and the lack of significant sediment oxygen demand suggest other regular sources of phosphorus separate from the sediment nutrient regeneration. The macrophyte surveys show limited rooted aquatic plants and phytoplankton tows generally show species associated with low nutrient availability.

Based on the available information, Great Herring Pond is impaired. This impairment is generally based on consistently limited clarity and high nutrient and chlorophyll concentrations. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Great South Pond

PPALS Pond Number: 378
MassDEP PALIS Number: 94054

Area (acres): 283
Bathymetry: 1970s spot depths
Maximum Depth (m): 12.5
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/27/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	5.1 m		
Total Depth	14.93 m		
Surface pH	6.71	6.5 – 8.3	MassDEP
Deepest DO	3.3 mg/L	6.0 mg/L	MassDEP
Shallow temperature	23.7°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.13 µg/L	1.7 µg/L	CCC
Surface TP	2.27 µg/L	10 µg/L	CCC
Surface TN	0.40 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	2.64		

OVERVIEW
Great South Pond is located in southern Plymouth is just south of Drew Road and north of May Hill Road. It receives surface water inflow from a connection to Boot Pond at its southernmost extent and discharges flow to Little South Pond along its northern shoreline (1). Great South Pond is within the Eel River watershed (2). Approximately half of the shoreline is developed, mostly along the eastern shoreline. There is no formal public access to the pond and it is not regularly stocked by MassDFW. MassDPH has a current fish consumption advisory for all fish from Great South Pond (3).

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). The pond was sampled 16 times between 1979 and 1980, including water quality, phytoplankton, and sediment samples, and surface DO, pH, temperature, and specific conductivity readings (4). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton measurements were collected in August 2008 (5) and April 2009 (6). The August 2008 measurements included a macrophyte survey. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Great South Pond is deep with consistently limited clarity. The two available summer temperature profiles (PPALS & 5) generally show stratification around 8-9 m and deep temperatures meeting the MassDEP cold water fishery criterion (≤20°C). Both accompanying summer dissolved oxygen profiles had deep concentrations below the MassDEP minimum regulatory limit with anoxic concentrations in August 2008. Comparison of surface and deep TP PPALS readings showed elevated deep concentrations consistent with sediment nutrient regeneration, but both surface and deep concentrations were less than the ecoregion threshold. PPALS chlorophyll-a concentrations were generally less than ecoregion threshold except for 9 m sample that is just above the hypoxic colder water layer. The August 2008 profile had supersaturated DO conditions near this depth, which would be consistent with an active phytoplankton population utilizing elevated TP leaking into the warmer, upper layer of the pond. The 1970's-era macrophyte survey (1) showed limited rooted aquatic plants, but the August 2008 survey (5) noted a dense growth of non-native Fanwort (*Cabomba caroliniana)* in the pond's southwest corner. The subsequent April 2009 macrophyte survey did not find the Fanwort (6). The summer 2008 phytoplankton tow found that green algae (*Gloeocysti)* and blue green algae (*Anabaena*) were the dominant species (5), while diatoms (*Asterionella)* and yellow-green algae (*Uroglenopsis)* dominated the

following spring (6). Blue-green algae dominance is generally associated with high nutrient availability, while diatoms tend to dominate in low nutrient settings.

Based on the available information, Great South Pond is impaired. This impairment is generally based on consistently limited clarity, summer dissolved oxygen hypoxia and anoxia in the deep cold water layer, and supersaturation dissolved oxygen conditions at the warm water/cold water boundary. Relative low nutrient and chlorophyll concentrations suggest that limiting sediment nutrient regeneration could address the impairments, but there could be some impacts from the surface water inflows from Boot Pond. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Gunners Exchange Pond

PPALS Pond Number: 325
MassDEP PALIS Number: 94055

Area (acres): 26.9
Bathymetry: 1970s spot depths
Maximum Depth (m): 7.6
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/20/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	6.4 m		
Total Depth	8.85 m		
Surface pH	6.70	6.5 – 8.3	MassDEP
Deepest DO	0.22 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.8°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.83 µg/L	1.7 µg/L	CCC
Surface TP	-	10 µg/L	CCC
Surface TN	-	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW

Gunners Exchange Pond is the southern basin of two connected ponds; the northern basin is Hoyt Pond. Gunners Exchange Pond is located to the east of Snake Pond Road in an area with numerous other ponds, including Ingalls Pond, Orchard Pond, Boot Pond, and Turtle Pond. It has no surface water connections other than to Hoyt Pond (1) and is located within the Eel River watershed (2). Most of the shoreline is undeveloped with large lots for the existing residential shoreline development. There is no formal public access to the pond and it is not regularly stocked by MassDFW.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Gunners Exchange Pond is relatively deep with only a slight loss of clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is much deeper than the 1970s-era Secchi reading of 4 m (1). Temperatures readings showed some stratification beginning around 7 m depth; dissolved oxygen at 7 m and deeper was anoxic (<1 mg/L) and less than MassDEP minimum. These deep dissolved oxygen conditions suggest significant sediment oxygen demand. Total phosphorus and total nitrogen analyses were not available, so confirmation of accompanying sediment nutrient regeneration is unavailable. Low surface chlorophyll-a concentration suggests that nutrient regeneration was not significantly impacting surface waters. The 1970's era plant survey indicated a significant Water Milfoil (*Myriophyllum sp.*) density in the shallower northern portion of the pond with epiphytic blue-green algae on the bottom. Bladderwort (*Utricularia sp.*) had a fairly dense ring around the southern deep basin. Fanwort density in the "toe" of the boot (1), while the 2010 survey also indicated significant plant density in this area, but identified the primary plants as Water-starwort, Water-milfoil, and Bladderwort (3).

Based on the available information, Gunners Exchange Pond is impaired based largely on the dissolved oxygen concentrations below MassDEP regulatory minimum and the dense macrophyte population. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies, including potential export of nutrients to Hoyt Pond.

Halfway Pond

PPALS Pond Number: 110
MassDEP PALIS Number: 95178

Area (acres): 229
Bathymetry: DFW map
Maximum Depth (m): 4
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	9/10/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2 m		
Total Depth	4 m		
Surface pH	6.80	6.5 – 8.3	MassDEP
Deepest DO	8.4 mg/L	5.0 mg/L	MassDEP
Shallow temperature	23.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.61 µg/L	1.7 µg/L	CCC
Surface TP	18.55 µg/L	10 µg/L	CCC
Surface TN	0.29 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	5.28		

OVERVIEW

Halfway Pond is located to the east of Mast Road and just to west of numerous other ponds, including Long Pond, Little Long Pond, Round Pond, and Gallows Pond. It has surface inflow at its northernmost shoreline and surface outflow to the Agawam River at its southernmost shoreline (1). It is located partially within the Wareham River estuary watershed (2). Most of the shoreline is undeveloped with large lots for the existing residential shoreline development and there are four small cranberry bogs nearby.

MassDFW records show that Halfway Pond was stocked with landlocked salmon from Maine in the 1870s and had been stocked with a variety of fish species prior to 1946, including: smallmouth bass, bullheads, white perch, yellow perch, pickerel, crappie and sunfish (3). Fish surveys of the pond were conducted in 1946, 1979, 1987 and 2000. There is public access via an informal access point and small parking lot provided by Wildlands Trust of Southeastern Massachusetts along the northwestern shoreline off Mast Road. According to MassDPH, there has been one closure of the pond for cyanobacteria blooms in 2014.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). The Six Ponds Improvement Association has sampled various locations in and around the pond 21 times between 2002 and 2013; only one of these sampling runs was within the PPALS sampling period (August 15 – September 30) and DO and temperature data was not available for these samplings. The 2014 PPALS sampling run appears to be one of three sampling runs conducted during the key management months of July through September.

WATER QUALITY

Halfway Pond is shallow with restricted clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is much deeper than the 1970s-era Secchi reading of 0.6 m (1). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with no significant sediment oxygen demand. Comparison of shallow and deep total phosphorus and chlorophyll-a concentrations suggest, however, that the sediments were releasing significant nutrients. 2002 summer TP readings from Six Ponds Improvement Association were much higher than recorded during the 2014 Snapshot. The surface concentrations for both of these factors were above ecoregion standards, which suggest sediment releases were being mixed into the water column. The 1970's-era survey noted that most of the pond bottom was covered with dense macrophyte growth, mostly Waterweed (*Elodea sp.*)(1). An extensive plant population would tend to add large quantities of organic material to the sediments, provide dissolved oxygen to the water column during the summer, and out-compete phytoplankton for nutrients. The restricted clarity and high chlorophyll-a concentrations measured in 2014 suggest that the relationship between phytoplankton and macrophytes and the nutrient fluxes within the pond are complex. Further the role of the water budget, including outflow to the Agawam River, would be a factor that would need to be considered in water quality management.

Based on the available information, Halfway Pond is impaired. This impairment is generally based on limited clarity, TP and chlorophyll-*a* concentrations above ecoregion thresholds, and sediment P generation (high bottom to surface TP ratio). Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Hedges Pond

PPALS Pond Number: 420
MassDEP PALIS Number: 94065

Area (acres): 30
Bathymetry: none
Maximum Depth (m):
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/11/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.1 m		
Total Depth	4.25 m		
Surface pH	5.73	6.5 – 8.3	MassDEP
Deepest DO	8.75 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.9 µg/L	1.7 µg/L	CCC
Surface TP	8.66 µg/L	10 µg/L	CCC
Surface TN	0.21 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.86		

OVERVIEW

Hedges Pond is located just to the west of Route 3 and east of Long Pond Road with Hyles Pond to its north and Little Herring Pond to its west. It appears to be a “true” kettlehole pond with no surface water inflows or outflows; its water level will be determined by groundwater and precipitation. Most of the shoreline is undeveloped with access via a dirt road on town land.

There are no records of MassDFW management or fish stocking.

Water quality samples were collected during the 2014 PPALS Snapshot appear to be the first water quality samples ever collected from the pond.

WATER QUALITY

Hedges Pond is relatively shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings show a well-mixed water column with some slightly over-saturated DO. Comparison of shallow and deep chlorophyll-a and total phosphorus readings show similar readings, reinforcing likely regular mixing of the water column. Available readings do not indicate that there was significant sediment nutrient regeneration at the time of the Snapshot.

Based on the single set of 2014 PPALS Snapshot readings, Hedges Pond is not impaired. This assessment is generally based on chlorophyll-a, TP, and TN concentrations near or below ecoregion thresholds and similar TP concentration at surface and bottom. Since this assessment is based on the results from only one sampling, additional monitoring would be required to confirm this assessment. Available monitoring is insufficient to resolve the need for or extent of management options.

Hoyts Pond

PPALS Pond Number: 390
MassDEP PALIS Number: 94070

Area (acres): 18.4
Bathymetry: 1970s spot depths
Maximum Depth (m): 5.5
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/20/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	4.7 m		
Total Depth	5.25 m		
Surface pH	6.76	6.5 – 8.3	MassDEP
Deepest DO	6.82 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.11 µg/L	1.7 µg/L	CCC
Surface TP	-	10 µg/L	CCC
Surface TN	-	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW
Hoyts Pond is the northern basin of two connected ponds; the southern basin is Gunners Exchange Pond. Hoyts Pond is located to the east of College Pond Road in an area with numerous other ponds, including Ingalls Pond, Orchard Pond, Boot Pond, and Turtle Pond. It has no surface water connections other than to Gunners Exchange Pond (1) and is located within the Eel River watershed (2). Most of the shoreline is undeveloped with large lots for the existing residential shoreline development. There is no formal public access to the pond and it is not regularly stocked by MassDFW.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Hoyts Pond is somewhat shallow with only a slight loss of clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is much deeper than the 1970s-era Secchi reading of 2.4 m (1). 2014 temperatures and dissolved oxygen readings generally show a well-mixed water column, but there was some loss of DO with increasing depth and slightly below saturuation throughout the water column. Low surface chlorophyll-a concentration suggests that nutrient regeneration was not significantly impacting surface waters, but total phosphorus and total nitrogen analyses were not available, so confirmation of lack of sediment nutrient regeneration is unavailable. The 1970's era plant survey indicated a significant Water Milfoil (*Myriophyllum sp.*) density throughout the pond out to a 2.4 m depth. A large, dense macrophyte population would tend to incorporate available nutrients and keep phytoplankton populations low and clarity high.

Based on the available information, Hoyts Pond is not impaired based largely on the dissolved oxygen concentrations above MassDEP regulatory minimum and low phytoplankton population. However, an extensive rooted aquatic plant (*i.e.*, macrophyte) population generally indicates a high amount of available nutrients within this ecoregion. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies, including potential export of nutrients to Gunners Exchange Pond.

Jakes Pond

PPALS Pond Number: 104
MassDEP PALIS Number: 95077

Area (acres): 5.3
Bathymetry: none
Maximum Depth (m):
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/11/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.5 m		
Total Depth	3.5 m		
Surface pH	5.99	6.5 – 8.3	MassDEP
Deepest DO	7.94 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.95 µg/L	1.7 µg/L	CCC
Surface TP	11.54 µg/L	10 µg/L	CCC
Surface TN	0.43 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.96		

OVERVIEW
Jakes Pond is located to the south of Fathom Road, east of Mooring Circle and north of Wall Pond. It appears to be a "true" kettlehole pond with no surface water inflows or outflows; its water level will be determined by groundwater and precipitation. Residential development with fairly large lots (>1 ac) occurs on the eastern and western shorelines, while the southern shoreline is undeveloped and the northern shoreline has a town beach area. Public access is informal via the beach area.

There are no records of MassDFW management or fish stocking.

Water quality samples were collected during the 2014 PPALS Snapshot appear to be the first water quality samples ever collected from the pond.

WATER QUALITY
Jakes Pond is relatively shallow with some loss of clarity at the time of the 2014 PPALS Snapshot. Temperatures and dissolved oxygen readings show a well-mixed water column with DO readings generally close to atmospheric equilibrium (*i.e.*, ~100% saturation). Comparison of shallow and deep chlorophyll-a and total phosphorus readings show similar readings, reinforcing likely regular mixing of the water column. Available readings do not indicate that there was significant sediment nutrient regeneration or sediment oxygen demand at the time of the Snapshot.

Based on the single set of 2014 PPALS Snapshot readings, Jakes Pond is not impaired. This assessment is generally based on TP and chlorophyll-*a* concentrations below their ecoregion thresholds, similar surface and bottom TP concentrations indicating insignificant sediment regeneration and DO concentrations throughout the water column close to 100%. Additional monitoring would be required to confirm this assessment. Available monitoring is insufficient to resolve the need for or extent of management options.

Little Pond

PPALS Pond Number: 295
MassDEP PALIS Number: 94182

Area (acres): 45.0
Bathymetry: DFW map
Maximum Depth (m): 15.5
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/9/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	6.4 m		
Total Depth	12.5 m		
Surface pH	6.70	6.5 – 8.3	MassDEP
Deepest DO	6.73 mg/L	6.0 mg/L	MassDEP
Shallow temperature	24.8°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.80 µg/L	1.7 µg/L	CCC
Surface TP	1.65 µg/L	10 µg/L	CCC
Surface TN	0.30 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.0		

OVERVIEW

Little Pond is located in the northern portion of the Town's Morton Park, just south of Little Pond Road. It is also just north of Billington Sea. Most of the shoreline is undeveloped except for a ~1,100 ft section along the northwestern shoreline that has extensive residential development. There is a boat launch area on the southern side of the pond within Morton Park and there are numerous beach areas.

MassDFW has conducted numerous fisheries management activities in the pond (1). Prior to 1946, the pond had been stocked with a number of fish species, including: smallmouth bass, bullheads, white perch, yellow perch, crappie and walleye. This pond was been "reclaimed" in 1954, 1957, 1961 and 1970. Little Pond receives stockings of brook, brown and rainbow trout in the spring and fall. It also receives annual stockings of broodstock Atlantic salmon and tiger trout (when available). The pond was treated with limestone in 1969 and 1982 to try to raise its pH.

Water quality samples and macrophyte and phytoplankton surveys were collected from the pond once as part of a 1970s-era baseline pond assessment (2). Little Pond was part of a 1982 water quality study with Billington Sea, in which water quality samples from Little Pond concentrated on bacteriological analyses and no nutrient samples or field (DO, pH, temperature) readings were collected (3). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton measurements were collected in October 2007 (4), July 2008 (5) and October 2008 (6). The two 2008 samplings also included macrophyte measurements. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Little Pond is deep with consistently limited clarity. The two available summer temperature profiles (PPALS & 5) generally show stratification (~8 m PPALS; ~6 m in ref. 5) with deep temperatures meeting the MassDEP cold water fishery criterion (≤20°C). The accompanying PPALS dissolved oxygen profile has deep concentrations above the MassDEP minimum regulatory limit, while the July 2008 DO profile had anoxic concentrations at 12 m and deeper. These results raise the question whether PPALS measurements over a deeper point would have also found anoxic conditions and raise additional questions about the water quality sampling results. Comparison of surface and deep TP PPALS readings showed similar concentrations that would be inconsistent with sediment nutrient regeneration; given the July 2008 DO profile, deep TP concentrations would be expected at least 2-3 times those measured at the surface. The PPALS DO profile does show some supersaturation between 7 and 9 m depth which would be consistent with phytoplankton utilizing higher deep TP concentrations. This same pattern was found between 5 and 8 m depth in the July 2008 profile. PPALS chlorophyll-a concentrations at all depths were less than ecoregion threshold, but these did show a doubling of surface concentration at 9 m. Overall, their relatively low concentrations suggest limited impact from sediment regeneration if it is occurring. The July 2008 survey (5) noted emergent rooted plants ringing most of the pond. The July 2008 phytoplankton tow found that a green algae (*Cosmarium)* was the dominant species (5), while a blue-green algae (*Microcystis*) was dominant in October 2007 (4) and October 2008 (6). Blue-green algae dominance is generally associated with high nutrient availability, while green algae tend to dominate in moderate nutrient settings.

Based on the available information, Little Pond is impaired. This impairment is generally based on consistently limited clarity, summer dissolved oxygen hypoxia and anoxia in the deep cold water layer, and supersaturation dissolved oxygen conditions at the warm water/cold water boundary. There are some inconsistencies in the water quality data that could be resolved through additional monitoring. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Little Herring Pond

PPALS Pond Number: 241
MassDEP PALIS Number: 94082

Area (acres): 77.9
Bathymetry: DFW map
Maximum Depth (m): 1.8
2014 Secchi Depth (m):
Lake Association: Herrings Ponds Watershed Association

PPALS Sampling	8/19/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	-		
Total Depth	-		
Surface pH	6.90	6.5 – 8.3	MassDEP
Deepest DO	-	6.0 mg/L	MassDEP
Shallow temperature	-	28.3°C	MassDEP
Surface Chlorophyll-a	8.07 µg/L	1.7 µg/L	CCC
Surface TP	41.86 µg/L	10 µg/L	CCC
Surface TN	0.74 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-		

OVERVIEW
Little Herring Pond is located to the west of Long Pond Road and directly north of Great Herring Pond. Other ponds located nearby include: Hyles Pond, Hedges Pond, Pickerel Pond, and Triangle Pond. Little Herring Pond has no surface water inflows, but does have an outflow to a series of wetlands and associated cranberry bogs that eventually flow into Great Herring Pond (1). Most of the shoreline has residential development and most of the residences have setbacks of 100 ft or more from the shoreline. Public access is a via a dirt road/Plymouth County right-of-way located off Little Herring Pond Road.

MassDFW records show that the pond was stocked with many species between 1909 and 1947, including: brown trout, chain pickerel, largemouth bass, white perch, yellow perch, brown bullheads and black crappie (2).

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (1) and a subsequent year-long, 12 sampling runs, baseline survey (3). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton and macrophyte measurements were collected in June 2011 (4). Town and Association staff have sampled the pond more than 20 times at two stations between 2009 and 2014. Samples have been analyzed for a number of constituents, including total phosphorus, pH, and nitrogen.

WATER QUALITY
Little Herring Pond is very shallow with a max depth of 1.8 to 2.4 m (3); a station depth reading and DO and temperature profiles were not measured during the 2014 PPALS Snapshot. Secchi readings during the year-long study generally were in the same maximum depth range, suggesting that clarity extended to the bottom, but there is no confirmation of this (3). June 2011 Secchi measurement at a 1.2 m station was on the bottom (4). 2014 PPALS total phosphorus, chlorophyll-a, and total nitrogen concentrations are all exceptionally high and are generally consistent with the data reported in the year-long sampling (3).

Given the transparency of light to the bottom and the shallow depth of the whole pond, the whole bottom is available for rooted aquatic plants. The baseline survey characterized most of the bottom covered with dense Waterweed (*Elodea sp.*) growth with sparse, scattered populations of emergent plants (3). The June 2011 survey indicated that dense monoculture growth of Coontail (*Ceratophyllum*) covered the southern pond, while filamentous algae covered the northern pond (4). The June 2011 plankton survey found a high preponderance of zooplankton suggesting samples were collected during an unbalanced period for the overall plankton population. The high clarity, high chlorophyll-*a* and nutrient concentrations measured in 2014 suggest that the relationship between phytoplankton and macrophytes and the nutrient fluxes within the pond are complex. Further the role of the water budget, including outflow to Great Herring Pond and watershed inputs, would be a factor that would need to be considered in water quality management.

Based on the available information, Little Herring Pond is impaired. This impairment is generally based on TP, TN, and chlorophyll-*a* concentrations exceeding ecoregion thresholds and past characterization of extensive plant coverage. Additional synthesis of available information and perhaps targeted data collection of streamflows, existing plant populations, sediment characteristics, and accompanying in-pond water quality would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Little Long Pond

PPALS Pond Number: 385
MassDEP PALIS Number: 95088

Area (acres): 52.2
Bathymetry: DFW map
Maximum Depth (m): 2.4
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	8/19/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.55 m		
Total Depth	2.1 m		
Surface pH	6.97	6.5 – 8.3	MassDEP
Deepest DO	12.4 mg/L	5.0 mg/L	MassDEP
Shallow temperature	23.2°C	28.3°C	MassDEP
Surface Chlorophyll-a	4.64 µg/L	1.7 µg/L	CCC
Surface TP	18.96 µg/L	10 µg/L	CCC
Surface TN	0.53 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.4		

OVERVIEW
Little Long Pond is located just west of Oar and Line Road and just north of Long Pond and Gallows Pond. The pond has surface water outflow to Long Pond (1). The eastern shoreline is completely developed with residential houses on 0.5-0.75 acre lots, while the western shoreline is partially developed. There is a paved state boat ramp that shares a parking lot with a matching boat ramp to Long Pond (2). The boat ramp is located off Clark Road at the southern end of the pond. There are no records of MassDFW management or fish stocking. According to MassDPH, there has been one closure of the pond for cyanobacteria blooms in 2012.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment (1) and then 16 times as part of 1981 pond assessment (3). Both assessments included macrophyte and phytoplankton surveys. DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton and macrophyte measurements were collected in July 2008 (4) and October 2008 (5). The Six Ponds Improvement Association has sampled various locations in and around the pond 15 times between 2002 and 2013; only one of these sampling runs was within the PPALS sampling period (August 15 – September 30) and DO and temperature data was not available for these samplings. The 2014 PPALS sampling run appears to be one of three sampling runs conducted during the key management months of July through September.

WATER QUALITY
Little Long Pond is very shallow, but had limited clarity during the 2014 PPALS Snapshot. Secchi readings during the year-long study (3) and July 2008 (4) generally were around the same depth as the Snapshot, although the October 2008 (5) reading was a bit deeper (2.2 m, on the bottom), which would be consistent with cooler temperatures and diminished phytoplankton growth. The July 2002 Six Ponds Improvement Association sampling shows higher TP concentrations than in September 2002; both readings are above ecoregion thresholds. 2014 PPALS total phosphorus, chlorophyll-a, and total nitrogen concentrations are all exceptionally high and TP and TN concentrations are generally consistent with the data reported in the year-long sampling (3).

2014 PPALS dissolved oxygen concentrations are supersaturated with respect to the atmosphere (129% to 161%), which is usually found in ponds with excessive nutrients and large plant populations (both macrophytes and phytoplankton). Similar saturation levels (136% to 138%) were measured in July 2008 (4) and saturation levels were also elevated (112% to 116%) in October 2008 (5).

Plant surveys in Little Long Pond have found extensive rooted plants and phytoplankton populations. The 1981 pond survey found that 95% of the bottom was covered with rooted plants with Waterweed (*Elodea sp.*) as the dominant species (3). The July 2008 observations again noted Elodea with the emergent Water-willow (*Decodon sp.*) almost completely around the shoreline (4); these observations were confirmed in October 2008, although the more complete survey did note more extensive diversity of species (5). The two phytoplankton surveys accompanying the 2008 pond visits found *Dinobryon* (a yellow-green algae) and *Microcystis* (a blue-green algae) as the predominant phytoplankton species. Blue-green algae are typically only a dominant species in pond settings with excessive nutrients.

Based on the available information, Little Long Pond is impaired based largely on the high nutrient levels, supersaturated dissolved oxygen concentrations, and extensive plant populations. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies. An additional factor to strongly evaluate in water and nutrient budget development and assessment is the outflow and potential nutrient impacts on Long Pond.

Little South Pond

PPALS Pond Number: 359
MassDEP PALIS Number: 94087

Area (acres): 65.2
Bathymetry: 1970s spot depths
Maximum Depth (m): 5.8
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/9/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	4.9 m		
Total Depth	5.5 m		
Surface pH	6.47	6.5 – 8.3	MassDEP
Deepest DO	8.71 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.9°C	28.3°C	MassDEP
Surface Chlorophyll-a	0.8 µg/L	1.7 µg/L	CCC
Surface TP	4.33 µg/L	10 µg/L	CCC
Surface TN	0.28 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	4.0		

OVERVIEW

Little South Pond is located south of Drew Road and east of Rocky Pond Road. It is just north of and has an inflow from Great South Pond (1). It has no surface water outflows and was once part of the town's public water supply system. All of the shoreline is undeveloped and surrounding land is all owned by the Town of Plymouth as part of the Plymouth Town Forest Wildlife Conservation Easement (2). Access to the ponds is informal and limited to a two car parking area off Drew Road. There are no records of MassDFW management or fish stocking.

Water quality samples and macrophyte and phytoplankton surveys were collected from the pond once as part of a 1970s-era baseline pond assessment (1). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton measurements were collected in May 2010 (3). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Little South Pond is shallow with little loss in clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is more than a meter deeper than the 1970s-era Secchi reading of 3.7 m (1). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with no measurable sediment oxygen demand. Comparison of shallow and deep total phosphorus and total nitrogen concentrations suggest that the sediments were releasing significant phosphorus, but not nitrogen. The 1970's-era survey noted a small patch of submerged aquatic plants, but most of the pond bottom was "free of any growth" (1). The May 2010 survey also noted "extremely sparse" macrophytes (3). The accompanying May 2010 phytoplankton tow was diverse with 19 species noted and predominant species of green algae (*Chlorella* and *Elakatothrix*) and yellow-green algae (*Mallomonas*). This mix of species would generally be associated with low nutrient conditions.

Based on the available information, Little South Pond is not impaired although the high bottom/surface TP ratio seems to indicate some sediment nutrient regeneration. This assessment is generally based on good clarity, DO near 100% throughout the water column, and TP, TN, and chlorophyll-*a* concentrations below ecoregion thresholds. Management steps to continue to sustain these conditions would include additional monitoring and synthesis of available information and identification, characterization and measurement of nutrient sources contributing to the pond, including more complete measurement of flows and nutrient loads from the connection to Great South Pond. This information would form the basis for evaluation of potential water quality management strategies.

Little West Pond

PPALS Pond Number: 263
MassDEP PALIS Number: 95093

Area (acres): 28
Bathymetry: 1970s spot depths
Maximum Depth (m): 4.9
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/26/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.6 m		
Total Depth	4.8 m		
Surface pH	7.0	6.5 – 8.3	MassDEP
Deepest DO	7.99 mg/L	5.0 mg/L	MassDEP
Shallow temperature	25.8°C	28.3°C	MassDEP
Surface Chlorophyll-a	3.19 µg/L	1.7 µg/L	CCC
Surface TP	9.89 µg/L	10 µg/L	CCC
Surface TN	0.53 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.15		

OVERVIEW
Little West Pond is located north and west of Federal Furnace Road and is hydrologically connected to Grassy Pond, Big West Pond, Spring Pond, and Great West Pond. Shoreline is well developed with mostly with single family residences. There is no formal public access.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey (1). The 1970s-era sampling run was accompanied by aquatic plant and phytoplankton surveys. No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Little West Pond is shallow with somewhat restricted clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is less than the 1970s-era Secchi reading of 4.6 m, but the water temperature of the 1970's-era reading (15°C) suggests that this reading was collected in the early winter or spring so the comparison may not be apt (1). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with no significant sediment oxygen demand. Comparison of shallow and deep total phosphorus, chlorophyll-a, and total nitrogen concentrations show no significant sediment nutrient release, although chlorophyll-a and TN concentrations are higher than ecoregion limits. The 1970's-era survey noted approximately 5 acres of dense Bladderwort (*Urticularia sp.*) stands, but little in the way of additional macrophytes either emergent or submerged (1). No updated plant surveys or phytoplankton tow results were available. The high TN concentrations are somewhat surprising, but this may be an impact of Little West Pond being the terminal pond in a series of linked ponds, including Big West Pond, Grassy West Pond, and Spring Pond. These connections would also be a factor that would need to be considered in water quality management.

Based on the available information, Little West Pond is generally not impaired, but some of the available suggest that it could also be characterized as borderline impaired. DO concentrations are near 100% throughout the water column and TP concentrations (both shallow and deep) are near the ecoregion threshold, but chlorophyll-a and TN concentrations exceed their respective ecoregion thresholds and clarity is somewhat limited (54% of water column). Among the steps to resolve the characterization would be additional monitoring and synthesis of available information, updated plant surveys, measurement of flow and nutrient loads between the linked ponds, and identification, characterization and measurement of nutrient sources contributing to the pond. This information would form the basis for evaluation of potential water quality management strategies.

Long Pond

PPALS Pond Number: 195
MassDEP PALIS Number: 95096

Area (acres): 221
Bathymetry: DFW map
Maximum Depth (m): 31.1
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	8/19/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.5 m		
Total Depth	28.2 m		
Surface pH	8.43	6.5 – 8.3	MassDEP
Deepest DO	6.73 mg/L	6.0 mg/L	MassDEP
Shallow temperature	24.5°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.13 µg/L	1.7 µg/L	CCC
Surface TP	12.99 µg/L	10 µg/L	CCC
Surface TN	0.55 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	4.4		

OVERVIEW
Long Pond is located west of Long Pond Road and east of West Long Pond Road. It is also just south of Little Long Pond and nearby Gallows Pond, Round Pond, and Halfway Pond. The pond receives surface water inflow from Little Long Pond (1) and has an outlet pipe that connects it to Halfway Pond (2). There is a paved state boat ramp that shares a parking lot with a matching boat ramp to Little Long Pond (3). Most of the pond shoreline has residential development with fairly large lots (>1 acre).

Long Pond is the deepest pond in Plymouth and because of this depth, MassDFW has focused fisheries management on trout and salmon stocking. Prior to 1948, however, fisheries management included stocking a diverse number of fish species, including brook, brown and rainbow trout, chinook salmon, landlocked salmon, sockeye salmon, smallmouth bass, bullheads, white perch, chain pickerel, walleye, rainbow smelt and alewives (3). The pond is now annually stocked with brook trout, brown trout, rainbow trout, and Atlantic Salmon.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment (1) and then 16 times as part of 1981 pond assessment (4). Both assessments included macrophyte and phytoplankton surveys. The Six Ponds Improvement Association has sampled various locations in and around the pond 22 times between 2002 and 2013; two of these sampling runs were within the PPALS sampling period (August 15 – September 30). DO, pH, temperature, and specific conductivity profile readings, as well as phytoplankton and macrophyte measurements were collected in July 2008 (5) and October 2008 (2).

WATER QUALITY
Long Pond is deep and had very limited clarity in all runs where Secchi readings were collected, although more recent summer readings are ~2 m less than those collected for the 1981 assessment (4). The available temperature profiles [Aug 2014 (PPALS); July 2008 (5) & October 2008 (2)] all show stratification around 8-10 m depth with deep temperatures meeting the MassDEP cold water fishery criterion (≤20°C). The accompanying dissolved oxygen profiles all show DO concentrations below the MassDEP regulatory minimum at depths of 14-16 m and deeper. In addition, the two summer DO profiles both have supersaturated conditions in the upper layer with maximum concentrations near the top of cold water layer. This pattern suggests that phytoplankton are concentrating here to utilize high nutrient releases from the cold layer. All DO profiles have anoxic concentrations (<1 mg/L) in the deepest waters with the October 2008 profile having anoxic conditions extending 13 m from the sediments (2). Comparison of surface and deep TP and TN PPALS readings showed increased deep

concentrations consistent with sediment nutrient regeneration. Chlorophyll-a concentration show a maximum at 9 m depth, which would be near the DO supersaturation depth and consistent with an active phytoplankton community growing on regenerated TP in the cold layer. The rooted plant survey conducted for the 1981 assessment noted no submerged plants and very sparse emergent plants (4). The July 2008 survey noted emergent rooted plants ringing most of the pond with limited submerged species "growing between cobble substrates" (5). This assessment was confirmed in the October 2008 survey (2). The July 2008 phytoplankton tow (5) found a diverse population of 27 noted species dominated by green algae (*Gloeocystis* and *Staurastrum*) and blue-green algae (*Microcystis*). The October 2008 tow showed a shift in the population with blue-green algae (*Aphanocapsa*) as the dominant species. Blue-green algae dominance is generally associated with high nutrient availability, while green algae tend to dominate in moderate nutrient settings.

Based on the available information, Long Pond is impaired. This impairment is generally based on consistently limited clarity, summer dissolved oxygen hypoxia and anoxia in the deep cold water layer, supersaturation dissolved oxygen conditions at the warm water/cold water boundary, and high nutrient and chlorophyll concentrations. Additional monitoring during summer conditions would help clarify, evaluate and refine the extent of the impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Long Island Pond
Little Island Pond

PPALS Pond Number: 367
MassDEP PALIS Number: 94088

Area (acres): 37.2
Bathymetry: DFW map
Maximum Depth (m): 5.2
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/28/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.75 m		
Total Depth	5 m		
Surface pH	7.24	6.5 – 8.3	MassDEP
Deepest DO	5.14 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.5°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.42 µg/L	1.7 µg/L	CCC
Surface TP	<1.55 µg/L	10 µg/L	CCC
Surface TN	0.49 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	>3		

OVERVIEW

Long Island Pond (also known as Little Island Pond) is located west of Hollis Road and east of Beaver Dam Road. It is also just west of Beaver Dam Pond and north of Great Island Pond. The pond has no surface water inflows (1) and is connected to an adjacent cranberry bog through a water level control structure. Most of the pond shoreline is undeveloped and owned by the Town via the Conservation Commission. There is no formal access. There are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Long Island Pond is shallow with somewhat restricted clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is slightly shallower than the 1970s-era Secchi reading of 3.2 m (1). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with some sediment oxygen demand. Comparison of shallow and deep total phosphorus, chlorophyll-a, and total nitrogen concentrations suggest that the sediments were releasing significant nutrients, but it appears that phosphorus was not readily available in the water column. The 1970's-era survey noted that blue-green filamentous algae covered nearly 2 acres of the bottom and rooted plants were dense in selected areas out to 1.5 m depth (1). If this plant distribution is sustained in 2014, macrophytes would likely be in a growth-oriented stage that would consume most of the phosphorus and leave little for phytoplankton in the water column. These plants would likely be the source of organic material that is causing sediment oxygen demand. The restricted clarity and low chlorophyll-a concentrations measured in 2014 suggest that the relationship between phytoplankton and macrophytes and the nutrient fluxes within the pond are complex. Further the role of the water budget, including inflow and/or outflow to the adjacent cranberry bog, would also be a factor that would need to be considered in water quality management.

Based on the available information, Long Island Pond is not impaired, but there are a number of issues that would need to be clarified to refine this characterization, including sediment TP regeneration, limited clarity, and current plant population. Among the steps to resolve these issues would be additional monitoring and synthesis of available information and identification, characterization and measurement of nutrient sources contributing to the pond. This information would form the basis for evaluation of potential water quality management strategies.

Micajah Pond

PPALS Pond Number: 173
MassDEP PALIS Number: 95102

Area (acres): 21.8
Bathymetry: DFW map
Maximum Depth (m): 7.9
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/28/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3 m		
Total Depth	8 m		
Surface pH	7.0	6.5 – 8.3	MassDEP
Deepest DO	7.33 mg/L	5.0 mg/L	MassDEP
Shallow temperature	25.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.53 µg/L	1.7 µg/L	CCC
Surface TP	<1.55 µg/L	10 µg/L	CCC
Surface TN	0.54 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	>5.9		

OVERVIEW
Micajah Pond is located east of Federal Furnace Road and west of Micajah Pond Road. It is also just north of Little Micajah Pond, near a number of small (0.2-2 acre) ponds, and is located within the Town Brook subwatershed to Plymouth Harbor (1). The pond is a true kettlehole pond with no surface water inflow or outflow (2). The pond shoreline is completely developed with residential dwellings on relatively small lots (mostly 0.2-0.4 acres) except for a town owned parcel with a beach off Colchester Drive. MassDFW has prepared a bathymetric map and identified the beach as an access point, but no fisheries management information is provided (3). MassDFW annual report lists that 1,100 pounds of fish were removed via poison application and the pond was restocked with largemouth bass, brown bullhead, and alewifes in Spring 1953 (4).

Water quality samples and macrophyte and phytoplankton surveys were collected from the pond once as part of a 1970s-era baseline pond assessment (2). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Micajah Pond is shallow with restricted clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is shallower than the 1970s-era Secchi reading of 5.5 m, but the recorded surface temperature (22°C) during the 1970s-era recording suggests it may have been late spring or late fall and, therefore, not comparable to the PPALS recording (2). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with some sediment oxygen demand and generally supersaturated oxygen conditions. Comparison of shallow and deep total phosphorus and total nitrogen concentrations suggest that the sediments were releasing some nutrients, but it appears that phosphorus was not readily available in the water column. The 1970's-era survey noted a ~3 acre area along the western shore with dense Bladderwort (*Utricularia*) growth, but little emergent shoreline plants or bottom-covering blue-green filamentous algae (2). If this plant distribution was sustained or expanded in 2014, these macrophytes would likely be in a growth-oriented stage that would consume most of the phosphorus and leave little for phytoplankton in the water column and help explain the water quality results including dissolved oxygen profile. The restricted clarity and low chlorophyll-a concentrations measured in 2014 suggest that the relationship between phytoplankton and macrophytes and the nutrient fluxes within the pond are complex.

Based on the available information, Micajah Pond is not impaired, but there are a number of issues that would need to be clarified to refine this characterization. This characterization is based on TP and chlorophyll-*a* concentrations below their respective ecoregion thresholds and DO concentrations throughout the water column that are near 100% saturation. However, the low clarity reading and high bottom to surface TP ratio raise some concerns. Among the steps to resolve these issues would be additional monitoring and synthesis of available information and identification, characterization and measurement of nutrient sources contributing to the pond. This information would form the basis for evaluation of potential water quality management strategies.

Morey Pond
Morey Hole

PPALS Pond Number: 214
MassDEP PALIS Number: 94102

Area (acres): 25.9
Bathymetry: DFW map
Maximum Depth (m): 4.0
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/21/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.85 m		
Total Depth	3.9 m		
Surface pH	6.6	6.5 – 8.3	MassDEP
Deepest DO	0.5 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.23 µg/L	1.7 µg/L	CCC
Surface TP	8.25 µg/L	10 µg/L	CCC
Surface TN	0.33 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.03		

OVERVIEW
Morey Pond (also known as Morey Hole) is located north of Ship Pond Road and south of Briggs Reservoir. It has a small surface water inflow along its western shore and a larger outflow to the Reservoir along its northern shore (1). The pond's northern shoreline is town owned land and undeveloped, while the southern shoreline is completely developed with residential dwellings on relatively large lots (mostly >1 acre). There is no formal access. There are no records of MassDFW management or fish stocking.

Water quality samples and macrophyte and phytoplankton surveys were collected from the pond once as part of a 1970s-era baseline pond assessment (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Morey Pond is shallow with restricted clarity at the time of the 2014 PPALS Snapshot; the PPALS Secchi reading is deeper than the 1970s-era Secchi reading of 2.1 m, but the recorded surface temperature (20°C) during the 1970s-era recording suggests it may have been late spring or late fall and, therefore, not comparable to the PPALS recording (2). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column with some significant sediment oxygen demand at the deepest recording. Comparison of shallow and deep total phosphorus and total nitrogen concentrations suggest that the sediments are not releasing significant nutrients. The 1970's-era survey noted ~30% of the pond bottom covered with relatively dense Bladderwort (*Utricularia*) growth, ~1 acre of bottom covered with blue-green filamentous algae, and little emergent or floating plant growth (2). The restricted clarity in the 1970s-era reading and low chlorophyll-a concentrations measured in 2014 suggest that the relationship between phytoplankton and macrophytes and the nutrient fluxes within the pond are complex.

Based on the available information, Morey Pond is not impaired, but there are some issues that would need to be clarified to refine this characterization. This characterization is based on TP and chlorophyll-*a* concentrations below their respective ecoregion thresholds and clarity that extends almost to the bottom. DO concentrations are generally near 100% saturation throughout the water column except near the sediments, but the bottom to surface TP ratio is not consistent with this deep measurement. Past measurements of extensive plant growth with blue-green algae suggest impaired conditions. Among the steps to resolve these issues would be additional monitoring and synthesis of available information and identification, characterization and measurement of nutrient sources contributing to the pond. This information would form the basis for evaluation of potential water quality management strategies.

North Triangle Pond

PPALS Pond Number: 419
MassDEP PALIS Number: 94110

Area (acres): 24.4
Bathymetry: DFW map
Maximum Depth (m): 3.66
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/9/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.5 m		
Total Depth	2.5 m		
Surface pH	6.16	6.5 – 8.3	MassDEP
Deepest DO	6.75 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.3°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.38 µg/L	1.7 µg/L	CCC
Surface TP	3.5 µg/L	10 µg/L	CCC
Surface TN	0.80 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	4.44		

OVERVIEW

North Triangle Pond is located north of Samoset Street and east of Industrial Park Road and Little Muddy Pond. It has no surface water inflows or outflows and is a true kettlehole pond (1). The pond is surrounded by a mix of various land uses, including residential lots of ~0.5 acres along its southern shore, office and industrial development along its western shore, and a mobile home park along its northern shore. Most of the residential development has uses within 50-100 of the shoreline, while the other development tends to be >100 ft from the shore. There is no formal access. There are no records of MassDFW management or fish stocking.

Water quality samples and macrophyte and phytoplankton surveys were collected from the pond once as part of a 1970s-era baseline pond assessment (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

North Triangle Pond is shallow with clarity to the bottom during the 2014 PPALS Snapshot; the PPALS Secchi reading is roughly equivalent to the 1970s-era Secchi reading of 2.7 m, but the station depth during the 1970s-era is not available for comparison (1). 2014 temperatures and dissolved oxygen concentrations show a well-mixed water column, but all dissolved oxygen readings are ~85% suggesting significant sediment oxygen demand. Comparison of shallow and deep total phosphorus and total nitrogen concentrations suggest that sediment oxygen demand is sufficient to release TP, but not TN. The 1970's-era survey noted significant plant aquatic plant populations with submerged plants (mix of Bladderwort, *Milfoil sp.*, and *Potamogetons sp.*) covering nearly the whole bottom, floating plants covering 87% of the surface, and abundant green and blue-green filamentous algae mixed among the submerged plants (1). This type of plant density typically is relatively static unless disturbed and allows for some availability of phosphorus. The lack of restricted clarity and low chlorophyll-a concentrations measured in 2014 suggest that the dense macrophyte population is outcompeting phytoplankton for available nutrients, but these relationships are likely complex and fluctuate with seasons and water level cycles.

Based on the available information, North Triangle Pond is impaired, mostly based on the extensive 1970s-era plant density. There are a number of issues that would need to be clarified to refine this characterization. Among the steps to resolve these issues would be additional monitoring and synthesis of available information and identification, characterization and measurement of nutrient sources contributing to the pond. This information would form the basis for evaluation of potential water quality management strategies.

Round Pond

PPALS Pond Number: 231
MassDEP PALIS Number: 95123

Area (acres): 22.0
Bathymetry: 1992 Living Lakes Report map
Maximum Depth (m): 6.1
2014 Secchi Depth (m):
Lake Association: Six Ponds Improvement Association

PPALS Sampling	9/10/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.65 m		
Total Depth	8 m		
Surface pH	6.19	6.5 – 8.3	MassDEP
Deepest DO	0.37 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	7.32 µg/L	1.7 µg/L	CCC
Surface TP	5.57 µg/L	10 µg/L	CCC
Surface TN	0.18 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.85		

OVERVIEW
Round Pond is located east of West Long Pond Road and south of Cornish Field Road. It is also just west of Long Pond and east of Halfway Pond. The pond is a true kettlehole pond and has no surface water inflow or outflow (1). Development around the pond is mostly residential with parcels ≥1 acre, although there is a large camp parcel along the eastern shoreline. There is no formal access. There are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment (1) and then 10 times between 1987 and 1991 as part of a pH assessment (2). The Six Ponds Improvement Association has sampled various locations in and around the pond 17 times between 2002 and 2013; one of these sampling runs was within the PPALS sampling period (August 15 – September 30). The 1970s-era baseline included macrophyte and phytoplankton surveys, which have not been repeated. The 1992 pH assessment focused on the impact of two additions of a combined 9.5 tonnes of limestone to the pond to raise its pH; sample analysis included nutrients and metals. Association sampling included a wide suite of compounds in the earlier samples and has narrowed mostly to nutrients in the more recent samples.

WATER QUALITY
Round Pond is shallow and had very changeable clarity when Secchi readings were collected, varying over a range of 3.3 to 6.5 (PPALS, refs 1 & 2). The available temperature profiles (PPALS, ref 2) show a generally well-mixed water column with similar temperatures from surface to bottom. The dissolved oxygen profile is generally similar to the temperature profile, except the PPALS profile had anoxic conditions at the deepest recording. Comparison of surface and deep total phosphorus PPALS readings showed increased deep concentrations consistent with sediment nutrient regeneration, but since total nitrogen concentrations were similar at shallow and deep samples, this suggests that the low DO/sediment TP regeneration is somewhat transitory. Chlorophyll-a concentration showed a maximum in the surface sample, which seems to suggest a watershed, rather than sediment, nutrient source. It is also possible that Round Pond was on the edge of an algal bloom when PPALS samples were collected. The plant survey conducted for the 1970s-era baseline pond assessment noted sparse macrophytes with limited submerged, emergent, and floating plants (1).

Based on the available information, Round Pond is borderline impaired based mostly on the high surface water chlorophyll-a concentration and deep anoxic dissolved oxygen measurement. This characterization is generally based on consistently limited clarity, summer dissolved oxygen hypoxia and anoxia in the deep cold water layer, supersaturation dissolved oxygen conditions at the warm water/cold water boundary, and high nutrient and chlorophyll concentrations. Additional monitoring during summer conditions would help clarify, evaluate and refine the extent of the impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Russell Mill Pond

PPALS Pond Number: 231
MassDEP PALIS Number: 95123

Area (acres): 43.3
Bathymetry: 1980 spot depths
Maximum Depth (m): 6.4
Lake Association:

PPALS Sampling	8/19/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.425 m		
Total Depth	6.4 m		
Surface pH	7.08	6.5 – 8.3	MassDEP
Deepest DO	0.04 mg/L	5.0 mg/L	MassDEP
Shallow temperature	20.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	8.93 µg/L	1.7 µg/L	CCC
Surface TP	18.4 µg/L	10 µg/L	CCC
Surface TN	0.35 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	5.63		

OVERVIEW
Russell Mill Pond is located west of Russell Mills Road, approximately 320 m west of Route 3. The Eel River flows into and out of the pond. A dam, that was recently updated, is located at the ponds downstream/eastern end; bathymetry of the pond suggests that it has been enlarged by the placement of the dam. An Eel River restoration project that removed a dam and changed cranberry bogs to more natural wetlands was recently completed just upstream of the pond (1). Residential development of the shoreline (~20 houses) is concentrated around the eastern end of the pond. There are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of 1970s-era baseline pond survey, which also include macrophyte and phytoplankton surveys (2). The pond was sampled 12 times between during 1980, including water quality, phytoplankton, and sediment samples, and surface DO, pH, temperature, and specific conductivity readings (3). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Russell Mill Pond is relatively shallow with limited 2014 clarity that generally matches more extensive clarity measurements collected in 1980. The 2014 PPALS temperature profile showed relatively cold water throughout the water column and some thermal stratification beginning near the surface. This profile may be related to a relatively short residence time. The PPALS dissolved oxygen profile showed concentrations below MassDEP minimums at depths of 2 m and deeper with anoxic concentrations at 4 m and deeper. Comparison of surface and deep TP PPALS readings showed elevated deep concentrations consistent with sediment nutrient regeneration with both concentrations greater than the ecoregion threshold. PPALS chlorophyll-a concentrations also showed a similar pattern. The 1970's-era macrophyte survey showed dense rooted aquatic plants and blue-green algae in the shallow western end of the pond, but relatively clear bottom in the deeper, eastern end of the pond (1).

Based on the available information, Russell Mill Pond is impaired. This impairment is generally based on consistently limited clarity, summer dissolved oxygen anoxia the deeper waters, indication of significant sediment regeneration, and total phosphorus and chlorophyll a concentrations greater than ecoregion thresholds. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Sabys Pond

PALS Pond Number: 94
MassDEP PALIS Number: 95050

Area (acres): 12
Bathymetry: none
Maximum Depth (m): 5
Lake Association:

PALS Sampling	9/11/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	3.76 m		
Total Depth	5 m		
Surface pH	6.25	6.5 – 8.3	MassDEP
Deepest DO	7.89 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.21 µg/L	1.7 µg/L	CCC
Surface TP	6.8 µg/L	10 µg/L	CCC
Surface TN	0.28 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.55		

OVERVIEW

Sabys Pond (aka Saby's Pond, Ellis Pond, and Sabres Pond) is located west of Federal Furnace Road and just to the east of Plymouth Airport. Some historic aerial photographs suggest occasional surface water connections to Little Sabys Pond to the south. Most of the shoreline is developed by an extensive campground development with the remainder developed with mostly with single family residences. There is no formal public access and no bathymetric map was found during the collection and review of historic ponds reports.

Review of available historic reports also suggest that water quality samples collected during the 2014 PALS Snapshot appear to be the first samples collected from the pond.

WATER QUALITY

Sabys Pond is relatively shallow with some loss of clarity at the time of the 2014 PALS Snapshot. Temperatures and dissolved oxygen readings show a well-mixed water column with no significant loss of DO near the sediments. Chlorophyll-*a*, total phosphorus, and total nitrogen readings at both shallow and deep sampling depths had concentrations below respective ecoregion thresholds. Review of nitrogen to phosphorus ratios show that phosphorus control will determine the water quality conditions in this pond.

Based on the available information, Sabys Pond is not impaired. Additional monitoring would be required to confirm this assessment. Most of the readings do not suggest areas of significant water quality concern, but available monitoring is insufficient to definitively resolve the need for any management options.

Savery Pond

PPALS Pond Number: 37
MassDEP PALIS Number: 94136

Area (acres): 29.4
Bathymetry: 1970s spot depths
Maximum Depth (m): 3.7
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	8/18/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.4 m		
Total Depth	3.5 m		
Surface pH	6.51	6.5 – 8.3	MassDEP
Deepest DO	4.99 mg/L	5.0 mg/L	MassDEP
Shallow temperature	23.6°C	28.3°C	MassDEP
Surface Chlorophyll-a	14.61 µg/L	1.7 µg/L	CCC
Surface TP	108.7 µg/L	10 µg/L	CCC
Surface TN	0.93 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	0.48		

OVERVIEW

Savery Pond is located west of Old Sandwich Road and south of Lake Road. The pond has no surface water inflows, but has a surface water outflow on its southeastern shoreline that feeds a stream that eventually flows to Ellisville Harbor (1). The pond also has managed hydrologic connections to two cranberry bogs (~10 acres total). Aside from the cranberry bogs, most of the shoreline is developed with residential housing on lots ranging from ~0.5 acres to >2 acres, as well as a large campground on the southern shoreline. There is no formal access and there are no records of MassDFW management or fish stocking. According to MassDPH, there have been two closures of the pond for cyanobacteria blooms, once in 2011 and again in 2014.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment, including macrophyte and phytoplankton surveys (1). No other pond water quality sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

Savery Pond is shallow with reduced clarity. The 2014 PPALS temperature profile showed a generally well-mixed water column with similar temperatures from surface to bottom. The PPALS dissolved oxygen profile is generally similar to the temperature profile, except all of the concentrations are low (% saturation levels range from 58% to 76%) and include a slight drop in concentration at the deepest recording. Surface and deep total phosphorus PPALS readings are exceptionally high, which is unexpected given the low DO concentrations. The surface TP concentration was higher than the bottom sample, which seems to suggest a watershed, rather than sediment, nutrient source. This concentration was also ~5X higher than recorded during the 1970s-era baseline pond assessment (1). The 1970s-era plant survey noted limited submerged, emergent, and floating plants, but also noted that filamentous blue-green algae covered approximately 5 acres of the bottom.

Based on the available information, Savery Pond is impaired based mostly on the high surface water chlorophyll-*a* and total phosphorus concentrations and limited clarity. Additional monitoring during summer conditions would help clarify, evaluate and refine the extent of the impairment, the nutrient sources contributing to the high phosphorus levels, and evaluate potential water quality management strategies.

Shallow Pond

PPALS Pond Number: 262
MassDEP PALIS Number: 94140

Area (acres): 20.2
Bathymetry: 1970s spot depths
Maximum Depth (m): 2.1
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/4/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.25 m		
Total Depth	1.25 m		
Surface pH	4.62	6.5 – 8.3	MassDEP
Deepest DO	7.71 mg/L	5.0 mg/L	MassDEP
Shallow temperature	28.1°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.65 µg/L	1.7 µg/L	CCC
Surface TP	4.9 µg/L	10 µg/L	CCC
Surface TN	0.81 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-*	*only one sample collected	

OVERVIEW
Shallow Pond is located south of Shallow Pond Lane and north of Indian Brook Road. The pond has no surface water inflows or outflows, but has a hydrologic connection to a large cranberry bog system (>90 acres) to its south (1). Aside from the cranberry bog, most of the upgradient and adjacent shoreline is undeveloped. There is a ~40 ft buffer that is located on the northern shoreline and is owned by the Town that separates residential development further to the north. There is no formal access and there are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment, including macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Shallow Pond is very shallow with a max depth of 2.1 m (1). Secchi readings during the 1970s-era baseline assessment were 1.8 m, which would also be consistent with the 2014 PPALS reading at a shallower station. PPALS surface chlorophyll-a and total phosphorus concentrations were below ecoregion thresholds. The 1970's-era assessment noted rooted, submerged plants covering the bottom [mostly Bladderwort (*Utricularia*)] with floating plants, mostly White Water Lilly (*Nymphaea*), ringing the pond out to approximately the 4 ft contour. The prevalence of these macrophytes helps to explain why chlorophyll-a and total phosphorus concentrations are low, clarity generally extends to the bottom, and total nitrogen concentrations are high.

Based on the available information, Shallow Pond is impaired. This characterization is largely based on the high density of macrophyte growth and it is acknowledged that this conclusion is based on limited data. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Ship Pond

PPALS Pond Number: 209
MassDEP PALIS Number: 94142

Area (acres): 12.3
Bathymetry: 1970s spot depths
Maximum Depth (m): 1.8
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/4/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	1.0 m		
Total Depth	1.0 m		
Surface pH	7.08	6.5 – 8.3	MassDEP
Deepest DO ([a]surface)	8.57 mg/L[a]	5.0 mg/L	MassDEP
Shallow temperature	25.9°C	28.3°C	MassDEP
Surface Chlorophyll-a	2.72 µg/L	1.7 µg/L	CCC
Surface TP	20.2 µg/L	10 µg/L	CCC
Surface TN	0.60 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	-[b]	[b]only one sample collected	

OVERVIEW
Ship Pond is located east of Route 3A and Lilly Pond and within 300 ft of Cape Cod Bay. The pond has inflow at its south end from an area that once had more cranberry bogs (>7 acres) than it does today (1). The pond also has an outflow to Cape Cod Bay at its northern end. Most of the western shoreline has residential development, set back 150-200 ft from the shoreline. Residential development along the northern shoreline is generally with 50 ft of the shoreline and the eastern shoreline is undeveloped and classified by the town assessor as undevelopable. There is no formal access and there are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment, including macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Ship Pond is very shallow with a max depth of 1.8 m (1). The single Secchi reading during the 1970s-era baseline assessment was 1.1 m, which would be consistent with the 2014 PPALS reading at a shallower station, but indicative of restricted clarity. PPALS surface chlorophyll-a and total phosphorus concentrations were above ecoregion thresholds. The 1970's-era assessment noted green and blue-green filamentous algae covering the entire bottom with floating and emergent macrophytes along portions of the shoreline. The balance between the macrophytes and filamentous algae helps to explain the high nutrient concentrations, as well as a surface dissolved oxygen concentration greater than atmospheric saturation (e.g., >100% saturation).

Based on the available information, Ship Pond is impaired. This characterization is largely based on the high density of filamentous algae growth and it is acknowledged that this conclusion is based on limited data. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

Wall Pond

PPALS Pond Number: 18
MassDEP PALIS Number: 95155

Area (acres): 12.8
Bathymetry: 1970s spot depths
Maximum Depth (m): 4.9
2014 Secchi Depth (m):
Lake Association:

PPALS Sampling	9/11/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi	2.0 m		
Total Depth	5.5 m		
Surface pH	6.49	6.5 – 8.3	MassDEP
Deepest DO	7.72 mg/L	5.0 mg/L	MassDEP
Shallow temperature	24.0°C	28.3°C	MassDEP
Surface Chlorophyll-a	1.54 µg/L	1.7 µg/L	CCC
Surface TP	6.60 µg/L	10 µg/L	CCC
Surface TN	0.44 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.19		

OVERVIEW
Wall Pond is located south of Great Wind Drive and north of Wind Song Drive. It is north of Rocky Pond and south of Jakes Pond. The pond is a kettlehole pond with no surface water inflows or outflows (1). The westernmost shoreline has a private beach and the easternmost shoreline is undeveloped (~25% of the whole shoreline). The remaining shoreline has residential development on roughly quarter-acre lots. There is no formal access and there are no records of MassDFW management or fish stocking.

Water quality samples were collected from the pond once as part of a 1970s-era baseline pond assessment, including macrophyte and phytoplankton surveys (1). No other pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY
Wall Pond is shallow and had reduced clarity during the 2014 PPALS Snapshot and in the 1970s-era baseline. The PPALS temperature and dissolved oxygen profiles showed a generally well-mixed water column with similar temperatures and DO concentrations from surface to bottom. DO concentrations were all slightly elevated (101 to 106% saturation), but the deepest sample only declines to 91% saturation. Surface total phosphorus and chlorophyll-a PPALS readings were both lower than ecoregion thresholds. Shallow and deep TP, chlorophyll-a, and total nitrogen were generally similar, indicating little sediment regeneration. The 1970s-era plant survey noted filamentous blue-green algae in selected shoreline area, but generally the pond had sparse submerged, emergent, and floating plants.

Based on the available information, Wall Pond is not impaired, but there are some concerns based on the historic filamentous blue-green algae and the consistent reduced clarity. It is acknowledged that this conclusion is based on limited data. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment, the nutrient sources contributing to the pond, and evaluate potential water quality management strategies.

White Island Pond

PPALS Pond Number: 422 (East Basin), 266 (West Basin)
MassDEP PALIS Number: 95173

Area (acres): 291
Bathymetry: 2009 SMAST
Maximum Depth (m): 4.8, East; 3.3, West
2014 Secchi Depth (m):
Lake Association: White Island Pond Conservation Alliance

PPALS Sampling	8/25/14		
Parameter	Pond	Standard/ Limit	Standard Source
Secchi (East/West basins)	2.1/1.7 m		
Total Depth (E/W)	4.7/4.5 m		
Surface pH (E/W)	6.68/6.94	6.5 – 8.3	MassDEP
Deepest DO (E/W)	8.14/8.35 mg/L	5.0 mg/L	MassDEP
Shallow temperature (E/W)	24.0/24.4°C	28.3°C	MassDEP
Surface Chlorophyll-a (E/W)	2.79/3.33 µg/L	1.7 µg/L	CCC
Surface TP (E/W)	8.25/12.78 µg/L	10 µg/L	CCC
Surface TN (E/W)	0.35/0.48 mg/L	0.31 mg/L	CCC
TP ratio (deep/shallow)	1.08/1.21		

OVERVIEW

White Island Pond is located west of Bourne Road, east of Wareham Road, and straddles the town boundary with Wareham. It is in an area with a large number of ponds, including Big Sandy Pond and Ezekiel Pond to the east and Deer Pond to the north. The pond has a significantly branched shoreline with one controlled surface water outlet off the southern end of the East Basin and two controlled surface water inlets on the northern end of the East Basin (1). The southernmost shoreline on the West Basin has a private association beach in the Town of Wareham, but there appears to be no formal public access. The northernmost shoreline of the East Basin has two large cranberry bogs (>35 acres each) and rest of the shoreline mostly has residential development with lot sizes generally between 0.25 and 0.5 acres. There are a total of 329 parcels around the shoreline (1). There are no records of MassDFW management or fish stocking. According to MassDPH, there have been three closures of the pond for cyanobacteria blooms: 2009, 2011, and 2013.

White Island Pond was identified as an impaired water body in the 2006 Massachusetts Integrated List and subsequent listings (2). MassDEP proposed TMDLs of 19 µg/L total phosphorus for each basin to address this impairment and USEPA approved the TMDLs in 2010 (3). The final TMDL and CSP/SMAST water quality assessment (1) identified the primary source of the impairment as phosphorus regenerated from the pond's sediments. In March/April 2014, the pond was treated with alum to inactivate this nutrient regeneration.

White Island Pond has been sampled a number of times. Water quality samples were collected once as part of a 1970s-era baseline pond assessment, including macrophyte and phytoplankton surveys (4). It was sampled eight times in 1976-1978 by MassDEQE (5). It was sampled by MassDEP three times in the summer of 2000 and five times during the summer of 2007 (3). The 2012 assessment included extensive data collection, including updated bathymetry, watershed delineation, measurement of stream outflows (2009-2010), characterization of the two bog systems and measurement of their inflows, sediment core collection and incubation to measure nutrient content, and 14 sampling runs at three stations, including temperature and dissolved oxygen profiles, Secchi clarity readings, and water quality samples that were analyzed for nutrients, chlorophyll, and other factors (1). No additional pond sampling appears to have been completed until the 2014 PPALS Snapshot.

WATER QUALITY

White Island Pond has two basins, both of which are relatively shallow. Both basins had reduced clarity during the 2014 PPALS Snapshot, but the clarity in the East Basin was ~2X greater than during the 2012 assessment (1) and equivalent to August readings in 1976 and 1977 (5). The West Basin, which received a lower dose of alum, had a Secchi depth shallower than any of the 14 readings recorded during 2010 (1) or any readings in 1976 and 1977 (5). The PPALS temperature and dissolved oxygen profiles generally showed well-mixed water columns in both basins with similar temperatures and DO concentrations from surface to bottom. DO concentrations were all close to balance with atmospheric saturation (~100% DO saturation). Surface total phosphorus PPALS readings were lower than the ecoregion threshold in the East Basin, but exceeded the threshold in the West Basin. Chlorophyll-a concentrations in both basins exceeded the ecoregion threshold. Comparison of shallow and deep total phosphorus, chlorophyll-a, and total nitrogen concentrations showed little evidence of sediment regeneration. The 1970s-era plant survey noted extensive macrophyte growth (mostly *Elodea*) in the northern portion of the East Basin with sparse floating submerged, emergent, and floating plants throughout the rest of pond except for bladderwort in a cove in the West Basin (4). The 1978 assessment confirmed the prevalence of Elodea and also noted filamentous algae covering the bottom in this portion of the pond (5).

Based on the available information, White Island Pond (East Basin) is not impaired and is certainly improved following the alum treatment, but the 2014 data shows there are some concerns based on clarity and chlorophyll-*a* concentration. The West Basin appears to be borderline impaired with lower clarity and higher chlorophyll-*a*, TP and TN concentrations than the East Basin. It is acknowledged that this conclusion is based on a single snapshot date. Additional monitoring and synthesis of available information would be required to evaluate and refine the extent of this impairment and the variability of the data, as well as potential water quality management strategies beyond the alum treatment.

Appendix C

Town of Plymouth PALS
2014 Snapshot
Water Quality Sampling Data

- Dissolved oxygen and Temperature profiles, Secchi clarity and total depth readings collected by Plymouth PALS samplers
- Plymouth PALS sampling locations over the deepest point in the pond. Sampling locations were recorded using GPS if location had not previously monitored by a Pond Association or the Town.
- Sample analysis results provided by the Coastal Systems Analytical Facility at SMAST-UMass Dartmouth

List of 2014 Plymouth PALS Sampling Locations	
Pond	Coordinates
Bartlett	N41 55.698 W70 33.449
Big Sandy	N 41 48'42.9" W 70 36'20.8
Big West	N 41 55.213 W70 42.62
Billington Sea East	N41 55 56.5 W 70 41' 00.9"
Billington Sea West	N 41. 56'08.1" W 70 41'41.8"
Bloody	N41 50.75 W70 34.91
Boot	N 41 53 776 W 70 39.665
Clam Pudding	N41 52' 43.5" W70 35' 09.5"
Clear	N 41 56'0.22" W 70 43'46.6
Deer	N 41 49' 14.831 W 70 37' 29.621
Ezekiel	N41 48.301 W70 36.693
Forges	N 41 51.176 W 70 36.667
Fresh	N41 54'21.8" W 70 33'21.1"
Fresh Meadow	N41 55.099 W70 44.839
Bartlett	N41 55.698 W70 33.449
Gallows	N41 51.789 W70 36.862
Great Herring	N41 47.843 W70 33.833
Great South	N 41 54.263 W70 40.063
Gunners	N41 53.432 W70 39.016
Halfway	N41 50.821 W70 37.039
Hedges	N41 49'38.4" W 70 33'50.5"
Hoyts	N41 53.86 W70 39.132
Jakes	N41 49'39.0 W70 36'16.1
Little	N41 56'32.7" W70 41'02.5"
Little Herring	N41 49.595 W70 34.54
Little Island	N 41 53'40.2" W 70 34' 34.6
Little Long	N41 52.16 W70 36.832
Little South	N41 54'57.7" W70 40'31.7"
Little West	N 41 44 22 W 70 42 22
Long	N41 51.57 W70 36.276
Micajah	N 41 55.703 W 70 41.831
Morey's Hole	N41 52.175 W70 33.34
North Triangle	N 41 56'57.6, W 70 42' 03.9"
Round	N41 51.177 W70 36.247
Russell Mills	N 41 55'2", W 70 37' 39"
Saby	N41 54'36.5" W 70 42' 42.1"
Savery	N 41 50.852 W 70 32.763
Shallow	N41 5'3 21.1" W 70 33' 12.9"
Ship	N 41 52' 15.1 W 70 32' 006"
Wall	N 41 49'32.0" W 70 36'06.3"
White Island East	N 41 48'27.4" W70 36'56.7"
White Island West	N41 48.253 W70 37.444

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (µg/L)	Phaeo (µg/L)	TP (µg/L)	TN (mg/L)
Bartlett	0.5	9/4/14	1.1	1.1	22.4	ND	6.97	14.3	2.33	2.48	32.10	0.31
Bartlett	1	9/4/14			22.6	ND	6.96	13.8	11.24	3.87	49.45	0.41
Bartlett	1.5	9/4/14			ND	ND	NS	NS	NS	NS		
Big Sandy	0.5	8/28/14	11.2	5.5	24.4	7.78	6.11	2.7	6.59	0.14	<0.77	0.28
Big Sandy	1	8/28/14			24.4	7.59	NS	NS	NS	NS		
Big Sandy	2	8/28/14			24.4	7.8	NS	NS	NS	NS		
Big Sandy	3	8/28/14			24.4	7.82	6.36	2.6	1.10	0.14	3.09	0.28
Big Sandy	4	8/28/14			24.4	7.85	NS	NS	NS	NS		
Big Sandy	5	8/28/14			24.3	7.59	NS	NS	NS	NS		
Big Sandy	6	8/28/14			24.3	7.62	NS	NS	NS	NS		
Big Sandy	7	8/28/14			24.7	6.79	NS	NS	NS	NS		
Big Sandy	8	8/28/14			23.5	4.74	NS	NS	NS	NS		
Big Sandy	9	8/28/14			22.7	4.74	NS	NS	NS	NS		
Big Sandy	10	8/28/14			17.5	2.14	5.89	6.0	24.33	10.86	39.91	0.90
Big Sandy	11	8/28/14			14.5	1.78	NS	NS	NS	NS		
Big West	0.5	8/26/14	4.8	3.15	25.6	8.65	6.95	7.1	1.21	0.17	1.65	0.44
Big West	1	8/26/14			25.4	8.64	NS	NS	NS	NS		
Big West	2	8/26/14			24.2	8.52	NS	NS	NS	NS		
Big West	3	8/26/14			23.8	8.52	NS	NS	NS	NS		
Big West	3.8	8/26/14			ND	ND	6.83	7.6	2.81	0.56	3.71	0.39
Big West	4	8/26/14			23.5	7.89	NS	NS	NS	NS		
Billington Sea East	0.5	8/25/14	1.5		24.2	10.24	9.22	15.9	15.59	<0.05	22.77	0.69
Billington Sea East	1	8/25/14			24.0	10.51	NS	NS	NS	NS		
Billington Sea East	1.5	8/25/14			23.9	10.6	NS	NS	NS	NS		
Billington Sea East	2	8/25/14			23.8	10.66	NS	NS	NS	NS		
Billington Sea East	2.3	8/25/14			ND	ND	9.21	15.7	14.03	<0.05	25.16	0.73
Billington Sea East	2.5	8/25/14			23.7	10.9	NS	NS	NS	NS		
Billington Sea East	3	8/25/14			22.9	10.1	NS	NS	NS	NS		
Billington Sea West	0.5	8/25/14	2.5	1.75	24.0	10.1	8.80	15.6	9.47	<0.05	15.05	0.90
Billington Sea West	1	8/25/14			23.9	10.44	8.80	15.5	9.31	<0.05	22.77	0.96
Billington Sea West	1.5	8/25/14			23.8	10.52	NS	NS	NS	NS		
Billington Sea West	2	8/25/14			21.1	11.86	NS	NS	NS	NS		
Bloody	0.5	9/10/14	11	8.85	24.2	8.52	7.24	4.8	6.30	1.43	8.25	0.37
Bloody	1	9/10/14			24.2	8.47	NS	NS	NS	NS		
Bloody	2	9/10/14			24.3	8.43	NS	NS	NS	NS		
Bloody	3	9/10/14			24.3	8.41	6.79	3.8	0.93	0.11	17.32	0.24
Bloody	4	9/10/14			24.3	8.83	NS	NS	NS	NS		
Bloody	5	9/10/14			24.3	8.36	NS	NS	NS	NS		
Bloody	6	9/10/14			24.3	8.33	NS	NS	NS	NS		
Bloody	7	9/10/14			24.3	8.31	NS	NS	NS	NS		
Bloody	8	9/10/14			24.2	8.32	NS	NS	NS	NS		
Bloody	9	9/10/14			24.2	8.31	6.78	3.7	0.86	0.20	4.33	0.23
Bloody	10	9/10/14			24.2	8.3	NS	NS	NS	NS		
Bloody	10.6	9/10/14			ND	ND	5.96	5.0	2.11	1.31	21.44	0.31
Boot	0.5	8/20/14	10.3	7	24.4	8.68	6.57	4.2	1.10	0.28		
Boot	1	8/20/14			24.3	8.66	NS	NS	NS	NS		
Boot	2	8/20/14			24.3	8.62	NS	NS	NS	NS		
Boot	3	8/20/14			24.3	8.6	6.95	4.3	1.39	0.37		
Boot	4	8/20/14			24.3	8.58	NS	NS	NS	NS		
Boot	5	8/20/14			24.2	8.5	NS	NS	NS	NS		
Boot	6	8/20/14			24.1	8.38	NS	NS	NS	NS		
Boot	7	8/20/14			23.6	8.23	NS	NS	NS	NS		
Boot	8	8/20/14			21.6	1.03	7.02	4.3	1.25	0.23		
Boot	9	8/20/14			16.7	0.41	NS	NS	NS	NS		
Boot	9.5	8/20/14			ND	ND	6.34	20.1	6.34	18.63		
Boot	10	8/20/14			15.3	0.34	NS	NS	NS	NS		

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (μg/L)	Phaeo (μg/L)	TP (μg/L)	TN (mg/L)
Clam Pudding	0.5	9/15/14	5.8	3	22.9	8.11	5.58	1.3	0.62	0.25	9.48	0.27
Clam Pudding	1	9/15/14			23.0	8.36	NS	NS	NS	NS		
Clam Pudding	2	9/15/14			22.9	8.57	NS	NS	NS	NS		
Clam Pudding	3	9/15/14			22.9	8.24	NS	NS	NS	NS		
Clam Pudding	4	9/15/14			22.9	8.31	NS	NS	NS	NS		
Clam Pudding	4.8	9/15/14			ND	ND	5.58	1.4	0.51	0.26	8.04	0.24
Clam Pudding	5	9/15/14			22.9	8.25	NS	NS	NS	NS		
Clear	0.5	8/26/14	7	2.1	24.4	8.68	7.75	13.1	5.03	<0.05	6.60	0.41
Clear	1	8/26/14			24.2	8.5	NS	NS	NS	NS		
Clear	2	8/26/14			24.1	8.66	NS	NS	NS	NS		
Clear	3	8/26/14			24.0	8.6	NS	NS	NS	NS		
Clear	4	8/26/14			23.4	8.36	NS	NS	NS	NS		
Clear	5	8/26/14			18.6	3.4	NS	NS	NS	NS		
Clear	6	8/26/14			13.9	2.5	6.45	18.0	4.76	0.49	8.25	0.30
Deer	0.5	8/26/14	5.5	3.6	24.1	8.11	5.81	1.7	1.97	0.25	4.53	0.31
Deer	1	8/26/14			24.0	8.13	NS	NS	NS	NS		
Deer	2	8/26/14			23.8	7.93	NS	NS	NS	NS		
Deer	3	8/26/14			23.5	6.62	NS	NS	NS	NS		
Deer	3.5	8/26/14			ND	ND	5.61	1.8	2.52	0.40	7.42	0.32
Deer	4	8/26/14			23.2	4.55	NS	NS	NS	NS		
Deer	5	8/26/14			23.0	4.34	NS	NS	NS	NS		
Ezekiel	0.5	8/25/14	5	3.1	24.5	8.96	6.70	4.5	4.78	<0.05	6.60	0.34
Ezekiel	1	8/25/14			24.2	8.98	NS	NS	NS	NS		
Ezekiel	1.5	8/25/14			23.9	8.79	NS	NS	NS	NS		
Ezekiel	2	8/25/14			23.9	8.87	NS	NS	NS	NS		
Ezekiel	2.5	8/25/14			23.8	8.69	NS	NS	NS	NS		
Ezekiel	3	8/25/14			23.7	8.66	NS	NS	NS	NS		
Ezekiel	3.5	8/25/14			23.7	6.64	NS	NS	NS	NS		
Ezekiel	4	8/25/14			23.7	8.79	6.59	4.6	4.44	0.48	4.12	0.33
Ezekiel	4.5	8/25/14			23.4	7.6	NS	NS	NS	NS		
Forges	0.5	9/4/14	3	3	25.7	9.55	4.21	10.7	0.79	0.26	3.50	0.19
Forges	1	9/4/14			23.4	10.42	NS	NS	NS	NS		
Forges	1.5	9/4/14			22.5	11.36	NS	NS	NS	NS		
Forges	2	9/4/14			21.3	11.85	7.00	10.3	5.82	0.12	12.16	0.29
Forges	2.5	9/4/14			19.8	9.58	NS	NS	NS	NS		
Fresh	0.5	8/26/14	10	3.6	25.1	8.76	6.97	7.6	1.19	0.20	2.89	0.49
Fresh	1	8/26/14			24.1	8.63	NS	NS	NS	NS		
Fresh	2	8/26/14			24.8	8.62	NS	NS	NS	NS		
Fresh	3	8/26/14			24.6	8.66	6.89	7.6	1.77	0.15	4.95	0.39
Fresh	4	8/26/14			24.2	8.56	NS	NS	NS	NS		
Fresh	5	8/26/14			23.1	8.24	NS	NS	NS	NS		
Fresh	6	8/26/14			23.3	7.15	NS	NS	NS	NS		
Fresh	7	8/26/14			20.0	4.76	NS	NS	NS	NS		
Fresh	8	8/26/14			15.3	3.83	NS	NS	NS	NS		
Fresh	9	8/26/14			13.0	3.37	6.18	9.0	11.69	0.37	11.75	0.37
Fresh Meadow	0.5	9/10/14	2.9	1.4	22.0	8.03	6.79	16.2	8.72	1.01	16.28	0.37
Fresh Meadow	1	9/10/14			22.0	7.72	NS	NS	NS	NS		
Fresh Meadow	1.5	9/10/14			22.0	7.71	NS	NS	NS	NS		
Fresh Meadow	1.9	9/10/14			22.0	7.85	6.83	16.1	5.82	2.38	35.13	0.44
Fresh Meadow	2	9/10/14			21.1	4.41	NS	NS	NS	NS		
Fresh Meadow	2.5	9/10/14			ND	ND	NS	NS	NS	NS		

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (µg/L)	Phaeo (µg/L)	TP (µg/L)	TN (mg/L)
Gallows	0.5	9/10/14	10	4.85	24.0	8	6.25	2.2	1.02	0.38	26.89	0.23
Gallows	1	9/10/14			24.2	7.9	NS	NS	NS	NS		
Gallows	2	9/10/14			24.3	7.92	NS	NS	NS	NS		
Gallows	3	9/10/14			24.2	7.93	6.23	2.2	0.80	0.31	3.71	0.23
Gallows	4	9/10/14			24.2	7.91	NS	NS	NS	NS		
Gallows	5	9/10/14			24.2	9.94	NS	NS	NS	NS		
Gallows	6	9/10/14			24.2	7.94	NS	NS	NS	NS		
Gallows	7	9/10/14			24.1	7.86	NS	NS	NS	NS		
Gallows	8	9/10/14			24.1	7.8	6.21	2.1	0.87	0.57	7.21	0.26
Gallows	9	9/10/14			24.1	7.35	NS	NS	NS	NS		
Great Herring	0.5	8/19/14	12.6	2	24.6	8.35	6.80	6.8	5.03	1.15	15.87	0.32
Great Herring	1	8/19/14			24.4	8.26						
Great Herring	2	8/19/14			24.1	8.16						
Great Herring	3	8/19/14			24	8.09	6.78	6.9	7.45	0.96	25.59	0.31
Great Herring	4	8/19/14			24	7.96						
Great Herring	5	8/19/14			23.9	7.83						
Great Herring	6	8/19/14			23.9	7.89						
Great Herring	7	8/19/14			23.9	7.78						
Great Herring	8	8/19/14			23.9	7.84						
Great Herring	9	8/19/14			23.8	7.74	6.75	6.9	3.72	1.19	46.83	0.29
Great Herring	10	8/19/14			23.8	7.4						
Great Herring	11	8/19/14			23.8	7.55						
Great Herring	11.5	8/19/14					6.94	10.6	6.50	2.46	21.03	0.32
Great Herring	12	8/19/14			23.8	7.26						
Great South	0.5	8/27/14	14.93	5.1	23.7	7.4	6.71	4.0	1.13	<0.05	2.27	0.40
Great South	1	8/27/14			23.8	7.5	NS	NS	NS	NS		
Great South	2	8/27/14			23.8	7.4	NS	NS	NS	NS		
Great South	3	8/27/14			23.8	7.3	6.66	3.9	0.81	<0.05	5.36	0.28
Great South	4	8/27/14			23.7	7.4	NS	NS	NS	NS		
Great South	5	8/27/14			23.7	7.3	NS	NS	NS	NS		
Great South	6	8/27/14			23.7	7.2	NS	NS	NS	NS		
Great South	7	8/27/14			23.7	7.2	NS	NS	NS	NS		
Great South	8	8/27/14			23.7	7.1	NS	NS	NS	NS		
Great South	9	8/27/14			23.7	7	6.58	4.1	2.39	0.10	4.53	0.41
Great South	10	8/27/14			20.8	5.5	NS	NS	NS	NS		
Great South	11	8/27/14			20.5	6.6	NS	NS	NS	NS		
Great South	12	8/27/14			18.1	3.8	NS	NS	NS	NS		
Great South	13	8/27/14			15.4	3	6.71	4.2	1.74	0.10	5.98	0.26
Great South	14	8/27/14			13.9	3.3	NS	NS	NS	NS		
Gunners	0.5	8/20/14	8.85	6.4	24.8	6.98	6.70	3.1	0.83	0.24		
Gunners	1	8/20/14			24.5	6.79	NS	NS	NS	NS		
Gunners	2	8/20/14			24.3	6.91	NS	NS	NS	NS		
Gunners	3	8/20/14			24.2	6.83	6.73	3.2	1.29	0.53		
Gunners	4	8/20/14			24.1	6.81	NS	NS	NS	NS		
Gunners	5	8/20/14			24.0	6.51	NS	NS	NS	NS		
Gunners	6	8/20/14			23.5	5.02	NS	NS	NS	NS		
Gunners	6.85	8/20/14			ND	ND	5.93	4.9	2.69	1.97		
Gunners	7	8/20/14			19.9	0.64	NS	NS	NS	NS		
Gunners	7.5	8/20/14			17.5	0.22	NS	NS	NS	NS		
Halfway	0.5	9/10/14	4	2	23.2	8.35	6.80	5.0	2.61	0.78	18.55	0.29
Halfway	1	9/10/14			23.2	8.33	NS	NS	NS	NS		
Halfway	2	9/10/14			23.3	8.32	NS	NS	NS	NS		
Halfway	3	9/10/14			22.8	8.4	6.79	4.6	22.66	19.00	97.96	0.97

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (μg/L)	Phaeo (μg/L)	TP (μg/L)	TN (mg/L)
Hedges	0.5	9/11/14	4.25	3.1	24.1	9.13	5.73	1.4	1.90	0.32	8.66	0.21
Hedges	1	9/11/14			24.0	8.9	NS	NS	NS	NS		
Hedges	2	9/11/14			24.0	8.8	NS	NS	NS	NS		
Hedges	2.5	9/11/14			24.0	8.72	NS	NS	NS	NS		
Hedges	3	9/11/14			23.9	8.75	NS	NS	NS	NS		
Hedges	3.5	9/11/14			ND	ND	5.69	1.3	1.97	0.25	7.42	0.20
Hoyts	0.5	8/20/14	5.25	4.7	25.5	7.48	6.76	3.0	1.11	0.82		
Hoyts	1	8/20/14			24.7	7.69	NS	NS	NS	NS		
Hoyts	2	8/20/14			24.3	7.44	NS	NS	NS	NS		
Hoyts	3	8/20/14			24.1	6.86	NS	NS	NS	NS		
Hoyts	4	8/20/14			24.0	6.87	NS	NS	NS	NS		
Hoyts	4.25	8/20/14			ND	ND	6.63	2.9	1.53	0.90		
Hoyts	5	8/20/14			24.0	6.82	NS	NS	NS	NS		
Jakes	0.5	9/11/14	3.5	2.5	24.1	8.29	5.99	2.4	0.95	0.95	11.54	0.43
Jakes	1	9/11/14			23.8	8.46	NS	NS	NS	NS		
Jakes	1.5	9/11/14			23.5	8.19	NS	NS	NS	NS		
Jakes	2	9/11/14			23.4	8.15	NS	NS	NS	NS		
Jakes	2.5	9/11/14			23.4	7.99	5.95	2.3	1.06	0.66	11.13	0.37
Jakes	3	9/11/14			23.4	7.94	NS	NS	NS	NS		
Little	0.5	9/9/14	12.5	6.4	24.8	8.47	6.70	4.2	0.80	0.33	1.65	0.30
Little	1	9/9/14			24.8	8.43	NS	NS	NS	NS		
Little	2	9/9/14			24.8	8.35	NS	NS	NS	NS		
Little	3	9/9/14			24.8	8.35	6.75	4.1	0.67	0.42	<0.77	0.31
Little	4	9/9/14			24.8	8.1	NS	NS	NS	NS		
Little	5	9/9/14			24.8	8.17	NS	NS	NS	NS		
Little	6	9/9/14			24.5	8.35	NS	NS	NS	NS		
Little	7	9/9/14			21.6	10.37	NS	NS	NS	NS		
Little	8	9/9/14			15.8	11.58	NS	NS	NS	NS		
Little	9	9/9/14			13.7	11.47	6.42	4.6	1.54	0.93	<0.77	0.32
Little	10	9/9/14			11.4	9.04	NS	NS	NS	NS		
Little	11	9/9/14			10.1	6.73	NS	NS	NS	NS		
Little	11.5	9/9/14			ND	ND	5.95	5.2	1.62	1.90	1.65	0.25
Little Herring	0.5	8/19/14	ND	ND	ND	ND	6.90	10.8	8.07	2.05	41.86	0.74
Little Island	0.5	8/28/14	5	2.75	24.5	7.91	7.24	15.2	1.42	0.33	<0.77	0.49
Little Island	1	8/28/14			24.4	8.03	NS	NS	NS	NS		
Little Island	2	8/28/14			24.4	8.1	NS	NS	NS	NS		
Little Island	3	8/28/14			24.3	8.07	NS	NS	NS	NS		
Little Island	4	8/28/14			22.5	5.14	6.70	19.2	3.01	2.23	4.74	0.73
Little Long	0.5	8/19/14	2.1	1.55	23.2	12.5	6.97	7.6	4.64	0.51	18.96	0.53
Little Long	1	8/19/14			22.5	13.9	NS	NS	NS	NS		
Little Long	1.4	8/19/14			ND	ND	6.91	6.7	4.10	0.98	26.46	0.53
Little Long	1.5	8/19/14			22.1	12.8	NS	NS	NS	NS		
Little Long	2	8/19/14			17.1	12.4	NS	NS	NS	NS		
Little South	0.5	9/9/14	5.5	4.9	24.9	8.77	6.47	2.8	0.80	0.29	4.33	0.28
Little South	1	9/9/14			24.9	8.69	NS	NS	NS	NS		
Little South	2	9/9/14			24.9	8.75	NS	NS	NS	NS		
Little South	3	9/9/14			24.9	8.57	NS	NS	NS	NS		
Little South	4	9/9/14			24.9	8.63	NS	NS	NS	NS		
Little South	4.5	9/9/14			ND	ND	6.52	2.8	0.98	0.26	17.32	0.25
Little South	5	9/9/14			24.9	8.71	NS	NS	NS	NS		
Little West	0.5	8/26/14	4.8	2.6	25.8	8.75	7.00	6.3	3.19	0.17	9.89	0.53
Little West	1	8/26/14			25.6	8.77	NS	NS	NS	NS		
Little West	2	8/26/14			24.6	8.81	NS	NS	NS	NS		
Little West	3	8/26/14			24.2	8.68	NS	NS	NS	NS		
Little West	3.8	8/26/14			ND	ND	6.89	6.2	5.57	0.66	11.34	0.45
Little West	4	8/26/14			23.7	7.99	NS	NS	NS	NS		

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (µg/L)	Phaeo (µg/L)	TP (µg/L)	TN (mg/L)
Long	0.5	8/19/14	28.2	2.5	24.5	11.2	8.43	6.9	2.13	<0.05	12.99	0.55
Long	1	8/19/14			24.3	11.3	NS	NS	NS	NS		
Long	2	8/19/14			24.2	11.4	NS	NS	NS	NS		
Long	3	8/19/14			24.0	11.4	8.84	7.2	2.27	<0.05	12.37	0.34
Long	4	8/19/14			23.0	11.4	NS	NS	NS	NS		
Long	5	8/19/14			23.9	11.5	NS	NS	NS	NS		
Long	6	8/19/14			23.9	11.3	NS	NS	NS	NS		
Long	7	8/19/14			23.8	11.3	NS	NS	NS	NS		
Long	8	8/19/14			23.7	11.6	NS	NS	NS	NS		
Long	9	8/19/14			23.3	12.4	9.55	7.1	10.97	<0.05	16.49	0.48
Long	10	8/19/14			16.7	13.4	NS	NS	NS	NS		
Long	11	8/19/14			16.7	19.6	NS	NS	NS	NS		
Long	12	8/19/14			13.0	19.7	NS	NS	NS	NS		
Long	13	8/19/14			8.4	19.1	NS	NS	NS	NS		
Long	14	8/19/14			7.8	5.8	NS	NS	NS	NS		
Long	15	8/19/14			7.3	3.2	NS	NS	NS	NS		
Long	16	8/19/14			7.2	4.9	NS	NS	NS	NS		
Long	17	8/19/14			6.5	2.9	NS	NS	NS	NS		
Long	18	8/19/14			6.6	1.3	NS	NS	NS	NS		
Long	19	8/19/14			6.5	1.4	NS	NS	NS	NS		
Long	20	8/19/14			6.2	0.7	NS	NS	NS	NS		
Long	21	8/19/14			6.5	0.9	NS	NS	NS	NS		
Long	22	8/19/14			6.3	0.9	NS	NS	NS	NS		
Long	23	8/19/14			6.3	0.7	NS	NS	NS	NS		
Long	28.4	8/19/14			ND	ND	6.18	8.0	0.82	1.57	57.26	0.75
Micajah	0.5	8/28/14	8	3	25.0	8.89	7.00	6.1	1.53	0.31	<0.77	0.54
Micajah	1	8/28/14			24.9	8.89	NS	NS	NS	NS		
Micajah	2	8/28/14			24.9	8.88	NS	NS	NS	NS		
Micajah	3	8/28/14			24.8	8.89	NS	NS	NS	NS		
Micajah	4	8/28/14			24.8	8.87	NS	NS	NS	NS		
Micajah	5	8/28/14			24.7	8.92	NS	NS	NS	NS		
Micajah	6	8/28/14			24.4	9.06	NS	NS	NS	NS		
Micajah	7	8/28/14			24.2	7.33	6.95	6.2	2.06	1.34	9.07	0.72
Morey's Hole	0.5	8/21/14	3.9	3.85	24.6	7.88	6.60	6.5	1.23	0.22	8.25	0.33
Morey's Hole	1	8/21/14			24.4	7.85	NS	NS	NS	NS		
Morey's Hole	2	8/21/14			24.2	7.79	NS	NS	NS	NS		
Morey's Hole	2.5	8/21/14			24.0	7.74	NS	NS	NS	NS		
Morey's Hole	2.9	8/21/14			ND	ND	6.61	6.5	1.40	0.56	8.45	0.33
Morey's Hole	3	8/21/14			23.9	7.35	NS	NS	NS	NS		
Morey's Hole	3.5	8/21/14			24.1	0.5	NS	NS	NS	NS		
North Triangle	0.5	9/9/14	2.5	2.5	24.3	7.19	6.16	3.8	1.56	0.75	3.71	0.76
North Triangle	1	9/9/14			24.3	7.15	NS	NS	NS	NS		
North Triangle	1.5	9/9/14			24.0	7.12	6.18	3.5	0.93	1.18	16.49	0.70
North Triangle	2	9/9/14			23.9	6.75	NS	NS	NS	NS		
Round	0.5	9/10/14	8	3.65	24.6	7.86	6.19	2.1	7.32	1.77	5.57	0.18
Round	1	9/10/14			24.6	7.83	NS	NS	NS	NS		
Round	2	9/10/14			24.6	7.81	NS	NS	NS	NS		
Round	3	9/10/14			24.5	7.82	NS	NS	NS	NS		
Round	4	9/10/14			24.5	7.83	NS	NS	NS	NS		
Round	5	9/10/14			24.5	7.71	6.16	1.9	1.61	0.20	10.31	0.19
Round	6	9/10/14			24.3	7.82	NS	NS	NS	NS		
Round	7	9/10/14			24.4	0.37	NS	NS	NS	NS		

Pond	Depth (m)	Date	Total Depth (m)	Secchi Depth (m)	Temp (°C)	DO (mg/L)	pH	Alk (mg $CaCO_3$/L)	CHLA (µg/L)	Phaeo (µg/L)	TP (µg/L)	TN (mg/L)
Russell Mills	0.5	8/19/14	6.4	1.425	20.6	8.56	7.08	9.2	8.93	0.40	18.35	0.35
Russell Mills	1	8/19/14			20.3	8.29						
Russell Mills	2	8/19/14			18.9	4.75						
Russell Mills	3	8/19/14			16.8	0.23						
Russell Mills	4	8/19/14			15.5	0.04						
Russell Mills	5	8/19/14			13.7	0.04						
Russell Mills	5.4	8/19/14			ND	ND	6.37	40.3	62.13	37.54	103.37	0.73
Russell Mills	6	8/19/14			12.4	0.04						
Saby	0.5	9/11/14	5	3.76	24.0	8.26	6.25	2.4	1.21	0.51	6.80	0.28
Saby	1	9/11/14			24.0	8.19	NS	NS	NS	NS		
Saby	1.5	9/11/14			23.9	8.11	NS	NS	NS	NS		
Saby	2	9/11/14			24.0	8.09	NS	NS	NS	NS		
Saby	2.5	9/11/14			24.0	8.19	NS	NS	NS	NS		
Saby	3	9/11/14			23.9	8.16	NS	NS	NS	NS		
Saby	3.5	9/11/14			23.9	7.91	NS	NS	NS	NS		
Saby	4	9/11/14			23.9	7.94	6.24	2.6	1.43	0.45	3.71	0.26
Saby	4.5	9/11/14			23.9	7.89	NS	NS	NS	NS		
Savery	0.5	8/23/14	3.5	1.4	23.6	6.4	6.51	5.8	14.61	1.23	108.66	0.93
Savery	1	8/23/14			23.5	6.33	NS	NS	NS	NS		
Savery	2	8/23/14			22.9	5.8	NS	NS	NS	NS		
Savery	2.5	8/23/14			ND	ND	6.36	5.7	14.57	1.49	51.62	0.95
Savery	3	8/23/14			22.6	4.99	NS	NS	NS	NS		
Shallow	0.5	9/4/14	1.25	1.25	28.1	8.43	4.62	BLD	1.65	1.37	4.95	0.81
Shallow	1	9/4/14			26.7	7.71	NS	NS	NS	NS		
Ship	0.5	9/4/14	1	1	25.9	8.57	7.08	22.6	2.72	1.20	20.20	0.60
Wall	0.5	9/11/14	5.5	2	24.0	8.63	6.49	3.9	1.54	1.18	6.60	0.44
Wall	1	9/11/14			24.0	8.83	NS	NS	NS	NS		
Wall	1.5	9/11/14			23.0	8.67	NS	NS	NS	NS		
Wall	2	9/11/14			23.8	8.77	NS	NS	NS	NS		
Wall	2.5	9/11/14			23.8	8.65	NS	NS	NS	NS		
Wall	3	9/11/14			23.7	8.63	NS	NS	NS	NS		
Wall	3.5	9/11/14			23.7	8.55	NS	NS	NS	NS		
Wall	4	9/11/14			23.7	7.92	NS	NS	NS	NS		
Wall	4.5	9/11/14			23.6	7.72	6.28	3.9	1.16	1.51	7.83	0.39
White Island East	0.5	8/25/14	4.7	2.1	24.0	8.31	6.68	6.8	2.47	0.38	8.25	0.36
White Island East	1	8/25/14			23.9	8.29	NS	NS	NS	NS		
White Island East	1.5	8/25/14			23.9	8.33	NS	NS	NS	NS		
White Island East	2	8/25/14			23.9	8.2	NS	NS	NS	NS		
White Island East	2.5	8/25/14			23.8	8.2	NS	NS	NS	NS		
White Island East	3	8/25/14			23.8	8.11	NS	NS	NS	NS		
White Island East	3.5	8/25/14			23.8	7.77	NS	NS	NS	NS		
White Island East	3.7	8/25/14			ND	ND	6.82	6.9	3.44	0.21	8.86	0.38
White Island East	4	8/25/14			23.7	8.17	NS	NS	NS	NS		
White Island East	4.5	8/25/14			23.6	8.14	NS	NS	NS	NS		
White Island West	0.5	8/25/14	4.5	1.7	24.4	8.72	6.94	6.0	3.33	1.16	12.78	0.48
White Island West	1	8/25/14			24.2	8.67	NS	NS	NS	NS		
White Island West	1.5	8/25/14			24.1	8.72	NS	NS	NS	NS		
White Island West	2	8/25/14			24.1	8.71	NS	NS	NS	NS		
White Island West	2.5	8/25/14			24.1	8.71	NS	NS	NS	NS		
White Island West	3	8/25/14			24.0	8.72	NS	NS	NS	NS		
White Island West	3.5	8/25/14			24.0	8.71	7.07	6.2	3.44	1.42	15.46	0.50
White Island West	4	8/25/14			24.0	8.35	NS	NS	NS	NS		