2018 Investigation of Twelve Sandwich Ponds




BY WATER RESOURCE SERVICES, INC.

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Introduction

The ponds of Sandwich represent valuable resources by themselves, but they are also an integral part of the overall ecosystem and community fabric of the Town of Sandwich. While much of the cumulative shoreline is under private control, many ponds have public access and some support major public facilities. All have been part of the community for many years. Consideration of their attributes and health is an integral part of any comprehensive water resources management plan. The ponds have not been the subject of any long-term detailed study, but some have been monitored as part of the Pond and Lake Stewards (PALS) program and the Shawme Ponds were the subject of multiple investigations by consultants. Water Resource Services Inc. summarized what was known of these twelve ponds in 2011 (WRS 2012), recommending that certain knowledge gaps be filled to support protection and management of these ponds. The Comprehensive Water Resources Management Plan prepared by Wright-Pierce in 2017 further recommended follow up evaluation of the ponds. This assessment arose from those recommendations, and included field investigations in summer of 2018, evaluation of current conditions and management needs, and recommendations for further action.

Study Approach and Methods

This assessment is based on review of existing information and sampling and assessment conducted mostly in August 2018. Available information was summarized by WRS (2012) and formed the basis for planned field investigations. More historic assimilation projects such as the Local Comprehensive Plan update of 2009, the Jacobs Engineering report (1999), and the ENSR report on the Shawme Ponds (ENSR 2001) were also revisited, and new efforts such as the Comprehensive Water Resources Management Plan (CWRMP, Wright-Pierce 2017) were consulted. The MA Division of Fisheries and Wildlife provided pre-1990 water depth maps and fishery data for 8 of 12 ponds included in this assessment; water depths were checked for those 8 ponds and maps were created for the other 4 ponds as part of this effort.

Water quality was sampled once for each targeted pond, including depth profiles for temperature, oxygen, pH, conductivity, turbidity and chlorophyll-a at the deepest point in each pond using a Hach-Hydrolab DS5 multi-probe sonde calibrated before each use. It also included water sampling for total phosphorus, dissolved phosphorus, nitrate+nitrite nitrogen, ammonium nitrogen, and total Kjeldahl nitrogen near the surface and bottom of each pond, with testing conducted at Enviro-Tech Laboratories in Sandwich, MA. Alkalinity was measured in the field with a titration kit. Secchi disk transparency was measured from the surface with a view tube to minimize glare and wind effects. Phytoplankton and zooplankton samples were collected, preserved with gluteraldehyde, and assessed in the WRS laboratory.

A grid of GPS points was established for each pond and each point was surveyed for water depth, sediment type, plant cover and biovolume, and relative abundance of plant species in August 2018. An underwater viewing system was employed, providing visual information, but no probing of the sediment was conducted.

Sediment was sampled in five ponds (Lawrence, Hoxie, Peters, Pimlico and Upper Shawme) with a gravity corer. The upper 10 cm (4 inches) of sediment was collected and shipped to IEH Laboratories in Seattle, WA for assessment of solids and organic content, iron, aluminum, calcium and the fraction of phosphorus bound to each, plus total phosphorus, organic phosphorus, biogenic phosphorus, and loosely sorbed phosphorus. These features allow an analysis of the potential for internal phosphorus loading.

Report Layout

General background information for all ponds is provided in the next section, followed by a pond by pond assessment of past and current conditions. Individual pond summaries include information on the pond, its watershed, water quality, visual sediment attributes (and sediment quality if assessed), pond biology (including phytoplankton, rooted plants, zooplankton, other invertebrates, fish and any observed waterfowl), and management needs and recommendations. The intent is to allow readers interested in only one pond to focus on that pond while providing the most comprehensive presentation of conditions for the purpose of water resource management planning at the town level.

Most quantitative data are summarized in a single table in the assessment of each pond. More detailed data are provided in the appendix. The table for each pond provides average values for historic studies where available and for the August 2018 assessment. Values are color coded as green, yellow or red, corresponding to “desirable”, “tolerable” or “problematic” values. Desirable values support all uses and require no management other than protection. Tolerable values are generally acceptable but might result in some impairment some of the time, depending on specific circumstances such as weather or a species of interest. Problematic values are associated with use impairment, such as low oxygen leading to reduced fish habitat or elevated phosphorus facilitating algae blooms. Problematic values may be cause for additional monitoring and/or remedial action if a designated use for the pond in question is clearly threatened but do not always raise the threat level to an extent that requires action. Where action is appropriate, it is covered in a section on management needs and recommendations.

General Background

Location of Ponds

The Sandwich Ponds (Figure 1) are surface water features within the Sagamore lens of the sole source aquifer of Cape Cod which tends to be at least 60 feet deep in Sandwich. Pathways of groundwater flow affect which lands contribute to which ponds, but there is expected variation in those pathways from season to season and year to year, depending mainly on precipitation. There are 63 ponds in total, but many are smaller than 10 acres. Twelve ponds were selected for further evaluation as part of this project, as a follow up to the last data review (WRS 2012), based on significant size, public access, natural resource significance, and/or elevated housing density along their shorelines. Key features as relates to this assessment are included in Table 1.

Origin of Ponds

Ponds in Sandwich are largely of kettlehole origin, formed by stranded blocks of ice in a large, sandy moraine associated with glaciers at the end of the last ice age, about 11,000 years ago. Dams were sometimes constructed to raise the water level, but with the very sandy soil, creation of completely artificial waterbodies is limited in this area. Of the ponds chosen for further examination, only the Shawme Ponds are not kettleholes, having been constructed by dam placement on Mill Creek to capture substantial groundwater flow that could then power a mill long ago. There may have been wetlands in the area now occupied by the ponds, but the maximum depth of each is <12 ft, compared to maximum depths of >20 ft in most kettlehole ponds. The Shawme Ponds are often called the Shawme Lakes and may have been named "lakes" due to artificial construction; kettleholes are traditionally called "ponds" on Cape Cod.

Kettlehole ponds rarely have any permanent stream inflows; they depend on precipitation and groundwater flow for inputs. Losses include evaporation and groundwater outseepage, but some have overflows that feed streams that reach the coast and allow anadromous fish such as alewife to enter ponds and spawn, with the fry spending the summer in the pond before heading downstream to the sea. Of the 10 apparent kettlehole ponds being examined here, Hoxie Pond can overflow through wetlands into Scorton Creek, but none of the other nine kettlehole ponds has a surface water outlet.

Figure 1. Sandwich Ponds, including all ponds covered in this assessment.

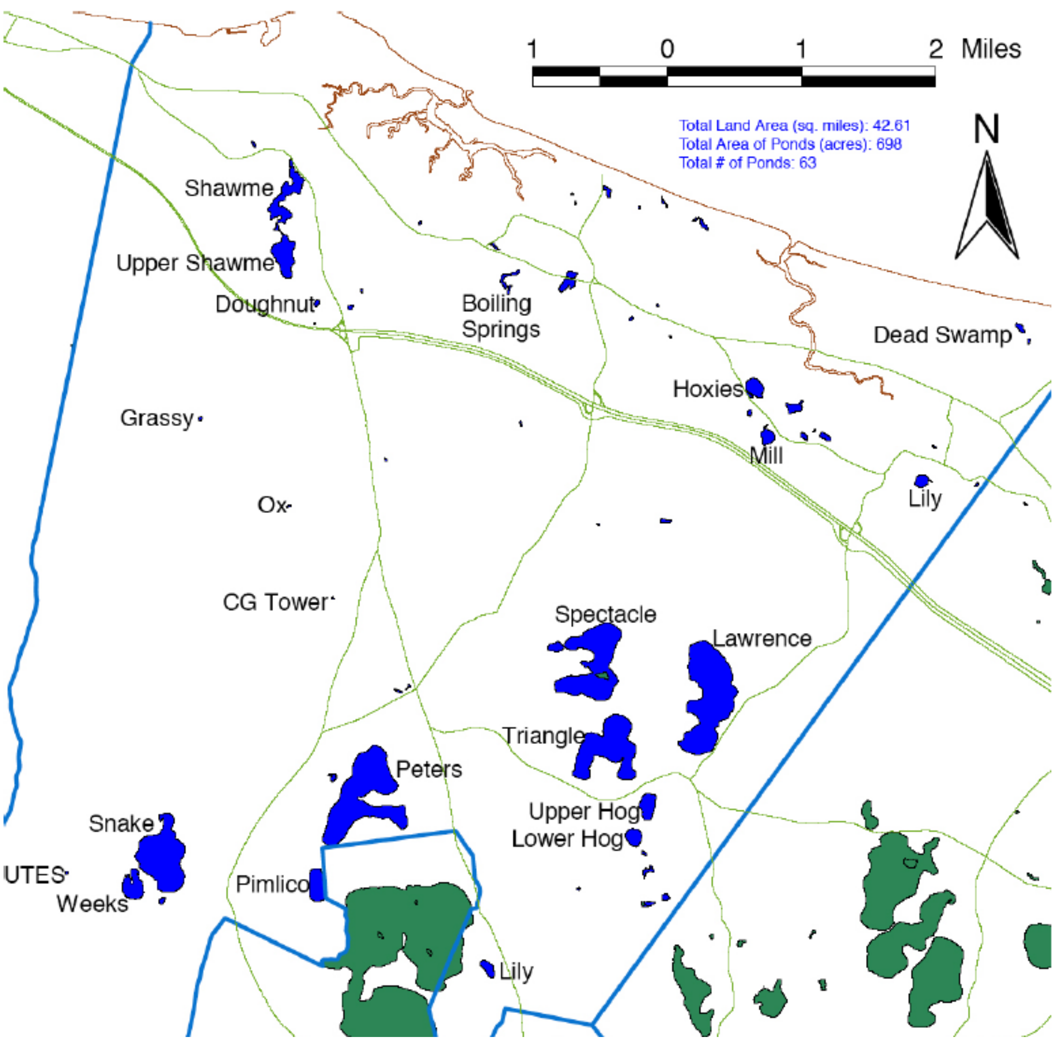


Table 1. Features of ponds evaluated in this assessment.

Pond	Area	Shoreline Length	Mean Depth	Max. Depth	Volume	Average Inflow	Detention Time
	(acres)	(miles)	(feet)	(feet)	(ac-ft)	(cfs)	(days)
Upper Shawme	21.0	0.80	6.1	11.6	128	7.00	9
Lower Shawme	24.0	1.50	2.5	5.3	61	8.00	4
Hoxie	8.0	0.42	12.2	35.0	98	0.21	235
Lawrence	138.0	2.30	15.9	27.6	2194	1.64	672
Spectacle	91.0	2.60	21.5	43.0	1957	1.52	651
Triangle	84.0	2.00	13.9	32.0	1168	1.24	475
Upper Hog	11.3	0.57	13.7	30.3	155	0.29	273
Lower Hog	7.8	0.50	12.9	24.3	101	0.24	211
Peters	127.0	2.90	25.1	54.0	3188	1.83	881
Pimlico	16.4	0.57	12.6	24.9	207	0.31	332
Snake	83.0	1.60	17.1	34.3	1419	1.08	665
Weeks	15.0	0.76	10.5	20.3	158	0.38	208

Historic Influences

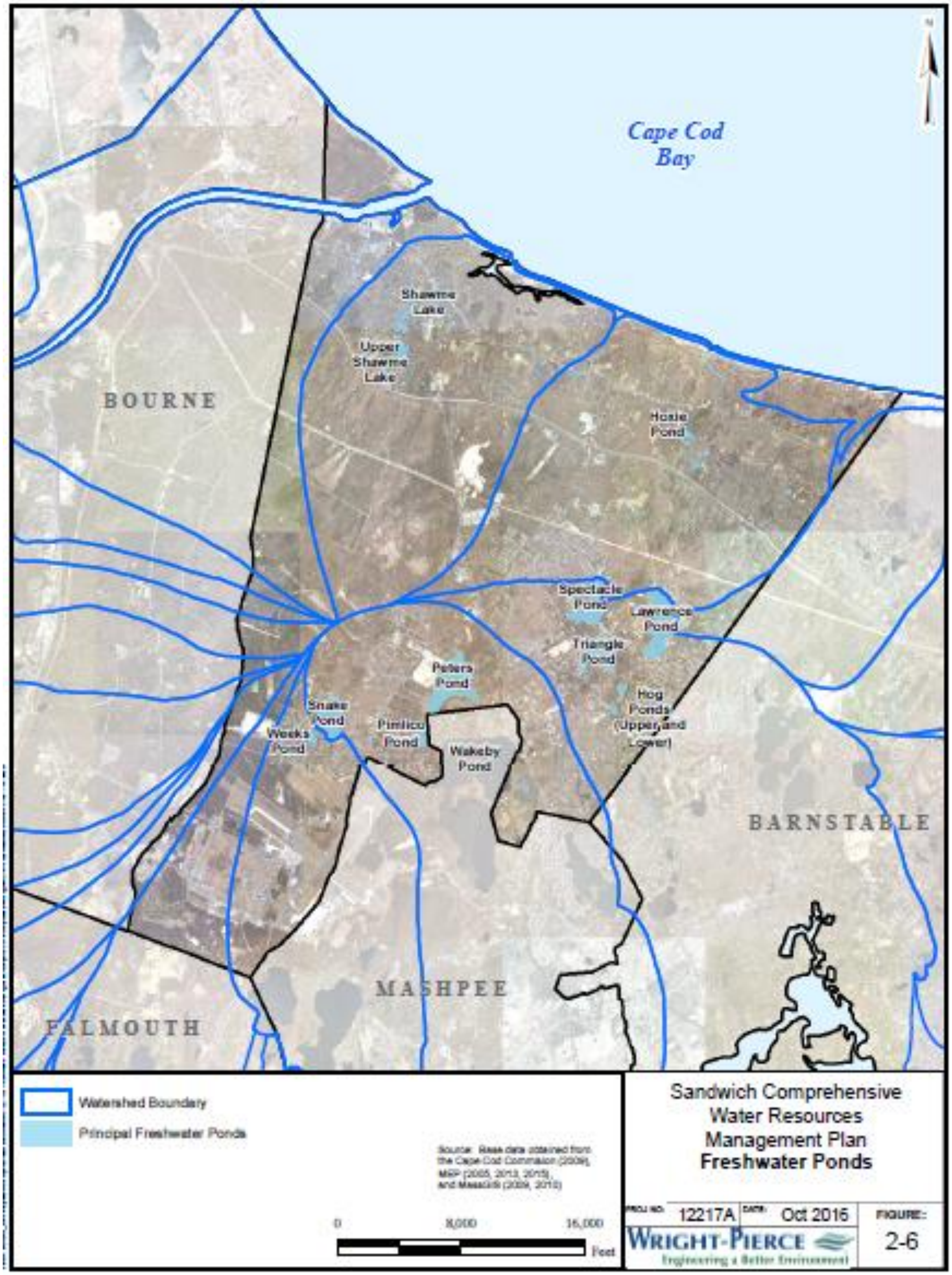
Initial settlement began in the 1600s, when Cape Cod was largely a dense forest of oak and pine on the high ground and a variety of trees in the lower lands, including sassafras, birch, beech, and maple. Evergreen holly and juniper were also common on the Cape at that time. The native Americans had conducted burns to open areas for agriculture, but not on the scale of clearing conducted by white settlers in the 1700s and beyond. By the late 1800s there were few trees in arable areas on the Cape, and most of the topsoil base accumulated over 10,000 years was lost to wind erosion. The sandy nature of the surficial soils as we know them today was the result.

Agriculture was the most influential land use on Cape Cod for several hundred years, at first more subsistence farming but later with a variety of larger vegetable farms and livestock operations, including major duck, goose and turkey farms that were often located near ponds on the Cape. Yet the sandy soils prevented most of the runoff that plagued surface water resources in many other areas of the northeastern USA subject to these agricultural pursuits. Cranberry farms became abundant in the late 1800s, and while the density has declined, cranberry farming is the most active form of agriculture on the Cape today. As bogs are almost always adjacent to a pond and utilize water from the pond for irrigation and flooding for harvest and frost prevention, the potential for impact from this agricultural source through return water is substantial. Aerial spraying of pesticides and nutrients is another mode of potential impact from cranberry bogs on nearby ponds that is rarely practiced today but was popular at one time. Where historic agriculture was adjacent to or actually on ponds impacts were sometimes notably severe, but few problems with water quality or pond condition have been reported in anecdotal accounts prior to the last 30 to 40 years. Hoxie Pond is the only studied waterbody with an active cranberry bog in its watershed.

As agriculture waned and residential development increased, more impervious surface was created and more wastewater disposal systems were created, increasing both runoff and groundwater impacts by human activity on the Cape. Sandy soils and limited piping systems still limit direct inputs of runoff to most ponds, but inputs to groundwater from runoff and wastewater have increased dramatically.

Camp Edwards and the Otis Air Force Base, collectively known as the Massachusetts Military Reservation (MMR) and now the Joint Base Cape Cod (JBCC), represented a source of groundwater contamination for many years, and remain an ongoing concern. Nitrogen and to a lesser extent phosphorus that was discharged to soil moved along groundwater flow gradients and was known to contaminate some water resources, the most well documented of which was probably Ashumet Pond (Jacobs Engineering 1999), a site of past and recent remediation. Other contaminants of concern from Camp Edwards include various solvents that have floated on top of the groundwater and contaminated wells that penetrate only into the upper level of the aquifer. The position of the “crown” of the aquifer is on the JBCC, with groundwater radiating out in all directions (Figure 2). Plumes from multiple sources on and off JBCC were mapped by others and were included in the CWRMP (Wright-Pierce 2017), so we have a reasonable appraisal of which ponds could be threatened by groundwater inputs. However, groundwater movement may vary over time, especially in response to variation in precipitation, so precise loading estimates are elusive.

Figure 2. Groundwater flow patterns in the Sandwich area.



Current Threats to Designated Uses

The primary current developed land uses are residential and commercial, with cranberry farming as the main agricultural activity. Transportation corridors (roads) associated with development constitute a major land use as well. Undeveloped lands include pine and oak forests in uplands and a variety of wetland types in the lowlands.

The major pollution threat to ponds is mainly nutrients from developed land and cranberry bogs. Stormwater runoff is one form of pollution that may be significant with the level of development now experienced by Sandwich, with nutrients, sediment, bacteria, salt or other deicing chemicals, hydrocarbons and larger trash items all potentially significant. Sandwich has developed a Stormwater Management Plan (SMP) that outlines current laws and regulations and specifies best management practices (BMPs) to address stormwater impacts. The SMP is intended to meet NPDES Phase II regulations and to provide a framework for protecting water resources. All storm drains in the town have been mapped, but the vast majority are leaching catch basins and do not discharge to any waterbody or stream. Such systems may impact groundwater quality but are not direct influences on ponds.

Wastewater disposal is generally recognized as the biggest external pollution threat and includes nutrients and various household products that can negatively impact ponds receiving significant groundwater flow. While there are a few small wastewater treatment facilities in Sandwich, the CWRMP (Wright-Pierce 2017) reports that approximately 97% of wastewater is disposed by onsite subsurface treatment systems with release into soil, particularly near the ponds assessed here. Some larger communal systems exist, but most properties are served by individual systems. Nitrogen is minimally removed by conventional onsite (septic) systems and concentrations can be predicted from housing density, related disposal features and precipitation/recharge. Concentrations high enough to impact coastal resources have been documented as part of the Massachusetts Estuaries Program and it is conceivable that ponds are being impacted as well, although impacts have been less studied. Phosphorus is adsorbed to soil particles and travels less freely, but adsorption capacity is lower for sand than many other soils and breakthrough to water resources can occur over time as adsorption capacity is exhausted. Hydrocarbons tend to "float" on the groundwater and create elongate plumes. Various solvents and personal care products mix with groundwater and should be diluted to a large extent, but some compounds (e.g., endocrine disruptors, hormone mimics) may cause impacts at very low concentrations. Viruses are known to move through soils and could contaminate ponds.

In recognition of the role that groundwater plays in surface water quality, Sandwich has also adopted a groundwater protection statute under its zoning process that regulates development within 300 feet of any pond or wetland. It is not certain that a 300-foot buffer is sufficient to protect associated surface water resources, but this is a generally recognized setback for limitation of phosphorus impacts and is thought to provide enough adsorption and dilution capacity to address many other contaminants.

In 2000 the Cape Cod Commission designated the Three Ponds Area of south Sandwich as a District of Critical Planning Concern to help protect these water resources. Such a district allows establishment of special regulations to protect resources in the designated area, which in this case includes 692 acres of land associated with Lawrence, Spectacle and Triangle Ponds. One focus of the district is protection of endangered species, and there are multiple listed plant species associated with some of the ponds in Sandwich. However, the District includes only the three ponds mentioned above, leaving other ponds with less protection.

The accumulation of nutrients in ponds on Cape Cod has become a significant issue for eutrophication (overfertilization) over the last couple of decades. There is a lot that is not thoroughly understood about this accumulation, such as whether there is a clear threshold for impact or how much organically bound phosphorus may contribute, but it is clear that phosphorus bound to iron can be released when oxygen is lacking and that iron-bound phosphorus is a major component of accumulated surficial sediment phosphorus in many Cape Cod ponds. It appears to take a fairly long time (many years) for enough phosphorus to build up to allow significant internal recycling, so the sources may not be consistent or obvious over time. Yet once internal recycling becomes a significant influence, it tends to accelerate and become a dominant influence in a few years. At that point, watershed inputs from surface or groundwater become less important to pond condition, which is typically poor as a consequence of algal blooms.

Internal recycling of phosphorus in deeper (>25 ft) ponds is facilitated by low oxygen at the bottom of those ponds and typically results in high bottom water phosphorus levels, but there is not enough light in deep water to support algal blooms. How much of that phosphorus gets into better lit upper waters where it can support algal blooms is a function of wind-induced mixing, upward diffusion, and iron sulfide formation, which limits the amount of iron available to re-bind the phosphorus when it reaches the upper waters. When sediment release of phosphorus results in concentrations >20 µg/L in upper waters, algal blooms tend to develop. As there is not nearly as much nitrogen being recycled with the phosphorus, the N:P ratio is relatively low and cyanobacteria (blue-green algae) are favored. Cyanobacterial blooms are also favored by warm summer temperatures, can float to form surface scums, and some forms can cause taste and odor and even toxicity. Such blooms are therefore a serious concern in Cape Cod ponds and have been increasing in frequency and severity over the last two decades.

Climate change is an issue for Cape Cod ponds, leading to greater extremes in weather. Higher precipitation in storms leads to more runoff, and warmer summer temperatures promote algal blooms and favor cyanobacteria. Rooted plant growths may also be favored. Variability will increase, and that may be more of a problem than any shift in average conditions. Lack of predictability requires greater management effort to maintain desirable conditions.

Invasive species represent another threat to use support, including both plant and animal species that can invade a pond and alter its utility for various uses. Cape Cod ponds are not particularly susceptible to zebra mussels or Asian clams (although Asian clams have been found in Hamblin Pond in Marstons Mills), but some invasive aquatic plants can thrive in the low alkalinity, acidic aquatic habitats of the Cape. Variable leaf water milfoil (*Myriophyllum heterophyllum*), fanwort (*Cabomba caroliniana*) and hydrilla (*Hydrilla verticillata*) are species of concern that have invaded Cape ponds already. Peripheral invasive species such as common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) are also present on the Cape and have damaged habitat value and compromised recreational uses.

Pond by Pond Assessment

Upper Shawme Pond

General Pond Features

Upper Shawme Pond, located along Rt 130 in the northwest portion of Sandwich (Figure 1) and sometimes called Upper Shawme Lake or the Upper Mill Pond, is the upstream part of a two-pond complex and covers about 21 acres to an average depth of 6.1 feet with a maximum depth of 11.6 feet and a volume of about 128 acre-feet (Table 1, Figure 3, Appendix). Field work in 2018 confirmed the bathymetry. This pond is unusual among Cape Cod ponds for having an actual dam that creates the pond, as opposed to natural formation from stranded ice. That dam was in poor repair in the early 2000s, but the outlet structure was replaced prior to 2011 with a more sophisticated and stable structure. A fish ladder was installed to allow alewife that run up Mill Creek from the bay into Lower Shawme Pond to continue into Upper Shawme Pond. Despite its current area, Upper Shawme Pond is not a Great Pond under Massachusetts law as a consequence of its origin, being created by human action (damming).

There is no permanent surface water inlet, but groundwater inflow is substantial and there are distinct springs in Upper Shawme Lake with classic “sand boils” where the flow is high enough to move sediment. Outflow averages about 7 cfs, resulting in an average detention time of only about 9 days. As groundwater flow is more constant than surface water flows, a near constant input of cold groundwater keeps detention time low and the pond is cool even in summer; the surface temperature in August 2018 was only 22^{o}C and dropped to 10^{o}C at a depth of 10 feet.

Sediment at the edge of the pond is largely sandy, but soft sediment has accumulated in water deeper than about 6 feet. Substantial soft sediment may have been present in wetlands that were flooded when the lake was created. Average soft sediment depth was about 8 ft in 2000, with a maximum depth of about 12 ft. Sediments are muck material, high in organic content and overlying mostly sand.

The shoreline is mostly wooded with access from just a few properties around it and a small homeowners association park at the southern end. The Cook Preserve spans most of the area east of the pond to Rt 130, while the Heritage Museum and Gardens are on the west side of the pond, and trails allow people to walk to within view of the pond. Designated uses for Upper Shawme Lake include swimming, boating and fishing, along with aesthetic and passive uses, but actual use is limited by access. Aside from an informal canoe launch just east of the outlet, which is down a channel from the main body of the pond, and the association dock at the southern end of the pond, access to the pond is very limited. As a breeding area for sea-run alewife, the lake is also important for fish and wildlife propagation.

Upper Shawme Lake was on the 2016 Integrated Waters List (MADEP 2017) for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology (mainly algae and rooted plants) and is supposed to be the subject of a TMDL (category 5).

Watershed Features

Upper Shawme Lake has a delineated surface watershed of approximately 440 acres. Approximately 55% of the total watershed of Upper and Lower Shawme Lakes is forested, with about 24% in residential uses

Figure 3. Bathymetry of Upper and Lower Shawme Lakes from pre-1990 MA DFW records.

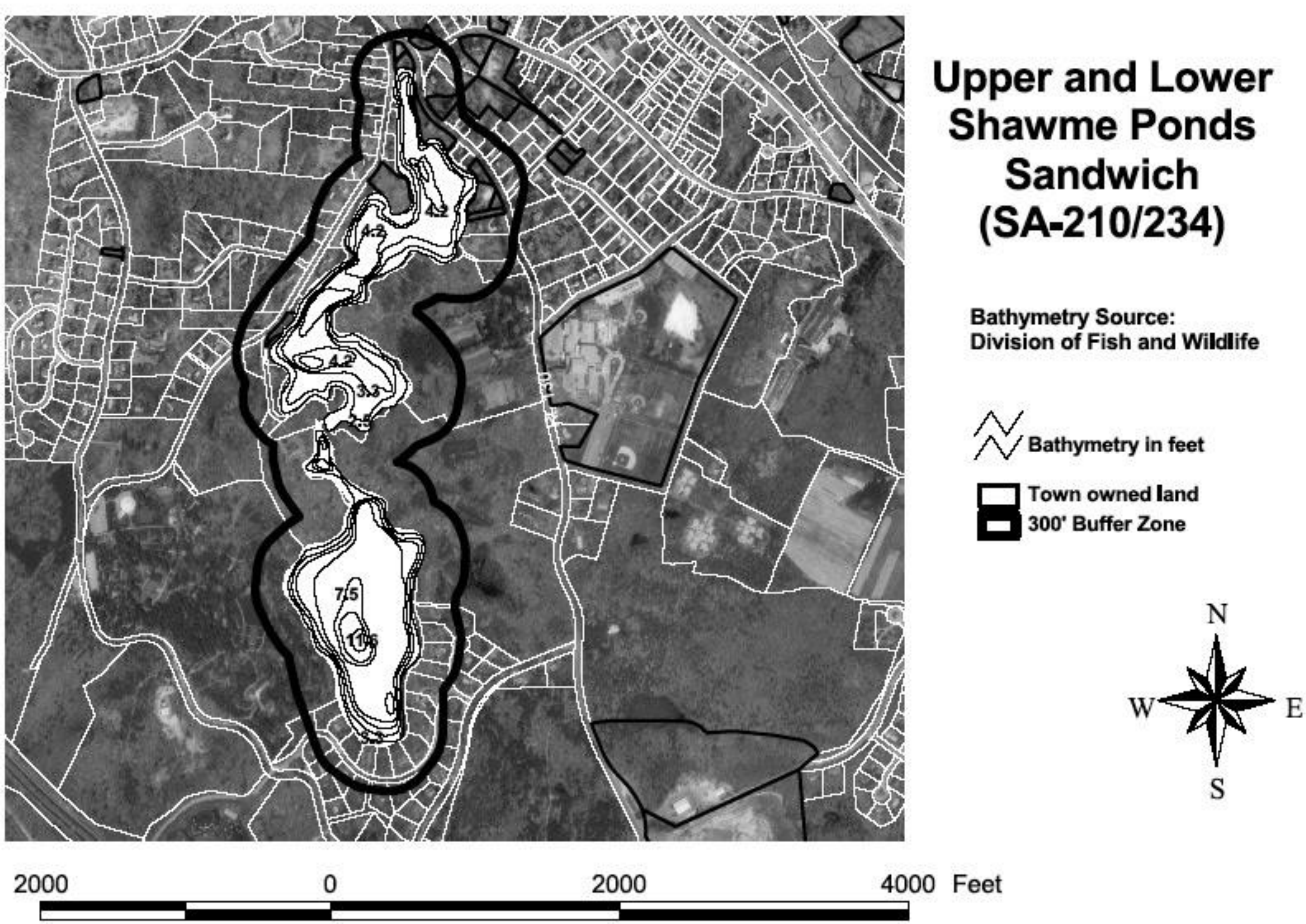


Figure 4. Shawme Ponds and general vicinity

and another 8% in other developed uses. The rest is wetland or lake, including an inactive cranberry bog on the east side not far upstream of the outlet. Highview Condominiums sit at the top of the drainage area, off to the southwest, with moderate density housing situated on the slope to the lake from the south. The Cook Trust lands extend along the east side, while the Heritage Museum and Gardens run along the west side. The general appearance of the surface watershed is as a mix of wooded and residential land (Figure 4). However, it is the groundwater contribution zone (Figure 2) that is most important to inflow quantity and probably quality to Upper Shawme Pond.

Identification of spring sources, culverts, drains and property parcels has been completed by both the Shawme Ponds Watershed Association and Lycott in separate efforts in the late 1990s, as summarized by ENSR (2001). Areas surrounding the Shawme Ponds are very permeable sandy loams, generating little runoff and suggesting that groundwater inputs will be dominant. However, there are two active storm drains from developed areas that do deliver stormwater to Upper Shawme Pond, so runoff is not an insignificant factor.

Groundwater seepage rates into Upper Pond from 2000 (ESS 2000 as summarized by ENSR 2001) ranged from 18 to 344 L/m^2/day which are high even for Cape Cod. Average monthly discharge out of the ponds has ranged from just over 1 cfs to 12 cfs, with an average of about 7 cfs. Assuming direct precipitation of 46 inches per year (about 0.3 cfs) and an equal volume of overland runoff, groundwater seepage would have to average 6.4 cfs to achieve the estimated observed average flow. For just the upper lake, the seepage rate would have to be 170 L/m^2/day to provide the observed flow, consistent with observed seepage rates. The groundwater contribution area is much larger than the surface watershed; based on a typical water yield of 1.3 cfs per square mile of contributing area, groundwater from about 3150 acres should be entering Upper Shawme Pond. This area extends south, east and west of the pond (Figure 2).

Pond Water Quality

Upper Shawme Pond was assessed in August 2018, with water quality and sediment sampling at the deepest point and 37 additional points surveyed for water depth, sediment type and plant community features (Figure 5). Water quality features from that assessment and any available historical records are summarized in Table 2. Upper Shawme Lake is on the Massachusetts 2016 Integrated List of Waters as a category 5 waterbody (MADEP 2017), requiring a TMDL for nutrients and eutrophication as evidenced by biological indicators, but it is not clear that this designation is properly supported. The water quality features for which we have data suggest that most values fall into the desirable or tolerable range. Only phosphorus in deeper water was elevated into the potentially problematic zone but was not extremely high (2018 values <30 µg/L, older values not well documented).

Total phosphorus values for surface inputs to Upper Shawme Lake from past studies were reported as 11-339 µg/L, a range with high values represented by stormwater discharges. Yet much of that phosphorus will be particulate and not immediately available to algae or rooted plants. Nitrogen values are generally low, especially considering the dominance of groundwater and the inputs from onsite wastewater disposal, but high nitrates are sometimes found in wells and the town spring near the outlet of Lower

Figure 5. Upper Shawme Pond survey points with bathymetry.

Table 2. Water quality, plankton and sediment summary for Upper Shawme Pond.

Upper Shawme Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	>5	14.2
Average pH	SU	ND	7.7
Surface Alkalinity	mg/L	ND	11
Average Conductivity	µS	ND	92
Surface Total P	µg/L	11 to 20	10
Surface Dissolved P	µg/L	<10	6
Bottom Total P	µg/L	10 to 50	29
Bottom Dissolved P	µg/L	10 to 50	23
Surface Nitrate/Nitrite N	µg/L	10	10
Bottom Nitrate/Nitrite N	µg/L	10 to 110	60
Surface Ammonium N	µg/L	10 to 130	290
Bottom Ammonium N	µg/L	60 to 160	ND
Surface Total Kjeldahl N	µg/L	ND	330
Bottom Total Kjeldahl N	µg/L	ND	350
Surface Total N	µg/L	Est. 400	340
Bottom Total N	µg/L	Est. 510	410
Surface N:P Ratio	Unitless	26	34
Bottom N:P Ratio	Unitless	26	14
Average Turbidity	NTU	ND	1.2
Secchi Transparency	m	1.5 to 3.0	2.2
Average Chlorophyll-a	µg/L	ND	6.9
Phytoplankton Biomass	µg/L	Blooms noted	3694
Cyanobacteria	%	Blooms noted	<1
Zooplankton Biomass	µg/L	ND	63
Zooplankton Mean Length	mm	ND	0.79
Sediment Fe-P	mg/kg	ND	37
Sediment Biogenic P	mg/kg	ND	148
Sediment Al:Fe Ratio	Unitless	ND	0.84
ND = No Data	Desirable	Tolerable	Problematic

Shawme Pond. Levels of phosphorus in seepage ranged from 19 to 280 µg/L over a period of about 20 years from 1980 to 2000 and levels of iron in groundwater are relatively low, suggesting that the associated phosphorus will not be completely inactivated by the accompanying iron when it reaches the pond. Oxygen appears plentiful in Upper Shawme Lake and may allow rapid in-lake inactivation of phosphorus by iron already in the pond after entry of phosphorus with groundwater. In any event, neither phosphorus nor nitrogen was especially high in the pond in 2018 and N:P ratios are moderate to high. The observed dominance by green algae in 2018 is consistent with observed nutrient conditions.

It should also be considered that fish production, especially by sea-run alewife, is a valued use of this pond, and at least moderate fertility is desirable for that use. Clarity was marginal but acceptable for other designated uses in August 2018, suggesting no real impairment by slightly elevated phosphorus levels. Other water quality features were at least tolerable, and many were desirable (Table 2). The pH was high for Cape Cod ponds, possibly a function of elevated photosynthesis by plants which removes carbon dioxide and raises pH. Flows and water levels in 2018 were higher than usual, so the 2018 assessment does not represent the complete range of conditions that might be encountered in the pond.

While not strictly a water quality feature, the upper 4-inch layer of sediment was sampled at the water quality station in Upper Shawme Pond, one of five ponds in which sediment sampling was conducted to evaluate the potential for internal loading of phosphorus. Phosphorus bound to iron in surficial sediments can be released under low oxygen conditions and fuel algae blooms. The aluminum to iron ratio in sediment is low (Table 2), suggesting that more P will be attached to iron than aluminum and subject to release if oxygen was low. Phosphorus bound to labile organic particles (termed “biogenic”) is less easily released, but normal decay can result in a substantial internal load from that source. As internally loaded phosphorus can greatly decrease the N:P ratio, it tends to favor cyanobacteria and is a concern.

For Upper Shawme Pond, iron-bound and biogenic phosphorus concentrations were quite low (Table 2). Additionally, the high oxygen concentration near the sediment-water interface suggests limited potential for phosphorus from these sources to circulate in the water column. Iron-bound phosphorus will remain bound, and any release from biogenic sources is likely to be bound by available iron in that area. Internal loading does not appear to be a significant factor in Upper Shawme Pond from the available data. However, when oxygen is as high as it was by day, there is potential for overnight oxygen depression as oxygen-generating photosynthesis ceases and respiration continues. This might explain the slightly elevated near bottom phosphorus concentration.

Pond Biology

Blooms of algae were not often reported prior to 2001, but cyanobacterial blooms have been noted over the decade leading up to the WRS (2012) summary and are probably the reason that Upper Shawme Lake was placed on the Integrated Waters List. No details of those blooms are available, and it is not certain that the blooms were cyanobacteria. The 2018 assessment (Table 2, Appendix) indicated moderate chlorophyll-a, slightly elevated phytoplankton biomass, but minimal cyanobacteria; planktonic green algae were dominant in August of 2018, a time when the probability of cyanobacteria was highest if such blooms were to occur. A long-term data base would be needed to draw conclusions, but Upper Shawme Pond exhibited no problem algae conditions in 2018 at the time of study visits.

Rooted plants have been reported as abundant for many years and included Robbin's pondweed (*Potamogeton robbinsii*), waterweed (*Elodea canadensis*) and aquatic mosses in the 1980s. Waterweed and coontail (*Ceratophyllum demersum*) were observed in fall of 2011, but no detailed survey was conducted. The August 2018 survey included observations at 37 points (Figure 5) and found 12 species of aquatic plants, none of which were invasive species. Most common were Robbin's pondweed, waterweed and aquatic mosses as in the past surveys. Coontail and chlorophyte (green algae) mats were the next most commonly encountered species. Shallow water species encountered included hedge hyssop (*Gratiola neglecta*), water starwort (*Callitriche* sp.) and duckweed (*Lemna minor*), the last of which is indicative of elevated nitrogen levels, which is not quite consistent with detected concentrations but does match past notation of elevated nitrates in springs. Other plants that were found from shallow to deeper water in this pond included slender naiad (*Najas flexilis*) and *Nitella* (a macroalga).

Bottom coverage was nearly complete, with a rating of 3.8 on a scale of 0 to 4, but biovolume (the portion of the water column filled with plants) was 1.8 on a 4-point scale, suggesting between 25% and 50% water column filling. The dominant species are submergent, so surface growths were minimal, and the condition would be considered excellent for fish habitat. Average depth for all survey points was 6.1 feet. Some peripheral growths were dense, creating possible access issues but most of the pond surface was open.

There is one very small patch of invasive common reed (*Phragmites australis*) in Upper Shawme Pond, just to the east of the spillway and fish ladder. It is literally just a couple dozen plants, a relatively new infestation, and will be addressed with the more extensive growths in Lower Shawme Pond in terms of management options. No purple loosestrife (*Lythrum salicaria*) was observed at Upper Shawme Pond.

Zooplankton biomass was about 63 µg/L, slightly above the "low" threshold of 50 µg/L and comprised mainly of cladocerans and copepods (Table 2, Appendix), a desirable composition. Mean body length of crustacean zooplankton was just under the 0.8 mm "large" threshold. While highly desirable *Daphnia* were absent (these provide the best grazing capacity for algae and food for small fish), the assemblage is generally healthy and functional within the food web.

No freshwater mussels or snails were observed in Upper Shawme Pond. This was by observation and not a detailed sampling program, but with 37 sites checked for sediment features and plants, if either mussels or snails were common, they would have been detected. Freshwater sponges were observed. A lack of mussels and snails most likely suggests very low calcium levels that prevent shell formation, although it is possible that mollusks were eliminated by some other water quality issue. Sponges are more common in water too acidic and low in calcium to support mollusks.

Pickerel has been listed as the main gamefish in the lake and the presence of other warmwater species is noted in past reports, but there are no fish survey data. There is an active alewife run, so past stocking was apparently successful in establishing a migratory population. A recent census indicated that about 8000 alewife reached Lower Shawme Pond and 3000 of those passed through the fish ladder to Upper Shawme Pond. However, the zooplankton community of Upper Shawme Pond does not suggest the level of impact that is typically observed when young-of-the-year alewife inhabit a pond; biomass and mean body length are not severely depressed. The level of reproductive success for alewife reaching Upper Shawme Pond is questionable and may warrant investigation.

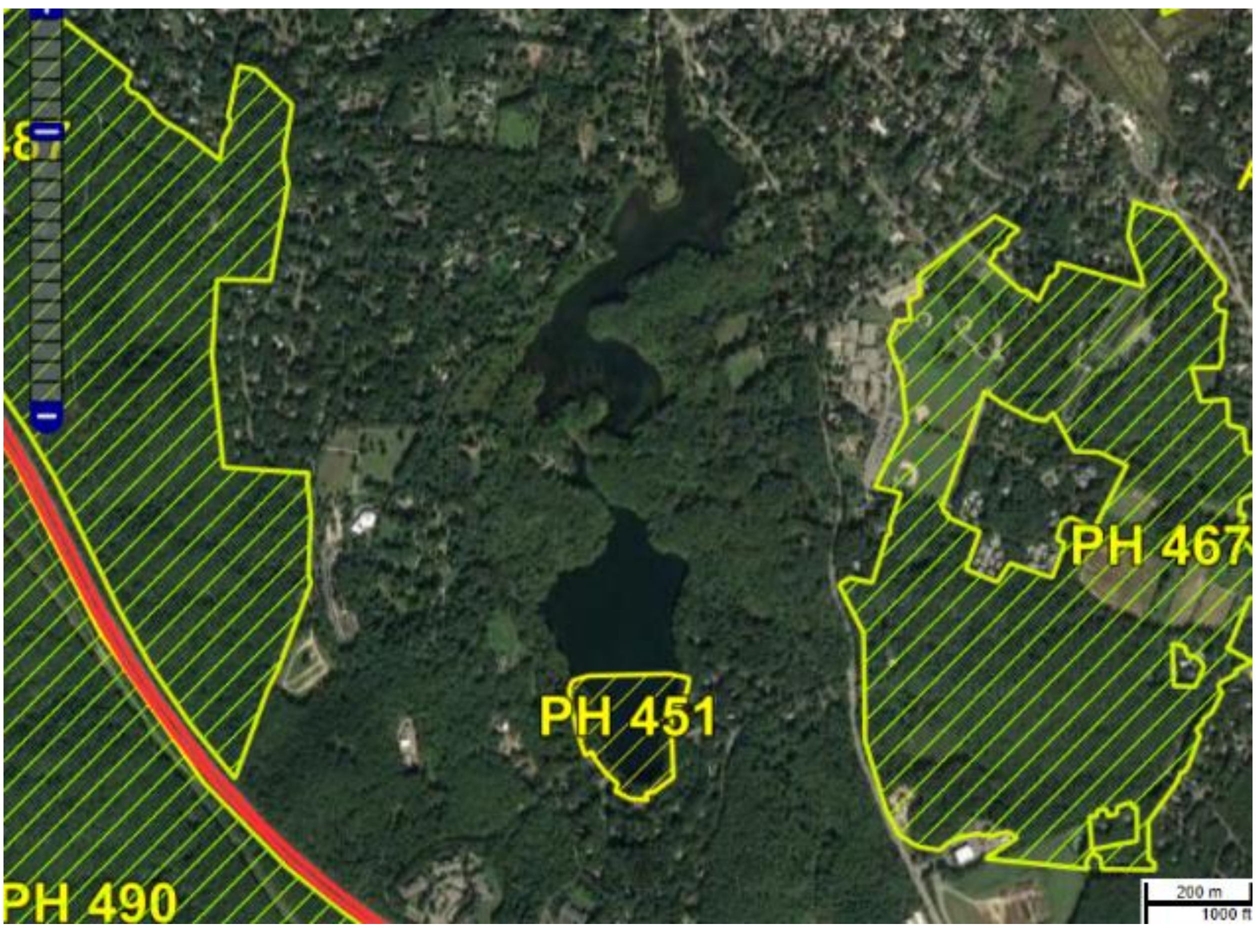
One resident across from the association park reported informally that Upper Shawme Pond used to have trout in it and some large specimens were caught. Given the cold temperature even in August and adequate oxygen concentrations from top to bottom in 2018, support of trout is entirely possible. With the current alewife run, trophy trout could be grown in this pond.

The southern 40% of Upper Shawme Pond is mapped as Priority Habitat for a listed (protected) species by the NHESP (Figure 6). WRS does not know what species might be present there, but the mapped area (PH451) is clearly an aquatic habitat. Any management action that could impact the southern portion of the pond would be subject to NHESP review.

Management Needs and Recommendations

It is not clear that Upper Shawme Lake needs reduced algae or plant growth based on the conditions observed in 2018. If swimming is a priority use, clearer water with fewer rooted plants would be desirable, but with the apparent current emphasis on boating and habitat and the rather cold temperature even in

Figure 6. NHESP habitat mapping for Shawme Ponds.



summer, it seems like current conditions are quite well suited to the other uses of fishing, boating and aquatic habitat. Continued tracking of alewife use is advised, and consideration should be given to stocking trout in Upper Shawme Pond to generate a coldwater fishery. Trout should survive the summer quite well despite the shallowness of this pond, and with adequate food resources represented by juvenile alewife, may facilitate a trophy fishery. Access may be a limitation on fishermen that will preclude DFW involvement and may affect town priority for trout stocking, but there is potential to create a prized fishery. The town should consider stocking trout in Upper Shawme Pond; a mix of rainbow and brook trout should do well there based on available data and a sea-run population might be established.

Management of *Phragmites* will be addressed in more detail with the Lower Shawme Pond assessment, as that pond has much more of this invasive plant. However, the very small infestation on the dam berm of Upper Shawme Pond could be physically removed with no more than a negative determination of applicability from the Conservation Commission under the auspices of the Wetland Protection Act. This Phragmites growth is at the opposite end of the pond and represents no threat to the Priority Habitat, so NHESP would not need to approve *Phragmites* control action in this case. It may be more effective to use an approved herbicide if such a program is put in place for Lower Shawme Pond and other Sandwich ponds with *Phragmites*, but the *Phragmites* in Upper Shawme Pond does not require herbicides on its own for control.

Protection of the shoreline should have a high priority but there are no imminent threats and any activity on land near the shoreline would require a permit under the Wetlands Protection Act, so the town has considerable control of this situation.

Additional monitoring of water quality is advised, as not all aspects of historic data and the 2018 assessment match up. If Upper Shawme Pond does experience cyanobacteria blooms, it would be appropriate to document them. If nitrogen or phosphorus concentrations are substantially elevated at times, it would also be helpful to document that. Assessment of phytoplankton, phosphorus, nitrogen, temperature and oxygen at least once in early summer and again in late summer would be helpful in confirming current understanding of pond condition over a period of several years.

Management of wastewater disposal and stormwater is always appropriate for the sake of maximizing lake water quality, and possible future wastewater and stormwater improvements are discussed in the CWRMP (Wright-Pierce 2017), but the cost of alternative wastewater and stormwater arrangements is not justified in the near-term by the 2018 data.

Lower Shawme Pond

General Pond Features

Lower Shawme Pond, sometimes called Upper Shawme Lake or the Lower Mill Pond, is the downstream part of a two-pond complex in northwest Sandwich (Figure 1) and covers about 24 acres in the "downtown" area to an average depth of 2.5 feet with a maximum depth of 5.3 feet and a volume of about 61 acre-feet (Table 1, Figure 3, Appendix). Field work in 2018 confirmed the bathymetry. The pond was created by damming Mill Creek to supply water power in colonial times. The outlet of Lower Shawme Pond is structured to allow fish access, and there is an alewife run from the bay each spring. Despite its current area, Lower Shawme Pond is not a Great Pond under Massachusetts law as a consequence of its origin, being created by human action (damming).

There are about 1.5 miles of shoreline, some of it wooded and some in residential backyards (Figure 4), although very few lawns extend to the pond edge. In many areas the shrub layer is so dense as to preclude access. There is some access through public property near the outlet end of the pond in town, but there are no developed boat launch or beach facilities. Groundwater enters from the east and west and storm drains add runoff during wet periods, but most inflow is surface water from Upper Shawme Pond. Inflow to Lower Shawme Pond averages about 8 cfs and detention time averages about 4 days.

Considerable organic sediment was likely present when the dam was built and flooded a wetland area and more muck has accumulated over time with incoming leaves and internal production of plants and algae. Thick muck deposits cover much of the pond, with just the edges having a sandy bottom.

Uses are primarily aesthetic and aquatic habitat, some small craft boating occurs, and the water quality designation suggests that the system should support swimming, but access is very limited. Lower Shawme Pond was on the 2016 Integrated Waters List (MADEP 2017) for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology (mainly algae and rooted plants) and is supposed to be the subject of a TMDL (category 5). Downstream of the pond Mill Creek is listed as impaired by bacteria and also requires a TMDL.

Watershed Features

The watershed of Lower Shawme Lake includes all the drainage area for Upper Shawme Lake plus an additional watershed area of approximately 162 acres. Approximately 55% of the total watershed of Upper and Lower Shawme Ponds is forested according to ESS (2001), with about 24% in residential uses and another 8% in other developed uses. The rest is wetland and lake. There is more developed land immediately adjacent to Lower Shawme Pond (Figures 4 and 7) and there are at least four active storm drains discharging to the pond, although two are near the outlet. Soils surrounding the Shawme Lakes are very permeable sandy loams, but with stormwater drainage systems associated with developed areas, runoff can be significant during storms.

Pond Water Quality

Lower Shawme Pond was assessed in August 2018, with water quality sampling at the deepest point and many additional points surveyed for water depth, sediment type and plant community features (Figure 7). Water quality features from that assessment and historical records are summarized in Table 3.

Figure 7. Lower Shawme Pond survey points with bathymetry.

Table 3. Water quality and plankton summary for Lower Shawme Pond.

Lower Shawme Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	>5	8.3
Average pH	SU	ND	7.4
Surface Alkalinity	mg/L	ND	12
Average Conductivity	µS	ND	123
Surface Total P	µg/L	15 to 30	19
Surface Dissolved P	µg/L	<10	14
Bottom Total P	µg/L	10 to 50	19
Bottom Dissolved P	µg/L	10 to 50	14
Surface Nitrate/Nitrite N	µg/L	10	10
Bottom Nitrate/Nitrite N	µg/L	10	10
Surface Ammonium N	µg/L	30 to 150	70
Bottom Ammonium N	µg/L	30 to 150	70
Surface Total Kjeldahl N	µg/L	ND	370
Bottom Total Kjeldahl N	µg/L	ND	370
Surface Total N	µg/L	Est. 500	380
Bottom Total N	µg/L	Est. 500	380
Surface N:P Ratio	Unitless	22	20
Bottom N:P Ratio	Unitless	22	20
Average Turbidity	NTU	ND	0.7
Secchi Transparency	m	1.0+	To bottom (1.2)
Average Chlorophyll-a	µg/L	ND	2.1
Phytoplankton Biomass	µg/L	Blooms noted	1293
Cyanobacteria	%	Blooms noted	<1
Zooplankton Biomass	µg/L	ND	1.2
Zooplankton Mean Length	mm	ND	0.3
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

Despite the impaired waters designation relating to eutrophication as evidenced by biological indicators, planktonic algae do not appear to be abundant and water clarity extended to the bottom in all areas assessed in August 2018. Rooted plant and filamentous algae growths are dense in many areas. The water quality features for which we have data suggest that most values fall into the desirable or tolerable range. The pH was high for Cape Cod ponds but was not outside the tolerable range for most aquatic species. Total phosphorus was elevated into the potentially problematic zone in historic samples and dissolved phosphorus was slightly elevated in bottom samples historically and in 2018. Values were not extremely high (<50 µg/L) but suggest that muck sediments throughout the pond are contributing through decay and will support dense growths of benthic algae mats and rooted plants, which is what was observed.

Groundwater was shown to be the dominant inflow source to Upper Shawme Lake, but seepage into Lower Shawme Pond is much lower at -5 to 21 L/m^2/day (ESS 2000 as summarized by ENSR 2001). Thick organic sediment deposits and lesser slopes in the immediate watershed decrease the direct groundwater contribution. Much of the groundwater in the area may flow under Lower Shawme Pond and never enter it. A land-based public spring near the outlet supplies a steady source, but evidence of groundwater inputs within Lower Shawme Pond is scarce. Some outseepage occurs in the downstream end, as the dam raises the pond water level above the natural groundwater elevation in this area. Groundwater quality is believed to be similar to that of Upper Shawme Pond, with the potential for elevated nitrogen and phosphorus levels, but there is no indication that direct groundwater inputs determine water quality in Lower Shawme Pond. Temperature in August 2018 was the same at surface and near bottom at the water quality station and over 28^{o}C, suggesting that most water in Lower Shawme Pond is overflow from Upper Shawme Pond that warms up on its way through the pond.

The primary influences on Lower Shawme Pond water quality are expected to be inputs from Upper Shawme Pond, interaction with organic sediment and occasional inputs of stormwater, although most of that stormwater enters in the downstream portion of the pond. The inputs from Upper Shawme Pond are generally of desirable quality, so slight increases in conductivity and phosphorus are most likely due to sediment-water interactions. Nearly all of Lower Shawme Pond has a layer of organic muck sediment. Oxygen will be adequate and light will penetrate to the bottom even if there are planktonic algae blooms (although none were observed in 2018), so decay of organic matter and release of nutrients are expected. Growth of rooted plants and algae mats (which gain nutrition and grow at the sediment-water interface before floating upward) can be supported throughout the pond even with relatively clean and clear water above. This appears to be the root cause of aesthetic issues in Lower Shawme Pond, not the quality of the overlying water. Turbidity was very low and water clarity was very high in August 2018. Rooted plant cover was extensive and algae mats accumulated in the outlet end of the pond.

Pond Biology

Blooms of algae do not appear to have been common prior to 2001 but have been noted over the decade leading up to the 2011 summary by WRS. No details of those blooms are available, and it is not certain that the blooms were cyanobacteria. The 2018 assessment (Table 3, Appendix) indicated low chlorophyll-a, moderate phytoplankton biomass, but minimal cyanobacteria. Small coccoid planktonic green algae were dominant in August of 2018, a time when the probability of cyanobacteria was highest if such blooms were to occur. Other algae observed included diatoms, desmids (greens), dinoflagellates and euglenoids;

species that prefer elevated organic content appear favored, consistent with expected sediment-water interactions in this pond. A long-term data base would be needed to draw more definitive conclusions, but Lower Shawme Pond did not exhibit problem phytoplankton conditions in 2018. However, zooplankton collection procedures that greatly concentrate any algae large enough to be held by the 53 µm mesh in the net used revealed several cyanobacteria not observed in whole water phytoplankton samples, including *Planktothrix* and *Pseudanabaena*. Planktonic blooms are possible, just not observed in this assessment.

Algal mats were locally abundant however, with representatives of both the *Spirogyra* and *Cladophora* groups of filamentous green algae observed. Mats grew on any bare sediment and in association with rooted plants. Peripheral accumulations were substantial, particularly near the outlet end of the pond, where both flow and wind will tend to concentrate floating growths. The N:P ratio in the water column was moderate, but the dominance of green algae suggests it is higher at the sediment-water interface.

Since at least the late 1980s the plant community of Lower Shawme Lake has been dense and dominated by waterweed (*Elodea canadensis*), with substantial growths of Robbin's pondweed (*Potamogeton robbinsii*), wild celery (*Vallisneria americana*) and bushy pondweed (*Najas flexilis*). Swamp loosestrife (*Decodon verticillatus*), purple loosestrife (*Lythrum salicaria*) and reed grass (*Phragmites australis*) have been reported along the shoreline, the latter two being invasive plant species. The plant community as assessed in August 2018 was a close match for the historic record. In addition to the abundant species above, lesser amounts of coontail (*Ceratophyllum demersum*), spikerush (*Eleocharis acicularis*) and bladderwort (*Utricularia vulgaris*) were observed, and very small quantities of a duckweed (*Lemna minor*), a macroalga (*Nitella* sp.) and an aquatic moss were found.

Common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) were found in 2018 at six peripheral locations (Figure 8) with *Phragmites* dominant and scattered plants of *Lythrum* on the margin of the patch. Patches ranged in size from about 50 to 150 feet in length but were generally thin at 10 to 15 feet of thickness at the shoreline. The patch closest to the outlet is accessible from land, but the others are largely inaccessible except by boat due to thick shrubby vegetation on the landward side. An additional very small *Phragmites* patch was found on the Upper Shawme Pond side of the berm that represents the boundary between the Upper and Lower Shawme Ponds. That small patch is easily accessible from land.

Bottom coverage was substantial but not complete, with a rating of 3.4 on a scale of 0 to 4, and biovolume (the portion of the water column filled with plants) was 1.7 on a 4-point scale, suggesting between 25% and 50% of the water column was filled with plants. The dominant species are submergent, so surface growths were nominal, although some peripheral growths were dense. Average depth for all survey points was 2.5 feet. There was more open water than one might suspect from a view from the public property near the outlet, but the pond is shallow and the potential for plant nuisances is high. Yet only the peripheral *Phragmites* and *Lythrum* are invasive species; the submergent assemblage is all native species that provide valuable wildlife habitat.

Figure 8. Phragmites patches at Upper and Lower Shawme Ponds

Zooplankton biomass and mean length were very low (Table 3), consistent with the presence of an alewife population. The young alewife swim with their mouths open, filtering out zooplankton on their gill rakers and usually greatly depressing the zooplankton community. Only the smallest zooplankton escape and are unable to generate populations at the higher biomasses that develop with larger zooplankton. *Daphnia* were absent (these provide the best grazing capacity for algae and food for small fish), and the assemblage will have little value for algae grazing or as food for small fish. This is the trade-off that is made when alewife are present, but many ponds develop a more dense zooplankton population with larger individuals over the winter after the young alewife have left the pond but before the adults return in spring to spawn. We do not have winter zooplankton data for Lower Shawme Pond.

No freshwater mussels or snails were observed in Lower Shawme Pond. This was by observation and not a detailed sampling program, but with 31 sites checked for sediment features and plants, if either mussels or snails were common, they would have been detected. Freshwater sponges were observed. The lack of mussels and snails most likely suggests very low calcium levels that prevent shell formation, although it is possible that mollusks were eliminated by some other water quality issue. Sponges are more common in water too acidic and low in calcium to support mollusks.

Warmwater fish species have been noted in past reports, but there are no fish survey data. There is an active alewife run, so past stocking was apparently successful in establishing a migratory population. A recent census indicated that about 8000 alewife reached Lower Shawme Pond and 3000 of those passed through the fish ladder to Upper Shawme Pond. In August of 2018 many bass were observed in the pond, many feeding on insects landing on or flying near the pond surface. It is not certain if these were largemouth or smallmouth bass or both. Sunfish and killifish were also observed. Lower Shawme Pond has great potential for surface flyfishing, as the water is shallow and clear and the fish were aggressive.

Waterfowl are abundant at Lower Shawme Pond. Multiple pairs of swans, some Canada geese, multiple species of ducks and at least two species of herons (great blue and little green) were observed in August 2018. Food resources are abundant, shelter is available, and human interactions are limited. Lower Shawme Pond represents a habitat oasis in a busy part of Cape Cod.

The Natural Heritage and Endangered Species Program maps do not show any Priority or Estimated Habitat for listed (protected) species at Lower Shawme Pond (Figure 6).

Management Needs and Recommendations

Designated uses for Lower Shawme Pond under its water quality classification include contact recreation, boating and fishing, along with aesthetic and passive uses plus fish and wildlife habitat. The pond is especially valued as a breeding area for sea-run alewife. Lower Shawme Lake was on the 2016 Integrated Waters List for not supporting designated uses as a consequence of excess nutrients and eutrophication as indicated by system biology and is supposed to be the subject of a TMDL (category 5). To fully support all designated uses, Lower Shawme Pond needs reduced algal mats and rooted plant growth. Yet there are no facilities to support swimming or other contact recreation beyond incidental contact from small boats, and the habitat value of this pond is high. Aesthetics could certainly be enhanced for passive uses, and access for small boats could be improved, but the degree to which algal mats and native rooted plants need to be reduced is debatable. Improvement to enhance aesthetics is reasonable, especially near the outlet where most public contact occurs, but there is no apparent need for a pondwide rehabilitation program.

One issue for Lower Shawme Pond worth addressing quickly is the relatively early infestation with common reed and purple loosestrife, two invasive species that should be controlled soon to avoid a much bigger problem later. There are multiple means for controlling *Phragmites* and *Lythrum*, and both physical and chemical controls could be viable in these ponds. Killing the entire plant is the goal, and herbicides provide the greatest probability of success in the shortest time. However, it is rare to get more than a 90% kill rate in the first year of application, as getting even application in a *Phragmites* and/or *Lythrum* patch is challenging and getting complete distribution of herbicide to all plant roots is not guaranteed. A three-year program is therefore advised, with sequential treatment as needed in years 2 and 3. At that point, *Phragmites* and *Lythrum* should be eliminated or reduced to such low densities that hand pulling is feasible as a follow up as warranted.

Physical approaches include hand pulling, excavation and fire. Hand pulling with some manual shovel work to get roots systems out is not really feasible for the growths in Lower Shawme Pond with minimal shore-based access. Mechanical removal with a hydrorake could be attempted from the water but will be more expensive than herbicides and will require at least as many years of repetitive action to gain control. Biological controls also exist, mainly for *Lythrum*, with a beetle most popular for introduction to larger stands, but the scale of application in Lower Shawme Pond is less conducive to this method.

If an herbicide is used, *Phragmites/Lythrum* patches are not accessible from shore except for location near the outlet (and the small patch on the outlet berm of Upper Shawme Pond, which should be addressed as well). A small boat could be launched from northeastern end of Lower Shawme Pond. Spraying from a small boat would seem to represent the best option in Lower Shawme Pond, but efficiency will be less than optimal and these patches will almost certainly require three years of control effort to achieve success.

Permits for herbicide treatment include an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals. The latter is provided by the MA Department of Environmental Protection and is relatively straightforward once an Order of Conditions has been issued. That Order of Conditions is written by the local conservation commission after a Notice of Intent is filed and properly reviewed and subject to public hearing by a vote of the conservation commission. Where there are protected species the Natural Heritage and Endangered Species Program must approve of the project, and where marine species are involved, the MA Division of Marine Fisheries must be consulted.

Only the very southern end of Upper Shawme Pond has any mapped habitat for protected species (Figure 6), so *Phragmites* or *Lythrum* control at the Shawme Ponds does not require NHESP approval. However, with the current alewife run, the DMF must be consulted; this is done by sending a copy of the Notice of Intent to that agency for review and comment prior to the public hearing. There are other ponds in Sandwich where *Phragmites* and/or *Lythrum* should be controlled, and a single Notice of Intent could be prepared for control at all ponds in need with review by NHESP and DMF then necessary. The project would qualify as an Ecological Restoration, which relaxes certain performance standards, although no significant negative impacts are expected.

If physical removal is attempted, hand pulling can be approved with a negative determination of applicability by the Conservation Commission. If mechanical equipment is employed and sediment is disturbed, the permitting could get much more complicated, but may be workable with a Notice of Intent under the Wetlands Protection Act.

Failure to address the *Phragmites* and *Lythrum* at this early stage of invasion is likely to result in a peripheral monoculture of *Phragmites* over a period of years, with attendant loss of habitat value and aesthetic appeal. Some areas of Cape Cod have been overrun by *Phragmites* and control becomes more difficult in terms of effectiveness, cost and regulatory constraints when the infestation is expansive. Note that three other ponds in Sandwich have small stands of *Phragmites* and/or *Lythrum* (Peters, Pimlico and Weeks Ponds) and a program that addresses all of them would be appropriate and may produce cost savings. The overall cost of a complete program for all Sandwich ponds with these invasive shoreline plants has been estimated at about $50,000 over three years for control with herbicides and at least $100,000 for control by physical means.

It should be noted that glyphosate would be a highly applicable herbicide to use for *Phragmites* and *Lythrum* control, but this chemical has been in the news these past few years for links to cancer and related health impacts. However, this is largely related to extensive use on genetically modified crops in giant agribusiness applications, and then only through selective use of data. The risk is negligible for targeted *Phragmites* or *Lythrum* control on such a small scale as envisioned here. People often fail to discern this very important difference, or that it is additives in the herbicide mixes used in agriculture that represent the greatest risk, and these additives are not used in aquatic environmental applications. The selective use of glyphosate for aquatic invasive species control has minimal similarity to the agricultural uses that have resulted in all the negative publicity or even use by homeowners on lawns. The formulations are different and aquatic use is much more limited.

Beyond the invasive species issue at a few points along the shoreline, it would be appropriate to limit native rooted plants and algal mats to enhance aesthetics and access in the outlet end of the pond, near the town center (Figure 9), where many people view the pond and where access by small boats could afford a very enjoyable experience. Ideally, this area would be dredged to remove the sediment that supports dense vegetative growths, but this is a highly disruptive and expensive approach that may not be feasible. Alternatively, methods including benthic barriers, mechanical harvesting, or herbicides could be applied. It is also possible to treat the surficial sediment to limit algal mat development, although this approach will not prevent most rooted plants from growing.

Benthic barriers are thin sheets of material applied to the pond bottom to prevent plant growth. These are very effective on a localized basis, but too expensive to use over large areas at about $1/square foot. Application to access points or along the channel leading to the outlet of Lower Shawme Pond could

Figure 9. Outlet end of Lower Shawme Pond

maintain open water and improve aesthetic appearance. Algal mats and plants from upstream could still move downstream with current and wind, but there would be little structure to keep them in the area and they should be flushed from the pond.

Mechanical harvesting could be conducted once each year, most likely in late spring, to clear the area of rooted plants and algal mats. A small harvester could be launched and could address the target area (some portion of the pond area shown in Figure 9) in a few days. Cost would probably prevent frequent harvesting on a contract basis but owning a harvester for this purpose would involve a substantial upfront capital cost and ongoing operation and maintenance costs that only make sense if more ponds need this type of attention.

Herbicides could be applied to the target area in late spring to reduce growths. Multiple herbicides may be applicable but given the variety of plants involved and the short detention time for the target area, use of diquat is probably most appropriate. This contact herbicide requires only a day or two of exposure to work on a broad array of plants. It may not, however, provide adequate control of algal mats. A cost not in excess of $5000 per year is envisioned.

Phosphorus inactivation involves application of aluminum or lanthanum compounds that bind phosphorus in surficial sediments and limit its availability for uptake. Algal mats have been prevented by this technique, but most plants have roots that extend deeper than the treatment can address. Such a treatment would not be very expensive and may be worth trying after any herbicide treatment to gain greater control of rooted plants and algal mats.

Beyond plant control in Lower Shawme Pond, ongoing shoreline protection is highly desirable. There are not imminent threats to shoreline and any such actions require permitting under the Wetlands Protection Act, so the town has considerable control in this regard. Other than limited patches of invasive species, shoreline conditions are quite desirable at this point in time. Keeping it that way should be a priority but does not involve any active expense.

Water quality and biological monitoring should be continued. It is not clear that phytoplankton are problems in this system but reports of past blooms and the traces of cyanobacteria in the zooplankton samples suggest that tracking algae on a longer timeframe is desirable. Likewise, the database for phosphorus and nitrogen is very limited, and temperature and oxygen conditions should be documented over multiple years. Monitoring once in early summer and once in late summer would be desirable.

Hoxie Pond

General Pond Features

Hoxie Pond covers 8.5 acres slightly south of Rt 6A and just north of Old County Road and the railroad in that area (Figure 1), although recent measurement suggests that the main body of the pond is 8 acres and the portion south of the railroad, not assessed in this investigation, represents the other half acre. The railroad cut that half acre off from the pond many years ago, and there is no apparent connection between the two waterbodies. Average depth is 12.2 feet while maximum depth is 35 feet (Table 1, Figure 10). Existing bathymetry was confirmed by this investigation. The volume is about 98 acre-feet and the detention time, based on combined estimated inputs of precipitation and groundwater, is about 235 days.

Hoxie Pond has a typical kettlehole bowl shape and has 0.42 miles of shoreline. There are no natural inlets, but the pond is connected to a cranberry bog to the west. The bog can draw water from the pond by pump and send it back by gravity. As the bog is about as large as the pond, water use can be substantial and water quality impacts are possible, but the bog does have a small supply pond within it and modern growing techniques can minimize impacts to receiving waters. No detailed assessment of bog operation has been conducted. Groundwater inflow is expected to be mainly from the south (Figure 2). Hoxie Pond can overflow to a wetland area that flows into Scorton Creek to the northeast, which discharges to the bay, but overflow is not common. The peripheral bottom is sandy, but grades into loose muck in water greater than about 10 feet deep.

There is no formal access, but the northern and western shorelines are on public property and a right of way is maintained across the berm that separates the pond from the cranberry bog. Access is difficult but not impossible from the railroad bed off Old County Road to the south of the pond. Fishing from carry in boats is popular in spring and fall, when a parking area on the cranberry bog property is open, but access to vehicles is currently prevented during summer by boulders placed at the entrance off Old County Road. Shoreline fishing is possible from sporadic openings in the vegetation surrounding the pond. The pond has been stocked with trout in the past, but there is no record of recent stocking. Abuse of the parking area, which is on private property, has been cited on social media as the reason the landowner blocks the access road with boulders during summer. As a consequence, the DFW has apparently ceased stocking Hoxie Pond. Swimming is popular during summer from informal "beach" areas accessed by foot and fishing for warmwater species still occurs. The pond is not a Great Pond under Massachusetts law, being under the 10-acre natural area threshold, and is listed as having no assessed uses by the MADEP (2017).

Watershed Features

The watershed of Hoxie Pond includes relatively few parcels near the pond, with one very large one extending downstream to Scorton Creek and including the former state game farm with considerable wetland (Figure 11). Of the six parcels in the upgradient direction of expected groundwater flow (from the south, Figure 2), five are developed, but not densely. The most prominent land use is the cranberry bog, which does withdraw water for irrigation and flooding from Hoxie Pond and returns most of that water to the pond. Further north there are more residential areas with small to moderate sized lots, while further west there are larger parcels that are largely undeveloped. A state fish hatchery produces trout downstream (north) of the pond off Scorton Creek, reportedly the oldest hatchery in the USA.

Figure 10. Bathymetry of Hoxie Pond from pre-1990 MA DFW records.

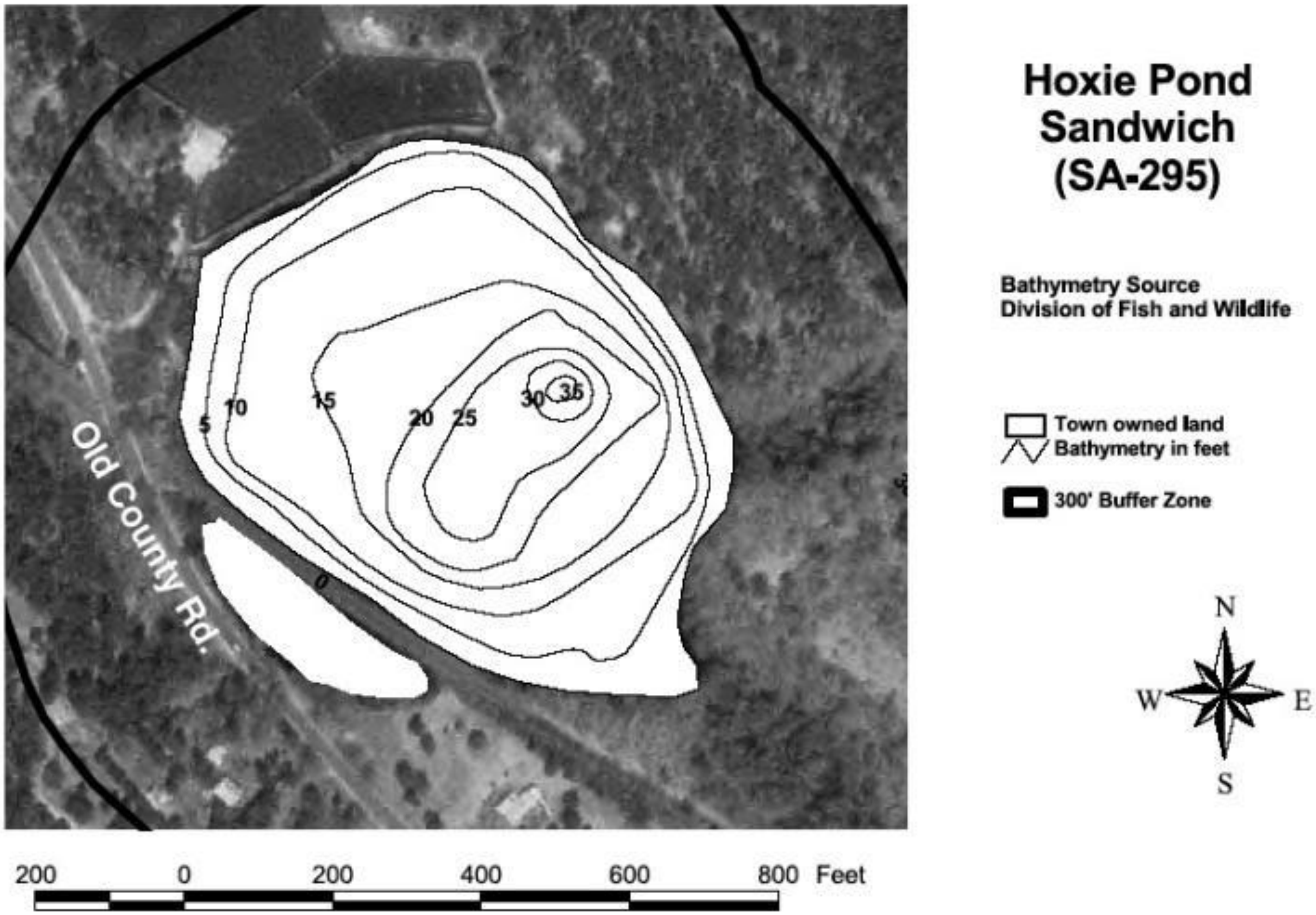
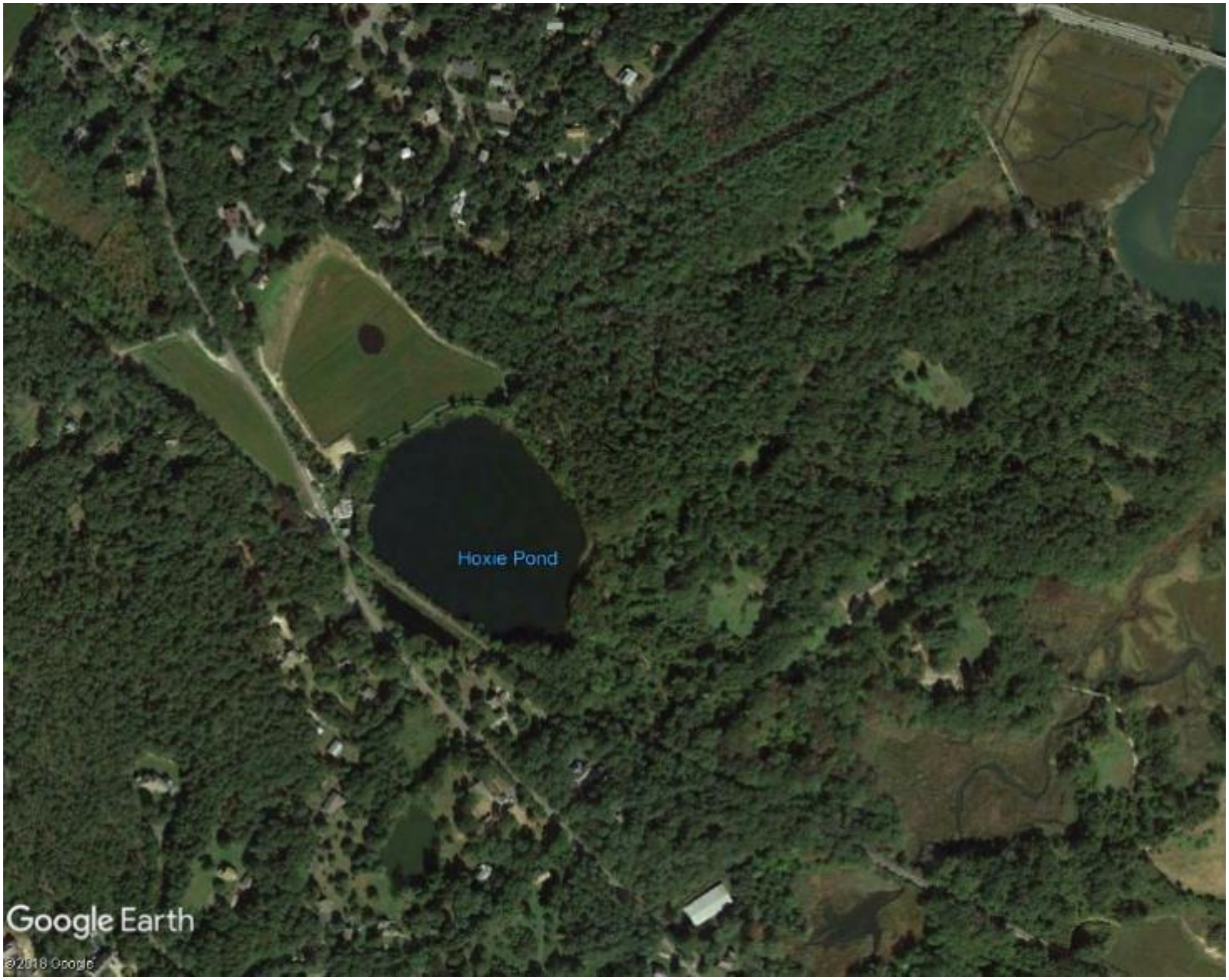


Figure 11. Hoxie Pond and general surrounding area.



Pond Water Quality

There are few known water quality data for Hoxie Pond prior to this investigation. Water clarity ranged from 5 to 12 feet (1.5 to 3.6 m) and oxygen was low below 18 feet of water depth, based on an online MA DFW listing last updated in 2007. No algal blooms have been reported, and Hoxie Pond is touted as a good swimming pond, but water clarity is marginal at times. The potentially large influence of the cranberry bog is a concern, but no major impacts have been described in available reports.

Sampling in August 2018 confirmed low oxygen in deeper water, with values <2 mg/L below a depth of about 15 feet (Appendix). With water warmer than 20°C at water shallower than 15 feet, there was no water in which trout could thrive in August. Alkalinity was low and the pH was slightly acidic (Table 4), but this is fairly typical of Cape Cod ponds in their natural state. However, the conductivity was moderate, higher than might be expected and likely indicative of inputs from the bog or bottom of the pond. Yet surface phosphorus concentrations were low and bottom values were moderate. Surface concentrations for forms of nitrogen were also low, but bottom values for TKN and total nitrogen were elevated. The bottom ammonium nitrogen value was not high, so the main forms of nitrogen contributing to elevated bottom nitrogen were organic. The N:P ratio was high, suggesting that green algae would be favored over cyanobacteria.

The top 4 inches of sediment were sampled at the deepest point and tested for a suite of features intended to inform us about possible internal phosphorus loading from that sediment. Both iron-bound and biogenic phosphorus were elevated in the sediment (Table 4, Appendix) such that internal loading could be substantial, and the aluminum to iron ratio is low, so with low oxygen near the bottom over an appreciable portion of the pond, higher phosphorus concentrations than were observed would be expected. The mechanism for this is unclear. The potential for high concentrations of available phosphorus is strong, but that is not what we are seeing, which is good for pond condition.

Water clarity was close to 10 feet by Secchi disk transparency in early August but had decreased to near 7 feet by late August. The water had a murky appearance, but there were few visible particles in the water and people apparently did not find it objectionable as there were people in the lake on each of two visits, both of which were weekdays. There was no odor or surface scums. Desmarais (2007) reports typical clarity near 5 feet during late summer and cites the cranberry bogs to the west as a major influence.

Pond Biology

Phytoplankton biomass was moderate overall (Table 4, Appendix) and chlorophyll-a and turbidity were also moderate. Two samples were taken (early and late August) and the first had moderate to almost high biomass while the second had low biomass. Golden algae dominated the first sample while no single algal division was abundant in the second sample. Cyanobacteria were nearly absent in the open water where samples were collected, but we did observe peripheral accumulations of buoyant cyanobacteria on the second date in late August. The wind undoubtedly blew those buoyant forms to the edge of the pond where they were visible, but when mixed into the open water the concentrations were negligible. This is consistent with the actual water quality assessed, but not with normal expectations with a relatively large adjacent cranberry bog, high sediment phosphorus, and low oxygen in deeper water. Hoxie Pond is in remarkably good condition considering the potential influences on its water quality.

Table 4. Water quality, plankton and sediment summary for Hoxie Pond.

Hoxie Pond			
Feature	**Units**	**Pre-2012 Value/Rating**	**Aug 2018 Value/Rating**
Bottom Dissolved Oxygen	mg/L	0.1	0.4
Average pH	SU	ND	6.6
Surface Alkalinity	mg/L	ND	7
Average Conductivity	µS	ND	164
Surface Total P	µg/L	ND	7
Surface Dissolved P	µg/L	ND	6
Bottom Total P	µg/L	ND	20
Bottom Dissolved P	µg/L	ND	10
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	20
Bottom Ammonium N	µg/L	ND	83
Surface Total Kjeldahl N	µg/L	ND	240
Bottom Total Kjeldahl N	µg/L	ND	1300
Surface Total N	µg/L	ND	250
Bottom Total N	µg/L	ND	1310
Surface N:P Ratio	Unitless	ND	36
Bottom N:P Ratio	Unitless	ND	66
Average Turbidity	NTU	ND	3.6
Secchi Transparency	m	2.55	2.75
Average Chlorophyll-a	µg/L	ND	4.3
Phytoplankton Biomass	µg/L	ND	1684
Cyanobacteria	%	ND	1
Zooplankton Biomass	µg/L	ND	53
Zooplankton Mean Length	mm	ND	0.99
Sediment Fe-P	mg/kg	ND	228
Sediment Biogenic P	mg/kg	ND	961
Sediment Al:Fe Ratio	Unitless	ND	0.15
ND = No Data	Desirable	Tolerable	Problematic

Plants were assessed at 44 points (Figure 12) with water depth, surficial sediment type, plant cover and biovolume, and relative abundance of plant species recorded (Appendix). The old bathymetric map was confirmed as reasonably accurate. Organic muck sediment was dominant at all sites deeper than 10 feet and was present at most sites deeper than 5 feet. Plant cover averaged 2.2 on a 0 to 4 scale (Table 4, Appendix), suggesting that 25 to 50% of the bottom was covered. Plants were present to a depth of almost 25 feet, suggesting adequate clarity to support those growths, although below about 20 feet the only growths were benthic algae mats. Plant density, assessed as biovolume or the portion of the water column filled by plants, averaged 1.2 on a 0-4 scale, indicating that between about 10 and 20% of the water column was filled by plants, not an excessive value.

A total of 18 submergent plant species were identified, although three were actually types of algae (chlorophyte green algae mats, cyanobacteria mats, and *Nitella*, a macroalga). Most abundant were common naiad (*Najas flexilis*) at 43% of surveyed sites, followed by cyanobacteria mats (13%), white water lily (*Nymphaea odorata*, 11%), bronze pondweed (*Potamogeton epihydrus*, 11%), and waterweed (*Elodea canadensis*, 10%). Other plants occurred sporadically, mostly in shallow water. While peripheral shoreline plants were not quantitatively surveyed, Hoxie Pond had no common reed (*Phragmites australis*) or purple loosestrife (*Lythrum salicaria*), both invasive species, or any other invasive plant species. The shoreline had dense growths of native buttonbush (*Cephalanthis occidentalis*), swamp loosestrife (*Decodon verticillatum*) and wild grape (*Vitis riparia*) in many areas, with just sporadic clearings mostly on the north and east sides where people access the pond regularly. The cyanobacteria mats are indicative of high sediment fertility and could cause taste, odor and toxicity, but no indication of any of these problems was evident and mats did not appear at the surface in August of 2018 (as commonly occurs in many ponds in late summer).

Zooplankton biomass was at the low end of the moderate range at 53 µg/L and mean size for crustacean zooplankton was high at almost 1 mm. There were a lot of rotifers present, which are small and depress the mean size for all zooplankton, but most of the biomass was cladocerans with some copepods present. The dominant zooplankter by biomass was a large bodied *Daphnia*, a very desirable form for both control of algae and as food for small fish. The large mean size for crustacean zooplankton suggests limited predation by small fish, and the fish community may be dominated by larger predators such as bass.

No freshwater mussels or snails were observed in Hoxie Pond. This was by observation and not a detailed sampling program, but with 44 sites checked for sediment features and plants, if either mussels or snails were common, they would have been detected. Low calcium content is likely to minimize shell formation for mollusks, although low oxygen will also restrict mollusk presence. Freshwater sponges were observed and are more common than mollusks when pH is low.

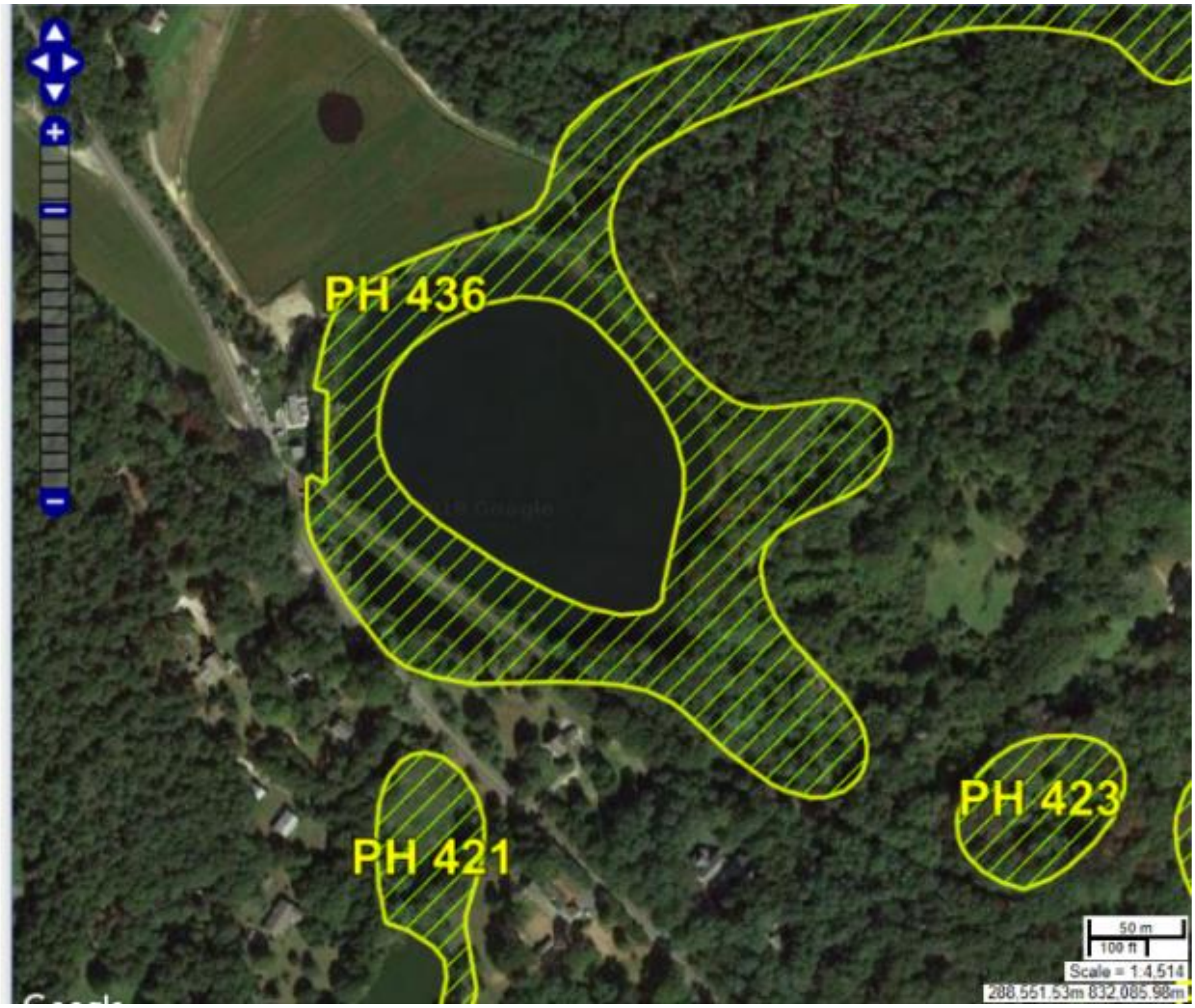
Hoxie Pond was reclaimed for trout management in August 1956 and was reclaimed again seven times prior to 1969, according to the DFW. Brook, rainbow and brown trout were stocked each spring on a put and take basis; some tiger trout may also have been stocked. The hatchery is nearby. During the most recent survey (more than a decade ago) the pond contained yellow perch, largemouth bass, brown trout,

Figure 12. Hoxie Pond survey points with bathymetry.

sunfish and banded killifish. Chain pickerel have also been caught in the pond. Despite the connection to the bay there is no mention of eels or alewife in the pond. Stocking ceased just a few years ago after the landowner blocked the access road with boulders during summer to halt illegal uses and general abuse of the site, but warmwater species such as bass and sunfish appear plentiful and the zooplankton size distribution suggests that larger predatory fish are dominant. Fishing has been cited as the primary use of the pond, although such use may have declined with the summer blocking of access for vehicles. It is still possible to carry in and launch cartop boats, canoes and kayaks, however, and the pond offers a very peaceful location for recreation and passive uses.

The periphery of Hoxie Pond and several nearby areas are mapped by NHESP as Priority Habitat for listed (protected) species (Figure 13). WRS does not have any information on which species are present, but the shallow portions of the pond are included, suggesting one or more peripheral species might be present but no deeper water forms.

Figure 13. NHESP habitat mapping for Hoxie Pond.



Management Needs and Recommendations

The primary uses of Hoxie Pond are fishing and swimming, although the use of the pond as a water source for the cranberry bog would also seem very important. The cranberry bog represents a potential threat to some designated uses but the available data do not suggest that the cranberry bog has had any clearly detrimental impact on Hoxie Pond. Further, Hoxie Pond is listed on the 2016 Integrated List (MADEP 2017) as a category 3 waterbody, indicating that no uses have been assessed. The results of this investigation suggest that contact recreation and fish and wildlife propagation are supported by the current condition of Hoxie Pond. The pond could be considered impaired for oxygen and may experience symptoms of eutrophication at times, but the 2018 conditions were acceptable for all known uses.

Low oxygen in water cold enough to support coldwater fish limits trout habitat; it was suspected that trout congregated near springs in the southern portion of the pond during summer when stocking was active, and no summer mortality was reported. Improving oxygen levels would be desirable, but in the absence of further trout stocking this seems non-essential. However, if there was interest in improving deep water oxygen, a circulation system could be employed. Such circulation would create warmer water from top to bottom, but without trout to support, the increased temperature would not be harmful to the warmwater fish present and increased oxygen would improve habitat availability. An appropriate mixing system would cost about $25,000 to install.

Water clarity seems marginal at times for swimming, but phosphorus concentrations were low and the murky appearance does not appear strongly related to algae. The loose muck on the bottom at depths greater than 5 feet may be subject to resuspension during windy periods, and this may explain the lower than expected clarity in relation to apparent low background fertility. Dredging would set the pond back in time considerably and remove accumulated sediment with some undesirable features, but there is no evidence that this sediment is measurably impacting water quality and the cost of dredging does not appear justified. Application of best management practices to the cranberry bog operation would certainly be appropriate, but the absence of apparent impacts suggests that current bog management is acceptable and may already be employing the best management techniques available.

There were no invasive species found in or around Hoxie Pond, and the current coverage and density of plants is consistent with pond uses. No plant control action appears necessary. The presence of Priority Habitat for state listed species means that any management activity in or around Hoxie Pond will need to be reviewed by the NHESP as well as the local conservation commission.

As this investigation included assessment in only one month (albeit the most critical month for use support evaluation), further monitoring is advisable. Collecting water quality and plankton data as done in this investigation from at least one date in each of late spring and late summer on an annual basis would build a database that would allow better assessment and appraisal of management needs over time.

Lawrence Pond

General Pond Features

Lawrence Pond is one waterbody the "Three Pond District" that also includes Spectacle and Triangle Ponds (Figure 1). Lawrence Pond has an area of 138 acres, about 2.3 miles of shoreline, a mean depth of 15.9 feet at maximum water level and a maximum depth of 27.6 feet (Table 1). Lawrence Pond is the largest pond by area wholly in the Town of Sandwich. Pond volume is estimated at just under 2200 acre-feet, the second largest pond volume in Sandwich after Peters Pond. The water level may drop by 2 feet over the course of summer and fall but remained high in 2018. Bathymetry (Figure 14) is slightly irregular but not unusual for kettlehole ponds. Existing bathymetry was confirmed by this investigation. Lawrence Pond has a largely sandy to rocky shoreline and sand and gravel in the shallow areas, grading to organic muck sediment at greater depths. There are no surface inlets or outlets at this pond. Groundwater flow is mainly from the west. Based on estimated precipitation and groundwater inputs, the detention time for water in Lawrence Pond is calculated at 692 days or just under 2 years.

The shoreline is largely developed on the north, east and south sides but is mostly undeveloped on the west side, excepting for the Cape Cod YMCA complex in the center of the western shore (Figure 15). Access for the public is informal, mainly a small area off Great Hill Road on the southeast side of the pond with no developed boat ramp or facilities. Cartop boats can be launched but parking is very limited. Attempts to launch larger craft resulted in the installation of posts to prevent trailer access in spring of 2018. There is also a gated access point on the south end with a potential boat launching area and a sign stating that it is under the control of MADEP but this area was not observed to be open or used.

The Cape Cod YMCA maintains a camp that occupies a substantial portion of the western shoreline. A homeowners association has a large land parcel with a beach and undeveloped boat launch on the east side that affords access for a portion of the homeowners off the pond to the east. Another beach complex at the north end of the pond serves homeowners off the pond to the north and yet another beach complex at the south end serves off-pond homeowners to the south. A trailer camping area also occupies a portion of the eastern shore and affords access to the pond for tenants. While truly public access is very limited, Lawrence Pond is heavily used by many people in the general vicinity. The pond is a Great Pond under Massachusetts law and is not listed as an impaired water by Massachusetts DEP (2017).

Watershed Features

The land area contributing water to the pond depends largely on groundwater flow path (Figure 2). Surface water runoff to Lawrence Pond appears minor; runoff from Great Hill Road and many adjacent lots along the eastern shore has been captured and routed to leaching catch basins as part of the town's stormwater mitigation plan. Groundwater flow is from the west, so many of the wastewater systems east of the pond and the many leaching catch basins serving roads to the east would be expected to flow away from Lawrence Pond. The main land uses to the west include the YMCA camp, considerable undeveloped land with conservation easements protecting it from development, and the area of Spectacle Pond and Triangle Pond with their YMCA camps. Joint Base Cape Cod (JBCC) is not within the contributory area for Lawrence Pond and there are no major groundwater threats to Lawrence Pond (Wright-Pierce 2017).

Figure 14. Bathymetry of Lawrence Pond from pre-1990 MA DFW records.

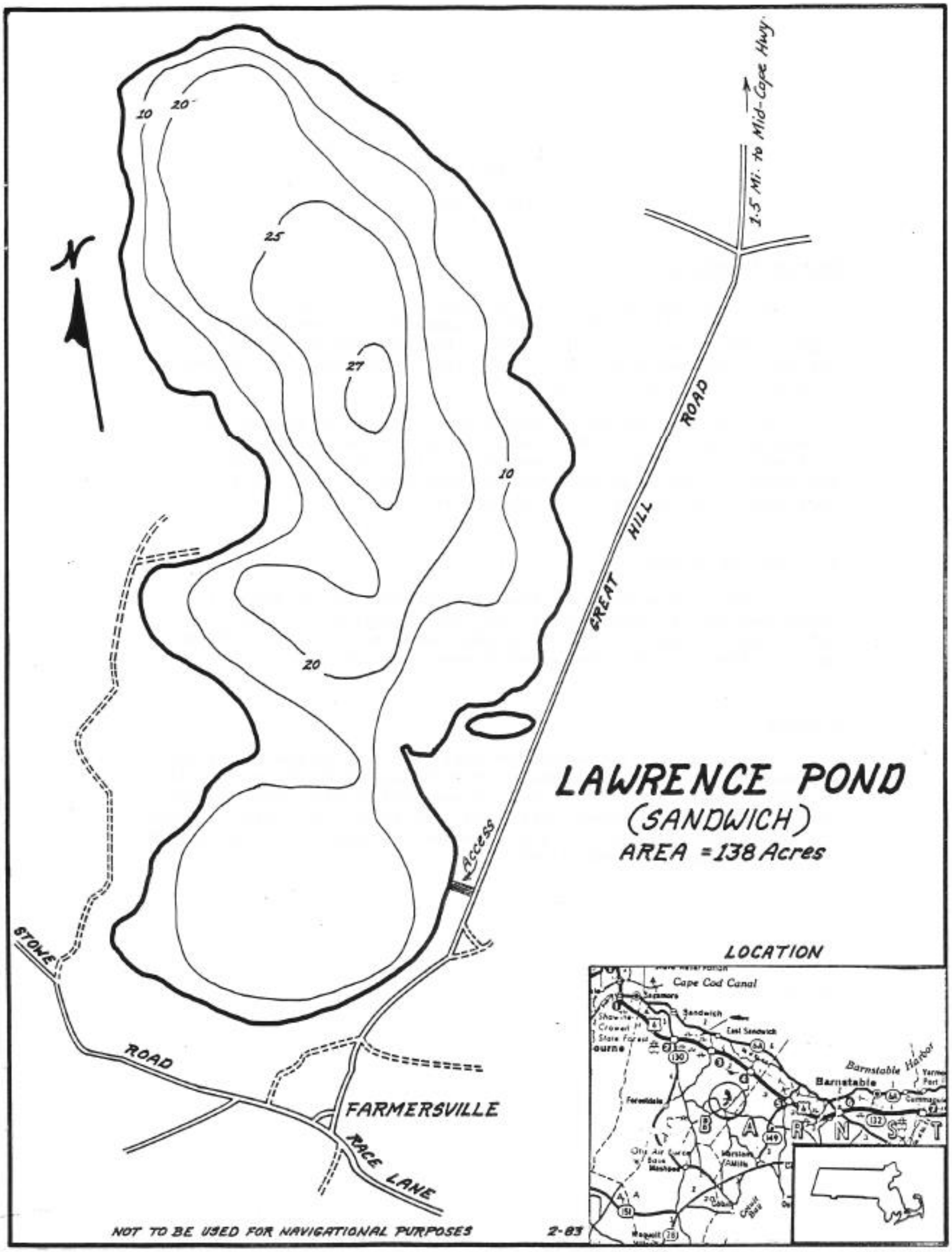
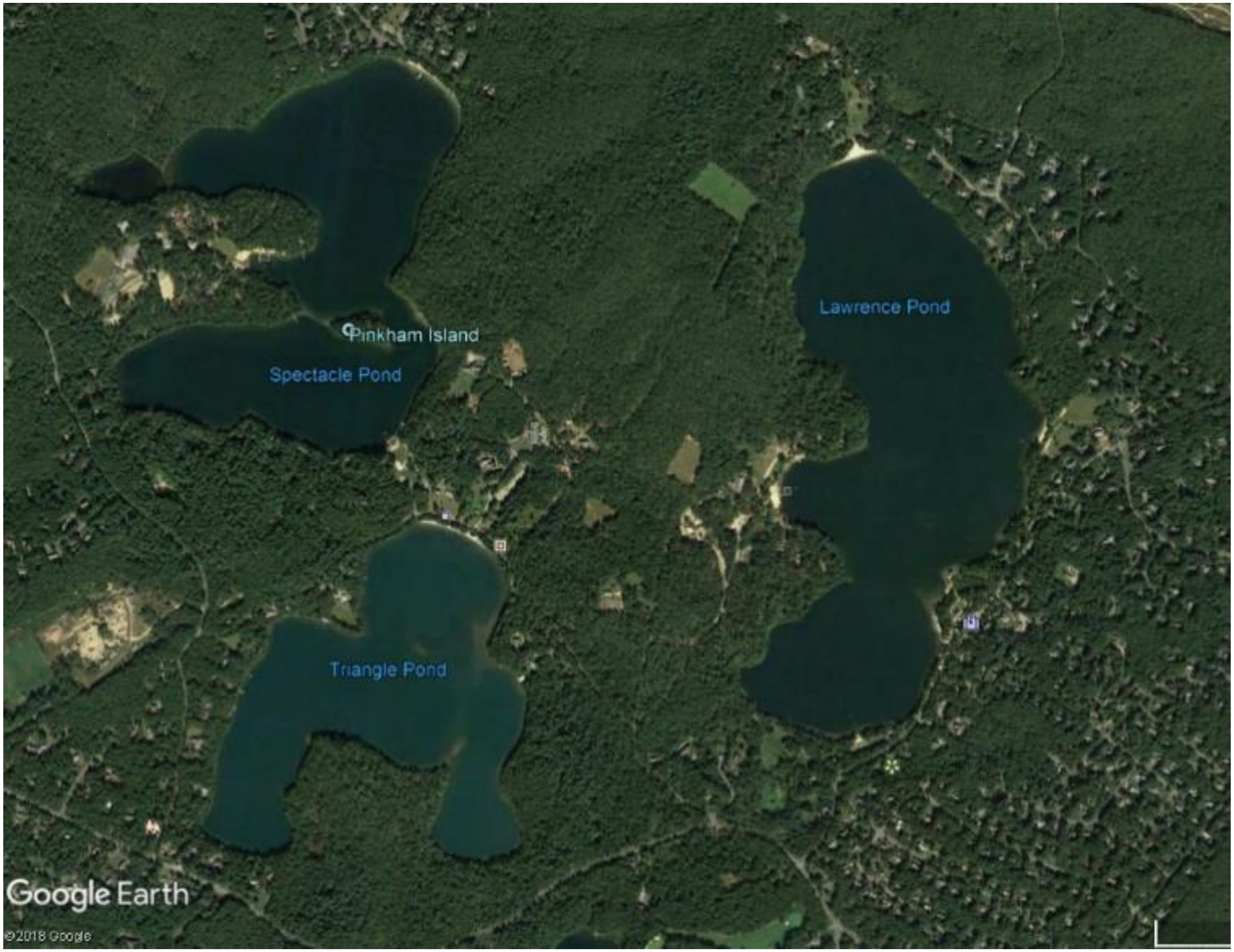


Figure 15. General vicinity of ponds in the Three Lakes District.



Pond Water Quality

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth. Water clarity ranged from 13 to 25 feet (4 to 7.7 m) in three samplings in 2008-2010, with depleted oxygen only right at the sediment water interface. The pond is normally too shallow to stratify strongly, so severe or prolonged oxygen problems would not be expected. The pH was acidic, alkalinity was very low, as were phytopigments and nutrients as of 2010. Phosphorus was <10 µg/L in all samples, while nitrogen was close to or less than 300 µg/L. Water color varied but appeared to be a function of natural color more than algae. Rooted plants were reported as sparse, but no detailed survey had been conducted as of 2010. Peripheral green algal mats were noted but no surface blooms had been reported prior to 2011.

Conditions appear to have changed in Lawrence Pond over the last decade, however, and pond users have noted a decrease in clarity and generally murky and green appearance by mid-summer in recent years. The 2018 water quality assessment found a decrease in bottom oxygen that pushes the pond into the zone where phosphorus bound to iron could be released (Table 5). The surface phosphorus concentration was <10 µg/L historically and in 2018, but the bottom phosphorus value rose dramatically from a historic average of 8 µg/L to 100 µg/L in 2018. We do not have nutrient data from 2011-2017, so just when this switch occurred is unknown. However, the real issue is a change in thermal structure such that deeper water remains separate, is not mixed regularly into the upper water layer, and allows oxygen to be depleted near the bottom in water deeper than 20 feet (6 m), leading to release of available phosphorus from the surficial sediment. This represents up to 42 acres of the 138-acre pond where elevated phosphorus concentrations may be found, a zone where light penetrates sufficiently to allow algal growth. The N:P ratio in that deeper water is low (10:1); this and light quality at that depth will favor cyanobacteria.

Note that the summer water level was high in 2018. The last time the water level was noted as being especially high was in 2010 (recorded as the highest water level in 15 years) and there were peripheral growths of filamentous green algae that were objectionable. Given that wind on Cape Cod usually mixes water to a depth of 20 to 25 feet, the higher water level in 2018 may have just been enough to limit wind mixing of that deeper water. July was unusually calm, further limiting mixing effects and allowing the bottom to go anoxic and release phosphorus. If the pond was much deeper, it might stratify each summer, but there would not be enough light at the bottom to allow algae growth. Lawrence Pond has a bathymetric structure that puts it near the boundary for waterbodies that stratify each summer, and variation in water depth and wind can make the difference. The last 4 years have all had spring or summer periods of warmer temperatures and less wind than normal; deeper water and the weather pattern may be the main factor in recent algae blooms in Lawrence Pond.

The loss of oxygen and release of phosphorus in deeper water tends to set up a recurring pattern. The resultant algae bloom adds phosphorus-rich organic matter to the bottom that expresses a high oxygen demand. Once enough phosphorus-rich, oxygen demanding sediment builds up, the oxygen loss and phosphorus release may be sufficient to regularly support blooms even. With a long detention time, phosphorus will build up in the water column and blooms may become more and more common. This does not yet appear to be the case with Lawrence Pond, however. Background surface phosphorus concentration was still low, and the 2018 bloom was not severe.

Table 5. Water quality, plankton and sediment summary for Lawrence Pond.

Lawrence Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	4.8	0.4
Average pH	SU	6.0	6.4
Surface Alkalinity	mg/L	6.7	2.0
Average Conductivity	µS	ND	56
Surface Total P	µg/L	7	9
Surface Dissolved P	µg/L	ND	6
Bottom Total P	µg/L	8	100
Bottom Dissolved P	µg/L	ND	5
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	35
Bottom Ammonium N	µg/L	ND	110
Surface Total Kjeldahl N	µg/L	ND	375
Bottom Total Kjeldahl N	µg/L	ND	1000
Surface Total N	µg/L	263	385
Bottom Total N	µg/L	268	1010
Surface N:P Ratio	Unitless	38	43
Bottom N:P Ratio	Unitless	34	10
Average Turbidity	NTU	ND	3.8
Secchi Transparency	m	5.4	3.4
Average Chlorophyll-a	µg/L	2.8	2.6
Phytoplankton Biomass	µg/L	ND	3262
Cyanobacteria	%	None reported	98
Zooplankton Biomass	µg/L	ND	5.4
Zooplankton Mean Length	mm	ND	0.66
Sediment Fe-P	mg/kg	ND	42.2
Sediment Biogenic P	mg/kg	ND	242
Sediment Al:Fe Ratio	Unitless	ND	1.06
ND = No Data	Desirable	Tolerable	Problematic

The sediment analysis (Table 5, Appendix) indicates relatively little iron-bound phosphorus in the sediment and only a moderate amount of biogenic phosphorus (organic phosphorus that is easily released). There is slightly more aluminum than iron in the bottom sediments, which is somewhat unusual for Cape Cod sediments, so more phosphorus is bound by aluminum than iron, which makes that phosphorus unavailable even when oxygen is low. An aluminum to iron ratio >3 is needed, however, to minimize phosphorus availability, much higher than observed. Lawrence Pond sediment has a higher solids content and lower organic content than any other Sandwich pond tested (Appendix), indicative of lower oxygen demand and lower available phosphorus content. It is possible to limit the impact of the phosphorus that is available by several proven means.

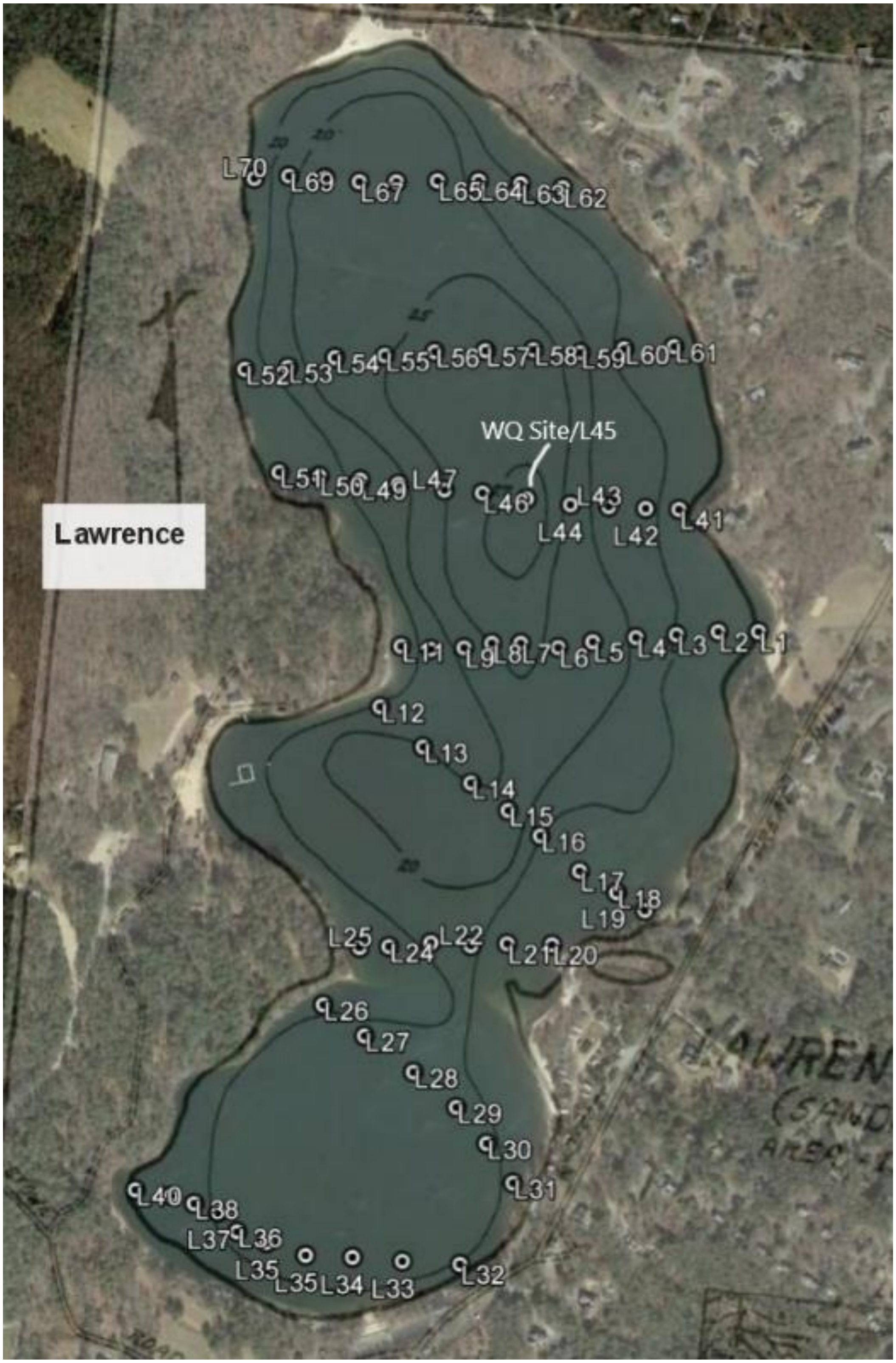
Water clarity in 2018 was just over 10 feet (3.1 m) in early August but increased to over 12 feet (3.7 m) by late August. Turbidity was also moderate. Such clarity supports all designated uses but is lower than what past data suggest is the norm. The historic average is almost 18 feet (5.4 m) prior to 2011 but Secchi transparency as low as 13 feet (4 m) has been recorded in the past. It appears that the algae develop in deep water with just enough light but adequate nutrients, then move upward in the water column. Once near the surface, there is little phosphorus available in the water column to sustain growth and the bloom dies out after a few weeks.

Pond Biology

Plankton were collected at one central site and 70 locations were visited in August 2018 to assess water depth, surficial sediment features and the plant community (Figure 16). A second phytoplankton sample was collected later in August to check on the bloom that was observed earlier in August. Phytoplankton biomass was about 3500 µg/L in early August and dropped to just slightly higher than the 3000 µg/L threshold for high biomass by late August (Table 5, Appendix). The composition was roughly the same, with the cyanobacterium *Planktolyngbya limnetica* highly dominant and just a few other algae from other divisions observed in samples. This species of cyanobacteria is common in Cape Cod lakes, is generally associated with mesotrophic (moderate fertility) waterbodies and is not a known toxin producer. It forms very thin (2 µm) filaments so is not visible in the water but gives it a murky greenish appearance. This alga is not especially buoyant and does not form surface scums. It relies on mixing events to reach the surface. Therefore, it is possible that it would not have shown up in the surface water without a mixing event after a deep-water growth phase, but such events are fairly common with the wind on Cape Cod.

The plant survey detected only 6 rooted plant species plus benthic mats of green algae (Chlorophyta) and cyanobacteria plus the macroalga *Nitella* (Appendix). Most abundant were the shallow water species quillwort (*Isoetes* sp. at 27% of sites) and spikerush (*Eleocharis acicularis* at 13%). *Nitella*, hedge hyssop (*Gratiola neglecta*) and green algae mats were next most abundant at 9-10% of sites surveyed. Plant cover rated a 0.8 on a 0 to 4 scale, indicating well under 25% cover of the bottom by plants. Plant biovolume rated an even lower 0.6 on the 4-point scale, indicating that well under 25% of the water column is filled with plants. The very sandy to gravelly substrate limits growths; light penetration is adequate to allow growth to at least 20 feet of water depth, but the substrate is not especially hospitable in any location. Lawrence Pond has always had a sparse plant community, but at least no invasive species were detected, including a lack of common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) around the periphery.

Figure 16. Lawrence Pond survey points with bathymetry.



Zooplankton biomass was very low at 5.5 µg/L but mean crustacean zooplankton length was in the middle of the desirable range at 0.66 mm (Table 5, Appendix). Rotifers, copepods and cladocerans were all represented, including one species of Daphnia, a desirable consumer of algae and food for small fish, but there were not many of any zooplankton species. Intense predation is a possibility, but it seems more likely that the extreme dominance by a largely inedible, low nutritional value cyanobacterium is responsible for low zooplankton abundance.

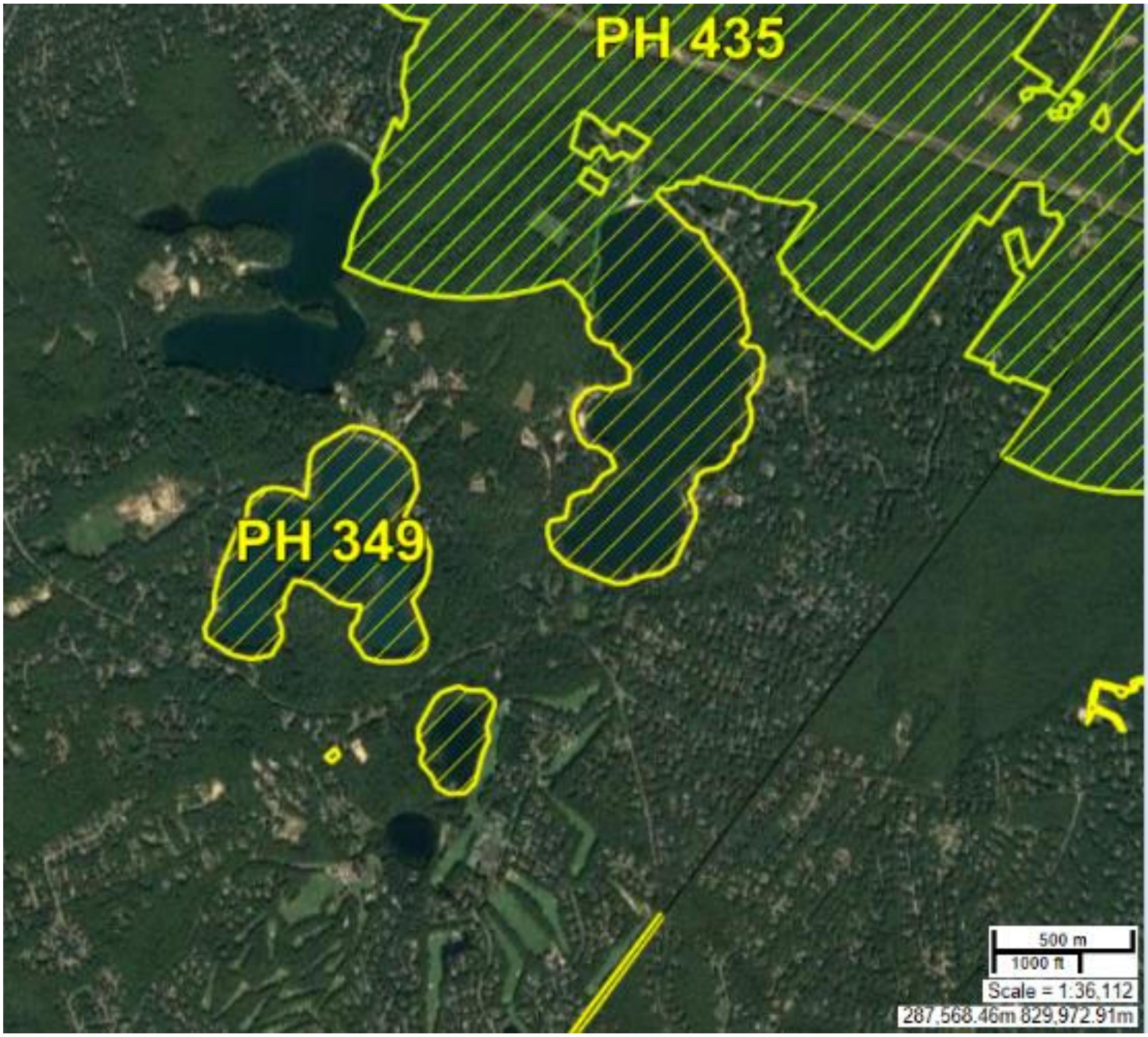
A few mussels were observed but no snails were detected over the 70 sites where visual reconnaissance was conducted. Freshwater sponges were observed, but not very abundantly. The invertebrate fauna of Lawrence Pond is sparse. Low alkalinity suggests low calcium that will limit formation and maintenance of mollusk shells.

Lawrence Pond historically hosted a typical warmwater fishery for Cape Cod, with largemouth and smallmouth bass, chain pickerel, yellow perch, pumpkinseed sunfish, brown bullheads and killifish. Stocking and assessment by the state Division of Fisheries and Wildlife occurred far in the past, as it did with many Cape Cod Ponds, but no recent survey data for fish are available and the recent condition of the fishery has not been documented. We were able to confirm that there is no record of alewife in this pond, so the very low zooplankton biomass is more likely related to poor quality food resources than to predation. The lack of access precluded much involvement by DFW in recent decades. Freshwater Guides (Desmarais 2007) reports that Lawrence Pond was treated with limestone to counter acidity and that yellow perch are the most abundant fish. Angling for bass and pickerel was reportedly rewarding but declining as of 2007.

NHESP has mapped all of Lawrence Pond as Estimated Habitat for one or more listed (protected) species under its program (Figure 17). This means that any activity in or around the pond must be approved by the NHESP prior to issuance of a permit under the Wetlands Protection Act, which is administered by the Sandwich Conservation Commission. WRS does not know which species may be present based on the NHESP map, but Lawrence Pond abuts the terrestrial Priority Habitat identified as PH435.

Management Needs and Recommendations
In comparison to the lack of apparent management needs expressed by WRS (2012), Lawrence Pond appears in need of water quality management to prevent summer cyanobacteria blooms and stem a trend that is likely to get worse over the next decade or two. The pond appears to be in the early stages of conversion from a well-oxygenated, low nutrient, relatively clear, limited algae state to one with lower oxygen near the bottom, increasing phosphorus concentrations and more frequent cyanobacteria blooms. Current conditions are not intolerable; the water has been murky in August the last few years and a non-toxic cyanobacterium has been dominant. The amount of phosphorus in the surficial sediments in deeper water is not extreme but release of phosphorus and light are apparently adequate to allow blooms to develop in deeper water and come to the surface with wind mixing. Phosphorus levels can be expected to increase slowly and for different and potentially more obnoxious cyanobacteria to bloom. It would be appropriate to take action in the next few years to reverse this trend.

Figure 17. NHESP habitat mapping for ponds in or near the Three Pond District.



The crux of the problem is available phosphorus from sediment with enough light reaching it to facilitate algae growth. A low N:P ratio and the quality of light at that depth (20+ feet) is such that cyanobacteria are favored. There are three ways to eliminate the problem: dredging, oxygenation and phosphorus inactivation. Dredging is true restoration, removing sediments that have accumulated since the end of the glacial period that formed this pond, but is very expensive and not typically performed if it is not essential to regain water depth. Lawrence Pond has lost very little depth; while detailed sediment probing was not conducted, it was apparent from the visual survey that muck deposits are not thick and extend over only a minor portion of the pond. Dredging does not appear justifiable in this case.

Oxygenation allows natural inactivation of phosphorus by iron, which is usually plentiful in Cape Cod ponds. There are seven main ways to oxygenate, three involving circulation and four aimed at oxygenating without vertical circulation on a large scale. Each has valid applications, but none is ideal or appropriate in all situations. One must understand the features of the lake and the goals of increasing oxygen content to select an approach, then delve into details such as the oxygen demand, extent and duration of unacceptable oxygen levels, and constraints on access, power availability, and facility construction. There may be more than one way to achieve desired conditions, in which case economics and institutional (e.g., permits, public perception, long term management) constraints will be important to decisions on how to proceed.

Given what we know of Lawrence Pond, the most applicable and probably the least expensive way to oxygenate the deeper waters would be an air driven circulation system. With no trout to support, maintaining a deeper colder layer is not essential, and such a layer is not stable in this relatively shallow lake anyway. A series of diffusers run from a compressor on shore could keep Lawrence Pond mixed, maintain adequate oxygen at the sediment-water interface, and prevent the release of phosphorus that fuels algae blooms. Such a system would operate over about 42 acres of the pond (the area deeper than 20 feet) but would not need to operate at all times since the pond is mixed much of the year naturally. Such systems are most effective when they prevent stratification, so operation at times between late May through July or possibly August would be needed. The capital cost of such systems averages about $1500 per acre addressed, so a cost of about $63,000 is envisioned, exclusive of any land acquisition cost, a land-based structure to house the compressor and controls, and any expense to bring power to the site. Annual operating costs, mostly for electricity, would be on the order of $5000 to $10,000.

The third option is to inactivate the surficial sediment phosphorus that is present. As it took many years for this phosphorus to build up, inactivation should provide years of relief. Iron does this naturally if it is abundant enough and oxygen is adequate, but aluminum and lanthanum have been used where oxygen is low and more permanent binding is desired. Aluminum has been the binder of choice in New England lakes to date and has a strong track record. The average duration of benefits for deeper lake treatments has been estimated at 21 years (Huser et al. 2016) and results have lasted more than a decade so far in other Cape Cod ponds (Wagner 2017).

Based on the sediment features assessed in this investigation, a dose of about 30 g/m^2 will be adequate to inactivate the phosphorus in the sediment and prevent it from supporting algae blooms. The cost of such a treatment over 42 acres of pond area deeper than 20 feet would be on the order of $75,000 and would require less than a week to conduct. Clarity should markedly improve in summer for at least a decade and probably two decades based on pond features. Additional sediment testing and recalculation of dose is advised (only one sample was collected in this investigation) before action is taken, but unless the sample from this investigation was unrepresentative, the suggested dose and cost should hold up. This appears to be the most appropriate approach to improving Lawrence Pond.

No plant management needs are apparent at Lawrence Pond. Shoreline protection is always appropriate but appears to be in place for this pond. Monitoring is recommended on a more frequent basis, with the water quality and plankton assessment from this investigation repeated once in late spring and once in late summer each year.

Spectacle Pond

General Pond Features

Spectacle Pond covers 91 acres in south Sandwich (Figure 1), part of the Three Pond District with Lawrence and Triangle Ponds (Figure 15). It has 2.6 miles of shoreline with an average depth of 21.5 feet and a maximum depth of 43 feet (Table 1). It has a volume of 1957 acre-feet and based on estimated precipitation and groundwater inflows it has a detention time of 651 days or 1.8 years. It is a “double kettlehole”, with two basins separated by a shallower sandy zone and an island (Figure 18). Existing bathymetry was confirmed by this investigation. The northern basin is considerably deeper than the southern basin. There are no surface inlets or outlets at this pond. Groundwater flow is mainly from the west (Figure 2). Nearshore areas are mostly sand and gravel, but organic muck sediments dominate in deeper water. The shoreline is largely wooded except where waterfront complexes have been built.

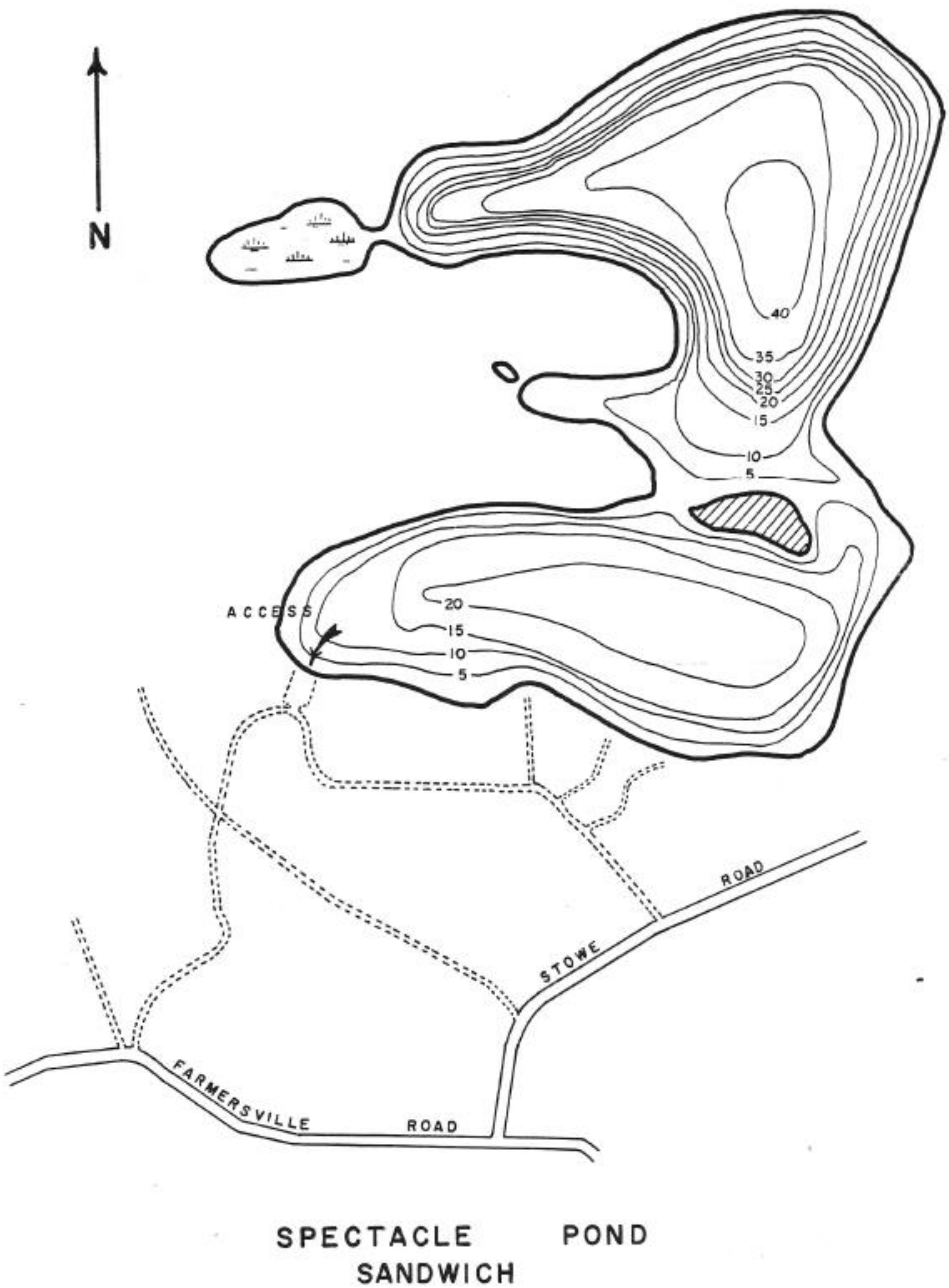
Public access is available at the southwest corner of the lake, including an undeveloped boat ramp, but public recreational facilities are very limited. Spectacle Pond is best known for its support of two YMCA camps, both associated with the South Shore YMCA. Camp Burgess occupies land between Spectacle and Triangle Ponds but has its main waterfront facility on Spectacle Pond. Camp Hayward is on the west side of Spectacle Pond (Figure 15) and has a separate waterfront complex from that of Camp Burgess. The pond gets extensive use from the two YMCA camps, which also hold programs on Pinkham Island between the camps. A third waterfront complex at the north end of the pond serves a homeowners association to the north. Additionally, there are scattered residences with waterfront access on the north and south sides. Slopes are steep to the north and most residents use the homeowners beach complex, but those to the south have fairly level and direct access to the pond.

Spectacle Pond is a Great Pond under Massachusetts law, being >10 acres in its natural area. The pond has been the subject of a Total Maximum Daily Load allocation for mercury contamination of fish tissue by Massachusetts DEP (2017), a regional effort in which Spectacle Pond was included, but is not considered otherwise impaired.

Watershed Features

The watershed of Spectacle Pond has not been delineated, but surface runoff is possible only from the immediate shoreline, much of which is undeveloped. The area to the north, which is densely residential, presents a runoff threat; this Lakewood Hills area has numerous leaching catch basins, installed around 2000 to minimize direct stormwater discharge to the lake. There is one direct entry storm drain at the southeast corner of the pond, draining part of the Burgess YMCA camp. Groundwater flow paths will be more important to pond inputs, and the dominant pathway for groundwater flow is from the mostly undeveloped land to the west. The JBCC is to the west but is outside the mapped contributory area of the pond, so there is no indication of any threat of groundwater contamination to Spectacle Pond from the JBCC (Wright-Pierce 2017).

Figure 18. Bathymetry of Spectacle Pond from pre-1990 MA DFW records.



Pond Water Quality

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth. Water clarity ranged from 10 to 16 feet (3 to 5 m) in three samplings in 2008-2010. There is thermal stratification at about 30 feet (9 m), with oxygen depression observed below that depth. Oxygen depletion occurred only in the last few feet above the bottom in the deepest area, however. The pH was slightly acidic in the north basin and slightly basic in the south basin. Alkalinity is very low and the elevated pH in the south basin is probably related to photosynthesis in this shallower basin, which removes carbon dioxide and raises pH. Phytopigments were low, although algal blooms have been reported for this lake in the past. Phosphorus levels ranged from 5.4 to 16.1 µg/L, while nitrogen ranged from 211 to 561 µg/L, both in the low to moderate range. Conditions were generally acceptable for designated uses of contact recreation and fish and wildlife propagation but did not appear to be overly stable with considerable year to year variation.

This investigation sampled water quality in August of 2018 and found generally acceptable conditions for nearly all parameters (Table 6). Oxygen was low in the deepest water but was not as low as in the historic record. Higher summer water level in 2018 may have slowed the loss of oxygen and variability in historic values has been noted. Alkalinity was also low, a natural feature of most Cape Cod ponds. Otherwise, most assessed features were either desirable or tolerable relative to their impact on designated uses. Values from 2018 tended to be similar to or more desirable than the 2008-2010 PALS data averages, but on the scale of most of those historic measures 2018 may have just been a better than average year.

Pond Biology

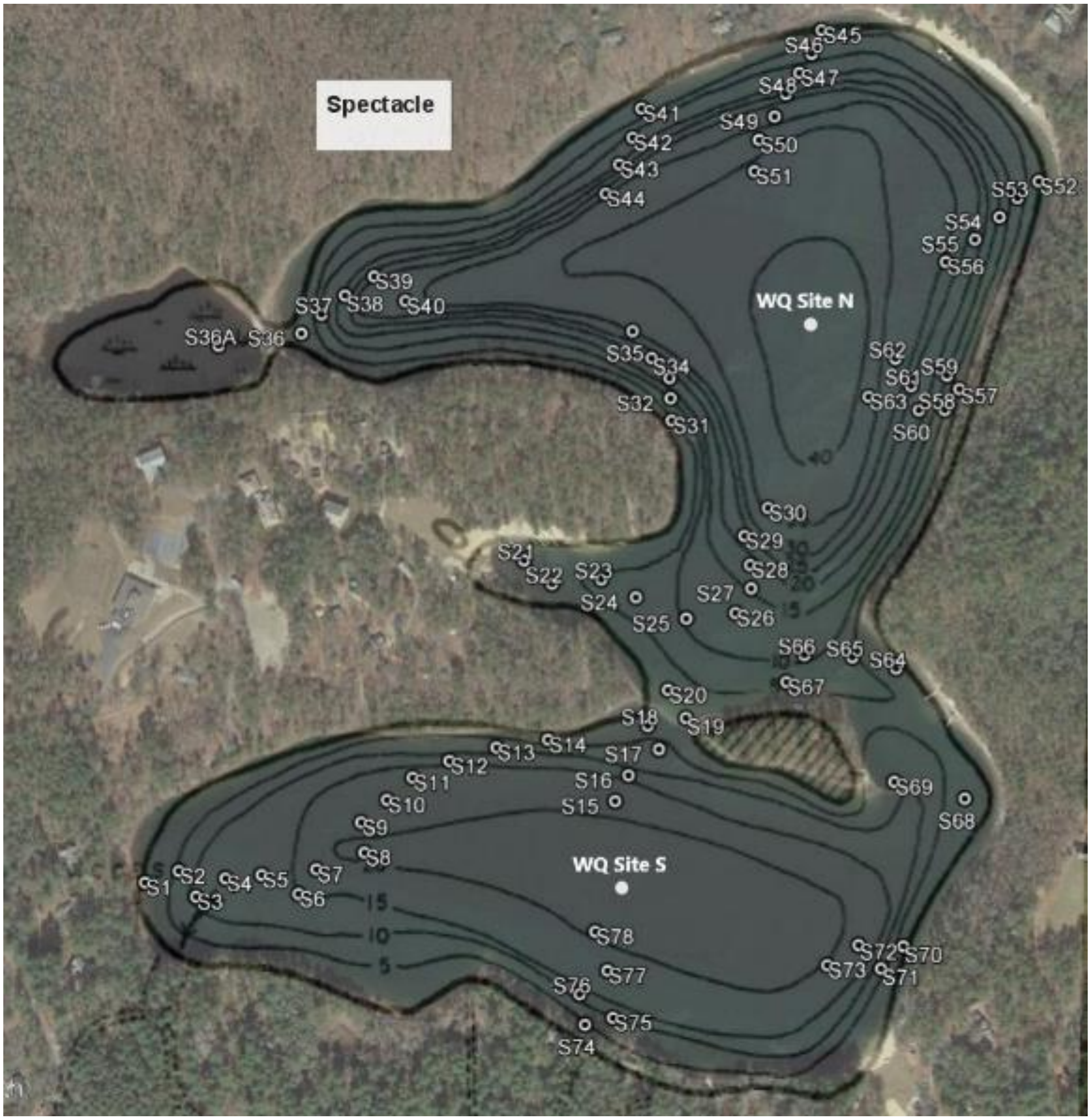
Plankton were sampled at central sites in the north and south basins of Spectacle Pond in August 2018 and a survey of water depth, surficial sediment types, plant cover and biovolume, and relative abundance of plants species was conducted with 77 sites visited (Figure 19). Phytoplankton biomass was low in both basins with an average cyanobacteria component of 2% and most algal divisions represented (Table 6, Appendix). Green algae accounted for the most biomass, but no algal division was abundant. Chlorophyll-a was one of the few assessed parameters that had a less desirable value in 2018 than in 2008-2010, but the value was still quite acceptable and water clarity as measured by Secchi disk was higher in 2018 than in the historic database. Algae blooms have been reported in the past, but no actual data are available; it has been assumed that cyanobacteria blooms may have occurred, but evidence is anecdotal. No algae problems were indicated by the 2018 data.

The survey of rooted plants found 12 species, although this includes benthic mats of green algae (Chlorophyta) and cyanobacteria plus the macroalga *Nitella*. The greatest plant diversity was found in the wetland area that constitutes the northwest corner of the pond and may not have been considered part of the pond in some studies. Plant cover averaged 2.0 on a 0 to 4 scale, indicating 25 to 50% cover of the pond bottom by plants. However, the cover pattern over water depth was unusual. There were few plants in water <5 feet deep, likely a function of coarse substrate and water level fluctuations. Cover increased from 5 to 11 feet of water depth as might be expected, but then was very low at depths of 12 to 17 feet for unexplained reasons. Cover then increased again to a depth of about 21 feet and decreased to a depth

Table 6. Water quality and plankton summary for Spectacle Pond.

Spectacle Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	0.1	1.2
Average pH	SU	6.1	7
Surface Alkalinity	mg/L	3.8	3.0
Average Conductivity	µS	ND	46
Surface Total P	µg/L	10	7
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	8	17
Bottom Dissolved P	µg/L	ND	5
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	45
Bottom Ammonium N	µg/L	ND	155
Surface Total Kjeldahl N	µg/L	ND	220
Bottom Total Kjeldahl N	µg/L	ND	270
Surface Total N	µg/L	317	230
Bottom Total N	µg/L	311	280
Surface N:P Ratio	Unitless	32	33
Bottom N:P Ratio	Unitless	39	16
Average Turbidity	NTU	ND	5
Secchi Transparency	m	4.0	4.7
Average Chlorophyll-a	µg/L	3.4	5.1
Phytoplankton Biomass	µg/L	Blooms noted	330
Cyanobacteria	%	Possible	2
Zooplankton Biomass	µg/L	ND	56.4
Zooplankton Mean Length	mm	ND	0.82
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

Figure 19. Spectacle Pond survey points with bathymetry.



of about 30 feet, presumably a function of low light. However, from 30 to 40 feet there was substantial cover by the macroalga *Nitella*, something often observed in very clear lakes like Lake George in New York or Sebago Lake in Maine, but not typically in Cape Cod ponds.

The most abundant plants in shallow water included spikerush (*Eleocharis acicularis*), pipewort (*Eriocaulon septangulare*) and hedge hyssop (*Gratiola neglecta*), typical of many Cape ponds (Appendix). From 5 to 11 feet the predominant plants were more spikerush and submerged arrowhead (*Sagittaria graminea*) intermingled with green algae (Chlorophyta) mats. The few plants in the 12 to 17 feet depth range were mostly quillwort (*Isoetes* sp.) and *Nitella*. Beyond 17 feet of water depth the primary plant was Nitella, but at varying densities as described above. There was nothing about the substrate that signaled the decrease in plant biomass between 12 and 17 feet, but slopes tended to be steep in that depth range and plant growths on steeper slopes are known to be fewer. Biovolume of plants, the portion of the water column filled, was consistently low with no values higher than 1 recorded on the 0 to 4 scale; the average was 0.8, suggesting much less than 25% of the water column was filled.

No invasive species were encountered in the pond and there was no common reed (*Phragmites australis*) or purple loosestrife (*Lythrum salicaria*) around the pond periphery.

Zooplankton biomass was just slightly higher than the low end of the moderate range at 56.4 µg/L and the mean length for crustacean zooplankton was just above the high end of the desirable range at 0.88 mm. The composition was a mix of copepods and cladocerans, including a very desirable species of large-bodied *Daphnia* that is helpful for controlling algae by grazing and makes excellent food for small fish. As the zooplankton of many ponds are decimated by predation by late summer, the marginally moderate biomass and continued presence of larger bodies species reflects positively on the biological structure of Spectacle Pond.

Mussels, snails and sponges were all observed during the survey at moderate densities. No quantitative survey was performed but this bodes well for the biological structure of this pond. However, alkalinity is low in this pond and suggests low calcium content and probable stress on mollusk with regard to shell formation and maintenance. Yet observed specimens appeared healthy.

Spectacle Pond has been stocked with trout and smallmouth bass in the past and the MA Division of Fisheries and Wildlife lists Spectacle Pond as receiving trout in both spring and fall each year. The thermal regime and oxygen distribution suggest that holdover trout will be supported. No recent fish surveys have been conducted but the typical suite of warmwater fish might be expected, including largemouth and smallmouth bass, sunfish, perch, brown bullhead, golden shiner and banded killifish (Desmarais 2007). The lake appears popular for fishing but management other than trout stocking appears very limited.

Spectacle Pond is on the Massachusetts 2016 Integrated Waters List as having a completed Total Maximum Daily Load (TMDL) for mercury in fish tissue. This TMDL is the result of a study of almost 100 Massachusetts ponds by the New England states plus New York and finalized in 2007. The TMDL document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, USA states outside of the region, and global sources. The majority of mercury pollution in the northeastern USA is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond, Spectacle Pond and Snake Pond were included in the project. This would affect the quality of fish living in the pond their entire lives, not trout caught within a year or so of stocking.

According to NHESP maps (Figure 17), Priority Habitat 435 for one or more listed (protected) species in Massachusetts abuts the wooded western shore of Spectacle Pond. WRS does not know what species may be present, although PH435 covers only terrestrial area. If any management actions involving disturbance of the western shore are proposed, the NHESP would have to approve prior to any issuance of a permit under the Wetlands Protection Act as administered by the Sandwich Conservation Commission.

Management Needs and Recommendations

Variability in water quality, reports of past algae blooms, the TMDL for mercury contamination of fish tissue and more recent reports of illness among YMCA campers have raised questions about the condition of Spectacle Pond but the 2018 investigation revealed very little of concern. Oxygen is not high in the deepest waters but is not depleted either and trout can be supported at mid-depths where the temperature is cold enough, but adequate oxygen can be found. No algae blooms were observed, and nutrient levels were low. The plant community has a somewhat odd distribution over depth, but no nuisances were observed, and some very favorable and varied habitat can be found over the area of the pond. No remediation of any condition observed in 2018 appears necessary.

The densely developed area to the north and northwest of the pond appeared to represent a possible threat to pond quality in past reviews, but this area appears to be outside the groundwater contribution zone and stormwater is directed to leaching catch basins in this area. Education of residents about their role in maintaining water quality would certainly be desirable but no structural controls appear necessary. The one direct entry storm drain from Camp Burgess warrants investigation and possible conversion to a leaching system but supporting data are lacking at this time.

The YMCA camps make great recreational use of Spectacle Pond, but no impacts are evident. The shoreline is largely vegetated, erosion is not excessive, and water quality remains acceptable for contact recreation. This investigation did not assess bacterial issues and with so many people in the swim areas of the two camps it could be a health issue. Periodic testing in accordance with state law is expected and no reports of related problems were encountered in this investigation.

Monitoring is recommended on a more frequent basis, with the water quality and plankton assessment from this investigation repeated once in late spring and once in late summer each year. With the suspected variation in water quality and some past complaints about conditions, more data would help establish that variability and any trends that might exist.

Triangle Pond

General Pond Features

Triangle Pond covers 84 acres in south Sandwich (Figure 1) and is part of the Three Pond District with Lawrence and Spectacle Ponds (Figure 15). It has 2 miles of shoreline with an average depth of 13.9 feet and a maximum depth of 32 feet (Table 1). It holds approximately 1168 acre-feet of water at full level. There was no available bathymetric map for this pond so one was created from the 75-point survey conducted as part of this investigation (Figure 20). The pond has three defined basins, two shallow ones with maximum depth of about 15 feet and one deeper one that reaches 32 feet. Nearshore areas are mostly sand and gravel, grading to organic muck sediment in deeper water. There are no surface inlets or outlets at this pond and the prevailing direction of groundwater flow is from the west (Figure 2). Based on known average precipitation and estimated groundwater inputs the detention time for water in Triangle Pond is about 475 days or 1.3 years.

South Shore YMCA Camp Burgess occupies the land to the north of Triangle Pond but does not make much use of the pond. Groups occasionally swim there and there is a long narrow sandy margin that functions as a beach but there is no boat launching facility for even for canoes or kayaks. Camp Burgess maintains a developed waterfront on Spectacle Pond to the north. Private property borders much of the east and west sides of the pond with homes on larger lots and set well back from the pond in most cases. Most of the southern side of the pond, off Farmersville Road, was given to the MA Division of Fisheries and Wildlife some years ago and remains wooded.

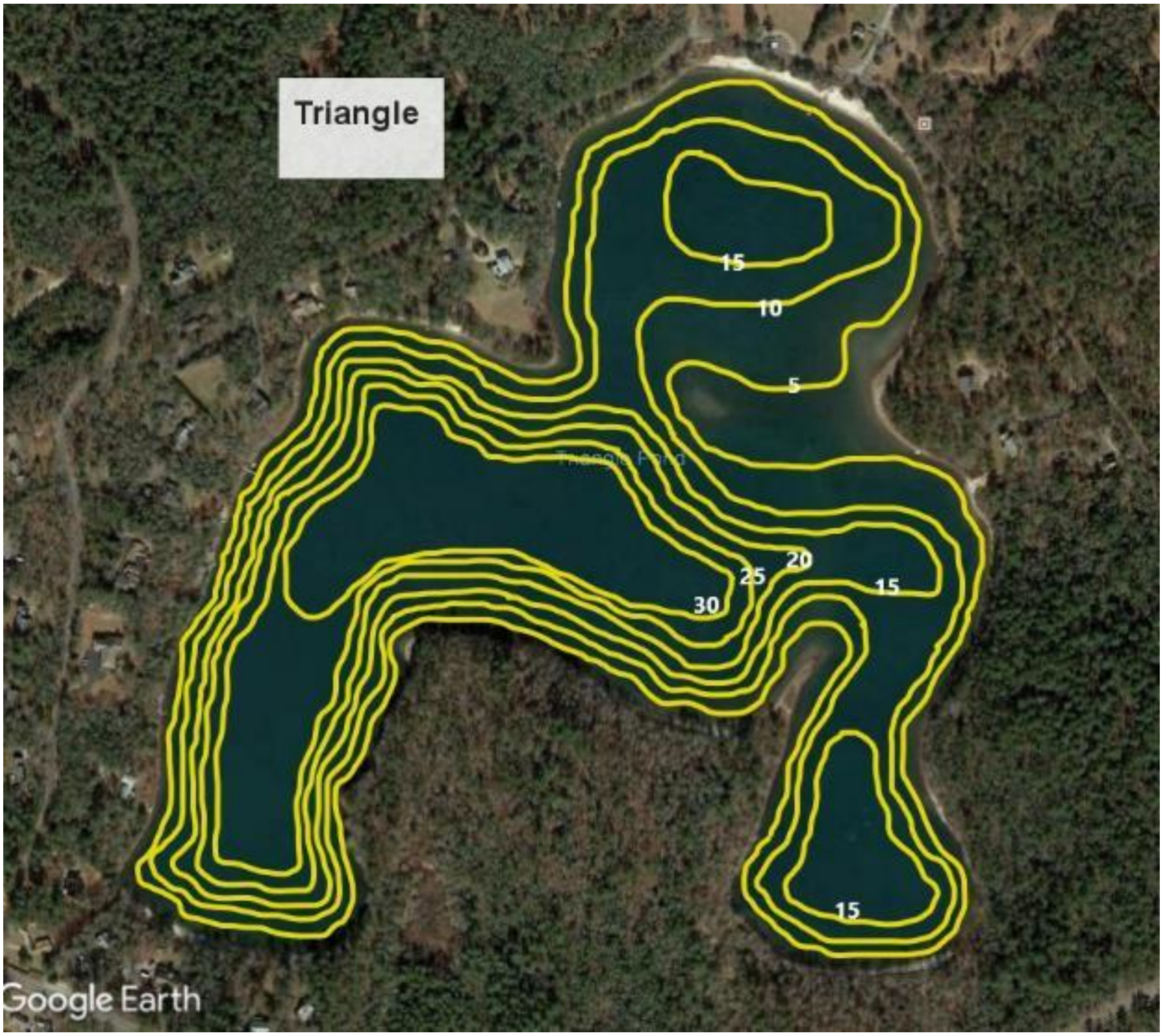
Public access to Triangle Pond is extremely limited. Access is theoretically available from a little-known state-owned parcel on the southeast side of the pond but the entrance from Farmersville Road is gated and locked and downed trees and poison ivy make passage from the road to the pond difficult. It may be possible to launch a canoe or kayak from this location, but no trailered boat can gain access at this point under current conditions and parking off Farmersville Road is very limited.

Triangle Pond is an underused pond in terms of human recreation. Homeowners around the pond have mostly unpowered watercraft with only one motorboat observed. There are no public facilities and access via the state property is challenging. The pond does provide a quiet oasis and excellent fish and wildlife habitat. It is a Great Pond under Massachusetts law and is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

The watershed of Triangle Pond has not been carefully delineated but only land in close proximity presents any threat of overland flow and development is light around this pond (Figures 15 and 20). Much of the nearby land is wooded or in seasonal use. There are leaching catch basins along Farmersville Road but no direct discharges to Triangle Pond. The prevailing direction of groundwater flow is from the west with some residential and wooded areas. The military reservation (JBCC) is also to the west but is mapped as outside the area of contribution to the pond. The CWRMP does not indicate any groundwater contaminant plumes in the area upgradient of Triangle Pond (Wright-Pierce 2017).

Figure 20. Triangle Pond bathymetry.



Pond Water Quality

Water quality data and some biological observations are available through the PALS program, supported by the School for Marine Science and Technology at UMASS Dartmouth. Water clarity ranged from 11 to 13 feet (3.4 to 3.9 m) in three samplings in 2008-2010. The pond appears to be just deep enough to undergo thermal stratification, with just a small deep-water layer below 27 feet (8 m); oxygen depression was observed below that depth, with oxygen depletion only right at the sediment-water interface in the deepest area. The pH is acidic and alkalinity is very low, as are phytopigments, although algal blooms have been reported for this lake with increasing frequency over the first decade of the new millennium. Phosphorus levels ranged from 5 to 31 µg/L in surface water, excluding one apparently erroneous high value, and reached 467 µg/L at the sediment-water interface in one sampling (2009). In other years the deep-water phosphorus concentration was much lower. Nitrogen ranged from <200 to almost 4000 µg/L. Overall variation in water quality appears high from the historic database.

The PALS database is a striking contrast to what WRS found in August 2018 (Table 7). Alkalinity remains low, a natural feature of most Cape Cod ponds, but virtually all other features exhibited more desirable values in 2018 vs the historic database. Bottom oxygen was 2.6 mg/L in August 2018; while this matches the historic average, some older values approached 0 mg/L. Phosphorus and nitrogen levels were low overall and lower than in past surveys. The N:P ratio was higher, not favoring cyanobacteria, chlorophyll-a and turbidity were lower, and water clarity as measured by Secchi disk transparency was much higher in 2018 (>21 feet vs <12 feet). There was a note in the 2010 PALS database that clarity in 2010 was higher than in recent years and that swimming was very nice; water level was high 2018 and 2010. However, as the WRS survey represents only one month (albeit the most critical one for use support) in one year and the historic database suggests high variability, the 2018 data may not be representative of conditions in all years.

Pond Biology

Phytoplankton were sampled in early and late August at the deepest point in the pond. The early August sample was from near the surface, while the late August sample was from a depth of 21.5 feet because an increase in oxygen was detected between 20 and 23 feet of water depth (Appendix). This often signals an accumulation of algae near the boundary between upper and lower water layers during stratification and the most common algae to accumulate are cyanobacteria and golden algae, with the former as a greater concern. Phytoplankton biomass was low in both samples (Table 7) and the dominant algae at the deeper station was a small green alga, not a threat to water quality or pond use. The most abundant alga near the surface was a small filamentous green alga, also not a problem for lake use. Cyanobacteria comprised 6% of the algae biomass but included innocuous species not known to form blooms or cause odor or toxicity. No phytoplankton issues are suggested by the 2018 data.

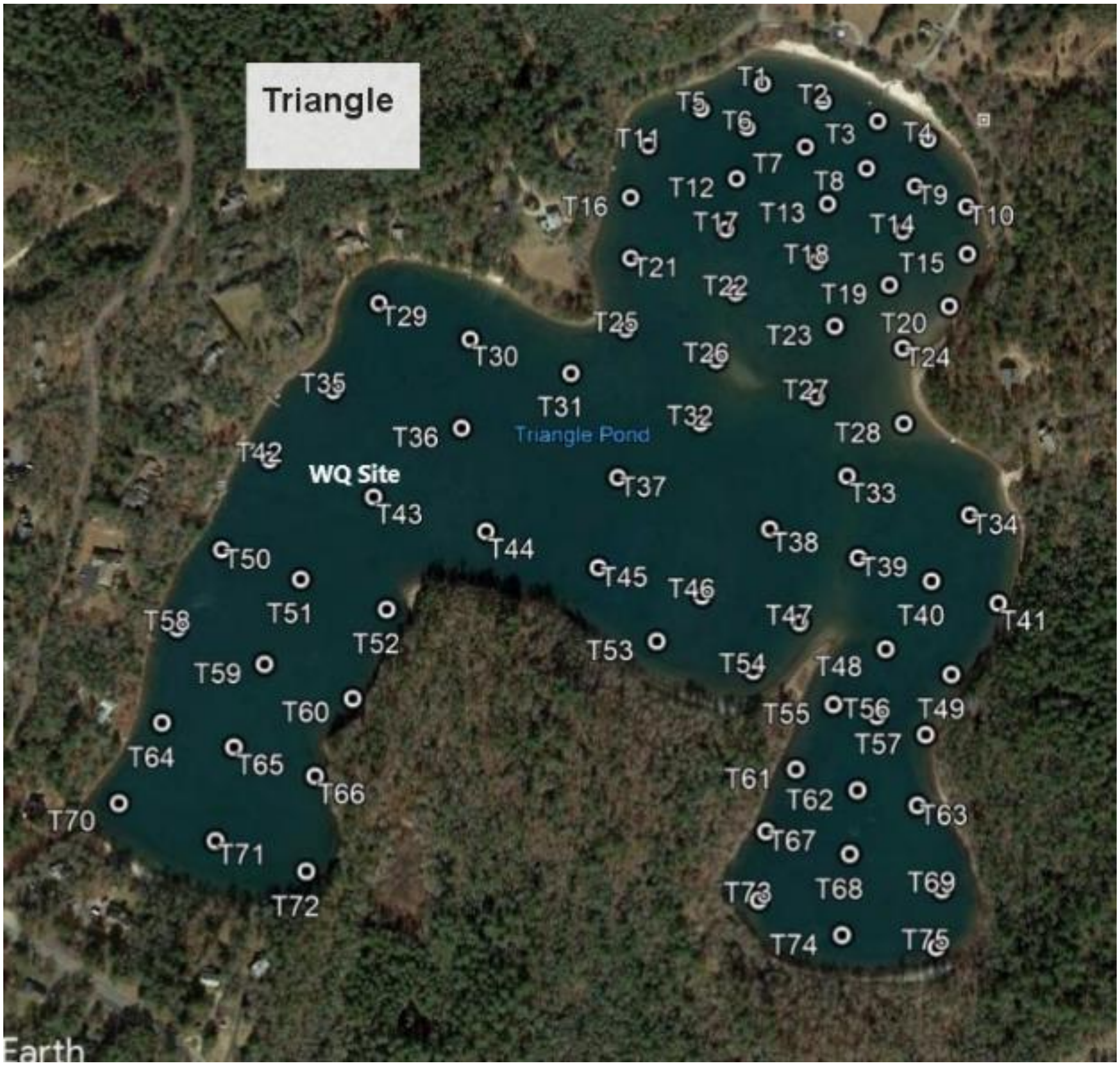
Rooted plants are reported as sparse in historic surveys, but no detailed survey had been conducted. In August 2018 WRS conducted a survey of water depth, surficial sediment type, plant cover and biovolume, and relative plant species abundance at 75 points (Figure 21). This facilitated construction of the bathymetric map in Figure 20 and allowed characterization of the plant community.

Only 6 species of rooted plants were identified, plus benthic green algae (Chlorophyta) and cyanobacteria mats (Appendix). The cover rating was 2.2 on a 0 to 4 scale, suggesting that between 25 and 50% of the pond bottom was covered by plants. The biovolume rating was 0.8 on the 0 to 4 scale, suggesting that <25% of the water column was filled with plants. By far the most abundant plant was common naiad (*Najas flexilis*), which was found at 61% of surveyed sites over a range of water depth from 3 to 20 feet and was dense at almost half the sites where it was found. All other rooted plant species were shallow water residents, including spikerush (*Eleocharis acicularis*), pipewort (*Eriocaulon septangulare*), hedge hyssop (*Gratiola neglecta*), quillwort (*Isoetes* sp.) and submerged arrowhead (*Sagittaria graminea*). Green algae mats occurred over the range observed for common naiad. There were no plants between about 20

Table 7. Water quality and plankton summary for Triangle Pond.

Triangle Pond			
Feature	**Units**	**Pre-2012 Value/Rating**	**Aug 2018 Value/Rating**
Bottom Dissolved Oxygen	mg/L	2.6	2.6
Average pH	SU	6.3	6.8
Surface Alkalinity	mg/L	3.5	6.0
Average Conductivity	µS	ND	65
Surface Total P	µg/L	14	7
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	176	14
Bottom Dissolved P	µg/L	ND	5
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	20
Bottom Ammonium N	µg/L	ND	20
Surface Total Kjeldahl N	µg/L	ND	330
Bottom Total Kjeldahl N	µg/L	ND	330
Surface Total N	µg/L	258	340
Bottom Total N	µg/L	1524	340
Surface N:P Ratio	Unitless	18	49
Bottom N:P Ratio	Unitless	9	24
Average Turbidity	NTU	ND	0.4
Secchi Transparency	m	3.6	6.5
Average Chlorophyll-a	µg/L	5.5	3.5
Phytoplankton Biomass	µg/L	Blooms noted	194
Cyanobacteria	%	Possible	6
Zooplankton Biomass	µg/L	ND	58
Zooplankton Mean Length	mm	ND	0.69
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

Figure 21. Triangle Pond survey points.



and 30 feet of water depth but cyanobacteria mats were found in >30 feet of water. Those mats had adequate light and undoubtedly the substrate provides sufficient nutrients.

No invasive plant species were detected and no peripheral growths of common reed (*Phragmites australis*) or purple loosestrife (*Lythrum salicaria*) were observed at Triangle Pond.

Zooplankton were sampled on one data in August 2018 at the deepest point of the pond. Biomass was slightly above the moderate threshold at 58 µg/L and the mean length of crustacean zooplankton was solidly in the desirable range at 0.69 mm. No rotifers were found, and the assemblage was a mix of copepods and cladocerans. Desirable *Daphnia* were absent but several other zooplankton species known to represent good food for small fish were found. Grazing capacity will be limited but algae were not a problem in Triangle Pond in 2018.

Mussels, snails and sponges were all observed in Triangle Pond. No quantitative survey was conducted, but the invertebrate biological structure of this pond appears favorable for fish and wildlife support. Alkalinity is low, suggesting low calcium and potential difficulty for mollusks for shell formation and maintenance, yet observed specimens appeared healthy.

A warmwater fishery is present, with smallmouth bass added historically, but no indication of any trout fishery. No survey records were encountered, and it does not appear that there has been active management of the Triangle Pond fishery in many years. Few fish were observed during the underwater survey for plants in August 2018 and relatively few fish were observed in shallow water. Great blue herons were observed hunting in the shallows and a few ducks were present, but the pond was generally very quiet during our visits.

All of Triangle Pond and its immediate shoreline is mapped by NHESP as Priority Habitat 349 (Figure 17). WRS does not know what species may be present but any listed species covered by this map is likely aquatic. Any active management of Triangle Pond will require approval by the NHESP prior to issuance of a permit under the Wetlands Protection Act administered by the Sandwich Conservation Commission.

Management Needs and Recommendations

Triangle Pond is used mainly for swimming, boating and fishing by people but serves as potentially valuable fish and wildlife habitat. It appears to support those uses and has not been placed on the state list of waters not attaining use designations, but concern over the decade prior to 2011 for increasing algae suggests that there is a threat to uses. Nutrient levels in some years are high enough to be a concern in that regard but the 2018 data indicate no significant problems.

There does not appear to be any localized watershed management need, but an evaluation of incoming groundwater quality would be worthwhile to assess that source. It is most likely that any phosphorus problem stems from internal loading from sediment phosphorus reserves accumulated over many years; inactivation of that phosphorus is a practical approach but does not appear necessary at this time.

It is likely that water level plays a key role in the condition of Triangle Pond, as high water results in a thicker bottom water layer during stratification and more oxygen to be consumed before low concentrations occur and allow both release and upward movement of phosphorus into a zone with enough light to support algae growth. Both 2010 and 2018 have been reported as clear water years and had high water levels. Low water level would translate into a thinner lower layer that would lose oxygen more rapidly and start generating an internal phosphorus load. The vertical distance to the zone with enough light to support algae growth would be shorter, leading to possible blooms. Water level cannot be practically managed in Triangle Pond but if blooms become problematic it would be possible to inactivate surficial sediment phosphorus to prevent its release and thereby thwart bloom formation.

Given limited and somewhat contradictory data for Triangle Pond, the most important management recommendation is continued monitoring at a greater frequency. At a minimum, Triangle Pond should be assessed for water quality and plankton as performed in this investigation at least once in late spring and once in late summer of each year. Sediment sampling to evaluate potential phosphorus release would also be worthwhile.

Upper Hog Pond

General Pond Features

Upper Hog Pond covers about 11.3 acres in south Sandwich (Figures 1 and 22) with about 0.6 miles of shoreline, an average depth of 13.7 feet and a maximum depth of just over 30 feet (Table 1). No bathymetric map was available prior to this study and one was created from 54 depth measurements made in August 2018 (Figure 23). The volume is approximately 155 acre-feet. Sediments tend to be sandy to gravelly in water less than about 9 feet deep and grade to organic muck sediment in water greater than 20 feet.

There are no surface inlets or outlets at this pond and the prevailing direction of groundwater flow is from the northwest (Figure 2), although land slopes around the pond are steep enough to suggest localized groundwater inflow from all directions. Based on average precipitation and estimated groundwater inflow, the detention time averages 273 days (0.75 years). Upper Hog Pond is in the northern portion of an area identified in the CWRMP (Wright-Pierce 2017) as a groundwater threat zone.

The shoreline is mostly wooded and privately held, so there is no public access. However, the area of the pond qualifies it as a Great Pond under a Commonwealth of Massachusetts statute, making the pond itself a public resource. Shoreline residents swim, boat and fish in Upper Hog Pond, but use is relatively lightly and the pond offers a very peaceful setting and substantial wildlife habitat. Upper Hog Pond is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

Upper Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, most seasonal, many derived from old hunting camps. An old, historic home was apparently relocated to the south end of this pond and represents the largest and most well-kept property in the area, with a sweeping lawn area between the house and pond. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via groundwater flow.

There are two golf courses to the east (Ridge Club) and south (Holly Ridge) but it is generally believed that groundwater in that area flows away from the Hog Ponds. The presence of the Ridge Club Golf Course just east of Upper Hog Pond is called out in a diagram of groundwater impact threats in the CWRMP (Wright-Pierce 2017) and a fairway for the Ridge Club runs along the eastern shore of Upper Hog Pond with just a small and sloping buffer strip that is densely forested. Past concern over possible inputs have reportedly led to improvements in fertilization practices, irrigation and drainage that should minimize impacts on the pond.

Pond Water Quality

Little was known of the water quality of Upper Hog Pond prior to this investigation. There are no reports of problems, the water appeared clear, and it is known as a local bird sanctuary, but water quality and related pond features had apparently not been assessed and reported in any organized fashion. This investigation sampled water at one central location and examined pond features at 54 locations (Figure 24).

Figure 22. General vicinity of the Hog Ponds

Figure 23. Upper Hog Pond bathymetry

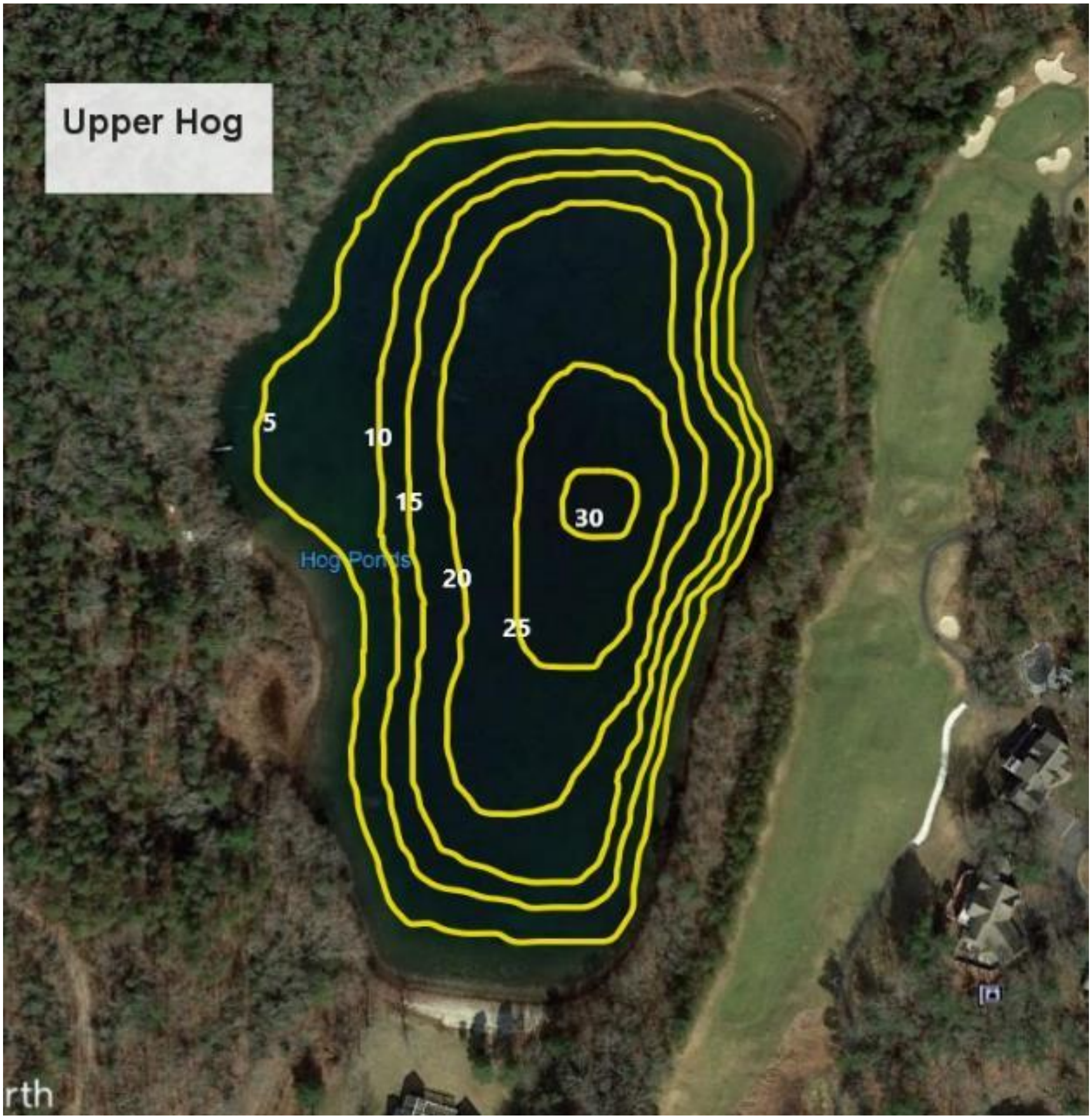


Figure 24. Upper Hog Pond survey points.

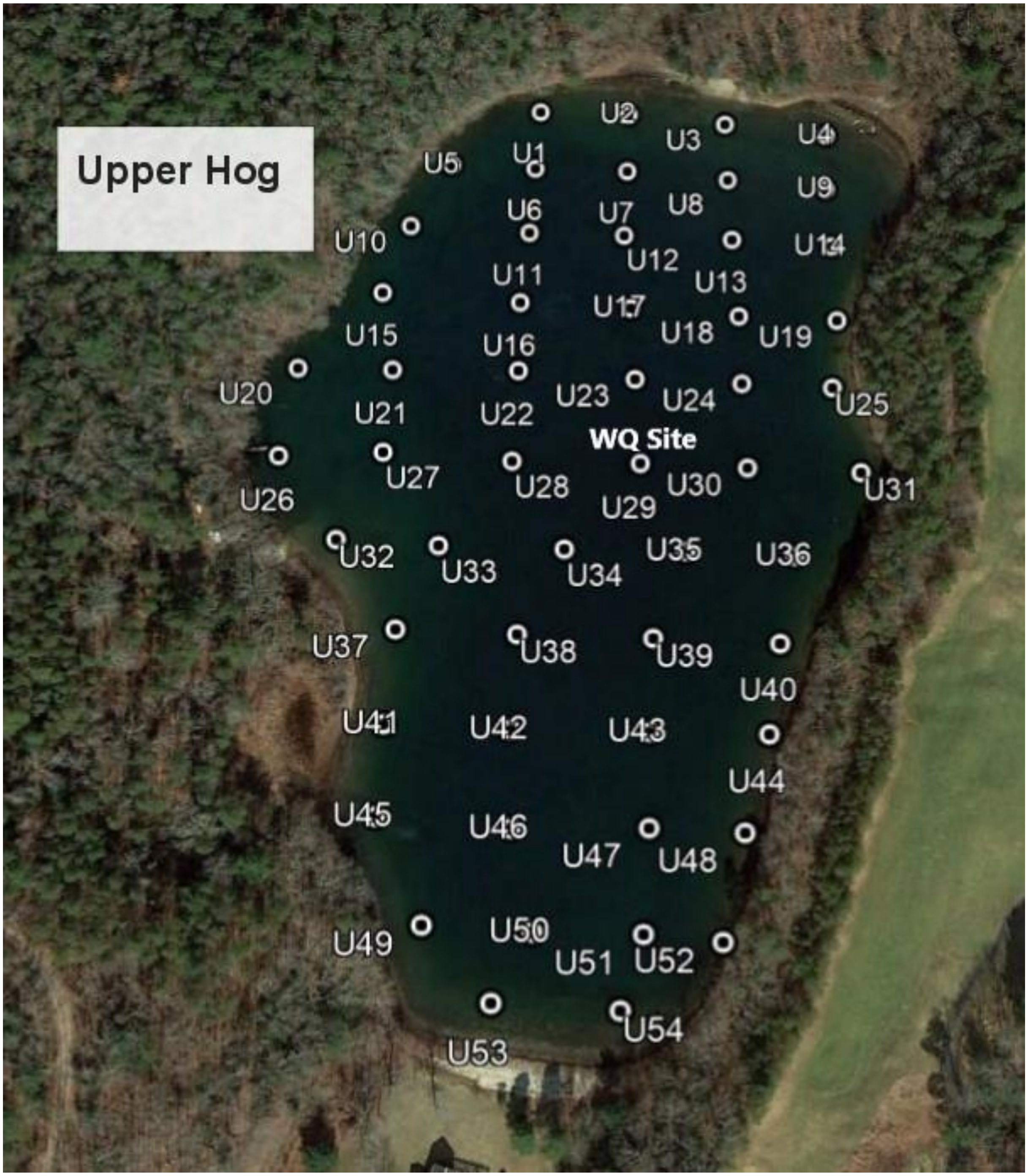


Table 8. Water quality and plankton summary for Upper Hog Pond.

Upper Hog			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	ND	2.1
Average pH	SU	ND	6.4
Surface Alkalinity	mg/L	ND	4.0
Average Conductivity	µS	ND	70
Surface Total P	µg/L	ND	11
Surface Dissolved P	µg/L	ND	7
Bottom Total P	µg/L	ND	12
Bottom Dissolved P	µg/L	ND	7
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	70
Bottom Ammonium N	µg/L	ND	20
Surface Total Kjeldahl N	µg/L	ND	330
Bottom Total Kjeldahl N	µg/L	ND	350
Surface Total N	µg/L	ND	340
Bottom Total N	µg/L	ND	360
Surface N:P Ratio	Unitless	ND	31
Bottom N:P Ratio	Unitless	ND	30
Average Turbidity	NTU	ND	0.3
Secchi Transparency	m	ND	6.5
Average Chlorophyll-a	µg/L	ND	1.5
Phytoplankton Biomass	µg/L	ND	455
Cyanobacteria	%	ND	10
Zooplankton Biomass	µg/L	ND	317
Zooplankton Mean Length	mm	ND	0.91
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

Based on a single sampling in August 2018 (Table 8), alkalinity in Upper Hog Pond is low, a natural feature of most Cape Cod ponds. Bottom oxygen was 2.1 mg/L in August 2018, low enough to stress fish at the bottom, but not extreme and only found over a small portion of the pond. Phosphorus concentrations were at the low end of the moderate range and nitrogen levels were low. The N:P ratio was at the boundary between high and moderate, not favoring cyanobacteria. Chlorophyll-a and turbidity were quite low and water clarity as measured by Secchi disk transparency was high in 2018 (21.5 feet or 6.5 m). As the WRS survey represents only one month (albeit the most critical one for use support) in one year, the 2018 data may not be representative of all conditions in all years, but overall water quality in Upper Hog Pond appears quite acceptable for all known pond uses.

Pond Biology

There are no known reports of algal blooms or related problems in Upper Hog Pond. During the August 2018 survey period the phytoplankton biomass was low and consisted mainly of the golden alga (Chrysophyta) *Dinobryon*. The cyanobacteria were represented mainly by *Merismopedia*, an innocuous form not known to produce taste, odor or toxins and rarely reaching significant cell densities or biomass. Chlorophyll-a concentrations were low and water clarity was high.

The plant community was assessed at each of the 54 sites in Figure 23 and revealed 9 species of rooted plants plus benthic green algae (Chlorophyta) and cyanobacteria mats and the macroalga *Nitella* (Appendix). The cover rating was 2.7 on a 0 to 4 scale, suggesting that between 25 and 50% of the pond bottom was covered by plants, closer to 50% than 25%. The biovolume rating was 0.9 on the 0 to 4 scale, suggesting that <25% of the water column was filled with plants. The most frequent vegetation was macroscopic filamentous green algae, observed at 72% of sites, followed by the macroalga *Nitella* (46%), quillwort (*Isoetes* sp., 31%) and snailseed pondweed (*Potamogeton spirillus*, 30%). However, Nitella achieved dense growths more than any other plant, followed by snailseed pondweed. The 7 other rooted plant species were shallow water forms rarely encountered in water >10 feet deep (Appendix).

Growths were scattered and rarely dense in water <10 feet deep, where the substrate was usually sand with some gravel mixed in. As muck accumulations increased so did plant density, but growths were close to the bottom and rarely extended very far upward in to the water column (resulting in low biovolume ratings). Plants were observed to depths of just under 28 feet, leaving the deepest zone devoid of plant growths and likely reflecting light and substrate limitations.

No invasive species were encountered, either below the surface or around the periphery of the pond, including a lack of common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*). No state listed (protected) species were observed, but the area adjacent to the pond is believed to support multiple protected plant species and the NHESP has mapped all of Upper Hog Pond and the immediately adjacent shoreline area as Priority Habitat (Figure 17). WRS does not know what protected species may be present, but any management activity in Upper Hog Pond will require approval by NHESP under the Massachusetts Endangered Species Act which is handled through the permitting process under the Wetlands Protection Act, administered by the Sandwich Conservation Commission.

Zooplankton were sampled at the water quality testing station and provided 317 µg/L of biomass (Table 8), a very high value, especially in late summer when predation by small fish is often high. Mean crustacean zooplankton length was 0.91 mm, also a high value and indicative of lower predation levels by small fish, consistent with the biomass level. There were very few rotifers, but a mix of copepods and cladocerans was found, including large bodied *Daphnia* that represent substantial grazing capacity for algae and a high quality food source for small fish.

No mussels or snails were observed over the 54 survey sites in Upper Hog Pond. Freshwater sponges were observed. Lack of mollusks may indicate that calcium content is too low to support shell development. Sponges tend to be more abundant in low pH water. There were a striking number of water striders on the pond surface and many dragonflies and damselflies observed in the air over the pond.

No fish surveys are known for Upper Hog Pond and there is no active management of fish. With the entire shoreline in private holdings, the DFW has not been involved in many years if ever and Upper Hog Pond is not stocked with trout. A warmwater fishery is expected, with bass, pickerel, sunfish, perch, bullheads, killifish and possibly other species. From the zooplankton biomass and size distribution it appears that predatory fish like bass are dominant and depress the panfish population.

Management Needs and Recommendations

No management needs are apparent at this time. Water quality and related features of Upper Hog Pond in August 2018 appeared acceptable for all intended uses and there are no reports indicating problems in the past. The pond lies within an area mapped as susceptible to groundwater threats, but no impacts have been identified. Lack of access limits use of this public pond but there is no strong impetus for the Town to create that access. One resident did approach the WRS team while the survey was in progress to ask if the survey was for the purpose of fostering greater access, so there is at least some local concern about expanded use of the pond.

Protection of Upper Hog Pond is warranted and is available mainly through the Wetlands Protection Act. This is a somewhat unusual situation, where the pond is a publicly owned resource, but the entire shoreline is held by private parties. The WPA governs activities on land near the shoreline and within the pond and can be used to prevent activities that might negatively impact the pond, even on private property. Additionally, any activity which could disturb the pond or nearshore land area is subject to review by the NHESP as this area is mapped as Priority Habitat for one or more protected species. However, WRS is not aware of any proposals to develop shoreline or undertake any activity that might impact the pond.

The primary need at this time is ongoing monitoring, as the August 2018 survey represents the only known data for Upper Hog Pond. At a minimum, Upper Hog Pond should be assessed for water quality and plankton as performed in this investigation at least once in late spring and once in late summer of each year. Sediment sampling to evaluate potential phosphorus release if bottom oxygen declines further would also be worthwhile. It may be worthwhile to assess current inputs from the Ridge Club but there was no clear indication of any significant inputs during this study.

Lower Hog Pond

Pond Features

Lower Hog Pond covers about 7.8 acres in south Sandwich (Figures 1 and 22), with about 0.5 miles of shoreline, an average depth of 12.9 feet and a maximum depth of about 24.3 feet (Table 1). As with nearby Upper Hog Pond, relatively little was known about this pond prior to this investigation. No bathymetric map was available, so one was created from depth measurements at 40 points in August 2018 (Figure 25). Pond volume is calculated at 101 acre-feet. Sediments tend to be sandy to gravelly in water less than about 9 feet deep and grade to organic muck sediment in water greater than 20 feet.

There are no surface inlets or outlets at this pond and the prevailing direction of groundwater flow is from the northwest (Figure 2), although land slopes around the pond are steep enough to suggest localized groundwater inflow from all directions. Based on average precipitation and estimated groundwater inflow, the detention time averages 211 days (0.58 years). Lower Hog Pond is in the northern portion of an area identified in the CWRMP (Wright-Pierce 2017) as a groundwater threat zone. This appears to relate to possible golf course inputs but there was no clear indication of any significant inputs during this study.

The shoreline is mostly wooded and privately held, so there is no public access. The area of the pond is too small (<10 acres) to qualify it as a Great Pond under a Commonwealth of Massachusetts statute and the ownership status of the pond bottom is unknown. Shoreline residents swim, boat and fish in Lower Hog Pond, but use is relatively light, and the pond offers a very peaceful setting and substantial wildlife habitat. Lower Hog Pond is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

Lower Hog Pond sits in a sandy bowl, a small but classic kettlehole formation. There are just a few residences around the pond, seemingly all seasonal, many derived from old hunting camps. The immediate watershed is largely forested, but there are more densely residential areas to the west that may influence the pond via groundwater flow. There are two golf courses to the east (Ridge Club) and south (Holly Ridge).

The clubhouse for Holly Ridge has a view of the pond, but the Ridge Club has the closest fairway to the pond. While groundwater from the closest areas may reach Lower Hog Pond, it is generally believed that most groundwater to the east and south flows away from the pond. A small buffer strip was maintained when the courses were built to minimize the chance of surface water impact. Holly Ridge used to have a pumphouse that pulled water from Lower Hog Pond and maintained a beach on the southwest shore of the pond but both uses have been discontinued and the former beach area is overgrown with small trees.

Pond Water Quality

Little was known of the condition of Lower Hog Pond prior to this investigation. There are no reports of problems, the water appears clear, and it is known as a local bird sanctuary. Water quality sampling at the deepest point in the pond (Figure 26) revealed high oxygen near the bottom at the deepest point (Table 9). Oxygen actually increased in deeper water, suggesting that photosynthesis by plants in the area was raising oxygen beyond what respiration and sediment oxygen demand were removing. However, when

Figure 25. Lower Hog Pond bathymetry

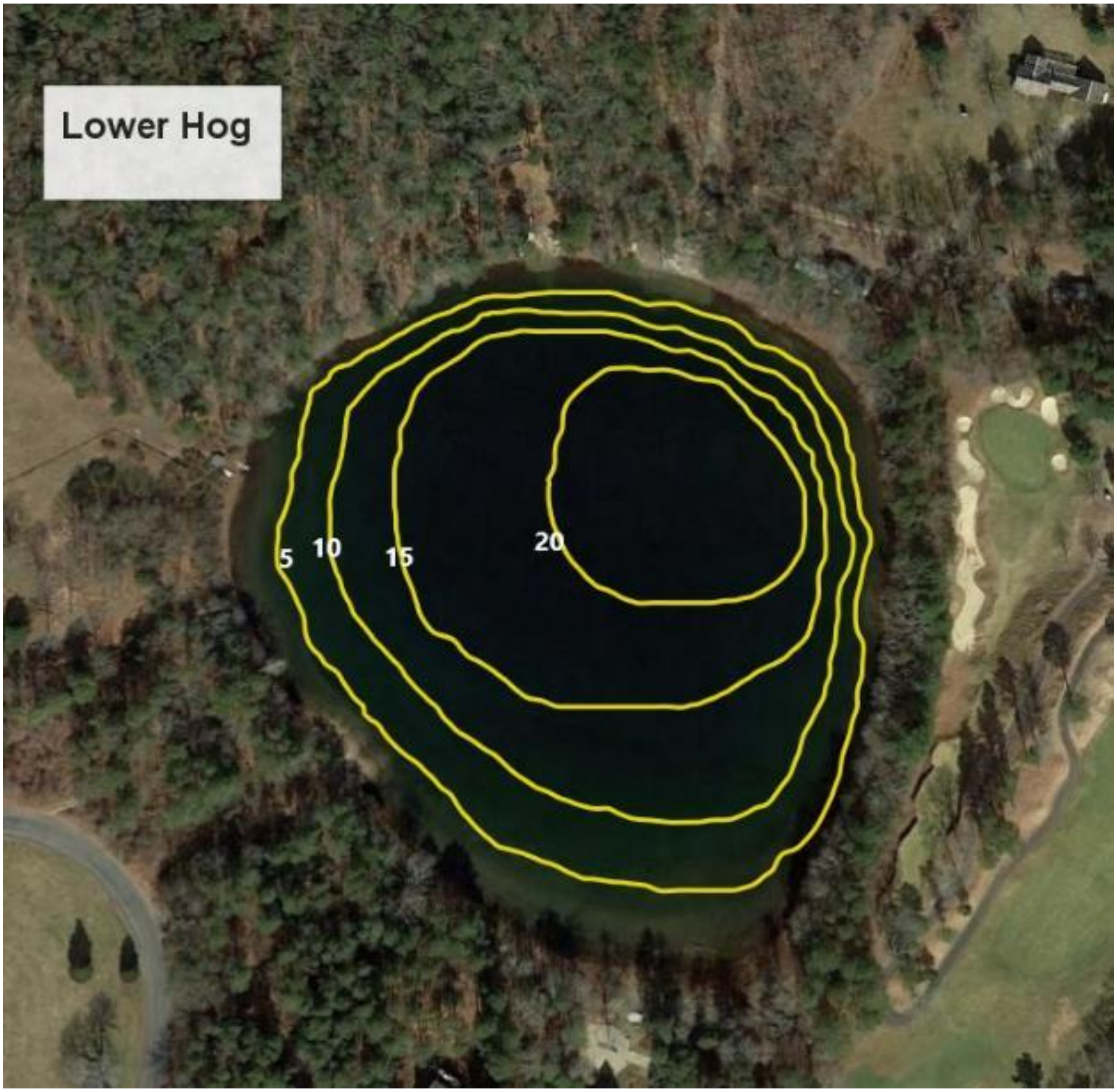


Figure 26. Lower Hog Pond survey points.

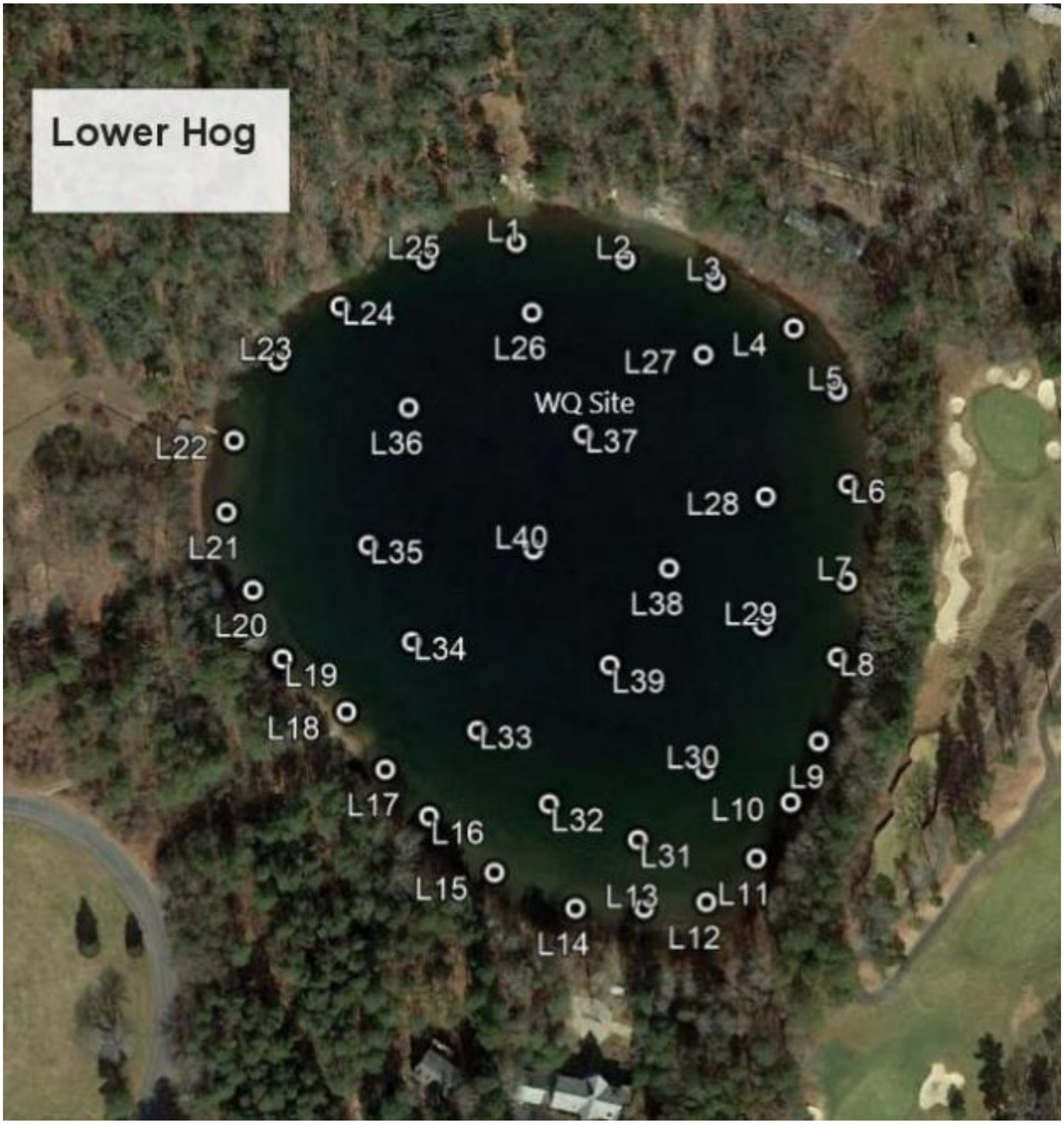


Table 9. Water quality and plankton summary for Lower Hog Pond.

Lower Hog			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	ND	9.5
Average pH	SU	ND	6.8
Surface Alkalinity	mg/L	ND	4.0
Average Conductivity	µS	ND	50
Surface Total P	µg/L	ND	20
Surface Dissolved P	µg/L	ND	7
Bottom Total P	µg/L	ND	49
Bottom Dissolved P	µg/L	ND	6
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	40
Bottom Ammonium N	µg/L	ND	20
Surface Total Kjeldahl N	µg/L	ND	220
Bottom Total Kjeldahl N	µg/L	ND	390
Surface Total N	µg/L	ND	230
Bottom Total N	µg/L	ND	300
Surface N:P Ratio	Unitless	ND	12
Bottom N:P Ratio	Unitless	ND	6
Average Turbidity	NTU	ND	0.7
Secchi Transparency	m	ND	5.5
Average Chlorophyll-a	µg/L	ND	3.5
Phytoplankton Biomass	µg/L	ND	157
Cyanobacteria	%	ND	41
Zooplankton Biomass	µg/L	ND	226
Zooplankton Mean Length	mm	ND	1.03
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

oxygen is at or above the saturation level by day it often declines substantially at night when oxygen production from photosynthesis ceases and respiration continues. This warrants further investigation, as this process could account for observed elevated phosphorus concentrations.

Alkalinity was very low, typical of most Cape Cod ponds and a natural phenomenon related to area geology. Yet the pH was only slightly acidic and quite acceptable for known pond uses. Concentrations of forms of nitrogen were low near the surface and bottom of Lower Hog Pond, but the concentration of phosphorus near the surface was at the boundary between moderate (tolerable) and high (problematic) and the concentration in deep water was high. This is not consistent with the elevated deep water oxygen concentrations measured by day, and suggests that there may be substantial swings in oxygen that allow night time release of phosphorus from muck sediments.

Despite somewhat elevated phosphorus levels, turbidity and chlorophyll-a concentrations were low and water clarity was high (Table 9). The N:P ratio was near the low end of the moderate range for the surface sample and low for the bottom sample, suggesting that cyanobacteria may be favored.

Pond Biology

Despite somewhat elevated phosphorus concentrations, phytoplankton biomass was low. About 41% of the phytoplankton biomass was cyanobacteria, consistent with the low N:P ratios, but the main cyanobacterium was *Merismopedia*, as found in Upper Hog Pond, and this is not a species known to produce taste, odor or toxins or to form dense blooms.

A survey of plants at 40 locations (Figure 26) revealed a total of 7 rooted plant species plus filamentous green algae mats (Chlorophyta), the macroalga *Nitella*, and an aquatic moss (Appendix). Green algae mats were most commonly encountered, at 83% of sites, while quillwort (*Isoetes* sp.) and pipewort (*Eriocaulon septangulare*) were found at slightly less than half the survey sites. Filamentous green algae were found at all depths, while the pipewort was in water <5 feet deep and the quillwort was found at the complete range of depths but achieved high density in water between 7 and 18 feet of water depth. The macroalga Nitella was found at 25% of surveyed sites but was dense in deeper water. Other plants were not frequently encountered and were mostly in shallow water (Appendix).

The mean plant cover rating was 2.9 on a 0 to 4 scale, suggesting that between 25 and 50% of the pond bottom was covered by plants, probably close to 50%. The biovolume rating was 1.0 on the 0 to 4 scale, suggesting that <25% of the water column was filled with plants. While there are no plant nuisances in Lower Hog Pond, there is extensive growth by plants over much of the pond bottom, just not extending far upward into the water column.

There were no invasive species observed, either submerged in the pond or around its periphery, including a lack of common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*). No state listed (protected) species were observed either, and the NHESP does not show any Priority or Estimated Habitat for listed species in or around Lower Hog Pond (Figure 17).

Zooplankton were sampled at the water quality station and included no rotifers but several species of copepods and cladocerans, including a substantial number of large bodied *Daphnia*, a cladoceran that has great filtering capacity for algae and represents desirable food for small fish. Biomass was high at 226 µg/L, especially for late summer when predation by small fish tends to be high. Mean crustacean zooplankton length was just over 1 mm, also a high value late in summer, suggesting that predation pressure by small fish is not too intense.

No mussels or snails were observed during the survey, but freshwater sponges were found. While this survey is not quantitative, if mussels or snails were common they would have been found. Low alkalinity suggest that there may not be enough calcium for shell formation and maintenance. Sponges are usually more abundant in low pH waters.

There is no record of the fish community of Lower Hog Pond and there is no active management of fish. With the entire shoreline in private ownership, the DFW has not been involved in many years, if ever, and Lower Hog Pond is not stocked with trout. A warmwater fishery is expected, with bass, pickerel, sunfish, perch, bullheads, killifish and possibly other species. From the zooplankton biomass and size distribution it appears that predatory fish like bass are dominant and depress the panfish population.

Management Needs and Recommendations

No management needs are apparent at this time, as the condition of Lower Hog Pond appears to support all current uses. Yet there is concern over slightly elevated phosphorus concentrations and how those may arise. Release from surficial sediment in deeper water is possible overnight if oxygen depression occurs during the absence of light and photosynthesis. Daytime oxygen levels were elevated, near or above saturation, and this often signals variation with low values overnight. There are no reports of algae blooms and the phytoplankton community was sparse in August 2018; biological structure with more large predatory fish, fewer panfish, and more large zooplankton may hold the phytoplankton in check despite available phosphorus at moderate to high levels. Measurement of oxygen profiles overnight would help clarify the situation and sediment testing to determine the amount of potentially available phosphorus is recommended.

The low N:P ratio is not indicative of groundwater as the immediate source of elevated phosphorus, but as Lower Hog Pond lies in a zone considered to have groundwater quality threats, further monitoring is also advisable to determine if the August 2018 conditions are representative. At a minimum, Lower Hog Pond should be assessed for water quality and plankton as performed in this investigation at least once in late spring and once in late summer of each year. Changes in fertilization, irrigation and drainage practices are believed to have minimized inputs from the nearby golf course fairways but it would be appropriate to document the lack of impact by sampling of groundwater and any stormwater runoff.

Protection of Lower Hog Pond would largely be accomplished through the Wetlands Protection Act administered by the Sandwich Conservation Commission. Activities in the pond or near its shoreline on land are covered by this law and its attendant regulations and apply to the private property surrounding the pond even though it is not a Great Pond by Massachusetts statute. No imminent shoreline threats were noted during this investigation and it appears that past threats have been largely reduced by prudent development and management.

Peters Pond

General Pond Features

Peters Pond covers about 127 acres in south Sandwich (Figures 1 and 27), although there is variability in areal estimates, with a range of 123 to 131 acres; some water level fluctuation occurs, so this is not unusual. Average depth is just over 25 feet while maximum depth is 54 feet (Table 1). The bathymetry is somewhat irregular, with an elongate cove to the east and the deepest part far to the north (Figure 28), but the existing bathymetric map was confirmed by measurements at 78 points in August 2018. Water volume is about 3188 acre-feet, making Peters Pond the deepest and largest pond by volume wholly in the Town of Sandwich. Sediments are rocky rubble, gravel and sand out to water depths of almost 25 feet, after which sediment grades to organic muck with complete muck coverage at depths greater than about 40 feet. The pond has no surface water inlets or outlet. Groundwater flow is mainly from the west. Based on direct precipitation records and estimated groundwater inflow, detention time is 881 days or 2.4 years.

Peters Pond is the most publicly used pond in Sandwich, with many large power boats launched on it during summer, considerable canoeing and kayaking, multiple swim areas, and state-sponsored stocking of brown, brook and rainbow trout in spring and fall. There is a paved state boat launch at the eastern end of the southeast arm of the pond, a paved town boat launch at the north end of the pond, plus campground launch areas that afford access for a fee. There is a large community association beach at the south end of the pond, two campground beaches on the east side of the pond, and the town beach complex at the north end of the pond. There is also an unofficial beach adjacent to the mining operation that sees use. The pond tends to be quiet early in the morning but becomes busy with motorized watercraft traffic on good weather days by 10 AM and boat traffic can be very high on nice weekends.

The shoreline is a mix of vegetated and developed land with generally steep slopes that continue into the pond. Yet erosion appears minor in most areas despite development, intense use and substantial wave action. The very coarse substrate appears to naturally armor the shoreline in many areas.

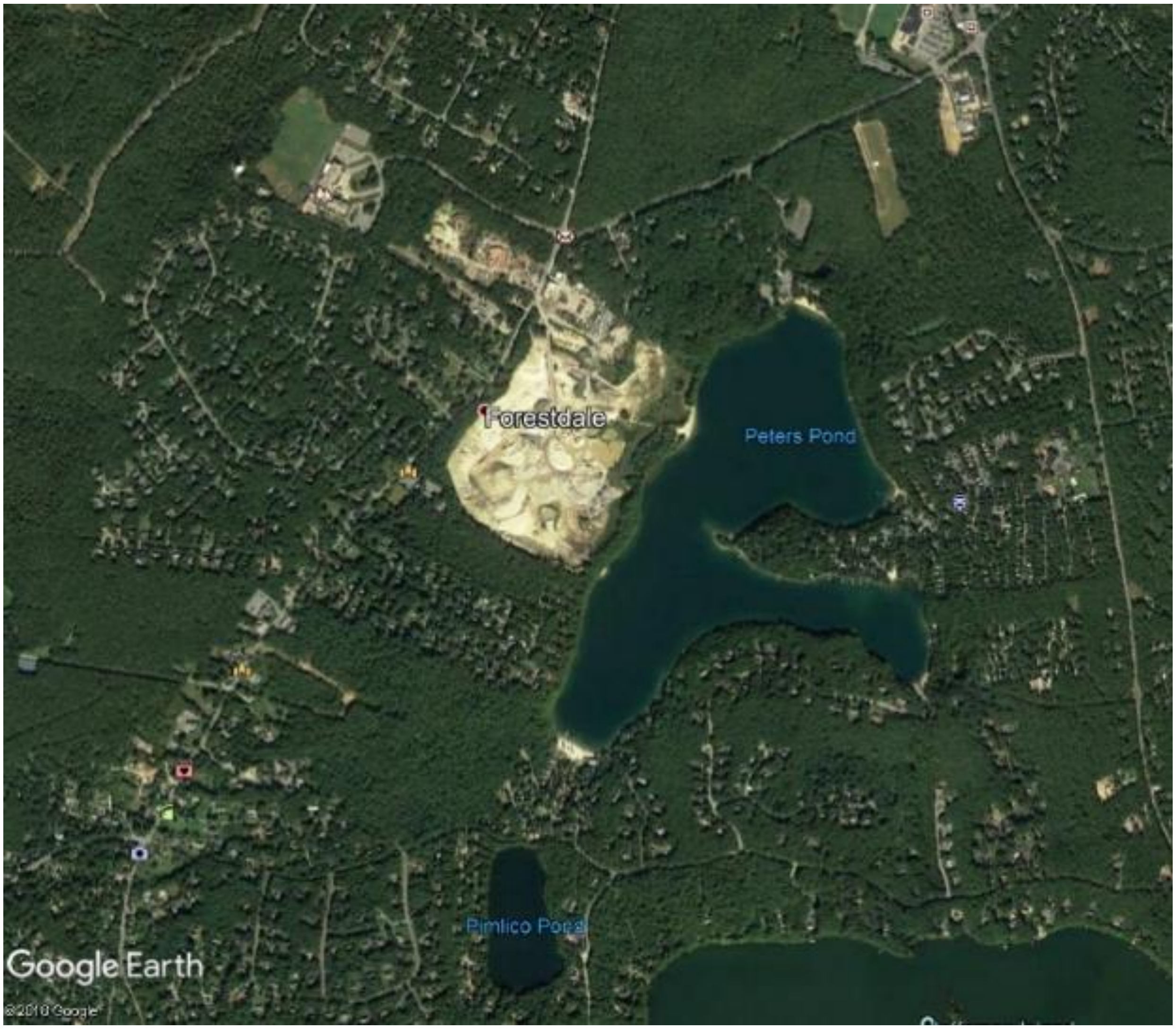
Peters Pond is a Great Pond under a Commonwealth of Massachusetts statute. It is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

The complete watershed of Peters Pond has not been delineated in detail, but the surface water drainage area is confined to less than 1000 feet from the pond in most directions by existing topography. There are three stormwater discharge pipes at the north end of the pond and one at the eastern tip of the southeastern arm of the pond, all related to road drainage; most residential areas have leaching catch basins. The groundwater contribution area extends west onto JBCC land and the crown of the groundwater table on this part of Cape Cod, a distance of about 1.5 miles (Figure 2). Groundwater also flows from the north from about three quarters of a mile away.

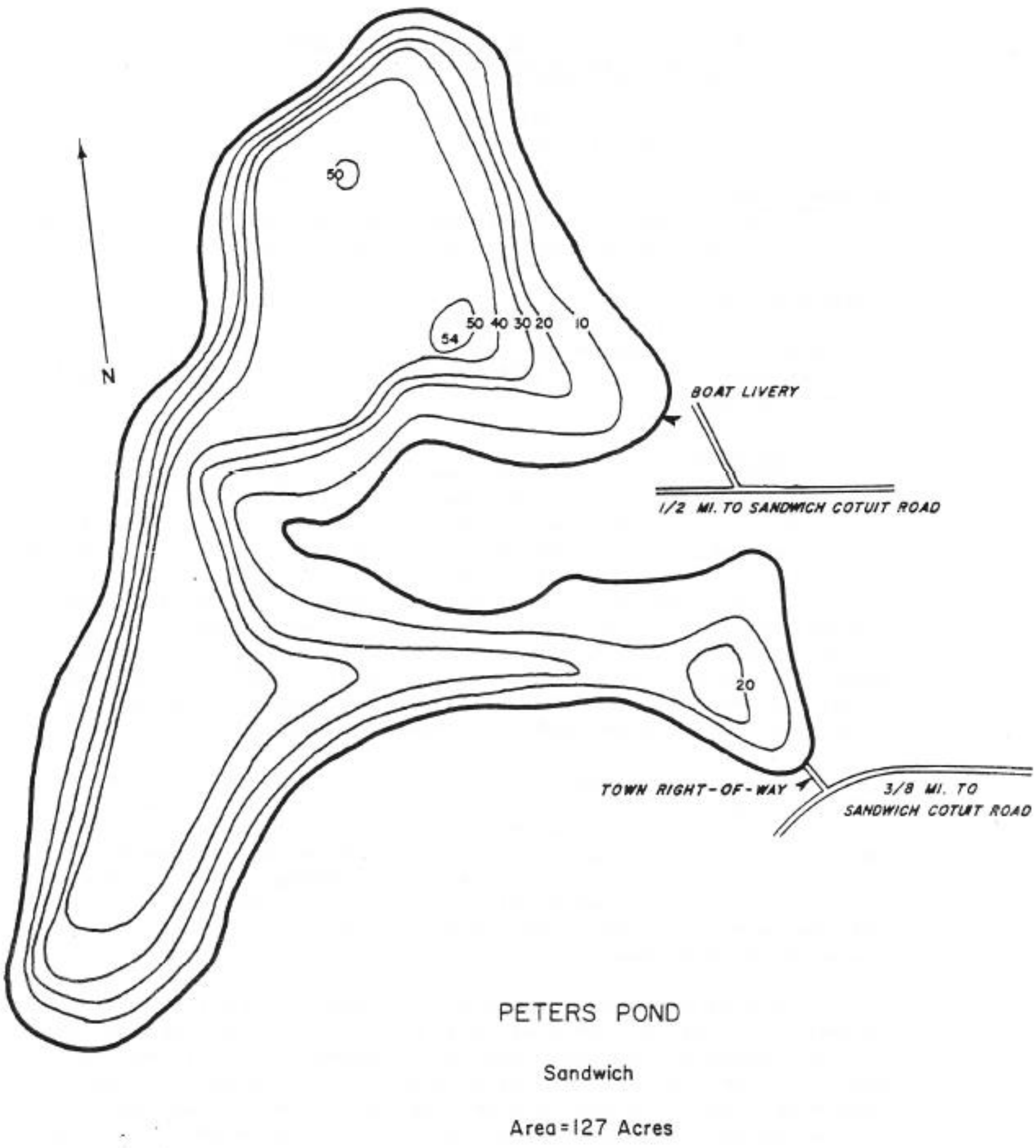
Contaminated groundwater plumes from JBCC apparently do not approach Peters Pond (Wright-Pierce 2017) but there are listed groundwater threats from the Forestdale School (which has a subsurface wastewater discharge) and from the gravel mining area just west of the pond (which is very large and has

Figure 27. General vicinity of Peters Pond.



leaching pits for washwater). Additionally, the mining operation reportedly experienced a blow out from a berm that dumped silty water into the pond over a decade ago. Onsite wastewater disposal from the many small homesite and trailer camps also represents a threat to the pond. Although groundwater mostly flows away from the pond on its east side, slopes are steep enough to allow some effluent-contaminated groundwater to reach Peters Pond. However, the depth to groundwater is substantial in most of the contributing area and phosphorus removal should be high.

Figure 28. Bathymetry of Peters Pond from pre-1990 MA DFW records.



Pond Water Quality

Based on the review in the Cape Cod Pond Atlas (Eichner et al. 2003), water quality in 1948 appeared excellent, with stratification at 30 ft but no oxygen depletion in the bottom waters (DO >4 mg/L). Yet in 1997 through 2001 the oxygen profiles exhibited no appreciable oxygen below 40 ft, an apparent deterioration of bottom water quality over a 50-year period, a common observation for deeper Cape Cod lakes. Data from the PALS program in 2001 indicate slightly acidic pH, alkalinity of 12 to 15 mg/L, low surface nutrients (phosphorus = 8 µg/L, nitrogen = 290 µg/L) and moderate to slightly elevated bottom nutrients (phosphorus = 28 µg/L, nitrogen = 400 µg/L). Chlorophyll-*a* was 5 µg/L at the surface and 20 µg/L in deep water. There have been reports of algal blooms in the southeastern cove and wind-driven blue-green scums at the northern cove end of the pond. In 1960 the DFW estimated that 19% of the pond volume would support trout in summer. Water quality data were not collected between 2002 and the 2018 WRS survey, so there is no documentation of conditions in the intervening years.

Water quality was assessed at two stations in August 2018, one in the northern basin at the deepest point in the pond (54 feet) and the other in the southeast arm of the pond, at its deepest point (20 feet) (Figure 29). Based on this limited sampling, not very much has changed in Peters Pond over the last 17 years (Table 10). Oxygen is still low at the bottom in the deepest part of the lake, but oxygen is adequate for trout and other sensitive organisms at depths <38 feet deep and not depleted until a depth of about 43 feet (Appendix). The portion of the pond that can support trout in summer is still about the same as in 1960. The pH remains slightly acidic and alkalinity is near the boundary between low and moderate. Phosphorus concentrations are low in surface water and slightly elevated near the bottom at the deeper station. Average water clarity as measured by Secchi disk is identical to data from the PALS program in 2001 at 16.5 feet (5 m).

The one difference that stands out is an increase in nitrogen over the last 17 years (Table 1). Surface concentrations in August 2018 were still considered low but were distinctly higher than in 2001. Bottom concentrations in August 2018 was moderate and more than twice the 2001 concentration. These values come from only a few samples and older data do not subdivide the forms of nitrogen to facilitate comparison, but these changes are beyond the expected range of natural variation. The result is that the N:P ratio in Peters Pond is much higher in 2018 than 17 years ago. This may be desirable as it reduces the advantage for cyanobacteria that can access dissolved nitrogen gas unlike other algae, but it does signify more nitrogen arriving at the pond, almost undoubtedly via groundwater and from wastewater disposal.

In addition to assessment of water quality in Peters Pond, a surficial sediment sample was obtained from the deepest part of the pond and tested for available phosphorus and related features (Appendix). The most available sediment phosphorus fraction, iron-bound phosphorus, tested at 118 mg/kg, a slightly high value (Table 1). Another potentially available fraction, the biogenic phosphorus, yielded a concentration of 447 mg/kg, in the high moderate range. The aluminum to iron ratio was 0.69, which is low and indicates that substantial phosphorus could be released under low oxygen conditions. The actual deep water phosphorus concentration is elevated but not extreme, suggesting that only limited release is experienced. Additional investigation is warranted, as internal loading tends to foster cyanobacteria blooms.

Figure 29. Peters Pond survey points.

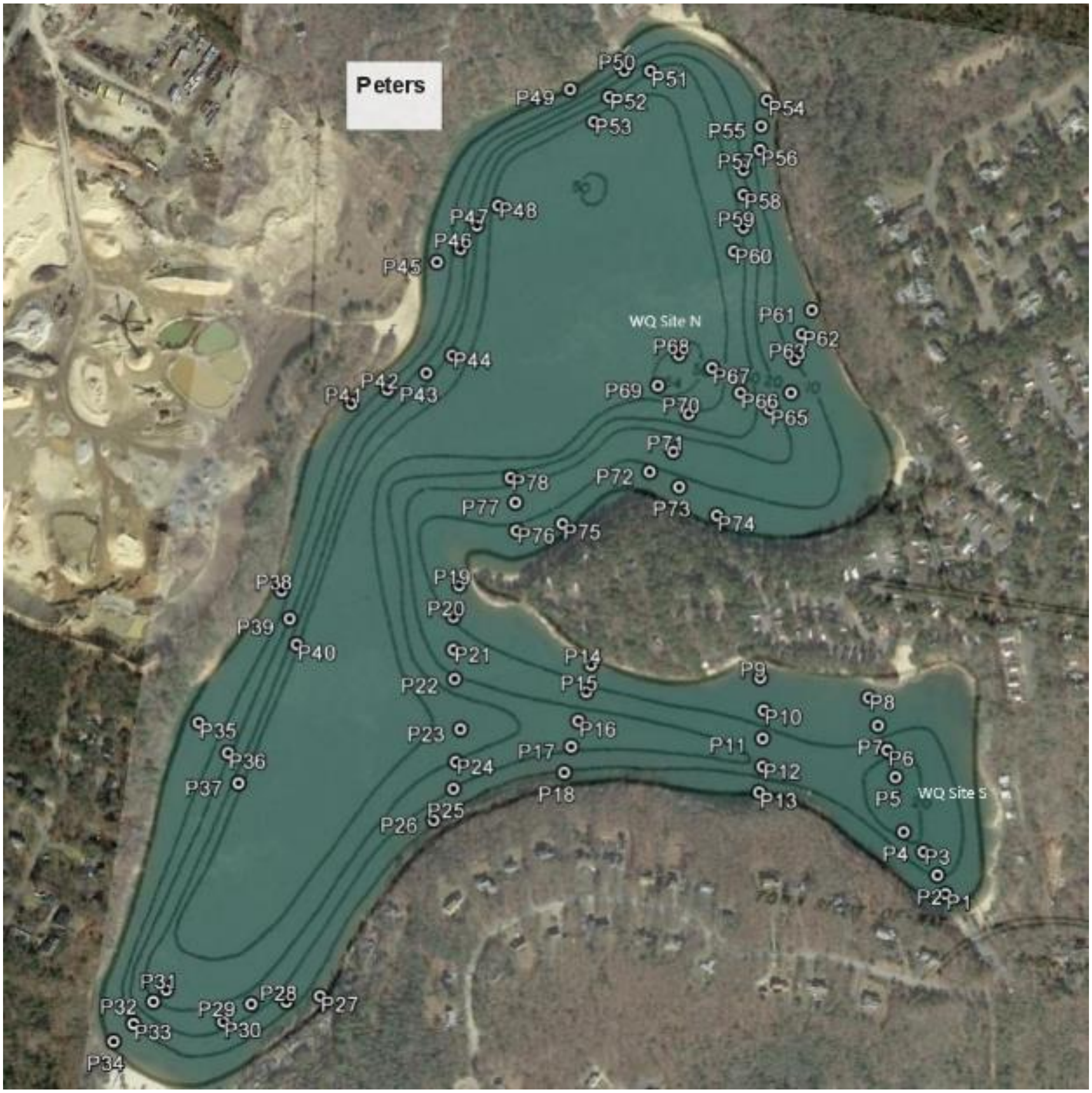


Table 10. Water quality, plankton and sediment summary for Peters Pond.

Peters Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	0.5 to 4.0	0.4
Average pH	SU	6.7	6.6
Surface Alkalinity	mg/L	11.6	9.0
Average Conductivity	µS	ND	104
Surface Total P	µg/L	8	6
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	28	27
Bottom Dissolved P	µg/L	ND	5
Surface Nitrate/Nitrite N	µg/L	ND	35
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	40
Bottom Ammonium N	µg/L	ND	320
Surface Total Kjeldahl N	µg/L	ND	340
Bottom Total Kjeldahl N	µg/L	ND	820
Surface Total N	µg/L	290	375
Bottom Total N	µg/L	400	830
Surface N:P Ratio	Unitless	36	63
Bottom N:P Ratio	Unitless	14	31
Average Turbidity	NTU	ND	3.5
Secchi Transparency	m	5.0	5.0
Average Chlorophyll-a	µg/L	4.7	3.0
Phytoplankton Biomass	µg/L	ND	1154
Cyanobacteria	%	ND	4
Zooplankton Biomass	µg/L	ND	92
Zooplankton Mean Length	mm	ND	0.87
Sediment Fe-P	mg/kg	ND	118
Sediment Biogenic P	mg/kg	ND	447
Sediment Al:Fe Ratio	Unitless	ND	0.69
ND = No Data	Desirable	Tolerable	Problematic

Pond Biology

Phytoplankton were sampled at the surface of both stations in Peters Pond in August 2018, plus at a depth of 28 feet (8.5 m) at the deeper northern station to evaluate possible algae associated with an increase in oxygen between water depths of 23 and 33 feet (7 to 10 m) (Appendix). Biomass was slightly above the moderate (tolerable) threshold at the surface of each station and no distinct increase in algae was found at the sampled depth of 28 feet (Table 1, Appendix). Cyanobacteria comprised only 4% of the phytoplankton biomass. Chlorophyll-a was low overall and slightly lower than in 2001. No phytoplankton issues were apparent in August 2018 despite past reports of blooms.

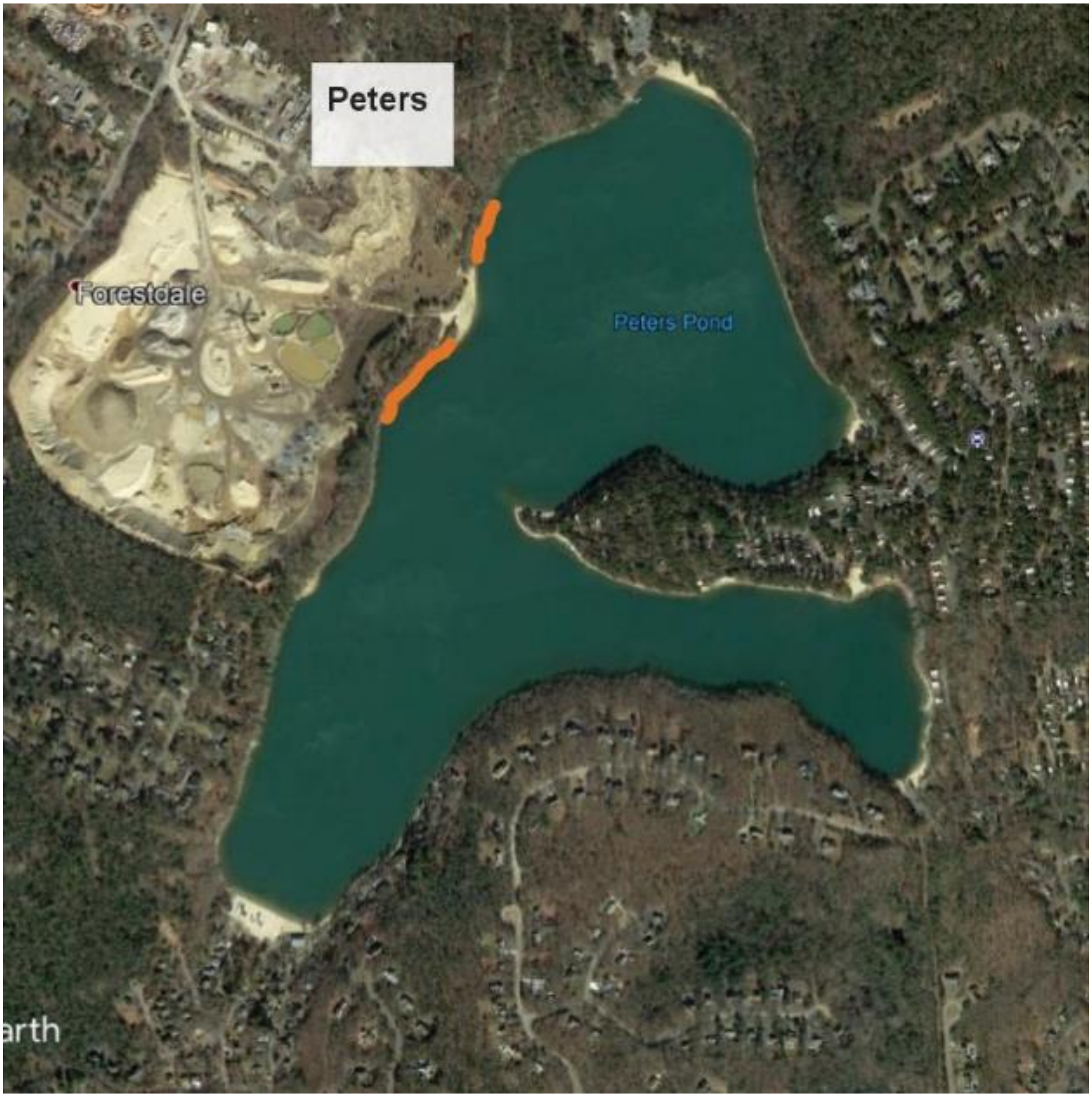
The plant community was assessed at 78 points (Figure 29). Six rooted plant species were found, along with benthic filamentous green algae (Chlorophyta) and cyanobacteria mats and the macroalga *Nitella*. Plants were infrequent and rarely dense (Appendix). *Nitella* was found at 10% of sites while spikerush (*Eleocharis acicularis*) was encountered at 8% of sites. Other plants and algae mats were found in only a single or very few locations. Average cover rating was 0.2 on a 0 to 4 scale, indicating very little cover by plants. Average biovolume rating was 0.5 on a 0 to 4 scale, suggesting that only a tiny portion of the water column was filled with plants. Over 75% of survey sites had no plants present. The very coarse nature of the substrate is the primary limiting factor; light penetration was adequate to support plants to a water depth of about 40 feet. Rooted plants were not observed beneath a water depth >25 feet although algae mats were found at up to 40 feet of water depth. This is consistent with past observations of very little plant growth in Peters Pond.

Common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*) were observed in two patches, both on the west side of the pond adjacent to the sand and gravel mining operation (Figure 30). Common reed is dominant, but a substantial amount of purple loosestrife can be found adjacent to it. The patches are on either side of the large sandy area prominent in aerial photographs on the west side of the pond, the northern patch extending about 150 feet and the southern one about 300 feet along shore at a thickness of no more than 15 feet. No submergent invasive species were detected in Peters Pond.

Zooplankton were collected at the two water quality sampling stations in August 2018. Biomass was just above the low end of the moderate range at the shallower station while biomass was above the high threshold at the deep station, leading to an average at the high end of the moderate range (Table 1). Mean crustacean length was similar at the two stations and averaged 0.87 mm, a high value. Rotifers, copepods and cladocerans were all present but most biomass was comprised of copepods and cladocerans and large bodied *Daphnia* were present. *Daphnia* are effective filter feeders, and both reduce algae abundance and provide a high quality food source for small fish. Their presence in late summer and the high mean crustacean zooplankton body length indicates that small fish are not abundant, and that gamefish are probably dominant in the fish community.

Mussels and snails were observed at survey sites, but no freshwater sponges were found. Invasive Asian clams (*Corbicula fluminea*) were observed in shallow water at two locations (GPS points P27 and P55 in Figure 29). Asian clams have turned up in several Cape Cod ponds over the last decade but are not yet widespread and the level of damage they may do remains uncertain. Crayfish were moderately abundant at shallower survey sites.

Figure 30. Phragmites patches at Peters Pond.



The former Division of Fisheries and Game, now the Division of Fisheries and Wildlife, was actively involved in the management of Peters Pond as early as 1911. A variety of salmonid species have been stocked over the last century and the pond was reclaimed (all fish killed or salvaged, followed by restocking of salmonids) in 1955. Historically, Peters Pond was habitat for a wide variety of warmwater fish species but was considered to have very poor population structure prior to reclamation. Warmwater species have recovered to some degree, with largemouth and smallmouth bass present along with yellow perch, several sunfish species, golden shiners and banded killifish. Peters Pond is stocked in spring and fall with multiple species of trout and received Atlantic salmon broodstock until that rearing program was discontinued about 2014. It is highly regarded as a fishing lake and can support holdover trout. Pickerel are also listed for Peters Pond, but habitat would be marginal at best with so few plants. American eel is also a listed species, but there is no outlet to the sea, so any eels would be landlocked.

Peters Pond is on the Massachusetts 2016 Integrated Waters List as having a completed Total Maximum Daily Load (TMDL) for mercury in fish tissue. This TMDL is the result of a study of almost 100 Massachusetts ponds by the New England states plus New York and finalized in 2007. The TMDL document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, USA states outside of the region, and global sources. The majority of mercury pollution in the northeastern USA is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond, Spectacle Pond and Snake Pond were included in the project. This would affect the quality of fish living in the pond their entire lives, not trout caught within a year or so of stocking.

The NHESP map of Priority and Estimated Habitat for the Peters Pond area (Figure 31) shows no listed (protected) species habitat in or around this pond.

Management Needs and Recommendations

Peters Pond is very popular for swimming, boating and fishing, and appears to support those uses. No algae blooms were encountered in this investigation, but past blooms, including cyanobacteria, have been reported. It does not appear that such blooms are pondwide but are rather the result of windblown surface accumulations in coves. The slightly elevated phosphorus in deeper water suggests release from an anoxic bottom below a depth of about 40 feet, equivalent to about 38 acres of area in this 127 acre waterbody. Yet the deep water phosphorus concentration of <30 µg/L is not high relative to what could be released.

If just 10% of the iron-bound phosphorus mass (0.57 g/m^2) in the upper 4 cm of the 38 acres (15.2 hectares) exposed to anoxic conditions was released over the course of a summer, the mass release would be about 8.6 kg and the concentration in the bottom layer of Peters Pond would be about 33 µg/L. This is usually assumed to be the minimum level of release observed from sediments exposed to anoxia; much higher release is possible. Given that there is background phosphorus already in the water, not even this much phosphorus is being released, but conditions could get much worse with longer anoxic exposure.

As it is, the relatively small amount of phosphorus being released into the deeper waters of Peters Pond is not making it to the upper water layer where the phosphorus concentration is routinely low (<10 µg/L). The key is an oxic zone between the point where phosphorus is being released (>40 foot depth) and the point where light is adequate to grow algae (twice the Secchi transparency, or about 33 foot of water depth). The presence of an oxic zone where upward migrating phosphorus can be naturally inactivated (mostly by iron) before it reaches a point where uptake by algae for growth can be accomplished is preventing algae blooms at this time. In some years the balance may be less favorable, leading to reported blooms, but the situation is not dire at this time. It may get much worse if the depth of anoxia rises, but

Figure 31. NHESP habitat mapping near Peters and Pimlico Ponds.

there appears to have been no significant change in the last 17 years despite a major change in the 50 years before that.

Getting more oxygen to the bottom of the pond will restrict phosphorus release and improve habitat. As maintenance of the two-story fishery (warmer upper layer and colder deeper layer) is highly desirable, use of mixing technologies would be inappropriate. Such mixing would make the water warmer overall and possibly eliminate summer habitat for trout. Oxygenating without completely mixing the pond is possible by several means, but not all methods are applicable to Peters Pond. The bottom layer is not thick enough to absorb diffused oxygen bubbles, the simplest approach. Putting a chamber of some kind in the pond to pull in, oxygenate, and release water back at the level from which it was withdrawn is workable but creates maintenance complications and is expensive. The most appropriate approach would involve withdrawing water from the deep layer, oxygenating in a shore-based container, and putting the water back. This is a bit more complicated than it sounds but is a proven technology known as sidestream supersaturation.

The cost of a sidestream supersaturation system will depend on the amount of oxygen to be supplied and we do not have enough data to properly calculate oxygen demand in this pond. Typical unit costs include averages of $8100 capital cost per acre addressed, $1800 capital cost per acre-foot treated, and $1200 capital cost per kilogram oxygen supplied (Wagner 2015). Annual operating costs have averaged $600 per acre, $60 per acre-foot, and $1200 per kilogram of oxygen delivered on a daily basis. While the range of possible costs is wide and use of averages is not advisable in planning a project, this suggests that a sidestream supersaturation system to address 38 acres of Peters Pond with an average layer depth of 5 feet might cost on the order of $300,000 to $350,000 to install and $12,000 to $23,000 to operate each year. It is not at all clear that such cost is justified at this time.

Alternatively, the phosphorus in the surficial sediment could be inactivated. Aluminum has been used in a dozen Cape Cod treatments to date with desirable results (Wagner et al. 2017). Based on just the one sediment sample, the recommended dose of aluminum would be about 27 g/m^2 and the cost would be about $70,000. This provides less habitat benefit than oxygenation but is much less expensive and would be expected to limit algae blooms for up to two decades with no further annual maintenance costs.

More monitoring is certainly justified, and the program carried out for water quality and plankton assessment in this study would be appropriate once in late spring and once in late summer each year. Further evaluation of sediment phosphorus concentrations is also recommended, covering a larger area than the one sample collected in this study. A set of five samples over the pond area >40 feet deep is suggested as adequate. It may be that less of an area than assumed here actually contributes, or that concentrations are lower than at the deepest point where sampling occurred, and that may explain the seemingly low release rate for phosphorus from sediments in Peters Pond.

Another management issue is the presence of common reed and purple loosestrife, both invasive shoreline plants that can expand and diminish habitat, recreation and property value. At this time there are only two stands, both close together on the western shoreline near the mining operation (Figure 30). These could be accessed from land and controlled by physical (repeated cutting or excavation of whole plants) or chemical (herbicide) application. Taking action before these invasive species spread farther is strongly recommended and could be combined with actions at other Sandwich ponds (Upper and Lower Shawme, Pimlico, Weeks Ponds) to control these same two plants.

A three-year program is advised, with sequential physical or chemical treatment as needed in years 2 and 3. At that point, *Phragmites* and *Lythrum* should be eliminated or reduced to such low densities that hand pulling is feasible as a follow up as warranted. The overall cost of a complete program for all Sandwich ponds with these invasive shoreline plants has been estimated at about $50,000 over three years for control with herbicides and at least $100,000 for control by physical means.

Permits for hand cutting and pulling might only involve a negative Determination of Applicability under the Wetlands Protection Act. If mechanical equipment is needed, an Order of Conditions under the WPA will be needed. Permits for herbicide treatment include an Order of Conditions under the WPA and a License to Apply Chemicals. The latter is provided by the MA Department of Environmental Protection and is relatively straightforward once an Order of Conditions has been issued. Any Order of Conditions is written by the local conservation commission after a Notice of Intent is filed and properly reviewed and subject to public hearing by a vote of the conservation commission. There are no protected species known for Peters Pond and its immediate shoreline so the Natural Heritage and Endangered Species Program would not need to be consulted.

It should be noted that glyphosate would be a highly applicable herbicide to use for *Phragmites* and *Lythrum* control, but this chemical has been in the news these past few years for links to cancer and related health impacts. However, this is largely related to extensive use on genetically modified crops in giant agribusiness applications, and then only through selective use of data. The risk is negligible for targeted *Phragmites* or *Lythrum* control on such a small scale as envisioned here. People often fail to discern this very important difference, or that it is additives in the herbicide mixes used in agriculture that represent the greatest risk, and these additives are not used in aquatic environmental applications. The selective use of glyphosate for aquatic invasive species control has minimal similarity to the agricultural uses that have resulted in all the negative publicity or even use by homeowners on lawns. The formulations are different and aquatic use is much more limited. However, growths of *Phragmites* and *Lythrum* are not so extensive that physical controls could not be applied at Peters Pond.

Another invasive species in Peters Pond is the Asian clam (*Corbicula fluminea*). It was found in only two locations, quite far apart, but an exhaustive survey was not conducted. This tends to be a shallow water species and the entire shoreline should be surveyed to determine how widespread it is. If not ubiquitous, it may be possible to counter this infestation. Benthic mats have most often been applied to kill these invasive mollusks. Control costing is premature until the extent of the infestation is known.

One additional concern for Peters Pond is the amount of boat traffic coming into the pond without any control over potential invasive species import. None of the Sandwich ponds have a boat inspection program or washing station available, but at Peters Pond with multiple boat launches and high accessibility this represents a major risk of invasive species introduction. The Asian clams found in August 2018 most likely arrived via boat and more introductions can be expected in years to come.

Peters Pond has fared well with minimal active management, and the substrate is not especially hospitable to plants, but the risk of invasive species is increasing. The cost of prevention is much less than the cost of remediation, just not less than the cost of doing nothing and being lucky. While the Town of Sandwich must consider priorities, it is recommended that the state boat ramp be manned at least on weekends to check incoming boats for invasive species, proper safety equipment, and even valid registration. Other launch points could benefit from such a program as well and having at least a boat washing station available at some nearby location would allow proper cleaning to be mandated without unreasonable inconvenience. The Environmental Police reportedly patrol Peters Pond, as it is the waterbody with the most access and allows larger motors than the other ponds, but the need goes beyond patrolling on the water.

A boat wash station might cost between $25,000 and $40,000 depending on size and features, exclusive of any land purchase, but one well located station could serve the whole town. Owners of washed boats could be given a certificate stating that washing has been performed and this could be required at launch sites before entry. This may seem overly cautious since Peters Pond and the other Sandwich Ponds do not appear to have any submergent invasive species in them yet, but remediation is difficult, and the cost is high enough to warrant greater protection of these valuable resources.

Pimlico Pond

General Pond Features

Pimlico Pond covers 16.4 acres in south Sandwich (Figures 1 and 32) to an average depth of 12.6 feet, with a maximum depth of just under 25 feet (Table 1). It has about 0.6 miles of shoreline. Bathymetry (Figure 33) indicates a simple kettlehole "bowl", although this pond is slightly shallower than most kettlehole ponds. The bathymetry was confirmed by measurement at 46 locations in August 2018, although the water level was higher than average and slightly deeper average and maximum depths resulted. Pond volume was calculated at 207 acre-feet. The shoreline has a generally wooded character despite being divided among about 20 residential lots. The periphery is mostly sandy with a little gravel and cobble, out to a depth of about 12 feet, after which the substrate grades in to organic muck with complete muck coverage beyond about 18 feet of water depth.

The pond has no surface water inlets or outlet. Groundwater flow is mainly from the west-northwest (Figure 2), but ground slopes are steep enough around the pond to pull in some localized groundwater from most of its periphery. Based on direct precipitation and estimated groundwater inflow the detention time averages about 332 days or 0.9 years.

Pimlico Pond is used for swimming, small craft boating and fishing. Public access to Pimlico Pond is from an undeveloped boat launch along Pimlico Pond Road with limited parking just off the road. The rest of the shoreline is privately held with homes mostly upgradient of the pond on sandy bluffs, but most residences have docks or small beach areas and it is apparent that the pond is enjoyed all summer. Pimlico Pond is stocked with trout each spring but does not have enough cold water to support a resident population all year.

Pimlico Pond is a Great Pond under a Commonwealth of Massachusetts statute. It is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

The immediate drainage area of Pimlico Pond is a small area of fairly steep hillside much of the way around the pond, with a number of small lots on the zoning map. However, many of these lots are not developed, and housing density around the pond is moderate. Most homes have substantial buffer zones and there has been relatively little clearing of trees. There is direct drainage off Pimlico Pond Road, with a single piped discharge and evidence of erosion and possible water quality impacts. Most of the surrounding residential area is served by leaching catch basins (Wright-Pierce 2017).

The area of groundwater contribution extends west-northwest between Peters and Snake Ponds and onto the Joint Base Cape Cod. The CWRMP (Wright-Pierce 2017) indicates no groundwater contaminant plumes intersecting with Pimlico Pond and does not identify any specific groundwater threats near Pimlico Pond. Onsite wastewater disposal from the developed area to the west represents a threat to pond water quality, but the vertical distance to groundwater is substantial and phosphorus removal would be expected to be high.

Figure 32. General vicinity of Pimlico Pond.

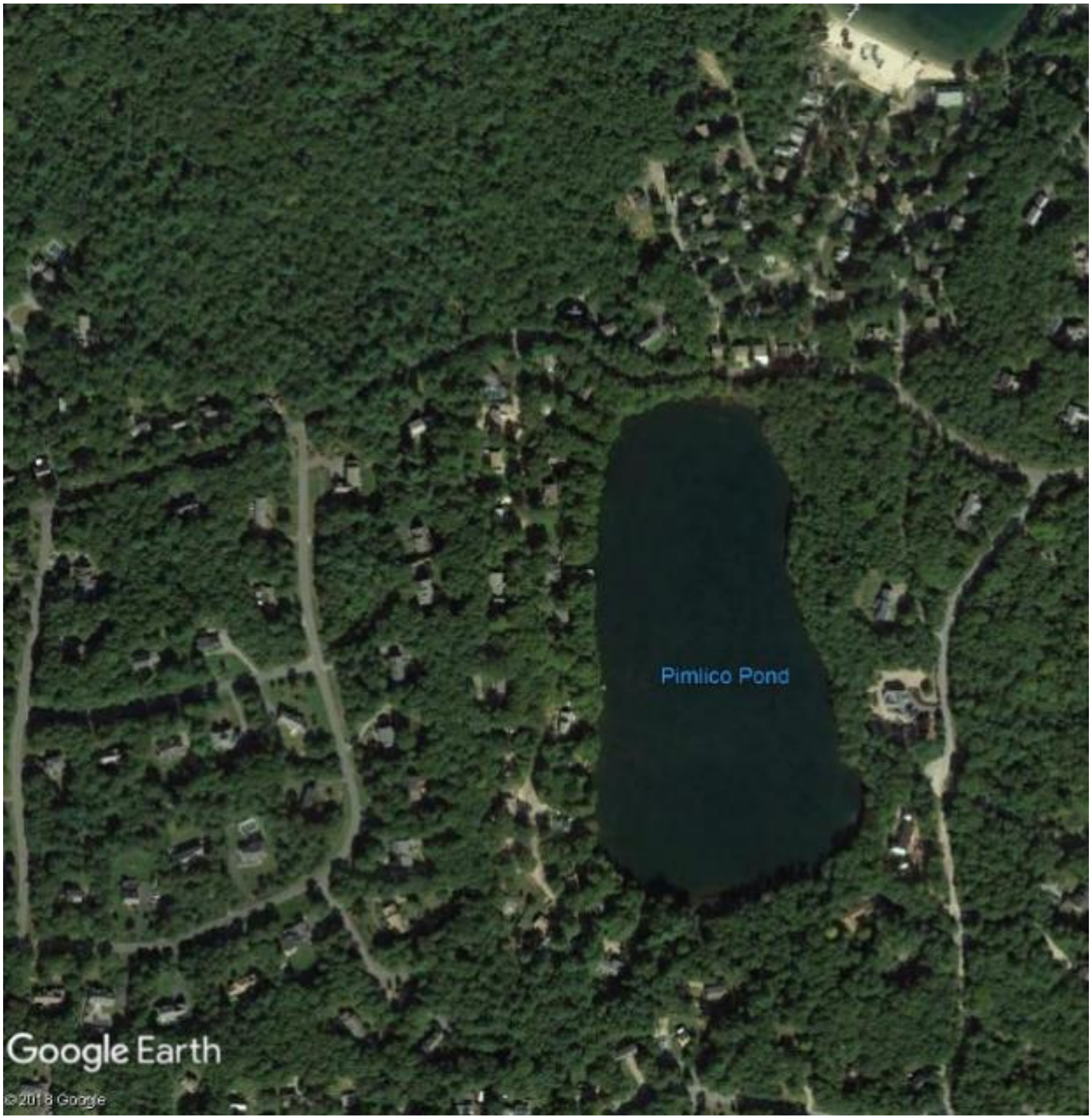
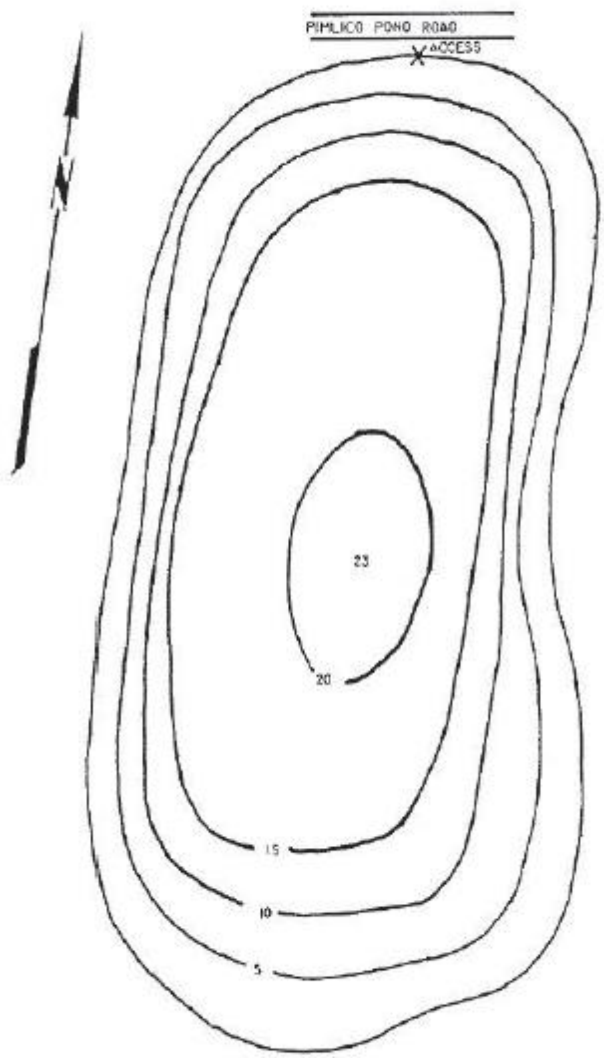


Figure 33. Bathymetry of Pimlico Pond from pre-1990 MA DFW records.



Pond Water Quality

Pimlico Pond was sampled in 2001 and 2002 as part of the PALS program (Eichner et al. 2003) and this is the only sampling known to have occurred at this pond. The pond was well mixed from top to bottom and there was no oxygen depression detected in late summer sampling. The pH was slightly acidic, alkalinity was low, and nutrient levels were also low to low-moderate. No algal blooms have been reported, suggesting acceptable water quality, but water clarity was only 13.8 feet (4.2 m), a moderate value.

Pimlico Pond was sampled in August 2018 as part of this investigation at its deepest point and surveyed at 46 additional locations (Figure 34). Unlike the 2003 review, WRS found oxygen depletion near the bottom under about 23 feet of water and slight oxygen depression in 20 feet of water, above which the

Figure 34. Pimlico Pond survey points.

Table 11. Water quality, plankton and sediment summary for Pimlico Pond.

Pimlico Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	7.0	0.1
Average pH	SU	6.6	6.8
Surface Alkalinity	mg/L	4.3	6.0
Average Conductivity	µS	ND	121
Surface Total P	µg/L	8	5
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	12	20
Bottom Dissolved P	µg/L	ND	7
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	30
Bottom Ammonium N	µg/L	ND	30
Surface Total Kjeldahl N	µg/L	ND	490
Bottom Total Kjeldahl N	µg/L	ND	740
Surface Total N	µg/L	320	500
Bottom Total N	µg/L	300	750
Surface N:P Ratio	Unitless	40	100
Bottom N:P Ratio	Unitless	25	38
Average Turbidity	NTU	ND	5.6
Secchi Transparency	m	4.2	3.0
Average Chlorophyll-a	µg/L	1.3	5.7
Phytoplankton Biomass	µg/L	ND	4073
Cyanobacteria	%	ND	0
Zooplankton Biomass	µg/L	ND	91
Zooplankton Mean Length	mm	ND	0.60
Sediment Fe-P	mg/kg	ND	71
Sediment Biogenic P	mg/kg	ND	500
Sediment Al:Fe Ratio	Unitless	ND	1.06
ND = No Data	Desirable	Tolerable	Problematic

pond was well oxygenated (Appendix, Table 11). However, there was an increase in oxygen between water depths of 13 and 16 feet compared to water above and below that depth that suggested a possible build-up of algae that photosynthesize and produce oxygen and cause the observed oxygen spike at mid-depth.

The temperature was not uniform, showing enough of a gradient to claim stratification with the thermocline between water depths of 13 and 16 feet (Appendix). The temperature 13 feet below the surface was almost 26^{o}C while the temperature at 20 feet of water depth was 16.4^{o}C and the largest temperature change (>5 C^{o}) was between 13 and 16 feet of depth. Pimlico Pond was thermally stratified in August of 2018 after a relatively hot and calm July but did not exhibit stratification during the 2001 and 2002 assessments in August of those years. The extra water depth encountered in 2018 may have been influential, preventing wind mixing all the way to the bottom and allowing stratification to set up during a warm period. Much more energy is required to break stratification once it has been established than to prevent stratification from occurring.

Alkalinity was low and the pH was slightly acidic, a natural condition for most Cape Cod ponds. Surface phosphorus concentration was low, but the bottom phosphorus concentration was at the boundary between moderate (tolerable) and high (problematic) and distinctly higher than the historic values from 17 years ago. The low oxygen at the bottom in the deepest water likely allowed for some release of phosphorus from the sediment in that area. Concentrations of forms of nitrogen were generally low, although a slightly elevated level of organic nitrogen at the bottom in 2018 pushed the total nitrogen concentration into the moderate (tolerable) zone. N:P ratios are high enough to discourage dominance by cyanobacteria.

Water clarity was moderate (tolerable) at 10 feet (3 m) but lower than in 2001 (14 feet or 4.2 m), turbidity was slightly elevated, and the water had a murky appearance. The pond was not unappealing but did not have the clarity and appearance of many of the other ponds assessed in August 2018.

Sediment was also collected from the deepest part of Pimlico Pond, one of five ponds sampled this way as part of this project. Iron-bound and biogenic phosphorus were both moderate (Table 11), although the biogenic (most readily available organic form) phosphorus concentration was at the boundary between moderate and high. The ratio of aluminum to iron was low, suggesting that available sediment phosphorus was sufficient to represent a threat to water quality under prolonged anoxia but was not extreme. This likely explains the deep water phosphorus level observed in August 2018 and emphasizes the importance of maintaining adequate oxygen in deep water.

Pond Biology

Pimlico Pond supports swimming, fishing and boating. Reported dense plant growths may not be impeding these uses, but concern over potential impairment has been expressed. It was hypothesized (Eichner et al. 2003) that rooted plants were controlling nutrients and limiting algae growth. The appearance in 2018 was somewhat different, with fewer rooted plants and more algae, consistent with the 2003 hypothesis.

Phytoplankton sampling occurred at the water quality assessment site (Figure 34) and revealed an elevated biomass but no cyanobacteria (Table 11). The diatom *Urosolenia* was dominant, which is unusual in late summer, as diatoms are more often associated with colder waters. However, *Urosolenia* is a very lightly silicified diatom (most diatoms are heavier and cannot stay afloat in warm water) with sparse cell contents and an elongate shape that helps limit settling. It tends to give the water a murky appearance without strong color or evident particles, consistent with field observations at Pimlico Pond. It is not toxic or odorous and is moderately nutritious for zooplankton although an elongate shape with long spines makes it harder to consume.

While no detailed survey had been conducted prior to 2018, the submergent plant community was reported as dense (Eichner 2003) and fragments of low watermilfoil (*Myriophyllum humile*), bladderwort (*Utricularia sp*.) and spikerush (*Eleocharis acicularis*) were observed on the shore at the public access point in fall of 2011 (WRS 2012). Water depth, substrate type, plant cover and biovolume, and relative abundance of plant species were assessed at 46 points in August of 2018 (Figure 34). Plant growth was detected to a depth of 22 feet, all but a small area of the pond, but cover was not high at a rating of 2.3 on a 0 to 4 scale, indicating that between 25 and 50% of the bottom was covered (Appendix). The biovolume rating was 0.9, suggesting that <25% of the water column was filled with plants. The reason for the change since 2002 is not known, but Pimlico Pond does not currently exhibit the dense plant growth noted in the past.

Eight species of aquatic plants were observed during the survey, along with both benthic filamentous green (Chlorophyta) and cyanobacteria mats and the macroalga *Nitella* (Appendix). Common naiad (*Najas flexilis*) was most frequently observed (33 of 46 sites or 72%), followed by quillwort (*Isoetes* sp.) at 48% of sites, spikerush (*Eloecharis acicularis*) at 35% and cyanobacteria mats at 33% of the sites. Other plants were less frequent and mostly found in shallow water. The milfoil noted in 2011 was not found; this is a species that often provides dense coverage in shallow ponds. The bladderwort found in 2011 was observed in 2018 but only at low frequency and density.

Naiad and *Nitella* formed moderate to dense growths in some areas of Pimlico Pond, the naiad at shallow to intermediate depths and *Nitella* at moderate to deeper depths. Very few dense or even moderate density growths of other species were observed in 2018.

No purple loosestrife (*Lythrum salicaria*) was observed at Pimlico Pond, but there were three patches of common reed (*Phragmites australis*) around the pond periphery (Figure 35). The smallest was just east of the public access area on what appears to be public property and is about 25 feet long and 10 feet thick. Another patch is found along private shoreline property on the southeast side of the pond and is about 50 feet long and 15 feet thick. The third and largest patch is at the south end of the pond and is overrunning a private beach and dock area at about 100 feet long and 20 feet thick. The property owners appear to have cut some of the common reed in this southern patch, but growths are still dense in much of this patch and recent expansion is evident.

Zooplankton sampling was conducted at the water quality assessment site (Figure 34) in August 201 and revealed a moderate biomass with a desirable mean body length for crustacean zooplankton (Table 11). The sample was dominated by quick swimming calanoid copepods and small bodied cladocerans, indicative of substantial predation by small fish. Grazing capacity would be considered moderate.

Figure 35. Phragmites patches at Pimlico Pond

Very few mussels and no snails or sponges were observed during the 2018 biological survey. While not a quantitative survey for these organisms, assessment at 46 locations should have detected them if present in any significant quantity. Mollusks tend to be rare to absent in water with low alkalinity and calcium content, but sponges are often more abundant in low pH waters. Low oxygen could also limit occurrence of these benthic organisms.

Pimlico Pond is stocked with trout in the spring by DFW but its warmer water in summer is not expected to allow holdover trout and it is not stocked in the fall. The pond is popular for spring trout fishing from canoes or rowboats or by wading. A warmwater fish assemblage is also present that includes largemouth and smallmouth bass, yellow perch, and pumpkinseed and bluegill sunfish (Desmarais 2007). No fish surveys were found that might provide more detail.

No Priority or Estimated Habitat for listed (protected) species is shown on maps prepared by NHESP that cover the Pimlico Pond area (Figure 31).

Management Needs and Recommendations

There may have been some transition from plant dominance to algae dominance in Pimlico Pond over the last 17 years, but the lack of data from that period prevents any trend analysis. It could just be a matter of the weather in the few study years available, with the higher water levels in 2018 fostering less rooted plant growth and favoring algae. The main uses of swimming, fishing and boating remain supported by current conditions as assessed in August 2018. The main management need is therefore ongoing monitoring to determine if there is a directional change in condition that might require management to maintain desirable features or if we are just seeing the range of natural variation for this pond.

Monitoring could follow the approach applied in the 2018 assessment with measurement of water quality and plankton, but with assessment in late spring and late summer of each year. For Pimlico Pond, an evaluation of the plant community would also be appropriate, as this feature figures more prominently in pond condition than in most of the other ponds assessed in 2018.

Protection of the pond through control of any additional building near the pond may be a management need, as the WRS (2012) report noted that there were a substantial number of undeveloped lots. It is not clear if current residences own those lots and keep them undeveloped to maintain the wooded nature of the nearshore land, but continuation of this largely wooded character is desirable.

Some mitigation of stormwater inputs from Pimlico Pond Road appears warranted. The Town of Sandwich has improved a number of drainage issues at other ponds and there is only the one drain discharging to Pimlico Pond. If that discharge can be eliminated or modified, it would be desirable but may not be essential. The launching ramp itself was recently paved about halfway from the road to the pond edge, presumably facilitating easier cartop boat launching without encouraging trailered boat launching. This does create some runoff that might be infiltrated by modification at the end of the ramp without compromising cartop boat launching.

There does not appear to be any need to control rooted aquatic vegetation. The Cape Cod Commission Pond Atlas (Eichner 2003) cautioned against rooted plant control without a better understanding of pond dynamics, and that was good advice. The 2018 survey suggested no rooted plant issue in need of attention, but there may be a future need for algae control. The currently dominant algae do not represent a human or ecological health problem, but water clarity is lower than it might be and a transition to less desirable forms could occur. More monitoring is needed.

The most pressing management need is control of common reed growth around Pimlico Pond. The three stands observed in 2018 (Figure 35) could be accessed from land and controlled by physical (repeated cutting or excavation of whole plants) or chemical (herbicide) application. The southeast patch represents more of a challenge for land access and both the southeast and south patches are on private property, so landowner permission will be needed. However, taking action before this invasive species spreads farther is strongly recommended and could be combined with actions at other Sandwich ponds (Upper and Lower Shawme, Peters, Weeks Ponds) to control this invasive species.

A three-year program is advised, with sequential physical or chemical treatment as needed in years 2 and 3. At that point, *Phragmites* should be eliminated or reduced to such low densities that hand pulling is feasible as a follow up as warranted. The overall cost of a complete program for all Sandwich ponds with these invasive shoreline plants has been estimated at about $50,000 over three years for control with herbicides and at least $100,000 for control by physical means.

Permits for hand cutting and pulling might only involve a negative Determination of Applicability under the Wetlands Protection Act. If mechanical equipment is needed, an Order of Conditions under the WPA will be needed. Permits for herbicide treatment include an Order of Conditions under the WPA and a License to Apply Chemicals. The latter is provided by the MA Department of Environmental Protection and is relatively straightforward once an Order of Conditions has been issued. Any Order of Conditions is written by the local conservation commission after a Notice of Intent is filed and properly reviewed and subject to public hearing by a vote of the conservation commission. There are no protected species known for Pimlico Pond and its immediate shoreline so the Natural Heritage and Endangered Species Program would not need to be consulted.

It should be noted that glyphosate would be a highly applicable herbicide to use for *Phragmites* control, but this chemical has been in the news these past few years for links to cancer and related health impacts. However, this is largely related to extensive use on genetically modified crops in giant agribusiness applications, and then only through selective use of data. The risk is negligible for targeted *Phragmites* control on such a small scale as envisioned here. People often fail to discern this very important difference, or that it is additives in the herbicide mixes used in agriculture that represent the greatest risk, and these additives are not used in aquatic environmental applications. The selective use of glyphosate for aquatic invasive species control has minimal similarity to the agricultural uses that have resulted in all the negative publicity or even use by homeowners on lawns. The formulations are different and aquatic use is much more limited. However, growths of *Phragmites* are not so extensive that physical controls could not be applied at Pimlico Pond, just at greater cost.

Snake Pond

General Pond Features

Snake Pond covers 83 acres in south Sandwich (Figure 1), offers about 1.6 miles of shoreline, has an average depth of 17.1 feet and a maximum depth of 34.3 feet (Table 1). Bathymetry (Figures 36 and 37) is bowl-like to 20 feet, with two separate depressions of 30 feet depth. The pre-1990 DFW bathymetry was checked through measurements at 63 points in August 2018. While the general pattern of depth in the older map (Figure 36) was confirmed, there were differences that prompted creation of a new map (Figure 37). The water was deeper than normal in August 2018, leading to some of the difference, but the contours in the north cove and addition of 5-foot depth intervals elsewhere represent improvements. The volume of Snake Pond is estimated to be 1419 acre-feet. The shoreline is sandy to gravelly with cobble in some areas, extending out to about 18 feet of water depth with very little organic muck sediment, after which the surficial substrate is all muck (Appendix).

The pond has no surface water inlets or outlets. Groundwater flow is from the north-northwest (Figure 2). Snake Pond is not far off the Joint Base Cape Cod (JBCC, formerly the Massachusetts Military Reservation) and the CWRMP (Wright-Pierce 2017) indicates that there is a plume of contaminated groundwater approaching Snake Pond from the JBCC. There is an additional contaminated plume from directly north that does not appear to originate on the JBCC, but no information is provided on the nature and extent of those plumes. As Snake Pond is fairly close to the crown of the groundwater table, the contributory zone is smaller than for many other ponds in Sandwich. The CWRMP also shows a groundwater flow division along Snake Pond Road such that Snake Pond and Weeks Pond are served by the same groundwater flow path. Based on direct precipitation and estimated groundwater inflow, the average detention time for Snake Pond is calculated at 665 days or 1.8 years.

Snake Pond is used for swimming, boating and fishing. There is a town beach complex on the south side off Snake Pond Road with ample parking, lifeguards and recreational facilities. There is a summer camp (Camp Good News) on the northeast side that has overnight and day camp sessions from late June through early August and can be rented for use at other times. Boat access is off Snake Pond Road on the southwest side with an undeveloped boat ramp and limited parking area. Most of the rest of the shoreline is private property. Snake Pond is a Great Pond under a Commonwealth of Massachusetts statute. It has a Total Maximum Daily Load allocation for mercury in fish tissue generated as part of a regional study but is not otherwise listed as an impaired waterbody by the MADEP (2017).

Watershed Features

The Joint Base Cape Cod (JBCC) is not far from the pond to the northwest and most of the groundwater contributory zone is on the JBCC. The Camp Good News property occupies a large parcel at the north end of the pond. Snake Pond Road and the town beach complex occupy the southern side of the pond. The remainder of the shoreline is broken into smaller lots, but there is substantial wetland around this pond and housing density is not as high as parcel listing might make it seem (Figure 38). Stormwater drainage systems are limited near this pond, and the town diverted stormwater from Snake Pond Road east of the pond into vegetated areas to limit impact to the pond. The CWRMP (Wright-Pierce 2017) shows some leaching catch basins around Snake Pond but no direct storm discharges to the pond.

Figure 36. Bathymetry of Snake Pond from pre-1990 MA DFW records.

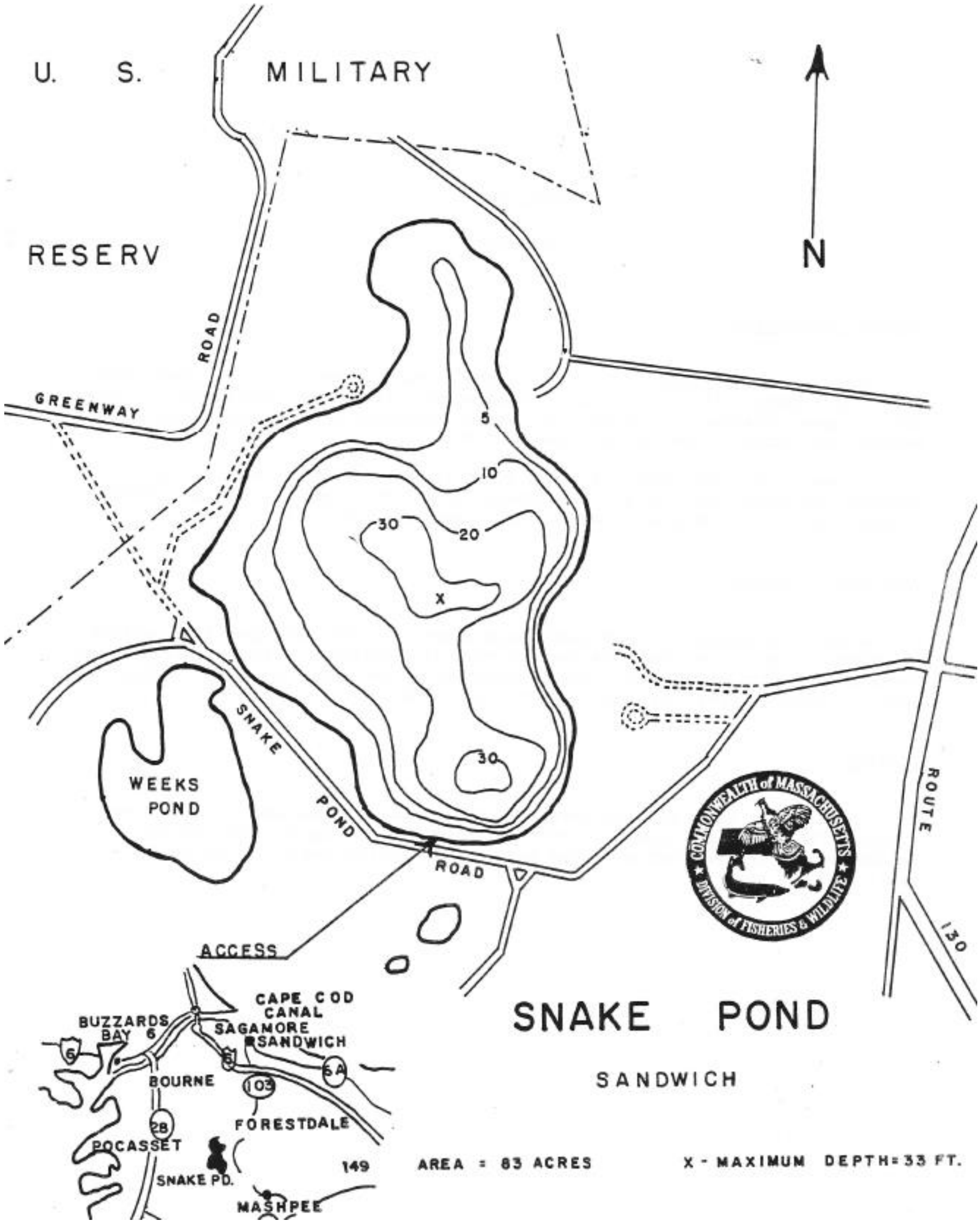


Figure 37. Bathymetry of Snake Pond from WRS 2018 measurements.

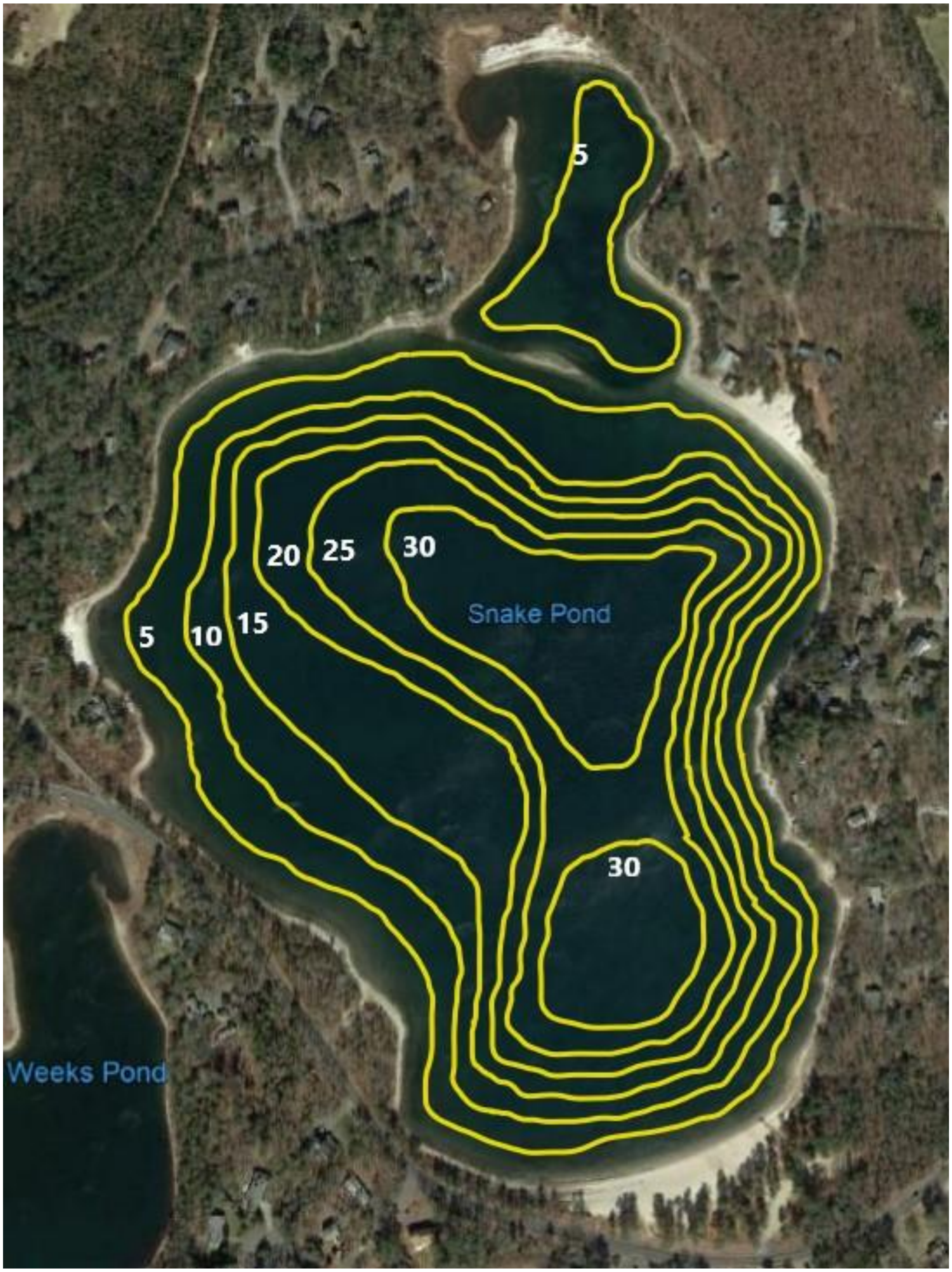
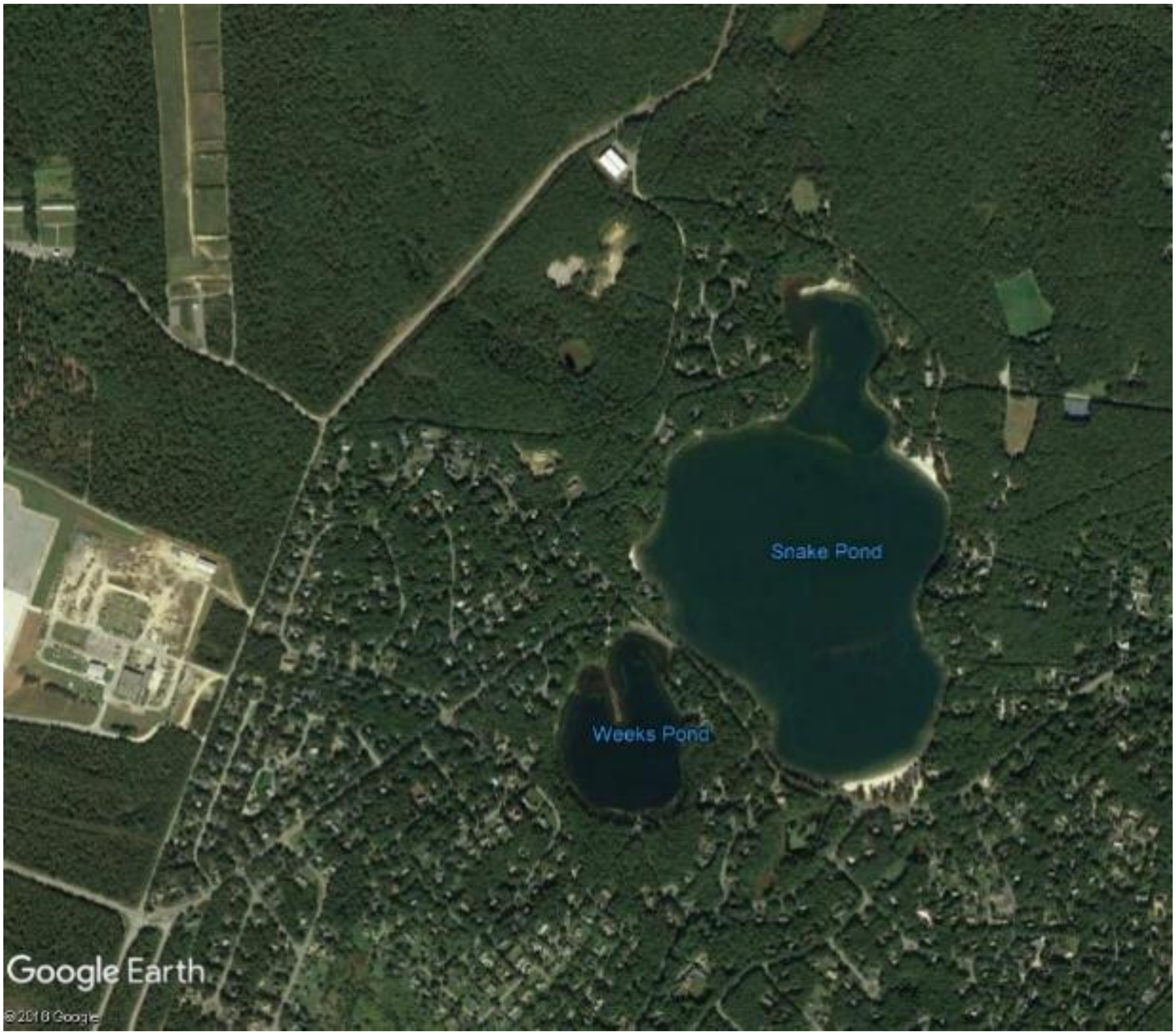


Figure 38. General vicinity of Snake and Weeks Ponds.



Pond Water Quality

A water clarity reading from at least two decades ago was 22 feet (6.7 m) and oxygen profiles in 1948, 1997, 2001 and 2002 indicate no anoxia near the bottom (Eichner et al. 2003). In 2001 the pH was slightly acidic, alkalinity was very low, chlorophyll was low (1-2 µg/L), phosphorus was moderate (12 µg/L) and nitrogen was very low (40 to 160 µg/L). It has been speculated that Snake Pond is in a relatively unimpacted condition and has been stable for over 50 years, but data from the last 16 years are lacking.

Snake Pond was sampled near the deepest point in the central basin (Figure 39) in August 2018. Testing revealed low alkalinity and slightly acidic pH, a natural condition for most Cape Ponds (Table 12). Oxygen was depressed but not depleted at the deepest point, slightly lower than in 2001 but better than many Cape Ponds with similar depth. Phosphorus and nitrogen levels were all low or barely in the moderate range. N:P ratios were much higher than 17 years ago. Water clarity was high at 21 feet (6 m), within the

Figure 39. Snake Pond survey points.

Table 12. Water quality and plankton summary for Snake Pond.

Snake Pond			
Feature	**Units**	**Pre-2012 Value/Rating**	**Aug 2018 Value/Rating**
Bottom Dissolved Oxygen	mg/L	4.0	2.6
Average pH	SU	6.6	6.7
Surface Alkalinity	mg/L	2.9	3.0
Average Conductivity	µS	ND	46
Surface Total P	µg/L	12	8
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	12	7
Bottom Dissolved P	µg/L	ND	5
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	120
Bottom Ammonium N	µg/L	ND	130
Surface Total Kjeldahl N	µg/L	ND	370
Bottom Total Kjeldahl N	µg/L	ND	450
Surface Total N	µg/L	160	380
Bottom Total N	µg/L	40	460
Surface N:P Ratio	Unitless	13	48
Bottom N:P Ratio	Unitless	3	66
Average Turbidity	NTU	ND	0.5
Secchi Transparency	m	4.0 - 6.7	6.3
Average Chlorophyll-a	µg/L	1.6	2.6
Phytoplankton Biomass	µg/L	ND	142
Cyanobacteria	%	ND	63
Zooplankton Biomass	µg/L	ND	306
Zooplankton Mean Length	mm	ND	1.00
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

range reported in past studies. Turbidity was very low. Overall water quality was excellent and there was no indication of deterioration since the last testing in the early 2000s. Other than a regional issue with mercury in fish tissue, Snake Pond appears to be in a natural condition that supports all designated uses.

Pond Biology

Phytoplankton were sampled at the water quality station in August 2018. Biomass was very low, but the most abundant algae were cyanobacteria at 63% of the biomass. This rates as potentially problematic under the rating system applied, but the taxa encountered were *Chroococcus, Aphanocapsa* and *Merismopedia*, none of which are known to produce taste, odor or toxins and are rarely found at bloom densities. The remaining biomass was comprised of flagellated golden algae, small green algae and a few diatoms. No phytoplankton issues were indicated.

Plants were surveyed at 63 stations (Figure 39) in August 2018. Nine species of aquatic plants were observed during the survey, along with both benthic filamentous green (Chlorophyta) and cyanobacteria mats and the macroalga *Nitella* (Appendix). The most frequently encountered plants were benthic filamentous green algae mats (41% of sites), spikerush (*Eleocharis acicularis* at 24%), hedge hyssop (*Gratiola neglecta* at 19%), *Nitella* (19%) and submergent arrowhead (*Sagittaria graminea* at 16%) (Appendix). The submergent arrowhead was the only species found consistently at high density, followed by *Nitella*; both of these plants grow close to the bottom, creating a carpet of valuable habitat.

Most plants were found in <10 feet of water, with mostly large forms of algae found deeper. The only vegetation beyond 28 feet of water depth was cyanobacteria mats, and these were restricted to the deeper water. The overall cover rating was 1.9, indicating cover averaging close to 25% of the bottom. The average biovolume rating was 0.8, suggesting that much less than 25% of the water column was filled by plants. No plant nuisances were observed, and cover by plants is generally scarce in Snake Pond. There were some significant stands of pondweed and expansive bottom growths of spikerush in the shallow northern cove, which in general had more complete bottom cover by plants than the main body of the pond to the south where 37% of all sites had no plants.

There were no invasive species observed, either submerged in the pond or around its periphery, including a lack of common reed (*Phragmites australis*) and purple loosestrife (*Lythrum salicaria*).

Zooplankton were collected at the water quality station in August 2018. Biomass was among the highest observed for Sandwich Ponds and was dominated by large bodied *Daphnia*, a zooplankter that efficiently grazes algae and makes excellent food for small fish (Table 12, Appendix). Average body length for crustacean zooplankton was a high 1 mm, suggesting limited predation by small fish and dominance by larger gamefish in this pond.

Mussels, snails and sponges were all observed during the biological survey of 63 sites. While this survey was not quantitative, there were a moderate number of mussels and very few snails or sponges. Low alkalinity suggests low calcium content that may restrict shell formation and maintenance by mollusks.

Snake Pond hosts a warmwater fishery, with chain pickerel, largemouth bass, smallmouth bass, golden shiner, white and yellow perch, pumpkinseed, white sucker and brown bullhead reportedly present

(Desmarais 2007). The pond is not very productive, but fishermen report catches of desirable sized fish of all species. The zooplankton size distribution indicates that larger fish should be abundant. The former Division of Fisheries and Game stocked the pond with various warmwater species decades ago, but no recent management appears to have occurred. It is not clear why Snake Pond has not been stocked with trout by DFW, as conditions are suitable and access is similar to that afforded by Spectacle Pond.

Snake Pond is on the Massachusetts 2016 Integrated Waters List as having a completed Total Maximum Daily Load (TMDL) for mercury in fish tissue. This TMDL is the result of a study of almost 100 Massachusetts ponds by the New England states plus New York and finalized in 2007. The TMDL document outlines a strategy for reducing mercury concentrations in fish in northeastern freshwater systems. This will require reductions from mercury sources within the Northeast region, USA states outside of the region, and global sources. The majority of mercury pollution in the northeastern USA is a result of atmospheric deposition, so there is little that Sandwich can do on its own. This TMDL could very well apply to all Sandwich Ponds, but only Peters Pond, Spectacle Pond and Snake Pond were included in the project.

State listed (protected) species are apparently present as the NHESP maps the entire pond as Priority Habitat 490 (Figure 40). WRS does not know what species inhabit PH490, but the entire pond and some distance onto shore is included, so it may be more than one species, as few individual species would make use of all habitat types included.

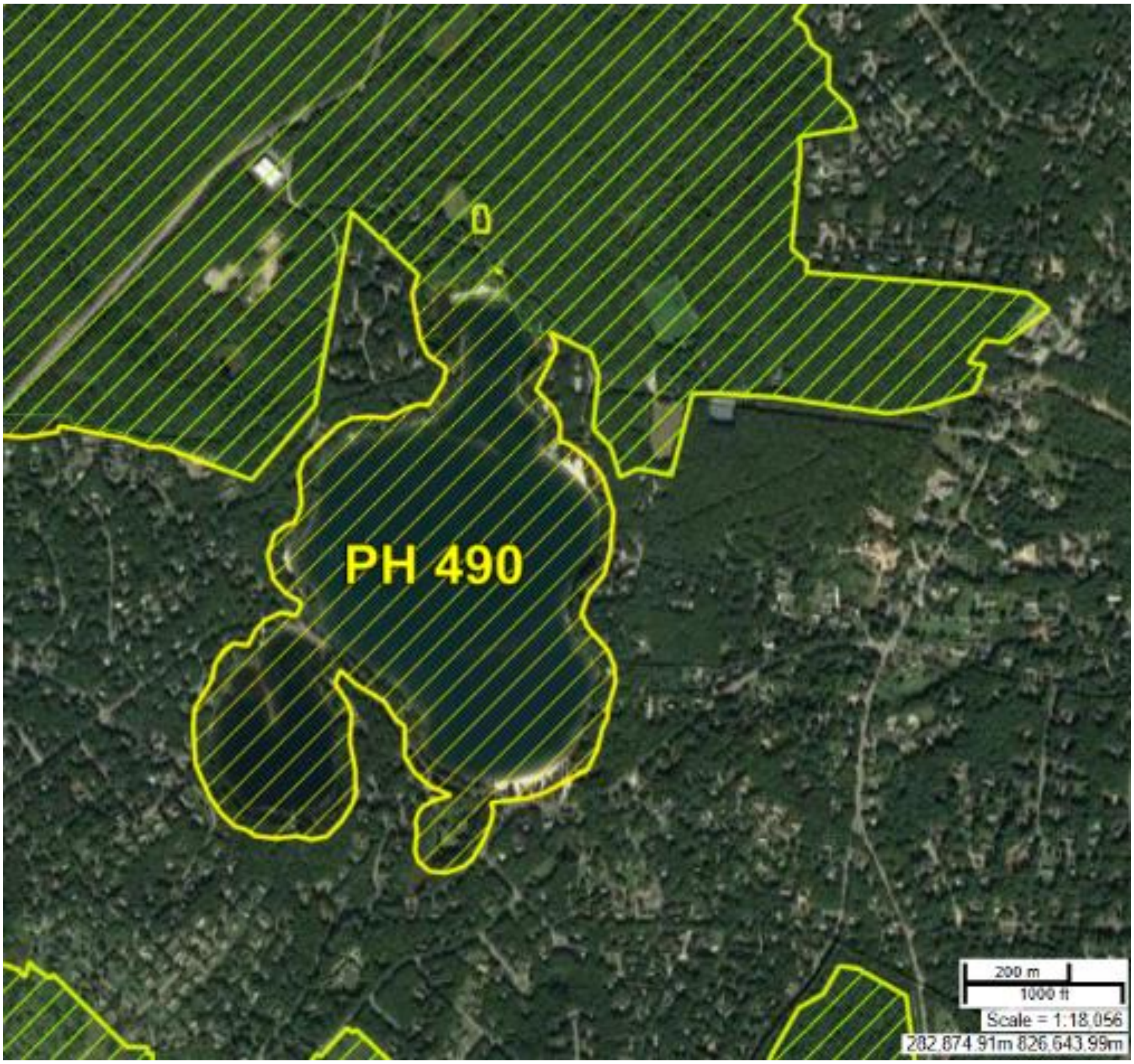
Management Needs and Recommendations

Snake Pond appears to meet its designated uses of contact recreation and fish and wildlife habitat. There are potential groundwater contamination zones identified west and east of the pond (Wright-Pierce 2017) but no impacts are apparent at this time based on the August 2018 field assessment of conditions in the pond. The town has been addressing stormwater issues as needs and opportunities present themselves, but there are no apparent impacts to Snake Pond at this time. Action to limit mercury inputs is called for by the regional TMDL, but this relates to widespread atmospheric contamination; there is little that Sandwich can do in this regard.

The primary need at Snake Pond appears to be protection of what seems to be a high quality aquatic habitat. The Wetlands Protection Act offers considerable protection for water resources from activities close to those resources and is administered locally by the Sandwich Conservation Commission. Beyond the jurisdictional reach of this law, the primary threat is from contaminants that enter groundwater upgradient from the pond. The key area is to the northwest on JBCC property, out of the control of the Town of Sandwich.

The other ongoing need is continued monitoring. There were no water quality data reported between 2002 and 2018. The 2018 assessment does not suggest any major change in Snake Pond, suggesting that monitoring may not be needed as frequently as for some of the other ponds. However, given the value of understanding year to year variation and tracking any trends, it is recommended that Snake Pond be included in a monitoring program that includes water quality and plankton assessment as performed in 2018 and conducted once in late spring and once in late summer each year.

Figure 40. NHESP habitat mapping near Snake and Weeks Ponds.



Weeks Pond

General Pond Features

Weeks Pond covers 15 acres adjacent to Snake Pond in south Sandwich (Figure 1), with just Snake Pond Road separating them. It is possible that they were connected at some point after the last glaciation, but they have been separate ponds in modern history and groundwater mapping (Wright-Pierce 2017) suggests different flow paths and contributory areas for each. There are 0.76 miles of shoreline. Little was known of the bathymetry of Weeks Pond before the 2018 investigation and a depth map was prepared based on measurements at 42 points in August 2018 (Figure 41). The average depth is 10.5 feet with a maximum depth of 20.3 feet (Table 1). Pond volume is calculated at 158 acre-feet.

The shoreline is mostly wooded despite multiple homesites, some with buildings close to the pond. The substrate is sandy to gravelly from shore out to a depth of about 8 feet, after which thin organic (muck) deposits occur in some areas but sand is still plentiful (Appendix). Beyond a water depth of about 14 feet the bottom is covered by muck sediment.

There are no surface water inlets or outlet to Weeks Pond. Groundwater inflow is primarily from the northwest, but it is a relatively short distance to the groundwater divide on the Joint Base Cape Cod (JBCC, formerly the Massachusetts Military Reservation). Slopes are steep enough around much of the pond that some localized groundwater may enter from other sides of the pond. However, the town wellfield south of the pond may affect groundwater flow paths. Based on direct precipitation and estimated groundwater inflow the average detention time for Weeks Pond is 208 days or 0.6 years.

Access to Weeks Pond is very limited. Snake Pond Road runs along the north side (Figures 38 and 41), but there is no place to park and access is impeded by a guardrail and vegetation including poison ivy. The town has a wellfield south of the pond and a pump station overlooking the pond, but this land area is fenced off and not open to the public. The remainder of the shoreline is private property with residences with pond access.

Weeks Pond is a Great Pond under Massachusetts law and is not listed as an impaired waterbody by the MADEP (2017).

Watershed Features

The surface watershed is rather small, extending less than a thousand feet in any direction. There are some leaching catch basins within the drainage area (Wright-Pierce 2017) but no direct stormwater discharges to the pond. Storm drainage improvements along Snake Pond Road were done in a way to prevent impact to Weeks Pond. The groundwater contribution zone extends mainly to the northwest through a residential area and on to JBCC land (Figure 38), but there is no indication of any contaminated groundwater plumes approaching Weeds Pond (Wright-Pierce 2017). There are numerous small land parcels around the lake, with 15 within 300 feet and upgradient in terms of expected groundwater flow. Twelve of those lots are developed, and a few buildings are very close to the pond, but the level of disturbance is not extreme. There is a town wellfield to the south that may draw some water indirectly from the pond, but there was no indication of any water level impact on Weeks Pond in 2018 when water levels were higher than average. The peninsula projecting into the pond from the north was completely

Figure 41. Bathymetry of Weeks Pond from WRS 2018 measurements.

under water in August 2018. The water level as shown in Figure 41 may be lower than average, but the peninsula supports terrestrial vegetation and is therefore not usually under water.

Pond Water Quality

No monitoring data were available for Weeks Pond prior to the 2018 investigation. No algal blooms have been reported, but public use of this waterbody is minimal due to access limitations. Water level fluctuations have been reportedly substantial at Weeks Pond, possibly related to pumping from the adjacent town wellfield, but no water level records were found. The likely interaction of Weeks Pond with town wells suggests that the town should have a strong interest in the water quality in Weeks Pond.

Weeks Pond was sampled at its deepest point (Figure 42) in August of 2018. Testing revealed low alkalinity and slightly acidic pH, a natural condition common to most Cape Cod ponds (Table 13). Oxygen near the bottom was quite high, suggesting daytime input by plants and/or algae. When oxygen is that high near the bottom by day, it often decreases dramatically at night when photosynthetic oxygen production ceases and respiration continues. Overnight oxygen measurement may be needed to understand this situation better. Surface phosphorus concentration was slightly elevated (in the moderate or tolerable range) but bottom phosphorus was distinctly high and suggests release from sediments, possibly mediated by overnight oxygen depression. Nitrogen concentrations were low, suggesting no major impact from wastewater in groundwater inflow, but resulting in low N:P ratios that may favor cyanobacteria.

Water clarity as measured by Secchi transparency was 16.5 feet (5 m), at the boundary between moderate (tolerable) and high (desirable). Turbidity was correspondingly low.

Pond Biology

Phytoplankton were sampled at the water quality assessment station (Figure 42). Biomass was very low, which was somewhat surprising given the slightly elevated surface phosphorus concentration and distinctly high bottom phosphorus level. Cyanobacteria represented only 9% of the total phytoplankton biomass and the species present were innocuous forms not known to cause taste, odor or toxicity or to form major blooms; this is also surprising given the low N:P ratio. The most abundant phytoplankton were small green algae usually associated with much higher N:P ratios. As this information was generated from a single sample from a single date, not too much should be read into these results; additional monitoring is highly recommended.

Prior to 2018, only shoreline observations of plants from 2011 were available. Pondweed (*Potamogeton* sp.) and spikerush (*Eleocharis acicularis*) were observed washed up on shore, and remnant stalks of what appeared to be bulrush (*Schoenoplectus validus*) were common in shallow water. Plants were assessed at 42 sites (Figure 42) in August 2018, with measurement of water depth, substrate type, plant cover and biovolume, and relative abundance of species. A total of 16 species of plants were identified, including 12 rooted vascular plants, benthic filamentous mats of green algae (Chlorophyta) and cyanobacteria, and two species of the macroalga *Nitella* (Appendix). Purple bladderwort (*Utricularia purpurea*) was the most frequently encountered plant at 67% of sites. Spikerush (*Eleocharis acicularis*) was the next most frequent plant at 64%, followed by green algae mats at 48% of sites. No other plant species was found at more than 30% of surveyed sites.

Figure 42. Weeks Pond survey points.

Table 13. Water quality and plankton summary for Weeks Pond.

Weeks Pond			
Feature	Units	Pre-2012 Value/Rating	Aug 2018 Value/Rating
Bottom Dissolved Oxygen	mg/L	ND	9.7
Average pH	SU	ND	6.8
Surface Alkalinity	mg/L	ND	3.0
Average Conductivity	µS	ND	84
Surface Total P	µg/L	ND	16
Surface Dissolved P	µg/L	ND	5
Bottom Total P	µg/L	ND	70
Bottom Dissolved P	µg/L	ND	23
Surface Nitrate/Nitrite N	µg/L	ND	10
Bottom Nitrate/Nitrite N	µg/L	ND	10
Surface Ammonium N	µg/L	ND	34
Bottom Ammonium N	µg/L	ND	60
Surface Total Kjeldahl N	µg/L	ND	310
Bottom Total Kjeldahl N	µg/L	ND	330
Surface Total N	µg/L	ND	320
Bottom Total N	µg/L	ND	340
Surface N:P Ratio	Unitless	ND	20
Bottom N:P Ratio	Unitless	ND	5.0
Average Turbidity	NTU	ND	0.4
Secchi Transparency	m	ND	5.0
Average Chlorophyll-a	µg/L	ND	2.8
Phytoplankton Biomass	µg/L	ND	139
Cyanobacteria	%	ND	9
Zooplankton Biomass	µg/L	ND	129
Zooplankton Mean Length	mm	ND	0.86
Sediment Fe-P	mg/kg	ND	ND
Sediment Biogenic P	mg/kg	ND	ND
Sediment Al:Fe Ratio	Unitless	ND	ND
ND = No Data	Desirable	Tolerable	Problematic

While not overly abundant, floating leaved plants were more common in Weeks Pond than other Sandwich ponds surveyed. Watershield (*Brasenia schreberi*), white water lily (Nymphaea odorata), yellow water lily (*Nuphar variegata*) and floating heart (*Nymphoides cordata*) were all found in shallow water and provided valuable habitat.

Plants were found at all depths in Weeks Pond; there was no light or substrate limitation on growth. The overall cover rating was 3.4 on a scale of 0 to 4, suggesting 50 to 75% of the pond bottom is covered by plants, likely closer to 75% than 50%. The biovolume rating was 1.6 on a scale of 0 to 4, indication 25 to 50% of the water column was filled. Plant density was patchy, with some areas much denser than others. Overall habitat value for fish and wildlife was high.

No purple loosestrife (*Lythrum salicaria*) was observed around Weeks Pond, but two patches of common reed (*Phragmites australis*) were found along shore just west of the pumphouse for the town wellfield (Figure 43). These patches are each about 50 feet long and 10 feet thick. No submergent invasive species were detected in Weeks Pond.

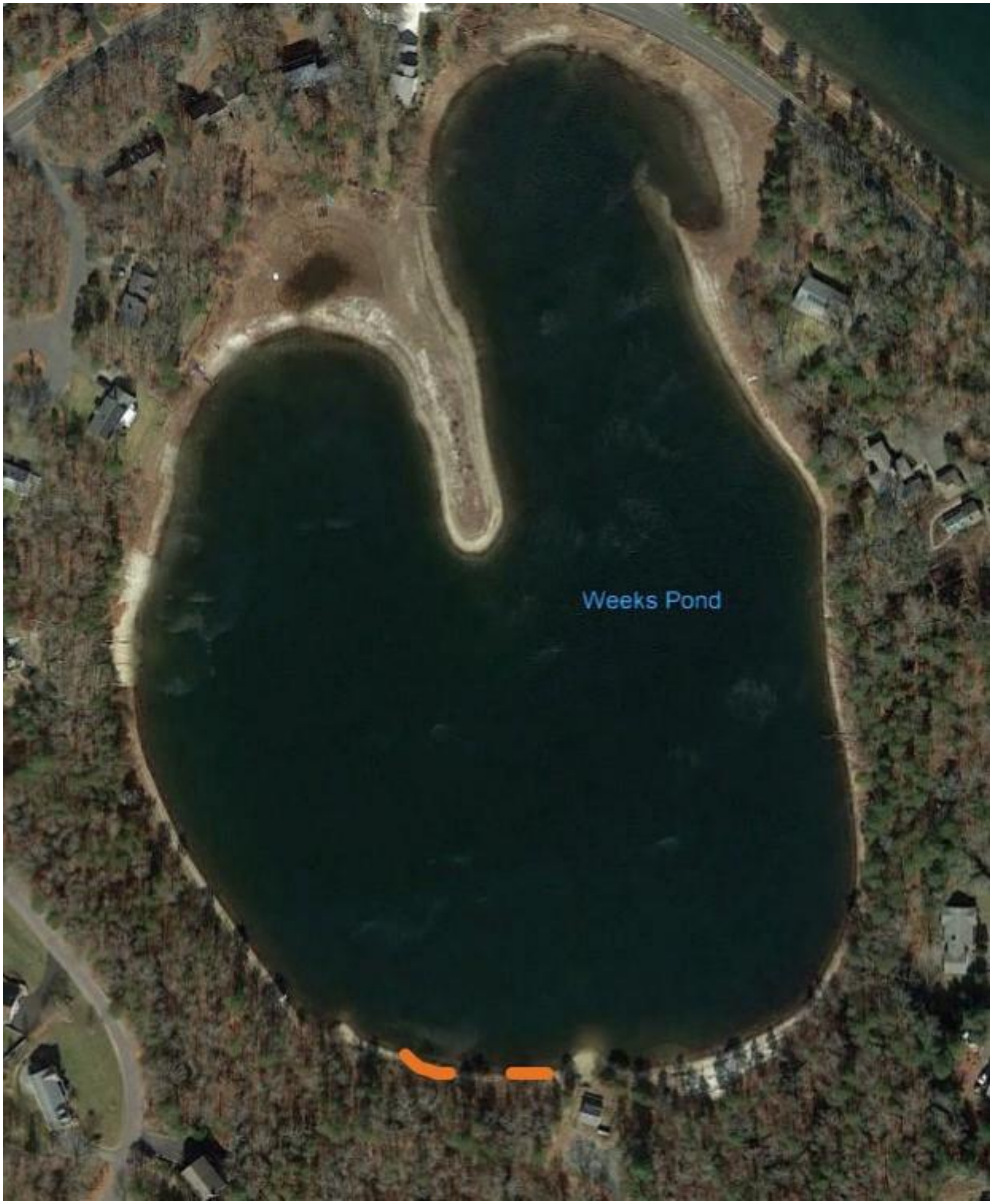
Zooplankton were also collected at the water quality station (Figure 42) in August 2018. Biomass was 129 µg/L, above the high threshold and desirable. Mean crustacean zooplankton body length was 0.86 mm, a high value that suggests limited predation by small fish; larger gamefish may be more abundant in this little fished waterbody. The most abundant zooplankton in terms of biomass were fast swimming calanoid copepods and the acid water cladocern *Holopedium*. No large bodied *Daphnia* were present, limiting grazing capacity and small fish food quality.

No mussels, snails or sponges were observed in Weeks Pond. While this was not a quantitative survey for these organisms, if they were present in significant quantities, they should have been detected during the survey of 42 sites. Low alkalinity indicates low calcium content and development and maintenance of mollusk shells may be difficult. Sponges tend to be more abundant in low pH water but the pH in 2018 was not especially low.

No data for fish appear to be available. A warmwater assemblage would be expected, including largemouth and possibly smallmouth bass, yellow perch, pumpkinseed and bluegill sunfish, banded killifish, and possible golden shiners and brown bullheads. Sunfish, largemouth bass and killifish were observed during the August 2018 survey. Even online fishing sites have no information on Weeks Pond; the lack of public access appears to be a major factor in use of the pond.

The NHESP has mapped all of Weeks Pond as Priority Habitat (Figure 40), indicating that at least one listed (protected) species is present. WRS does not know what species inhabit PH490, but the entire pond and some distance onto shore is included, so it may be more than one species, as few individual species would make use of all habitat types included.

Figure 43. Phragmites patches at Weeks Pond



Management Needs and Recommendations

Weeks Pond appears to meet its intended uses of contact recreation and fish and wildlife habitat. Water supply could be added to that list of uses, given the nearby wellfield and likely water interaction. There is no indication of any groundwater quality issue. Stormwater has been managed to a reasonable degree and no direct discharges to the pond are known. For the purpose of water supply, minimizing human interaction with the pond and wellfield is desirable, and the lack of public access may be appropriate.

The primary problem to be addressed is the invasion of common reed, which currently exists as two small patches near the wellfield pumphouse (Figure 43). These patches could be accessed from land and controlled by physical (repeated cutting or excavation of whole plants) or chemical (herbicide) application. The simplest access would be through the wellfield, requiring coordination with the Sandwich Water Department. Taking action before this invasive species spreads farther is strongly recommended and could be combined with actions at other Sandwich ponds (Upper and Lower Shawme, Peters, Pimlico Ponds) to control this invasive species.

A three-year program is advised, with sequential physical or chemical treatment as needed in years 2 and 3. At that point, *Phragmites* should be eliminated or reduced to such low densities that hand pulling is feasible as a follow up as warranted. The overall cost of a complete program for all Sandwich ponds with these invasive shoreline plants has been estimated at about $50,000 over three years for control with herbicides and at least $100,000 for control by physical means.

Permits for hand cutting and pulling might only involve a negative Determination of Applicability under the Wetlands Protection Act. If mechanical equipment is needed, an Order of Conditions under the WPA will be needed. Permits for herbicide treatment include an Order of Conditions under the WPA and a License to Apply Chemicals. The latter is provided by the MA Department of Environmental Protection and is relatively straightforward once an Order of Conditions has been issued. Any Order of Conditions is written by the local conservation commission after a Notice of Intent is filed and properly reviewed and subject to public hearing by a vote of the conservation commission. There are protected species known for Weeks Pond and its immediate shoreline so the Natural Heritage and Endangered Species Program would need to be consulted. Weeks Pond is the only possible location of *Phragmites* control where the NHESP would need to be involved.

It should be noted that glyphosate would be a highly applicable herbicide to use for *Phragmites* control, but this chemical has been in the news these past few years for links to cancer and related health impacts. However, this is largely related to extensive use on genetically modified crops in giant agribusiness applications, and then only through selective use of data. The risk is negligible for targeted *Phragmites* control on such a small scale as envisioned here. People often fail to discern this very important difference, or that it is additives in the herbicide mixes used in agriculture that represent the greatest risk, and these additives are not used in aquatic environmental applications. The selective use of glyphosate for aquatic invasive species control has minimal similarity to the agricultural uses that have resulted in all the negative publicity or even use by homeowners on lawns. The formulations are different and aquatic use is much more limited. However, growths of *Phragmites* are not so extensive that physical controls could not be applied at Weeks Pond, just at greater cost.

Beyond *Phragmites* control, the only action recommended at this time is ongoing monitoring. The lack of water quality data for a Great Pond linked to water supply is somewhat surprising; knowledge of conditions in the pond should be expanded to aid overall water resource management. Monitoring could follow the approach applied in the 2018 assessment with measurement of water quality and plankton, but with assessment in late spring and late summer of each year. Additionally, water level monitoring is recommended for Weeks Pond, as there have been claims of substantial fluctuations. The intersection of water supply and protected species habitat is a place the town should avoid, but a lack of data affords little defense. It is also advisable to test the surficial sediment in the deepest part of Weeks Pond for available phosphorus as performed for five other ponds in the 2018 assessment. The elevated deep water phosphorus and moderate surface phosphorus concentrations are a concern and are likely to be related to release from surficial sediments. It is further recommended that oxygen be assessed overnight to determine if nighttime oxygen depression is occurring as suspected.

Understanding Key Influences on the Ponds

Low Alkalinity and pH

The geology of Cape Cod provides very little buffering capacity via soils and the generation of acids through decay result in acidic water in most ponds. The pH can be very low, but mostly it is between 6.0 and 7.0, a tolerable range for the vast majority of aquatic organisms. The low buffering capacity means that pH fluctuations could be large in response to inputs, so low alkalinity lakes are flagged in most evaluations as threatened or susceptible. Yet with the success of the Clean Air Act and limited stormwater runoff on Cape Cod, actual pH fluctuations in the low direction are rarely large. The bigger risk involves high productivity by rooted plants or algae that removes carbon dioxide through photosynthesis and raises the pH. Fortunately, the upper pH limit for most aquatic organisms is high (>8.5) and is rarely observed in Cape Cod ponds.

The alkalinity of the assessed Sandwich ponds ranged from 2 to 30 mg/L, although surface values were all <12 mg/L. Deeper water sometimes accumulates substances that raise alkalinity. The pH ranged from 6.3 to 7.9, but only the Shawme Ponds and the shallower basin of Spectacle Pond exhibited pH values >7.1. Mollusks will have some difficulty forming and maintaining shells in many of these ponds due to low calcium content, but some low alkalinity ponds do support major populations of mussels. Low alkalinity and pH will also affect which plant species grow best in these ponds.

In the past there have been efforts to counter the low buffering capacity of acidic ponds with calcium additions. Apparently one such treatment was conducted at Lawrence Pond, but no details appear available. Such treatment may work for a time but ultimately the natural low alkalinity, low pH condition will prevail. There is no recommended ongoing action, but those interested in water management in the Town of Sandwich should be aware of this natural condition, as it affects both surface and groundwater. Water supply management will involve various treatments of potable water, most notably to limit pipe corrosion, but any such treatment is done just prior to distribution, not out in the environment.

Water Level

The water level in the Shawme Ponds is controlled by their respective dams. Water levels could drop below the dam crest in very dry periods or rise higher above it during a major storm, but with groundwater as the main water source, the level will be relatively constant. This is not the case for the other 10 ponds assessed in this investigation, however, as they are all kettlehole ponds formed by stranded ice at the end of the last glacial period and water levels are linked to the groundwater table. Direct precipitation and some minor runoff can cause short-term fluctuations of inches, but the groundwater table is known to vary by at least 2 feet over the course of most years and can vary as much as 4 feet.

The Sandwich kettlehole ponds will tend to be at maximum elevation in spring after a period of higher precipitation and potentially some snowmelt and at a time when water demands by the human population are not at peak. The water level is then expected to decline through summer and into fall, with increased groundwater table elevation usually beginning around November. But this annual pattern can be disrupted by the weather or withdrawals (e.g., possibly the wellfield by Weeks Pond). The ponds were experiencing very high water levels in August 2018 when most of the field work for this investigation was conducted, the result of a fairly wet spring and only a few weeks of especially hot, dry weather in summer.

Water level can have a major impact on pond ecology. Flooding around the edge can disrupt the life cycle of certain plants, many of which are endangered, or provide additional foraging habitat for fish or birds preying on those fish. Yet the largest impact is in deeper water, depending on the morphometry of the pond, where the presence and depth of stratification may have pronounced impact on oxygen and sediment-water interactions. On the Cape we expect wind mixing to prevent stratification at depths of less than 20 feet, while lakes with more than 30 feet of water depth almost always stratify. Where the normal maximum depth of a lake is between those values, the water level may aid or impede stratification.

Several Sandwich ponds exhibited conditions in 2018 not completely consistent with past data. Lawrence Pond showed signs of stratification that are usually absent, but with an extra 1-2 feet of water depth at least temporary stratification was established. The wind mixes from the top down, and with the pond being deeper, an unmixed layer developed at the bottom. This allowed the oxygen in the bottom layer to be depleted and facilitated increase phosphorus availability at a depth where there was still enough light to grow algae. This is believed to be the cause of the observed cyanobacteria bloom. Likewise, Pimlico Pond had deeper water in 2018 and was stratified slightly above the bottom unlike the condition documented in 2001. Pimlico Pond also had an algae bloom in 2018, although it did not include cyanobacteria.

The extra depth can actually be a benefit to ponds which are deep enough to stratify normally. The upper layer remains at about the same thickness, creating a thicker bottom layer in summers of greater water depth. That thicker layer may resist oxygen loss longer; more water with more oxygen at the same rate of oxygen loss will mean that low oxygen conditions are achieved later in summer if at all. Triangle Pond did not lose its oxygen at the bottom and the depth at which Peters Pond experienced anoxia was deeper than what historic data suggest. Additionally, the presence of an oxygenated zone between whatever depth has no oxygen and the depth at which light is adequate to support photosynthesis creates a "gauntlet" for upward diffusing phosphorus, allowing it to recombine with iron and precipitate out before reaching the depth at which algae can utilize that phosphorus. The potential damage from oxygen loss near the bottom can be mitigated to some degree by greater depth.

Water level is not something that can be easily managed in the Sandwich kettlehole ponds. Oxygen can be managed by mixing systems or oxygen input methods and phosphorus availability can be reduced by addition of phosphorus inactivators such as aluminum. These are valid approaches to improving Cape Cod ponds suffering from internal phosphorus loading caused by low oxygen at the bottom. Dredging would represent true restoration, removing oxygen-demanding, phosphorus-rich sediment that has accumulated over centuries, but is too expensive to apply in most cases. Those interested in the condition of Sandwich kettlehole ponds should be aware of the influence of water depth and tracking of annual water levels (monthly measures would be appropriate) is recommended.

Detention Time

The amount of time that water spends in a pond influences its condition. When water moves through quickly, on the order of days to a couple of weeks, it is hard for phytoplankton to accumulate to bloom proportions. This seems to be the case for the Shawme Ponds, where inflows are high and flushing is extensive, leading to detention times of 4 (Lower) and 9 (Upper) days. Algae mats that grow on the bottom or get entangled in rooted plants can remain, and phytoplankton species that start on the bottom and synchronously rise to the top may form temporary blooms, but the detention time is too short for blooms to develop in the water column.

In the other ponds, however, detention times are long, ranging from 208 days in Weeks Pond to 881 days in Peters Pond. There is error associated with the estimation of these detention times, but beyond about 180 days (6 months) the exact numbers don't really matter. The water remains in the pond long enough for the impact of any contaminants to be completely expressed, there is ample time for sediment-water interactions to affect water quality, and flushing is inadequate to wash out algae that accumulate over the growing season. Nutrient inputs to these ponds will be processed in the pond and remain there. Some nutrients will be permanently sequestered in the sediment, but some, like iron-bound phosphorus, can come back out of the sediment to support algae blooms when oxygen is low at the bottom.

The impact of any one storm, discharge, spill, or other input is not likely to be overwhelming, but the ponds will accumulate contaminants over many years and gradually deteriorate in condition. Watershed management is always a valid part of lake management, but once a pond with a long detention time has accumulated enough contaminants (most importantly phosphorus) to exhibit problems, watershed management is very unlikely to solve those problems. Protection keeps a pond in desirable condition, but in-lake methods are needed to rehabilitate most damaged ponds.

Groundwater Inputs

Much has been written about the importance of groundwater on Cape Cod and the CWRMP for Sandwich does an excellent job putting what we know in perspective with regard to the water resources of Sandwich. All of the ponds studied in this investigation have water budgets dominated by groundwater inputs. This is not at all the norm in other parts of Massachusetts, and one must be careful when interpreting approaches to water resource management elsewhere for possible application on the Cape. Surface water runoff is a large influence in other areas of Massachusetts, including urban runoff in developed areas and agricultural runoff in farm communities, and direct discharge of wastewater can also be a major influence on water quality. The Cape has much less of these influences, with groundwater and direct precipitation as the main conduits for contaminants to reach ponds.

Some amount of phosphorus will enter the ponds with groundwater. These inputs are unlikely to be large in any year, and phosphorus entering with groundwater will most likely be bound quickly by iron also travelling in the groundwater, but this process continuously adds to the sediment reserves of potentially available phosphorus and may facilitate substantial internal loading in the future. The Shawme Ponds receive the most groundwater of those studied in 2018, and the available data do not indicate the phosphorus load per unit time to be extremely high, although it is somewhat elevated. In the case of the Shawme Ponds with short detention time, much of this phosphorus may be flushed downstream. But for the other ponds with much longer detention times and no surface water outlets, incoming phosphorus will accumulate and may eventually support algae blooms. It may take a long time (decades), but eventually this phosphorus is likely to degrade the ponds if oxygen is not maintained at the bottom.

Recent evaluation of groundwater flow and linked onsite wastewater disposal in southeastern Massachusetts sandy soils (Schellenger and Hellweger 2019) indicates that inputs to the groundwater from onsite wastewater disposal systems can result in movement of phosphorus to surface waterbodies for decades or even centuries. Sand is not the best phosphorus binder, and while most phosphorus will be removed with enough contact with sand, long-term movement can be expected. That means that even if a sewerage system is installed in an area of previous onsite disposal there will be ongoing inputs to the downgradient surface waters for many years. Consequently, the legacy of onsite wastewater disposal is a long-term input to downgradient ponds that may eventually cause issues.

An analysis of phosphorus loading via groundwater is beyond the scope of this investigation, but based on the long-term prognosis above, management of that load will be very difficult in the watershed. Minimizing that load is desirable but not always practical. The use of mixing, oxygenation or inactivation technologies in the ponds is likely the best option if and when internal recycling issues arise.

Stormwater Inputs

Stormwater is not as big an influence on Cape Cod as it is in many other parts of Massachusetts, but it is not a non-issue either, and the provisions of the stormwater program under the National Pollutant Discharge Elimination System apply to Cape Cod. The CWRMP does a credible job describing the current stormwater generation and routing situation and the Town of Sandwich has done an admirable job managing stormwater where problems have been identified. The use of leaching catch basins should prevent most stormwater discharge issues, and soil filtration is an excellent treatment for many contaminants.

However, dissolved nitrogen will move readily through soils and long-term movement of phosphorus in groundwater has been documented as described above, so converting surface runoff to groundwater is not a complete solution. It is recommended that residents be educated about the impact of their residential property management practices on water resources and that all practical steps be taken to minimize the use of products that can lead to increased contaminant loading to the ponds. Progress has been made with regard to phosphorus, which has been removed from wash detergent, dish detergent, and most recently most lawn fertilizers. Yet considerable nitrogen is still used in fertilizer and other contaminants such as pesticides can be obtained by residents and used without training or supervision. Education is an ongoing task and must be repeated at a frequency that exceeds the rate of turnover for the town population.

Dynamic Conditions

Waterbodies are not static; conditions can be expected to vary with many factors, most notably the weather, so predictability is limited. There is a general trend toward increasing fertility over time as nutrients accumulate, but the pace of that transition can vary tremendously. With enough data over enough time, trends may become evident, but without long-term data it is very difficult to know if an observed condition is transient or not.

The 2018 investigation of 12 Sandwich ponds represented the second sampling in at least 16 years for some and was the first known sampling for a few. Where there were distinct differences from a past assessment, some effort was made to describe plausible reason for the change, but we can't be very sure of those causes. While monitoring involves some cost, there is no substitute for well collected data when managing water resources.

Overall, the condition of the 12 studied Sandwich ponds in 2018 was appropriate to their uses; there were no imminent threats to the health of users and most ponds were in a generally desirable condition. However, we do not know if 2018 was representative of the last decade or the decade to come. We know that the summer water level in 2018 was about as high as it has been in anyone's memory and that this had positive effects on some ponds and negative impacts on others. We observed very few algae blooms in 2018 but know that blooms have been reported in the past for some ponds that did not have blooms in 2018. And Lawrence and Pimlico Ponds had blooms in 2018 when none have been reported from more than a decade ago. There is uncertainty in the analysis that can only be reduced by the collection of more data in coming years.

Invasive Species

The invasion of a pond by new species is a natural process. After all, there were few if any species present when the ponds were formed over 10,000 years ago and whole aquatic ecosystems have developed since then. However, when people add new species to which the system is not in any way adjusted, ecological chaos can result, and this can translate into very real impairment of uses and economic cost to those seeking to maintain desirable conditions. The former Department of Fish and Game put fish in many of the ponds, in some cases poisoning the existing fish community in an attempt to start over. Some of the fish they added could be considered invasive by today's standards, but at the time it was thought that this was appropriate management. More recently there have been inadvertent introductions from boats and birds and maybe some intentional introductions for the sake of perceived beauty (e.g., purple loosestrife) or "diversity". Windblown seeds can support invasions over shorter distances (e.g., common reed).

The definition of an invasive species is not consistent everywhere, but a very functional definition is a species that has not previously been present and causes ecological or economic harm when added. Native species can also cause ecological or economic harm if they get too abundant, but that does make them invasive. Non-native species may be integrated into a community without catastrophe, when also makes them non-invasive. Proper concern is placed on the introduction of truly invasive species, as prevention is far preferable to remediation.

Five of the 12 studied ponds have common reed patches around them. None are severely infested, but we don't know how long that invasive species has been present or the rate of expansion. We do know that common reed can expand to form a monoculture around a pond and that habitat and property value will be significantly diminished by such expansion. The same can be said for purple loosestrife, which was found at only 2 of the 5 ponds with common reed and in association with it. Eliminating those plants as quickly as possible will represent the least expensive approach to maintaining desirable features at those ponds. Waiting will cause more damage and increase the cost of control. The probability of eradication also decreases with the length of time a species has been established in an area.

The only other potentially invasive species found in this investigation was the Asian clam, which was detected at 2 locations in Peters Pond. It is not clear that this species is truly invasive in accordance with the definition above, but it is not viewed as a desirable addition, having been linked to more frequent cyanobacteria blooms and competing with native mollusks. Knowing the extent of the invasion by the Asian clam would help determine if implementation of localized controls is worthwhile.

It is far better to prevent the introduction of invasive species than to remediate such introductions, but not all avenues of introduction are easily controlled. Boats are implicated in many invasive introductions, and the limited access to Sandwich ponds may be protective, but where access is afforded there is a responsibility to manage that access to limit invasive introductions. Once a species gains a foothold in one accessible pond, others are put at risk. Peters Pond is the most obvious case, having multiple boat ramps that handle watercraft of all sizes that come from many other waterbodies, and being the one studied pond with Asian clams. Species that have arrived on Cape Cod but appear absent from Sandwich ponds include hydrilla (*Hydrilla verticillata*), fanwort (*Cabomba caroliniana*), and variable watermilfoil (*Myriophyllum heterophyllum*). The Town of Barnstable spends tens of thousands of dollars annually on average to address these invaders. Sandwich would do well to avoid this scenario and should consider an inspection and washing program for boats coming from other waterbodies.

Where invasive species already have a foothold, such as the 5 ponds with common reed (Phragmites), eradication efforts are strongly recommended while infestations are still minor. A program with a cost of $50,000 to $100,000, exclusive of any additional consulting aid for planning and permitting, has been prescribed for these ponds. Early action will prevent either much greater ecological damage or much higher costs for later control.

Regulatory Programs

Great Pond Status

A Great Pond in Massachusetts is a waterbody of at least 10 acres in its original state as of the mid-1600s. It is by law the property of the Commonwealth, and while the property around a Great Pond can be private, access by the public cannot technically be prevented. The original language grants foot access as long as the accessing party does not trample the landowner's crops or scatter his livestock! However, the reality today is that without a public parcel abutting a pond it is not much accessed by the public. A large number of waterbodies have been created by damming streams since then and these are not Great Ponds; Upper and Lower Shawme Ponds fall into this non-Great Pond category. Lower Hog Pond and Hoxie Pond are not Great Ponds because they are too small. The remaining ponds studied in this project are Great Ponds.

The Commonwealth of Massachusetts had an active lake management program at one time and being a Great Pond afforded some priority for management funding. Managing Great Ponds today has largely fallen to the towns in which such ponds lie or to lake associations with an interest in a Great Pond. But they remain the property of the Commonwealth and subject to all the attendant regulations. This includes those regulations that apply to all waterbodies (e.g., the Wetlands Protection Act) and some that apply only to Great Ponds (Chapter 91, which governs structures in lakes, drawdown and dredging). There is no current benefit to being classified as a Great Pond, but there may be an extra burden when management is attempted. This classification of a pond has influence on its management but is not an ecological process.

Impaired Waters Listing

Section 305b of the federal Clean Water Act calls for states to evaluate whether or not waterbodies meet their designated uses on a biennial basis. Section 303d of that same act calls for all waters not meeting state water quality standards to be put on a list for follow up action to meet those standards. States tend to publish an integrated list, showing where all waters of the state stand in relation to these provisions. Being on the impaired waters list affords some priority for state funding to improve conditions, but it guarantees nothing. Many waterbodies have been on that list for close to two decades with no attention. One might think that the combination of being a Great Pond and being on the impaired waters list might garner support at the state level, but that has not been the case. The impetus to protect or rehabilitate a waterbody is almost always local these days. This influences the ponds administratively, not ecologically.

Mapped Priority or Estimated Habitat

Under the Massachusetts Endangered Species Act, the Natural Heritage and Endangered Species Program is responsible for maintaining a database of state listed species for protection and maps of known (Priority) and presumed (Estimated) habitat for those species. This is not a precise science; a circle of a defined radius is drawn around a known location for a species and may include wholly unsuitable habitat. For example, the map for a rare shoreline plant could include the deepest part of a pond where no plants grow or a paved parking lot away from shore. Yet if a proposed project includes any area included in a Priority or Estimated Habitat the NHESP must approve of that project before implementation. Only Spectacle, Lower Hog, Peters and Pimlico Ponds of the 12 studied ponds do not have Priority Habitat within them; the other 8 are at least partly covered by such habitat and most management actions will require review by NHESP. This influences pond management, not pond ecology or water quality.

Wetlands Protection Act

The WPA was created mainly to reduce the loss of wetlands in Massachusetts but applies to all aquatic habitats; lakes and ponds are technically wetlands. This act is administered by the local conservation commission but overseen by MADEP. The regulations related to the WPA have been adjusted several times, most recently in late 2014, and most changes have increased the regulatory difficulty of managing ponds. For example, there is no exemption or short-cut for rapid response to a new invasive species infestation and it may take months to gain approval for an action that should be taken within weeks to be most effective. If a project cannot meet all performance standards linked to whatever resource area is being affected, there is a “limited” project status that can be sought. However, the most recent revision of the regulations grants limited project status mainly to pond projects that can be called ecological restoration. This holds true for most invasive species control efforts, although even some of those projects have been challenged, but projects to reduce the density of native plants are not clearly eligible and it is not at all clear how harmful algal blooms are viewed under the current regulations. Those contemplating pond management need to be very aware of the provisions of the WPA, its regulations, and how the project is presented in a public hearing. This affects pond management, not ecological processes.

Common Needs

Public Access Need Determination

The range of access to ponds in Sandwich is quite wide. Peters Pond offers multiple means of access for people and watercraft with few restrictions. Weeks Pond is almost inaccessible, and given its relation to public water supply, this may be entirely appropriate. Upper and Lower Hog offer no public access, but Upper Hog is a Great Pond to which citizens of Massachusetts are supposed to have access. Triangle Pond has a substantial public parcel abutting it, but actual access through that parcel is very difficult. Pimlico Pond has a small public access area focused on cartop boat launching for fishing. Spectacle and Snake Ponds have undeveloped public access that is not well known, but at the level of use observed, seems suitable. One can reach Upper or Lower Shawme Ponds on foot via public property but getting any kind of watercraft onto those ponds is challenging. Snake, Lawrence, Spectacle and Peters Ponds have town or association beaches on them that afford substantial access to a limited population. Hoxie Pond used to have vehicular access but now has only foot access during summer and this appears to have caused a cessation of trout stocking by the DFW. The access situation appears to have developed haphazardly with little consideration on a townwide scale. It is not necessarily a bad situation, but it would be appropriate for the town to consciously consider what level of access should be afforded to at least the Great Ponds and justify a plan for maintaining or altering the status quo.

Boat Inspection and Washing Capacity

Prevention of invasive species introductions is far less expensive than remediating invasions after they occur and doing nothing relies on luck that has run out in many cases. Peters Pond has 3 invasive species, at least one of which is very likely to have arrived with a boat. There are multiple invasive species already on Cape Cod that have yet to reach the Sandwich ponds and the town should want to keep it that way. The most prudent action is to require that boats be properly washed before being launched on a Sandwich pond. The most practical way to support such protection is to establish a boat washing station at a convenient location and require proof that boats entering Sandwich ponds have been properly washed. This requires equipment and manpower, representing a very real cost, but some or all of it can be recovered by washing fees. This represents active prevention and is one more responsibility added to what very well may be a long list for whichever town department is asked to handle it, but it should be considered, and a conscious decision should be made.

The most effective approach applied elsewhere has involved boat ramp inspections with any boat having an invasive species found on it or its trailer turned away. If a nearby boat washing station exists, those wishing to launch a boat can be directed to it. If a boat has been washed at a designated facility, the owner can be issued a certificate documenting the wash which is presented to the ramp monitor and allows entry (although the boat must still pass inspection). This also offers an opportunity to check on registration and proper safety equipment such as life vests and a fire extinguisher.

The logical place for a boat wash station is somewhere near Peters Pond, and the dead end of John Ewer Road just beyond the boat ramp (technically Peters Path, but not a throughway) would seem like an appropriate location, although there may well be others within town. But as the Peters Pond state boat launch is well used and Peters Pond in general is the focus of boating activity in Sandwich, somewhere close to that pond would seem best. Use of other ponds should come with encouragement to wash boats between uses to minimize the risk of invasion. Much like residential property management, this is a function of education that needs to be repeated to make sure everyone is aware of the issue and need for protection.

Additional Monitoring

Additional monitoring has been recommended for each pond. This is simply because there are so few data for these ponds, and they are resources worth understanding better and managing. In some cases, the management focuses on protection and in others there are actual remedial actions to be taken, but all management is best informed with recent, relevant data. At a minimum, each pond should be enrolled in the Pond And Lake Steward (PALS) program that focuses on a single sampling in late summer, much as was done for this investigation. WRS sampled forms of nitrogen and phosphorus, not just the total, and assessed the actual composition of the plankton. PALS will provide slightly less data from a pond profile at its deepest point, but this is valuable data when collected annually over an extended period of years. Volunteers usually collect the samples, requiring some training, coordination and a central repository for equipment held in common. This has not been done in Sandwich for many years but is worthwhile and represents the least expensive way to keep in touch with pond conditions. If volunteers can be recruited it is recommended that a shoreline survey be added to the standard protocol to check for common reed and purple loosestrife and to detect any mussels or snails in each pond.

If the PALS program is not something in which the town wishes to participate, contracting for monitoring is certainly possible. A single sampling of each pond with a shoreline survey will require about 4 days by two people plus lab costs, estimated at approximately $15,000. WRS has recommended two samplings per year, once in late spring and once in late summer, so an annual cost of $30,000 might be anticipated if the full recommended program is carried out. All of the ponds warrant more monitoring, but the program could be tailored over time as enough data are collected to have a sense on the range of conditions likely to be encountered in each pond. Any additional data collection is a step in the right direction.

In some cases, WRS recommended sediment sampling where not completed in 2018. Sediment samples could be collected at the same time as water quality data at minimal additional cost. The laboratory analysis cost for each pond would be on the order of $500/sample.

Additional plant surveys are worthwhile, but not necessarily on an annual basis. Once every 5 years should be adequate if there is a program to at least survey the shoreline and nearshore areas for any invasive species that might show up.

Conclusions

The 12 Sandwich ponds assessed in this investigation represented a range of origin, area, depth and uses. For the most part they are meeting their designated uses, but in some cases there are signs of current impairment or indications for larger problems in the not too distant future. The status and needs of these ponds can summarized as follows:

Upper Shawme Pond – The 2018 assessment found no serious problems, but there are past reports of excessive rooted plants and algae. This pond has great potential as a trout fishery but lacks sufficient public access; consider enhancing an access point for cartop watercraft and requesting that the MDFW stock trout in this pond. Remove the one small patch of common reed on the outlet berm. Monitor effectiveness of alewife migration to Upper Shawme Pond.

Lower Shawme Pond – The 2018 assessment found shallowness and substantial organic sediment deposits to be the overriding influences. Rooted plants and algae mats are dense in places, but mainly impact aesthetics at the outlet end. Water quality was generally acceptable and clarity was high. Remove the common reed and purple loosestrife patches around the pond and consider options for controlling rooted plants and algae mats in the downstream section of the pond. Consider plant and algae removal in the downstream portion of the pond if there is interest in improving aesthetics near the town center.

Hoxie Pond – The 2018 assessment found low oxygen in the bottom layer of the pond and cessation of trout stocking as an apparent consequence of summer access limitation. The cranberry bog to the west represents a threat to water quality but no excessive impact was found and the pond generally met its use designation. Consider mixing, oxygenation, inactivation or dredging if there is sufficient interest in enhancing the pond as a fishery and recreational resource.

Lawrence Pond – Historically reported as a high quality pond, the 2018 assessment found low oxygen near the bottom, with release and use of phosphorus to generate a cyanobacteria bloom of a non-toxic species. Impairment of this Great Pond is not extreme, but is a harbinger of conditions to come, and recommendations are made for remediation. Consider mixing, oxygenation, inactivation or dredging in to improve this pond in the near future.

Spectacle Pond – The 2018 assessment found conditions that supported designated uses, but there are past reports of algae blooms and more recent concerns over water quality as pertains to human health. While all the ponds should be assessed more often than they have been, more monitoring of this highly used Great Pond seems especially warranted.

Triangle Pond – The 2018 assessment found very high quality conditions, some contrary to past reports regarding deep water oxygen and algae blooms. This Great Pond lacks adequate public access but warrants more monitoring to determine the range of occurring conditions. Possible management like what has been proposed for Lawrence Pond may be applicable if algae blooms are documented.

Upper Hog Pond – The 2018 assessment found very high quality conditions and is the first such assessment on record for this pond. This Great Pond lacks adequate public access but the demand for access has not been quantified. It has no apparent problems to be remediated. It does lie in an area identified as threatened by groundwater contamination from the neighboring golf course, but this does not appear to be a major threat and relates mainly to historic fertilizer applications to nearby sections of the course. Some monitoring to document any influence from the golf course is warranted.

Lower Hog Pond – The 2018 assessment found that this pond generally supported its designated uses but is not a Great Pond and has no public access. It has no apparent problems to be remediated. It does lie in an area identified as threatened by groundwater contamination from the neighboring golf course, but as with Upper Hog Pond, this does not appear to be a major threat and relates mainly to historic fertilizer applications to nearby sections of the course. Conduct dissolved oxygen profile investigation in the next few years and document any influence from the golf course.

Peters Pond – The 2018 assessment found conditions that supported the designated uses of this Great Pond, but it does have patches of invasive common reed and purple loosestrife that should be removed, and invasive Asian clams were found. This is the most accessible and publicly used pond in Sandwich and warrants both better control of incoming boats to thwart species invasions and more monitoring to track features that provide warning of future problems and support proactive management. This pond warrants ongoing monitoring as a high use water resource with multiple threats to its condition.

Pimlico Pond – The 2018 assessment found a decline in conditions since the last assessment 16 years ago, but it is not clear from the available data whether this is a trend or just extremes within the range of naturally occurring conditions in this Great Pond. Further monitoring is recommended. Low oxygen in the deepest water and a diatom bloom represented mild impairment. Patches of common reed should be removed.

Snake Pond – The 2018 assessment found high quality conditions and very little change since the last assessment over 16 years ago. A new bathymetric map was generated for this Great Pond. Snake Pond may be the highest quality and most stable pond in Sandwich. It is not stocked with trout and the MDFW should be approached about considering such stocking. Snake Pond also warrants more monitoring to document its range of conditions.

Weeks Pond – The 2018 assessment appears to represent the first data for this Great Pond. Situated adjacent to a town wellfield, the pond appears to meet all use designations but warrants further monitoring. Access is very limited, which may be appropriate given its potential importance to public water supply. Conduct dissolved oxygen profile investigation in the next few years and monitor water levels, which appear to fluctuate to a greater degree in this pond than others.

General – It is recommended that there be on-going outreach regarding residential fertilizer use and on-site wastewater disposal system management. Development of a brochure for residents on their role in preserving water quality in town is advised and there are examples from other towns that can be used as templates. It is also recommended that pond users be educated with regard to invasive species recognition and management, especially as it pertains to boat washing. An algae report form should be developed for use in documenting conditions related to apparent algae blooms to allow anyone to bring such conditions to the attention of the town. This could be an online form with the option to include photographs with instructions on how to best maximize the value of observations.   Consider conducting surveys regarding public desire for access to Great Ponds in Sandwich and evaluate how much access is warranted and sustainable based on user demands, pond condition, and pond susceptibility to negative influences.

Recommendations for remediation, enhancement, protection and monitoring have been made for this suite of ponds, representing a substantial ongoing effort. Yet these ponds are only 12 of 63 ponds within the Town of Sandwich, and with so many water resources to consider and potentially manage, the town needs to establish priorities within the context of public needs and budget. These ponds were chosen for study as a function of their perceived public value, and fortunately the condition of most is consistent with use designations. Yet there are issues that warrant attention in the near future and discussion should ensue on how to best accomplish the tasks that will preserve the valued features of these ponds for future generations.

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APPENDIX A: Data from 2018 Field Operations

	Date	Time	Depth	Temp	DO	DO	Sp. Cond	pH	CHL	Turbidity	Alkalinity	Secchi
Pond	M/D/YY	HH:MM:SS	meters	°C	mg/l	% Sat	µS/cm	Units	µg/l	NTU	mg/l	m
Lawrence	8/6/2018	9:48:57	0.1	28.0	8.2	106.6	56	6.5	1.6	3.3	2.0	3.1
	8/6/2018	9:48:39	1.0	27.8	8.1	104.1	56	6.5	1.8	3.3		
	8/6/2018	9:48:23	2.0	27.6	8.0	103.4	56	6.5	2.0	3.4		
	8/6/2018	9:47:46	2.9	27.4	8.3	106.1	56	6.5	2.1	3.7		
	8/6/2018	9:47:02	4.0	27.1	7.9	100.5	55	6.4	3.9	3.8		
	8/6/2018	9:46:34	5.0	27.0	6.7	85.2	56	6.4	3.8	4.2		
	8/6/2018	9:46:10	6.0	26.6	6.7	84.9	56	6.4	2.8	4.7		
	8/6/2018	9:45:26	7.0	23.1	0.6	6.8	55	6.4	36.8	7.0		
	8/6/2018	9:44:59	8.0	18.3	0.4	4.4	94	6.3	10.0	6.8	10.0	
Hoxie	8/7/2018	12:07:54	1.1	29.1	8.1	107.1	169	6.6	2.1	2.3	7.0	3.3
	8/7/2018	12:07:26	2.1	28.1	8.0	103.5	169	6.6	2.7	2.5		
	8/7/2018	12:07:07	3.0	27.7	7.5	96.6	168	6.5	2.7	2.6		
	8/7/2018	12:06:40	4.0	23.7	5.5	65.6	161	6.5	8.3	2.8		
	8/7/2018	12:05:47	4.0	22.2	2.6	30.6	161	6.5	7.3	3.1		
	8/7/2018	12:05:21	5.0	15.2	1.0	10.4	161	6.6	3.6	3.3		
	8/7/2018	12:04:18	5.9	11.5	1.6	14.5	161	6.7	3.5	3.8		
	8/7/2018	12:04:57	6.0	11.1	0.7	6.1	161	6.6	4.8	3.5		
	8/7/2018	12:03:13	7.1	9.0	0.4	3.4	164	6.8	3.4	8.8	23.0	
Peters North	8/7/2018	8:46:09	0.5	27.7	8.5	108.9	101	6.8	1.4	2.5	9.0	5.0
	8/7/2018	8:45:58	1.0	27.7	8.5	109.0	101	6.8	1.5	2.5		
	8/7/2018	8:45:44	2.0	27.7	8.5	109.1	101	6.8	1.6	2.5		
	8/7/2018	8:45:28	2.9	27.6	8.5	109.6	101	6.8	1.9	2.6		
	8/7/2018	8:45:14	4.0	27.6	8.6	110.9	101	6.7	2.1	2.6		
	8/7/2018	8:44:56	4.9	27.0	8.6	109.6	100	6.7	2.3	2.6		
	8/7/2018	8:44:33	6.0	26.5	8.8	110.9	101	6.6	2.9	2.6		
	8/7/2018	8:44:09	7.0	23.1	12.0	142.4	100	6.6	3.2	2.5		
	8/7/2018	8:43:46	8.0	17.5	14.0	148.6	100	6.6	3.5	2.5		
	8/7/2018	8:43:08	9.0	13.9	13.5	132.4	100	6.6	3.7	2.7		
	8/7/2018	8:42:51	10.1	12.2	11.4	107.5	98	6.6	4.6	2.8		
	8/7/2018	8:42:20	11.0	10.9	7.5	68.5	98	6.6	5.4	3.3		
	8/7/2018	8:41:59	11.9	10.1	2.6	23.2	100	6.6	3.9	3.8		
	8/7/2018	8:41:27	13.1	9.7	0.4	3.4	100	6.5	4.7	5.5		
	8/7/2018	8:41:05	14.0	9.3	0.4	3.3	109	6.5	2.8	6.2		
	8/7/2018	8:40:35	14.9	8.9	0.4	3.2	127	6.4	2.7	6.0		
	8/7/2018	8:40:42	15.0	8.9	0.4	3.3	131	6.4	2.7	7.0	30.0	

	Date	Time	Depth	Temp	DO	DO	Sp. Cond	pH	CHL	Turbidity	Alkalinity	Secchi
Pond	M/D/YY	HH:MM:SS	meters	°C	mg/l	% Sat	µS/cm	Units	µg/l	NTU	mg/l	m
Peters South	8/14/2018	8:19:03	6.4	25.3	0.0	0.1	111	6.6	12.7	4.1		4.1
	8/14/2018	8:19:39	6.0	26.2	1.6	20.0	104	6.6	2.5	3.5		
	8/14/2018	8:20:04	5.0	26.9	6.0	76.0	99	6.7	1.9	3.4		
	8/14/2018	8:20:29	4.0	27.1	7.4	93.8	100	6.7	2.1	2.9		
	8/14/2018	8:21:00	3.0	27.1	7.6	97.2	100	6.8	2.0	2.5		
	8/14/2018	8:21:17	2.0	27.1	7.6	97.3	100	6.8	2.0	2.4		
	8/14/2018	8:21:32	1.0	27.1	7.6	97.4	100	6.8	1.9	2.3		
	8/14/2018	8:21:43	0.1	27.1	7.7	97.5	100	6.8	1.9	2.2		
Pimlico	8/5/2018	14:45:14	0.1	29.0	8.2	107.7	125	6.9	2.1	4.5	6.0	3.0
	8/5/2018	14:44:38	1.0	28.6	8.2	106.9	125	6.8	7.6	4.8		
	8/5/2018	14:44:11	1.8	27.3	8.3	105.9	124	6.8	2.2	5.2		
	8/5/2018	14:43:36	3.0	27.0	8.5	108.3	125	6.8	4.1	5.7		
	8/5/2018	14:43:09	4.0	25.9	10.5	131.2	120	6.8	7.8	6.4		
	8/5/2018	14:42:39	5.0	20.6	13.9	157.1	107	6.8	10.6	7.2		
	8/5/2018	14:42:09	6.0	16.4	5.2	53.6	106	6.9	53.7	10.5		
	8/5/2018	14:41:42	6.9	14.3	0.1	1.1	132	6.8	11.3	14.1	7.0	
Snake	8/5/2018	16:09:17	0.1	28.0	8.0	102.9	46	6.8	0.9	0.5	3.0	6.3
	8/5/2018	16:08:48	0.9	27.9	8.0	103.2	46	6.8	2.6	0.5		
	8/5/2018	16:08:29	2.0	27.5	8.0	102.3	46	6.8	2.0	0.5		
	8/5/2018	16:08:03	3.0	27.1	7.9	100.6	46	6.8	1.7	0.5		
	8/5/2018	16:07:22	4.1	27.0	7.8	98.7	46	6.8	1.9	0.5		
	8/5/2018	16:22:31	5.0	26.8	7.7	97.2	46	6.6	1.9	0.5		
	8/5/2018	16:22:14	5.9	26.7	7.4	94.0	46	6.6	2.0	0.5		
	8/5/2018	16:21:45	7.0	22.7	5.3	62.4	45	6.6	3.9	0.5		
	8/5/2018	16:21:28	8.0	18.2	3.8	40.9	45	6.6	3.7	0.5		
	8/5/2018	16:21:09	8.6	16.9	2.6	27.5	46	6.7	5.0	0.5	4.0	

	Date	Time	Depth	Temp	DO	DO	Sp. Cond	pH	CHL	Turbidity	Alkalinity	Secchi
Pond	M/D/YY	HH:MM:SS	meters	°C	mg/l	% Sat	µS/cm	Units	µg/l	NTU	mg/l	m
Spectacle N	8/6/2018	13:52:46	0.1	28.9	8.0	104.7	47	6.8	1.5	2.1	3.0	4.7
	8/6/2018	13:52:30	1.0	28.8	8.0	104.9	47	6.8	7.1	2.1		
	8/6/2018	13:52:06	2.1	28.5	8.0	104.5	47	6.8	8.1	2.1		
	8/6/2018	13:51:24	3.0	27.6	8.0	103.3	46	6.7	2.1	2.1		
	8/6/2018	13:51:04	4.0	27.4	8.0	102.8	46	6.7	3.1	1.9		
	8/6/2018	13:50:27	5.0	27.2	7.3	93.0	46	6.6	3.6	1.7		
	8/6/2018	13:50:04	6.0	23.6	5.7	68.0	46	6.6	3.2	1.5		
	8/6/2018	13:49:48	7.0	17.9	7.2	76.8	45	6.7	3.3	1.5		
	8/6/2018	13:49:27	8.0	14.7	7.3	72.9	44	6.7	2.6	1.4		
	8/6/2018	13:49:09	9.0	12.4	5.5	52.4	44	6.8	2.7	1.5		
	8/6/2018	13:48:48	10.1	11.5	3.5	32.0	45	6.8	2.5	1.5		
	8/6/2018	13:48:17	11.0	11.0	2.1	19.6	45	6.9	5.0	1.9		
	8/6/2018	13:47:42	11.3	10.9	1.2	10.7	45	7.0	1.9	2.0	4.0	
Spectacle South	8/6/2018	13:04:22	0.2	28.6	7.9	102.8	47	7.3	1.6	2.6		4.7
	8/6/2018	13:04:10	1.0	28.3	7.9	102.5	47	7.3	1.8	2.6		
	8/6/2018	13:03:39	2.0	27.8	7.9	101.8	46	7.3	2.0	2.8		
	8/6/2018	13:03:15	3.0	27.6	7.9	101.1	46	7.4	2.6	2.9		
	8/6/2018	13:02:42	4.0	27.5	7.6	98.0	46	7.4	3.9	3.3		
	8/6/2018	13:02:01	5.0	27.2	7.1	91.0	47	7.4	5.1	5.0		
	8/6/2018	13:01:32	5.7	26.9	8.1	103.4	46	7.5	16.6	7.6		
Triangle	8/6/2018	11:20:20	0.1	28.3	8.1	104.8	65	6.8	1.1	0.3	6.0	6.5
	8/6/2018	11:20:07	1.0	27.9	8.1	104.7	65	6.8	1.2	0.3		
	8/6/2018	11:19:50	2.1	27.8	8.1	104.0	65	6.8	1.3	0.3		
	8/6/2018	11:19:32	3.0	27.6	8.1	103.6	65	6.8	1.3	0.3		
	8/6/2018	11:19:06	3.9	27.4	8.2	105.1	65	6.7	1.7	0.3		
	8/6/2018	11:18:37	6.0	25.4	10.5	130.2	65	6.7	3.3	0.3		
	8/6/2018	11:18:04	7.1	20.7	10.2	115.0	64	6.8	5.2	0.4		
	8/6/2018	11:17:48	7.5	19.4	7.8	86.7	64	6.8	6.0	0.4		
	8/6/2018	11:17:29	8.0	18.1	5.5	58.4	64	6.9	6.9	0.4		
	8/6/2018	11:17:10	8.8	16.6	2.6	27.3	65	7.0	7.1	0.5	12.0	

	Date	Time	Depth	Temp	DO	DO	Sp. Cond	pH	CHL	Turbidity	Alkalinity	Secchi
Pond	M/D/YY	HH:MM:SS	meters	°C	mg/l	% Sat	µS/cm	Units	µg/l	NTU	mg/l	m
Upper Hog	8/8/2018	16:13:06	0.1	30.1	7.8	104.5	73	6.4	1.0	0.3	4.0	6.5
	8/8/2018	16:12:18	0.9	29.2	7.7	102.2	73	6.4	1.0	0.3		
	8/8/2018	16:11:31	2.1	28.7	7.4	97.6	73	6.4	1.3	0.3		
	8/8/2018	16:11:17	3.0	28.0	7.7	100.2	73	6.3	1.5	0.3		
	8/8/2018	16:11:04	4.0	24.1	8.7	104.6	70	6.4	1.6	0.3		
	8/8/2018	16:10:50	5.0	19.9	9.8	109.0	69	6.4	1.6	0.3		
	8/8/2018	16:10:26	6.0	17.6	9.5	100.9	68	6.5	1.7	0.3		
	8/8/2018	16:10:04	7.0	16.9	9.0	93.8	67	6.5	2.1	0.3		
	8/8/2018	16:09:38	8.1	16.3	5.0	51.1	68	6.5	2.1	0.3		
	8/8/2018	16:09:09	8.8	15.8	2.1	21.4	69	6.6	1.6	0.3	2.0	
Lower Hog	8/8/2018	11:30:09	0.1	29.5	7.5	99.8	45	6.8	1.6	0.5	4.0	5.5
	8/8/2018	11:29:50	1.0	29.1	7.6	100.1	44	6.8	1.7	0.6		
	8/8/2018	11:29:22	2.0	28.5	7.6	99.7	44	6.8	2.2	0.6		
	8/8/2018	11:28:54	3.0	25.1	9.8	120.5	43	6.9	4.2	0.6		
	8/8/2018	11:28:32	4.0	19.7	9.4	104.2	41	6.9	4.7	0.8		
	8/8/2018	11:28:14	5.0	16.6	9.6	99.4	39	7.0	5.7	1.2		
	8/8/2018	11:27:42	5.8	15.2	9.5	95.7	39	7.1	9.6	1.8	3.0	
Upper Shawme	8/28/2018	11:48:36	0.2	22.4	15.2	177.3	123	7.7	4.6	1.3	11.0	2.2
	8/28/2018	11:48:15	1.0	17.4	15.8	167.6	100	7.7	7.0	1.2		
	8/28/2018	11:47:48	2.0	11.8	14.9	139.2	93	7.7	8.0	1.1		
	8/28/2018	11:46:14	3.0	10.6	14.2	129.5	52	7.9	8.0	1.2		
Upper Shawme Outlet	8/7/2018	10:07:15	0.3	26.2	9.9	124.2	127	7.3	3.9	0.1		
Lower Shawme	8/7/2018	11:04:46	0.2	28.2	8.3	107.2	123	7.4	2.0	0.1	12.0	1.2 (Bottom)
	8/7/2018	11:05:16	1.0	28.2	8.3	107.7	123	7.4	2.1	1.3		
Weeks	8/7/2018	14:41:28	0.5	29.6	8.0	107.0	86	6.8	2.2	0.1	3.0	5.0
	8/7/2018	14:41:07	1.0	29.2	7.7	101.5	86	6.8	2.4	0.4		
	8/7/2018	14:40:46	2.0	28.4	7.7	99.9	86	6.8	1.7	0.4		
	8/7/2018	14:40:16	3.0	27.8	7.7	99.8	85	6.8	2.9	0.4		
	8/7/2018	14:39:35	4.0	27.3	7.3	92.7	85	6.8	3.7	0.4		
	8/7/2018	14:37:38	4.8	24.4	10.0	121.8	78	7.0	3.5	0.4		
	8/7/2018	14:38:51	5.5	22.7	9.7	114.3	79	6.8	3.1	0.4	3.0	

Lake	Station	Sample Depth (m)	Date (DD/MM/YY)	Nitrate/Nitrite N (mg/L)	Ammonium N (mg/L)	Total Kjeldahl N (mg/L)	Total P (mg/L)	Dissolved P (mg/L)
Lawrence	Central	0.1	8/6/2018	0.01	0.03	0.40	0.008	0.005
Lawrence	Central	0.1	8/6/2018 dup	0.01	0.04	0.35	0.010	0.007
Lawrence	Central	8.0	8/6/2018	0.01	0.11	1.00	0.100	0.005
Triangle	Central	0.1	8/6/2018	0.01	0.02	0.22	0.007	0.005
Triangle	Central	9.0	8/6/2018	0.01	0.02	0.27	0.014	0.005
Spectacle	North	0.1	8/6/2018	0.01	0.06	0.34	0.008	0.005
Spectacle	North	12.0	8/6/2018	0.01	0.09	0.33	0.020	0.005
Spectacle	South	0.1	8/6/2018	0.01	0.03	0.32	0.006	0.005
Spectacle	South	6.0	8/6/2018	0.01	0.22	0.33	0.014	0.005
Snake	Central	0.1	8/5/2018	0.01	0.12	0.37	0.008	0.005
Snake	Central	10.0	8/5/2018	0.01	0.13	0.45	0.007	0.005
Weeks	Central	0.1	8/7/2018	0.01	0.03	0.31	0.016	0.005
Weeks	Central	6.0	8/7/2018	0.01	0.06	0.33	0.070	0.023
Pimlico	Central	0.1	8/5/2018	0.01	0.03	0.49	0.005	0.005
Pimlico	Central	7.5	8/5/2018	0.01	0.03	0.74	0.020	0.007
Peters	North	0.1	8/5/2018	0.06	0.03	0.36	0.005	0.005
Peters	North	16.0	8/5/2018	0.01	0.56	0.99	0.027	0.005
Peters	South	0.1	8/5/2018	0.01	0.05	0.32	0.007	0.006
Peters	South	6.0	8/5/2018	0.01	0.08	0.64	0.011	0.005
Upper Hog	Central	0.1	8/8/2018	0.01	0.07	0.33	0.011	0.007
Upper Hog	Central	8.5	8/8/2018	0.01	0.02	0.35	0.012	0.007
Lower Hog	Central	0.1	8/8/2018	0.01	0.04	0.22	0.020	0.007
Lower Hog	Central	7.5	8/8/2018	0.01	0.02	0.39	0.049	0.006
Upper Shawme	Central	0.1	8/28/2018	0.01	-	0.33	0.010	0.006
Upper Shawme	Central	3.0	8/28/2018	0.06	-	0.35	0.029	0.023
Upper Shawme	Outlet	0.1	8/7/2018	0.01	0.29	0.32	0.008	0.006
Lower Shawme	Central	0.5	8/7/2018	0.01	0.07	0.37	0.019	0.014
Hoxie	Central	0.1	8/7/2018	0.01	0.02	0.24	0.007	0.006
Hoxie	Central	9.0	8/7/2018	0.01	0.83	1.30	0.020	0.010

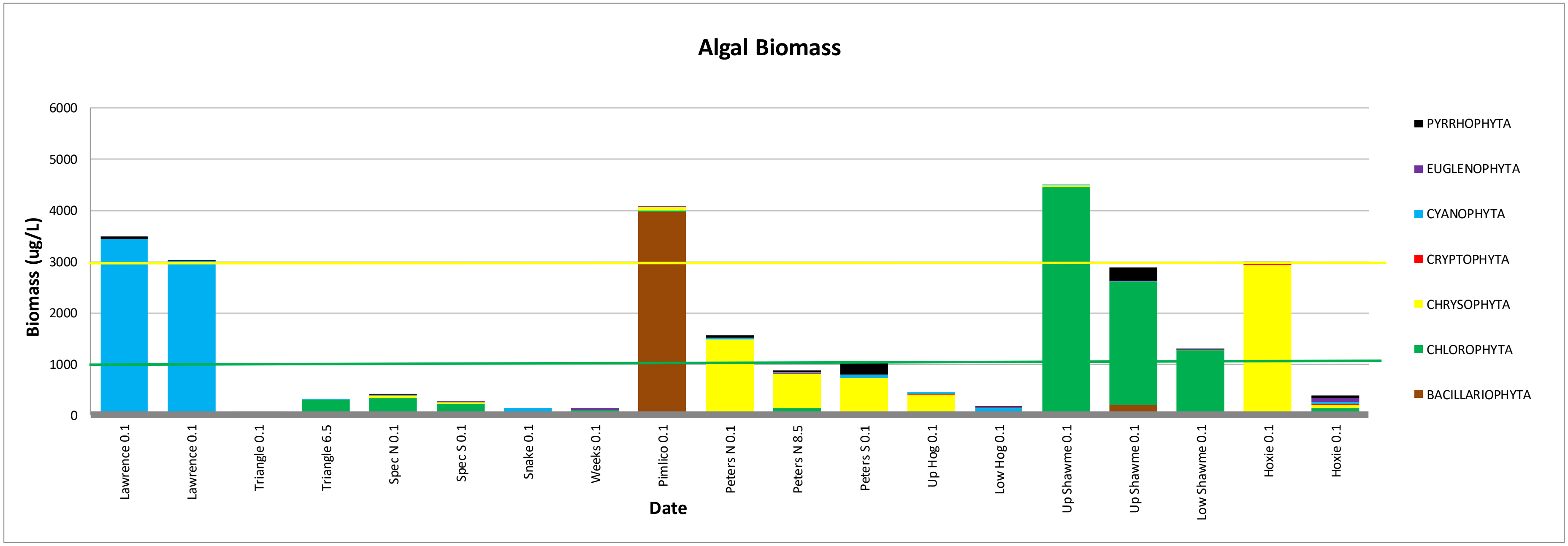
Evaluation Criteria for Pond Features

Feature	Importance	Units	Desirable	Tolerable	Problematic
Oxygen	Oxygen supports most life forms, prevents undesirable sediment-water interactions	Milligrams per liter, mg/L	>5	2 to 5	<2
pH	Acid-base status, impacts most life forms	Standard Units, SU	6 to 8	5 to 6, 8 to 9	>9
Alkalinity	Buffers pH change, limits pH variation	Milligrams per liter as $CaCO_3$, mg/L	>20	10 to 20	<10
Conductivity	Represents dissolved solids, lower is better	Microsiemens (conductance), µS	<100	100 to 400	>400
Total P	Phosphorus is usually the nutrient that limits algae growth, important to all plants	Micrograms per liter, µg/L	<10	10 to 20	>20
Dissolved P	Dissolved form should be non-detectable if P is limiting	Micrograms per liter, µg/L	<5	5-10	>10
Nitrate/Nitrite N	Nitrates and nitrites are available N sources for most algae	Micrograms per liter, µg/L	<300	300 to 600	>600
Ammonium N	Ammonium is an available N source for algae, but un-ionized forms can be toxic to aquatic life	Micrograms per liter, µg/L	<300	300 to 600	>600
Total Kjeldahl N	Sum of organic and ammonium N, added to nitrate/nitrite N to provide estimate of Total N	Micrograms per liter, µg/L	<500	500 to 1000	>1000
Total N	Nitrogen is an important plant and algae nutrient, ratio to P often determines which algae will grow	Micrograms per liter, µg/L	<600	600 to 1200	>1200
N:P Ratio	Mass ratio of N to P, low values promote cyanobacteria, high values promote green algae	Ratio, no units	>30	30 to 10	<10
Turbidity	Measures light scattering by particles, lower is clearer	Nephelometric Turbidity Units, NTU	<3	3 to 10	>10
Secchi Transparency	Measures clarity of water, higher is better	Meters, m	>5	5 to 2	<2
Chlorophyll-a	Photosynthetic pigment common to all algae, determines productivity, indicator of biomass	Micrograms per liter, µg/L	<4	4 to 10	>10
Phytoplankton Biomass	Quantity of algae present, affects water clarity and quality	Micrograms per liter, µg/L	<1000	1000 to 3000	>3000
Problem Cyanobacteria	Portion of algae biomass represented by Cyanobacteria that may be toxic	Percent of biomass, %	<25	25 to 50	>50
Zooplankton Biomass	Quantity of zooplankton present, affects algae grazing capacity and food for small fish	Micrograms per liter, µg/L	>100	100 to 50	<50
Zooplankton Mean Length	Indicator of fish community size distribution and algae consumption capacity, too small or too large can represent problems	Millimeters, mm	0.4 to 0.8	>0.8	<0.4
Sediment Fe-P	Quantity of readily available P if oxygen is depleted	Milligrams per kilogram of sediment, mg/kg	<50	50 to 100	>100
Sediment Biogenic P	Quantity of available P even with oxygen present	Milligrams per kilogram of sediment, mg/kg	<200	200 to 500	>500
Sediment Al:Fe Ratio	More aluminum will better bind P under range of oxygen conditions, so higher is better	Ratio, no units	>3	1 to 3	<1

SEDIMENT FEATURES	SOLIDS	WATER	ALUMINUM	IRON	CALCUIM	TOTAL ORGANIC CARBON	TOTAL P	LOOSELY BOUND P	FE BOUND P	AL BOUND P	BIOGENIC P	CA BOUND P	ORGANIC P
Pond:	%	%	(mg/kg)	(mg/kg)	(mg/kg)	%	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
PETERS P68 A	9.40%	90.60%	16419	23630	3228	9.65	1353	<2.00	95.5	576	411	99.3	582
PETERS P68 B							1527	<2.00	141.0	629	483	96.4	661
PIMLICO P24 A	12.90%	87.10%	15408	14568	1692	8.70	1216	<2.00	56.3	647	362	45.4	468
PIMLICO P24 B							1585	<2.00	86.1	653	638	47.4	798
HOXIE H22 A	6.98%	93.00%	13153	87016	2129	15.50	5731	<2.00	195.0	4099	817	270	1167
HOXIE H22 B							6505	<2.00	261.0	4493	1105	292	1460
LAWRENCE L44 A	25.00%	75.00%	14002	13221	1062	3.47	800	<2.00	29.2	480	163	52.8	238
LAWRENCE L44 B							1032	<2.00	55.2	508	321	45	424
U SHAWME 135 A	11.00%	89.00%	1193	1425	1774	9.05	371	<2.00	41.5	157	107	17.4	155
U SHAWME 135 B							416	<2.00	32.9	165	188	10.2	208

PHYTOPLANKTON BIOMASS (UG/L)	Lawrence 0.1	Lawrence 0.1	Triangle 0.1	Triangle 6.5	Spec N 0.1	Spec S 0.1	Snake 0.1	Weeks 0.1	Pimlico 0.1	Peters N 0.1	Peters N 8.5	Peters S 0.1	Upper Hog 0.1	Lower Hog 0.1	Upper Shawme 0.1	Upper Shawme 0.1	Lower Shawme 0.1	Hoxie 0.1	Hoxie 0.1
TAXON	08/06/18	08/29/18	08/06/18	08/13/18	08/06/18	08/06/18	08/05/18	08/07/18	08/05/18	08/05/18	08/14/18	08/05/18	08/08/18	08/08/18	08/07/18	08/28/18	08/07/18	08/07/18	08/28/18
BACILLARIOPHYTA																			
Centric Diatoms																			
Cyclotella	0.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urosolenia	0.0	0.0	0.0	0.0	14.4	12.0	0.0	0.0	3967.2	0.0	12.2	0.0	6.7	49.2	0.0	0.0	0.0	0.0	0.0
Other Centric Diatoms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Araphid Pennate Diatoms																			
Asterionella	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fragilaria/related taxa	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.0	0.0
Synedra	0.0	0.0	0.0	0.0	9.6	8.0	3.7	0.0	6.1	0.0	0.0	0.0	0.0	0.0	22.1	204.0	28.6	29.4	0.0
Tabellaria	0.0	0.0	0.0	0.0	38.4	20.0	0.0	0.0	0.0	26.2	28.6	33.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monoraphid Pennate Diatoms																			
Achnanthidium/related taxa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Biraphid Pennate Diatoms																			
Cymbella/related taxa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0
Gomphonema/related taxa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	5.1	0.0	0.0
Navicula/related taxa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitzschia	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	0.0	4.6
CHLOROPHYTA																			
Flagellated Chlorophytes																			
Chlamydomonas	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0
Pandorina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.2	0.0	0.0
Coccoid/Colonial Chlorophytes																			
Ankistrodesmus	0.0	0.0	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	4.1	4.6
Coelastrum	0.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crucigenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	4.1	5.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0
Elakatothrix	0.0	0.0	2.2	3.1	1.2	1.0	0.0	9.5	1.5	0.8	2.0	1.7	1.1	0.4	0.9	0.5	0.0	0.0	1.7
Golenkinia	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oocystis	0.0	0.0	13.4	204.0	115.2	32.0	0.0	17.0	0.0	0.0	0.0	0.0	35.8	6.6	4268.8	2366.4	1183.2	0.0	0.0
Paulschulzia	0.0	0.0	9.0	16.3	19.2	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pediastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quadrigula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scenedesmus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	13.9
Schroederia	0.0	0.0	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0	0.0	0.0	14.0	10.3	0.0	12.8	0.0	0.0	29.0
Sphaerocystis	0.0	0.0	0.0	32.6	57.6	40.0	0.0	0.0	9.1	6.6	16.3	10.1	13.4	9.8	0.0	0.0	0.0	0.0	0.0
Tetraedron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	83.5
Tetrastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Filamentous Chlorophytes																			
Ulothrix	0.0	0.0	39.2	25.5	66.0	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desmids																			
Closterium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.4	0.0	0.0
Cosmarium	0.0	0.0	0.0	4.1	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	0.0
Mougeotia/Debarya	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.8	0.0	0.0	0.0	0.0	0.0	0.0	144.4	0.0	0.0	0.0	0.0
Staurastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	3.0	0.0	61.2	0.0	0.0	0.0	14.7	20.4	4.1	11.0	4.6
Staurodesmus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Xanthidium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

PHYTOPLANKTON BIOMASS (UG/L) - continued																			
	Lawrence 0.1	Lawrence 0.1	Triangle 0.1	Triangle 6.5	Spec N 0.1	Spec S 0.1	Snake 0.1	Weeks 0.1	Pimlico 0.1	Peters N 0.1	Peters N 8.5	Peters S 0.1	Upper Hog 0.1	Lower Hog 0.1	Upper Shawme 0.1	Upper Shawme 0.1	Lower Shawme 0.1	Hoxie 0.1	Hoxie 0.1
TAXON	08/06/18	08/29/18	08/06/18	08/13/18	08/06/18	08/06/18	08/05/18	08/07/18	08/05/18	08/05/18	08/14/18	08/05/18	08/08/18	08/08/18	08/07/18	08/28/18	08/07/18	08/07/18	08/28/18
CHRYSOPHYTA																			
Flagellated Classic Chrysophytes																			
Chromulina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dinobryon	0.0	54.0	0.0	0.0	36.0	30.0	27.6	0.0	57.0	1439.1	673.2	667.8	336.0	0.0	27.6	0.0	0.0	2870.4	69.6
Mallomonas	0.0	0.0	0.0	0.0	0.0	2.5	2.3	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.6	20.7	0.0
Tribophytes/Eustigmatophytes																			
Centritractus	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
CRYPTOPHYTA																			
Cryptomonas	0.0	0.0	0.0	0.0	3.6	2.0	0.0	0.0	0.0	0.0	4.1	0.0	2.2	1.6	0.0	8.2	2.0	1.8	3.5
CYANOPHYTA																			
Unicellular and Colonial Forms																			
Aphanocapsa	0.0	0.0	0.0	4.1	1.2	0.5	4.6	8.5	0.0	2.5	6.1	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chroococcus	0.0	0.0	13.8	0.8	0.0	0.0	82.8	0.0	0.0	8.4	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gomphosphaeria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.9	10.2	56.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Merismopedia	0.0	0.0	0.0	3.3	0.0	0.0	2.9	3.4	0.0	0.0	0.0	0.0	44.8	64.3	0.0	0.0	0.0	0.0	0.0
Snowella	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Filamentous Nitrogen Fixers																			
Aphanizomenon	175.5	1131.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dolichospermum	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.8
Filamentous Non-Nitrogen Fixers																			
Lyngbya	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	4.1	0.0	0.0	0.0
Planktolyngbya	3262.5	1827.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudanabaena	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0
EUGLENOPHYTA																			
Trachelomonas	0.0	0.0	0.0	0.0	0.0	5.0	0.0	26.5	7.6	0.0	0.0	0.0	0.0	4.1	0.0	0.0	5.1	32.2	92.8
PYRRHOPHYTA																			
Ceratium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.7	44.4	36.5	0.0	0.0	0.0	266.2	0.0	0.0	0.0
Peridinium	42.0	25.2	0.0	0.0	12.6	0.0	0.0	0.0	0.0	0.0	0.0	197.8	0.0	8.6	0.0	0.0	10.7	9.7	36.5
DENSITY (CELLS/ML) SUMMARY																			
BACILLARIOPHYTA	**1.0**	**0.0**	**0.0**	**0.0**	**72.0**	**52.5**	**10.6**	**0.0**	**3973.3**	**26.2**	**53.6**	**35.7**	**6.7**	**49.2**	**35.0**	**204.0**	**50.0**	**29.4**	**4.6**
Centric Diatoms	0.0	0.0	0.0	0.0	14.4	24.5	0.0	0.0	3967.2	0.0	25.0	0.0	6.7	49.2	0.0	0.0	0.0	0.0	0.0
Araphid Pennate Diatoms	1.0	0.0	0.0	0.0	48.0	28.0	10.6	0.0	6.1	26.2	28.6	33.6	0.0	0.0	22.1	204.0	43.9	29.4	0.0
Monoraphid Pennate Diatoms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Biraphid Pennate Diatoms	0.0	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	12.9	0.0	5.1	0.0	4.6
CHLOROPHYTA	**6.0**	**0.0**	**63.8**	**299.9**	**268.8**	**161.0**	**11.5**	**98.1**	**35.0**	**7.4**	**87.7**	**26.9**	**64.4**	**28.7**	**4428.9**	**2402.6**	**1220.4**	**23.5**	**137.5**
Flagellated Chlorophytes	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.2	0.9	0.0
Coccoid/Colonial Chlorophytes	0.0	0.0	24.6	270.3	193.2	81.0	11.5	60.4	18.2	7.4	26.5	26.9	64.4	28.7	4269.7	2382.2	1183.7	4.1	132.8
Filamentous Chlorophytes	0.0	0.0	39.2	25.5	66.0	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Desmids	0.0	0.0	0.0	4.1	9.6	0.0	0.0	37.6	16.7	0.0	61.2	0.0	0.0	0.0	159.2	20.4	24.5	18.4	4.6
CHRYSOPHYTA	**0.0**	**54.0**	**0.0**	**0.8**	**36.0**	**32.5**	**29.9**	**2.9**	**57.0**	**1439.1**	**673.2**	**667.8**	**336.8**	**0.0**	**27.6**	**2.6**	**2.6**	**2891.1**	**69.6**
Flagellated Classic Chrysophytes	0.0	54.0	0.0	0.0	36.0	32.5	29.9	2.9	57.0	1439.1	673.2	667.8	336.0	0.0	27.6	2.6	2.6	2891.1	69.6
Non-Motile Classic Chrysophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haptophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tribophytes/Eustigmatophytes	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Raphidophytes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CRYPTOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**3.6**	**2.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4.1**	**0.0**	**2.2**	**1.6**	**0.0**	**8.2**	**2.0**	**1.8**	**3.5**
CYANOPHYTA	**3438.0**	**2958.0**	**15.6**	**8.2**	**13.2**	**0.5**	**90.3**	**11.9**	**0.0**	**47.8**	**16.9**	**60.4**	**44.8**	**64.3**	**9.2**	**4.1**	**2.0**	**0.0**	**34.8**
Unicellular and Colonial Forms	0.0	0.0	15.6	8.2	1.2	0.5	90.3	11.9	0.0	47.8	16.9	60.4	44.8	64.3	0.0	0.0	0.0	0.0	0.0
Filamentous Nitrogen Fixers	175.5	1131.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.8
Filamentous Non-Nitrogen Fixers	3262.5	1827.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	4.1	2.0	0.0	0.0
EUGLENOPHYTA	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5.0**	**0.0**	**26.5**	**7.6**	**0.0**	**0.0**	**0.0**	**0.0**	**4.1**	**0.0**	**0.0**	**5.1**	**32.2**	**92.8**
PYRRHOPHYTA	**42.0**	**25.2**	**0.0**	**0.0**	**12.6**	**0.0**	**0.0**	**0.0**	**0.0**	**35.7**	**44.4**	**234.4**	**0.0**	**8.6**	**0.0**	**266.2**	**10.7**	**9.7**	**36.5**
TOTAL	**3487.0**	**3037.2**	**79.4**	**308.8**	**406.2**	**253.5**	**142.3**	**139.3**	**4072.8**	**1556.2**	**879.9**	**1025.1**	**455.0**	**156.5**	**4500.6**	**2887.6**	**1292.9**	**2987.7**	**379.3**
BIOMASS DIVERSITY	**0.12**	**0.34**	**0.60**	**0.56**	**0.95**	**0.90**	**0.58**	**0.95**	**0.07**	**0.17**	**0.45**	**0.50**	**0.42**	**0.69**	**0.12**	**0.29**	**0.20**	**0.10**	**0.86**
BIOMASS EVENNESS	**0.17**	**0.57**	**0.77**	**0.50**	**0.81**	**0.79**	**0.64**	**0.85**	**0.07**	**0.18**	**0.39**	**0.46**	**0.45**	**0.69**	**0.12**	**0.28**	**0.18**	**0.10**	**0.80**

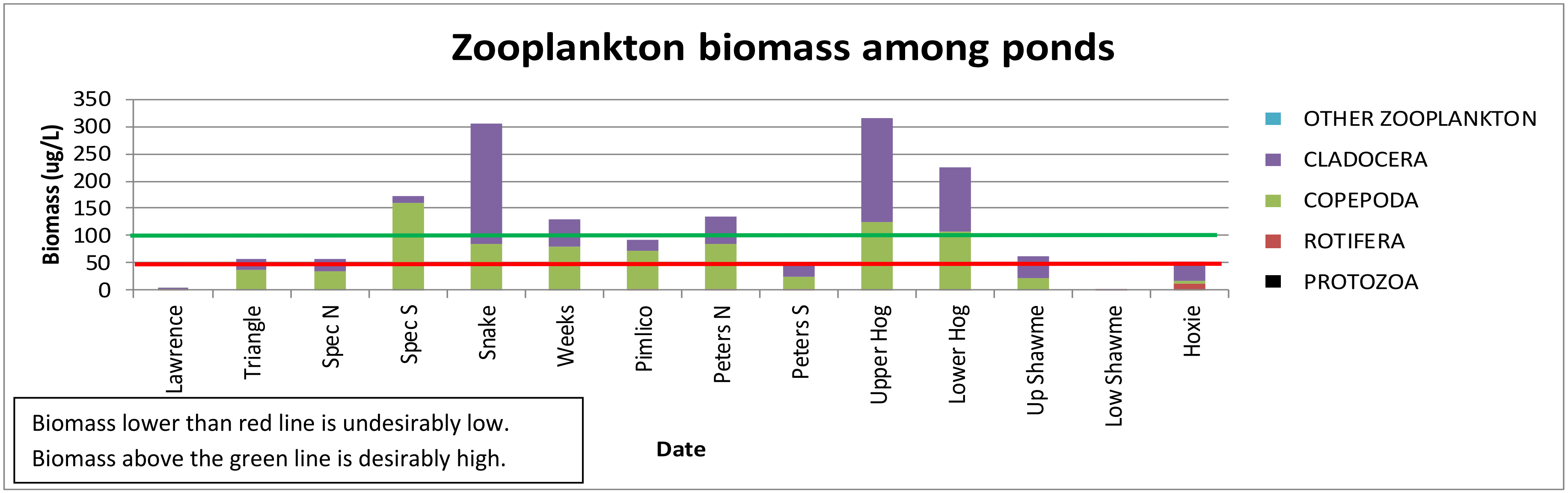


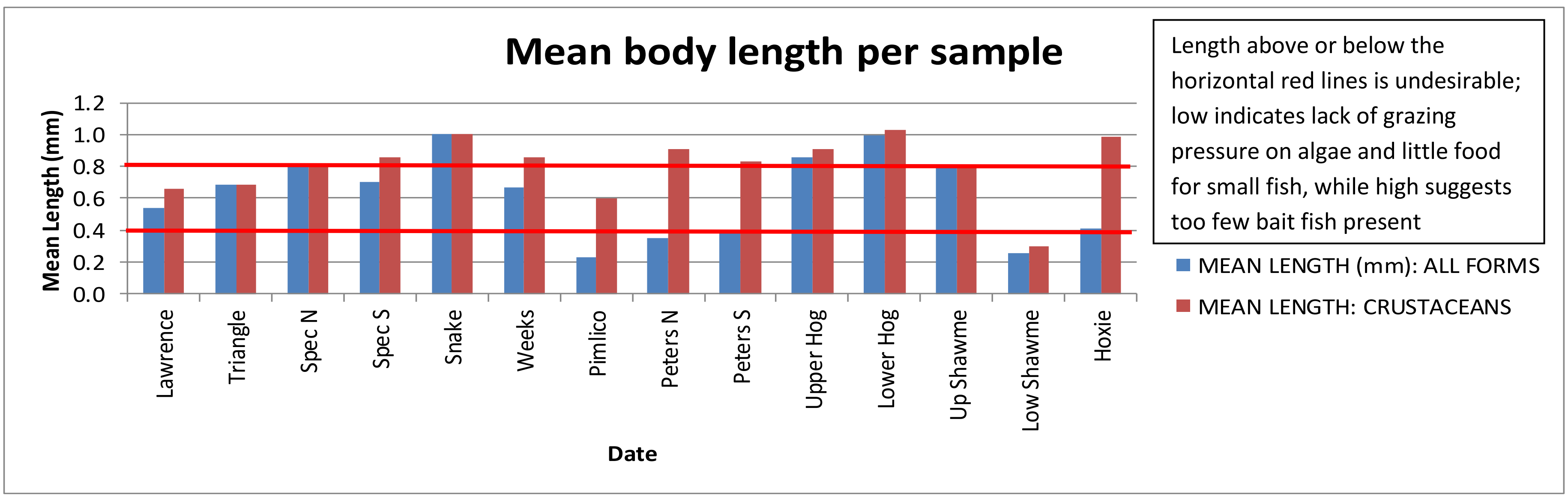
Green line represents the biomass below which no algae-related problems are expected.

Yellow line represents the biomass above which algae-related problems are likely, although not all algae cause problems at that threshold.

Biomass between the lines will create problems in rare instances, particularly if cyanobacteria (Cyanophyta) are involved, but this is a transition zone.

ZOOPLANKTON BIOMASS (UG/L)	Lawrence	Triangle	Spec N	Spec S	Snake	Weeks	Pimlico	Peters N	Peters S	Upper Hog	Lower Hog	Up Shawme	Low Shawme	Hoxie
TAXON	**8/6/18**	**8/6/18**	**8/6/18**	**8/6/18**	**8/7/18**	**8/7/18**	**8/5/18**	**8/5/18**	**8/5/18**	**8/8/18**	**8/8/18**	**8/28/18**	**8/7/18**	**8/7/18**
ROTIFERA														
Asplanchna	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	10.7
Brachionus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Conochilus	0.0	0.0	0.0	0.2	0.0	0.3	2.5	1.6	0.9	0.1	0.0	0.0	0.0	0.3
Hexarthra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kellicottia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Keratella	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Ptygura	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichocerca	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COPEPODA														
Copepoda-Cyclopoida														
Mesocyclops	0.3	2.0	7.1	0.4	1.8	0.5	0.9	3.6	1.2	15.8	4.4	19.5	0.0	3.1
Copepoda-Calanoida														
Diaptomus	0.2	21.5	23.2	154.2	77.9	76.6	59.4	71.3	17.9	94.7	98.4	0.2	0.0	1.4
Other Copepoda-Nauplii	0.6	13.4	3.9	4.5	5.0	2.9	9.5	7.9	3.5	15.4	5.4	2.1	0.0	2.0
CLADOCERA														
Alona	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0
Bosmina	0.0	1.9	0.7	11.7	3.7	3.3	18.9	0.0	1.3	1.0	0.4	5.8	0.6	0.4
Ceriodaphnia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia ambigua	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia pulex	0.0	0.0	10.2	0.0	180.2	0.0	0.0	43.0	21.5	92.0	100.4	0.0	0.0	31.2
Diaphanosoma	0.5	19.2	11.3	1.7	0.5	6.2	0.0	2.6	3.9	1.0	0.4	26.2	0.0	1.1
Holopedium	0.0	0.0	0.0	0.0	36.5	39.3	0.0	0.0	0.0	96.4	16.6	7.9	0.0	3.1
SUMMARY STATISTICS	**Lawrence**	**Triangle**	**Spec N**	**Spec S**	**Snake**	**Weeks**	**Pimlico**	**Peters N**	**Peters S**	**Upper Hog**	**Lower Hog**	**Up Shawme**	**Low Shawme**	**Hoxie**
BIOMASS	**8/6/18**	**8/6/18**	**8/6/18**	**8/6/18**	**8/7/18**	**8/7/18**	**8/5/18**	**8/5/18**	**8/5/18**	**8/8/18**	**8/8/18**	**8/28/18**	**8/7/18**	**8/7/18**
PROTOZOA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ROTIFERA	2.0	0.0	0.0	0.4	0.0	0.3	2.5	1.6	0.9	0.1	0.0	0.0	0.6	11.2
COPEPODA	1.2	36.9	34.2	159.1	84.7	80.0	69.9	82.7	22.7	126.0	108.2	21.8	0.0	6.4
CLADOCERA	2.2	21.1	22.2	13.4	221.0	48.8	18.9	50.1	26.7	190.4	117.8	41.1	0.6	35.7
OTHER ZOOPLANKTON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL ZOOPLANKTON	5.4	58.0	56.4	172.9	305.6	129.1	91.3	134.4	50.2	316.5	226.0	62.8	1.2	53.3


Zooplankton biomass among ponds
Biomass (ug/L)
350
300
250
200
150
100
50
0
Lawrence
Triangle
Spec N
Spec S
Snake
Weeks
Pimlico
Peters N
Peters S
Upper Hog
Lower Hog
Up Shawme
Low Shawme
Hoxie
OTHER ZOOPLANKTON
CLADOCERA
COPEPODA
ROTIFERA
PROTOZOA
Biomass lower than red line is undesirably low.
Biomass above the green line is desirably high.
Date


Mean body length per sample
Mean Length (mm)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Lawrence
Triangle
Spec N
Spec S
Snake
Weeks
Pimlico
Peters N
Peters S
Upper Hog
Lower Hog
Up Shawme
Low Shawme
Hoxie
Date
Length above or below the horizontal red lines is undesirable; low indicates lack of grazing pressure on algae and little food for small fish, while high suggests too few bait fish present
MEAN LENGTH (mm): ALL FORMS
MEAN LENGTH: CRUSTACEANS

Abbrev.	Scientific Name	Common Name
B schreb	Brasenia schreberi	Watershield
Call	Callitriche sp.	Water starwort
C dem	Ceratophyllum demersum	Coontail
Chloro	Chlorophyta	Filamentous green algae mat
Cyano	Cyanophyta	Filamentous blue-green algae mat
Eleo	Eleocharis acicularis	Needle rush
El can	Elodea canadensis	Canada waterweed
Erio	Eriocaulon septangulare	Pipewort
Grat	Gratiola neglecta	Hedge hyssop
Iso	Isoetes lacustris	Lake quillwort
Lemna	Lemna minor	Duckweed
Lob	Lobelia dortmanna	Water lobelia
Moss	Bryophyta	Aquatic moss
N flex	Najas flexilis	Common naiad
Nit S	Nitella sp	Shallow growing stonewort
Nit D	Nitella flexilis	Deep growing stonewort
Nu var	Nuphar variegata	Yellow water lily
Ny od	Nymphaea odorata	White water lily
Ny cord	Nymphoides cordata	Little floating heart
Poly	Polygonum amphibium	Aquatic knotweed
P bicup	Potamogeton bicupulatus	Snailseed pondweed
P epi	Potamogeton epihydrus	Ribbonleaf pondweed
P. oak	Potamogeton oakesianus	Oakes' pondweed
P rob	Potamogeton robbinsii	Robbins' pondweed
P spir	Potamogeton spirillus	Northern snailseed pondweed
Pros	Proserpinaca pectinata	Mermaid weed
S gram	Sagittaria graminea	Submergent arrowhead
Schoeno	Schoenoplectus validus	Bullrush
Sparg	Sparganium sp	Burr-reed
U rad	Utricularia radiata	Floating bract bladderwort
U gib	Utricularia gibba	Submerged bladderwort
U pur	Utricularia purpurea	Purple bladderwort
U vulg	Utricularia vulgaris	Big bladderwort
Val am	Valisneria americana	Water celery

Plant species abbreviations and key to cover, biovolume and relative abundance for following tables.

1 = 1-25%

2= 26-50%

3 = 51-75%

4 = 76-100%

t = trace

s = sparse

m = moderate

d = dense

Upper Shawme Pond																		
	Depth	Sediment	Cover	Biovol	Plant Species													
Station	ft	m/s/g	0-4	0-4	Call	C dem	Chloro	Eleo	El can	Grat	Lemna	Moss	N flex	Nit D	P rob	Sparg	U gib	Val am
1	2	s	3	2	s		m				s	t			s	t	s	
2	3.3	s	4	1								m			s		t	
3	4.3	s	3	1		s			s			m		t	s		s	
4	5.3	m/s	4	2		s			d						s			
5	5.5	s	4	2		s	m		s		t	m			s		s	
6	6	m/s	4	2		s	d		s								s	
7	6.6	m	4	2					m			d			m		t	
8	6.8	m/s	4	2		t	m		m				s		s			
9	7.3	m/s	4	2								d			s		s	
10	6.3	m/s	4	2			m		m			m			m			
11	7.1	m	4	2			s		d			s	s		s			
12	6.8	m	4	2			m		s			d			s			
13	7.1	m/s	4	2			d		s			m	s	t	s			
14	6.6	m	4	3											d			
15	6.3	s	3	1		s	m		t	t		s						
16	5	s	4	1					t		t	m	t				s	
17	5	s	4	2			s					s			d		t	
18	6.3	m	4	2			s		t			s			d			
19	8.1	m	4	2					m						m			
20	6	m/s	4	2					d			t			t			
21	6.3	m/s	4	2		s	m		m				t					
22	6.8	m/s	4	1			d				t	m						
23	6.3	m/s	4	2					m			m			t		t	
24	7.8	m/s	4	2					d						m			
25	6.8	m/s	4	2					s			s			m		s	
26	6	m/s	4	2					s			m			d			
27	7.1	m/s	3	1	s	t					t	s						
28	5.3	s	4	2	s	t	s		m					s	s			
29	6.8	m	4	2											d			
30	6.6	m							s						d			
31	6.6	m	4	2								t			d			
32	5.5	s	3	1			s					m		s	s		s	
33	3.5	s	4	2					s			s			m		t	
34	6.8	m	3	2					s			s		s	m			
35	6.3	m	4	2											d			
36	6.3	m	4	2		s			d		t	s					s	
37	6.8	m	4	1					m			t			m		t	
Avg/Sum	6.1		3.8	1.8	3	10	15	0	26	1	6	26	5	5	30	1	15	0

Lower Shawme Pond																		
	Depth	Sediment	Cover	Biovol	Plant Species													
Station	ft	m/s/g	0-4	0-4	Call	C dem	Chloro	Eleo	El can	Grat	Lemna	Moss	N flex	Nit D	P rob	Sparg	U gib	Val am
38	1.7	m	4	2		t			s		t	m			m		t	
39	2.2	m	1	1					s		t				s			
40	2.2	m	4	3					d						s			m
41	2	m	3	1		t	t		m						t		t	t
42	2	m	3	1					s						s			s
43	2.2	m	4	1			s		d									
44	2	m	4	1					d									s
45	2	s	4	2					d									m
46	2.2	m	3	2		m			m						t			
47	3	m	2	1			s		s									
48	3	m	3	3					s				s	t				m
49	2.8	m/s	4	3		s			m									d
50	2.2	m	4	1					m				m					
51	2.5	m	2	1		s			s									
52	2.2	m	4	2					d					t				t
53	2.2	m	3	3					d				m					y
54	2.7	m	4	1		s			s				m					
55	2.5	m	4	2		s			m				m					
56	2.5	m	4	3					s				t					d
57	2.7	m	4	1									d					
58	2.5	m	3	2			m						m					
59	3.3	m	4	1					m				m					
60	2.5	m	2	1									s					
61	2.7	m	4	2				m					m		t		t	t
62	2.2	m	4	1				d					s		s			
63	2.5	m	4	1		t	s	d							t			t
64	3.3	m	4	3				d					t					t
65	3.5	m	3	1				m					t		s			
66	3.8	m	2	1				s										
67	2.7	m	3	2				m					s					s
68	3	m	3	2			t	m					t					m
Avg/Sum	2.5		3.4	1.7	0	8	6	8	20	0	2	1	16	2	10	0	3	15

Hoxie Pond																						
	Depth	Sediment	Cover	Biovol	Plant Species																	
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Erio	Grat	Iso	N flex	Nit D	Nu var	Ny od	Ny cord	Poly	P epi	P spir	Schoeno	U gib	U vulg
1	5.2	m/s	4	3								s			d							
2	3.5	m/s	4	4											d			s				
3	3.8	m/s	4	3	s			m				s		m	m		s	e				
4	8.3	m/s	4	1				m			s	m										
5	5.5	m/s	4	2				s				m		s	m					t		t
6	6.3	m/s	3	1				m			s	s										t
7	3.3	m/s	4	3	s		s								d							
8	5	m/s	3	1		m	s					s						s		s		
9	12.1	m	3	1		m																
10	12.4	m	3	1		s							m									
11	12.7	m	3	1									m									
12	10.1	m	4	1				s				s	m									t
13	8.3	m/s	4	1								d										t
14	2.2	m/s	4	3	s			t				s		t	d							
15	6.3	m/s	3	2	m							s			s						t	
16	13.9	m	1	1							t		s						t			
17	18.5	m	2	1		s																
18	23.1	m	2	1		s																
19	23.1	m	2	1		s																
20	28.7	m	0	0																		
21	31.2	m	0	0																		
22	30.2	m	0	0																		
23	27.1	m	0	0																		

Hoxie Pond																						
	Depth	Sediment	Cover	Biovol	Plant Species																	
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Erio	Grat	Iso	N flex	Nit D	Nu var	Ny od	Ny cord	Poly	P epi	P spir	Schoeno	U gib	U vulg
24	16.5	m	2	1		s																
25	3	s	1	1			s	t		s				t	t			t				
26	3	s	1	1				t	t	t					s			t		s		
27	8.1	s	1	1	s							s										
28	14.7	m	1	1		s							t									
29	20.5	m	2	1	s	s																
30	23.8	m	3	1	m	m																
31	26.9	m	0	0																		
32	27.1	m	0	0																		
33	20.5	m	3	1		m																
34	17.2	m	2	1							s	s	s									
35	6	s	2	1					s			s						t			s	
36	2	sg	1	1					s									s				
37	8.1	m/s	2	1	m							s										
38	10.9	m	2	1		s						s										
39	9.4	s	2	1		s					t											
40	6	s	2	1							s	s						t			t	
41	2.5	s	3	1			s	s				s				t		s				
42	4.3	s	1	1				t				s						t			s	
43	1.5	s	1	1											t					t		
44	4.5	m/s	4	2								t		s	m			t				
Avg/Sum	12.2		2.2	1.2	8	13	4	10	3	2	6	19	6	5	11	1	1	11	1	4	4	4

Lawrence Pond													
	Depth	Sediment	Cover	Biovol	Plant Species								
Station	ft	m/s/g	0-4	0-4	C dem	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	Nit
1	3.3	s	0	0									
2	10.1		3	1				m					
3	19.5	m/s	1	1								s	
4	26.5	m	0	0									
5	27.4	m	0	0									
6	27.6	m	0	0									
7	26.6	m	0	0									
8	24.9	m	0	0									
9	23.6	m/s	1	1			s						
10	16	m/s	1	1		s		s					
11	6.8	s	1	1				s					
12	3	sgc	0	0									
13	19.8	m	0	0									
14	21.3	m	0	0									
15	22.8	m	1	1			s						
16	20	m	0	0							s		
17	12.7	m/s	1	1									
18	7.8	s	1	1				s		t	s		
19	6	sg	4	1				d		t			
20	4.3	sg	0	0									
21	7.6	sg	1	1							s		
22	8.3	s	1	1		s		s			s		
23	8.3	s	1	1				s		s	s		
24	6.8	sg	1	1		t		s			s		
25	5.5	scg	0	0									
26	6.3	sg	4	1		s		d		s	s		
27	15.7	m	0	0									
28	18	m	1	1									s
29	18.8	m	1	1									s
30	14.9	s	1	1									
31	5.5	sgc	0	0									
32	3.8	sgc	0	0									
33	11.6	s	1	1		s					s		
34	17.2	m/s	0	0									
35	17	m/s	1	1							t		s

Lawrence Pond													
	Depth	Sediment	Cover	Biovol	Plant Species								
Station	ft	m/s/g	0-4	0-4	C dem	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	Nit
36	18.8	m	1	1			s						s
37	18.5	m	1	1			s						
38	17.7	m/s	1	1									s
39	15.4	m/s	1	1									s
40	4	sg	3	1				m	s	s			
41	6.3	s	3	1		s		m					
42	20.8	m/s	1	1							t		s
43	27.6	m	0	0									
44	27.4	m	0	0									
45	27.1	m	0	0									
46	26.6	m	0	0									
47	21.3	m	1	1									s
48	15.4	m/s	1	1							s		t
49	12.9	m/s	2	1							m		
50	8.1	s	2	1						s	s		
51	6.6	sg	1	1				s		s	s		
52	3.5	sgc	1	1						s		t	
53	10.1	s	1	1		s					s		
54	14.2	s	1	1							s		
55	18	m	1	1	s								
56	21	m	0	0									
57	26.9	m	0	0									
58	26.4	m	0	0									
59	26.9	m	0	0									
60	11.6	s	1	1							s		
61	5.5	sgc	1	1						s			
62	7.8	s	0	0									
63	16.8	s	1	1		s					s		
64	23.6	m	1	1			s						
65	26.4	m	0	0									
66	26.1	m	0	0									
67	25.9	m	0	0									
68	24.6	m	0	0									
69	20.5	m/s	2	1									s
70	10.1	s	2	1		t		t		s	s		
Avg/Sum	15.9		0.8	0.6	3	10	6	14	2	11	20	3	11

Spectacle Pond																
	Depth	Sediment	Cover	Biovol	Plant Species											
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Erio	Grat	Iso	N flex	Nit D	P bicup	S gram	U gib
1	3.8	s	3	1			d		s	s						
2	7.1	s	4	1											d	
3	10.1	s	4	1											d	
4	11.6	s	3	1	s		m			s					s	
5	15.2	m	0	0												
6	16.7	m	0	0												
7	18.5	m	1	1								s	s			
8	19.8	m	4	1	s								d			
9	19.5	m	4	1									d			
10	19	m	4	1									d			
11	14.7	m/s	0	0												
12	10.5	s	4	1	s		d									
13	4.8	s g	1	1					s	s		s				
14	2.7	s g	1	1												
15	16.7	m/s	1	1							s	s	s			
16	16.2	m/s	1	1							s					
17	13	m/s	0	0												
18	8.6	s	4	1			s		s						d	
19	4.3	s g	0	0												
20	5.5	s g c	2	1				s			t		s			
21	3.5	s	1	1			s					t				
22	4	s g c	0	0												
23	6	s	4	1	s										d	
24	7.1	s	4	1	s		d						s			
25	13.9	m	0	0												
26	20.8	m	3	1		m					m					
27	24.3	m	2	1									m			
28	26.9	m	2	1									m			
29	34.5	m	4	1									d			
30	38.3	m	2	1		m										
31	4	s g	1	1					s	s						
32	7.6	s	4	1			s			t			d			
33	12.9	s	4	1							t		d			
34	18.8	m	0	0												
35	29.4	m	1	1									s			
36	6.3	s	4	1					m					t	d	t
37	11	m/s	3	1			s					m				
38	16	m	0	0												
39	21.5	m	1	1							s		s			
40	26.6	m	0	0												
41	4.5	s g	1	1			s		t	t		t				

Spectacle Pond																
	Depth	Sediment	Cover	Biovol	Plant Species											
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Erio	Grat	Iso	N flex	Nit D	P bicup	S gram	U gib
42	9.9	s	4	1			d				s					
43	15.2	m	0	0												
44	31.5	m	3	1									d			
45	4.8	s g	1	1			s			t		t				
46	6.3	s	4	1	s											
47	13.9	m	0	0												
48	21.8	m	2	1									m			
49	30.2	m	3	1									d			
50	34.3	m	3	1									d			
51	37.6	m	0	0												
52	4.2	s	1	1			t		t	t						
53	11.6	s	1	1							s					
54	16.2	s	4	1							d					
55	22.6	m/s	2	1							m		m			
56	29.2	m	3	1									d			
57	6	s	2	1	s		s									
58	11.4	m/s g	0	0												
59	16.7	m/sg	1	1							s					
60	19.5	m/sg	1	1									s			
61	23.8	m	2	1									m			
62	32.7	m	4	1									d			
63	37.3	m	2	1		s										
64	3.8	S	1	1						s						
65	7.3	s	3	1	s		s						s		s	
66	10.1	s	2	1	s		t								s	
67	5.3	s g	2	1	s		s			s						
68	6	s	4	1								t			d	
69	5.8	s	4	1	s										d	
70	3.8	s g	1	1						s			s			
71	12.7	m/s	0	0												
72	15	m/s	0	0												
73	20.3	m/s	4	1			s						d			
74	3.5	s g	1	1						t			s			
75	8.8	s	2	1			s				s					
76	17	m/s	3	1							s		m			
77	20.8	m	4	1									d			
Avg/Sum	15.0		2.0	0.8	13	4	19	2	8	13	14	9	30	2	11	2

Triangle Pond												
	Depth	Sediment	Cover	Biovol	Plant Species							
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	S gram
1	6.3	s	4	1							t	d
2	8.8	s	4	1							d	
3	8.3	s	4	1							t	d
4	3.5	s	0	0								
5	12.1	s	4	1							d	
6	15.2	s	4	1							d	
7	12.7	s	0	0								
8	14.2	s	4	1							d	
9	12.1	s	4	1							d	
10	7.1	s	3	1	t						t	d
11	11.9	s	3	1							d	
12	16.5	s	4	1							d	
13	14.4	s	4	1							d	
14	11.9	s	0	0								
15	7.3	s	0	0								
16	12.7	sg	1	1							t	
17	9.1	sg	2	1							s	
18	10.6	sg	0	0								
19	5.3	s	1	1							s	
20	3	s	0	0								
21	6.6	s	4	1			d		s			
22	8.8	s	4	1							d	
23	8.8	s	4	1							d	
24	3.8	sg	3	1			m				t	
25	12.4	sg	2	1							s	
26	3	sgc	2	1			s				s	
27	6.8	s	4	1	s		d				s	
28	2.7	sg	1	1	s					s		
29	8.6	s	4	1	s							d
30	18.2	m/s	2	1	s						s	
31	11.4	s	3	1							m	
32	8.3	s	3	1							m	
33	8.8	sg	3	1							m	
34	8.9	s	4	1	s		m				m	
35	17	sgc	1	1							s	
36	31.2	m	1	1		s						
37	30.2	m	1	1		s						
38	23.3	m	0	0								
39	15.3	sg	2	1			t		t		s	
40	16.7	s	4	1							d	
41	7.8	s	2	1			m				s	

Triangle Pond												
	Depth	Sediment	Cover	Biovol	Plant Species							
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	S gram
42	11.9	sgc	1	1						s	t	
43	31.2	m	2	1		s						
44	27.6	sgc	0	0								
45	27.6	m	0	0								
46	25.5	m	0	0								
47	4.5	sgc	1	1	t		s		s		s	
48	11.9	s	4	1	m						d	
49	7.7	s	2	1			s			s	s	
50	24.1	sgc	0	0								
51	28.7	m	0	0								
52	11.9	sgc	0	0								
53	15.2	s	4	1							d	
54	8.1	s	3	1			m		t	t	s	
55	7.6	s	3	1			m		s			t
56	11.3	s	3	1	s		m					
57	3.3	s	1	1			s	t	s			
58	10.4	sgc	2	1			s	s		s	t	
59	27.6	m	0	0								
60	7.1	s	4	1							d	
61	4.5	sg	1	1	s							
62	16.5	s	4	1							d	
63	13.4	m/s	1	1								s
64	8.9	s	3	1			m	s	s	s		
65	26.6	m	0	0								
66	7.8	sg	2	1	s				s			s
67	12.4	s	2	1	s		s				s	
68	18.2	m	3	1							d	
69	14.9	m/s	4	1						s	d	
70	10.2	sg	1	1								s
71	20.4	m/s	1	1							t	
72	14.2	sg	3	1			m				m	
73	11.9	m/s	4	1							d	
74	14.7	s	4	1							d	
75	7.5	sgc	1	1					s		s	
Avg/Sum	12.9		2.2	0.8	14	4	18	4	10	8	47	9

Upper Hog Pond																
	Depth	Sediment	Cover	Biovol	Plant Species											
Station	ft	m/s/g/c	0-4	0-4	Eleo	Erio	Chloro	Cyano	Grat	Iso	N flex	Nit D	P spir	Pros	S gram	U gib
1	4	S G	4	1		t	m			t			s	m		
2	3.3	S	4	1		m	s							d		
3	5.3	S	4	1			m			m					s	
4	4.8	S	3	1			s				s		s	s		
5	7.3	S	3	1			s	s		s				s		
6	19.5	M	4	1			m					d				
7	21	M	4	1			s					d				
8	19.5	M	3	1			s			s		m				
9	10.1	M/S	4	1			s	s		d						
10	8.8	S	3	1			s			m	s					t
11	22.1	M	4	1								d	t			
12	22.8	M	4	1			s				s	d	m			
13	22.1	M	4	1			t				t	d	s			
14	10.6	M/S	0	0												
15	9.6	M/S	3	1			s	s								
16	22.8	M	4	1								m	m			
17	24.1	M	2	1								t	s			
18	23.1	M	2	1			t					s	s			
19	3	S G	2	1		s	s									
20	7.3	S	3	1			m							t	m	
21	13.4	M/S	4	1			m			m		s				
22	22.8	M	4	1								s	m			
23	25.9	M	2	1								m	m			
24	23.3	M	3	1								s	s			
25	4.8	S G	2	1		s	s									
26	7.1	S	3	1			s	m		t				t		
27	7.1	S	3	1			s							t		
28	22.6	M	2	1								s	s			
29	29.7	M	0	0												
30	24.1	M	2	1								s	s			
31	4	S	3	1		m	s									
32	3.3	S	1	1			s									
33	11.4	M/S	4	1			s			d		s				
34	24.1	M	4	1						s		d	m			
35	27.6	M	1	1								t	s			
36	9.4	M/S	1	1		t	s								s	
37	8.6	S	3	1			m		t	t						
38	23.1	M	4	1			t			s		d				
39	28	M	0	0												
40	3.4	S	1	1		s	s								t	
41	3.5	S	1	1		s	s		s				s			
42	22.8	M	2	1						s		s				
43	22.1	M	4	1			m					d				
44	5.8	S	2	1		s	s									
45	6	S	2	1		s	s		s						s	
46	22.3	M	3	1			t			t		d				
47	15.7	M/S	4	1			s			d		t				
48	3	S G	2	1		m	s									
49	4	S G	1	1			s									
50	12	M/S	4	1			t			d		s				
51	14.2	M/S	4	1			t			t		d				
52	4.5	S G	3	1		m										
53	3.8	S	1	1			s									
54	4	S	2	1	s		m									
Avg/Sum	13.7		2.7	0.9	1	12	39	4	3	17	4	25	16	7	5	1

Lower Hog Pond														
	Depth	Sediment	Cover	Biovol	Plant Species									
Station	ft	m/s/g	0-4	0-4	Eleo	Erio	Chloro	Iso	Moss	Nit D	Ny od	Pros	S gram	U gib
1	4.4	S	4	1		t	m	d					s	
2	4	S	3	1		m	m		s			s		s
3	3	S	0	0										
4	1.5	S	4	1	s	s	s					t		
5	5.3	S	0	0										
6	4.2	S	2	1		m	s							
7	2.6	S G	1	1		t								
8	4.1	S	2	1		s		s						
9	5.3	S	2	1			s		s					
10	6.1	S	2	1			s		s					
11	2.8	S G	1	1		s		t						
12	3.1	S	3	1		s	s							
13	3.2	S	1	1		s	s						t	
14	3.3	S	1	1		s	s					t		
15	3.2	S	4	1			m	m				t	s	
16	4.1	S G	1	1		s	s							
17	3.2	S G	2	1		t	m							
18	3.9	S G	1	1		s	s							
19	4.3	S G	2	1		m	s							
20	4	S	1	1		t	s							
21	3.3	S	3	2		s	m							
22	5.1	S	4	1			m	d					s	
23	3.4	S	4	1		m	s	m			t	m		
24	8.3	S	4	1			s	d						
25	6.7	S	4	1			s	d						
26	18	M/S	4	1			s	d						
27	21.1	M/S	4	1				m						
28	19.8	M	4	1			t							
29	16.7	M/S	4	1			m	d						
30	9.5	M/S	4	1		t	t	m						
31	8.3	M/S	4	1			m	d		s				
32	9.1	M/S	4	1			t	d		s				
33	11.9	M/S	4	1			t	d		s				
34	14.9	M/S	3	1			s	m		s				
35	13.8	M/S	4	1			s	d		s				
36	17.5	M	4	1			t	m		m				
37	24.3	M	4	1			s			m				
38	19.3	M	4	1				t		d				
39	17.7	M	4	1			s			d				
40	19.3	M	4	1			t			d				
Avg/Sum	8.6		2.9	1.0	1	18	33	19	3	10	1	5	4	1

Peters Pond													
	Depth	Sediment	Cover	Biovol									
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Grat	Iso	N flex	Nit D	P spir
1	3.9	0	0	0									
2	11.1	S	1	1		s							
3	16.2	m	0	0									
4	20	m	1	1		s							
5	17	m	0	0									
6	11.6	s g c	0	0									
7	8.3	s g c	0	0									
8	5	s g c	0	0									
9	5	sg	0	0									
10	16.5	s	1	1								s	
11	21.8	m	0	0									
12	8.6	s g c	2	1				s					
13	4	s g	0	0									
14	7.3	sgc	0	0									
15	20.5	s g c	0	0									
16	21.5	m/s g	0	0									
17	10.1	s g c	0	0									
18	5	s g	1	1									
19	2.7	c	0	0									
20	8.1	s g c	0	0									
21	23.3	m c	0	0									
22	39.3	m	2	1	s	s							
23	37.6	m	0	0									
24	18	s g c	0	0									
25	7.1	s g c	0	0									
26	3.3	s g c	0	0									
27	5.5	s g	0	0									
28	16.2	s g c	0	0									
29	26.9	m/ s g	0	0									
30	32	m	0	0									
31	29.2	m	1	1		s							
32	17.5	s g c	0	0									
33	8.1	s g c	0	0									
34	3.3	s g c	0	0									
35	8.3	s	0	0									
36	17	m/ s g	0	0									
37	32	m	0	0									
38	3.3	s g	3	1			s					m	
39	17.5	s g c	0	0									
40	27.6	m/s g	0	0									

Peters Pond													
	Depth	Sediment	Cover	Biovol									
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Grat	Iso	N flex	Nit D	P spir
41	3.8	s	2	1								s	
42	14.2	s	2	1			s			s			
43	17.7	s g c	0	0									
44	28.2	m	0	0									
45	8.1	s	3	1			m						t
46	18.2	s g c	6	1			s					s	
47	24.3	s g c	2	1								s	
48	40.6	m	1	1	t	t							
49	4	s g	3	1			m		s			s	
50	7.6	s	3	1			s					m	
51	12.9	s g c	1	1								s	
52	20	s g c	0	0									
53	37	m/s g	0	0									
54	2	s g	1	1							s		
55	4.5	s g c	0	0									
56	8.1	s g c	0	0									
57	13	s g c	0	0									
58	19.3	s g c	0	0									
59	22.8	m s g	0	0									
60	28.2	m	0	0									
61	3.8	s g c	0	0									
62	5.5	s g c	0	0									
63	10.4	s g c	0	0									
64	17.2	s g c	0	0									
65	23.1	s g c	0	0									
66	34.5	m r	0	0									
67	50.8	m	0	0									
68	52.5	m	0	0									
69	53.1	m	0	0									
70	34.5	m r	0	0									
71	14.4	s g c	0	0									
72	10.4	sgc	0	0									
73	6.3	s g c	0	0									
74	3	s g c	0	0									
75	3	sgc	0	0									
76	8.2	s g c	0	0									
77	16.2	s g c	0	0									
78	26.6	m/c	0	0									
Avg/Sum	16.7		0.5	0.2	3	6	7	2	2	2	2	9	2

Pimlico Pond															
	Depth	Sediment	Cover	Biovol	Plant Species										
Station	ft	m/s/g	0-4	0-4	Chloro	Cyano	Eleo	El can	Erio	Grat	Iso	N flex	Nit D	P epi	U pur
1	7.6	m/s	2	1			s			t	t	s			s
2	7.1	s	3	1	s		s		s		s	s			t
3	4.5	s	3	1			s		s	t		s			
4	6.8	s	2	1			s				t	s			
5	16.5	m/s	3	1		s					m	s			
6	17.7	m	3	1	s	s					s			t	
7	15.7	m/s	3	1		s					s	s			
8	7.8	s	2	1		s		t		t		t			
9	7.6	sg	3	1		s	t				s	t			s
10	12.1	sgc	3	1	s			s			s			t	
11	20.3	m	2	1		s					s		s		
12	20.5	m	3	1									d		
13	15.2	m	3	1							s	s	m		
14	4.5	s	4	1					s			d			
15	4.3	s/c	3	1					s			m			
16	12.1	m/s	3	1		t	t				s	s			
17	21.8	m	1	1		s									
18	21	m	1	1							t	t	s		
19	17	m/s	2	1							s	s			
20	9.6	s	2	1		s	t				t	s			
21	7.3	s	4	1								d			
22	18.8	m	3	1								s	m		
23	21.8	m	1	1		s									
24	24.9	s	0	0											
25	21.3	m	1	1							s				
26	9.6	m/s	3	1			s					m			
27	4.5	s	3	1			s		t			m			
28	5.8	s	3	1			s			s		s			
29	16	m/s	2	1	s						s		s		
30	22.8	m	0	0											
31	23.1	m	0	0											
32	20.8	m	1	1		s									
33	14.9	m/s	2	1		s					s	s			
34	9.9	s	2	1			s					s			
35	4.3	s	1	1					t	t		t			
36	5.8	s	3	1								m			
37	15.4	m/s	3	1	t	s					s	t			s
38	17.2	m/s	3	1		s					s	s	s		
39	11.1	s	2	1			s				s				
40	14.2	m/s	2	1		t					s	s			s
41	8.8	s	4	1							t	d			
42	7.1	s	3	1			s			t		s			
43	6	s	2	1					s	t		s			
44	7.8	s	2	1			s			t		s			
45	6	s	4	1			d					s			
46	4.3	sg	3	1			m		s	t		s			
Avg/Sum	12.6		2.3	0.9	5	15	16	2	8	9	22	33	7	2	5

Snake Pond																
	Depth	Sediment	Cover	Biovol	Plant Species											
Station	ft	m/s/g	0-4	0-4	C dem	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	Nit D	P bicup	Pros	S gram
1	4	ms	3	3		s		s		t				d	t	
2	4.3	ms	3	1		s		m				t		s		
3	5	s	3	1				m		t	s				t	
4	5.5	s	4	1		s										d
5	5.3	s	4	1		s										d
6	7.1	s	4	1		s		d								
7	3.8	s	3	1		s		m		t						
8	4.8	sg	3	1		s		m		s						
9	7.3	s	4	1				m				m				
10	6	s	3	1				m								
11	8.6	m/s	3	1		s										m
12	3.8	s	3	1		s		m		s						
13	6.3	s	4	1		s										d
14	9.1	m	4	1									d			
15	6	sg	3	1		s		m		m						
16	6.6	s	4	1		s										d
17	7.8	s	4	1		s										d
18	8.6	s	4	1		s										d
19	8.1	s	4	1		s										d
20	8.6	s	4	1		s										d
21	6.8	sg	1	1		s		s								
22	5.5	sg	1	1				s		s						
23	26.4	m	0	0												
24	18	sg	3	1									m			
25	11.4	sg	0	0												
26	13.2	sgc	0	0												
27	22.6	m	3	1									m			
28	24.9	m	0	0												
29	27.6	m	3	1									m			
30	30.4	m	0	0												
31	34	m	1	1			s									
32	14.2	m	4	1									d			

Snake Pond																
	Depth	Sediment	Cover	Biovol	Plant Species											
Station	ft	m/s/g	0-4	0-4	C dem	Chloro	Cyano	Eleo	Erio	Grat	Iso	N flex	Nit D	P bicup	Pros	S gram
33	11.6	s	1	1		t							d			
34	4.5	s	0	0												
35	4.8	c/s	1	1		s			t	s						
36	15.7	sg	0	0												
37	33.5	m	1	1			s									
38	34.3	m	1	1			s									
39	6.6	sg	1	1				t		t						
40	13.4	sgc	0	0												
41	26.6	m	4	1									d			
42	32.2	m	1	1			s									
43	14.9	sgc	3	1	t	s						m	m			
44	14.7	sg	0	0												
45	17.5	sg	0	0												
46	12.1	sg	0	0												
47	4.5	sgc	1	1		t							t			
48	3.8	sgc	1	1		s										
49	9.4	sgc	0	0												
50	17.2	s	1	1								t	t			
51	25.1	m	2	1									s			
52	31.7	m	1	1			s									
53	22.8	m	2	1								t	s			
54	11.4	s	0	0												
55	4.8	sg	2	1		t		s		s						
56	4.3	sg	1	1		s				s						
57	13.2	s	0	0												
58	18.5	m	0	0												
59	9.1	sg	0	0												
60	10.4	sg	0	0												
61	5.3	sg	2	1				s		s						
62	2.7	sg	1	1		t										
63	7.3	s	4	1		s										d
Avg/Sum	12.8		1.9	0.8	3	27	6	16	2	13	2	6	13	3	3	11

Weeks Pond

	Depth	Sediment	Cover	Biovol	Plant Species															
Station	ft	m/s/g	0-4	0-4	B schreb	Chloro	Cyano	Eleo	El can	Erio	Grat	N flex	Nit S	Nit D	Nu var	Ny od	Ny cord	P spir	U rad	U pur
1	5.3	s	4	1		t	s	o	t						t					
2	6.2	s	4	2		s	m									m	s			s
3	3.3	s g	2	1			s	s		t	t		m							
4	6.3	s g	3	1			s	s									t			
5	7.6	m/s	4	2				m					s			m				s
6	3.8	s	2	1		t		s		s	t									
7	4	s g	2	1		s	t	s		t		t					t			
8	7.8	s	4	3		s	t	s								d				s
9	4.5	s g	3	1		s	s	m												
10	6.6	s	4	1		s		d												t
11	7.8	s g	3	1		s		s												s
12	5.3	s g	2	1		s		s									t			s
13	6.6	s	4	1		s		d								t				t
14	16.2	m/s	3	1			m							s						s
15	10.1	s	3	1		s		m								t				s
16	4.5	s g	2	1		m		s		t	s		t							
17	4.3	s	4	2		m		s				t				m	t			t
18	5	s	3	2		s		m			t					m				s
19	7.8	s	4	1				m									s			m
20	5.3	s	3	1				m												
21	8.6	m/s	4	3								s	m			d				s
22	15.2	m	2	1								s		s						t

Weeks Pond																					
	Depth	Sediment	Cover	Biovol	Plant Species																
Station	ft	m/s/g	0-4	0-4	B schreb	Chloro	Cyano	Eleo	El can	Erio	Grat	N flex	Nit S	Nit D	Nu var	Ny od	Ny cord	P spir	U rad	U pur
23	7.1	s	3	1			s	m												
24	18.8	m	4	1										d						t
25	7.8	s g	3	1		s		m												s
26	8.8	s	4	3								t	m			m				s
27	16.2	m	4	1								s		d						
28	13.9	m	4	1								s		d						t
29	19	m	4	1								t		d				t		t
30	7.6	s	3	2	m	s		m				t					m			s
31	8.8	m/s	4	3		s							m			d				s
32	16.7	m	4	1								t		d				t		t
33	19	m	4	1										d						t
34	20.3	m	1	1			s							s						
35	6.3	s	3	3	m	s		m									s			s
36	9.4	m/s	4	3				m				t	s			d				s
37	17	m	4	1			t					t		d				t		
38	18.8	m	4	1										d				t		
39	9.9	m/s	4	3	d			s									t			s
40	9.2	m/s	4	3	d	s		s				t							s	s
41	8.8	s	4	3	d			t								t	t		t	s
42	5.3	s	4	3	m	s		s					t				s			
Avg/Sum	9.5		3.4	1.6	6	20	11	27	1	4	4	13	8	11	1	12	11	4	2	28

APPENDIX B: Data from 2008-2010 PALS Surveys

Lawrence Pond water quality and related observations from the PALS program, 2008-2010.

Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
8/20/2008	0.5	2	8.2	4.5	54.4%	24.6	5.91	6.02	1.80	2.05	0.46	8.8	239.1	brown/green	<1%	
8/20/2008	1					24.7	6.18							brown/green		
8/20/2008	2					24.8	6.22							brown/green		
8/20/2008	3					24.8	6.07							brown/green		
8/20/2008	4					24.9	6.11							brown/green		
8/20/2008	5					24.9	6.13							brown/green		
8/20/2008	6					24.8	6.08							brown/green		
8/20/2008	7					24.8	5.95	6.17	1.90	2.68	0.48	8.1	242.4	brown/green		
8/20/2008	8					24.8	6.08							brown/green		
9/8/2009	0.5		8.1	7.7	95.1%	22.8	8.7	5.32	2.10	1.07	1.11	4.5	233.1	blue	Emergent grasses/sedges: 1%, other: 1%, no waterlilies or floating algal mats	
9/8/2009	1					22.9	8.5							blue		
9/8/2009	2					22.9	8.5							blue		
9/8/2009	3					22.9	8.4							blue		
9/8/2009	4					22.9	8.4							blue		
9/8/2009	5					22.9	8.3							blue		
9/8/2009	6					22.9	8.3							blue		
9/8/2009	7					22.8	8.3	5.36	2.10	1.04	0.95	6.2	252.3	blue		
9/8/2009	8					22.8	8.2							blue		
8/26/2010	0.5	2	8.7	4	46.0%	22.9	6.50	6.93	27.5	2.91	1.38	7.6	314.3	brown	<1%	Higher than normal accumulation of green algae around the shore. Also highest water level in at least 15 years
8/26/2010	1					24.4	6.20							brown		
8/26/2010	2					24.5	5.90							brown		
8/26/2010	3					24.5	5.90							brown		
8/26/2010	4					24.5	5.80							brown		
8/26/2010	5					24.5	5.70							brown		
8/26/2010	6					24.4	5.50							brown		
8/26/2010	7					24.4	5.50							brown		
8/26/2010	8					19.9	1.90	6.40	4.6	1.91	0.84	8.4	306.9	brown		
8/26/2010	9					18.0	0.20							brown		

Spectacle Pond water quality and related observations from the PALS program, 2008-2010.

Pond	Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
Spectacle	8/26/2008	0.5	4	12.2	4.1	33.7%		6.78	6.32	3.40	2.07	0.55	5.7	247.4	blue	10% submerged algae	
Spectacle	8/26/2008	1					24.9	6.80							blue		
Spectacle	8/26/2008	2					24.9	6.75							blue		
Spectacle	8/26/2008	3					24.8	6.73	6.62	3.50	1.71	0.27	6.0	218.4	blue		
Spectacle	8/26/2008	4					24.8	6.71							blue		
Spectacle	8/26/2008	5					24.8	6.71							blue		
Spectacle	8/26/2008	6					24.8	6.67							blue		
Spectacle	8/26/2008	7					24.6	6.56							blue		
Spectacle	8/26/2008	8					22.7	7.13							blue		
Spectacle	8/26/2008	9					18.5	9.08			2.03	0.91	5.4	217.2	blue		
Spectacle	8/26/2008	10					16.5	8.26							blue		
Spectacle	8/26/2008	11					14.7	3.65	6.37	3.40	2.34	1.28	6.9	211.0	blue		
Spectacle	8/26/2008	12					13.8	0.17							blue		
Spectacle	9/8/2009	0.5		11.3	5	44.2%	23.3	6.7	5.69	3.40	1.81	0.95	16.1	272.0	ND	Waterlilies: <1%, floating algae: <1%, emergent grasses/sedges: up to 10%	
Spectacle	9/8/2009	1					23.2	6.1							ND		
Spectacle	9/8/2009	2					ND	ND							ND		
Spectacle	9/8/2009	3					23.1	6.7	5.54	3.20	2.16	0.72	7.9	281.8	ND		
Spectacle	9/8/2009	4					23.1	6.5							ND		
Spectacle	9/8/2009	5					23.0	6.3							ND		
Spectacle	9/8/2009	6					23.1	6.2							ND		
Spectacle	9/8/2009	7					22.9	6.0							ND		
Spectacle	9/8/2009	8					22.9	5.8							ND		
Spectacle	9/8/2009	9					21.5	4.1	5.32	4.30	4.29	2.89	9.1	372.9	ND		
Spectacle	9/8/2009	10					18.6	3.2							ND		
Spectacle	9/8/2009	11					17.2	1.0	5.77	4.50	3.17	2.73	8.9	375.0	ND		
Spectacle	9/8/2009	12					16.8	<0.1							ND		
Spectacle	8/31/2010	0.5	3	7.2	3	41.7%	24.0	7.43	6.45	4.1	0.89	<0.05	14.1	561.0	blue/green	<1%	Samplers could not find deepest area
Spectacle	8/31/2010	1					23.9	7.33							blue/green		
Spectacle	8/31/2010	2					23.6	7.18							blue/green		
Spectacle	8/31/2010	3					23.3	7.26	6.48	4.2	2.39	1.44	9.7	320.0	blue/green		
Spectacle	8/31/2010	4					23.0	6.92							blue/green		
Spectacle	8/31/2010	5					22.8	6.88							blue/green		
Spectacle	8/31/2010	6					22.3	6.29							blue/green		
Spectacle	8/31/2010	7					21.4	2.96	6.72	4.0	0.85	0.84	10.5	380.4	blue/green		

Triangle Pond water quality and related observations from the PALS program, 2008-2010.

Pond	Date	Depth (M)	Number of Samples	Total Depth (M)	Secchi Depth (M)	% Secchi	Temp (C)	DO (mg/L)	pH (SU)	Alk (mg $CaCO_3$/L)	Chla (ug/L)	Phaeo (ug/L)	TP (ug/L)	TN (ug/L)	Water Color	Plants	Notes
Triangle	8/26/2008	0.5	3	9.2	3.9	42.1%	25.2	6.73	6.45	3.20	1.32	0.43	141.7	199.4	blue green	10% bottom algae	pond receding
Triangle	8/26/2008	1					25.0	6.67							blue green		
Triangle	8/26/2008	2					24.8	6.66							blue green		
Triangle	8/26/2008	3					24.8	6.67	6.45	3.10	1.29	0.32	31.4	179.9	blue green		
Triangle	8/26/2008	4					24.7	6.60							blue green		
Triangle	8/26/2008	5					24.6	6.50							blue green		
Triangle	8/26/2008	6					24.5	6.47							blue green		
Triangle	8/26/2008	7					24.4	6.42							blue green		
Triangle	8/26/2008	8					21.7	2.39							blue green		
Triangle	8/26/2008	9					19.1	0.07	6.11	9.40	1.17	15.06	42.4	302.5	blue green		
Triangle	8/26/2008	10					18.3	0.04							blue green		
Triangle	9/8/2009	0.5		8.8	3.6	40.9%	22.8	8.3	5.88	3.30	2.25	0.92	4.5	262.1	ND	Waterlilies:<1% to none, floating algae: <1% to none, emergent grasses/sedges: <2%	
Triangle	9/8/2009	1					22.9	8.7							ND		
Triangle	9/8/2009	2					22.8	8.6							ND		
Triangle	9/8/2009	3					22.8	8.5	5.60	3.20	1.56	1.01	11.9	256.6	ND		
Triangle	9/8/2009	4					22.8	8.5							ND		
Triangle	9/8/2009	5					22.8	8.4							ND		
Triangle	9/8/2009	6					22.8	8.3							ND		
Triangle	9/8/2009	7					22.8	8.2							ND		
Triangle	9/8/2009	8					22.5	7.2	5.77	4.50	15.99	107.32	467.9	3962.0	ND		
Triangle	9/1/2010	0.5	3	9.7	3.4	35.1%	24.5	7.66	6.69	4.1	0.17	0.56	10.5	365.2	blue/green	<1%	Water level highest in many years- least amount of algae in years! Very nice swimming
Triangle	9/1/2010	1					24.3	7.51							blue/green		
Triangle	9/1/2010	2					24.0	7.46							blue/green		
Triangle	9/1/2010	3					23.6	7.44	6.60	3.6	0.56	0.11	9.9	284.3	blue/green		
Triangle	9/1/2010	4					23.2	7.42							blue/green		
Triangle	9/1/2010	5					22.8	7.47							blue/green		
Triangle	9/1/2010	6					22.4	7.32							blue/green		
Triangle	9/1/2010	7					21.8	6.86							blue/green		
Triangle	9/1/2010	8					20.2	5.35							blue/green		
Triangle	9/1/2010	9					16.0	0.42	6.28	7.0	3.35	2.47	18.9	307.3	blue/green		